CONTRIBUTIONS TO
HIMALAYAN GEOLOGY ②

STRATIGRAPHY AND STRUCTURE OF KASHMIR AND LADAKH HIMALAYA

about the book

This is the second volume in the series *Contributions to Himalayan Geology*. The papers contributed to this volume share between them the common theme of "Stratigraphy and Structure of Kashmir and Ladakh Himalaya." They present a wide diversity of material demonstrating the on-going advances in this field. The volume is expected to provide a rich fare to the students of Himalayan Geology as well as a means for communication among geoscientists.

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STRATIGRAPHY AND STRUCTURE OF KASHMIR AND LADAKH HIMALAYA

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Volume 2 Stratigraphy and Structure of Kashmir and Ladakh Himalaya

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STRATIGRAPHY AND STRUCTURE OF KASHMIR AND LADAKH HIMALAYA

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Preface

This is the second volume of the series *Contributions to Himalayan Geology*. The papers contributed to this volume share between them the common theme of "Stratigraphy and Structure of Kashmir and Ladakh Himalaya." They present a wide diversity of material demonstrating the on-going advances in this field. The volume is expected to provide a rich fare to the students of Himalayan Geology as well as a means for communication among geoscientists.

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Chandigarh
October, 1983

Contents

Regional Stratigraphy, Palaeontology and Structure of Kashmir and Ladakh Himalayas

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INTRODUCTION

KASHMIR AND Ladakh Himalayas constitute the most important segment of the Himalayan mountain chain, as this region displays a cross-section of rock-units belonging to Indian plate, Tibetan block of Eurasian plate and the collision zone between the two lithospheric plates. This region lies in NW Himalaya, and the account given here deals with only that part of Kashmir and Ladakh which encompasses the area within the cease-fire limit of India.

Lydekker (1883), Middlemiss (1810), and Middlemiss & Bion (1913) were the pioneers, whereas Wadia (1928, 1930, 1934) was among the earliest workers to study the geology of Kashmir and Ladakh. Later important contributions came from Gupta (1969), Shah (1978), Sharma (1976) and Fuchs (1975). In recent years Ladakh has been the focus of increased geological interest because the Indus Tsangpo Suture passes through it. Recently, several accounts of this region have been published (Gupta and Kumar, 1975; Shah *et al.*, 1976; Frank *et al.*, 1977; Thakur and Virdi, 1979; Thakur, 1981).

The authors have been working in Kashmir and Ladakh for the last several years. An attempt is made here to present the compiled and synthesised data pertaining to stratigraphy, palaeontology and structure in the light of their own investigations.

REGIONAL FRAMEWORK

The Himalayas have been devided into longitudinal zones (Gansser, 1964), viz., Sub-Himalaya, Lesser Himalaya, Higher Himalaya, Tethys Himalaya and Trans Himalaya. Although this classification is successfully applicable to Kumaun Himalaya, we find difficulty in adhering to it in Kashmir and Ladakh Himalayas. Though the rocks of Kashmir basin are classically considered as belonging to the Tethyan facies (Valdiya, 1964), they do not lie in axial continuation with the belt of Kumaun Himalaya. The sedimentary sequence of Zanskar area lies in continuation of the Tethyan sequence of Spiti. It is now proved that the rocks of the Dauladhar range and its continuation to Kashmir do not constitute the Central Crystallines, but the Zanskar Crystallines are the continuation of Central Crystallines (Thakur, 1980). Similarly, there is a difference of opinion regarding location of Main Central Thrust in Kashmir. Indus-Tsangpo Suture, which was described as a line, represents a wide zone of continent-continent or continent-volcanic arc collision.

The Kashmir and Ladakh region has been classified into following tectono-stratigraphic zones (Figure 1) :

(1) Outer Himalaya Zone;
(2) Para-autochthon Zone;
(3) Kashmir Nappe Zone;
(4) Zanskar Zone;

(5) Indus Zone;
(6) Karakoram Zone.

Outer Himalaya Zone forming southernmost zone of Tertiary rocks includes Siwalik and Murree Groups together with isolated inliers of Great Limestone (= Shali Limestone) and Eocene rocks. It is delimited to the

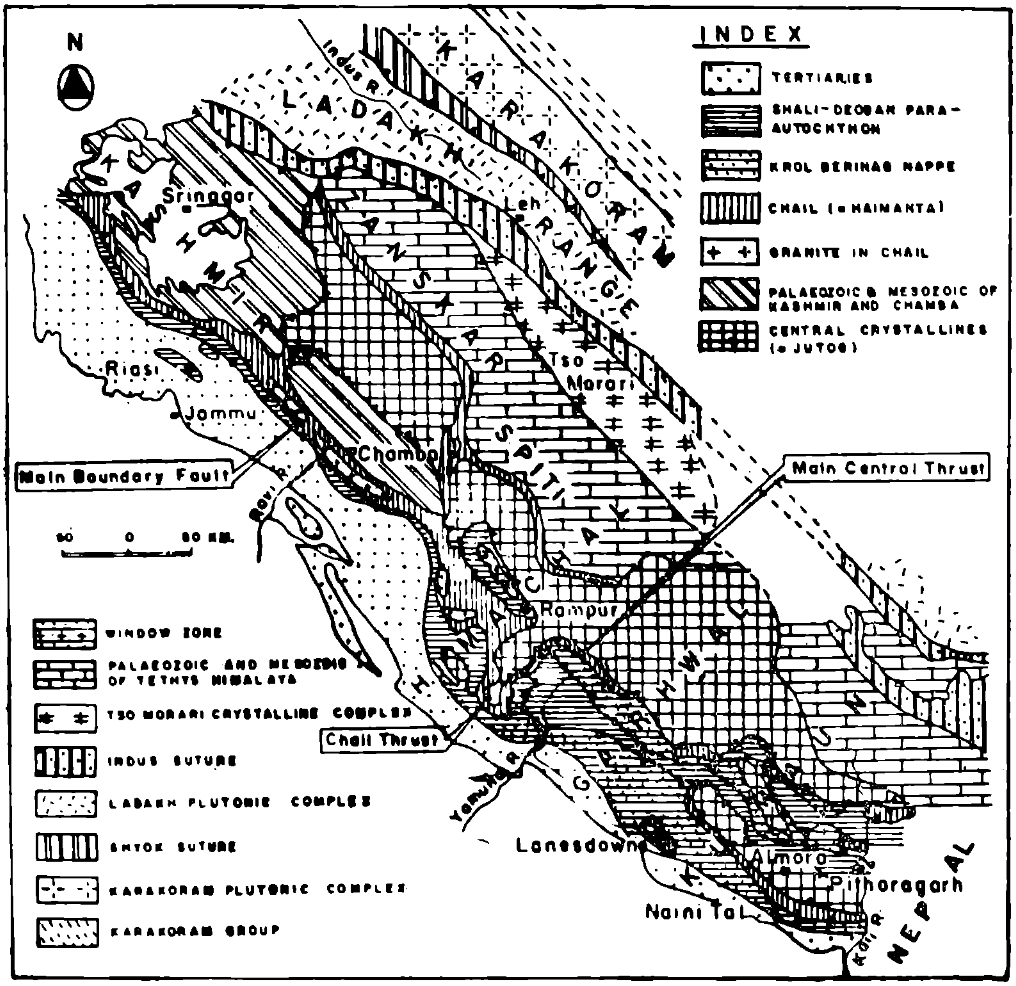

Figure 1. Tectonic map of Western Himalaya (modified after Thakur, 1981).

north by a thrust (Muree Thrust) from the Para-autochthon Zone. The Para-autochthon Zone, which Wadia (1931) designated as folded autochthonous belt, consists of a Schuppen Zone comprising of rock units of Shali-Deoban Para-autochthon (Thakur, 1981) and of the Kashmir Nappe Zone. The Kashmir Nappe Zone is made up of a sequence ranging in age from Precambrian to Triassic and folded into a large synclinorium. Its base is marked by Panjal thrust that has brought the rocks of the synclinorium to rest over the Para-autochthon Zone. Zanskar Crystalline Complex and Zanskar Supergroup are the two principal tectonic units of the Zanskar Zone; the former constitutes the basement for the Late Precambrian to Mesozoic sequence of the latter. Zanskar Crystalline Complex represents NW extension of the Central Crystallines, and the rock units of Zanskar Tethys Supergroup joins to SE with the Tethys Himalaya sequence of Lahaul and Spiti and to NW and SW with the rocks of Kashmir Nappe Zone. Tso Morari Crystalline Complex is also included in Zanskar Zone on the basis of geographical location, but its anomalus tectonic relationship is not yet clearly understood. Indus Zone is separated to the south from the rocks of Zanskar Zone by a south dipping thrust designated as Zanskar Thrust.

It consists of extrusives of Dras and Khardung formations, intrusives of Ladakh plutonic complex, flyschoid sediments of Lamayuru Formation, molassic sediments of Kargil Formation, and Ophiolitic melanges of Shergol and Zildat melanges and Nidar ophiolite. Karakoram Zone is delimited from the Indus Zone by a northerly steeply dipping Shyok thrust. It consists of ophiolitic and sedimentary rocks of Shyok Formation, intrusives of Karakoram plutonic complex and sedimentaries of Karakoram Group.

Outer Himalaya Zone

The autochthon of Outer Himalaya Zone consists of, apart from Great Limestone, mainly Tertiary rocks. These rocks form the southernmost belt of Jammu and Kashmir. Lydekker (1876, 1883) and Medlicott (1876) gave the earliest accounts of the rocks of this belt. In later years the pioneer work of Middlemiss (1909) and Wadia (1928, 1932) on the geology of Kashmir include the study of Tertiary rocks. However, the major thrust in geological investigation came from the workers of Oil and Natural Gas Commission, who in search for hydrocarbons started a systematic mapping of the Tertiary belt of this region in 1957. The stratigraphy and structure of Tertiary rocks of Jammu and Kashmir described here is based upon the synthesis made by Rao and Rao (1979) and Karunakaran and Rao (1979).

The principal stratigraphic units of the Outer Himalaya Zone are : Siwalik Group, Muree Group, Subathu Formation and Great Limestone. Their lithological characteristics and age is summarised in Table 1.

TABLE 1—OUTER HIMALAYA ZONE

Upper Siwalik	Plio-Pleistocene	Conglomerates, sand rocks, clays
Middle Siwalik	Pliocene	Micaceous sandstone, clays, siltstones
Lower Siwalik	Mio-Pliocene	Grey and brown clays, sandstones
Upper Murree	Miocene	Massive, grey sandstone, siltstone, grey, yellow clay
Lower Murree	Lower Miocene-Upper Eocene	Brown, red sandstone, siltstone, clay alternations
Subathu Formation	Middle Eocene-Palaeocene	Olive green shales with foraminiferal limestone bands, coal layers in the bottom
	Unconformity/Thrust	
Waishnodevi Limestone		Cherty dolomitic limestone, quartzite

1.1. Siwalik Group

The Siwalik Group has been divided into Lower Siwalik, Middle Siwalik and Upper Siwalik formations.

LOWER SIWALIK. The Lower Siwalik has an estimated thickness of 1830 m and consists of sandstone and claystone. The sandstones are light grey, thick-bedded, fine-to-medium-grained, calcareous at places, but mainly micaceous. The femic minerals in sandstone give an appearance of the salt and pepper texture. The claystones are light red and greenish grey-coloured and micaceous with calcareous veins. Based on correlation elsewhere with similar rocks of Lower Siwalik, a Middle Upper Miocene age has been assigned to it.

MIDDLE SIWALIK. The Middle Siwalik consists of sandstones and clays and is approximately 1700 m in thickness. It has been divided into three members. The lower member is made up of massive sandstone, the middle member consists of alternation of clay and sandstone and the upper member shows coarse sandstone grading into arkose and grit. The sandstones of Middle Siwalik are coarser than those of Lower Siwalik and have pebbles of varying size and composition. The sandstones are greenish grey to grey in colour, medium-to-coarse-grained and richly micaceous. They are also arkosic and contain significant proportion of felspar. Nodules and concretions occurring as calcareous segregates are distributed towards the basal part of the succession. The pebbles in sandstone are mainly of quartzite, limestone and slate. The clays are soft and vary in colour from pale-red and orange and tinges of red and green to variegated colours. The Middle Siwalik has a conformable relationship with the underlying Lower Siwalik and the overlying Upper Siwalik. The first appearance of a massive conglomerate at places marks the boundary between the Upper and the Middle Siwalik.

UPPER SIWALIK. The total thickness of the Upper Siwalik is estimated at about 800 m. It is divided into lower and upper units. The lower unit consists of coarse-grained, poorly cemented, loosely packed friable sandstone. The sandstone is made up of poorly sorted quartz grains, kaolinised felspars and femic minerals and pebbliferous and at place with interbedded thin (1 m) conglomerate bands. The upper unit consists of massive conglomerates with interstratified clay sandstone with thin bands of bentonite clay. The conglomerate contains pebbles of sandstone, siltstone, claystone, green trap, limestone, shale, phyllite and granitoid gneiss. The pebble imbrication indicates current direction towards SE and SW.

The boundary between the Upper Siwalik and Middle Siwalik sequences is normal and gradational. The terrace gravels overlie unconformably the Upper Siwalik.

1.2. Murree Group

The Murree Group is divided into lower and upper divisions. The Lower Murree is made up of alternating sandstones, siltstones and claystones. The sandstones are purple to grey, fine-grained with calcareous veins and intraformational conglomerate bands. The claystones are brown to purple, silty and micaceous in nature. The total thickness of Lower Murree is about 2000 m.

Kalakote Zone occurring a few feet above the base of Lower Murree contains rich collection of vertebrates of Artiodactyla and Tapiroidea, Creodontia, Crocodila, Chelonia and skeletal fish remains. This assemblage belongs to Lower Upper Eocene (Sahni, 1971; Ranga Rao, 1972).

The Upper Murree is about 1830 m in thickness and consists of thickly bedded grey to greenish-grey sandstone together with alternation of claystone, siltstone and intraformational conglomerate. Presence of tree trunks and plant impressions like *Sabal major* indicate continental environment for its deposition.

1.3. Subathu Formation

The Subathu Formation is exposed within the Murree belt as thin rims surrounding the inliers of Great Limestone in Kalakote-Riasi-Sawalkote area and as thin faulted inlier strips within the Lower Murree close to the Murree Thrust in Punch and Mudun. In Kalakote area it has a total thickness of 153 m consisting of grey and carbonaceous shales with two impersistent coal seams in the lower part and foraminiferal limestone, marls and olive green and silty shales in the upper part. Northeast of Riasi, near Rohatkot the basal part of this formation is made up of milky and dirty white current-bedded quartzite with occassional thin conglomerate bands interbedded with shales. The shales have yielded *Globorotalia* cf. *imitata*, *Chielogumbilina midwayensis*, *Globoanomalina* sp., *Sobbotina-triloculionoidea*, *Bolivinella* sp. etc., of Palaeocene age (Krishnan and Rao, 1970). The foraminiferal assemblage from Kalakote area, including *Nummulites atacicus* var. *chumbiensis*, *Assilina granulosa*, *Lockhartia hunti*, *Cibicides* sp., *Triloculina* and *Fasciolites oblonga* indicates Lower to Early Middle Eocene age (Singh, 1973).

The outcrops of Subathu Formation exposed near Satara, east of Punch were described as Jokhan Limestone of Miocene age by Wadia (1928). Geological investigation by ONGC workers (Rao and Rao, 1979; Karunakaran and Rao, 1979) has shown that Jokhan Limestone is part of Subathu Formation consisting of 100 m thick olive green shales and lenticular foraminiferal limestone bands with minor amount of red clays, red shales and greenish grey fine-grained sandstone. A 5 m-thick band which overlies this sequence has yielded *Assilina epinoza*, *Assilina involuta davisii* and *Orbtolites* spp. These fossils indicate their correlation with the *Assilina spinosa* Zone (Middle Laki) of the Subathu Formation of Kalka-Solan area.

The lower part of the Subathu Formation suggests lagoonal restricted and paralic conditions of deposition, whereas the upper part indicates deposition under shallow marine environment which gradually gave way to continental and brackish water environment of Lower Murree.

1.4. Great Limestone

Great Limestone consists of dolomitic and cherty limestone together with minor quartzite and slate locally interbedded with limestone. It forms inliers within the Murree Group; the largest inlier, Waishnodevi Limestone, has a length of approximately 80 km and width of 20 km and forms a broad open anticline. Earlier workers assigned an Upper Palaeozoic age to this limestone, but Gupta and Dixit, (1971) and Raha and Sastry (1973) on the basis of algal stromatolites have assigned Lower Riphean age to this unit. The base of this unit is not exposed and it is unconformably overlain by the Subathu Formation. According to prevailing view, the inliers of limestones within to Murree Group are interpreted as the upfaulted blocks of the basement exposed. But the authors consider these limestone units to form klippen over the sediments of Murree Group.

2. Para-autochthon Zone

Wadia (1931) divided the Kashmir Himalaya into three tectonic units. From south to north these are : (*a*) The Foreland comprising of Middle Tertiary rocks; (*b*) The Autochthonous Folded Belt of Carboniferous-Eocene rocks; (*c*) The Nappe Zone of the inner mountains composed of the older Himalayan crystalline rocks.

According to Wadia (1931), the Autochthonous Folded Belt forms a strip of tightly compressed vertically disposed strata, or of recumbent folds varying from a few metres to about 7.5 km in breadth, which intervenes between the Foreland Murrees and the crystalline schists of the Nappe Zone of the inner mountains. The inner and outer boundaries of this belt are defined by Panjal and Murree thrusts, respectively. Wakhaloo and Shah (1970) redesignated this belt as Schuppen Zone characterized by isoclinal folding, thrusting and imbrications.

Srikantia (1973) has shown that in its NW extension the Shali Structural Belt of Simla Himalaya (Precambrian in age) joins with the Autochthonous Folded Belt of Wadia. In recent years Rao and Rao (1979) have carried out detailed mapping of this belt. Their mapping also indicates continuation of the Shali Structural Belt of the Dalhousie area of Himachal into Poonch of Jammu and Kashmir. They have assigned an Upper Carboniferous to Permian age to this belt. The stratigraphy of this belt, modified after Rao and Rao (1980) is given in Table 2.

In our interpretation we agree with Srikantia's contention that the Autochthonous Folded Belt is a NW extension of the Shali Structural Belt. But we do not consider the entire thickness of the Autochthonous Folded Belt to be stratigraphically equivalent to the rock units of Shali Structural Belt, as there are definite fossiliferous horizons of Agglomeratic Slate, Zewan Formation and Subathu Formation within this belt. Also, We do not subscribe to the view of Rao and Rao (1979) in assigning Upper Carboniferous to Permian age to the whole of the Autochthonous Folded Belt. According to our interpretation, as indicated in Table 2, this belt is a Para-autochthone zone consisting of rock units of the Shali Structural Belt (Shali Deoban-Para-autochthon) and

TABLE 2—PARA-AUTOCHTHONE ZONE (Autochthonous Folded Belt of Wadia, 1931)

Stratigraphic Unit	*Characteristic Lithology*	*Age*	*Authors*
Subathu Formation	Fossiliferous limestone, shale with coal seams	Lower to Middle Eocene	Outer Himalaya Zone
	Thrust		
Zewan Formation	Fossiliferous sandy limestone, shale and quartzite	Permian	
Panjal Trap	Volcanic trap and ash beds	Permo-Carboniferous	Kashmir Nappe Zone
Agglomerate Slate Succession	Laminated silty siliceous slate with quartzite lenses with conglomerate and ash beds	Upper Carboniferous	
	Thrust		
Baila Formation	Lenticular, nodular limestone, with carbonaceous shale and occasional quartzite		Shali-Deoban
Gamir Formation	Alternations of slaty shale, flatty and laminated limestone with thick bedded quartzite	Precambrian	Para-autochthone Zone
	Thrust		
Shali Trap	Foliated, phyllitic, chloritic with ash beds and quartzites at different level		

Kashmir Nappe zone. These units form a schuppen-zone that has resulted due to southward movement of the Kashmir nappe along the Panjal Thrust over the foreland of the Shali Structural Belt.

3. Kashmir Nappe Zone

Wadia (1928, 1957) described the Precambrian to Triassic sequence of the Kashmir valley and Pir Panjal range forming a gigantic nappe whose base is defined by Panjal Thrust. This nappe was supposed to be rooted further north in Zanskar range. Doubts have been expressed in recent years on the existence of nappe structure and Panjal Thrust (Sharma, 1978) in Kashmir. The presence of Kishtwar window as defined by Fuchs (1975) does lend support to Wadia's interpretation of nappe structure, and a large scale translation and rooting of nappe in Zanskar as envisaged by Wadia may also hold good.

Stratigraphically, Kashmir Nappe Zone consists of a sequence which ranges in age from Precambrian to Triassic with isolated patches of Jurassic at places. The basal part of this sequence (Precambrian to (?) Lower Palaeozoics) is essentially made up of low grade metamorphics of green schist facies together with granitoid bodies. The overlying sequence is made up of sedimentary and volcanic rocks. Marine environment with contemporaneous volcanic activity prevailed through most of the Precambrian to Triassic (and Jurassic at places) except locally where continental conditions prevailed during the Upper Palaeozoic times.

The rocks of the 'Kashmir Nappe Zone' form a synclinorium whose axis runs NW-SE passing through the Kashmir valley. To the south, the basal part of the synclinorium is thrust over along the Panjal Thrust to the rocks of Para-autochthonous Zone, and to the north it joins with the Tethyan rock sequence of Zanskar Supergroup. The stratigraphy and palaeontology of the Kashmir Nappe Zone is described below.

3.1 Palaeozoics

Based on the stratigraphy and facies variation the Palaeozoic rocks of Kashmir can be distinguished into two main belts, i.e., the northern belt (Baramula, Anantnag, Srinagar districts, etc.) and southern belt (Poonch, Badarwah districts, etc.).

NORTHERN BELT (BARAMULA, ANANTNAG, SRINAGAR DISTRICTS). The rocks of Salkhala Group in parts of Hundwara, Trehgam and Shamsaburi areas of Baramula district pass upwards into a thick sequence of Dogra Slates and fossiliferous Cambrians. The Lower Cambrian strata consist of annelid slates, sandstones and quartzites, whereas the younger units consist of clay, slate, limestone and quartzite. The Middle and Upper Cambrian strata have yielded trilobites and brachiopods and are characterized by the presence of *Solenopleurae-Anomocare* and *Conocoryphe* assemblages, respectively. The sequence overlying the fossiliferous Cambrians has yielded rich assemblage of brachiopods, trilobites, crinoids, cystoids of Ordovician and Silurian age. The presence of Middle Devonian brachiopod *Euryspirifer specious* has been described from the argillaceous intercalations found within the Muth Quartzite of this area.

In the Anantnag District of Kashmir, the Cambrian sequence has not yielded any definite fossils. The occurrence of Ordovician graptolites (*Climacograptus, Didymograptus, Glossograptus*) was recorded by Berry and Gupta (1967). In addition Ordovician brachiopods, crinoids and cystoids have been described from the Gauran Beds. The Harpatnar Beds have yielded Early to possibly Middle Ludlowian graptolites. The Naubug Beds have yielded a rich and varied fauna represented by brachiopods, trilobites, corals, lamellibranchs, gastropods, crinoids, cystoids, blastoids, cephalopods of Late Silurian to Early Devonian age. The beds lying immediately at the base of the Muth Quartzite in the Kotsu section have yielded Lower Devonian plant fossils. The dark calcareous shales at the base of Muth Quartzite in the section SW of Margan Pass have yielded fish remains, whereas Devonian conodonts have been described from near Lutherwan. The Silurian-Devonian boundary in this part of Himalayan lies within the Naubug Beds.

The Muth Quartzite exposed in different parts of Kashmir has yielded well-preserved fauna represented by brachiopods, corals, bryozoans, crinoids, trilobites, cephalopods, gastropods, lamellibranchs, etc. The fauna (including *Calceola sandalina*) from the Muth Quartzite is suggestive of Middle Devonian age for the fossiliferous part of the Muth Quarrzite. The overlying quartzite sequence in parts may represent Upper Devonian age. The palaeontological and stratigraphical evidences are suggestive of the fact that the lower boundary of the Muth Quartzite fluctuates from one section to another in different parts of Kashmir. Certainly, major part of this quartzite sequence is of Middle to Upper Devonian age.

The Muth Quartzite is overlain by the Syringothyris Limestone which has yielded brachiopods, crinoids, corals, conodonts, etc. of Tournaisian to Early Visean age. The occurrence of plant fossils has also been recently recorded from the Lower Carboniferous sequence of Lidder valley. The overlying Fenestella Shales contain bryozoans, brachiopods, lamellibranchs, gastropods, crinoids, etc. The brachiopod and lamellibranch fauna from the Fenestella Shales has recently been revised by Waterhouse and Gupta (1977, 1978). The fauna from the Fenestella Shales is suggestive of Late Visean to Bashkirian age. The Agglomeratic Slate Succession is represented by rocks of marine, terrestrial, glacial and volcanic facies which ranges in age from Upper Carboniferous to Lower Permian. The *Gangamopteris* Beds have yielded well-preserved fishes and amphibians. The Panjal Volcanics range in age from Permian to Triassic and at places are intercalated with intertrappean beds. In the Guryul Ravine section the Panjal Traps are overlain by the novaculities and siliceous shales. The Zewan and Khunmuh formations have yielded rich fauna which ranges in age from Middle Permian to basal Triassic. The Permian-Triassic boundary lies within the Khunmuh Formation and is best seen in the Guryul Ravine and Barus sections.

SOUTHERN BELT (POONCH, BHADARWAH DISTRICTS). The Pir Panjal belt extending from Poonch to Bhadarwah forms the southern belt and shows a complete facies variation of the Palaeozoic rocks from the northern belt described above. Wadia (1928, 1934) classified this sequence into Salkhala Formation, Dogra Slates and Tanawals on account of the absence of fossils and dissimilarity in lithology when compared to the Palaeozoic rocks of northern belt. Shah (1978) classified this sequence into Dhera Gali Formation (phyllite and schists), Bafliaz Volcanics, Sailan Formation (laminated pebbly mudstone) and Suinar Formation (conglomerate-orthoquartzite). These units in fact form part of the Tanawals described earlier by Wadia. Similarly, Kalmund Formation and Gamir Formation of Thana Mandi area (Sharma *et. al.*, 1978) are nothing else but part of the Tanawal sequence. The lower age limit of the Tanawal Formation has been defined on the basis of Cambrian acritarchs found within this sequence of type area in Pakistan (Fuchs and Gupta, 1979). The granites intruding into the lower part of Tanawals in the Dalhousie area have been dated as 500 m.y. The upper age limit of the Tanawal Formation has been defined on the basis of the interfingering relationship and gradual passage of this formation with the Agglomeratic Slate Succession. In some sections, the Tanawals (Tanols) show lateral facies variation to dolomites which have yielded Silurian-Devonian fossils (Martin *et al.*, 1962; Davies and Ahmed, 1963). The limestone intercalations within the Tanols in the area south of Sach Pass have yielded Upper Devonian conodonts. We assign a Late Precambrian to Lower or Middle Carboniferous age to the Tanol Formation. The Bhadarwah Slates, Sewa Paragneisses, Sunbain Quartzite and Langera Conglomerate (Sharma, 1976) in the Bhadarwah area represent SE extension of the Tanol Formation.

3.2. Mesozoics

Marine Mesozoic rocks are extensively developed in different parts of Kashmir and these are essentially represented by a thick sequence of fossiliferous Triassics and a few outcrops of Jurassics. The Triassic succession exposed in different parts of Kashmir has generally been classified on the basis of ammonites and other megafossils. Sometimes it becomes difficult to assign precise age to the sequence within the Triassic because of the complete absence of poorly preserved nature of the fauna. However, this problem has partially been solved in recent years by the find of conodonts and other microfossils from different stratigraphic levels within the Triassic succession exposed in various parts of Kashmir. This has helped in defining stratigraphic position of various units within the Triassic and to correlate them with the Triassic succession exposed in other parts of the Himalaya. Of the important contributions on the Triassic conodont biostratigraphy of Kashmir, a mention may be made of papers by Gupta (1976, 1978), Gupta and Kachroo (1977) and Kachroo *et al.* (1980). Chhabra (1977) and Kachroo (1981) have carried out systematic stratigraphic and palaeontological work in some sections as part of their Ph.D. Thesis. The results of these investigations are yet to be published.

LOWER TRIASSIC. The Permo-Triassic sequence in the Guryul Ravine section and spur near Barus has been subject of investigation during the last few years, in consequence of which salient contributions have been made on this important problem in the Kashmir Himalaya. Sweet (1970) recorded the occurrence of *Anchignathodus typicalis* and *Ellisonia teicherti* from the Guryul Ravine section. *Anchignathodus typicalis* defines a zone that straddles the boundary between the Permian and Triassic Systems in different parts of the world. The strata lying above the beds yielding *Anchignathodus typicalis* in the Guryul Ravine section have yielded conodonts which are dominated by *Neogondolella carinata*. *Neogondolella carinata* has also been recorded from the Pastun section. The overlying beds yielding *Neospathodus dieneri* in the Guryul Ravine section are associated with *Ellisonia triassica* and *E. gradata*. The occurrence of conodonts belonging to *Neospathodus dieneri* Zone (*Neospathodus dieneri*, *Cypridodella conflexa*, *C. mulleri*, *Ellisonia* sp. and *Neohindeodella triassica*) has been recorded from the sequence exposed at Lam. The conodont fauna at this locality is associated with foraminifers and ostracodes (*Monoceratina* and *Bairdia*). The conodonts belonging to the *Neospathodus cristagalli* Zone (*Neospathodus cristagalli*, *Prioniodina latidentata*, *Ozarkodina tortilis*, *Enantiognathus ziegleri*, *Hindeodella triassica*, *Diplododella magnidentata*, *Cypridodella mulleri* and *C. conflexa* have been described from the thinly bedded limestone overlying the beds, yielding *Neospathodus dieneri*. These conodonts are also associated with foraminifers and ostracodes similar to those described from the underlying *Neospathodus dieneri* Zone. *Neospathodus cristagalli* in the Guryul section is associated only with *Ellisonia gradata* and *E. triassica*. The lower part of the beds classified as 'Member H' (= *Meekoceras* Bed of Middlemiss, 1909) by Nakazawa *et al.* (1975) has yielded *Neospathodus dieneri*, *N. waageni*, *N. discreta*, *Neogondolella carinata*, *Cyprododella mulleri*, *C. conflexa*, *Ellisonia* spp. and *Neohindeodella triassica*. This conodont assemblage (*Neospathodus waageni Assemblage*) coincides with the ammonoid *Owenites kashmirites*.

The Spathian succession in the Guryul Ravine section, Khrew and at Mandakpal has yielded characteristic conodonts belonging to the *Neogondolella jubata* Zone (*Neogondolella jubata*, *N. elongata*, *Neospathodus triangularis*, *N. homeri*, *N. spathi*). The overlying beds in the Guryul Ravine section and Khrew contain *Neospathodus homeri*, *N. triangularis*, *N. spathi*, *Cypridodella conflexa*, *C. mulleri*, *C. medicris*, *C. unilata*, *Ellisonia* spp. and *Neohindeodella triassica*, age for the beds yielding them. The 'Nodular Limestone' at Khrew, Pastan and Narastan has yielded *Neospathodus timorensis*, *N. homeri*, *N. triangularis*, *Cypridodella conflexa*, *C. mulleri* and *Ellisonia* sp., *Neospathodus timorensis*, suggestive of uppermost Spathian age for the beds yielding them.

The Lower Triassic sequence exposed near Pahalgam has yielded micro-planktons, acritarchs and tasmanitids.

MIDDLE TRIASSIC. Good exposures of Anisian rocks have been recorded at Lam, Mandakpal, Pahalgam-Aru section, whereas Anisian and Ladinian rocks are well developed along the Seshnag-Amarnath section.

The Anisian succession at Lam and Mandakpal has yielded conodonts belonging to *Neospathodus kokeli* Zone (*Neospathodus kokeli*, *N. homeri*, *N. kedahensis*, *Cypridodella conflexa*, *C. mulleri*, *Ellisonia* spp. and *Neohindeodella triassica*). Similar conodonts have recently been found in the section exposed along the Pahalgam-Aru road.

The succession exposed along the Sheshnag-Amarnath section consists essentially of buff-coloured thin-bedded sandy limestones which at places contain *Daonella lomelli* and is associated with bands of shales and sandstones. The limestone units have yielded rich conodont fauna which includes *Gladigondolella tethydis*, *Neogondolella navicula navicula*, *N. concentrica*, *N. mombergensi*, *Epigondolella mungoensis*, *E. hungarica*, *Metapolygnathus polygnathiformis* and *M. excelsus*.

UPPER TRIASSIC. The Upper Triassic succession exposed on the Sheshnag-Amarnath section has yielded Carnian conodonts (*Metapolygnathus polygnathiformis*, *Neogondolella navicula* and *Epigondolella nodosa*). The lower units of this succession contain *Halobia* cf. *comata*, whereas the upper units have yielded poorly preserved specimens of *Spiriferina* (Gupta, 1976*a*, *b*).

The occurrence of *Monotis salinaria*, *Waldhemia globularsi*, *Rhaetina gregaria*, etc., of Noric age has been recorded from the section exposed around Verinag (Tewari *et al.*, 1977). Tewari *et al.* (1978) and Gupta *et al.* (1978) have also recorded the occurrence of following foraminifers, holothurian sclerites, conodonts, fish scales, etc. from the Upper Triassic limestone exposed near Zamalgam :

(*a*) Conodonts : *Epigondolella hungarica*, *E. mungoensis*, *E. nodosa*, *E. bidentata*, *Gladigondolella malayensis*, *G. tethydis*, *Neogondolella mombergensis*, *Metapolygnathus polygnathiformis*, *M. parvus*, *M. spatulatus spatulatus*, *Neogondolella navicula navicula*, *N. navicula steinbergensis*, *Cratognathodus kochi*, *Cratognathodus* sp., *Lonchodina muelleri*, *L. spengleri*, *Prioniodella prioniodelloides*, *P. discrescens*, *Prioniodella* spp.

(*b*) Foraminifers : *Ammodiscus* sp., *Variostoma crassium*, *V. spinosium*, *Lenticulina* sp., *Frondicularia* sp.

(*c*) Holothurian Sclerites : *Thellia* aff. *subcirculata*, *Eocandina subhexagina*, *Calclamna germanica Acanthotheelia spiniperforata*, *Fissobractites* sp.

The microfauna referred to above is suggestive of Norian age for the fossiliferous limestone.

The upper part of the Noric succession in the Lachlung La-Zanskar sections also contains *Epigondolella bidentata* in association with *Misikella hernstenii* and *Neogondolella navicula steinbergensis* (Skwarko *et al.*, 1976).

JURASSIC. The occurrence of isolated patches of Jurassics has been recorded from the synclinorium flexures at the top of Banihal Pass. The succession at these localities has yielded poorly preserved specimens of stretched *Belemnites*.

4. Zanskar Zone

Zanskar Crystalline Complex and Zanskar Supergroup and Tso Morari Crystalline Complex are main tectonic units of this zone (Figure 2).

4.1. *Zanskar Crystalline Complex*

A belt of crystalline rocks having an average width of 20 km is exposed all along the SW part of the Zanskar extending from Tsarap Lingtichu in the east to Sanko in the west. It forms a doubly plunging anticlinorium of regional dimension with a NW-SE trend and closing towards NW in the area between Dras and Suru rivers and towards SE near Shinkun La. Along its northern contact the Zanskar Crystalline Complex forms the basement for the Late Precambrian to Cretaceous-Eocene sequence of the Tethyan zone of Zanskar Supergroup. To the south of it lies the rocks of Late Precambrian to Triassic age of the Bhadarwah-Chamba synclinorium whose relationship is not clearly understood because of lack of geological knowledge of the intervening area (Figure 2).

Zanskar Crystalline Complex has been classified into two broad units (Srikantia *et al.*, 1978). The lower unit consists of streaky and banded gneisses, porphyroblastic and augen gneisses, together with garnet, staurolite, kyanite and sillimanite-bearing gneisses and schist bands. Leucocratic gneiss, rich in muscovite and tourmaline, alternates with coarse-grained biotite gneiss; and amphibolite occurs interbedded within the gneisses. This metamorphic complex is intruded by several granitic, alpitic and pegmatitic bodies. The upper unit is characterized by metasedimentary rocks and migmatite gneisses. It is mainly made up of quartz-biotite schist, quartz-felspar-biotite schist, muscovite schist, calc-phyllite, amphibolite schist, quartz schist and marble together with local occurrences of migmatites and gneisses. Two types of granitic intrusions representing two different phases occur within the crystalline complex. These are foliated biotite granites and unfoliated leucocratic granites.

Based on lithostratigraphy, metamorphic features and tectonic setting the Zanskar Crystalline Complex is correlated with the Central Crystalline Complex of Himachal, Garhwal and Kumaun (Thakur, 1980). The radiometric dating has been attempted for Central Crystalline rocks of these areas. The isotopic data, Rb-Sr, whole rock presented by different workers (Bhanot *et al.*, 1976; Mehta, 1977) for this basement indicated ages of 1830 m.y. for the gneisses, 500-600 m.y. for the deformed granites and of 12-15 m.y. for the micas. These ages have been interpreted by Thakur (1980) as reflecting reactivation of the crystalline basement during different orogenic cycles. It can be inferred that the Zanskar Crystalline Complex may have also undergone deformation and metamorphism similar to that of the Central Crystalline Complex of the Kumaun Himalaya.

4.2. *Zanskar Supergroup*

Zanskar Supergroup with a thickness over 9000 m consists predominantly of Proterozoic and Palaeozoic argillites and arenites together with Permian volcanic rocks and Mesozoic to Eocene carbonates. It is continuous with the Tethys sediments of the Spiti region to SE and with the rocks of the Kashmir basin to the NW and SW. The rocks of the Zanskar Supergroup overlie the Zanskar Crystalline Complex with a gradational passage. They represent platform-type deposits on the continental margin of the Indian plate.

Recently Nanda and Singh (1977) and Srikantia *et al.* (1978) have carried out geological mapping and have described the stratigraphy and structure of the Zanskar Supergroup. One of the authors (V.J.G.) has done detailed biostratigraphic studies of the rocks of this Supergroup and based on his studies the stratigraphy of the individual formation is described here.

PHE FORMATION (CAMBRIAN-LOWER ORDOVICIAN). The rocks belonging to the Cambrian System are exposed in different parts of Ladakh and good sections of these are met with in the Luneak valley of Zanskar where these are classified as part of the Phe Formation. Lithologically the rocks consist of a thick sequence of slates, phyllites, argillaceous quartzites and carbonaceous shales, which are well developed in the Lingtichu (Kurgiakh) and Doda valleys (32°54′45″ : 77°34′00″).

The lower part of the Phe Formation is dominated by the argillaceous sediments represented by phyllites which show development of schistosity near Icheri, giving superficial resemblance to the underlying crystallines. The phyllites are overlain by the dark grey and greenish slates containing at places (Kurgiakh and Ichar) pyrite crystals. A thick band of carbonaceous shales is found at the base of the sequence on the right bank of the Tsarap Lingtichu in Padam-Shila area. The slate sequence near Marling and Ichar is interbedded with fine-to-medium-grained quartzite bands which at places have developed phyllitic partings. The lower part of the Phe Formation in the Luneak Valley contains fucoid remains similar to those found in the Dogra Slates of Kashmir. The slate, shale and quartzite units of the Phe Formation have also yielded *trilobites* (*Elliptocephalus hoffi*, *Agraulos* sp, *Ptychoparia* sp., *Asaphus* sp., etc.) and a few primitive brachiopods suggesting Cambrian to Lower Ordovician (?) age for the beds. Das (1976) has also referred to the find of trilobites (*Ptychoparia* sp. and *Asaphus* sp.) in the slate units of this formation exposed on the bank of Kurgiakh nala and has assigned an Upper Cambrian to

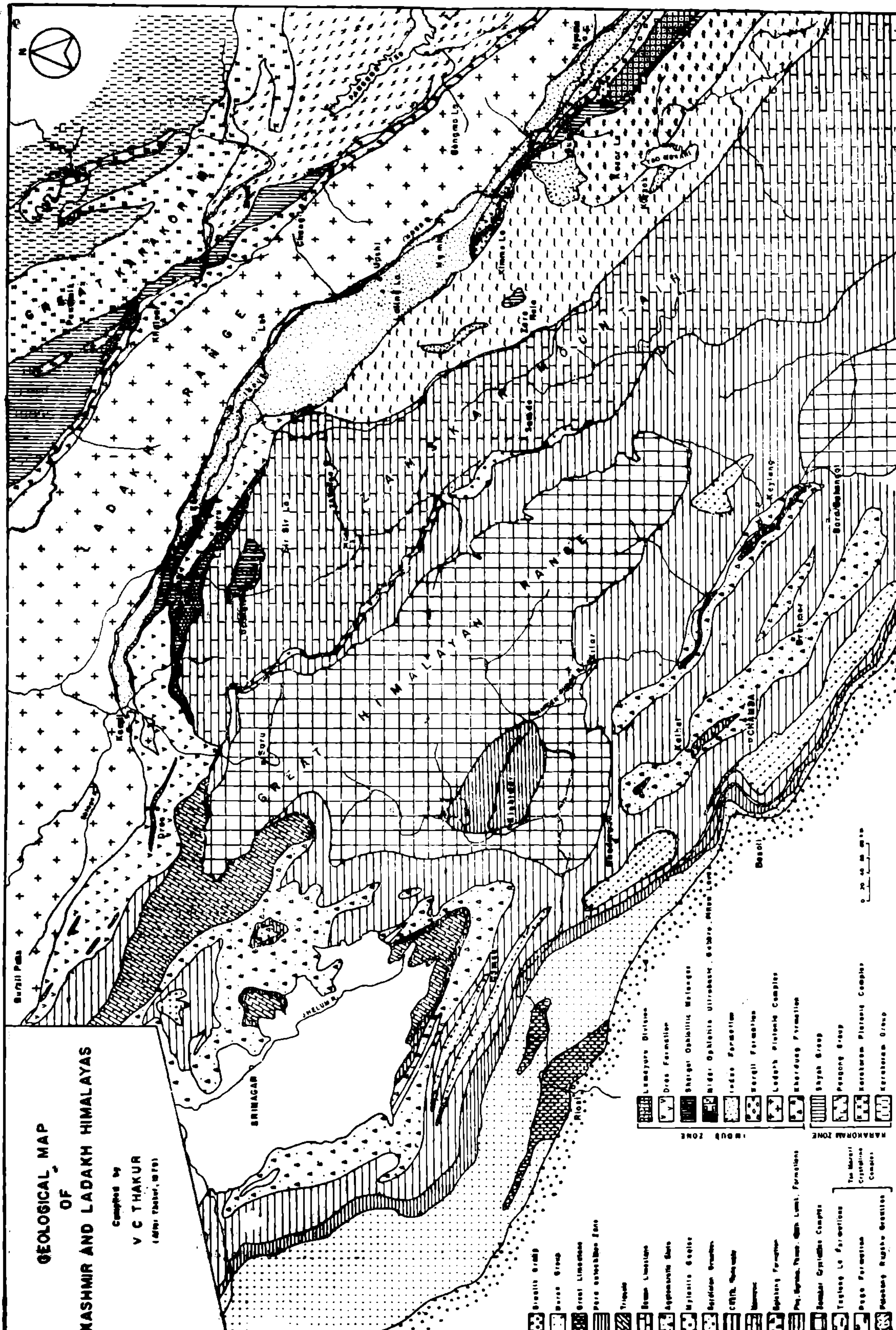

Figure 2. Regional geological map of Kashmar-Ladakh Himalayas (modified after Thakur, 1979).

Lower Ordovician age to it.

The brown-coloured dolomites interbedded with cross-bedded quartzites in the Zing-Zingbar area and Panchi nala section may, in parts, be of Cambrian age. The slate and quartzite sequences near Darcha have yielded fucoid remains.

TABLE 3—CLASSIFICATION AND CORRELATION OF THE PALAEOZOIC ROCKS OF LADAKH

System	*Lingti Valley and Sarchu Plains* (Gupta, 1973)	*Luneak Valley and Adjoining Areas*
Permian	Sarchu Limestone Malung Shales	Ralakung Volcanic Succession Grey to cream-coloured thinly bedded limestone, shales and phyllites
	Unconformity	
Carboniferous	Fenestella Shales Lingti Series	Luneak Formation
Devonian	Muth Quartzite	Muth Quartzite
Silurian	Dirty grey quartzite, earthy shales and sandstones yielding *Orthis basalis*, *O. testudinaria*, etc.	Tanze Formation
Ordovician	Dirty grey quartzite, earthy shales and sandstones yielding *Orthis* (*Dalmanella*) *chaungzonensis*, *Monotrypa*, etc.	Karsha Formation
Cambrian	Shaly phyllite, quartzite and grey limestones yielding *Hyolites* and *Coleoloides*	Phe Formation
	Crystallines—granites, schists, quartzites, marbles, migmatites, etc.	Suru Crystallines-Gneisses (banded gneisses, augen gneiss, streaky gneiss), schists, intruded by pegmatites and quartz veins

KARSHA FORMATION (UPPER ORDOVICIAN-LOWER SILURIAN). The Phe Formation in the Luneak valley is conformably overlain by medium-to-coarse-grained dark blue to pale grey crystalline limestones of varying thickness which are interbedded at places with bands of quartzites, phyllites and greywackes. The succession overlying the Phe Formation is classified as part of the Karsha Formation. The lower units of this succession have yielded trilobites (*Onnia abducta*, *Dalmanites* cf. *gracilis*), cystoids (*Codiocystis* sp., *Dendrocystis* sp.) and a few primitive brachiopods suggesting Caradocian to Ashgillian age for the fossiliferous beds. The limestone bands near Karsha-(32°32′00″ : 77°54′15″)-Tokpo-Sasringe have also yielded poorly preserved brachiopods. A thin band occurring near the top of the succession and grading into calcareous phyllites has yielded specimens of *Spirifer* (*Howellella*) *laeviplicata* and *Pisocrinus* cf. *P. pilula*. *Spirifer* (*Howellella*) *laeviplicata* is suggestive of Silurian age, whereas the *Pisocrinus* cf. *P. pilula* is a north hemisphere form ranging in age from Early Silurian to Early Devonian.

The phyllitic horizon forming the upper part of the Karsha Formation contains poorly preserved specimens of brachiopods (*Plectambonites* (?) sp.), deformed pygidia of trilobites (*Dalmanites* (?) sp.) and crinoid oscicles and stems. The poorly preserved fauna from the upper units of the Karsha Formation is indicative of Silurian age. The lower units of this formation may probably grade into the Ordovician succession.

A thick sequence of green shales, pink and purple quartzites, siltstones, brown-weathered dolomites and lenses of conglomerates near Mirbutphung (32°52′ : 77°27′) in the Yunnam valley, around Tempola (32°48′ : 77°18′) in Panchi nala section and inliers west of Surichun La may be of Ordo-Silurian age. The dolomites at places contain stems and oscicles of crinoids.

In the Zingzingbar-Baralacha La Section of Lahaul-Ladakh region the Ordovician-Lower Silurian succession is represented by dirty grey quartzites, earthy shales and sandstones containing a few poorly preserved brachio-

TABLE 4—CLASSIFICATION OF THE PALAEOZOIC SUCCESSION OF LUNEAK VALLEY, LADAKH

Nanda and Singh (1976)			*Srikantia* in *Srikantia et al.* (1978)			*Gupta (1978)*	*Gupta (1979)*
Riman Member Phitsi Member	Ralakung Formation-Permian		Kuling Formation (160 m)	Gungri Member Gechang Member	Permian	Ralakung Volcanic Succession-Permian	Ralakung Volcanic Succession-Permian
							Unconformity
Member C Member B Member A	Tanze Formation	Upper Member Middle Carboniferous Lower Member Lower Carboniferous	Kanawar Group (1750 m)	Gammachidam Formation Po Formation Lipak Formation	Carboniferous	Luneak Formation Lower Carboniferous	Luneak Formation Lower Carboniferous
	Kenlung Formation	Devonian	Muth Formation (150 m)	Middle to Upper Devonian		Muth Quartzite Devonian	Muth Quartzite Middle to Upper Devonian
D Member C Member B Member A Member	Thaple Formation	Silurian	Takche Formation (30 m)	Upper Silurian to Lower Devonian		Tanze Formation Silurian	Tanze Formation Upper (?) Silurian Lower Devonian
Thidsi Member Mauling Member	Karsha Formation	Ordovician				Karsha Formation Upper Ordovician Silurian	Karsha Formation Upper Ordovician to Upper Silurian
Thonde Member Doda Member Tsarapchu Member	Phe Formation	Cambrian	Haimanta Group	Thango Formation (400 m) Kunzamla Formation (800 m) Batal Formation		Phe Formation Cambrian	Phe Formation Cambrian-Middle Ordovician
Unconformity							
	Suru Formation Precambrian					Suru Crystallines Precambrian	Suru Crystallines Precambrian

pods, bryozoans and crinoid stems and oscicles. Near the top of the Baralacha La, this succession has yielded a few poorly preserved orthids. The calcareous siltstones, argillaceous limestones and grey to buff-coloured limestone yielding brachiopods, bivalves and crinoids in the Tempo La section in Panchi nala and Suraj Dal may be of Silurian age. The brachiopods from this section are similar to those found in the Karsha Formation.

TANZE FORMATION (UPPER SILURIAN-LOWER DEVONIAN). The Karsha Formation in the Luneak valley is conformably overlain by a thick succession of gritty quartzites, shales, phyllites, slates and conglomerates which is classified as part of the Tanze Formation. This succession is well exposed between Tanze (34°08′30″ : 77°13′15″) and Kargiakh villages. The lower units of this succession are essentially represented by purple to grey-coloured gritty quartzites which have yielded well-preserved crinoids (*Crotalocrinites* (?) sp., *Parapisocrinus ollulagrandis* and an indeterminate Melocrinitid). *Crotalocrinites* is known to occur in the Middle and Lower Upper Silurian strata of Europe, Russia and North America. Melocrinitids range from Early Silurian through Devonian. *Parapisocrinus olullagranids* is reported from Upper Silurian to Lower Devonian rocks of Bohemia. The conglomerate bands occur interbedded within the quartzites in the middle part of the succession. The upper units of this succession have yielded trilobites (*Phacops* cf. *tindoutensis*), crinoids (*Triscrinus orisconeavus*) and fish remains. The fauna is suggestive of Middle Devonian age for the upper part of the Tanze Formation. The uppermost units of the Tanze Formation are essentially conglomeratic and the conglomerates are composed of pebbles of purplish quartzites, phyllites and limestones which are cemented together with calcareous and siliceous matrix indicating their source from the underlying crystallines, Phe and Karsha Formation. The entire sequence at places is traversed by veins of quartz. The Tanze Formation may range in age from Upper Silurian to Lower Devonian.

MUTH QUARTZITE (MIDDLE TO UPPER DEVONIAN.) The snow-white Muth Quartzite forms the most important stratigraphic marker in Ladakh. Its good sections are exposed at the top of Baralacha La, Sarchu Plains, Yunnam valley, Nirubutphung and parts of Luneak valley. In the Tanze area of Luneak valley, the conglomerates of the Tanze Formation are conformably overlain by a thick horizon of hard, compact, milky white, mottled siliceous and jointed white quartzite, which at places show presence of brown ferruginous specks similar to those found in the Naubug valley of Kashmir. Occasionally, sericitic material is found at the contact along the bedding plane of quartzite. The quartzites at places show cross bedding and ripple marks. The upper units of this succession at places has well-developed sequence of argillaceous dolomites weathering to brown colour.

The Muth Quartzite exposed at the top of Baralacha La has yielded *Schellwienella williami*. The limestone intercalations within this quartzite have yielded conodonts, fish remains as well as invertebrate carapace fragments ornamented with thin parallel ridges. The fish remains although very fragmentary may be referred to as acanthodian scales and spines. The conodonts from this locality include *Polygnathus linguiformis linguifoxmis*, *P. pennatus*, *P. webbi*, *P. varcus*, *P. coelata*, *P. estaensis*, *Ancyrodella rotundiloba rotundiloba*, *Ancyrodella rotundiloba alata*, *Bryantodus typicus*, *Ozarkodina regularis*, *Lonchodina* sp., *Icriodus* sp., *Hindeodella subtilis*, etc.

The Muth Quartzite has been assigned Middle to Upper Devonian age on the basis of fossils found within the quartzite succession exposed in different parts of the Himalaya.

LUNEK FORMATION (LOWER CARBONIFEROUS). The Lower Carboniferous succession in parts of Ladakh is represented by the grey limestones and quartzites, which at places is intercalated with brownish calcareous and arenaceous shales. The limestone is hard and splintery and is associated with gypsite at a number of places. This succession is richly fossiliferous and contains well-preserved brachiopods (*Syringothyris cuspidata*), crinoids and a few poorly preserved specimens belonging to other groups. In the area southeast of Surichun La in Ladakh, the limestone has yielded a few specimens of crinoids (*Proampelocrinus himalayaensis*, *Kallimorphocrinus indicus*), conodonts (*Gnathodus delicatus*, *G. punctatus*, *Ozarkodina curvata*, *O. roundyi*, *Panderodella glabra*, *Polygnathus inornata*, *P. communis*, *P. radina*, *Siphonodella cooperi* and *Spathognathodus longus*), ostracodes (*Paraparchites* sp.), bryozoans, fish scales and brachiopods (*Retichonetes chiplonkeri*, *Chonetes kashmiriensis*).

The Lower Carboniferous succession in the Luneak valley is classified as part of the Luneak Formation. It consists of a thick succession of grey to greyish black and bluish limestone, slates, carbonaceous shales and white quartzite. The lower part of the sequence is essentially dominated by limestones whereas in the upper part slaty and shaly sequences dominate. The limestone units have yielded several forms of brachipods (*Syringothyris cuspidata*, *Rhynchonella* sp., *Retichonetes chiplonkeri*, *Chonetes kashmiriensis*, *Derbyia* sp., *Choristites mosquensis*), a few poorly preserved bryozoans (*Polypora* sp.) and conodonts (*Elitcognathus lacerata*, *Gnathodus bilineatus*, *G. defecius*, *Idiognathodus* sp., *I. delicatus*, *Pseudopolygnathus prime* (?), *Siphonodella cooperi*, *Siphonodella* sp., *S.* cf. *cooperi*, *Spathognathodus campbelli* and *Ligoncdina*), crinoids (*Proampelocrinus himalayensis* and *Kallimorphocrinus indicus*), and ostracodes (*Paraparchites* sp.). In the area between western and eastern parts of Sarchu nala and Upraru the bluish grey limestone is associated with gypsum beds. However, in the Nirbutphung area white quartzite dominates the succession, where these are intruded by basic dykes and are associated with calc-silicate rocks.

The Luneak Formation around the village Tanze (34°08′30″ : 77°13′15″) and to the south appears to have a tectonic contact with the underlying Muth Quartzite. The maximum development of this formation is seen in the nallah north of the Tanze village, where it consists essentially of grey to greyish black platy limestone which at places is interbedded with thin bands of black shales, dolomitic limestone, slates and sandstones. In the Kurgiakh (33°03′50″ : 77°13′40″)-Thaple (33°03′45″ : 77°13′00″) areas the limestone is associated with beds of gypsum.

The Lower Carboniferous succession in the Lingti valley of Ladakh is classified as part of the Lingti Series which is essentially composed of grey limestone and black shales. The first outcrop of the grey limestone containing brachiopods is met with at Kilang. In addition, the occurrence of this limestone has also been observed at the top of several peaks around Baralacha La. The fossils from this limestone include *Productus semireticulatus*, *Linoproductus cora*, *Syringothyris* sp., *Rhynchonella* sp., *Spirifer* sp., *Strophalosia* sp., *Syringopora* sp., *Orthoceras* sp., and a few crinoid stems and ossicles.

Mathur and Pal (1979) have recorded the presence of Lower Carboniferous fossils from the blocks of crystalline limestone exposed in a cliff 400 metres, north of Lamayuru in Ladakh. The fossiliferous limestone is exotic in nature and is associated with the Lamayuru Flysch (Triassic) which lies above the Indus Formation with a tectonic contact. The fossils from the limestone blocks include *Syringothyris cuspidata, Dielasma kanauricum, Eumphalus* sp., *Phillipsia* aff. *cliffordi, Campyloceras* sp. These fossils are suggestive of Lower Carboniferous age for the fossiliferous limestone. Similar limestone horizons have also been recorded from near Mulbekh.

MIDDLE CARBONIFEROUS. The fossiliferous limestone succession (Luneak Formation) of the Luneak valley is conformably overlain by the grey and cream-coloured limestone and shale. This succession may belong to Late Mississippian and its upper limits may extend upto Pennsylvanian or even younger. In some sections, the Luneak Formation is overlain by the white, greyish white quartzite and carbonaceous shales with local intercalations of calcareous bands and nodules. These are at places intruded by dolerite dykes. In some sections of the Baralacha La area the Po Formation rests directly over the Muth Quartzite, whereas in the area east of Sarchu nala it is cut off along a fault. This sequence in the Upraru section has yielded rich assemblage of fossils including bryozoans, corals, brachiopods and bivalves. The upper units of the limestone exposed SE of Surichun La in Ladakh have yielded Chesterian to Pennsylvanian (possibly Morrowian) conodonts *Ozarkodina roundyi, Panderodella glabra, Polygnathus inornata, P. communis, P. radina, Siphonodella cooperi* and *Spathognathodus longus* belonging to *Siphonodella cooperi-Gnathodus punctatus* Zone.

The black carbonaceous shales lying above the Syringothyris Limestone in the Baralacha La-Kilang Section correspond to the Fenestella Shales. The Fenestella Shales exposed in different parts of the Himalaya have yielded Mid-Visean to Bashkirian fauna.

UPPER CARBONIFEROUS. In the area south of Baralacha La and north of Sarchu the Po Formation is overlain by diamictites. These in turn are overlain by coarse gritty quartzitic sandstones and conglomerates. The clasts range in size from granule to cobble and are subrounded to subangular in shape. These are composed of white and purple quartzite, brown to grey dolomite, slate, limestone, vein quartz and quartzo-felspathic granite. The clasts are embedded in quartzitic matrix with ferruginous to siliceous cements. The quartzite interbeds show graded bedding.

RALAKUNG VOLCANIC FORMATION. In the Zanskar valley, Ladakh, there is a linear belt of volcanic rocks, extending from Ringdom Gompa in the west to the Lingti valley in the east, which have been considered as equivalent of the Panjal Volcanic Succession of Kashmir by Singh *et al.* (1976). Srikantia *et al.* (1978) have used the term Phe Volcanics for this volcanic succession and have also correlated these valcanics with the Panjal Volcanic Succession of Kashmir.

The Ralakung Volcanic Formation is made up of basic to intermediate volcanic rocks of greenish grey colour, medium-to-fine-grained and at places schistose in nature. On the basis of mineralogical and textural characters, the massive, porphyritic and vesicular varieties have been recognised. Under the microscope, the massive variety shows abundance of felspar microlites, altered clinophyroxenes, epidote, calcite, ilmenite, quartz, clinozoisite and chlorophasite which are embedded in a palagonised glassy mass. Flow pattern though faint is often recognisable. The porphyritic variety consists of plagioclase, felspar, diopside-augite, quartz and iron ore with palagonised glassy base. The main alteration products are chlorite and epidote. A few grains of hypersthene and olivine are also noticed. The vesicular variety is composed of saussuritised plagioclase felspar, mostly albite occurring as microlite laths and crystals with definite boundaries. Microlites form a felted mat and show no sign of directional orientation. The other mineral constituents are augite and diopside which, at times, are replaced by epidote and chlorite set in a glassy base with iron oxides as opaque minerals as masses and skeletal bodies. Apatite, calcite and ilmenite occur as accessories. The vesicles have an average size of 0.5 centimetres and are ovoid, ellipsoidal, rounded and elongated in shape. These vesicles are commonly filled with quartz, epidote, calcite, chlorite, pumpellyite and zeolites. The ferromagnesium minerals occurring as amygdule are generally isotropic but are slightly anisotropin in spherulitic or fibrous form which is identified as chlorophasite.

The chemical analysis of the representative samples of Ralakung Volcanic Formation shows higher soda and potash content, and slightly lower TiO_2 content than the Panjal Volcanics. Ralakung Volcanic Formation shows an imperceptible gradation between the tholeiitic and alkali olivine basalts. The solidification index is between 32 and 43. According to Gupta *et al.* (1979) Ralakung Volcanic Formation belongs to middle and late stages of fractionation but no late stage differentiates have been recognised. Both these volcanics, i.e., Ralakung and Panjal show a remarkable resemblance in differentiation of the constituents. Only in case of CaO and Na_2O, the Ralakung Volcanic Formation shows a sharp decrease in the late stage.

Singh *et al.* (1976) proposed the classification for the Ralakung Volcanic Formation as shown in Table 5.

The Ralakung Volcanic Formation in the area west of Rangdum Gompa along the Sankpoo river is highly

TABLE—5

Formation	Member	Lithology
Ralakung Volcanic Formation	Riman Member	Dark green, greyish green, hard compact, fine-to-medium-grained, vesicular to amygdaloidal lava flows with inter-trappean limestone containing fossils of Zewan affinity
	Phitsi Member	Dark grey-brown Agglomeratic Slates and conglomerates with fragments of quartz and phyllite embedded in a fine-grained matrix

altered and consists of light to dark green schistose rocks, biotite-hornblende gneiss and amphibolite. In the area south of Rangdum a boss of coarse-grained porphyritic two-mica granite-gneiss is seen in contact with the Ralakung Volcanics. The Upper Palaeozoic rocks of the syncline south of this granite gneiss body are altered to rocks of amphibolite facies (Fuchs, 1977). Similar succession is also exposed in the Suru (Panikar) region and Chilung Pass. The amphibolites found associated with the calc-mica schist in these areas represent Ralakung Volcanic Formation.

In the Tanze section of Luneak Valley, the Ralakung Volcanic Formation (280 m thick) overlaps the Luneak Formation of Early Carboniferous age and the volcanics are best developed around Ralakung (33°21′00″N : 76°43′00″E). In some sections these volcanic rocks directly overlie the Cambrian-Lower Ordovician beds whereas the intermediate succession from Ordovician-Carboniferous has been faulted out (Das, 1976).

The basal members of the Ralakung Volcanic Formation near Tanze have a horizon up to 30 m thick of pyroclastic and tuffaceous rocks consisting of rock fragments of varying types and sizes, resembling the volcanic facies of the Agglomeratic Slate of Kashmir. It grades conformably into the lava flows which correspond to the Panjal Traps of Kashmir.

Joshi and Arora (1976) have reported the occurrence of a thin sedimentary band at the top of Ralakung Volcanic Formation. This band has yielded Upper Permian fossils (*Xenaspis* sp. cf. *X. carbonaria* and *Cyclolobus* sp.) indicating upper limit of these volcanics as Middle to Upper Permian.

The inter-trappean limestone in the Riman Member has yielded *Productus cora*, *Spiriferella rajah*, *Spirifer tibeticus*, *Eumphalus* sp., *Bellerophon* sp. and *Pentacrinus* sp., indicating its age to be Lower to Middle Permian.

Gupta and Waterhouse (1978) have described (?) *Derbyia* sp., *Kiangsiella* sp., *Juresania* aff. *juresanensis*, *Retimarginifera* sp., and (?) *Cleiothyridina semiconcava* from the upper units of the marine intercalations found within the Ralakung Volcanic Formation. This fauna clearly differs from those of the *Eurydesma cordatum* (Asselian) and *Taeniotherus permixtus* Zones of the Nagmarg Formation, Kashmir and from the *Brachythyrinella* Zone of the Bijni Tectonic Unit of Garhwal (Waterhouse and Gupta, 1977, 1978). This fauna underlies fossils of the *Lamnimargus himalayensis* Zone and as such should come within the Late Sakmarian to Kazamian time interval. According to Gupta and Waterhouse (1978), the occurrence of *Derbyia*, *Retimarginifera* and *Reticulatia* from the upper units of the Ralakung Volcanic Formation is indicative of a Baigendzinian age. This age is also supported from the presence of shells close to the Baigendzinian species *Cleiothyridina semiconcava*. On the other hand, *Juresania* might indicate Aktustinian age, and its being of Kungurian age cannot be ruled out. In spite of these contradictions, it could be safe to assign Aktustinian age to the fauna, i.e., Upper Sakmarian or possibly Baigendizinian. These conclusions are open to revision till more data is available.

SARCHU SERIES (PERMIAN). The Sarchu Series can be subdivided into two stratigraphic units, i.e., the Malung Shales and the Sarchu Limestone. Both these units seem to have tectonic contacts with one another and as a result Sarchu Limestone apparently lies over the Malung Shales. The Permian rocks in Ladakh are developed in the area around Sarchu plains.

The Malung Shales are well exposed in the Malung river and these consist of a thick succession of grey and black carbonaceous micaceous shales, limestones and sandstones. The shales are generally unfossiliferous whereas the limestones and sandstones have yielded the fossils of *Eurydesma cordatum*, *Callispirina* sp., *Spirigerella* sp., *Crurithyria extima*, *Hustedia* sp., *Strophalosia* sp., *Conularia* sp., *Straparolus* sp., *Naticopsis* sp.

Gupta and Waterhouse (1978) have examined part of fauna from the Malung Shales and have assigned Early Permian age to it.

The Sarchu Limestone lies in the juxtaposition with Malung Shales which contain *Eurydesma hobartense* of

Lower Permian age. The Sarchu Limestone is well exposed in the Sarchu nala and consists of a thick succession of pale brown and grey limestones. The basal members of this limestone succession have yielded rich assemblage of fusulinids (*Schwagerina princeps*, *S. nelsoni*, *S. laxissima*, *S. diversiformis*, *S. garlockensis*, *Triticites ventricosus*, *T. meeki*, *T.* (*Jigulites*) *altas*, *Pseudofusulina* sp., *Parafusulina kattaensis*, *Fusulina prolifica*). The fusulines appear to be of Early Permian age (Gupta *et al.*, 1970; Gupta and Kahler, 1973). The Early Permian age of this horizon is also confirmed by the find of an isolated specimen of *Juresania* in the beds immediately above the fusulina-bearing horizon.

The upper units of Sarchu Limestone have yielded fauna corresponding to *Lamnimargus himalayensis* Zone and these include *Lamnimargus himalayensis*, *Spiriferella rajah*, *Spiriferellina* sp., *Neospirifer* sp., (?) Comarotoachid gen. and sp. indet.

Lamnimargus himalayensis is reliably known only from the *L. himalayensis* Zone of the Tibetan Zone in the Himalaya and is considered to be of Punjabian age. *Spiriferella rajah* is also common in this zone, but possibly ranges into higher faunas of North-West Nepal, correlated with the Darashamian Stage (Waterhouse, 1978).

The limestones forming the transition between the fusuline-bearing horizon and the *Lamnimargus himalayensis* Zone have yielded conodonts identified as *Ozarkodina tortilis*, *Gnathodus* sp., *Gondolella rosenkrantzi*, *Cyprodella mulleri*, *Ellisonia* sp. The conodonts are suggestive or Kungurian or Kazanian age for the beds yielding them (Waterhouse, 1976).

Srikantia *et al.* (1978) have recorded the occurrence of *Eurydesma cordatum* and *Deltopecten* cf. *mitchelli* from the Kuling Formation (Permian) exposed near Baralacha Ban area, about 7 km southeast of Baralacha Pass, in the Lahaul valley. The identification of *Eurydesma cordatum* by Srikantia *et al.* (1978) does not seem to be correct. According to Gupta and Waterhouse (1978) the specimen figured by Srikantia *et al.* (1978) has a high umbo and short but very high outline that recalls *Eurydesma manenderagarhensis* from Manendergarh.

In the area south and southeast of Uparu (about 6 km southeast of Baralacha La) a thick succession of conglomerates and sandstones of Lower Permian age overlies the rocks of Kanawar System (Lower to Middle Carboniferous). The conglomeratic horizon is, in turn, overlain by the calcareous sandstones and Productus Shales of Middle to Upper Permian age.

TRIASSIC. The Triassic rocks are exposed in different parts of Ladakh and good sections of these are exposed in the Luncak Valley, Sarchu Plains and in the region between Sarchu and More Plains. No systematic attempt has till date been made to work out the detailed biostratigraphy of the Triassic rocks of this region similar to the studies made by earlier workers in Kashmir, Spiti and Kumaun.

The Triassic rocks of Ladakh are poor in megafossils and this fact makes it difficult to classify them precisely and to correlate them with the corresponding horizons exposed in other parts of the Himalaya. The stratigraphy of the Triassic rocks has been further complicated due to the fact that these rocks in Ladakh are highly folded and it is difficult to work out their precise thickness on account of their being devoid of megafossils. During the course of palaeontological investigations in different parts of Ladakh during several field seasons good collections of Triassic rocks were made from different stratigraphic horizons. The samples collected from Baralacha La (32°45′ : 77° 24′ 30″), Sarchu (32°48′ 00″ N : 77° 30′ 50″ E), Uparu (32°40′ 30″ : 70° 27′), Lachlung La (30° 05′ 30″ : 77° 36′ 30″), Tingting Khur (32° 54′ 30″ : 70° 35′), Togosiru (33° 10′ 30″ : 77° 47′ 30″) and Gata were macerated for the study of conodonts and other microfossils. Some of these samples have proved fruitful and yielded good assemblage of conodonts of Dienerian-Smithian, Ladinian, Carnian and Norian age.

A generalized stratigraphic succession of the Triassic rocks exposed in different parts of Ladakh is given in Table 6.

SCYTHIAN-LADINIAN. The Permian rocks in parts of Ladakh are conformably overlain by about 10 m thick sequence of thinly bedded grey limestone with intercalations of shaly horizons which are well exposed in the area south and east of Sarchu. This includes a number of stratigraphic horizons which correspond to the classic sections exposed in different parts of the adjoining Spiti valley. These zones include from the basal *Otoceras* Beds of the basal Triassic age to the *Daonella* Limestone of Ladinic age.

The grey siliceous limestone at Togosiru lying immediately above the carbonaceous shales of Permian age has yielded Dienerian-Smithian conodonts including *Neogondolella carinata*. The limestone yielding conodonts in the Togosiru section has also yielded specimens of *Claraia* and *Pseudomonotis*. Similar sequence is also exposed in Tingting Khar area where the limestone contains broken shells of bivalves.

In view of the difficulties in distinguishing the sequence overlying the *Daonella* Limestone on lithological

TABLE—6

Rhaetic	Kioto Limestone (500-700 m)	Massive limestone and dolomites with *Spirigera noetlingi* *Megalodon ladakhensis* and *Dicerocardium ladakhensis*
Noric		Quartzite, limestone and shales with *Athyris maniensis*, *Spirigera* spp., etc. (50 m)
		Sandy and shaly limestone with *Monotis salinaria* (20 m)
		Limestone, shale and quartzites with *spiriferina griesbachi* (50 m)
		Coral limestone and sandstones with *Spiriferina griesbachi*, *Athyris maniensis* and *Monotis salinaria* (20 m)
Carnic		Hard, dark splintery limestone, shaly limestone (20 m)
		Dolomitic limestone with brachiopods (*Dielasma*, etc.) (80 m)
		Shaly limestone and shales with *Spiriferina*, *Rhynchonella* (70 m)
		Dark limestone with *Halobia* cf. *comata* (40 m)
Ladinic		Dark splintery limestone with *Halobia* cf. *comata* and *Spiriferina* (25 m)
		Black limestone and shales with *Daonella lommeli* and *Ptychites* (60 m)
Anisic		Upper Muschelkalk—concretionary limestone with *Ptychites rugifer* (4 m)
		Lower Muschelkalk dark compact black shale and limestone with *Spiriferina stracheyi* and *Keserlinsites dieneri* (1.00 m)
		Dark shaly nodular limestone with *Rhynchonella griesbachi* (15 m)
Scythian		Grey limestone with shaly intercalations containing *Pseudomonotis* and *Flemingites rohilla* (8 m)
		Grey limestone with shaly intercalations containing *Pseudomonotis* and *Flemingites rohilla* (8 m)
		Thin-bedded limestone with *Meekoceras varaha* (0.8 m)
		Grey limestone with *Ophioceras sakuntala* (0.4 m)
		Brown limestone with *Otoceras woodwardi* (0.5 m)

Permian shales, limestone and interbedded quartzite

grounds, the possibilities of a part of this sequence corresponding to the *Halobia* and grey beds of Carnic age cannot be ruled out.

In the Upraru section of Ladakh, the Triassic sequence is more than 300 metres thick and has yielded characteristic bivalves (*Daonella lomelli*, *D. indica*, *Pseudomonotis*) in association with *Juvavites* etc. The lower units of this section exposed in the Upraru area have also yielded poorly preserved ammonites of (?) Anisian age. The hard limestone containing bivalves has yielded fairly well-preserved conodonts of Longobardian age.

CARNIC. The Carnic succession in parts of Ladakh is represented by thickly bedded crystalline, grey, white and brown limestone corresponding to the *Tropites* Beds of Spiti. These beds are well exposed in the Umnag nala section. The lower units of these comprise grey shales with bands of limestone, whereas the upper units contain grey, white or creamy white, friable limestone with intercalations of thick bands of grey calcareous shales. The grey limestone exposed near the top of Lachlung La has yielded Cordevolian-Julian conodonts.

NORIC. The strata corresponding to the grey beds of Carnic age are conformably overlain by a thick sequence which consists of grey phyllitic slates, slaty shales, dark sandy and shaly limestone, sandstone and quartzites. This succession at places is fossiliferous but it is difficult to demarcate precisely the biostratigraphic zones within this sequence. The lower units of this sequence possibly belong to the *Juvavites* Beds which are well exposed in the higher reaches of Umnag and Kurbarudin *nalas* and in the section exposed between Lachlung La and More Plains.

The middle part of the succession is essentially argillaceous and is intercalated with limestone bands which may correspond to the 'Coral Limestone' of Noric age. The youngest unit in the succession is essentially represented by grey platy limestone yielding at places *Monotis salinaria*. The limestone exposed in the Gata area have yielded a few corals (*Montlivaltia* sp.) and brachiopods (*Rhynchonella* sp., *Terebratala* sp.), bivalves (*Pecten* sp.), etc.

The beds referred to above are, in turn, followed by about 50 metres thick succession of fine-to-medium-grained, brown, grey and white massive quartzites. In some sections, i.e., Kurbarudin *nala* section the quartzitic horizons are interbedded with bands of limestone. In the Umnag *nala* section these quartzites have yielded brachiopods of probable Upper Noric age.

The greyish blue and black limestone exposed near Kangla Jar is at places oolitic in nature and contains at places fragmentary corals of probable Upper Noric age. Similar succession exposed at the top of Lachlung La have yielded well-preserved assemblage of Lacian conodonts (*Gondolella steinbergensis*, *G. navicula*, *Metapolygnathus abneptis abneptis*, *M. abneptis spatulatus*, *M. posterus*, *M. bidentatus bidentatus*, *Cratognathodus kochii*, etc.) The conodonts are suggestive of Upper Norian age for the beds yielding them. Similar fauna has also been recorded recently from the Upper Triassic succession of northeastern Kumaun (Gupta *et al.*, 1978).

The uppermost units of the Triassic succession in Ladakh are represented by 500 to 700 metres thick sequence of massive limestone and donomites yielding at places well-preserved specimens of *Megalodon ladakhensis* and *Dicerocardium cordatum*. The limestone is of hard, grey and massive nature and is similar to the famous Kioto (=*Megalodon*) Limestone of the Spiti valley.

JURASSIC OF LADAKH. Jurassic crinoids have been described from the Spiti Shales Succession occurring in the core of a synclinal fold in the Charrap valley by Gupta and Webster (1980). The following stratigraphic sequence within the shales is described :

4. Black shales with ferruginous horizons containing Crinoids, *Solanocrinites* (*Comatulina*) *himalayensis* and *S.* (*C*) *truncus* and poorly preserved ammonites (=Lochambal Formation) —50 m.
3. Black nodular shales —15 m.
2. Carbonaceous and dark calcareous shales containing *Eugeniacrinites formosus* and *E. himalayensis* (=Chidamu Formation) —20 m.
1. Dark grey to greyish black nodular shales—15 m.

Horizon no. 2 yields *Eugeniacrinites formosus* and *E. himalayensis* and may correspond to the Chidamu Formation of the Spiti Shale Succession which is considered to range from Upper Kimmerdgian to Lower Tithonian. Horizon 4, yielding *Solanocrinites* (*Comatulina*) *himalayenis* and *S.* (*C*) *truncus* corresponds to the Lochambal Formation of Spiti Shale Succession which is considered to range from Upper Tithonian to Berriasian or Valanginian.

4.3 Tso Morari Crystalline Complex

In the western Ladakh, rocks of the Indus Suture Zone come in direct contact against the sediments of the Zanskar Supergroup, whereas in the eastern Ladakh a belt of low to high grade metamorphic rocks referred to as the Tso Morari Crystalline Complex intervene between the two (Figure 2). These rocks were previously described as Precambrian and a continuation of the Central Crystallines (Berthelsen 1953; Gansser 1964; Gupta *et al.* 1970; Shankar *et al.* 1976 and Srikantia and Bhargava 1978). Recently, Virdi *et al.* (1978) have reported numerous fossiliferous horizons in the upper part of the metamorphics; the fauna in these has a Tethyan affinity and indicates Upper Carboniferous to Triassic age.

Rocks of the Tso Morari Crystalline Complex are folded into a large doubly plunging, NW-SE, anticline called Tsokar-Kiagar La Anticline showing progressive regional metamorphism. The kyanite grade in the core passes to chlorite grade towards the outer limbs of the structure. Thakur and Virdi (1979) have divided the rocks of the Tso Morari Crystalline Complex into three units. These are : Puga Formation, Taglang La Formation and Polokong Rupshu Granites.

PUGA FORMATION. Puga Formation constitutes lower part of the Tso Morari Crystalline Complex. It consists of medium to high grade metamorphic rocks such as biotite, garnet kyanite and sillimanite-bearing schist and gneisses, augen gneiss and amphibolites. These rocks occupy the core of the anticlinal structure and show progressive decrease in metamorphic grade without any apparent break to the chlorite grade of the overlying metasediments of the Taglang La Formation. To NE, rocks of the Puga Formation are overthrust by the Shergol Melange of the Indus Suture Zone, and to SW they show gradual passage without any apparent stratrigraphic and metamorphic break into overlying rocks of the Taglang La Formation. As the rocks overlying the Puga

Formation have yielded Upper Carboniferous to Lower Triassic fauna, it is inferred that the age of the Puga Formation may be as old as Lower Palaeozoic. Hence the Tso Morari Crystalline Complex cannot be correlated with the Central Crystallines of Precambrian age.

TAGLANG LA FORMATION. The Taglang La Formation is composed of low to high grade metamorphic rocks which have been derived from originally pelitic, semipelitic, calcareous and marly sediments. These sediments were intruded by basic rocks which now occur as concordant bands of amphibolites. The rocks show a southward increase in the grade of metamorphism from chlorite zone near Gya through biotite zone near Taglang La to garnet zone around Debring and at the northern end of More Plains to kyanite zone on the western bank of Tsokar. The grade of metamorphism decreases again towards south till we have low grade phyllite with bands of marble abutting against the Mesozoic Tethyan sediments of Zanskar Supergroup.

On the northwest bank of Tso Morari the mica gneiss of Puga Formation is overlain by calcareous schist (100 m) which, in turn, passes into a band (50 m) of crystalline limestone. This band has yielded deformed bivalves and crinoid stems. It also contains thin layers of phosphatic limestone. Limestone with clasts of phosphatic limestone bivalves and crinoid stems also occurs near Lato, Prang Sumdo, Chaksa La, Kiamaru La and Shiul La. The fossiliferous limestone band within the Taglang La Formation showing such a wide lateral continuity along the strike has also yielded conodonts (*Neogondolella bisselli*) and foraminifers (*Hyperammina* sp., *Thuraminoides* sp., *Hemidiscus* sp., *Lituotuba* sp., *Ammobaculites* sp. and ostracods (*Bythocypris* sp.) of Lower Permian age (Virdi *et al.*, 1978). The shaly limestone exposed at the northern end of the Tsokar on the southern slopes of the Kiameri La contains *Conularia* sp. These fossils indicate Upper Carboniferous age (Dr. Azmi, pers. comm.). The faunal assemblages thus indicate that the great thickness of Taglang La Formation may range in age from Carboniferous to Triassic.

POLOKONG LA AND THE RUPSHU GRANITES. A coarse-grained, foliated and porphyritic granite containing felspars, quartz, muscovite, biotite and amphibole is exposed at Polokong La. This body of granite has a fairly wide distribution and occurs as a stock intruding into the surrounding rock of the Taglang La and the Puga Formations. Granite bodies of similar composition but of smaller size are also exposed in Zara *nala* where the enclosing sediments, phyllite and limestone of Taglang Formation, show good development of hornfelses.

The Rupshu Granite occurs as a concordant body within the sediments of Taglang La Formation exposed on the western bank of the Tso Morari, south of Kurzok forming the cliffs of Mata mountain. The granite body is massive and unfoliated in the central part and becomes progressively foliated towards the margins. This type of structural features suggest that the granite has been intruded synkinematically along a shear zone. The Rupshu Granite is coarse-grained, porphyritic, foliated to unfoliated and contains quartz, feldspars muscovite, biotite, hornblende and tourmaline. Xenoliths of phyllite, sandstone and gabbro occur within this granite. Metasediments enclosing the granite show the formation of hornfelses. An aplitic phase intruding the coarse-grained granite is also present. All these features indicate intrusive nature of Rupshu Granite. As the Polokong La Granite and Rupshu Granite are intrusive into Upper Palaeozoic to Triassic Taglang La Formation and also as they do not have petrological affinity with the granites of Central Crystallines and the Ladakh Granitic Complex, it is inferred that they are neither Palaeogene nor Neogene in age; and hence they may be Late Mesozoic (Jurassic (?) in age (Virdi *et al.*, 1978).

5. Indus Zone

Indus Zone is divided into Indus Suture Zone and Shyok Suture Zone. These two zones are characterized by ophiolitic rocks.

5.1. Indus Suture Zone

The Indus Suture Zone is separated from the Zanskar sedimentaries in the west and from the Tso Morari Crystallines in the east by the south hading Zanskar Thrust. Its northern contact with the rocks of Shyok Suture Zone is defined by the north hading Shyok Thrust (Figure 2). Based on field studies, the Indus Suture Zone is divided into the following tectonostratigraphic units: Lamayuru Division, Dras Formation, Shergol Ophiolitic Melange, Zildat Ophiolite Melange, Nidar Ophiolite, Indus Formation, Kargil Formation, Ladakh Plutonic Complex and Khardung Formation.

LAMAYURU DIVISION. The Lamayuru Division includes the Lamayuru and Namikala Flysch described by Frank *et al.* (1977). In western part it consistsof monotonous, phyllitic olive-coloured shales, silts with fine often graded sandstones. Large and lenticular bodies upto a few kilometre long 'exotic' limestone are conspicuously placed within the Lamayuru Division at localities—Fotu La, Bodh Kharbu and Mulbekh. The exotic blocks of limestone have yielded fauna of Carboniferous (Mathur and Pal, 1978) and Permian (Tewari and Pande, 1980) age. In the eastern part of the belt the Lamayuru Division consists of dark grey, phyllitic, silty, often calcareous shales with fine-graded sandstone layers with well-preserved flute casts. The calcareous silty shale has yielded *Daonella indica*, *D. longobarica*, *D. moussoni* indicating a Ladinian age. *Belemnites* were recorded in the upper part by Fuchs (1979) who suggested that the upper age limit of the Lamayuru Division may be as young as Jurassic, though not necessarily so, as *Belemnites* occur from Late Palaeozoic (rarely) to the end of Cretaceous.

DRAS FORMATION. The Dras Formation consists of approximately 4000 m thick sequence of volcanics and associated sedimentaries, principally andesite, diabase, lavas with local occurrence of pillow lava, rhyolite, agglomerate and other volcanoclastics together with chert, jasper and limestone. This volcanic association was earlier designated as the Dras Volcanics by De Terra (1935) after the village Dras. In this paper it is accorded a status of Formation and redesignated as the *Dras Formation*. The Dras Formation is largely made up of volcanics at Dras and in the area between Dras and Kargil, but as this belt is followed laterally from Kargil eastwards the associated sedimentaries increase, become predominant and acquire flyschoidal character at localities between Pashykyum and Khalsi. The interbedded sedimentaries within the volcanics consist of red and olive green shales, radiolarian cherts, jaspers, gritty sandstone and limestone which have yielded *Orbitolina*, *Hippurites* and Bryozoa of Middle and Upper Cretaceous age. Gupta and Kumar (1975) also assigned Middle and Upper Cretaceous age on the basis of *Orbitolina* recorded in limestone bands and other microfossils from near Gye in the Dras Formation. Wadia (1937) derived a Lower and Middle Cretaceous age from the *Orbitolina* occurring in limestone of Dras Formation in Burzil pass area. Ultramafic bodies of dunite, harzburgite, pyroxenite and serpentinite occur within the volcanics of Dras Formation. Gansser (1964) and Srikantia & Bhargava (1978) interpreted these bodies to be ultrabasic emplacement within Dras Volcanics, but Vardarajan and Jhingran (1977) considered these to be intrusives of Alpine type. However, according to Srikantia & Razdan (1980), the ultrabasic bodies are tectonically disrupted parts of an ophiolite slab that was emplaced within the Dras Formation. The volcanics of Dras Formation have been petrochemically identified into arctholeites, calc-alkaline-lavas and shonshonites. Geochemical data indicate that these volcanics are products of an island arc formed as a result of magma generation in the upper mantle or upper part of descending slab of oceanic lithosphere (Gergan, 1978). The volcanic suite of Dras Formation in some parts has suffered metamorphism of lower green schist facies showing mineral assemblages of albite + actinolite + chlorite + prehnite + actinolite + chlorite.

OPHIOLITES OF WESTERN INDUS SUTURE ZONE. There is no true ophiolite sequence in the western Indus Suture Zone. However, the melange belts contain within them disrupted components of the ophiolite, and hence such type of melange is called ophiolitic melange.

SHERGOL OPHIOLITIC MELANGE. Frank *et al.* (1977) claimed that they were the first workers to recognise the ophiolitic melanges (for definition, see Gansser, 1974) in the Ladakh area. They pointed out that these melanges reflect the deep-seated disturbances within the suture zone. Three belts of the ophiolitic melanges are recognised between the area Pashkyum and Khalsi in the western part of Indus Suture Zone. These belts are exposed at : (*a*) Pashkyum-Khalsi; (*b*) Shergol-Mulbekh-Lamayuru; and (*c*) South of Lamayuru below the Zanskar Thrust. A typical ophiolitic melange section is exposed at village Shergol in the Wakha river section. The Shergol-Mulbekh Lamayuru belt is taken as the type section, and hence all the melange belts are designed as 'Shergol Ophiolitic Melange.'

The ophiolitic melange band of the Pashykum-Khalsi comprises of limestone, shale, diamictite, grit, volcanigenic sediment, tuffaceous shale, quartz arenite together with pods and lenticular bodies of serpentinite, pyroxenite, diabase and gabbro, with minor amount of basalt, andesite and rhyolite. The ultramafics show tectonic contact with the enclosing sediments and volcanics. The limestone band in this melange belt has yielded *Orbitolina*, lamellibranchs, corals, gastropods and echinoids (Srikantia and Bhargava, 1978). Some of the important fossils reported from this band are : *Orbitolina* sp., *Anomalina* sp., *Belemnites* sp., *Acicularia comanchense* Johnson, *A. khalsiensis* Pal and Chaterjee, *Lithophyllum* cf. *L. antiquam* Lemoine, *Permocleulus budaensis* Johnson, *P. ladakhanensis* Pal and Chaterjee, *P. texana* Johnson, *Cenomanella archiaciana* (D'Orb), *Damesia cretacea* (Mull), *Garramites nitidus* Stephenson, *Isanda* sp., *Otostoma* sp., *Stomatella cretacea* Pal and Chaterjee, *Collenia* sp., *Lissochilus* sp., *Ostostoma* sp., *Stomatella cretacea* Pal and Chaterjee. This assemblage indicates an Albian-Cenomanian age.

The ophiolitic melange band of the Shergol-Mulbekh-Lamayuru area is made up of an association of shale, slate, phyllite, diamictite, limestone, quartz arenite, jasperoid shale, chert, pyroclastis and agglomerates together with serpentinite, pyroxenite, diabase with dykes of dolerite and gabbro. Shah and Sharma (1977) have reported microfaunas of Middle and Upper Cretaceous age from the cherts and jasperoid shales of the melange near Mulbekh.

OPHIOLITES OF EASTERN INDUS SUTURE ZONE. Shankar *et al.* (1976) described the geology and tectonic set up of the south-eastern part of Ladakh. They described Sumdo Formation as an ophiolite suite consisting of basic volcanics including amygdaloidal and porphyritic flows, pillow lavas and agglomerates, limestone and calcareous grits. Thakur and Virdi (1979) have re-mapped SE region of Ladakh and do not agree with the interpretation of Shankar *et al.* (1976) of the regional geology of the area with respect to Sumdo Formation in describing it as an ophiolite suite and considering ultramafites as a separate unit intrusive into the former. However, they have found a fairly complete sequence of ophiolites in the area between Nidar and Kyun Tso, and according to their interpretation the Sumdo Formation and ultramafites are classified into two tectono-stratigraphic units : (*a*) Zildat Ophiolitic Melange; and (*b*) Nidar Ophiolite. These two units, the former being thrust over by the latter, are bounded with thrust contacts by the sediment of Indus Group in the north and Tso Morari Crystalline Complex in the south.

ZILDAT OPHIOLITIC MELANGE. A belt of ophiolitic melange having lithological components similar to that of the Shergol Ophiolitic Melange occurs in the eastern part of the Indus Suture Zone. The melange consists of agglomerate, pyroclastics, volcanic tuffs and lavas together with isolated lenticular blocks of serpentinite and limestone. The melange zone extends from SE of Rumtesy upto Kiamur La where it pinches out but reappears north of Zildat La and is traced through Sumdo and Kyun Tso. In this belt, glaucophane schist has been observed at several localities, and the typical mineral assemblage of the schist comprises of glaucophane-lawsonit-quartz-garnet-epidote-sphene-rutile (Virdi *et al.*, 1977). The ophiolitic melange appears to have undergone strong tectonic deformation as the volcanics have acquired schistosity and pebbles in conglomerate and amygdales in basalt show flattening and strong preferred orientation of their long axes.

NIDAR OPHIOLITE. A fairly complete sequence of an ophiolite slab with a maximum 10 km width is thrust over rhe Zildat Ophiolitic Melange. It consists of three principal units, viz., Ultramafics, Gabbros and Pillow lavas. The Ultramafics primarily consist of pyroxenite together with peridotite and dunite. This unit has a width of about 2 km north of Tsokar and widens to about 8 km in the Nidar-Kyun Tso section. The serpentinised pyroxenite contains podiform chromite bodies near Chaksa La, Kidmang and Kurzok. The Gabbros are massive and layered, contain related basic rocks and intrude into the pyroxenite and peridotite. The xenoliths of ultramafics are common in the gabbro body near the contact zone. Leucocratic intrusions and coarse-grained basic pegmatites, product of late stage differentiates of basic magma, are observed in the gabbro body. The Pillow lavas constitute the topmost unit of the Nidar Ophiolite sequence. This unit consists of basic to intermediate volcanics with pillow lava structure. The upper part of this unit is layered in nature, containing volcanic lavas interbedded with chert, jasper, grit and sandstone. The grit and sandstone are intra-formational containing clasts of cherts, jaspers and volcanics. The cherts contain radiolarians and other fossils indicating Cretaceous age.

KLIPPEN OF OPHIOLITIC MELANGES. Fuchs (1977, 1979) reported the occurrence of a klippe, Spongtang klippe, of the ophiolitic melange within the Mesozoic sediments of the Zanskar Tethys Supergroup in the Spongtang area of Zanskar mountains. The ophiolitic melange consists of flysch sediment, serpentinite limestone, radiolarian cherts, peridotite and basic volcanics. This sequence is underlain with tectonic contact by Lamayuru division unit which, in turn, is thrust over the steeply folded rocks of the Mesozoic of the Zanskar Tethys Supergroup. Srikantia and Razdan (1981) have called this klippen unit as Shilakong Ophiolite Nappe and correlated it with the Kiogar-Amlang La Ophiolite Nappe complex of Kailash in South Tibet-North Kumaun region.

Three smaller size klippen of the ophiolitic melange have been described at localities Zara Nala, north of Tsokar and Kurzoke in eastern Indus Suture Zone by Thakur and Virdi (1979). They overline the Tanglang La Formation of Tso Morari Crystallines.

INDUS GROUP. The belt of clastic sediments of conglomerate, sandstone, siltstone and shale lying between the Ladakh Plutonic Complex in the north and Shergol Ophiolitic Melange, Nidar Ophiolite and Tso Morari Crystalline Complex in the south is exposed along the entire length of the Indus Suture Zone in Ladakh. It has a varying width ranging from 5 km (minimum) to 10 km (maximum). These rocks have been a subject of controversy regarding their flysch or molasse nature, age and nomenclature. They have been variously named by different workers: Indus Flysch (Lydekker, 1883; De Terra, 1935; Tewari and Pande, 1970); Ladakh Molasse (Tewari, 1964); Indus Formation (Shankar *et al.*, 1976); Kargil Formation (Shah *et al.*, 1976); Indus Molasse (Frank *et al.*, 1977; Sharma and Kumar, 1978); Karu Molasse and Indus Flysch (Pal *et al.*, 1978); and Indus Group (Srikantia and Razdan, 1980; Thakur, 1980). To avoid this controversy a non-genetic nomenclature, Indus Group is adopted. The Indus Group is subdivided into Kargil Formation and Indus Formation.

KARGIL FORMATION. It forms the northern belt of sediments directly transgressing the Ladakh Plutonic Complex and is best exposed at Kargil and Karu. At these localities the conglomerate overlies unconformably the eroded surface of the granitoids. Near the contact zone the conglomerate and grit have felspathic matrix and clasts of granitoids make up to 70% of the total volume. The other clasts in the conglomerate are of vein quartz, volcanics, radiolarites, carbonate and gneiss. The Kargil Formation comprises dominantly of conglomerate with alternation of sandstone and shale layers, but at localities Basgo and Saspul it is made up of red silty shales and cross-bedded sandstone.

Sahni and Bhatnagar (1958) described several fresh water mulluscs (*Unio kohli*, *Melania* sp.) and specimens of plant leave (Trachycarpus-palm leave, *Sabal major*) from Wakka river section and assigned Eocene age to Kargil Formation. Dixit *et al.* (1971) described a tooth of *Hyoboops*, and Tewari and Sharma (1972) reported gastroda (*Subzebrinus gudei*) and charophyta (*Grambastichara* cf. *tornata* : *G.* cf. *cylinclerica*; *Harrisichara* cf. *vasiformis*) assigning Mio-Pliocene age to Kargil Formation. However, the occurrence of rich alveoline assemblage of Lower Eocene and Lower Middle Eocene in carbonate pebbles in conglomerate (Frank *et al.*, 1977) indicates a post-Eocene age.

Thakur and Virdi (1979) have described three large outliers of molasse sediment at localities north of Tsokar, Thachang La and west of Shiul and around Liyan Gompa which have been designated as Liyan Formation by Shankar *et al.* (1976). This belt of molasse rests unconformably over the Indus Formation, Zildat Ophiolitic Melange, Nidar Ophiolite and Tso Morari Crystalline Complex. The conglomerates of molasse have clasts derived from the rock types of these formations, and shales and sandstones have yielded fresh water gastropods and plant fossils. On the basis of these fossils and close lithological similarity, they can be correlated with the Kargil Formation. The transgressive relationship of the molasse sediment with the different lithostratigraphic units including Indus Formation observed in SE region of Ladakh by Thakur and Virdi (1979) refutes the contention of Shah *et al.* (1976) and Colchen (1977) who proposed a lateral facies variation between the flysch and molasse sequence.

Sharma and Gupta (1978) have reported a Northern Molasse unit that rests unconformably over the northern margin of the Ladakh Granitoids in eastern Ladakh.

Although the molasse sediments now occur as isolated erosional outliers over the northern and southern margins of the Ladakh Plutonic Complex and transgressing over the different units of the Indus Suture Zone, it is apparent from their aerial disposition that the basin of deposition was widespread covering all the older rocks. The molasse sedimentation is post-orogenic and post-dating the magmatic, metamorphic and major thrusting events in the region.

INDUS FORMATION. The southern belt of Indus Group called as 'Hemis Conglomerate' by Frank *et al.* (1977) has been designated here as Indus Formation. It is separated from the Kargil Formation or Ladakh Plutonic Complex by a steep thrust in the north and to the south it is in tectonic contact with the Shergol Ophiolitic Melange, Nidar Ophiolite, Dras Formation and Tso Morari Crystalline Complex. The Indus Formation consists of a thick sequence of about 4000 m of alternating conglomerate, sandstone, siltstone and occasional shales. Frank *et al.* (1977) described limestone clasts in conglomerate containing fossils of Lower Cretaceous and Permian age, thus implying that it cannot be older than Eocene and can possibly be much younger than this. Recently Sah and Sharma (1980) have reported *Sabal major* in Hemis Conglomerate near Hemis Gompa assigning it Oligo-Miocene age.

Pal and Mathur (1977) and Pal *et al.* (1978) have divided this Indus Formation into five members as follows :

Member E — Conglomerate flysch with subordinate sandstone and siltstone.
Member D — Red shaly flysch with subordinate sandstone and siltstone.
Member C — Grey shaly flysch with subordinate sandstone and siltstone.
Member B — Arenaceous flysch with subordinate shale.
Member A — Red and green shaly flysch with subordinate conglomerate and limestone.

On the basis of sedimentary features, Indus Formation is described as flyschoidal in nature by these workers. Tewari *et al.* (1970), Pal and Mathur (1977) and Pal *et al.* (1978) have described faunal assemblages indicating a Middle Cretaceous to Eocene age for the Indus Formation. On the basis of faunal assemblages, Mathur (*Annual Report WIHG*: 1978-79 & 79-80) has divided the Indus Formation into ten biostratigraphic zones: Zone I-Lower Cretaceous, Zone II-Middle to Upper Cretaceous, Zone III-Palaeocene, Zone IV-to X-Lower Eocene.

The age of Indus Formation has now become a controversial problem. As the conglomerates contain clasts derived from Shergol Ophiolitic Melange, Nidar Ophiolite, Dras Formation and limestone ranging in age from Permian to Cretaceous, Indus Formation cannot be correlated, nor considered as homotaxial equivalent of the melange, ophiolite and volcanics of Cretaceous age. Field observations lead us to interpret that Pal *et al.* (1978) have probably included the units of Shergol Ophiolitic Melange of Khalsi area into their bio-zones I-III. A detailed study of the Indus Formation is needed to solve the controversy of age and environment of deposition of Indus Formation.

LADAKH PLUTONIC COMPLEX. These are also known as 'Ladakh Granites' or 'Ladakh Intrusives' by earlier workers which outcrop conspicuously as the Ladakh range extending as a NW-SE trending belt along the entire length of the Indus Suture Zone in Ladakh. The major part of the Ladakh Plutonic Complex consists of intrusives of tonalite, granodiorite and granite, but they also contain bodies of mafic complex ranging in composition from gabbro, gabbro norite, gabbroic anorthosite to diorite and tonalite as in Kargil area. Rai (1978) has described multiple cycles of magmatic activity resulting from two parental magmas responsible for the emplacement of basic and acidic rocks. Sharma and Gupta (1978) have recognised broadly three zones in the Ladakh Plutonic Complex forming a batholith of great regional dimension. The three zones are: Aureole Zone, the Border Zone and Core Zone. The Aureole Zone is characterized by large scale emplacement of apophyses and tongues of granodiorite and tonalite in the host rock showing contact metamorphism, as a result sandstone and grit of the host rocks are transformed into amphibolitic schists. This type of activity of the Border Zone is comprised dominantly of tonalite and granodiorite with occasional hornblende poor pink felspar granite, and is exposed along the southern flank of the Ladakh Plutonic Complex between Upshi and Khalsi. The dykes of aplite, pegmatite and dolerite as well as gabbroid intrusions within this zone are seen near Likir and Karu. The Core of the batholith, best exposed around Hanu and Gaik, is made up of pink porphyritic granite and leucogranite. The tonalite and granodiorite of the Border Zone occur with occasional tongues of the former in the latter. It consists of euhedral and pink-coloured potash felspar and cream-coloured plagioclase phenocrysts in a coarse-grained groundmass of quartz, felspars, hornblende and biotite. The leucogranite which varies in texture from apalitic and granitic to pegmatitic consists of pink porphyritic granite. It comprises of quartz, microcline, perthite, plagioclase, biotite, muscovite and titaniferous magnetite.

Xenoliths of varying dimensions from a few cm to tens of metres are frequently observed in the granites. They range from tabular, elongated, subrounded to rounded shape and are dominantly of basic composition. Near Khardung La the xenoliths of basic rocks constitute roughly 40-50% of the total volume. Also, large enclaves measuring a few sq km area of acid and basic rocks occur within the body of the granites.

In the Dras-Kargil as well as Astor-Deosai area, one phase of the granite intrudes the Dras Formation of Cretaceous age (Wadia, 1937). Also, they intrude the Khardung Volcanics of Cretaceous age in the Shyok valley (Thakur *et al.*, 1981). The Kargil Formation of Miocene age rests unconformably over the Ladakh Plutonic Complex. Such stratigraphic field relationship suggests a post-Cretaceous and pre-Miocene age to the granitoids. There is a lack of geochronological data on the granitic rocks of plutonic complex except a few radiometric dates such as 48 m.y. for whole rock Rb/Sr (Desio *et al.*, 1979), 28 m.y. for whole rock K/Ar (Sharma *et al.*, 1978) and 60 m.y. for whole rock Rb/Sr (Gansser, 1980). Two samples of the granitic rocks of Ladakh Plutonic Complex have been analysed with end value of 2 ÷ 1.8 and — 1.43, and both these values have been interpreted as a record of material derived from an oceanic crust contaminated by crustal material as for California or Japan (Alligra and Othman, 1980).

KHARDUNG FORMATION. The volcanics overlying northern margin of the Ladakh Plutonic Complex in Shyok valley were called 'Shyok Volcanics' by Sharma and Gupta (1978). To differentiate these volcanics from the volcanics associated with the ophiolitic rocks of the Nubra and Shyok valleys, Thakur *et al.* (1981) redesignated the Shyok volcanics as Khardung volcanics after Khardung village where these are best exposed. As the volcanics also contain sedimentaries, these are now classified as part of Khardung Formation. The Khardung Formation constitutes a sequence of acid and basic volcanics together with volcaniclastic sedimentaries towards the top. They overlie the Ladakh Plutonic Complex, the latter showing an intrusive junction to the former, and are overlian with a steeply northeasterly dipping thrust contact by the Shyok Group. The Khardung Formation consists of rhyolite, rhyodacite, dacite with interbedded welded tuffs, ignimbrites, agglomerates, volcanic breccia and flow breccia. The volcanics are in general massive flows though amygdaloidal varieties are also seen.

Petrographic studies (Gupta and Sharma, 1978) show that felsic lavas predominate over the basics. Rhyolite, rhyodacite, trachyte, trachy-andesite, andesite and basalt are the main petrographic types. Rhyolite shows a porphyritic to glassy and felsitic texture and is composed of potash felspar, plagioclase and potash felspar embedded in a hyalopilitic to felsitic groundmass. Trachytes are characterized by fluxion texture and consist of plagioclase and potash felspar phenocrysts embedded in a felsic groundmass of microletes of felspar with iron ore and intersertal quartz. The trachy-andesite shows hyalopilitic to porphyritic texture and is made up of plagioclase, potash felspar and quartz. Andesite shows a pilotaxitic and porphyritic texture and consists of plagioclase, augite and pigeonite. The volcanic breccia consists of fragments of lava, chert, quartz and felspar embedded in a glassy to felsic matrix.

The volcanics overlie the northern margin of the Ladakh Plutonic Complex in the area of Thoise, Hundar, Deskit, Khardung, Digar Sultak and Tangse, but further east they overlie the southern margin of the granitoides forming an envelope. The volcano-sedimentaries contain fossiliferous horizons. One fragment of calcareous shale from southern slopes of Nebok La has yielded species of *Orbitolina parma* and *Orbitolina discoidea* indicating a Lower Cretaceous age. One sample of the volcanics of Khardung Formation has been dated 38 $\pm$ 2 m.y. (Upper Eocene) by K/Ar method (Sharma *et al.*, 1978). The Khardung volcanics may range in age from Lower Cretaceous to Upper Eocene.

5.2. *Shyok Suture Zone*

Preliminary accounts of the geology of the Nubra-Shyok region have been given by Sharma and Gupta (1978) and Thakur *et al.* (1981). Additional geological information now available on what were formerly terra-incognito areas of Nubra-Shyok region has necessitated a revision of the tectono-stratigraphy of the Shyok Suture Zone. In consequence of such revision, the Shyok Suture Zone is divided from south to north into following litho-stratigraphic units : Gondwana Group, Shyok Group and Pangong Group.

GONDWANA GROUP. A sedimentary sequence consisting of ortho-quartzite, calcareous sandstone, breccia and carbonaceous shale is exposed at a locality forming a small hillock along the left bank of Indus, about 50 km upstream of Loma. The carbonaceous shale, which overlies the quartzite, has yielded plant fossils represented by *Ptillophyllum cutchense* Morris, *Ptillophyllum acutifolium*, *Brndhyphylum* sp., *Elatocladus* sp. cf. *E. Plana* (Fst) Seward, *Taeniopteris* sp. (Sharma *et al.*, 1980) and a large number of equesetalean (like) stem impressions devoid of leaves or leaf sheaths. The assemblage of fauna indicates an Upper Jurassic age showing an Upper Gondwana affinity. The plant-bearing Gondwana rocks occur as a thrust slice between the Khardung Formation and Shyok Group. The plant-bearing Gondwana beds have been so far reported from the area lying south of the Indus Suture Zone, i.e., the supposed line of collision between Indian and Eurasian plates. The Gondwana Group mentioned herein lies north of the Indus Suture Zone.

SHYOK GROUP. It consists of a sequence of sediments, metasediments, ultramafics and volcanics sandwitched between the Karakoram Plutonic Complex in the north and the Khardung Formation or Ladakh Plutonic Complex in the south. The sequence has been thrust at a steep angle over the Khardung Formation and has an intrusive contact along its northern margin with the granitic-intrusives of Karakoram Plutonic Complex (Figure 2). Thakur *et al.* (1981) divided the Shyok Formation referred to here as group into a northern, Summur Member and the southern, Khalsar Member.

The Summur Member is made up of basic volcanics associated with green and purple sandstone, siltstone and shale together with occasional bands of black platy limestone containing corals and bryozoa of Permian to Permo-Triassic in age. Lenticular bodies of serpentinite and pyroxenite also occur in association with volcanics and sedimentaries. A narrow band of medium grade metamorphics comprising of amphibolite, marble and schist occur north of Trit bridge and around Summur. Its extension furthur southeastward merges with the southern unit. The southern unit, Khalsar Member consists of green phyllite, chlorite schist, quartzite, cherty and sandy limestone and basic volcanics. The limestone contains crinoid oscicls, bivalves and other indeterminable fossils. The volcanics is made up of weakly metamorphosed lavas, pyroclastics together with tectonically emplaced pyroxenite. Small bodies of diorite occur as intrusive into the metasediments.

The lithological units of the Shyok Group neither have any stratigraphic superposition order nor they show regular litho-stratigraphic continuity. They occur as thrust slices and large lenses forming a tectonic melange. The melange has ophiolitic components, and hence can be described as ophiolitic melange (Gansser, 1974).

Intrusive bodies of tonalite, similar to those of Ladakh Plutonic Complex, measuring a few hundred m in width and a few km in length occur within the Shyok Formation at several localities including Trit, junction of Nurba ahn Shyok rivers and Saltoro hills.

PANGONG GROUP. Pangong Group forming a NW-SE trending belt of metamorphics of greatly variable width (1 to 15 km) is sandwitched between the Karakoram Plutonic Complex in the north and the Shyok Group or Khardung Formation in the south. Its southern contact is delineated by the north hading steep thrust, the Shyok Thrust, whereas its northern contact with the Karakoram Granitoids is intrusive. The metamorphics of Pangong Group show low to medium grade regional metamorphism. The low grade rocks consist of calcareous phyllite, mica-schist, foliated meta-volcanics and chlorite schist with bands of limestone and quartzite. The medium grade rocks consist of garnet schist, kyanite schist, hornblende schist, biotite, schist, biotite gneiss, calc-silicate rocks, marble and migmatites with aplite and pegmatite veins.

6. Karakoram Zone

Karakoram Plutonic Complex and Karakoram Group are the two tectono-stratigraphic units of this zone.

6.1. Karakoram Plutonic Complex

The central region of the Great Karakoram range is occupied by granitic rocks forming a NW-SE trending belt between the rocks of the Shyok Group and Pangong Group in the south and Karakoram Group in the north. Wysse (1940), Aloisi (1932) and Fisher (*in* : De Terra, 1932) were the earliest workers to describe the petrography of the granitoid rocks of Karakoram. Three granites of regional occurrence are recognised, viz., biotite-granites, biotite-muscovite granites and hornblende granites. These granites are intimately associated and connected by transitional varieties and are also cataclastic in nature. Potash felspar (orthoclase and microcline), plagioclase felspar, biotite, hornblende and muscovite are the most commonly occurring minerals in these rocks. Granite porphyry together with quartz porphyry have been described as marginal facies of a large body of biotite-granite from the Sasser Pass-area.

The southern contact of the granites of the Karakoram Plutonic Complex with the rocks of Shyok Group is intrusive, but at some localities it is locally tectonised showing development of mylonite gneiss. The Palaeozoic and Mesozoic rocks of the Karakoram Group are locally metamorphosed and intruded by the Karakoram Granitoids.

De Terra (1932) attributed a Variscan age to granite of southern slope of Ladakh range and its equivalent in the Great Karakoram range. On the other hand, the strong metamorphism exhibited by sediments associated with the conglomeratic slate, amphibolite, sericite slate, schistose marble and dark phyllite with brachiopods (*Productus*) indicates a post-Palaeozoic age of Ladakh Granite (Norin, 1946). Desio (1936) has described the Late Palaeozoic and Triassic Tethys deposit in the head region of the Shigar and the Nubra valleys which are intensely metamorphosed and are interbedded with biotite orthogneiss, suggesting a post-Triassic age of the granite. Wysse (1940) has observed intrusion of quartz porphyry, dyke of the marginal zone of granite porphyry into the limestone of Upper Dogger; and Srimal *et al.* (1979) have reported intrusive nature of the granite into limestone and slate of Permian age of the Karakoram Group.

KARAKORAM GROUP. The rocks of Karakoram Group occur in a wide belt across the northern margin of the Great Karakoram, Aghil and Qizilag ranges that extend towards SE into the western Chang Thang region (Norin, 1946). They range in age from Lower Permian to Lower Cretaceous.

Renz and Reichel (1940), who have studied the Palaeozoic fossils collected by Wysse in the Karakoram Group, distinguished the following main divisions :

Upper Artinskian	Crystalline limestone with Fusulinidae and Verbeekindae, light grey limestone with *Fenestella*.
Lower Artinskian	Sandy limestone with *Parfusulina erucaria* var. *caracoramensis*, P. cf. *verheuili* var. *levidensis*
Upper Uralian	Sandy limestone with *Triticites wyssi*, *Pseudofusulina vulgaris* var. *globosa*, *Parafusulina aghilensis*, marly limestone with bryozoans
Lower Uralian	Limestone

In the northeastern Ladakh the black shales containing *Fenestella* are exposed in the Aghil Ranges of Middle Karakoram. These shales seem to be the oldest fossiliferous Palaeozoic rocks exposed in the Karakoram basin.

In the area southeast of Aghil the *Fenestella* Shales are overlain by a pebbly silt and mudstone succession (Harpa Tso Formation) which, in turn, is followed by fossiliferous Permian limestone. At places this succession is overlain by the beds yielding *Gangamopteris* sp. and other plant fossils similar to those of the *Gangamopteris* Beds of Kashmir.

The *Fenestella* Shales in the Aghil Ranges of Middle Karakoram are overlain by a thick succession of limestone and marls containing *Parafusulina* and other fossils of Lower Permian age. Similar sequence is also exposed along the northern slope of the Karakoram range where it has been classified as part of the Shaksgam Series. This limestone has yielded representatives of fusulinids (*Parafusulina shiptoni*), bryozoans (*Polypora* sp.), brachiopods (*Productus punctatus*, *P. pustulosus*, etc.), etc.

Bhandari *et al.* (1981) have recorded the find of Lower Permian fusulinids from the Saser Bangha Formation of Saser-Brangsa-Margo areas of Shyok valley of Karakoram region. Among the forms identified are included *Triticites ventricosus*, *Condofusulina laxa*, *Monodiexodia kattaena*, *Pseudofusulina* cf. *fraundilentra*. The limestone overlying the fusulinid-bearing beds contains brachiopods, bryozoans, algae, etc. of Permian age.

The occurrence of limestone corresponding to the *Lamnimargus himalayensis* Zone of Punjabian age has been correded from Depsang, Remo valley and from near the source of Shyok river. The fauna from these localities include *Lamnimargus himalayensis*, *Linoproductus gerardi*, *L. tenuistriatus*, *Productus purdoni*, *Syringothyris lydekkeri*, *Spirifer tibetanus*, *Lyttonia nobilis*, camarotoechiid gen. and sp. indet.

The limestone-yielding fossils of *Lamnimargus himalayensis* Zone in the Shyok river (near its source) and in south Karakoram is conformably overlain by the limestone corresponding to the Zewan Formation of Kashmir This limestone has yielded *Glyptaphiceras*, *Chonetes variotula*, *Marginifera spinosa*, *Orthotetes armenianus*,, etc.

Weller (1935) recorded the occurrence of *Phillipsia sumatrensis Paraphillipsia korpinskyi P. pahara* and *Pseudophillipsia* (?) sp. from eastern Karakoram range of Ladakh, near the boundary between Kashmir and Tibet. The trilobites were collected from a thrust block of Permian Limestone in Chanchemmo valley, 11km upstream from the hot springs of Kyam and 1.65km east of the junction of the Chang-Chenmo and Silung Kongma valleys. The Permian strata at this locality attain a thickness of about 28 metres and the trilobites were collected from 9 metre thick band of coralline limestone which lies above the 10-metre thick succession of limestone containing bryozoans and *Productus* and is overlain by a thick sequence of grey and reddish, somewhat sandy, coralline limestone and brownish, sandy, shaly marl.

The Shaksgam Formation on the southern slope of Mesherbrum area of Shyok valley in eastern Karakoram may possibly be of Upper Carboniferous-Permian age. Gircha Formation in north Karakoram has yielded Lower Permian fossils and this formation is correlative with the Shaksgam Formation.

In the Upper Chang-chen-mo the Triassic deposits apparently rest conformably upon the Permian with a thick basal conglomerate. In the Deep Sang, Dainelli (1934) has described a Triassic sequence consisting of cherty limestone, dolomitic limestone and inter-stratified shale of several 100 metre thickness and containing *Megalodon* and *Dicerocardium*. In Lingzhi-Thang, De Terra (1932) has described a number of sections of Triassic which have yielded *Dielasma julicum* of Norian age.

The Jurassic sequence of the Karakoram Group is made up of shale and marly limestone and to the north also of continental fluvial formations. Some important diagnostic fossils of Jurassic age are : *Camptonectes lens* Sow, *Trigonia* sp., *Perisphinctes furcula Neum*, *Calamys* (*Rdulopecten* off *tipperi* Cox and *Lopha* sp.) *Halobia cordelleriana*.

Norin (1946) described plant fossils from dark shales limestone sequence from the Qara-tagh area. The fossils identified by Halle are : *Neocalamites* (?) sp., *Klukia exilis*, *Sphenopteris* sp., *Sphenopteris*, *Ruffordia*, *Geopperti*, *Chladophelbis* sp., *Nilssonia orientalis*, *Nilssonia* cf. *mediana*, *Ginkgo digitata*, *Ginkgo sibirica*, *Baiera* sp. (*B. gracilis*), *Podozamites lanceolatus*, *Pitogophylum* cf. *nordenskioldii*.

The Lower Cretaceous deposits are closely associated with the Triassic and Jurassic formations forming a common sequence in the Karakoram Group, whereas the Upper Cretaceous formations extend further north into Kunlun Plains. There is a great similarity in lithological characters and facies between the Lower Cretaceous and older Mesozoic formations. Some of the diagnostic fossils are : *Orbitolina* sp., *Spiroplectammina* sp,, *Glandulina* sp., *Alveolina* sp., *Globogerina* sp. and *Rotalinidae* sp., *Exogyra columba*.

STRUCTURE

An analysis of structural framework and major structures like folds and faults on a regional scale extending from Outer Himalaya Zone in South to Karakoram Zone in north of Kashmir-Ladakh Himalayas indicates three phase of deformation, referred to as D_1, D_2 and D_3. The structures resultant from these deformations are dealt with separately under each tectono-stratigraphic zone.

Structure of Outer Himalaya Zone

The autochthon of Outer Himalaya Zone consists of Siwalik Group, Murree Group and Subathu Formation together with inlier of Great Limestone. Its northern margin is delimited by Murree Thrust that separates the pre-Tertiary rocks of Para-autochthon Zone from the Murree Group, and to the south the Upper Siwalik dip underneath the alluvium.

Large open type folds and thrusts of regional dimension trend NW-SE. Suruinsar Anticline, Udhampur, Syncline. Kud Syncline, Kalakote Anticline and Mendhar Syncline are the major folds, and Khishanpur Thrust, Madun Thrust and Waishnodevi Thrust are the major thrusts of the Outer Himalayan Zone. These large-scale folds and thrusts belong to D_2 phase of deformation.

Structure of Para-autochthon Zone

The northern boundary of Para-autochthon Zone is defined by Panjal Thrust that has brought the rocks of Kashmir Nappe to override it. The Para-autochthon Zone represents largely NW extension of Shali-Deoban of the Lesser Himalaya, but southward movement of Kashmir Nappe over this zone has caused tectonic incorporation forming a schuppen zone. This zone consists of thrust bound units of Shali-Deoban Formation, Kashmir Nappe and Subathu Formation. The formation of schuppen zone is related to D_1 phase of deformation that may be associated with the southward movement of the Kashmir Nappe.

The inliers of Great Limestone and similar other limestone bodies occurring within the Tertiary rocks are interpreted by us as klippen and not as upthrust blocks of the basement. These klippen of limestone inliers have their roots in the Para-autochthon Zone.

Structure of Kashmir Nappe Zone

Kashmir Nappe consists of a sequence of Late Precambrian to Triassic and forms a synclinorium. This synclinorium is a major structure of D_2 phase of deformation. The Kashmir Nappe has moved southward, some 15-20 km along Panjal Thrust over the Shali-Deoban and Berinag formations of Lesser Himalaya. The evidence for this movement is well documented in the Kishtwar window, where rock units similar to Larji-Rampur window are surrounded on all sides by the sequence of Kashmir Nappe.

The basal part of Kashmir Nappe comprising of metamorphics of amphibolite facies can be traced to the Zanskar Crystalline Complex, and Palaeozoic and Mesozoic sequences of Kashmir Nappe occur as infolded synclines within the crystalline complex in the Warwan valley (Vohra, 1976) and Suru valley (Fuchs, 1979). These observations suggest that the Zanskar Crystalline Complex of the Great Himalayan Range forms the root-zone for the Kashmir Nappe sequence.

D_1 phase of deformation was responisble for the formation of Kashmir Nappe and its southward movement along the Panjal Thrust. The Kashmir Nappe along with Panjal Thrust was later folded by D_2 phase of deformation into a large synclinorium trending in NW-SE direction. Bhadarwa-Chambah Synclinorium also belongs to D_2 phase of deformation. A large NE-SW antiformal fold, a cross-fold, indicating a major culmination is located along the Kishtwar window. The cross-fold belongs to D_3 phase of deformation.

The basal part of the Kashmir Nappe sequence consists primarily of phyllite and quartzite together with subordinate volcanics and large intrusive bodies of granites (Ramban, Kundkaplas and Dulhousie granites). This sequence which may range from Late Precambrian to Cambro-Silurian in age, represents NW extension of the rocks of Chail Nappe of Simla Hills (Thakur, 1981).

Structure of Zanskar Zone

Zanskar Crystalline Complex and Tso Morari Crystalline Complex form major antiforms, and intervening between these antiforms occurs a synclinorium of Zanskar Supergroup. These major structures trending NW-SE belong to D_1 phase of deformation. Antiforms of both the crystalline complexes are doubly plunging, NW and SE, forming dome-type structures. It appears that doubly plunging nature of the antiforms has resulted due to cross-folding by D_3 phase of deformation.

Zanskar Crystalline Complex constitutes the basement for Precambrian to Mesozoic sequence of Zanskar Supergroup. It has been reactivated during Himalaya orogeny with the formation of an embryonic nappe of crystallines and with southward glide of Kashmir Nappe from its root zone. During its reactivation the rocks of Zanskar Crystalline Complex have undergone a progressive regional metamorphism.

Tso Morari Crystalline Complex consists of metamorphosed Palaeozoic and Mesozoic sediments. Its northern margin is thrust against the Indus Suture Zone and southern margin against the rocks of Zanskar Supergroup.

Zanskar Supergroup forms a synclinorium and it is thrust over the rock units of Indus Suture Zone. It demarcates northern margin of Indian Plate representing sediments of the continental margin. The basal part of the Zanskar Supergroup consists of phyllite and quartzite with granite bodies. This sequence joins with Haimanta Formation of Lahaul valley and can also be correlated with the basal part of Kashmir Nappe (= Chail Formation).

Structure of the Indus Suture Zone

Tectonic features. The relations of the Ladakh Plutonic Complex to the spatially associated volcanogenic products vary. North of Dras they are overlain, along their southern margin by rocks of the Dras Formation. Similar relations are recorded by Wadia (1937) for the Astor-Deosai area which lies about 100 km NW of Dras while Khardung Formation also overlies the plutonic suite east of Nyoma in the eastern Indus valley and in the Shyok valley. However, cross-cutting relations are shown between the plutonic complex and the Dras and Khardung formations. These relationships are interpreted as indicative of the products of a volcanic arc with plutonic complex representing the deeper level (Thakur, 1981).

The Lamayuru division, Shergol Ophiolitic Melange, Dras Formation and Nidar Ophiolite occur as NE-directed thrust slabs. Klippen of the Shergol Ophiolitic Melange occur at Spongtang (Fuch, 1979), Zaranala and Kurzok (Thakur and Virdi, 1979) tectonically overlying the rocks of the Zanskar Supergroup and the Tso Morari Crystalline Complex. The disposition of these klippen, indicating their derivation from Indus Suture Zone, suggests that the thrusts of the suture zone were initially SW-directed, similar to all other major thrusts in the Himalayan region. It appears that at some later stage the thrusts were rotated to acquire their present northeasterly convergence. On account of steepening in the suture zone, it is suggested that all the major thrusts are listric in geometry and are rooted towards the main lineament of the Indus Suture Zone. An analysis of minor structural elements shows three distinct phases (D_1, D_2, and D_3) of ductile deformation, of which D_1 and D_2 indicate compression in a NW-SE direction. The first compressional phase gave rise to thrusts leading to emplacement of the ophiolitic rocks over the continental margin sediments of the Zanskar Supergroup. During the second compressional phase, the thrusts were folded and antiformal and synformal structures of regional scale formed. The third phase of deformation produced cross folds with NE-SW axial directions, giving rise to the large domal structures wiih the Tso Morari and Zanskar crystalline complexes in their cores.

Blue schist facies metamorphic rocks occur in the Shergol Ophiolitic Melange (Virdi *et al.*, 1977; Frank *et al.*, 1977). It is inferred that these products of high pressure metamorphism are related to subduction of an oceanic slab and predate the thrust movements of the D_1 deformational phase.

Structure of Karakoram Zone

Because of markedly different tectono-stratigraphy, the Shyok Suture Zone cannot be a repetition of the Indus Suture Zone (Thakur, 1981). In addition, while the latter has rock assemblages that are generally considered to be characteristic of a subduction zone, this is not the case for the Shyok Suture Zone. Its assemblage of cross-bedded clastic sediments of volcanic provenance, limestone and shale interbedded with basalt and andesite and mafic and ultramafic igneous bodies is like the one noticed in a back-arc basin. Both the nature and disposition of these rock assemblages in the Shyok Suture Zone can be accounted for on the basis of the closure of a back-arc basin as the result of a second phase of subduction subsequent to suturing of the Indian lithospheric plate, along the Indus suture, against the southern margin of a volcanic island-arc represented by the volcanic assemblages of the Khardung and Dras formations and the granitoids of the Ladakh Plutonic Complex (Thakur, 1981). This volcanic arc is considered to be an easterly extension of the island-arc with calc-alkaline magmatism described by Tahirkheli *et al.* (1979) from Northern Pakistan where the 'Kohistan sequence' lies to westerly extension of the rock units of the Indus and Shyok suture zones.

The recent discovery of Late Jurassic fauna of Gondwanaland affinity north of the Indus Suture Zone (Sharma *et al.*, 1980) suggests that the boundary between the Indian and Eurasian plates does not lie along the Indus Suture. Neither can it lie along the northern margin of the Shyok Suture, the 'northern megashear' of Tahirkheli *et al.* (1979) and Gansser (1980), as this is an intrusive junction with the Karakoram Plutonic Complex.

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Permian Fusulinids from Karakoram Region, Ladakh Himalaya, India

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THE PRESENT paper records the find of Lower Permian fusulinids from the Saser Brangsa-Margo areas of the Upper Shyok valley of Karakoram region, Ladakh.

A well-developed sequence of Upper Palaeozoic and Mesozoic rocks is exposed in the Upper Shyok valley of Karakoram mountains (Plate 1, Fig. 1). The stratigraphic set-up of the rocks exposed in the Saser Brangsa-Margo areas is as follows (Srimal *et al.*, 1979) (Plate 1, Fig. 2) :

Murgo Formation (Triassic)

Saser Brangsa Formation	Post-Permian	Karakoram granitoids and andesitic dykes intrusive into the limestone and slate sequence of Carboniferous and Permian age.
	Permian	Well-developed grey slates, shales, buff-coloured platy limestone. The upper part of the limestone is nodular and contains Permian fossils (brachiopods, bryozoans, etc.). The lower part of the limestone contains fusulinids, foraminifers, algae, bryozoans, etc. (approx. 750 metres thick)
	Carboniferous	Black graphitic slates, aphenitic limestone with intraformational conglomerate, crystalline marble, etc. (approx. 500 metres thick)

The sequence refened to above is bounded in the south by the Karakoram Granitoid. The Karakoram Granitoid is essentially coarsely crystalline, quartz, felspar, biotite-muscovite granites which often contain hornblende. This is intrusive into the limestone-shale-slate sequence of Upper Palaeozoic age which has been classified as part of the Saser Brangsa Formation by Srimal *et al.* (1979). The contact effect of this intrusive with the country rock is marked by the development of garnet-bearing schists and pockets of marble. In addition, stocks of the intrusive granitoids, etc., are also observed within the limestone-shale-slate sequence in its eastern extensions.

The Saser-Brangsa Formation constitutes the basal part of the Tethyan sediments of the Karakoram basin. The lower units of this formation consist of crystalline marble, cherts and grey aphenitic limestone. The presence of a yellowish intraformational conglomerate with clasts of chert, marble and limestone has also been noticed. This is conformably overlain by a thick sequence of black slates, shales and limestones. The shales and slates are rhythmically bedded. The lower units of impure bands of limestone have yielded fairly well-preserved fusulinid fauna of Lower Permian age. Among the forms identified are included *Triticites ventricosus* (Meek and Hayden), *Codonfusulina laxa* Douglass, *Monodiexodina kattaensis* (Schwager) and *Pseudofusulina* cf. *fraundulenta* Kireeva.

Triticites ventricosus (Meek and Hayden) is a characteristic form of the Lower Permian age and has very wide geographical distribution in North America, Europe and Asia. In Wolfcamp part of Kansas, this form occurs about 35 metres above the Pennsylvanian/Permian boundary. *Codonfusulina laxa* Douglass and *Monodiexodina kattaensis* (Schwager) have been described from the Amb Formation in the Salt and Khisor Ranges of West Pakistan (Douglass, 1970). *Triticites ventricosus* (Meek and Hayden) and *Parafusulina* cf. *fraundulenta* Kireeva have also been recorded from the Lower Permian limestone exposed in the Sarchu Plains of Ladakh (Gupta and Kahler, 1973).

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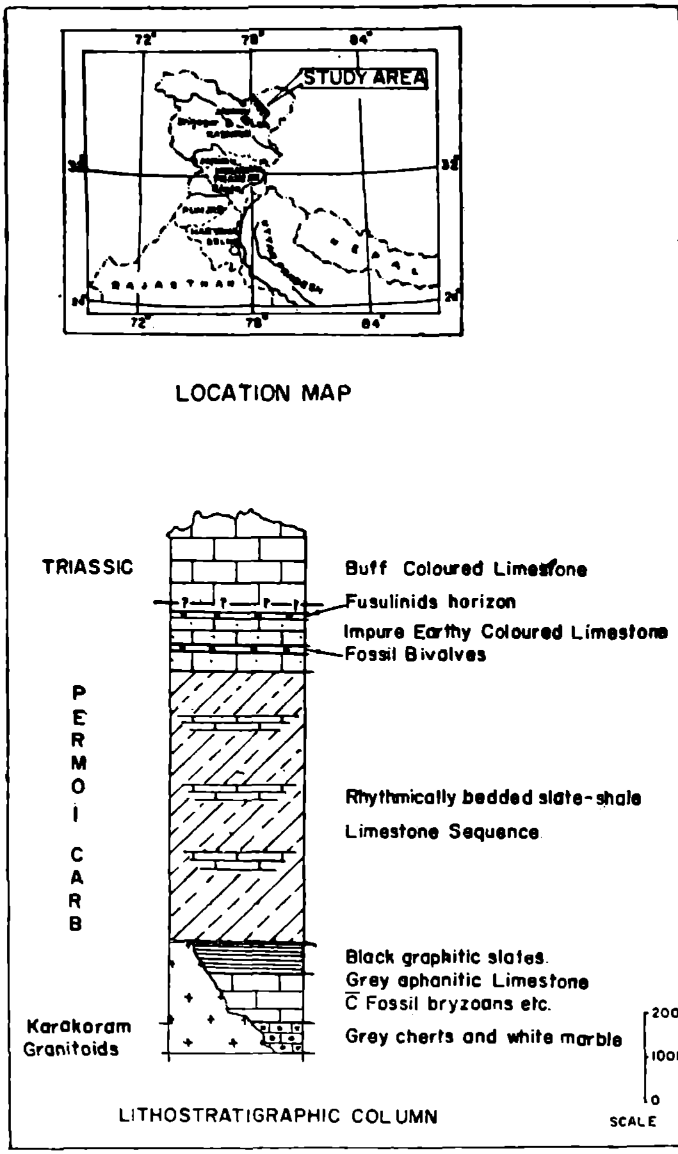
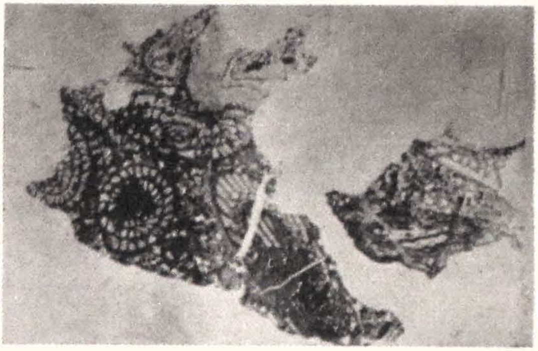


Figure 1.

The fusulinids have been recorded only from a few localities in the Himalaya and the new find provides us additional data for regional correlation and understanding of the palaeobiogeography during the Upper Palaeozoic times.

The first reference to the occurrence of fusulinids from India was made from the Sarchu Limestone of Ladakh Himalaya by Gupta *et al.* (1970). Subsequently, Gupta (1972, 1973) and Gupta & Kahler (1973) described additional forms of fusulinids from this limestone. Among the forms recorded from the Sarchu Limestone, Ladakh, mention may be made of *Triticites ventricosus*, *T. meeki*, *T. (Jigulites) altus*, *Schwagerina princeps* and *Pseudofusulina* cf. *fraudulenta*. On the basis of fusulinids lower part of the Sarchu Limestone yielding fusulinids has been assigned Lower Permian age.

Azmi (1976) has recorded the occurrence of *Schwagerina princeps* from the limestone unit in the lower part



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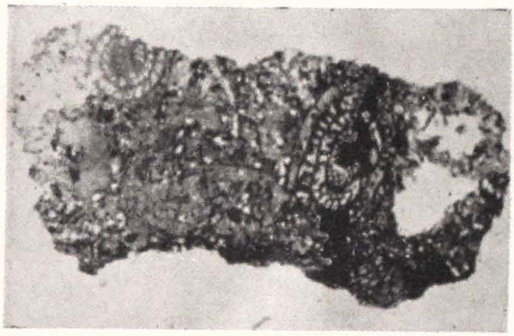

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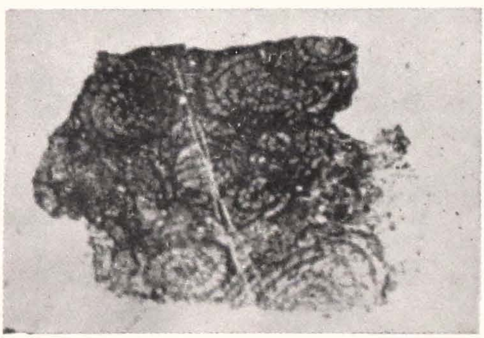

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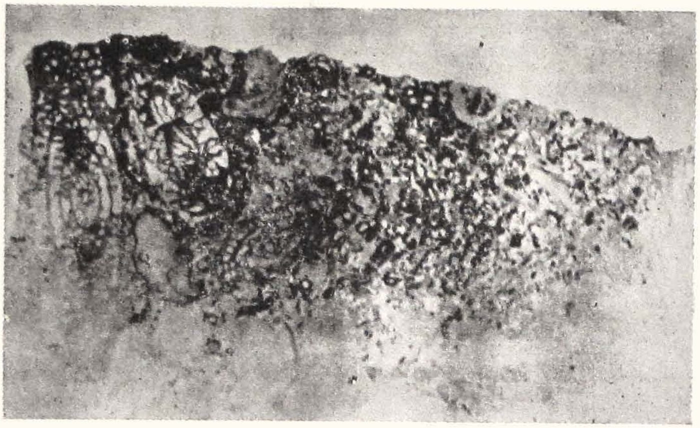
Plate 1. Figs 1-3. *Condofusulina laxa* Douglass × **60.**

of the Gangamopteris Beds of Zewan spur, Kashmir. In a recent publication, Azmi *et al.* (1980) have referred to the occurrence of rich fusulinid fauna from a limestone boulder (not *in situ*) in the Shyok valley of Ladakh. These workers have identified the presence of *Parafusulina* cf. *kattaensis* and other forms of fusulinids closely resembling to *Schwagernia* (?) sp. from these rolled boulders. In addition, fusulinids have also been described from the Lower Productus Limestone of the Salt Range, Pakistan (Dunbar, 1933).

Desio (*in* Pascoe, 1959 : 802) recorded the occurrence of *Neoschwagerina* in association with lamellibranchs, gastropods and corals from grey and black limestone which is occasionally schistose exposed on the gigantic tops of Broad and Gashserbrum (26,360 feet) on the northern slopes of the Masherbrum-Bride chain upto the



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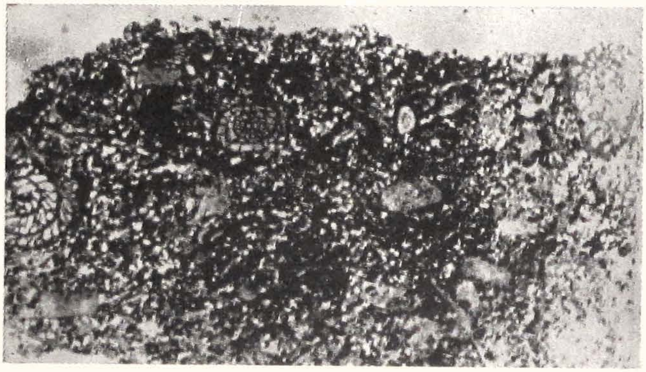

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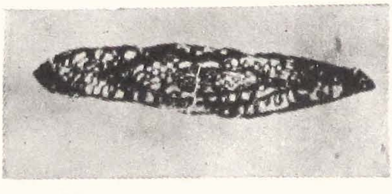

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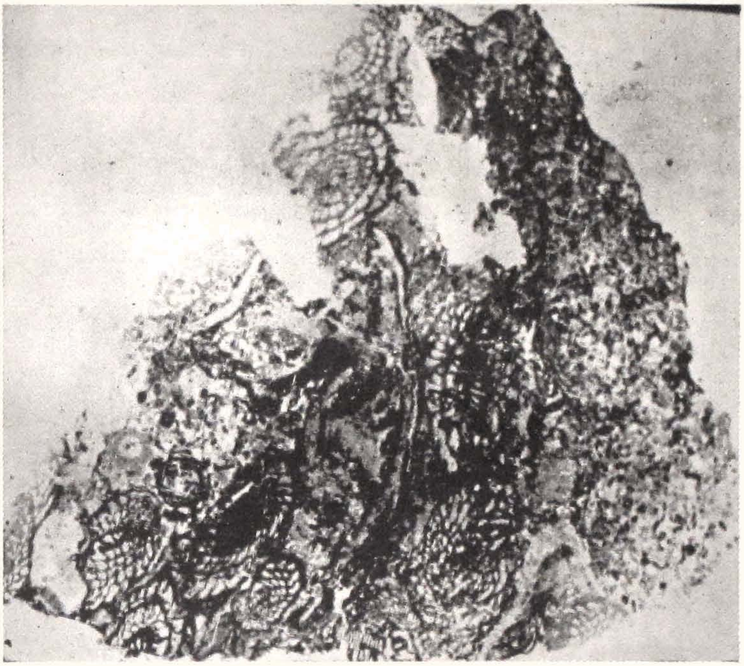
Plate 2. **Figs 1-2.** *Monodiexodina kattaensis* (Schwager) × 40. **Fig. 3.** *Triticites ventricosus* (Meek and Hayden) × 10.

Chogolisa Saddle and the greater part of the Panmah basin. In addition, *Parafusulina shiptoni* has also been recorded in association with *Polypora* sp. and several brachiopods (*Productus* spp., *Dielasma*, *Reticularia*, *Martinia*, etc.) from the grey limestone and black calcareous shales (= Shaksgam Series) exposed in the lower Sarpo Laggo valley and the Shaksgam valley along the northern slope of the Karakoram range (Kenneth Mason, *in* Pascoe, 1959 : 802). The fossiliferous beds were assigned unquestionable Permian age. Tewari (1979) has recorded the occurrence of *Robustoschwagerina* from the pebbly quartzites, slates and lensoid dolomites of the Blaini Formation exposed between Nainital-Gethia-Bhowali region. The beds yielding fusulinids have been assigned Lower Permian age.

The limestone from the Saser-Brangasa Formation yielding fusulinids contains also other foraminifers (*Climacammina sphaerica* (?), *Deckerella composita* (?) etc.), algae (*Permocalculus* sp.) and bryozoans.



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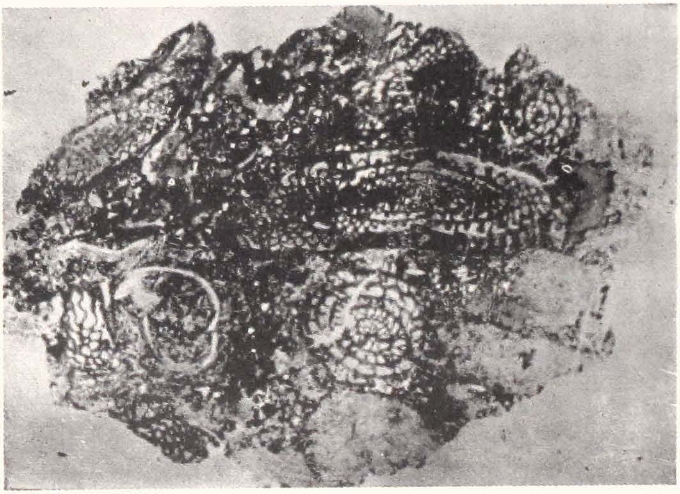

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Plate 3. **Fig. 1.** *Pseudofusulina* cf. *fraudulenta* Kireeva and *Monodiexodina kattaensis* (Schwager) × 40. **Fig. 2.** *Monodiexodina kattaensis* (Schwager) × 40.

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Geomorphological Observations in the Ladakh Area (Himalayas) : Quaternary Evolution and Present Dynamics

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ABSTRACT

Located in the northwestern part of the Himalayas, the Ladakh area includes the Ladakh Massif itself and the Zanskar Range, which are separated by the upper Indus valley. The whole region is a good example of an arid, continental, subtropical high mountain. The geomorphology is controlled by a probably old emphasis of a well-differentiated rock-ground : the heterogeneous Ladakhi granodiorite and the varied Zanskar sedimentary rocks of the Indus Suture Zone. The cold Quaternary and Recent periods are the cause of a typical shaping : graded valley-sides and periglacial aggradational piedmonts, which are mainly due to both frost-wedging and snow-solifluction processes. The Indus valley is localised on a remarkable structural axis of the Himalayas. Along the valley, the large extent of the Quaternary deposits (morainic, fluvio-glacial, slush-flowed and periglacial ones) and their stepping are probably the result of colder climates, probably wetter than today, together with positive movments, which are still active in the whole area considered.

INTRODUCTION

LADAKH, THE 'Little Tibet', is a remote area located at the border between the monsoon Asiatic mountains and the high and desertic plateaux of central Asia. It lies entirely on the northern side of the Great Himalaya, beyond the Kashmir mountains. It is organized around the upper Indus valley (altitudes between 2700 m and 3600 m), a narrow and longitudinal furrow, constricted between two distinct massifs : from the south, the Zanskar Range, which reaches 7156 m (Nun Kun), to the north, the so-called Ladakh Range (Span Puk, 6213 m) and further to the northwest, the Karakorum Range (8660 m) (Fig. 1*a*).

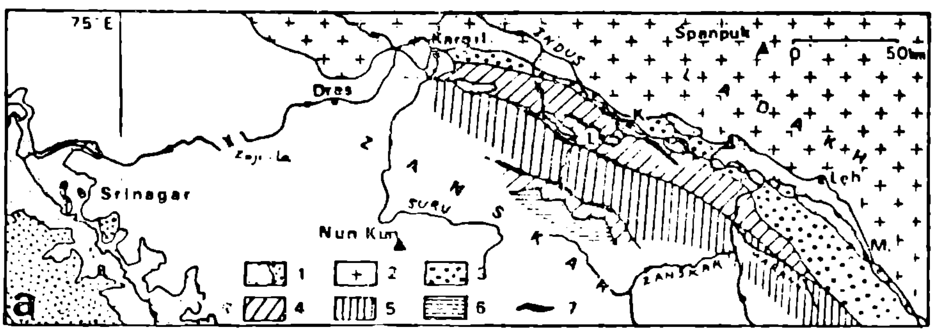


Figure 1(*a*). Main lithological units of the Ladakh Area. Sketch drawn from Ganssser (1977) and Bassoullet *et al.* (1978). **1.** Quaternary deposits, **2.** Granodiorite. 3. Alternation of conglomerates, sandstones, shales. 4. Schists, locally with sandstones or limestones (flyschs). 5. Limestones mainly. 6. Ophiolites. 7. Serpentinites. Name of the places : K—Khalsi; L—Lamayuru; M—Martselang. Arrows and letters *a, b, c, d, e* indicate the orientation of the sections, Fig. 3.

Few studies have been done on the Quaternary Period and the geomorphology of this area. Besides the numerous observations done by the explorers during the last century (Cunningham, 1854; Drew, 1875, . . .), the most detailed but now rather old studies are those of Dainelli (1922), de Terra (1934, 1935) and Paterson (1939), through which a first comprehensive interpretation of the recent evolution of the Western Himalayas has been proposed (for a review, see Gupta, 1976). Recently, interest in Ladakh has been renewed, stimulated by the introduction of the theory of 'plate tectonics' and thanks to the opening up of the area by the Indian authorities. But little work has been specifically done on recent evolution (Gupta and Kachroo, unpubl. data; Fort, 1978). The aim of this paper is to give a general idea of the geomorphology of Ladakh, and to highlight some prominent topics : the effects of the cold climates of the Quaternary age, the influence of the dryness on the geomorphic processes of a high mountain, the structural influences on the regional geomorphology. I shall adopt a regional plan, presenting successively the Ladakh area, then the Ladakh and the Zanskar Ranges, then the Indus valley, ending with an attempt to reconstruct the Quaternary history of this area.

LADAKH AND ITS PRESENT ENVIRONMENT

(a) Ladakh Area : A Cold and Dry Subtropical High Mountain

The regional individuality and homogeneity of Ladakh are mainly due to its climatic and biogeographic characteristics. Owing to its position behind the Higher Range, Ladakh already belongs to the domain of the high and dry subtropical mountains (as Hindu Kush. . .) which is of a marked continental trend. Its dryness is due to the barrier function of the Higher Range, which stops the humid atmospheric masses coming from the south (monsoon) and the west (westerly currents).

Its present climate is characterized by important annual and daily thermic amplitudes. The station of Leh, situated on a wide fan of the right bank of the Indus valley (3500 m) is, in this sense, very representative (Table 1).

TABLE 1—CLIMATIC DATA OF THE STATION OF LEH (3500 m), LADAKH
(from O. H. K. Spate *et al.*, 1967)

	J	*F*	*M*	*A*	*M*	*J*	*Jt*	*A*	*S*	*O*	*N*	*D*	*Total*
T°C	—8.2	—7.3	—0.6	6.1	9.9	14.3	17.0	16.1	12.1	5.9	0.1	—5.5	
P mm	9.16	7.62	7.62	5.08	5.08	5.08	12.7	12.7	7.62	5.08	0.0	5.08	82.82

The contrasts are accentuated by altitude and by the position in relation to the big mountainous masses : in the centre of the Zanskar Range, Dras (3500 m) has winter temperatures lower than —40°C. Precipitation is very low—Leh receives only 80 mm water/year. It mainly falls during winter, as it depends on westerly air masses of mid-latitudes (mediterranean influences). But in summer, the effects of the Indian monsoon, although much reduced, can still be felt, in particular in the Zanskar Range. In most cases, the precipitations fall as snow. The winter cover of snow, which may be several metres deep in Zanskar, melts very quickly during spring and produces a large amount of melted water, which plays a basic role in the current morphogenic activity.

During intermediate seasons, the altitude and the low relative moisture of the air (40% average from May to November) explain the importance of sunlight and radiation. The general dryness is increased by the constant winds, all the more violent because they are channelled into the valleys.

The vegetal cover is scarce, discontinuous but well-adapted to the extreme conditions of the climate : dwarfed and stunted shapes are common. Xerophytic shrubs and bushes are the most frequent (Caragana, Artemisia, Juniperus) and are subject to degradation. Shrubby forests are specifically located in some flood-plains. Other vegetal cover is very open, limited to suitable sites, creating a very complex vegetal mosaic, according to the topography, moisture and quality of the soils. But the use of wood (for fire, construction timber. . .) by a population which is, however, quite small (4 inhabitants/km^2) accelerates the disappearance of the last relics of riverain forests.

(b) A Bedrock with a Very Differentiated Lithology and Structure

The geological background corresponds to the *Indus Suture Zone* (Gansser, 1977), along which Indian and

Eurasiatic plates are supposed to have collided. The suture line divides two distinct domains : to the north, the tonalitic *Ladakh Massif* (granites, diorites, gabbros), to the south, the very complex *Zanskar Range*, which includes several litho-structural units : the Lamayuru Flysch (Gansser, 1977), the Shillakong Tethyan carbonates (Bassoullet *et al.*, 1978), the Dras-Nindam Flysch (Shah *et al.*, 1976), the ophiolitic klippe of Spongtang (Fuchs, 1979), the Rupshu Granite (Gansser, 1964). Thrust contact between the units of the Suture Zone are usual (serpentinite lenses mainly) (Fig. 1*a*).

Between these two domains, the *Indus Molasse Unit* (Tewari, 1964) covers the Indus Suture Zone : continental clastic rocks, conglomeratic to shaly. A lower autochthonous formation is directly transgressive on the Ladakh Granites (Gansser, 1977); the basal conglomerates are locally weathered. This formation is thrust by the 'Hemis Conglomerates' (Frank *et al.*, 1977), which are also in thrust contact with the Ophiolitic Suture Zone units.

All these units have suffered intense but inequal deformation (ranging from Late Cretaceous to Oligocene (?)) and also, to an extent, very low grade metamorphism (Frank *et al.*, 1977; Bassoullet *et al.*, 1980). The results are expressed differently, according to the petrography and the units considered : the granodioritic intrusives are densely jointed and foliated (Frank *et al.*, 1977); the Indus conglomerates are folded and faulted; the Zanskar units are very much affected by several (4 to 5) mineral and fracture cleavages of various orientations (Bassoullet *et al.*, 1980).

In this context, the location of the *Quaternary deposits* seems particularly remarkable. The main aggradational basins are located along the contact line between Ladakh intrusives and sedimentary conglomeratic rocks (Indus valley, Kargil basin). Other various deposits crop out in restricted and less well-defined areas, due mainly to the great variety of types of sediments (fluviatile, glacial, fluvio-glacial, slush-flowed, periglacial, eolian. . .) and to their staged altitudes (Fort, 1978). The main *geomorphological problems* are the following :

— In a similar climatic environment, two types of high and dry mountains are geologically opposed : the Ladakh Massif and the Zanskar Range. How does the geomorphology express these contrasts? How did the two mountains suffer the effects of the various geomorphic processes acting during the Quaternary Period and Recent time?
— The upper Indus valley is notable because of its course and well-preserved Quaternary deposits. Does the study of this valley enable us to reconstruct the recent evolution of the area? Does it solve some more general problems such as the glacierization of the Range and the possibility of recent deformations?

The following lines will give and propose some answers.

THE LADAKH MASSIF

The Ladakh Massif is dominated by flat summits (6000-6200 m) which have been considered to be remnants of an old planation surface, attributed to an Early Tertiary age (De Terra, 1934). The massif is well-dissected by a pattern of subparallel valleys (NNE-SSW), the directions of which are controlled by the joint network. Its southern limit is steep : it is divided into long and prominent spurs, separating wide aggradational fans, developed at the issue of the adjacent valleys. The originality of its landforms is mainly due to crystalline bedrock, which has been selectively exploited by the various morphogenic processes—humid, cold, arid, which occurred in the area.

(a) The Geomorphology is First Dependent on Various Petrographic and Structural Conditions

The Ladakh intrusives are predominantly tonalites to granodiorites (Shah *et al.*, 1976). Plutonism was accompanied by volcanism (andesite and dacite rocks, see Frank *et al.*, 1977; Sharma *et al.*, 1978). The whole batholith, crosscut by late felsic and mafic dykes, is usually considered as Paleocene-Eocene (Brookfield, 1981) or younger (Sharma *et al.*, 1978) and represents an Andean-type magmatic arc.

On the basis of this petrographic constitution and from a geomorphological point of view, we may oppose an *inner dioritic-tonalitic zone* to an *outer more granitic one*. The dark colour of the *inner zone* is very noticeable in the landscape. The zone is characterized by gentle shapes and by wide valleys, whose slopes are fairly well-graded and blanketed by a voluminous debris cover : screes, layered-slope deposits (upper valleys of Sakti, Leh, Likir, Temisgam. . .).

The *southern flank* is steep and rather narrow : a belt of from one to several km thick pink porphyric granite outcrops, rich in biotite and very foliated ('gneissose structure' of Shah *et al.*, 1976). Numerous leucogranitic, aplitic and basis dykes have been observed. Due to the proximity of the base level (Indus), erosion has been very active, taking advantage of the inequal petrographic constitution and the inequally dense jointed network of the granites. Usually, aplitic dykes are prominent, except when they are very fractured. The dark intrusions, closely shattered, give small sharp ridges or small steep walls, constantly renewed by an active macro-disaggregation. In some places, the pink granitic outcrops favour compact and smooth slabs, but elsewhere, their locally intense fracturation produces 'woolsacks' due to spheroidal weathering (near Phyang, Tharu, Likir, between Himis Shukpa and Yangtang, . . .). Such modelling cannot be understood without the propensity to disaggregation and the preparation of the rock itself (numerous cleavages, at all scales, especially at the macroscopic scale) and without the occurrence of particularly efficient processes able to disagreggate the rocks.

(b) The Cold and Current Processes are Responsible for the Present Modelling of the Slopes

The cold climates of the Quaternary age have affected the geomorphology of Ladakh Massif in an inequal way. Modelling by the periglacial processes (frost wedging mainly) is especially well-marked on the slopes. These have been graded either by disaggregation alone (north flank of Nimu Basgo) or by both disaggregation and scree aggradation (inner part). Well-layered deposits, accumulated at the foot of the slope, show the influence of both frost and reworking by melt-snow (slush) flows.

The width of the valleys, with 'U' shapes, cannot be necessarily considered as real proof of an effective glacierization of the range. But it could be interpreted in a more certain way as the result of exploitation by disaggregation and erosion of the petrographic and structural contrasts, which occurred before (or between) glaciation(s) of the range (Plate 1).

Plate 1. The valley of Shakti, Cimre and Taktak (Ladakh side) seen from Hemis monastery (3500 m) (Zanskar side). Note the contrasts of landforms, due to the lithology.

But the undoubted *glacial heritage* is evident at the outer southern limit of the range, where voluminous and curved frontal morainic ridges (Sankar-Leh, Phyang, Basgo, Likir, Himis Shukpa, Temesgam) (Fig. 1*b*), have been well-preserved. They witness a valley-tongue type of glaciation I named '*Leh stage*', which did not however come out of the mountain.

In the inner and upper part of the mountain, the bottom of the most important valleys (Temesgam, Himis, Saspul, Basgo) is partly filled with abundant morainic accumulations, which become more thick upwards the valleys. They suggest a more recent valley-tongue glaciation, of debris-covered type, which indicates a definite tendency to dryness. I named it '*Kar stage*' (near Kar Gompa, in Temesgam valley). This glaciation was followed

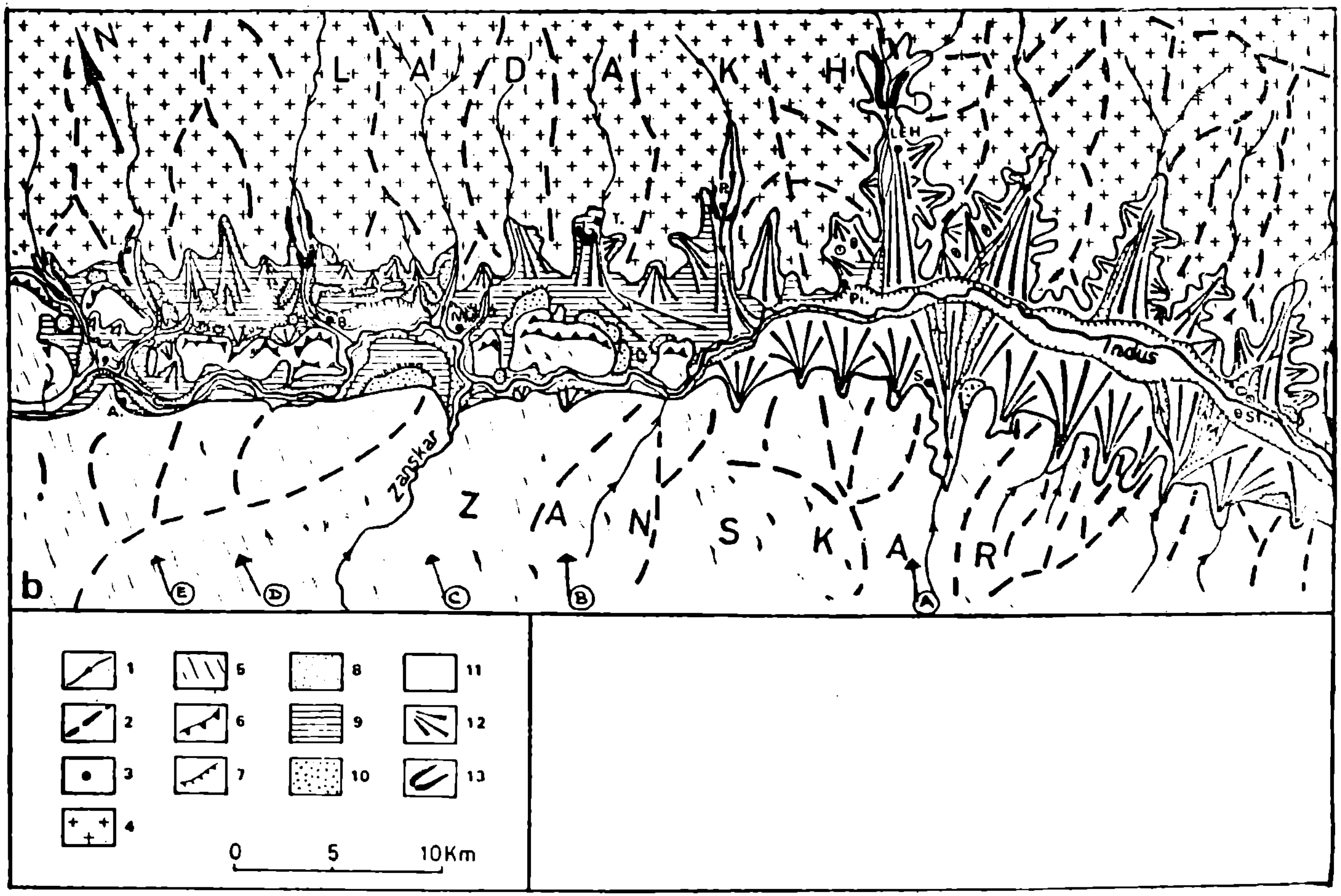


Figure 1(b). Geomorphology of the Indus valley. 1. Rivers. 2. Main ridges. 3. Village. 4. Granodiorite of Ladakh. 5. Sedimentary folded formations of Zanskar. 6. Monoclinal crest developed in the Indus molasses. 7. Scarp of terrace 8. T1 terrace. 9. T2 terrace. 10. T3 terrace. 11. Lower terrace and Indus floodplain. 12. Fans of the T2 level. 13. Frontal moraines, overlaid or entrenched within T2 level. Name of the places : A—Alchi; B—Basgo; L—Likir; N—Nimu; P—Phyang; Pi—Pitok; S—Stock; Sa—Sabu; Sl—Saspul; St—Stakna; T—Tharu.

by a still more recent one, of the same type, which probably may be related to a subactual stage (Little Ice Age (?)).

However, the existence of a glaciation older than the 'Leh stage' cannot be excluded. In fact, discontinuous deposits remain as ridges along both sides of the valleys. Their shapes, their heterometric internal fabric, the absence of any bedding, induce me to consider them as lateral moraines, belonging to a stage during which ice has probably spread out the mountain and filled partly the Indus valley (see further).

The *dryness* is the most outstanding factor of the *current dynamic processes*, which seems to supplant the role of frost, even if similar forms (convergence features) are not rare between the two families of processes. In altitude, the present snow-line (southern side) is situated around 5600-5800 m. There are very few glaciers (field and Landsat imageries observations). The highest parts of the cirques are now occupied by typical rock-glaciers, periglacial forms which indicate an arid environment (Likir, Temesgam valleys). At the foot of the range, in spite of the scarce local occurrence of 'taffonis' (holes of desaggregation) which suggest the presence of local atmospheric moisture, the general dryness of the environment is revealed by a dark-brown desert varnish, coating the surface of the granitic outcrops or boulders. The varnish is often attacked by disaggregation processes (cryo- and thermo-clasty) which are still active. The slopes are sprinkled with blown sands, which, locally, may constitute a rather thick cover (SW of Leh, Basgo) or individual dunes (SW Sabu) : the wind, strengthened by the channelling of the Indus or adjacent valleys, accentuates the effects of the aridity.

Thus, the geomorphology of the Ladakh Range has been greatly influenced by the foliated and jointed bedrock, which is directly responsible for the location of valleys and gullies. In comparison with other granitic mountains, which suffered intense periglacial processes as well (European Alps, Pyrenees), the Ladakh Range offers original landforms, shaped by a selective frost-disaggregation, the effects of which are very similar to those observed in more warm and humid areas. The valley-glaciers acted only in reworking huge amount of debris, furnished by frost and accumulated into prominent moraines. Currently, frost and dryness are the predominant factors.

THE ZANSKAR RANGE

The Zanskar Range is very different from the Ladakh Massif. Firstly, the mountain consists of several parallel and sharp ridges, which are steep and narrow and are separated in some places by wide and high basins. Due to its more southerly location and its altitudes (which progressively increase southwards up to more than 7000 m at the Nun Kun), Zanskar is also a more humid area, especially during the summer monsoon, and receives a huge amount of snow. This character explains why past and present forms of glaciation are not so negligible here.

Zanskar also basically differs from Ladakh in its structural pattern. In spite of the great variety of their nature and significance, the rocks are mainly sedimentary. They have suffered several intense phases of folding and thrusting, the last of the phases resulting in determining the nearly vertical dip of the formations. The lithologic contrasts have been made apparent by a selective erosion.

(a) The Major Forms are Mainly Due to the Lithologic Contrasts

Independently of the structural units, well-defined by the geologists (Tewari, 1964; Shah *et al.*, 1976; Frank *et al.*, 1977, Bassoullet *et al.*, 1978, . . .), it is possible to set up a scale of resistance for the different lithologic units cropping out along the northern flank of the Zanskar Range.

The *calcareous rocks* (multicoloured limestones of the Tethyan sequence [Fuchs, 1979] or Shillakong limestones [Bassoullet *et al.*, 1978]; the exotic blocks of shelf carbonates in Lamayuru unit) generate the steepest slopes of the area, especially because the dip is frequently close to the vertical : slabs, deep and narrow gorges (Shillakong, Honupatta). The strongly indurated conglomerates of the Indus Formation (particularly the Hemis Formation) can locally determine the same compact morphology.

Elsewhere, the selective dissection has exploited the *alternation of shale and sandstone/conglomerates* of the clastic Indus Formation; accurately reflecting the thickness of the beds (ranging from decimetric to plurimetric scale). The general south dipping of the basal conglomerates, which overlay the Ladakh batholith, and the late folded and faulted deformations (northwards retroversed), affecting the upper series formerly isoclinally folded, are responsible for a monoclinal modelling, an alternation of narrow furrows and sharp assymetric ridges, with an 'en chevron' back-slope (N of Khalsi) (Plate 2) and some local synclinal valleys (upper Gompa, Hemis).

But in general, the *shaly facies* predominates in the area : red silty gypsiferous shales of the Indus Formation

(Basgo), the argillaceous and calcareous flysch of Lamayuru (siltstones, fine-grained sandstones), the volcano-clastic flysch of Dras-Nindam (sandstones, volcanic lithic clasts and tuffs, pelites). Due to their intense tectonic fragmentation, these shales are particularly subject to frost shattering and so provide a large amount of fine debris. Generally, long valley-sides can be seen, covered with frost-clastic screes, which have developed below gentle slopes or below cryoclastic slopes which are in the process of becoming graded. Snow and melting waters are locally active : rills, superficial mass-wasting (slumps, debris/rock-slides) due to snowy solifluction.

Plate 2. The furrow of the Indus Valley near Khalsi, seen from the main road (left side of the Indus, 3500 m). Note the terraces of the Indus (T2 level) and the 'chevron' shapes in the molassic Indus Formation.

However, in spite of their limited outcrops, the *serpentinites* determine the occurrence of the most spectacular forms of solifluction. For instance, the belt, which separates continuously the Dras Volcanics (to the north) from the Lamayuru Flysch (to the south) along a nearly vertical contact and which corresponds to an 'ophiolitic melange' (Gansser, 1977) is distinctly outlined by a series of solifluction flows, single (Kalkul, East of Fatu La (see Plate 3) or left bank of the Indus valley, along the hair-pin-bends of the road coming down to Khalsi) or complex (Shergol, near Mulbeck, or Mundik, near Bhod Kharbu), which rework a lot of debris. One should not confuse their considerable extension with the extension of the melanges s.s. (Fig. 2).

These observations lead us to the conclusion that the resistance scale of the rocks has to be connected with their inequal frost-liability. The predominance of shaly rocks is responsible for the development of an intense superficial dynamic due to both solifluction and frost wedging.

(b) The Glacial and Periglacial Morphologies are Mainly Heritages

In the upper valleys of the northern Zanskar Range, the present snow-line is around 5200-5300 m (north facing slopes) and 5400-5500 m (south facing slopes). Glaciers often appear below summits exceeding 5500 m (Spongtang, 5923 m; Stok Kang Ri, 6128 m, Chiberang Ri, 5945 m) : most of these are cirques-glaciers or little ice-caps, which in places extend to valley-tongues, fringed by impressive lateral and frontal moraines. The extremity of the tongue is generally blanketed by thick debris cover, which reduces the rate of the ice-retreat.

Lower down the valleys, *glacial remains* are more or less well-preserved. A first and generalized stage, probably subactual in age (Little Ice Age (?)) appears around 4800 m, close to the present glaciers. The shapes and inter-weaving of morainic ridges, plus the abundance of kame or kettled deposits, also demonstrate a debris-covered glacier type (Fig. 3).

Lower still, several stationary stages can be recognized by the abundance of morainic deposits and forms, spread across the valleys (*'Nimaling stages'*, in Markha valley) (Plate 4) and by the petrographic components of

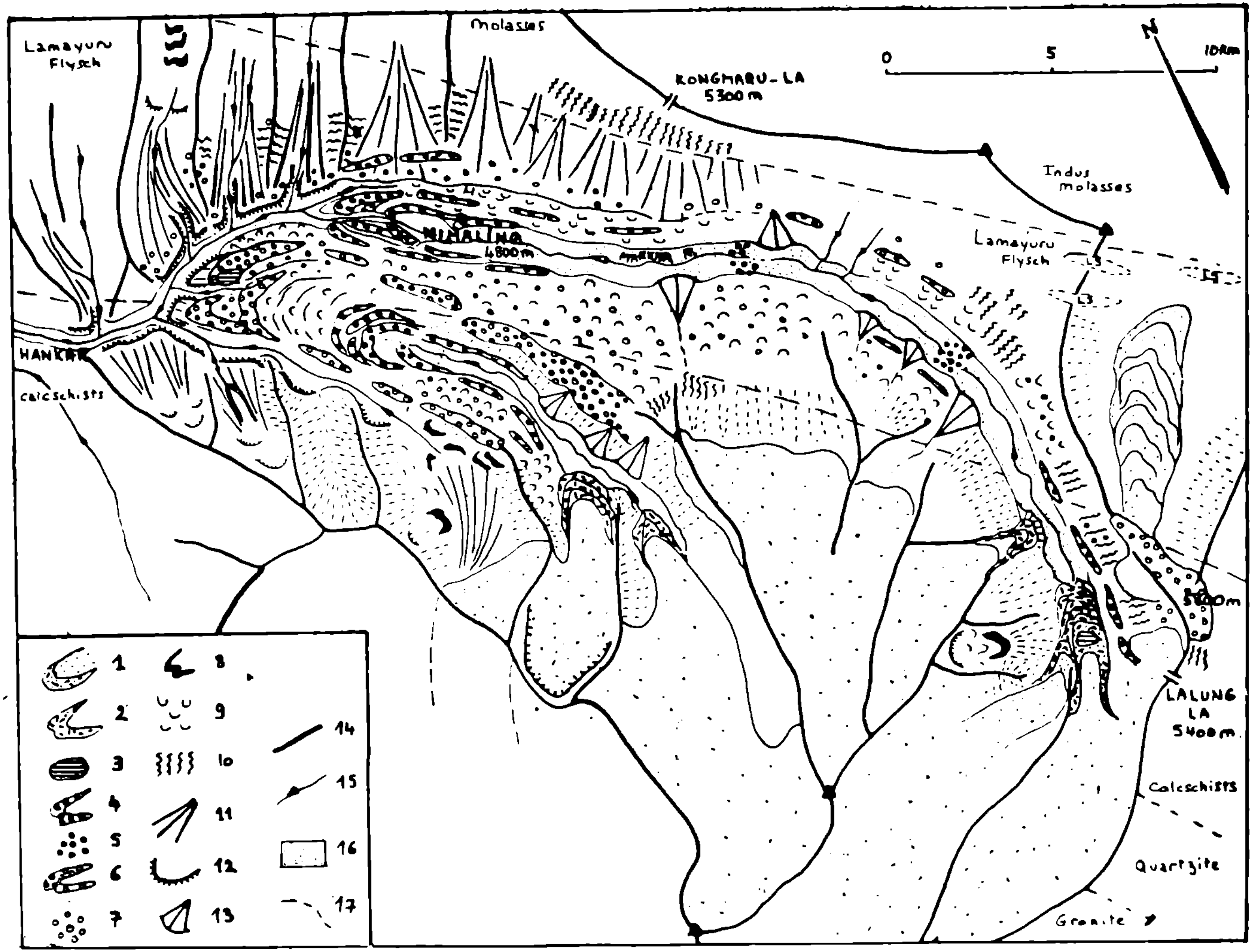


Figure 2. Geomorphology of the Upper Markha Valley (Zanskar Range). 1. Glacier and its present moraine. 2. Subactual moraine. 3. Kettle (lake) of the moraine (debris-covered type of glacier). 4. Nimaling stage. 5. Intermediate stages subactual and Nimaling stages. 6. Hankar stage. 7. Erratic boulders of the Hankar stage and older stages, if any. 8. Gelifluction lobe. 9. Generalized soli-gelifluction (often reworking erratics) and superficial gelifluction. 10. Striped ground. 11. Slush-fan (snowy solifluction). 12. Scarp. 13. Torrential of avalanched cone. 14 Ridge, crest. 15. River. 16. Present flood plain of the Markha river. 17. Geological contours (from personal observations and unpublished data collected by the Swiss team of Lausanne. A. Baud, personnal communication), I.F.—Indus Formation; L.F.—Lamayuru Flysch; L.S.—Exotic blocks (limestones); Z.F.—Calcschists (Zanskar Form.); Qt.—Quartzites; G.—Granite of Rupshu.

the moraines. The glacial tongues definitely flowed down to 4000 m, accumulating voluminous frontal and lateral moraines. For instance, I distinguished the '*Hankar Stage*', at 4000 m in the upper Markha valley (boulders of Rupshu Granite lying on the Lamayuru Flysch) (a first geological survey has been done by the Swiss team, A. Baud, oral information), the '*Spong Stage*' (boulders of foliated harzburgites, T. Juteau, oral information) at 4500 m in the Spong valley, above the Honupatta gorges (Fig. 3).

Plate 3. The soli-gelifluction lobe of Kalkul (E of Fatu La), at 3750 m. The serpentinite lobe flowed upon the outcrops of grey flyschs of Lamayuru.

Lower still, no definite glacial deposits have been observed : this may be partly due to the gorges which isolate the upper part of these mountainous valleys from the lower part, near the confluence with the Zanskar or Indus rivers. Moreover, even if morainic deposition could have occurred formerly in these valleys, the intensity of flow discharges should have erased all the remains. Nevertheless, glacier-tongues probably spread much lower down as indicated by the erosional 'U' shapes of the valley-slopes (at the foot of a calcareous wall, Markha valley), but they apparently did not reach the Indus valley, as the Ladakhi tongues did.

In connection with these morainic deposits, *lateral aggradations* have occurred, reworking tilly or colluvial material and creating extensive and sloped talus-fans. Some of these talus-fans may be considered as juxta-glacial or proglacial cone-terraces, built up by melt waters (upper Markha valley, 4800 m). Most of them are the result of a thick accumulation of heterogenous and local material, which mainly consists of coarse clastic fragments, embedded within an abundant fine matrix. The good layering and the thickness of the deposit suggest a *slush-flowed*† *aggradation*, produced by sudden and rapid discharges appearing below deglaciated but snow-covered slopes. These slushflowed fans are particularly well-exposed near Nimaling (4200 m, upper Markha valley) (Plate 4), but are already deeply dissected. The section shows that the thick (200 m) accumulation buries a former valley and that the upper part of the fill contains few boulders of morainic origin (Hankar Stage) interbedded within the slush-flowed sediments. These boulders predate the fans, which were still active when the glacial Hankar Stage occurred. These *slush-flowed fans* are probably one of the most *characteristic features* of the Zanskar modelling. We may however notice that their frequent occurrence is only restricted to the shales and flyschs outcrops.

Thus, besides a definitely glacial-shaped morphology and by means of a particularly easily frost-liable bedrock, the occurrence of original periglacial forms as slush-flowed fans may be understood as the most representative features of a cold but already dry mountain. In this environment, solifluction is a process as active as cryoclasty. The occurrence of this cold type of solifluction is in relation to an abundant snow cover, which is able to melt

†See the definition given by A. L. Washburn (1973 : 166) : "*slushflow* is transitional to fluvial action on the one hand and to true avalanching on the other. It can be a discontinuous slow process as well as very rapid, and is characteristic of periglacial environments in areas where snow thaw in the spring produces more meltwater than can drain through the snow".

in a very short time, due to the intense insolation (high altitudes and dryness of the air); this process (described by A. Washburn (1973) for the high latitudes), which produces huge discharges, explains the extension of mass-

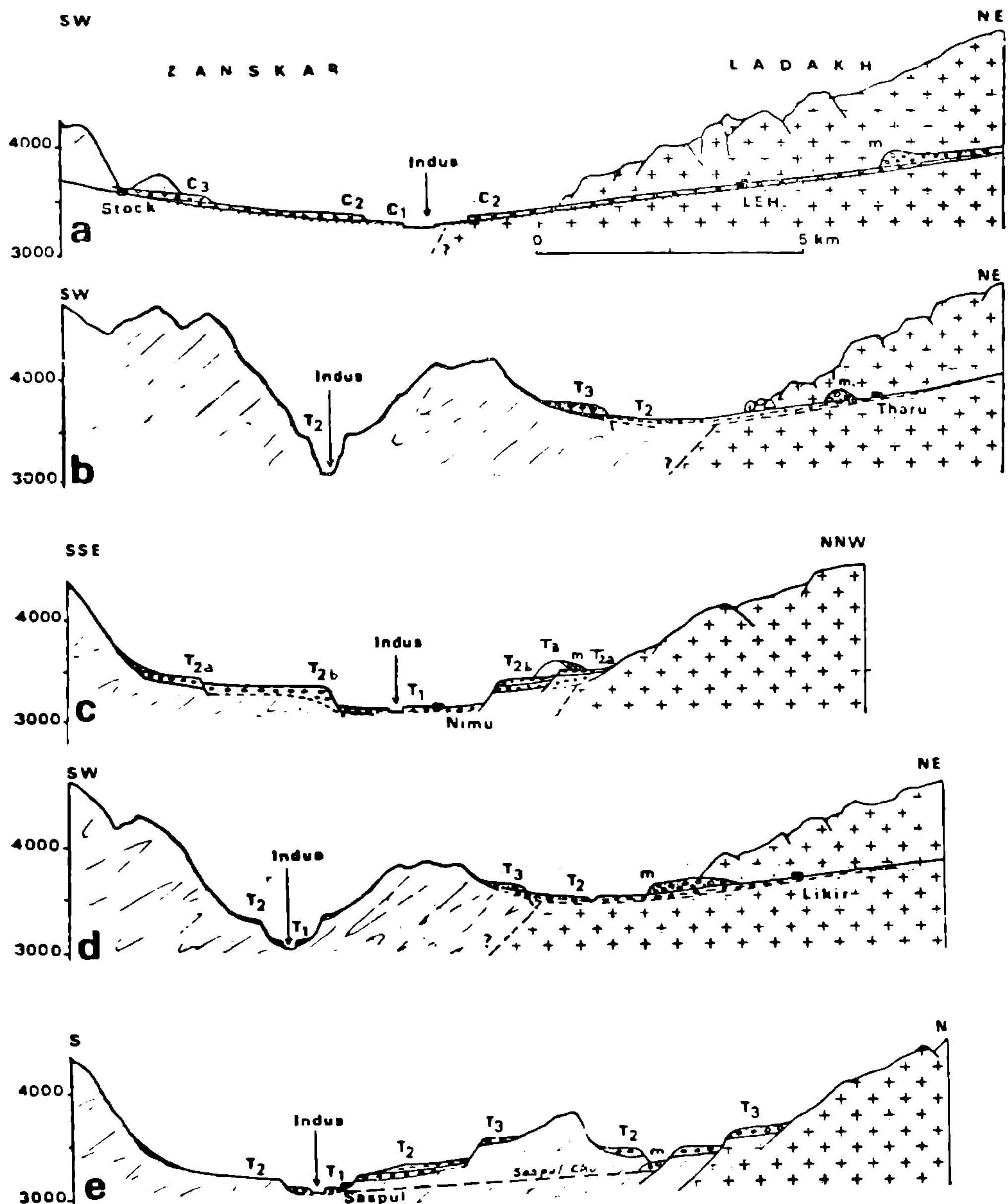


Figure 3. Cross profiles of the Indus Valley. a. Leh basin. b. 'Altipiano' of Tharu. c. Basin of Nimu-Basgo. d. 'Altipiano' of Likir. e. Basin of Saspul-Alchi. m—Moraines. ?—Non observed, but probable location of the contact between Ladakh granodiorite and molasses of the Indus Formation. The granodiorite is represented by crosses, the molasses by hatches, the letters T1, T2, T3 and C1, C2 and C3 refering to the text.

wasting and the widespread aggradational slush-flowed fans. These processes are still active in Zanskar (Fort, 1981*b*) but are mainly located at the upmost parts of the valleys (above 4700 m) : this may suggest a present increasing dryness of the mountain.

Plate 4. The landforms of the upper Markha Valley (4500 m). On the foreground, the frontal moraines of the Nimaling stage made of Rupshu granitic boulders. On the background, the remarkable slush-fans (200 m thick), having buried the sides of the former valley (flyschs of Lamayuru).

THE INDUS VALLEY

In the area presently opened to foreigners, the Indus valley appears as a wide furrow, running parallel to the main morpho-structural units of the Himalayas (WNW-ESE) and precisely located along the Indus Suture line, between the granodioritic and sedimentary areas. This particular location, most obvious around Leh, explains the opposition between the two sides of the valley. But downstream from Pitok, the parallelism between the valley and the structures is less evident : the river, shifted slightly towards the south, cuts across the molassic Indus Formation. Then a new geomorphologic opposition can be noted, between an upper part of the valley, the Leh basin, and the lower part (downstream), constituted by an alternation of gorges and small basins, located at the main confluences (Nimu, Saspul, Nurla) (Fig. 1*b*).

(a) The Leh 'Basin'

The basin stretches between Martselang (3380 m) and Pitok (3200 m). The valley appears as a wide intramountanous plain, progressively connecting the mountainous sides with wide coalescing fans, which create an *aggradational piedmont* (Plate 5). The river meanders freely and spreads widely over a large and marshy flood-plain, regularly submerged during the snow and ice-melting season.

The contrast between the two slopes of the valley is mainly due to their inequal degree of dissection. On the left side, the contact between the basin and the mountain is sharp, steep and rather rectilinear. An asymmetric crest, developed within the Indus Conglomerates, dominates the valley as a high wall, interrupted only by numerous but narrow gullies, at the issue of which the fans extend (Plate 5). On the right side of the valley, the granodioritic massif advance closely towards the Indus river by long prominent spurs, with much dissected contours, between which wide gulfs are protected and sealed off by abundant sandy deposits.

The major geomorphological feature is the *large extension of the fans* (F2 level) which built up at the foothills : fans of Leh, Sabu, Thikse, . . . (right side), Stock, Shushok, Hemis (left side), which gently slope towards the fluvial Indus plain. Varying between 5 to 10 km in length, they have a slope of 7° to 5°. The petrographic nature of their components influenced the morphology of the fan surface (Fort, 1981*a*).

Although limited in extent, *other morphological levels* represented in the Leh basin are :

(i) An upper and very restricted level appears north of Stackna (+70 m) beyond the Indus. It is made of coarse material (granodioritic components) and has a rough fabric, except for some local occurrence of well-layered and well-sorted beds. The top of the deposit dips northwards (towards the Ladakh Massif). We shall discuss later the interpretation of this upper level, which must be related to similar shapes found downstream from the Leh basin (Basgo . . .).

(ii) An upper fan (F3), which is mainly found on the left side of the valley, dominates the F2 surface of about 100 m upstream (Martselang) and of less than 50 m downstream (Stock).

(iii) A lower fan (F1) is slightly embedded within the major level (F2). It obviously corresponds to a torrential dynamic.

What significance could be given to the major fans (F2), responsible for the present geomorphic landscape? The width and volume of the fans required an abundant supply of debris and a huge amount of water, able to create such discharges and spreading even during a rather short period. A contrasted climate is undoubtedly the origin of such a dynamic. But was it a warm or a cold climate? It is more likely that it was a cold climate since it has been shown that during the Quaternary age the Ladakh Range suffered an extensive glaciation, which presumes a generalized coldness of the climate. Moreover, in this context of a high mountain, that is both cold and dry, a fast rate of ice-melting determines the concentration of the melted waters and so favours the building up of thick fluvio-glacial fans : a good illustration of this process is the present fans of the northern side of the Karakorum Range (which represents a very similar environment to that of Ladakh) observed by Trinkler (1931). In the same way, the fans of Leh, Stock or Martselang may be interpreted as fluvio-glacial fans as well (Fort, 1978). But the other smaller fans, which developed at the issue of lower valleys, more limited in extent and which bear no evidence of real glaciation, correspond much more certainly to the result of melting snow discharges, reworking and then spreading the frosted debris taken off the upland slopes.

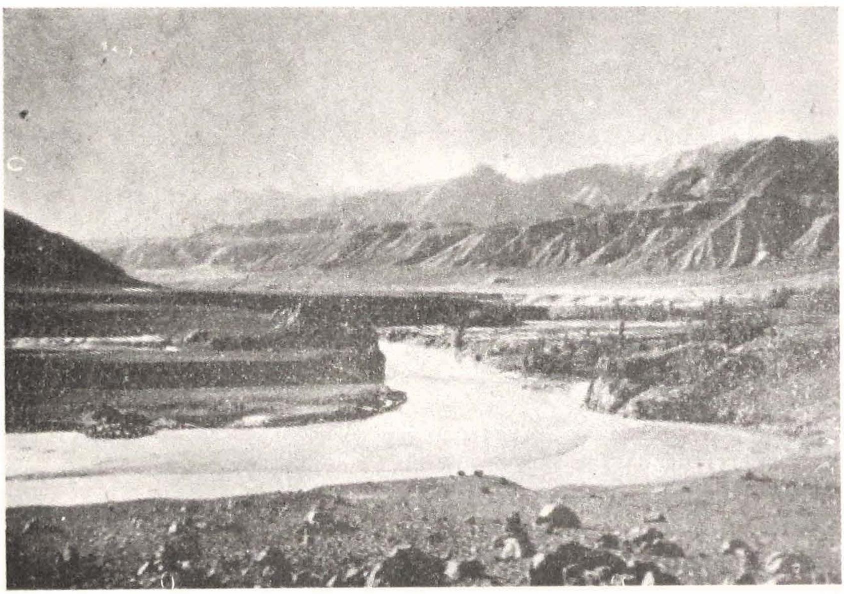
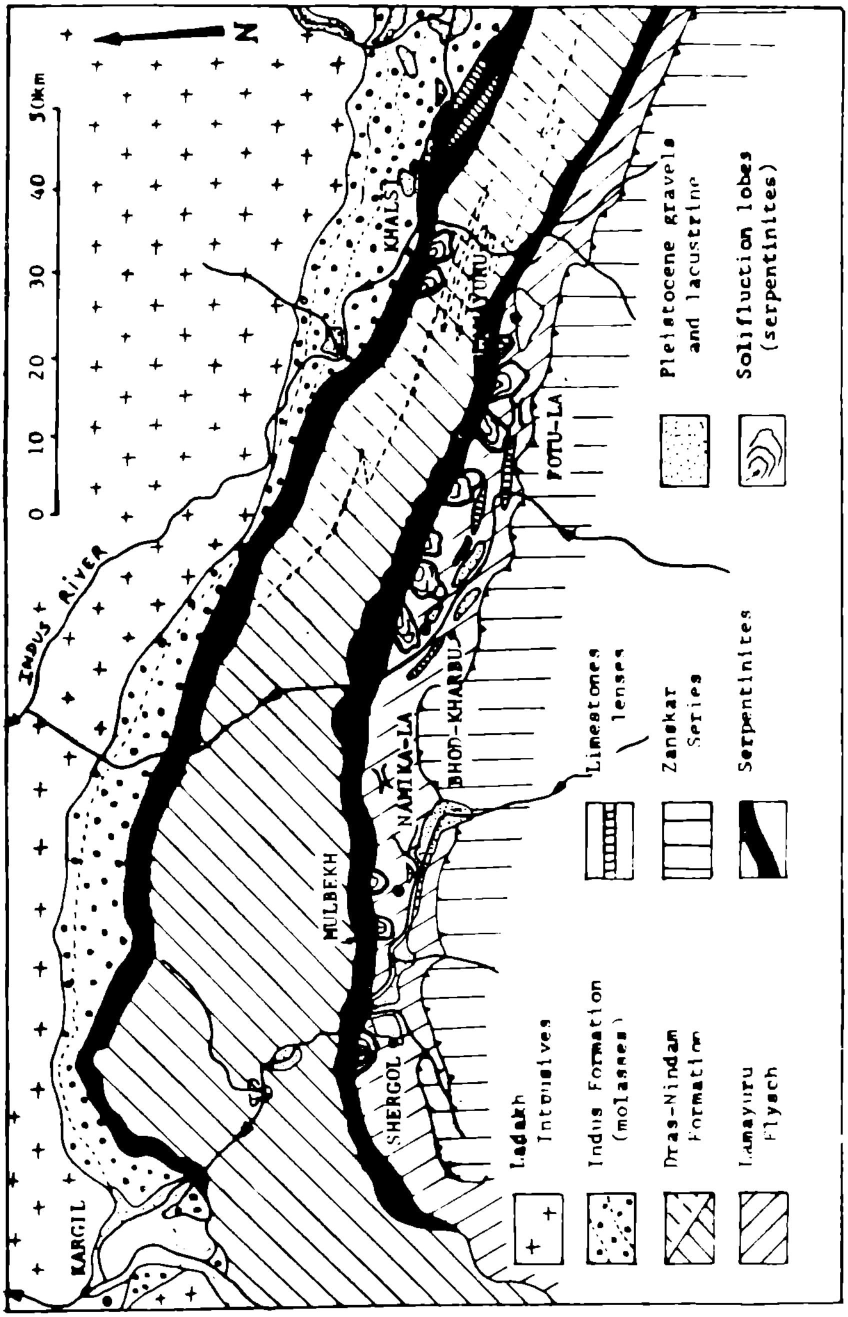


Plate 5. From Thikse monastery (3400 m). view towards Indus flood-plain and the fan-piedmont, developed at the foot of the Zanskar Range (Indus conglomerates).

(b) The Lower Section of the Upper Indus Valley

The lower section, which stretches between Pitok (3200 m) and Khalsi (2700 m) differs from the previous Leh basin because of its longitudinal and cross profiles. The longitudinal profile indicates a fast descent, consisting of an alternation of local basins (Nimu-Basgo, Saspul-Alchi, . . .) and deep gorges (Pitok to Nimu, Basgo to Saspul, . . .) (Fig. 1*b*). The cross-profiles are more complex (Fig. 4). Across the basins, the valley is wide and


N
0
10
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50km
INDUS RIVER
KARGIL
SHERGOL
MULBEKH
NAMIKA-LA
BHOD-KHARBU
FOTU-LA
KHALSI
LAMAYURU
Ladakh Intrusives
Indus Formation (molasses)
Dras-Nindam Formation
Lamayuru Flysch
Limestones lenses
Zanskar Series
Serpentinites
Pleistocene gravels and lacustrine
Solifluction lobes (serpentinites)

Figure 4.

is characterized by three main staged terrace levels, the relative altitude of which is increasing downstream (near Khalsi). Along the intermediate sections, these staged levels are more difficult to observe, in the sense that the valley seems to be split on either side of the monoclinal reliefs, shaped into the Indus Formation. In the south, the gorges of the Indus deepen. In the north, a high surface extends out at about 3500 m, formerly described and named 'altipiano' by Dainelli (1922) : this surface is located along the contact between granodiorite and the Indus Formation. Here only the two higher levels can be observed, whereas in the entrenched sections only the two lower levels can be seen (Fig. 4).

What are the geomorphological and sedimentological characteristics of the three observed levels? How may they be correlated with the three fans described upstream?

The *first level* (T1) at +20 m altitude above the Indus flood-plain and a sub-Recent terrace (To), corresponds to a terrace and is sometimes aggradational (Basgo) and sometimes erosional (Nimu) (see Plate 6).

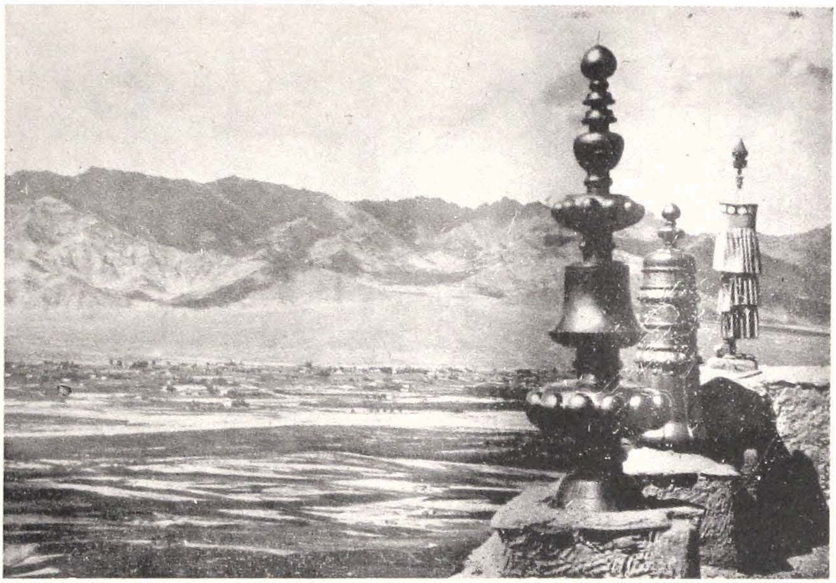

Plate 6. The basin of Nimu-Basgo, seen from the road (3050 m) (east). Note the staging of the terraced-levels : T1 (erosional and aggradational); T2, with its warped surface (in fact subdivided into two levels) of fluvio-glacial and slush-flowed aggradations; T3 (left side of the picture) which represents a morainic remnant.

The *second level* (T2) which dominates the Indus valley from 150-200 m, appears as a large plane sloping down towards the Indus. It constitutes the major topographical surface of the 'altipiano.' It corresponds to an aggradational fan, made of unsorted and very roughly bedded material of local origin (molassic debris coming from the neighbouring slopes). This material may be interpreted as periglacial—frost-shattered or/and slush-flowed—accumulations. But different sections show that these sediments were deposited on an inequally dissected topography, directly buried (Basgo) or filled up by alluvial deposits, coming from the Indus river and/or from adjacent Ladakhi tributaries (Saspul) (Fig. 5 and Plate 7). This T2 level is sometimes subdivided into two levels (NW Nimu) (Plate 6), the lower one being dissected within the main one and consisting of torrential or slush-flowed material as well. The occurrence of this sub-level is generally caused by the proximity of the regional base level (Indus). We may notice that the frontal moraines ('Leh Stage'), issued out of the main valleys of the Ladakh Range, in some places overlay this T2 level (Himis Shukpa) and are elsewhere clearly entrenched within (Saspul Chu, Temesgam. . .).

A *third level* (T3) exists above T2 (+ 50 m to + 100 m high). It is discontinuous and it corresponds basically to an erosional level (NW Basgo), developed within the Indus Formation (basal conglomerates, very rich in volcanic clasts, giving a characteristic green colour which stands out clearly against the purple shales, around Basgo and Nimu). Since the period of its shaping, this level has been dissected and only few patches remain.

Fairly often, the T3 erosional level is accompanied by some remarkable deposits, blanketing its surface and scarps. These deposits are found anywhere along the 'altipiano' and not particularly at the exit of the main adjacent valleys. They frequently appear as elongated smooth ridges. At Basgo for instance, they correspond to an

Plate 7. The Saspul basin, seen from the west and from the road (2800 m). Note the T1 alluvial terrace (foreground) and the T2 complex level which corresponds to local fluvial aggradation (on the left), then to a generalized periglacial aggradation, having buried a flat erosional surface (fluvial origin). The T3 level is not visible here.

accumulation of exclusively intrusive material (granitic, dioritic and volcanic clasts) coming from the Ladakh batholith, overlying the Indus Formation. They are characterized by a great heterogeneity of the grain-sized components, that is either very badly or non-layered. When considering the Ladakhi environment (see above the 'conclusions' concerning the geomorphology of that range), we may interpret these sediments as moraines, which must have been deposited by ice occupying a great part of the Indus valley.

(c) Correlations Between the Two Parts of the Upper Indus Valley

The downstream section of the Indus valley is different from the Leh basin because of : (i) the greater extension of the upper level T3, and (ii) the complexity of the level 2, the construction of which corresponds to the succession of several aggradational phases : alluvial, torrential or slush flows and, lately, morainic deposition.

Correlations may nevertheless be made. Similarities may be noticed :

(1) Along the two sections, the main level (T2 and C2) is always overlaid or entrenched by fresh and well-shaped frontal moraines of the 'Leh stage', and thus it must be older than the moraines.

(2) The material forming the basal aggradation of T2 level—boulders, embedded within a sandy silty matrix—may be considered as very abundant glacio-fluvial aggradation. To explain the shaping of the T2 surface, we invoke the same causes as those we suggested for C2 (see above) : the granitic boulders come from the Ladakhi side, which was glaciated.

(3) Between Pitok and Phyang, the geometric continuum between the C2 and T2 surfaces is very clear, in spite of the contrary slope of the cone of Phyang, which dips towards upstream. Thus, C2 and T2 levels must be related; they represent the same period of morphogenesis, which was dominated by a cold, dry and very contrasted environment, where the radiation was probably strong.

It is more difficult to relate together the upper levels, in the sense that upstream they are very scarcely present. I found morainic deposits upon the T3 erosional level. Is the enigmatic deposit beyond Stakna (right bank of the Indus river) a remnant of glacial deposits as well? I consider it as very probable, but further investigations are necessary.

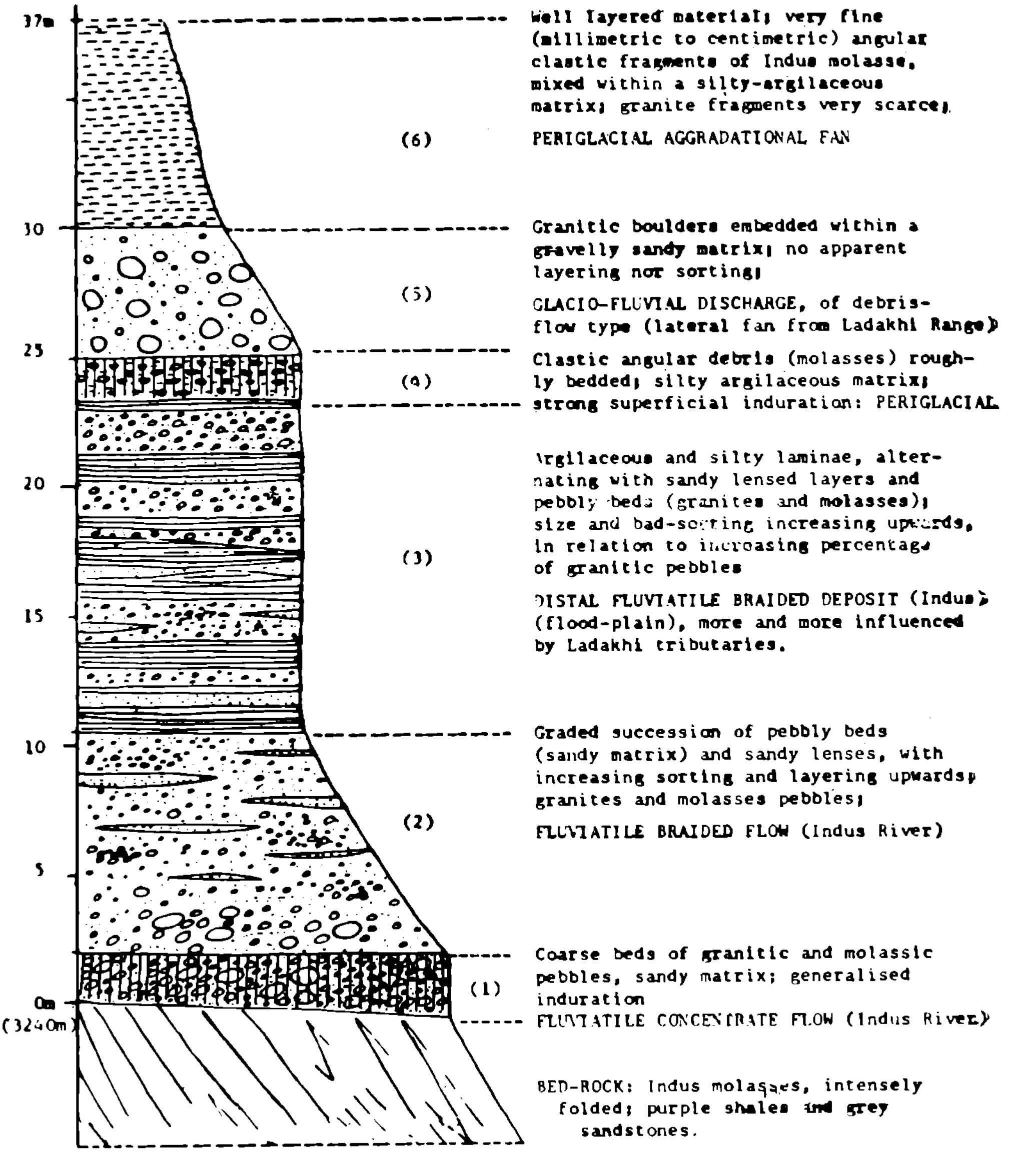

Figure 5. Section across the T2 terrace of Saspul (Detail). The section is located in a gully, between Saspul village (T1 level) and the pass to Ling-Likir (T2 level). Detailed section of Fig. 5, *e*. Above the pedimented bed-rocks (Indus Formation), thick cover of successively fluviatile, periglacial, glacio-fluvial and periglacial aggradations. The petrographic components are helpful for determining origin and processes of transport : granites coming from the glaciated Ladakhi Range, molasses coming from the proximal slopes of the Indus valley, mixed granitic and molassic pebbles are both carried by the Indus River itself.

Correlations between the Indus valley and the neighbouring ranges are summarized in Table 2. It shows a consistent relation between the valley and the surrounding mountains. Two main glacial stages are represented, the Indus stage and the Leh/Hankar/Spong stages, which were separated by an important and complex aggradational period (see Fig. 5). From the Leh stage up to now, the geomorphic environment becomes more and more influenced by the dryness, with the occurrence of debris-covered type of glaciers and currently the predominance of periglacial forms close to rock-glaciers (Fort, 1981).

TABLE 2—CORRELATIONS BETWEEN INDUS VALLEY, LADAKH AND ZANSKAR RANGES (ATTEMPT)

Ladakh Range	*Indus valley*	*Zanskar Range*
SUBACTUAL FRONTAL MORAINE	PRESENT FLOOD PLAIN	SUBACTUAL FRONTAL MORAINE
	Dissection	
Dissection	SUB-RECENT TERRACE To	Dissection
Successive phases of retreat KAR STRGE (Temesgam valley)	Dissection	Successive phases of retreat NIMALING STAGE (Markha valley)
Dissection	GLACIO-FLUVIAL CONES C1	Dissection
Frontal moraines LEH STAGE (Cimre, Phyang, Likir, Saspul, Himis, Temesgam . . .)	Dissection Altipiano definitively left	HANKAR STAGE (Markha valley) SPONG STAGE 2 (Spong valley)
Dissection	GLACIO-FLUVIAL CONES C1—TERRACES T2	Dissection
INDUS STAGE GENERALISED GLACIATION (Morainic ridges of Basgo, Nimu, upon the altipiano)	Indus river shift southwards	SPONG STAGE 1 U-shaped valleys (Markha)
	AGGRADATIONAL CONES C3 (upstream)	
Dissection	EROSIONAL TERRACES T3 (downstream, altipiano)	Dissection

Remarks. I noted here only the results of my own field observations, on the basis of morphological and sedimentological criterions. However, that proposal does not exclude other older events, particularly older glaciations, which probably occurred but of which no certain remain has been left.

—No absolute date is currently available.

—Here, I consider that dissection is basically due to uplift of the Himalayas. Dissection relatively decreases in intensity during the phases of deglaciation, when a huge amount of water and debris is provided and favours aggradation.

GENERAL INTERPRETATION AND CHRONOLOGY

At the end of this study, two more general problems may be evoked : the location of the Indus valley and the chronology of events which occurred during the Quaternary Period.

(a) The Location of the Indus Valley

The recent geomorphological evolution of the Indus valley resulted in the development of three more or less staged alluvial levels. But, in fact, these levels developed within a wider shape, suggesting the great age of the location of the valley. What is its origin? Various but not exclusive hypotheses may explain the individualisation and then the progressive entrenching of the valley:

(i) The valley could represent the *permanence of a subsidence area*, closely located to the Ladakh intrusives and the volcano-sedimentary formations of the Indus Suture Zone, which formerly appeared in the palaeogeographic pattern, in the sense that it has determined the sedimentation of the Indus molassic formation —"the upper . . . molasse was deposited by large, braided and meandering streams flowing eastwards between the Ladakh batholith and the uplifted Dras and Lamayuru units. . ." (Brookfield, unpublished data, cited in Andrews-Speed *et al.*, 1980).

(ii) The location of the valley may also be the result of the *late deformations*, responsible for a general northwards thrusting of the whole Indus Formation above the Ladakh batholith and its detritic cover (basal conglomerates, see Frank *et al.*, 1977) : the thrust has certainly caused the appearance of a crest-front, at the foot of which the former Indus may have flowed.

(iii) Looking at the general pattern of the Himalayan hydrographic network, the Indus river may be considered as one of the most spectacular *antecedent rivers* (see Fort, 1980), flowing across the Transhimalayan and Himalayan structural units (note particularly its gorges across the Ladakh batholith, firstly south of Pangong Lake, and then before Skardu). The former course settled upon a flat surface, which locally corresponds to the erosional upper surface of the Ladakh Range. Then, the river started to cut across the geological bedrock, locally reorganizing its course according to the erosional potential of the rocks. The contact line between the Ladakhi batholith and the Indus Series might have been utilized by the selective erosion of the river, which encountered non-resistant layers, because of their lithology (shales and silts of the Indus Formation) or/and because of their weathering : this weathering, noticed in several places along the contact, must have been determined to a considerable extent by the intense tectonic shears along the border of the batholith. In the same way, later tectonic stages might have warped the erosional surface and helped to create a tectonic trough.

(iv) We cannot exclude the occurrence of more *recent movements*, which may have more precisely defined the location of the valley along the contact batholith/Indus Zone. I have suggested the occurrence of slight relative movements around the Leh basin on the basis of my geomorphological observations (Frot, 1978), particularly in considering the strong contrast existing between the Leh basin, where all the dissection or aggradational levels tend to converge towards the Indus flood-plain, and the downstream sections of the valley, where the staged levels are more and more entrenched. Using the results obtained after a numerical analysis of the Landsat Imageries of the area (automatic map, see Fort, 1981*a*), I have shown the existence of a structural alignment, stretching WNW-ESE between Pitok and Thikse, whose interpretation may still be debated (I suggested an irregular strike-slip feature, along which differential uplift or subsidence can occur).

These four hypotheses are helpful to understand the localisation of the Leh basin and the altipiano. But how can we explain the splitting of the valley, west of Pitok?

G. Dainelli (1922) suggested a change in the course of the Indus, caused by several *generalized glaciations*, during which the entire valley was covered by the ice, and the previous hydrographic pattern was completely disorganized. After the melting of the ice, the Indus changed its course by taking that of its two main tributaries, the Rumbock Chu (south of Pitok) and the Zanskar River (south of Nimu). This interpretation is confirmed by the recognition of the deposits above the T3 level as being morainic (see above, especially for the deposits of Stakna, Basgo, . . .) and it can be considered to be valid. But that is not sufficient to explain the asymmetry of the Indus valley, the predominance of the deposits coming mainly from the Ladakhi side, and the rather pronounced slope of the terraces of the right side towards the Indus. We may invoke the active *periglacial processes* (particularly slush-flowed fans) which were probably increased by the southward exposure on the Ladakh side (the melting of the snow is much faster on a southern slope than on a northern one, as on the Zanskar side) and so is responsible for a greater amount provided by the Ladakh Range. I cannot exclude the influence of a differential uplifting either (Fort, 1978).

(b) Chronology

We can summarize the succession of events as follows :

(1) development of a complex polygenic flat surface (upper erosional surface of Ladakh, found elsewhere in Tibet);
(2) general dissection of the reliefs, particularly along the Indus furrow. Does this dissection have to be considered a direct consequence of the major uplift of the Himalayan Range? (See discussions and references cited in Fort, 1980);
(3) shaping of the upper level (T3); this level might be connected with a first period of glaciation in this area;
(4) dissection of the T3 level; occurrence of a widespread glacierization, filling certainly the Indus valley between Nimu and Khalsi, and may be also the upper part, upstream of Leh;
(5) shaping of the main T2-C2 level : result and final (melting) stage of a long cold and glaciated period; late periglacial stage;
(6) dissection (very limited in the Leh basin);

(7) new spell of cold, occurrence of a valley-tongues glaciation (Leh stage); on the Zanskar side the glaciers never came out of the mountain;
(8) deglaciation and shaping of the T1-C1 level;
(9) dissection;
(10) very limited glacierization, of debris-covered tongue type;
(11) very recent terraces To and flood-plain.

Because of the lack of absolute chronological data, we cannot date these events precisely. But, on the basis of other investigations carried out on the Nepalese Himalayan range (Fort, 1979, 1980), I may presume and suggest that : (1) has probably occurred around the Miocene-Pliocene periods and (2) might have started at the end of the Pliocene period, whereas (3) to (8) might have occurred during the Pleistocene period and (9) to (12) may probably be considered as Holocene. I would like to stress on the fairly 'poor' glacial history of the Ladakh range. The lack of more glacial remnants can be explained by a subsequent erosion and/or the fact that if the area has suffered a previous extensive glacierization, remnants must be found much more further (downstream), where the glaciers are supposed to have accumulated. In this case, it is not surprising to find in the upper Ladakh the more recent and well-preserved deposits, all the more preserved because of the dryness.

We may conclude by emphasizing the distinctive characteristic of Ladakh as an exemplary cold and dry high mountainous area. This characteristic can be recognised by the following geomorphological evidence :

—the selective shaping of a very contrasted geological bedrock, in relation to the lithology and to the effects of various and intense stages of deformation,

—the inequal action of the cold climates according to their dryness : when the climate was cold and a little more humid (Pleistocene Period), the glacial erosion was as important as the periglacial actions; but with the progressive increase in dryness (late Pleistocene and Holocene periods), the periglacial processes became predominant; an efficient frost wedging acted together with snow gelifluction, which is probably the most specific process of this kind of environment.

Today, although less pronounced, the same processes are still active in the whole area.

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Study on Himalayan Stratigraphy in South Xizang (Tibet)

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ABSTRACT

This paper deals with the middle segment of the Xizang Himalayas. The tectonic lithofacies belts from north to south are as follows : (i) Tethyan Himalayan belt, which can be further subdivided into North Sub-Belt and South Sub-Belt. The Mesozoic sediments in the North Sub-Belt are of eugeosynclinal type, while the Palaeozoic, Mesozoic and Cenozoic sediments in South Sub-Belt are of platform type; (ii) High Himalayan belt or Central Crystalline belt. New discoveries in stratigraphy and paleontology in recent years and the stratigraphic characteristics of the tectonic lithofacies belts in South Xizang are emphasized. For the purpose of correlation, the Mesozoic strata in the southern part of the Gandise-Nyainqentanglha region, which is situated in the north and separated by the Yarlung Zangbo Ophiolite Zone from the Xizang Himalayan region are also briefly introduced and an outline of the geological evolution of the Xizang Himalayas is discussed.

INTRODUCTION

THE MIDDLE segment of the Himalayas is introduced as Xizang Himalayas in this paper. Generally, Xizang Himalayas is separated by the Yarlung Zangbo Ophiolite Zone from Gandise-Nyainqentanglha and can be divided into 2 units : Tethyan Himalayan belt in the north and High Himalayan or Central Crystalline belt in the south. Only a small part of the latter is in China territory, while the greater part is in Nepal. Since the Himalaya has complex geological structures and geological history as well as its extraordinary high altitude exercises a great influence on natural environments and human activities (Scientific Expedition to Xizang, Academia Sinica, 1973), it is a critical region for valuable scientific exploration and interesting inquiries in many subjects and has long attracted the close attention of scientists throughout the world.

At the beginning of the present century, Hayden (1907) made a geological survey from Yadong via Gyangze to Lhasa and discovered for the first time the marine Jurassic, Cretaceous and Lower Tertiary strata. The fossils he collected were studied by Douvillè (1916) and Arkell (1953). Later, Heron (1922), Odell (1925), Wager (1934, 1939), members of the British Expedition to Mt. Qomolangma also made geological surveys to Mt. Qomolangma and its northern slope during 1920s and 1930s. Wager (1934, 1939) subdivided the strata at Mt. Qomolangma into Mount Qomolangma Limestone Series, Mount Qomolangma Pelitic Series and Lower Mount Qomolangma Limestone from top to bottom and correlated the Mount Qomolangma Limestone Series with the Lachi Series of northern Sikkim. The age of this sequence was referred to Carboniferous to Permian. On the founding of the People's Republic of China in 1949, large scale expeditions and geological surveys began and have been successively made up to the present. Among them mention may be made of : the survey of the Xizang working team organized by the Culture and Education Committee of the Government Administration Council and headed by the geologist Li Pu in 1951-53, covering Xigaze and Shannan districts, approaching Rongpu Lamasery at the northern slope of Mt. Qomolangma; the geological surveys to Mt. Qomolangma and its northern slope for the first time by the Chinese Mountaineering and Scientific Expedition in 1959-60 which led to drawing of some geological and structural sketch maps; the surveys made by the scientific investigation team of Mountaineering expedition to Mt. Xixabangma headed by geographer Shi Ya-Feng and geologist Liu Tung-Sheng in 1964 which led to the discovery of Pliocene *Quercus* fossils at the northern slope of Mt. Xixabangma for the first time (Hsü Jen, 1973*a*), and of Triassic *Ichthyosauria* fossils at Suri hill in Tingri county (Shi Ya-Feng and Liu Tung-Sheng, 1964); the multi-purpose, multi-disciplinal extensive scientific surveys to Mt. Qomolangma region for the second time organized by the Scientific Expedition to Xizang, Academia Sinica and headed by Liu Tung-Sheng 1966-68, as a result of which the Ordovician, Silurian and Devonian strata were discovered for the first time in that region, the age of the limestone at the peak of Mt. Qomolangma was studied and referred to Ordovician as well as several new discoveries and significant supplements in sequences from the Carboniferous to Lower Tertiary were made. Palaeontological specimens of 20 and more taxa including *Glossopteris* fossil plant on their first discovery (Hsü Jen, 1973*b*) were described and on this basis, strata of various geological periods were subdivided in detail and correlated so that a comparatively complete stratigraphic system in Mt. Qomolangma region was preliminarily established (Mu An-Tse *et al.*, 1973); the geological surveys from 1973-79 during the multi-purpose scientific expedition to Qinghai-Xizang Plateau sponsored by Academia Sinica including the surveys to Mt. Qomolangma region for the third time in 1974-75 and strata of Gondwana facies were discovered for the first time at the northern slope of Mt. Qomolangma (Yin Ji-Xiang and Guo Shi-Zeng, 1976). After many surveys to the Xizang Himalayas and its adjacent regions mentioned above, a large amount of geological reports and papers were contributed and published, which paved the way for convening of the International Symposium on Qinghai-Xizang (Tibet) Plateau held in Beijing in 1980. It was in this Symposium that the Chinese geologists contributed many academic communications along with the geoscientists from India, Pakistan, Nepal and many other countries, and a post-Symposium scientific tour to Xizang Himalayas was organized. Studies and discussions of the Chinese and foreign scholars on Himalayas and its neighbouring region constituted a good start to reveal the mystery of continental plate motions. Since 1981, as a result of the surveys that covered an extensive area in Qinghai-Xizang Plateau including Xizang Himalayas by research teams of geoscientists to Qinghai-Xizang Plateau, Academia Sinica and all sorts of research teams from Ministry of Geology, many new discoveries have been made in stratigraphy, paleontology and tectonics.

Data obtained from all the successive scientific surveys show that since the end of Palaeozoic, roughly taking Yarlung Zangbo river as a boundary, the regions to its south and north underwent different stratigraphic and sedimentary histories and can be assigned to different tectonic belts, respectively. To the north of Yarlung Zangbo river, it is Gandise-Nyainqentanglha Tectonic Belt which was a part of the Eurasian Plate, while to the south of the river, it is Himalayan Tectonic Belt, a part of the Indian Plate. Prior to Mesozoic, they were possibly all combined in Gondwanaland (Veevers *et al.*, 1975). In this paper, the stratigraphic features of Xizang Himalayas are emphasized and some correlations are made to enquire into the geological evolution in this region. The Mesozoic strata at the southern margin of Gandise-Nyainqentanglha which is the neighbouring region of the Himalayas to the north are also briefly introduced. On the basis of these remarks, an outline of geological evolution of Xizang Himalayas is preliminarily discussed.

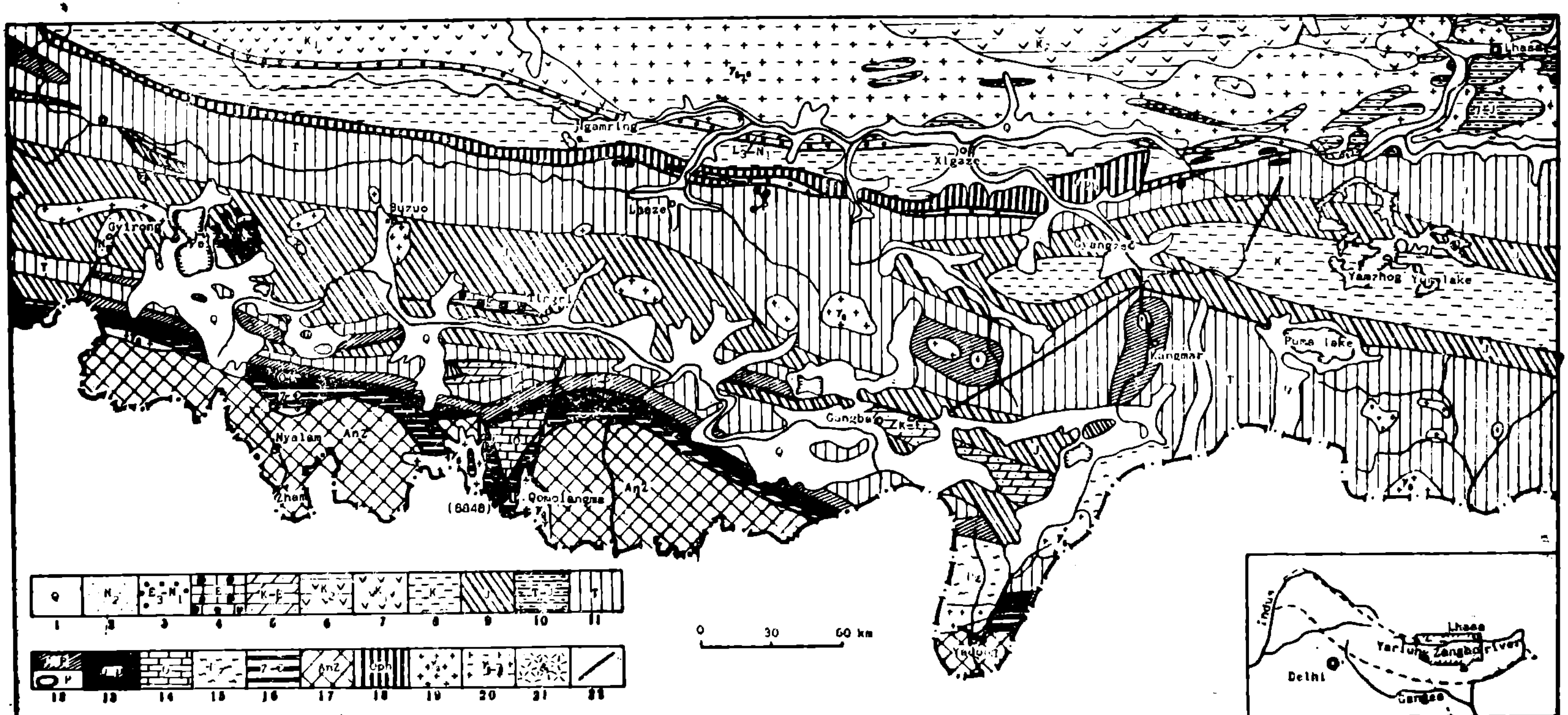
MESOZOIC STRATIGRAPHY OF THE SOUTHERN PART OF GANDISE-NYAINQENTANGLHA AND YARLUNG-ZANGBO OPHIOLITE ZONE

The Mesozoic strata in the southern part of Gandise-Nyainqentanglha can be divided into 3 lithofacies belts from north to south, i.e., Cretaceous Intermediate-acid Volcanic-sedimentary Rock Belt, Gandise Magmatic Rock Belt and Cretaceous Flysch Belt.

Cretaceous Volcanic-sedimentary Rock belt is mainly distributed to the north of Lhasa and the northern bank of Yarlung Zangbo river to the west of Xigaze. In Lhasa district, the Lower Cretaceous consists of alternations of marine and continental coal-bearing clastics conformable on the Upper Jurassic limestone, and in the lower part (1,600 m thick), it is coal-bearing clastics yielding plant fossils *Weichselia reticulata* (Stockes et Webb.), *Onychiopsis elongata* (Geyler); the middle part (900 m thick) quartz sandstone intercalated with slates; the upper part (1,000 m thick), mainly marl and purple red clastics yielding foraminifera *Orbitolina tibetica* Cotter, ammonoid *Whligella* cf. *chansayensis* Jacob (Chen Guo-Ming *et al.*, 1980; Yin Ji-Xiang *et al.*, eds. 1980). The Upper Cretaceous (1,560 m) consists of calci-alkalic intermediate-acid volcanics intercalated with red beds unconformable on the Lower Cretaceous. The Lower Cretaceous along the northern bank of Yarlung Zangbo river consists mainly of Intermediate-acid volcanics interlayered with crystalline limestone.

Gandise Magmatic Rock Belt mainly comprises granodiorite, granite and small amount of diorite of Yanshan and Himalayan periods (110-20 m.y.) intruding into the Mesozoic strata, which mainly consists of sandstone, slate intercalated with limestone-bearing Triassic and Jurassic fossils(?) *Posidonia* sp., *Ptygmatis* sp., etc.).

The Cretaceous Flysch Belt to the south of magmatic rock belt mainly consists of sedimentary rocks with flysch structure of Angren Formation in Xigaze Group. The Qiuwu Formation and Qiabulin Formation in the



The Chinese national boundaries in this map are drawn after the 1/4,000 000 map of the People's Republic of China published by the Cartography Publishing House, Beijing 1980

Figure 1A. Geological map of Xizang Himalayas: Legend 1. Q Fluvial, glacial and lacustrine sediments. 2. N_2 Yebokanggale Group, Woma Formation, Date Formation. 3. E_3-N_1 Liuqu Conglomerate, Qiuwu Formation, Qiabuling Formation. 4. E Zongpu Group, Zebu Ri Formation. 5. K-E (undivided) Limestone, shale and sandstone. 6. K_2 Lingzizong Formation. 7. K_1 Lingbuzong Formation, Chumulong Formation, Takena Formation. 8. K Jiabula Formation (K_1), Zongzhuo Formation (K_2), (North Sub-Belt); Kangpa Group (K_1—K^1_2), Zongshan Formation (K_2), Jidula Formation (K_2) (South Sub-Belt) (above: Himalayan belt); Xigaze Group (K) (Gandise-Nyainqentanglha Belt). 9. Ritang Formation (J_1), Gyangze Formation (J_2), Weimei Formation (J_3) (North Sub-Belt); Pupuga Formation (J_1), Niehnieh Hsiungla Formation (J^1_3), Lalongla Formation (J^2_3), Menbu Formation (J_3) (South Sub-Belt). 10. T-J (undivided) Sandstone, shale, limestone. 11. T Tulong Group (T_1 — T^{2-1}_3), Qulonggongba Formation (T^{2-2}_3) Derirong Formation (T^{2-3}_3) (South Sub-Belt); Zongbei Formation (T_1), Xiukgan Formation (T_2), Gyirong Group (T_3) (North Sub-Belt). 12. Ĉ-P Yali Formation (C_1), Naxing Formation (C_1 + C_2), Gilung Formation (C_3), Selung Group (P). 13. OD Rouqiecun Formation (O^1_1), Chiatsun Group (O_{1+2}), Hongshantou Formation (O_3), Shiqipo Formation (S_1), Pubu Group (S_{2+3}), Liangquan Formation (D_1), Pochu Group (D_{2+3}). 14. O Mt. Jolmo Lungma Formation. 15. P_z (undivided) Slate, phyllite, crystalline limestone. 16. Z-є North Col Formation. 17. AnZ Kyanite schist, sillimanite gneiss, migmatite 18. Oph Ophiolite Belt. 19. γ_6 Two-mica granite, tourmaline muscovite granite (Himalayan period) 20. γ_{5-6} Granodiorite and granitoids (Yanshan-Himalayan periods). 21. δ_5 Diorite (Yanshan period). 22. Fault.

lower part of the Xigaze Group as formerly proposed by Wu Hao-Ruo *et al.* (1977) are possibly Tertiary continental sediments and it seems improper to place them into the Cretaceous Xigaze Group. The flysch sediments of the Xigaze Group intercalate with limestone and conglomerate and display a fault-contact with the possible Tertiary molasse of the Qiabulin Formation in the north and also fault-contacts with the Yarlung Zangbo Ophiolite Zone in the south. Only locally the flysch sediments are suspected to have a continuous transition to the Lower Cretaceous in the ophiolite zone. Fossils of Aptian-Turonian stages, e.g., foraminifers *Orbitolina texana* (Roemer), *Palorbitolina lenticularis* (Clumenbad), pelecypod *Bournonia* sp. and ammonoid *Mammites* sp. are found in Xigaze Group. In Zhongba which is situated to the west of Xigaze, Maestrichtian ammonoid *Sphenodiscus* sp. was already described in the variegated rock series without flysch structure lying on the Xigaze Group and the fossil-bearing strata transit upwards continuously to the marine Lower Tertiary intercalations yielding foraminifers *Miscellanea miscella* (d'Archiac et Haime), *Actinosiphon tibetica* (Douvillè) (Qian Dingyu *et al.*, 1982). The Cretaceous Flysch Belt is probably in the same tectonic belt with the Cretaceous-Tertiary 'Indus Flysch' exposed in Ladakh (Frank *et al.*, 1977) and its sedimentary characteristics are similar to the Great Valley sequence in California, U. S. A. (Ingerall, 1979).

The Yarlung Zangbo Ophiolite Zone trending E-W is in discontinuous belt-like extension. To the west, it connects with the Indus Ophiolite Zone and to the east turning south, it connects with the ophiolite zone along the Burmese-Indian border. The ophiolite zone, which is interpreted as the suture line between the Eurasian continent and South Asian sub-continent, mainly consists of harzburgite, sheeted dykes and pillow lava with very few cumulite exposed. Two series of sedimentary rocks associate closely with the ophiolite : ophiolitic clastics distributed mainly to the north of the ophiolite and radiolarian cherts distributed mainly to the south of the ophiolite. Ophiolitic clastics consist mainly of cyclothems of greyish green and purple-red sandstone, siltstone and shale, in the lower part more siliceous shale and chert intercalated with basic lava and tuff are found and the thickness seen is 50-300 m. This clastic series conformable on the pillow lava probably transits gradually to the Xigaze Group to the north; nevertheless, fault-contacts are found at most of the places. Its clastic constituents are mainly composed of plagioclase, pyroxene, and debris of basalt and siliceous rock as well as ophiolite occasionally. Radiolaria *Acaeniotyle umbilicata* (Rüst), *Archaeospongoprunum tehamaensis* Pessagno, *Vitorfus* sp., *Patulibracchium* sp., etc., are discovered in cherts and the age is estimated to be late Early Cretaceous to early Late Cretaceous. Radiolarian siliceous rock is mainly composed of medium-thin bedded red with partly green chert intercalated with siliceous shale-bearing well-preserved *Archaeospongoprunum tehamaensis* Pessagno, *Thanarla praeveneta* Pessagno, *Hsuum* (?) *stanleyensis* Pessango, etc., and the age is Tithonian-Cenomanian. The thickness seen reaches 300 m or so and along both sides of the siliceous rock, fault-contacts occur (Fig. 2).

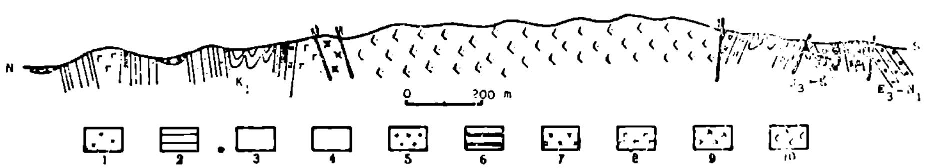


Figure 2. A Section of the Yarlung Zangbo Ophiolite Belt, 20 km southeast of Xigaze. 1. Quaternary, 2. Shale, 3. Siltstone, 4. Sandstone, 5. Conglomerate, 6. Siliceous shale, 7. Chert, 8. Basalt, 9. Dykes, 10. Harzburgite.

STRATIGRAPHY OF THE TETHYAN BELT

On the basis of the distinctions in the stratigraphic characteristics and structural deformation, taking roughly a line from Kangmar-Sa'gya-Suzuo as the boundary, the Tethyan Himalayan Belt can be subdivided into two sub-belts : North and South. The strata of the North Sub-Belt mainly cover the region between the north of the low-divide at Lhagoi Kangri and the Yarlung Zangbo Ophiolite Zone. Late Palaeozoic strata are similar to those of the South Sub-Belt, but the Mesozoic strata from Late Triassic onwards all present flysch structure and intercalate with radiolarian cherts and intermediate-basic volcanics, which is distinctive from the platform-type feature in South Sub-Belt. Tectonically, tight foldings inverted to the south and many thrusts developed showing generally light-grade metamorphism. Strata of South Sub-Belt mainly cover the region between the south of the low-divide of the Lhagoi Kangri in South Xizang and the northern piedmont of the High Himalayas. Relatively complete sections are found at the northern slope of Mt. Qomolangma, Nyalam, Tingri and Gangba districts embracing a nearly continuous marine sequence from Sinian-Cambrian (?) to Eocene. In Yamzhog lake

area of the Shannan district in South Xizang, the Palaeozoic strata which correspond to those in Mt. Qomolangma region are all truncated by faults, and Mesozoic eugeosynclinal sediments that can be corresponding to those of the North Sub-Belt are spread over the whole lake area.

A. Stratigraphy of North Sub-Belt

Fossil-bearing sequence in the North Sub-Belt embraces the period from the Upper Carboniferous to the Upper Cretaceous.

The Carboniferous

Distributing at the core of the Kangmar arch structure, the Upper Carboniferous Kewoxika diamictite is evidenced by brachiopod *Stepanoviella* sp., and the thickness seen is 200 m. The lithofacies and horizon of the diamictite can be correlated with Zhadari diamictite of the Gilung Formation at the northern slope of Mt. Qomolangma. The underlying strata are unexposed and upwards it transits continuously into the Permian.

The Permian

The lower part is Kangmar Formation, black slate, approximately 100 m thick; the upper part is Baidingpu Formation (250 m thick), mainly limestone yielding brachiopods *Neospirifer kubeiensis* Ting emend. Chang, *Chonetella nasuta* Waagen, coral *Tachylasma* sp., etc. The sequence bearing the fossil assemblage is similar to the Chubujeka Formation at the northern slope of Mt. Qomolangma in South Sub-Belt.

The Triassic

The sequence wide spread in Xigaze and Shannan districts is mainly the Upper Triassic, while the Middle and Lower Triassic strata are exposed sporadically. A good section of the Lower Triassic is found at the East Hill of Zombe in Lhaze county, which is recently named as Zombe Formation (thickness seen 86 m) and both the upper and lower parts of this formation are truncated by faults. The lithology is characterized mainly by grey shale intercalated with many medium-thin-bedded limestones yielding pelecypods *Claraia concentrica dingjiensis* Zhang, *Pseudoclaraia* cf. *himaica* (Bittner), *Eumorphotis* sp., ammonoids *Anasibirites kingianus* (Waagen), *Keyserlingites sp.*, *Anakashmirites nivalis* Diener, *Dinarites* sp., belemnite *Asteroconites* sp. and fish fossils. A good section of the Middle Triassic is cropped out in Xiukang of Lhaze county and recently named as Xiukang Formation (thickness seen 181 m). It consists of interbeddings of grey calcareous shale and medium-thin-bedded limestone conformable on the Lower Triassic and the upper part is also cut off by fault. In the lower part of the Xiukang Formation pelecypods *Halobia rugosoides* Hsü, *H.* aff. *subcomata* Kittl, *Daonella* cf. *moussoni* Mer., and in the upper part, *Daonella indica* Bittner are collected. The Upper Triassic, i.e., the Gyirong Group is widely spread in Xigaze district of South Xizang. It mainly comprises cyclothem of variegated sandy shale, siliceous shale and sandstone intercalated with greyish red radiolarian chert bands and thin beds and basic volcanics as well as a little limestone. The thickness seen is 2,000 m yielding *Monotis* (*M.*) *salinaria* Bronn, *Halobia superbescens* Kittl.

The Jurassic

The Lower Jurassic crops out sporadically and based on sections in Lhunze, Shannan district, the Ritang Formation of the Lower Jurassic (350 m) is mainly comprised of shale and marl yielding ammonoids *Psiloceras provincialis* (Quenstedt), *Prodactylioceras enodum* (Quenstedt). The Gyangze Formation of the Middle Jurassic (greater than 200 m) is thin-bedded limestone, lamella marl intercalated with bedded tuff-bearing ammonoid *Delecticeras* sp. The Weimei Formation of the Upper Jurassic (more than 700 m) comprises interbeddings of black silty shale and medium-thin-bedded grey sandstone yielding ammonoids *Himalayites* sp., *Haplophylloceras strigile* (Blanford), belemnite *Belemnopsis elongata* Yin, etc. In the western part of Xigaze district, the Upper Jurassic consists of sandstone and shale intercalated with cherts.

The Cretaceous

The lower part of the Jiabula Formation of the Lower Cretaceous (1,000 m) consists of shale with nodules-bearing ammonoids *Thurmanniceras grandium* Chao, *Calliptychoceras walkeri* (Uhlig), belemnite *Hibolithes jia-*

bulensis Yin, etc.; the middle part of siliceous shale intercalated with chert beds bearing a few belemnite and pelecypod fossils; in the upper part, shale-bearing pyrites, ammonoids and belemnites are occasionally found. The Zongzhuo Formation of the Upper Cretaceous (more than 1,000 m) consists mainly of sandstone and shale with flysch structure and turbidite embodied with blocks composed of cherts, limestone, quartz sandstone of olistostrome origin, and in the matrix cherty bands and lens are also seen. One of the blocks is composed of grey chert bearing Early Cretaceous Berriassian radiolaria *Petanellium riedeli* Pessagno, *Gongylothorax favosus* Dumitrica, *Parvicingula boesii* (Parona), etc., and in the chert of the matrix surrounding the blocks, Turonian radiolaria *Gongylothorax verbeeki* (Tan Sin Hok), *Pseudodictyomitra pseudomacrocephala* (Squinabol), etc., are collected (Wu Hao-Ruo and Li Hong-Sheng, 1982). The Zongzhuo Formation also intercalates with multi-bedded pelagic limestone, in the upper part of which foraminifers *Globotruncana stuartiformis* (Dalbiez), *G. Linneiana tricarinata* (Quereau) are found and the age of the fossils reaches Campanian-Maestrichtian, which so far is the highest fossil horizon known in the North Sub-Belt of the Tethyan Himalayas (Fig. 3).

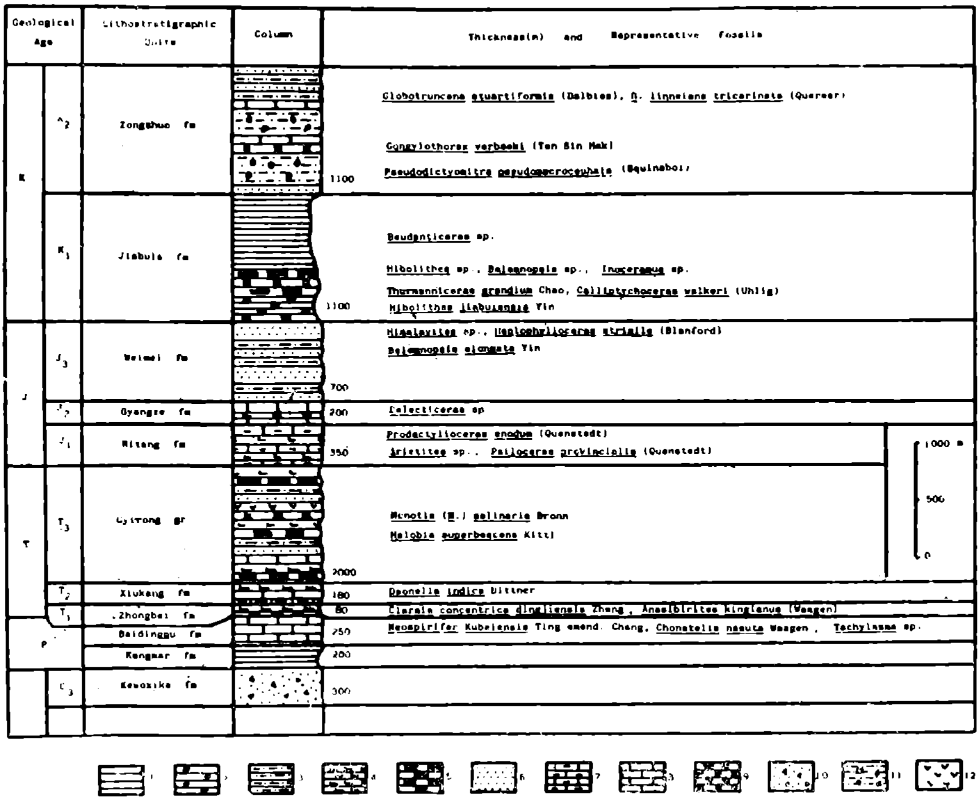


Figure 3. A comprehensive stratigraphic column in the North Sub-Belt of the Tethyan Himalayas in South Xizang. **1.** Shale, **2.** Shale with nodules, **3.** Sandy shale, **4.** Calcareous shale, **5.** Sandstone, **6.** Argillaceous limestone, **7.** Limestone, **8.** Chert, **9.** Glaciomarine diamictites, **10.** Olistostrome, **11.** Basic volcanics.

B. Stratigraphy of South Sub-Belt

Except for the Sinian-Cambrian strata which are argillaceous rock series with flysch-like structure undergone light-graded metamorphism, the sedimentary rocks from the middle and upper parts of the Lower Ordovician to the Eocene are unmetamorphic and the lithologic assemblages are rather simple yet with abundant fossils. The total thickness exceeds 16,000 m, and mostly neritic sediments representing the platform type are found. Fauna from Ordovician to Devonian can be assigned to those of North China, Central China and West China types. In the Carboniferous and Permian strata, sediments and biotas of Gondwana facies are discovered, while the Mesozoic and the Early Tertiary sediments and biotas belong to the Tethyan type (Fig. 4).

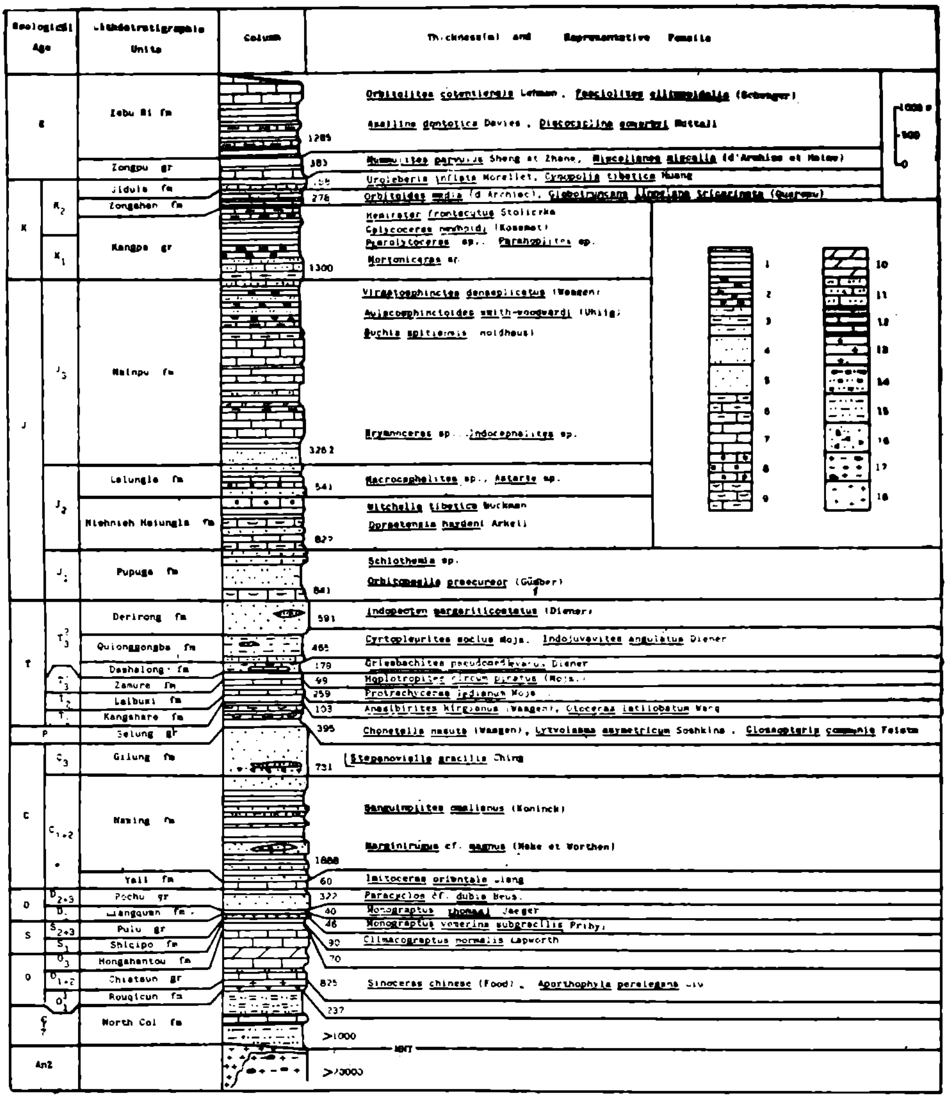


Figure 4. A comprehensive geological column in the South Sub-Belt of the Tethyan Himalayas in South Xizang. **1.** Shale. **2.** Shale with nodules. **3.** Sandy shale. **4.** Siltstone. **5.** Quartz sandstone, sandstone. **6.** Argillaceous limestone. **7.** Limestone. **8.** Oölitic limestone. **9.** Bioclastic or shaly limestone. **10.** Dolomitic limestone. **11.** Sandy limestone. **12.** Marble. **13.** Crystalline limestone. **14.** Sericite quartz schist. **15.** Biotite quartz schist. **16.** Glaciomarine diamictite. **17.** Augen and banded migmatite. **18.** Granite of Himalayan period.

The Sinian-Cambrian

The sequence is represented by the North Col Formation (more than 1,000 m) at the northern slope of Mt. Qomolangma. The lower part is comprised of biotite quartz schist intercalated with marble and the upper part of sericite quartz phyllite. This formation is possibly fault-contacted with the underlying pre-Sinian gneiss or separated from the gneiss by tourmaline-bearing muscovite granite. On the basis of the lithology and horizon, this formation can be correlated with the Larjung Formation of Nepal, the Martoli Series and the lower part of Garbyang Series of Kumaun, India (Yin Ji-Xiang and Guo SHi-Zeng, 1978).

The Ordovician

The Rouqicun Formation (237 m) conformably lying on North Col Formation consists of quartz schist and crystalline limestone and the degree of its light-graded metamorphism is rapidly weakened upwards and gradually transits into the fossil-bearing Lower Formation of Chiatsun Group of the upper and middle parts of the Lower Ordovician. The Lower Formation of Chiatsun Group (726 m) consists mainly of gray limestone yielding nautilus *Ordosoceras-Manchuroceras* Zone in the lower part and *Dideroceras-Paradnatoceras* Zone in the upper part, and brachiopods *Aporthophyla perelegans* Liu, *Orthambonites* sp., etc. The age is referred to Llanvirnian. The Upper Formation of the Chiatsun Group (97 m) consists of light red limestone yielding nautilus *Sinoceras chinense* (Food), *Michelinoceras xuanxianense* Chang, *Beloitoceras xizangense* Chen, *Curtoceras* sp., etc. The age is referred to Middle Ordovician and the fossil assemblage is similar to that in the Yangtze region in South China. The upper formation of the Chiatsun Group transits upwards to Hongshantou Formation (70 m) comprising variegated sandy shale possibly of a Late Ordovician age because of it being conformably underlain the Lower Silurian.

The Silurian

The Shiqipo Formation (90 m) of the Lower Silurian consists of sandstone, shale and limestone yielding graptolites *Climacograptus normalis* (Lapworth), *Streptograptus lobiferus* (M'Coy), *Oktavites circularis* (Elles et Wood), *Monograptus priodon* (Bronn), etc., equivalent to *Orthograptus vesiculosus* Zone-*Streptograptus crispus* Zone. The fossil assemblages are similar to those of the Dark Band Formation of Nepal. The Pulu Group (46 m) of the Middle and Upper Silurian is comprised of quartz sandstone, shale intercalated with limestone yielding graptolite *Monograptus vomerina subgracilis* Pribyl, nautilus *Michelinoceras (Kopaninoceras) jucundum* (Barrande). The Silurian in Spiti, India consists of a sequence of shaly facies, the lithology and fossil assemblages of which are difficult to correlate with those in Mt. Qomolangma region.

The Devonian

The Liangquan Formation (40 m) of the Lower Devonian conformably overlies the Silurian, the lower part consisting of shale and the upper part of interbeddings of limestone and shale yielding graptolites referred to *Neomonograptus himalayensis* Zone. Apart from the index fossil of the zone, *Monograptus thomasi* Jaeger, *M.* cf. *yukonensis* Jackson et Lenz., tentaculitids *Nowakia awaria* (Richter), etc., are found. The age of the strata bearing fossils is referred to Praguian. The Pochu Group of the Middle and Upper Devonian comprises quartz sandstone in the lower part (256 m) and shale intercalated with sandstone in the upper part (66 m) bearing pelecypod *Paracyclos* cf. *dubia* Beushausen and coral *Metriophyllum* sp. The lithology and horizon of the Pochu Group can be correlated with those of Muth Quartzite spread in Kashmir and Kumaun, India.

The Carboniferous

The Yali Formation of the Lower Carboniferous (60 m) consists of fine crystalline limestone intercalated with siltstone yielding ammonoid *Imitoceras orientale* Liang, brachiopod *Tylothyris* cf. *pseudopostera* (Besnossova), etc., and the age is Tournaician. The Naxing Formation (1,989 m) from the upper part of the Lower Carboniferous to the Middle Carboniferous consists of fine clastics with flysch-like structure and its lower part is composed of sandstone intercalated with shale and siltstone as well as conglomeratic lens; the middle part of shale intercalated with quartz sandstone and a little sandy limestone; and the upper part of quartz sandstone and sandy shale. Brachiopods *Fusella yaliensis* Ching, *Schuchertella* cf. *gueizhouensis* Yang, *Syringothyris lydekkeri* (Diener), *Marginirugus* cf. *magnus* (Meek et Worthen), pelecypods *Sanguinolites omalianus* (de Koninck), *Wilkingia nyangensis* Chen et Liu, *Aviculopecten* cf. *chuniukouensis* Yin, etc., are collected and the horizon can be correlated with the Syringothyris Limestone in Kashmir and other equivalent strata in the Himalayan region. The Gilung Formation (731 m) of the Upper Carboniferous consists of diamictites of glaciomarine facies (Chataje diamictite) and siltstone in the lower part, yielding brachiopods *Stepanoviella gracilis* Ching, *Trigonotrita* cf. *narsahensis* (Reed), *Lissochonetes* cf. *geinitzianus* (Waagen), *Attenuatella convex* Armstrong, etc. (Ching Yu-Gan *et al.*, 1977); quartz sandstone intercalated with sandy shale in the upper part. The fossil horizon of the lower part of Gilung Formation can be correlated with the Umaria marine beds overlying the Talchir Boulder beds in India (Yin Ji-Xiang and Guo Shi-Zeng, 1976).

The Permian

The Chubuk Formation (20 m), the lower part of the Selung Group of the Permian, is comprised mainly of shale with fine sandstone presenting fault contact with the underlying Upper Carboniferous strata. The Chubujeka Formation (375 m), the upper part, consists of siltstone, sandy shale and gray brown bioclastic limestone. The Chubuk Formation yields *Glossopteris* flora : *Glossopteris communis* Feistm., *G. indica* Schimp., *Dizeugotheca qubuensis* Hsü, *Dichotomopteris qubuensis* Hsü, *Raniganjia qubuensis* Hsü, *Sphenophyllum speciosum* (Royle) Mc-Clelloud, *Sphenopteris* cf. *hugesii* (Feistm.) etc., and the fossil assemblage can be correlated with those of the Raniganjia Formation in the upper part of the Damuda Group in India (Hsü Jen, 1973*b*, 1976*a*). The Chubujeka Formation yields brachiopods *Lamnimargus himalayensis* (Diener), *Neospirifer kubeiensis* Ting emend. Chang, *Spiriferella salteri* Tschernyschew, *S. rajah* (Salter), *Costiferina indica* (Waagen), *C. alata* Waterhouse, *Anidanthus 'fusiformis'* Waterhouse, *Wyndhamia circularis* Chang, *Taeniothaerus* cf. *subquadratus* (Morris), corals *Tachylasma paradoxium* Wu, *Lophophyllidium* sp., *Lytvolasma asymetricum* Soshkina, ammonoid *Uraloceras xizangensis* Liang. The fossil assemblage and horizon of the sequence can be correlated with those of the Wargal Limestone and the Chhidru Formation (i.e. Punjabian) in Salt Range, Pakistan, the Zewan Series in Kashmir and the equivalent sequences in other regions of the Himalayas.

In Gandise-Nyainqentanglha to the north of the Yarlung Zangbo Suture Line, whether there exist sequences of Gondwana facies similar to those at the northern slope of Mt. Qomolangma is still in dispute. Diamictites (pebbly mudstone) are widely spread in the Carboniferous-Permian sequence of this region. Some suggested that it was 'tillite' (Pan Yu-Sheng *et al.*, 1980). According to the observation by Yin Ji-Xiang, the diamictites in the region north of the Yarlung Zangbo Suture Line have the following features :

(i) diamictites in many members with great thickness are found both in the Upper Carboniferous and the Lower Permian, e.g. 11 members of diamictite are found in the Lower Permian (4,000 m). A single member of diamictite can reach a thickness of tens to hundreds metres and the total thickness is 1,855 m;
(ii) there is a similarity of lithology (the composition, size and arrangement of the pebbles) among the diamictitic members;
(iii) the diamictite is intercalated with interlayered conglomerates and quartz sandstone;
(iv) the diameters of the pebbles are generally smaller than 10 cm;
(v) some gradation in granularity is shown;
(vi) the pebbles are mainly composed of sedimentary rocks, while granitic and metamorphic rocks are absent or rare;
(vii) *Fusulina* and reef corals are found in the limestone interlayered in the diamictite;
(viii) observation under scanning electron microscope shows that the surface of the quartz grains in the diamictite has no mechanic etching features which are quite common on the surface of the quartz grain in the glacio-marine diamictite in Mt. Qomolangma region (Yin Ji-Xiang and Wen Chuan-Fen, 1982).

The lithologic characteristics mentioned above indicate that the genesis of the diamictite north of the Yarlung Zangbo Suture Line seems to have no direct relationship with glaciation. Considering that the Carboniferous-Permian in this region is mainly composed of cyclothems of sandstone and slate with flysch-like structure intercalated with volcanics, which is similar to the geosynclinal sediments, the genesis of diamictite can possibly be related with mud flows and turbidity currents in the mobile zone of the sea floor and referred to fluxo-turbidite. Nevertheless, the influence of glaciation at the end of Late Palaeozoic might also have affected this region, since *Bandoproductus hemiglobicus* Ching, which is similar to *Bandoproductus umariensis* (Reed) described in the Umaria marine bed of India were collected in the Upper Carboniferous shale overlying the diamictite and (?) *Stepanoviella flexuosa* Waterhouse was also found in the lower part of the Lower Permian (Jin Yu-Gan and Sun Dong-Li, 1981). In South Xizang and South Asia, the co-existence of the typical species of the Gondwana flora with those of the Cathysia flora has not yet been evidenced by the paloeobotanists (Hsü Jen, 1976*a*, *b*), so the palaeobiogeographical province boundary between the two floras in Qinghai-Xizang region may still be placed along the Yarlung Zangbo Suture Line (Li Xing-Xue and Yao Zhao-Qi, 1980).

The Triassic

The Kangshare Formation of the Lower Triassic (103 m) conformably overlying the Permian is a series of interbeddings of dolomite, limestone and shale. In ascending order, *Gyronites psilogrus* Zone, *Owenites* Zone and *Procarnites* horizon are found representing the middle and upper parts of the Indusian and the Olenikian. The

Laibuxi Formation (259 m) of the Middle Triassic consists of limestone intercalated with shale, and ammonoids *Japonites magnus* Zone, *Anacrochodiceras nodosum* Zone, *Protrachyceras-Joannites* horizon associated with pelecypod *Daonella indica* Zone are found in ascending order representing Anisic and Ladinic stages. The Zamure Formation (T_3^1, 99 m) at the bottom of the Upper Triassic consists of interbeddings of bioclastic limestone and sandy shale; Dashalong Formation (T_3^{2-1}, 179 m) in the lower part consists of interbeddings of limestone and shale bearing *Nodotibetites nodosus* Zone, *Griesbachites-Gonionobites* Zone representing the lower part of Noric; the Qulonggongba Formation (T_3^{2-2}, 465 m) in the middle part consists mainly o I sandy shale interbedded with siltstone intercalated with bioclastic and sandy limestone and ammonoids *Indojuvavites angulatus* Zone, *Pinacoceras metternichii* Zone in ascending order associated with Ichthyosauria *Himalayasaurus tibetensis* Dong are found representing the middle part of Noric stage; the Derirong Formation (T_2^{2-3}, 591 m) in the upper part consists of quartz sandstone intercalated with dolomite, sandy limestone bearing pelecypod *Indopecten margariticostatus* (Diener) representing the upper part of Noric (Wang Yi-Gang and He Guo-Xiong, 1976).

The Jurassic

The Pupuga Formation of the Lower Jurassic (841 m) conformably overlying the Triassic consists of limestone, sandy shale in the lower part, quartz sandstone and shale in the upper part bearing ammonoids *Schlothemia* sp., *Sulciferites* sp., *Gleviceras* sp., *Nyalamoceras nyalamense* Wang, foraminifers *Orbitopsella praecursor* (Gumbel), *Rhapydiomina urensis* Henson; the Niehnieh Hsiungla Formation of the lower part of the Middle Jurassic (822 m) consists of interbeddings of shaly and oölitic limestone and quartz sandstone intercalated with sandstone and shale bearing ammonoids *Dorsetensia haydeni* Arkell, *Witchellia tibetica* Arkell, pelecypods *Camptonectes* (*C.*) *lens* (Sowerby), *C.* (*C.*) *laminatus* (Sowerby) representing the Bajocian. Lalongla Formation of the upper part (541 m) of the Middle Jurassic consists of quartz sandstone intercalated with limestone and shale with nodules bearing ammonoids *Macrocephalites* sp., *Choffatia* sp., *Indocephalites* sp., and pelecypods, etc., representing the Bathonian-Callovian stage. Menbu Formation of the Upper Jurassic (3,262 m) consists of shale and argillaceous limestone, bioclastic limestone intercalated with quartz sandstone in the lower part; with interbeddings of limestone and shale with nodules in the middle part; and interbeddings of shale with nodules and siltstone in the upper part bearing ammonoids *Virgatosphinctes denseplicatus* (Waagen), *Pterolytoceras exoticum* (Oppel), *Haplophylloceras pinque* Ruf., *Aulacosphinctoides smith-woodwardi* (Uhlig), *Berriasella oppeli* (Kilian), belemnite *Belemnopsis uhligi* Stevens, pelecypod *Buchia blanfordiana* (Stoliczka), etc. The assemblage and horizon of the formation can be correlated with those of the Spiti region, India (Chao Jin-Ke, 1976; The 11th Team of the Geological Expedition to the Qinghai-Xizang Plateau, Ministry of Geology, 1981).

The Cretaceous

The Kangpa Group (K_1 — K_2^1, 1,300 m) lying conformably on the Jurassic consists of shale intercalated with marl and sandstone bearing ammonoids '*Neohoploceras*' sp., *Mortoniceras* (*Pervinquieria*) *kangbaense* Chao, *Diploceras subodelaruei* Spath, *Oxytropidoceras roissycanus* (d'Orbigny) of Valanginian-Alptian in the lower part; ammonoids *Acanthoceras* sp., *Calycoceras newboldi* (Kossmat), echinoidea *Hemiaster frontacutus* (Stoliczka) of Cenomanian in the upper part. The Zongshan Formation (278 m) in the middle part of the Upper Cretaceous consists of limestone intercalated with calcareous shale bearing foraminifers *Globotruncana linneiana tricarinata* (Quereau), *Orbitoides tissoti* Schlumberger, pelecypod *Bournonia haydeni* Douville, echinoidea *Hemipneustes compressus* Noetling representing Campanian-Maestrichtian. Jidula Formation (188 m) in the upper part of the Cretaceous consists of quartz sandstone intercalated with limestone bearing ostracod *Uroleberis inflata* Huang, foraminifera *Verneuilina* sp., algae *Acicularia antiqua* Pia, *Cymopalia tibetica* Morellet. From the study of the fossils, the age of this formation whether it should be referred to Late Cretaceous or Palaeocene has not yet been settled.

The Lower Tertiary

The Zongpu Group (383 m) conformably overlying the Jidula Formation consists of massive limestone intercalated with shale and the top of the group is truncated yielding foraminifers *Nummulites parvulus* Sheng et Zhang, *Orbitolites complanatus* Lamarck, *Fasciolites ellipsoidalis* (Schwager), *Miscellana miscella* (d'Archiac at Haime), *Keramosphaera tergestina* (Stache), gastropod *Campanile brevius* Douville, etc., representing Palaeocene (Danian-Sparnacian) to the Middle Eocene (Lutetian). In another section of the same region, the Zebu Ri Formation consists of shale (967 m) in the lower part bearing foraminifers *Nummulites gallensis* Heim, *Orbitolites complanatus* Lamarck, *Assilina orientalis* Douville and limestone (318 m) in the upper part bearing *Nummulites incrassatus* de la Harpe, *Discocyclina sowerbyi* Nuttall, *Assilina placentula* (Deshayes), *Fasciolites* (*F.*) *oblongus* (d'Orbigny). The fossil assemblage of this formation resembles those of Middle Eocene in Salt Range, Pakistan and Assam, India representing Lutetian stage with some elements reaching Late Eocene. The Zebu Ri Formation is regarded as the highest marine horizon in Mt. Qomolangma region.

In the northern piedmont of the High Himalayas, the lowest Tertiary horizon of continental facies with fossil evidence is the Yebokanggale Group (more than 1,000 m) at the northern slope of Mt. Xixabangma of Late Pliocene fluviolacustrine sediments which mainly comprise gray sandstone and conglomerate lying unconformably over the metamorphic rock and bearing fossil plants *Quercus semicarpifolia* Smith, *Q.* cf. *panosa* Hand.-Mzt. (Shi Ya-Feng and Liu Tung-Sheng, 1964; Hsü Jen, 1973*a*). In fluviolacustrine sediments of the Woma Formation (450 m) in Gyirong Basin and the Date Foramation at Yagru Xongla, *Hipparion* fauna was found bearing *Hipparion gyirongensis* Ji, Xu et Huang, *Chilotherium xizangensis* Ji, Xu et Huang, etc. (Huang Wan-Po and Ji Hong-Xiang, 1979; Huang Wan-Po *et al.*, 1980). These sediments rest unconformably on the Jurassic and the Palaeozoic strata and their age is referred to Late Pliocene.

In Pleistocene of the Quaternary, glaciofluvial, gravel and lacustrine sand sediments of 3 glacial and interglacial ages were found in Xizang Himalayas (Chao Xi-Tao *et al.*, 1976). In addition, the Holocene strata mainly consist of sediments of lacustrine, moraine, glaciofluvial, diluvial, alluvial and aeolin facies.

THE STRATIGRAPHICAL AND GEOLOGICAL CHARACTERISTICS OF THE PRE-SINIAN METAMORPHIC ROCKS IN THE HIGH HIMALAYAN BELT

Geological sections of the High Himalayan Belt or Central Crystalline Belt can be observed only in Nyalam district in South Xizang, which is composed of a series of medium-graded metamorphic rocks. The tectonic sequences and the metamorphic zones from north to south are given in Table 1.

TABLE 1—THE TECTONIC SEQUENCES OF THE HIGH HIMALAYAN BELT

Geologic ages		*Tectonic sequences*	*Metamorphic zones*	
Z—C		North Col Formation	Biotite Zone of Green Schist Facies	N ↑
		MNT		
AnZ	Nyalam Nappe	Kangshan Nappe	Sillimanite Zone I	
		Quxam Thrust (QT)	Sillimanite Zone II	
			Sillimanite Zone I	
		Dingringbo Nappe		
			Kyanite Zone	
		MCT		
Z		Midland Metasediments Group	Biotite Zone of Green Schist Facies	

The Dingringbo Nappe is mainly composed of gneiss including sillimanite gneiss, sillimanite-almandine gneiss, almandine-biotite schist (gneiss), biotite-quartz (plagioclase) schist and quartzite. Nearby Zham, staurolite-kyanite-sillimanite gneiss, kyanite schist and marble are found and the total thickness reaches 13,000 m. The bottom of this metamorphic rock sequence lies in the Nepalese territory and is separated from the Midland metasediments Group by the MCT. The Kangshan Nappe is mainly composed of banded and augen migmatite intercalated with sillimanite gneiss, biotite gneiss quartzite and marble in the upper part. The total thickness reaches 9,000 m. The Kangshan Nappe is separated from the Dingringbo Nappe by the Quxam Thrust, and from the North Col Formation to the north by the MNT or the Jangling Granite (Fig. 5).

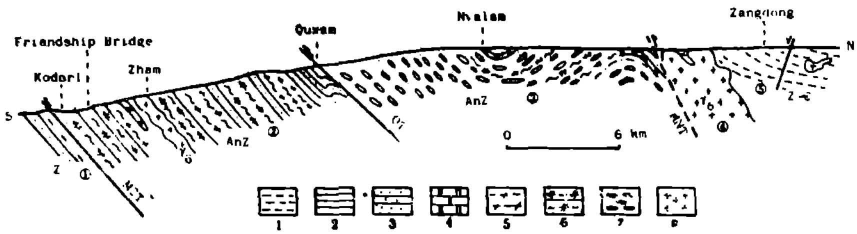


Figure 5. A geological structural section of the High Himalayas from Nyalam to Zham in South Xizang. (1) Midland Metasediments Group (Z) (in Nepal). (2) Dingringbo Nappe. (3) Kangshan Nappe. (4) Jangling Granite. (5) North Col Formation. (Z-C) MCT Main Central Thrust. QT Quxam Thrust. MNT Main North Thrust. 1. Sericite quartz phyllite, biotite quartz schist. 2. Quartz schist. 3. Quartzite. 4. Marble. 5. Sillimanite gneiss, almandine-biotite gneiss. 6. Kyanite schist, kyanite-sillimanite gneiss, staurolite-kyanite-sillimanite gneiss. 7. Migmatite. 8. Tourmaline-muscovite granite (γ_6).

A study of the metamorphic zones of the Nyalam Nappe (Zhang Qi and Li Sha-Hua, 1981) shows that the higher graded metamorphism is found in the lower part of Kangshan Nappe and the upper part of Dingringbo Nappe, and the degree of metamorphism weakens both to the south and to the north: Sillimanite Zone II in the center and outwards, Sillimanite Zone I → Kyanite Zone (absent in Kangshan Nappe) → Green Schist Facies Biotite Zone in succesive order. As for the age of the metamorphic rocks, the strata involved in Sillimanite Zone II can also be regarded as the oldest and gradually younger both to the south and to the north, which means that the Kangshan Nappe could be a reversed metamorphic rock sequence. Another inference could be made that the Nyalam Nappe is an overturned anticline, and the core of the anticline coincides with the thermal anticline of the metamorphism. After the formation of the anticline, the Kangshan Nappe was thrusted over to the south along the Quxam thrust and the structure of the anticline core was deformed. The Dingringbo Nappe was thrusted over to the south along the MCT.

The metamorphic rocks of the Nyalam Nappe can be correlated with the Dhumpu Gneiss (Bordet *et al.*, 1971) and Himalayan Gneiss (Hashimoto, S. *et al.*, 1973) in Nepal. The reconstruction of the metamorphic rocks shows that the primary rocks were composed of argillaceous argillo-sandy rocks and a little basic volcanics with flysch structure and the thickness is greater than 20,000 m, which possibly may be referred to sediments of geosynclinal type. Since the metamorphic rocks underlie the North Col Formation, the age is speculated to be pre-Sinian or late Middle Proterozoic to early Late Proterozoic.

AN OUTLINE OF THE GEOLOGIC EVOLUTION OF XIZANG HIMALAYAS

"The rise of the Himalayas from the floor of the Mediterranean Sea is an epic of the geological history of Asia" (Wadia, 1964). However, the rise of the Himalayas from the sea floor was a very complex natural process, the clues of which should be found not only from the geological records of the Himalayas itself, but also from the interrelations in geological evolution between the Himalayas, the adjacent Indian Peninsula and the E-W extending mountain ranges on Qinghai-Xizang Plateau or East Tethys. Based on these deductions, an outline of the geological evolution of Xizang Himalayas is preliminarily suggested.

Z — C The Vindhyan system (Crawford and Compston, 1970) in the northern part of Indian block, the Midland Metasediments Group in Nepal (Hashimoto, S. *et al.*, eds., 1973), the North Col Formation in Mt. Qomolangma region (Yin Chi-Hsiang and Kuo Shin-Tseng, 1978) and the Nyainqentanglha Group in Gandise-Nyianqentanglha region (Yin Ji-Xiang *et al.*, eds., 1980) were representative sediments of miogeosynclinal type of this period. Besides, sediments of deeper sea water or eugeosynclinal environment may possibly be found in Kunlun Mts. further north (Fig. 6-A).

O—S The Kathmandu Group in Nepal (Hashimoto, S. *et al.*, eds., 1973) and the equivalent sediments in Xizang Himalayas and Gandise-Nyainqentanglha region are all representatives of stable environments, which are composed of carbonate and argillaceous sediments without volcanics. In Ordovician, regions of present Qamdo, East Xizang and Ganzi, western Sichuan as well as Kunlun Mts. were possibly eugeosynclinal environments, and sandy argillaceous, carbonate siliceous sediments with cyclothems were deposited, the thickness of sediments exceeding 6,000 m. At the end of Ordovician and the beginning of Silurian, this region was affected by the Caledonian orogeny, resulting in some local districts the absence of sediments of the Silurian or the Silurian to Early Devonian. The sea trough inherited from Z-C period may possibly be the primitive Palaeo-Tethys (Fig. 6-B).

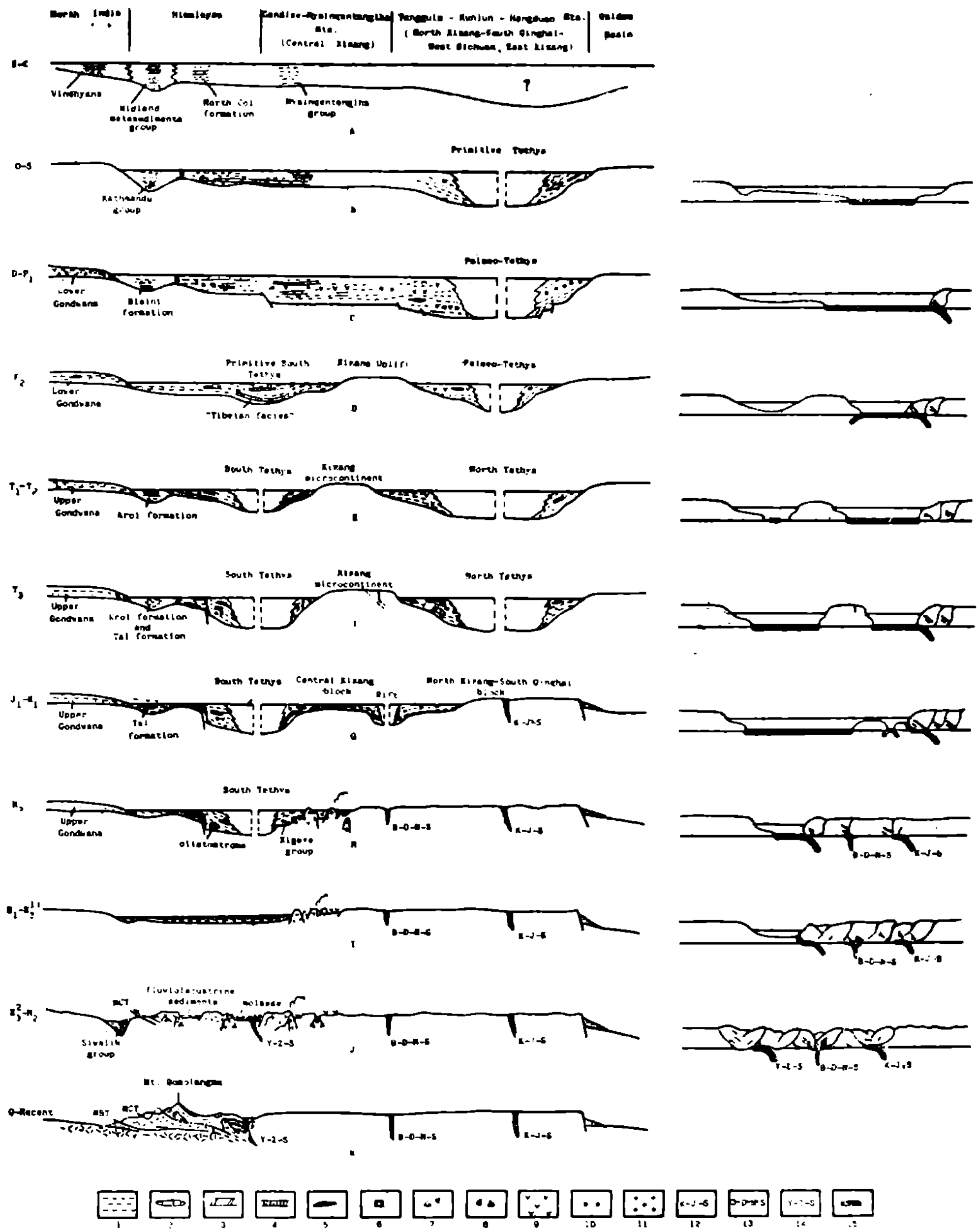


Figure 6. A sketch map of the geological evolution of the Xizang Himalayas and its adjacent regions. 1. Argillaceous rock. 2. Limestone. 3. Dolomite. 4. Siliceous rock, chert. 5. Coal measure. 6. Gypsum. 7. Tillite, glaciomarine diamictite. 8. Fluxoturbidite. 9. Intermediate-acid volcanics. 10. Basic volcanics. 11. Granodiorite, granite. 12. Kekexili-Jinsha river suture line. 13. Banggong lake-Dongqiao-Nujiang river suture line. 14. Yarlung Zangbo river suture line. 15. Oceanic crust.

D—P_1 In Devonian, the Indian block was still an uplift region, to the north on its shelf, i.e., in present Himalayan region, argillaceous and sandy sediments were deposited and further north reaching Gandise-Nyainqentanglha region, carbonate sediments were deposited. From Carboniferous of Late Carboniferous, the Indian block began to be influenced by continental glaciation and in some fault-depressions, the Lower Gondwana was accumulated (Ghosh and Bandyopadhyay, 1969). The present Himalayan region was shelf shallow sea receiving fine clastic sandy and argillaceous sediments of alternations of marine and continental facies, and shelf neritic facies intercalated with diamictite of glaciomarine facies and carbonate sediments. To the north of Gandise-Nyainqentanglha region, in Carboniferous-Early Permian, the sedimentary environments were unstable and volcanism occurred. Sandy argillaceous sediments and fluxoturbidite with cyclothems were deposited, the thickness of the sedimentary strata exceeding 7,000 m. Further north-east approaching the present Kunlun Mts. and Hengduan Mts. region, in Carboniferous and Early Permian, eugeosynclinal environments prevailed, e.g. in the east of this sedimentary region in present Ganzi district, clastics of huge thickness (more than 10,000 m) intercalated with cherts and basic volcanic appeared. At the end of Early Permian, the Hercynian movement began and the oceanic crust of the Palaeo-Tethys subducted under the continental crust on both sides, so that the area of the sea reduced (Fig. 6-C).

P_2 From the end of Early Permian to Late Permian, geosynclinal environment still prevailed in the present Ganzi, Qamdo districts. At the end of Late Permian, the Hercynian movement intensified and the Palaeo-Tethyan oceanic crust subducted both under the continental crusts in the south and in the north. In the north, the ancient Kunlun Mts. was formed on the upthrust side of the subduction zone, while in the south, the continental crust of the upthrust side in the subduction zone uplifted prominently, i.e., the 'Xizang uplift' and Cathysia flora of the North Continent migrated to the northern part of this uplift, which is the present southern piedmont of Tanggula Mts. Along with the consumption of the oceanic crust, the Palaeo-Tethys reduced considerably and the continental crust in the south thinned under tension stress. The region where formerly subjected to neritic sediments of platform-type gradually deepened forming the primitive South Tethys (Fig. 6-D).

T_{1-2} The South Tethys at this stage was possibly still a small ocean. The southern margin of the ocean or the seaward northern rim of the Indian block remained a wide shelf shallow sea. The Palaeo-Tethys to the north of 'Xizang uplift' revived in Early and Middle Triassic forming the large extensive North Tethys, the southern part of which covered the present Qamdo district, where locally eugeosynclinal environment occurred accompanied with intermediate-acid volcanic eruptions. In the northeastern part of the ocean which is now Ganzi district, the eugeosynclinal environment prevailed intercalated with volcanic clastics with a thickness exceeding 5,000 m. The 'Xizang uplift' was surrounded by the ocean since Early Triassic and completely from the Gondwana continent forming 'Xizang microcontinent'. In rivers, lakes and intermontane basins, the continental Upper Gondwana accumulated continuously on the Indian block (Fig. 6-E).

T_3 Owing to the outbreak of the Indochina movement, the North Tethyan oceanic crust subducted under the North Continent and finally vanished, leading to the formation of Bayan Har Mts. at the upthrust side of the subduction zone. The Xizang microcontinent joined the North Continent along Kekexili (Hoh Xil)-Jinsha river suture line. The shelf shallow sea along the northern margin of the Indian block approximately corresponds to the present Lhagoi Kangri district in South Xizang and the block-faulted depression to the north of Lhagoi Kangri. The depth of this shelf sea reached an extent such that turbidite and radiolarian chert occurred indicating expanding and deepening of the South Tethyan Sea (Fig. 6-F).

$J_3 - K_1$ It was the most developed mature stage of South Tethys, and in the eugeosynclinal sedimentary environment inherited from the former stage, radiolarian chert, turbidite and basic volcanics were developed. To the south, along the northern margin of the Indian block, comparatively stable shelf neritic environment prevailed, yet in the transitional zone from the shallow sea to the ocean sandy argillaceous sediments intercalated with carbonates of miogeosynclinal type were developed. Since the beginning of Middle Jurassic, to the north of the South Tethys, the middle part of Xizang microcontinent which had joined the North Continent in former stage cracked again resulting in the mid-Xizang block situated in the south, while the South Qinghai-North Xizang block evolved in the north. At the beginning, the aulacogene widened forming a rift and narrow oceanic crust as well as eugeosynclinal sediments occurred. As the early episode of the Yanshan movement at the end of Late Jurassic took place, the geosynclinal sediments rapidly came to an end and the 2 small continental blocks separated in the former stage rejoined again forming the Banggong lake-Dongqiao-Nujiang river suture line (Fig. 6-G).

K_2 Approximately since early Early Cretaceous (130 m.y.), Gondwanian India was separated from the East Gondwana continent and singly drifted northwards away from Australia and Antarctica (Powell, 1979) promoting the South Tethyan oceanic crust subducted along the trough into the southern margin of North Continent. Gandise-Nyainqentanglha Mts. of Andean type was formed at the upthrust side of the subduction zone accompanied with extensive magmatic intrusions and volcanic eruptions on a large scale, and Gandise island arc emerged. Since middle Late Cretaceous (80 m.y.), the subduction of the oceanic crust accelerated, at the upthrust side of the subduction zone, intensive intermediate-acid magmatic intrusions and extensive calc-alkali volcanic eruptions continuously occurred and lay unconformably over the Lower Cretaceous which had already strongly deformed. Mèlange was spread over the subducted side of the subduction zone (Fig. 6-H).

$E_1 — E_3^1$. Under the influence of the early episode of the Himalayan movement, owing to the convergence of Gondwanian India (or Indian Plate) and the North Continent (or Eurasian Plate), South Tethyan oceanic crust was completely consumed by subduction at this stage, and only a narrow relic shallow sea was left over, which survived to the end of Eocene or the beginning of Oligocene. During the vanishing process of the relic sea, to the north, extensive magmatic intrusions and volcanic eruptions were still active in Gandise-Nyainqentanglha region. As the relic sea eventually blotted out, the North and South Continents collided and joined into a universal Eurasian Continent. The joint of these two continents is called Yarlung Zangbo Suture Line (Fig. 6-I).

$E_3^2 — N_2$. After vanishing of South Tethys, the collision and combination of the South and North Continents persisted up to Miocene and in the same stage the Himalayan movement reached its summit, presenting intensive folding, thrusting and extensive magmatic activities accompanied with regional metamorphism and migmatization. Since Middle Miocene, the Himalayas gradually uplifted and the Siwalik Series of huge thickness was accumulated in the southern piedmont of the Himalayas, while sandy and argillaceous sediments bearing *Hipparion* fauna were accumulated in rivers and lakes along the northern piedmont of the High Himalayas, and molasse of fluvial and piedmont facies of huge thickness was accumulated in the intermontane basins between the Himalayas and Gandise-Nyainqentanglha Mts. (Huang Ji-Qin and Chen Bin-Wei, 1980) (Fig. 6-J).

Q — Recent. Since Pleistocene to the present times, the Himalayas and the Qinghai-Xizang Plateau have risen as a whole forming eventually plateau landform the 'World's Roof.' Owing to the continuous northward compression, the Himalayas become the transistional Zone of collision and compression between continental plates. The intensive deformation of the Himalayas has not pre-empted all the geodynamic forces which still propagate through the plateau and affect the neotectonic patterns of most of the regions in China.

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Triassic System of Himalayas*

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INTRODUCTION

THE MARINE Triassic rocks have very wide geographical distribution in the Tethys belt of the Himalaya extending for more than 2000 km long belt stretching from Pamir in the northwest through Kashmir, Kishtwar, Chamba, Ladakh, Karakoram, Lahaul, Spiti, Kumaun, Nepal and as far as Burma in the southeast. Isolated outcrops of these sediments are also found in Assam, Sikkim and Bhutan. The Triassic rocks in the Lesser Himalayan Zone are represented by a thick succession of dolomites and limestones (Krol Limestone and its equivalents) which is well-developed in different parts of Punjab, Kumaun and Nepal Himalayas. In parts of Kashmir and Ladakh, the Triassic is also represented by the volcanic facies (Panjal Volcanic Succession and Ralakung Volcanic Succession) which at places is intercalated with inter-trappean beds.

Good sections of Triassic rocks in Kashmir have been recorded from the Pir-Panjal Range, Lidder valley, Sind valley, Wardwan, Khunmuh-Khrew, Pastannah, etc. Rocks of this age have also been reported from parts of Kishtwar and Chamba (Kalhel Limestone). The Tandi Limestone in southern Lahaul which had earlier been considered to be of Precambrian age has yielded Triassic ammonites and conodonts.

In Karakoram and Ladakh, the rocks belonging to the Triassic System are exposed in the Shyok valley, Dras valley, Zoji La, Zanskar basin, Rupshu, Lachlung La, Yunam, etc., whereas in Lahaul good sections of these are met with in the Chharap valley and near Tandi. In recent years considerable work has been done on these sections and rich assemblage of conodonts and other microfossils has been recorded from different stratigraphic horizons.

The Triassic successions of Spiti and northwestern Kumaun have attracted world-wide notice on account of the rich assemblage of ammonites found therein. However, in recent years, these sections have been investigated in detail for the conodont biostratigraphy and considerable new data has been published. Best known sections of the Triassic rocks in these regions are exposed in Lingti river section (Lilang System) of Spiti and Niti and Painkhanda sections in northwestern Kumaun. The rocks belonging to this age are also exposed in the Dharma and Lissar valleys of eastern Johar and parts of Byans. In the Kali and Kuti valleys of northeastern Kumaun, the Triassic succession is not very rich in fossils and as such is divided essentially on lithological basis into Chocolate Series, Kalapani Limestone, Kuti Shales and Kioto (=*Megalodon*) Limestone. In parts of the Malla Johar sections of Kumaun Himalaya the Triassic rocks are found within the exotic blocks of the Tibetan facies which is somewhat different from the Triassic succession of the Himalayan facies found in the Tethys belt of the Himalaya.

STRATIGRAPHIC HORIZON

The Triassic rocks of the Himalaya show great variation in thickness from one region to another and this may be attributed to abrupt facies change and condensation. The maximum thickness (3,000 to 4,000 metre) of the Triassic rocks is encountered in the Kashmir region. In Spiti region this succession attains a thickness of 1,250

*This paper was presented at the "Triassic Global Geology" Symposium held at Wurzurg (West-Germany) in February, 1982.

metres whereas its thickness in Painkhanda area is 1,229 metre. In the southeastern section this thickness is reduced to 483 metres.

The boundary between the Permian and Triassic rocks in the Himalaya has been investigated in detail. Good sections for the study of this boundary problem are exposed in Kashmir where the boundary between the Permian and Triassic systems has been defined within the Khunmuh Formation. The rocks corresponding to Punjabian Stage are very widely distributed in different parts of Kashmir, Ladakh, Spiti, Kumaun, Nepal, Sikkim and Bhutan. In contrast to this, the outcrops of Djulfian strata are meagre whereas the Dorashamian is very well represented, especially the Vedian Substage in Nepal and the Gangetian-Ellesmerian levels in northwest Nepal and Kashmir. The palaeogeographic history of the Himalaya indicates that the late Middle Permian saw an extensive marine invasion of much (but not all) of the Tibetan Zone, sedimentation persisted in the Kashmir region, and more in a small basin of north-west Nepal into the late Middle and Late Permian before the onset of world-wide marine incursion with the *Otoceras* and *Ophiceras* ammonoid communities, within the Himalayas. Critical study of the sections in different parts of the Himalaya has revealed that the *Otoceras-Ophiceras* (Ellesmerian-Gangetian) beds are very thin and these beds lie paraconformably above the beds yielding Punjabian faunas with little sign that the Djulfian and early Dorashamian sediments and faunas are missing.

In the Spiti valley, the *Otoceras* Beds in the Lilang Section have yielded a few Late Permian platform conodonts (*Gondolella orientalis, G. subcarinata* in association with *G. planata, G. carinata* and *Anchignathodus* spp.). A sample from the *Otoceras* Beds of Shalshal cliff in Kumaun Himalaya has also yielded *G. orientalis, G. subcarinata, G. planata* and *G. carinata*. Similar conodont assemblage has also been recorded from the beds corresponding to the *Otoceras* Beds from Yuger, Marling and Tanze sections of northwest Himalayas. The conodonts referred to above from different sections of the Himalaya are suggestive of Dorashamian age for the beds yielding them. These beds are overlain by the strata yielding *Ophiceras* and corresponding to the *Ophiceras* Beds. The *Ophiceras* Beds in the Lilang section of Spiti and adjoining areas have yielded conodonts belonging to the genus *Neospathodus* (*N. kummeli, N. novaehollandiae, N. praekummeli*, etc.). The late Permian gondolellid conodonts disappear and *Neospathodus* type of forms make appearance in the beds forming transition between the *Otoceras* Beds below and *Ophiceras* Beds above.

In the Guryul Ravine section of Kashmir, unit E.I of the Khunamuh Formation has yielded rich assemblage of Permian brachiopods (in association with *Claraia*) which have stunted growth in contrast to those found in the underlying Zewan Formation. This unit has been considered Dorshamian as it lies above the beds yielding *Cyclolobus* and below the horizon containing *Otoceras*. The presence of stratigraphic gaps (paraconformities/ unconformities) near the *Otoceras* Bed in the western part of Kashmir and between *Cyclobus* Beds below and *Otoceras* Beds above in eastern Kashmir have made the stratigraphy complicated. The presence of forerunners of *Otoceras* has not been encountered in any of the sections of Himalaya where *Otoceras* is present. The appearance of this genus seems to be facies-controlled. According to Kozur (pers. commun.) not only do Permian brachiopods occur together with *Otoceras*, the whole microfauna (condonts, ostracodes, spores and pollen, etc.) are clearly Permian in *Otoceras*-bearing beds. Therefore, it is not clear at which level these forms as well as *Otoceras* make their first appearance. *Julfotoceras* is believed to be an *Otoceras* that begins in the beds corresponding to higher Djulfian which lie below the Dorashamian.

Some workers have assigned Lower and Upper Greisbachian ages to the *Otoceras woodwardi* Zone and *Ophiceras* Zone, respectively. They are of the opinion that the *Otoceras woodwardi* Zone cannot be assigned to the latest Permian (Dorashamian) because it contains typical Lower Triassic bivalves, such as *Eumorphotis venetiana, E* aff. *bokharica, Leptochondria minima, Promyalina* sp. and lacks representative Dorashamian conodonts (*Anchignathodus julfensis* and *Gondolella subcarinata*). They believe that *Otoceras woodwardi* is certainly derived from the Dorashamian *Julfotoceras tarazi* Bando. The occurrence of platform and blade-type conodonts (*Hindeodus minutus* (Ellison), *H. parvus* (Kozur and Pjatakova), *Isarcicella isarcica* (Huckriede) and *Isarcicella*(?) sp.) has been recorded by Japanese geologists from the Permian and Triassic limestone and calcareous rocks exposed in the Guryul Ravine section of Kashmir. According to these workers *Anchignathodus typicalis* Zone can be subdivided into three zones based on the stratigraphic distribution of *H. minutus, H. parvus* and *Isarcicella isarcica*. The first two zones according to them correspond to the *Otoceras tibeticum* Zone.

Permo-Triassic section similar to that of Guryul Ravine section is also exposed in the area north of Pir Panjal Range between Upper Munde in the east and 1 km west of Lamar in the west. In the Pir Panjal Range brachiopods (*Linoproductus, Spinomarginifera* and *Derbyia*) and pelecypod (*Eumorphotis* and *Etheripecten*)-bearing beds are associated with *Claraia stachei* in the lower part of flaggy shales. The upper parts of these shales are rich in *Claraia concentrica* and ammonoids (*Lytophiceras* aff. *ptychodes, Hypophiceras*(?), *Ophiceras, Glyptophiceras*(?) sp.). The presence of *Otoceras* has not so far been recorded from this section and the ammonoid fauna found in typical

Ophiceras fauna. The possibility of finding *Otoceras* in the thin limestone layers in the flaggy shales cannot be ruled out. Good sections of these fossiliferous outcrops in the Pir Panjal Range are exposed near Upper Munda, Malidar Gali and Khowurwat Gali. The occurrence of *Pseudomonotis*-bearing beds belonging to lowermost Lower Trias has also been recorded from western part of Pir Panjal Range. The presence of fossiliferous Lower Triassic rocks has also been recorded from the Dolpo (Barbung Khola) and Thakkhola region of Nepal yielding *Ophiceras, Meekoceras* and *Clypeoceras* fauna.*

Triassic Sequence and Biostratigraphic Correlation

The Triassic succession in different parts of Himalaya is essentially represented by calcareous facies which at places is intercalated with arenaceous and argillaceous horizons. These sediments have yielded rich and varied fauna which include representatives of ammonites, brachiopods, lamellibranchs, gastropods, corals, conodonts, holothurian sclerites, foraminifers, ostracodes, fish remains, etc. The ammonites from different stratigraphic horizons have been extensively used for biostratigraphic correlation with the Triassic sequence exposed in different parts of the Himalaya. The ammonoid biostratigraphic zones within the Lower Triassic are represented by *Otoceras, Ophiceras, Meekoceras* and *Hedenstroemia* Beds. The characteristic ammonoids within the Middle Triassic include *Gymnites, Ptychites, Durgaites dieneri, Ceratites (Paraceratites) trinodosus*, etc. The lower part of the Upper Triassic among others includes *Halobia, Tropites* and *Juvavites*. The middle and upper parts of the Upper Triassic are poor in ammonites.

Bivalves, brachiopods, corals and other megafossils have been used to resolve some of the stratigraphic problems in the absence of ammonoids. Of the most important bivalves from the Triassic mention may be made of *Daonella lommeli* from the Ladinian and *Monotis salinaria* from the lower Upper Norian. Both these bivalves have extensive geographical distribution in the Himalaya. In recent years valuable data has been collected from some of the Triassic limestone sequences which were generally considered to be unfossiliferous and whose precise stratigraphic position was in dispute. These limestone horizons have yielded rich assemblage of conodonts, holothurian sclerites, foraminifers, ostracodes, fish scales, etc. The microfauna from different stratigraphic horizons within the Triassic succession has provided an additional tool for correlating some of the sequences whose precise position was disputed.

The Kioto Limestone forms a persistent stratigraphic horizon through the entire stretch of Himalaya and constitutes an important stratigraphic marker. The lower units of this limestone succession in all regions of the Himalaya lie above the beds yielding *Monotis salinaria* of lower Upper Noric age. The Upper Triassic succession exposed near the Jawahar Tunnel and Verinag is essentially represented by hard black limestone shales and quartzites. This succession has yielded megafossils (*Monotis salinaria, Waldhemia globularis, Rhaetina gregaria*, etc.), supporting Noric age for it. The lower parts of the Kioto Limestone have yielded brachiopods, lamellibranchs, conodonts (*Misikella hornsteini*), etc. of middle Upper to upper Upper Norian age. It seems possible that the Rhaetic succession in terms of ammonoid stratigraphy in the Himalaya is much thinner than the Rhaetic sequence exposed in different parts of Northern Alps. The upper units of the Kioto Limestone contain well-preserved megalodontids (*Rhaetomegalodon (Megalodon) cultridens, Megalodon ladakhensis, Dicerocardium himalayensis, Conchodon*, etc.), *Involutina, Heterastridium* and a few burrows (possibly *Thalassinoides*). The marly beds at the base of the Kioto Limestone exposed in the Lungar Jumpa Nar of the Chharap valley have yielded ostracodes (*Hungarella* sp., *Bairdia* sp., *Bairdiacypris* sp., *Paracypris* sp., *Lutkevichinella* sp., *Reubenella* sp., and (?) *Cytherella* sp.). The micropalaeontological investigations of a few thin sections from the upper part of the Kioto Limestone succession from Zanskar region of Ladakh and Lilang section of Spiti, have revealed the presence of fairly well-preserved specimens of *Triassina hantkeni* and other involutinids similar to those found in West Carapathians.

In the Chharap valley of Lahaul this sequence has yielded brachiopods (*Triadithyris rotunda* and *Fissirhynchia* cf. *fissicostata*). These beds are overlain by 5 to 10-metres-thick band of limestone belonging to the 'Lithiotis' facies which is well-developed in parts of Ladakh, Kumaun and Nepal and contains poorly preserved fossil algae (*Dasycladacea*), foraminifers and a broken shell arranged parallel to the bedding. It is indicative of shallow water deposition within the Lower Jurassic (Sinemurian to Pleinbachian) and this facies is typical of the southern margin of the Tethys. The boundary between the Triassic and Jurassic succession may possibly lie above the beds containing large megalodonts belonging to the genus *Conchodon*. The Kioto Limestone succession ranges

*For details regarding stratigraphic implication of *Otoceras woodwardi* reference may be made to the paper by Gupta and Kozur being published in this volume.

in age from middle Upper Norian to Lower Dogger. The beds overlying the Kioto Limestone have yielded Middle and Upper Dogger fossils. The fossil contents, lithology and sedimentology of the Kioto Limestone suggests its identity with the lagoonal facies of the Dachstein Limestone of Northern and Southern Alps.

Conodont-bearing Triassic Sequences

The conodonts from the Lower Triassic sequence of Kashmir are represented by an assemblage which includes *Neospathodus dieneri, N. cristagalli, N. waageni, N. jubata, Ellisonia gradata,* etc. In the Lam section *Neospathodus dieneri* is found associated with *Neospathodus waageni* and *N. jhelumi*. This horizon may correspond to the *Neospathodus waageni* Zone of Smithian age. Similar conodont assemblage has also been recorded in the Guryul Ravine section, etc. The strata yielding *Noespathodus waageni* and associated conodonts have also yielded foraminifers (*Ammodiscus* and *Nodosaria*), Ostracodes (*Bairdia, Monoceratina* and *Hungarella*), micro-fish remains and micro-gastropods. The uppermost part of the Lower Triassic succession of the Guryul Ravine, Khrew, Mandakpal and Narastan sections has yielded *Neospathodus jubata, Neospathodus homeri-N. spathi* assemblages. The presence of conodonts belonging to *Neospathodus timorensis* Zone has been recorded from Khrew, Pastun and Narastan. The Early Anisian in Kashmir is represented by *Neospathodus gondolelloides** and *N. kockeli* assemblages whereas the Upper Anisian is characterized by *Paragondolella excelsa, Neogondolella cornuta* and *Gladigondolella* assemblages. The Middle and Upper Triassic rocks in different parts of Kashmir, Ladakh and parts of Kumaun have yielded rich assemblage of platform conodonts. Of the most important conodonts mention may be made of *Neogondolella constricta, N. mombergensis, E. mungoensis, Metapolygnathis polygnathiformis, Epigondolella bidentata*. The Middle Triassic succession of Niti pass has yielded *Neogondolella constricta* and *Neogondolella nitiensis*.

The conodont-bearing horizon of Niti Pass has also yielded foraminifers (*Ammodiscus, Ammodiscoides, Spirillina, Lituotuba, Glomospira* and *Glomospirella*), ostracodes (*Bairdia, Monoceratina, Hungarella* and *Judahella*), bryozoans (*Archimedes*), etc. The Upper Triassic limestone exposed near Zamalgam, near Verinag, Kashmir has yielded *Epigondolella bidentata, Metapolygnathus parvus, Neogondolella navicula steinbergensis, Cratognathodus kochii, Cratognathodus* sp., *Lonchodina muelleri, L. spengleri, Prioniodina prioniodelloides, Prioniodella discrescens,* etc. The conodont fauna is suggestive of Noric age for the fossiliferous beds.

The lower units of the Anisian and Ladinian succession in the Seshnag-Amarnath section of Kashmir and Lachlungla-Umasila section in Ladakh have yielded *Gladigondolella tethydis* and *Neogondolella navicula navicula* whereas the upper units contain *Gladigondolella tethydis, Neogondolella excentrica, N. excelsa, N. navicula navicula*. *Neogondolella constricta* and *N. excelsa* are characteristic forms of the Upper Anisic age and as such the boundary between the lower and upper units of the Anisic succession is drawn at the point where these two forms appear for the first time. The lower part of the Ladinic succession has yielded *Gladigondolella tethydis, Neogondolella excelsa* and *N. navicula navicula*. The boundary between Anisic and Ladinic succession is drawn at the point where *Neogondolella excentrica* disappears as this form is characteristic of Upper Anisic age. The upper part of the Ladinic succession has yielded *Gladigondolella, Epigondolella multidentata, E. mungoensis, Neogondolella excelsa* and *N. navicula navicula*. The appearance of *Epigondolella mungoensis* and *E. multidentata* demarcates the boundary between the lower and upper parts of the Ladinic succession as both these forms are characteristic of Upper Ladinic age.

The base of Carnic succession in both the Seshnag-Amarnath section (Kashmir) and Lachlungla-Umasila section (Ladakh) is demarcated at the level where *Neogondolella excelsa, Epigondolella mungoensis* and *E. multidentata* disappear. The presence of *Metapolygnathus polygnathiformis* and *Neogondolella navicula navicula* has been recorded from several stratigraphic levels of the Carnic succession. The base of Noric succession in these areas is drawn at the point where *Metapolygnathus polygnathiformis* disappears as this form does not extend into the beds younger than Carnic age. The Noric succession has yielded only poorly preserved specimens of *Neogondolella navicula navicula* and *N. navicula steinbergensis*.

The limestone lying 50 metres above the beds yielding *Juvavites* and other fragmentary fossils at the top of Lach-Lang-La has yielded *Neocavitella indica*† and *Himalayella*†† in association with other conodonts. The lower

* Bender and Kockel (1963) recorded the occurrence of conodont species *Spathognathodus gondolelloides* with figures, stratigraphic range lithologs and associated fauna from Hydaspian (Lower Anisian) rocks of Chios. The detailed description of this species was published subsequently by Bender (1968). Nogami (1968) also described similar conodont species under the name *Gondolella timorensis* from uppermost Scythian to lowermost Anisian rocks of Portuguese Timor.

† *Neocavitella indica* is a form of higher Sevatian. Such forms are normally persent in the beds above *Metapolygnathus bidentatus* together with *Gondolella steinbergensis*. The lower surface of the Himalayan form seems to have resemblance with that of *Paragondolella* and it has some similarity with the transition field between *Paragondolella* and *Misikella*.

†† *Himalayella* differs widely in its characters from *Neohindeodella*.

units of this succession have yielded well-preserved assemblage of Lacian conodonts (*Neogondolella halstattensis, Gondolella polygnathiformis* and *Metapolygnathus abneptis abneptis*. The upper units of this succession have yielded Alaunian (?) conodonts (*Metapolygnathus abneptis abneptis, M. abneptis spatulatus* and poorly preserved specimens of *Gondolella steinbergensis*). The conodont assemblages from the lower and upper units of Lachlungla may correspond to *Epigondolella abneptis abneptis* Assemblage Zone and *Epigondolella abneptis spatulatus* Assemblage Zone, respectively. The occurrence of Pelsonian conodonts (*Neogondolella nitiensis, Paragondolella bulgarica, Cartognathodus kochi* and *Hindeodella* sp.) has been recorded from the Tidong valley of Kashmir. The Triassic sequence of this area has also yielded Carnian conodonts (*Gladigondolella tethydis, G. malayensis*), and conodonts (*Gladigondolella tethydis, Neogondolella polygnathiformis, Ozarkodina saginata* and *O. tortilis*) of Julian age have also been recorded from west of Popa, Dolpo area, Nepal.

The Niti Limestone of northwestern Kumaun has yielded *Neogondolella nitiensis, P. bulgarica* and *Cratognathodus kochi* assemblages of Lower Anisian (Pelsonian) age. The Kalapani Limestone in the type area and Sumna section of Malla Johar of northeastern Kumaun has yielded Pelsonian conodonts in association with ostracodes (*Bairdia* sp., *Polycope* sp., *Cytherella* sp., *Hungarella* sp., *Monoceratina* sp., *Bythoceratina* sp., *Monsmiralibia* sp., (?) *Palaeomonsmiralibia* sp., *Thaumatocypris* sp.). The marly horizons at the base of Kioto Limestone in the Kuti area of northeastern Kumaun contain Norian conodonts (including *Paragondolella steinbergensis*), holothurian sclerites (*Calclamna germanica, Calclamnella* sp., *Theelia immissorbicula, Acanthotheelia* sp., *Fissobractites*, (?) *Eocaudina* sp., etc.), foraminifers (*Ammodiscus annuloids, Ammobaculites eumorphus, Ammovertella polygra*, etc.), crinoids (*Osteocrinus* sp., *Ossicrinus* sp. and *Anicrinus* sp.) suggesting an age within the *Bicrenatus* Zone. In the fossiliferous beds, the foraminiferal assemblage shows a relationship with that known from the Upper Norian (Bhaetian) marls of Zlambach. Identical microfauna (foraminifers, holothurian sclerites, conodonts, fish scales and teeth) have also been recorded from the limestone succession exposed at Zamalgam, near Verinag, Kashmir. The pelagic crinoids associated with the conodonts are characterized by the complete lack of thecas. The marly horizons with the basal units of Kioto Limestone succession in the Chharap valley of Lahaul have yielded rich assemblage of ostracodes including *Hungarella* sp., *Bairdia* sp., *Bairdiacypris* sp., *Paracypris* sp.. *Lutkavichinella* sp., *Reubenala* sp. and (?) *Cytherella* sp.

The conodonts from the lowermost part of the Triassic succession in Spiti include four different species of *Neospathodus* (*Neospathodus cristagalli, N. dieneri, N. waageni* and *N. kummeli*) occurring together. The simultaneous occurrence of these forms in a single specimen puts doubt regarding the different zones proposed earlier on the basis of these conodont forms. The overlying succession exposed near Lilang, along Lingti river has yielded conodonts belonging to *Neospathodus homeri* Zone of Upper Scythian age (*Neospathodus homeri* and *N. triangularis*), *Neospathodus gondolelloides* Zone of Aegian age (*Hindeodella suevica, Neospathodus gondolelloides*), *Neospathodus regale* Zone of Upper Aegian age and *Neogondolella cornuta* Zone of Illyrian age (*Paragondolella bifurcata, P. hanbulgi, Gladigondolella tethydis* and *Neogondolella cornuta*). In addition, conodonts belonging to *Neogondolella mombergensis* Group from the upper part of Ladinian and *Paragondolella halstattensis* from the Noric strata have also been found in the Lilang section of Spiti. The conodont-bearing Middle Triassic rocks in all the sections in the Himalaya have yielded fish scales (*Hybodus* sp., *Saurichythys* sp., and *Gyrolepis* sp.), foraminifers (*Ammodiscus* sp., *Glomospirella* sp., *Glomospira* sp., and *Nodosaria* sp.) and ostracodes (*Hungarella ussuriensis, Patellacythere* sp., *Praebythoceratina* sp., *Paraberounella* sp., *Monoceratina* sp., *Judahella* sp., and *Bairdia austriaca*).

CONCLUSION

The conodont fauna from the Triassic rocks exposed in different parts of the Himalaya has close similarity with the conodonts recorded earlier from within the Tethys Realm. The similarity in fauna facilitates a direct comparison of biostratigraphic zones based on conodonts with the sections rich in ammonites, bivalves and brachiopods. A general analysis of the conodont fauna from Spiti suggests a typical Mediterranean character. This is in particular supported by the predominance of multielements of *Gladigondolella tethydis* and occurrence of taxa characteristic of the Alps and the Balkans in the Himalayan material.

Microplanktonic investigations of the Triassic rocks in recent years have yielded some positive results. The Lower Triassic marine shales exposed near Pahalgam have yielded *Leiosphaeridia* cf. *L. wenlockia, Leiosphaeridia* spp. *Tasmanites* sp., etc. The fossiliferous limestone and shale succession exposed in the Chhotahoti region of Kumaun Himalaya contain *Leiosphaeridia* cf. *L. wenlockia* and *Tasmanites* spp. The limestone with *Belmenites* of the Barahoti region is composed of *Leiosphaeridia minuta, Leiosphaeridia* cf. *L. wenlocki*.

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Lower Carboniferous Plant Fossils From Near Banihal, District Doda, Jammu and Kashmir

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THE PRESENT paper records the occurrence of Lower Carboniferous plant fossils from a quartz-graywacke, shale and conglomerate succession exposed near Karawa village (75°′ 11′15″ : 33°26′20″), about ½ km west of Banihal (Fig. 1). The specimen under reference is represented by lycopod stems which resemble in all characters to *Lepidodendropsis*, recorded earlier from the Lower Carboniferous rocks from North America, Africa, Australia, Europe, Himalaya, China and Malaysia (Pal and Chaloner, 1979).

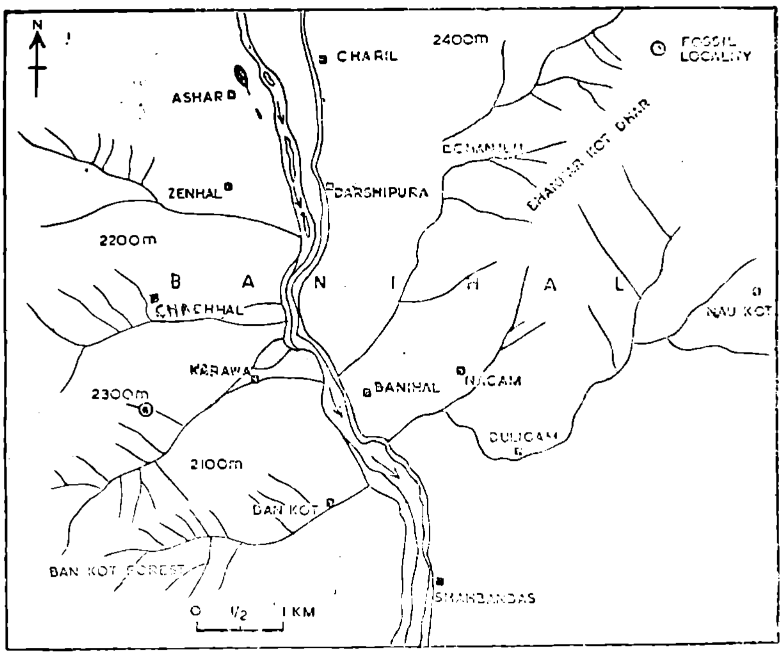

Figure 1. Location map.

The plant-bearing horizon lies conformably above the fossiliferous *Syringothyris* Limestone of Tournaisian to Visean age and is overlain by the *Fenestella* Shale of Late Visean to Bashkirian age. The quartz-graywacke, shale and conglomerate succession is about 700 m thick and forms a transitional zone between the *Syringothyris* Limestone below and the *Fenestella* Shale above. In fact, the plant-bearing beds seem to correspond to the Gund Formation of Pal and Chaloner (1979). Pal and Chaloner (1979) have recorded the occurrence of rich assemblage of Early Carboniferous plant fossils corresponding to *Lepidodendropsis* flora from the Gund Formation exposed in the Charial-Naugam section, north of Banihal and also from the Liwar-Kotsu section of the Liddar valley in Kashmir. In addition, Gothan and Sahni (1937) had earlier recorded the occurrence of Lower Carboniferous flora from the Thabo stage of Po-Series in Lower Spiti valley. For details of the distribution of *Lepidodendropsis* flora and its stratigraphic implications, reference may be made to Pal and Chaloner (1979) and Gothan and Sahni (1937). The find of Lower Carboniferous plant fossils from Karawa village is significant and a thorough search from this area may yield rich assemblage of plant fossils similar to those recorded earlier from the Gund Formation of Kashmir (Pal, 1978; Pal and Chaloner, 1979) and from Thabo Stage of Spiti valley (Gothan and Sahni, 1937). Kapoor and Srivastava and Kapoor (1969) pioneered palaeobotanical studies in the Carboniferous rocks of Kashmir.

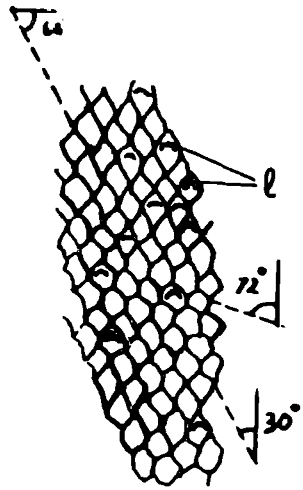

Figure 2. *Lepidodendropsis*. Diagrammatic sketch to show crescentric lingular pits (l).

Lycopodiales
Lycopod Stem

Genus : *Lepidodendropsis* sp.
(Fig. 2, 3*a*-*d*)

Diagnosis. Imprints of stem with spirally arranged leaf cushions, cushions broad in the middle part tapering upward and downward, cushions have crescentric lingular scars.

Description. The preserved part of the stem is about 13 cm in length and 2.8-3 cm in breadth. Figure 2 shows hand sketch of the basal part of the stem with rhomboidal leaf cushions and lingular scars. The stem shows spirally arranged rhomboidal leaf cushions 9 in each diagonal row and 6 breadthwise within the area of 6 sq cm. The leaf cushions are closely spaced. The crescentric lingular scars are seen inside the leaf cushions (Figs. 2, 3*b*, and 3*c*). The leaf cushions are about 5 mm in length and 3 mm in breadth. The various angles of inclination of the spiral are shown in Fig 2. Although the specimen is fairly well-preserved, it is not possible to observe all the characters in detail The presence of crescentric lingular scars and rhomboidal leaf cushions indicates that the present specimen is identical to the genus *Lepidodendropsis* Lutz, 1933 and has close affinity to *Lepidodendropsis fenestrata* Jongmans and Koopmans, 1940.

Locality. West of Karawa village, Banihal.

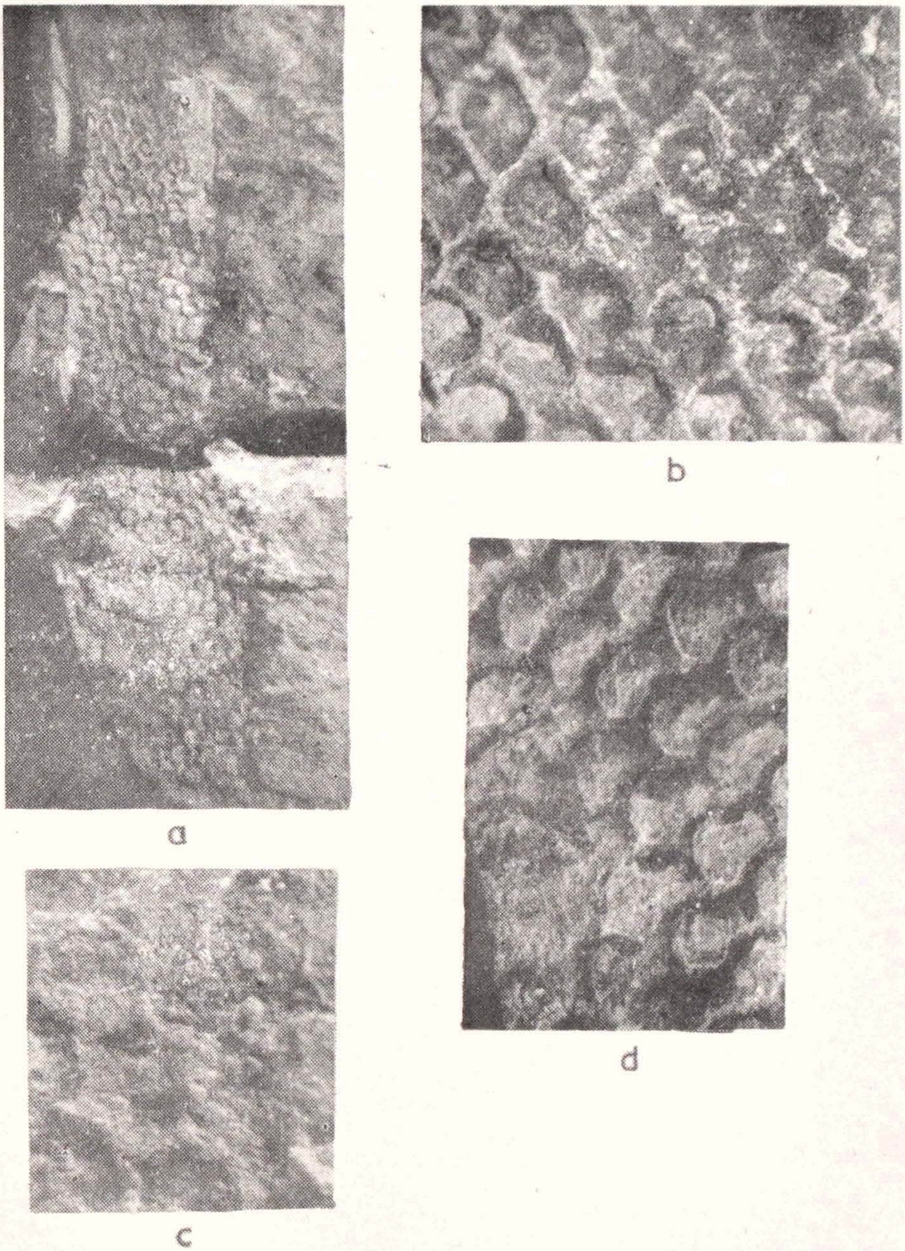

Figure 3. **a.** *Lepidodendropsis* sp. Imprint of Stem × 1. **b.** Enlarged view of a part of 3*a* × 5. **c.** Enlarged view showing lingular pits from the upper part of 3*a* × 6. **d.** Enlarged view of the basal part of 3*a* × 5.

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Northern Ladakh, a Scene of Explosive Volcanic Activity in Early Cenozoic

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ABSTRACT

In the northwestern Himalaya four phases of volcanicity have been recognized which continued intermittantly from Lower Palaeozoic to Early Cenozoic. The youngest phase of the volcanicity is represented by Oligocene-Eocene Shyok Volcanics which form the subject matter of this paper. These volcanics extend as a linear belt along the northern margin of Ladakh batholith and are represented by acidic to intermediate lavas (rhyolite, dacite, andesite) and pyroclastics (ignimbrites, ash flows, tuff flows, lapillistone and volcanic breccia). The calc alkine character and the abundance of pyroclastics in these volcanics indicate explosive volcanism under island arc palaeo-environment.

INTRODUCTION

THE NORTHWESTERN Himalaya has been a theatre of pronounced volcanic activity which continued intermittantly from Palaeozoic to Early Cenozoic. The earliest phase of the volcanicity (Lower Palaeozoic (?) Ordovician) recorded in this region is represented by Bafliaz Volcanics which are exposed along western Pir Panjal (Wakhaloo and Shah, 1968; Sharma and Gupta, 1972*a*; Gupta *et al.*, 1981; Shah *et al.*, 1978). Gupta (1979) considers that the spilite and keratophyre rocks of Bafliaz Volcanics are genetically related and have been formed by the differentiation of a tholeiitic magma under marine environment.

The second and more extensive phase of the volcanicity is represented by the Panjal Volcanics which have their maximum development in Kashmir Himalaya but continued northeastward into Zoji La, Suru valley and Zanskar Range of the Ladakh region (Wadia, 1928, 1934; Raiverman and Mishra, 1975; Nanda *et al.*, 1978; Virdi *et al.*, 1978; Fuchs, 1979; Srikantia and Razdan, 1980). This volcanic phase is predominantly of Permo-Carboniferous age but has transgressed into Triassic in the Erin valley, northwest Kashmir and is followed by a thick sequence of Triassic shale and limestone in the southeastern part. The nature of the Panjal Volcanics is predominantly tholeiitic in character (Sharma and Gupta, 1972*b*; Bhat and Zainuddin, 1978; Divakara Rao, 1980).

The third phase of the volcanicity took place in Cretaceous and is represented by Dras Volcanics in the northwestern part and Samdo Formation (Shanker *et al.*, 1976) in the southeastern part whereas in the central part of the Ladakh region the marine sedimentary influence (Indus Flysch) is more pronounced (de Terra, 1935; Wadia, 1937; Shah *et al.*, 1976; Frank *et al.*, 1977; Sharma and Kumar 1978; Gupta and Kumar, 1980). Dras Volcanics and Sumdo Formation have been grouped together under Indus Volcanics by Sharma and Kumar (1978). The best exposed sections of the Indus Volcanics in the Ladakh region are along Dras-Kargil national highway in the northwest and Mahe-Sumdo in the southeast. These volcanics are massive, amygdaloidal and show pillow structure and are dominantly tholeiitic in character (Pande and Rai, 1979). However, spilitic, andesitic and shoshonitic volcanics are also reported (Shah and Gergan, 1979). The Ophiolitic Melange Zone of Upper Cretaceous age (Shah and Sharma, 1977; Shah and Gergan, 1979) has emplaced within these volcanics along a number of deep-seated fractures. Sharma *et al*, (1978) have reported K/Ar age of 77.5 $\pm$ 1 m.y. for the volcanics associated with the Ophiolitic Melange Zone.

The fourth and the youngest phase of the volcanic activity in the northwestern Himalaya is exposed in a linear belt (about 400 km long and 7-8 km wide), in part, in Shyok valley, Tangtse valley and Upper Indus valley along the northern flank of Ladakh Range. Gupta and Sharma (1978) and Sharma and Gupta (1978) recorded the occurrence of acidic volcanics, pyroclastics and volcano-sedimentaries along Khardung-Khalsar section in the Shyok valley and named them as Shyok Volcanics. However, Bhandari *et al.* (1978) and Thakur *et al.* (1981) named a part of these volcanics as Khardung Volcanics. Sharma *et al.* (1978) on the basis of K/Ar age data have suggested that the acid part of the Shyok Volcanics exposed near Khardung represents a much younger phase (38 ± 2 m.y.) of eruption in Ladakh region and is separated in space and time from that of the Indus Volcanics (77.5 ± 1m.y.).

GEOLOGIC SETTING

The geologic set-up of the Ladakh region has been discussed by a number of workers in the recent years (Tewari, 1964; Gupta *et al.*, 1970; Gupta and Kumar, 1975; Raiverman and Misra, 1975; Shah *et al.*, 1976; Shanker *et al.*, 1976; Frank *et al.*, 1977; Fuchs, 1979; Pal and Mathur 1977; Srikantia and Bhargava, 1978; Thakur and Virdi, 1979).

In the Ladakh region of northwestern Himalaya, NW-SE trending Southern and Northern Crystallines (Sharma and Kumar, 1978) and associated Tethyan sediments of Zanskar-Spiti Basin are cut obliquely by a narrow linear belt of the Indus Volcanics and associated flyschoid sediments. The Ladakh batholith has emplaced along the northern margin of orographic unit at present called the Ladakh Range. The northern flank of the Ladakh Range is covered by acid volcanics, pyroclastics and associated volcano-sediments of the Shyok Volcanics which are quite distinct from those of the Indus Volcanics in both their character and age (Fig. 1).

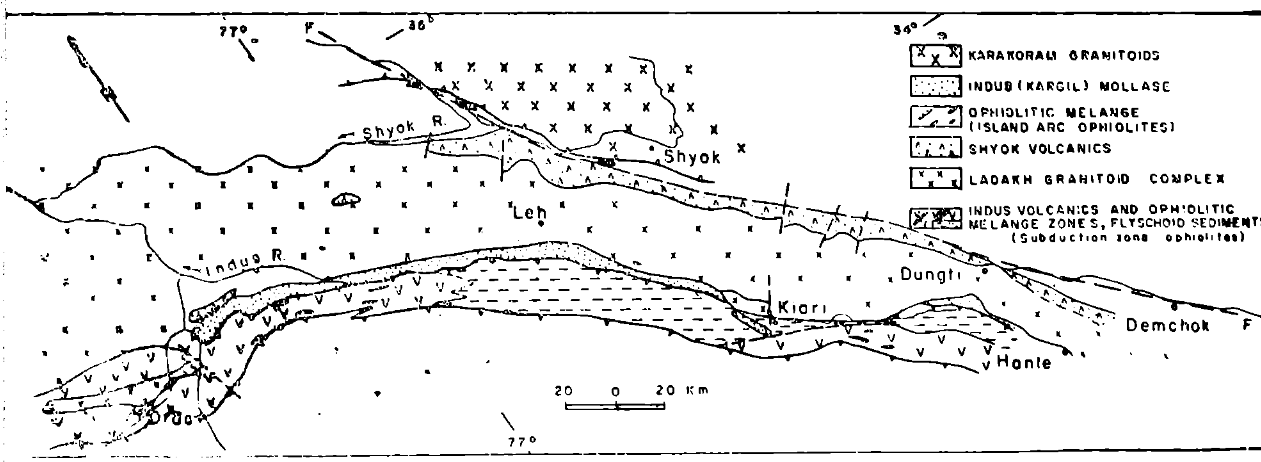

Figure 1. Generalised geological map of Ladakh showing Shyok Volcanics and Indus Volcanics with respect to other formations.

The present authors have observed ophiolitic melange sequence comprising peridotites, serpentinites and associated basic volcanics emplaced into the Ladakh batholith, north-east of Tsoltak. Similar rocks also occur between Tangyar and Nabuk La and further northwest into the Nubra valley (Fig. 1). The authors are of the opinion that the ophiolitic melange sequence which has cut through the Ladakh Granite, the Shyok Volcanics, possibly the Lower Cretaceous rocks near Nubuk La and also the Upper Palaeozoic sequence of Nubra Valley is younger than the ophiolitic melange of the Indus Suture Zone, the two being 30 to 50 km apart. Following Miyashire (1977) the Ophiolitic Melange Zone of the Shyok-Nubra region in our opinion represents island arc ophiolites associated with calc-alkaline volcanics (Shyok Volcanics) whereas those of the Indus Suture Zone associated with predominantly tholeiitic volcanics (Indus Volcanics) and blueschist represent subduction zone ophiolites.

The various lithotectonic units in the Ladakh region from south to north are shown in Table 1, Fig. 2 and Fig. 3.

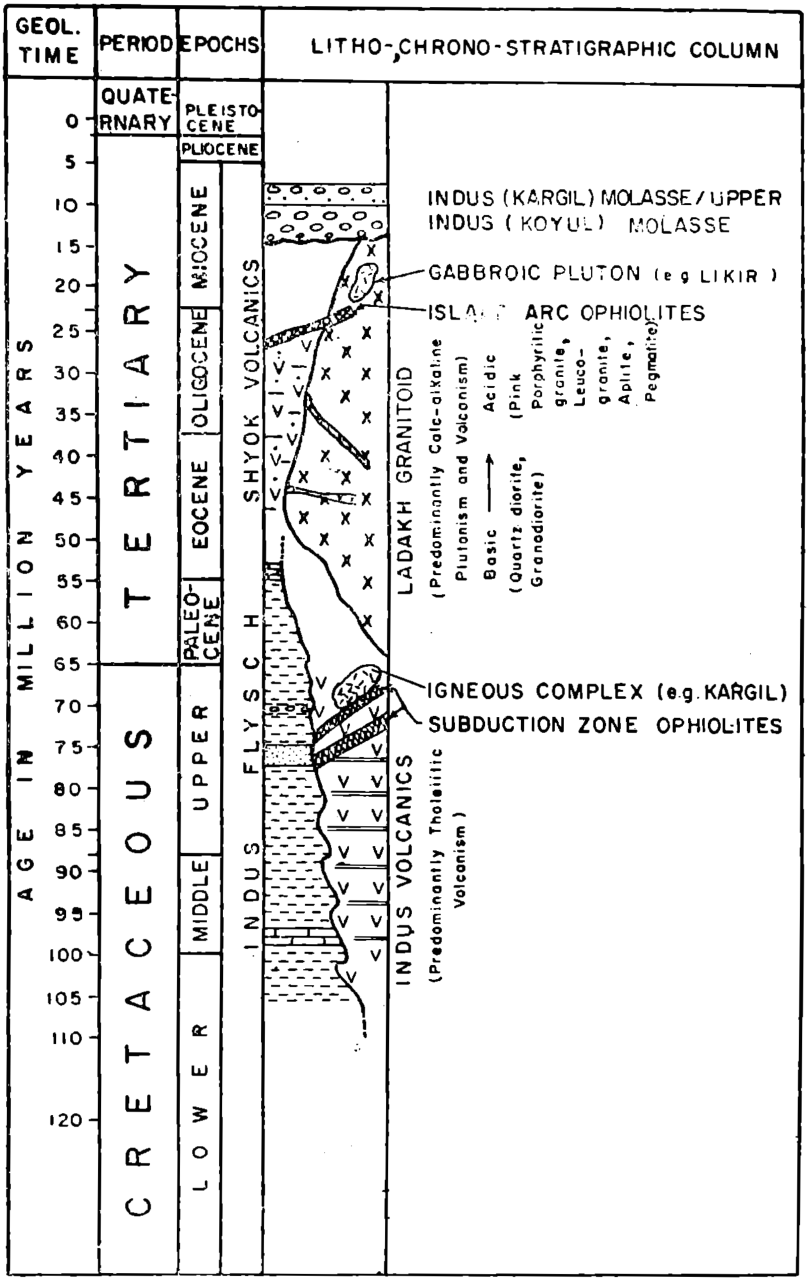

Figure 2. Chrono-, litho-stratigraphic column of Ladakh.

SHYOK VOLCANICS AND THEIR EXPLOSIVE NATURE

Extent and Mode of Occurrence

Since the first reporting of the Shyok Volcanics along Leh-Panamic section (Sharma and Gupta, 1978) a num-

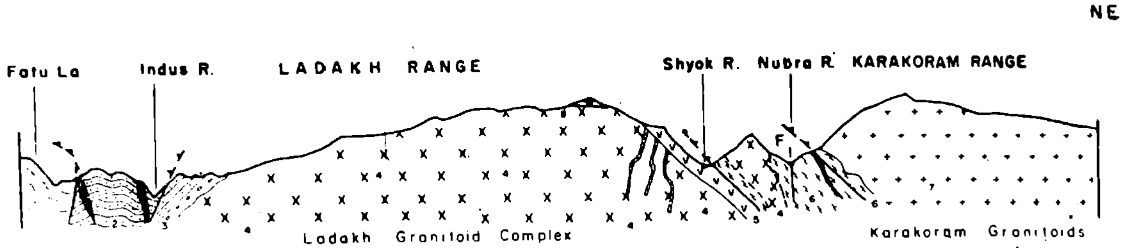

Figure. 3. Generalized cross-section across Ladakh-Karakoram Ranges showing relationship between various lithotectonic units; (1) Triassic shales and limestones of Tethyan facies; (2) Indus Volcanies with subduction zone ophiolites and flyschoid sediments; (3) Kargil Molasse; (4) Ladakh Granitoid Complex; (5) Shyok Volcanics; (6) Palaeozoic metamorphites, Island Arc ophiolites and associated volcanics; Karakoram Granitoids.

ber of traverses have been taken by the authors to delineate the extent of these volcanics and study their relationship with the Ladakh batholith. These volcanics in the northwest occur as eroded patches unconformably overlying the Ladakh batholith at Hamboting La and Chorabat La and from thereon these are exposed in a linear belt along the northern flank of the Ladakh Range from Turtuk in the northwest through Khardung, Tangtse, Taruk, Chushul, Dungti to Damchok in the southeast (Fig. 1). From Nubra-Shyok confluence towards southeast these volcanics run along the Nubra-Gartang Fault (Gupta and Sharma, 1978) for a considerable distance.

TABLE I—MAJOR LITHOTECTONIC UNITS OF LADAKH REGION FROM SOUTH TO NORTH

North	Karakoram batholith (Tegar Granite) associated Palaeozoic metamorphites
	- - - - - - Shyok (Northern) Thrust - - - - - -
	Ophiolitic melange and associated basic volcanics (*Island arc ophiolites*) Upper Palaeozoic metamorphites
	- - - - - - Nubra-Gartang Fault - - - - - -
	Upper Indus (Koyul) Molasse
	~~ Unconformity ~~~~~~
	Shyok Volcanics
	Eruptive unconformity
	Upper Jurassic Gondwana and Lower Cretaceous sediments
	- - - - - - Tectonic/intrusive contact - - - - - -
	Ladakh Batholith
	~~ Unconformity ~~~~~~
	Indus (Kargil) Molasse
	- - - - - - Thrust (interformational) - - - - - -
	Ophiolitic melange and basics (*Subduction Zone Ophiolites*) Indus Volcanics and flyschiodal sediments
	- - - - - - Dras (Southern) Thrust - - - - - -
South	Crystallines and the Tethyan Sediments

A special reference to the presence of unweathered and fresh pebbles of rhyolite, dacite, andesite, volcanic breccia, agglomerates, tuffs and ignimbritic rocks has been made by Frank *et al.* (1977), who discussed the composition of the Hemis conglomerate in the Indus valley. These authors further remarked that acid volcanic pebbles have not been reported from other localities except Mt. Kailash (Burri, *in* Heim and Gansser, 1939). This observation of Frank *et al.* (1977) further substantiates the presence of the Shyok Volcanics in the higher reaches of Ladakh Range similar to those of Hamboting La and Chorabat La as observed by the present authors. It is therefore, evident, that the Shyok Volcanics formed an extensive sheet over the Ladakh Granite which together provided provenance for the Hemis conglomerate and its equivalents towards south of the Ladakh Range. The presence of pebbles of acid volcanics in the Kailas conglomerate also suggests that the Shyok Volcanics which have been observed to extend upto Damchok by the present authors would further continue along the Nubra-Gartang Fault towards southeast up to the Mt. Kailas.

Nature of the Volcanics

The Shyok Valcanics are characterized by the presence of a thick sequence of acid to intermediate lava flows, ash flows, tuffs, volcanic breccia, agglomerates and ignimbrite. These volcanics in the lower part are interbedded at places with a sequence of chert, limestone and greywackes. The sedimentary influence in this sequence is more pronounced around Chushul. In general, the volcanic component of the Shyok Volcanics shows abundance (more than 50%) of pyroclastics (ignimbrites, ash flows, tuffs etc.) over the lava flows. Although the type section of the Shyok Volcanics along Khardung-Khalsar section shows a good development of acidic lava flows but towards northwest and southeast the influence of the pyroclastics appears to be more. This association of acid lava flows and the pyroclastics is characteristic of the volcanism under island arc palaeoenvironment (Garcia, 1978).

(*a*) *Lava Flows*. The lava flows range from rhyolite, decite to andesite. Mostly the flows are massive but some are amygdaloidal and are studded with epidote, quartz, calcite etc. The flows range from porphyritic to aphyric as well as spherulitic and are well-bedded and jointed and dip towards NE with amount varying from 30° to 50°. Flows and pyroclastics characteristically alternate in widely varying proportions. In some of the cases there is a distinct banding in the flows. This banding is due to varying size and quantity of phenocrysts and elongated rock fragments and thus indicates that this part of the Shyok Volcanics is ignimbritic. Some banding is also due to the flow in viscous acid lavas. The appearance of banding is deceptive in some of the flows because of dark grey; commonly pinkish to reddish and purple to brown finely disseminated iron in the case of felsic lavas and ignimbrites but low in the case of intermediate lavas.

(*b*) *Pyroclastics*. The pyroclastic deposits include ash flows, tuff flows, crystal tuff, vitric tuff to welded tuff (ignimbrite) to lapillistone and volcanic breccia. The different tuffs show varying degress of compaction, welding and sorting. Quartz, potash feldspar, plagioclase and glass shards are present in varying proportions inthese tuffs.

A characteristic feature of the ash flow deposits is the formation of *accretion lapilli* of varying size and shape. These lapilli (volcanic pisolites) range in diameter from 2 to 15 mm but in certain cases they range upto 30 mm (Fig. 4). According to Fisher (1961) lapilli may range from 2 mm to 64 mm. The lapilli in the Shyok Volcanics vary in shape from circular to oval to elliptical and occasionally show concentric or spiral structure. In most of the cases the fine ashy material forms a thin rim (1 to 5 mm) around the early formed nucleii of quartz and feldspar crystals or a bleb of semi-consolidated lava. The smaller-sized lapilli are made up of a fine consolidated ash whereas the larger ones have a nucleus of quartz and feldspar and a comparatively thinner rim (< 1 mm) of fine-grained ash. The lapilli in the present case appear to have been formed by accretion of fine ash around a wet nucleii of early crystals or semiconsolidated blebs of lava falling through a cloud of ash at the time of explosive volcanic activity. The lapilli with concentric ashy layers and spiral structure possibly suggest their formation by rolling in ashy matrix, on the ground, before final consolidation. The nature and the origin of lapilli, in general, have been discussed in detail by Stearns (1925), Moore and Peck (1962) and Macdonald (1967).

A marked variation in the proportion of lapilli in the ash flows of the Shyok Volcanics has been observed. At places the concentration of lapilli in fine-grained dark grey to dark brown ash flows is quite high resulting thereby in the formation of *lapillistone* (Fig. 5) as observed along Taruk-Gun La section. In certain cases the lapilli are embedded in ashy matrix along with glass shards and crystals of quartz and feldspar. The occasional presence of broken lapilli and the earlier formed crystals suggest stress conditions during the explosive activity and their flight in the ash cloud.

In the *ignimbrites* of Shyok Volcanic sequence eutaxitic structure (streaky appearance/flow structure) is common (Fig. 6) and phenocrysts of quartz and potash feldspar are aligned in a felsic to a glassy groundmass. The phenocrysts of quartz are mostly embayed and those of feldspar show magmatic corrosion. The ignimbritic rocks generally vary in composition from rhyolitic to dacitic. It has been observed that the ash flow tuffs show a gradation at places from a relatively consolidated tuff at the top to a thoroughly welded, massive, lava-like rock towards the base. The welding of such deposits has been explained by Gibson (1970, *vide* Hyndman, 1972) due to the high temperature of the tuff and the weight of overlying material. Smith (1960) has also discussed in detail the genesis of ash flow deposits.

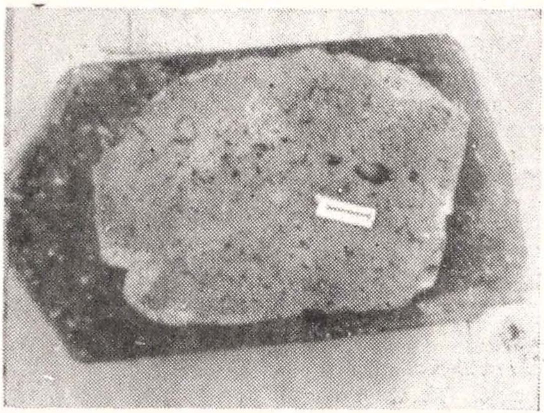

Figure. 4. Photograph showing the varying size and shape of lapilli.

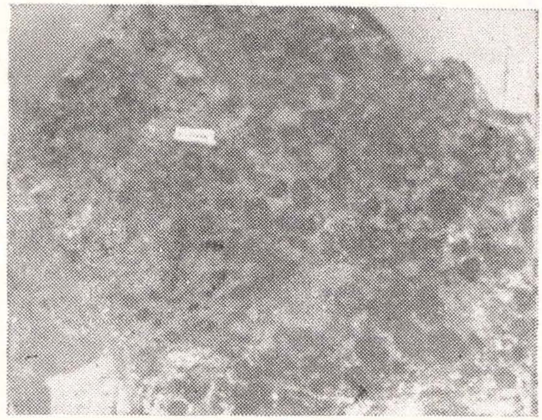

Figure. 5. Photograph showing the concentration of lapilli in lapillistone.

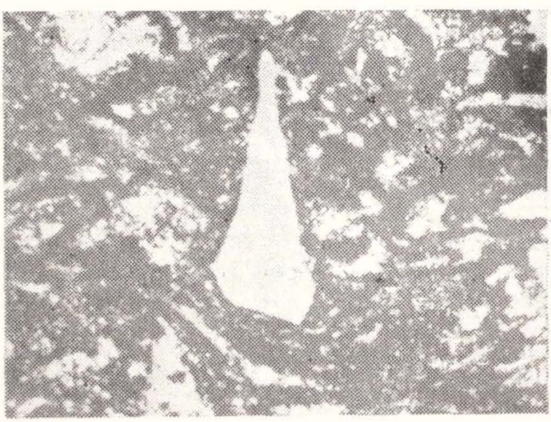

Figure. 6. Photomicrograph showing eutaxitic along with an embayed quartz phenocryst in Ignimbrite (crossed nicols × 63).

The *volcanic breccia* includes both monolithic and polylithic types. Monolithic breccia has good development along the Khardung Khalsar road where it is found interbedded with pinkish to reddish-coloured rhyolitic flows. Here the fragments are mostly of the rhyolitic rock which are angular in form. Tne monolithic breccia might have been formed by the fragmentation of earlier solidified crust of lava flow and its cementation by the still molten lava. In the case of polylithic breccia the fragments include coarse-grained to very fine-grained felsic lava, andesite and lithic tuff derived from earlier consolidated flows due to explosive eruption.

AGE OF SHYOK VOLCANICS

Stoliczka (1874) made a passing reference on the occurrence of greenish, chloritic, thin-bedded to massive rocks exposed near Khardung and correlated them with the Panjal Trap of Kashmir (considered at that time to be of Silurian age). Lydekker (1980) while commenting on Stoliczka's reported occurrence of volcanics did not consider these to be of igneous origin on the basis of his observation in the Tangtse area. However, the recent studies have confirmed Stoliczka's report (Gupta and Sharma, 1978; Sharma and Gupta, 1978; Bhandari *et al.* 1979 and Thakur *et al.*, 1981).

The age of the Shyok Volcanics has been briefly discussed by Sharma and Gupta (1978) and Sharma and Kumar (1978), who consider these volcanics to be younger than the Ladakh Granite. A sample collected from the base of these volcanics near Khardung has been dated as Upper Eocene (i.e. 38$\pm$2 m.y.) using K/Ar method by Sharma *et al.* (1978). Recently Thakur *et al.* (1981) have reported the presence of lower Cretaceous (Aptian) fossils *Orbitolina parma* and *Orbitolina discoides* from calcareous shales in the southern slopes of Nabuk La where the Shyok volcanics are also exposed. On the basis of this fossil find the age of Shyok Volcanics has been considered as Lower Cretaceous to Eocene by these authors.

On the basis of regional studies carried out in the area, the present authors consider that the Shyok Volcanics overlap different stratigraphic horizons at different places, i.e. Lower Cretaceous flyschoid sequence near Nabuk La, south east of Tangtse and Chushul; Upper Jurassic rocks of Gondwana affinity near Fukche (Sharma *et al.*, 1980) and Ladakh Granits at different places.

The major part of the Ladakh batholith has been considered to be a polyphase intrusion starting sometime in Late Palaeocene (55 to 60 m.y.) and subjected to continued differentiation and crystallization in successive phases through Eocene to Late Oligocene or Early Miocene, i.e., 20-25 m.y. age (Sharma *et al.*, 1981, in press). Since the base of the Shyok Volcanics overlying the Ladakh Granite near Khardung has been dated as 38 $\pm$ 2 m.y., the younger and more acidic phase of the Ladakh Granite would not only emplace into the upper part of the Ladakh batholith but also continue into the overlying Shyok Volcanics as observed by Bhandari *et al.* (1979) and Thakur *et al.* (1981). The present authors have also observed the occurrence of felsic dykes (granite porphyry) intruding into the Ladakh Granite and Shyok Volcanics near Hamboting La.

The detailed geochronological study of these volcanics is in progress, however, in the light of the available geological and geochronological data the Shyok Volcanics may be of Eocene-Oligocene age. It may be mentioned that in the regional geologic setting similar rocks (Utror Volcanics) in the adjoining Kohistan region have been reported to be of Middle to Upper Eocene age because of their close association with Baraul Banda slates yielding Lower Eocene fossils (Tarhirkheli, 1979).

DISCUSSION

The presence of acidic to intermediate lava flows (rhyolite, dacite, andesite), abundance of pyroclastic material in the Shyok Volcanics and a few chemical analyses carried out suggest calc-alkaline character and explosive nature of this volcanicity. The close association of these volcanics with the Ladakh Granite (represented by quartz-diorite, granodiorite and granite) also of calc-alkaline nature, possibly, suggests that the volcanism and plutonism are, in part, genetically related. The presence of acidic feeder dykes through the Ladakh Granite to overlying Shyok Volcanics further substantiates the above view. Similar genetic correlation between the calc-alkaline plutonism and volcanism under island arc conditions, in general, have been mentioned by Condie (1975). Recently, Garcia (1978) has also suggested that the island arcs are the sites of explosive volcanic activity and calc-alkaline magma generation.

In the light of the field and preliminary laboratory data the Shyok Volcanics indicate an island arc palaeoenvironment during Early Cenozoic. However, the detailed petromineralogical, geochemical and geochronological data on these volcanics and associated magmatic rocks under progress, would throw much light on the crustal-mantle dynamics of this part of the Northwest Himalaya.

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Geological Studies in the Indus Suture Zone of Ladakh (Himalayas)

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ABSTRACT

New data on the geology of the Indus Zone in Ladakh are presented (stratigraphy, paleontology, petrology, tectonic), which allow us to propose a new diagram of geodynamic evolution.
The Khalsi Limestone is considered as the basal part of the Indus Formation; it contains foraminifera and *Rudistacea* of the Upper Aptian-Lower Albian. The Nindam Flysch shows some thin intercalations of carbonate with a Cretaceous age; the petrographical study of the Dras Volcanics showed that the sub-alkaline basaltic lavas have been metamorphosed in the prehnite-pumpellyite facies. The Mesozoic series of Zanskar-Shillakong Nappe is distinguished from the classic Himalayan Mesozoic Cenozoic succession; characteristic is the occurence of an unconformity between Cretaceous Pelagic Fatula Limestone and the older formations. Elements present in the tectonic sole of the ophiolitic nappe are described. The ophiolitic nappe is mainly constituted by harzburgitic foliated tectonites; associated rocks are dunites, lherzolites, podiform chromites and pyroxenitic, gabbroic and diabase dykes.

INTRODUCTION

The upper Indus valley separates two main ranges. To the north, the Ladakh ranges, mainly granitic and granodioritic, represent a large Cretaceous to Eocene batholith of Andean type; to the south extend the Zanskar ranges.

From north of Khalsi to Ringdom Gompa southward several structural units are distinguished:

- Ladakh Batholith (Transhimalaya);
- Indus Formations;
- Dras-Nindam Nappe;
- Lamayuru Nappe;
- Zanskar-Shillakong Nappe;
- Ophiolitic Nappe;
- High Himalaya unit (Tethysian series).

Many recent studies were devoted to this area : Andrieux *et al.* (1977), Bassoullet *et al.* (1978-80-81), Frank *et al.* (1977), Fuchs (1977-1979), Gupta *et al.* (1975), Shah *et al.* (1976-1977), Srikantia and Bhargava (1978), Srikantia and Razdan (1980).

We present here complementary data on stratigraphy, tectonic of the different units and petrology on volcanics of Dras and Ophiolites. We propose a new interpretation of geodynamic evolution of Indus Suture Zone.

I. INDUS FORMATIONS

These thick terrigenous subsident formations with flyschoid or molassic characters (Fig. 1) rest at the North on the Transhimalayan batholith while southward they are in tectonic contact with the Nindam flysch of the Indus Zone. It is not our purpose here to describe this formation previously analysed by many authors, which has given Upper Cretaceous and Tertiary faunas.

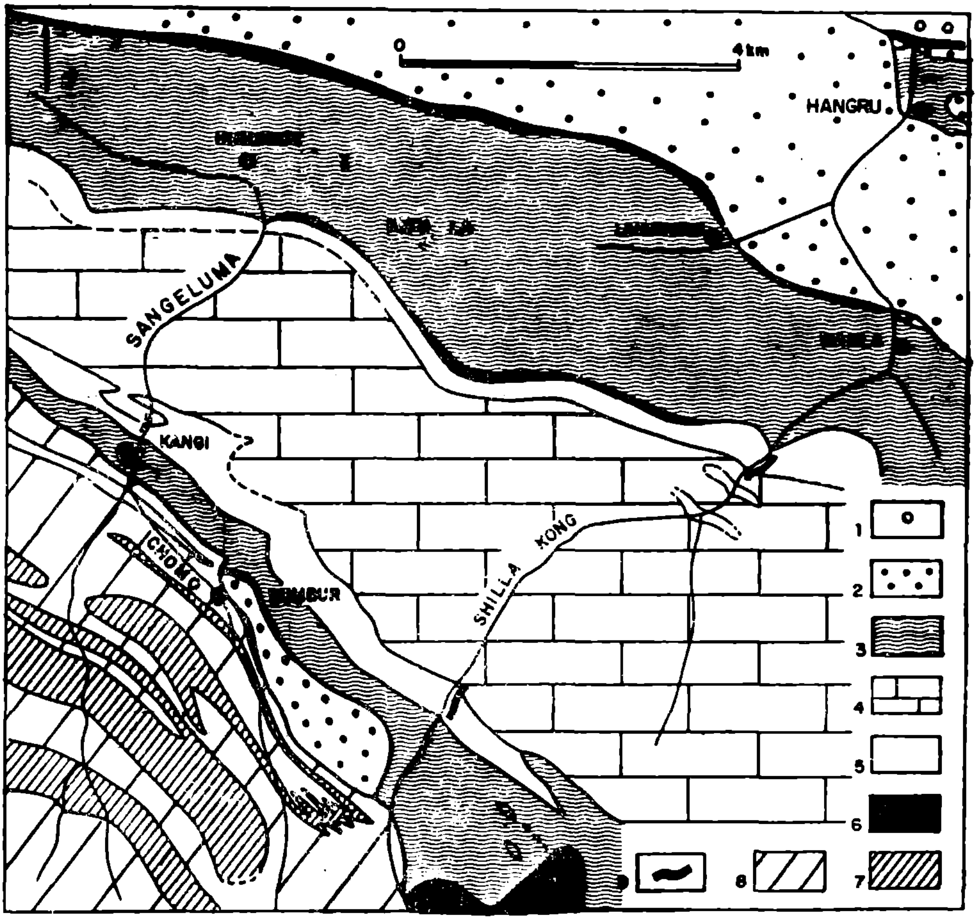

Figure 1. Geological sketch map of the Indus Suture Zone between Heniskot, Wanla and Kangi. 1—Indus Formations. 2—Nindam Flysch. 3—Lamayuru Flysch. 4—Mesozoic Tethysian Series of Zanskar-Shillakong Nappe. 5—Upper Cretaceous Fatula Limestone. 6—Ophiolitic Nappe and Serpentines. 7—Calcareous beds (Paleocene and Eocene) of Himalayan Series. 8—Himalayan (Tethysian) Series. 9—Places of sections.

The position of the fossiliferous limestones with *Orbitolinas* SW and E of Khalsi is disputed. Some authors consider them as part of the Dras-Nindam Formation (Gansser *in* Frank *et al.*, 1977; Fuchs, 1977). However, for us it is a basal part of the Indus Formations.

These limestones were studied in two places, SW of Khalsi and E of this village (Figs. 2 and 3).

I.1. Section SW of Khalsi

It is on the left bank of Indus along the road and the Yapola river before its junction to Indus. From south to north, the succession is as follows (Fig. 3) :

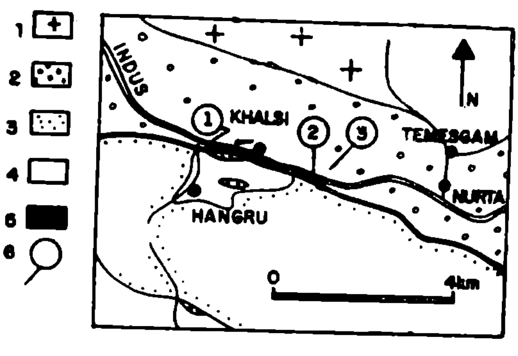

Figure 2.

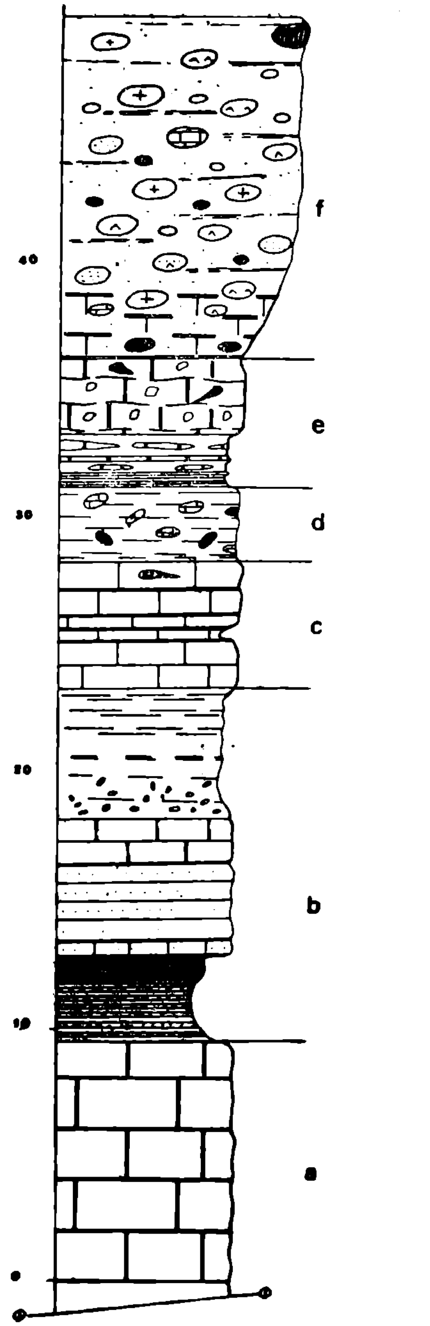

Figure 3.

Figure 2. Localisation sketch map of Khalsi Limestones sections. 1—Transhimalayan batholith. 2—Indus Formation. 3—Nindam Flysch. 4—Lamayuru Flysch. 5—Serpentine. 6—Places of sections.

Figure 3. Stratigraphical succession in the Khalsi Limestones SW of this locality (legend cf. text).

(*a*) Dark-grey limestones, in some decimeters thick, intercalated with thin levels of shale with Orbitolinas† and molluscan fragments. . .10 m. Various microfacies has been observed :
Biomicrite with foraminifera, algae, mollusca remains and Spicules of Porifera.
Orbitolina (*Mesorbitolina*) gr. *texana* Douglass,
Orbitolina (*Mesorbitolina*) *subconcava* Leymerie,
Orbitolina (*Mesorbitolina*) *parva* Douglass,
'*Cuneolina*' *scarcellai* de Castro,
Nezzazata sp., *Ammobaculites* sp.,
Lithocodium aggregatum Elliott, *Ethelia alba* (Pfender),
Boueina sp.,
Biomicrosparite with coarse sand grains,
Biomicrite with algae and *Orbitolinas* : *Lithocodium* aggregatum Elliott,
Solenopora cf. *melobesoides* Pfender.
A thin microbreccia with organic remains (*Orbitolinas*, bioclasts) together with felspaths and weathered fragments of microlitic lavas, cemented by calcite and chlorite, has been observed within the shales. The Orbitolinid association indicates an Upper Aptian-Lower Albian age.

(*b*) Sandy grey-green shales, greenish fine sandstone and silty shales with two intercalations of limestones (0.60 and 1.80 m); total. . . 14 m.

(*c*) Massive brecciated limestone with a thin layer of shales. . . 5 m. It is a breccia with calcareous lithoclasts and fragments of Rudists; microfacies of lithoclasts :
Biomicrite or biosparite with *Orbitolina* and algae (*Lithocodium aggregatum* Elliot, *Triploporella* cf. *fraasi* Steinmann, *Ethelia alba* (Pfender).

(*d*) Polygenic conglomerate with calcareous and volcanic elements. . .3 m. Calcareous lithoclasts of silicified and brecciated limestones and elements of microlitic lavas in a greenish pelitic argillaceous matrix.

(*e*) Shales and calcareous breccias about. . .5 m. At the bottom, black shales (0.50 m) are followed by shales and lenticular brecciated limestones interbedded. At the top, a massive calcareous breccia (3 m) shows calcareous pebbles and Rudists (*Radiolitinae*).

(*f*) Massive conglomerate with sandy cement and centimetric to decimetric pebbles. . . some tens of metres. The elements are composed of white quartz, rhyolitic and andesitic tuffs, granodiorite and gabbros. The upper levels are masked by the Indus Terraces. This succession shows a progressive evolution of carbonatic plateform deposits invaded by detrital material of northern origin (Transhimalayan batholith and volcanics).

I.2. Section of the Orbitolina Limestones, E. of Khalsi

The same Orbitolina limestones are cut by the road Khalsi-Leh at some kilometres E of Khalsi. The overturned beds show a section comparable to the first one but with thinner detrital material at the upper part. Over thin-bedded black limestone with *Hedbergella* sp. are superposed two massive beds of limestones (ten-metres thick) with abundant bioclasts, Rudists and *Orbitolina* sp.

In the lower part was found *Favusella washitensis* Carsey and, higher, *Sphaerulites* sp. (cf. *Sph. cantabricus* Douv.††) of Aptian-Albian age.

Other Aptian-Albian fossils were found, out of place, in the same area :

Orbitolinids : *Orbitolina* (*Mesorbitolina*) *subconcava* Leymerie (*sensu* Schroeder), *O.* (*Mesorbitolina*) *texana* Douglass.

Rudists : *Polyconites* sp., *Eoradiolites* sp. (cf. E. *gilgitensis* Douville) (det. Prof. J. Philip).

The tectonic contact, figured by Fuchs between these limestones and the shales of the Indus Formations is of secondary importance. We consider that the Orbitolina limestones represent the lower levels of the Indus Formations. New data on the equivalent Xigatzé Group in Southern Tibet strengthen this opinion.

II. THE DRAS-NINDAM FORMATIONS

Dras Volcanics and Nindam Formation are lateral equivalent. In the NW the formation is mainly composed

†Determination of Orbitolinids by Dr. E. Fourcade.
††Determinations J. Philip.

of volcanic rocks whereas the Nindam flysch, a volcano sedimentary flysch or greywacke flysch, is well characterized eastward of Shergol.

II.1. Sedimentary and Volcano-sedimentary Nindam Formation

In the Nindam Flysch the following succession can be observed (Fig. 4) :

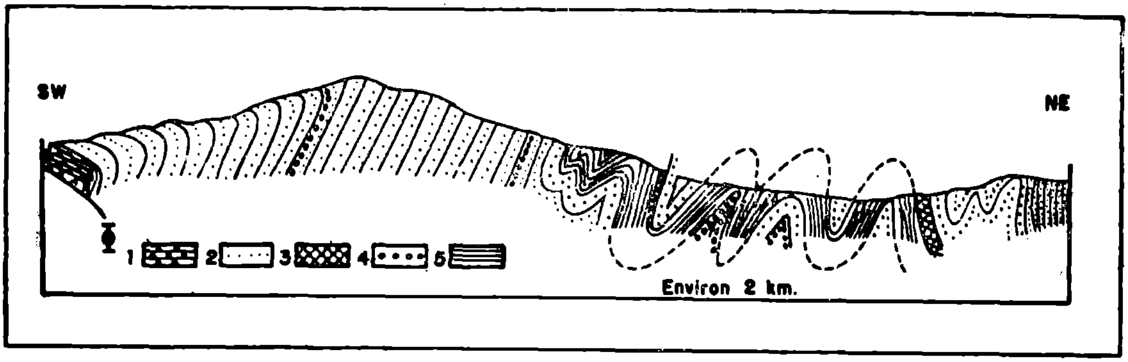

Figure 4. Section of Nindam Formation along the road Lamayuru-Khalsi. 1—Radiolarites and fine-grained tuffites. 2—Greywackes, quartzites and thin pelitic beds. 3—Conglomerates and intraformational breccias. 4—Calcareous siltstones.

—At the lower part, alternances (50-70 m) of fine-grained, green and red thin bedded tuffites with some rare decimetric beds of quartzites and intraformational breccias of green tuffitic elements.

—A thick series (several hundreds of metres) composed of greywackes alternating with violaceous silts and green quartzites. Masses of diabases are found and also conglomeratic levels reworking the precedent facies.

—A thick series of alternance of grey quartzitic sandstones in decimetric layers, and of sometimes slightly calcareous grey sandy silts.

This formation along the road Lamayuru-Khalsi yielded two fossiliferous levels :

(*a*) tuffitic breccia with one fragment of broken reworked *Orbitolina* sp. (post-Aptian to post-Cenomanian),
(*b*) thin more calcareous intercalation in the Upper levels with *Hedbergella* sp. and badly preserved *Globotruncana* sp. (G. *tricarinata*(?) or *coronata*(?)) which Dr. Sigal presumes to be of Turonian-Senonian age.

II.2 Pillow-lavas of the Dras Formation

II.2.1. Field Description

Pillow-lavas and associated sediments outcrop widely around the village of Dras, and make up the mountains along the river Dras and the road going from Dras to Kargil. In the landscape, they form dark and massive formations. The characteristic morphology of pillow-lavas appears clearly from place to place, but is generally difficult to distinguish, because of crushing and recrystallization. We made detailed studies in two areas :

(*a*) Outcrop along the road from Zoji-La to Dras, 2-3 km before Dras, along the Dras river. Here the volcanics and associated sediments—fine-grained Radiolaria-rich greywackes—are sub-vertical. In spite of general crushing, the pillow morphology is well visible (Plate 1.1).

Plate 1. **(A) Pillow Lavas from the Dras Formation.** 1—Pillow-lavas outcropping along the road from Dras to Zoji-la, along the Dras river, 3 km from Dras. These pillows are associated with tuffites and radiolaria-rich greywackes of Cretaceous age. 2—Outcrops of pillow-lavas located on the right side of the river Dras, visible from the road from Dras to Kargil (18 km from Dras, 5 km before Tazgam). 3—Same outcrop, closer. 4—Same outcrop, detail : primary corrugations are still visible on the glassy margin of the pillow-lava tubes.
(B) Pillow-Lavas from the Infra-Peridotitic Slices. 5-6—Basaltic pillow-lavas, cemented by micritic limestones of unknown age. The sediment has penetrated inside the pillows by the radial cracks, sometimes filling hollow pillow-tubes (Fig. 5). Delicate exfoliation of the glassy margins of the pillows in the interpillow spaces is visible in Fig. 6. These outcrops are huge blocks detached from the infra-periodotitic slices, visible at 4.700 m between the Shillakong strait and the Nigoutsè La. 7—Hydroclastic pillow breccias. Huge brown pillow fragments are set in a green hyaloclastic matrix. These volcanics are associated with Upper Triassic sediments. The outcrop is located just beneath the peridotite nappe, between the Sirsir La and Photaksar. 8—Basaltic breccias, cemented by recrystallized micritic limestone (unknown age), from the same area.

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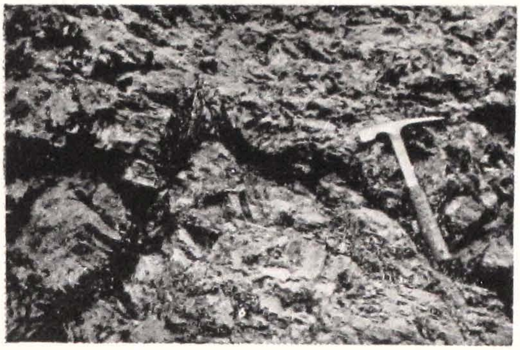

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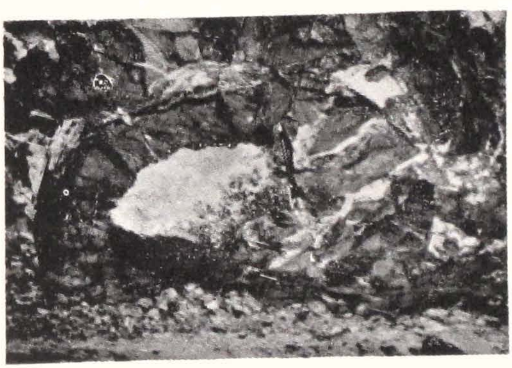

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Plate 1.

(*b*) Road from Dras to Kargil. At 18 km from Dras and 5 km before Tazgam, nice pillow-lava forms can be seen on the southern side of the valley. A bridge on the river Dras allows to cross the river and to study an outcrop of exceptional quality and dimensions. It is a huge and complex formation of basaltic pillow-flows, massive flows, dike swarms and tuffites. The pillows have an elongated tube-like morphology (Plate 1, figs. 2, 3 and 4); their corrugated glassy skin has been perfectly preserved (Plate 1, fig. 4).

II. 2.2. Petrography of the Dras Volcanics

A—Textures

Besides the classical groundmass textures which consist of a succession of variolitic, spherulitic and microlitic zones from margin to core, the Dras pillow-lavas are most typically subaphyric to phyric, up to 18% phenocrysts of Plagioclase (11%) and Clinopyroxene (7%) in the core. These phenocrysts generally form clusters.

Another feature of Dras pillows is a so-called 'pustule facies'; the pustules are 0.5 to 1 cm large clear zones, very vesicular, microlitic and not or poorly porphyric. Whatever may be their shape they are always iron-rich, and get a predominantly red-brownish colour near the pillow margin (Plate 3, fig. 1). Sometimes, one can observe in these pustules arborescent features of altered Plagioclase microlites, or quenched clinopyroxene 'combs'. The very small vesicles are filled with calcite, chlorite and prehnite.

The pustules are separated by a microlitic poorly phyric matrix which also contains centimetric vesicles filled with quartz, prehnite, pumpellyite and chlorite. The groundmass mainly consists of chlorite, sphene and opaque minerals. This pustule feature is not restricted to pillow-lavas since it also exists in a sheet flow between the pillow-lavas.

B—Mineralogy

(i) *Magmatic minerals* are olivine, plagioclase, clinopyroxene and opaque minerals.

—Olivine, since it is totally altered, can be suspected only when exhibiting its euhedral habit. It is transformed in chlorite and pumpellyite or clay minerals. Phenocrysts (0.5-2 mm) or microphenocrysts (0.1-0.5 mm) show resorptions or glassy inclusions. Olivine never forms aggregates with plagioclase, contrary to clinopyroxene.

—Plagioclase is more or less altered in epidote, chlorite, prehnite or calcite. Optical determination gives a composition of andesine (30-35% An). The euhedral phenocrysts show magmatic etching and microphenocrysts very often glassy inclusions.

Plagioclase microlites, generally replaced by albite, show all kinds of quenched features : 'swallow-tails, belt-buckles', arborescent feature. The matrix consists of chlorite, pumpellyite, epidote, sphene and opaque minerlas.

—Clinopyroxene is the only magmatic which did not undergone alteration; it is conspicuously fresh. Microprobe analysis gives a composition of diopside-endiopside with very poor amount of Al_2O_3 and TiO_2, indicating a subalkaline magma.

Three generations at least were found; etched phenocrysts, euhedral or subhedral microphenocrysts (analyzed), very often associated with plagioclase clusters (Plate 3, fig. 3), and quenched microlites, very abundant in the variolitic and spherulitic zones, just as in the pustule facies.

(ii) *Secondary minerals*. A very tight brown-orange coloured Palagonite border can be seen in radial cracks, just as at the boundary between the pillow margin and the sediments.

Nevertheless, palagonitisation must have been very limited since associated hyaloclastite is not palagonitized, but recrystallized in chlorite, pumpellyite and sphene. Calcite, chlorite and a little epidote are met in altered plagioclase phenocrysts, the matrix being a mixture of chlorite, pumpellyite, albite, sphene and opaque minerals. However, the most conspicuous metamorphic paragenesis are met in vesicles, specially in the pustule facies. The following assemblages have been noticed in the vesicles :

—Pumpellyite
—Pumpellyite-prehnite
—Pumpellyite-prehnite-chlorite
—Pumpellyite-albite (Plate 3, fig. 2)
—Prehnite
—Prehnite-chlorite
—Quartz

Metamorphic conditions were those of the prehnite-pumpellyite facies.

It is worth while to remark here that a gresopelitic sediment with primary contacts with the Dras pillows contains Radiolarias, indicating oceanic conditions.

The Diabase dykes. Some diabase dykes have intruded the pillow-lavas, developing a chilled margin. Plagioclase microlites are completely altered in calcite. The core gets progressively an ophitic texture; the plagioclase laths (1-2 mm) are altered into calcite, chlorite, or prehnite; clinopyroxene occurs as granules or as phenocrysts, just as very rare hornblende. Nevertheless, cooling must have been rapid, because of the existence of a very vesicular glassy groundmass, devitrified in the chlorite and opaque minerals. Vesicles are filled with ch orite, pumpellyite and prehnite.

III. THE LAMAYURU FLYSCH

The Lamayuru Flysch is formed by the indefinitely repeated alternances of grey to black silts and calcareous grey silts in centimetric beds. Locally, there appear layers of black quartzite (10-30 cm) or sandy zones constituted by a great number of thin sheets of clear medium-grained sandstones. Beds of sandstones of more than 1 m thickness are exceptional (example south of Lamayuru). In the Shergol area some masses of diabases and also tuffitic greenish levels are interstratified in this flysch. Zones with beds of grey limestones were also observed with transition between thin centimetric beds of microbreccias to huge blocks.

In a recent publication (Bassoullet *et al.*, 1981) we distinguished the main types as : olistolites or sedimentary klippen and olistolite breccias; strata of limestones; allodapics limestones.

The reworked facies are characteristic of a platform environment lying near the margin of the flysch basin; the platform should have been subjected to a synsedimentary tectonic. Beyond the confirmation of the existence of Triassic layers, the discovery of Jurassic microfossils allows us to consider that a part of the Lamayuru flysch belongs to Upper Trias to Middle Jurassic (Bassoullet *et al.*, 1981).

IV. THE MESOZOIC SERIES OF THE ZANSKAR-SHILLAKONG NAPPE

This sequence was observed in the Shillakong gorges south-west of Shilla and in the Sangueluma Chu, north of Kangi. The tectonic unit of Zanskar Nappe is composed essentially of a thick succession of limestones strongly folded, forming a high mountanous barrier south of the Lamayuru depression. The series can be divided in two parts (Fig. 5):

(i) Mesozoic basal part : Quartzite Series, Kioto Limestones, Spiti Shales and Giumal Sandstones (Upper Trias to Neocomian);

(ii) Fatula Limestones (multicoloured limestones), Upper part of Lower Cretaceous to Senonian.

IV.1. Quartzite Series

This formation (about 300 m) was observed in the median part of the Shillakong gorge; it is composed of limestones, sandy limestones sandstones and pelitic shales.

The lowest observed part shows well-bedded dark limestones of micritic or grainstone structure interbedded with micaceous sandstones. Some levels contain lamellibranches and gastropods. It is covered by brown weathering sandstones with remains of plants. In the upper part dark pelitic shales predominate with intercalations of decimetric beds of bioclastic limestones with corals and lamellibranches. No determinable faunas were found in this formation which by its position can be considered as the lower part of Upper Trias.

IV.2. Kioto Limestones

This formation (300 m) is essentially composed of well-bedded limestones with some minor shaly intercalations and very rare thin layers of sandstones. The limestones are strongly deformed, often laminated, recrystallized or dolomitized.

The lower part is formed by thicker beds with several levels containing Megalodontidae, well illustrated by Fuchs (1979). Among them can be recognized large forms of *Megalodon* type and other referable to *Dicerocardium*. In that part were observed sedimentological sequences with alternances of biomicritic beds with Megalodon, grainstones, bioturbated levels with *Thalassinoides*-type burrows and rarely stromatolitic layers, suggesting very shallow water environment. Badly preserved Foraminifers : *Involutina* cf. *sinuosa* (Weynschenk) were identified. Elsewhere were found specimens of *Heterastridium conglobatum* (Reuss) of Norian age.

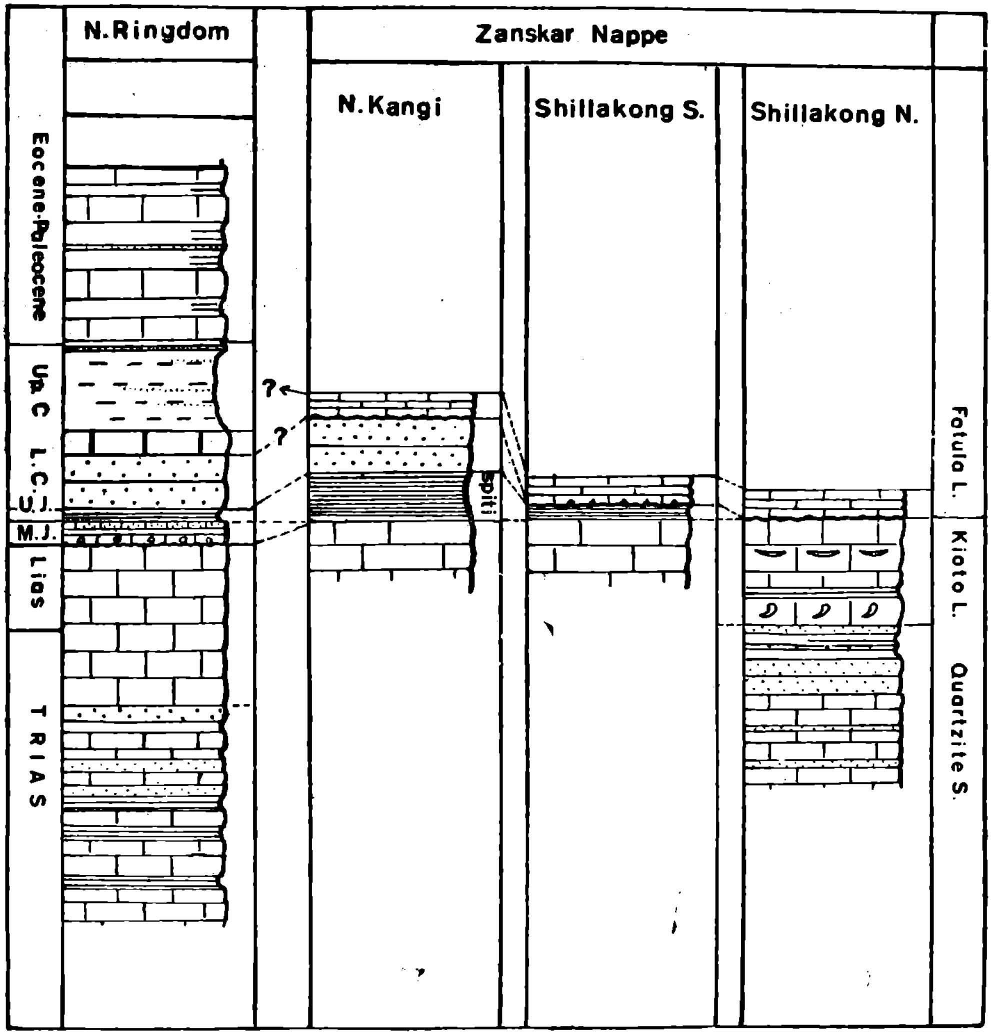

Figure 5. Stratigraphical logs of the Mesozoic series of the Zanskar-Shillakong Nappe and of the Himalayan (Tethysian) Series between Kangi and Ringdom Gompa.

The upper part is composed of well-bedded limestones with predominating grainstone texture and some intraformational breccias with a conspicuous *Lithiotis*-bearing level. Some Dasyclad algae were discovered, including *Palaeodasycladus* cf. *mediterraneus* Pia, of Liassic age. Also from this part, very deformed and poorly preserved foraminifers can be tentatively referred to *Orbitopsella* sp. (Middle Liassic).

So the available data give Upper Triassic (Norian-Rhaetian) to Liassic ages for this formation.

IV.3. Spiti Shales

This characteristic formation was observed in two places:

—In the Shillakong gorges, about 500 m just before the southern end of the narrows. It is composed of black laminated slates with stretched nodules, of relatively feeble apparent thickness (about 10 m). It rests upon the grainstones of Upper Kioto Limestones and is stratigraphically covered by the cretaceous Fatula Limestones. One specimen of Ammonite (Perisphinctidae indet), was found at the foot of this outcrop.

—In the Sangeluma Chu valley, 1 km north of Kangi village. This outcrop was firstly discovered by Fuchs (1977). In this place, Spiti shales are interbedded between Kioto Limestones and Giumal Sandstones. We also discovered several remains of Ammonites (Perisphinctacea indet) of undetermined Malm age.

IV.4. Giumal Sandstones

Giumal Sandstones were not found in the Shillakong section but only north of Kangi where they are formed by a thick succession of brown-weathered well-bedded sandstones resting upon Spiti Shales and normally covered by Fatula Limestones.

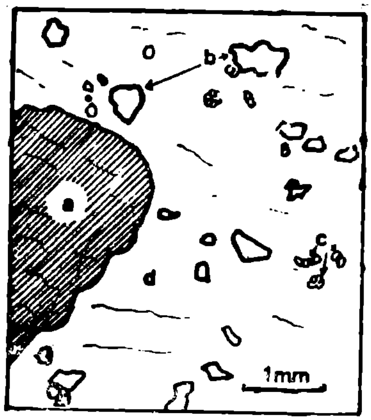

Figure 6. Microfacies of a microconglomeratic level (base of Fatula Limestone, at the southern end of the Shillakong gorges). a—Lithoclast of Spiti Shale. b—Coarse quartz grain. c—*Hedbergella* sp. d—Calcareous micritic matrix.

IV.5. Fatula Limestones (Multicoloured Limestones)

This formation consists of well-bedded fine-grained limestones with characteristic, pale green, light-grey, lie de vin colours. Its age was once considered as Triassic by Fuchs (1977) on account of resemblances of facies with Scythian-Anisian Alpine facies and this opinion was shared by Bassoullet *et al.* (1978). However, we discovered Campanian Globotruncanids in these limestones (Bassoullet *et al.*, 1978*b*) in the northern rim of the Zanskar Nappe near Fatula pass. Our study of Shillakong section confirms this attribution to Cretaceous.

The southern part of the Shillakong gorges where Fatula Limestones are in contact with the precedently described Spiti Shales is of particular interest. There, on the left bank, we found in the basal beds of the Fatula Limestones, in a light grey bed, a microbreccia with black sorted grains of sand in a micritic cement containing pelagic foraminiferal fauna. Dr. J. Sigal, who studied it, recognized *Hedbergella* sp. (cf. *rohri* (Bolli), *H.* cf. *bejouaensis* (Sigal), or *H.* cf. *trochoidea* (Gandolfi)). For him this fauna has very probably an Upper Aptian-Lower Albian age. In this place, Fatula Limestones rest upon Spiti Shales. Near Kangi the same limestones are superposed to Giumal Sandstone. In the northern end of the Shillakong gorges near Shilla, alike Fatula pass, the Fatula Limestones are in stratigraphical contact with the Kioto Limestones.

So it appears there is an unconformity below the Cretaceous Fatula Limestones which are transgressive on eroded Liassic to Neocomian formations. Many samples were collected in these multi-folded, often laminated, multicoloured limestones, some show remains of very badly preserved Globotruncanids which, for Dr. Sigal, can be ranged from Vraconian to Senonian. Hence, the presently recognized age for this formation is from probable Upper Aptian-Lower Albian to Campanian.

The mesozoic series of Zanskar Nappe has typical characters of the Himalayan Tethysian zone. However, if we compare it with the adjoining more complete Himalayan series north of Ringdom Gompa (see below), we can observe differences. The most evident is the existence of two different Cretaceous facies (Fatula multicoloured limestones and Chikkim Limestones).

V. THE EXOTIC BLOCKS

V.1. The Exotic Blocks of Lamayuru (Figs. 7a and 7b)

From bottom to top, the following lithostratigraphical succession can be observed (Fig. 7*b*).

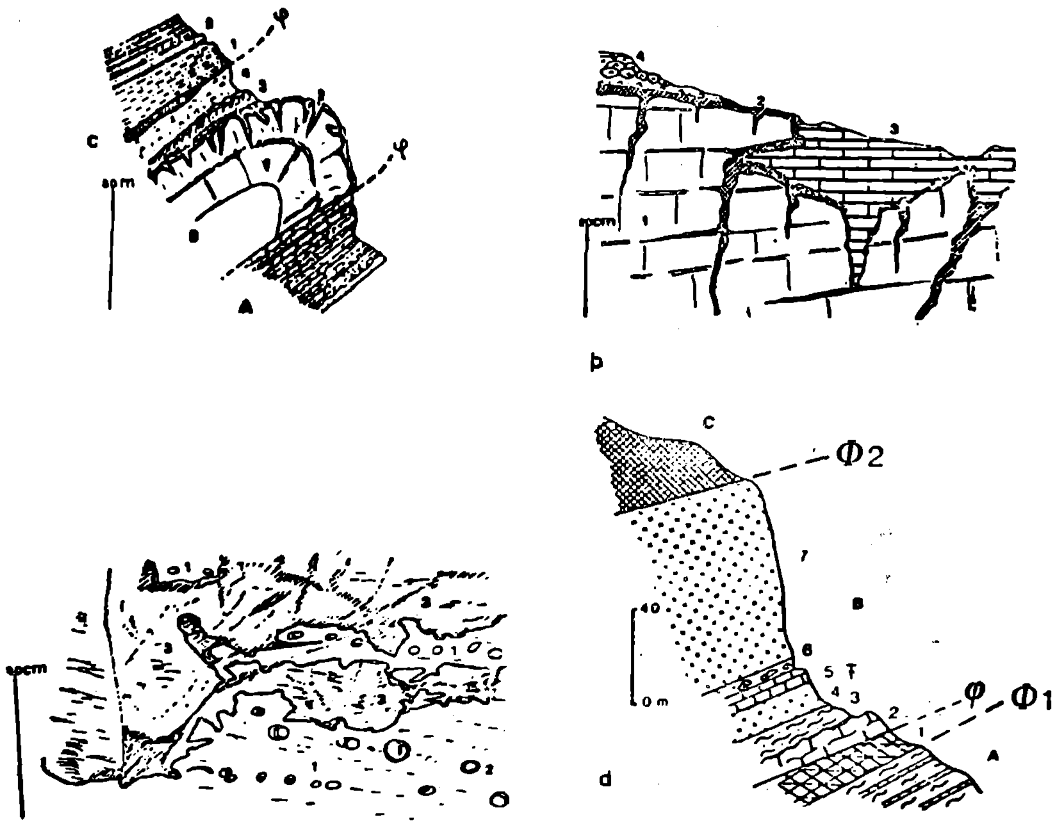

Figure 7. Exotic blocks :

7a : Cross-section of the Lamayuru exotic block. A—Lamayuru flysch in reverse position. B—Lamayuru exotic block : (1) Neritic limestones, Uppermost Permian; (2) Polymetallic crusts, neptunian dykes and pelagic lens of Lower Triassic limestone; (3) Pillow lavas and agglomerates; (4) Tuffaceous sandstone; (S) Tectonic sheet of serpentine. C—Nindam-Dras Flysch unit : (1) Tuffs and radiolarites; (2) Shales and quartzites; Φ_1 and Φ_2 tectonic contacts.

7b : Top of the Lamayuru exotic block; (1) Late Djulfian neritic limestone (*Colaniella, Paleaofusulina* biozone—det. M. Lys), (2) Polymetallic crust, (3) Lower Scythian pelagic limestone (Fauna with *Meekoceras lilangense* Kraft, *Meekoceras* aff. *discus* Waagen, . . . etc. similar to the fauna of the Lilang section (*Meekoceras* beds) in Spiti area—det. J. Guex), (4) Tuffs and pillow lavas.

7c : Cross-section of the exotic block at the base of the ophiolitic nappe (legend in text).

(*a*) Pale green or pink crinoidal limestones, 20 to 30 m thick, in decimetric beds, folded in antiform. Thin sections show structures of a biosparudite of biosparite with abundant remains of bryozoa crinoids, brachiopoda and many foraminifers and algae (Lys, 1980), index of the mesogean Djulfian :
Tubiphytes obscurus Maslov, *Gymnocodium bellerophontis* (Roth), *G. nodosum* Ogilvie-Gordon, *Mizzia velebitana* (Schubert), *Deckerella composita* Reit., *Climacammina sphaerica* Pot., *C. sumatrana* (Voltz), *Hemigordius ovatus* Gr. *H. Gr. reicheli* Lys, *Agathammina pusilla* (Gein.), *Globivalvulina vonderschmitti* Reichel, *Paraglobivalvulina mira* (Reit.), *Dagmarita chanakchiensis* Reit., *Frondina permica* S. de C. et Dess., *Ichtyolaria permotaurica* S. de C. et Des., *Neoendothyra reicheli* (Reit.), *Reichelina cribroseptata* Erk, *Nankinella orbicularia* Lee, *Codonofusiella nana* Eerk.
Occurring with very characteristic forms of the mesogean Djulfian :

Ungarella stellata Korde, *Tuberitina collosa* Reit., *Valvulinella bykowski* (Schubert) = *Abadehella coniformis* Okim. et Ishii, *Protonodosaria globifrondina* S. de C. et Des., *P. praecursor* (R. Chern.), *Nodosaria sagitta* Mik. Maklay, *Stipulina* n. gen. Lys, *Colaniella parva* (Colani), *Pararcichelina reticulata* Mik. Maklay.
The irregular corroded surface of the limestones is coated by millimetric to centimetric thick polymetallic crusts (Fe, Mn).

(*b*) Limestones or dolomitized limestones infilling neptunian sills or dykes. Some dykes could be followed laterally for several metres into the Permian limestones. One of these cavities contains an accumulation of ammonites and some fragments of volcanic tuffs. The following species were recognized (Guex *in* Bassoullet *et al.*, 1978*b*):
Meekoceras lilangense Krafft, *Clypeoceras* sp. aff. *crassus* Krafft, *Meekoceras* aff. *discus* Waagen in Krafft et Diener or *disciforme* Krafft. This fauna is very similar to *Meekoceras* beds (Lower Scythian) of the Lilang section in the Spiti region (Hyden *in* Gupta, 1975).

(*c*) Tuffs, tuffaceous standstones, submarine lava flows (pillows) and volcanic agglomerates are interbedded with dark radiolarites and red tuffaceous limestones.

V.2. The Exotic Blocks of the Base of the Ophiolitic Nappe (Fig. 7c)

Within the basal tectonic sole (tectonic melange) of the ophiolitic nappe itself, we observed:

(*a*) Without common sedimentary matrix, several small exotic blocks exhibiting various microfacies: red radiolarites, volcanodetritic microbreccias (with *Orbitolina*) sp.), metaquartzites, marmorized massive limestones of Dachstein-type affinity. A bed of this block exhibits primary contact between lavas (vesicular pillows), and red fossiliferous limestones (Hallstadt-type), in some cases poorly preserved conodonts suggest an Upper Triassic age.

(*b*) In the upper Photang river area, below the main ophiolitic unit, we have the following succession (Fig. 7*d*):

A Lamayuru flysch more and less tectonized;
Φ_1 A major overthrusting contact;
B A tectonic assemblages of numerous distinct formations:
B_1 : Highly disturbed tectonic breccia reworking elements from *A* and *B*.
B_2 : Black and grey massive limestones : algae, corals, brachiopods, etc., indicating a shallow water sedimentary environment of deposition. This limestone is highly recrystallized and gives no biostratigraphical data. At the top of the same limestone we observed a black polymetallic crust.
B_3 : Red and brown fine mudstone rich in radiolaria.
B_4 : Green tuffs.
B_5 : Red, pink and white well-bedded limestones; this highly fossiliferous horizon (ammonites) is very similar to the classical Halstatt facies. According to Dr. T. Tozer, these ammonites are of Carnian affinities. The conodont assemblage suggests a Carnian age (det. Dr. Hirsch, Geological Survey of Israel).
B_6 : In transitional contact above this upper-Triassic limestone, a first flow of massive lava and agglomeratic tuff reworking small blocks of the same pink limestone.
B_7 : About 100 m of lavas flows locally exhibiting pillow structures.
φ Major overthrusting contact.
C Schistose and highly tectonized serpentine.

In conclusion the field evidence furnished by Lamayuru exotic block and stratigraphical succession in the tectonic sole of the ophiolitic nappe (Upper Photang area) suggests that the continental rifting processes initiated at the lowermost part of Triassic (Lamayuru block) continued to the end of the Triassic (Photang area). This intra-Gondwanian continental break up is linked with the first stages of the birth of the Neotethysian oceanic basin.

VI. THE PILLOW-LAVAS FROM THE SOLE, INFRA-PERIDOTITIC METAMORPHIC SLICES AND PERIDOTITE NAPPE

VI.1. Pillow-Lavas from the Sole of the Peridotite Nappe

Tectonic slices mainly made of volcanic material and associated sediments appear under the huge Spongtang peridotite nappe all along the northern margin of the nappe.

VI.1.1. Field Description

Two types of volcanics have been observed :

—In the first type, huge blocks of pillow-lavas are associated with hyaloclastites and micritic pinkish limestones of unknown age. These blocks are widespread in the area located south of the Shillakong straits, going to the Nigoutse-La, between 4,500 and 5,000 m. The micritic limestone fills the inter-pillow spaces and penetrates into the pillows by the radial cracks, filling cavities and hollow tubes (Plate 1, fig. 5). Delicate exfoliation of the palagonitic rims of the pillows in the limestone is well visible by places (Plate 1, fig. 6). In the mylonitized base of these slices, the pillows have a pale-green colour due to development of secondary prehnite and epidote. These pillow-lavas are quite identical to those of the Dras Volcanics.

—In the second type, sub-aphyric pillow-lavas are associated with large volumes of hyaloclastic breccias (Plate 1, fig. 7) and basaltic breccias (Plate 1, fig. 8). Upper Triassic limestones are interbedded at places in the volcanic unit. The lavas are strongly deformed and recrystallized in the greenschist facies at the base of these slices, with development of epidote, quartz, chlorite and albite. This type is found just beneath the peridotites, in a large area between the Sirsir La and Photaksar.

VI.1.2. Petrographic Description

Two types of pillows have been distinguished from their petrography, besides volcanic breccias :

—The first type is quite alike the Dras pillows, except the better 'freshness' of olivine which underwent lesser alteration. Abundant clinopyroxene-plagioclase clusters are met in all the samples (Plate 3, fig. 3). Clinopyroxene is always fresh, but plagioclase is very often sericitized. Clinopyroxene (endiopside-augite) cannot be distinguished from the Dras one. Here, alteration minerals consist of chlorites, pumpellyite, sphene, albite, calcite, clinozoisite, and in more roughly tectonized pillows, vesicles are filled with prehnite or epidote.

—The second type is restricted to pillows associated with triassic limestones. Their petrography is quite different. Pillows are mostly microlitic, subaphyric, with some vesicles. Microlites or rare phenocrysts consist only of calcitized plagioclase which do not form clusters, and there is no clinopyroxene in most pillows, except in some volcanic agglomerates where it has the same composition as in Dras pillows. Vesicles are filled with chlorite and opaque minerals, just as the groundmass; veins may be filled with epidote and calcite (Plate 3, fig. 4).

VI.2. Infra-Peridotitic Metamorphic Slices

We have not observed these rocks *in situ*, but several blocks of amphibolites and metaquartzites found just at the base of the peridotite nappe suggest that, as in most ophiolitic complexes in the world, such metamorphic slices exist only beneath the peridotites.

(i) Dynamometamorphic para-derived schistose quartzites, strongly microfolded, of red-pink colour. Cleavage is marked by muscovite and opaque minerals. Some quartzitic veins also contain epidote. Other metamorphics seem to be at least partially ortho-derived since one finds abundant clinopyroxene relicts associated with sphene in a quartzitic martix.

(ii) Amphibolites are the mesozonal metamorphics. They have a nematoblastic texture, the hornblende prisms being very homogeneous in size (0.5-1 mm). Plagioclase is severely sericitized, forming locally stretched phenoblasts. Some chlorite may form masses (Plate 3, fig. 5).

VI.3. The Peridotite Nappe

VI.3.1. Field Description

The huge mass of the peridotites is the highest tectonic unit. Most of our observations come from the highest part of the Yapola valley, where the northern front of the peridotite nappe is easily accessible.

The peridotites are generally fresh and form as pectacular cliff several hundreds of metres high (Plate 2, fig. 1). All along the cliff, the peridotites are mainly made of foliated harzburgites (Plate 2, fig. 2), with a foliation plane dipping strongly eastwards. A discrete layering is often visible, due to variations in the OPX-OL ratio. The foliation plane is mostly sub-parallel to the layering, but may intersect it at high angle (Plate 2, fig. 3). Dunitic

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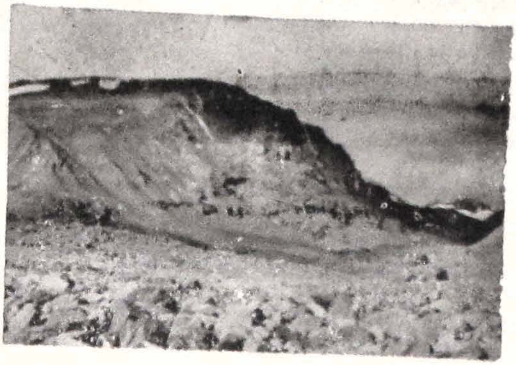


2

3



4

5



6

Plate 2. **The Peridotite Nappe.** 1—General view of the front of the peridotite nappe, at the northern margin of the Spontang-Photaksar klippe, in the high Yapola valley. 2—Outcrop of fresh tectonites (harzburgites) at the base of the peridotite cliffs, in the high Yapola valley. 3—Relationships between the layering (S_0) and the foliation (S_1) in the harzburgites Block in the Yapola river. 4—Schlieren of massive chromite in fresh harzburgites, deformed and flattened in the foliation plane (S_1) (High Yapola valley). 5—Block showing a gabbro-pegmatite disk in the harzburgites, highly deformed by plastic flow. Foliation in the gabbro is parallel to the foliation in the harzburgitic host-rock (high Yapola valley). 6—Isolated diabase dyke in the harzburgites, with a chilled margin at the contact (high Yapola valley).

masses occur in the harzburgites : their structural relations with the harzburgites appear to be complex, and they present schlierens of massive chromite flattered in the foliation plane (Plate 2, fig. 4). Clinopyroxene is scarce (1-2%), but appears as large crystals in some areas where it can represent 8-9% of the rocks (lherzolites). Isolated dykes of pyroxenites (coarse-grained enstatitites and Websterites), of gabbro-pegmatites (some of them plastically deformed as the harzburgitic host-rock) and fine-grained diabases with chilled margins appear at several places. Some evidences of *in situ* partial melting have been found in some dunitic areas, where interstitial plagioclase appears.

VI.3.2. Petrographic Description

(A) Tectonites

Most of these are harzburgites, whose modol analysis (3000 pts./thin section) gives the following average mineralogical composition: Orthopyroxene—30-33% (most enstatite); Olivine—63-67.5%; Clinopyroxene—1.3-1.8% (diallage); Chromite—0.8-2.6%.

Texure is typically porphyroclastic. Olivine phenoclasts are always stretched, show kink-bands and an undulose extinction; small olivine sub-grains have recrystallized from phenoclasts, showing triple junction at 120°. Enstatite phenoclasts are less stretched than olivines, but show numerous kink-bands, and sigmoidal deformed cleavages. Very often, clinopyroxene occurs as exsolution lamellae in these cleavages (Plate 3, fig. 8). Enstatite may be poecilitic with respect to olivine. Brown-red chromite grains are generally xenomorph to subautomorph. The harzburgites are very fresh; nevertheless, in some samples, talc begins to form, specially around phenoclasts.

Up to now, only one serpentinized iherzolite could be determined, containing 8.5% clinopyroxene.

Many dunites have a porphyroclastic texture; these are also tectonites. They are conspicuously fresh. The olivine phenoclasts show kink-bands; they are set in a mortar groundmass of olivines or by small recrystallized olivines with triple junction (Plate 3, fig. 7). In these dunites, some rodingitized plagioclase n sts indicate *in situ* partial melting (Plate 3, fig. 6).

(B) Dykes

GABBRO. The gabbro dykes are tectonized and rodingitized. The only relicts are clinopyroxene (diallage) and orthopyroxene, both strongly kinked. Tremolite appears in the cleavages of diallage, and small orthopyroxenes with triple junction grow from the megacrystals. These are not stretched, but they are set in a pyroxene mortar matrix.

PYROXENITES. Websterite dykes are found in serpentinized dunite. Clinopyroxene (diallage) poekiloblasts contain olivine and orthopyroxene (hypersthene) which also take place in its cleavages. Some chromite is found at the dyke margin. Tectonized orthopyroxenites dykes cut across harzburgites; orthopyroxenes show numerous kink-bands, where tremolite is quite often located.

VI.3.3. Diabase Dykes

The diabase dykes are found in serpentinites, and develop a chilled margin. In the margin, some veinlets contain abundant and very pure Grossular crystals, with probably prehnite. The core of the dyke shows the ophitic texture, where clinopyroxene and hornblende are associated with altered plagioclase.

VII. THE HIMALAYAN (TETHYSIAN) MESOZOIC AND CENOZOIC SERIES

The Tethysian Series were studied along a crossing of Zanskar from Kangi to Ringdom Gompa and around

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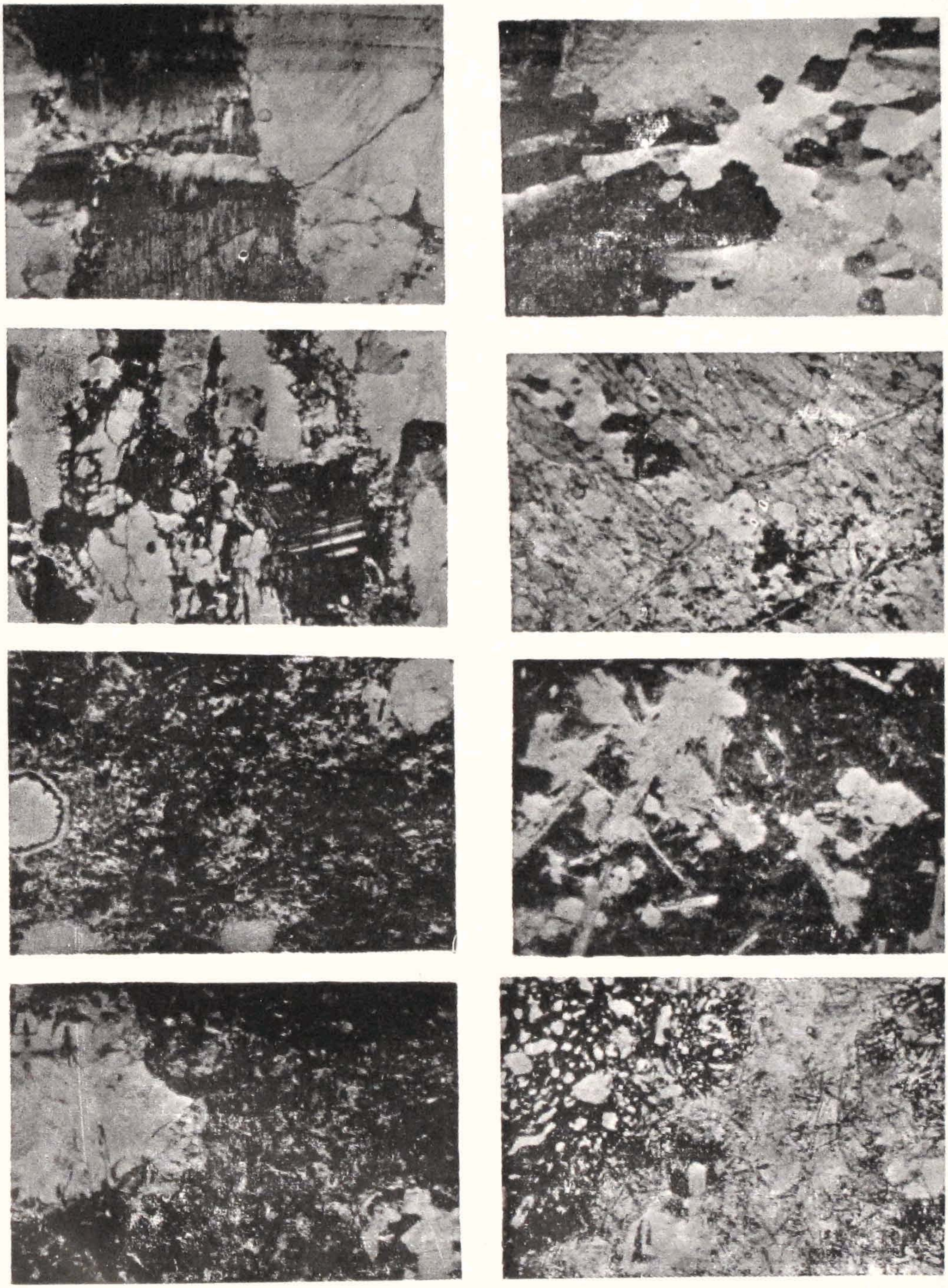
Plate 3. 1—OL 79 27 (PL) : Dras pillow showing vesicular 'pustules' in a fine-grained matrix showing euhedral olivine with glassy inclusion and quenched clinopyroxens. 2—OL 79 28 (CP) : Dras pillow showing vesicles filled with quartz (upper left corner) and pumpellyite-albite (right corner). 3—OL 79 44 (PL) : 'Dras-like' pillow from the infra-peridolitic slice showing the typical cluster features (Plag-CPX). 4—OL 79 110 (PL) : Aphyric pillow of Triassic age with a microlitic and vesicular texture. The vesicules are filled with chlorite and opaques. 5—OL 79 130 (PL) : Amphibolite from the infra-peridotitic slices showing nematoblastic texture. 6—OL 79 76 (CP) : Interstitial plagioclase crystals in a porphyroclastic Dunite : evidence of *in situ* partial melting. 7—OL 79 75 (CP) : Porphyroclastic dunite showing olivine with kink-bands and sub-grains with triple junction. 8—OL 79 80 (CP) : Harzburgite showing a kinked orthopyroxene with clinopyroxene exsolution lamellae and olivine (right of OPX) with kink-bands.

All pictures are at the same scale. Their width represents 3.5 mm. PL means polarized light. CP means crossed polarisors.



1 2
3 4
5 6
7 8

Plate 3

the village of Kangi (Dumbur, Chomo river valley).

The oldest formations outcrop North of Ringdom Gompa and the youngest one (Kangi La Formation) on the both sides of the Kangi La pass. First data about these series were precedently brought by Fuchs (1977, 1979) and more partially by Metzeltin and Nicora (1977), Gaetani *et al.* (1980) and for Ringdom by Nanda and Singh (1976).

North of Ringdom, above the Panjal Traps (Upper carboniferous-Lower Permian) and dark metamorphosed calcschists and phyllites correlated with the Middle-Upper Permian Zewans of Kashmir (Fuchs, 1979), begins the thick mesozoic succession, strongly metamorphosed at its lower part.

VII.1. Zangla Formation (Nanda and Singh 1976) (about 500-700 m)

The lower part is composed of alternances of blue-grey limestones, pelitic shales, calcschists. In the limestones, micritic texture predominates with some lumachellic levels.

In the upper part alternate dark limestones, grey shales and calcschists interbedded with thick intercalations of pale crystalline limestones and sandstones, sometimes with ripple-marks.

Various microfacies were found in the limestones : micrite, biosparite or oosparite, and some intraformational breccias. A calcschist yielded undeterminable *Pteriidae* (cf. *Monotis* ?) of Triassic aspect. Only poorly preserved lamellibranchs and gastropods were observed.

This formation can be connected with the 'Lilang System' of Spiti and contain, more eastward, Lower-Middle and Upper Triassic fossils (Nanda and Singh, 1976).

VII.2. Kioto Limestones

Dark-grey well-bedded limestones (beds several decimetres thick) . . . about 300 m.

Prevalent microfacies are grainstones with oolitic or oncolitic elements and bioclastic limestones with remains of echinoderms, lamellibranches, gastropods and serpulids. Minor micritic beds were also observed.

Some levels show the same tectonically deformed burrows of *Thalassinoides*-type as in the Kioto Limestones of the Shillakong serie.

By correlation with the Shillakong Serie, this formation can be considered as Upper Triassic to Lower Jurassic (up to Lower Dogger ?). The upper surface of the last bed is covered by a ferruginous coating, which probably indicates a break of sedimentation.

VII.3. 'Ferruginous Oolite' (30 m)

The following sequence can be observed from bottom to top. :

(*a*) Sandy ferruginous limestone with ferrugineous oolites and belemnites (2.5 m)—(chloritized oolites);
(*b*) Grey silty shales (20 m);
(*c*) Fine-grained sandstones with ocre weathering (5 m);
(*d*) Bioclastic sandy limestone with ferruginous ooids (Hematite) and fossils (*Belemnites*, Lamellibranchs and crinoids) (3 m).

This facies is well-known in several regions of Himalaya (Spiti, Kumaun, Nepal) and by correlation can be dated as Callovian.

VII.4. Spiti Shales

Black slates . . . 20-30 m (Upper Jurassic).

VII.5. Giumal Sandstones . . . about 200 m

Coarse to fine sandstones with brown weathering and some subordinate blackish silty intercalation.

At 4 m below the top can be observed a slight unconformity; a conglomeratic level with black centimetric pebbles of sandy silts and some *Belemnite* remains above an eroded surface (Lower Cretaceous).

VII.6. Chikkim Limestones

Whitish-grey limestones in pluridecimetric or metric beds . . . (40 m).

Microcrystalline structure by recrystallization showing outlines of Globotruncanid foraminifers. The passage with the Giumal Sandstones is gradual at the bottom. *Belemnites* were found in the 8 lowermost metres.

The age of these limestones can be considered as Cenomanian to Senonian by comparison with the Spiti region. It agrees with the ctiation by Fuchs (1979) of *Globotruncana* ex gr. *lapparenti* (Turonian-Santonian).

VII.7. Kangi La Formation (Fig. 8)

Thick formation of shales, brecciated or fine-grained limestones, sandy limestones, sandstones . . . more than 100 m.

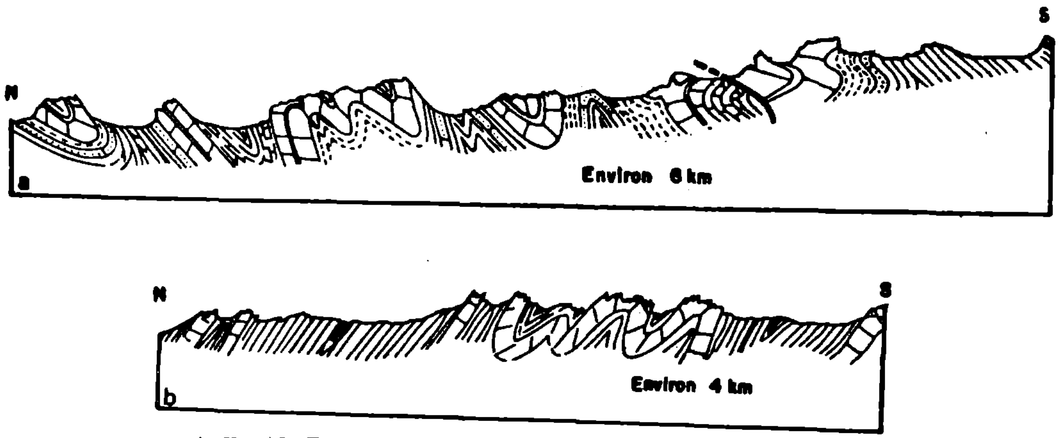


Figure 8. Sections across the Kangi La Formation : a—between Kilchu and Kangi (Sangeluma Chu and Kong river valleys). b—in the Chomo valley.

Fuchs (1977) introduced the name of Kangi Flysch for the southern part of the outcrop of this thick-folded formation on both sides of the Kangi La pass. But it appears that the limestones between Kilchu and Kangi La, and south of Dumbur wrongly attributed by this author to Kioto Limestones and Quartzites Series are interbedded in the upper part of the same formation.

From bottom to top the succession can be resumed as follows :

(*a*) Pale grey shales with sandy beds observed above the Chikkim Limestones along the Spumboth Chu, South of Kangi La (about 100-200 m). (Probably Upper Cretaceous before Upper Maestrichtian.)

(*b*) Sandstones and brown weathered sandy limestones, interbedded with shales (about 15 m). In the limestones north of Kangi La were found :

Omphalocyclus macroporus Lmk
Siderolites calcitrapoides Lmk
(Upper Maestrichtian.)

These key horizons were first discovered by S. Metzeltin and Nicora (1977) and described in detail by Gaetani *et al.* (1980).

(*c*) Alternance of thick dark sometimes brecciated limestones (generally some tens of metres thick) with grey, reddish or greenish pelitic shales and rare beds of sandstones (total : several hundreds of metres). Besides Paleocene and Eocene microfaunas already mentioned by Italian authors (Metzeltin and Nicora, 1977; Gaetani *et al.*, 1980)' Lower Eocene association were found, particularly :

(*i*) *North of Kangi La*

—Biomicrite with *Nummulites atacicus* Leymerie *Alveolina* sp. (elongated form) Upper Ilerdian with a reworked pebble with *Siderolites* sp. (Upper Cretaceous).

—Biomicrite with *N.* ex gr. *atacicus* Leymerie globular and elliptical Alveolinas, *Miscellanea miscella* D'Archiac et Haime, *Distichoplax* biserialis (Dietr.).

(Middle to Upper Ilerdian).

(*ii*) *South of Dumbur*

At about 500 m south of Dumbur an anticline structure in the black limestones is cut by the Chomo valley. Along the river, on the left bank, the vertical beds shows a section of about 50 m on each flank, with alternance of decimetric or metric beds and interstratified breccias composed of black sharp-shaped elements of micritic limestones and cherts, with nummulites.

The microfacies are biomicrite or biosparite with foraminiferas. Three samples have given characteristics faunas :†

(i) *Alveolina* sp.,
Glomalveolina sp.,
Opertorbitolites sp.,
(ii) *Nummulites* gr. *deserti* La Harpe
Miscellenea miscella d'Archiac and Haime
Alveolina sp.
Miliolids
(Lower Ilerdian)
(iii) *Nummulites* gr. *globulus* Leymerie
Alveolina sp. (elliptical form)
(Lower Ilerdian)
On the same anticline, on the right bank :
(iv) *Nummulites* gr. *globulus* Leymerie
Nummulites sp. (more primitive form)
Assilina sp.
Ranikothalia sp.
(Lower to Middle Ilerdian)

At about 2 km upstream, in the Chomo valley, samples originated from more southern cliffs contain :

(i) *Ranikothalia* sp., *Miscellanea miscella* d'Archiac et Haime (Upper Paleocene)
(ii) *Glomalveolina* sp., *Alveolina* sp. *Orbitolites* sp. (Lower Ilerdian).

VIII. TECTONIC

The complex structure of the Indus zone in Ladakh has resulted from the superposition of several tectonic events described below.

VIII.1. The Different Structural Units

VIII.1.1. The Himalayan Group

This group (Plate IV, fig. *b*) shows metamorphic series (Tibetan slab), including Upper Palaeozoic formations and sedimentary, slightly metamorphosed, Mesozoic and Cainozoic series; these are characteristic of Himalayan facies (Tethys or Tibet Himalaya in literature). Two major tectonic events are the cause of major structures:

(*a*) the oldest one (H1) shows large south-recumbent folds with regional cleavage and epimetamorphism; to the south the regional cleavage merges into the metamorphic foliation of the Tibetan slab,
(*b*) the second one (H2) shows north-recumbent or asymmetric folds, associated with a regional fracture cleavage.

† Determinations by A. Blondeau

Plate 4. a—South of the Shillakong-Zanskar Nappe (on left) and the west part of the Ophiolitic Npppe (on right) : 1 and 3—Cretaceous Fatula Limestone; 2—Lamayuru Flysch; 4—*Sole* of the Ophiolitic; 5—Ophiolitic Nappe.
b—Fold in the Himalayan Series south of Kangi La : 1—Giumal Sandstone. 2—Chikkim Limestone.
c—Hangru Synform : N—Nindam Flysch; Lm—Lamayuru Flysch; Φ—thrust; S_3—second generation fracture cleavage (parallel to fold axial plans of synform); S_1—first generation cleavage.

a

b

c

Plate 4.

VIII.1.2. The Lamayuru Nappe

This nappe is formed of flysch-like series with calcareous olistolites; the age ranges from Middle Triassic to Middle Jurassic; the formation are epimetamorphic and like as in the Zanskar unit (see below) four tectonic phases are known; the unit is entirely reverted and thrusted above the Himalayan Tertiary and Cretaceous.

VIII.1.3. The Nindam Nappe

This nappe (Plate IV, fig. *c*) shows quartzitic and greywacke flysch of Cretaceous age, interfingering with volcanites (Dras Volcanics); on the southern side it is wedged (sandwiched) between the Lamayuru and the Ophiolitic nappe, on the southern side it appears thrusted above the Cretaceous-Tertiary Indus detritics.

VIII.1.4. The Zanskar-Shillakong Nappe

This nappe (Plates V and VI : fig. 9) shows a Mesozoic (Trias to Upper Cretaceous) epimetamorphic series; there are some analogies with the Himalayan Mesozoic, particularly well-expressed in the Jurassic and the Lower Cretaceous; but also important differences in the unconform Upper Cretaceous; four generations of structures are characteriz d :

(*a*) the oldest one (*Z*1) shows a southward recumbent isoclinal folding associated with a regional cleavage and epimetamorphism;
(*b*) to the second one (*Z*2) belong northward asymmetric folds and a second cleavage;
(*c*) the main characteristics of the third one (*Z*3) are planes of shearing and thrusting and a flat lying fracture cleavage; the southern thrust above the Lamayuru nappe belongs to this phase;
(*d*) the last phase *Z*4 is responsible for the synformal northward asymmetric buckling of the whole nappe.

VIII.1.5. The Ophiolitic Nappe

This nappe (Plate IV, fig. *a*) shows various facies of an ophiolitic assemblage (particularly harzburgites with metamorphic tectonic fabric, volcanic-pillow lavas and agglomerate, and metamorphic rocks) lying on a complex tectonic sole (serpentinites, triassic volcanites, slices of Nindam Flysch or of Zanskar Nappe); the nappe is thrusted above the Lamayuru unit and the Himalayan zone.

On the other hand, there exist various serpentine zones (melange zones) sometimes associated with radiolaritic or calcareous (Permo-Trias of Lamayuru) blocks; they are interspersed in many tectonic contacts (between Zanskar and Lamayuru nappes northern contact, between Nindam and Lamayuru nappes . . .); one of these serpentine zones separates the northward thrusted Nindam unit and the Cretaceous Tertiary Indus detritics.

VIII.1.6. The Indus Detritics

The detritics lie unconformably on the Laddakh Granitoids, form a thick molassic complex of Cretaceous to Eocene age deformed by northward asymmetric folds (phase I 1) accompanied by a fracture cleavage, and cylindric folds (phase I 2); the granitoids represent an Andean-type magmatic belt of Cretaceous and Eocene age; the oldest magmatic facies give reworked pebbles in the Upper Aptian-Albian conglomerates; the last phase (I 3) is characterized by a NOOO to NO3O fracture network; also well-developed in all the other units, they are open and vertical and sometimes show a short left lateral motion pattern.

VIII.2. Chronology of the Tectonic Events (Fig. 10)

In the absence of disconformities, although it is difficult to determine precisely the age of the deformation, yet it may be possible to establish a tentative chronology. In the Kangi area (Fig. 9) field observations show that

Plate 5. a—South contact of the Zanskar-Shillakong Nappe. 1—Cretaceous Fatula Limestone; 2—Lamayuru Flysch; 3—Eocene beds with nummulites; 4—Sheet of Fatula Limestone. b—Details of Photaksar escarpment. Example of refolding fold; S_0-S_1. Schistosity and stratification; S_2. Second generation fracture cleavage (strain slip).

Plate 6. a-b—Refolding in the Fatula Limestones in the Southern end of Shillakong gorges. S_0-S_1. Stratification and schistosity; S_2. Second generation fracture cleavage (strain slip); S_3-S_4. Third and fourth generation fracture cleavage.
c-d—Isoclinal fold in the Kioto Limestones along the Shillakong river (Zanskar-Sh llakong Nappe). Same legend as for a-b.

a

b

Plate 5.

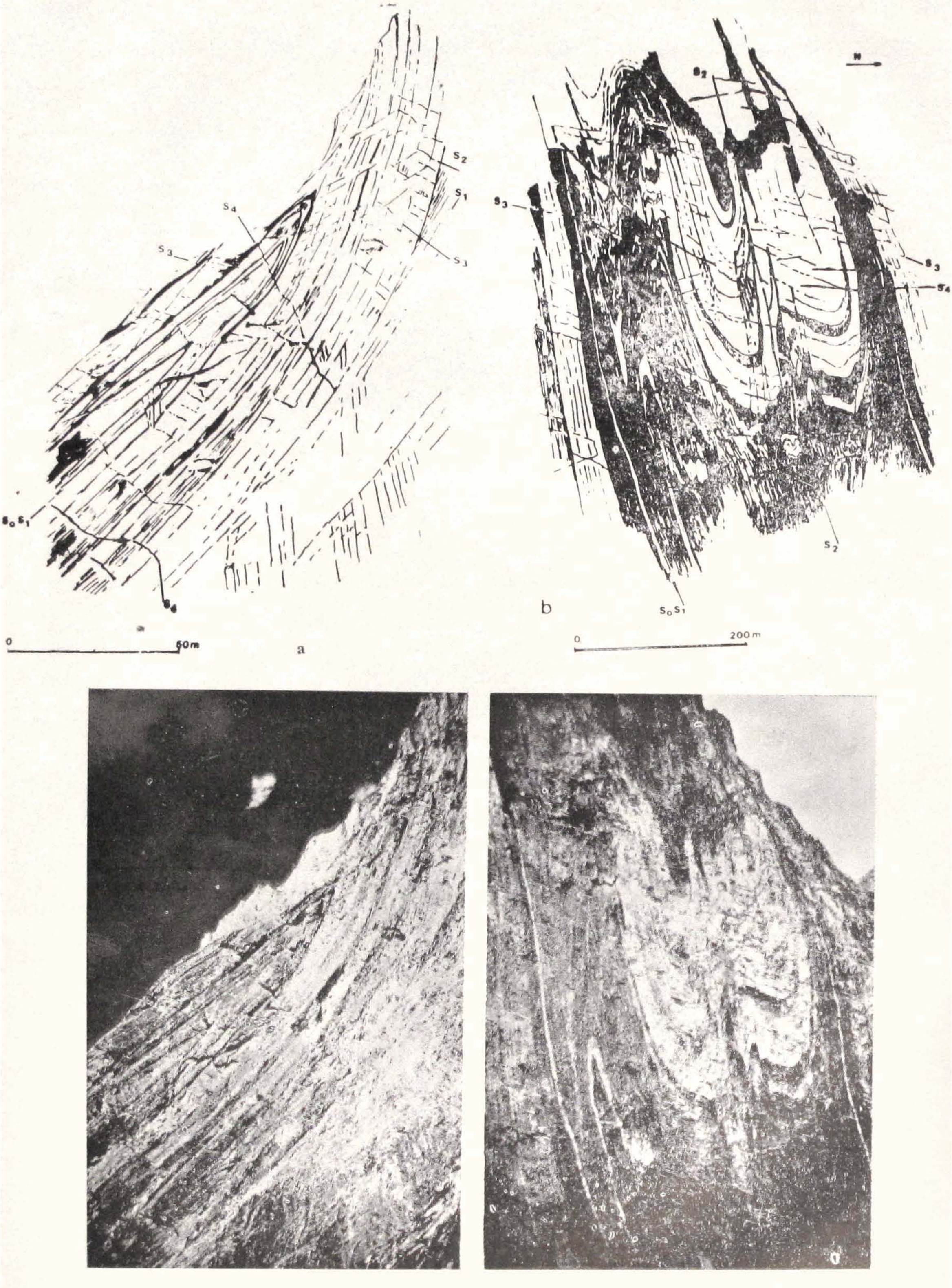


Plate 6.

the last deformation of the Zanskar Nappe (Z 4) corresponds to the last structures of the Himalayan Series (H 2). Near Hangru (Plate IV, fig. C) one observes that the tectonic contact between the Lamayuru and Nindam nappes

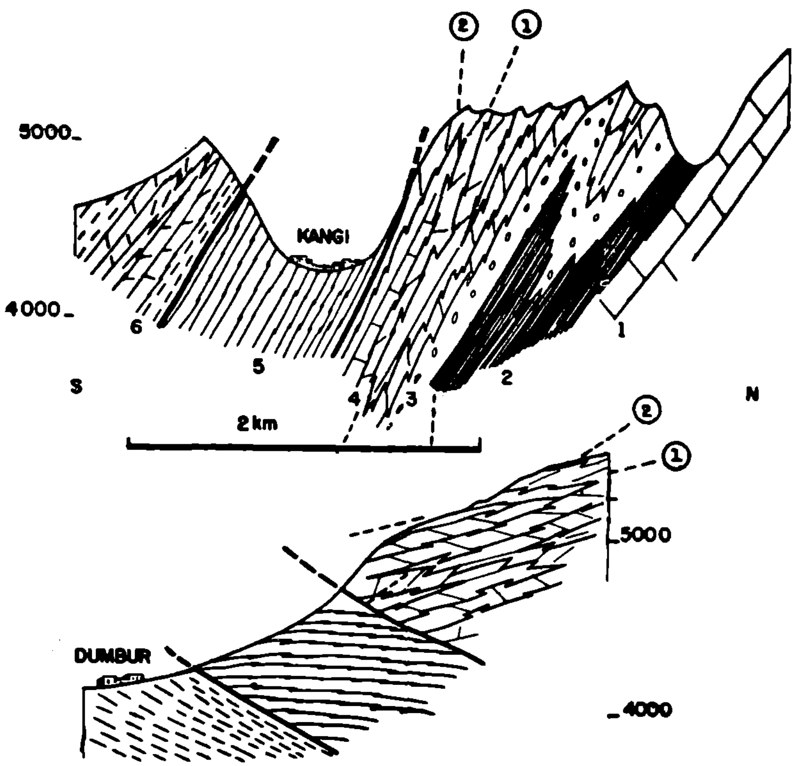


Figure 9. Two structural sections in the Kangi area. 1 to 4—Zanskar Nappe (1 : Upper Triassic to Lower Jurassic limestones and marbles = Shillakong Limestones; 2 : Upper Jurassic slates = Spiti Shales; 3 : Lower Cretaceous quartzites = Giumal Series; 4 : Upper Cretaceous calcshists = Fatula Limestones). 5—Lamayuru Nappe (Upper Triassic to Middle Jurassic flysch). 6—Himalayan Series, Upper Cretaceous slates Kangila Formation.

is nearly parallel to the first cleavage (Phase L1 = N1 = Z1) and cross-cutted by the second one (Phase L2 = N2 = Z2); one observes also that this second cleavage of the nappes is first present in the Indus detritics (Phase I1). Results are summarized as follows :

(*a*) Phase Z1 (= L1 = N1) : Southward recumbent folds, thrusting, epimetamorphism in the Zanskar and Lamayuru nappes;
(*b*) Phase Z2 (= L2) = I1 : Northward refolding of the nappes, first structures in the Indus detritics;
(*c*) Phase Z3 (= L3) : Southward shearing of the structural edifice;
(*d*) Phase Z4 (= L4) = H2 = I2 : Northward retrodeversement.

Structures of Phase Z2 affect the Upper Cretaceous, structures of Phase I1 affect the Middle Eocene. It remains to establish in this sketch the position of the first Himalayan (H1) event. There are two possibilities :

(i) H1 = Z1; the similarity in the style of the structures favours this hypothesis; there exists only one metamorphic event but two zones of culmination are needed (Zanskar and Lamayuru nappes are more metamorphic than the Upper Cretaceous and Tertiary of Himalayan Series); the whole tectonic should be post-Middle Eocene.
(ii) H1 = Z3; there is a normal and continuous decrease in the intensity of the structures from Tibetan Slab to Zanskar Nappe; the metamorphism of Zanskar and Lamayuru nappes should be slightly older than

that of Himalayan Series; the Z1-phase can be pre-Middle Eocene. This hypothesis seems to us more convenient.

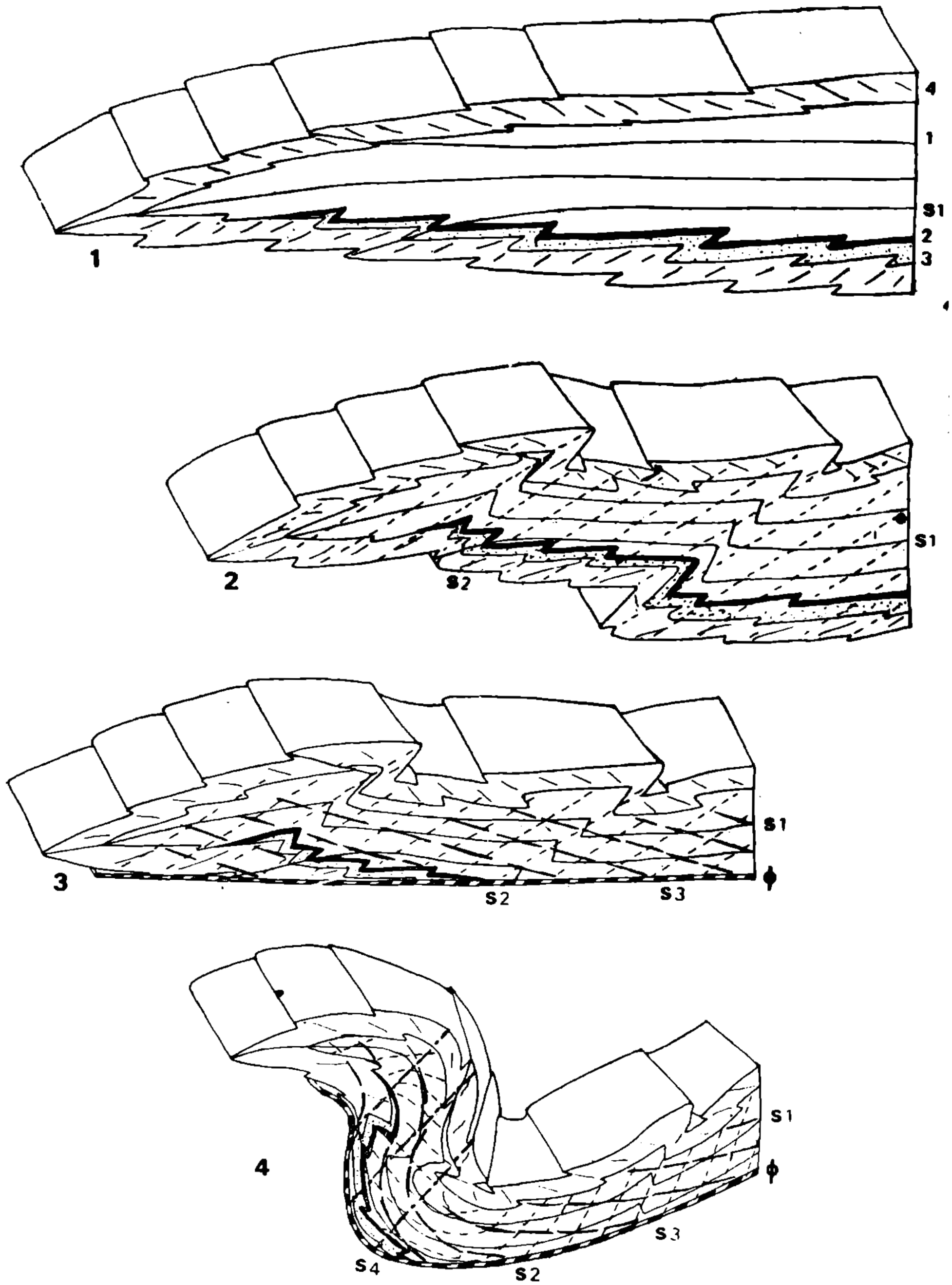


Figure 10. Sketch of the superposition of deformations in the Zanskar Nappe. 1—Upper Triassic to Liassic Shillakong Limestones. 2—Upper Jurassic Spiti Slates. 3—Lower Cretaceous Giumal Quartzites. 4—Upper Cretaceous Fatula Calc-schists. *S1*, *S2*, *S3* and *S4* = Cleavage related to the superposed deformations (*S1*—metamorphic regional cleavage, *S2* and *S3*—strain slip to fracture regional cleavages, *S4*—fracture local cleavage).

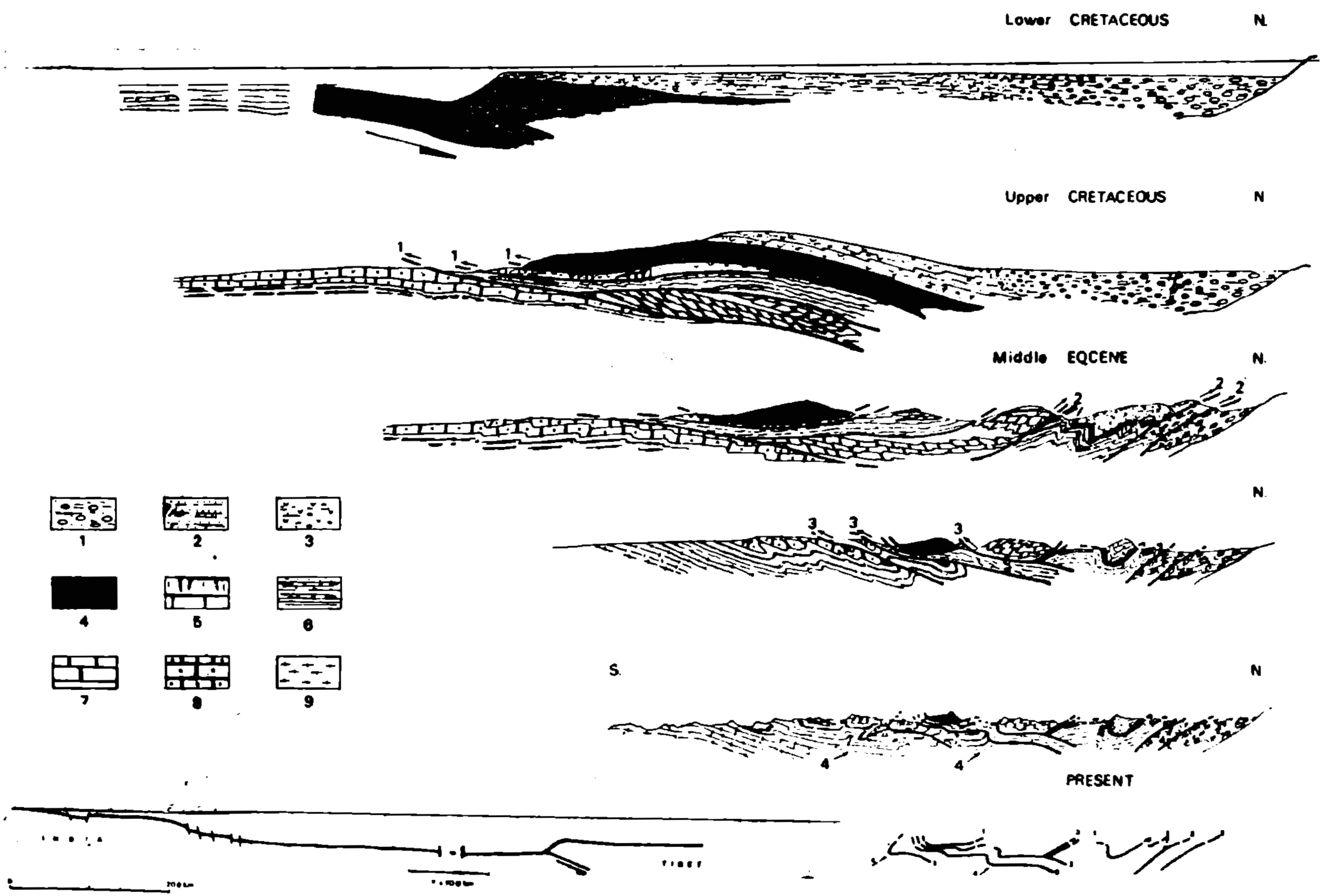


Figure 11. Interpretative geodynamic evolution of the Indus Suture Zone, in sections 1, 2, 3 and 4 representing four phases of structural evolution. 1—Indus Formation. 2—Nindam Formation. 3—Dras Formation. 4—Ultrabasic rocks. 5—Exotic blocks of the sole of the Ophiolitic Nappe. 6—Lamayuru Flysch. 7—Mesozoic Zanskar-Shillakong Nappe Formations. 8—Himalayan (Tethysian) Formations. 9—Metamorphics.

One must recall here also that the occurrence of magmatic pebbles in conglomerates as old as Upper Aptian-Albian in age are evidences of magmatic and orogenic events older than phase-Z1.

IX. CONCLUSION

During Cretaceous time the evolution is classical of an active margin on the northern side of the Tethyan Ocean. The southern margin, or Gondwanian margin, remains still a passive, or Atlantic margin. The Indus detritics figure as the sedimentary furrow of a fore-arc basin; the arc itself is shown by the Ladakh batholite. Between Late Cretaceous, tectonized in the Zanskar unit, and Middle Eocene, the collision occurs between India and Eurasia. The resulting structures are complex. The first phase is characterized by south-vergent structures in the Zanskar, Lamayuru, Dras-Nindam and Ophiolitic nappes. The second phase is north-vergent and well-documented in the Indus detritics, the Zanskar, Lamayuru and Dras-Nindam nappes. In the third phase of strengthening, the whole structural edifice is affected; this phase is contemporaneous with the M.C.T. motion and the main metamorphic event in the High Himalayan range. In the last phase, the strengthening becomes maximal; the preceding units and tectonic contacts are folded or refolded in north-vergent structures. So the actual fan-shaped structure is interpreted to have resulted from the superposition of four main structural events alternatively south-vergent and north-vergent which represent the structural adaptation to the continuous northward drift of India, the continuous collision or *undamped collision*.

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Permian Brachiopod and Bivalve Zones in the Himalaya of India and Nepal

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INTRODUCTION

THE PRESENT contribution is a supplement to the paper already published by the authors (Waterhouse and Gupta, 1977) wherein an attempt has been made to fit the Permian rocks and faunas of the Himalaya into the world pattern of stages. In this paper, we propose to synthesize the data published till date on the Permian biostratigraphy of the Himalaya through the discussion of faunal zones.

Eurydesma Zone

This zone is well-developed in the basal part of the Nagmarg Formation of the Agglomeratic Slate Succession of Kashmir at Bren Spur. *Eurydesma* of the *E. hobartense* lineage is the most characteristic form found within this zone at Bren in association with the bivalves *Deltopecten* and *Myonia* and brachiopod *Tomiopsis*. This zone lies just above the Golabgarh Boulder Formation.

The *Eurydesma* Zone is of late Asselian age and is correlative with the extensive *Eurydesma* faunas of Gondwana, ranging from the *Eurydesma* beds in the Speckled Sandstone of Salt Range, Pakistan, and the *Eurydesma* fauna found at the base of the *Tomiopsis* Stage in Wardak, Afghanistan and comparable faunas of Argentina, South Africa and Australia. The occurrence of *Eurydesma* has recently been recorded from several sections exposed in different parts of Spiti valley (Waterhouse and Gupta, 1982).

Taeniothaerus (Reedoconcha) permixtus Zone

The upper units of the Nagmarg Formation exposed in the Bren Spur, Kashmir have yielded diverse fauna represented by *Aperispirifer*, *Tomiopsis*, *Cyrtella* (or *Punctocyrtella*) *nagmargensis* and abundance of *Taeniothaerus permixtus*. Similar faunas are also known to occur in the Marbal valley and other areas of Kashmir (Bion, 1928, Reed, 1932). The stratigraphic units between the *Eurydesma* Zone and the *Taeniothaerus* (*Reedoconcha*) *permixtus* Zone have yielded large number of poorly preserved bivalves. Due to their indeterminable nature, it is not possible for the time being to classify these beds into any definite biostratigraphic zone. The *Taeniothaerus* (*Reedoconcha*) *permixtus* Zone is essentially of mid-Sakmarian (Sterlitamakian) age.

The fauna similar to that of *Taeniothaerus* (*Reedoconcha*) *permixtus* Zone is also known to occur in the Tramwala Formation of Bhallesh Group in Kishtwar and Katargali Formation. The recently discovered fauna from the Boulder Slate Sequence of Bijni Tectonic Unit exposed near Jogira and Dogadda in Garhwal also corresponds to this zone. The brachiopod fauna from this locality includes a member of the Strophalostinae, and *Cancrinella* and, of most importance, a species allied to *Spirifer narsahensis*, described earlier from the Umaria Marine Bed of Peninsular India (Reed, 1928). According to the present authors, fauna from Garhwal includes ***Brachythyrinella*** cf. ***narsahensis***, ***Archnaelosia***, ***Cancrinella*** cf. ***farlayensis*** and ***Deltopecten*** allied to ***mitchelli*** points

TABLE 1—PERMIAN BRACHIOPOD AND BIVALVE ZONES OF THE HIMALAYA IN INDIA AND NEPAL

International		*Himalayan*	*Typical genera*	*Typical area*
Stage	*Substage*	*Zone*		
Dorashamian	Ellesmerian and Gangetian	*Ophiceras and Otoceras*	*Claraia*, *Ophiceras*, *Otoceras*, *Glyptophiceras*	Panjang Khola, NW Nepal Guryul Ravine, Kashmir
	Ogbinan	*Atomodesma variabile*	*Glabrichonetes*, *Atomodesma*	NW Nepal, Kashmir
	Vedian	*Marginalosa kalikotei*	*Rugaria Megasteges Cancrinella Pondospirifer*	NW Nepal
Djulfian	Baisalian	*Krotovia arcuata*		NW Nepal
	Urustenian	*Pyramus silicius*	*Permophorus*, *Schizodus Bellerophon*, *Retispira* spp.	Kashmir, NW Nepal
Punjabian	low-mid. Chhidruan		*Waagenoconcha Costiferina*, *Anidanthus Spiriferella Fusispirifer* spp.	Lower Zewan Fm
	Kalabaghian	*Lamnimargus himalayensis*		Kashmir
Kazanian	Sosnovian			
	Kalinovian			
Kungurian	Ufimian			
	Irenian			
	Filippovian			
Baigendzinian	Krasnoufimian	*Retimarginifera*	*Derbyia*, *Juresania*	Ladakh
	Sarginian			
Sakmarian	Aktastinian			
	Sterlitamakian	*Reedoconcha permixtus*	*Taeniothaerus*, *Punctocyrtella Tomiopsis*	Bren Spur Kashmir
	Tastubian	*Stepanoviella Brachythyrinella*	*Neochonetes Subansiria Tomiopsis*	Bijni, Garhwal, Umaria
Asselian	Kurmaian	*Eurydesma*	*Myonia*, *Tomiopsis*	Bren Spur, Kashmir
	Uskalikian			
	Surenan			

Note. 'Typical genera' refers to species and generic abundance, not to restricted generic ranges.

to a Sakmarian age and is correlative with the upper Nagmarg Formation of Kashmir and Umaria Marine Beds of Peninsular India.

The *Brachythrinella* fauna of Garhwal is slightly older than the *Taeniothaerus* (*Reedoconcha*) *permixtus* Zone of

Kashmir and is correlative with the *Stepanoviella* faunas of Afghanistan, Peninsular India, and Beckett Shale of Western Australia and Mount Jolmo Lungma region (Waterhouse and Gupta, 1979). As such the *Taeniothaerus* (*Reedoconcha*) *permixtus* Zone is restricted to the upper part of the Nagmarg Formation, and is separated from the *Eurydesma* Zone by rather nondescript faunas at Bren spur that may be found to match the *Brachythyrinella* faunas of Garhwal, fauna from the Umaria Marine Bed of Peninsular India and Mt. Jolmo Lungma of Mt. Everest region.

The Sarchu Limestone of Ladakh has yielded fusulinid fauna in association with *Juresania*. The occurrence of *Triticites, Pseudofusulina* and *Schwagerina* is suggestive of an early Permian age for this limestone. Similarly the occurrence of *Schwagerina princeps* has also been recorded from the limestone units in the lower part of the *Gangamopteris* Beds of the Zewan Formation.

Retimarginifera Subzone

The limestone intercalations within the Ralakung Volcanic Succession exposed in the Luneak valley of Zanskar, Ladakh have yielded a well-preserved but poor fauna which may belong to this subzone. The fauna includes *Derbyia, Plicatifera, Juresania, Retimarginifera, Reticularia* and *Cleiothyridina*. This fauna has close similarity with the fauna from the lower Amb Formation of Salt Range, Pakistan through *Cleiothyridina semiconcava* (Waagen) which is suggestive of Baigendzinian age. This is also supported by the approach of *Retimarginifera* to *R. perforata* (Waterhouse) from Baigendzinian (but also Kungurian) Byro Group of the Carnorvon Basin in Western Australia. *Juresania* is closely similar to *J. juresanensis* (Chernyschev) from the Sakmarian Stage in the Urals. The fauna from this zone is probably of Baigendzinian age but the possibilities of its being of Sakmarian age cannot be ruled out.

Lamnimargus himalayensis Zone

This zone is fairly wide spread in the Himalaya and is typified by faunas of the lower Zewan Formation of Kashmir. The characteristic fossils from this zone include *Neochonetes vishnu* (Salter), *Waagenoconcha gangeticus* (Diener), *Lamnimargus himalayensis* (Diener), *Costiferina alatus* Waterhouse, *Anidanthus fusiformis* Waterhouse, *Spiriferella rajah* (Salter), *Neospirifer moosakhailensis* (Davidson) var. *ambiensis* (Waagen), *Fusispirifer nitiensis* (Diener) and *Hoskingia latouchei* (Diener). Similar faunas are also known to occur in the Talai Formation of Kishtwar; Salooni Formation of Chamba; Kuling Shales of Spiti and Kinnaur, Sarchu Limestone of Ladakh, Productus Shales of Byans; Kringkrong Limestone and Kuling Shales of Kalapani-Kuti sections of northeastern Kumaun; Lachi Group of Sikkim, Productus Shales of the Black Mountain area of Bhutan, Selung Group of South Tibet and the Nangung Formation of Namlang Group of West Nepal. The exotic blocks of Chitchun No. 1 and Malla Sangcha in South Tibet may possibly belong to this zone.

The *Lamnimargus himalayensis* Zone is correlated with the Punjabian Stage as is exemplified by the Kalabagh Member and lower-to-middle Chhidru Formation of the Salt Range, Pakistan.

Pyramus silicicus Zone

The Popa Member of the Senja Formation in northwest Nepal has yielded fauna including *Permophorus* and *Schizodus* corresponding to this zone. Similar fauna also occurs within the beds lying just above the *Lamnimargus himalayensis* Zone. These beds correspond to Zewan faunal division III in two stratigraphic members of Nakazawa *et al.* (1975). The lower member (Zewan Member C) is characterized by the presence of *Cyclolobus walkeri, Anchignathodus typicalis* Sweet and *Neogondolella carinata* Clark. The upper member (Zewan Member D) contains *Anchignathodus typicalis* Sweet and *Ellisonia triassica* Muller, *Xenodiscus* sp. and molluscan assemblage including *Bellerophon blandfordianus* (Waagen), *Retispira ornatissima* (Waagen), *Permophorus* cf. *subovalis* (Waagen).

The *Pyramus silicicus* Zone is of basal Djulfian age and belongs to the Urushtenian Substage.

Krotovia arcuata Zone

This zone is represented within the Pija Shale Member of the Senja Formation in northwest Nepal and is characterized by the presence of *Krotovia* and other brachiopod species.

The *Krotoria arcuata* Zone is of Upper Djulfian age and corresponds to the Baisalian Substage.

Marginalosia kalikotei Zone

This zone is represented in the Nisal, Nambdo and Luri Members of Senja Formation of Dolpo region in northwest Nepal and characterized by a suite of fossils including *Marginalosia kalikotei* Waterhouse and several species of *Cancrinella, Neospirifer, Spiriferella, Hoskingia*, etc. No correlative faunas corresponding to this zone have so far been reported from other parts of the Himalaya. This zone is of lower Dorashamian age and belongs to Vedian substage.

Atomodesma variabile Zone

This zone is represented within the uppermost units of the Senja Formation in northwest Nepal and contains chonetid fauna dominated by *Atomodesma variabile* Waterhouse. Similar faunas are also possibly found with the faunal division IV of Nakazawa *et al.* (1975) within the Zewan Formation of Kashmir.

This zone is of middle Dorashamian age and belongs to Ogbinan Substage. It matches the *Paratirolites* beds of Armenia, Iran and Madagaskar.

Claraia-Otoceras-Ophiceras Zonal Complex

The faunas from the beds overlying the *Atomodesma variabile* Zone have traditionally been placed at the base of the Triassic period due to the complete absence of the Palaeozoic brachiopods from the beds yielding *Otoceras* and *Ophiceras*. However, in recent years several papers have been published recording occurrence of Permian brachiopods in association with *Otoceras* and *Ophiceras* in Kashmir (Nakazawa *et al.*, 1975) with *Otoceras* in northwest Nepal and several other localities (Waterhouse, 1972, 1973). *Otoceras* is a member of a family which is uniquely of Permian age. Kozur (1974) on the basis of conodonts and other studies, Newell (1973) on the basis of bivalvia, and Waterhouse (1972, 1976) on the basis of brachiopods have argued that the *Otoceras* beds at least are essentially of Permian affinity.

The fossiliferous beds corresponding to this zone are well represented in the topmost part of the Zewan Formation in Kashmir (Zewan faunal division IV of Nakazawa *et al.*, 1975 and Lamellibranch Zone of Diener, 1900). This zone is about 2.6-metres thick in the Guryul Ravine Section and 3-metres thick in the section exposed north of Barus.

The beds overlying the *Atomodesma variabile* Zone in Nepal are represented by 2-metres thick carbonate succession forming base of the Panjang Formation and containing *Otoceras concavum* at the very base which, in turn, is overlain by beds with numerous ammonoids with various forms of brachiopods including chonetids, productids and '*Crurithyris*' s.l. having Permian affinity. This is again followed by 6-metres thick horizon of red and green calcareous shale containing ammonoids in association with Permian-type Productida and the carbonate beds overlying these have yielded 'Smithian' (or mid-Scythian) ammonoid and brachiopod fauna.

Otoceras-Ophiceras bearing carbonate beds in the Tibetan Zone or other parts of Himalaya (including South Tibet) lie directly above the Kuling/Productus Shales or Selang Group with the *Lamnimargus himalayensis* Zone. In these areas the *Marginalosia kalikotei* and *Atomodesma* Zones are entirely missing and so there appears to be a sharp faunal break encouraging placement of the Permian-Triassic boundary at the base of *Otoceras* Beds. In fact, the base of the Smithian Substage, as defined by Tozer (1967) is just as distinct, and it does not contain any of the Permian-type brachiopods or conodonts that are found in the beds yielding *Otoceras*.

Bhatt *et al.* (1981) have recorded the occurrence of late Permian condonts *Gondolella orientalis* and *G. subcarinata* in the *Otoceras* Beds of Spiti.

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Geological Observations in the Eastern Zanskar Area, Ladakh Himalaya

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ABSTRACT

East of the Zanskar river (Ladakh), the Indus Suture Zone separates the north Indian border nappes of Gondwana from the peri-Gondwana elements of Trans-Himalaya. During geological investigations between the Indus and the Tsarap, we have found 4 major tectonic subdivisions :

—the Ladakh and molasse units north of the suture zone;
—the suture zone with Dras-Nindam and Markha units, the last one being correlated with the Lamayuru nappe of Bassoullet *et al.* (this volume);
—the Nimaling-Tso Morari metamorphic unit (northern Crystalline) with Langtang overlying metasediment group;
—the Zanskar units comprising four units of Tethyan sediments and the southern Crystalline with its palaeozoic metasedimentary cover.

New data on the stratigraphy and the structures on this partly unexplored area are given.

I. INTRODUCTION

Geological observations between the upper Indus valley and the Tsarap east of the Zanskar river have shown the following structural units :

1. the Ladakh unit comprising the Ladakh batholite and the autochtonous molasse;
2. the allochthonous molasse and flysch unit,
3. the Dras-Nindam unit;
4. the Markha unit;
5. the Nimaling-Tso Morari complex unit;
6. the Zalung Karpo unit:
7. the Khurna unit;
8. the Zumlung unit;
9. the Zangla unit;
10. the Ringdom-Phugtal unit (part of the high Himalayan slab).

Very few geological studies were concerned with the whole of the area except Stoliczka (1865) and Lydekker (1880, 1883). Dainelli (1935) gives some indications on the Markha valley and more recently Pal *et al.* (1979) studied the molasse belt, south of Leh. We present here the first geotraverse from the Zalung Karpo La to Zangla, and the different units are studied along a crossing from Martselang on the Indus to Tungri on the Doda. A complete geological report would be given in French by Baud *et al.* (in preparation).

II. THE UNITS NORTH OF THE SUTURE ZONE

The Ladakh Unit

Many recent studies have analysed the Ladakh batholite and its autochthonous sedimentary cover (cf. Frank *et al.* 1977; Sharma *et al.*, 1979; Pal *et al.*, 1979; Srikantia *et al.*, 1980). The transgressive levels of the molasse on the meta-granodiorite were recently illustrated by Frank *et al.* (1977, Figs. 3, 4, 8) and by Sharma *et al.* (1979, Figs. 8, 9, 10). The age of this transgression is now still in dispute, Upper Aptian for Bassoullet *et al.* (this vol.), Cenomanian for Srikantia *et al.* (1980), Senonian for Dainelli (1935) and Mio-Pliocene for Pal *et al.* (1977). We have no new data on this unit.

The Allochtonous Molasse and Flysch Unit

This unit is thrusted northward on the autochthonous molasse (Basgo-Upshi Thrust of Pal *et al.* 1979). In the area between Indus and Markha valley, we recognise nine lithological subdivisions (2-6 in Fig. 2, description in Baud *et al.*, in preparation). The Hemis (2) and Stok Kangri (5) formations are conglomertic (conglomerate layers rhytmically repeated) with limestone pebbles containing Nummulite (post-Early Eocene). In the area of Gongmaru La, a red, continental molasse (6) with rain and birdfoot prints caps this allochthonous molasse and flysch unit.

III. THE SUTURE ZONE UNITS

The following two units form the suture zone s.s. outcrop on the right flank of the Markha valley :

(i) The Dras Nindam Unit

This composite unit (7 in Fig. 2) comprises :

(*a*) flyschoid sediments with calc-schists and volcanic microbreccias;

(*b*) polygenic coarse breccias with volcanics, radiolarites and brecciated carbonates with large foraminifera (Nummulites?);

(*c*) coloured melange with ultramafics and exotics.

Well-developed W of the Zanskar river, this unit disappears eastward and does not reach the upper part of the Markha valley (Fig. 1). The contact with the molasse belt consists of a major thrust locally with numerous ophiolite lenses (3 in Fig. 1).

(ii) The Markha Unit

All along the right flank of the Markha valley we have a flysch unit (8 in Fig. 2) with highly deformed marble boulder blocks and limestone lenses. We think that the calcareous schists with boudins of dark marble reported by Kelemen *et al.* (in press) north of Chilling on the Zanskar river correspond to the Markha flysch. This flysch is bounded by deep angle faults from the Dras and Nimaling adjacent units. The microfacies of the limestone lenses consist of recrystallised peloides-ooides skeletal packstones to grainstones. Often graded, these elements are resedimented from an adjacent shelf. One thin section shows a rich microfauna with calcareous algae and *Lucasella cayeuxi* (Lucas) indicating an early Dogger age (det. R. Wernli). This new data is significant in that it enables us to correlate this unit with the Lamayuru flysch recently described by Bassoullet *et al.* (1981). These authors have found the same microfauna in lenses of allodapic limestones near Lamayuru. Thus we can state the great extension of the Triassico-Jurassic flysch along the suture zone and the structural and paleogeographical importance of this unit.

IV. THE NIMALING COMPLEX UNIT

This unit is made of a crystalline gneissic basement, with metagranite intrusives in a cover of sedimentary quartzites and dolomites. In tectonic contact, a thick metasedimentary series of calcareous schists, grits and shales (the Langtang Group, 9 in Fig. 2) can be observed.

(i) The Crystalline

It is a domal body of metagranite and gneiss outcrops in the SE part of the upper Markha valley (3 in Fig. 3). We have found three major types of rocks :

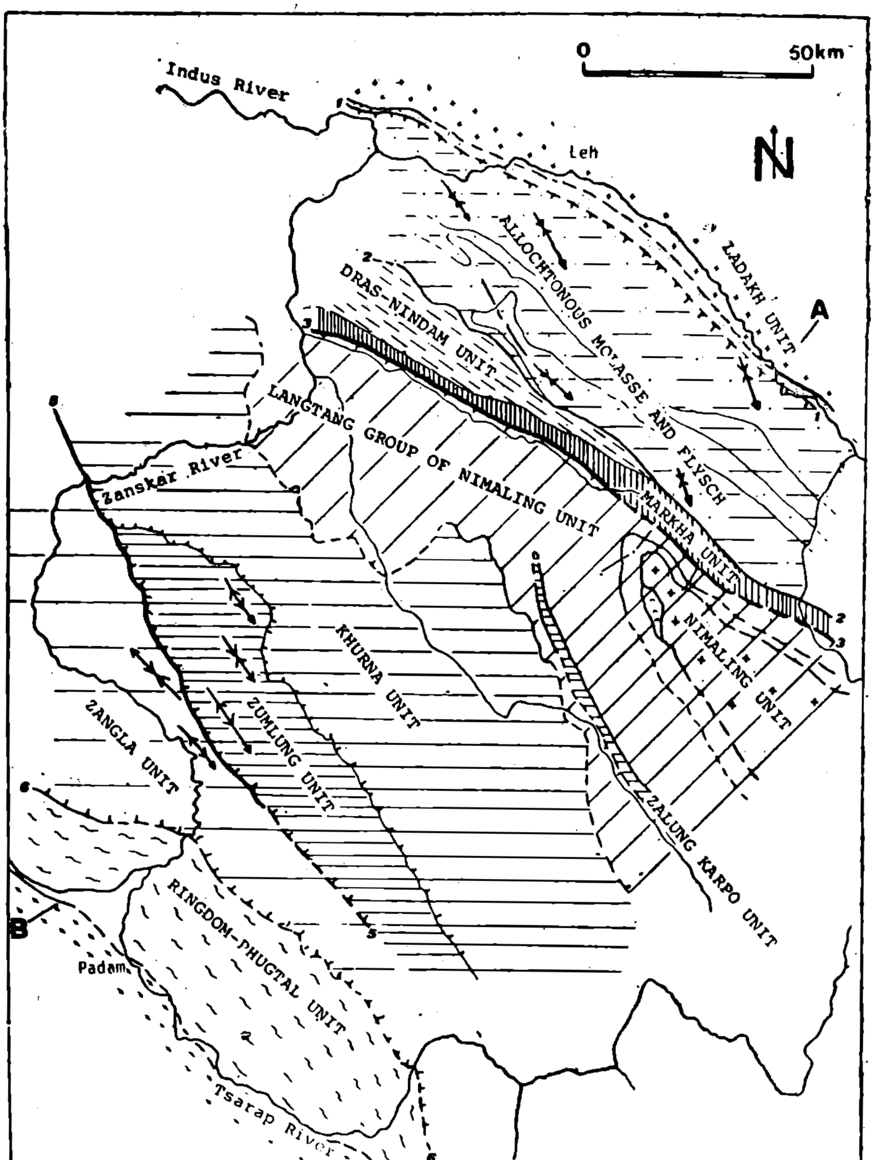

Figure 1. Structural sketch map of the eastern Zanskar. A-B : location of the structural cross section of Fig. 2. 1—Basgo-Upshi Thrust. 2—Kanda La-Gongmaru La Thrust. 3—Skiu-Lato fault. 4—Nimaling-Langtang Thrust. 5—Zangla Thrust. 6—Thonde-Phugtal Thrust.

(*a*) banded gneiss that we correlate with the Puga Formation of Sah (1980);
(*b*) metagranite intrusive with pegmatitic apophyses that we correlate with the Polakongka La Granite of Sah (1980);
(*c*) metabasic rocks in the western part of the massif.

(ii) The Metasedimentary Cover

Quartzites and dolomites with granitic veins and apophyses overlie the crystalline, the relationship between the intrusive and the metasediments being shown in Fig. 4.

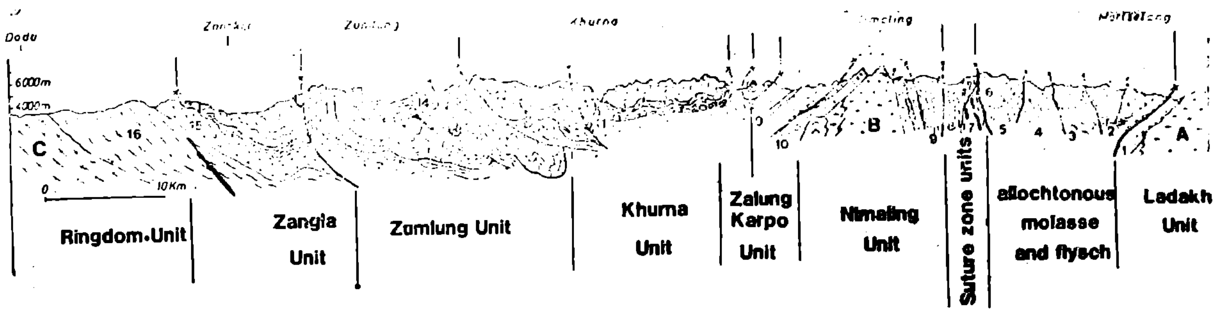

Figure 2. General cross-section through eastern Zanskar from Martselang to Tungri. A—Ladakh (Transhimalayan) batholite. B—Nimaling Crystalline. C—Great Himalayan (Central) Crystalline. 1—Autochthonous molasse. 2—Hemis conglomerates. 3—Sumdo red molasse. 4—Chogdo Flysch. 5—Stok Kangri conglomerates. 6 - Gongmaru-La continental red molasse. 7—Dras-Nindam Series. 8—Markha Flysch. 9—Langtang meta-sedimentary group. 10—Quartzite and dolomite series. 11—Lilang Group. 12—Kioto Group. 13—Spiti and Giumal Formations. 14—Chikkim Formation and (?) Kangi La Flysch. 15—Panjal Traps. 16—Phe Formation.

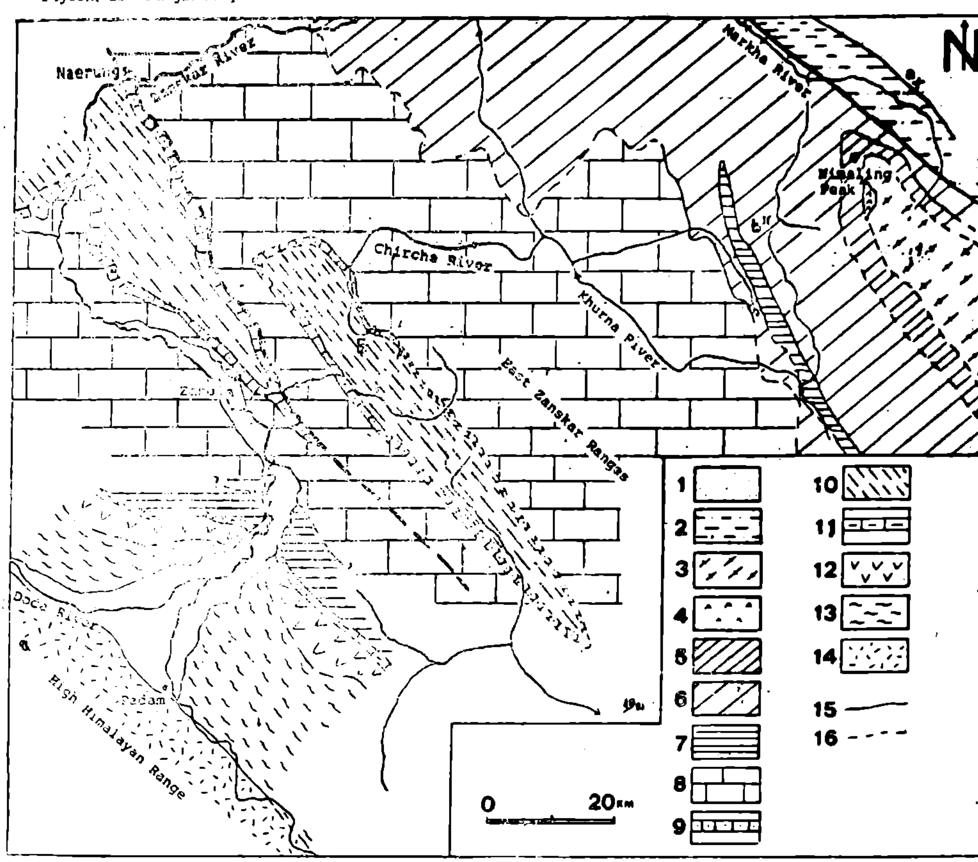

Figure 3. Geological sketch map of the eastern Zanskar, SW of the Markha valley. 1—Gongmaru-La continental red molasse. 2—Markha Flysch with lower Dogger Limestones lenses. 3—Nimaling Crystalline : gneisses with intrusive meta-granite. 4—Nimaling basic massif. 5—Meta-quartzite and dolomite serie. 6—Langtang meta sedimentary group (Upper Palaeozoic ?, mesozoic?) 7—Part of the Lilang Group (Lower to Upper Trias). 8—Kioto Group (Uppermost Trias-Lower Dogger). 9—Spiti Shales and Giumal Sandstones (Upper Jurassic-Lower Cretaceous). 10—Chikkim Limestones and(?) Kangi La Flysch (Upper Cretaceous). 11—Supra Panjal Traps shales (Zewan Formation(?) of the Upper Permian). 12—Panjal Traps (Upper Carboniferous(?)-Lower Permian). 13—Phe Formation (Lower Palaeozoic(?)). 14—Great Himalayan Crystalline (Suru Formation or central gneisses.) 15—Geological or structural line, observed. 16—Geological or structural line, ERTS deduced. a—Gongmaru La; b—Zalung Karpo La; c—Chirche La.

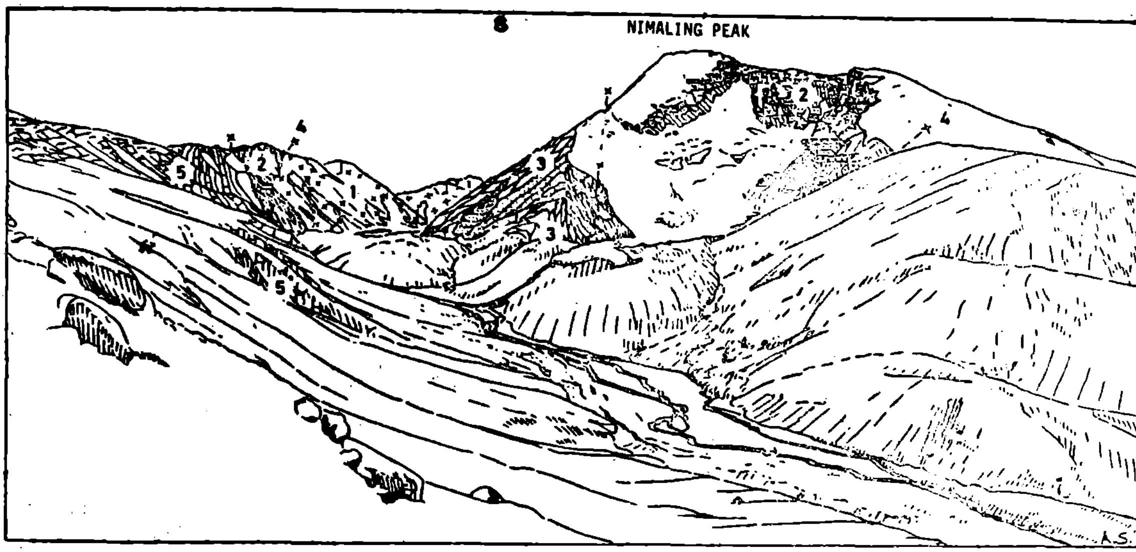

Figure 4. The Nimaling Peak area from the north. 1—Nimaling meta-granite. 2—Meta-quartzite with rare dolomitic beds. 3—Dolomitic marble. 4—Post-metamorphic fault. 5—Basal part of the Langtang meta-sedimentary group.

(iii) The Langtang Group

In tectonic contact with the underlying quartzites and dolomites, this metasedimentary group plays an important structural role as shown in Plate I and Fig. 1. About 3 km-thick, this group is formed by at least five formations (Fig. 5). The almost total lack of fossils does not allow us to give an age, nor to accept or reject the Upper Palaeozoic age given eastward along the Leh-Manali road by Gupta *et al.* (1970). This group outcrops along the left flank of the Markha valley from the Nimaling massif to the Zanskar river. We interpret the metasediment accompanied by a sudden increase in metamorphic grade reported by Kelemen *et al.* (in press) along the Zanskar river as corresponding to Langtang Group, and not to Kioto or younger formations. West of the river, we think that the Langtang Group disappears under the Shillakong nappe of Bassoullet *et al.* (this volume). Vertically exposed in the Markha valley (root zone), this group envelops the Nimaling Massif and southwestward underlies the Zanskar units (Plate I).

V. THE ZANSKAR UNITS

On crossing the mountain ranges between the pass of Zalung Karpo and the village of Zangla in the Zanskar valley, we were surprised to discover several tectono-morphological units consisting of Tethyan sediments ranging from early Triassic to late Cretaceous.

(i) The Zalung Karpo Unit

This unit overlies the calc-schists of the Langtang Group and outcrops directly southwestward of the Zalung Karpo La-Yar La pass zone. The strong deformation of the whole of the calc-schists sequence does not allow the determination of the nature and the exact position of the base contact. In the lower part of the unit, the presence of *Posidonia* sp. and *Claraia* sp. (det. B. Gruber) indicates an early Triassic age. In the upper part, corals, limestones and dolomites were found (see profile in Fig. 6). We correlate this series with a part of the Lilang Group of Spiti (Stoliczka, 1865).

(ii) The Khurna Unit

This strongly folded unit is composed of Kioto Limestones about 1500m-thick. The basal part consists of braun weathering limestones and shales of the upper Lilang Group where two Ammonoidea were found : a Tibe-

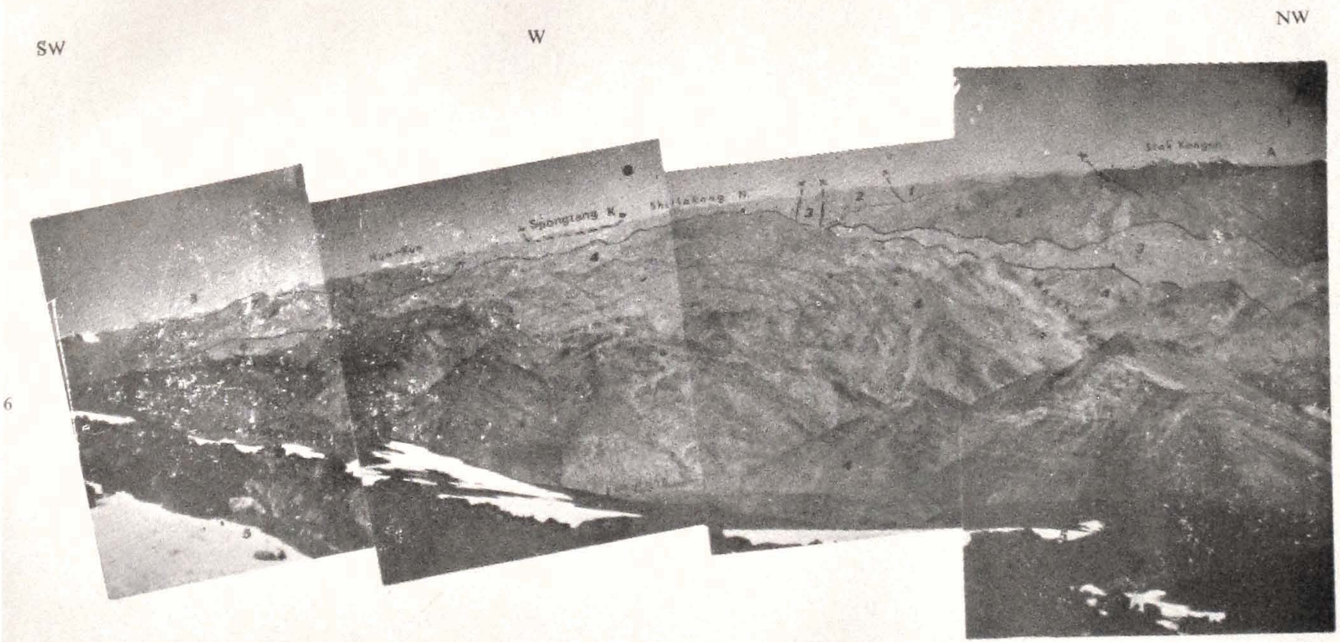

Plate I. Panoramic view of the suture zone, the Nimaling and Zanskar units westward of the Nimaling Massif. A—Ladakh Range. B—Great Himalayan Range. 1—Stok Kangri molasse. 2—Dras-Nindam unit. 3—Markha unit. 4—Langtang Group of the Nimaling unit. 5—Quartzite of Nimaling. 6—(On the right) Zalung Karpo unit. 7—Khurna unit.

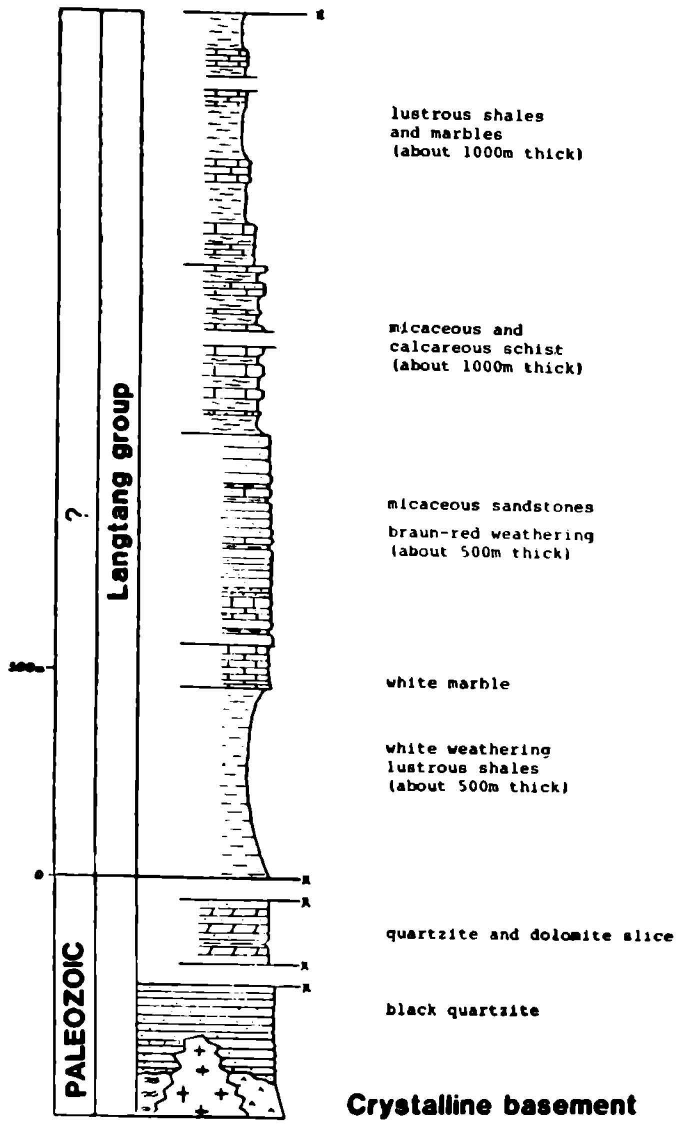

Figure 5. Lithologic column of the Nimaling unit.

tide and *Bihatites bihatiensis* (Diener, 1923) of the Subcolombianus zone (Alaun II, upper Norian, det. F. Tatzreiter). Directly above, the massive Kioto Limestone begins with coral limestones containing *Heterastidium* sp. (basal Rhetian). The Kioto Group is subdivided into two formations (Fig. 7) : the Para Formation with the Megalodons limestones and the Tagling Formation with the Lithiotis limestones (cf. Gupta, 1976) in the lower part and the Belemnite beds in the upper part. Between the two formations there occur emersive levels, locally with palaeokarstic features. Westward, this unit crosses the Zanskar river (Kelemen *et al.* in press) and forms the Zanskar-Shillakong Nappe of Bassoullet *et al.* (this volume).

(iii) The Zumlung Unit

Crossing this unit, we were surprise to discover in the upper Chirche valley a late Jurassic to late Cretaceous

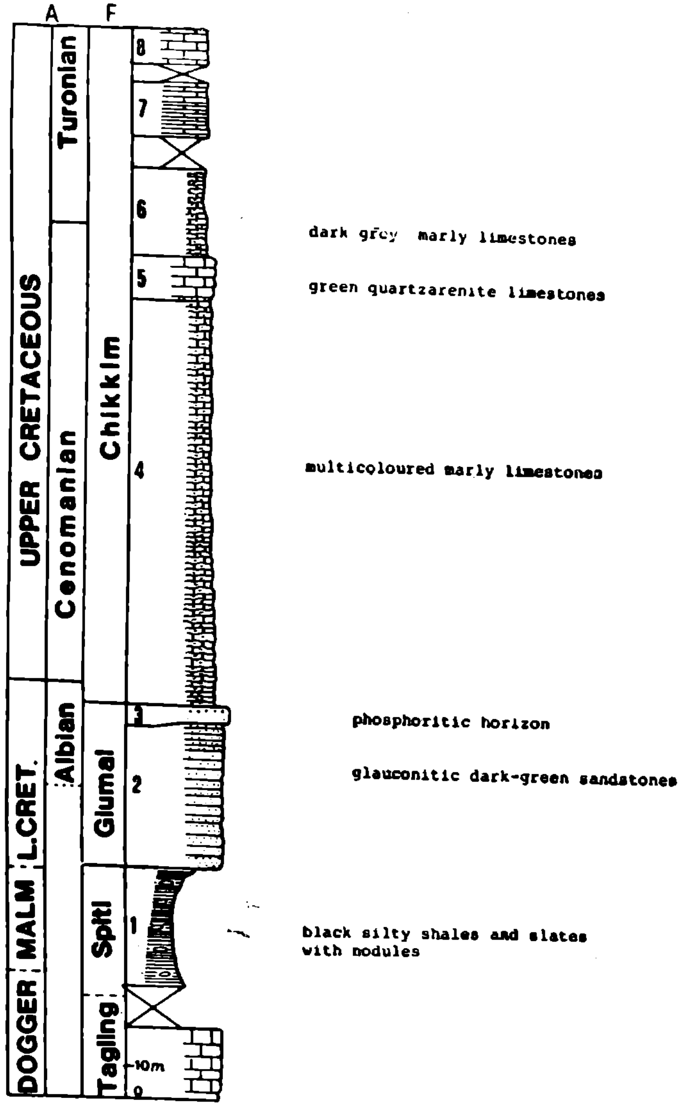

Figure 6. Stratigraphical column of the Zanskar units.

sequence with the Spiti Shales, the Giumal Sandstones and the Chikkim Limestones (Plate II). A stratigraphical profile is given in Fig. 8. The uppermost beds of Giumal Sandstones and the Chikkim Limestones contain a rich planctic foraminiferal fauna (det. M. Caron; list in Baud *et al.*, in prep.). The lowermost beds of the Chikkim Limestones are assigned the late Albian age. They are ovelain by green and red-coloured limestones and quartz-arenite limestones containing foraminiferal biozones of the Cenomanian and Turonian. The younger sediments were not sampled and we can not correlate these with the late Cretaceous-early Tertiary sequence of the Kangi La-Oma Chu area (Fuchs, 1977; Gaetani *et al.*, 1980; Kelemen *et al.*, in press; Bassoullet *et al.*, this volume). In the Zumlung gorge, east from Zangla, the Kioto Limestones form a large anticline. A lithological profile through the NE flank is given in Fig. 7. The uppermost beds, rich in Belemnites (Laptal beds)(?) contain foraminifera with Valvulinidae of probably early Dogger age (det. M. Septfontaine).

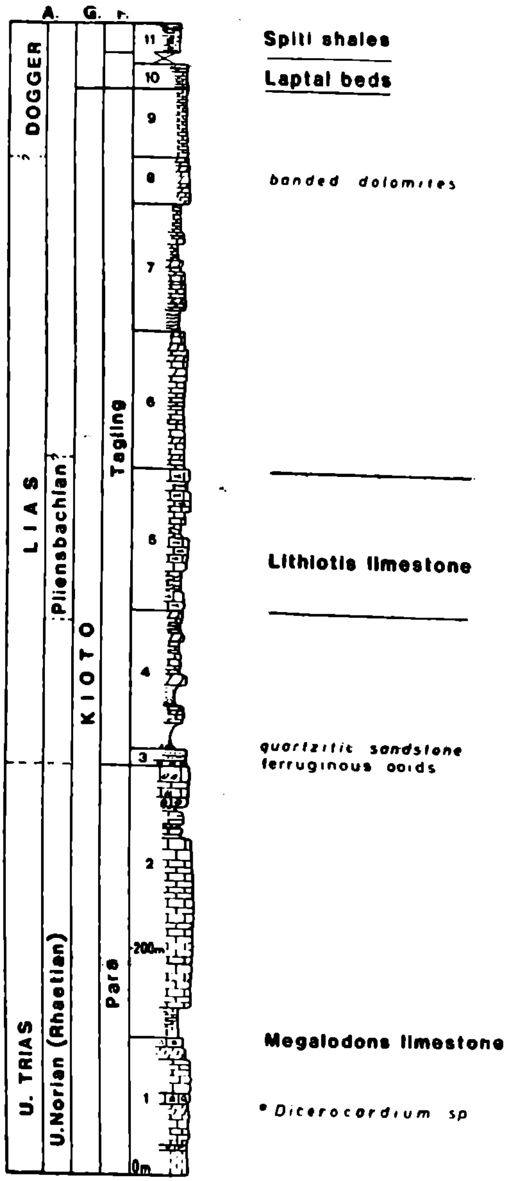

Figure 7. Stratigraphical profile of the Kioto Limestones in the Zumlung Gorge.

(iv) The Zangla Unit

A view of the northern part of this unit is given in Plate III, where we can see a broad syncline with Chikkim Limestones and (?) Kangi La Flysch overlying Giumal Sandstones, Spiti Shales and Tagling Formation of the Kioto Group. The name Zangla Formation for the Triassic rocks of the Zanskar area (Nanda *et al.*, 1976) seems inappropriate to us, because the area of Zangla is entirely made of Jurassic to Cretaceous rocks (see Plate III and Fig. 3). The southern part of this unit is formed by highly folded Kioto Limestones, by the Lilang Group (Figs. 2 and 3) and possibly by the Zewan Formation in the area N of Thonde. The entire unit is overthrusting the Panjal Traps of the Ringdom-Phugtal unit. Northwestward, the Zangla unit crosses the Zanskar river and supports, in the western Zanskar, the Spongtang Ophiolite Klippe (Kelemen *et al.*, in press).

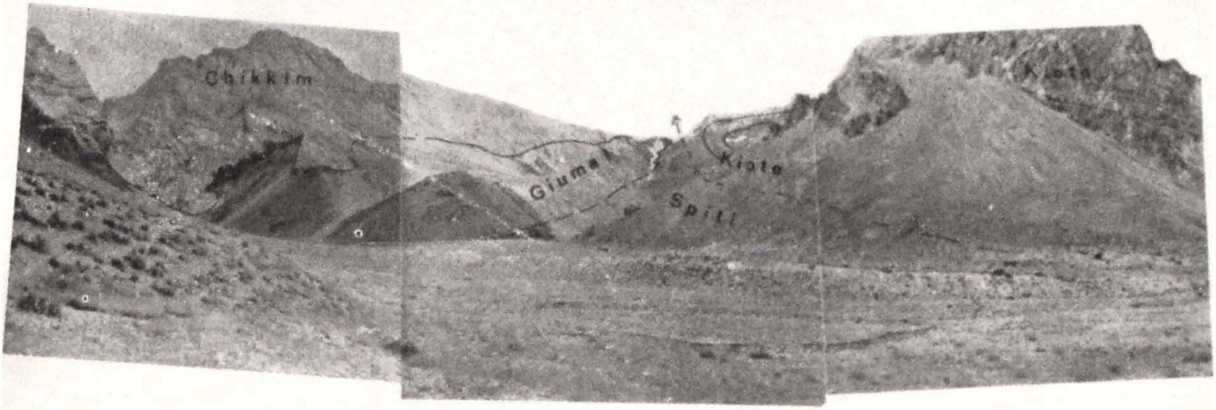

Plate II. Upper Chirche valley (4500m) : Jurassic-Cretaceous sequence of the Zumlung unit.

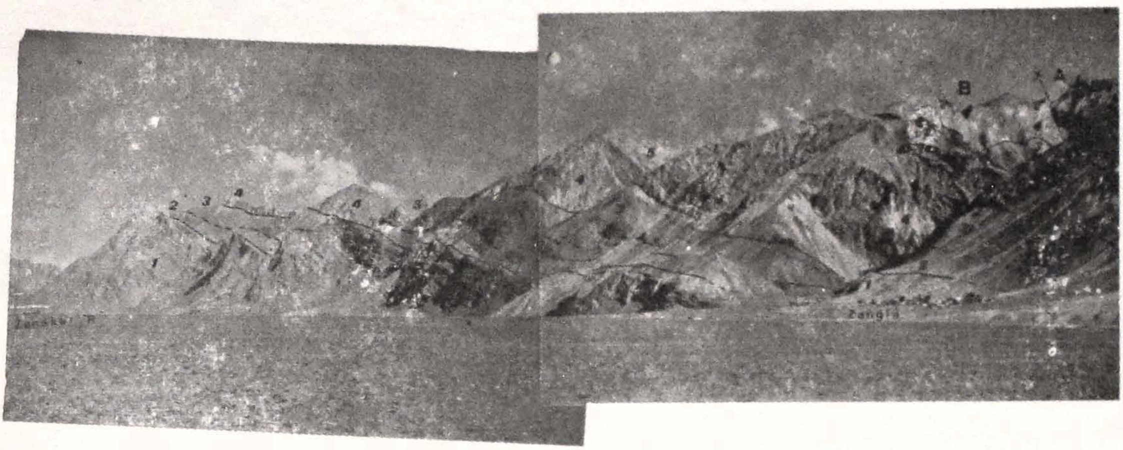

Plate III. General view of the northern Zangla area. **A**—Zumlung unit. **B**—Zangla unit. **1**—Tagling Formation of Kioto group **2**—Spiti Shales. **3**—Giumal Sandstone. **4**—Chikkim Limestone. **5**—Kangi La Flysch?. **X**—Zangla Thrust.

(v) The Ringdom-Phugtal Unit

This unit is a part of the Great or Central Himalaya and is formed by a crystalline basement (Tibetan slab or southern crystalline), by palaeozoic metasediments overlain by the late Paleozoic Panjal Traps. A good description of these series is given by Nanda *et al.* (1976, 1978).

VI. STRUCTURE AND METAMORPHISM

Our observations are too sketchy to propose a chronology of the tectonic and metamorphic events; only the main data are given :

(i) There is a great difference in the grade of deformation and metamorphism between the molassic belt and the suture zone belt. Very low in the autochtonous molasse, the grade of deformation is higher in the allochtonous molasse and flysch unit, with an hectometric open to isoclinal, disharmonic folding accompanied by a subvertical fracture cleavage. The metamorphism is anchizonal. In the Markha unit of the suture zone, we observe an isoclinal folding of an older cleavage and there, the metamorphism reaches the epizone.

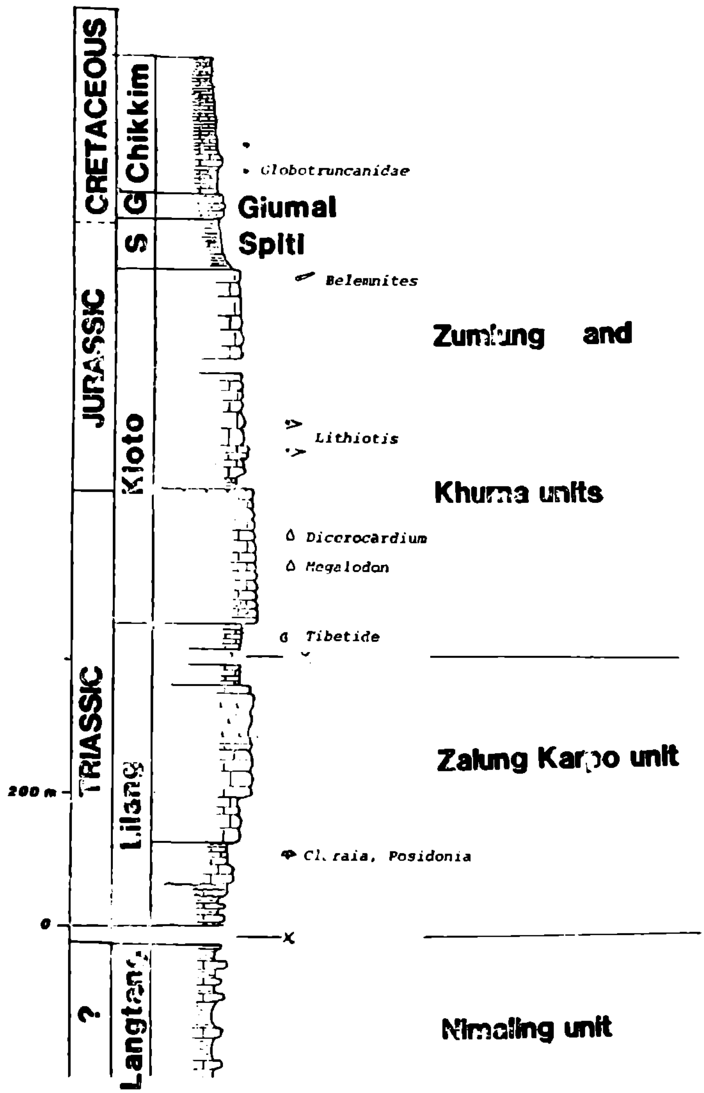

Figure 8. Stratigraphical profile of the Middle Jurassic to Upper Cretaceous series of the Zumlung unit in the upper Chirche valley.

(ii) In the Indus valley, the thrust plane of the allochtonous molasse and flysch unit dips southwestward with a low angle (1 in Fig. 1, and Fig. 2). The suture zone in the Markha valley is bounded by two major structural lines : the Kanda La Gongmaru La Thrust and the Skiu-Lato fault. The latter is correlated with the Zanskar fault of Fuchs (1977, 1979) and Kelemen *et al.* (in press) and has probably an important strike-slip motion (3 in Fig. 1).

(iii) The Nimaling unit shows a regional high epizonal metamorphism super-imposed on a contact metamorphism of the metasediment intruded by the Nimaling Granite. This unit is interpreted as an uplifted block plunging westward (Figs. 1 and 3 and Plate 1).

(iv) At least three phases of strong deformations are recorded in the Langtang Group of the Nimaling unit. The structural style along the Markha valley suggests a root zone and the generalized subvertical position of the latest generation of fold axes indicates important horizontal shearing (strike-slip motion of the Skiu-Lato fault).

(v) The northern Zanskar units show deca to hectometric kink folds with subvertical axial planes superposed on large isoclinal folds. The metamorphism seems to be decreasing from upper epizone to anchizone, from the Nimaling Massif to the Zanskar units. We interpret the Zalung Karpo unit as a dislocated remnant of the Khurna unit.

(vi) The southern Zanskar units are characterized by the great development of chevron folding. The Zumlung unit consists of a large syncline plunging southeastward and bordered by two southwestward overturned anticlines (Figs. 1, 2, and 3). In the NE, the Kioto Limestones of the Khurna unit overthrust this unit and in the SW we have a major structural line : the Zangla thrust (5 in Fig 1). This thrust crosses the Zanskar river near Naerung (Kelemen *et al.*, in press) to join the Kangi-Shingo La main thrust.

(vii) The highly folded Zangla unit overthrusts the Panjal Traps along a northward dipping folded thrust plane.

In conclusion, the Gondwana-peri-Gondwana contact appears here to be more complex than supposed until now, with the presence of nappes and structures showing late transcurrent movements. This key eastern Zanskar area needs further detailed researches with correlative fossil finds to allow a new model of geodynamic evolution.

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Structure and Tectonics of the Area Between Kargil and Bodhkharbu, Western Ladakh, Kashmir Himalaya

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ABSTRACT

The area is divided into three main tectonic provinces, the Tethyan (Tibetan) Zone, Indus Zone and Ladakh Zone. The Tethyan Zone contains Zoji La Formation (Upper Permian to Middle Trias) at the base and Matayin Limestone (Middle Trias to Lias) on the top. In Zoji La Formation fold axes are E-W and NE-SW with tight folding. Matayin Limestone has open folding in south but near the Dras Thrust isoclinal folding is prevalent. Indus Zone contains Dras Formation and tectonically associated mélange belts, with complex fold trends. Ladakh Zone consists of Ladakh Granite overlain by Kargil Formation, which has E-W, NE-SW and NW-SE fold trend. These three major zones are divided by two main thrusts, the Dras Thrust and Kargil Thrust. Dras Thrust brings into juxtaposition the rocks of the Tethyan and Indus Zone. Along the Kargil Thrust, Dras Formation (Aptian to (?) Maestrichtian) overrides the younger Kargil Formation (Palaeocene to (?) Miocene). These thrusts are due to post-Miocene deformation. Fold patterns associated with this deformation are chevron, asymmetric, recumbent, isoclinal conjugate, parallel, harmonic and disharmonic. Besides the boundary thrusts, minor faulting and transverse, N-S structures are also known. Tectonic sequence seems to start with the mélange emplacement within the Dras Formation. Post-Miocene deformation caused major boundary thrusts and finally transverse structures developed. A subduction/obduction setting is envisaged, but options are open, till more basic data is gathered.

INTRODUCTION

THE AREA of study falls in the western part of Ladakh and covers about one thousand sq km (Fig. 1). It is broadly delimited by latitudes 34°.20′ : 34°.35′ N and longitudes 76°.00′ : 76°.35′ E. A number of earlier workers have contributed to the geology of the region and following deserve mention; Stoliczka (1866), Drew (1875), Lydekker (1883), Middlemiss (1921), De-Terra (1935), Sahni and Bhatnagar (1958), Tewari and Mamgain (1963), Pande *et al.* (1969), Tewari *et al.* (1970), Pande and Gupta (1970), Dixit *et al.* (1971), Bhandari *et al.* (1972), Raiverman and Mishra (1974), Gupta (1974); Gupta and Kumar (1975), Shanker *et al.* (1976), Gansser (1977), Gupta (1976), Colchen and Le Fort (1977), Andrieux *et al.* (1977), Frank *et al.* (1977), Fuchs (1977), Virdhi *et al.* (1977), Kumar (1978), Sharma and Gupta (1978), Sharma and Kumar (1978) and Rai and Pande (1978). Regional stratigraphy of the western Ladakh has been discussed by the authors earlier (Shah *et al.*, 1976). However, stratigraphic succession for this part of the area is given in this paper in Table 1. Geological map (Fig. 2) and cross-sections (Fig. 3) help to show the stratigraphic and structural relations precisely. The biostratigraphy is mainly based on the faunal studies by the authors (Shah *et al.* 1976; Shah and Sharma, 1977; Sharma and Shah, 1977, 1980, *a*, *b*, *c*; Klootwijk *et al.* 1979 and Sharma, 1980). The present paper is one in a series of papers in which an effort is made to present basic data, in a restricted area.

TECTONIC SETTING

The area lies in the Indus Suture Zone. This zone is supposed to represent the trace of a subduction line

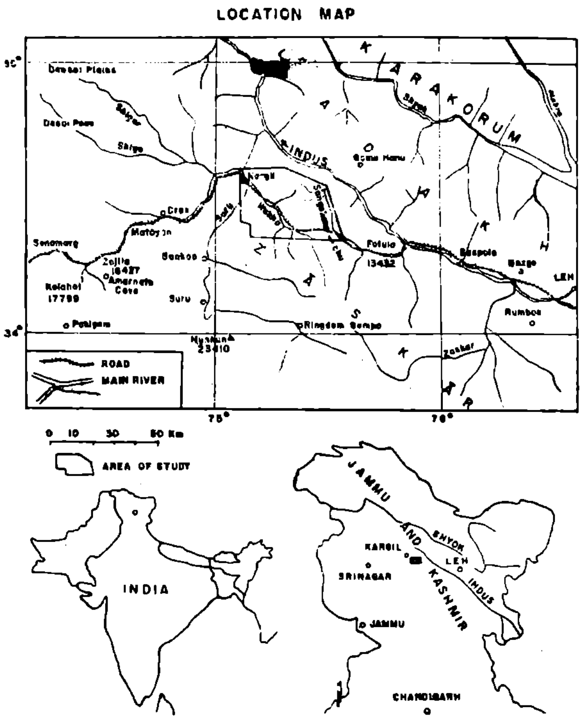


Figure 1. Location map.

corresponding to the collision surface of the Indian and Asian plates (Gansser, 1977; Le Fort 1975; Klootwijk *et al.*, 1979). It lies between the Ladakh Granite massif in the north and Tethyan Himalaya in the south. Crawford (1974) and Kaila and Hari Narain (1976) conclude that there was no continent-to-continent collision along the Indus Suture Zone and the boundary of Indian plate lies along the Tien Shan-Nan Shan belt. Thus, on a regional basis, the area is situated in the region of complex tectonic belts like Shyok Suture, Indus Tsangpo Suture, major lineaments like North-Trans-Himalayan Lineament (Srivastava *et al.*, 1977), Suru Tectonic Axis (Raiverman and Mishra, 1974) and a series of intricate sheer zones containing ophiolitic mélange, exotic blocks and klippes (Fuchs, 1979). The region is highly tectonized and is essentially a zone of compression.

TECTONIC PROVINCES

A glance on the tectonic map (Fig. 4) indicates that the region can be divided into three distinct broadly E-W trending tectonic units, demarcated by two major fundamental thrusts. The three belts from south to north are :

1. The Tethyan (Tibetan) Zone;
2. Indus Zone;
3. Ladakh Zone.

1. The Tethyan Zone

Abutting against the Indus Suture Zone, in the south is a synclinorium containing Mesozoic-Palaeogene sequence. In the area studied, northern fringe of this synclinorium is exposed. The rocks comprise flysch-like, Zoji La Formation (Upper Permian to Middle Trias) at the base and a platform facies, Matayin Limestone (Middle Trias to Lias) on the top. Fold pattern in the Zoji La Formation is complex as most of the argillo-

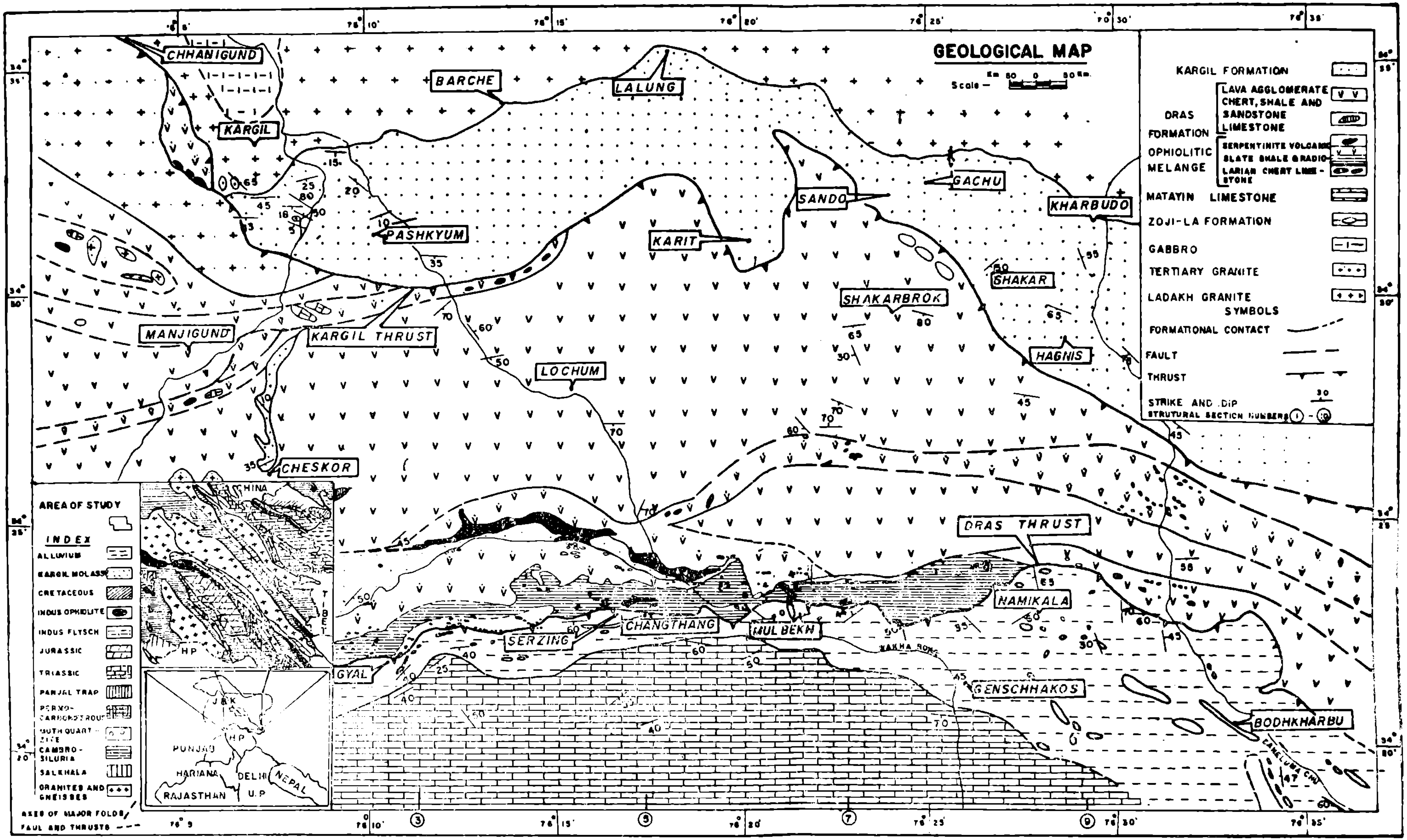


Figure. 2. Geological map.

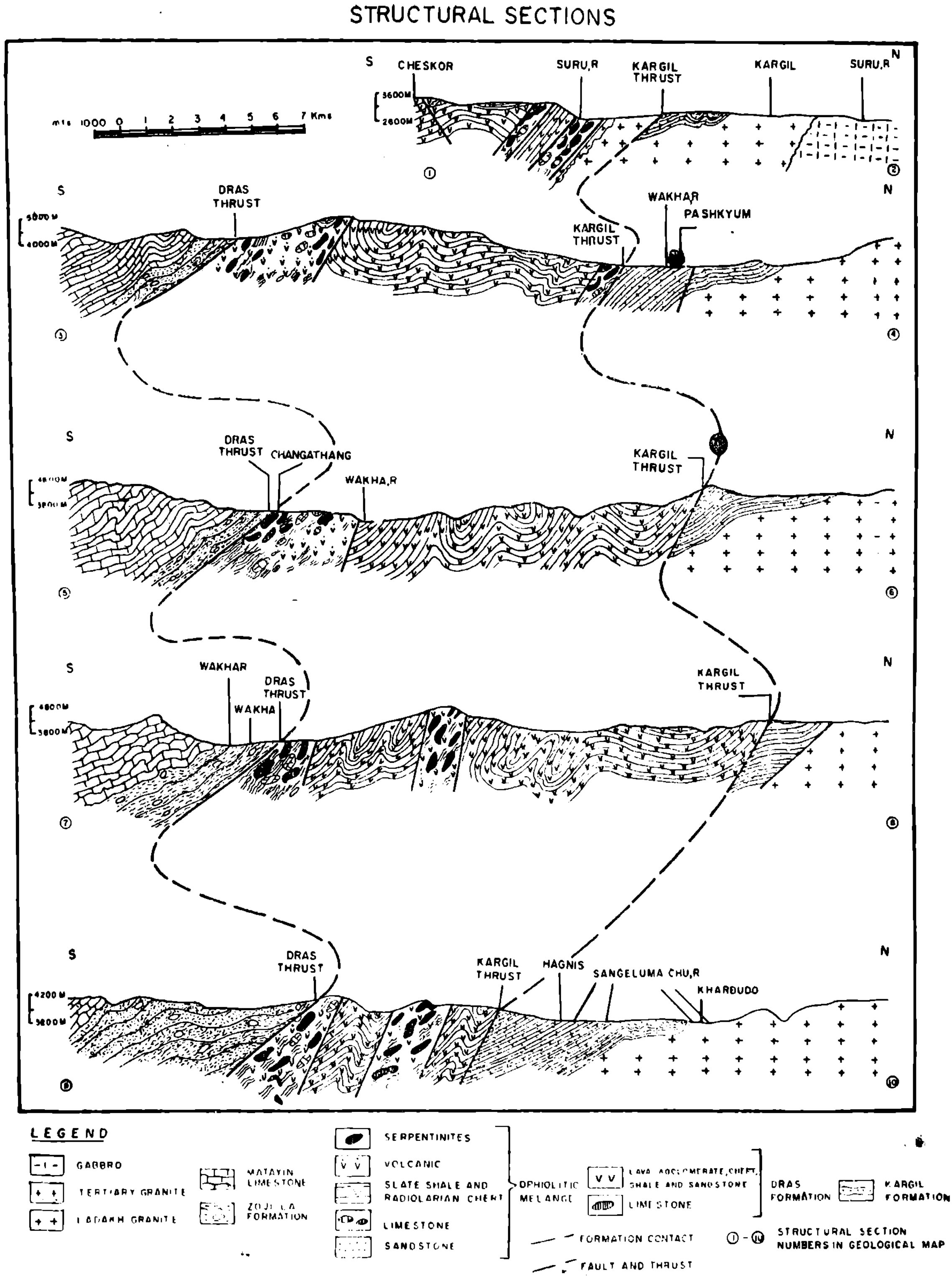


Figure. 3. Structural Sections.

TABLE 1—STRATIGRAPHIC SUCCESSION OF THE AREA

Litho-stratigraphic Units	*Generalised lithological description*	*Thickness (metres)*	*Age*
Kargil Formation	Mainly conglomerate, conglomerate with grey sandstone, purple shale, sandstone alternations; at the base, middle and top respectively, with cross bedding, clay galls and ball and pillow structure; in the western part	2000	(?) Miocene
	Thin-bedded alternations of greenish grey shale and khaki grey sandstone/siltstone with few limestone bands with ripple marks, sole marks, convolute bedding etc., in the eastern part		Palaeocene
- - - - - - - -	Kargil Thrust or Unconformity	- - - - - -	- - - - - -
Dras Formation	Massive and porphyritic, andesite and basalt, pillow lava, with volcanic breccia, agglomerate and tuff; interbedded chert, shale, sandstone and limestone	> 3000	(?) Maestrictchian Aptian
- - - - - - - -	Tectonic contact	- - - - - -	- - - - - -
Ophiolitic Mèlange	Mixture of blocks of serpentinite, magnesite, radiolarite, limestone, shale/slate, volcanics in a chaotic complex		Blocks of Cretaceous or older age emplaced in Cretaceous or later
- - - - - - - -	Tectonic contact	- - - - - -	- - - - - -
Matayin Formation	Green, purple and violet-cream and grey limestone and dolomite with arenaceous carbonate rock at the base and cream-coloured grey, thick-bedded massive rocks at the top	> 1500	Lias Middle Trias
Zoji La Formation	Cream-coloured phyllite and slaty shale, highly fissile and splintery, thin-bedded, brown limestone marl and rare carbonaceous shale with huge limestone blocks and frequent white quartz veins	300	Upper Permian to Middle Trias
Granite Group	Tertiary Granite (intrusive in Dras Formation) Mainly tonalite with veins and dykes of aplite and dolerite		Tertiary
	Ladakh Granite (northern basement) mainly granodiorit-tes diorite and leucogranite. Norite with marble and dykes of aplite and dolerite		Pre-Tertiary

calcareous facies is incompetent and has yielded quickly under stress and strain. Major fold axes are E-W mainly but NE-SW trend is also exhibited. The folding is mainly tight. Matayin Limestone comprising a thick-bedded carbonate facies has relatively open folds to the south but closer to the Dras Thrust isoclinal folding is prevalent. It is more pronounced with repeated inversion in the Zoji La Formation. The folds show three trends of folding; a main NE-SW trend, NW-SW and E-W trends.

2. The Indus Zone

The zone lies between the Dras Thrust to the south and Kargil Thrust to the north. The zone contains Dras Formation and tectonically associated mélange belts. Fold trends of blocks in mélange are complex. The main fold axes in the zone trend WNW-ESE to NW-SE which turns sharply to N-S in the Suru section. Folding is tight. Further eastwards normal trend is gradually resumed.

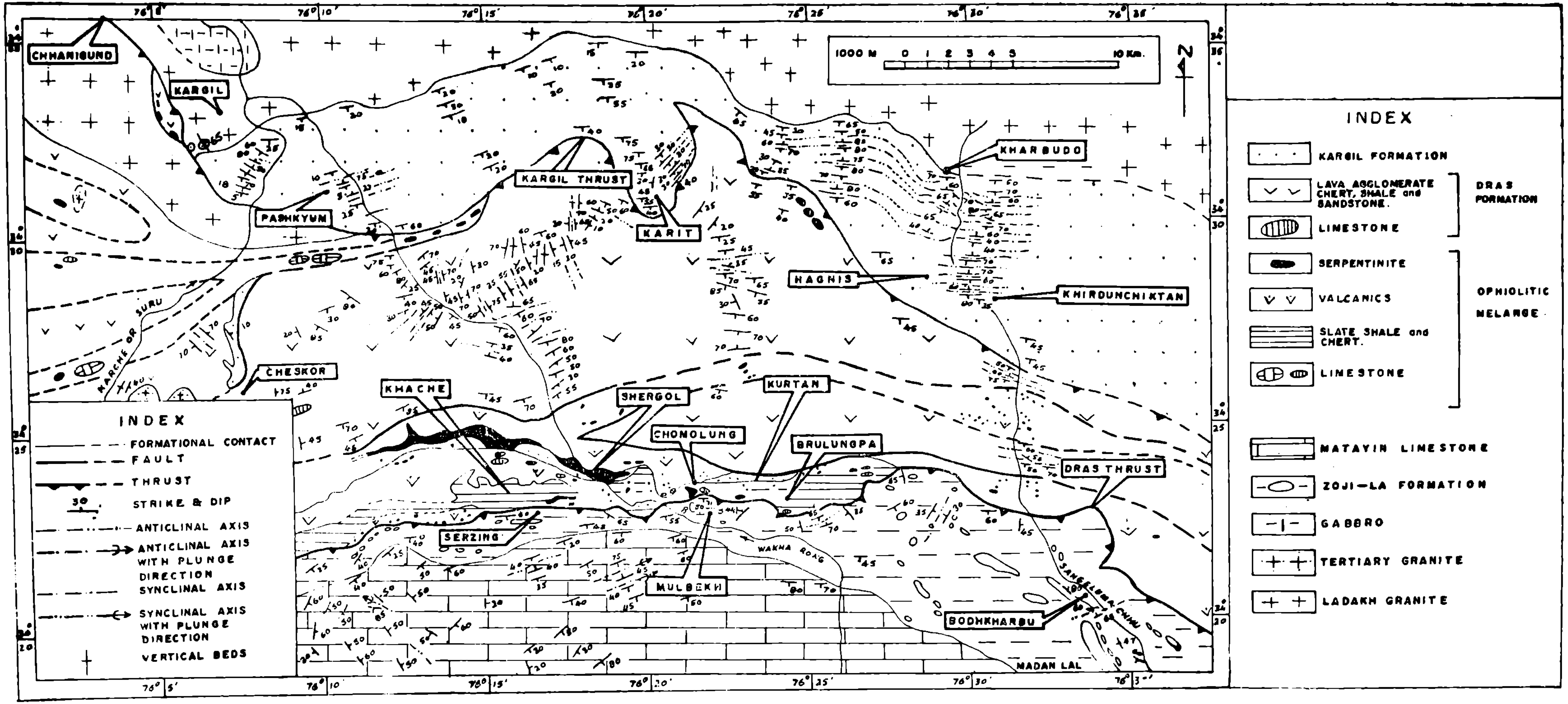


Figure. 4. Tectonic map.

3. The Ladakh Zone

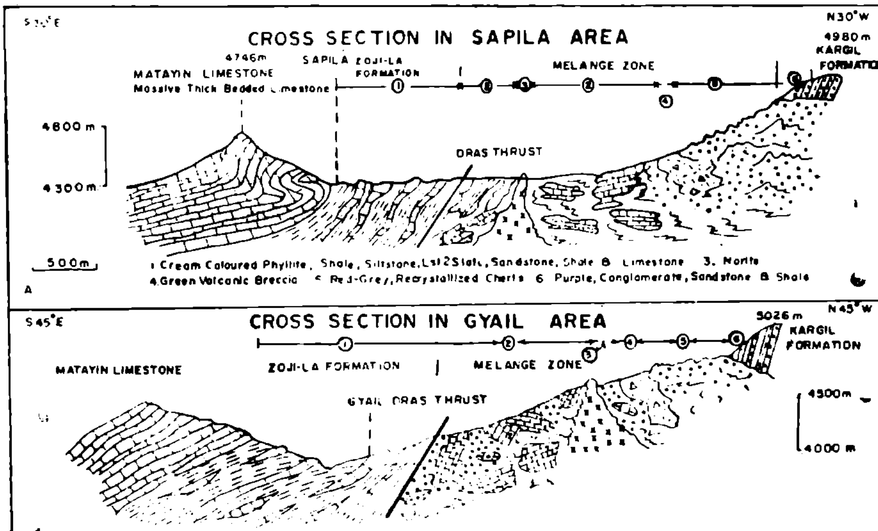
The Ladakh Zone consists of Ladakh Granite overlain by Kargil Formation. Fold axes of the Kargil Formation have a general E-W trend, except for the Karit area where NE-SW trend is also observed. Near Kargil a local NW-SE trend is also noticed. Folding is essentially open in the purple-grey facies but is tight in the olive-grey facies.

BOUNDARY THRUSTS

Present study has revealed the existence of two boundary thrusts in the area, Dras Thrust and Kargil Thrust in the south and north, respectively.

Dras Thrust

This thrust brings into juxtaposition the rocks of the Tethyan and Indus zone. Rocks of Upper Permian to Lias (Zoji La Formation and Matayin Formation) override the Dras Formation (Aptian to (?) Maestrichtian). This tectonic line extends to the E and W on a regional scale. The tectonic trace has a north-west south-east direction near Bodhkharbu, but later in the west it attains an east-west trend. It is a north-vergent overthrust, although the usual Himalayan trend in the south is south-vergent. Distinct change in the lithotectonic setting on both sides of the thrust helps in its delineation. Hade of the thrust is about 20° in the west but gradually steepens (30°-40°) eastwards. The thrust is clearly seen at Khangral, Mulbekh, Sapi La (Fig. 5A) and Gyal area (Fig. 5B). This is the case with all the major structures in the Suture Belt.



1 Cream Coloured Phyllite, Shale, Siltstone, Ls! 2 Slate, Sandstone, Shale & Limestone 3. Norite 4. Green Volcanic Breccia 5 Red-Grey, Recrystallized Cherts 6 Purple, Conglomerate, Sandstone & Shale

2 Radiolarian Chert, Shale & Oolitic Limestone With Crinoidal Stems. & Slates etc 5 Dark Grey, Greenish Grey Tuff With Red Recrystallised Chert. 1 3 4 & 6. Are Same as in Fig 'A' Above

Figure 5. Cross-sections in Sapi La, Gyal area.

Kargil Thrust

Along the Kargil Thrust, Dras Formation (Aptian to (?) Maestrichtian) overrides the younger Kargil Formation (Palaeocene to (?) Miocene). To the west near Kargil, this thrust brings in contact the Kargil Formation and Tertiary Granite on the one hand and Tertiary Granite and Ladakh Granite on the other, with thrust slices of ophiolitic mélange and Dras Formation. It is an upthrust and hades steeply southwards. Near Pashkyum it is the mélange belt which comes in contact with the Kargil Formation along this thrust. Linear behaviour of the tectonic trace is slightly complex. In the east it is NW-SE, but between Hagnis and Pashkyum it takes a sharp turn to south and then north and continues again in a somewhat NW-SE trend. This thrust is also clearly defined at Lamsu-Sando area (Fig. 6A), Shakar (Fig. 7A) and in Marpoyul area (Fig. 8C) where folded Dras Formation over rides the Kargil Formation. Dras Formation thrust slices near Kargil are highly tectonised and deformed. As Kargil Thrust affects the Palaeocene (?) Miocene rocks of Kargil Formation, it is also related to the major post-Miocene tectonic deformation like the Dras Thrust.

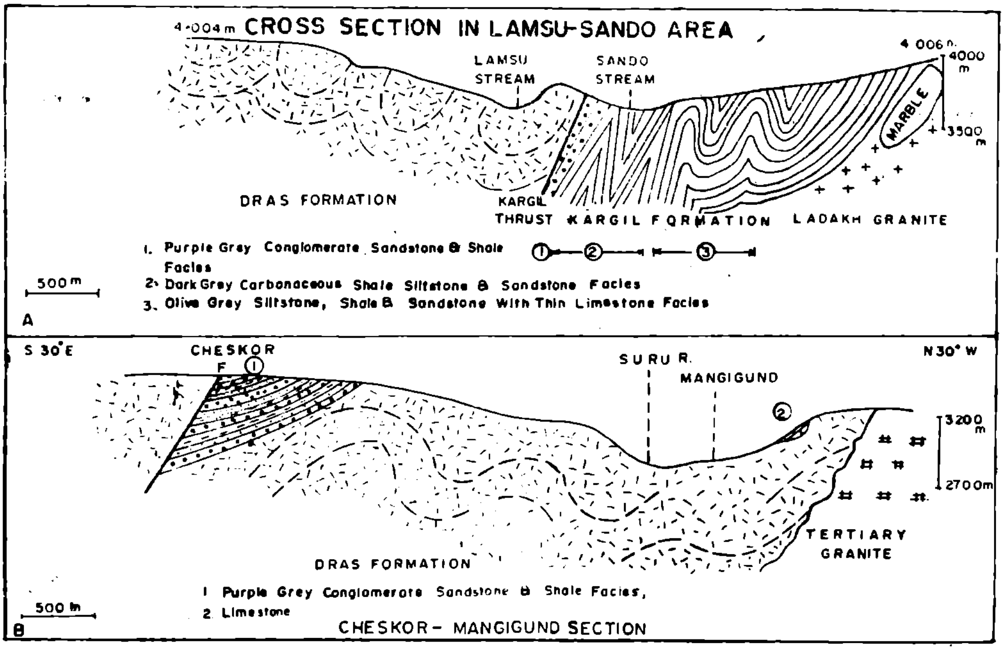


Figure 6. Cross-sections in Lamsu-Sando; Cheskor-Mangigund area.

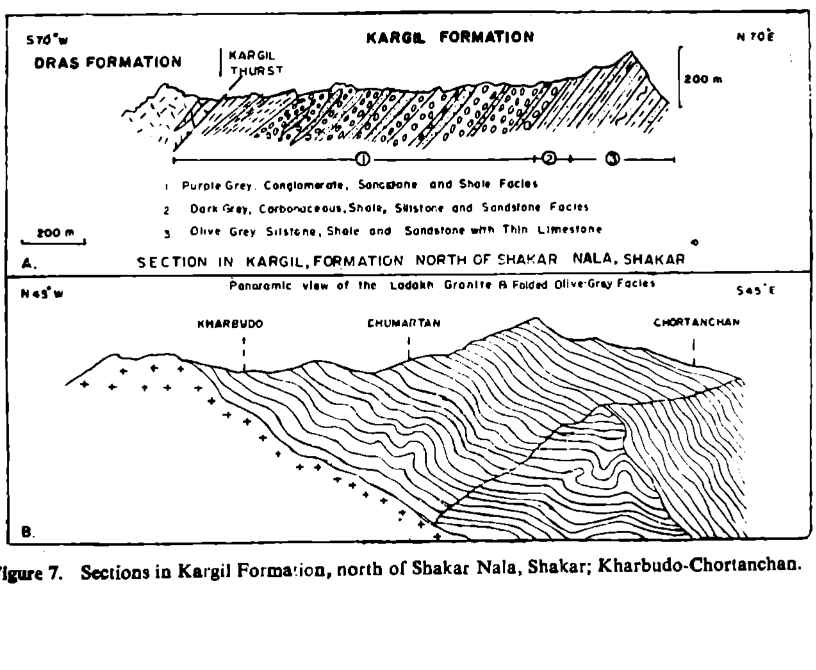


Figure 7. Sections in Kargil Formation, north of Shakar Nala, Shakar; Kharbudo-Chortanchan.

FOLDS

Major fold patterns are related to the deformation which caused the thrusting movement. Orientation of these folds is similar to the thrust traces. The study of folds is confined to the description of single folds, fold systems, description of folds as seen in profile and orientation of its axial surface and hinge line etc. Fabric and microscopic studies are beyond the scope of this work. Pattern of folding is chevron, asymmetric, recumbent, isoclinal conjugate, parallel, harmonic and disharmonic. Boudinage structure is also observed. Folding is open as well as tight (Fig. 9D). A general north-vergent deformation is noted.

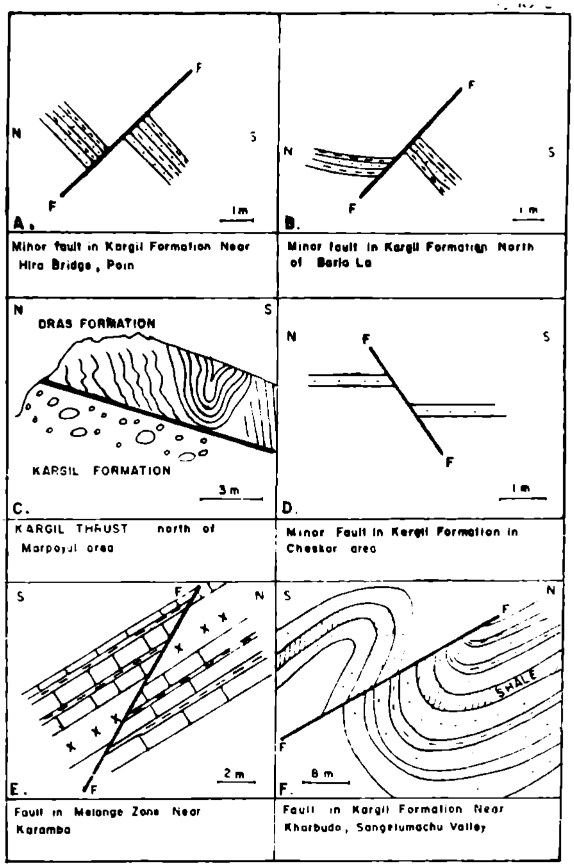


Figure. 8 Fault patterns in the area.

Chevron Folds

Characteristic chevron folds with limbs of equal length, symmetrical fold pattern, angular closures or hinges are noted in the Zoji La Formation (Fig. 9C). Limbs are small and apical angle is 80°-90°. Chevron folds are noted in the blocks of mélange zone also (Fig. 10C). In these the apical angle is 80°-90°. Dras Formation shows chevron folds only occasionally (Fig. 11A). Limbs are large and special angle is 80°-90°. Olive-grey facies of Kargil Formation also exhibit such folds (Fig. 12C and Fig. 6A). The hinges are mostly angular. Rocks are alternating siltstone/sandstone and shale with rare limestone, i.e., a thin alternation of competent and incompetent beds. Apical angles are from 30° to 45°.

Chevron folds are considered to evolve in an evolutionary sequence from sinusoidal folds through concentric to chevron folds (Johnson, 1977 : 171). Such folds may result in multilayers comprising interbedded soft and stiff layers firmly bonded together, or multilayers where there is perfect slippage between layers. These are usually confined to flysch-like rocks (Hills, 1972 : 246). Flexural folding (a term, after Dennis, 1972) seems to be the folding process. Such folds are formed in response to compressive stress acting along the layering (Paterson and Weiss, 1962).

Open Symmetrical and Asymmetrical Folds

Open folds (Fig. 12A, B, E, F), occur in the purple-grey facies of the Kargil Formation. Apical angle varies from about 60° to 130°. Fold closures are mostly rounded and curvilinear. Axial planes indicate a polyclinal nature (Fig. 12D). Fold pattern is parallel and harmonic. The fold axis is mostly north-vergent. At times Dras Formation also exhibits open folding (Fig. 11 B,E), the limbs being very big.

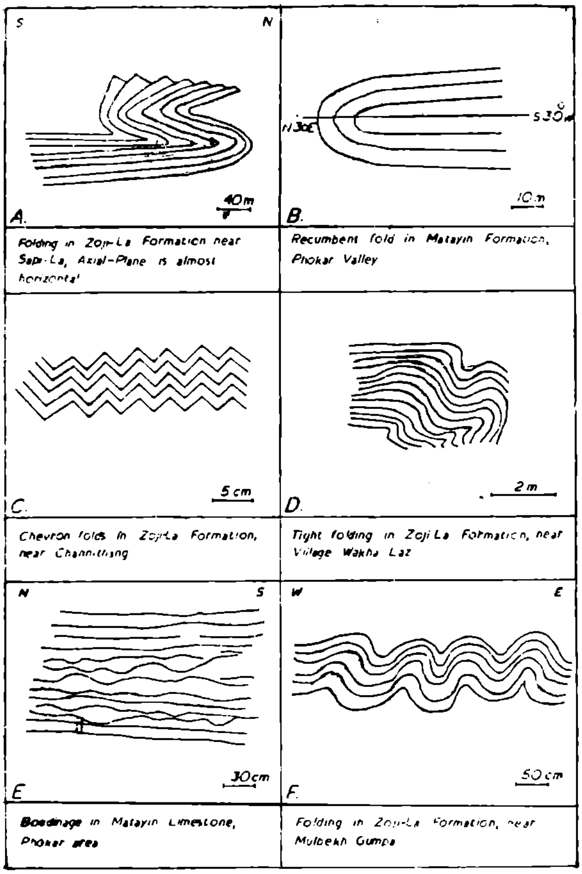


Figure. 9. Folding patterns in the area Zoji La and Matayin Formations.

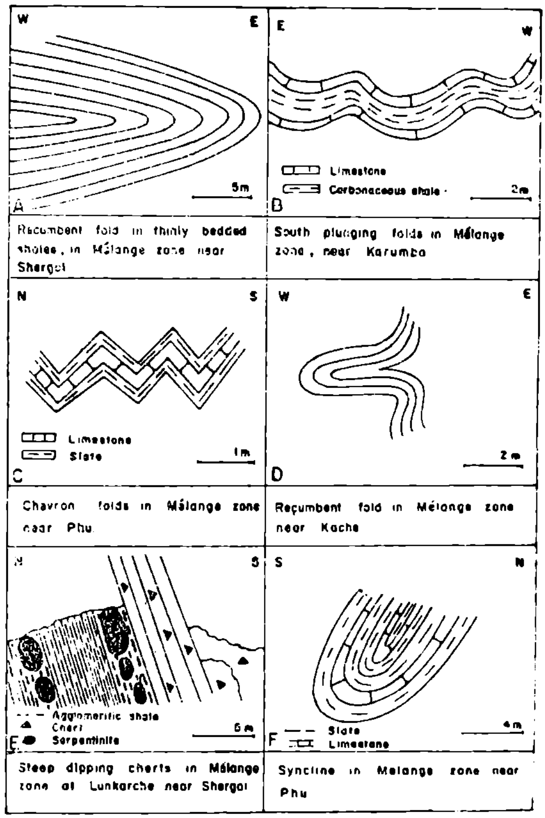


Figure. 10. Structural patterns in mélange zone.

Disharmonic Folding

Such folds are observed in Dras Formation (Fig. 11C). Purple agglomeratic shale (incompetent) beds are in between the volcanic flows. Zoji La Formation also shows such folding in the cores of the incompetent shales between competent limestone.

Conjugate Folding

Such folds have axial surfaces inclined to one another at high angles. Kargil Formation (Fig. 7B and Fig. 12E) and Dras Formation (Fig. 11 F) exhibit this fold pattern.

Recumbent Folding

Such fold pattern with horizontal axial plane is seen in Zoji La Formation (Fig. 9A, B). The hinge zone is north-vergent. Even in the mélange zone recumbent folding is seen (Fig. 10A, D).

Isoclinal Folding

Fold patterns with axial planes (parallel) are seen in Zoji La Formation (Fig. 9F), in mélange zone (Fig. 10B) and in Dras Formation (Fig. 11D; also structural sections, Fig. 3).

Boudinage Structure

Such structures are seen in Zoji La Formation, Matayin Limestone (Fig. 9E). Here limestone (competent) is

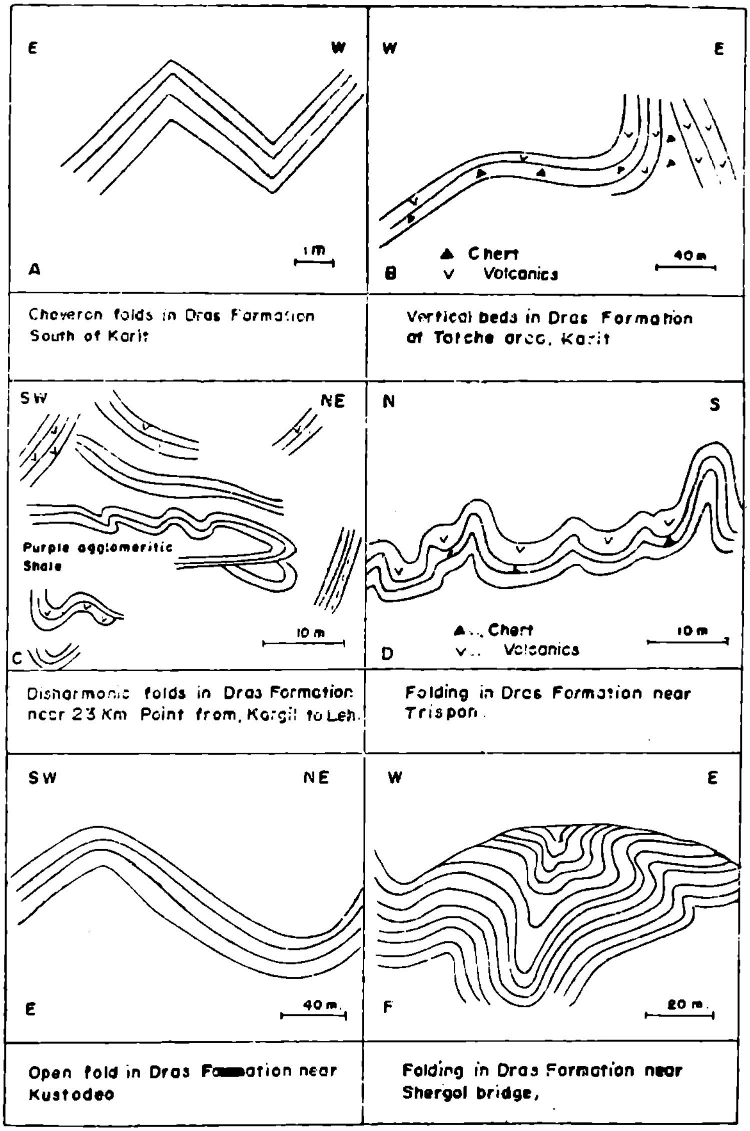


Figure. 11. Folding patterns in Dras Formation.

interbedded with shale (incompetent). Necking of limestone is observed. Boudinage mullions (De-Sitter, 1956) is observed in Dras Formation in shales near Shergol.

Plunging Folds

Matayin Formation exhibits plunging folds (Fig. 4). Plunge of the NE-SW folds is in the NE direction, whereas in the NW-SE set, it is NW. Angles of dip are high, 20°-80°.

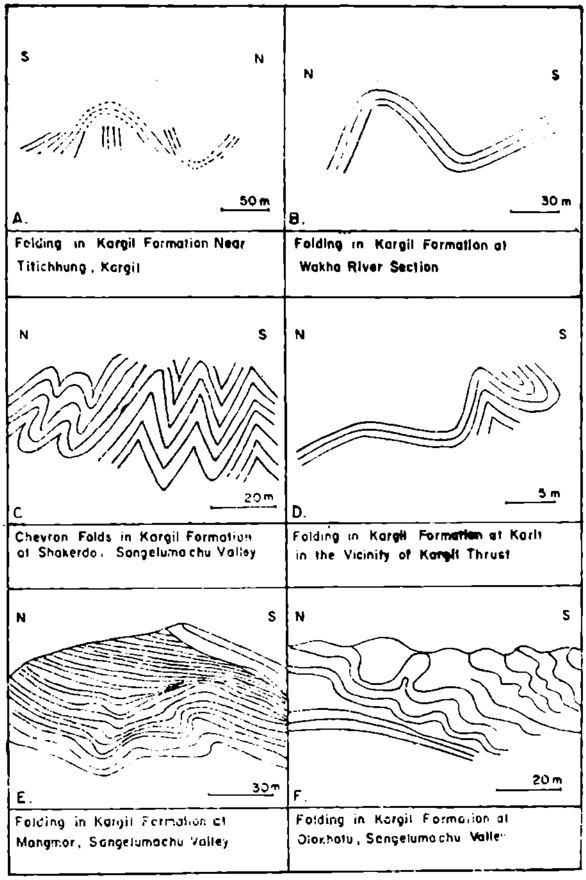


Figure. 12. Folding patterns in Kargil Formation.

FAULTS

Faults in this region are of two types, the major boundary thrusts as referred to earlier and cross faulting. In addition to these, local strike faults occur and are seen in Kargil Formation (Fig. 8A, B, D, F) and in sedimentary blocks in ophiolitic mélange zone (Fig. 8E). The displacements are very small. A reverse fault is seen at Cheskor. Kargil Formation is overridden by the Dras Formation (Fig. 6B). The fault trace is N-S, which is transverse to general structural trend.

OPHIOLITIC MELANGE ZONES

Three ophiolitic mélange zones are noted in the area. The northern mélange starts from near Pashkyum and extends towards Mangigund area, where it bifurcates into small zones; one such subzone is seen west of Kargil town. Blue-schist facies have been reported, near Pashkyum, by Gansser (1977) within the ophiolitic mélange zone.

The southern ophiolitic mélange zone is more prominent and bifurcates into two. The main zone is tectonically in contact with the Tethyan facies in the south and Dras Formation in the north. The other ophiolitic mélange zone starts from the main zone near Shergol and runs to the east, through Pillu, Kayonli, in the Sangaluma Chu valley. This zone is tectonically in contact with the Dras Formation (Figs. 2 and 3).

Huge blocks of serpentinite are very prolific and some of these have E-W trend. Other blocks show very chaotic dips, as these have suffered tremendous deformation. Some of these blocks show tight recumbent and chevron folding and high dips towards south (Fig. 10E, F) as seen near Lunkarche, in Sangeluma Chu valley these have same southern dips.

TRANSVERSE STRUCTURES

As discussed earlier, most of the structures have an E-W to SE-NW trend. But there are some structures which are nearly N-S or slightly NW and NE in trend, these are represented by fold axes in Dras Formation between Pashkyum and Karit (Fig. 4), Cheskor fault showing N-S alignment, NW turn of the Kargil Thrust in the Kargil area and NW plunge direction of folding in Matayin Limestone.

Transverse structures of the similar nature are known in the Himalaya as well (Valdiya, 1973, 1979). Raiverman and Mishra (1974) suggested a N-S trending Suru Tectonic Axis in Kargil area and opined that it had a long history since at least early Palaeozoic till Recent times.

TECTONIC SYNTHESIS

The various structures, whose qualitative descriptions have been given above, can now be resolved into various sets and related to different phases of deformation. This synthesis has to be worked on their mutual relationship.

It is apparent that all the three tectonic units mentioned above have universally suffered a north-vergent deformation, irrespective of their earlier tectonic situation. All the boundary thrusts and east-west folds are a result of this deformation and they are noticeable throughout the belt. It is possible to date this movement as post-Miocene since the youngest rocks involved are those of the Kargil Formation. Obviously this happens to be a major deformational phase which could be related to the Himalayan folding known in the Tethyan and Lesser Himalayan belts.

The mélange belts have also been affected by this deformation but the mélange emplacement is obviously an earliear phenomenon since their extension is oblique to the boundary thrusts and the latter cut them as well. The mélange belts have a general ESE-WNW trend against an E-W trend of the thrust and as a result a number of such belts extend linearly within the Suture Zone at intervals from west to east and get overlapped or cut out by the Dras and Kargil thrusts. From this it is clear that the latest deformation while bringing about the thrust movement has also folded the originally tectonically emplaced mélange zones. The exact time of the emplacement of the mélange belts is difficult to determine but there is reason to believe it to be Cretaceous (probably later part of it) since they are emplaced within the Dras Formation and themselves contain fossiliferous blocks of Cretaceous age.

Following the major north-vergent deformation there has been some cross-faulting which also affects the thrusts and major fold structures. This cross-faulting also includes cross structures like the Suru Lineament and these are post-thrust phenomenon and probably a result of relief movements and basement adjustments.

The tectonic sequence can, therefore, be summarised as follows :

1. Mélange emplacement within the Dras Formation (? Cretaceous).
2. Major compressive north-vergent deformation bringing about the overriding of the Tethyan Zone on the Suture Zone and the Suture Zone on the Ladakh Zone and also development of major folds and related EW axial plane schistosity (Miocene or later).
3. Development of transverse structures in the entire belt as a result of relief movements and basement adjustment (Later Tertiary or Quaternary).

GLOBAL TECTONICS

It is customary to fit the pattern in a plate tectonic framework. The presence of mélange zones with serpentinite (Shah *et al.*, 1976; Gansser, 1977); blue-schist facies (Frank *et al.*, 1977; Virdhi, *et al.*, 1977; Desio, 1978);

paired metamorphic belt (Kumar, 1978); magmatic island arc system with a gradational suite ranging from tholeiite series, calc-alkaline series to Shoshonite series (Shah and Gergin, personal communication) support a subduction/obduction hypothesis. Oceanic closure is further indicated by the absence of the pelagic facies of Cretaceous (radiolarites) *in situ* (Shah and Sharma, 1977) and the presence of Upper Permian exotic blocks (Tewari and Pande, 1970; Sharma and Shah, 1977). Presence of imbricate north-vergent thrusts (counter thrusts) and crustal shortening of 1000 km (Molnar and Tapponnier, 1975) go in favour of this conclusion. Palaeomagnetic data from the Ladakh intrusives (Klootwijk *et al.*, 1979) supports the movement of greater India towards north, resulting in its collision with an island-arc system and later composite mass collided with the Asian Plate, the data supports the crustal shortening. Similar facts are noted in the west in the Quetta Belt (Gansser, 1979) and in the east of Lahasa, along the Yarlung Zangbo Ophiolite Belt (Yin Jixiang, 1980) in China. But in the light of the data available it is difficult to conclude whether the plate boundary existed in the Indus Suture Zone itself or somewhere away from it in the north. The fact remains that most of the belt is concealed due to later deformation and original position of the mélange zone is not known. It would be difficult to pinpoint the exact position of collision. This is more so because mélange belts have also been located north of the Ladakh Granite in Shyok valley. It is not known whether they are allochthonous like those of the Indus Suture Zone or autochthonous which seems rather unlikely from the description available (Gupta and Sharma, 1978).

From this it can be concluded that, while the evolution of the belt is the result of the collision and subsequent subduction-obduction within the plate tectonic framework, the location of the plate boundary still remains an open question.

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Indus Suture Zone of Ladakh and Plate Tectonics—A Reappraisal

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ABSTRACT

The Indus Suture Zone in the Himalaya is characterized by lithological and tectonic features which are widely regarded as surface expressions of zones of crustal subduction. The zone also marks the line along which the Indian and Eurasian landmasses collided during the Early Tertiary times to produce the Himalayan mountains which are regarded as type example of collision mountains. With the advent of theory of plate tectonics many models have been proposed to explain the geotectonic evolution of the Indus Suture. The paper discusses the salient features of these models. A new model has been proposed in the light of studies in the Eastern Ladakh.

INTRODUCTION

THE INDUS Suture Zone of Ladakh and its extension in Pakistan and Tibet is now widely regarded as the 'line' along which the Indian and the Eurasian landmasses embrace each other. Recent geological and geophysical studies have shown that the zone represents a palaeo-suture or a subduction zone along which the wide gap of the Tethys closed during the northward movement of the Indian Plate and its consumption due to subduction under the Eurasian Plate.

Though the suture zone has been traced for over 2500 km in Pakistan and India along the river Indus and along the Brahmaputra in Tibet, a detailed account of the geological features is available only of the region in Ladakh and Pakistan. There is not much new information available on the Tibetan region except for that provided by Heim and Gansser (1939) and Gansser (1964, 1977). The Ladakh region where the 'suture zone' is well-documented has been a subject of study for well over a century. Stolickzka (1865) and Lydekker (1883) were the earliest to give geological accounts of different parts followed by De Terra (1935), Dainelli (1934-35), Wadia (1937), Norin (1946), Berthelsen (1953), Tewari (1964) and Gansser (1964). Recent contributors to our knowledge of the Indus Suture Zone and its surroundings include Gupta *et al.* (1970), Gupta and Kumar (1975), Shah *et al.* (1976), Shah (1977), Shankar *et al.* (1976), Frank *et al.* (1977), Fuchs (1977, 1979), Gansser (1977), Virdi *et al.* (1977, 1978), Pal and Mathur (1977), Pal *et al.* (1978), Sharma and Gupta (1978), Sharma and Kumar (1978), Srikantia and Bhargava (1978), Srikantia and Razdan (1980), Thakur and Virdi (1979), Thakur *et al.* (1981), Virdi (1971, *a*, *b*, *c*), Desio (1974, 1979) and many others.

Investigations by various authors have shown that the Indus Suture Zone is characterized by a well-developed suite of ophiolites, mélanges, radiolarian cherts, jaspers, blueschists, thick sequence of eugeosynclinal sediments, huge batholiths of granitic rocks and wide aerial extensions of acidic and basic volcanics and volcanoclastic sediments. The zone is also characterized by paired metamorphic belts of high and low pressure types (Virdi, 1981, *a*, *b*, *c*). All these features and lithological assemblages are typical of the regions of crustal subduction or the Benioff zones (Le Pichon *et al.*, 1973; Miyashiro, 1973; Virdi 1978, 1981 *a*, *b*, *c*). Accepting the Indus Suture Zone as a subduction zone, numerous evolutionary models have been and are being proposed. In this paper an attempt has been made to give salient features of these models. A new model is proposed in the light of investigations carried out in Eastern Ladakh by the author to explain the geotectonic evolution of the Indus Suture and development of the Himalaya.

REGIONAL GEOLOGICAL SET-UP

The Indus Suture Zone and the surrounding region of Ladakh is constituted by a wide spectrum of rock types developed under a wide variety of geological processes normally operative at the zones of plate convergence or the destructive plate margins. Table 1 gives a summary of the characters of various lithounits from north to south, while Fig. 1 shows the litho-tectonic setup in the eastern Ladakh.

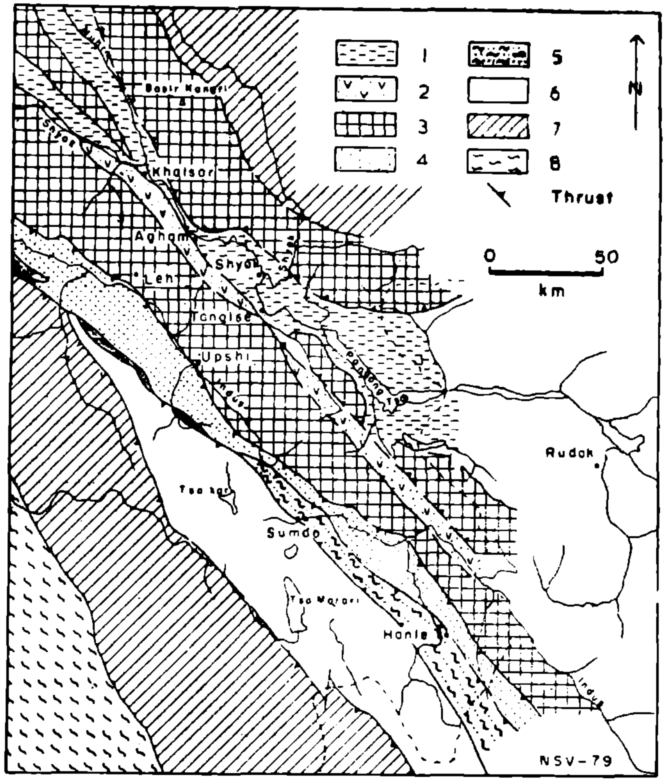

Figure 1. Geological map of the eastern Ladakh showing different litho-units : 1 = the Pongong metamorphic belt; 2 = Khardung volcanics and volcano-sediments; 3 = Ladakh and Karakorum batholiths; 4 = Indus flysch; 5 = Zildat-Sumdo metamorphic belt; 6 = Tso Morari Crystallines; 7 = Tethyan sediments and 8 = Central Crystallines. (Based on Thakur and Virdi, 1978 and author's own observations.)

For further details of the litho-characters and aerial disposition, the reader may refer to accounts given by Berthelsen (1953), Tewari (1964), Gupta *et al.* (1970), Gupta and Kumar (1975), Shankar *et al.* (1976), Shah *et al.* (1976), Gansser (1977), Frank *et al.* (1977), Sharma and Gupta (1978), Sharma and Kumar (1978), Thakur and Virdi (1979), Thakur *et al.* (1981), Virdi *et al.* (1977, 1978), Virdi (1981 *a*, *b*) and Fuchs (1977, 1979).

Geotectonic Evolution

Long before the advent of the theory of plate tectonics and its application to the mountain belts, Argand (1924), Wegner (1929) and Holmes (1944) had described the Himalaya as a product of collision between India and Asia due to northward drift of India after the split of the Gondwanaland. With the aquisition of new geological information from the Indus Suture and other parts of the Himalaya, a number of models involving the concepts of plate tectonics have been proposed to explain the development of the suture vis-a-vis the geodynamic evolution of the Himalaya (Dewey and Bird 1970; Powell and Connaghan, 1973; Le Fort, 1975; Shankar *et al.*, 1976; Frank *et al.* 1977; Tahirkheli *et al.*, 1979; Powell, 1979 and Virdi, 1981 *a*, *b*, *c*). The salient features of these models are discussed in the sequel.

(*a*) *Dewey and Bird* (1970) were the first to propose that the Himalaya represent the type example of mountains developed due to continent-continent collision. Majority of the subsequent models are based on their ideas on orogenesis and plate tectonics. They recognised two types of mountain belts, the first developed over a subduction zone where the oceanic plate is being consumed. It may be an island arc if the non-consuming plate is also oceanic, e.g., the Japanese islands or Cordilleran if it is continental, e.g., the Andes. The second type of mountain belt is the result of collision between a non-active Atlantic type continental margin with another continent with a marginal trench. The trench-bearing margin may be associated with an existing or developing Cordilleran type orogen or an island arc.

A systematic sequence of events in the approach of two continents, one with an Atlantic type margin and the other with a trench margin, shown by Dewey and Bird (1970, p. 2643, Fig. 13) clearly reveals that the collision type of mountains such as the Himalaya develop in two stages. In the first stage consumption of oceanic plate occurs along the trench due to subduction and continues till the two continents approach each other and collide. This leads to production of a cordilleran type of orogen or an island arc system. This is followed by the second stage, the collision, when the mountains develop due to underthrusting of one landmass by the other.

TABLE 1—LITHOLOGY OF THE INDUS SUTURE ZONE AND THE SURROUNDING AREA IN EASTERN LADAKH
(Excluding the transgressive Mio-Pliocene molasse)

	Rock unit	*Lithology*	*Probable age and environment of formation*
North	Karakoram Batholith	Mica granite, tonalite, gneisses and migmatites	Late Cretaceous to Eocene and Neogene batholiths intrusive in Pongong Belt
		Intrusive junction, locally tectonised	
	Pongong Metamorphic Belt	*Sumur Member* : crystalline limestone, micaschist, basic lavas, serpentinite, shale, sandstone, conglomerate; garnet kyanite schist and amphibolite. *Khalsar Member* : Chlorite schist, quartzite, limestone, amphibolites etc.	Upper Palaeozoic to Triassic (?) Platform sediments probably deposited in back-arc sea and at southern margin of the Tibetan Plate
		Khalsar-Tangtse Thrust	
	Khardung Volcanics	Rhyolite, dacite, andesite, ignimbrite, tuff, agglomerate, volcanic breccia, chert, limestone, sandstone and conglomerate	Creto-Eocene Island-arc volcanism
		Intrusive Junction	
	Ladakh Batholith	Mainly granite and tonalite, with some diorite, gabbro, aplite and pegmatite	Upper Cretaceous to Oligocene (?) Batholiths intrusive into Island arc volcanics and Pongong Belt rocks
		Thrust or unconformity (?)	
	Indus Formation	Alternations of sandstone, shale, conglomerate with limestone	Cretaceous to Late Eocene Eugeosynclinal flysch deposits
		Thrust	
	Zildat-Sumdo Ophiolitic Belt	Serpentinite, peridotite pyroxenite, gabbro, pillow lavas, jaspers, cherts, tuffs, pyroclastics, dolerites, blueschists and green schists	Cretaceous to Early Eocene Trench sequence formed at subduction zone
		Zildat Fault	
	Tso Morari Crystallines	Low to high-grade metamorphics derived from Upper Palaeozoic to Triassic sediments, and basic extrusives; Intrusive granites with thermal aureoles	Upper Palaeozoic to Triassic Platform deposits at northern margin of Indian Plate
		More Plain Fault	
South	Tethyan Sediments	Limestone, sandstone, shale, quartzite, mudstone, with basic volcanics also, Richly fossiliferous	Cambrian to Cretaceous marine sediments deposited in the Teths

(*b*) *Powell and Connaghan* (1973, p. 7, Fig. 4) also proposed an evolutionary model wherein two stages of convergence of the Indian and Asian plates, first from Cretaceous to Middle Eocene and second from Early Miocene to Pleistocene are envisaged. The Himalaya are regarded as produced not by continent-continent collision but due to underthrusting of one continental block along a deep crustal fracture within one of the lithospheric plates.

The Indus Flysch and associated Dras Volcanics are regarded as indicative of subduction at the southern margin of the Asian Plate. Heat rising from the subduction zone may have generated batholiths in Tibet above the lower part of the sialic crust and their eruptive products provided volcanic detritus for the Indus flysch which was probably deposited during Early and Late Cretaceous. The collision between the Indian and the Eurasian plates occurred along the Indus Suture before Middle Eocene when the Nummulitics were deposited throughout the Himalaya. The Eocene transgression was due to down-buckling at the collision margins of two plates as the subducting Indian Plate became jammed through buoyancy constraints of its 35-km thick continental crust. Between Middle Eocene and Early Miocene, there was little relative movement between the two plates and isostatic readjustments are reflected now by Oligocene regression and uplifts. Since Early Miocene, the active tectonic zone has been the Main Central Thrust and not the Indus Suture as is evidenced by the seismicity distribution over the Himalaya.

More recently Powell (1979) has proposed a tectonic history of the Indus Suture Zone and its extension in Pakistan. According to him, after the fragmentation of the Gondwanaland, India started its northward movement and by 70 m.y. the Indo-Pakistani sub-continent had separated from Madagaskar but still lay well south of the northern edge of the African continent. At this time, the palaeomagnetic data shows that Tethys was still 2000 km wide (*op. cit.*, p. 16) but shrinking rapidly as India moved north at the rates between 15 and 20 cm/year. The end of the rapid northward flight of India occurred around 55 m.y. ago. Geologically, this time is very important for the initial contact had probably already occurred between the Indo-Pakistani continent and the island arc or the continental margin at the southern edge of Eurasia. The zone of convergence conciding with the Zagros Thrust line in the west and passing through Chitral probably continued eastwards into the Indus Suture Zone.

(*c*) *Le Fort* (1975) has also proposed a model for formation of the Himalaya where again a two-stage development is envisaged. The first stage resulted into an Andean-type orogenic belt at the southern margin of the Asian Plate due to subduction of the Tethyan ocean floor. This stage was interrupted when the Indian continent began to impinge on the Tibetan mass about 45 m.y. ago (Middle Eocene) along a zone corresponding to the former trench. This is now preserved as the Indus-Tsangpo Suture. The better state of preservation of the ophiolitic rocks in northwestern region is explained due to its having undergone less under-thrusting than the eastern and central regions where a larger width of the elevated Tibetan Plateau is observed. The model of Le Fort (1975) is similar to that of Powell and Connaghan (1973) though it differs in the amount of underthrusting of the Indian Plate below the Asian Plate. He also does not favour the height of Tibetan Plateau as a result of doubling of crust due to superposition. After the collision along the Indus Suture, the thrusting was accomodated first along the Main Central Thrust and then the Main Boundary Fault.

(*d*) *Shankar et al.* (1976) proposed a model for the evolution of the Indus Suture Zone, according to which (*op. cit.*, p. 52) after the split of the continents of the Gondwana land, the Indian Plate started drifting due North. The entire region between the Indian and the Asian plates was occupied by shallow epicontinental sea where fossiliferous Triassic to Middle Cretaceous sediments were deposited.

By the Cenomanian times, the Indian Plate had reached close to the Asian Plate and subduction of the northern edge of the Indian Plate commenced under the Asian Plate resulting into rupturing and uplift of the oceanic crust and development of the Indus Suture Zone. Intermittent outpouring of volcanic lavas took place, which now occur as pillow lavas associated with agglomerates, tuffs and are interlayered with phyllites and limestones. With continued northward drift and consequent squeezing due to continental collision, earlier crystallized heavier layers of ultramafites were pushed up as crystal mesh and emplaced in the form of cold intrusion in the uppermost Cretaceous after the deposition of coralline limestone of Upper Cretaceous to Lower Tertiary age.

With the opening of the Indus Suture Zone, the entire sea floor over it was shattered and its sediments were uprooted and transported southwards along with the ultramafic and basic volcanic flows as olistostromal masses now seen at several places as exotic blocks overlying the Tethys zone sediments. Concomitant with the ultramafic and basic volcanic activity in the suture zone, an uplift of the southern edge of the Asian Plate took place, with the gradual emergence of the Ladakh and Karakorum ranges by extensive granitic activity during the Late Cretaceous to the Early Tertiary period. This resulted into the formation of a linear shallow intercontinental basin where a thick pile of coarse detritus referred to as the Indus Formation was deposited during post-Eocene(?)-Miocene period. The youngest phase of igneous activity was represented by Chumathang Granite of post-Miocene or Pliocene age which intrudes the Ladakh Granite as well as sediments of Indus Formation. Events in the Indus Suture Zone took place concomitantly with intense mountain-building activity in the Himalayan region and outpouring of voluminous flood basalts on the Indian Shield.

(*e*) *Frank et al.* (1977) also regard the Indus-Tsangpo Suture as the remnant of the former oceanic crust between Asia and the Indian sub-continent. In their model they assume the oldest rocks of Indus Suture zone to be their Lamayuru Flysch. The flyschoid-pelitic sedimentation continued in some zones from the Middle Triassic to the Lower Tertiary. No volcanic influence is known in this sequence deposited adjacent to the Zanskar platform-type sediments and separated from the Dras Volcanics by the southern mélange zone. Whereas the Zanskar sediments definitely rest on old sialic crust, the authors are not clear however as to on which rock series the Indus Flysch was resting. In their model it is assumed that metamorphic basement, if at all present, was extremely thin. Further to the north an older oceanic crust with thin sedimentary cover may have existed. The Dras Volcanics, basaltic to andesitic in composition including the Upper Cretaceous sediments, developed in the northern part of the Indus Flysch Zone. The volcanicity was related to an oceanic rift volcanism rather than Island arc volcanism. The Ladakh intrusives regarded as a continuous Late Cretaceous to Early Tertiary magmatic event presumably formed as a result of the consumption of the former crust between India and the Asian continent. The consumption is suggested firstly along Shyok and later along the Indus Suture Zone. The mélange zones on both sides of the Dras Series developed in the late stages of convergence. Even major slices of ultramafics have been dragged into these tectonically highly disturbed zones. The large-scale over-thrusting of the Spongtang Klippe (Fuchs, 1977) to the south is a pronounced post-(? Middle)-Eocene tectonic feature which has correspondence in the Amlang-la area of Tibet (Heim and Gansser, 1939). Though the mechanism of over-thrusting is not clear, most probably it is in close relationship with final closure of the ocean by collision of the two continental masses which presumably ended before that time (40 m.y.) when also the drift rate dropped remarkably (Molnar *et al.*, 1977). The renewed convergence ($\pm$ 20 m.y.) caused pronounced N-vergent thrust planes in this area whereas in the southern Himalaya the south vergent nappes developed (Main Central Thrust). Younger thrust planes partly along the mélange zones cut obliquely the older structures and so tiny relicts of glaucophane schist were brought up to the surface in the Kargil area.

Transformed to a narrow and steepened zone between thickened continental masses, except for late strike slip movements, the Indus-Tsangpo Suture Zone then became inactive.

(*f*) *Tahirkheli et al.* (1979) have proposed a two-stage tectonic evolution of the Kohistan collision zone in northern Pakistan. The zone constitutes the north-western extension of the Indus-Tsangpo Suture Zone of Ladakh and Tibet. In this region also there is evidence of thrusting of oceanic material into the Indian continent and the presence of blueschist facies metamorphism.

Fig. 2 shows a synthesis of possible tectonic evolution as envisaged by Tahirkheli *et al.* (1979). The first stage includes subduction of the Tethyan ocean floor beneath an Island arc and a marginal basin through subduction of its floor beneath the Asian mainland, followed by a second collision and complete suturing.

In each of the two successive stages of suturing, the deformation appears to be linked not to the subduction itself, but to the choking of the subduction zone, resulting from collision with the continental crust, such material being both too light and too thick to be pulled down farther than some tens of kilometres.

Thus, Tahirkheli *et al.* (1979) also propose subduction along two suture zones with northern younger and the southern older in contrast to Gansser (1977) and Frank *et al.* (1977) who would put an older northern and a younger southern suture in Ladakh region.

SUGGESTED MODEL

A careful study of Table-1 and Figure 1 would reveal that the rock assemblages in various litho-units correspond to those observed in regions of convergent plate boundaries. According to Condie (1976) and many others, when zones of crustal subduction are studied from the trench in the direction of the dip of subduction zone, we get the following characteristic petro-tectonic assemblages :

(*a*) The trench — Mélange, large blocks of broken and sheared rocks of diverse origin set in a sheared matrix, ophiolites and blueschists, volcanics, volcano-clastic sediments with cherts and jaspers.

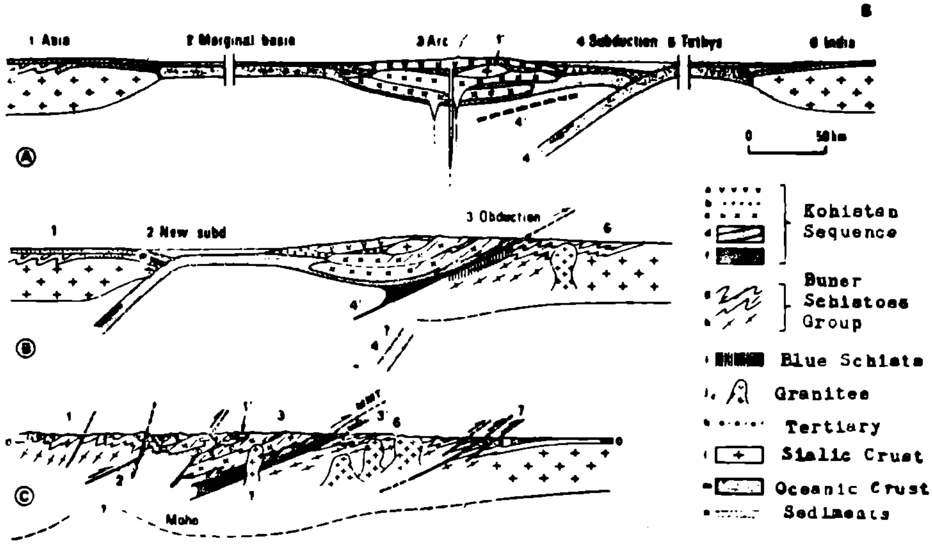

Figure 2. Three possible stages of the India-Eurasia collision in Kohistan. A : *Late Cretaceous* : 1—Continental crust of Asia (with Mesozoic and Palaeozoic cover). 2—Marginal basin. 3—Calcalkaline volcanic/plutonic arc and subordinate sediments (with some sialic remnants, 1). 4—Main subduction zone. 5—Tethyan ocean, already almost closed. 6—Indian Shield, with unfolded Palaeozoic and Mesozoic (?) cover. *B* : *Early Tertiary* : 1—idem. 2—New subduction zone induced at the margin of the Asian mainland by collision of India with the arc. 3—Arc (and oceanic material) obducted on Indian Shield. 4—Detached sinking slab. 4'—New thrust surface activated by the collision (MMT). 6—Indian Shield. *C. Late Tertiary* : 1—'Asia' begins to deform strongly. 2—Northern suture (obliterated locally by strike-slip faulting). No ocean floor left. 3—'Kohistan sequence', with sialic remnants (1') and post tectonic granitic plutons. 6—'Buner (or Lower Swat) schistose group' with mesozonal metamorphism (blueschist slice, 3). Numerous granitic plutons. 7—Boundary overthrusts on recent sediments. *Legend* : a—Calcalkaline volcanics; b—Mesozoic sediments associated with arc; c—metagabbros; d—amphibolites; f—overthrust mantle rocks; g—folded Palaeozoic, with cleavage; h—orthogneiss; i—high-pressure (blueschist) metamorphism; j—post-tectonic granitic plutons; k—Tertiary sediments; l—sialic crust; m—oceanic crust (and amphibolites in Kohistan basic complex); n—unfolded sedimentary cover of continents.

(*b*) The arc-trench gap — Eugeosynclinal assemblage and uplifts.
(*c*) The arc — Calc-alkaline volcanism and granitic rocks.
(*d*) The rear-arc area — Eugeosynclinal assemblage merging with deep-sea sediments or miogeosynclinal assemblage.

Thus in Ladakh from south to north, the Zildat-Sumdo Ophiolitic Belt and Dras Volcanics correspond to trench or subduction zone; the Indus flyschoidal sediments to the arc-trench gap, the Ladakh batholith and Khardung Volcanics to the arc, while the Pongong belt does so to the rear-arc area.

The petro-tectonic assemblages mentioned above developed during the northward movement of the Indian Plate during late Mesozoic and its consumption along the trench at the southern margin of the Eurasian land-mass (Fig. 3). Though Dewey and Bird (1970) and Le Fort (1975) favour the development of a Cordilleran type of orogen before the actual collision of the Indian and Eurasian plates took place, the author favours the production of an island arc system off the southern margin of Eurasia and the formation of back-arc sea similar to the Japan Sea (Fig. 3) in which younger Mesozoic rocks were deposited over the already existing platform deposits of Palaeozoic age (Desio, 1974, 1979). This way we can explain the close association of flyschoidal sediments, volcanics and small lenticular bodies of serpentinite occurring in the upper part of the Pongong belt in the Shyok valley. Frank *et al.* (1977) and Gansser (1977) cite the ultrabasics of Shyok valley as indicative of an older subduction zone. The author does not agree with this view as small amounts of basic and ultrabasic activity always accompany early phases of geosynclinal sedimentation (Auboin, 1965; Miyashiro, 1967).

The development of an island arc system was accompanied by volcanism and emplacement of calc-alkaline plutons into already deposited sediments, volcanics and volcano-clastics. Towards the ocean side of the island arc, flyschoidal sediments were deposited represented by the Indus Formation. The granites and volcanics exposed in the island arc region in the north, the metamorphics of the Tso Morari belt and ophiolites of the Sumdo belt in the south provided sediments to the flysch basin. This is further confirmed by pebbles of granite, gneiss, schists, hornfelses, volcanics, basics and ultrabasics, cherts, jaspers and limestones containing Permian fossils (Frank *et al.*, 1977). The fossiliferous limestone pebbles may be from the Thag-lang la Formation of the Tso Morari Crystallines (Virdi *et al.*, 1978), which have yielded Upper Palaeozoic fauna of Tethyan affinity. These eugeosynclinal sediments were deposited on the continental shelf and slope, marginal to a northerly sialic crust of the Tibetan landmass.

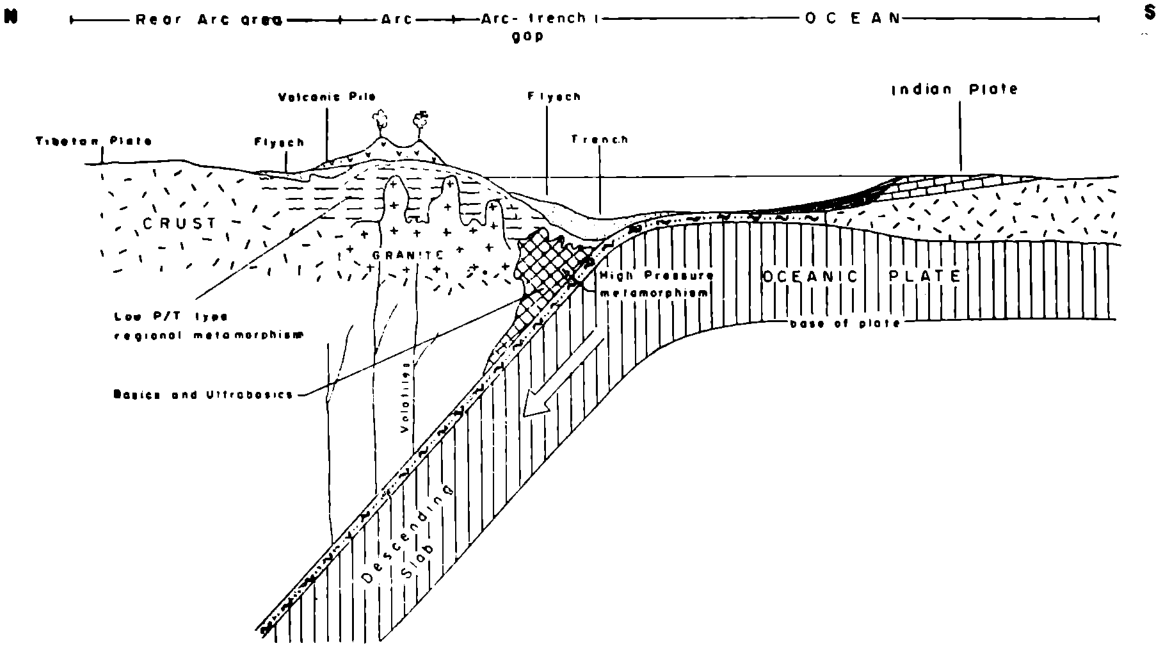

Figure 3. Schematic model for the development of paired metamorphic belts in the Indus Suture Zone of Himalaya, prior to the collision of Indian and Tibetan plates.

Progressive encroachment of the continental lithosphere plate over the descending oceanic plate due to movement of two plates towards each other caused tectonic thickening of the mélange. Also rapid relative movement and pressure loading due to overthrusting of continental plate would have allowed for the great down-buckling of byoyant, relatively cold and chaotically deformed eugeosynclinal rocks. This resulted into high pressure metamorphism with the production of blueschists and also conversion of basaltic material into amphibolite and greenschists.

During the final stages when the oceanic plate had nearly been consumed and the Indian and Tibetan landmasses were approaching each other, the northward movement of India could have been responsible for widespread overthrusting along the Benioff zone. This produced the Lato-Nidar thrust between flysch and the ophiolites. Other thrusts could have also produced an imbrication of older and younger units of mélange (Zildat-Sumdo belt) as well as between the Indus flyschoidal sediments. Such structural complications may be responsible for the observed intimate association of feebly and more metamorphosed mélange rocks as well as their complex tectonic contacts with roughly co-eval Indus Formation. This stage possibly continued upto the end of Oligocene when due to continued northward movement, the mélange was thrust over the Tso Morari Crystalline or over the Triassic sediments as in Kargil-Dras region. At places the south directed thrusting is so pronounced that we get klippen of mélange now 10 km away from the main thrust zone, e.g., around Karzok, Spontang, Spongchan etc. (Fuchs 1977; Thakur and Virdi, 1978). At other places the sediments have nearly overlapped the mélange and are now in direction contact with the Tethyan sediments of the Tso Morari belt as is observed near Lato in the Upshi-Gya section.

Paired Metamorphic Belts in The Indus Suture Zone

Like other zones of plate convergence or subduction in the circum-Pacific region, the Indus Suture Zone also exhibits a pair of metamorphic belts with a northern low-pressure and a southern high-pressure belt. Details of mineralogical and other features have been described by the author elsewhere (Virdi, 1981 *a*, *b*).

Of the two metamorphic belts, the northern Pongong belt is characterized by andalusite-kyanite type metamorphism accompanied by andesitic and rhyolitic type volcanism and granitic activity. The southern or the Zildat-Sumdo belt displays glaucophanic metamorphism accompanied by basic and ultra-basic (ophiolitic) rocks (Virdi *et al.*, 1977; Thakur and Virdi, 1979).

The two belts are now separated by the Ladakh batholith and the Indus flyschoidal sediments (Fig. 1). It has been proposed by the author that the two belts developed prior to the collision of the Indian and Tibetan landmasses when due to northward movement and consumption of oceanic crust of the Tethys an island arc system was produced north of the trench marking the subduction zone. The high-pressure belt developed on the ocean side of the trench when thick cold oceanic slab was dragged down the subduction zone into regions of unusually high pressure and low geothermal gradient. North of the trench, the southern continental margin of the Tibetan Plate was characterized by a volcanic chain and underlying sediments deposited in the back-arc region. The sediments were deformed and metamorphosed by granitic plutons to produce a low-pressure metamorphic regime (Fig. 4).

Recently, Kumar (1978 : 128) proposed that in the northwestern Himalaya the Central Crystallines on the south and the Puga-Sumdo formations together on the north (the latter named as Tso Morari Crystallines and the Zildat-Sumdo Belt by the author, see Fig. 1 and Table 1), suggest to be a pair of metamorphic belts similar to those observed in Japan, California and Taiwan (Miyashiro, 1967, 1972, 1973). This view further corroborated by Sharma and Kumar (1979 : 266) is, however, untenable and contradictory to all the models proposed so far, for the evolution of the Himalaya. This would require the Tibetan Plate to move towards south and consumption of the oceanic crust of the Tethys along a subduction zone dipping due south. Then only will the high-pressure belt develop in the north and a low-pressure belt in the south. The inference of Kumar (1978) has been contradicted not only by the author (Virdi, 1981*a*, *b*) but Powell and Connaghan (1973, p. 9) also, who assert that the "Central Gneiss and ophiolite-bearing Indus Flysch do not represent a paired metamorphic belt as they are of distinctly different metamorphic ages", i.e., the metamorphic episodes affecting the two regions are widely separated in space and time. It is thus the Pongong Belt and Zildat-Sumdo Belt which together represent a true pair of metamorphic belts.

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The Limits of Indian Plate Drift

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ABSTRACT

Both structural and palaeontological data preclude the possibility that India was separated from Asia in the Late Paleozoic by a huge 6000 km wide ocean. Migration of shallow water benthic fauna and even of terrestrial plants and tetrapods was possible in both directions across this assumed ocean. The ophiolites of the Indus-Tsangpo Suture are remnants of a non-sialci ('oceanic' crust) formed in the main tensional phase of the Tethys during the Late Triassic to Early Cretaceous as in other parts of the tethys.

INTRODUCTION

During the last few years almost dogmatically a huge northward drift (about 6000 km) of the Indian peninsula during the Mesozoic time was postulated. According to this extremely mobilistic model India should be situated in the Late Paleozoic near Madagascar, East Africa, Antarctica and Australia. Between India and Asia a huge ocean of about 6000 km width was placed (see Fig. 2). The plate tectonic reconstructions differ somewhat in the exact position of the Indian 'plate' (adjacent to Africa or to Australia), but a continental connection between India and Antarctica was postulated in almost all plate tectonic reconstructions.

Only a few papers with moderate mobilistic or non-mobilistic reconstructions were published during the last ten years (e.g., Meyerhoff and Teichert, 1971; Meyerhoff and Meyerhoff, 1972; Kozur, 1976; Acharyya, 1979; Belousov *et al.*, 1979). In all these reconstructions India was separated in the Late Paleozoic from Antarctica and Australia and no huge northward drift of India of about 6000 km was accepted.

In the mobilistic concepts the Indus-Tsangpo Suture is usually assumed to represent the northern limit of Gondwana India (Gansser, 1964; Le Fort, 1975) separating the Gondwana floral and faunal realm in the south from the Cathaysia realm in the north. The newest data strongly contradict this opinion.

STRUCTURAL EVIDENCES

In the whole Tethyan realm of western Asia and Europe no Tethyan or Palaeotethyan ocean was in existence during the Permian and Lower Triassic periods. Arabia-Africa and Eurasia were connected in this time and only continental deposits or shallow water sediments of an epicontinental sea were deposited in this area (see Kozur, 1976; Argyiadis *et al.*, 1980). Further in the east, in Iran, also no traces of an oceanic Permian Palaeotethys can be found. There are widely distributed Permian and Scythian shallow water sediments and above all in the Lower Permian there are also many gaps in the sedimentation. Also, from the Pamir and Himalaya no evidences for Permian oceanic crust or Permian deep-sea sediments are actually available. According to a personal communication from Prof. L. E. Ricou. Orsay, in the Tethyan Himalaya Sequence (Tibetan Sequence) Paleozoic shallow water sediments and diamictites of the uppermost Carboniferous are present. In the northward following Late Cretaceous wild flysch olistoliths with Permian shallow water sediments are present. The ophiolite sequence of the Indus-Tsangpo Suture is clearly Mesozoic in age (see, e.g., Acharyya, 1979; also Prof.

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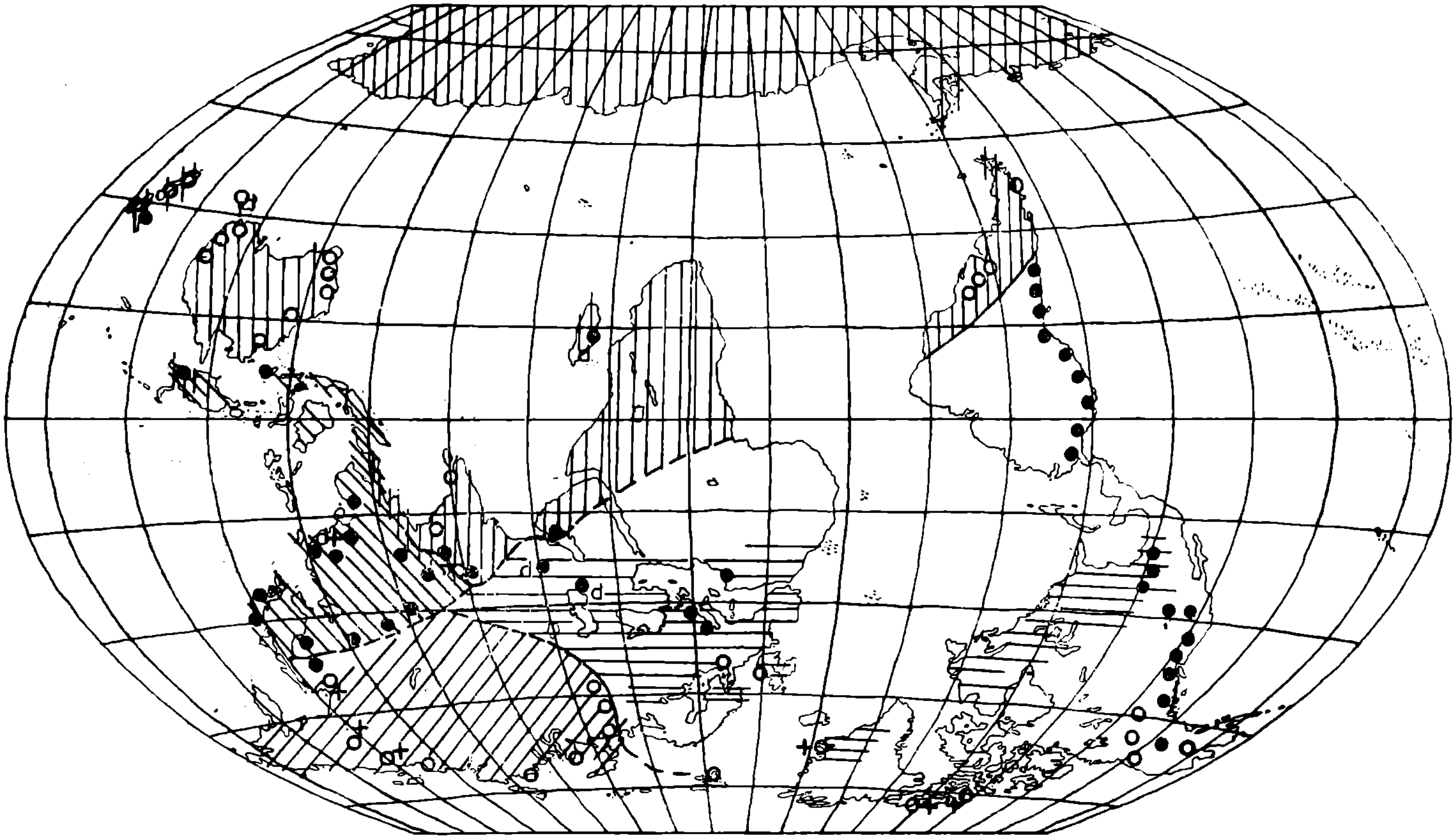

Figure 1.

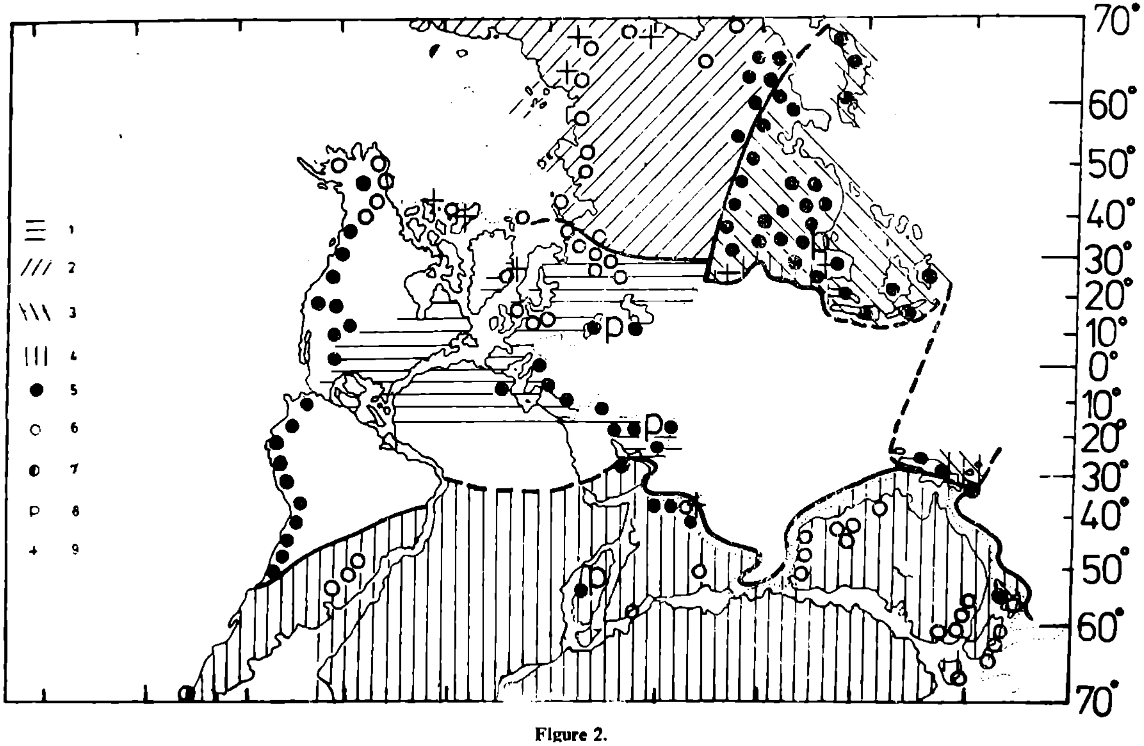

Figure 2.

L. E. Ricou, personal communication). Only the Kikixeli Suture further in the north with transgressive Norian could be regarded as the suture of an old ocean between India and Asia, but the palaeontological evidences do not support this possibility. Moreover, ophiolites are only locally present here to a minor extent (see Fig. 1 in Acharyya, 1979) and restricted to a limited area. Even in the Permian of Pamir shallow water sediments predominate. There are also some deeper water sediments, but neither Permian deep-sea sediments nor Permian ophiolites occur. Therefore, in the whole of Himalaya and adjacent regions no evidence exists for a subduction of a huge Palaeozoic ocean between India and Asia.

From the Turkey to the Alps the tensional phase of the Mesozoic Tethys is rather well-studied. The first breaking apart through the Permoscythian platform happened here during the Upper Scythian (Olenekian Stage) and basal Anisian (e.g., Chios, Dobrogea, Trans-sylvanian Nappe System), but became more widespread during the Middle Anisian to Lower Ladinian. At the end of the Triassic (in the East) and in the higher Liassic or still later (in the West) the tension became so strong that in long, but rather narrow belts the sialic crust almost disappears. These are the 'oceans' in the sense of plate tectonics, but surely such areas without sialic crust within the Alpine orogene were never so broad as present-day oceans. They were no real barriers against the migration of shallow water benthic animals across these areas. On the contrary the present-day oceans form such barriers and the benthic shallow water animals migrate only along their margins. In a geological short time, those 'oceans' were again subducted and their remnants are present in the true ophiolitic belts (unfortunately, often all submarine lava sequences, frequently associated with radiolarites are regarded as ophiolitic sequences and remnants of oceanic crust, but these sequences were formed on continental crust, see Marcoux and Ricou, 1979). On the other hand, the real oceans exist considerably longer than the non-sialic belts within the geosynclines. For instance, the Pacific Ocean was already a huge ocean in the Late Paleozoic and Triassic. Only along its margins, but not across this ocean the Permian and Triassic shallow water organisms and even the most nectic ones could migrate (see Kozur, 1976). Even if we assume that the Atlantic Ocean was not present earlier than the Lower Jurassic, then this ocean existed (and will exist !) considerably longer than the tensional structures without sialic crust within the geosynclines that did never exist longer than about 100-130 m.y. This is the basic distinctive feature of all real oceans and the non-sialic tensional structures should not be designated as oceans.

The orogenetic development of the Himalaya is very similar to that of other parts of the Alpine Mediterranean regions. There are no structural or stratigraphical evidences to substantiate that the ophiolites of the Indus-Tsangpo Suture are older than Late Triassic. But only in this suture the true ophiolites are widespread enough so that here, at least theoretically, the remnants of a large ocean could be assumed. However, since the ophiolites of the Indus-Tsangpo Suture are not older than Late Triassic and most probably not younger than Aptian-Albian, they do not represent the remnants of a true ocean but the remnants of a non-sialic tensional structure alike other parts of the Tethys. In all cases these ophiolites cannot be the remnants of a huge (about 6000 km-wide) Palaeozoic ocean between India and Asia.

PALAEONTOLOGICAL EVIDENCES

For a long time the close similarity or even correspondence of the Indian Late Palaeozoic flora and fauna

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Figures 1 and 2. Floral and faunal distribution in the Permian according to the fixistic (Fig. 1) and mobilistic (Fig. 2) models. The mobilistic model does not contradict the formation of the Atlantic ocean during the Mesozoic and Cenozoic time. But, of course, the floral distribution at both sides of the Atlantic could also be explained by later subsided land bridges or subsided islands, e.g. in the Thule province. Even without land bridges the Gondwana flora could migrate through the Antarctic to South America and the Euramerian floras of Europe and North America could migrate through Greenland.

Quite impossible according to the floral and faunal distribution is the separation of India and Asia by a huge Late Palaeozoic ocean. The Gondwana-Cathaysia mixed floras of Himalaya, Thailand, Yunnan and New Guinea could not be explained in such reconstruction. Also the isolated occurrence of *Otoceras* at the northern Gondwana margin in India 6000 km away from the occurrences in southern Asia could not be explained. Moreover, the Cathaysia tropical floral province would have a N-S distribution from about 15°N to 70°N with an isolated occurrence several 1000 km in south in New Guinea about 30°S separated by a huge ocean from the remaining Cathaysia province. The warm water and boreal faunas of the northern hemisphere would have a general N-S distribution across the paleolatitudes.

Legends : 1. = Eurameric floral realm; **2** = Angaride floral realm; **3** = Cathaysia floral realm; **4** = Gondwana floral realm; **5** = Warm water fauna (Tethyan fauna); **6** = Boreal and notal faunas; **7** = Rather warm water fauna, but not typical Tethyan one; **8** = *Paratirolites* fauna of uppermost Permian; **9** = *Otoceras* fauna of topmost Permian.

with those of Australia, Antarctica, and South Africa† as well as the occurrence of diamictites of the uppermost Carboniferous on the one hand and the apparently quite different flora in the adjacent Tethys and Cathaysia realm on the other lent a strong support for the huge (about 6000 km) northward drift of India towards Asia since the end of the Permian. The very sharp boundary between the Gondwana and Cathaysia floral (and faunal) realm should be at the Indus-Tsangpo Suture that was assumed to be the suture line (ophiolites) of the large ocean between India and Asia. Sharma *et al.* (1980) have recorded the occurrence of Upper Gondwana plants (*Ptilophyllum cutchense* Morris, *Ptilophyllum* sp., *Elatocladus* sp. cf. *E. plana* (Fst) Seward, *Taeniopteris* sp., *Brachyphyllum* sp. and a large number of equesetalean (-like) stem impressions (devoid of leaves or leaf sheafs) from a small hillock along the left bank of Indus, about 50 km upstream of Loma, which is situated north of the Indus Suture Zone. The plant fossils occur in a thin zone which is about half a metre thick and these beds are found in small detached hillocks. Lithologically, the plant-bearing beds consist of dark-coloured quartzites, creamish quartzite, calcareous sandstone, conglomeratic breccia and carbonaceous shales.

Lately, it has become clear that this concept is quite invalid. *Lystrosaurus* that was found formerly only in Antarctica, South Africa, and India is now also known in the southern and northern foothills of Tien Shan, in the Cathaysian Shansi Basin (Acharyya, 1979) and even east of Moscow (Kalandadze, 1975). Since this tetrapode is absent in the well-studied sections in central and western Europe as well as in North Africa and most of the occurrences of *Lystrosaurus* outside of 'Gondwana' are known from China, its migration route was most probably from India to Asia.

In Kashmir, clearly a marginal part of 'Gondwana', the Carboniferous flora with Cathaysian and Europian affinities is followed by the Permian Gondwana flora (*Gangamopteris*, etc.) in a sequence of marine and continental beds. Together with this Gondwana flora that contains also Cathaysian elements a typical European tetrapod fauna with *Archagosaurus ornatus*, *A. kashmiriensis*, and *Actinodon risiensis* occur (Acharyya, 1979; Boy, in press; personal communication, Prof. J. Boy, Mainz). The migration route of these elements is most probably the same as for the Cathaysian floral elements and in reversed direction for *Lystrosaurus*, because in Gondwana-Africa quite different Permian tetrapods are known.

North of the Transhimalayan Batholith, about 150 km north of the Indus-Tsangpo Suture, folded beds with diamictites of the uppermost Carboniferous and with *Gangamopteris* of the Permian are present.

Also in Thailand, Yunnan and New Guinea mixed Cathaysian-Gondwana floras or successions of Cathaysian and Gondwana floras occur. The Lower Triassic shallow water benthic microfauna of Kashmir and of the Salt Range is quite the same as that from the Asiatic northern margin of the Tethys (see also Kozur, 1976). Also, such stenohaline marine shallow water benthic faunas that are unknown in the Lower Triassic from the western part of the Tethyan faunal realm are present both at the southern margin of the Himalayan Tethys and on the northern margin of the Asiatic Tethys. Therefore, a shallow water connection between Asia and the northern margin of India was still present in the Lower Triassic. In the later Mesozoic the floral and faunal connections between the northern and southern margin of the Asiatic Tethys were rather more restricted than during the Permian and Lower Triassic. So, in the Thakkhola area of Nepal a typical Upper Gondwana (Early Cretaceous) flora occurs. In the Lesser Himalaya the Blaini diamictites of the uppermost Carboniferous has 'northern' affinities, whereas the Late Mesozoic Krol-Tal sequence of the same area has 'Gondwana' affinity (tensional phase of the Tethys during the Jurassic and Early Cretaceous). However, even during this time the migration of terrestrial floral elements and of shallow water benthic fauna across the Tethys was possible to some extent so that the tensional structure without sialic crust within the Himalayan Tethys was certainly not very broad unlike the present day oceans.

Gupta and Webster (1980) have discussed the possible plate tectonic relations between India and Timor on the basis of the existence of similar forms of *Deltoblastus* in both the regions. These regions are at present about 8,000 km apart but the presence of *Deltoblastus* in both the regions implies their closer proximity during Permian times as blastoids have generally a restricted geographic distribution at the genus level. The occurrence of *Deltoblastus* both in Timor and Kashmir is not proof of a greater proximity between the two areas in the remote past but it only suggests that this genus lived in the same seaway connecting the two areas under similar climatic-ecologic conditions.

†As pointed out by Truswell (1980 : 109) there are in reality big differences between the Gondwana flora on the different continents. "Details of microfloral composition throughout Gondwanaland suggest that this floristic unity was more apparent than real . . . differences in the microfloras may be quite pronounced within the region." According to him the differences in the microfloras between India and Antarctica are considerable. More similarity exists between India and Africa. This is not surprising, because there was a link between India and Africa via Iran and Arabia in the Late Palaeozoic as today.

Whereas all latest findings show that no huge Palaeozoic ocean was present between Asia and India there are also evidences that India was never situated adjacent to Australia, Antarctica, and Africa. Between Australia and Madagascar a large sea was present already in the Late Permian and Early Triassic (see Kozur, 1976). Acharyya (1979) could prove the occurrence of marine Permian along the SE coast of India. Moreover, in his opinion the marine Early Permian ingressions in central India came neither from the east nor from the Himalaya, but along the Narmada lineament from the west. If this view is correct, then also west of India marine Permian was present.

If India was adjacent to Antarctica in the Late Palaeozoic and larger part of the Mesozoic, then the Gondwana sequence of the Amery Ice Shelf (eastern Antarctica) and of the Mahadani valley (southeast India) must be the same. The similarity of the Precambrian basement is not convincing, because similar Precambrian basement can be found in many parts of the world. The Gondwana sequence of the Amery Ice Shelf (see Mond, 1972) and of the Mahadani valley is quite different. The Mahadani valley sequence is closely related to other Indian Gondwana sequences with variegated reddish shales of the uppermost Permian and Lower Triassic, indicating a warm and drier climate. In the Amery Ice Shelf during this time grey beds with coal seams were present indicating a wet and probably cooler climate. So, the southeast India Mahadani valley sequence belongs to the same climatic realm as the remaining India with warm and drier climate in the Upper Permian and in the Lower Triassic (the time of evaporite maxima in the sense of Meyerhoff, 1970). On the contrary the assumed adjacent part of Antarctica belongs to another climatic belt with wet and probably cooler climate like the whole Antarctica in this time. This is quite in agreement with the hypothesis of Meyerhoff that in the time of evaporite maxima in the polar regions no ice caps are present, but a wet mild climate can be observed. Therefore, the time of the evaporite maxima with continental red beds in many parts of the world is the time of coal-bearing beds in Antarctica.

No equivalents of the Late Jurassic-Early Cretaceous Athgarh Sandstone of the Mahadani valley section with *Ptilophyllum* and Wealdon flora are present in the Amery Ice Shelf section. This is all the more surprising, because the Athgarh Sandstone lies even on Precambrian basement near the coast. In this case, especially this sequence, should be present in the Amery Ice Shelf section, if India was adjacent to Antarctica.

Therefore, according to the Gondwana sequences in the Amery Ice Shelf section of Antarctica and the Mahadani valley section of SE India both continents or subcontinents respectively could not be in adjacent position during the time span of Late Palaeozoic to Early Cretaceous.

CONCLUSIONS

1. The ophiolites of the Indus-Tsangpo Suture are not the remnants of a huge Palaeozoic ocean between India and Asia, but remnants of non-sialic crust formed during the main tensional phase of the Mesozoic Tethys during the Late Triassic to the Early Cretaceous like in other parts of the Tethys.
2. This non-sialic crust was formed within the northern part of India and not north of India.
3. Floral and faunal exchange between the Gondwana and Cathaysia (and Eurameric) realms were possibly during the Carboniferous, Permian and Lower Triassic. Even terrestrial tetrapods could migrate in both directions between Asia and India. Therefore, the possibility of the existence of a huge ocean between India and Asia in the Late Palaeozoic and Early Triassic can be ruled out.

The floral and faunal differences between the Permian Gondwana and Cathaysia realms were ecologically controlled. In spite of this fact, mixed faunas and floras are known from the areas near the boundary of both realms and some elements of the 'northern' and 'southern' floras and faunas penetrated far into the Gondwana and Cathaysia realms respectively.

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Reconnaissance Geology of the Area between Leh and the Markha Valley, Ladakh

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ABSTRACT

The relatively unstudied Leh-Markha valley area of Ladakh contains nine major stratigraphic units. Molasse deposits on the north unconformably overlie thick Eocene shelf and flysch units to the south. The latter are overthrust by a complex set of units, including ophiolitic olistostromes, mélanges, flysch and molasse units. Along the Markha valley, these units are in turn faulted (? overthrust) by a thick limestone-shale sequence and then by the Precambrian? to Triassic Zanskar parautochthon. This paper summarizes field observations made in 1981 and must be regarded as only preliminary.

INTRODUCTION

During July and August, 1981, I made several traverses between Leh and the Markha valley (Fig. 1), with the aim of studying the thick molasse units and the fossiliferous Eocene sequence recorded by Dainelli (1933-34). Surprisingly, a thick Eocene flysch sequence and an ophiolitic mélange and olistostrome were discovered.

Previous work on the area south of Leh is limited. Stoliczka (1866), Lyddekker (1880) and La Touche (1888) recorded Numulitic limestone from Skio, the Shingo La (Kunda La) and from Rumbock. Dainelli (1933-34) made a traverse southwards from Leh across the Kunda La, recording Eocene fossils which were described by Fossa Mancini (1928). Recently, Frank *et al.* (1977) noted some of the features of the molasse east of Leh and Pal *et al.* (1978) and Pal and Mathur (1977) made tectonic and sedimentary observations and published maps of the area between Leh and the Markha valley. However, my observations differ somewhat from theirs.

The map on Figure 1 is based on two complete traverses (from Leh to Skio, and Hankar to Hemis) and one partial traverse (from Chaluk up the valley of the Lada Chu). Periodic observations were also made in the Markha and Indus valleys. Extrapolation between these traverses were made, where possible, from sattellite photographs.

DEFINITIONS

In view of the frequent use, and misuse, of the terms 'flysch' and 'molasse' in Ladakh, I will define these terms as used here.

The term 'flysch' (small letter) is used for thick sequences of re-deposited deep-water clastics (Rupke, 1978). The term 'molasse' (small letter) is used for thick post-orogenic successor basin or foreland basin continental to shallow marine clastics, sometimes with deeper water 'flyschoid' turbidite units (cf. Mitchell and Reading, 1978). Further discussion of these terms will be in a comprehensive paper covering all the clastic units in Ladakh (Brookfield and Andrew-Speed, in preparation).

STRATIGRAPHY

The sequences can be divided up into nine main units of differing character and/or separated by faults or unconformities (Figs. 1, 2). Since I do not have all the data required for formal stratigraphic descriptions, the units are simply designated by numbers or letters (Table 1).

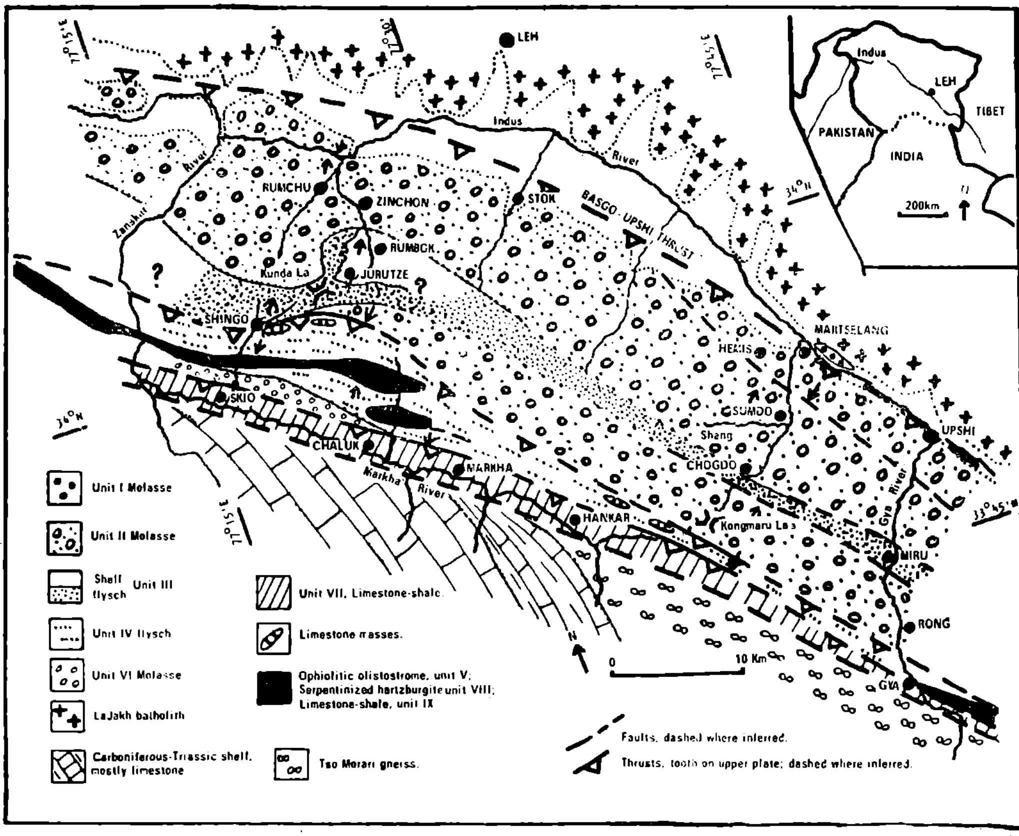

Figure 1. Tentative geological map between Leh and Markha (inset shows location). Blank along Indus valley is recent sediments. Eastward extension based on Pal and Mathur (1977) and Gupta *et al.* (1970). Base map was drawn from satellite photographs, due to inaccuracies in 1 : 250,000 maps at present available. Names are spelled as on 1 : 250,000 maps, where cited, otherwise according to previous authors.

TABLE—1 UNITS DISTINGUISHED IN LEH-MARKHA VALLEY AREA

Unit	*Lithology*	*Environment*	*Age*
1	Arkosic sandstone, conglomerate, minor siltstone and shale	Alluvial fan molasse	?Post-Oligocene
2	Multicoloured conglomerate, sandstone and shale	Braided-meandering stream, minor lacustrine, molasse	Post-Eocene
3	Red sandstone and shale overlain by calcareous sandstone and shale and graded calcareous sandstone and shale with thin limestones	Marginal marine and freshwater shelf, overlain by deep shelf flysch.	Eocene
4	Thinly bedded calcareous sandstone and calcareous shale	Deep shelf flysch	?
5	Conglomerate, conglomeratic sandstone and phyllite (Ophiolitic olistostrome)	(?)Deep to shallow shelf	?
6	Conglomeratic sandstone and shale	Braided stream molasse	?
7	Limestone and shale, thin-bedded	Shallow-deep shelf	?
8	Serpentinized hartzburgite	Ocean floor	?
9	Thin limestone and green-red shale	(?)Deep shelf-ocean floor	?

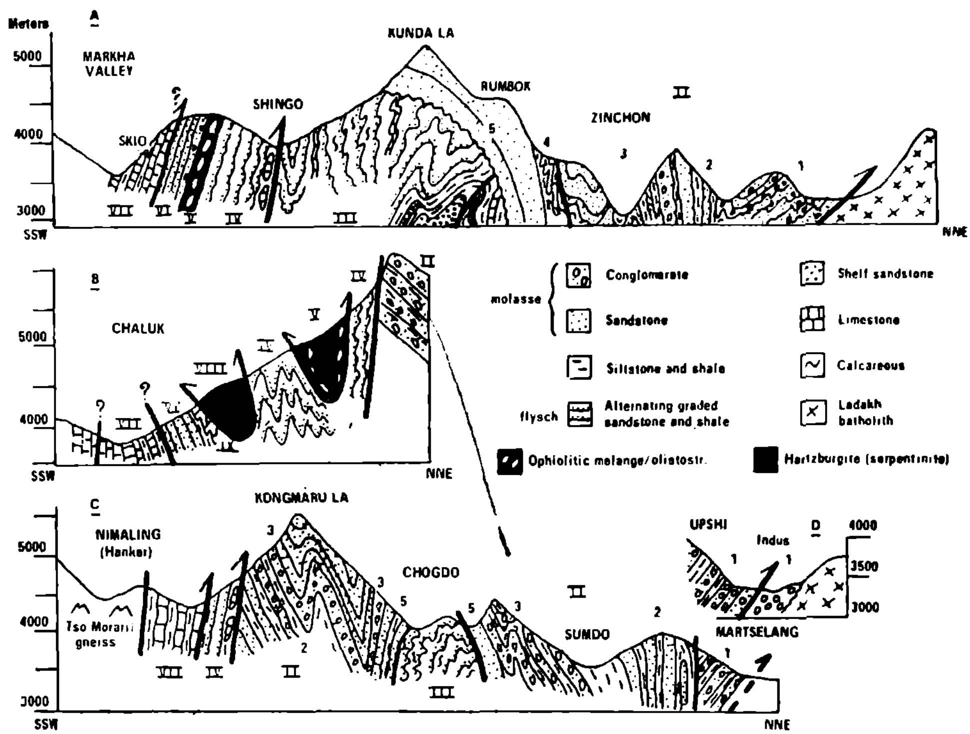

Figure 2. Tentative cross-sections. A—from Indus to Skio. B—NNE from Chaluk. C—Martselang to Nimalung (Kongmaru La). D—Inset just SE of Martselang to show autochthonous molasse. Roman numerals—units. Numbers—members.

Unit I. Autochthonous molasse of the Upshi area (cf. Frank *et al.*, 1977). This unit consists of conglomeratic granular arkoses, pebbly sandstones and sandy silty shales arranged in thick coarsening upwards cycles up to twenty metres thick. It is unconformable, and derived from the Ladakh batholith complex of late Eocene to Oligocene age (Brookfield and Reynolds, 1981). The deposits are typical of alluvial fans.

Unit II. Parautochthonous molasse. This unit is thrust over Unit I along the Basgo-Upshi thrust (Fig. 1; Pal *et al.*, 1978; Frank *et al.*, 1977) and *apparently* unconformable on the Eocene flysch sequence at Rumbock and Chogdo, though this needs confirmation. Unit II consists of braided, and less commonly meandering, stream conglomerates, sandstones and interbedded siltstones and shales, with rare lacustrine beds. It reaches a total thickness of perhaps 5,000 metres, but contains only a few poorly preserved non-marine bivalves and plant fossils. Four of Pal *et al.*'s (1978) members can be recognized in this unit (their members A, B, and parts of members C and D); though since my sub-units do not exactly correspond with theirs, I have designated them with numbers rather than letters.

(i) *Member* 1, the Hemis conglomerate of Frank *et al.* (1977), Pal *et al.*'s member 'A', consists of thick tabular and festoon cross-bedded coarse conglomerates, granular low-angle tabular and festoon cross-bedded sandstones and red, green and grey silty shales with thin fine-grained graded sandstones. The total thickness is in excess of 1500 metres. The beds are arranged in fining-upwards sequences up to 50 metres thickness, and represent deposits of large braided, or meandering streams with braided channels, with extensive floodplains. Pebble composition varies from a quartz-diorite dominated assemblage in the western areas to an 'ophiolite'-dominated assemblage in the eastern areas (e.g. at Hemis). This *may* represent different stratigraphic levels, or be source effect, since current directions at Hemis indicate a north-easterly flow, while in the west, near Zinchon, flow is generally south-east (though these directions are based on very few observations). Only rare indeterminate plant remains were recorded from Member 1.

Member 1 is highly deformed at its northern thrusted margin, and either overturned and faulted (Zinchon) or simply faulted (Hemis) at its southern margin. Though folded and faulted it *apparently* grades downwards into Member 2 at Zinchon, with increasing thickness of black carbonaceous silty shales, and the disappearance of conglomerates. It also appears to overlie Member 2 along the Kargil-Leh road, east of Nurla.

(ii) *Member* 2, Pal *et al.*'s (1978) Member 'B', consists of grey, green and occasionally red silty shales, interbedded with planar, tabular and festoon cross-bedded lithic and felspathic sandstones : conglomerates are rare. Member 2 forms the cores of anticlines around Zinchon and is faulted against Member 1 south of Martselang. Sediments similar to Member 2 can be seen underlying Member 1 on the Kargil-Leh road east of Nurla and at Basgo to the west (cf. Frank *et al.*, 1977). Due to folding the thickness of Member 2 is difficult to estimate but appears to be in excess of 1,000 metres.

The sandstones form very regular beds alternating with shales, and their thickness generally varies between 1 and 10 metres. The combination of thick overbank and relatively thin tabular sandstones suggests meandering streams, though the actual channel sandstones suggest shallow, partially braided channels. Probably the sediments were deposited by high-sinuosity ephemeral streams with braided channels.

(iii) *Member* 3, Pal *et al.*'s (1978) Member 'D' and part of their 'C', consists mainly of alternating beds of moderately well-sorted, low-angle cross-bedded lithic sandstones, and conglomeratic sandstones, with rounded pebbles, passing up into festoon cross-bedded lithic sandstones, and shales and siltstones with thin-graded sandstones. Each cyclical unit, where complete is between 5 and 50 metres thick. Alike Member 2, these sediments were deposited by relatively high-sinuosity, probably braided channel, streams with extensive floodplains. The greater irregularity and coarseness of Member 3 indicates a more proximal or fluctuating environment. Due to folding, the total thickness is again difficult to estimate but is perhaps 2,000 metres.

At Sumdo, the upper 500 metres of Member 3 consist of thick red silty shales and thin sandstones, forming a distinct mappable unit in the Shang valley, and extends eastwards to Miru (Pal and Mathur, 1977).

(iv) *Member 4*, part of Pal *et al.*'s (1978) Member 'C', consists of highly deformed alternating thin ripple drift cross-laminated grey calcareous silty shales and thin greenish-grey calcareous shales, with rare indeterminate non-marine bivalves. Member 4 represents a lacustrine unit, but only occurs south of Zinchon, where it is *apparently* conformable between Members 3 and 5. Due to intense folding its thickness is difficult to estimate but appears to be about 50 metres. It is absent in the Sumdo-Chogdo area, either because of facies change or faulting.

(v) *Member* 5, part of Pal *et al.*'s (1978) Member "c", consists of medium-bedded coarse-to medium-grained, green felspathic sandstone and conglomeratic sandstone, alternating with thin greenish siltstones and silty clays, and passing downwards into alternating red and green, fine-to medium-grained felspathic sandstones and shales. Total thickness is about 500 metres north of Rumbok. At Chogdo, the lower red section is absent. Member 5 is apparently unconformable on the Eocene sequence (unit III) at both Rumbok and Chogdo. The dominance of braided channel deposits in the member suggests proximal braided streams.

Unit III. This unit is the Eocene sequence noted by Dainelli (1933-34), plus a thick calcareous flysch sequence to the south of it. It forms parts of Pal *et al.*'s (1978) Members 'C' and 'D'. A rough section is shown on Figure 3, but the rocks are intricately folded and faulted, and this section must be regarded as tentative until more detailed work is completed. Foraminiferal limestone, occurring throughout the sequence (apart from the basal red part) indicate an Eocene age. Unit III is apparently unconformably overlain by Unit II, and overthrust by Unit IV. It can be subdivided into two members.

(*a*) *Member 1* consists of lower part of medium-bedded red fine-grained quartz sandstones alternating with red and brown siltstones and shales passing up into an upper part of brownish sandstones, calcareous shales and thin limestones. This member is about 800 metres thick. Dainelli (1933-34) recorded marine molluscs from the upper part and euryhaline molluscs from the top of the lower part. The limestones contain foraminifera of lower to middle Eocene age (Cuisian (Ypresian) to lower Lutetian) (Fossā Mancini, 1928). The deposits represent marginal marine to freshwater environments passing up into shelf deposits.

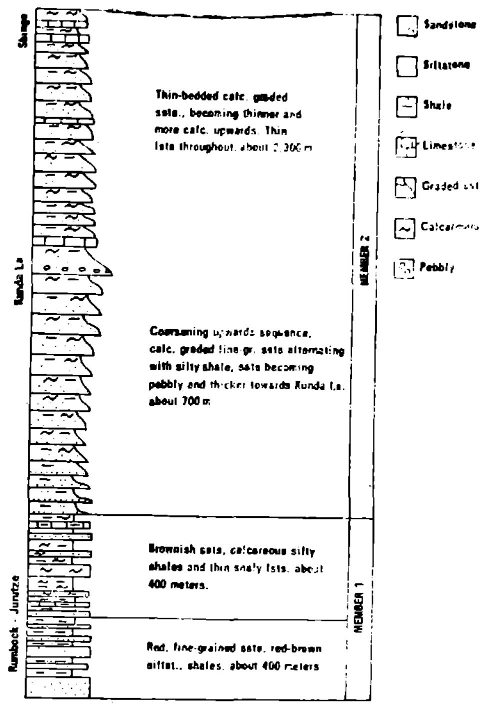

Figure 3. Tentative section of Eocene sequence between Rumbok and Shingo.

(*b*) *Member 2* consists of a thick flysch sequence of thinly bedded graded calcareous lithic and quartz sandstones, alternating with thinly laminated calcareous shales and rare thin foraminiferal limestones. The foraminifera are yet to be identified but include *Nummulites* and *Assilina* of Eocene age. This exceedingly thick sequence is folded and faulted: assuming no repetition by folding it is about 3,000 metres thick. The absence of deep-sea fan deposits, the generally fine-grained nature of the sedimentation and the stratigraphic position above a shallow shelf sequence suggest a deep shelf environment. The coarser central part *may* represent the top of the section, if fold or fault repetition occurs: future fossil identification will decide.

Unit IV, part of Pal *et al.*'s (1978) Member E, is very similar to Member 2 of unit III, but is separated from it by a major fault with large masses of limestone along the fault. The limestone masses can be seen high up on the northern side of the Markha valley from Skio to the Kongmaru La. Unit IV consists of thinly bedded alternating buff fine lithic and quartz sandstones, alternating with calcareous shales and, assuming no repetition by folding it is about 2,000 metres thick. No fossils were found. Like Unit III, Unit IV was possibly deposited in a deep shelf environment.

Unit V, part of Pal *et al.*'s (1978) Member E, consists of 30 metres of sheared red conglomerate, conglomeratic sandstone and sandstone, interbedded with red siltstones and shales, overlain by about 100 metres of very thickly bedded poorly sorted sheared greenish conglomerate alternating with grey-green phyllites. This unit is an ophiolitic olistostrome, containing rounded pebbles of chert, basic and ultrabasic rocks and angular pebbles of buff fine-grained calcareous sandstone in a sheared poorly sorted fine silty clay matrix. Unit V appears conformable with Unit VI above, into which it passes gradually. Its sharp contact with Unit IV may be conformable, unconformable or faulted. North of Chaluk, Unit V forms a tight syncline with large masses of serpentinite above the conglomerates.

No fossils were recorded, though the lower red section is reminiscent of the unit at Gya, from which Gupta *et al.* (1970) recorded Cenomanian microfaunas.

Unit VI, conformable on unit V, consists of three members :

(i') *Member* 1, at the base, consists of about 100 metres of thick conglomeratic lithic sandstones (with pebbles like those of unit V), alternating with graded parallel laminated coarse- to-medium-grained sandstones with intraformational clay pebbles, and siltstones and shales. These generally form fining upwards fluviatile sequences.

(ii') *Member* 2 is about 100 metres thick and consists of massive and festoon cross-bedded, thick-bedded fine-grained sandstones, with occasional thin siltstone and shale interbeds.

(iii') *Member* 3 consists of about 500 metres of alternating thick tabular, low-angle cross-bedded fine- to medium-grained red sandstones, up to 2 metres thick, and red and green siltstones and shales with thin-graded fine-grained sandstones.

Unit VI resembles the deposits of moderately sinuous braided streams. The whole sequence is intensely folded, with compressed isoclinal folds throughout the unit, in which the axial planes dip SSW at about 45°.

Unit VII consists of 15 metres of thick-bedded limestone, overlain by at least 1500 metres of thinly bedded clastic limestone, alternating with calcareous shale and black carbonaceous shale. No fossils were recorded.

Unit VII forms a fault block between the Zanskar Phanerozoic sequence to the south and the flysch and molasse belt to the north (Figs. 1, 2).

Unit VIII only occurs north of Chogdo, where it forms an isolated fault-bounded overturned syncline of highly sheared hartzburgite and serpentinized hartzburgite.

Unit IX underlies the southern margin of unit VIII, and consists of intricately folded thinly bedded limestone alternating with green and red shales, perhaps 100 metres thick.

CORRELATION OF UNITS

In the absence of diagnostic fossils, only Unit III can be dated, as Lower to Middle Eocene. Units I and II are probably post-Oligocene or post-Eocene. Lithological analogy as a basis for dating (often done in Ladakh, as elsewhere) is very dangerous, particularly in view of the development of similar deep shelf limestones in both Triassic and Upper Cretaceous times, and flysch in Triassic, Jurassic, and Eocene times, and also because of the strong deformation bringing units of widely differing ages into close proximity. Many of the units undoubtedly contain fossils, at least microfossils, which will enable them to be adequately dated eventually. Until then, I will refrain (regretfully) from building castles in the air from inferred ages. Hence no geological history of the area is included in the paper.

NOTES ON STRUCTURE AND METAMORPHISM

In the area between Leh and the Markha valley, the molasse units form a major anticlinorium, with the main axis running between Rumbok-Jurutze and Miru (Pal *et al.*'s (1978) Miru Anticlinal). The anticlinorium is thrust over the Ladakh batholith complex to the north, and truncated on the south by a thrust sheet including Units IV to VI. Major folds within the anticlinorium are generally large open folds, though tight isoclinal folds occur in some of the less competent units (e.g., Unit IV), where they are associated with faulting. Axial plane slaty cleavage starts developing south of Zinchon on the west, and south of Chogdo on the east, as the folds tighten up towards the thrust contact on the south (Fig. 2). Other observations are in accord with Pal *et al.*'s (1978) structural observations, though the ages they assign to deformation episodes are speculative.

The thrust sequence of Units IV to VI shows more intense isoclinal folding, and at least in places slight metamorphism up to low greenschist facies (e.g., the Phyllites in Unit V). Unit VII, the limestone-shale sequence of the Markha valley is also intensely folded in places, though this would be expected in such an incompetent unit.

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Ladakh-Deosai Batholith and its Surrounding Rocks

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ABSTRACT

The Ladakh-Deosai batholith is a part of the granitoid complex which occurs all along the Transhimalayan region, coinciding with the Indus-Tsangpo Suture. This batholith is composed chiefly of quartz-bearing rocks that vary in composition from quartz diorite, granodiorite, quartz monzodiorite, quartz monzonite to granite with occasional masses of diorite, gabbro, pyroxenite and anorthosite on the one hand, and aplite, pegmatite, granophyre and lamprophyre dykes on the other. The major part of the batholith appears to have emplaced into weakly to moderately metamorphosed strata of the Palaeozoic and Mesozoic age, during the Early Cenozoic time (around 50 m.y. ago); however, some parts of it may be old granitic basement also. The Gaik granite exposed between Gaik and Kiari has recently been dated as Permo-Triassic (235 ± 13 m.y.) by Rb-Sr whole rock isochron method. The strata on two sides of the Ladakh-Deosai batholith are quite different. On the north, the Palaeozoic metamorphites, Late Mesozoic flyschoid rocks (shales, graywacke, limestone sequence) and the Early Cenozoic acid volcanics dominate while, on the south, Indus Flysch, tholeiitic basalt (Indus Volcanics) and associated ophiolitic melange (of Cretaceous-Eocene age) constitute the major host rocks into which the Ladakh batholith emplaces. The contact between the host rocks and the batholith is covered by a linear belt of Indus Molasse (Miocene-Pliocene?) between Kargil and Hanle except from Upshi to Chuma Thang where a fault brings the batholith in direct contact with the Indus Flysch.

INTRODUCTION

THE LADAKH Range is a magnificent mountain range that stretches for 500 km in the Transhimalayan region of the northwestern Himalaya from Indus-Shyok confluence in the northwest to Hanle in the southeast. The Shyok River lying north of it separates this range from that of the Saltoro Range and the Karakoram Range, and the Indus River in the south from that of the Zanskar Range. The Deosai Mountain starting from the Indus-Gilgit confluence continues southeastward upto Kargil where it ends in-between the Zanskar and the Ladakh ranges. The Deosai Plains lie to the south of the Deosai Mountains.

The Deosai-Ladakh batholith is a distinctly different and much older entity than the physiographic Deosai Mountain, Deosai Plain and the Ladakh Range. These mountain ranges for most of their extent expose the rocks of the Ladakh-Deosai batholith except for a part of the northern slope of the Ladakh Range which is covered by the volcanics. A few eroded patches of this volcanic cover are also seen at the higher reaches of Ladakh and Deosai ranges near Chorbat La, Hamboting La and a pass south of Satpura (Fig. 1). This batholith is composed dominantly of granitoid rocks. Gabbroic intrusives of various dimensions are common besides the weakly to moderately metamorphosed Palaeozoic and Mesozoic sedimentaries and volcanics host rocks occurring as relicts and xenoliths. The Ladakh batholith dominantly represents the early Cenozoic plutonic phase of the Late Mesozoic-Early Cenozoic magmatic activity which dominated this part of the Transhimalayan region; however, some parts of the Ladakh batholith also represent the Hercynian basement.

The Ladakh-Deosai batholith is one of the largest and the best exposed batholiths with least soil or vegetation cover. It occurs in an interesting tectonic setting of global importance—the Indus Suture Zone. A detailed study of this batholith might form a splendid subject and contribute substantially to the basic question, "how were the great batholiths of granitised rock formed" but difficult and inaccessible terrain of the Ladakh and Deosai regions prevented a detailed study of this batholith so far. It is, however, only recently that a few systematic and

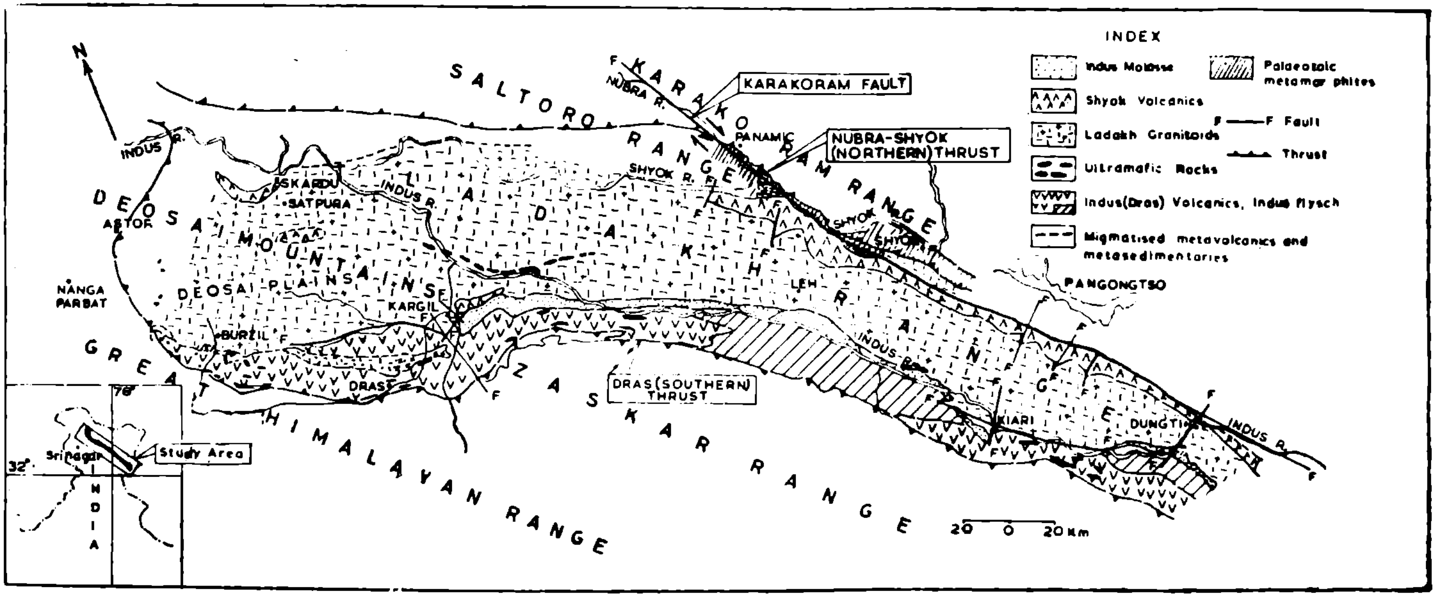

Figure 1. Geological map of the Ladakh-Deosai batholith and its surrounding rocks (compiled from different sources and author's own observations).

detailed geological traverses across the Ladakh Range by the present author could provide some insight into this massive batholith. The emerging geological picture about it would depend much on the detailed petrological, geochemical and geochronological study under progress. However, an attempt has been made here to briefly introduce the Ladakh batholith and its surrounding rocks to the interested readers.

LADAKH-DEOSAI BATHOLITH

The Ladakh-Deosai batholith commonly called as Ladakh batholith because of its maximum development in the Ladakh Range occurs as an elongated arc-like body, convex towards north, measuring more than 600 km in length, 20-80 km in width and 3 km in exposed thickness. Even in the deepest cut sections the base of this granitoid body is nowhere exposed. Besides its best exposures in Ladakh region, this body also continues westward in Astor-Deosai-Skardu region as reported by Auden (1935) and Wadia (1937) and eastward from Hanle into the Tibetan region as shown by Gansser (1977) in the Satellite Imagery map of Himalayan region. Gansser (1977, Fig. 1) inferred the presence of at least four such bodies all along the 2000-km long Himalayan Arc coinciding with Indus-Tsangpo Suture Zone.

The Ladakh batholith is composed chiefly of quartz-bearing rocks that vary widely in composition from quartz diorite, granodiorite, quartz monzodiorite, quartz monzonite to granite with occasional masses of diorite, gabbro, pyroxenite and anorthosite on the one hand, and aplite, granophyre, pegmatite and lamprophyre dykes on the other. The plutons of acidic composition intrude into those of the basic composition with sharp contacts and the tongues of the former intrude the latter. The rocks in different plutons can be readily distinguished from one another in the field by differences in mineral composition and texture as is evident in the Gaik-Kiari and Hanu Thang areas.

From the two sections, (i) Kiari-Upshi and (ii) Skirbuchan-Batalik, where the deep gorge of Indus river has cut through the Ladakh batholith exposing its deeper levels, one can see some sort of zoned nature of the batholith (becoming more acidic towards the core) and the intrusive relationship of one pluton with the other. Near Kiari, the alternating red and green sandstone and sandy shale unit of Indus flysch is in tectonic (fault) contact with greenish-grey colour, non-porphyritic, coarse-grained quartz dioritic to granodioritic rock carrying 1 cm long crystals of hornblende. This tectonic contact between the Indus Flysch and the Ladakh granitoid continues westward upto Upshi and eastward upto Chuma Thang and further east. Within a few hundred metres of the contact, the granitic rock develops large phenocrysts of pink and white feldspars and the rock attains porphyritic character which continues for a few kilometres till we reach Gaik Nala where coarse-grained leucogranite intrudes the pink porphyritic granite with a greater force. Smaller tongue-like projections and apophyses of the leucogranite, a few tens of metres across, cut through the pink porphyritic granite near the margin, besides the aplitic and pegmatitic veins which run for a longer distance in the pink porphyritic granite. These aplitic and pegmatitic veins carry disseminated crystals of titano-magnetite. The detailed account of the mode of occurrence and their significance as geothermometres has been discussed elsewhere by Choubey and Sharma (1979). Besides titano-magnetite the pegmatite veins also carry tight books of muscovite and biotite, beryl, garnet and chalcopyrite. It is interesting to mention here that the pink porphyritic granite and the leucogranite exposed in this section is either devoid of or very much poor in hornblende and are thus different from the commonly occurring hornblende-bearing granite (quartz diorite and granodiorite) of the Ladakh Range.

In the northwestern part of the Ladakh batholith the pink prophyritic granite exposed along the Indus valley between Biama and Achini Thang carries large panidiomorphic phenocrysts of feldspars more or less like those of the Gaik-Kiari area. Besides, these granites also carry well-developed, stout crystals of hornblende and a large number of xenoliths of basic composition.

Presence of gabbroic and dioritic pluton either intruding the Ladakh granitoid as remarked near Likir and West of Garkon, or in tectonic contact with it as between Kargil and Chhainigund, has been observed. The basic igneous complex of Kargil which varies in composition from gabbro, norite, anorthosite, pyroxenite and hornblendite to diorite is exposed as an elongated body measuring about 6 km wide and a few tens of kilometres long. This plutonic body is in tectonic contact with the granitic rocks of the Ladakh batholith. Rai and Pande (1978) who studied the petrology and petrochemistry of this complex in detail consider that the igneous rocks which range in composition from ultrabasic to acidic emplaced in six stages between Upper Cretaceous and Miocene.

In the Dras-Kargil section the hornblende-bearing granitoid body measuring about 80 km long and 10 km wide exposes around Tasgam on the Dras-Kargil Road. This granitoid body intrudes into the Dras Volcanics and associated ophiolitic mélange zone and shows many evidences of migmatisation and thermal metamorphism. Wadia (1937) also observed intrusive nature of the hornblende granite with the volcanics near Minimarg in the Burzil area.

On the Dras-Kargil road, the main body of the Ladakh batholith is exposed about 5 km north of Kharbu where it is in tectonic (fault) contact with the metabasics of Dras Volcanics. The petrography and the geochemistry of these granitic rocks has recently been described by Vardarajan *et al.* (1980). According to these authors, the major part of their so-called Kargil Granitic complex is quartz monzodiorite and occurs between the Ladakh Granitic Complex and the Dras Volcanics. These rocks, according to them, represent remobilization of Ladakh Granitic Complex somewhere at the close of the Dras Volcanic episode in the area.

The Ladakh batholith exposed between Khalsi and Upshi and east of Dungti shows wide variations in its composition from quartz diorite to granodiorite and granite and so far it has not been possible to demarcate plutons of different composition because of the difficult terrain, although the efforts are still being made.

SURROUNDING ROCKS

The general distribution of exposed prebatholithic rocks in the Ladakh Range, Deosai Mountains and adjoining areas is shown in Figure 1. The reconstruction of the stratigraphic and structural history of these rocks is exceedingly difficult and beset with uncertainties, because of the dominantly volcanic character of the country rocks, paucity of mega-fossils in metasedimentaries and the little attention paid to them so far due to the difficult terrain. Nevertheless, the broad relations so far understood, though not the detailed one can be useful to draw a generalised picture for further detailed study.

Deosai Plains-Deosai Mountains Regions

The geological information about the northwestern part of the batholith exposed in parts of Deosai Mountains and Deosai Plains, i.e., Astor, Burzil Pass, Skardu and Olthingthong, is based on the description given by Wadia (1932, 1937), Auden (1935), and Desio (1978). The observations made by these authors have been corroborated by the present author in the adjoining parts of Kharbu, Kargil and Batalik.

Wadia (1937) observed that the hornblende granite (quartz diorite and granodiorite) exposed southeast of Astor through Burzil towards Dras intrudes into the stratified tuffs, ash beds and trap flows invaded by dykes, sills and bosses of gabbro, pyroxenite and serpentinite thereby suggesting the post-Cretaceous nature of this granite. The intrusive nature of the hornblende granite with the Dras Volcanics is clearly observed near Kalapani and northwest of Minimarg where bays and tongues of granite intrude into the volcanics.

Wadia (1937) also observed rounded to subrounded pebbles and boulders (a few centimetres to about half a metre in diameter) of feldspar porphyries, hornblende granite, trap, jasper and chert, quartzite, slate and limestone embedded in a matrix either of lava showing fluxion lines or of tuff, thereby resulting in agglomeratic conglomerate bed exposed in the deeply cut southern side of the Nagai valley east of Minimarg. This agglomeratic conglomerate bed (300 m thick) locally exposed in the area according to Wadia (1937) indicates explosive volcanic action which might have taken place at the end of the volcanic period.

Auden (1935) also reported the occurrence of rhyolites, tuffs and porphyritic hornblende andesite near the pass south of Satpura (on way to the Deosai Plains) and compares this phase of the volcanicity with the younger explosive phase reported by Wadia from Burzil area. Auden further observed that this suite of volcanics is not metamorphosed in spite of its proximity to hornblende granite.

The description of the acidic volcanic phase reported by Wadia (1937) and Auden (1935) from Minimarg and the pass south of Satpura is similar to that of the Shyok Volcanics (Sharma and Gupta, 1981, this volume) which occurs as a relict of an extensive cover over the Ladakh granitoid near Hamboting La and Chorabat La. The presence of hornblende granite boulders in these volcanics as observed by Wadia (1937) and the absence of thermal metamorphism besides their proximity to hornblende granite (Auden, 1935) clearly suggest post-hornblende granite age for these volcanics. These observations further substantiate the present author's views (Sharma and Gupta, 1978, and Sharma and Kumar, 1978) that the explosive phase of the acid volcanism (Shyok Volcanics) is younger than a part of the Ladakh granitoids (hornblende-bearing quartz diorite and granodiorite) which consolidated during its early stage.

Dras-Kargil-Batalik Area

As mentioned earlier, a plutonic body of the granitoid rocks intrudes the Dras Volcanics and associated ophiolitic mélange near Tasgam on Dras-Kargil Road. The basic host rock, near its contact with the granite, has changed to amphibolite and hornfelds, and is intruded by a number of veins and tongues of granite resulting in a migmatitic rock. Relicts of basalts are occasionally seen. Towards the higher levels of the granite hornblende-feldspar pegmatite are common within the metamorphosed basics and represent the volatile activity by the granite. Tongues of granite intruding the volcanics are commonly seen southeast of Kharbu and are also exposed in the Suru Valley near Trizpan. The ophiolitic mélange exposed along the Dras nala north of the Tasgam has also been cut across by the granite body and marginally altered.

A sequence of volcanics and associated flyschoid sediments is exposed once again between Shimsha and a point 5-km north of Kharbu on the Dras-Kargil road. The porphyritic basalt, amygdaloidal basalt and the fine-grained massive basalt exposed near Kharbu gradually change to foliated schistose metavolcanics, chlorite schist, actinolite-tremolite schist and amphibolites within one kilometre of the granite contact. The metabasics show banding and stretching near the contact. The original mafic minerals of the volcanics have been flattened along the foliation and changed to chlorite. Within the foliated metavolcanics relicts of massive and less foliated volcanics are occasionally seen near the contact with the granite. These metabasics are silicified, migmatised and veins of quartz and granitic composition frequently traverse these rocks. The boudinage of quartz and granite within the foliated metavolcanics and folding of some these veins and the metabasics suggest post-emplacement deformations which caused granite body to thrust over these rocks. Due to thrusting the granite near the contact has also been foliated and has developed gneissose structure.

Recently, Srikantia and Razdan (1980) grouped these metavolcanics, metasedimentaries, amphibolites and migmatite intruded by granites, under the Kharbu Group. These authors believe that the granitoids and gabbroids in the Batambas area along with an unconformable cover of the Indus Group (Kargil Molasse) sediments, extending westward to Tasgam and beyond, occur in a tectonic window framed by the Dras volcanics. They also fix the upper age limit of the Ladakh Granitic Complex as pre-Upper Cretaceous and consider that the Ladakh Granitic Complex and Kharbu Group autochthon represent a major geanticline separating the Karakoram and other Tibetan basins from the Himalayan basins. The present author does not see any sound justification to believe that the Ladakh granitoid intruded into an older metamorphics at least in this part, grouped as Kharbu Group by Srikantia and Razdan (1980). On the contrary the metabasics, metasedimentaries, amphibolites, migmatites and gneisses observed near the granite contact represent metamorphosed Dras volcanics and associated flyschoid sediments, and this part of the Ladakh Granitoid Complex is most probably post-Upper Cretaceous in age, as discussed later in this paper.

In the granitoid body between Chhainigund and Kargil only a few xenoliths of the host rock are seen. Much of the host rock appears to have been digested by the granitic melt. Only a few xenoliths of the basic composition have been noticed which are comparatively smaller in size towards the middle part and gradually increase in size and frequency towards the marginal zone. The subparallel arrangement of these xenoliths indicates their free movement in the melt. Such xenoliths are quite frequently seen near the Suru-Shingo confluence.

Auden (1935) and Desio (1978) report that the hornblende granites (quartz diorites) along the Shingo River, after Olthingthang, become richer and richer in basic inclusions and increase in size until they are several hundred metres in length. Auden (1935) considers these xenoliths to be original basalt and dolerites which have been metamorphosed by granite to epidiorites and hornblende granulites. Smaller inclusions have often lost their igneous structure, except for occasional phenocrysts and consist of a granoblastic assemblage of hornblende, biotite, oligoclase-andesine and sphene whereas in larger inclusions the igneous structure is still discernible. Xenoliths of slates, quartzites and amphibolites with little metamorphism marked by marginal formation of hornfels have been reported just south of Tarkuti by Auden (1935) and Desio (1978). The present author while working near Silmo, northeast of Junkar also observed quartzitic and amphibolitic xenoliths measuring a few tens of metres in length. Towards Batalik the metabasic host rock profusely intruded by granite, aplite and pegmatite veins has resulted in a zone of hornfelsic amphibolite.

Upstream along the Indus river near Darchik, the massive to weakly foliated biotite granite gradually changes into migmatised quartzites, metabasics, hornblende granulites and amphibolites. This zone has a regional extent and continues towards Hanu Yogma in the east. A narrow zone of mafic and ultramafic rocks has been observed between Darchik and Garkong. Similar rocks have also been reported by Auden (1935) and Desio (1978) from Papaldo and Gidiaksdo. The observations of the present author on the Ladakh granite and its host-rocks between Kargil and Dah through Batalik suggest that this part is the eastern extension of the rocks reported by Auden (1935) and Desio (1978) between Olthingthang and Karmang.

At Hamboting La and to its west towards Junkar a thick sequence of acid volcanics, ignimbritic welded tuff, volcanic breccia, chert and limestone representing the Shyok volcanics occurs as a relict cover of the Ladakh granitoid. These volcanics and the underlying granites have been cut through by a number of felsic dykes and veins of granite-porphyry near Silmo which possibly represent the feeders for the overlying acid volcanics. These volcanics are also devoid of the thermal metamorphic effects near their contact with the granites. Similar acid volcanics occur as a linear belt all along the northern limb of the Ladakh batholith (Sharma and Gupta, this volume). The acid volcanics of the Hamboting La area are lithologically similar to those described by Auden (1935) from Satpura area of the Deosai Mountains.

Further upstream in the Indus Valley, a body of the hornblende-bearing pink porphyritic granite is exposed around Hanu Thang. The presence of well-digested metabasic xenoliths in abundance in this granite is of interest. These xenoliths are a few tens of contimentres across, well-rounded and marginally granitised. Large number of such rounded xenoliths embedded in coarse-grained pink porphyritic granite at places give appearance of a conglomeratic rock. It is worthwhile to remark that the frequency, size, shape and the degree of alteration in these xenoliths vary as we move towards the higher level of the granite body and possibly suggest nearness to the basic cover rock which contributed these xenoliths. The down sinking xenoliths in magma underwent rounding, reduction in size and granitisation.

As the southern margin of the Ladakh batholith is covered unconformably by a narrow linear belt of molassic rocks, much of its intrusive relation with the prebatholithic rock is obscured. The lithology of this molassic unit called Indus (Kargil) Molasse has been described in detail by Tewari (1964); Shah *et al.* (1976); Franks *et al.* (1977) and Sharma and Kumar (1978).

The xenoliths of metavolcanic and metasedimentary rocks are commonly distributed throughout the Ladakh granitoid body extending upto Upshi; however, they are more abundant towards the margin and at the higher levels of the granite body.

Leh-Khardung-Khalsar-Tirit Area

In this section the Ladakh batholith is observed to extend upto Khardung where it is covered by the Shyok Volcanics represented by rhyolite, decite, andesite, ignimbrite, ash flows and volcanic breccia. Schistose, amphibolitic and quartzitic xenoliths of varying sizes have been observed within this granitoid body. The presence of phyllites, schists, quartzites, and crystalline limestones near North Pullu, Khalsar and Tirit intruded by granitic rocks suggests the metamorphic character of host rocks. These metamorphites near Tirit in the Shyok valley have yielded Upper Palaeozoic fossils (Bhandari *et al.*, 1979 and Thakur *et al.*, 1981). Similar metamorphic rocks have also been observed at other places along the northern margin of the Ladakh batholith.

Likche-Chuma Thang Area

Along the Upshi-Nyoma road West of Likche, an outcrop of the migmatised rocks intruded by the granite is exposed. The host-rock intricately folded and intruded by the granite has been greatly altered and migmatised, however, it still reveals quartzitic, metagreywacke, metavolcanic and slaty character. The lithology of the marginal zone here is similar to what has been noticed near Batalik and further west. It appears that these host rocks before their intrusion by granite were also subjected to low- to medium-grade metamorphism. Similar set-up is revealed in the Nair Nis Nala and near Chuma Thang where hornfelsic development besides migmatization has also been observed, indicating thereby that the thermal metamorphism overprinted in the already metamorphosed sedimentary and volcanic host-rocks which were subsequently migmatised due to granite intrusion.

AGE OF THE LADAKH-DEOSAI BATHOLITH

The age of the Ladakh-Deosai batholith has been discussed by the earlier workers mostly on the basis of the field relations. Stoliczka (1874) considered the 'Ladakh gneiss' to be of Silurian age, whereas Lydekker (1880) compared it with 'Central Gneiss' exposed elsewhere in the Himalaya and considered it to be probably of Precambrian age. Auden (1935) and Wadia (1937) on the basis of their observations in the Skardu-Satpura and Astor-Burzil areas, respectively, considered the hornblende granite (quartz-diorite and granodiorite) to be Tertiary, as it intrudes into the volcanics and limestones containing Upper Cretaceous-Eocene fossils. Auden (1935) also observed that the hornblende granite intrudes into the biotite-bearing granite near Shyok-Indus confluence and the latter may be of an earlier age, i.e., Hercynian, Caledonian, or even Precambrian.

Desio *et al.* (1964) gave, for the first time, a radiometric (Rb-Sr) age of 48 m.y. for the granodiorite from Satpura, South of Skardu, confirming the views of Auden (1935) and Wadia (1937) regarding the post-Cretaceous age of their hornblende granite. Some of the subsequent workers (Shankar *et al.*, 1976*a*, 1976*b*; Shah *et al.*, 1976; Srikantia and Bhargava, 1978; Pal *et al.*, 1978 and Srikantia and Razdan, 1980) were somehow not convinced with the radiometric age given by Desio *et al.* (1964) and believed that the major part of the Ladakh batholith, particularly the one exposed in the Ladakh Range, is pre-Upper Cretaceous in age. Most of these workers based their views on their field observations on a limited area and an occurrence of an unconformable contact between the Indus Formation containing Upper Cretaceous fossils and the Ladakh Granite near Nyoma reported by Shankar *et al.* (1976*b*). The present author studied this section again and has observed that a thin molassic unit containing palm impression lies in between the Indus Formation and the Ladakh Granite of Shankar *et al.* (1976*b*) and the contact between the two is tectonic. This section will be described in detail by the author elsewhere. Some of the workers advocating the pre-Upper Cretaceous age of the Ladakh granite batholith also believe that in the late Tertiary times widespread acid igneous activity resulted into Kargil Granite (Shah *et al.*, 1976; Shankar *et al.*, 1976; Vardarajan *et al.*, 1980), Chuma Thang and Kiari granite, pegmatites, aplites, quartz and quartz-fluorite veins (Shankar *et al.*, 1976*a*, 1976*b*).

The other group of workers who consider the Ladakh Granite to be post-Upper Cretaceous in age are Frank *et al.* (1977) and Rai and Pande (1978). Sharma and Kumar (1978) on the basis of their inferences and the observations of Shankar *et al.* (1976*b*) from Nyoma considered the age of the Ladakh Granite from Early Cretaceous to Lower Miocene. Sharma *et al.* (1978) reported K-Ar age of 28 ± 1 m.y. for the pink porphyritic granite from Hemiya in the Upshi-Kiari section. Recently, Sharma *et al.* (1981) also reported the fission track ages of sphene and apatite from different parts of the Ladakh batholith. The age of sphene varies from 25 to 34 m.y. with an average of 29 m.y. and that of the apatite from 12 to 25 m.y., with an average of 18 m.y. Although the fission track and K-Ar ages represent cooling ages, since the last thermal event, this age data supported by 38 m.y. (Rb-Sr) age of a granite boulder from Hemis conglomerate (Desio and Zanettine, 1970) and 48 m.y. age of a granodiorite sample from Skardu, does suggest that the major part of the Ladakh batholith is post-Upper Cretaceous in age.

Recently, Trivedi *et al.* (1981) reported the first Rb-Sr isochron age of 235 ± 13 m.y. for the Gaik Granite, a part of Ladakh batholith exposed between Gaik and Kiari. The pink porphyritic granite here is intruded by a leucogranite, aplite and pegmatite. Near Likche, this granite profusely intrudes into the weakly metamorphosed host rock, thereby resultant migmatisation. Besides thermal metamorphism and migmatisation, the host rock still retains quartzitic, metagreywacke, metavolcanic and slaty character. Similar host rock is also observed in the Nair Nis Nala and near Chuma Thang and shows good development of hornfels. Along the northern margin of the Ladakh batholith similar host rock is seen near Tirit and Khalsar where it has yielded Upper Palaeozoic fossils (Norin, 1946; Bhandari *et al.*, 1979; Thakur *et al.*, 1981).

Trivedi *et al.* (1981) also reported isochron mineral age of 30 ± 3 m.y. for the biotites of the Gaik Granite indicating thereby that the Rb-Sr clock in biotite got reset during subsequent thermal increase sometimes in the Upper Oligocene. The concordence of Rb-Sr biotite age, K-Ar whole rock age and fission track sphene age from this part of the Ladakh batholith suggests that the Hercynian basement, represented by Upper Palaeozoic metamorphites and the Gaik Granite, of the Indus Suture Zone got sufficiently heated during the large-scale emplacement of Ladakh Granite in the Early Cenozoic period. This region once again attained thermal stability towards the Upper Oligocene as indicated by the resetting of radiometric clocks in minerals.

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An Early Djulfian (Permian) Brachiopod Faunule from Upper Shyok Valley, Karakorum Range, and the Implications for Dating of Allied Faunas from Iran and Pakistan

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ABSTRACT

An early Djulfian brachiopod fauna is described from pale limestone of Upper Shyok Valley, south Karakorum Range, and correlated with early Djulfian faunas of the north Karakorum Range (Sinkiang), Salt Range (Pakistan), central and north Iran, Armenia and elsewhere. The younger Permian sequence of Abadeh, central Iran, is discussed in detail, and it is shown that the Abadeh Formation and faunas are younger than the Hachik deposits of Armenia, and probably equivalent to the *Codonofusiella* beds at the base of the Djulfian Stage. It appears that the *Comelicania-Janiceps-Phisonites* Zone, typical of the Vedian substage, is not present, or has not been collected in central Iran, although it constitutes a very significant and easily recognised level elsewhere. It is suggested that the Abadehan 'Stage' is of only substage rank and that the type section of the substage should be located where a host country is willing to grant ready access. It is pointed out that fusulines, ammonoids and conodonts are either too rare, or too restricted in distribution to provide fossils of prime value for world-wide correlation. The younger Permian beds and faunas of the Salt Range, Pakistan, are also re-examined, and three members erected within the Chhidru Formation, the Kufri Member (the lower and middle Chhidru Formation of former workers), the Ganjaroh Member (the topmost or bivalve bed of Waagen, 1891), and the Landa Sandstone Member, for the white sand at the top of the Chhidru Formation. The Chhidruan Substage is represented by the Kufri Member, not the full Chhidru Formation, and the Kufrian Substage may therefore be used as a substitute name for the Chhidruan Substage if accuracy be desired. The two younger members Ganjaroh and Landa are of Djulfian age, belonging to the Urushtenian (or Abadehan) Substage and Baisalian Substage respectively.

It is pointed out that the Guadalupian biostratigraphic unit is not suitable for stage use, but has much to recommend it as a series roughly equivalent to Middle Permian. It is suggested that the world Early Permian stages be referred to the Cisuralian Series, and Late Permian stages be referred to the Transcaucasian Series. If it were desired to have the best possible world stratotypes, the late Permian Longtanian (-Lungtanian) and Changsingian stages of China would substitute for the Armenian-based stages, and could be referred to the Yichangian or Lopingian Series (name tentative).

Newly named taxa are *Tropidelasma karakorumensis*, *Edriosteges shyokensis*, *Liosotella multiplicata*, *Araxathyris umbonalis* and *Labaia erecta* for species from the Karakorum, and *Enteletes granti*, *Derbyia postplicatella*, and *Linoproductus periovalis* from the Landa Sandstone Member and *Spinomarginifera kathwaiensis* and *Martinia acutomarginiformis* from the Kathwai Member, Salt and Surghar Ranges; *Linoproductus crassicostatina* from the Senja Formation, Nepal, and *Acosarina liaoi* from the Changsing Formation of China. We consider that Aulostegacea are closer to Productids (s. l.) than to Strophalosiids (s. l.) and arose from Productellacea.

INTRODUCTION

BRACHIOPODS DESCRIBED in the present work were found in the Saser Brangsa-Margo areas of the upper Shyok Valley, in the Karakorum region of Ladakh. They probably come from the limestone reported in the upper Shyok valley by Gortani in Pascoe (1959, p. 804) where he listed several recognisably similar brachiopods, including *Orthotetes armenicus* Arthaber, *Streptorhynchus* aff. *shanensis* Diener, *Productus lineatus* Waagen, *Marginifera spinoso-costata* Abich and *Strophalosia longa* Necaev.

The limestones yielding Permian fossils described in the present paper have been classified as part of the Shyok Group which overlies tectonically the Khardung Formation. The lower part of the Shyok Group has yielded fossils with Himalayan affinity. This is overlain by beds containing fusulinids which, in turn, are followed by the pale fine limestone, etc. of upper Shyok Group containing Armenian fauna. For details of the stratigraphy of this region reference may be made to the paper by Bhandari *et al.* (1982) published in this volume.

I. SYSTEMATIC DESCRIPTIONS : KARAKORUM RANGE

Repository

The material described here is kept at the Centre of Advanced Study in Geology, Panjab University, Chandigarh.

Phylum Brachiopoda
Family Schizophoriidae Schuchert and Le Vene, 1929
Genus *Acosarina* Cooper and Grant, 1969
Acosarina sp.
Pl. 1, figs. 1-3

Diagnosis. Small transverse shells with well-formed dorsal sulcus and narrow hinge.

Present material. One specimen with valves conjoined.

Dimensions (in mm):

Width	*Length*	*Height both valves*	*Hinge width*	*Umbonal angle ventral valve*	*Cardinal angle*
16	13	9.2	8	110°	140°

Description. Shell small, transverse, inflated, with prominent ventral umbo, incurved over hinge; ventral interarea high, distinct; dorsal interarea low. Dorsal sulcus narrow and groove-like posteriorly, broad and shallow anteriorly. Costellae fine, 3-4 per mm anteriorily, differentiated in two orders.

Resemblances. This specimen appears very close to the species *Orthotichia doraschamensis* Sokolskaya recorded by Abich (1878, pl. 8, fig. 9; Sokolskaya in Ruzencev and Sarytcheva 1965, pl. 25, fig. 9) from the *Oldhamina* fauna of the younger Djulfian (Baisalian) beds of Armenia. Sestini and Glaus (1966) also reported the species from the Nesen Formation, north Iran, of Djulfian age. However, the Armenian-Iran species have a ventral sulcus and no dorsal sulcus, and so is presumably not congeneric. From the lower Changsing beds of south China, Liao (1980b, pl. 1, figs. 35-38) ascribed shells to *Asosarina doraschamensis*, but the Chinese specimens, inspected at the Palaeontological Institute, Nanjing, have a narrow dorsal groove, widening anteriorly, somewhat as in the present form. Unlike the Karakorum specimen, the Chinese ventral valve is little inflated, and the hinge is narrow and the shape narrower. It is described as a new species *Acosarinaliaoi* later in the text.

Family Orthotetidae Waagen, 1884
Genus *Orthotetes* Fischer de Waldheim, 1850
(?)*Orthotetes* sp. or spp.
Pl. 1, figs. 4, 5

A ventral valve has branching fine costellae, with wide hinge and low inflation reminiscent of the genus *Orthotetes*. A more inflated dorsal valve with similarly fine ribs increasing by intercalation, and a shallow median sulcus might belong to the same species, or different species, or different genus.

Family Streptorhynchidae Stehli, 1954
Genus *Tropidelasma* Cooper and Grant, 1969
Tropidelasma karakorumensis n. sp.
Pl. 1, figs. 6-9

Holotype. Specimen figured in Pl. 1, figs. 6, 7.

Diagnosis. Small elongate shells with distorted ventral umbo and ventral interarea of moderate to low height, ornament differentiated.

Plate 1. **1-3.** *Acosarina* sp. 1, 3, dorsal and ventral views of specimen with valves conjoined, × 3. 2. ventral valve × 3. **4, 5** (?) *Orthotetes* sp. or spp. 4, ventral valve, × 1, 5, dorsal valve × 2. **6-9**, *Tropidelasma karakorumensis* n. sp. 6, 7, dorsal and ventral views of holotype, × 1. 8, 9, ventral and posterior views (ventral valve on top) of immature specimen with valves conjoined × 3, × 2. **10**, *Orthothetina* sp., ventral valve showing internal plates, × 2. **11-16**, *Edriosteges shyokensis* n. sp., × 1. 11, 15, ventral and dorsal views of holotype. 12, 13, 16, ventral valves. 14, dorsal interior with part of ventral valve.

Material. Four specimens with valves conjoined, three ventral valves and three dorsal valves.

Dimensions (in mm) :

Width	*Length*	*Height*
14.5	13	6.5
30.5	35	15.5

Description. Shell variable in shape, slightly elongate to slightly transverse, ventral umbo irregular, with angle in different specimens varying between 90° and 14)°; hinge wide, placed in some specimens at maximum width; ventral interarea only moderately high, lying at right angles to commissure is small specimens, in plane of commissure in large shells, with smooth, raised flat pseudodeltidium, bearing high convex monticulus, outer area marked by horizontal growth lines. Dorsal interarea low, lying in plane of commissure in larger specimens. Shell outline variable, subquadrate to subrectangular, maximum width at hinge or near anterior third of shell length, cardinal angles bluntly obtuse. Ventral valve gently convex in front of umbo, without sulcus, may have low median swelling anteriorly. Dorsal valve well-inflated just in front of hinge, bearing eccentric median sulcus extending from just in front of umbo to anterior margin. Costae sturdy with rounded crests and low sides, and interspaces of similar width, numbering about 11 in 5 mm medianly and 9 in 5 mm laterally; costae increase by intercalation, starting as very fine threads, gradually becoming as strong as others. Dorsal costae slightly narrower, with fewer intercalated fine costae. Both valves also crossed by growth steps; low plicae present anteriorly; punctation of shell not known.

Internally, ventral teeth supported by short dental plates. Dorsal cardinal process with deep median cleft on outer face, and moderately widely diverging crural support plates.

Resemblances. None of the species of *Tropidelasma* described by Cooper and Grant (1974) from the Permian beds of Texas have such coarse costae and all have a higher ventral valve with higher interarea.

Schuchertella anonyma Merla (1934, text fig. 17, p. 280) possibly belongs to *Tropidelasma* and has a low interarea like that of the present form, but its ventral valve is higher, and the hinge wider. The strength of the costae is not easy to assess from the figure. It comes from early Djulfian beds of the Karakorum Range.

Family Meekellidae Stehli, 1954
Genus *Orthothetina* Schellwien, 1900
Orthothetina sp. indet.
Pl. 1, fig. 10

A fragment of a ventral valve with differentiated costae shows two long dental plates, diverging at a low angle, as seen in this genus.

Family Echinostegidae Muir-Wood and Cooper, 1960
Genus *Edriosteges* Muir-Wood and Cooper, 1960
Edriosteges shyokensis n. sp.
Pl. 1, figs. 11-16.

Holotype. Specimen figured in Pl. 1, figs. 11, 15.

Diagnosis. Inflated shells with vaulted visceral disc, narrow well-formed sulcus and narrow ears bearing a number of spines.

Material. Ten specimens with valves conjoined, and two ventral valves, possibly with the dorsal valve masked.

Dimensions (in mm) :

Width	*Length*	*Height*	*Hinge width*	*Umbonal angle*	*Cardinal angle*	*Sinal angle*
47	42	22.5	38	90°	100°	15°

Description. Shells moderately large, elongate, and well-inflated, the visceral disc exceeding a height of 12 mm in mature specimens. Ventral interarea well-formed, with delthyrium; umbonal cicatrix present. Narrow shallow ventral sulcus commences close to umbo; dorsal fold very low. Posterior umbonal walls convex in profile, and ears small, but well-defined, very gently convex, ventral profile subgeniculate at trail. Dorsal disc very gently concave, and curving abruptly into long trail. Spines close set, and numerous over ventral valve, about 3 mm apart in quincunx, more numerous over ears, just over 1 mm apart, possibly forming row along hinge. Valve also ornamented by fine capillae, 3 in 1 mm, and anteriorly marked by low uneven impersistent rugae; growth lamellae and growth steps inconspicuous. Dorsal ornament of capillae, no spines.

Interior poorly preserved, but cardinal process, and anterior pustules visible in dorsal valve. Brachial ridges in typical outline.

Resemblances. Edriosteges poyangensis Kayser (1883), also figured and discussed by Huang (1932, p. 66), Zhan (1979, p. 73, pl. 7, figs. 1-4), and Liao (1980*a*, pl. 3, figs. 10-13) is close, but more geniculate, with less vaulted ventral valve and larger ventral ears. The species comes from the Wuchiaping-Lungtan beds in the Djulfian Stage of south China, and was also reported from the Yamamba Limestone of the Sakawa Basin, Japan, by Yanagida (1973). 'Guadalupian' (Punjabian) specimens ascribed to the species in Ruzencev and Sarytcheva (1965, pl. 32, figs. 4-6) from Armenia have slightly broader visceral disc and more widely diverging umbonal shoulders. *Edriosteges ogbinensis* Sarytcheva in Ruzencev and Sarytcheva (1965, p. 211, pl. 32, figs. 7, 8) is fairly close but appears to have a less defined sulcus and less vaulted visceral disc, and more transverse outline. It comes from the *Oldhamina* beds of the Baisalian substage, Djulfian Stage, in Armenia.

Edriosteges multicostatus Muir-Wood and Cooper, 1960 (and see Cooper and Grant, 1975, p. 840) from the Cathedral Mountain and Road Canyon Formations of the Glass Mountains, Texas, of Baigendzinian and Kungurian age, is moderately close in many aspects, but has more ear spines and more emphasized concentric ornament. *E. tumitus* Liao (1980*b*, pl. 3, figs. 7-9) from the lower Changsing beds of west Guizhou is transverse with a broad flattish disc. *E. acuminatus* Liao (1980*b*, pl. 4, figs. 12-14) from the lower Lungtan *Edriosteges poyangeniss* Zone is perhaps the closest ally, in having similar spinose ears, but the shells, poorly perserved, appear to be less narrow. *E. subplicatilis* (Frech), revised by Liao (1980*b*, pl. 4, figs. 15-17) from the same zone also has a more transverse outline and more pronounced growth lines.

Comment on the Relationships of the Aulostegacea

The appearance of the brachial ridges on *Edriosteges*, as small compressed loops at the end of a long almost straight ridge extending from the adductor scars is very like the pattern seen on members of the Productidina, and different from that seen in the Strophalosiidina. Muir-Wood and Cooper (1960) classed the Aulostegidae with the Strophalosiidae in the Strophalosiacea, and distinguished them from the Productacea because the ventra valves were cemented by an umbonal cicatrix on the ventral valve, and had a well developed ventral interareal. On the other hand, several authors have pointed out that members of the Aulostegidae, now Aulostegacea, resemble genera classed in the Productacea by Muir-Wood and Cooper (1960), examples including *Waagenoconcha* and *Juresania*, and allies. In discussing classification and relationships between these groups, Waterhouse (1978*a*), noted similarities shown by Aulostegacea to Buxtoniidae, and considered that on the whole the Buxtoniidae were allied to the Productacea. Undoubted differences do exist between the Strophalosiacea and Aulostegacea. For example, the absence of teeth, the strong tendency of the muscle scars to be non-dendritic until late in ontogeny, and the presence of a dorsal interarea are features-typical of Strophalosiacea, and their counter features help unite Aulostegacea with Productidina. On the other hand, the stress placed by Muir-Wood and Cooper (1960) on scar of attachment and ventral interarea must not be discounted, and in addition, no member of the Aulostegacea, as far as we are aware, shows any sign of the minute pedicle reported for juveniles of various members of the Productidina. But the balance in favour of an association with the Productidina seems to be greatly strengthened in our view by the nature of the brachial ridges, which are productoid, not strophalosioid, in their size and outline. (Even so, it must be admitted that the well-preserved material from Hydra, Greece, suggests that we cannot entirely rely on normal modes of preservation of the brachiophores.)

The two short septa which may lie either side of the alveolus in various Productidina, including *Juresania*, and some Aulostegids may or may not be significant : perhaps they represent vestigial remains of the septa of chonetids, or modified dental ridges of Strophalosiids, but might be new structures, and if so, may have arisen independently in various stocks.

We are inclined to consider that the Aulostegacea belong to the Productidina rather than Strophalosiidina—whilst pointing out that the Aulostegacea do appear to contain, under the Cooper and Grant (1975) classification, some genera that should be relocated (see Waterhouse, 1978*a*). An origin ultimately from members of the Productellacea now seems likely to us, because some Productellacea share with Aulostegacea an interarea, procardinal ridges, Productidin brachial loops, and, also of great importance, ornament dominated by spines, with inconspicuous or no radial ornament (e.g. *Orbinaria*, *Linoproductus*). It may transpire that the Productellacea includes primary members of Strophalosiidina and various strands presently classed within the Productidina, and this is certainly implied by different ornaments in different genera, though full study is hindered by inadequate knowledge of dorsal interiors for some genera of Productellacea.

Subfamily Chonosteginae Muir-Wood and Cooper, 1960

Genus *Chonostegoides* Sarytcheva, 1965

Chonostegoides cf. *baissalensis* Sarytcheva, 1965

Pl. 2, figs. 1-3.

(cf. 1965 *Chonostegoides baissalensis* Sarytcheva, in Ruzencev and Sarytcheva, p. 214, pl 33, fig. 7).

Holotype. Specimen PIN 2071/47, figured in Ruzencev and Sarytcheva (1965, pl. 33, fig. 7), kept at Palaeontological Institute, Moscow.

Diagnosis. Shells with highly convex ventral valve bearing median sulcus; costal bases broad.

Present material. Two ventral valves and specimen with valves conjoined.

Plate 2. **1-3**, *Chonostegoides* cf. *basisalensis* Sarytcheva. **1, 3**, dorsal and ventral views × 2. 2, ventral valves × 3, **4-6**, *Krotovia jisuensiformis* Sarytcheva × 3. 4, 5, dorsal and ventral aspects of specimen with valves conjoined. 6, oblique ventral aspect of slightly distorted ventral valve. **7-11**, *Liosotella multiplicata* n. sp. 7-9, 11, ventral valves, × 2. 10, 11, dorsal and ventral views of holotype, × 3, × 2. **12**, *Transeunatia bellus* (Zhan), × 2.

Dimensions (in mm) :

Width	*Length*	*Height*	*Hinge width*	*Umbonal angle*
27.5	24	10.5	18	95°

Description. Shells suboval in outline, with one apparently transverse, bearing median flattening or shallow ventral sulcus on different ventral valves; hinge moderately wide, with interarea, and rounded cardinal extremities. Spine bases 2 mm long and 0.7 mm wide over middle of véntral valve, 5 in 5 mm bases more extended anteriorly. Dorsal spines numerous, 0.3 to 0.4 mm in diameter.

Resemblances. In the width and length of the ventral spine bases and presence of a shallow median ventral sulcus, these specimens resemble *Chonostegoides baissalensis* Sarytcheva from the Hachik beds of Armenia, but the sulcus is slightly deeper in the holotype. Of the two other species described by Sarytcheva, *O. ogbinensis* is a rounder shell with finer spine bases and faint if any sulcus, and *O. armenicus* has a swollen venter and coarse elongated spine bases. Both of these species come from the Gnishik level in Armenia.

Family Overtoniidae Muir-Wood and Cooper, 1960

Genus *Krotovia* Frederiks, 1928

Krotov a jisuensiformis Sarytcheva, 1965

Pl. 2, figs. 4-6.

1965 *Krotovia jisuensiformis* Sarytcheva, in Ruzencev and Sarytcheva (1965, p. 216, pl. 34, figs. 5-8).

Holotype. Specimen PIN 2071/78, figured by Ruzencev and Sarytcheva (1965, pl. 34, fig. 5), kept at Palaeontological Institute, Moscow.

Diagnosis. Small elongate shells with highly vaulted ventral valve and minute spines.

Present material. Four ventral valves, and specimen with valves conjoined.

Dimensions (in mm) :

Width	*Length*	*Height*	*Hinge width*	*Umbonal angle*
14	16	8.5	10	100°
11.5	16.5	11	9.5	70°
10	14	8		75°

Description. Shells small, elongate, ventral vaive highly arched, dorsal valve moderately concave, visceral disc thick. Ventral umbo strongly incurved, posterior umbonal walls high, median shell either convex, or slightly flattened, hinge moderately wide with tiny projecting ears. Ventral spines fine, 0.4 mm in diameter anteriorly, spaced 8-9 in 5 mm along concentric rows anteriorly, close-set, arranged in quincunx, with inconspicuous bases. Some bases prolonged anteriorly as low radial ruge. Concentric ornament inconspicuous, dorsal ornament not preserved.

Resemblances. These specimens are identical in shape and ornament with the distinctive form *Krotovia jisuensiformis* Sarytcheva, described from the Gnishik and Hachik beds of Armenia. Some of the specimens figured as *Productus* (*Pustula*) *curvirostris* Schellwien by Likharev (1936, pl. 9, figs. 15-21) appear to be similar in shape and ornament, and may prove to be conspecific. They come from the Urushten beds of the Caucasus. Taraz *et al.* (1981 : 121) listed the species from the Surmaq Formation and lower Abadeh Formation of Punjabian and Urushtenian age in central Iran.

Family Marginiferidae Stehli, 1954

Genus *Liosotella* Cooper, 1953

Discussion. Liosotella is very close indeed in most attributes to the genus *Marginifera* Waagen, but may be distinguished by its persistent costae. Similarly, costate species from Asia that have previously been referred to *Marginifera* may therefore be referred to *Liosotella.*

Liosotella multiplicata n. sp.

Pl. 2, figs. 7-11.

Holotype. Specimen figured in Pl. 2, figs. 10, 11.

Diagnosis. Small narrow shells with little if any ventral sulcus; costae strong and few, uneven in strength, number 10-15, usually about 12.

Material. Twenty ventral valves, three specimens with valves conjoined.

Dimensions (in mm) :

Width	*Length*	*Height*	*Umbonal angle*
18	17.5	11	95°
17	17	10	
13	13	6.5	90°
12	16	10	

Description. Specimens variable in shape, some elongate, others subrounded, others transverse. Ventral umbo incurved and extended over hinge, which is almost as wide as shell at maximum width placed in front of mid-length, ears small, convex, acute, posterior walls steep; dorsal valve very gently concave, geniculate. Most specimens have rounded venter but transverse specimens and one of subequal width/length have shallow median sulcus. Spines form single row along umbonal slopes, and scattered over ventral valve, with few on ears; none on dorsal valve. Costae number 12-13 on shells of equable dimensions, and 10-12 on narrow shells, 12-15 on transverse specimens. Outer flanks of shell almost smooth, with discontinuous costae. Some costae arise in interspaces anteriorly, and may remain fine especially in narrow shells.

Ventral adductor scars elongate, smooth; diductors impressed, striated, marginal ridge not large. Dorsal valve with marginiferid cardinal process, septum extending just in front of mid-length; adductor scars smooth, small. Marginal ridge curves around disc, strong across ears and wide anteriorly; brachial ridges low.

Resemblances. Although the shells vary in shape, they all have an almost comparable number of costae, and spines are similar. Somewhat similar shells are referred to *Marginifera magniplicatus* Huang (1932, pl. 1, figs. 15-17) from Kueichow. Liao (1980*b*, pl. 6, figs, 44, 45) ascribed the species to *Liosotella* in recording shells from the lower Lungtan beds (Djulfian) of south China (west Guizhou). The Chinese specimens have a subrounded outline with no sulcus, and show only 7 costae from a ventral aspect, fewer than on present specimens. Similar specimens were recorded from the Gnishik and Hachik horizons of the Lesser Caucasus in Armenia by Ruzencev and Sarytcheva (1965, pl. 37, figs. 2-4). *Liosotella wordensis* King, 1931, as figured by Cooper and Grant (1975, pl. 411, figs. 1-71; pl. 412, figs. 19-42) from the Cathedral Mountain, Getaway, Road Canyon and Word Formations of Baigendzinian to Kazanian age in Texas is close in general appearance, but tends to be consistently though slightly more transverse, with more pointed ears. *Productus* (*Marginifera*) *typicus elongatus* Huang (1932) from mid-Permian beds of China has up to 15 ribs that are finer and lower than in the new species. This species has been reported from early Djulfian beds of the Karakorum Range by Merla (1934, pl. 25, figs. 16-23) and ribs in Merla's specimens are also fine, and of even strength.

Genus *Transennatia* Waterhouse, 1975

Transennatia bellus (Zhan, 1979)

Pl. 2, fig 12.

1936 *Productus* (*Marginifera*) *gratiosus* Waagen var. *timorensis* [not Hamlet] Likharev (1936, p. 118, pl. 4, figs. 11-19; pl. 9, fig. 37).

1979 *Asioproductus bellus* Zhan (1979, p. 85, pl. 6, figs. 7-13; pl. 9, figs. 8-10; text fig. 18). (See for synonymy.)

Holotype. Specimen figured by Zhan (1979, pl. 6, fig. 8), kept at Beijing Geology Museum.

Diagnosis. Shells small with gently convex ventral disc and geniculate trail, costae fine over disc and trail.

Present material. One ventral valve.

Dimensions (in mm) :

Width	*Length*	*Height*
20	12	4

Description. Shell transverse and little inflated, with low posterior walls diverging from inconspicuous umbo at angle of 85°, hinge apparently at maximum width, ears large, gently convex, visceral disc gently convex, low and geniculate, sulcus commences at umbo and widens forward at angle close to 20°. Costellae fine, numbering 9 in 5 mm at start of trail, converging inwards towards centre of sulcus, crossed by fine concentric lirae, 3 in 1 mm, branching into two or three laterally, forming low beads across radial ribs. Spines form prominent row across inner ears, and scattered over anterior slopes beyond sulcus.

Resemblances. The ornament on this specimen is distinctly finer than that found in *Transennatia gratiosus* (Waagen) from the Chhidru Formation of Pakistan and Himalayas, and widely reported from Asia, and the shell also has a flatter disc and shorter trail. It appears identical with a suite of specimens from the Shuitsutang (Wuchiaping) beds of Guangtung and the Urushten beds of the Caucasus described by Likharev (1936). Likharev had identified his specimens with a variety of *Productus gratiosus* named *timorensis* by Hamlet (1928) from the Basleo beds of Timor. The Timor form has a larger shell with sturdy costae, very like *gratiosus* Waagen. Zhan (1979) ascribed other shells to synonymy of *bellus*, including *Productus* (*Dictyoclostus*) aff. *gratiosus* of Huang (1932, pl. 2, figs, 3) from the Lyttonia beds of Kueichow.

Family Costipiniferidae Muir-Wood and Cooper, 1960

Genus *Spinomarginifera* Huang, 1932

Spinomarginifera spinosocostata (Abich, 1878)

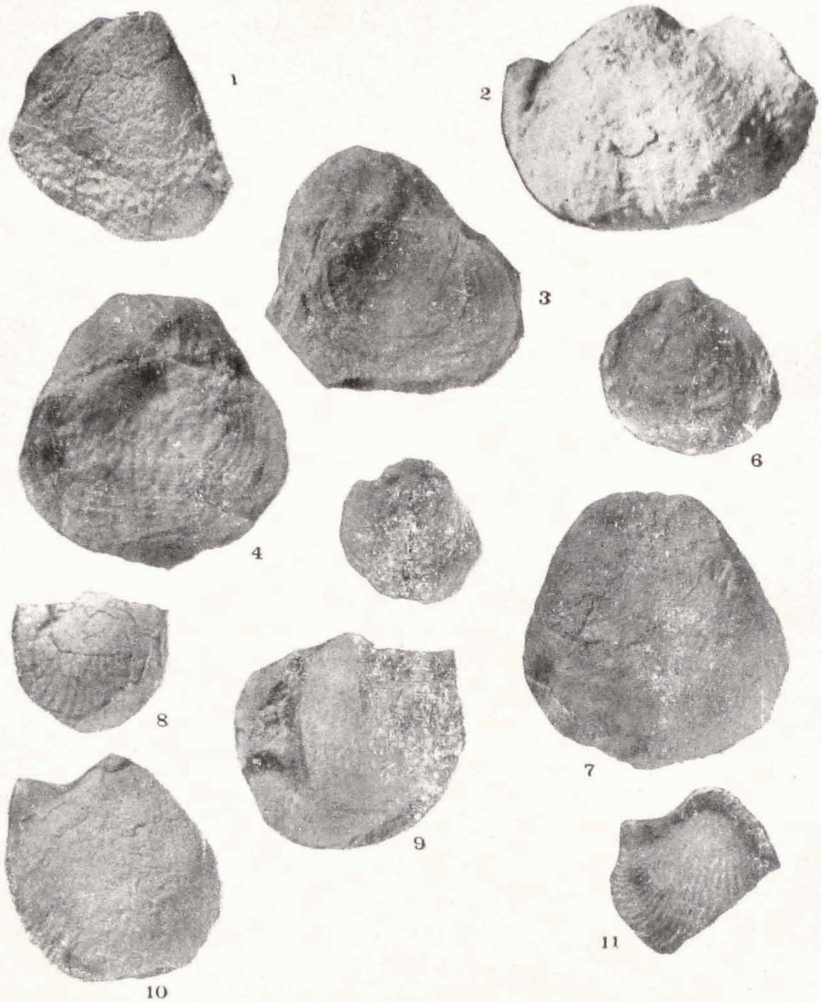

Plate 3. **1**, *Spinomarginifera ciliata* (Arthaber), ventral aspect, × 3. 2, ? *Spinomarginifera spatiosus* (Likharev), ventral valve, × 2. **3-7**, *S. spinosocostata* (Abich). 3, dorsal view of specimen with valves conjoined, × 3. 4, 7, dorsal and ventral views of specimen with valves conjoined, × 3. 5, dorsal external cast, × 3. 6, ventral valve × 3. **8-11**, *Ogbinia dzhagrensis*. Sarytcheva. 8-10, ventral valves × 3. 11, specimen with both valves, ventral valve stripped back to show dorsal valve, × 3.

Pl. 3, figs. 3-7.

1978 *Productus spinoso-costatus* Abich (1978, p. 41, pl. 10, figs. 6, 7, 10).

1965 *Spinomarginifera spinosocostata* Sarytcheva 1965 p. 225, pl. 37, figs. 6-8). (See for synonymy and typology.)

Holotype. Specimen figured by Abich (1878, pl. 10, fig. 6), Kranityar Museum LGI 35/99.

Diagnosis. Small narrow shells with tumid venter and elongate swollen spine bases.

Present material. Two specimens with valves conjoined, a ventral valve and dorsal valve.

Dimensions (in mm) :

Width	*Length*	*Height*
13	14.4	7.5
11	11.5	6.5

Description. Shells small with incurved narrow ventral umbo, umbonal angle close to 90°, ventral disc with median flattening, dorsal disc gently concave. Ventral spines emerging from short wide ribs, may be also swollen at base; dorsal spines possibly but not definitely present on specimen with valves conjoined, numerous on separate dorsal valve.

Resemblances. These specimens appear to belong to *Spinomarginifera spinosocostata* (Abich). The species is recorded from the *Araxilevis* and *Oldhamina* beds of the Baisalian Substage, Djulfian Stage, Lesser Caucasus in Armenia. A specimen assigned to this species from $P2^a$ beds in the Caucasus by Likharev (1936, pl. 10, fig. 37) appears to differ in having finer costae anteriorly and less swollen bases posteriorly. Taraz *et al.* (1981: 121) listed the species from the Surmaq, Abadeh, and Hambast Formations of central Iran, of Punjabian to Djulfina age. A specimen from poorly dated, possibly Djulfian or younger beds of Malayasia, was compared to the species by Yanagida and Aw (1979, p. 131, pl. 28, fig. 17).

Spinomarginifera ciliata (Arthaber, 1900)
Pl. 3, fig. 1.

1900 *Marginifera spinosocostata* Abich sp. var. *ciliata* Arthaber (1900, p. 264, pl. 20, fig. 9).
1965 *Spinomarginifera ciliata* Ruzencev and Sarytcheva (1965, pl. 37, fig. 12).
1966 *S. ciliata* Sestini and Glaus (1966, p. 903, pl. 64, fig. 7).

Holotype. Sole specimen figured by Arthaber (1900).

Diagnosis. Shells suboval in shape, with very fine spines lacking conspicuous bases or rugae.

Present material. A ventral valve.

Description. Shell slightly transverse in outline, moderately inflated, with very shallow anterior sulcus. Spines very fine, numbering 2-3 in 2 mm along rows only 0.6 mm apart anteriorly.

Resemblances. This species is distinguished by its fine spines, and has a shallow sulcus as in the specimen figured in Ruzencev and Sarytcheva (1965). The species is reported from the Lesser Caucasus in the *Oldhamina* and *Haydenella* beds of the upper Djulfian Stage, and from the Nesen Formation of comparable age in Iran. The material figured as this species from the Caucasus by Likharev (1936, pl. 10, figs. 35, 36) seems to have slightly fewer spines. Taraz *et al.* 1981: 121) listed the species from the lower Abadeh Formation of early Djulfian age in central Iran. Somewhat similar fine spines are developed on a shell figured as *Spinomarginifera helica* from the upper Barabash beds of Primoyr by Likharev and Kotlyar (1978, pl. 20, figs. 21, 22).

?*Spinomarginifera spatiosus* (Likharev, 1936)
Pl. 3, fig. 2.

1939 *Productus* (*Marginifera*) *spatiosus* Likharev (1939, p. 121, pl. 11, figs. 13-19).

Holotype. Specimen figured by Likharev (1939, pl. 11, fig. 13).

Diagnosis. Small transvere shells with scattered spines, lacking conspicuous bases, low costae, distinct sulcus.

Present material. A ventral valve.

Description. Shell transverse, with low umbo extended beyond hinge, and subrounded cardinal extremities. Ventral spines narrow with small bases in quincunx, about 2 mm apart, and shallow sulcus over anterior disc persisting on to trail. Low costae anteriorly, 5-6 in 5 mm.

Resemblances. The specimen agrees in shape with *Marginifera spatiosus* Likharev and has the same shallow short anterior sulcus and low anterior costae. Spines and spine bases appear to be similar. The species has been described from the Urushten beds of the Caucasus. The generic position may require further study as the row of spines found along the ventral umbonal slopes of *Marginifera* is not clearly indicated in Likharev's figures or the present specimen, and dorsal spines are possibly illustrated in the figure by Likharev (1936, pl. 11, fig. 17).

Family Chonetellidae Likharev, 1960
Genus *Ogbinia* Sarytcheva, 1965
Ogbinia dzhagrensis Sarytcheva, 1965
Pl. 3, figs. 8-11.

1965 *Ogbinia dzhagrensis* Sarytcheva in Ruzencev and Sarytcheva, (1965, p. 230, pl. 38, figs. 12-14; text fig. 36).

Holotype. Specimen PIN 2071/65, figured in Ruzencev and Sarytcheva (1965, pl. 38, fig. 13), kept at Palaeontological Institute, Moscow.

Diagnosis. Small subpentagonal shells with arched venter, small pointed cardinal extremities, well developed but low costae.

Present material. Six ventral valves.

Dimensions (in mm).

Width	*Length*	*Height*
13.5	13.5	7
13.5	10.5	4.5

Description. Shells small, with arched ventral valves, incurved broad umbo, umbonal angle measuring close to 110°, hinge at maximum width with tiny pointed cardinal extremities. Costellae fine, 3-4 in 2 mm anteriorly; spines masked by poor preservation.

Resemblances. These specimens appear to be identical with those described from the Gnishik and Hachik horizons of the Lesser Caucasus, Armenia, in Ruzencev and Sarytcheva (1965). A species from the Urushten beds of the Caucasus described by Likharev (1936, pl. 9, figs. 22-26) as *Productus* (*Productus*) *chamishkjensis* appears to be close in shape and ornament, and although figures of the two species suggest that some specimens of the Urushten species have slightly coarser ribs, it appears very difficult to separate the two. Taraz *et al.* (1981; 121) listed the species from the Surmaq Formation of Punjabian age in central Iran.

Superfamily Linoproductacea Stehli, 1954

Family Linoproductidae Stehli, 1954

Genus *Linoproductus* Chao, 1927

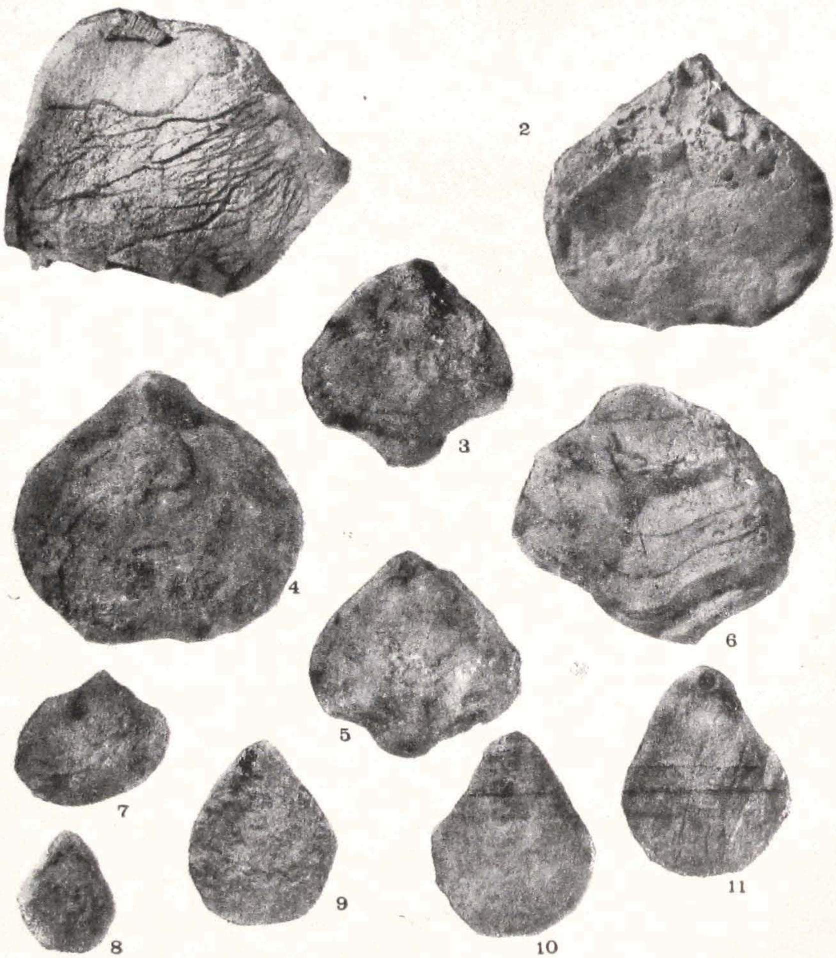

Plate 4. 1, *Linoproductus triangularis* Likharev, broken ventral valve, × 1. **2, 4,** *Araxathyris* cf. *abichi* (Arthaber), ventral and dorsal views, × 2. **3, 5, 6,** *A. umbonalis* n. sp. × 2. 3, 5, dorsal and ventral views of holotype. 6, ventral aspect of specimen with valves conjoined. **7**, *Cruricella tschernyschewi* (Likharev), ventral valve, × 2. **8, 9**, *Notothyris* sp., dorsal and ventral aspects of specimen with valves conjoined, × 2, × 3. **10, 11**, *Labaia erecta* n. sp. ventral and dorsal aspects of holotype, × 2.

Linoproductus triangularis (Likharev, 1936)
Pl. 4, fig. 1.

1936 *Productus* (*Productus*) *cora* d'Orbigny var. *triangularis* Likharev (1936, p. 103, pl. 5, figs. 1-3; pl. 6, figs. 4-5).

Holotype. Specimen figured by Likharev (1936, pl. 5, fig. 1).

Diagnosis. Large elongate shells with flat or concave anterior venter and fine costae.

Present material. A single specimen with valves conjoined.

Description. Specimen more than 65 mm wide with posterior half destroyed, 9-11 costae in 5 mm anteriorly, extensively flattened to slightly depressed venter, and thick visceral disc, more than 15 mm thick.

Resemblances. The specimen approaches *Linoproductus triangularis* (Likharev) from P2ᵉ *beds* (Kazanian) in the Caucasus. The species has a flattened to weakly sulcate venter and fine costae. Shells from the same beds that were assigned to *L. lineatus* (Waagen) by Likharev (1936, pl. 7, figs. 1-3) have similar fine costae, with flat to gently convex venter and might be allied.

Family Athyrididae M'Coy, 1844
Genus *Araxathyris* Grunt, 1965
Araxathyris n. *umbonalis* n. sp.
Pl. 4, figs. 3, 5, 6. Text fig. 1A.

Holotype. Specimen figured in pl. 4, figs. 3, 5.

Diagnosis. Subpentagonal shells lacking posterior groove, with anterior broad-floored sulcus in ventral valve, well-formed flat-crested dorsal fold over anterior shell, short anterior costae on both valves over flanks.

Material. Three specimens with valves conjoined.

Dimensions (in mm).

Width	*Length*	*Height*	*Unbonal angle*	*Single angle*
20	19.5	14.5	70°	25°

Description. Shell well-inflated with extended narrow ventral umbo, bearing terminal foramen, steep posterior walls and rounded cardinal extremities. Posterior ventral valve convex, ventral sulcus commencing at mid-length, with wide gently convex floor and steep sides; dorsal fold also commences well in front of umbo, with wide gently convex crest, steep sides, and short median groove. Some four costae lie on each valve over lateral flanks on anterior half of ventral valve and anterior third of dorsal valve.

Ventral teeth supported by short vertical plates each side of foramen. Dorsal interior with short subhorizontal hinge plate between dental sockets (Fig. 1A).

Resemblances. This species is almost identical with *Araxathyris protea* (Abich, 1878) as discussed and revised by Grunt in Ruzencev and Sarytcheva (1965: 241) from *Oldhamina* beds in the super Djulfian Stage of south Armenia, and Nesen beds of Iran (Sestini and Glaus, 1966) but has a smooth posterior shell, without the ventral groove. The presence of short rugae around the anterior may also be distinctive, though of uncertain significance. Less regularly spaced rugae are suggested in a figure of *Araxathyris protea multilobata* (=*protea*) by Arthaber (1900, pl. 21, fig. 8c) and the specimen has similar short groove over the dorsal fold.

Araxathyris kandevani Sestini and Glaus (1966, pl. 65, figs. 4-5) from the Nesen Formation of North Iran is somewhat similar with narrow and inconspicuous posterior groove, but is distinctly more transverse, and the species was also reported from the *Edriosteges poyangensis* Zone (lower Lungtan) of Guizhou by Liao (1980*a*).

Araxathyris shuizhutangensis Chan (in Hou *et al.*, 1979, pl. 8, figs. 7-8, 10, 15-16) from the Shuitsutang Formation of Guangtung (close to upper Lungtan in correlation) is moderately close but has a narrower less linguiform sulcus.

Araxathyris cf. *abichi* (Arthaber, 1900)
Pl. 4, figs. 2, 4.

Cf. 1900 *Spirigera abichi* Arthaber (1900, p. 280, pl. 22, figs. 10-12).

Cf. 1965 *Araxathyris abichi* Grunt, in Ruzencev and Sarytcheva (1965, p. 244, pl. 43, fig, 3; text fig. 43). (See for synonymy, typology, and diagnosis).

Present material. Two specimens with valves conjoined.

Dimensions (in mm) :

Width	*Length*	*Height*	*Umbonal angle*
28	28	15	77°

Description. Shell subpentagonal in outline with prominent narrow ventral umbo extended well beyond hinge line, bearing high narrow foramen, dorsal umbo also well-developed with angle of 95°. In front, shell outline subrounded, and maximum width placed in front of mid-length. Ventral sulcus shallow and inconspicuous, groove-like posteriorly in front of smooth umbo, wider anteriorly. Dorsal valve very slightly swollen medianly near anterior margin, and anterior commissure slightly retracted.

Resemblances. These specimens compare with *Araxathyris-abichi* (Arthaber) from the *Oldhamina* beds of the upper Djulfian Stage of south Armenia, as revised by Grunt in Ruzencev and Sarytcheva (1965), but the ventral umbo is less incurved and narrower, and the posterior walls less massive than in the present material. A dorsal groove is lacking in Grunt's figured specimen, but is shown in figures of Arthaber (1900).

Family Ambocoeliidae George, 1931
Genus *Crurícella* Grant, 1976
Crurícella tschernyschewi (Likharev, 1939)
Pl. 4, fig. 7.

1934 *Ambocoelia planoconvexa* Simic (1934, p. 100, pl. 4, figs. 2-4).
1939 *Ambocoelia* (?*Crurithyris*) *tschernyschewi* Likharev (1939, p. 114, pl. 25, figs. 11 a-d).
1963 *Ambocoelia* (*Crurithyris*) *tschernyschewi* Shreter (1963, p. 134, pl. 7, figs. 7-11).
1965*a* *Crurithyris tschernyschewi* Sestini (1965*a*, p. 62, pl. 7, fig. 1).
1980*a* *Crurithyris subspeciosa* Liao (1980*a*, p. 276, pl. 1, fig. 6, not 5, 7-10).

Holotype. Specimen figured by Likharev (1939, pl. 25, fig. 11c).

Diagnosis. Small shells with swollen ventral valve and comparatively well-formed hinge.

Present material. A ventral valve.

Dimensions (in mm) :

Width	*Length*	*Height*	*Width hinge*
11.3	11.3	4	6

Description. Shell of moderately large size for genus, with swollen ventral valve and incurved ventral umbo, angle measuring 90°; hinge wide, cardinal extremities well rounded. No sulcus; surface of shell ornamented by fine pustules, 10-12 in 1 mm along irregular concentric rows.

Resemblances. This specimen is identified with *Cruricella tschernyschewi* initially described from Urushten beds of the Caucasus, and recorded also from Djulfian beds of Armenia by Arthaber (1900; 266), according to Sestini (1965*a*; 201), from the middle Ruteh fauna of early Djulfian age in north Iran (Sestini, 1965*a*), and from Djulfian deposits of the Bukk Mountains, Hungary (Shreter, 1963) and west Serbia (Simic, 1934). Early Permian specimens have also been referred to the same species, but as discussed by Shreter 1963; 136), the early Permian specimens have a shallow sulcus or groove on the ventral or dorsal valve. A shell figured as *Crurithyris subspeciosa* by Liao from the *Edriosteges poyangensis* Zone, lower Lungtan of west Guizhou, China, appears to be similar. *C. subspeciosa* (Liao, 1980*a*, pl. 8, figs. 5, 7-10) from the lower Changsing deposits of the same region is more oval in shape, but close.

Family Notothyrididae Likharev, 1960
Genus *Notothyris* Waagen, 1882
Notothyris sp.
Pl. 4, figs. 8, 9.

Material. A specimen with valves conjoined.

Dimensions (in mm) :

Width	*Length*	*Height*
9.5	12	6.5

Description. Shell small, elongate, ventral umbo with large foramen, and moderately incurved, valve most inflated near hinge, without sulcus or anterior plicae. Dorsal valve less inflated, bearing two anterior short plicae separated by shallow sulcus; margin to each side undulose, anterior commissure paraplicate. Shell finely punctate.

Resemblances. This specimen approaches the shell referred to *Notothyris nucleola* (Kutorga) by Ruzencev and Sarytcheva (1965, pl. 44, fig. 9) from the Gnishik fauna of south Armenia, but lacks ventral plicae. Allied specimens range from Punjabian to Djulfian according to a fossil list for beds in central Iran (Taraz *et al.*, 1981; 121). Kutorga's species, as figured by Chernyshev (1902) and others—see Branson (1948 : 434)—has ventral plicae and is characteristic of early Permian faunas of Asia. It was reported from early Permian beds of the Karakorum by Merla (1934, pl. 23, figs. 20-32), with a range of plical development.

Family Labaiidae Likharev, 1960

Genus *Labaia* Likharev, 1956

Labaia erecta n. sp.

Pl. 4, figs. 10, 11. Text-fig. 1 B.

Holotype. Specimen figured in pl. 4, figs. 10, 11.

Diagnosis. Elongate shells with broad extended umbo and widely diverging not massive posterior walls.

Material. Eight specimens with valves conjoined and one ventral valve.

Dimensions (in mm) :

Width	*Length*	*Height*
16	20	10

Description. Shell elongate with prominent erect ventral umbo terminated by foramen over 1.5 mm wide in holotype, posterior walls moderately steep, gently concave in outline and diverging at 60°, persisting well forward; dorsal umbo broad and tucked under ventral delthyrium, which is masked by matrix. Maximum inflation lies just in front of mid-length, and both valves most inflated just behind, the ventral valve twice as high as the dorsal; anterior outline smoothly oval. No sulcus or fold, and no median flattening in profile. Shell minutely punctate, about 25 pores in 1 mm posteriorly, and surface crossed by faint growth lines, 5-6 in 1 mm.

Dental plates not developed. Dorsal socket ridges heavily thickened and sited close to lateral walls, no visible median septum.

Resemblances. This species has more extended and less massive posterior walls than in *Labaia muirwoodae* Likharev (1956) from the Urushten fauna of the Caucasus. *L. dmitrievi* Grunt in Grunt and Dmitriev (1973, pl. 13, fig. 13; text figs. 50, 51) from the Darvas Stage of the Pamirs (Kizildjilgin Suite) is closer in appearance, but posterior walls are convex in outline and not as long.

Age of the Fauna

From consideration of the brachiopod species, and overall consideration of what little is known of Karakorum Permian stratigraphy, a Djulfian, and probably early Djulfian, i.e., Urustenian or Abadehan age appears probable. This is most strongly indicated by the presence of *Cruricella tschernyschewi* (Likharev), regarded by Waterhouse (1976*a*) as a key species for the Urushtenian or Abadehan Substage, occurring in faunas of this age in southern Europe, north Iran, Caucasus, and south China, as well as the Karakorum. Further direct correlation with the Urushten beds of the Caucasus is indicated by the species *Krotovia jisuensiformis*, *Transennatia bellus*, (?) *Spinomarginifera spatiosus* and perhaps *Ogbinia dzhagrensis.* Other species indicate a possible or likely Abadehan-Urushtenian age, *Tropidelasma karakorumensis* approaching another Karakorum species of Urushtenian age; *Edrosteges shyokensis* approaching *E. poyangensis* of early and late Djulfian age in south China, *Krotovia jisuensiformis* reported from the Abadeh Formation of central Iran, *Liosotella multiplicata* approaching *L. magniplicatus* Huang from lower Lungtan beds of south China, *Spinomarginifera spinosocostata* and *S. ciliata* being listed from the Abadeh Formation of central Iran, *Notothyris* perhaps resembling *N. nucleola* listed from the Abadeh Formation of central Iran, and *Labaia erecta* approaching *L. muirwoodae* from Urushten beds of the Caucasus. A slightly younger Djulfian age, i.e., Baisalian Substage, is indicated by some species though not as many as those favouring an Urushtenian correlation. *Edrosteges poyangensis* which resembles *E. shyokensis* is found in Baisalian faunas of south China (upper Lungtan), *Transennatia bellus* is found in the Shuitsutang beds of Guangtung, China;

TABLE I : LIST OF SPECIES AND THEIR AFFINITIES FROM PERMIAN LIMESTONE OF SHYOK VALLEY. SPECIES LISTED (AND SO UNCHECKABLE) INDICATED BY "?"

Species	*Age elsewhere in Armenia, Iran, Karakorum, China*			
	Punjabian Stage		*Djulfian Stage*	
	Kalabaghian	*Chhidruan*	*Urushtenian*	*Baisalian*
Acosarina sp.				
(?)*Orthotetes* sp.				
Tropidelasma karakorumensis n. sp.			aff.	
Orthotetina sp.				
Edriosteges shyokensis n. sp.	aff.		aff.	aff.
Chonostegoides cf *baissalensis* Saryt.		cf		
Krotovia jisuensiformis Saryt.	×	×	×	
Liosotella multiplicata n. sp.	aff.	aff.	aff.	
Transennatia bellus (Zhan)			×	×
Spinomarginifera spinosocostata (Abich)	?	?	?X	×
S. ciliata (Arthaber)				×
(?)*Spinomarginifera spatiosus* (Likh.)			×	
Ogbinia dzhagrensis Sarytceva	×	×	?×	
Linoproductus triangularis (Likh.)				
Araxathyris umbonalis n. sp.				aff.
A. cf. *abichi* (Arthaber)				cf.
Cruricella tschernyschewi (Likh.)			×	
Labaia erecta n. sp.			aff.	
Notothyris sp.	aff.	?	?	?
Total aff. or uncertain	3	3	5	4
Total present	2	2	6	3
Total	5	5	11	8

Spinomarginifera spinosocostata and *S. ciliata* occur in Baisalian beds of Armenia, the latter species also found in the Nesen beds of north Iran. *Araxathyris umbonalis* approaches Baisalian species from Armenia, Iran and south China, and *Notothyris* sp. approaches *N. nucleola* listed from the Hambast Formation of central Iran.

These Djulfian resemblances far outweigh the Punjabian similarities. *Edriosteges shyokensis* approaches specimens identified as *E. poyangensis* from Gnishik beds of Armenia, and *Chonostegoides* is comparable to *C. baissalensis* from Hachik beds of Armenia. *Krotovia jisuenisformis*, though apparently ranging higher, was initially described from Gnishik-Hachik faunas of Armenia, *Liosotella multiplicatus* approaches *L. magniplicalus* from Gnishik-Hachik faunas of Armenia; and *Spinomarginifera spinosocostata* has been listed from the Surmaq Formation of central Iran; *Ogbinia dzhagrensis* was initially described from Gnishik and Hachik beds of Armenia, and *Notothyris* approaches *N. nucleola* from the Gnishik fauna of Armenia. *Linoproductus triangularis* of the Karakorum Range is identified with a species from the Punjabian or slightly older beds (P2^{a}) of Caucasus, and *Acosarina* sp. approaches a Dorashamian species from the lower Changsing Formation of China. Overall, the fauna is clearly of Djulfian age, and shows a preponderance of affinities with the Urushten faunas of the Caucasus and correlative faunas of Iran and China (Table 1), in spite of the fact that Urushtenian faunas and beds are very poorly represented in the most intensely studied of sequences in the region in Armenia. A number of species range up from Punjabian faunas—especially Gnishik and Hachik faunas of Armenia, and some persist into the Baisalian faunas of the upper Djulfian Stage, in a pattern normal for species ranges. There are very few affinities with earlier (i.e., Kazanian) or younger (i.e., Dorashamian) species. The Urushtenian age is strongly supported by the presence of *Cruricella tschernyschewi*, and abundance of *Orthoteilna, Edriosteges, Spinomarginifera* and *Araxathyris*, genera which are especially well-developed in Djulfian faunas of south Asia and south Europe.

II. CORRELATION TECHNIQUES. HAZARDS OF SIMPLISTIC ANALYSIS

Important Sequences of younger Permian Rocks and Marine Rocks and Faunas

There are few sequences in the world that display a fairly complete and fossiliferous marine sequence of younger Permain rocks, overlain by Early Triassic rocks. Areas of high degree of importance insofar as they are almost complete and fossiliferous include outcrops in Armenia-Iran (e.g., Ruzencev and Sarytcheva, 1965; Taraz *et al.*, 1981); Kasmir-Nepal (Nakazawa *et al.*, 1975; Waterhouse, 1978*a*); south China (Zhao Jinke *et al.*, 1978), and New Zealand (Waterhouse, 1982). Regions of secondary but considerable importance include those of central Asia—Pamirs and noth (perhaps with some gaps), south-east Europe (lacking pre-Djulfian marine rocks); Japan (with tectonically complicated sequences and many undescribed faunas), and north Thailand (with sequences of high potential significance, yet to have faunas described). Areas that are still less complete, insofar as Djulfian and early and middle Dorashamian marine faunas and rocks are very scarce or absent, include the otherwise much studied regions of Texas—north Mexico, and north-east Siberia.

Poorly known sequences within the Karakorum and Afghanistan may also be significant when sequences are better understood and faunas fully described or revised.

Any discussion of younger Permian correlations must take into account ALL *repeat* ALL, *of the fairly complete marine sequences.* And this is precisely what some authorities fail to do. As a result, their work is incomplete, and therefore unsatisfactory.

Grave Errors by Some Palaeontologists in Correlation Procedure

What some studies do is simply focus attention on a few of the preceding areas, and ignore the rest. The selected areas are generally those of Armenia-Iran, south China, and perhaps United States, though this is so incomplete that it also is occasionally ignored. Although the outcrops of south Europe are close to those of Armenia, and far more fossiliferous, they are ignored, and certainly no account is taken at all of the Himalayas or New Zealend in poorer studies. One of the chief reasons appears to be what almost amounts to an obsession, or at least a deliberate concentration of attention on some fossil groups that are extremely limited in distribution, and, therefore, because they are limited, are more readily amenable to study, without overwhelming students by too much data that do not suit some simplistic and even incorrect theory. The favourite fossils are the ammonoids, fusulines, and conodonts, in that order. The order is perhaps the reverse of usefulness. Ammonoids do range from tropical to temperate climatic zones, but are sporadic anywhere. Of the above sequences, they are found principally in Armenia and south China and Japan, and the less complete United States sequences. Their rarity in the other significant areas, and in many sequences within the most fossiliferous parts of China and Iran-Armenia, means that they are too limited to allow world-wide correlation, or even correlation within the palaeotropics or even interbasinal correlation. Fusulines and conodonts are more abundant in more sequences, but fusulines disappear before the close of the Permian, and both fusulines and conodonts are concentrated only in the palaeotropics—and very patchily at that, making a mockery of any attempt at *world* correlation. Primacy cannot be granted to these fossils. Instead, brachiopods must be regarded as the most useful fossil for correlation and for data on palaeoecology, climate, and evolution, because they are most numerous, and most widespread, and only they allow world-wide correlation in marine rocks for all climatic zones, polar and temperate, as well as tropical. Bivalves and gastropods have some use; bryozoa would probably be useful but have not been adequately studied, and small foraminifera and other microfossils have high potential value, but are patchy in distribution, and not studied widely. There is a much fostered myth that brachiopods range too long, and being sessile in adulthood, were not widely distributed and so were of little use. In fact, brachiopod genera range for no more than fusuline genera, and many species are short-lived, and widely distributed. No ammonoid, fusuline, or conodont genus was as widely distributed geographically as brachiopod genera such as *Neochonetes, Cancrinella, Linoproductus, Neospirifer, Dielasma*—and we can add so many. Some species are wideseread and short-lived. For example, *Cruricella tschernyschewi* (Likharev) was named as a key species for the Urushtenian (Abadehan) Substage by Waterhouse (1976*a*). It is found in south Europe, Caucasus, Iran, Karakorum and south China. Few ammonoid, conodont or fusuline species range so widely, for a similarly brief interval. The Karakorum fauna has been relatively easy to date as early Djulfian (Urushtenian), a precise correlation, solely on the basis of brachiopods. Furthermore, these brachiopods enable correlation with sequences beyond the reach of any time-correlation framework based on fusulines, conodonts or ammonoids, taking in very readily the sequences of south Europe, Elburz Mountains (Iran), Karakorum, Salt Range of Pakistan, and Himalayas of Nepal, and extendable as far as New Zealand. Fusulinacea, ammonoids, and conodonts, at intervals where they are present—and that is all too often seldom, to never—may help provide confirmatory evidence for some sections only.

III. THE URUSHTENIAN OR ABADEHAN SUBSTAGE—NOT STAGE

Nemenclature

Two rival names have been proposed for the same stratigraphic interval and fauna to which we refer the Karakorum faunas from the Shyok valley. One is the Abadehan Stage (Taraz, 1971; Taraz *et al.*, 1981). The other is Urushtenian Substage of the Djulfian Stage (Waterhouse, 1972, 1976*a*, 1978*b*). One of us, as author of one of the two names, admits to being not particularly concerned about which name is adopted for general use. To Dr. H. Taraz, who independently conceived of the 'Abadeh' as 'Stage' goes considerable credit for not only correctly recognising the unit, but for defending it against criticism during the 1973 Calgary conference on the Permian/Triassic boundary, when one of us (J. B. W.) must have been one of his very few defenders—when Urushtenian was already in press. The following facets should be considered in deciding which name should be used.

(i) Law of priority

Although the name Abadehan was proposed a little before Urushtenian, as pointed out by Waterhouse (1976, 1978*b*), the history of geology is replete with various kinds of nomen nuda, in which proposals and names are not substantiated. Stages and substages depend on rocks and faunas or floras. The faunas or floras must be described before they are usable. Lists mean nothing, virtually nothing. We are still waiting for the Abadehan 'Stage' to be validated by faunal descriptions. The faunas have not been described, other than in one work by Bando (1979) on ammonoids. Excellent data has now been provided on occurrences of stratigraphic intervals and fossil names (Taraz *et al.*, 1981), but that is not enough. By contrast, many elements of the type Urushtenian fauna, and its correlates over the world, were published before proposal of the substage. Part of a huge brachiopod fauna, the bivalves, fusulines, and other elements have been described, sufficing to impose faunal limits on the substage, and allow correlation with other regions, and clearly discriminate between Urushtenian and older and younger faunas. Presumably other essential elements of the Abadehan fauna, including fusulines, brachiopods and molluscs will be soon described. The data of validification of the Abadehan 'Stage' will date from publication of those systematic studies, and will clearly post-date the date of validification of the Urushtenian Substages.

(ii) Richnes and applicability of faunas

However, we do not consider the law of priority to be of prime importance. One important factor lies in the richness of the faunas. In that regard, the Urushten Formation is probably very much richer than the Abadehan fauna in brachiopods, bivalves and fusulines, but we are not aware if any search has been made for conodonts, for example. We would consider the type Abadehan to be rich enough for correlation purposes. Of course, richness or diversity of fauna/flora is only one aspect. It seems likely that even richer faunas may be found in south China. There must be retained some degree of nomenclatural stability, and some faunally limited stages (such as the Kazanian Stage) do suffice for correlation, and have served long in the literature as a marker unit.

(iii) Historical consideration

We consider that the Permian Period has along been associated with the Soviet Union, so that where possible, and if no violence is done to historical achievements, the Soviet Union should house standard sections and type sections for the Permian Period.

(*iv*) *Freedom of access*

Overriding other considerations is freedom of access, at least during part of the year, for geologists to inspect type sections. *A world stratotype must be available to geologists from the world.* Although an allowance may be made for intervals of war or political strain between countries when freedom of access has to be restricted to at least some citizens of some countries, we should normally be able to expect that the country hosting the world type section of any stage and substage would allow geologists entry subject to normal regulations. Otherwise, the country must yield curatorship of the type section, or propose moving the type section to a more accessible area free of military or political restriction. In view of this important reason, we deem it premature to decide in favour of ultimately in favour of either Urushtenian or Abadehan—or any other name, and of course hope that the difficulties of access may prove short-lived. In the meantime, we shall use Urushtenian Substage, because: (*a*) more of its faunas have been described; (*b*) its faunas are richer, especially for brachiopods, and therefore more widely useful; (*c*) it enjoys prior date of validification at 1972 as opposed to post-1982; (*d*) it lies within the Soviet Union.

Whatever name is used, we must stress that the term substage reflects better—very much better, the relationship of Urushtenian-Abadehan faunas of the Djulfian Stage, and Baisalian Substage. No evidence supports Taraz *et al.* (1981 : 105) in their assessment that the Abadehan merits stage rank. Justification and explanation of the Adadehan 'Stage' by Taraz *et al.* (1981) is sketchy. Their text also is confusing, and indeed misleading, over the limits of the Djulfian Stage and usage by other authors. Taraz *et al.* (1981 : 104) stated that they would redefine the Djulfian to be the same as the Baisalian of Waterhouse. This is not satisfactory, and as Baisalian was defined in the sense they want to use Djulfian, they should use Baisalian. This mistreatment of priorities and definitions allows a very biased and muddled presentation of correlation and historical summary (see Taraz *et al.*, 1981 : 104) that would have been avoided had rules been followed.

Failure to define and delimit Abadehan Stage

The section entitled Abadehan by Taraz *et al.* (1981) provides no meaningful definition of the stage or its faunal attributes. It is stated that the Abadehan is pre-Djulfian (meaning pre-Baisalian) because it underlies Djulfian (meaning Baisalian) faunas and rocks, but this, though correct, is simply stratigraphically meaningful, not faunally significant, because we are not told how to distinguish Abadehan from 'Djulfian', i.e., Baisalian faunas. Speculatively, Taraz *et al.* (1981) suggested that the Abadehan is younger than the *Yabeina* Zone—which is acceptable, and is to be correlated with the Wuchiaping– which part not specified, through *Codonofusiella.* It was considered that the Amarassi ammonoid fauna is equivalent to the La Colorada beds of Mexico, as first established through *Eoaraxoceras* (see Spinosa *et al.*, 1970), and it was suggested that these beds are Abadehan. Precisely that correlation was first proposed some years ago by Waterhouse (1976*a*), and is acceptable still in our view, but Taraz *et al.* (1981) were unable to suggest any clear and direct relevance to the Abadehan faunas and beds. Instead they further speculated on a vague and ill-defined alleged correlation with the Kalabagh-lower Chhidru of the Salt Range, Pakistan, stating that these latter faunas shared *Xenodiscus carbonarius*, a *Codonofusiella-Reichelina* assemblage, and a few species of foraminifers and brachiopods. We give little value to the long-lived species *Xenodisus carbonarius*, and discuss the *Codonofusiella-Reichelina* assemblage in the Kalaobaghian-lower Chhidru beds subsequently. Some useful data is provided for a few short-lived species of *Abadehella, Discospirella*, and *Hemigordius* amongst small foraminifers, and *Codonofusiella*, and conodonts. Overall, to summarize, we are not told how to basically distinguish the 'Abadehan Stage' from the 'Djulfian Stage,' because *Codonofusiella* and allied small foraminifers and conodonts also occur in the 'Djulfian' (= Baisalian). The correlative faunas in south Europe, Pamirs, and Luntang of south China were ignored by Taraz *et al.* (1981) and no data relevant to the faunas and sections of the Karakorum, Himalayas of Kashmir and Nepal or New Zealand were provided at all. The discussion of sections in Mexico, United States and Timor are acceptable, but of little basic relevance. We thus have not been provided with any definition of the faunal content of the 'Abadehan Stage', even in its type region, and there is no world synthesis. It is difficult to see that Taraz *et al.* (1981) have in fact recognised and discriminated a stage. No definition is provided, no key and restricted species or faunal abundances are firmly indicated, and no world-wide attributes—and stages must be world-wide—are provided. From the data they summarize, it is difficult to avoid the conclusion that the Abadehan beds are simply a fuller expression of the *Codonofusiella* beds thinly represented in the Armenian sections, like the Urushten beds of the Caucasus, and they have essentially the same fauna, with a few different species, as the Baisalian (upper Djulfian) fauna of Armenia.

The nature of the Urushtenian Substage (Abadehan 'Stage')

The Urushtenian Substage may be characterized, following Waterhouse (1976*a*), as an interval of rock with faunas closely allied to those of the overlying Baisalian Substage, both forming the Djulfian Stage. The Djulfian Stage is characterized by various brachiopods, as discussed previously, and below, by presence of species of *Codonofusiella* and absence of *Neoschwagerina* and *Yabeina*, and by the presence of the ammonoid family Araxoceratidae. The Urushtenian Substage is discriminated from the Baisalian Substage by members of primitive Araxoceratidae, without advanced members, and species rather than genera of *Codonofusiella* and *Reichelina*, and various brachiopods, with some distinct species such as *Cruricella tschernyschewi* (Likharev). A few new brachiopod genera appeared, including *Ogbinia*, and perhaps *Araxathyris*, and *Orthotetina* and *Spinomarginifera* became particularly common in the realm of tropical-subtropical Eurasia. Although some further new genera appeared in the Baisalian, the overall generic composition in terms of brachiopods in Caucasus-Armenia-Iran and south Europe is very much the same in both Urushtenian and Baisalian, with the Urushtenian showing a greater diversity in the Caucasus than any known Baisalian fauna. In the Tachtabulakh Suite of the Pamirs a two-fold division of faunas also readily suggests two Djulfian faunas, sharing a number of species, with older equivalent to Urushtenian, and the younger matching Baisalian (Grunt and Dmitriev, 1973, Table 2; Waterhouse, 1976*a*: 163).

Fanuas from palaeotemperate areas add particularly critical information to the fundamental nature of the Urushtenian and Baisalian faunas. In south Europe, Caucasus, Iran, Armenia and Pamirs, the two are not easy to discriminate, and share many species, and genera, and even abundances. The diversity and presence/absence varies somewhat, but in no clear or consistent direction, except that the Urushtenian is clearly extraordinarily diverse, and might therefore indicate exceptionally favourable conditions for life, perhaps due to favourable warm climate, compared with slightly older and slightly younger faunas. Faunal affinities differ consistently in the same sense in temperate realms of the Karakorum-Himalayas and cool-cold water region of New Zealand. In the north Karakorum, and Shyok valley, the Urushtenian fauna has clearly stronger affinities with warm-water faunas than the underlying Punjabian fauna. It has several genera of tropical-subtropical affinity (*Chonostegoides*, *Ogbinia*, *Spinomarginifera*, *Araxathyris*, others) whereas the underlying Punjabian fauna has some cold-water links such as *Spiriferella-Fusispirifer-Paraconularia*—see Waterhouse (1980)—and other genera typical of temperate faunas. Therefore, the climate changed from a cool one prevalent in Punjabian times to a warmer one in Urushtenian times. In the Himalayas of Nepal, the cool-water Punjabian fauna is overlain by the Urushtenian bivalve fauna, with links not only to the Salt Range, but to tropical-subtropical areas of Japan and elsewhere, and is followed in turn by a cool-water Baisalian fauna, with two genera *Terrakea* and *Tomiopsis* that were particularly common in the cold-water realm of east Australia (Waterhouse, 1978*a*). This indicates again that the Urushtenian fauna was a warm-water fauna, preceded and followed by cool-water faunas. In New Zealand the cool-water fauna of the *Piekonella multicostata* zone, dominated by east Australian genera, and with links to the Punjabian faunas of the Salt Range and Himalayas, is followed by an Urushtenian fauna in the *Spinomartinia spinosa* Zone with some unusual genera not characteristic of Australian Permian faunas, and therefore indicative of warmer water conditions. (The Urushtenian fauna is followed in New Zealand by an unusual fauna of indeterminate climatic affinities, for it is a deep-water ammonoid faunule, with *Episagiceras*, *Durvilleoceras*, and a goniatite close to *Pseudogastrioceras*.)

In summary, all data indicates that the Urushtenian fauna at the base of the Djulfian Stage commenced with a change in climate to warmer conditions, with the loss of *Neoschwagerina* and *Yabeina*, development of Araxoceratidae, as *Eoaraxoceras* (in La Colorada beds of Mexico, and Amarassi of Timor), flourishing of *Codonofusiella*, and several brachiopod genera, and introduction of a few new brachiopod genera. Temperature cooled somewhat at the end of the substage, and the climatic change introduced a new faunal regime, more markedly in cooler temperate parts of the globe, such as the Himalayas, and New Zealand, and with rather less change in tropical-subtropical regions, affecting world biota which changed to become typical of the Baisalian Substage.

The Chinese faunas are so vast that they require more space than is available here to analyse. However, the faunas of south China, from the Luntang and Wuchiaping Formations, appear to us to belong to the Djulfian Stage *sensu* Waterhouse (1976*a*). Two faunas are present (see Zhao *et al.*, 1978). The two are very similar, and are very probably Urushtenian and Baisalian in age. Moreover, the lower Lungtan fauna has '*Crurithyris subspeciosa* Liao,' which appears inseparable from *Crurícella tschernyschewi* (Likharev). The entire fusuline and brachiopod composition of the two faunas, Urushtenian-Abadehan and Baisalian, strongly suggest a close alliance, best aggregated in one stage, we call Djulfian. Direct inter-correlations are most strongly indicated by brachiopod species, reinforced by local but valuable ammonoids.

IV. SEQUENCE AND CORRELATION OF YOUNGER PERMIAN FORMATIONS IN CENTRAL IRAN

For closer understanding of the significane and correlation of the Karakorum fauna we turn our attention to nearby sequences in Asia. Sequences of the Lesser Caucasus and Pamirs are relatively well-known (Ruzencev and Sarytcheva, 1965; Stepanov *et al.*, 1969; Grunt and Dmitriev, 1973), and significant faunal sequences in the Elburz Mountains have been described by Sestini (e.g., 1965), with overall assessment provided in Waterhouse (1976*a*). A valuable succession has been recently documented in central Iran in the Abadeh region north of Shiraz, and it has been claimed that this sequence provides the stratotype for the 'Abadehan Stage,' with faunas we deem to be correlative with the present fauna from the Karakorum. We therefore assess the sequence in terms of our Karakorum study, and offer some correction to the interpretation by Taraz *et al.* (1981) of the faunas from central Iran.

In their study Taraz *et al.* (1981) concentrated on younger Middle and Late Permian sequences and recognised three Permian formations—the Surmaq, Abadeh, and Hambast. The lithostratigraphy was analysed and fossils listed fairly comprehensively. The formations were divided into several lithologic units, and we follow their studies in analysing the succession of faunas, unit by unit.

Surmaq Formation

Taraz *et al.* (1981) correlated units 1-3 with the Gnishik beds of Armenia, as clearly indicated by the brachiopods they list, and supported, more indirectly, through Fusulinacea. The upper part of Unit 1 was correlated with the *Neoschwagerina simplex*, *N. craticulifera* and *N. margaritae* Zones of Asia and Unit 2 correlated also with the *N. margaritae* Zone; Unit 3, with *Orientoschwagerina abichi* and other species was correlated "most probably with the *Yabeina globosa* Zone or *Lepidolina multiseptata* Zone in Japan, and the *Yabeina* Zone in Pamir and south China." This correlation, on which much weight was subsequently attached by Taraz *et al.* (1981), seems very poorly documented, and yet it is in accord with the proposal by Waterhouse (1972, 1976*a*) on the basis of more wide-ranging analyses of brachiopods and ammonoid that the Gnishik faunas match in part the *Yabeina-Lepidolina* faunas of Asia and New Zealand. That there is full equivalence also between Surmaq units 1, 2 and the *Neoschwagerina margaritae* and *N. craticulifera* Zones of east Asia, as claimed by Taraz *et al.* 1981) is not certain. These named species do range beyond their zonal limits, *N. margaritae* for example being widely reported as occurring with *Lepidolina multiseptata*, in west Japan, Cambodia and New Zealand (Waterhouse, 1976*a* : 132). But a sequence of zones seems to be present, to suggest that the Gnishik faunas match both Kazanian and Punjabian faunas of the world standard. Whether or not Ruzencev and Sarytcheva (1965) have unwittingly lumped condensed faunas of these ages into one age remains to be determined.

Bando (1979) described *Xenodiscus murata*i Bando from the top of Unit 1. *Xenodiscus* has only been found in Punjabian (= *Yabeina*) and younger rocks. Taraz *et al.* (1981 : 83) have argued that the species is primitive, and that the range of the genus must be extended. Perhaps, but it does underline the need for more work.

Age and Correlation of the Abadeh Formation

The faunal elements of Unit 4 at the base of the Abadeh Formation are analysed, but not systematically described in Taraz *et al.* (1981 : 84-86). It was noted that foraminifera from the basal subunit were like those of the Gnishik beds, and were followed by a new assemblage, including *Abadehella* species. It was compared, without any specific documentation, with small foraminifera from the Hachik beds, and vaguely with the Pamirian fauna of the Kalabelsk beds, and was stated to be of "intermediate character between the Khachik and Dzhulfian faunas of Transcaucasia" (Taraz *et al.*, 1981 : 84). This statement seems somewhat in conflict with preceding comments, but is acceptable to us—in other words, the small foraminifera are between Hachik and 'Djulfian' (Baisalian) in age, and are therefore Urushtenian. It is claimed that *Abadehella* has "a rather limited vertical but wide geographic age distribution." Yet, *Abadehella* ranges only through south Asia, a fraction of the earth's crust, and occurs in the lower Zewan faunas of Kashmir, *Palaeofusulina* limestones of Malayasia, *Lepidolina multiseptata* and *L. kumaensis* faunas of Japan, indicating a fairly lengthy time range, from at least Kalabaghian if not slightly older to perhaps Changsinghian-Dorashamian.

The only fusulinids are species of *Sphaerulina, Schubertella* and *Codonofusiella* and amongst brachiopod species, six were said to occur in older beds, six in younger beds and 9 were restricted, and included species of *Orthotetina* and *Spinomarginifera* typical of the Baisalian faunas of Armenia, with *Septospirigerella* more typical of Gnishik-Hachik faunas, according to our analysis. Taraz *et al.* (1981 : 85) appear to agree: "Consequently, the brachiopod fauna shows an intermediate nature between the underlying and the overlying units as in the case of foraminifers. Five species have a range of the Gnishik to Khachik, six species occur in the Dzhulfa (= Baisalian) beds in Armenia, five species in the Ruteh Formation in Central Alborz and seven in the Nesen Formation. The fauna has several species shared with the Wujaping fauna in South China." These conclusions surely then indicate an Urushtenian age, that is, post Gnishik-Hachik, pre-Baisalian correlation. Astonishingly, Taraz *et al.* (1981 : 85) do not accept their own evidence. Instead, they assert, "Based on the common species of brachiopods, the Unit 4b can reasonably be compared to the Khachik beds in Transcaucasia and a part of the Nesen Formation in Elikah Valley of Alborz Mountains." They might just have logically correlated the Unit 4 fauna with the Gnishik beds, or Baisalian beds. It is quite clear that Taraz *et al.* (1981) were not swayed by the foraminiferal and brachiopod evidence, but simply trying to fit them into a preconceived, and we believe partly erroneous, correlation framework. Their own evidence itself fits better with our proposal, as in Ruzencev and Sarytcheva (1965) and Waterhouse (1976), that the thin *Codonofusiella* beds of Transcauscasia are of lower Djulfian age, just below the Baisalian faunas, and post-Hachik in age and nature. Elsewhere, the equivalent *Codonofusiella* beds are thicker and more fossiliferous, and include the Urushten beds of the Caucasus, and the Abadeh faunas of central Iran.

Disappointingly, Taraz *et al.* (1981 : 103) made little attempt to counter the Ruzencev and Sarytcheva (1965) claim that the *Codonofusiella-Reichelina* beds of south Armenia were Djulfian in age, not to mention names of authorities who had taken counter views that had been analysed and rejected by Waterhouse (1976*a*). Instead they discussed the Djulfian age of the faunas from the *Araxilevis* beds, an age under little dispute, and therefore not obviously relevant to the discussion. In our view, the *Codonofusiella* beds are Djulfian, because *Codonofusiella* is also common in the younger Djulfian, and is missing from the underlying Hachik-Gnishik beds. Furthermore, the Hachik faunas are clearly closer to those of the Gnishik than to Abadehan or Baisalian faunas which make up the Djulfian Stage. By including the *Codonofusiella* beds, which are at separate level, with the Hachik, a misleading impression is given of the faunal content.

Conodonts of the Abadeh Formation Unit 4 belong to the *Sweetognathodus sweeti* and overlying *S. gnathodus* Zone of Kozur *et al.* (1978), or *Gondolella bitteri, Stepanovietes inflatus, Merrililna divergens* Assemblage Zone of Kozur (1978 : 107), indicated as equivalent to the *Codonofusiella* beds of Armenia (Kozur, 1978 : 111), as we also contend. Bryozoa add little of value because they have been so rarely studied that their ranges or geographic distribution are poorly known. No significant bivalves or gastropods are known.

Unit 5 of the Abadeh Formation has fusulines and small foraminifers, many shared with Unit 4. Nodosariids increase and are a dominant element in Unit 6, classed as 'Djulfian' (= Baisalian), and three conodont species *Merrillina divergens, Gondolella bitteri*, and *Anchignathodus typicalis* persist into the Baisalian faunas of the overlying Unit 6. These underline our claim that the faunas from the Abadeh Formation are allied to those of the Baisalian Substage and that both are in one Djulfian Stage. The ammonoid *Cyclolobus*, discussed below, is also shared between the Abadeh and overlying Hambast Formations.

Age of the Hachik Formation

We cannot agree with Taraz *et al.* (1981) that the Hachik faunas, minus the *Codonofusiella* beds, match those of the Abadeh Formation. As shown in the preceding analyses, the fossil evidence does favour a position for Abadeh between the Gnishik-Hachik faunas on the one hand, and the Baisalian (upper Djulfian) faunas on the other. The faunal lists and several conclusions drawn by Taraz *et al.* (1981) confirm this diagnosis. In our belief, the Hachik faunas are very close to those of the Gnishik faunas, as shown clearly and also emphasised by Ruzencev and Sarytcheva (1965). We append a faunal list of brachiopods to reinforce the similarity. Admittedly, one of us (J. B. W.) learned in a visit to Armenia in 1967 that local geologists considered that the Hachik faunas were richer, and had more species than shown in the published analyses. But the weight of published evidence firmly favours a close association between Gnishik-Hachik faunas on the one hand, and Urushtenian (= Abadeh)-Baisalian faunas on the other. The sets of faunas should be assigned to only two stages, Punjabian and Djulfian.

A three-stage classification is misleading, because Urushtenian (Abadeh) faunas do not differ substantially from Baisalian faunas.

Hambast Formation

Careless use of faunal zones

Units 6 and 7 in the Hambast Formation are analysed by Taraz *et al.* (1981 : 87). Baisalian brachiopods are accompanied by *Araxoceras* and other genera establishing firm correlation with the type Baisalian of Armenia, and an occurrence of *Eoaraxoceras rhznencevi* is noted, a species found also in the La Colorada beds of Mexico, to show that *Eoaraxoceras* began in Urushtenian and extended to Baisalian. *Cyclolobus* has also been recorded. In Unit 7, *Paratirolites*, *Iranites* and *Shevyrevites* are present, the latter genus in the lower part, the three together in the middle, and *Paratirolites* at the top. Taraz *et al.* (1981) discriminated three ammonoid zones on the basis of this sequence, but this sort of zonation is to be deplored, because the so-called zones are very thin, and very restricted in distribution, and seem much more likely to represent successive fossil communities, rather than zones. Much more work is needed to establish their zonal character than has so far been accomplished, and the almost casual proposal of zones in such a fashion will simply overwhelm the literature with meaningless trivia. Several conodont zones are also erected, narrowly based on incoming and disappearing species (Taraz *et al.*, 1981 : 88), of probably only severely local significance, and not all agreeing with the ammonoid 'zones'. Different zones again are proposed for the foraminifera!

In our understanding, a fossil zone ought to range through a faunal province and consist of fossil communities which varied across the province under the control of various environmental parameters. The Surmaq ammonoid and conodont 'zones' of Taraz *et al.* (1981) imply that a short-lived series of provinces followed one after the other in rapid succession. The Taraz 'zones' should probably be designated communities and subzones, to imply that the succession is not of prime temporal significance, but reflected local vicissitudes in communal development and environmental variation. Communities elsewhere we suggest may have contained the same species, in different associations and of slightly different ages. We do not think that the ranges of these ammonoid and conodont species in the Hambast Formation represent the full ranges, and we suspect that other sequences, even nearby, will show different ranges and different associations. We suggest that it would be more objective to treat the occurrences as communities, each representing a fossil subzone. It remains to be established whether the subzones each represent, very meagrely, a genuine faunal zone, which is possible, or only part of a zone together with other subzones, which is more likely. The principles are enunciated more fully by Waterhouse (1976*b*). Indeed, as pointed out by Taraz *et al.* (1981 : 89) the ranges of the many of fossils vary even in nearby Armenia. It seems unwise to designate bio-zones from just a few outcrops. Zones should cover an extensive area, and certainly in this context will probably incorporate outcrops of central and north Iran, and Armenia, and possibly extend into other regions as well. Disturbingly, the conodont zones of Taraz *et al.* (1981) for the Abadeh Formation do not even agree with those of Kozur *et al.* (1978) for the conodonts, or with Bando (1979) for the ammonoids. They have so finely drawn that they are likely to be quickly overturned by new discoveries. Good and enduring work is that which has a high degree of predictiveness, and will be reinforced, rather than overturned or substantially amended, by new discoveries. There seems to be great trouble, amongst workers dealing with foraminiferal conodont, and ammonoid faunas of the late Permian in arriving at any sort of stability in zonation.

Taraz *et al.* (1981 : 90) correlated units 6 and 7 with the 'Djulfian' (= Baisalian) and Dorashaman Stages, respectively of Armenia. They noted that the conodont *Gondolella orientalis* appeared in the uppermost part of the *Vedioceras nakamurai* Subzone in the Surmaq Formation, and in the middle part of the somewhat older *Araxoceras* beds in Djulfa. Yet the *G. orientalis* Zone supposedly followed the *Vedioceras* beds, according to other workers. There are discrepancies, as is to be expected, when attention is focused on minutae of no great significance.

Kozur *et al.* (1978) correlated only the upper part of Unit 7 in the Hambast Formation with the Dorashamian Stage, whereas Taraz *et al.* (1981) correlated all of Unit 7 with the Dorashamian, stating that they relied on brachiopods and ammonoids, rather than conodonts. Neither set of correlations is completely satisfactory. But it is clear that Unit 6 is equivalent approximately to the Baisalian faunas of Armenia. The faunas of Unit 7, which occur in distinctive red limestone of what should be recognised as a different formation, seem to indicate a middle Dorashamian age, correlative with the Ogbinan Substage of Waterhouse (1972; 1976*a*,) based principally

TABLE 2—FAUNAS IN IRAN AND ARMENIA, SHOWING DISCREPANT FIRST APPEARANCES OF *GONDOLELLA ORIENTALIS*

Abadeh, Iran	Dorasham, Djulfa, Armenia
Lower Hambast Formation	*Baisalian Substage*
Vedioceras nakamurai Subzone *G. orientalis*	*Vedioceras-Haydenella* beds
Araxoceras tectum Subzone	*Oldhamina* beds *Araxoceras*
Araxilevis beds	*Araxilevis* beds *G. orientalis*

on *Paratirolites*, and including other ammonoids such as *Shevyrevites* and conodonts of the *Gondolella orientalis* 'Zone' and *Anchignathodus julfensis* Zone as recognised by Taraz *et al.* (1981). Yet according to Kozur (1978 : 108), the *G. orientalis* Zone is found in the upper Baisalian (i.e., with *Araxoceras*) and is typified substantially by the absence of *G. leveni* and *G. subcarinata.* This is a major discrepancy, for Taraz *et al.* (1981, Fig. 8) identified *Shevyrevites* and *Paratirolites* from the same zone, and we agree with them in assigning more weight to the ammonoids. These ammonoids are characteristic of the Ogbinan Substage of Waterhouse (1972, 1976*a*). The overlying beds with *Paratirolites* and also *Shevyrevites* at the base, together with conodonts of the *Anchignathodus julfensis* Zone, also belong in our view to the Ogbinan Substage.

Vedian Substage

Now we draw attention to a very critical difference from the interpretations of both Kozur (1978) and Taraz *et al.* (1981). According to available evidence, the fauna of Vedian Substage is missing from the Abadeh sequence. The key fossils, the ammonoid *Phisonites* and brachiopods *Comelicania* and *Janiceps*, and associated faunas, are not found. Perhaps conodonts have been found, and misinterpreted—we cannot tell, because Kozur (1978) does not record conodonts from the Vedian Substage or *Phisonites-Comelicania Zone*. Taraz *et al.* (1981) dismissed the significance of the Vedian Substage, stating that *Phisonites* was of only local development. This may well be true—many ammonoids in the late Permian are extremely local, and therefore of little use. But the same cannot be said of the brachiopods *Comelicania* and *Janiceps*. These are found also with substantial faunas in the Bellerophonkalk widely over south Europe, and range as far east as China.

Through careful correlation based on assessment of benthonic faunas, documented and systematically described, it has been possible to trace the Vedian faunas extensively throughout the globe, including significant faunas in the middle and upper Senja Formation of Nepal, the lower Changsing of south China, the Huai Thak Formation of north Thailand, and Gujo fauna of Japan, and lower Stephens Formation of New Zealand (Waterhouse 1976*a*, 1978*a*). Taraz *et al.* (1981) can hardly set such extensive and correlative faunas aside as insignificant, or 'local'. The Vedian faunas are distinctive. But their significance has been minimised in the faunas of Iran, partly because of incomplete collecting, and partly through failure to analyse accurately the faunal sequence of south Armenia. At Kuh-e Ali Bashi, for example, the *Comelicania-Janiceps* horizon was completely overlooked by Teichert *et al.* (1973), yet Stepanov *et al.* (1969) found that fauna, in the very same sequence. Clearly the fauna is meagerly developed in Iran, but that does not reduce its significance. An additional factor that should be taken into consideration is that the Vedian Substage was a cool time (Waterhouse and Bonham-Carter, 1975), when conodonts and ammonoids did not flourish. Thus, the risk of collection failure is enhanced for studies which fail to pay sufficient attention to benthonic fossils.

Thus we claim that the Vedian Substage is represented either by few faunas, perhaps misinterpreted or misinterpreted in the lists, or by hiatus in the Abadeh area of central Iran. A likely place for a hiatus is at the base of the distinctive red limestone (Unit 7), which is clearly a member or formation that should be separated from the Hambast Formation (Unit 6) under a different name.

Unit a (Lower Triassic)

The faunas in the lower Triassic are summarised in Table 3. Taraz *et al.* (1981 : 91) point out some differences from the preliminary assessment by Kozur *et al.* (1978), finding that *Isarcicella isarcica* entered the succession sooner, and that Dorashamian species *Gondolella orientalis* and *G. subcarinata* are found 3 m above the base in one section. They were possibly, but not definitely, reworked, according to Taraz *et al.* (1981), and in our opinion, add further evidence that the beds are really Dorashamian-late Permian. This is reinforced by the presence of *Bellerophon* gastropods, nowhere known in faunas of definite Triassic age. The *isarcica* Zone is very restricted in Kashmir, and ranges further in central Iran, co-extensive with the range of *Ophiceras*, according to Taraz *et al.* (1981 : 94).

TABLE 3 : COMPARISON OF AMMONOID AND CONODONT ZONES BETWEEN KASHMIR AND ABADEH

[From Taraz *et al.* (1981: 95)]

		Kashmir (India)				Abadeh (Iran)	
F		*Paranorites-Vishnuites* Zone		*Neospathodus cristagalli* Zone		*Neospathodus dieneri* Zone	
		?		*Neospathodus dieneri* Zone		*Vishnuites, Lytophiceras, Acanthophiceras*	
E	E3	*Ophiceras* Zone	*Ophiceras* sp. Subzone	*N. kummeli* Zone	a		
				Gondolella carinata Zone			*Isarcicella isarcica* Zone
			Ophiceras tibeticum Subzone	*Isarcicella isarcica* Zone			*Anchignathodus parvus* Zone
	E2			*Anchignathodus parvus* Zone		Missing?	
		Otoceras woodwardi Zone		*Anchignathodus typicalis* Zone			

Summary of the Sequence in Central Iran

1. The Surmaq Formation appears to range from Kungurian (Kubergandian) to perhaps Punjabian age, and is thus relatively condensed. Important fusulines include *Eopolydiexodina, Neoschwagerina craticulifer, N. margaritae* and *Orientoschwagerina chen*. The upper faunas are correlative with the Gnishik beds and perhaps the Hachik beds of Armenia. The brachiopods and other fossils correlate with the Punjabian (Kalabagh, lower and middle Chhidru Formation) of the Salt Range.
2. The Abadeh Formation is of Urushtenian or Abadehan age. Its uppermost faunas match those of the *Codonofusiella-Reichelina* beds of Djulfa and Dorasham. The faunas overall correlate with those of the Urushten beds in the Caucasus, and distinctive faunas of the lower Bellerophonkalk of south Europe, and in the Karakorum, Popa Member of Nepal, bivalve bed or Ganjaroh Member near the top of the Chhidru Formation in Salt Range, Pakistan, and lower Lungtan Formation of Kiangsi and Yunnan etc., south China. There is no evidence to suggest correlation with the Hachik Formation below the *Codonofusiella* beds of Armenia.
3. The Abadeh faunas are essentially very close to those of the Baisalian (Djulfian) beds of Armenia, above the *Codonofusiella* beds and below the *Comelicania* beds, containing the *Haydenella-Vedioceras, Oldhamina-Araxoceras* and *Araxilevis* faunas—that is, the Baisalian Substage. The Abadeh faunas belong with the Baisalian faunas to the Djulfian Stage.
4. The lower Hambast Formation has faunas correlative with the Baisalian Substage of Armenia.
5. The Vedian Substage, typified by *Janiceps, Comelicania* and *Phisonites* in Armenia-Iran and south Europe, is apparently absent from the sequence in central Iran, with a hiatus, or incompletely collected fauna between units 6 and 7.
6. The upper Hambast Formation has *Shevyrevites-Paratirolites* and other faunal elements indicating correlation with the Ogbinan Substage of Armenia.

V. YOUNGER PERMIAN ROCKS AND FAUNAS OF THE SALT RANGE, PAKISTAN

Although the Salt Range sequence has few direct species links with the Karakorum fauna, several of its species are found at other Karakorum localities of the same age, with similar brachiopods, and elements of the same fauna extend both into the Himalayas to the east, and into the Caucasus Mountains and Iran-Armenia to the west. We therefore discuss the sequence further, in the light of recent discoveries of foraminifera, and the newly realised Urushtenian fauna in the Salt Range.

Stratigraphy and Faunal Subdivisions of the Chhidru Formation, Salt Range

Discussion of faunal correlations for younger Permian deposits in the Salt Range is now hampered by the realization that the Chhidru Formation contains at least three discrete faunal levels, which cannot be expressed adequately because no formal rock units have been proposed for units within the Chhidru Formation. In the interests of communication, and to ensure stability of nomenclature, we here formally divide the Chhidru Formation into three members.

Kufri Member

Name. Named from Kufri hamlet, east of Chhidru.

Type section. Area west of Chhidru Nala, north of dip slopes of upper Wargal Formation.

Lithology. Mostly sandstones and limestones about 205 ft thick. Base of section shown some 400 yards north-west, showing almost 70 ft of calcareous sandstone, underlain by 35 ft yellow brown shale. The section is measured and described in detail by Teichert (1965 : 15, 18). The member extends widely through the Salt and Surghar Ranges.

Fauna. The fauna is comprehensively described by Waagen (summary 1891) and Reed (1944), with a number of subsequent studies, including important discoveries of *Codonofusiella* and *Reichelina* by Tayyab *et al.* (1981).

Age. The faunas from this member typify the Kufrian Substage, proposed as a substitute name for the Chhidruan Substage, used as stage in many papers, e.g. Furnish (1973). The attributes and extent of the substage are discussed by Waterhouse (1976*a*), and see below.

Ganjaroh Member

Name. From Ganjaroh, north of Chhidru.

Type section. Same as for Kufri Member, commencing immediately above.

Lithology. Calcareous sandstone, usually 1-2 ft thick, highly fossiliferous with brachiopods, bivalves and gastropods especially prominent. This corresponds with the 'topmost or bivalve bed' of Waagen (1891), 'schicht 12' or 'topmost Bellerophon bed' of Schindewolf (1954), and the 'uppermost richly fossiliferous unit' of Kummel and Teichert (1970 : 31). The member extends widely through the Salt and Surghar Ranges, with sections provided by Kummel and Teichert (1970, Fig. 4).

Fauna. The fauna is characterized by a wealth of bivalves and gastropods, and was first evaluated by Waagen (1891). Its significance as a discrete fauna was not appreciated until work in the Himalayas recognised that the fauna extended into north-west Nepal (Waterhouse, 1978*a*, *b*), and into the Karakorum Range (Waterhouse, 1981) and Armenia-Iran-Caucasus.

Age. The fauna is regarded as Urushtenian or Abadehan Substage, lower Djulfian Stage, after Waterhouse (1978*a*) and discussed herein.

Landa Sandstone Member

Name. From Landa, western Salt Range.

Type Section. As above, west of Chhidru, continuing upsection from top of Ganjaroh Member to base of Kathwai Member.

Lithology. White-to-yellow grey fine-to-medium sandstone with some hard calcareous lenses in lower part, top 6-9 inches shaly. Some 13 ft thick in this section. Extends throughout Salt Range and Surghar Range, with sections measured by Kummel and Teichert (1970).

Fauna and flora. Some conodonts are found (Sweet, 1970), and a number of palynomorphs are recorded by Balme (1970). Brachiopods were described by Grant (1970) and re-evaluated herein.

Age. It is considered that the fauna and flora is probably of younger Djulfian age, i.e., Baisalian. Foster (1979) has recognised strong links with the *Protohaploxypinus microcorpus* Zone in the upper Baralaba Coal Measures and lower Rewan Formation of the southern Bowen Basin, Queensland.

Correlation for Part of Permian Sequence within Salt Range, Pakistan

According to our analyses, the faunas of the Salt Range represent a significant but not complete segment of Permian time. Above the earliest Permian beds, the Amb Formation has faunas dated as Baigendzinian (Waterhouse, 1976*a*) with the uppermost beds, called the Katta beds by Waagen (1891 : 241) placed in the overlying Wargal Formation by some authorities (e.g., Waagen, 1891) and formally named by Waterhouse (1981). According to analysis in Waterhouse (1976*a*, 1981) the Katta faunas are likely to be of Kungurian age, and the overlying lower and middle beds of the Wargal Formation were considered to be of Kazanian age. The Kalabagh Member at the top of the Wargal Formation, and the Chhidru Formation, or more precisely, the lower and middle Chhidru Formation which we call the Kufri Member, we consider to typify the Punjabian Stage, and to match approximately the Word (above the Road Canyon Formation) and Capitan faunas of United States, as in Waterhouse (1976*a*). The Kalabaghian faunas are very rich, and quite close to the less diverse faunas of the lower and middle Chhidru Formation. Allied faunas extend into the Himalayas of Kashmir, Nepal, Spiti and Tibet and elsewhere, and eastwards into south-east Asia, especially Cambodia, and Japan, and Chandalaz Suite of south Primoyr (Waterhouse 1976*a* : 148), into Timor, and with perceptible elements persisting as far east as New Zealand. In Japan, China, south-east Asia and New Zealand the Punjabian faunas are accompanied by the fusulines *Yabeina* and *Lepidolina*, (and *Neoschwagerina*) and there are rare occurrences of the ammonoid *Timorites*. To the west, allied faunas extend into Iran and Armenia as most of the Ruteh faunas (levels 1, 2 especially) and the Gnishik-Hachik-faunas (Waterhouse, 1976*a*).

Above the middle Chhidruan faunas of the Salt Range comes the 'topmost bivalve bed' or Ganjaroh Member, with an Urushtenian-Abadehan fauna, as discussed herein, followed by the white sand, or Landa Sandstone Member with a Baisalian fauna. Faunas of the same age in the Himalayas are restricted to thin poorly fossiliferous deposits of Kashmir, and more fossiliferous deposits in north Nepal, whereas extensive and more fossiliferous deposits developed to the east in China, and to the west in Iran, Armenia, Caucasus and south Europe.

Significance of Fusulinacea

Some of these correlations find strong support from new assessments, and new discoveries of Permian Fusulinacea in the Salt Range by Tayyab *et al.* (1981). They assessed the age of the fusulines from the middle of the Amb Formation as indicating a probable correlation with the *Cancellina* Zone, and suggested that the upper Amb Formation (i.e., Katta beds) were at least as young as *Neoschwagerina simplex* (i.e., Kungurian). This is in very close agreement with independent brachiopod-based assessments by Waterhouse (1976*a*, 1981). Nakazawa and Kapoor (1977) identified *Neoschwagerina* aff. *margariate* from the basal part of the Wargal Formation. This would indicate to us a younger Kazanian or upper Wordian age, with the beds and faunas of the *Neoschwagerina craticulifera* Zone apparently missing. But Nakazawa and Kapoor (1977), followed by Tayyab *et al.* (1981), deduced that this species *N. margariate* implied a Capitanian or later age for the beds. This age seems to be too young, and we shall shortly analyse the reason for it.

Codonofusiella and *Reichelina* range virtually throughout the Wargal Formation according to Tayyab *et al.* (1981, Fig. 6) and 'primitive' *Colaniella* and then more advanced species appear in the Kalabagh Member. Much the same species occur in the 'main part' (i.e., Kufri Member) or lower and middle part of the Chhidru Formation. The species have at the time of writing not been described or illustrated.

To Tayyab *et al.* (1981) and Taraz *et al.* (1981) these foraminifera implied a firm correlation with the *Codonofusiella-Reichelina-Colaniella* faunules of the Wuchiaping beds of south China and Abadeh and Baisalian (Djulfian) faunas of Iran-Armenia. The underlying philosophy supporting these correlations is the understanding that Fusulinacea exhibited a simple sequence dominated in turn by *Neoschwagerina*, then *Yabeina*, followed by *Codonofusiella*, followed by *Palaeofusulina*. This sequence is particularly well-exhibited in south China, in the Maokou, Wuchiaping, and Changsing Formations. Simplistically therefore, according to the Fusulinacea, and Tayyab *et al.* (1981), the basal Wargal Formation with *Neoschwagerina* would appear to be correlative with the lower Maokou

Formation, and the remainder of the Wargal Formation, and the lower-and middle Chhidru Formation, or Kufri Member with *Codonofusiella*, would be correlative with the Wuchiaping of China. The upper Maokou, with *Yabeina*, and the Changsingian equivalents, appear to be missing from the Salt Range. However Tayyab *et al.* (1981) nowhere mention this apparent *Yabeina* gap. In our opinion, there is no significant gap between the beds with *Neoschwagerina* and the beds with *Codonofusiella*, and the brachiopod faunas do not indicate any such hiatus. This is a very vital point. If there is no hiatus, the Tayyab *et al.* model is disproved, for it means that the *Codonofusiella* could have commenced more or less at the same time as *Yabeina*—in different faunal provinces.

In addition, Tayyab *et al.* (1981: 14) suggested that the upper Djulfian, and the entire Dorashamian, in terms of the Armenian sequence, are missing. We here prove that the lower and middle Dorashamian only are missing.

Relying on Fusulinacea from a very few sequences does of course over-simplify the problem of correlation, because a scheme that supposedly reconciles a mere four sequences is less likely to be correct than one which reconciles twice that number. For that reason, the sequences of south Europe, Nepal, Kashmir, New Zealand and Thailand, set aside by the Japanese studies (Tayyab *et al.*, 1981) must not be ignored, inconvenient though they may be. All show a development of faunas that forms a pattern inconsistent with that interpreted for south China, Armenia-Iran, United States and central Asia by Tayyab *et al.* (1981). Even within the few areas considered by the Japanese studies, inconsistencies abound. The world-wide range of *Codonofusiella* and *Palaeofusulina* is much greater than their extent in Chinese beds equivalent to the Wuchiaping and Changsing, respectively. The type species of *Codonofusiella* comes from the Capitan of United States, and this is generally accepted as pre-Djulfian in age, equivalent to Maokou rather than Wuchiaping in China. *Palaeofusulina* is particularly inconvenient for the simple Fusuline sequence, for it does not obey simplistic rules. It has a long time range and flourished at intervals contemporaneously with *Codonofusiella*, or even earlier—with *Colaneilla* in Tachtabulak beds (Djulfian) of Pamirs (Taraz *et al.*, 1981 : 192), and in Greece (Nakazawa *et al.*, 1975*b*), and in Nikitin (?Kazanian) and Urushten beds of the Caucasus (Likharev, 1966 : 396-397). Hou *et al.* (1979 : 38) showed that *Palaeofusulina* occurred with *Codonofusiella* in the Shuitsutang Formation of Guangtung, China, in beds equivalent to upper Wuchiaping.

Coloniella also is not limited in range. Species of supposedly primitive morphology persisted, and the *Colaniella douvillei* Zone is regarded as contemporaneous with the *Neoschwagerina margritae* Zone (=Kazanian!) in Japan (Ishii *et al.*, 1975 : 114). *Codonofusiella cuniculata* occurs with *Yabeina yasubaensis* (=*Lepidolina multiseptata* age) (Ishii *et al.*, 1975 : 114) and several species occur with *Lepidolina kumaensis* in the Maizuru Group of Japan (Ishii *et al.*, 1975 : 113, 114).

Thus *Colaniella*, *Codonofusiella*, and *Palaeofusulina* all overlap with *Neoschwagerina*. *Neoschwagerina*, *Colaniella* and *Codonofusiella* overlap with *Yabeina* and *Lepidolina*. Very roughly, *Colaniella* and *Neoschwagerina* appeared before *Codonofusiella*, *Yabeina* and *Lepidolina*, and *Colaniella*, *Codonofusiella* and *Palaeofusulina* outlasted the others, with *Palaeofusulina* and *Reichelina* the last to flourish.

This means that the reliance on a simplistic model that envisages successive waves of species of *Yabeina-Lepidolina*, followed by *Codonofusiella* and finally *Palaeofousulina* is ill-founded, and contradicted even within China, central Asia, and Japan. Taraz *et al.* (1981: 102) suggested that the *Palaeofusulina* Zone was diachronous between east and west Tethys. Yet, in fact, *Palaeofusulina* was not diachronous and was established in some parts of both east (China) and west (Greece) and central Tethys (Pamirs) during Djulfian times. The fossils in question certainly flourished at the given intervals, in restricted areas. Their full ranges were much longer, and it seems likely that their episodes of success occurred at different times in different places. As a result, their correlation value is reduced, and other factors, including general stratigraphic succession, and other faunal elements must be taken into account.

Thus, the occurrences of *Codonofusiella* and *Colaniella* in the Salt Range must be treated with caution. Essentially, Nakazawa and his colleagues (Tayyab *et al.*, 1981) are reducing the significance of the *Yabeina-Lepidolina* faunal interval, referred to the Punjabian Stage in Waterhouse (1976*a*), and the *Neoschwagerina margaritae-N. craticulifera* interval, or Kazanian Stage (Waterhouse, 1976*a*). In fact, just what has happened to the *Yabeina-Lepidolina* 'Zone' equivalents in the Salt Range is not made clear by Tayyab *et al.* (1981). Is it supposed to be represented by thin beds, or absent? We are not told. We would have thought that a rather important matter to discuss, because Grant (1970) and Waterhouse (1976*a*) have asserted that the *Yabeina-Lepidolina* faunas of south-east Asia were matched by Wargal-Chhidru faunas of southeast Asia, giving well-documented reasons. No explanation or counter-argument is given. We are left to deduce that there is a hiatus, or severe compression of the *Yabeina-Lepidolina* equivalents. But fossils do not indicate any such compression or hiatus, as far as we are aware. We therefore maintain that much of the Wargal—with *Codonofusiella*—and the Kufri Member of the Chhidru Formation are likely to be correlative with the *Yabeina-Lepidolina* faunas and beds. The Wargal and Chhidru cannot be Djulfian, as maintained by Tayyab *et al.* (1981) because as we shall show, Djulfian faunas are found above Wargal-Kufri beds, not in them. The condensing of faunal zones by Tayyab *et al.* 1981 has led to several zonal sequences becoming severely squeezed, with crowded faunal zones, and not enough either barren intervals or time and faunal gaps in sequences. We agree with the columns for China and Japan (see Nakazawa and Kapoor, 1977, table opposite p. 2), which also agrees with the scheme in Waterhouse (1976*a*). But the 'gap' in the Chinese sequence above *Yabeina* in the upper Maokou Limestone is shown to be filled elsewhere by lower Djulfian sediments and faunas, whereas we consider it was occupied by allied *Yabeina-Lepidolina* faunas, of younger Punjabian age. Other correlations show several anomalies. For example, the Puruhauan of New Zealand is shown inadequately as occupying a *Yabeina* (supposedly late Capitan to Abadehan interval), but in fact, with four extensive zones in sediments over 3000 m thick, it extended into late Djulfian (Baisalian) and even were that change made, is still over-crowded. We consider the Word to range as high as late Kazanian. But, as we have demonstrated, the fossils most heavily relied upon by Tayyab *et al.* (1981) show too many inconsistencies internally, to be criticized point by point—let us rather summarize our view of correlations relevant to the fossils and rocks under review.

We summarize the Salt Range sequence as follows.

1. In conformity with Tayyab *et al.* (1981), the Katta beds at the top of the Amb Formation are correlative with the *Neoschwagerina simplex* Zone of Asia, of approximately late Kungurian (Irenian) age (see Waterhouse, 1976*a*, 1981) and also share brachiopod affinities with the lower Rat Buri Limestone of south Thailand (= younger Rat Buri to the north), and brachiopod-ammonoid faunules of Tai Wei, Timor (Waterhouse, 1981).

2. The lower Wargal beds (Unit 2) with *Neoschwagerina* cf. *margaritae* of Nakazawa and Kapoor (1977) appears to be of upper Kazanian (Sosnovian) age, which we consider to be late Word—i.e., Appel Ranch—rather than Capitan. The lower Kazanian (Kalinovian) and Ufimian faunas are presumably poorly represented, or absent, in the basal Wargal Formation (= *N. craticulifera* Zone).

3. Overlying Wargal beds require further study. They have been asssumed to be Kazanian, that is essentially the same as the *Neoschwagerina margaritae* Zone by Waterhouse (1976*a*), but the presence of *Codonofusiella* and other Fusulinacea as set out by Tayyab *et al.* (1981) may mean that the faunas are almost the same as those of the overlying Kalabagh Member.

4. The Kalabagh Member at the top of the Wargal Formation has a particularly rich fauna, including many species of formation, brachiopoda, bivalvia and gastropoda.

5. The overlying Chhidru Formation, in its lower and middle parts, or what we call the Kufri Member, has a rather similar fauna, significantly less diversified, and typified by a few new species of brachiopoda and mollusca, including several forms of cold-water genera. Nakazawa and Kapoor (1977) have stated that the boundary between the Wargal and Chhidru Formations may be time transgressive, but the interval would not be long, and no faunal evidence has been provided of any major transgression.

The two faunas from the two units (Kalabagh and Chhidru-Kufri) are regarded as typifying the Punjabian Stage, subdivisible into two closely allied substages, Kalabaghian and Chhidruan, by Waterhouse (1976*a*). Elements of these faunas appear to extend eastwards into south-east Asia, especially Cambodia, Timor and even New Zealand, and northwards into Japan, and to a very modest extent China, where however correlation is not convincing, because Maokou faunas are few other than for Fusulinacea. In east Asia, including New Zealand, *Yabeina* and *Lepidolina* are present, and the ammonoid *Timorites* is found rarely, as well as *Waagenoceras* and other genera persisting from the *Neoschwagerina* (Kazanian) faunas.

Elements of the same Punjabian fauna appear through the Himalayas as long recognised by Diener (1915) in the *Lamnimargus himalayensis* Zone of Waterhouse and Gupta (1981). The ammonoids *Xenodiscus* and *Cyclolobus* reinforce brachiopod correlations in this respect, and the Tetraxid foraminifer *Abadehella* reinforces one aspect of these correlations, occurring in the lower Zewan Formation of Kashmir, and in Cambodia, and *Reichelina-Colaneilla* limestones of the Maizuru belt in Japan. (But we consider that the genus ranges further into younger faunas as well.) To the east similar faunas appear, as generally agreed, in the Gnishik beds of Armenia, and lower Ruteh faunas of north Iran, but unlike Taraz *et al.* (1981), we consider that the Hachik faunas below the *Codonofusiella* beds of Armenia are very like those of the Gnishik fauna, with the same relationship as between Kalabagh and Chhidru faunas in the Salt Range, and also comparable in relative diversity. The same diversity ratio occurs in New Zealand also, a rich fauna, with *Lepidolina*, followed by a fauna with more east Australian—

cold-water links. Like Grant (1970), we consider that the Kalabagh-Kufri interval is matched by the Capitan faunas of Texas-New Mexico, where *Codonofusiella* is also present, with the ammoniod *Timorites*.

6. The upper part of the Chhidru Formation has two distinct faunas, the lower fauna in the 'topmost' or 'bivalve' bed of Waagen (1891), which we have named the Ganjaroh Member, and the overlying white sand, or Landa Sandsone Member, each with a fauna of Djulfian age. The lower is regarded as Abadehan (=Urushtenian), and can be traced as an extensive fauna from the Salt Range into the Himalayas as the Popa Member (*Pyramus silicius* Zone) of Nepal; upper Zewan Formation, Member D, Faunal Division 111, of Kashmir (Nakazawa *et al.* 1975*a*; Waterhouse, 1978*a*; 147), the Shyok limestone with its fauna described herein, some north Karakorum localities (Merla, 1934), Ruteh level 3 and(?) 3 of the Elburz Mountains, Iran (Sestini, 1965*a*), and Abadeh Formation of central Iran (Taraz *et al.* 1981). This fauna appears to extend into the Caucasus as the Urushten beds (Waterhouse, 1976*a*; Likharev 1966), and into the Pamirs as the lower Taktabulak fauna (Grunt and Dmitriev, 1973). Elements of the same fauna indeed extend into south Europe, and Lungtan beds of south China. Possibly the La Colorada beds of Mexico occupy this interval, with the *Metadoliolina lepida* beds at the top of the Chandalaz Formation of Primoyr, and arguably, the Lamar horizon in the Bell Canyon Formation of United States, though Taraz *et al.* (1981) suggested this might be slightly older. The *Spinomartinia spinosa* Zone of New Zealand is considered to be correlative.

7. The Chhidru white sand, or Landa Sandstone Member, has a younger but rather closely allied fauna, with several species allied or identical to species of upper Djulfian (Baisalian) age, from the Lungtan Formation and correlatives of south China and Baisalian (upper Djulfian) faunas from Armenia, and Nesen Formation of north Iran, and lower Hambast Formation of central Iran (Ruzencev and Sarytcheva, 1965; Sestini and Glaus, 1966; Taraz *et al.* 1981). Allied faunas are present in Japan, and distinct faunas with rather few direct links are developed in the Pija Member of Nepal (*Krotovia arcuata* Zone) and Greville Formation of New Zealand (*Durvilleoceras woodmani* Zone).

These two upper Chhidru faunas of the Salt Range are significant. The bivalves of the lower fauna, and brachiopod species of the upper interval formed part of the two faunas that extended through central Asia as far as Iran and Armenia, and help confirm that there are two closely allied faunas in sequence, distinguished as marking the Urushtenian (Abadehan) and Baisalian Substages, associated by us as one Djulfian Stage, and distinguished from the underlying Punjabian Stage. The Djulfian faunas are represented in central Iran by the Abadeh and lower Hambast faunas, and in Armenia by the *Araxilevis*, *Oldhamina-Araxoceras*, and *Vedioceras* faunas (Baisalian Substage), and probably by the underlying *Codonofusiella* beds (Abadehan or Urushtenian Substage). These faunas lie definitely above the Punjabian faunas of the Chhidru-Kufri and Kalabagh beds in the Salt Range. Punjabian faunas are represented also in the Surmaq Formation of central Iran, and Gnishik and Hachik faunas (below *Codonofusiella*) of Armenia. Therefore the correlations between the Hachik fauna, Abadeh fauna, and Kalabagh fauna, preferred by Taraz *et al.* (1981) and Tayyab *et al.* (1981) are not possible. Nor is the correlation between upper Djulfian (Baisalian), Hambast and Chhidru Formations preferred in the same studies. This means in turn that *Coloniella* and *Codonofusiella* range from Punjabian to Djulfian. They are not restricted to a Djulfian (or Urushtenian-Abadehan to Baisalian interval) as claimed by Taraz *et al.* (1981). Similarly, the ammonoids *Cyclolobus* is not restricted either to one stage. Any argument to the contrary seems difficult to sustain for the following reasons :

(*a*) The Djulfian faunas follow Kalabagh-Chhidru faunas in clear and widely agreed succession in the Salt Range, so they must be sequential, not correlative.
(*b*) Fusulines show variable and inconsistent ranges no matter how they are arranged, indicating that ranges were lengthy, and that abundances varied.
(*c*) It is impossible to reconcile the sequences to the Himalayas and New Zealand with faunas of Armenia, Iran and Salt Range unless the Punjabian sequences of the Salt Range are older than Djulfian.
(*d*) The Armenian sequence, and indeed the sequence in central Iran and north Iran strongly support a Punjabian followed by Djulfian Stage, on brachiopod evidences.

8. No early or middle Dorashamian fauna appears to be present in the Salt Range sequence. We consider that *Ophiceras connectens*, and the few Permian-type brachiopod species near the base of the Kathwai Member of the Mianwali Formation indicate a Griesbachian age-Ellesmerian level.

The Tethyan Stages of Leven *et al.* (1980)

The reductionist tendencies of Tayyab *et al.* (1981) stand in contrast to the summary of Tethyan faunas by Leven *et al.* (1980), in which a rather full sequence of fusuline faunas is enumerated and used to propose 'Tethyan' biostratigraphic units. Sequences from central Asia were deemed particularly valuable for middle Permian sequences (above the Sakmarian, for which reliance is still placed on the Urals). However, the Leven (1980) scheme shows some depressing inadequacies. Although supposedly applicable to the 'Tethys', it shows very limited applicability indeed to what we would have supposed was a huge segment of Tethyan rocks, or rocks formed near the ancient Tethys, through parts of southern Europe and Iran, Afghanistan, and especially the Himalayas. Like so many schemes, it has placed prime reliance on fusulinacea, and, where these become restricted in the late Permian, on Ammonoidea. As a result, most rocks cannot be correlated or fitted into the scheme, except on crude principles of sequences and juxtaposition. Even the long-established Kungurian, Ufimian and Kazanian Stages cannot be accurately fitted in. The scheme betrays a complete misunderstanding of the nature of Kungurian and Kazanian faunas through severe miscorrelation. We also perceive an inability to relate the fusuline sequence in any way to significant geological or climatic events, so that there is a lack of proportion in levels recognised, ranging from puny ammonoid communities, to full zones, all classed as of equal importance. Moreover, the ranges of various fossils, especially fusulinacea, are not properly given in all instances. A number of species that range for more than one zone are listed only in one of the zones—and inconvenient ranges are omitted. Is is not time that specialists interests, and pretences were set aside? Fusulines will not suffice to subdivide and classify the Permian in any comprehensive or profound manner. They are of local interest only, and scarcely reach the late Permian, nor Gondwana, or other parts of the globe.

The severe limitations of the fossils may perhaps explain why Leven (1980) proposed 'Tethyan Stages.' Time-rock subdivisions and age subdivisions are not local. Surely they must be world-wide. The proposal of local time units is completely inappropriate nowadays. What is needed are local zones, not local times.

Substage Terminology: Kufrian Substage

The preceding review, based on recent discoveries of fusulinacea, and a vital reassessment of the nature and age of upper Chhidru faunas, demonstrates that early understanding of the Punjabian Stage, and its constituent substages Kalabaghian and Chhidruan must be modified. In particular, the Chhidruan Substage, as conceived and refined, no longer corresponds with earlier concepts, for the Chhidru Formation from which it was named includes meagre developments of the lower and upper Djulfian Stage. We formally suggest that the Chhidruan Substage be replaced by Kufrian Substage, based on rocks and faunas of the Kufri Member, of the Chhidru Formation. This is a nomenclatural change, not a change in concept, which dates back to the early 1970's.

We encounter less difficulty with regard to Punjabian, because the term has been tied to a concept rather than specific formation or member. It is true that it may be preferred to retain Chhidruan, amended to exclude the beds and faunas of the upper part of the formation, because we cannot go on changing names every time we need to slightly change boundaries or concepts. Time will tell.

Stage Terminology: Guadalpian Versus Punjabian Stage

A major consideration centres around the use of Punjabian or Guadalupian as a stage unit. The Guadalupian of the west Texas encompasses splendid sections of well-exposed rock and comprehensively described faunas, and certainly would offer a superb world standard. It would seem to us to be better regarded as a series name rather than stage, for it encompasses a lengthy interval, as shown in Table 4.

Contact with older rocks and rich faunas is good; but overlying faunas are poorly developed. The nearby Bell Canyon Formation displays a better sequence of faunas than seen in the Capitan Formation, and we consider that the Lamar Member at the top might be of early Djulfian age, though this is disputed by Taraz *et al.* (1981). It would appear necessary to have several stages within the Guadalupian. Even the Word and Capitan encompass more than a stage each. Historically, of course, the Kungurian and Kazanian enjoy long prior usage, and are very applicable especially to the Arctic realm, and to Gondwana, so that we would personally prefer to see the historical Russian scheme preserved, subject to the right of ready access to type outcrops. But setting history aside, there is no denying the usefulness of the sequences and faunas in the Glass Mountains and nearby. What particularly impresses us are the following three major facets: (i) rich faunas have been systematically described,

TABLE 4 : MARINE SUBDIVISIONS RELEVANT TO GUADALUPIAN 'STAGE' OR SERIES†

Russia Urals, Russian Platform		*Armenia*			*United States West Texas*	
		Djulfian Stage	Baisalian Substage		Capitan	Guadalupian
			Urushtenian Substage			
		=Punjabian Stage	Hachik Gnishik			
Kazanian Stage	Sosnovian Substage			Word	Appel Ranch	
	Kalinovian Substage				Willis Ranch	
	Ufimian Substage				China Tank ?	
Kungurian Stage	Irenian Substage				——?——	
	Filippovian Substage				Road Canyon	

†The Appel Ranch, Willis Ranch and China Tank carbonates are separated by intervals with less studied faunas. China Tank may be Ufimian or Irenian, and further study is required.

(ii) the Guadalupian contains a sequence of stages and substage in reasonably close juxtaposition, whereas under current schemes, other stratotypes are divided between the Urals-Russian Platform, and Salt Range—or elsewhere; (iii) the Glass Mountains and Guadalupe Mountains are made accessible to overseas experts. We would note that we find some difficulty in deciding where the Ufimian faunas of the Soviet Union fit in the Guadalupian succession—so there just might be a break in the sequence. But it seems more likely that the sequence is complete, and requires more biostratigraphic analysis.

Three ideal series for the world Permian

There is thus much to be said for giving serious consideration to the use of Guadalupian as a series name, rather than a stage name. Were this to be done, other names would also have to be used to balance a geographic term for series, and we propose that the Permian be subdivided as shown in Table 5.

TABLE 5

	Series	*Stage*	*Type areas*
Late	Transcaucasian Series	Dorashamian Djulfian	Principally Armenia, with prime sequences also in Himalayas (Kashmir, Nepal) and China
Middle	Guadalupian Series	Punjabian Kazanian Kungurian	At present in Pakistan and Urals-Russian Platform, or to be moved with other names to Glass and Guadalupe Mountains with Capitan, Word and Roadian
Early	Cisuralian Series	Baigendzinian Sakmarian Asselian	Urals, as is becoming widely agreed.

We consider that these suggestions might have wide appeal, as they are straightforward and aggregate type regions in a more simplified manner than in the scheme elaborated in Waterhouse (1976*a*). The Guadalupian differs from that scheme in two aspects: firstly, in substituting for Russian-Indian stages, it becomes more difficult to apply directly to the extensive faunas and deposits of Gondwana and the Arctic, and secondly, it closes below the Djulfian, whereas Waterhouse (1976*a*, 1978) preferred to include Djulfian with Middle Permian, to conform with the rhythmic spacing of climatic changes. We also note that the world ranging correlations of Roadian and Wordian have not yet been achieved—and perhaps little attempted,—if we set aside the handful of ammonoid-based stations. So we do not know if Roadian is Kungurian, or only Filippovian, and we do not know if Roadian is Kungurian, or only Filippovian, and we do not know the exact Arctic-Urals-Gondwana counterparts of the China Tank fauna. But the faunas are so rich in brachiopods and other less widely ranging fauna that correlation should be possible.

We are also aware that sequences in China offer some advantages over those of the Transcaucasus in their abundance and clarity of sequence. The sequences are widely exposed and very fossiliferous, as for example along the Yangtze River west of Yichang, in Hupei Province. Were we to select world Permian stratotypes from amongst the very best of sequences, and disregard the historical background, and were we free to assume that access would be granted to the international community of scholars, we would recommend the sequence and terminology for the Permian System as given in Table 6.

TABLE 6

Series	*Stage*	*Type areas*
Yichangian (Lopingian) Series	Changsingian (Chanxing)	Hupei, also Sichuan, Guizhou etc., south China
	Longtanon (Lungtanian)	
Guadalupian Series	Capitan	Glass and Guadalupe Mountains of Texas, New Mexico
	Wordian	
	Roadian	
Cisuralian Series	Baigendzinian	Fore-Urals, Urals, Soviet Union
	Sakmarian	
	Asselian	

These amount to substantial nomenclatural changes from the more historically based interpretation of the world Permian sequences unravelled by Waterhouse (1976*a*), with a shift away from Russian names and therefore type sections, but conceptually, there is very little change, for the overall world correlations in Waterhouse (1976*a*; 1978*a*) have stood up well. Some uncertainty, as indicated, surrounds the exact faunal limits of the Guadalupian stages, an important matter, because the Russian equivalents are very widely applicable in spite of their reduced faunas. We also need to verify or discard Yichangian as a suitable name for the Chinese-based series. The term Lopingian might be an appropriate alternative, with considerable use in the past. More recently it appears to be applied especially to Lungtan-Wuchiaping equivalents.

It is to be hoped that the Permian Subcommission which was established in 1976 under the aegis of IGCP might eventually come to consider actively these various proposals and begin to seek agreement on international stage usage for the period. Perhaps it might be considered that a start has been made, through circulation of a little newsletter, and the holding of a few meetings, generally in central Europe, and attended by a few people with some interest in the matter.

VI. BRACHIOPOD SPECIES FROM THE SALT RANGE

Grant (1970) has described small but important brachiopod faunules from the highest beds of the Chhidru Formation and basal beds of the Mianwali Formation in the Salt Range, and neighbouring areas. He was able to demonstrate that the brachiopods had not been reworked, and named or identified specifically a few forms. The ensuing decade of increased attention to faunas close to the Permian-Triassic boundary has not diminished the importance of Grant's work, and has served to underline the unusual nature of the brachiopods, proving that they do indeed differ from those of underlying Permian faunas, just as Grant (1970) established, and differ to lesser extent from other late Permian faunas known from Iran-Armenia, and from south China. We therefore re-examine the descriptions and figures of Grant (1970) to evaluate the age and relationships of the faunules. Several species we show to be new, and several are related to Djulfian species described from elsewhere in south Asia.

The brachiopods come from two levels, the white sand now named the Landa Sandstone Member at the top of the Chhidru Formation, and dolomite at the base of the Kathwai Member, Mianwali Formation. The material is kept at the Smithsonian Institute, United States National Museum, Washington D.C., and details of localities, descriptions, discussions and figures are provided by Grant (1970).

SYSTEMATIC DESCRIPTIONS

Family Enteletide Waagen, 1884

Genus *Enteletes* Fischer de Waldheim, 1825

Enteletes granti n. sp.

1970 *Enteletes* sp. 1 Grant (1970, p. 131, pl. 1, figs. 1-5).

Holotype. Specimen USNM 153694, figured by Grant (1970, pl. 1, fig. 4, 4a), from Landa Sandstone Member ('white sand'), Tapan Wahan, Salt Range.

Diagnosis. Small suboval to slightly transverse shells with moderately narrow sulcus and about 3 pair of lateral plicae.

Resemblances. This species is described by Grant (1970) and was compared with *Enteletes socialis* Reed, 1944 and *E. conjunctus* Reed, 1944 from the Kalabagh beds at the top of the Wargal Limestone, and a Himalayan species described by Diener from the Chitichun no. 1 limestone in south Tibet. A species somewhat closer in size and transverse outline and general appearance is *E. lateroplicatus* Sestini and Glaus (1966, pl. 63, figs. 1-2) from the Nesen Formation, Elburz Mountains, of Baisalian (upper Djulfian) age. This species is slightly more inflated, with narrower plicae that might be more numerous in the large holotype (pl. 63, fig. 5).

Genus *Orthotichia* Hall and Clarke, 1892

Orthotichia minuta (Abich, 1878)

1878 *Streptorhynchus peregrinus* var. *minutus* Abich (1878, p. 78, pl. 9, fig. 1).

1965 *Orthotichia minuta* Sokolskaya in Ruzencev and Sarytcheva (1965, p. 200, pl. 19, figs. 4, 5). (See for typology diagnosis, and description.)

1970 *Orthotichia* sp. 1, Grant (1970, p. 132, pl. 1, figs. 9-11, 13).

1980*a* *Acosarina minuta* Liao (1980*a*, p. 272, pl. 1, figs. 23-28).

Resemblances. Grant's specimens from the white sand (Landa Sandstone Member) at Tapan Wahan, Salt Range, come close in size and shape to the Armenian shell described from the Baisalian Substage, Djulfian Stage, of Armenia. Liao (1980*a*) assigned the species to *Acosarina*, but his specimens from the Djulfian Lungtan Formation, and lower Changsing Formation of early Dorashamian age, do not appear to have a dorsal sulcus. The specimens from Armenia and Salt Range have a shallow anterior ventral sulcus.

Family Derbyiidae Stehli, 1954

Genus *Derbyia* Waagen, 1884

Derbyia postplicatella n. sp.

1970 *Derbyia* cf. *plicatella* Waagen, Grant (1970, p. 134, pl. 1, figs. 14-19).

Holotype. Specimen USUM 153707, figured by Grant (1970, pl. 1, fig. 17) from white sand (Landa Sandstone Member) at Tapan Wahan, Salt Range.

Diagnosis. Small *Derbyia* with high ventral interarea and subdued anterior plications.

Description. These shells are small and subelongate with abruptly rounded cardinal extremities and relatively high interarea below a twisted ventral umbo. The ventral valve is flatly convex anteriorly, and the dorsal valve slightly swollen medianly. Wrinkles are strongly developed anteriorly, and radial plicae are irregular and weak. Grant (1970) did not accept *Plicatoderbyia* Thomas, proposed for *Derbyia* with radial plicae, as a meaningful genus.

Resemblances. *Derbyia plicatella* Waagen (1884, pl. 55, fig. 3) from the upper Chhidru Formation is close but has a lower ventral interarea and more regular slightly more conspicuous radial plicae. *Derbyia disalata* Liao (1980*a*, pl. 2, figs. 3-9) from the Djulfian Lungtan fauna of south China has a high interarea but a dorsal sulcus is present. The interarea of *D. acutangula* (Huang) from the Lungtan Formation of south China is also moderately high. The specimens from Guizhou that were figured by Huang (1933, pl. 3, figs. 12-18) are close in ornament and shape except for the more alate cardinal extremities.

Family Costispiriferidae Muir-Wood and Cooper, 1960

Genus *Spinomarginifera* Huang, 1932

Spinomarginifera kathwaiensis n. sp.

1970 *Spinomarginifera* sp. Grant (1970, p. 137, pl. 2, figs. 1-3).

Holotype. Specimen USUM 153712, figured by Grant (1970, pl. 2, fig. 1), from dolomite unit of Kathwai Member, Mianwali Formation, Chhidru Nala, Salt Range.

Diagnosis. Transverse shells without ventral sulcus or dorsal fold.

Resemblances. As Grant (1970) pointed out, this species is close to but larger than *Spinomarginifera helica* (Abich) from Djulfian faunas of Iran and Armenia, and has a similar transverse non-sulcate visceral disc. But ventral spine bases are longer and spines are more prolonged within the shell. The dorsal valve is ornamented by dimples, without spines for certain, so that the generic identity is not completely established. *S. jiaozishanensis* Liao (1980*b*, pl. 4, figs. 18-20) from the lower Changsing Formation of south China is also close, but has a slightly less swollen visceral disc. *S. alpha* Huang as figured by Liao (1980*a*, pl. 2, figs. 15-17, from the Changsing Formation of south China is also close in the convexity of the ventral valve, but is narrower with shorter spine bases externally. The holotype of S. *alpha* as figured by Huang (1933, pl. 5, fig. 12) from "the Permian coal series of Kucichow" has elongate spine bases within the shell, and is closely allied, though distinguished by its narrower shape.

Family Linoproductidae Stehli, 1954
Genus *Linoproductus* Chao, 1927
Linoproductus periovalis n. sp.

1970 *Linoproductus* sp. Grant (1970, p. 138, pl. 2, figs. 7-9).

Holotype. Specimen USNM 153719, figured by Grant (1970, pl. 2, fig. 8) from Landa Sandstone Member, Tapan Wahan, Salt Range.

Diagnosis. Small suboval to subquadrate shells with gently convex or weakly sulcate ventral valve and low dorsal median swelling anteriorly, costae coarse, numbering 6-7 in 5 mm anteriorly.

Description. Shells small, somewhat variable in shape, but subrounded or subquadrate, not elongate, some shells with very wide anterior ventral flattening or sulcus, and dorsal fold. Costae unusually coarse.

Resemblances. This species is unusual in outline and shape, and comes close in these respects to *Linoproductus crassicostina* n. sp., described below from the Nisal and Luri Members of Vedian (lower Dorashamian) age in Nepal. *L. crassicostina* differs in having slightly coarser costae, and a slightly more swollen visceral disc, and swollen spine bases are more conspicuous on some specimens. Nevertheless the two species are unusual. Other species that may have formed with these two as evolving and related lineage are *Linoproductus lineatus* (Waagen) and *L. superba* Reed from Kalabagh-Kufri beds of the Salt Range, as large shells with elongate disc and coarse costae.

Family Martiniidae Waagen, 1883
Genus *Martinia* M'Coy, 1844
Martinia acutomarginiformis n. sp.

1970 *Martinia* sp. Grant (1970, p. 145, pl. 3, figs. 4-6).

Holotype. Specimen USUM 153734, figured by Grant (1970, pl. 3, figs. 4, 4*a*, 4*b*) from base of dolomite unit, Kathwai Member, Mianwali Formation, Narmia Spring, Surghar Range.

Diagnosis. Small *Martinia* with narrow pointed ventral umbo, widely flaring sulcus with long anterior tongue, and narrow angular cardinal extremities.

Description. Shells characterized by long straight posterior margins diverging to abruptly rounded extended (but not alate) cardinal extremities, with anterior-lateral margins converging on sulcal long tongue-like extension in ventral valve. Dorsal valve moderately inflated with low angular anterior fold and more widely diverging posterior umbonal walls, of more usual outline.

Resemblances. As Grant (1970) pointed out, this species comes closest to *Martinia rhomboidalis* Girty, 1909, revised by Cooper and Grant (1976 : 2271) but has a much less angular outline and broader more incurved ventral umbo, with other differences. *M. rhomboidalis* comes from the Capitan Formation and Lamar Member, Bell Canyon Formation, in Texas. Yanagida (1973) identified the species in the Yamamba Limestone of the Sakawa Basin in Japan.

Age Implications

(*a*) *Landa Sandstone Member*. These few species support a Djulfian age for the white sandstone or Landa Sandstone Member at the top of the Chhidru Formation. *Enteletes granti* appears to compare most closely with *E. lateroplicatus* Sestini and Glaus (1966) from the Nesen Formation, of Baisalian age in the Elburz Mountains. *Orthotichia* from the same unit appears to belong to *O. minuta* (Abich) from Baisalian beds of Armenia, and perhaps from the Djulfian Lungtan Formation (and lower Changsing Formation) of south China. *Derbyia postplicatella* comes close to *D. plicatella* from the upper Chhidru Formation of the Salt Range, and closer in its high interarea to *D. acutangula* (Huang) from the Lungtan Formation of Djulfian age in south China. *Linoproductus periovalis* n. sp. is close to *L. crassicostatina* n. sp. from the Senja Formation of Nepal, of Vedian age, and also to *L. lineatus* Waagen and *L. superba* Reed from the Kalabagh and lower-middle Chhidru Formation beds of the Salt Range, and is intermediate in morphology, and perhaps in age between these two sets of species. Thus these species are all consistent with a Djulfian age, and favour a Baisalian correlation.

(*b*) *Basal Kathwai Member*. The new species of *Spinomarginifera* most closely approaches a Changsing species, *S. alpha* Huang, and to less extent *S. jiaozishanensis* Liao, also from the Changsing Formation. *Martinia acutomarginalis* n. sp. is an unusual species, conceivably derived from and therefore slightly younger than *M. rhomboidalis* Girty of Capitan and Lamar deposits in United States. Kapoor and Nakazawa (1977) have suggested that the dolomite grades up into and is the same as the underlying white sand, of the Landa Sandstone Member, but we doubt if it is possible to be sure of this just from outcrop, and consider that *Ophiceras* found in the basal dolomite indicates an Ellesmerian age—upper Griesbachian—with the Vedian and Ogbinan, i.e., *Comelicania-Janiceps*, and *Paratirolites* faunas, and *Otoceras* faunas (Gangetian) missing. Ambocoeliids appear to be common in the *Otoceras-Ophiceras* beds, and *Crurithyris* (=*Orbicoelia*) *extima* Grant abounds in this horizon.

VII. NEW SPECIES FROM LATE PERMIAN OF NEPAL

Genus *Linoproductus* Chao, 1927

Linoproductus crassicostina n. sp.

1978 *Linoproductus superba* not Reed, Waterhouse (1978*a*, pp. 74, 119, pl. 11, figs. 6-8; pl. 23, figs. 2-4).

Holotype. Specimen UQF 68903, figured by Waterhouse (1978*a*, pl. 11, figs. 6, 8) from Nisal Member, Senja Formation, northwest Nepal.

Diagnosis. Subrounded shells with gently convex to flattened venter and coarse costae, measuring 4-5 in 5 mm at anterior and lateral margins, spine bases somewhat swollen, few.

Discussion. *Linoproductus superba* Reed from the Kalabagh and Kufri Members of the Salt Range, with other specimens discussed in Waterhouse (1978*a*) and elsewhere in this text has finer costae, numbering 6-7 in 1 mm. The costal count in Waterhouse (1978*a*, p. 75) errs, perhaps a printing or typing error, with 4-5 costae in 5 mm, not in 1 mm.

VIII. NEW SPECIES FROM LATE PERMIAN OF CHINA

Genus *Acosarina* Cooper and Grant, 1969

Acosarina liaoi n. sp.

1980*b* *Acosarina doraschamensis* (not Sokolskaya) Liao (1980*b*, p. 272, pl. 1, figs. 35-38).

Holotype. Specimen 1/43382 figured by Liao (1980*b*, pl. 1, figs. 35-38) from lower Changsing deposits of west Guizhou.

Diagnosis. Subrounded shells with more inflated dorsal valve, and narrow dorsal groove, widening at anterior margin.

Description. Shell small with low ventral and more inflated dorsal valve, subrounded in outline with pointed ventral umbo and more massive dorsal umbo. Ventral valve gently rounded in section, dorsal valve with narrow median posterior groove, widening at anterior margin in short sulcus. Costellae number 3-4 per mm.

Resemblances. This species is less transverse than *Orthotichia doraschamensis* Sokolskaya (1965), discussed previously, and has a narrow dorsal groove.

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APPENDIX

BRACHIOPOD LISTS FOR PUNJABIAN AND DJULFIAN STAGES IN SOUTH ASIA

Armenia

The sequence in Armenia has been set forth in Ruzencev and Sarytcheva (1965), also analyzed by Waterhouse (1976*a*). The Gnishik beds contain the following brachiopod species :

Parenteletes sp., *Geyerella* sp., *Edriosteges poyangensis* (Kayser), *Chonostegoides ogbinensis* Sarytcheva, *C. armenicus* Sarytcheva, *Vediproductus vediensis* Sarytcheva, *Spinomarginifera labaensis* (Likharev), *Linoproductus cora* (Orbigny), *Keyserlingina caucasica* (Likharev), *Phricodothyris asiatica* (Chao), *Martiniopsis inflata* Waagen, *Recticulariina* aff. *netschajewi* Ivanova, *Notothyris nucleolus* (Kutorga), *Dielasma plica* Kutorga, *D. elongatum* (Schlothelm), and share other brachiopod species with the overlying Hachik beds:
Orthotichia, avushensis Sokolskaya, *Orthotetina vediensis* Sokolskaya, *O. iljinae* Sokolskaya, *Chonostegoides baissalensis* Sarytcheva, *Richthofenia lawrenciana* (Koninck), *Richthofenia caucasica* Likharev, *Krotovia jisuensiformis* Sarytcheva, *Marginifera magniplicata* (Huang), *Spinomarginifera lopingensis* (Keyserling), *Ogbinia dzhagrensis* Sarytcheva, *Terebratuloidea minor* Waagen, *Terebratuloidea davidsoni* Waagen, *Septospirigerella baissalensis* Grunt, *Composita subtriangularis* Reed, *Dielasma mongolicum* (Grabau).

Note that no species are restricted to the Hachik beds.

The Urushtenian Substage (Waterhouse, 1976*a*) is poorly represented by beds with *Codonofusiella* in Armenia. The overlying Baisalian (upper Djulfian) faunas are well-developed, and the following brachiopod species have been listed in Ruzencev and Sarytcheva (1965 : 69).

(*a*) Shared with Gnishik and Hachik beds below :

Neochonetes armenicus Sokolskaya, *Leptodus richthofeni* Kayser, *Spiriferellina* ex gr. *cristata* (Schlotheim), *Uncinunellina timorensis* (Beyrich), *Wellerella arthaberi* Chernyshev, (?)*Permophricodothyris indica* (Waagen), *Rhipidomella* (*Rhipidomella*) *vediensis* Sokolskaya, *Septospirigerella megridagica* Grunt, *Orthotetina arakeljani* Sokolskaya, *O. dzhulfensis* Sokolskaya.

(*b*) Restricted in Armenian section to Baisalian faunas (*Araxilevis, Oldhamina* and *Haydenella* levels of Ruzencev and Sarytcheva (1965) :

Orthotichia doraschemensis Sokolskaya, *O. minuta* (Abich), *Parenteletes ruzhencevi* Sokolskaya, *Orthotetina persica* Schellwien, *Orthotetina eusarkos* (Abich), *O. peregrina* (Abich), *Edriosteges ogbinensis* Sarytcheva, *Tschernyschewia typica* Stoyanow, *T. yakowlewi* Stoyanow, *Dorashamia abichi* Sarytcheva, *Araxilevis intermedius* (Abich), *Tyloplecta yangtzeensis* (Chao), *Alexenia* cf. *gratiosa* (Waagen), *Spinomarginifera spinosocostata* (Abich), *S. ciliata* (Abich), *S. helica* (Abich), *Compressoproductus djulfensis* (Stoyanow), *Haydenella tumida* (Waagen), *Ogbinia productinaeformis* Sarytcheva, *Chonopectoides permicus* Sarytcheva, *Oldhamina transcaucasica* (Stoyanow), *Leptodus nobilis* (Waagen), *Gubleria armenica* Sarytcheva, *Spinolyttonia arakeljani* Sarytcheva, *Poikilosakos dzhulfensis* Sarytcheva, *Uncinunellina jabiensis* (Waagen), *Wellerella dorashamensis* Sokolskaya, *Pseudowellerella araxensis* Sokolskaya, *Stenoscisma armenica* Sokolskaya, *Martiniopsis subpentagonalis* Waagen, *Crenispirifer dzhulfensis* Ivanova, *Araxathyris araxensis* Grunt, *A. protea* (Abich), *A. felina* (Arthaber), *A. quadrilobata* (Abich), *A. lata* Grunt, *A. emarginata* (Girty), *A. abichi* (Arthaber), *Notothyris djoulfensis* (Abich).

(*c*) Shared with overlying Dorashamian Stage :

Spinomarginifera pygmaea Sarytcheva, *Haydenella kiangsiensis* (Kayser), *H. minuta* Sarytcheva, *Araxathyris araxensis minor* Grunt.

The overlying faunas are typified by the brachiopods *Comelicania triangularis* Grunt and *Janiceps janiceps* (Stache), two key species for the Vedian Substage of the lower Dorashamian Stage (see Waterhouse, 1976*a*).

The Urushtenian beds which are poorly represented in Armenia are well-developed in the Caucasus, and the very large suite of Productida have been described by Likharev (1936), as well as other key species including *Codo-*

nofusiella and *Cruricella tschernyschewi* (Likharev), but the complete fauna is yet to be described. Urushtenian faunas are also discussed as belonging to an Abadehan Stage by Taraz (e.g. 1971).

Iran

From the Abadeh area of central Iran, a useful sequence of faunas has been listed in a study by Taraz *et al.* (1981). Brachiopods from the Surmaq Formation are listed in Taraz *et al.* (1981, p. 121, fig. 21) as *Orthotichia avushensis* Sokolskaya, *O. peregrina* (Abich), *O.* cf. *vediensis* Sokolskaya, *Meekella arakeljani* (Sokolskaya), *Neochonetes armenicus* Sokolskaya, *Edriosteges poyangensis* (Kayser), *Edriosteges* sp., *Chonostegoides armenicus* Sarytcheva, *Richthofenia lawrenciana* (de Koninck), *Krotovia jisuensiformis* Sarytcheva, *Avonia* sp. A, *Vediproductus vediensis* Sarytcheva, *Liosotella magniplicata* (Huang), *Spinomarginifera spinosocostata* (Abich), *S. helica* (Abich), *Obginia dzhagrensis* Sarytcheva, *Linoproductus lineatus* (Waagen), *Wellerella arthaberi* (Chernyshe), *Stenoscisma* aff. *pinguis* (Rothpletz), *Spirigerella timorensis* (Rothpletz), *S. subtriquetra* Ching and Liao, *Araxathyris yunnanensis* Yang, *Composita subtriangularis* (Reed), *Cryptospirifer* n. sp., *Trigonotreta* sp., *Phricodothyris asiatica* (Chao), *P. indicus* (Waagen), *Phricodothyris* sp. A, *Crenispirifer* sp. A, *Martinia corculum* Kutorga, *Martinia warthi* Waagen, *Martiniopsis* sp., *Dielasma elongata* Schlotheim, *Notothyris nucleolus* (Kutorga), *N. pseudojoulfensis* Likharev.

Bachiopods listed from the Abadeh Formation are :

Orthothetina sp. A, *O. djhulfensis* Sokolskaya, *O.* sp. B, *O. regularis* Huang, *Krotovia jisuensiformis* Sarytcheva *Tyloplecta yangtzeensis* (Chao), *Tyloplecta* n. sp., *Liostella magniplicata* (Huang), *Spinomarginifera ciliata* (Arthaber), *S. spinosocostata* (Abich), *S. helica* (Abich), *S. lopingensis* (Kayser), *Leptodus* sp. A, *L. nobilis* (Waagen), *Uncinunella* n. sp., *Septospirigerella baissalensis* Grunt, *S. megridagina* Grunt, *Phricodothyris* sp., *P. asiatica* (Chao), *Spiriferellina hochuanensis* Liao, *Crenispirifer* sp. B, *Martinia corculum* Kutorga.

Brachipods listed from the Hambast Formation are :

Orthotichia peregrina (Abich), *O. dzhulfensis* Soklaskaja, *O.* cf. *persica* (Schellwien), *O. eusarkos* (Abich), *Araxilevis intermedius* (Abich), *Tyloplecta yangtzeensis* (Chao), *Tyloplecta* n. sp., *Spinomarginifera spinosocostata* (Abich), *S. helica* (Abich), *Leptodus nobilis* (Waagen), *Leptodus* sp. B, *Araxathyris araxensis* Grunt, *A. minor* Grunt, *Notothyris* aff. *nucleolus* (Kutorga).

An important sequence of younger Permian rocks is found in the Elburz Mountains of Iran, with numerous Brachiopoda, and other faunal elements, and as usual, scarcely any ammonoids. Foraminifera have not been described. The Ruteh Formation has been collected at several intervals, with faunas belonging to the Punjabian (Kalabaghian-Chhidruan restricted intervals) levels 1, 2, and 5 of Sestini (1965*a*), and Urushtenian (level (?) 3, probably 3) of Sestini (1965*a*). The bulk of the brachiopods as described by Sestini (1965*a*) include the following species :

Orthotichia indica (Waagen), *Derbyia altestriata* Waagen, *Streptorhynchus* cf *lenticulare* Waagen, *Streptorhynchus semiplanum* (Waagen), *Streptorhynchus* sp. ind., *Neochonetes assereto* Sestini, *Marginifera typica crassicostata* Reed, *Spinomarginifera spinosocostata* (Abich), *Spinomarginifera helica* (Abich), *Spinomarginifera sintanensis* (Chao), *Haydenella khasorensis* (Reed), Echinoconchid, *Costiferina* cf. *indica* (Waagen), *Reticularia*(?) sp. ind., *Tylopecta* cf. *yangtzeensis* (Chao), *Linoproductus* sp., *Linoproductus lineatus* (Waagen), *Cancrinella* sp., *Stepanoviella* sp., *Compressoproductus djulfensis* (Stoyanow), *Stenoscisma waageni* (Nechaev), *Phricodothyris asiatica* (Chao), *Spiriferellina cristata* (Schlotheim), *Cleiothyridina* cf. *capillata* (Waagen), *Cleiothyridina globulina* (Waagen), *Cleiothyridina subexpansa* (Waagen), *Cleiothyridina uralica* (Grabau), *Dielasma grabaui* Sestini, *Dielasma itaitubense* (Derby), *Dielasma* cf. *plica arcuatum* Reed, *Dielasma* sp. ind., *Whitspakia acutangula* (Waagen).

The upper Ruteh faunas differ a little from level 3(?) (Sestini, 1965 : 24) and include the following species :

Orthotichia indica (Waagen), *Orthothetina* cf. *armeniaca* (Arthaber), *Spinomarginifera sintanensis* (Chao), *Linoproductus* cf. *lineatus* (Waagen), *Crurithyris tschernyschewi* Likharev, *Whitspakia* cf. *biplex* (Waagen).

Presumably 3 is of much the same age, with—

Orthothetina armeniaca (Arthaber), *Orthothetina* cf. *eusarkos* (Abich), *Orthothetina* sp., *Meekella* cf. *uncitoides* Chernyshev, *Spinomarginifera spinosocostata* (Abich), *S. pseudosintanensis* Huang, *S. sintanensis* (Chao), *Linoproductus* sp., *Cancrinella* sp., *Dielasma itaitubense* (Derby), described by Sestini (1965 : 23).

The younger Nesen Formation is clearly correlative with the Baisalian fauna of Armenia, and includes the following brachiopod species (Sestini and Glaus, 1966: 892) :

Enteletes cf. *dzhagrensis* Sokolskaya, *E. lateroplicatus* Sestini and Glaus, *Orthotichia dorashamensis* Sokolskaya, *Orthothetina glausi* Sestini and Glaus, *O. peregrina* (Abich), *Spinomarginifera ciliata* (Arthaber), *S. helica* (Abich), *S. spinosocostata* (Abich), *Tyloplecta persica* Sestini and Glaus, *T. yangtzeensis* (Chao)., *Oldhamina* sp., *Leptodus richthofeni* Kayser, *L. nobilis* (Waagen), *L.* cf. *tenuis* (Waagen), *Poikilosakos* cf. *petaloides*, *Araxathyris araxensis* Grunt, *A. felina* (Arthaber), *A. kandevani* Sestini and Glaus, *A. protea* (Abich), *Permophricodothyris iranica* Sestini and Glaus, *P. ovata* Pavlova.

Taraz *et al.* (1981, Fig. 12) offered a comparable list for their collections from the Nesen Formation :

Orthotichia cf. *doraschamensis* Sokolskaya, *Enteletes lateroplicatus* Sestini and Glaus, *Orthothetina* cf. *dzulfensis* Sokolskaya, *O. glausi* Sestini and Glaus, *Orthothetina* spp. A, B, C., *O. eusarkos* (Abich), *Tyloplecta* n.sp., *T. yangtzeensis* (Chao), *Haydenella* cf. *minuta* Sarytcheva, *H. tumida* Waagen, *Haydenella* sp., *Spinomarginifera helica* (Abich), *S.* cf. *ciliata*, (Arthaber), *Leptodus nobilis* (Waagen), *Araxathyris kandevani* Sestini and Glaus, *A.* cf. *araxensis* Grunt, *A. felina* (Arthaber), *Phricodothyris asiatica* Chao, *P. iranica* (= *Permophricodothyris*) Sestini and Glaus, *P. indicus* (Waagen), *Phricodothyris* n. sp.

Brachiopoda and Mollusca from the North Karakorum Range, Sinkiang

Faunas collected by the Filippi expedition to the Rimu Glacier area of the Karakorum were described by Merla (1934). A provisional faunal list from reassessed identifications is given in Table 1.

TABLE—1

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Orthotichia sp.			•		•				
Schizophoria parenteletiformis Huang			•		•				
Orthotetina cf. *armenica* Arthaber					•				•
O. convergens Merla						•			
O. flabellum Merla					•				•
Q. flabellum var *protracta* Merla						•			
Sicelia sp.					•				
Ombonia girtyana Merla			•		•				
Derbyia spp.					•				
Streptorhynchus sp.					•				
(?)*Tropidelasma anonyma* Merla									•
'*Chonetes*' *huangi* Merla					•				
Chonetid cf. *tenuilirata* Chao						•			
Rugaria substrophomenoides (Huang)					•	•			
(?)*Chonetinella glabellipunctatus* (Merla)					•				
Waagenoconcha spp.					•				
•*Krotovia* sp.						•			

Table 1 (*contd.* on p. 228)

Table 1 (*contd.* from p. 227)

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
**Costiferina* '*spiralis*' (Waagen)		•							
'*Productus*' *cardinalis* Merla					•				
'*Productus*' *dorsigerus* Merla					•				
**Transennatia* sp.			•						
Lamnimargus himalayensis (Diener)				•					
Spinomarginifera spp.			•		•	•	•		
**Marginifera* sp.					•				
Liostella elongatus (Huang)		•			•			•	•
Cancrinella sp.					•				
**Compressoproductus* sp.					•				
Elivina tenuisulcatus (Merla)				•					
(?)**Pteroplecta* sp.			•	•					
(?)*Punctocyrtella* sp.			•						
Neospirifer sp.			•			•	•		•
Squamularia sp.			•						
Spiriferinid sp.			•						
(?)*Dielasma* sp.			•						
Hemiptychina sp.			•						
Bellerophon jonesianus Koninck	•								
B. squamatus mongolicus Grabau						•			
B. rotularis Merla						•			
Euomphalus aff. *crotalostomiformis* Wanner						•			
Naticopsis khurensis Waagen						•			
N. gastridia Merla						•			
Holopella aff. *trimorpha* Waagen	•								
Metacoceras reedianum Merla	•								
Etheripecten hiemalis (Salter)									•
Palaeolima eulyrata Merla									•
Pseudomonotis sp.									
Atumodesma leonardii Merla (= *Variabile*?)						•	•		
Cypricardella cf. *amarassiensis* Wanner									
Schizodus pinguis Waagen						•			
Permophorus caudatus (Merla)									•
Permophorus sp.									•
Megadesmus cyrtos (Merla)									•
'*Allorisma*' *perelegans* Waagen									•
'*A*'. *euphotis* Merla									•
A. simplex Merla									•
A. tellinoides Merla									•
Sanguinolites subundatus Merla						•			•

Localities: 1. Murgo; 2. Jarcand; 3. Depsang; 4. Rimu 4; 5. Rimu 5; 6. Left front; 7. Alto sciaiok; 8. Valleta 3; 9. Rimu base. Asterisked species not figured.

Locality 4 (Rimu 4), might be of Punjabian age, if the identification of *Lamnimargus himalayensis* is correct. The remainder are likely to be of early Djulfian age, especially 'left front' with its Bellerophon fauna, and Rimu base with its bivalves, showing clear links with the topmost or bivalve bed—now Ganjaroh Member of the Salt Range, and the other localities, especially at Depsang (= 3), and Rimu 5, with their Djulfian brachiopods.

Other faunas have been described from the Shaksgam valley, north Karakorum, as summarized by Sestini (1965*b*), with an early Permian age likely.

Brachiopods and Bivalves from Nepal

A fine and significant sequence of younger Permian rocks and faunas is well-developed in northern Nepal, extending east from Dolpo for some 100 miles, with faunas described by Waterhouse (1978*a*). As elsewhere, ammonoids are virtually absent, conodonts scarcely represented and small foraminifera few. The fauna from the Nangung Formation, of Punjabian age, in the *Lamnimargus himalayensis* Zone is as follows :

Orthotichia sp., *Orthotetes bisulcatus* Waterhouse, (?)*Arctitreta* sp., *Demonedys* sp. *Sulcataria pentagonalis* Waterhouse, *Chonetinella* n. sp., *Paramesolobus lissarensis* (Diener), Chonetid gen. and sp. indet. (?)*Strophalosia* sp., *Megasteges* sp., *Waagenoconcha gangeticus* (Diener), (?)*Chonetella* sp., *Marginifera typica* Waagen, (?)*Echinauris* sp., *Lamnimargus himalayensis* (Diener), *Reticulatia* sp. (?) Dictyoclostid gen. and sp. indet. A., Dictyoclostid gen. and sp. indet. B., *Costiferina alatus* Waterhouse, Retariid gen. and sp. indet. *Cancrinella* sp., (?) *Uncinunellina* sp., ?*Rhynchopora* sp., (?)*Stenoscisma* sp., ?*Cleiothyridina subexpansa* (Waagen), *Spiriferelia rajah* (Salter), *Neospirifer ambiensis* (Waagen), Spiriferacean gen. and sp. indet., (?)*Spiriferellina* sp., *Callispirina* sp., Elythid gen. and sp. indet., *Martiniopsis* sp., Spiriferidin, gen. and sp. indet., (?)*Dielasmina* or *Fletcherithyris* sp.

The overlying Popa Member at the base of the Senja Formation has a small fauna dominated by bivalves :

Waagenoconcha aff. *purdoni semicircularis* Reed, (?)*Fusispirifer* sp., (?)*Modiolus* sp., (?)*Lithodomina* sp., *Schizodus pinguis* Waagen, (?)*Megadesmus* sp., *Pyramus silicius* Waterhouse.

This is deemed to be of Urushtenian age, and the overlying Pija Member is assigned to the Baisalian Substage, from the *Krotovia arcuta* Zone, containing the following brachiopod species :

Aulostegid gen. and sp. indet., *Krotovia arcuata* n. sp., Dictyoclosid gen. and sp. indet., (?) *Cancrinella* sp., *Terrakea* n. sp., Rhynchonellacea gen. and sp. indet., (?) *Cleiothyridina* sp., (?) *Pteroplecta* sp., *Neospirifer* cf. *moosakhailensis* (Davidson), *Tomiopsis* cf. *himalayanicus* Waterhouse.

Salt Range, Pakistan
Wargal Formation

More time is needed than we can afford to provide a completely satisfactory faunal list for younger Permian deposits of the Salt Range, Pakistan. For the Wargal Formation, scrutiny of the individual fossil lists in Reed (1944) suggests that the following brachiopod species are found. We provisionally divide the lists into three, L—lower, M—middle part of the formation, and U—upper Wargal or Kalabagh Member, where Reed (1944) provides sufficient data. This information is not however given for all species.

There has been some controversy over the stratigraphic position of the Cephalopod beds near Jabbi (Jabi). Although Waagen (1891) placed them high in the Chhidru Formation (in a position equivalent to between the Kujri and Ganjaroh Members), as followed by Kummel and Teichert (1970), Grant (1968) argued for a position equivalent to the Kalabagh Member. This seems to be supported by the fossil list provided by Waagen (1891), which shows that many species do not otherwise occur in the Kufri Member, but are found in the Kalabagh Member. We are therefore inclined to accept Grant's thesis. In endeavouring to complete lists, we indicate Jabbi specimens with (J). Possibly some species left on the Chhidru Formation are also really Kalabagh, assuming Grant (1968) is right, as indicated by (J).

A number of our generic determinations are very tentative, and we have followed Reed (1944) who probably named too many species :

M *Enteletes sublaevis* Waagen, M *E. pentameroides* Waagen, U *E. latesinuatus* Waagen, L *E. ferrugineus* Waagen M *E. kayseri* Waagen, U *E. subequivalvis* Gemmellaro, *E. singularis* Reed, U *E. conjunctus* Reed, U *E. socialis* Reed, U *E. waageni* Gemmellaro, *E. lamarcki* Fischer de Waldheim, M or base of U-*E. laevissimus* Waagen, U *E. Enteletina acutiplicatus infrequens* Reed, *Enteletoides redux* Reed, U *E. tenuiplicatus* Reed, L or base of M—*Orthis* (*Perditocardinia*) *uralica subelongata* Reed, *Schizophoria juresanensis* Chernyshev, U *Orthotichia indica* (Waagen), MU *O. derbyi* Waagen, M *O. janiceps* Waagen, LM *O.* (?)*marmorea* Waagen, L *Rhipidomella incisiva* Waagen, U *Meekella* (?)*punjabica* Reed, U *M. eximiaeformis* Waagen, U *M.* cf. *bashkirica* Chernyshev, L *Streptorhynchus deltoideus* Waagen, L U *S. pelargonatus* Schlotheim, U *S. mistus* Reed, L *S. lenticularis* Waagen, M or U *S. cruticulatus* Reed, U *S. distortus* Waagen, L *S. capuloides* Waagen, U *S. memor* Reed, MU *S. pectiniformis* (Davidson) (J), U *S. pectiniformis pauciplicata* Reed, *S. pectiniformis fasciculata* Reed, *S. pectiniformis latesinuata* Reed, *S. compressa* Reed T, top of M or base of U *Kiangsiella pectiniformis fissicostata* Reed, U *Schucheterlla purdoni* Reed, U *S. asperula* Reed, M *S. operculatus* Waagen, *S. semiplana* Waagen (J), M *Derbyia vercherei* Waagen, U *D. subsinuata* Reed, *D. gratulis* Waagen, LMU *D. regularis* Waagen, U *D. grandis* Waagen (J), L U *D. subaurita* Reed, U *D. hemispherica raditata* Reed, U *D. aurita* Reed, *D. altistriata* Waagen (J), LMU *D. plicatella* Waagen (J), U *Derbyia* (*Plicatoderbya*) *aemula* Reed, *D.* '(*Plicatoderbya*)' *zemula* Reed, M or U *Chonetina wynnei* Reed, LU *C. dalmiriensis* Reed, M *C. semiovalis* (Waagen), *Sulcataria*? *morahensis* (Waagen),? *Lissochonetes* '*geinitzianus*' (Waagen), (?)*L. compressa* (Waagen), U *Waagenites dichotoma bilotensis* Reed, *W. dichotoma pluriplicata* Reed, U *W. squamulifera* (Waagen), (J), U *W. aequicosta* (Waagen) (J), L *Rugaria strophomenoides* (Waagen), MU *W. dichotoma* (Waagen), M *W. deplanata* (Waagen), U *W. grandicostata* Waagen (J), MU *Echinalosia indica* (Waagen) (J), U *E. linearis* (Reed), *E. remota* (Reed), (?) *E. rarispina* (Waagen), '*Leptalosia* cf. *ovalis* Dunbar and Condra,' *Orthothrix excavata* (Geinitz), LMU *Richthofenia lawrenciana* Koninck (J), top M or base U *Richthofenia sinensis* Waagen, *Cardiocrania indica* Waagen, L '*Aulosteges horrescens* (Verneuil),' *Aulosteges wangenheimi* Verneuil, *A. wangenheimi punjabica* Reed, U *A. dalhousei* (Davidson), LM *Tschernyschewia mysius bakhensis* Reed, *T. transindicus* Reed, *T. parilis* Reed, MU *T. mysius* Enderle, U *T. fugax* (Reed), (?) U *T. punjabensis* Reed, M *T. typicus* Stoyanow, MU *T. typicus gemina* Reed, U *W. humboldti dumosa* Reed, U *W. xenia prolonga* Reed, U *W. abichi* Waagen (J), U *W. abichi serialis* Waagen (J). U *W. abichi consors* Reed, *W. abichi pseudotuberculata* Reed, *W. abichi densipustulata* Reed, U *W. abichi pseudo-palliata* Reed, U *W. irginae aliena* Reed, U *W. cylindricus* (Waagen) (J), '*Ruthenia*' (=W.) *purdoni circularis* Reed, top M or base U '*R*'. *purdoni mirkalanensis* Reed, '*Ruthenia*' *vagans* Reed, U (?) *Juresania coelebs* Reed, U *J. scalaris semituberculata* Reed, top of M or base of U *Juresania* sp., U *Echinoconchid vicinalis* Reed, LMU *Chonetella nasuta* Waagen (J), *C.* (?) *indica* Waagen, MU *Haydenella tumidus* (Waagen) (J), U *H. vihianus salinaria* Reed, *H. quaesitus* Reed, *H. khasorensis* Reed, U *Ogbinia semicarinata* Reed, MU *Marginifera typica* Waagen (J), MU *M. ornata* Waagen, U *M. ovalis* Waagen, U *M. ferox* Reed, MU *Transennatia gratiosa* (Waagen), *Echinauris* (?) *Spinomarginifera opuntia* (Waagen), U *Productid* cf. *jisuensis* Chao, *P.* cf. *morrisi* Chao, (?)*Kutorginella* sp., LU *Costiferina subcostatus* (Waagen); LU *C. indicus* (Waagen), U *C. tardatus* (Reed), MU *C. vishnu* (Waagen), U *C. aratus* Waagen (J), *Chaoiella* sp., *Tyloplecta yangtzeensis* (Chao), *Proboscidella* cf. *kutorgae* Chernyshev, Dictyoclostid *celsus* Reed, U '*Plicatifera* cf. *funiculatus* Mansuy', LMU (*Linoproductus*) *lineatus* Waagen, U *Asperlinus asperulus* (Waagen) (J), U *Stepanoviella* cf. *lahuseni* Likharev, U *S.* cf. *kulikii* Fredricks, U (?) *Anidanthus implicata* Reed, U 'Anidanthinid' cf. *weyprechti* Toula, U *Compressoproductus morahpressus* Waterhouse and Piyasin, U *Compressoproductus mongolicus subcircularis* Reed, *C. mytiloides* (Waagen) (J), *C. corniformis* Chao, U *Leptodus tenuis* Waagen, U *L. nobilis* (Waagen), *Oldhamina decipiens* Koninck (J), LMU *Terebratuloidea minor* Waagen, *T. ornata* Waagen, *T. ornata uniplicata* Reed, MU *T. davidsoni* Waagen, *T. trifida* Reed, *T. depressa daudensis* Reed, *T. pinguis* Waagen, *Wellerella saxatilis* (Reed), *W. saxatilis salaria* Reed, *W. naliensis* Reed, *theobaldi* (Waagen) (J), *U. jabiensis* (Waagen) (J), *Uncinuloides diffissa* Reed, *U. imitatrix* Reed, *U. postera* (Waagen) (J), U *Rhynchotetra*? *dubia* Reed, *R. mansuyi* Reed, L *R. tantillus* Reed, MU (?) *Pugnoides morahensis* (Waagen), *Rhynchopora relegata* Reed, *R. relegata variabilis* Reed, *R. nikitini* Chernyshev, *R. nikitini scorsa* Reed, U *R.* (?)*wynnei* Waagen, U *R.* (?)*complanata* Reed, *R. variabiis* Stuckenberg, MU *Stenoscisma purdoni* Davidson, U *S. mutabilis* Chernyshev, U *S. schlotheimi vagata* Reed, U *S. biplicata* Stuckenberg, U *S.* cf. *netschajewi* Chernyshev, U *S.* cf. *hofmanni* (Krotow), MU *S. humblentonesis* (Howse), U *S. superstes* (Verneuil) (J), U. *S. irregularis* Reed, MU *S. humbletonensis* (Howse), *S. pinguis* (Waagen), U *Septacamera* cf. *applanata* (Chernyshev), U. *S.* cf. *tanankouensis* (Ozaki), U *S.* cf. *thevenini* (Kozlowski), *Psilocamara sellapreacuta* (Reed), *Uncinella indica* Waagen, *Hustedia grandicosta* (Davidson), *H. grandicosta subcircularis* Reed, *H. grandicosta elongata* Reed, U *H. indica chittidilensis* Reed, U *H. indica interplicata* Reed, *H. rhynchospiroides* Reed, top of M or base of U—*Hustedia indica lineata* Reed, LM *H. indica*

(Waagen), U *H. sulcata* Reed, *Cleiothyridina ambigueformis* (Waagen), LU *C. interposita* Reed, MU *C. subexansa* (Waagen) (J), LMU (?)*C. globulina* (Waagen) (J), LMU *C. capillata* Waagen (J), U *C. capillata subcarinata* Reed, U *C. capillata pinguis* Reed, U *C. capillata triparta* Reed, U *C. capillata saecculus* Reed, U *C. capillata tenuis* Reed, LU *C. gerardi* Waagen (Diener), U *C. xetriformis* Reed, LMU *C. pectinifera* (Sowerby), *C. pectinifera venusta* Reed, U *C. dalmiriensis* Reed, LMU *C. simulans* Reed, MU *C. accola* Reed, U *C. saraiensis* Reed, *C.* cf. *bajtuganensis* Nechaev, U '*C. royssiana* (Keyserling),' LU *Composita grossula* Waagen (J), U *C.* (*or Araxathyris*) '*protea*' *complanata* Reed, U *C.* '*protea*' *parilis* Reed, U *C.* '*protea*' *subalata* Reed, MU *C.* '*protea*' *inflata* Reed, U *C.* '*protea*' *patula* Reed, U *C. indosinensis* Mansuy, U *C. globularis misriensis* Reed, *C. globularis crassa* Reed, L *C. globularis naruensis* Reed, LMU *Spirigerella derbyi* Waagen (J), U *S. derbyi subpentagonalis* Reed, *S. paraliensis* Reed, LMU *S. hybrida* Waagen, MU *S. media* Waagen, U *S. fusiformis* Waagen (J), LMU *S. ovoidalis* Waagen, MU *S. proxima* Reed, U *S. timorensis* (Rothpletz), *S. timorensis semisinuata* Reed, LU *S. grandis* Waagen (J), MU *S. grandis obesa* Grabau, U *S. gigas* Reed, U *S. obovata* Reed, *S. obovata selliformis* Reed, U *S. discorse* Reed, U *S. minuta* Waagen (J), U *S.* cf. *pertumida* Diener, U *S. praelonga* Waagen (J), U *S praelonga carinata* Reed, U *Spiriferella scopulosus* Reed, U *Elivina blanfordi* Reed, U *E. blasii semiovalis* Reed, *E. interplicatus bashkirica* (Chernyshev), LMU *Neospirifer moosakheylensis* (Davidson), U *N. moosakheylensis humilis* Reed, *U. warchensis scabrosa* Reed, U *N. sodalis* Reed, L U *N. cameratus externa* Reed, M *N. oldhamianus* (Waagen), U *N. trimuensis* Reed, M U *Choristitella internatus* Reed, MU *C. wynnei* waagen, U *Purdonella lunwalensis* Reed, MU *P. multiradiatus* Reed, U *P. limitaris* Reed, U *P. conformis* Reed, MU *Spiriferellina cristata commixta* Reed, U *S. bilotensis* Reed, *S. bilotensis curta* Reed, M U *S. nasuta* (Waagen), *S. panderi buriensis* Reed, MU *Calllspirina ornata* (Waagen) (J), *Mansuyella* cf. *holzapfeli* Chernyshev, MU *M.* cf. *margaritae Gemmelaro*, U *Reticulariina transindica* Reed, U *Paraspiriferina ghundiensis* Reed, MU *P. punjabensis* Reed, *U Mentzelia naliensis* Reed, *Phricodothyris asiatica* (Chao), U (?) *Permophricodothyris waageni subquadrata* (Reed), U (?)*P. nummulina* (Reed), U (?)*P. bilotensis* (Reed), (?)*P. attenuata* (Reed), (?)*P.* cf. *pulcherrima* (Gemmellaro), U (?)*P.* cf. *caroli* (Gemmellaro), U (?)*P.* cf. *frechi* (Renz), M (?)*P. elegantula* (Waagen), U (?)*P. indica* (Waagen), U (?)*P. inaequilateralis* (Reed), MU *Martinia semiplana* Waagen, U *M. warthi* Waagen, MU *M. elongata* Waagen, U *M. chidruensis* Waagen, U *M. rhomboidalis* Reed, U *M. acutomarginalis* Diener, *M. buriensis* Reed, U *M. uralica longa* Reed, *M.* (*Ella*) *blanfordi* Reed, U *Tomiopsis punjabica* (Reed), MU (?)*T. salaria* (Reed), U *Cryptacanthia indica* Reed, U *Dielasma bakhense* Reed, L *D. elongatum* Schlotheim, U *D. redux* Reed, L *D. plica* Kutorga, *D. plica arcuata* Reed, L *D. nexile* Reed, *D. truncatum misrikhanensis* Reed, *D. acutangulum subcuneata* Reed, LU *D. nummulus* Waagen, *D. sultanense* Reed, *D.* cf. *darvasicum* Chernyshev, U *D.* (?)*ovoidale* Reed, *D. guttula* Waagen, U *Whitspakia acutangulum* (Waagen), *W. biplex* (Waagen), *W. breviplicatum* (Waagen) (J), *W. acutangulum* (Waagen) (J), U *W. problematicum* (Davidson), *Hemiptychina truncata* Reed, *H. truncata banschangensis* Reed, *H. morrisi* Grabau, *H. patula* Reed, U *H.* (?) cf. *schellwieni* Gortani, U *H. crebriplicata* Waagen, U *H. sparsiplicata* Waagen, U *H. himalayensis mediosulcata* Reed, MU *H. himalayensis lata* Reed, *H. himalayensis obligata* Reed, *H. warchensis pyriformis* Reed, U *H. inflata* Waagen, U *H. amygdala* Reed, U *Dielasmina crassiplicata* Reed, U *D. gravida* Reed, U *D. globosa* Reed, U *D. peregrina* Reed, U *D. extensa* Reed, MU *D. plicata* (Waagen), *D. perovalis* Reed, *J Notothyris warthi* Waagen, LU *N. simplex* Waagen, U *N. subvesicularis* (Davidson), MU *N. Lenticularis* Waagen, top of M or base of U *N. daudensis* Reed, U *N. minuta* Waagen, U *N. multiplicata* Waagen, U *N. fissicostata* Reed, U *N. revocata* Reed, LU *N. simplex* Reed, U *N. vesicula* Waagen (J), MU *N. duplicata* Reed, U *N. buriensis* Reed, U *N. lucida* Reed, LMU *N. ghundiensis* Reed, LU *N. praelecta* Reed, *N. praelecta acuta* Reed, U *N. gojraensis* Reed, *N. warthi crassa* Reed, *N. inflata bisecta* Reed, L *N. lochardi oviformis* Reed, *N. inaequiplicata* Reed, *N. sarinensis* Reed, MU *N. djoulfensis* (Abich), *N.* (?)*riparia* Reed, U *N. warthi* Reed, U *N. revocata* Reed, U *N. duplicata* Reed, *Gefonia*? *emerita* (Reed), *G. bifrons* Reed, U *Heterelasma problematicum* (Davidson), U *H. biplex protracta* Reed, *H. biplex pumila* Reed, U *H. breviblicata* Reed, LU (?)*Beecheria pseudoelongata* Reed, U *B. hochstetteri discrepans* Reed.

Brachiopods from the lower and middle Chhidru Formation, Kufri Member, include :

Enteletes waageni Gemmellaro, *Enteletoides tenviplicatus* Reed, *Schizophoria juresanensis* Chernyshev, *Orthotichia sulcata* Reed, *Meekella* cf. *eximaeformis* Toulo, *Schuchertella asperulus* Reed, *Kiangsiella pectiniformis* Davidson (J), *Derbya hemispherica scutalis* Reed, *D. subsinuata* Reed, *D. grandis* Waagen (J), *D. regularis* Waagen, *D.* ('*Plicatoderbya*') *plicatella* (Waagen) (J), *Neochonetes squama* (Waagen), *Rugaria buriensis* Reed, *Lissochonetes* cf. *ambiensis* (Waagen), *Waagenites*? *morahensis* (Waagen), (?) *W. trapezoidalis* (Waagen), *Sulca-*

toria avicula (Waagen), *Sulcataria bipartita* Waagen, *Echinalosia linearis* (Reed), *E. salmunensis* (Reed),(?) *Chonostegoides blanfordi* (Reed), *Tschernyschewia vicinalis* Reed, *Waagenoconcha serialis* (Waagen) (J), *W. abichi* (Waagen) (J), *W. purdoni* Davidson, *W. paraliensis* Reed, *W. prolongata* Reed, *W. castrensis* Reed, *W. irginae aliena* Reed, *W. 'humboldti' silvana* (Stuckenberg) *W. 'humboldti' xenia* Reed, *W. 'humboldti' conjuncta* Reed, (?) *W. cylindricus* (Waagen) (J), *W. cylindricus discreta* Reed, *Chonetella nasuta* Waagen (J), (?) *Haydenella tumida* Waagen (J), *Transennatia gratiosa* (Waagen) (J), *Marginifera ornata* Waagen, *Spinomarginifera* (?) (*Echinauris*) *opuntia* Waagen (J), *Costiferina indicus* (Waagen) (J), *C. paucicostata* Reed, *C. aratus* (Waagen) (J), *C. subcostatus* (Waagen), *C. subvexa* Reed, (?) *Peniculauris* sp., Dictyoclostid, *Tyloplecta yangtzeensis adumbrata* (Reed), *T. yangtzeensis tumefacta* (Reed), *Dictyoclostid craticulatus defossa* Reed, (?) *Kutorginella genuinus* (Kutorga), *Linoproductus lineatus* (Waagen), (J) *L. lineatus sirrensis* Reed, *L. superba* Reed, *L. abrupta* Reed, *Leptodus nobilis* (Waagen), *Oldhamina decipiens* de Koninck, *Terebratuloidea pingus* Waagen, Rhynochonellid *wynnei* Waagen, *Uncinulinoides imitatrix* Reed, Rhynchopora *relegata* Reed, *Stenoscisma schlothemi vagata* Reed, *S. waageni* Nechaev, *S. irregularis* Reed, *S. purdoni* Davidson,? *Septacamera humbletonensis divisa* Reed, *S. mutabilis* Chernyshev, *S. cuneiformis* Reed, *Hustedia indica* Waagen, *Cleiothyridina subexpansa* (Waagen), *C. ambigueformis* (Waagen), *C. capillata* (Waagen), *C. pectinifera* (Sowerby), *C. pectinifera venusta* Reed, *C. capillata dalmiriensis* Reed, *C. gerardi* (Diener), *C. interposita* Reed, *C. warchensis* Reed, *C. accola* Reed, *C. grossula* Waagen,(?) '*Araxathyris protea*' *complanata* Reed, *Spirigerella derbyi* Waagen (J), *S. alata* Waagen, *S. media* Waagen, *S. hybrida* Waagen, *S. praelonga* Waagen (J), *S. proxima* Reed, *S. ovoidalis* Waagen, *S. timorensis* Rothpletz, *S. grandis* Waagen (J), *S. grandis elongata* Reed, *S. obovata* Reed, *S. derbyi* Waagen (J), *S. derbyi compressa* Reed, *S. praelonga* Waagen (J), *S. praelonga carniata* Reed, *S. paraliensis* Reed, *S. hybrida* Waagen, *S. fusiformis* Waagen (J), *Spiriferella scopulosus* Reed, *Elivina interplicatus* (Rothpletz), *E. blasii semiovalis* Reed, *Neospirifer moosakheylensis* (Davidson) (J), *N. scabrosa* Reed, *N. ravana plicatifera* Reed, *N.* cf. *dunbari* King, *N. ambiensis* (Waagen), *N. warchensis* Reed, *Choristitella internatus* Reed, *Purdonella limitaris* Reed, *P. conformis* Reed, Spiriferinid *vercherei* Waagen, *Spiriferellina panderi buriensis* Reed, *Mansuyella* cf. *margaritae* (Gemmellaro), (?)*Permophricodothyris indica* (Waagen), (?) *P. spatulata* Reed, (?) *P inaequilateralise* Gennellaro, *Martinia warthi* Waagen, *M. semiplana* Waagen, *M. chidruensis* Waagen (J), *M. elongata* Waagen, *Martinia acutomarginalis crenata* Reed, *M. subrhomboidalis* Reed, *M.* cf. *kraffti* Bittner, *Ella simensis substricta* Reed, *Ella blanfordi* Reed, *Fredericksia khurensis* Reed, *Martiniopsis inflata* Waagen, *Cryptacanthia indica* Reed, *C. indicalata* Reed, *C. Whitspakia acutangulum* (Waagen) (J), *W. breviplicatum* (Waagen) (J), *Hemiptychina sparsiplicata intermedia* Reed, *H. himalayensis lata* Reed, *H. truncata elongata* Reed, L *H. inflata* Waagen, *Dielasmina plicata* Waagen, *Notothyris buriensis* Reed, *N. praelecto* Reed, *N. warthi crassa* Reed (J), *N. revocata* Reed, *N. multiplicata* Waagen.

Species from the topmost or Ganjaroh Member are listed by Waagen (1891). A few species are found in older faunas. The following brachiopods are present : *Streptorhynchus distortus* Waagen, *Marginifera ornata* Waagen, *Cleiothyridina subexpansa* (Waagen), '*Spiriferina*' *subornata* Waagen, *Neospirifer ambiensis* (Waagen). Mollusca are more common and secure correlation with the Popa Member of Nepal and the north Karakorum faunas of Merla (1934), which also share brachiopod species with Iran and the Caucasus Mountains. Mollusca include :

'*Nuculina*' *subacuta* Waagen, *Nucula ventricosa* Hall, *N. trivalis* Eichwaldt, *Dolabra corbina* Waagen, *Lithodomina typa* Waagen, *L. abbreviata* Waagen, *Lithodomus atavus* Waagen, *Mytilus patriarchalis* Waagen, *Avicula chidruensis* Waagen, *Lima footei* Waagen, *Aviculopecten subexoticus* Waagen, *Pecten praecox* Waagen, *Euchondria subpusilla* Waagen, *Pleurophorina complanata* (Waagen), *P. acuteplicatus* Waagen, *Cleidophorus striatulus* Waagen, *Allorisma perelegans* Waagen, *Lucina* (?) *progenitrix* Waagen, *L.* (?) *bombifrons* Waagen, *Gouldia*(?) *primaeva* Waagen, *Astarte*(?) *ambiensis* Waagen, *M. praecox* Waagen, *Schizodus cardissa* (Waagen), *S. pinguis* Waagen, *S. rotundatus* Brown? (?=*Schizodus emarginatus* Reed), *Pseudomonotis inversa* Waagen, *P. radialis* Phillips, *Euomphalus pusillus* Waagen, *Bellerophon blanfordianus* Waagen, *B. jonesianus* Koninck, *B. orientalis* Waagen, *Warthia polita* Waagen, *Bucania angustifasciata* Waagen, *B. integra* Waagen, *B. ornatissima* Waagen, *Sphaeriola arandaeva* Waagen, *Euphemus indicus* Waagen, *E. laevis* Waagen, *E. apertus* Waagen, *E. pusillus* Waagen, *Baylea*(?) *durga* Waagen, *B. sequens* Waagen, Pleurotomariid *punjabica* Waagen, *Murchisonia* (*Goniasma*) *conjungens* Waagen, *Neritomopsis minuta* Waagen, *Phasianella hirenicola* Waagen, *Margarita prisca* Waagen, *Holpolella trimorpha* Waagen, *Temnocheilus multituberculatus* (Waagen).

Reed (1944) does not provide sufficient detail to allow us to decipher if any of his Upper Productus Limestone lists come from the Ganjaroh Member. Clearly much needs to be done to ascertain the full list. Also close scrutiny is needed of the Mollusca, to establish modern generic determinations.

From the Landa Sandstone Member, the following species are found :

Enteletes granti Waterhouse and Gupta, *Enteletes* sp., *Orthotichia minuta* (Abich), *Orthotichia* sp., *Orthothetina* sp., *Kiangsiella* sp., *Derbyia postplicatella* Waterhouse and Gupta, Chonetid gen. and sp. indet., *Aulosteges* sp., (?)*Megasteges* sp., *Chonetella* sp., *Richthofenia* sp., *Waagenoconcha* sp., *Linoproductus periovalis* Waterhouse and Gupta, *Lyttonia* sp., *Hustedia* sp., *Spirigerella* sp., *Cleiothyridina* cf. *capillata* (Waagen), *Neospirifer* sp., *Spiriferella* sp., *Callispirina* sp., *Martinia* sp., *Hemiptychina* sp., *Whitspakia* spp, Dielasmatid gen. and sp. indet.

A Faunule from the *Lamnimargus himalayensis* Zone in the Upper Shyok Valley, Southern Karakorum Range

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ABSTRACT

A small brachiopod faunule, and a conulariid and bivalve are described from the Upper Shyok valley, south Karakorum Range. New species are described as *Paraconularia elegans*, *Svalbardia quadrata*, *Strophalosia diadema*, *Punctocyrtella vagrans* and *Pachymyonia prolonga*, and *Fusispirifer marcouiformis* Jin, 1976 is referred to a new genus *Transversaria*. Eight of the fourteen species are found in the *Lamnimargus himalayensis* Zone of the Himalayas, two species in the Punjabian of the Salt Range, and one in correlative beds at Chitichun no. 1 in southern Tibet, and the fauna is considered to be of Punjabian age. Provincial affinities are strongly with the Himalayan faunas, and the affinities with correlative faunas of Armenia and Iran are not very marked. However, a faunal list of brachiopods from nearby beds in the Shyok valley suggests closer links with the Chitichun no. 1 and Malla Sangcha faunas of south Tibet.

INTRODUCTION

THE PRESENT paper describes part of a small faunule collected from the dark metamorphosed silty shales of the Saser Brangsa-Margo areas in the upper Shyok valley in the Karakorum region of Ladakh. For details of the geology of the area reference may be made to the paper by Bhandari *et al.* (1982) published in this volume.

Repository and Note on Collection

The specimens are housed at the Centre of Advanced Study in Geology, Panjab University, Chandigarh. The collection is not a large one, and consists of shelly material, with some natural moulds, mostly in black micaceous somewhat metamorphosed siltstone. A few specimens of *Lamnimargus*, *Anidanthus* and *Spiriferella* are found in brown siltstone with a slight greenish hue, possibly from either a different matrix or more weathered material. In addition to the material described, crinoid stems are prominent, and two pectinid bivalves are present.

Systematic Descriptions

Phylum Coelenterata
Genus *Paraconularia* Sinclair, 1948
Paraconularia elegans n. sp.
Pl. 1, figs. 1, 3.

(?) 1899 *Conularia tenuistriata* not M'Coy, Diener (1899, p. 18, pl. 7, fig. 6).
Holotype. Specimen figured in pl. 1, fig. 3.
Diagnosis. Slender specimens with fine costae, numbering 7 in 5 mm.
Present material. Over 20 specimens.

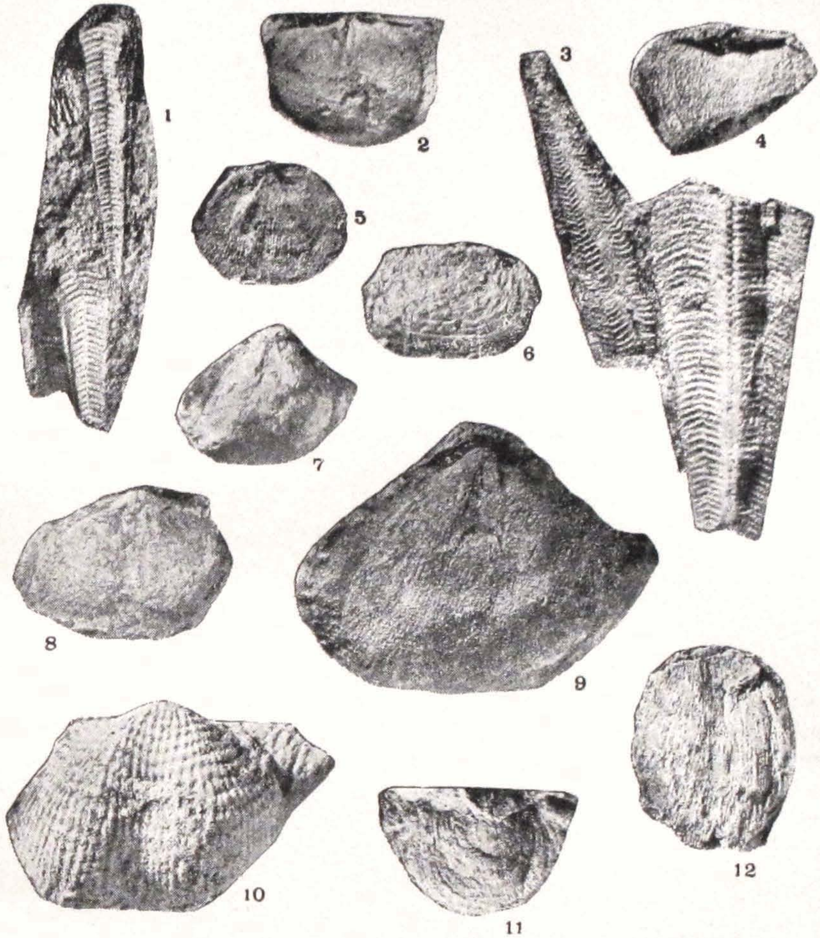

Plate 1. 1, 3, *Paraconularia elegans* n. sp. × 2, holotype is specimen to right on fig. 3. 2, 4, 5, *Svalbardia quadrata* n. sp., × 2. 2, internal mould, ventral valve. 4, Holotype, external mould, dorsal valve with posterior of ventral valve. 5, Rubber latex cast of dorsal interior. 6-9, *Strophalosia diadema* n. sp. 6, Holotype, dorsal external mould, × 1. 7, 9, Ventral internal mould, before and after leaching in acid, × 1, × 2. 8, Ventral valve with decorticated shell. × 1. 10, *Lamnimargus himalayensis* (Diener), ventral aspect, x 2. 11, 12, (?)*Cancrinella* sp. posterior and anterior fragments of internal moulds of ventral valves, × 2.

Description. Specimens up to 50 mm in length, and face up to 8 mm across at aperture; faces of equal size, and arranged in rhomb, 80° for narrower angle and 100° for wider angle. Apical angle about 14°. Face varies from almost flat to gently concave, to moderately concave near aperture in larger specimens, with degree of distortion not certain. Ribs even in spacing over faces, about 7 in 5 mm near base and 6-7 in 5 mm near aperture, arching aperturally over face, in some specimens offset along mid-line, and may be disrupted by narrow groove. Costae inflected aperturally across corner groove, without swelling and generally continuous, not disrupted; corner grooves moderately narrow. Small pustules appear to cover the exterior, 2-3 over each interspace vertically; no intercostal ribs or tubercles visible.

Resemblances. These specimens appear to be very close to a species recorded by Diener (1899, pl. 7, fig. 6) from quartz sandstone of Ladakh, with identical shape and ribs. The cross-section in Diener (1899, pl. 7, fig. 6*b*) accurately shows that faces are of subequal width, but has exaggerated the concavity of each face, judged from inspection of the material by J. B. W. in 1980. Diener also shows some ribs alternating across the corner grooves, unlike the arrangement in present specimens, and J. B. W. also noted presence of weak tubercles. Unlike present specimens, possible interrib flutings were present, so that identity is not completely established.

Diener (1899) compared his material to *Conu'aria tenuistriata* M'Coy (1847, p. 307, pl. 17, figs. 7, 8) from sandstone at Muree, Hunter Valley, New South Wales. Unlike present specimens M'Coy stated that sides or faces were of unequal width, and the ribs are very fine. A ridge passes along the corner groove, as in *Notoconularia* Thomas. and M'Coy's species was referred to that genus by Thomas (1969).

Paraconularia ornata Waterhouse (1980) from the *Plekonella multicostata* Zone of upper Punjabian age in New Zealand is of comparable age, but has a more flaring outline and more fluted, ornamented faces. *Conularia laskeri* Sahni and Srivastava (1956, pl. 36, figs. 9-11) from a Sakmarian fauna in Sikkim has costae numbering 8-9 in 5 mm according to Sahni and Srivastava (1956), although their figure suggests there are only 4-5 in 5 mm. Faces are of subequal length, and the specimens widen at a greater angle than in present material.

Discussion. The present collection contains two examples of two specimens lying side by side in juxtaposition, with possibly opposite base, as if they had grown together in small clumps. Two specimens are of subequal size, like the example found in the New Zealand Permian (Waterhouse, 1980), and in the other case one specimen is large and the other small.

Phylum Brachiopoda

Genus *Svalbardia* Barchatova, 1970

Type species. *Chonetes capitolinus* Toula, 1875.

Diagnosis. Shells with non-capillate spinose exterior, shallow ventral sulcus and low or no dorsal fold, dorsal valve very gently concave, both valves thick. See Afanasjeva (1977).

Discussion. The genus *Svalbardia* has recently been discussed by Archbold (1981). He does contribute to our understanding of the genus, but misconstrues its attributes over several vital features in suggesting that the genus might be related to and perhaps a senior synonym of *Capillonia* (Waterhouse, 1973). *Capillonia* is completely different. It shares a number of features in common, including a smooth ventral exterior, and Archbold (1981) argued that the dorsal valve is smooth, not finely capillate as assessed by Waterhouse (1973). Whatever the ornament of *Capillonia*, the type species is readily distinguished from *Svalbardia*, because its dorsal valve is deeply concave, and thin, not gently concave to flat, and somewhat thickened, as in *Svalbardia*. Furthermore, the exterior of *Svalbardia* is flecked by numerous fine close-set spines and bases. The exterior of *Capillonia* lacks these spines and bases. The two genera are not identical. *Capillonia* is much more closely related to *Lissochonetes*, and *Leurosina*. Even the overall shape shows this,—like a half-moon, in contrast to the crudely rectangular or subquadrate outline of *Svalbardia*.

Svalbardia quadrata n. sp.

Pl. 1, figs. 2, 4. 5; pl. 3. fig. 1.

Holotype. Specimen figured in pl. 1, fig 4.

Diagnosis. Small shells with subquadrate outline.

Material. About 33 ventral valves, 7 dorsal valves and 7 specimens with valves conjoined.

Description. Shells small, complete ventral valve measuring 16.5 mm wide, 12.5 mm long and 4.5 mm high; hinge wide with small subalate ears at maximum width; area almost in plane of commissure, very shallow ventral median sulcus with sinal angle close to 22°; dorsal valve very gently concave with scarcely any fold, shell surface apparently smooth, apart from low concentric ornament on both valves, shell thick. Hinge and body spines not known.

Ventral median septum short, high, with two large teeth, low broad ridges pass forward each side for most of length of shell; adductor scars tiny, weakly raised, diductor scars faintly impressed; low marginal ridges encircle valve, well-developed across ears, low pustules most prominent outside and just within ridge.

Dorsal cardinal process broad, bilobed; median septum low, raised for short distance near mid-length; dental sockets deep, enclosed by low ridge that emerges laterally from cardinal process and passes along hinge, stopping before ears.

Resemblances. *Svalbardia capitolinus* Toula (see Afasnasjeva, 1977) comes from early mid-Permian faunas of the Arctic, in the Brachiopod Chert and Spirifer Limestone of Spitsbergen, Assistance Formation of Ellesmere Island, Vorkut Suite of Pai Hoi, and Talatin Suite of Petchora Basin. It is close to the present species but has a narrow ventral sulcus and slightly more rectangular outline.

Afanasjeva (1977; p. 29) mentioned *Paeckelmannia toulai* Dunbar (1955) from Greenland as being related to

Svalbardia, but *toulai* is a more transverse shell with more deeply concave dorsal valve, and dorsal capillae, and Waterhouse (1973) referred it to *Capillonia*.

Paramesolobus lissarensis (Diener, 1897*b*) from the Productus Shales of Himalayas, Zewan beds of Kashmir, and Nangung Formation of Nepal is close in general appearance but has a more concave dorsal valve and less thickened shell, with a narrow fold along the ventral sulcus (see Waterhouse, 1978: 25).

Svalbardia thomasi Archbold (1981) from the Nalbia and Baker beds of the Carnarvon Basin, Western Australia, is small with rounded cardinal extremities and is rarely feebly sulcate. It is of early Kungurian and perhaps late Baigendzian age.

Genus *Strophalosia* King, 1846

Strophalosia diadema n. sp.

Pl. 1, figs. 6-9; pl. 3, figs. 2-4.

Holotype. Specimen figured in pl. 1, fig. 6; pl. 3 fig. 2.

Diagnosis. Moderately large and inflated shells with low ventral interarea, ventral spines of fine and coarse diameter.

Material. Four ventral valves and dorsal valve.

Description. Ventral valve of moderate size, one measuring 36 mm wide, 26 mm long and 13 mm high, moderately inflated, with low ventral interarea lying in plane of commissure, and shallow median sulcus or median flattening for much of shell length. Spines rather coarse and unevenly scattered, in concentric rows, erect spines up to 1.2 mm wide anteriorly, and narrower spines 0.5 to 0.6 mm in diameter over much of shell, a number inclined at about 30° from the surface.

Dorsal disc gently concave, with prominent growth lamellae, somewhat irregular and forming a few whorls, but without spines. Trail probably geniculate.

Teeth narrow, widely diverging, ventral adductors elongate, smooth, divided by median groove, diductors moderately impressed; low marginal ridge passes around valve, spine bases open anteriorly into interior. Dorsal interior not known.

Resemblances. *Strophalosia gerardi* King, 1850 comes from Ladakh and is comparable in size and outline. The holotype of *S. gerardi* has a steeper posterior wall, but this has been deformed, and no sulcus is present. Spines are as coarse as anterior spines on the present species, but less closely spaced, and posterior spines on *S. gerardi* are coarser than those on present material. The dorsal valve is more concave posteriorly in *S. gerardi*, and less geniculate. Of other strophalosiid species found in the younger Permian of the Himalayas, *Echinalosia indica* (Waagen) or allied shells (see Waterhouse, 1978) is smaller, with arched disc lacking a sulcus, and differentiated ventral spines, and well-developed dorsal spines. *Marginalosia kalikotei* (Waterhouse, 1975, 1978) is comparable in size to present specimens and may be sulcate and shows other similarities, but the ventral spines are fine. Dorsal spines are present in the genus *Marginalosia*. *Wyndhamia circularis* Zhang in Zhang and Ching (1976) from the Jilong Group of Jilong country, Tibet, is a somewhat larger shell with faint sulcus, and more densely spinose ventral valve.

Genus *Lamnimargus* Waterhouse, 1975

Lamnimargus himalayensis (Diener, 1899)

Pl. 1, fig. 10, pl. 3, fig. 5.

1899 *Marginifera himalayensis* Diener (1899, p. 39, pl. 2, figs. 1-7; pl. 4, figs. 1, 2).

1979*a* *Lamnimargus himalayensis* Gupta and Waterhouse (1979*a*, pp. 8, 15; pl. 1, figs. 3-8; pl. 3, fig. 6). (See for synonymy, typology and diagnosis).

Present material. Three ventral valves (two possibly with dorsal valve conjoined), and seven specimens with valves conjoined.

Discussion. One specimen shows the ventral interior well, with smooth large adductor scars and deeply scored diductor scars. Marginal ridge wide along posterior hinge, low in front.

The species has also been reported from Tibet by Jin (= Ching) in Zhang and Ching (1976), from Tidong Valley, Kinnaur, by Gupta and Waterhouse (1981) and from Bhutan by Gupta and Waterhouse (1979*b*). We must refute the very significant misidentification of the species from the upper Zewan Formation, Kashmir, in Fauna IV, member E, by Nakazawa *et al.* (1975). These Kashmir specimens, examined at the Geological Survey of India, Calcutta, by J. B. W., belong in fact to *Transennatia* Waterhouse, 1975, and resemble *T. pitakpaivani* Waterhouse from the Huai Tak fauna of north Thailand, and *Transennatia* sp. of Waterhouse (1978) from Luri Member, Senja Formation, in northern Nepal. All are probably of Vedian age, a substage meagrely represented in Kashmir.

Genus *Cancrinella* Frederiks, 1928

(?)*Cancrinella* sp.

Pl. 1, figs. 11, 12.

Present material. At least 20 ventral valves and 1-2 dorsal valves.

Description. Shells small and well-arched, with low wrinkles and numerous fine costellae, numbering 12-15 in 5 mm, ventral spine bases 1.5 mm long, tapered. Not known if dorsal spines absent, and if ventral adductors were dendritic : the specimens thus might be *Terrakea.*

Genus *Anidanthus* Waterhouse, 1928

Anidanthus fusiformis Waterhouse, 1966

1966 *Anidanthus fusiformis* Waterhouse (1966, p. 21, pl. 4, figs. 1, 4, 5; pl. 8, fig. 3).

1979*a* *A. fusiformis* Gupta and Waterhouse (1979*a*, p. 9, pl. 1, fig. 9). (See for synonymy, typology and diagnosis.)

Present material. Four fragmentary ventral valves.

Description. The ventral valve is probably transverse, and well-inflated with umbonal angle ranging from 90° to 110°; disc without a sulcus, and with costae numbering 9 in 5 mm anteriorly near the mid-line. A few spine bases lie over the disc. Ventral muscle scars are visible.

Discussion. *Anidanthus fusiformis* is found in the *Lamnimargus himalayensis* and *Marginalosia kalikotei* Zones of the Himalayas (see Gupta and Waterhouse, 1979*a*; 9). The species has also been recorded from Bhutan and from the Kinnaur district by Gupta and Waterhouse (1979*b*, 1981).

Genus *Punctocyrtella* Plodowski, 1968

Punctocyrtella vagrans n. sp.

Pl. 2, figs. 3-5.

Holotype. Specimen figured in pl. 2, figs. 4, 5.

Diagnosis. Transverse shells with about 20 pairs of plicae. Broad ill-defined sulcus.

Present material. A ventral and dorsal valve.

Description. Ventral valve moderately large with 9 pairs of plicae and perhaps many more, and wide sulcus with angle of 20°; inner pair of plicae lies within sulcus, striate, diductor scars also visible. Dorsal valve 47 mm wide, 20 mm long and 4 mm high, subalate and transverse with some 20 pairs of plicae, and low broad smooth fold, micro-ornament of fine spines with low grooves in front.

Resemblances. The specimens have more plicae than in (?)*Punctocyrtella plodowskii* Waterhouse (1978) from the late Permian Senja Formation of Nepal, and so come close to the early Permian forms *P. spinosa* Plodowski (1968, 1970) from Afghanistan with 21-25 plicae, and more sharply defined sulcus. *Spirifer nagmargensis* Bion in Bion and Middlemiss (1928) from Kashmir which was assigned to *Punctocyrtella* by Plodowski (1970) comes closer in its plicae, but has a median groove in the dorsal fold, and should be compared to *Subansiria* Sahni and Srivastava, 1956. *Subansiria* has also been recorded from east Australia but the Australian species have ornament of fine spines and grooves, whereas *Subansiria* appears to lack surface spines.

The species called *Syringothyris cuspidata* Martin by Diener (1899, pl. 4, figs. 9,10) from black crinoidal limestone of Kuling, Spiti, is somewhat similar in dorsal aspect, with a few more plicae, and ventral plicae are numerous and sulcus sharply bordered.

Genus *Pteroplecta* Waterhouse, 1978

Pteroplecta sp.

Fragments of two ventral valves are present, with characteristic paucicostate plicae and well-defined growth lamellae. The genus was first described from faunas of the Late Permian Senja Formation in Nepal, and includes *Spirifer joharensis* Diener from the Productus Shales of the Himalayas, as well as possible species from the Amb Formation of the Salt Range, Pakistan.

Genus *Spiriferella* Chernyshev, 1902

Spiriferella rajah (Salter, 1865)

Pl. 2, figs. 1, 2.

1865 *Spirifer rajah* Salter (1865, p. 59 (with two figures), 111.

1979*a* *Spiriferella rajah* (Salter), Gupta and Waterhouse (1979*a*, pp. 11, 16; pl. 1, figs. 10-14; pl. 2, figs. 1-10; pl. 3, figs. 1, 9-10). (See for synonymy, typology and diagnosis).

Present material. Three ventral valves.

Discussion. The species has also been listed from Bhutan by Gupta and Waterhouse (1979 : 255) and Kinnaur by Gupta and Waterhouse (1980 : 346).

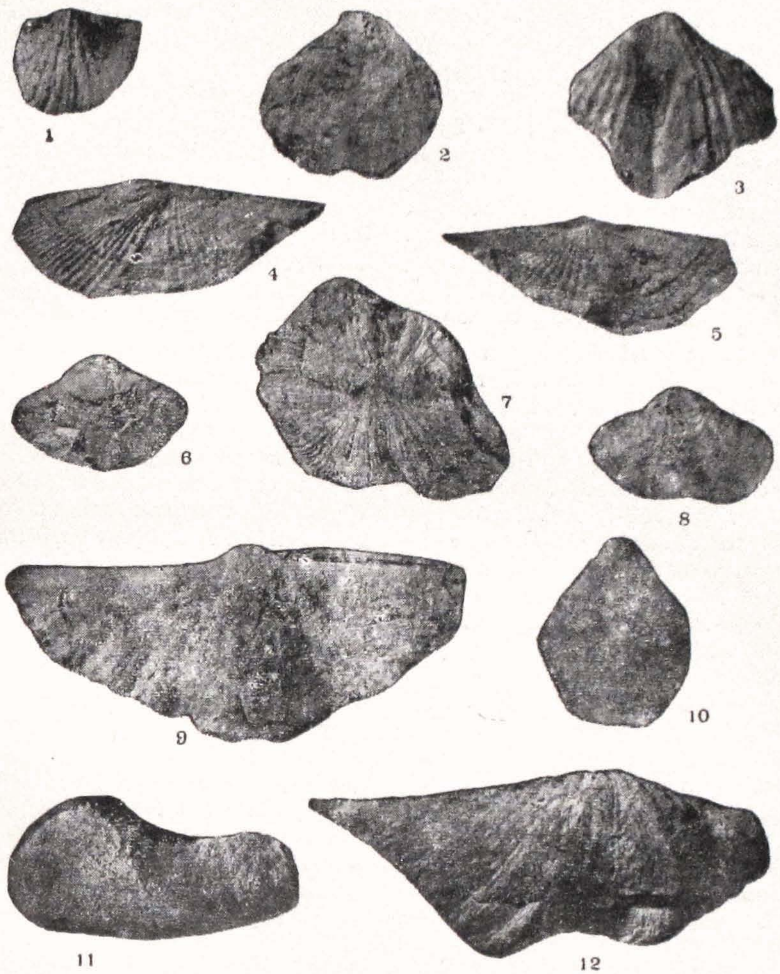

Plate 2. 1, 2, *Spiriferella rajah* (Salter), ventral valves, × 2. 3-5, *Punctocyrtella vagrans* n. sp. × 1. 3, Ventral internal mould. 4, 5. Holotype, external mould and rubber latex cast of dorsal valve. 6, 8, *Tomiopsis* cf. *himalayanicus* Waterhouse, dorsal and ventral aspects, × 1. 7. *Neospirifer ambiensis* (Waagen), dorsal valve on top, × 1. 9, 12, *Fusispirifer nitiensis* (Diener) × 1. 9, Dorsal internal mould. 12, Partly decortciated ventral valve. 10, (?)*Dielasma biplex* Waagen, ventral valve, × 1. 11. *Pachymyonia prolonga* n. sp., holotype, left aspect, × 1.

Genus *Neospirifer* Frederiks, 1919

Neospirifer ambiensis (Waagen, 1883)

Pl. 2, fig. 7.

1883 *Spirifer ambiensis* Waagen (1893, p. 515, pl. 48, figs. 1a-e.

1978 *Neospirifer* cf. *ambiensis* Waterhouse (1978, p. 4, pl. 4, figs. 8-16; pl. 26, figs. 8, 9). (See for synonymy, typology and diagnosis).

1979a *N.* cf. *ambiensis* Waterhouse and Gupta (1979a, p. 31, pl. 5, figs. 8, 9).

Present material. A specimen with valves conjoined, splayed apart.

Discussion. Ribs are fine and numerous in this specimen, with rounded crests in front of slightly raised ridges posteriorly. Waterhouse (1978) suggested that Himalayan specimens belong to *N. ambiensis*, and although final certainty is lacking we propose to accept full identification. The present specimen appears close to the holotype, and to the specimen figured from the Nangung Formation in Nepal figured in Waterhouse (1978, pl. 4, fig. 9, 10).

Genus *Fusispirifer* Waterhouse, 1966

Fusispirifer nitiensis (Diener, 1897*b*)

Pl. 2, figs. 9, 12.

1897*b* *Spirifer nitiensis* Diener (1897*b*, p. 41, pl. 4. figs. 4, 5*a-c*).

1897*b* *Spirifer moosakhailensis* not Davidson; Diener (1897*b*, p. 35, pl. 5, fig. 1—part, not pl. 3, figs. 3-4; not pl. 4, figs. 1-2).

1899 *Spirifer* cf. *nitiensis* Diener (1899, p. 65, p. 5, fig.9).

1903 *Spirifer nitiensis* Diener (1903, p. 106, pl. 4, fig. 6*a*, *b*; 7*a*, *b*).

1966 *Fusispirifer nitiensis* Waterhouse (1966 : 44). (See synonymy, typology and diagnosis).

1973 *Fusispirifer nitiensis* Mu *et al.* (1973, pl. 3, fig. 7).

Present material. Four ventral valves, two dorsal valves and four specimens with valves conjoined.

Discussion. These specimens have the strong plicae typical of the species. As Jin (Ching), in Zhang and Ching (1976) pointed out, other specimens from Nepal recorded by Waterhouse (1966) include forms with low plicae, and they are referred by Jin (Ching) *ibid.*, p. 209) to *F. nitiensis semiplicata* Jin. The same is true of Senja specimens from Nepal figured by Waterhouse (1978). According to Jin (Ching) *Fusispirifer nitiensis semiplicata* is found in the *Callitomarginatia* assemblage of Tibet and thought to be slightly younger than the *Taeniothaerus* assemblage, which is clearly part of the *Lamnimargus himalayensis* Zone of Waterhouse and Gupta (1977, 1981). Unlike the sequences in Nepal and Kashmir, the succession in Tibet appears to be scattered and the assemblages are not found in sequence. It would appear from the Nepalese succession that *Fusispirifer semiplicata* is of late Permian age, as it occurs in the Senja Formation in Nepal.

Transversaria n. gen

Type species. *Fusispirifer marcouiformis* Ching (= Jin) in Zhang and Ching (1976).

Diagnosis. Very transverse spiriferids, related to *Spirifer* and possibly to *Fusispirifer* and *Neospirifer* but lacks plicae, finely costate.

Discussion. This species has been described by Jin from the *Taeniothaerus* assemblage in the Shilong Group, Naxi Nielamu County, Naxing area, Tibet. It differs from *Fusispirifer* in the lack of plicae.

Transversaria marcouiformis (Jin, 1976)

1976 *Fusispirifer marcouiformis* Jin, in Zhang and Ching (1976, p. 209, pl. 12, figs. 9-11; pl. 13, figs. 1, 2, 21-23).

1966 *Neospirifer* sp. Yang Zun-yi (*Report of Scientific Exploration of Xi Xia bang ma feng* 1966, 3, p. 137, pl. 2, figs. 3, 4 (M 9).

Lectotype. Specimen figured in Zhang and Ching (1976, pl. 13, figs. 1, 2, 21, 22), here designated.

Description. We provide a translation from the original text. "Shell large, very transversely elongate, width reaches 170 mm; ventral valve strongly convex; sulcus narrow with an apical angle of about 20°; dorsal valve flat, and low.

Costae fine and uniform in size; flat and low, about 9 in 10 mm, interspaces narrow. When outer layer striped fine striae are seen; these are 4-5 in 1 mm; no plication.

Interior of ventral valve with high, short dental plates which are thick at basic part; full of callosity inside the visceral cavity; muscle scars inserted into the shell layers with fine long median ridge.

Comparison. According to its transversely elongate outline, narrow sinus etc. this species is indicated to *Fusispirifer*; it resembles "*Spirifer*" *marcoui* Waagen by its fine and uniform costae, narrow interspaces and no plication and differs from *Fusispirifer*; therefore, it represents a new species.

Locality and horizon. Din r. country Re-ju Xiang Su-re shan, Permian shilong group. Nielamu country Tulong-Nienie Xiongla.

(The preceding text was kindly translated for us from the original by Mr. Liu Fa, Changchun College of Geology, China.)

Genus *Tomiopsis* Benedictova, 1956

Tomiopsis cf. *himalayanicus* Waterhouse, 1978

pl. 2, figs. 6, 8.

cf. 1903 *Spirifer distefanii* not Gemmellaro, Diener (1903, p. 189, pl. 9, figs. 2-4).

cf. 1978 *Tomiopsis* cf. *himalayanicus* Waterhouse (1978, p. 58, pl. 6, fig. 22). (See for synonymy, typology, and diagnosis.)

Present material. Specimen with valves conjoined.

Description. Specimen small, 36 mm wide, 22 mm long and 18 mm high (both valves), transverse, moderately inflated, with incurved ventral umbo, angle measuring 110°, broad sulcus, sinal angle measuring 35°, with broad gently concave floor, and low fold with gently rounded crest, four pair of low plicae on each valve. Ventral adminicula extend for about one third of the length of the valve, well-spaced.

Resemblances. This specimen is close to ***Tomiopsis himalayanicus*** Waterhouse, though not exactly identical, having a different number of plicae from the type specimen. So far only a few specimens of this species are known, from the two localities near the Po Valley in Spiti recorded in Diener (1903) and from the Pija Member of the Senja Formation in Nepal (Waterhouse, 1978). All vary somewhat, so that it is difficult to ascertain if we have several species, poorly represented, or one somewhat variable species.

Genus *Dielasma* King, 1859
(?)*Dielasma biplex* Waagen, 1882
pl. 2, fig. 10.

1882 *Dielasma biplex* Waagen (1882, p. 249, pl. 25, figs. 3-5).

1897*a* *D. biplex* Diener (1897*a*, p. 74, pl. 11, figs. ?5, 6-7).

1911 *D. biplex* Diener (1911, p. 38, pl. 5, fig. 25).

1915 *D. biplex* Diener (1915, p. 98, pl. 10, figs. 10-11).

1928 *D. biplex* Hamlet (1928, p. 69, pl. 10, figs. 15-16).

Lectotype. Specimen figured by Waagen (1882, pl. 25, figs. 5*a-d*), here designated.

Diagnosis. Moderately large shells with rhomboidal outline, and shallow anterior sulcus, feebly defined, with low median swelling, and very low bordering plicae.

Present material. A ventral valve.

Description. A large ventral valve 39 mm long, 31 mm wide and 15 mm high with a shallow anterior sulcus, bordered by low anterior plicae and with a very low median plication. Dental plates high.

Resemblances. This specimen is close in general shape and size to (?) *Dielasma biplex* Waagen, especially specimens from Chitichun no. 1, south Tibet, figured by Diener (1897*a*). The median fold in the very shallow and poorly defined sulcus and lateral plicae are low and broad. The species is wide-ranging and short-lived apparently, having been reported from the Wargal Formation, Salt Range; Chitichun no. 1, and Productus Shales at Mandakpal, Kashmir, and Basleo beds of Timor (Hamlet, 1928). Specimens vary, but no more than the range exhibited by Dielasmatid species analysed by Campbell (1965). However, individuals from the Shan States, described by Diener (1911), though somewhat similar, are narrower than other specimens and so are tentatively excluded from synonymy.

The generic position is not established. Campbell (1965) showed that shells of somewhat similar shape occurred in three genera, *Fletcherithyris*, *Hoskingia* and *Gilledia*. In shape, *biplex* is closest to *Fletcherithyris*, and perhaps it belongs to *Dielasma*, a closely related genus.

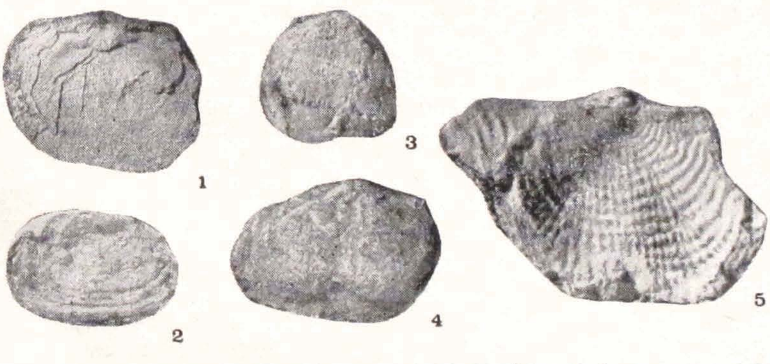

Plate 3. **1**, *Svalbardia quadrata* n. sp. decorticated dorsal interior, × 2. **2-4**, *Strophalosia diadema* n. sp, × 1. **2**, Rubber latex cast of dorsal exterior (see also pl. 1, fig. 6), holotype. **3**, Rubber latex cast of ventral exterior, showing some spines. **4**, Decorticated ventral valve. **5**, *Lamnimargus himalayensis* (Diener), dorsal view of specimen with valves conjoined, figured in pl. 1, fig. 10, × 2.

Phylum Mollusca
Class Bivalvia
Family Edmondiidae King, 1850
Genus *Pachymyonia* Dun, 1932
Pachymyonia prolonga n. sp.
Pl. 2, fig. 11.

Holotype. Specimen figured in pl. 2, fig. 11.

Diagnosis. Species characterized by elongate posterior part of shell.

Material. One specimen with valves conjoined.

Description. Specimen small for genus, but probably mature, measuring 58 mm in length, 28 mm in height, both valves 26 mm wide. Umbones orthogyrous, incurved, broad with angle of 130°, placed 14 mm from anterior margin. Anterior dorsal margin well-rounded in outline, without lunule dorsally, ventral margin curved, and lateral flanks broad with low median broad ridge and shallow depression each side; umbonal ridge strongly defined, concave dorsally in outline except at umbo, posterior dorsal face wide, narrow posterior gape. Ornament of well-defined ridges of uneven strength, with a few larger wrinkles, and fine growth lines; posterior dorsal face marked only by growth lines.

Resemblances. Species from Early and Middle Permian deposits of Australia and New Zealand, as reviewed by Waterhouse (1969; 32n), are all higher less elongated snells, and so readily distinguished from the present species.

Correlation

The following species have been described from the micac ous dark beds of Shyok valley:

**Paraconularia elegans* n. sp.
Svalbardia quadrata n. sp.
Strophalosia diadema n. sp.
**Lamnimargus himalayensis* (Diener)
?*Cancrinella* sp.
**Anidanthus fusiformis* Waterhouse
Punctocyrtella vagrans n. sp.
Pteroplecta sp.
**Spiriferella rajah* (Salter)
**Neospirifer ambiensis* (Waagen)
**Fusispirifer nitiensis* (Diener)
**Tomiopsis* cf. *himalayanicus* Waterhouse
*(?)*Dielasma biplex* Waagen
Pachymyonia prolonga n. sp.

Asterisked species are found also in the *Lamnimargus himalayensis* Zone of the Himalayas.

Of these fourteen species, eight are found also in the *Lamnimargus himalayensis* Zone in the Himalayas, in various formations, as reviewed by Waterhouse and Gupta (1977), and indeed eight of the twelve named species are shared with Himalayan faunas. *Neospirifer ambiensis* (Waagen) is also found in the Chhidru Formation and (?) *Dielasma biplex* Waagen in the Wargal Formation of the Salt Range. The *Lamnimargus himalayensis* fauna is believed to be of Punjabian age as defined by Waterhouse (1976) and elaborated in our accompanying article in this volume.

Provincial Affinities

The fauna from the Shyok valley is not entirely the same as those found in the *Lamnimargus himalayensis* Zone of the Himalayas, in so far as one-third of the species cannot be identified exactly with species found in the latter zone. Most other species that have not (as yet) been found in the latter zone belong to genera that occur, or might be expected to occur, in the Himalayas – *Svalbardia*, which is found in Western Australia and the Arctic, in comparable palaeolatitudes, and (?)*Cancrinella*, *Punctocyrtella* and *Pteroplecta*, which are found either in the zone, or in slightly younger or older faunas of the Himalayas. The fauna does therefore appear to be much the same as correlative faunas of the Himalayas, and the additional species are of Himalayan affinities, and do not suggest a close approach to correlative faunas of Iran and Armenia, for example, where the Gnishik and Hachik faunas show some similarities, but contain a greater diversity of genera and species, including species of *Parenteletes, Geyrella, Edriosteges, Vediproductus, Keyserlingina* in the Gnishik beds, and *Richthofenia, Chonostegoides, Spinomarginifera, Ogbinia* and *Septospirigerella* shared with the Hachik beds. However, it seems likely that our present collection is not a complete sample of the Shyok faunas of this level, and this is confirmed by the much greater diversity of species and genera reported from Gortani (1920, *Atti. Acc. Linci ser.* **29** : 53-55) by Pascoe (1975 : 803-804). The species shown in Table 1 were listed, and we follow that order.

TABLE 1

Genus and species listed	*Possible genus*
Productus (Linoproductus) aagardi Toula,	*Anidanthus*
Productus (Linoproductus) tenuistriatus de Vern.,	*Cancrinella*
Productus "semireticulatus" Mart., (*Dictyoclostus*)	
Productus (Echinoconcha) punctatus Mart.,	
Productus (Avonia) curvirostris Schellw.,	*Krotovia*
Productus incisus Schellw.,	
Productus gruenewaldti Krot.,	
Marginifera himalayensis Dien. (predominant),	*Lamnimargus*
Spirifer (Elivina) tibetanus Dien. (common)	*Elivina*
Spirifer (Elivina) interplicatus Rothpl.,	
Spirifer (Paeckelmannella) niger Waag.,	*Pteroplecta*
Spirifer bisulcatus Sow.,	
Spirifer aff. *lydekkeri* Dien.,	(?)*Punctocyrtella*
Spiriferina (Mansuyella) ornata Waag.,	(?)*Callispirina*
Spiriferina multiplicata Waag.,	
Camarophoria mutabilis Tschern.,	*Stenoscisma*
Camarophoria mutabilis var. *biplicata* Stuck.,	
Camarophoria superstes de Vern.,	
Camarophoria crumena Mart.	
Streptorphynchus cf. *pectiniformis* Waag.,	
Orthis (Schizophoria) aff. *supracarbonica* Tschern.,	*Orthotichia*
Martinia applanata Waag.,	*Martinia*
Hustedia remota Eichw..	*Hustedia*
Hustedia indica Waag.,	
(?)*Martiniopsis convexa* Tschern.,	*Martiniopsis*
Hemiptychina pseudo-elongata Schellw.,	(*Beecheria*?) *Hemiptychina*
Hemiptychina sublaevis Waag.;	
Notothyris nucleolus Kut.,	*Notothyris*
Notothyris exilis Gemm.,	
Notothyris simplex Waag.,	
Notothyris cf. *pulchra* Gemm.,	
Athyris subexpansa Waag.,	*Cleiothyridina*
Pugnax osagensis Shum.,	
Dielasma aff. *elongatum* Schloth.	

Our list of possible genera—which must be of very uncertain reliability because the original list has never been supported by descriptions or figures, strongly suggests a fauna very like those typical of the *Lamnimargus himalayensis* Zone, and thus largely confirms the affinities of our much smaller sample. It will be noted that several of our species do not seem to have been present in the collection listed by Gortani. It is difficult to assess the generic position of dictyoclostids such as '*semireticulatus*' and *gruenewaldti*, and to know if *Elivina* was accurately identified. It would be particularly interesting to be able to examine the shells identified as *Echinoconchus punctatus*, as this suggests an element rare or absent from the Himalayas, and approaching species of Armenia-Iran. *Pugnax* also is difficult to interpret. Overall, the Gortani list, with its array of Productidina and possible *Elivina* and *Stenoscisma*, *Notothyris* and *Hemiptychina*, suggests a greater degree of similarity to the fauna from Chitichun no. 1 of southern Tibet, whilst retaining strong Himalayan links. It would be of great interest to be able to verify this, because in Permian times the Chitichun fauna lay a little north and nearer the Permian palaeoequator than Himalayan faunas of the same age, and faunas of the Shyok valley also might be expected to also have lain a little north of the Himalayan palaeolatitude, even discounting the influence of what the Indus Suture represents. However, our own fauna is more Himalayan in appearance, and we must place more reliance on what we have been able to examine at first hand.

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How Wide was the Tethyan "Ocean"

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ABSTRACT

Permian faunal evidence suggests that the Tethyan seaway north of the Himalayan and Karakorum Ranges was not a major ocean during the Late Palaeozoic era, and the Indus suture does not mark the closing cicatrix of a major ocean that existed in Permian times. The Karakorum Range lay in the southern Permian hemisphere, longitudinally close to the Himalayas.

INTRODUCTION

IN THE rapidly changing world of thought about past continental relationships and displacements, some hypotheses of even a few years vintage soon become stale and lead nowhere, or serve only as a kind of Aunt Sally, to be attacked and set aside in the course of setting forth new observations and explanations. It begins to look as though the concept of a great wedge-shaped ocean alleged to have existed between the supposed southern supercontinent Gondwana and a northern supercontinent Laurasia very much belongs to this category. It was drawn by Dietz and Holden (1970), and elaborated by Smith *et al.* (1973)—and numerous other references to the same effect, on the basis of computer-assisted reassemblies of contours at the Atlantic continental shelves. Such a simple approach, combined with use of the 'new tool' of computers may have bedazzled geologists, but even so, it was difficult, if not impossible, to apply such reconstructions to the heartland of continents, especially Asia, where crustal convergence rather than divergence had occurred, and so left no trace of marine contours to be assessed. To justify reconstructions of Asia, and a separation between north and south Asia, it was suggested, without proof, that continents were 'rigid'. If they were rigid, then marine contours far away could be relevant, and it may be possible to allow positional interpretations for crust some thousands of kilometres away from data points. Provided that is, that no major faults and sutures have intervened. Currently the unproven rigidity concept is still accepted in some circles, but the intervention of faults is allowed to give some semblance of flexibility in coping with obvious inapplicabilities and irrelevance of far-away data points.

But geologists more familiar with detailed regional geology of central Asia have found little support for a great Tethyan ocean of Permian age (Stocklin, 1981; Crawford, 1979; Jin, 1981). It is true that many authors plot in detail a northward movement of the Indian subcontinent (e.g., Powell, 1979), but it is noteworthy that such studies generally allow themselves freedom by omitting assessments of what lay to the north—i.e., Powell's study focusses on the Karakorum and neighbouring areas to the west-east and south; but is not concerned with the Pamirs, Ferghana or Kazakhstan. My own understanding from what I have seen and read of the alleged Tethys Ocean relevant to Pakistan, India and Tibet is this: that any Tethyan ocean was of minor dimensions during the late Palaeozoic era, and that much of the Tethys, during the Carboniferous and Permian periods, comprised epicontinental seaways, with relatively minor development of volcanic arcs which appear to have been intracontinental to at least some extent.

FAUNAL EVIDENCE

The late Palaeozoic Tethyan Ocean is supposed to have closed along the Indus or Tsang Po suture. This closure should thus have brought together rocks and faunas once separated by thousands of miles, from latitudes differing by as much as 30°. Faunal and rock stratigraphic differences therefore should be extremely marked. But they are not. Jin (1981) has already outlined the relevant geology and faunas in Tibet, where rocks and faunas north of the Tsang-Po approximate those of the south. In the Karakorum Range, several Permian brachiopod faunas are now well known (see studies by Waterhouse and Gupta, this volume). They are close enough to those of the Himalayas to suggest that in Middle and Late Permian times, the Karakorum and Himalayan faunas developed in one faunal province. Yet the Karakorum Range lies north of the Indus, and the Himalayas lie south. The faunas may be summarised from accounts by Waterhouse and Gupta in two accompanying papers in the present volume. An older fauna, of Punjabian age, is very like that of the Himalayas, and belongs to the same *Lamnimargus himalayensis* Zone. This fauna is of limited geographic extent. It is pervasive through the 'Tethyan realm' of the Himalayas, including Kashmir, Nepal, Bhutan, Sikkim, south Tibet, Ladakh, and extends into the northern Karakorum of Sinkiang. Its eastward extent has probably been masked by subsequent tectonic destruction, but elements of the fauna appear in Cambodia (Chi-Thuan, 1961), and the fauna is well represented in Timor. A separate province developed in Armenia-Iran and a different one again in Guizhou-Sichuan-Guangtung Hubei etc., of south China, extending into Sikhote Alin and Japan, with different provinces again in central United States-Mexico, north-east Siberia, and New Zealand. Something of an amalgam between faunas of Armenia-Iran and to less extent Himalayas developed in the Salt Range, Pakistan, and Madagascar. Less well-developed brachiopod faunas of Afghanistan, Pamirs, and Ferghana do not allow adequate analysis. In comparative terms, provinces were fairly strongly developed during this time interval, restricted in terms of both latitude and longitude, and the Karakorum faunas belong with the Himalayan faunas in one faunal province, and one fairly close geographic entity. Separation by 30° latitude is most unlikely—and overall considerations suggest separation by no more than 5° latitude, if that. In longitudinal terms, the two regions must have been close, with a range of 1-10° likely.

The overlying Djulfian faunas of the Karakorum are different. Essentially they belong to one very widespread faunal province, that extended from south Europe through Armenia, Caucasus, Iran, Pamirs, Karakorum, Himalaya, Salt Range, into south China, and perhaps Japan and perhaps Malaysia. The only other strongly differentiated province that existed then was in far-away New Zealand, and a different poorly known relict province is known in Mexico. Within the Asian province developed several subprovinces, and a distinctive bivalve fauna appeared in the Salt Range, Pakistan, and the Himalayas of Nepal, and in the Shaksgam Valley of the northern Karakorum Range; Sinkiang.

The preceding comments are, of course, by way of a summary, based on reasonably intimate knowledge of Permian faunas, and more detailed analyses will be presented subsequently.

POSITION SOUTH OF PERMIAN EQUATOR

The conclusion that the Karakorum lay close of the Himalayas, in almost the same palaeolatitude, and therefore south of the Permian equator, must conflict with the concept of a major Tethyan ocean that closed along the Indus suture. Such a model would place the Karakorum in the northern hemisphere. But the Karakorum lay south of the tropics, which passed, at least in faunal terms (Waterhouse and Bonham-Carter, 1975) through Ferghana and central Asia.

The Westward Continuation of the Indus Suture

There is some uncertainty about the westward continuation of the Indus Suture, but a position somewhere between the upper Shyok-Hini-Drosh fault in the north and the Patan Fault in the south appears likely, with Talent and Mawson (1979 : 97) favouring the southerly position. Wherever the position, the faunal implications remain the same: the Indus Suture was not of oceanic magnitude. Even if the fault ran north of the Shyok Valley, it must be noted that the Shaksgam faunas of the north Karakorum Range are much the same as those of the Shyok valley and are also like those of the Himalayas for these intervals of time. (Early Permian faunas from the Shaksgam valley have differing provincial affinities. Provincial affinities keep changing through time, so that whilst this places a high demand on temporal accuracy, the very plexus of shifting similarities enables closer resolution of past geographic proximities.)

Are the Shyok Localities in Fault Slivers and therefore Meaningless?

The geology of the upper Shyok valley is complicated, and highly faulted (Desio, 1979). It is thus possible that slivers have been displaced across a major suture. But this would only be significant (in terms of width of the Tethys in the event of northward displacement, and as stated previously, the Shyok faunas resemble both Himalayan and northern Karakorum faunas. The faunas of the north Karakorum appear to lie too far north to have been tectonically displaced from south of the Indus Suture or its westerly continuation through extensive nappe transport. It is perhaps more likely that extensive strike-slip faulting has deranged the original latitudinal arrangement of rocks and faunas, to repeat some sequences and elide others.

Gondwana

According to current practice, the demonstration that the rocks of the Karakorum Range were deposited not far from the Himalayas means that they come to be considered 'part of Gondwana', a fate that appears to befall country after country—one may mention Tibet, Afghanistan (with its tillite and Australian-type early Permian faunas), and no doubt the Pamirs, for they also have early Permian tillite. In the same terms, parts of Burma, Thailand and Malaysia with pebbly mudstone are 'Gondwana'. But the term does not have much meaning if a southerly supercontinent Gondwana had never been separated from a northerly supercontinent Laurasia by a vast ocean. If one supercontinent Pangaea had existed, continent would have lain close to continent, and Gondwana will go on expanding its nomenclatural domain until it has incorporated Kolyma and Omolon massif of north-east Siberia. The older model has been preserved however in a modified way by McElhinney *et al.* (1981), in which several segments of Asia are shown from palaeomagnetic data to have been discrete land masses in an ancient huge Tethyo-Pacific ocean. However very substantial faunal and geologic analyses do not support an equivalent latitudinal position claimed by McElhinney *et al.* (1981) for Kolyma and at least the western segment of south-east Asia—both placed between 40° and 20° N, and even palaeomagnetic studies help establish that west Thailand occupied a southerly station during the Permian Period (Bunopas *et al.*, 1978; Bunopas, 1981), not between 40°N and 20°N. A southerly position of west Thailand, Burma, Malayasia is further buttressed by the diamictites and faunas (Waterhouse, 1982).

Late Palaeozoic faunas and rocks of Kolyma are well khown, and must have accumulated well to the North by mid-Permian times, at a latitude north of Razakhstan and all of south-east Asia, and not very different from Verchoyan. We may wonder about the position of the rest of Siberia. Perhaps Kolyma really lay in Permian temperate latitudes, as shown by Waterhouse and Bonham-Carter (1975), close to 40°-50° north, reasonably close to the palaeomagnetic results. But we doubt if any other parts of Siberia lay much further north: these segments must be brought southwards, to close up the Tethyan gap, and fall back into some degree of proximity with Kolyma.

CONCLUSIONS : WHERE WAS THE KARAKORUM REGION IN THE PERMIAN?

Analysis of Permian faunal distributions adds yet more evidence to suggest that the Gondwana was separated from Laurasia principally by epicontinental seas, with only minor development of ocean crust. This means that those rocks and faunas which accumulated during middle and late Permian times to later form part of the Karakorum Range lay in the southern hemisphere, south of the Permian equator, probably in warm temperate latitudes somewhat south of the Permian tropics. Latitudinally the faunas and rocks of the Karakorum Range lay a little north of the Himalayas near 20° south and south of Armenia, and longitudinally close to the Himalayas, during the Permian Period.

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Biostratigraphy of Ramnagar Beds (Miocene) of Udhampur District (Jammu and Kashmir), Northwest India

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ABSTRACT

Biostratigraphical investigations of Sivalik sediments exposed around Ramnagar (32°49'N : 75°22'E) in Udhampur District of Jammu and Kashmir (northwest India) reveal that the beds represent Chinji Formation (Lower Sivalik Subgroup) of Upper Miocene (Upper Tortonian) age. The fossils are generally restricted to small disconnected pockets. Certain pockets of the area are highly fossiliferous and have yielded rich assemblage of vertebrates representing more than one fossil communities and a few molluscs, coprolites and charophyte remain in association with poorly preserved ostracods and fish scales.

The sedimentation of these beds appears to have taken place under fluvial (floodplain) environment. Palaeontological and lithological studies of the area suggest that this part of Northwestern Himalaya was probably under tropical rain forest conditions during Late Miocene period. In Jammu and Kashmir, the stratigraphic junction of Chinjis with the underlying Kamlials is gradational and conformable though these show a probable break in deposition with the overlying Nagris of Middle Sivalik Subgroup.

INTRODUCTION

THE NEOGENE molasse sediments exposed around Ramnagar (32°49'N; 75°22'E) in Jammu and Kashmir State represent the Chinji Formation of Sivalik Group of Indian stratigraphy. Intensive investigations bearing on the biostratigraphy in this part of Northwestern Himalaya were undertaken by the authors. The beds are situated about 275 kilometres east of Chinji village (whence Chinji Formation derives its name) of Pakistan. In general, the Chinjis show a variable thickness of 400-1800 metres. Geologically, the formation has been assigned an Upper Tortonian (Upper Miocene) age on the basis of vertebrate fauna, flora and its stratigraphic position. In Jammu and Kashmir, the stratigraphic junction between Chinjis and underlying Kamlials of Middle Miocene is gradational and conformable. A probable break in deposition between Chinjis and overlying Nagris was suggested by Lewis (1937).

Earlier workers including Colbert (1935), Dutta *et al.* (1976), Chopra *et al.* (1977), Suneja and Kumar (1979), Suneja *et al.* (1978, 1980), Suneja and Kaul (1980) and Vasishat *et al.* (1978, 1979) have published significant reports on the palaeontology and/or palaeoecology of Ramnagar beds. The fossil fauna of the area is of special interest for it contains primates including well-known hominid *Ramapithecus* and a few other hominoids (Dutta *et al.*, 1976; Chopra, 1980).

PRESENT OBSERVATIONS

The outcrops of the area often well-exposed along the streamlet and road cuttings, exhibit a significant uniformity in their lithological features. The formation shows an alternate arrangement of arenaceous and argillaceous rock units—a characteristic of Sivalik Group in general, indicating their seasonal deposition. Dark pinkish to chocolate clays, shales and argillites comprise the argillaceous units, whereas arenaceous units are represented

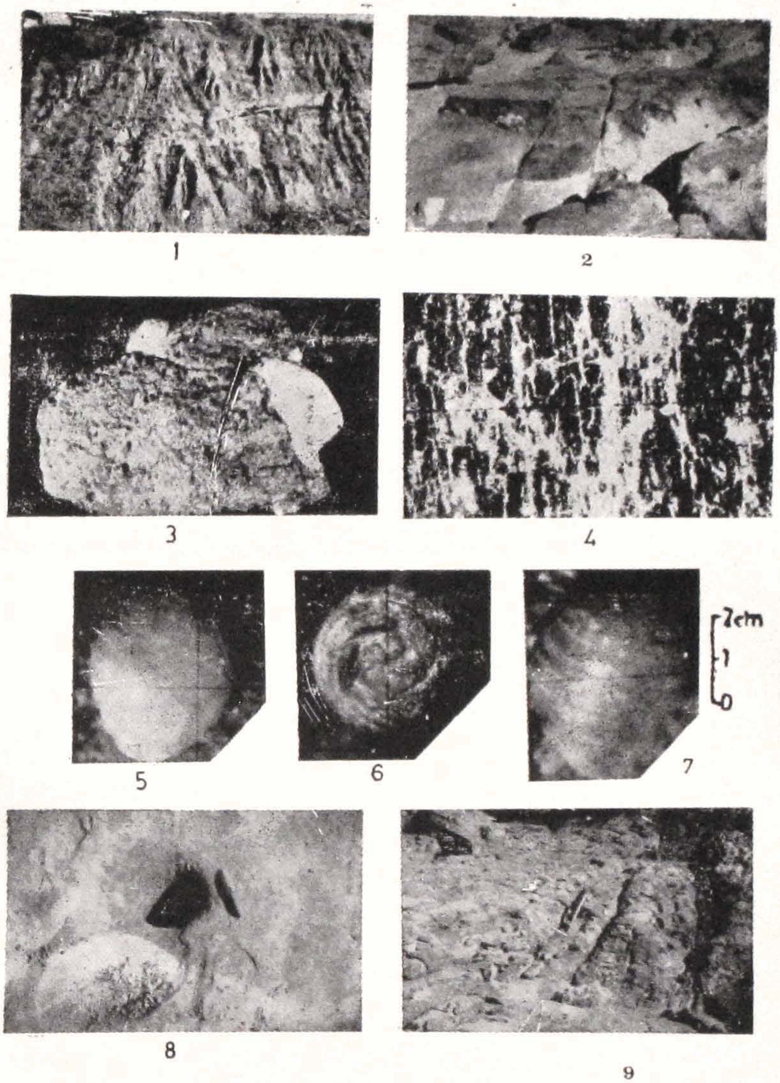

Plate 1. **1.** Alternate deposition of arenaceous and argillaceous rock units in the west of Kermon village. The outcrops show differential weathering. Conspicuous rills and gullies have been cut in the argillaceous beds on account of dissecting action of rain water. **2.** Development of two sets of joints in the sandstone bed exposed about two km. SSE of Ramnagar. **3.** Handspecimen of graywacke with a reptlian(?) fossil bone, collected from a fossiliferous locality exposed about hundred meters north of Thaplal village. **4.** Photomicrograph of longitudinal section of fossilised wood showing distribution of xylumrays. **5.** Lateral aspect of *Tectochara meriani meriani* × 60. **6.** Apical aspect of *Tectochara meriani meriani* × 60. **7.** Lateral aspect of *Tectochara meriani huangi*. × 60. **8.** Pothole (due to erosion) on the upper surface of a medium grained highly weathered sandstone bed exposed about two km. SSE of Ramnagar. **9.** Desiccation fissures developed on the upper surface of sandstone stratum exposed about two km. SSE of Ramnagar.

by greyish to dirty greenish sandstones. The argillaceous rock units dominate over arenaceous ones and show variegated colours. The sandstones are cross-bedded and contain a high percentage of feldspar of metamorphic origin. The sandstones are subjected to weathering and assume various shapes. Nodules of different shapes, limonitised, are generally enclosed within this lithological unit.

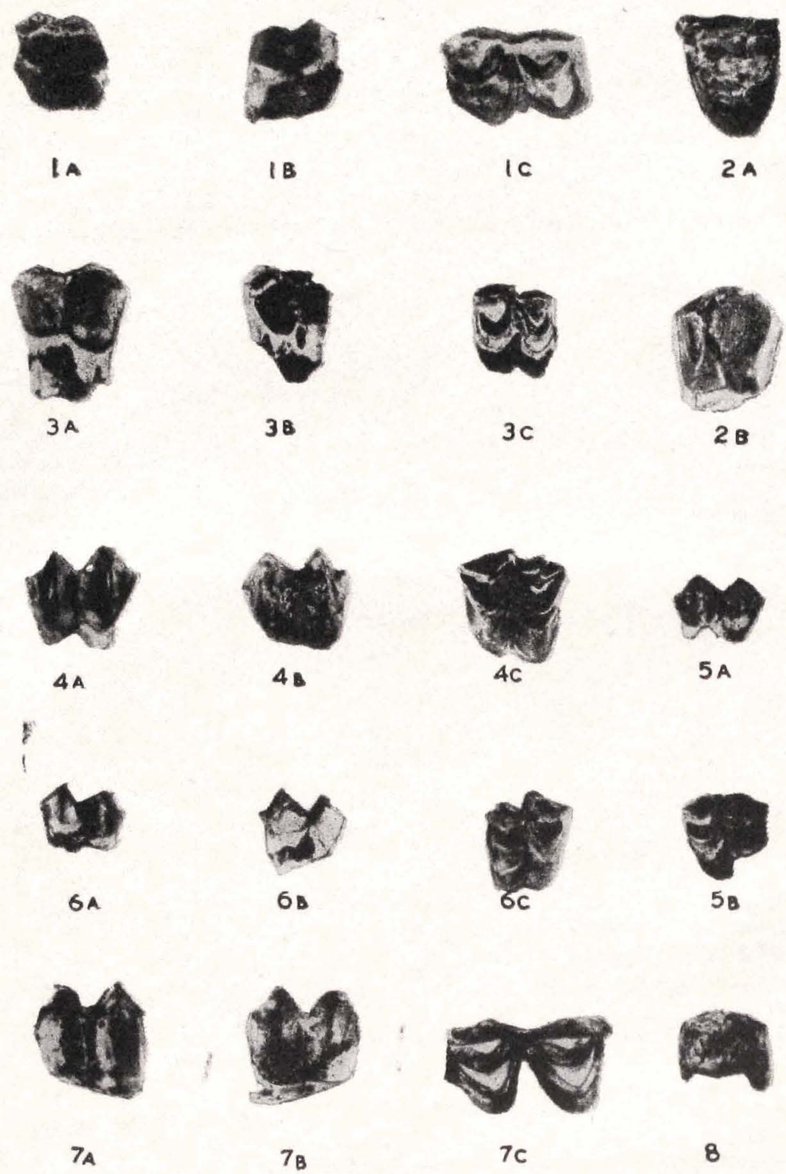

Plate 2. *Helicoportax* cf. *H. praecox* (Left mandibular M_1 or M_2). 1A. Buccal view, 1B. Lingual view, 1C. Crown view. (Scale : Max. antero-post. diam. = 13.70 mm.). ? *Gazella lydekkeri* (Upper right P4) : 2A. Crown view, 2B. Buccal view. (Scale: Max. antero-post diam. : 9.20 mm,) ? *Gazella lydekkeri* (Upper right M^1) : 3A. Buccal view, 3B. Lingual view, 3C. Crown view. (Scale : Max. antero-Post. diam. = 13.00 mm.) *Dorcatherium minus* (Upper right M^2) : 4A. Buccal view, 4B. Lingual view, 4C. Crown view. (Scale : Max. Antero-post. diam. = 11.40 mm.) *Dorcatherium minus* (Upper right M^1) : 5A. Buccal view, 5B. Crown view. (Scale : Max. anteropost. diam. = 9.40 mm). *Dorcatherium minus* (Left maxillary M^1) : 6A. Buccal view, 6B. Lingual view, 6C. Crown view. (Scale : Max. antero-post. diam. = 9.00 mm.) *Streptiportax* (?) sp. (Left mandibular DM_2) 7A. Buccal view, 7B. Lingual view, 7C. Crown view. (Scale : Max. antero-post. diam. = 17.25 mm.) ? *Dicoryphochoerus haydeni* (Upper right M^1) : 8. Crown view.

Both the arenaceous and argillaceous rock units of Chinjis exposed in this part of northwestern Himalayan basin are highly fossiliferous at certain pockets. The fossil assemblage is represented by an admixture of vertebrate and invertebrate fauna coupled with macro-and micro-floral remains and coprolites. The fragmentary nature of fossils indicates that they were subjected to intense weathering and local crustal disturbances during/after their fossilization. The vertebrate faunal assemblage recovered from the area comprise mammalian dentitions and postcranial skeletal material. The remains could be assigned to different groups including bovids, tragulids, suids, carnivores, proboscideans, rhinocerotid and rodents suggesting that more than one terrestrial communities existed at the time of sedimentation. The reptilian spikes, scutes and limb bones and also piscean remains including pectoral spines, supra-occipital parts and vertebrae (stream community) occur in disconnected pockets in this basin (Suneja and Kumar, 1979). The macrofloral remains from greenish sandstones and argillites consist of badly preserved leaf impressions and fossilized angiospermous woody tissues. Algal remains in the form of fossilized charophytic gyrogonites represent the microflora.

The vertebrate fossils of the area (Plate 2) are by and large affined to the Chinji fauna of Pakistan (Pilbeam *et al.*, 1977) occurring about 275 km west of Ramnagar basin. The forms are in part also comparable to the Nagri remains of Haritalyangar (Prasad, 1970) in Himachal Pradesh. The palaeontotogical discrepancies between Ramnagar (India) and Chinji (Pakistan) appear to have been due to the difference in the stratigraphic levels within the same geological formation (Suneja and Kaul, 1980).

The algal remains of the area comprising *Tectochara* spp. are quite comparable with the microfloral assemblage earlier reported from Chinjis of Kangra district in western Himachal Pradesh (Bhatia and Mathur, 1978).

The occurrence of rich assemblage of mammalian remains and angiospermous flora (Plates 1, 2) is suggestive of fresh water conditions during the sedimentation of Chinji Formation. The variety of mammals in the fossil collection indicates that during Upper Miocene mammalian fauna flourished in profusion near the basin of deposition. The presence of rich assemblage of mammalian fauna, plant remains and fossilized woody tissues suggests that the area supported a luxuriant growth of angiospermous flora. Probably, it constituted the chief food for mammalian populations. The general forest conditions are indicated by the occurrence of dental remains of suids like *Listriodon*, giraffids like *Giraffokeryx* and proboscideans like *Dinotherium*. The tropical rain forests generally grow best upto an average altitude of 6000 feet (Kalapesi, 1978).

The presence of jaw fragments of bovids like *Helicoportax* and other closely related forms reveals that the area supported a rich grassland forest. The tragulids like *Dorcatherium* inhabited river banks. The abundance of fossil scutes and limb-bones of crocodiles and turtles in the basin is suggestive of a valley covered by fresh water streams with a climate sufficiently warm to support mammalian and reptilian fauna. The piscean material belongs to a group of fishes, generally inhabiting fresh water muddy streams in a valley plain. The evidence of the exis-

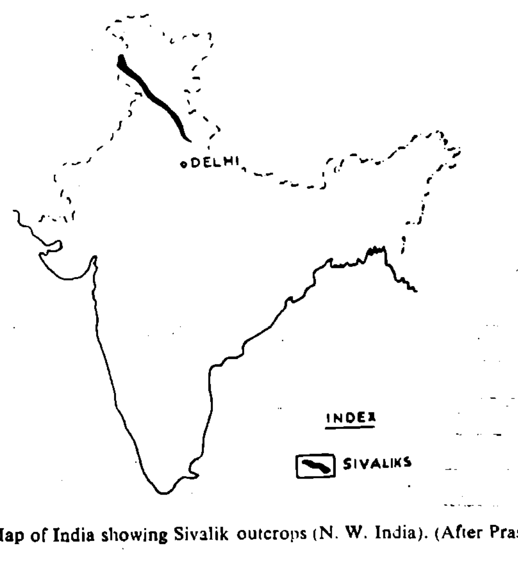

Figure. 1. Map of India showing Sivalik outcrops (N. W. India). (After Prasad, 1975).

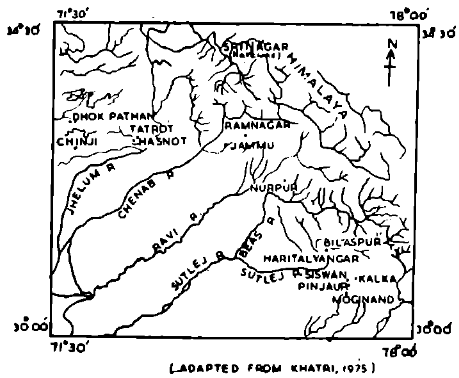

Figure 2. Important fossiliferous sites of the Sivaliks (India and Pakistan).

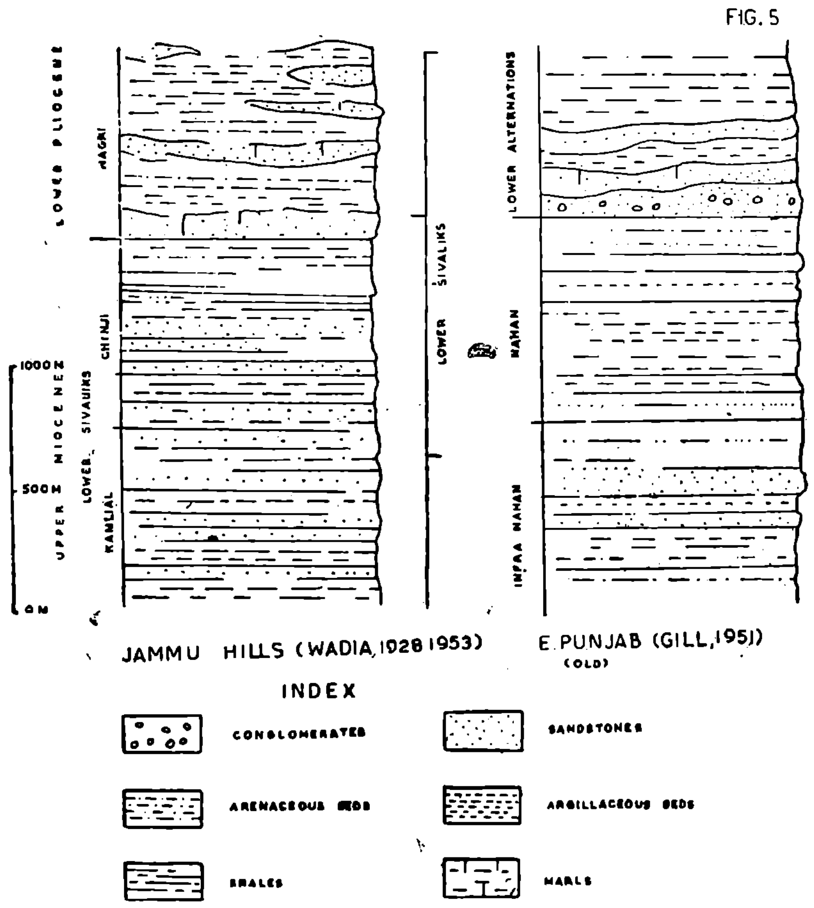

Figure 3. Generlized stratigraphic columns of Jammu Hills and East Punjab. (After Gansser (1964).)

tence of disconnected water sheets or inland lakes is forthcoming by the recovery of piscean and reptilian remains from this part of Sivalik basin (Suneja and Kaul, 1980). This is further supported by the recovery of fossilized charophytic fructifications belonging to the genus *Tectochara* in association with gastropod opercula. The charophytes grow, as a rule, in soft mud and require shallow clean water (Pal *et al.*, 1962).

The general occurrence of chocolate to reddish silicious argillaceous beds in this area indicates warm and humid conditions at the time of sedimentation. According to Krynine (1949) the red colouration of the majority of red beds develops under acidic oxidizing conditions where annual rainfall is more than 40" (102 cm) and temperature 60F (16C). The green-coloured material indicates a high degree of oxidization (Weller, 1960). General warm and shallow water conditions are also indicated by the presence of calcareous cementing material in most of the competent and incompetent rock units of the tract under consideration.

The heavy mineral suit consists of angular to subangular grains of garnet, tourmaline, staurolite and epidote. The presence of garnet indicates the occurrence of metamorphic rocks in the source area; tourmaline is suggestive of acidic crystalline, pegmatitic injected metamorphic terrains and argillaceous metasedimentaries; staurolite suggests crystalline metamorphic rocks in the provenance.

The prevalence of subangular to subrounded quartz grains (average roundness 0.14 to 0.27) and angular to subangular suit of heavy minerals together with the presence of undigested rock fragments in the arenaceous rock units suggests that the material was not moved a great distance from its source area.

The presence of features like current bedding, assymetrical ripple marks, undigested rock fragments in the competent beds and predominant red colour of incompetent beds also suggests their rapid accumulation under shallow-water conditions in warm humid oxidizing environment. In addition, the shrinkage cracks of different orders present generally on the surface of arenaceous rock units are indicative of short dry spells prevailing at the time of their sedimentation and also floodplain conditions of their deposition.

On studying the representative rock samples from different stratigraphic levels for environmental analysis it was observed from the scatter plots of skewness versus standard deviation, simple skewness measure versus simple sorting measure and mean size versus standard deviation (Friedman, 1967) that fluvial conditions existed during the sedimentation of Ramnagar beds in northwestern India. Skewness versus standard deviation when plotted following Moiola and Weiser (1968) corroborates this inference on environment during sedimentation of the Chinji Formation. Publication of detailed petrological investigations of the formation is under way.

To conclude, it can be said that during the sedimentation of Chinji Formation in the area investigated the ecological niche comprised angiospermic belt interspersed with open woodland country, grassy plains with disconnected water sheets. A temporary break in deposition, after the Chinjis were laid, *may* have occurred in this Northwest Himalayan basin.

ACKNOWLEDGEMENTS

One of us (IJS) is grateful to Dr. K. N. Prasad, Director, Geological Survey of India (Southern Region), Hyderabad for his valuable comments and suggestions.

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Trace Fossils from the Indus Suture Zone, Ladakh

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ABSTRACT

The trace fossils *Gyrochrote* and *Helminthoides* recovered from the dark grey shales of the Indus Suture Zone indicated that the sediments were deposited on a Middle to Upper Mesozoic shelf slope which supplement previous microfossil discoveries from other sections.

INTRODUCTION

THIS IS the first report of trace fossils from the Indus Suture Zone on the basis of which recognition of Upper Cretaceous rocks in Indus Suture has been done. The Indus Suture Zone is a typical mixture of Ophiolite melange, molasse and flyshoid rocks varying in colour from dark to light-yellow, red, brown, green, etc. The rocks from which these trace fossils are being described are exposed between Lamayuru and Khalsi on the Srinagar-Leh national highway. The strata yielding these trace fossils is exactly at 5.5 km from Lamayuru towards Khalsi. The strata is among the typical red and green alternating bands of Indus Flysch and these are below the red shale which turns to dark grey shale type giving an appearance of siltstone immediately underlying which is fine sandstone band. Tewari *et al.* (1970) also reported some Upper Cretaceous benthonic and planktonic foraminifera near Gya (Ladakh) which have shown their affinity with that of Santonian and Campanian rocks of Western Australia and Eastern Europe. So far there is no other report from the Indus Flysch. The present collection includes two tapes of trace fossils although other individuals may also be present. Most of the trace fossils are fragmentary because of highly folded and crumpled zone of Indus Flysch near Lamayuru.

TRACE FOSSILS

Though the traces are very well-preserved to be identifiable at the genetic level, firm specific determination has not been possible in the instance. However, efforts have been made in specifying the *Gyrochorte*. The two main forms which have been identified are *Gyrochorte* and *Helminthoides*.

Gyrochorte

This trace (Fig. 1) is well-preserved along the bedding planes in the form of ridges which are biserially arranged. The pads numbering 36 are transverse obliquely placed to these ridges and both the series are separated by a median furrow. Ridge at right angle to the bedding is elliptical in shape with longer axes about a centimetre and the shorter axis 0.6 cm and the pads having thickness of 0.1 to 0.2 cm. It ranges in age from Cambrian to ? Tertiary. But the species *G. comosa* from Switzerland is reported from Middle Jurassic.

Repository of Type material : No. WIF/A 301, Museum, Wadia Institute of Himalayan Geology, Dehra Dun.

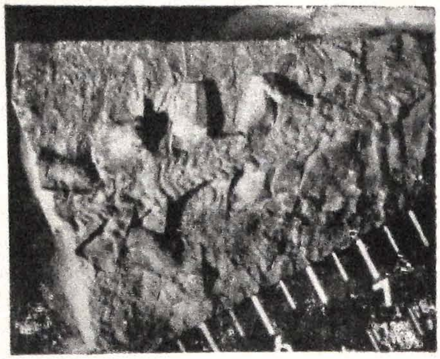

Figure 1. *Gyrochrote*

Helminthoida

This trace (Fig. 2) is also present along the bedding-planes, shows winding in contact with one another, simple trail, no ornamentation is visible. It comprises 2 mm wide trails mostly curved and at places concentric also. They range from Cretaceous to Tertiary, but *H. labyrinthica* is reported from the Flysch in Australia from Upper Cretaceous.

Figure. 2. *Helminthoida*

These both *Gyrochorte* and *Helminthoida* indicate Middle Jurassic and Upper Cretaceous ages respectively. Although identifications, even at the generic level, are in part necessarily tentative, the overall aspect of the fauna is firmely indicative of Upper Cretaceous age.

Repository of Type material : No. WIF/A 302, Museum, Wadia Institute of Himalayan Geology, Dehra Dun.

DISCUSSION

Considering the importance of trace fossils in environmental stratigraphy and global tectonics an effort has been to understand the common facies and depth, related with these trace fossils, on the basis of studies done by Crimes and Crossley (1968) and Tanaka (1971).

It is observed that on transition from deep to shallow water *Helminthoida* disappears with radiating traces in the shallower deposits. On the other hand, *Gyrochorte* are preserved in shallow-water sediments if there are no bioturbation by other burrowers. However, both are confined to the bathyal to abyssal zones. In such zones the environmental conditions are ordinarily quiet for long periods and so in shallower part fine-grained sandstones, siltstones or limestones accumulate. Similar deposits are present in the flysch of Indus Suture Zone.

Based on these observation, stratigraphic relations and age considerations, it appears that this pre-orogenic pile could have plausibly been deposited on a Mesozoic shelf slope.

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A Note on the Occurrence of Oncolitic Limestone and Trace Fossils in the Area South of Margan Pass, Kashmir Himalaya, India

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INTRODUCTION

THE PRESENT note records the occurrence of oncolitic limestone and trace fossils from the stratigraphically unclassified sequence lying below the Gauran Beds in the section exposed south of Margan Pass (33°44′44″ : 75°29′ 14″), Anantnag District, Kashmir. Lithologically, the rocks lying below the Gauran Beds consist essentially of light-grey to greenish-grey thinly foliated phyllites, dark grey slates and quartzites which at places are interbedded with carbonaceous schists and light grey massive limestone. This sequence has not yielded any determinable fossils and is generally referred to Late Precambrian or Cambrian age. The occurrence of oncolitic limestone similar to that of Margan Pass has also been observed by the authors in the area southwest of Zajibal Gali (32°25′32″ : 74°57′54″) in the Baramula District, Kashmir. The oncolitic limestone in this area is represented by 12-15 metres thick band associated with grey phyllites, silty shales and siltstones. This sequence is classified as part of the Kangan Formation of Sind Group.

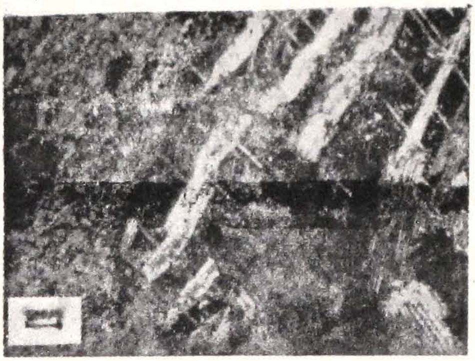
The authors during the stratigraphical investigations in the area south of Margan Pass came across a 2-metres thick band of oncolitic limestone interbedded within the grey to greenish-grey phyllites. In addition, the authors recorded the presence of some structures (possibly trace fossils) at several stratigraphic levels within this sequence. A brief description of the oncolitic limestone and these structures is given in the present note.

ONCOLITIC LIMESTONE

Description

This structure consists of ovoids approximately 5 mm in diameter dispersed in a micritic matrix. The ovoids have a fuzzy boundary, and are composed of neomorphic spar with irregular and zig-zagged intercrystalline boundaries. The crystal terminations reveal indistinct laminations which have been obscured by extensive recrystallization (Plate 1, fig. 1). One of the ovoids has a distinct nucleus (Plate 1, fig. 1) with a sharp margin. The average crystal size within the nucleus is much smaller than that of the extra-nucleolar part. The oval shape, presence of laminations, albeit indistinct, together with the observation that recrystallization to an advanced stage is restricted to the ovoids indicates that these are of probable algal origin.

Apart from the oncolitic ovoids, the specimen consists of microspar (up to 15 μ), micritic calcite and neomorphic spar showing a comparatively lesser degree of recrystallisation.



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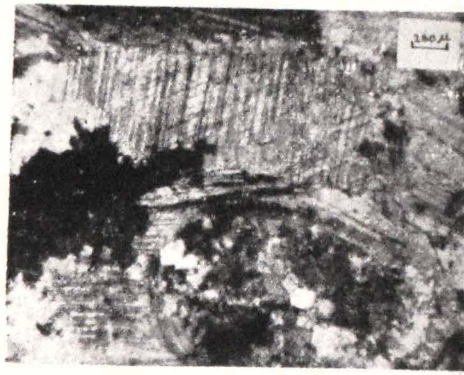

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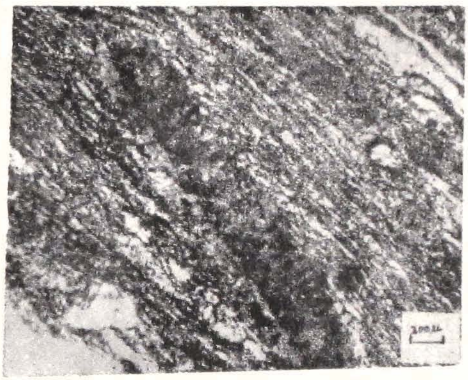

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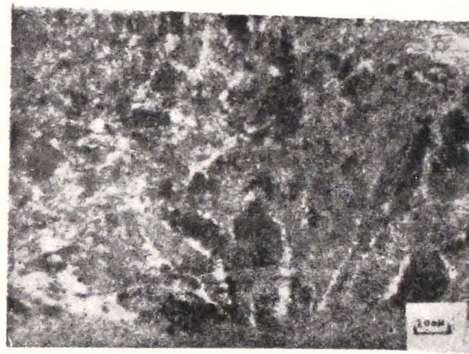

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Figure 1. (a, b). Indistinct laminations are obscure because of recrystallisation. Note the distinct nucleus.
Figure 2. Micritic laminae with complex morphology surrounding an elongate structure with serrated margin.
Figure 3. Oval-shaped body with chamber-like structures composed of dense micrite.
Figure 4. Trace fossil, possibly formed by trilobite.
Figure 5. Unidentifie 'organic' structure in argillaceous limestone.

One elongate structure, about 2.5 mm in length, appears to have a serrated margin. It consists of dark-coloured dense micrite. The micritic laminae surrounding this structure are of complex morphology—wavy and interlaced (Plate 1, fig. 2). Figure 3 in Plate 1 shows another oval-shaped algal body with dark chamber-like features composed of dense micrite of a relatively darker hue. The inter-chamber area is composed of micrite and microspar of a lighter hue.

Figure 4 Plate 1 shows curvilinear sub-parallel series of ridges in hyporelief, dimensions of individual ridge being: length 4-5 cm, height 0.3 cm and width of the order of 0.5 cm. Most ridges are uniform in width but non-uniform and tapering ridges are also present. Other faint scratch marks are also present on a slightly undulatory surface. General structure is suggestive of formation by trilobites.

Figure 5 in Plate 1 represents parallel mini-ridge-like structure, straight, with intercrestal distance of the order of 1 mm and closely spaced transverse annulations on the ridge surface.

The Study of Dyke Swarm in the Kargil Igneous Complex Ladakh, Jammu & Kashmir, India

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ABSTRACT

The Kargil Igneous Complex, between Shamsha and Manjigund, forms the southern part of the 'Ladakh Batholith' and is characterized by a variety of igneous rocks. The oldest rocks encountered are gneisses, schists and limestones which are associated with volcanics. The volcanics have suffered low-grade metamorphism upto the greenschist facies and are repeatedly intruded by basic and acidic plutons. The basic plutons constituting pyroxenite-hornblendite, morite and gabbro came first and were followed by the intrusion of tonalite and granite. All these rocks of the complex are traversed by a swarm of dykes ranging form basic to acidic in their mineralogical and chemical composition. These dykes have been classified into dolerites, lamprophyres, aplites and pegmatites. The dykes mark the close of the igneous activity in the area. The wide variation in the composition of dykes suggests the existence of more than one magma responsible for the formation of Kargil Igneous Complex.

INTRODUCTION

THE KARGIL Igneous Complex between Shamsha and Manjigund, a southern part of the Ladakh Batholith in the Trans-Himalayan Zone has a very good record of igneous activity. The igneous rocks of the complex vary from ultrabasic to acidic and from volcanics, plutonics to swarm of dykes. Dykes traverse all the earlier rocks. These minor intrusions mark the close of igneous acivity in the area. Occurrence of dykes, having various dimensions and contrasting composition, is of great significance in establishing a genetic relationship of the rocks of the complex. Dykes are small measuring from 5 cm to 60 cm in thickness and several metres in length. In order to understand the magmatic history of the area it is necessary to know the behaviour and parentage of dyke swarm.

The dyke swarm constitutes a group of NNE-SSW and NE-SW trending dolerites, lamprophyres, aplites, pegmatites, quartz and calcite veins. Lamprophyric dykes cutting across Dras Volcanics have been reported by Wadia (1937). However, no detailed study has been done on these dykes. The present paper deals with the detailed petrographic study followed by a petrochemical discussion. On the basis of petrochemistry it has been eatablished that the dolerites and lamprophyres belong to tholeiitic series of rocks whereas the acidic dykes are of calc-alkalic parentage. Both basic and acidic dykes have traversed all the basic and acidic plutons. Thus, the presence of dyke swarm indicates that there were both acidic and basic magmas even during the last phase of magmatic cycle.

GEOLOGICAL SETTING

Various lithological units of the Kargil Igneous Complex have been studied by Rai (1977) and Rai & Pande (1978). The oldest rocks encountered are gneisses, schists and limestone which are associated with volcanics as isolated bodies. The volcanics are the eastern extension of Dras Volcanics which have suffered low grade of metamorphism upto the greenschist facies and are repeatedly intruded by basic and acidic plutons. The basic plutons constituting pyroxenite-hornblendite, norite, and gabbro came first and were followed by the intrusion of tonalite and granite. These rocks of the Kargil Igneous Complex are traversed by a number of dykes and sills throughout the area. The dykes and sills are classified according to their mineralogical composition and textural features as : (i) dolerites; (ii) lamprophyres; (iii) aplites; (iv) pegmatites; (v) quartz; (vi) calcite veins.

Among the dykes dolerites are the most common which cut across granite, tonalite, gabbro, norite and metamorphites. It is noteworthy that the frequency of occurrence of dolerite dykes is very high in the tonalite. The general trend of these dykes is NNE-SSW. Nevertheless, there also exists deviation from this general trend (Fig. 1).

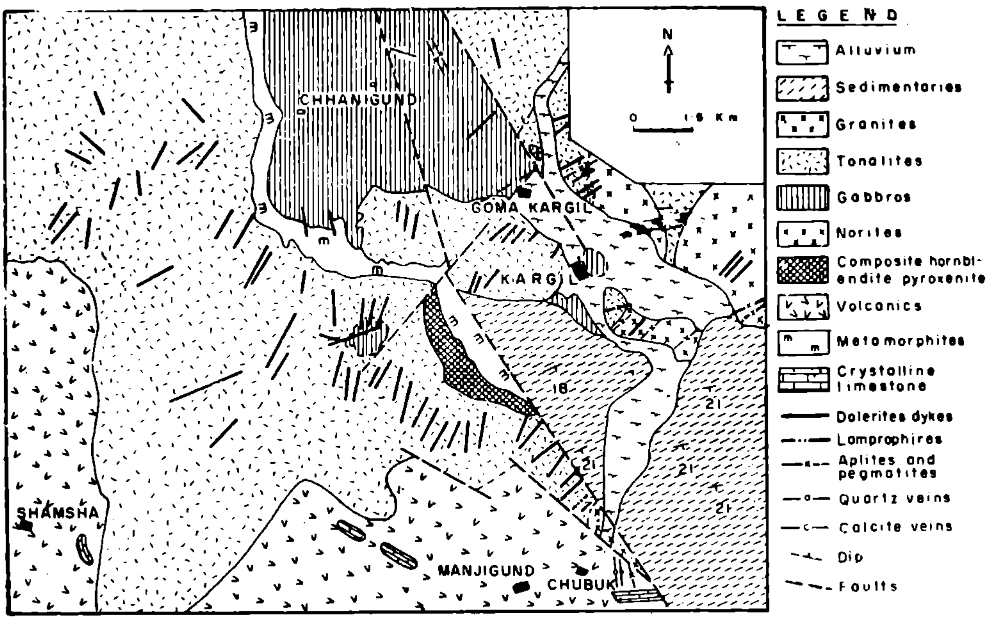

Figure 1. Geological map of Kargil Igneous Complex, Ladakh district (modified After Rai, 1977).

Lamprophyric dykes in the area traverse tonalite in the southwest of Titichuming. These dykes are very limited in number, vary in width from 5 cm to 20 cm and run for hundreds of metres in northeast-southwest direction.

Aplites and pegmatites do not form any particular trend. Aplites are most common in norite, tonalite and granite. These form sills in the volcanics near Shamsha. Pegmatites are confined to the tonalite and gabbro of the area.

Quartz veins penetrate the volcanics at Chubuk and also at Manjigund. These veins form zig-zag pattern and often branch into several small veins. Two calcite veins have been recorded within the tonalite near the confluence of Dras and Suru rivers where tonalite is in contact with gabbro.

PETROGRAPHY

Dolerites

On textural basis dolerites can be classified as : (*a*) porphyritic, and (*b*) non-porphyritic. Megascopically, the melanocratic, massive and hard dolerites often show spheroidal weathering and the surface is marked with dull reddish brown hue or tint. However, the rock when fresh shows dark to greenish-black colour. No contact or chilling effect has been observed near the margin of the dykes. Porphyritic dolerites are characterized by large whitish phenocrysts (1 mm to 15 mm) of feldspars embedded in a dark fine-grained groundmass.

The dolerites show fine-to medium-grained crystallined; inequigranular ophitic or porphyritic or crude flow texture. Massive and nonporphyritic variety shows allotriomorphic texture. At times mafic minerals show a crude preferred orientation giving a flow texture to the rock. A few dolerites show marked alteration where pyroxenes have been replaced by bluish green hornblende.

Plagioclase, augite, hypersthene and hornblende with biotite, chlorite quartz, epidote sphene, apatite, magnetite and ilmenite form the mineral assemblage in the rock. On the basis of mineral composition, the dolerites can be further classified as : (i) dolerite (normal); (ii) hypersthene dolerite (noritic dolerite); (iii) andesitic dolerite; (iv) quartz dolerite; (v) diabase.

Plagoiclase

The dolerites of the Kargil area show appreciable variation in an content (An_{35}-An_{58}) of plagioclase. Andesine appears to be more prominent and forms large phenocrysts in porphyritic varieties. Labradorite is characteristic

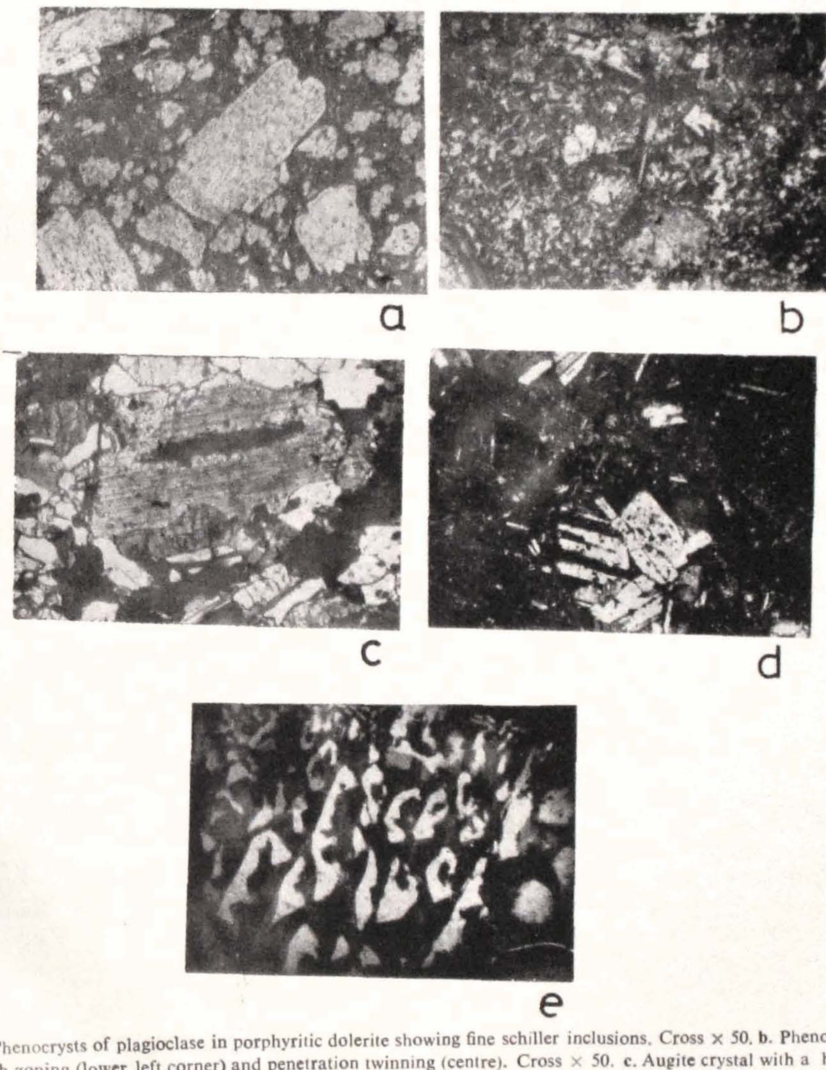

Plate 1. **a.** Phenocrysts of plagioclase in porphyritic dolerite showing fine schiller inclusions. Cross × 50. **b.** Phenocrysts in dolerite with zoning (lower left corner) and penetration twinning (centre). Cross × 50. **c.** Augite crystal with a hypersthene core (dark) in the hypersthene dolerite. Cross × 35. Plagioclase forming clusters of phenocrysts in the lamprophyre. Cross × 50. **e.** pegmatites with graphic intergrowth. Cross × 18.

of normal dolerites. Plagioclase have a tendency to form phenocrysts in the finegrained, dolerites. A few phenocrysts show schiller inclusions (Plate I). The phenocrysts show twinning, mostly a combination of more than one twin laws and also penetration twinning (Plate I, *b*). Zoning and clouding is also present. In contrast, the plagioclase in the groundmass forms microlaths which are twinned after carlsrbad law and are fresh and free from inclusions.

Hypersthene

Orthopyroxene (hypersthene) is rare in these dykes. However, it is a dominating pyroxene in a single dyke that traverses gabbro (exposed at about 1 km northeast of Chhainigund). Hypersthene is pleochroic from pink to green, 2 v is 68° to 74°. It forms the core of a few augite crystals in the hypersthene dolerites (Plate I *c*).

Augite

Augite frequently forms larger crystals and is intergrown with laths of plagioclase, thus giving rise to ophitic texture. Colourless, prismatic augite crystals (rarely greenish in colour with faint pleochroism) show a high angle of extinction (38°-44°) and 2v varies widely (56° to 63°).

Hornblende

Hornblende is the only amphibole encountered in these rocks. It is brownish green in fresh dykes whereas altered in dykes it is bluish green and forms large plates. It dominates pyroxenes in andesitic and quartz bearing dykes. Extinction angle varies (CVZ) from 17°-22° and 2v from 66°-68°.

Quartz

Quartz exist in quartz dolerites as a minor constituent. It forms anhedral grains with sutured borders.

Lamprophyres (Spessaratite)

Megascopically, the mesocratic rock is medium-to coarse-grained. Prismatic, greenish black phenocryst of hornblende measuring about 2cm are easily identifiable in hand speciman. Under the microscope the rock shows porphyritic texture where hornblende and plagioclase feldspar form euhedral crystals (Plate I, *d*) embedded in a fine matrix mainly composed of plagioclase microlites with mafic minerals.

The rock is essentially composed of plagioclase and horblende with subordinate amount of pyroxenes, biotite, muscovite, calcite and magnetite. The mafic minerals are commonly altered.

Plagioclase

Plagioclase (An_{40}-An_{66}) is the dominating mineral constitutent of the rock. It shows euhedral to subhedral form with clouding and contains dark opaque inclusions. However, smaller crystals are more or less water clear. Winning after albite or complex laws is common. Weak, normal and oscillatory zoning is quite significant in the plagioclase.

Pyroxenes

Pyroxenes, both clino- and ortho- are present as subordinate mineral constituent of the rock. Hypersthene is pale green, pleochroic from pale green to green and contains schiller inclusions. Augite, the only clino-pyroxene, shows faint pleochroism from pale yellowish green to light green and extinction angle varies from 39° to 44°. The colouration might have appeared in augite due to initiation of the alteration.

Hornblende

Reddish brown tabular laths or prisms of hornblende occur as large euhedral and subhedral crystals. Besides phenocrysts hornblende forms microlites in the groundmass. Some of the phenocrysts with well-developed six sides have crystallized parallel to each other. It shows a characteristic pleochroism from pale brown to reddish brown and oblique extinction (16° to 20°). There are some phenocrysts showing twinning. Inclusions of plagio clase and magnetite are common. In a few cases, relict core of pyroxene in hornblende has been observed.

Muscovite, biotite and sericite are the flaky minerals present in this rock.

Magnetite occurs as inclusions in all the minerals but more frequently associated with mafic minerals.

Calcite Crystals are clear and twinned. Anhedral to subhedral grains are enclosing plagioclase laths. Calcite might have crystallized during the release of Cao from the pyroxenes and plagioclase.

Aplites and Pegmatites

Besides the basic dykes the area is charactrized by a medium- to course-grained leucocratic aplitic and pegmatitic veins, dykes or sills. These quartzo-felspathic rocks can be classified into the following types :

(i) APLITES

(*a*) Tonalite aplites;
(*b*) Granite aplites.

(ii) PEGMATITES

(*a*) Quartz-plagioclase pegmatites;
(*b*) Tourmaline pegmatites;
(*c*) Muscovite pegmatites.

Tonalite aplites are more common and confined to the norites, metavolcanics and metamorphites. Granite aplites are restricted to tonalite and granite. Quartz-plagioclase pegmatites traverse gabbro. Tourmaline pegmatites cut across tonalite, and muscovite pegmatites form small dykes and sills in the metavolcanics near Shamsha.

Medium- to coarse-grained tonalite aplite showing greyish white to cream white colour is mottled with brown and brownish black biotite and hornblende. The rock is hard, compact and equigranular. Under the microscope it shows hypidiomorphic and allotriomorphic texture. Quartz, plagioclase and orthoclase are the dominating constituents.

Creamy white or pinkish-coloured granite aplites are medium-grained and compact. In thin sections the rock shows aplitic texture (allotriomorphic) and is composed of quartz, potash feldspars and plagioclase decalcification of plagioclase is common. The irregular fractures in the phenocrysts are filled with calcic material.

Pegmatites showing frequently graphic and granophyric texture (Plate I, *e*) are very coarse-grained. Quartz-plagioclase pegmatites are characterized by the presence of milky-white plagioclase and at times, by pinkish quartz. The rock exhibits hypidiomorphic granular texture. Quartz and plagioclase are the essential rock constituents. Potash feldspars (orthoclase), biotite, magnetite, apatite and zircon form minor minerals. Mica pegmatites, at times show cataclastic as well as rudely foliated texture, foliation is defined by preferred orientiation of mica flakes. Tourmaline often occurs as radiating crystal aggregates. Quartz, microcline, microcline-microperthite, twinned and untwinned orthoclase, tourmalime, biotite and muscovite are the mineral constitutents of these pegmatites.

Quartz

Anhedral to xenomorphic water clear quartz, often showing wavy extinction and sutured border, is the dominating mineral constitutent of these quartzofelspathic dykes. It varies in proportion from dyke to dyke.

Plagioclase

Twinned and untwinned plagioclase (An_8-An_{36}) form large plates which show an intergrowth with quartz in the pegmatites. Oligoclase is the dominating feldspar in tonalite aplites and also in quartz-plagioclase pegmatites and becomes nearly equal or subordinate feldspar in granite aplites.

Potash Feldspar

Potash feldspar is represented by orthoclase, microcline, and microcline-microperthite. Euhedral to subhedral grains of orthoclase are twinned after carlsbad law, but untwinned grains are also common. These grains are clouded and show alteration. In the pegmatites, microcline and microline microperthite are characterized by patchy cross-hatched twinning corroded margin and are lobed in shape. Some of these microcline grains are embayed by quartz and enclose small relics of twinned plagioclase.

Biotite with brown colour and marked pleochroism is present in all the dykes.

Muscovite is colourless and observed to occur in mica pegmatite, forming small flakes. *Tourmaline* is brown in colour, diachroic and shows colour zoning. At times, the minerals form clusters of radiating needles. Tourmaline crystals are six-sided or prismatic with prominent and irregular cross fractures.

Diopside, the only pyroxene, is rare, and restricted to granite aplites only.

Hornblende is common in tonalite aplites. It has the same characters as observed earlier in dolerites and lamprophyres.

Magnetite, *apatite* and *zircon* are the common accessory minerals whereas bluish green *Chlorite*, yellowish *epidote* and *sphene* are the common secondary minerals.

Quartz Veins

Thin milky-white to dirty-white veins of quartz are free from any kind of alteration. Under the microscope quartz veins show a xenomorphic quartz with locally developed cataclastic texture, where quartz grains form fine aggregate and mortar structure. Water clear quartz showing wavy extinction is characterized by trails of opaque inclusions and sutured or lobed outlines. *Magnetite* and *zircon* are scattered throughout the rock.

Calcite Veins

These veins are dull grey in colour and are often tint with reddish brown colour and hence easily distinguishable from the tonalite. The stained thin sections (stained with alizarin red's) indicate that the veins are entirely composed of carbonate minerals, predominantly of calcite which becomes purplish in colour on staining. Colourless dolomite is also present but in small amount. Both calcite and dolomite form large crystals with rhombic cleavage and polysynthetic twinning. *Quartz*, *plagioclase* and *iron oxide* are present in negligible amount.

GEOCHEMISTRY

Nine unaltered representative samples of dykes were analysed by the rapid methods of Shapiro and Branock (1962). The analytical data along with CIPW norms are given in Table 1. Zavaritskii numbers have been calculated and are represented in Table 2. Various ratios calculated from the chemical analyses are also given separately in Table 2. The whole rock analyses indicate the dolerites and lamprophyre to form a group of rocks which are undersaturated to intermediate in terms of SiO_2. The acidic dykes form a silica oversaturated group. The basic dykes are enriched in TiO_2, FeO, Fe_2O_3, CaO, MgO and P_2O_5 and depleted in K_2O and total alkalies as compared to the acidic ones.

In terms of normative composition, dolerites vary from nephline and olivine-bearing to quartz-bearing rocks. Except K252, hypersthene exist in the norm of all the basic rocks. Normative corundum also appears in two of the acidic dykes which have comparatively less Na_2O, though there is no model corundum in these rocks. Appearance of corundum in the norm is considered to be due to the deficiency of alkalies in such rocks. The normative corundum is partially controlled by Na/(Na + K) ratio (Cawthorn and Brown, 1976).

Some important features of the chemistry of these rocks are explained by different plots based on different parameters. In all the plots a single dolerite dyke does show an alkaline affinity and hence its parentage can be doubted since the rock is rich in plagioclase phenocrysts and is unlikely to represent a parent magma composition. The large amount of basic plagioclase caused a considerable decrease in SiO_2.

Solidification index (SI) (Kuno, 1968) calculated for these rocks varies from 21 to 42 though the values for aplites are very low (14 to 0.83). Another index (differentiation index, DI), which is the measure of rocks basicity, fluctuates between 20 to 45 in the basic dykes, 60-74 in quartz-plagioclase pegmatite and above 90 in the aplites. FeO/Fe_2O_3 ratio is high (58) for one of the aplitic rock and shows unsystematic variation in other dykes. Variation of various oxides with respect to differentiation index in the dyke rocks of Kargil Igneous Complex is shown in Figure 2. SiO_2 and K_2O increase with the increase of DI values. In contrast, FeO, Fe_2O_3, MgO and CaO show an opposite trend. Al_2O_3 shows higher values between DI values 30 to 65 and remains almost constant in rest of the part. Na_2O does not follow a systematic change. It has a progressive increase between DI 20 to 45 and decreases thereafter. Aplites give abnormal distribution in the diagram.

Chemical and mineralogical characters of rocks have been discussed with the help of Zavaritskii diagram (Zavaritskii, 1964) which represents various characters of a rock in a very condensed form. All the chemical properties of a rock are represented by only two projections on either sides of SB axis. On the right-hand side of the SB axis in the plot (Fig. 3.), the nearly uniform length of vectors (except K181) is suggestive of iron enrichment. Further the slope of vectors indicate magnesium rather than lime enrichment, except K266. Steepness of vectors on the left-hand side of the diagram is indicative of impoverishment of potash in comparison to soda. Vectors are quite close to SB axis, hence the rocks are not poor in felsic constitutents. The interspace between the vectors

TABLE 1 : CHEMICAL ANALYSES OF DYKE ROCKS

Sr. No. *Sample No.*	*1* *K252*	*2* *K306*	*3* *K108*	*4* *K231*	*5* *K19*	*6* *K244*	*7* *K181*	*8* *K266*	*9* *K103*
SiO_2	45.77	50.56	50.51	48.61	55.65	49.51	75.30	70.60	69.37
TiO_2	2.38	1.28	1.11	1.91	1.28	1.71	0.08	0.12	0.50
Al_2O_3	15.00	15.15	14.75	16.72	16.44	16.94	14.19	15.40	16.75
Fe_2O_3	3.46	1.70	1.96	3.43	2.56	2.28	0.01	0.37	0.35
FeO	9.84	9.21	8.18	8.41	5.23	7.36	0.58	0.58	2.81
MnO	0.12	0.26	0.10	0.13	0.10	0.10	Traces	0.04	Traces
MgO	8.04	8.88	9.20	5.75	4.11	4.21	0.02	0.97	1.55
CaO	10.21	10.05	10.20	8.67	8.23	11.13	1.15	1.32	5.31
Na_2O	3.11	2.01	1.98	3.50	3.51	3.10	2.00	3.87	2.10
K_2O	0.85	0.58	0.51	0.51	1.89	0.72	0.01	6.13	0.53
P_2O_5	0.22	0.14	0.14	0.95	0.31	0.91	Traces	0.01	0.10
H_2O	1.05	0.39	1.25	1.33	0.91	2.26	0.97	0.87	0.54
Total	100.05	100.21	99.92	99.92	100.22	100.23	100.31	100.28	19.91
CIPW Norms									
Q	—	—	0.72	—	4.74	1.20	37.80	20.10	40.14
Or	8.34	3.34	2.78	2.78	11.12	3.89	35.58	36.14	2.78
Ab	15.46	16.77	16.77	29.34	29.34	26.20	16.77	33.01	17.82
An	22.80	30.86	30.02	28.63	23.63	30.30	5.84	6.39	25.58
C	—	—	—	—	—	—	2.24	—	3.47
Ne	5.82	—	—	—	—	—	—	—	—
Di	21.91	14.93	16.92	6.96	13.66	15.92	0.89	2.93	7.86
Hy	—	28.79	26.54	16.20	10.93	11.93	—	—	—
Ol	15.50	—	—	4.64	—	—	—	—	—
Mt	4.42	2.35	3.02	4.87	3.71	3.25	0.23	0.70	0.70
Il	4.56	2.43	2.13	5.17	2.43	3.19	0.15	0.15	0.11
Apt	0.34	0.34	0.34	2.35	0.67	0.02	Traces	Traces	0.34

K 252, K108, K231, K19—Dolerites, K306—Norite dolerite, K 244—Lamprophyre, K181—Granite aplite, K266—Aplite, K103—Quartz-plagioclase pegmatite.

TABLE 2 : ZAVARITSKII VALUES AND VARIOUS RATIOS FOR THE DYKES OF KARGIL IGNEOUS COMPLEX

Zavaritskii Values	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
a	8.8	5.1	5.0	8.4	10.4	8.2	12.2	17.2	5.3
b	32.2	30.0	30.0	26.2	19.6	22.8	6.6	2.6	9.9
c	5.5	7.3	7.3	7.2	5.8	7.9	1.2	2.0	6.4
s	53.5	58.4	57.7	58.2	64.2	61.1	80.1	79.0	78.4
f'	37	34	32	43	37	42	8	37	31
m'	42	50	52	44	42	33	1	63	27
c'	21	16	17	14	21	28	9	0	21
t	4.0	2.0	1.6	2.9	1.7	2.5	0.1	0.1	1.0
v	8	26	6	11	11	9	2	16	4
Ratios									
$FeO+0\cdot9Fe_2O_3 = FeO^t$	12.95	10.74	10.94	11.50	7.53	9.41	0.59	0.91	1.23
FeO^t/MgO	1.61	1.21	1.19	2.01	1.83	2.24	0.30	0.94	0.79
Normative Plagioce Composition	47.5	64.8	64.2	49.4	44.6	53.6	25.8	16.2	58.9
Normative colour Index	46.36	48.70	48.61	37.84	30.73	34.29	1.27	3.78	9.47
$FeO+Fe_2O_3/FeO+Fe_2O_3+MgO$	.62	.55	.52	.67	.65	.70	.96	.49	.67
FeO/Fe_2O_3	0.35	0.10	0.21	0.41	0.49	0.31	0.02	0.64	0.13
Na_2O+K_2O	3.96	2.59	2.49	4.01	5.40	5.82	8.01	10.00	2.63
$2\times Fe_2O_3+FeO$ (as FeO)	16.76	12.61	12.10	15.27	10.35	11.92	0.60	1.32	3.51
'S'	5.66	0.89	0.83	2.87	2.31	2.24	1.99	3.62	0.26
O	24.99	38.57	38.52	31.13	33.46	33.37	42.84	30.76	58.26
DI	20.62	20.11	20.27	32.12	45.20	31.29	90.15	89.25	60.74
SI	31.78	39.68	42.14	26.55	23.76	23.83	0.23	8.14	21.12

'S' —Serial Index (Rittman, 1960)
'O' —0 Index (Sugimura, 1959)

on the left and right hand sides of SB axis is less in acidic dykes as compared to basic ones. From this it is evident that basic dykes are richer in anorthite contents. Positions of the vectors of acidic dykes near the top of the diagram depicts that these rocks are rich in SiO_2 and poor in mafic constitutents. On the contrary, vectors for the basic rocks show moderate enrichment in mafic constitutents and improverishment of SiO_2.

The dyke swarms show a discontinuous variation along tholeiitic and calcalikaline trends. The basic dykes fall

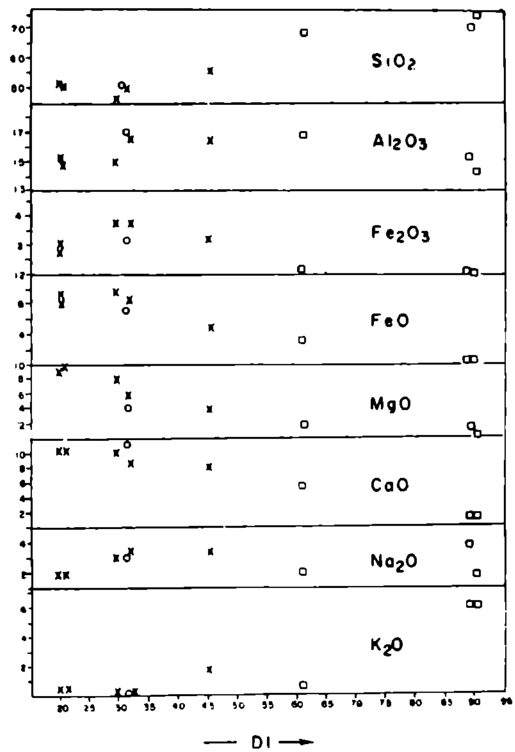

Figure 2. Plot of oxide vs. differentiation index for the dyke rocks.

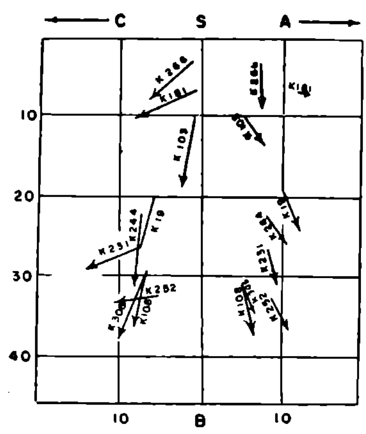

Figure 3. Zavaritskii diagram for the dykes.

in a field of middle stage Karroo dolerites in the AFM diagram (Fig. 4). Among the quartzo-felspathic dykes quartz-plagioclase pegmatite lies very close to this field whereas aplites fall in the 'A' corner.

In order to decipher the parent magmas of these dykes, the weight percentage of elements and normative composition have been used. The alkali-silica diagram (Fig. 5) and Né-Ol'-Q' (normative) triangular diagram (Fig. 6)

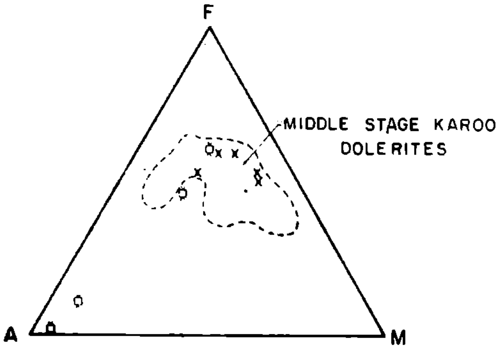

Figure 4. AFM triangular plot showing the distribution of points for various dykes.

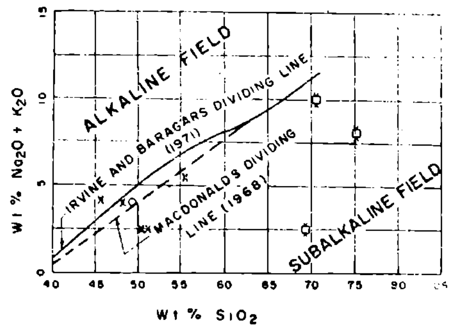

Figure 5. Alkalies-silica variation diagram with different dividing lines between alkaline and subalkaline fields superimposed.

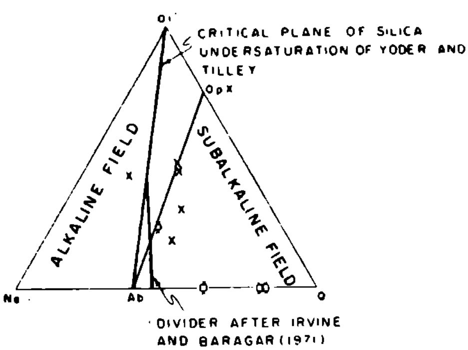

Figure 6. Né-Ol′-Q′ triangular variation in the dykes. Planes of silica undersaturation superimposed.

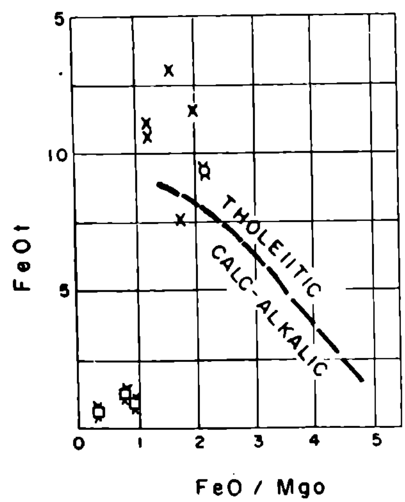

Figure 7. Total iron (FeO^t) vs. iron-magnesium ratio (FeO^t/MgO) plot with tholeiitic and calc-alkalic field.

gave a subalkaline nature for these rocks. There are two major series demarcated within the subalkaline series. FeO^t vs. FeO^t/MgO (Miyashiro, 1974) has been used to further classify these rocks into tholeiitic and calc-alkaline series. Except the porphyritic dolerite, the basic dykes occupy tholeiitic field and acidic dykes lie in the calc-alkaline field (Fig. 7). Normative colour-index has been plotted against normative plagioclase composition (Irvine and Baragar, 1971). Dolerities and lamprophyre fall in the basalt field, quartz-plagioclase pegmatite in the andesitic field and aplites in dacite and rhyolite field (Fig. 8).

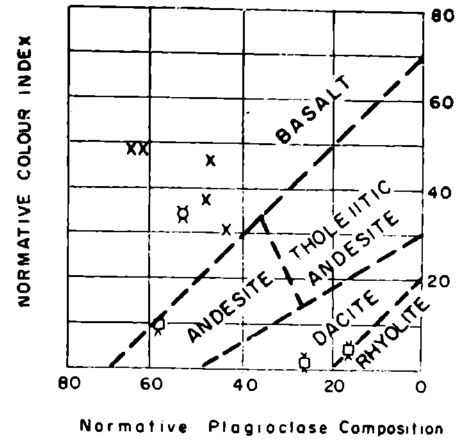

Figure 8. Plot of normative colour index vs. normative plagioclase composition for the dykes.

PETROGENESIS

Swarm of dykes in the Kargil area represents the end phase of magmatic activity in that part. The dykes follow the joint patterns indicating that the host rocks were cooled and joints were developed before the emplacement of dykes. The igneous rocks in which the dykes traversed represents a quite shallow depth of crystallization from which it is evident that the dykes came in nearly subsurface conditions. These rocks differ from each other either in textural feature, mineralogical composition or in their chemical characters. The general trend shown by these rocks (in the oxides vs. DI) misleads one to give a single magmatic origin, yet their wide separation from each other and field relationship do not support this one magma idea. As there is a wide variation in the types of dykes, their origin has to be discussed separately.

Dolerites

Porphyritic to non-porphyritic dolerite dykes are fine- to medium-grained. Due to very small thickness there is no compositional or textural difference from margin to centre. Undersaturated minerals like olivine and nepheline are absent in the studied dykes. In the porphyritic dyke the plagioclose phenocrysts are embedded in a fine groundmass. It is difficult to identify the minerals of the groundmass. Such dykes have been termed as basaltic dykes. The plagioclase phenocrysts are partially corroded and embayed. These characters suggest that the plagioclase were crystallized at depth and during their journey to shallower depth corrosion took place due to release of pressure.

The normal dolerites do not show any significant character. Chemically, dolerites are comparable with the tholeiitic composition. In the AFM diagram (Fig. 4), these rocks plot near the Skaergaard trend but there is a definite deviation from the main Skaergaard trend as established by Wager and Brown (1967) on the initial dry magma. However, it is not possible in the nature to have such a dry melt. Presence of water, beside other volatiles, can cause oxidation of the magma to an appreciable extent. Therefore, the deviation from the main Skaergaard trend is due to the presence of volatiles in the magma responsible for the formation of these rocks. Moreover, these dykes fall well within the superimposed Karroo dolerite field (Fig. 4), a tholeiitic magma has been established for the Karroo dolerites. Therefore, it is conclusive that the dolerites are derived from the tholeiitic magma.

Lamprophyres

Origin of lamprophyres is controversial and the trend of these dykes in the tonalite is more or less parallel to those of dolerites. Hornblende phenocrysts are the characteristic of these rocks. Chemically, the rock is poor in

K_2O and total alkalies. This points towards their affinity with the basic rocks of the area. Hatch *et al.* (1968) considered a dioritic source for lamprophyres containing hornblende and intermediate plagioclase. In general the origin of lamprophyres has been discussed by several workers as a product of alkaline olivine basalt magma which underwent modifications due to assimilation and differentiation under different conditions (Beger, 1923; Bowen, 1928; Bederke, 1947; Eskola, 1954; Kaitaro, 1976; Turner and Verhoogen, 1960; Upton, 1965; Jopline, 1966; Velde, 1967; Hyndman, 1972). According to Nemec (1971) the tholeiitic magma can given rise to such rocks after contamination of alkalies and volatiles at some depth.

In the Karigil area, however, there is no evidence supporting the existence of alkaline olivine basalt magma for the formation of these rocks. At the same time the rocks are poor in alkalies. It seems plausible that the lamprophyres of this area have been derived from a tholeiitic magma, of course, of different phases under high oxygen pressure and in water saturated environment (cf. Lewis, 1973). This would also explain the formation of large phenocrysts of hornblende. Most probably, the temperature of crystallization was depressed by high water content in the magma, thus crystallization of hornblende took place instead of pyroxenes (Barth, 1951, 1962). Mineralogical and geochemical characters of lamprophyres also suggest that the lampropyres are the products of tholeiitic magma.

Aplites and Pegmatites

Aplites and pegmatites are considered to be the last phase of either basic or acidic magma which have enriched in potash and total alkalies after sufficient modification due to the removal of early crystallized material. Aplites and pegmatites, except, quartz-plagioclase pegmatite, are derived from tonalitic and granitic magmas. Formation of quartz-plagioclase pegmatite is quite different from the above mentioned origin. The rock occurs well within the gabbro pluton. Quartz and plagioclase are the chief mineral constituents. Potash feldspar, which should have been dominating, occurs in a subordinate amount. This observation is further supported by a very low K_2O as well as total alkaline as compared to the aplites. Keeping in view these points, the genesis of this rock cannot be correlated with other aplites and pegmatites of the area. On the other hand, it differs from basic dykes not only in colour but also chemically and mineralogically.

Since these rocks have intruded the gabbro quite inside from the margin of the pluton, their origin can be traced to the same magma that was responsible for the gabbro. Occurrence of such leucocratic rocks within the melanocratic rocks has been described by various workers while investigating the ophiolites (Wilson, 1959; Bear, 1960; Brunn, 1960; Thayer and Himmelberg, 1968; Bailey *et al.*, 1970; Moores and Vine, 1971; Davies, 1971; Coleman, 1971; Coleman and Peterman, 1975; Page, 1972). Moores and Vine (1971) concluded that a tholeiitic magma in subcrustal environment can give rise to extensive development of gabbros and leucoratic differentiates. Hence the pegmatite in the gabbro was formed from the residual tholeiitic magma (Rai, 1977) after the crystallization of gabbro pluton.

From the above discussion and various geochemical plottings it can be concluded that these dyke rocks are not derived from a single magma. There were at least two magmas (tholeiitic and calc-alkaline) even at the last phase of igneous activity. It is inferred from the study of these dykes that the evolution of igneous rocks in the Kargil Igneous Complex is related to different magma sources.

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Petrology of Dras Volcanics Around Shamsha and Manjigund South-West Ladakh

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ABSTRACT

Dras Volcanics represent the earliest igneous activity in the Kargil area, a western part of 'Indus Suture Zone.' These volcanic rocks are exposed around Shamsha to the west and Manjigund to the south of Kargil town. Major part of the volcanics is basalt with subordinate amount of andesites and tuffs. The volcanics show low-grade metamorphism. However, along the margins with tonalite and granite intrusions hornfelses have developed due to thermal effect. Petrography and major oxide geochemistry suggest a tholeiitic parent magma for the Dras Volcanics.

INTRODUCTION

A CONTINUOUS belt of volcanics and ultrabasic rocks has been recorded from Gilgit to Hanle, Northwestern Himalaya (Fig. 1). A good geological account of volcanic rocks occurring along the Dras-Burzil section is given by Wadia (1937). However, the rocks of eastern part remained almost unstudied. The volcanics constitute an ophiolite belt (Gansser, 1959, 1964, 1977) that resulted from the subduction of Indian Plate under the Asian Plate (Powell and Conaghan, 1973). It is essentially composed of basaltic and andesitic flows alongwith tuffs. These volcanic rocks are intruded by ultrabasic, basic and acidic plutons. The exact primary nature of these volcanics has been obliterated due to repeated intrusions of various plutons, causing thermal metamorphism along the intrusive contacts. The most significant feature of these volcanics is the presence of limestone blocks and lenses (rafts) of varying shapes and sizes. The linear alignment of the igneous rocks alongwith submarine basic volcanics, along the Indus Suture Zone, and their close association with the Indus Flysch has recently led many workers to postulate various mechanisms of emplacement in the light of the plate-tectonic hypothesis and to speculate on various possibilities regarding the geological conditions prevailing in this northwestern part of Himalaya at that time. This group of rocks has been considered as the only unique example suggesting the Alpine type of eugeosynclinal conditions that existed in Himalayan Orogenic Belt (Gansser, 1959). Later, Powell and Conaghan (1973) postulated this Ladakh area to be a subduction zone between the Indian Plate in the south and the Asian Plate in the north. The Indian Plate moved northward and collided with the Asian Plate, probably during the Upper Cretaceous-Lower Eocene period—the age of the Dras volcanics (Dewey and Bird, 1970; Powell and Conaghan, 1973, 1975; Dewey and Burke, 1973; Graham *et al.*, 1975; Warsi and Molnar, 1977; Frank *et al.*, 1977).

The basic volcanics forming an ophiolitic belt in the Trans-Himalayan Zone and extending from the south of Nanga Parbat in the west to Hanle in the east, have been termed as 'Dras Volcanics' (Wadia, 1937). Wadia (1937) contended that the volcanics are 2000-m thick and are characterized by several lava flows with tuffs, purple and green-coloured volcanic ash and agglomeratic beds containing fragments of shale, chert and jasper. Volcanic activity probably started either in Late Cretaceous or Early Tertiary times. He gave an Eocene age to these volcanics on the basis of fossil finds. The base of volcanics is not exposed any where in the study area, hence their exact thickness could not be calculated.

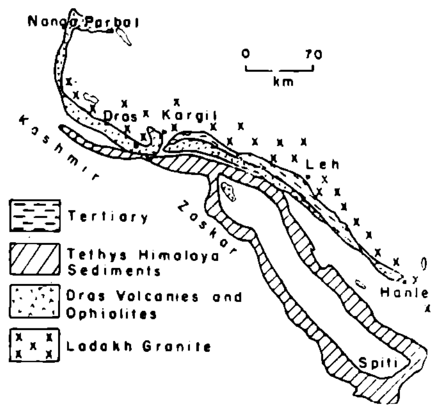

Figure 1. Distribution of Dras Volcanics along the Indus Suture Zone (after Geological Survey of India).

The present paper deals with petrographic and geochemical studies of volcanics, exposed around Shamsha and Manjigund (Kargil area).

GEOLOGICAL SETTING

The Dras volcanics form a thick, dark carapace partially surrounding the intrusive rocks of the Kargil Igneous Complex (Rai and Pande, 1978). To the west of Kargil, volcanics are exposed around Shamsha village on either side of Dras river. The volcanics are again exposed at Manjigund and Chubuk to the south of Kargil town (Fig. 2). At both the localities the volcanics are intruded by tonalite and granite (Rai and Pande, 1978; Pande and

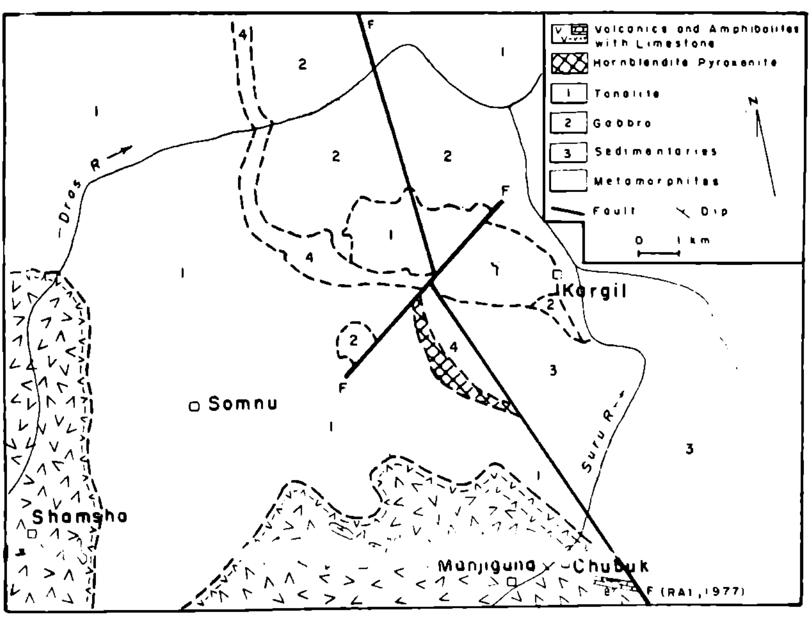

Figure 2. Geological sketch map of the Kargil igneous complex, Ladakh (After Rai, 1977).

Rai, in press). The intrusive contacts are sharp and nearly vertical. A crude foliation parallel to the intrusive contact has developed within the volcanics. Nevertheless, foliation gradually decreases away from the contact and finally disappears rendering the rock perfectly massive. This suggests a forceful intrusion of the younger plutons. Association of limestone blocks or rafts with random orientation is quite common. Dolerites, lamprophyres, aplites, pegmatites and quartz rich dykes cut across these volcanics at several places

PETROGRAPHY

The volcanic rocks have suffered low-grade metamorphism and show chloritization and epidotization. Near the contact with tonalite and granite the rocks show development of relatively higher grade mineral assemblage (hornblende-actinolite assemblage). The volcanic sequence is composed of basic lava flows with rare occurrence of tuffs. Tuffs are characterized by fine flakes of chlorite and dusty cluster of iron oxide with microfolds (Plate I*a*). Well-defined foliation with phenocrysts of orthopyroxene and rarely of talc (Plate I*b*) has developed in the basalts at some places. In general, basaltic rocks show blastophitic texture (Plate I*c*). Andesitic bodies are comparatively fresh and characterized by a porphyritic texture (Plate I*d*).

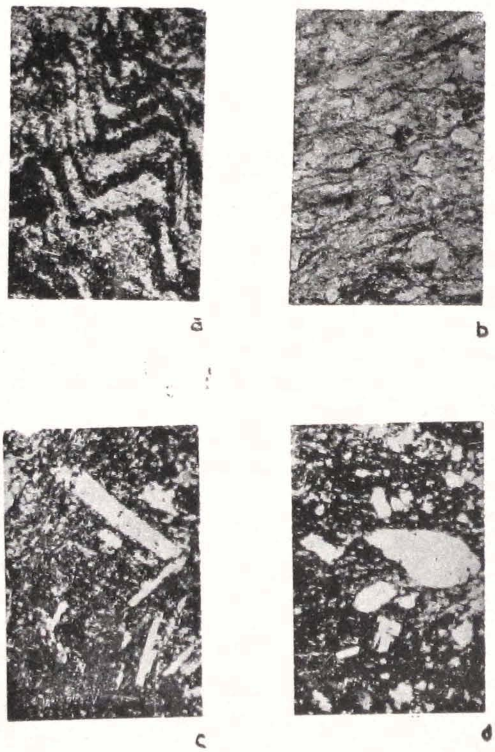

Plate I. **a**. Microfolds in tuffs associated with basic volcanics of Kargil area, × 50. **b**. Volcanics showing development of foliation with orthopyroxene and talc phenocrysts. × 30. **c**. Basaltic texture in the volcanics. Labradorite laths are randomly oriented in a fine groundmass. × 50. **d**. Porphyritic texture in the andesite volcanics. × 30.

The volcanics are constituted by a variety of mineral assemblages represented by plagioclase, pyroxenes, amphiboles, quartz, magnetite, apatite and zircon with variable secondary minerals like epidote, calcite, sphene, chlorite and talc.

PLAGIOCLASE

Colourless, but often clouded, laths of plagioclase (An_{33-67}) range from microlites in the groundmass to well-developed phenocrysts (1 mm to 10 mm). Twinning after Carlsbad and Baveno laws is common while simple albite twins are rare. Saussuritization and epidotization of basic plagioclase is very common. Zoned oligoclase phenocrysts of all shapes are full of iron oxide inclusions.

PYROXENES

Hypersthene is pale green with marked pleochroism (X-pale pink, Y = greenish brown and Z = green) and is characterized by two sets of pyroxenic cleavage. It shows alteration to amphibole.

Augite forms colourless to pale green enhedral and xenomorphic crystals. Pale green variety shows feeble pleochroism. The mineral shows oblique extinction ($Z \wedge C$ (30° to 42°), in some grains extinction is as low as 28°, $2V$ ranges from 56° to 58°.

Rare *diopside* occurs as small anhedral grains with oblique extinction ($Z \wedge C$ = 40°) and its $2V$ is 60°. It shows alteration to amphibole and chlorite.

AMPHIBOLES

Hornblende is pale brown with distinct pleochroism from pale brown to green. The prismatic crystals give low extinction angle ($Z \wedge C$ = 12°-13°), however, $2V$ varies from 66° to 70°. Bluish green *hornblende* is quite common. It forms large tabular laths at times with schiller structures. Pleochroism is: X = greenish yellow, Y = green and Z = deep bluish green. Its extinction angle and $2V$ vary from 14° to 23° and 68° to 71°, respectively. Pale green acicular to prismatic laths or fibrous aggregates of *actinolite* show pleochroism from pale yellowish green to bluish green or green. Prismatic laths are marked by a prominent set of cleavage and cross fractures. Extinction angle is 15° to 18° and has high $2V$ (80°-83°).

Pale yellow *epidote*, light green *chlorite*, clear *calcite*, anhedral *quartz*, brownish *sphene*, and tiny *talc* flakes are the secondary minerals formed at the expense of plagioclase and mafic minerals.

GEOCHEMISTRY

The major elements representing the chemical composition of the volcanic rocks from Shamsha, Manjigund and Chubuk are listed in Table 1 with CIPW norms. Various ratios calculated from the weight percentage of oxides are given in Table 2. Dominant normative minerals are plagioclase, diopside and olivine. On the basis of normative quartz these rocks fall in undersaturated group.

The chemical data plotted in AFM diagram (Fig. 3) shows iron enrichment which points to the tholeiitic nature of the volcanics. Irvine and Baragar (1971) have used 'normative plagioclase composition' either with Al_2O_3 (wt%) or 'normative colour index' to demarcate various field in a sub-alkaline rock series. All the points fall well within the basalt field when the 'normative colour index' is plotted against the 'normative plagioclase composition' (Fig. 4). Tholeiitic nature of these basalts has been established by plotting $Al_{23}O$ vs. normative plagioclase composition (Fig. 5). Similarly, a tholeiitic parentage has been traced out with the help of Miyashiro's (1974) diagrams (Figs. 6, 7).

DISCUSSION

The controversy posed by the Dras Volcanics is due to their unique occurrence forming a linear belt from Nanga Parbat to Hanle and close association with the Indus Flysch. Their southern border is a major tectonic junction and as a result these volcanics are in juxtaposition with the Triassic limestone of Zanskar range. Due to similarity, the Dras Volcanics were previously grouped with the Panjal Traps. Douville (1926) described *Orbitoline* from the limestone collected by Hayden within these volcanics. Later, Wadia (1937) also recorded the occurrence of similar fossils; with these discoveries the age of Dras Volcanics has been finally fixed as Upper Cretaceous to Lower Eocene, which coincides with the first phase of Himalayan Orogeny. Wadia (1937) and Gansser (1964) were of the opinion that these volcanics mainly constitute basalts with less andesites.

TABLE 1—CHEMICAL ANALYSES OF VOLCANIC ROCKS

Oxides	*K 290*	*K 295*	*K 328*	*K 337*	*K 128*	*K 166*	*KV_1*	*KV_2*
SiO_2	47.87	47.10	44.61	43.93	48.10	50.34	48.17	46.90
TiO_2	0.69	0.48	1.51	0.86	0.88	1.15	1.54	0.57
Al_2O_3	15.61	14.77	15.20	16.04	15.93	14.15	15.71	14.72
Fe_2O_3	3.15	2.71	2.43	4.20	1.26	2.44	1.84	3.65
FeO	8.72	8.53	8.73	10.62	6.26	8.39	8.14	9.54
MnO	0.12	0.09	0.11	0.11	0.08	0.12	0.10	0.94
MgO	6.50	7.33	9.60	7.68	7.14	8.05	4.88	5.82
CaO	12.13	12.53	13.05	12.43	13.20	11.31	11.80	14.29
Na_2O	3.81	3.10	2.10	2.10	4.10	1.50	3.05	2.10
K_2O	0.41	2.13	1.00	0.95	1.81	0.41	1.01	0.50
P_2O_5	0.10	0.12	0.11	0.08	0.14	0.02	0.14	0.08
H_2O	0.94	1.16	1.64	1.08	1.14	1.18	1.91	1.13
Total	100.05	100.05	100.09	100.08	100.04	99.06	100.29	100.24
				CIPW-Norms				
Q						3.60		
Or	2.22	12.23	6.12	6.12	10.56	2.22	6.12	2.78
Ab	20.96	6.16	6.42	8.38	2.10	12.58	21.48	15.98
An	26.46	20.29	28.91	31.14	19.74	30.81	26.13	29.19
Ne	5.96	10.86	6.17	5.11	17.61	—	2.21	0.99
Di	28.44	33.38	28.31	24.15	36.41	20.52	25.84	33.96
Hy	—	—	—	—	—	22.65	—	—
Ol	10.71	10.68	15.87	16.16	6.93	—	10.36	9.78
Mt	4.64	3.94	3.48	6.03	1.86	3.48	5.57	5.34
Il	1.37	0.91	2.89	1.67	1.67	2.28	2.89	0.91
Apt	0.34	0.34	0.34	0.34	0.34	Traces	0.34	0.34

TABLE 2—VARIOUS RATIOS AND PARAMETERS FOR VOLCANIC ROCKS

	K290	*K 295*	*K 328*	*K 337*	*K 128*	*K 166*	*KV_1*	*KV_2*
Al_2O_3/SiO_2	0.33	0.31	0.34	0.37	0.33	0.28	0.28	0.31
FeO/Fe_2O_3	2.77	3.15	3.59	2.53	4.97	3.44	2.12	2.61
θ	27.90	18.52	30.41	30.46	22.49	40.87	29.86	30.58
CaO/Na_2O	3.18	4.04	6.21	5.92	3.22	7.54	3.87	6.80
DI	29.14	29.25	18.71	19.61	30.27	18.40	29.81	19.15
$Na_2O + K_2O$	4.22	5.23	3.10	3.05	5.95	1.91	4.06	2.60
Na_2O/K_2O	9.29	1.46	2.10	2.21	2.27	3.66	3.02	4.20
[MgO + FeO + Fe_2O_3 + MgO]	35.15	39.28	46.00	33.97	48.44	42.37	28.77	29.17
[Feo + Fe_2O_3]/[FeO + Fe_2O_3 MgO]	64.62	60.53	53.76	63.06	51.30	57.36	71.06	69.38
[$Na_2O + K_2O$]/[$Na_2O + K_2O$ + CaO] × 100	25.81	29.45	19.20	19.70	30.93	14.45	25.60	15.39
A	16.4	19.7	11.8	10.3	27.1	8.2	16.4	10.3
F	58.3	52.6	51.7	63.9	40.2	47.1	63.9	66.7
M	25.3	27.7	36.5	25.8	32.7	34.7	19.7	23.0
FeO^t	11.56	10.91	10.92	14.40	7.39	10.59	9.80	12.83
FeO^t/MgO	1.78	1.50	1.13	1.88	1.03	1.31	2.00	2.20
Normative plagioclase composition	46.1	47.7	63.4	64.8	40.1	71.00	50.9	62.3
Normative colour index	45.2	48.9	50.6	48.0	46.8	48.9	44.7	50.0

Dras Volcanics were considered to be emplaced along the subduction zone and are of andesitic composition (Powell and Conaghan, 1973). Recently, Frank *et al.* (1977) have classified them as ranging from andesitic to basaltic in composition. These workers have stressed on the presence of albite, although albite occurs only in a few localities (as minor constitutent), but andesine and labradorite are the most common plagioclase feldspars in these rocks. Most of the volcanics studied by the authors from Shamsha, Manjigund and Chubuk contain hornblende and actinolite as the main ferromagnesian minerals. Primary olivine has not been observed in any rock; however, talc as pseudomorphs after olivine is present at places around Shamsha.

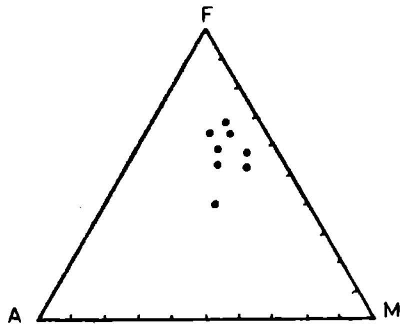

Figure 3. AFM diagram for the volcanic rocks of Kargil Igneous Complex.

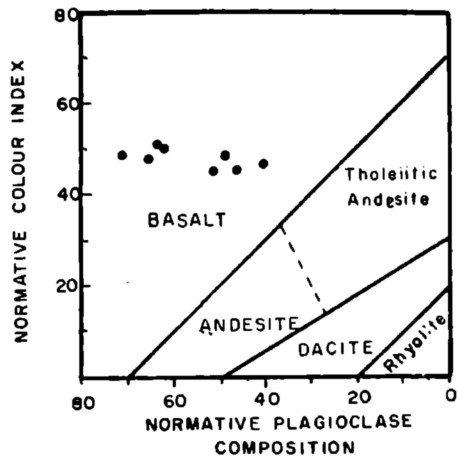

Figure 4. Plot of 'normative colour index' vs 'normative plagioclase composition' for Kargil Volcanics.

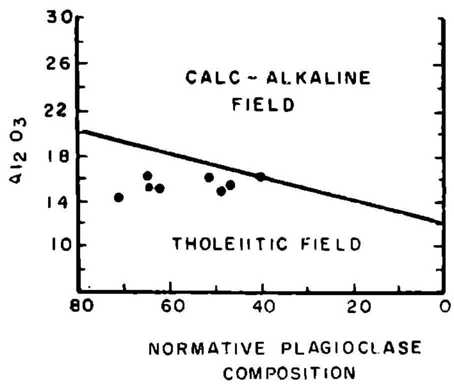

Figure 5. Plot of Al_2O_3 vs 'normative plagioclase composition' for Kargil Volcanics.

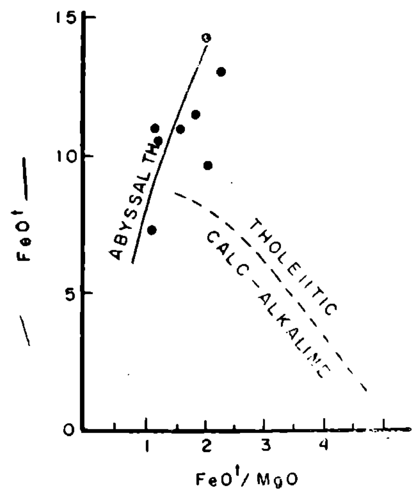

Figure 6. Variations of total iron (FeO) vs FeO'/Mg'O ratio for the volcanics of Kargil area.

Though the present study is confined to a small part of the whole volcanic belt, it is important to note that the basaltic flows are associated with Dras Volcanics. Further, the basalt volcanics are the products of a tholeiitic magma, yet the presence of andesitic volcanics, which are characteristic of calc-alkalic rock series, with these basaltic rocks presented an enigmatic situation. However, Cawthorn and O'Hara (1976) and Allen and Boettcher (1978) held that the fractionation of hornblende from the tholeiite basalt can give rise to andesitic magma. Hence, basaltic and andesitic volcanics were generated from a single tholeiite magma. Volcanism took place more or less with the first phase of Himalayan Orogeny along deep fractures. Therefore, orogenic environment for the basalt-andesite volcanism in the Kargil area is obvious.

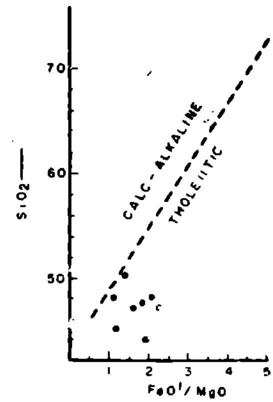

Figure 7. Variations of SiO_2 vs FeOt/Mgo ratio for the volcanics of Kargil area.

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Quaternary Stratigraphy of the Himalaya with Remarks on the Neogene-Quaternary Boundary

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ABSTRACT

The paper discusses in detail the Quaternary stratigraphy of freshwater sediments of the Himalaya which extends from Kashmir in the northwest to Assam in the southeast. The ideal sections for the study of Quaternary deposits of Himalaya include Pinjor and Boulder Conglomerate Formation of the Siwalik Group of Lesser Himalaya; parts of Karewa Formation of Kashmir; fluvio-glacial deposits of the Kargil Basin of Ladakh, Spiti, Kinnaur, Kumaun and eastern Himalaya; fossiliferous and implentiferous deposits of Yangbajain, Nyalam and Yarleb in Tibet, etc. The Pinjor and Boulder Conglomerate Formations of the Siwalik Group and parts of Karewa Formation have yielded rich assemblage of vertebrate and plant fossils which have helped in better understanding of the stratigraphy and palaeoecology of the Quaternary rocks of the Himalaya. In addition the occurrence of human artifacts has also been recorded from several parts of northwestern Himalaya which has thrown significant light on the cultural evolution of the Pre-historic man in this part of the Indian subcontinent.

The boundary between Plio-Pleistocene sediments exposed in different parts of the Himalaya is discussed in detail on the basis of palaeontological, palynological, stratigraphical, radiometric and palaeomagnetic data collected from different parts of the Himalaya.

INTRODUCTION

THE ROCKS belonging to Quaternary age have very wide geographical distribution in the Himalaya and good sections of these are met with in parts of Kashmir, Ladakh, Spiti, Kinnaur, Kumaun, Nepal, Tibet and foothills of the Himalaya. The Karewa Formation of Kashmir and upper units of the Siwalik Group of the foothills offer good sections for the study of Plio-Pleistocene boundary.

I. KASHMIR

A 2000-m thick succession of lacustrine, fluviatile, glacio-fluvial and loessic deposits which were deposited in ancient Karewa lake and are at places interstratified with glacial till of Plio-Pleistocene age is exposed in different parts of the Kashmir valley and these sediments are classified as part of 'Karewa Formation' (Table 1). These sediments lie unconformably above the Panjal Traps, Palaeozoics or the Triassic limestone. Good sections of these are exposed near Pampur, Latopura, Awantipur, Bijbihara, Srinagar Aerodrome, Hirpur, Nagum, Darind, Mirgund, Pattan, Bove, etc.

Several papers have been published during the last few years on various aspects of palaeontology and stratigraphy of the Karewa Formation. Godwin Austen (1859, 1864) was the first to study the Karewas systematically. Lydekker (1883) considered the Lower Karewas to be of mainly fluviatile origin, and Upper Karewas of lacustrine origin. He correlated the Lower Karewas in particular with the Upper Siwaliks, and on this basis assigned them a Lower Pleistocene age. Oldham (1893) also correlated the Lower Karewas with the Upper Siwaliks. Middlemiss (1911, 1924) assigned Pliocene age to the Lower Karewas. Dainelli (1922) recognized the presence of four glacial advances in the Karewas of Kashmir whereas de Terra and Hutchinson (1936) established five glacial advances within these deposits. De Terra and Paterson (1939) studied extensively the Karewa deposits all over the Kashmir valley and considered Lower Karewas to be of fluvio-glacial origin. Sahni (1936*a*, *b*) emphasizing the lacustrine origin for the Karewa deposits discussed the presence of glacial and interglcial phases and the corresponding climatic variations. According to Krishnan (1960), the Lower Karewas are of fluvio-glacial and lacustrine origin and probably pre-glacial in age. Gansser (1964) remarked that the glacial effects are more pronounced in the Upper Karewas and that the bed rock sometimes shows locally developed breccia or conglomerate. The underlying moraines, according to him, are too small and insignificant to be related to 1st glaciation.

TABLE 1—CLASSIFICATION OF THE KAREWA SEDIMENTS OF KASHMIR BASIN

	Singh (1971), *Gupta* (1976)		*Farooqi and Desai* (1974)		*Bhatt* (1976)
PLEISTOCENE	Moraines and terraces of IV Glacial Stage IIIrd Glacial Stage	SHOPIAN FORMATION	Ts—4 Member		
			Ts—3 Member		
	Well-bedded sands and buff clays, silts with boulders and erratics, buff-varved clays and silts		Ts—2 Member		
			Disconformity		
	Basal Boulder Bed IInd Glacial Stage		Ts—1 Member		
	Unconformity		Angular Unconformity		
PLIOCENE	Fine buff and bluish grey clays, silts, sands, gravels varved clays and lignite	POKHARAPURA FORMATION	Laminated clays, minor sand, conglomerate and lignite	NAGUM FORMATION	Three sets of river terraces (Loam Member (older loam) (Laminated (Silt Member (Gravel Member
	1st Glacial Stage				
	Dark carbonaceous shales and sandstones with thick conglomerates and lignite seams				
					Angular Unconformity
			Hirpur Conglomerate Member Boulder Conglomerate		Hirpur Formation—Clays sandy clay, conglomerate, varved sediments, lignite and sand
	Unconformity		Hiatus		Hiatus
Palaeozoic and Mesozoic	Panjal Traps and Triassic Limestones		Panjal Traps and Triassic Limestones		Palaeozoic and Triassic

Bhatt (1965) is of the opinion that the Lower Karewas consist of deposits of pre-glacial, Ist Glacial and Ist Interglacial time whereas the Upper Karewas comprise 2nd Glacial and 2nd Interglacial deposits. In a subsequent paper, Bhatt (1976) has remarked that the Karewa sedimentation began near about Pontian Stage of the Pliocene Period. He considers that the upper limits of the Karewa sedimentation mark a time-transgressive event, i.e., the top of Karewa sequence in the southwestern part of the Kashmir basin signifies the 2nd Interglacial stage of Pleistocene Period whereas Karewa sedimentation transgressed into holocene in the northeastern part of the basin. Bhatt and Chatterjee (1979) have suggested that the Karewas sequence should include only those rock strata which were deposited in the ancient Karewa Lake during Plio-Pleistocene times and followed subsequently by loessic capping. They have stressed that the sediments deposited subsequent to loessic capping, i.e., the present day fluvial and lacustrine deposits should not constitute part of the Karewa sequence. Roy (1975) carried out a detailed study of fossil diatoms from Karewas and assigned Mio-Pliocene age to the Lower Karewas, and Pleistocene age to the Upper Karewas, The details regarding the lithology, classification and morphoclimatic aspects of the Karewa deposits have been discussed in detail by Fort and Gupta (1979).

TABLE 2—GENERALIZED STRATIGRAPHIC SUCCESSION OF THE KAREWA FORMATION

(After Gupta, 1976)

Age/Formation	*Lithology and approximate thickness*	*Predominant fauna and flora*	*Correlation with Siwaliks*
PLEISTOCENE — KAREWA FORMATION — UPPER 609.60 m	Moraines and terraces of IV Glacial Stage III Glacial Stage	Locally abundant fragmentary plant fossils, rich molluscan and ostracode assemblage	
	Well-bedded sands and buff clays, silts with boulder and erratics, buff-varved clays and silts	Rare vertebrate fossils, viz., *Rhinoceros palaeindicus* and *Cervus* sp.	
	Basal Boulder Bed II Glacial Stage		
	Unconformity		Upper Siwaliks: Boulder Conglomerate Pinjor
PLIOCENE — KAREWA FORMATION — LOWER 1674.40m	Fine buff and bluish grey clays, silts, sands, gravels varved clays and lignite seams	Well-preserved fossil leaves, fruits spore of the rose, cinnamon, oak, maple, walnut, trapa; diatoms; *Elephas hysudricus*, *Rhinoceros* sp., *Cervus* sp. and fish remains; locally abundant molluscan and ostracode taxa	
	I Glacial Stage		Tatrot
	Dark carbonaceous shales and sandstones with thick conglomerates and lignite seams Silts and clays Pre-Glacial		
	Unconformity		
Palaeozoic	Panjal Traps and Triassic Limestone		

The Karewa deposits have yielded a rich and diverse fauna and flora which among others include ostrocodes, molluscs, vertebrate fossils, charophytes, plant leaves, fruits, diatoms, spores and pollens, etc. (Gupta, 1976).

The Karewa Formation has been the subject of discussion for a long time in view of the good sections which it offers for the study of Neogene-Quaternary boundary. As discussed above, the opinions regarding the lower and upper age limits of the Karewa Formation vary considerably and they range from Miocene to Pleistocene.

The Lower Karewas have generally been correlated with the Upper Siwaliks. Lydekker (1883) assigned Pliocene age to the Lower Karewas whereas De Terra and Paterson (1939) considered them to be of Pleistocene age on the basis of the find of *Elephas hysudricus* in them and correlated them with the Pinjor Formation of the Upper Siwaliks. Middlemiss (1911, 1924) and Wadia (1941, 1951) assigned Plio-Pleistocene age to the Karewa Formation. Pilgrim (1944) correlated the Lower Karewas with the Lower Boulder Conglomerate Formation. According to Wadia (1957), it is impossible to draw the Plio-Pleistocene boundary in the thick sequence of Lower Karewas and he is of the opinion that the basal beds of the Lower Karewas may reach a horizon as old as the Dhok Pathan Formation (Pontian).

Agrawal *et al.* (1981) on the basis of palaeomagnetic measurements of the samples from the Kerawa Formation have suggested that the Neogene-Quaternary boundary lies between conglomerates III and II of the zonal classification of Hirpur Formation as proposed by Bhatt and Chatterjee (1979) and basing olduvai palaeomanetic event (1.75-1.91 m.y.) as the N/Q boundary. According to them "Palaeomagnetic measurements probably indicate that the Nagums are in the Brunhes Normal Epoch (< 720,000); a Matuyama Reversal Epoch was detected in a 10 m thick deposit below conglomerate III; most of the sand and mud deposits below and above conglomerate II indicate Gauss Normal Epoch (2.47-3.41 m.y.); the Gilbert Reversed Epoch (3.41 to 5.44 m.y.) is witnessed above conglomerate I. This chronology is only preliminary and is subject to revision with our more detailed measurements."

TABLE 3— CORRELATION OF SIWALIK GROUP

		Potwar/Chandigarh/Nalagarh, etc.	*Poonch*	*Tawi Valley (Jammu)*	*Kangra*
SIWALIK GROUP	Upper Siwalik *Sub-Group*	Boulder Conglomerate Formation	Upper	Bahu Conglomerate	Boulder Conglomerate Formation
		Pinjore Formation	Siwalik		
		Tatrot Formation		Nagrota Formation	Upper
	Middle Siwalik *Sub-Group*	Dhok Pathan Formation	Sand Rock Formation		Alternations
		Nagri Formation		Bantalao Formation	Lower
		Chinji Formation	Helan Formation	Nandini Formation	Alternations
		Kamlial Formation	Mang Formation Palandri Formation	Jhajjar Formation	Nahan Formation Infra Nahan Formation
	Lower Siwalik *Sub-Group*	Upper Murree Group	Upper Murree Group	Khud Palkhei Formation	Upper Dharamsala Group

The author is of the opinion that considerable work with multidisciplinary approach still needs to be done on the Karewa sediments to work out microstratigraphy before anything definite can be said about N/Q boundary. Till such time the widely accepted palaeontological criterion (vertebrate fossils, ostracodes, charophytes, etc.) should be taken for consideration to demarcate the N/Q boundary within the Karewa Formation, i.e., the angular unconformity between the lower and upper Kårewas or between Pokharapura and Shopian Formations of Farooqi and Desai (1974) or Hirpur and Nagum Formations of Bhatt (1976).

II. LADAKH

The Quaternary sediments in the Ladakh region of the Himalaya are fairly well-developed along the Indus valley and these are generally represented by morainic, fluvioglacial, slush-flowed and preglacial deposits. The geomorphological aspects of these sediments have been discussed in detail by Fort (1982). According to her, the Indus valley appears to represent a wide furrow running parallel to the main morpho-structural units of the Himalayas (WNW-ESE) and located along the Indus Suture Line. On the basis of her investigations in the Leh Basin, Indus valley and Zanskar region, she has correlated the gemorphological features of the three regions. For details, reference may be made to the paper by Fort (1982) published in this volume.

At Lamayuru the remnants of lacustrine deposits of Quaternary age lie at an altitude of 3600 m. The erosion of these after the first glaciation has led to the formation of a deep gorge about 600 m deep through which flows the tributary of Indus.

Late to Postglacial terraces are also well developed in the Quaternary basin of Kargil. These were investigated long time back by De Terra (1935) who mentions the presence of argillaceous, well-bedded lacustrine horizons above the gravel beds which constitute bed rock in the deepest gorges. The sharp contact of these beds suggests sudden damming due to landslide below Kargil. According to De Terra (1935) these events happened after the Second Glaciation and he believes that the 3rd Glaciation only partially covered the Kargil area. Burgisser *et al.* (1982) have suggested that this lake most probably was formed after the strong erosion following the 3rd Glaciation.

The remnants of Quaternary lake deposits can also be seen in the large basin of Khapalu, along the Shyok river but these sediments have mostly been eroded by strong fluvial activity. According to Burgisser *et al.* (1982), "some floods might have been caused by the breakthrough of a lake dammed by landslide and moraine material in the upper Hushe valley at the front of Masherbrum." Gansser (1980) observed the presence of well-bedded salty to fine sandy lacustrine sediments at this locality. Thomson (1852) and Nieve (1913) recorded widespread occurrence of such Quaternary deposits in the large basin further up the Shyok river at the confluence with the

Nubra. Quaternary lake deposits also occur near Chula in the middle Zanskar. Similar deposits have also been recorded from west of Skardu which were formed due to damming of the Skardu Lake.

III. SPITI

The occurrence of Late Pleistocene to Subrecent (?) lacustrine deposits have been recorded by Jain *et al.* (1969) from near Jete in the upper Spiti valley. These deposits have yielded ostracodes (*Cypridopsis vidua, Herpetocypris* sp; *Candona candida*), fruits of chara and dimunitive gastropods. The fluvioglacial deposits and glacial moraines of Quaternary age have very wide geographical distribution throughout the Spiti valley.

IV. KUMAUN

The Quaternary lacustrine deposits are exposed near the village Garbyang. These deposits were formed due to damming of Kali river by glacial moraines and landslides of Budhi (Heim and Gansser, 1939). The middle part of lacustrine deposits at this locality is intermingled with lateral glacial moraines which might have come from the Tinkar valley indicating the influence of side-valley glaciers of the last glaciation on the lake sediments.

V. KINNAUR

The Quaternary deposits similar to those of Ladakh as discussed earlier are exposed in the upper reaches of Sangla valley and Sutlej valley of Kinnaur District, Himachal Pradesh (Gupta, 1976).

VI. NEPAL

VI.1 Kathmandu Valley

The Kathmandu valley is covered by a thick succession of Plio-Pleistocene and Recent sediments of fluviatile and lacustrine nature which are represented by clays, sand clays, silts, micaceous sandstones, carbonaceous clays, peat and lignite. These sediments are well-exposed near the Tribhawan Air port, Pashupatinath temple, opposite the Guneshwari Temple, Lovenkhel, Lokundol, Harishidhi, Khumbolkhola, Kokdukhola, Gulkhola etc. The thickness of these sediments varies considerably from one place to another and the thickest (500 meters) sequence is developed near Harishidhi. The generalised sequence of the Kathmandu valley sediments as exposed in the field is as follows :

KATHMANDU VALLEY	UPPER	4. Mountain wash and talus
		3. Pebbles, coarse sand, fine sand and sandy clay
SEDIMENTS	LOWER	2. Carbonaceous clay (Kalimati)
		1. Boulder Bed

The occurrence of Plio-Pleistocene vertebrate fossils from the Kathmandu valley sediments has been recorded by Sharma (1973) and Gupta (1975). Sharma (1973) figured a tooth of *Stegodon* whereas Gupta (1975) reported specimens of *Elephas planifrons, Hexapropodon sivalensis* and *Crocodylus* sp. from the hard clay bands overlying the lignite beds exposed near Lokundol (adjoining Chapagaon at the head portion of Nakhukhola) in the Kathmandu valley. These fossils are identical to those known from the Upper Karewa Formation of Kashmir and the Pinjaur Formation of the Siwalik Group. The fossils are indicative of Lower Pleistocene age for the beds yielding them though the possibility of these representing in part Pliocene succession cannot be rulted out.

The upper part of the Kathmandu valley sediments has very wide geographical distribution throughout the Kathmandu valley. For details of the geology and stratigraphic aspects of the Kathmandu valley sediments reference may be made to the paper by Fort and Gupta (1979).

VI.2. Pokhara Basin

The Pokhara basin (900 m) is located at the foot of the hills of the Annapurna range (8000 m). Four different types of Quaternary deposits can be recognised in the Pokhara basin, i.e., calcareous breccias, weathered alluvial deposits, calcareous gravelled deposits and Recent alluvial deposits.

The calcareous breccias which is essentially composed of dolomitic elements with a little amount of calc-schists and crystallophyllian is of two generations. The first generation breccia outcrop on the lower ridge around the basin and represents a slope deposit reworked by torrential sheet of flows, probably a part of ancient aggraded sediment. The breccias of second generation are found against the lower slopes of the Seti valley where they fossilize the steep flanks of the former Seti valley and can be interpreted as slides or coarse slope deposits.

The weathered alluvial deposits are exposed at a few places only and are represented by boulders and gravels of metamorphosed elements. These deposits represent remnants of an older Seti Khola course.

The calcareous gravelly deposits constitute the main filling of the Pokhara Basin. These deposits have been variously interpreted as of lacustrine, fluviatile or fluvio-glacial origin by different workers. According to Fort and Gupta (1982) there must have existed small lakes which were laterally dammed by the huge deposits of sediments carried by Seti river. The relative low percentage of gneissic elements (Tibetan slab) supports reworking of morainic deposits accumulated in the inner part of the High range. The high percentage of lime (element and matrix) explains the local strong induration and development of karstic phenomena.

The Recent alluvial deposits occur as thin cover on the different-staged terraces of Seti river and are recognisable by their high percentage of gneissic and schistose elements.

VII. TIBET

The Late Glaciation lacustrine deposits are developed along the Tsangpo river and its tributaries lying between the Himalayan and Trans-Himalaya zones. The lower sedimentation in this area has played an important role and influenced the corresponding lakes of the upper Indus. The lacustrine sediments of Quaternary age are very widespread in the Southern Tibet. The occurrence of fossiliferous and implentiferous deposits of Quaternary age has been recorded from Yangbajain, Nyalam and Yarleb in Tibet, etc. (Academia Sinica, 1980*a*, *b*).

VIII. FOOT-HILL ZONE

The Quaternary deposits in the foot-hill zones are represented by the Pinjor and Boulder Conglomerate Formation constituting upper part of the Siwalik Group. These deposits are developed all along the foot-hill zone of the Himalaya but good sections of these are developed in the Haritalyangar area of Bilaspur (i.e., Chakrana, Bhapral, Lanjhata, Mianse, Mehrana and Gandharuin), Kangra valley, Hamirpur, Udhampur area of Jammu, sections exposed near Chandigarh and Kalka, Naraingarh Tehsil of Ambala and Mohand area near Dehradun. Recently, presence of these deposits has been recorded from north of Gidhniya village in the Dang valley of Western Nepal. For details of the lithology of the Upper Siwalik rocks and their classification reference may be made to Gupta (1976).

The Upper Siwalik rocks (Tatrot, Pinjor and Boulder Conglomerate Formations) have yielded a rich and varied fauna on the basis of which precise stratigraphic position of the various units has been defined. The vertebrate fauna, charophytes and ostracodes from the Tatrot Formation indicate Upper Pliocene age for it. Of the vertebrate fossils recorded from the Upper Siwaliks, *Pentalophodon khetpuralensis*, *Stegodon bombiforms*, *Hipparion antelopinum* and *Hippophyus tatroti* are essentially restricted to the Tatrot Formation.

The Pinjor Formation is characterized by the presence of *Archidiskodon*, *Equus* and *Leptobos* and the fauna in general is suggestive of Villafranchian age for it. Varying opinions have been expressed from time to time to define the Neogene-Quaternary Boundary within these sediments and all these views have been synthesized in detail by Prasad (1975), Gupta (1976), and Agrawal *et al.* (1981). The palaeomagnetic studies in recent years support the view that the fauna consisting of *Equus*, *Elephas* and *Bos* appeared 2.47 m.y. at the base of Gauss/Matuyama boundary (Opdyke *et al.*, 1979). This boundary coincides with the Tatrot/Pinjor boundary and the Olduvian event falls within the Pinjor Formation (Agrawal *et al.*, 1981).

It is now generally accepted that the Pliocene-Pleistocene boundary can be recognised at the Olduvai normal magnetic event which is approximately 1.8 m.y. before present (Nikiforova, 1978).

The occurrence of vertebrate fossils has recently been recorded from Western Nepal (Munthe and Gupta, 1982). This fauna was collected from badland exposures immediately north of Gidhniya village and includes *Stegodon insignis*, *Elephas planifrons*, *Equus siwalensis*, *Hexapropodon sivalensis*, *Cervus sp.* and two taxa of bovids. The Gidhniya assemblage is correlatable with the Pinjor Formation and may be between 1.5 and 2.9 million years. Gidhniya fauna can be related to the Pliocene-Pleistocene boundary on the basis of concurrent ranges of fossils and available palaeomagnetic data from Pakistan. The precise correlation of the fossiliferous beds is difficult in view of the fragmentary nature of the specimens. More search is needed for better collection of the material before anything finally can be said regarding its exact age. In addition to this, Sharma (1973) has also figured a mandible of the hippopotamus *Hexaprotodon* from Janakpur in Eastern Nepal.

The well-developed river terraces along the major rivers in different parts of the northwestern Himalaya have yielded human artifacts which have thrown significant light on the cultural evolution of the Pre-historic man in this part of the Indian sub-continent.

IX. CONCLUSION

The lacustrine, glacial, fluvio-glacial and fluviatile deposits of Quaternary age are very widely distributed throughout the entire stretch of the Himalaya. In the higher Himalayas these deposits were essentially formed due to blocking of river courses by glaciers, landslides, etc., and were short-lived. Detailed stratigraphical sedimentological, palynological and geochemical work is needed to establish the geological history of these deposits. Systematic work on these deposits may lead to the proper understanding of the morphotectonic features and evolution of the Himalaya during the Quaternary Period.

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Remarks on the Age of the Otoceras woodwardi Zone and other Otoceras-bearing Beds

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ABSTRACT

The youngest marine Permian of the world is well-developed in South China. The Upper Permian Changhsingian in its type region is younger than the Dorashamian as indicated by the Upperr Changhsingian conodonts found above the Dorashamian. The uppermost part of the Changhsingian as defined by Zhao *et al.* (1978) is contemporaneous with the *Otoceras woodwardi* Zone. *Otoceras* cf. *woodwardi* does not occur above the Changhsingian as reported by Tozer (1979). This species is not an *Otoceras* and it derives in fact from a *Koninckites-Paratirolites* fauna according to the new data published by the Chinese ammonoid workers and it occurs about 40 m above the Changhsingian.

Real *Otoceras* has now been reported by Zhao *et al.* (1981) from the unnamed ammonoid zone forming the topmost part of Changhsingian as defined by Zhao *et al.* (1978). On the basis of the new findings of *Otoceras* this typical Upper Permian fauna (even with the latest *Pseudogastrioceras*) is considered by Zhao *et al.* (1981) to be part of the Triassic.

The present paper discusses in detail the Permian character of this fauna.

INTRODUCTION AND DISCUSSION

THE OPINIONS regarding the age of *Otoceras*-bearing beds differ considerably. At the turn of the century the *Otoceras*-bearing beds and the *Otoceras woodwardi* Zone were never equated. The *Otoceras*-bearing beds were placed entirely or at least to some extent in the Upper Permian. The *Otoceras woodwardi* Zone was included by some authors into the Triassic (e.g., Mojsisovics *et al.*, 1895), and by others into the Upper Permian (e.g., Noetling, 1901). The *Otoceras woodwardi* Zone *sensu* Mojsisovics *et al.* (1895) in addition to the *Otoceras woodwardi* Zone *sensu stricto* comprises the Lower and Middle Scythian. With the exception of *Ophiceras* all ammonoid genera that according to Mojsisovics *et al.* (1895) support the Triassic age of this zone (in spite of the Palaeozoic holdovers *Otoceras* and *Episageceras*) are not present in the *Otoceras woodwardi* Zone. These genera come from the beds younger than the *Otoceras woodwardi* Zone (Kozur, 1972, 1974, 1978). Noetling (1971) classified the *Otoceras woodwardi* Zone *s.l.* in the *Otoceras woodwardi* Zone *s.str.* (in this sense it is used also today) and suggested the *Ophiceras tibeticum* Zone and the *Meekoceras noetlingi*. Therefore according to him the *Otoceras* is a representative of an Upper Permian ammonoid family (that was accepted at that time by all ammonoid workers) and he considered the *Otoceras woodwardi* Zone to be of Upper Permian age. According to the priority the *Otoceras woodwardi* Zone (in its present day scope) belongs to the Upper Permian.

Subsequent to Noetling's (1901) publication, most of the ammonoid workers placed the *Otoceras woodwardi* Zone into the Triassic as the paper by Noetling (1901) was not well-known. In spite of this fact, the *Otoceras woodwardi* Zone was used in the sense of Noetling (1901) by several workers. Mojsisovics *et al.* (1895) certainly did not place the *Otoceras woodwardi* Zone *s.str.* into the Triassic, because they regarded *Otoceras* and *Episage-*

ceras as Palaeozoic genera and considered the *Otocerus woodwardi* Zone to be of Triassic age on the basis of ammonoid genera that are not present in the *Otoceras woodwardi* Zone *s.str.*, but are found only in the real Triassic ammonoid zones above it.

The Permian faunal elements were found by several workers in the *Otoceras woodwardi* Zone and according to some of them these faunal elements could be reworked. As a result several papers on the occurrence of Permo-Triassic 'mixed faunas' from the *Otoceras woodwardi* Zone were published. The 'Triassic' ammonoid genus *Otoceras* and 'Triassic' bivalves were found associated with Permian brachiopods, conodonts, foraminifers, etc. But *Otoceras* is by no means a Triassic ammonoid genus. On the contrary it is the last representative of a typical Upper Permian superfamily. The 'Triassic' bivalves (*Claraia, Eumorphotis venetiana, Leptochondria minima, Promyalina* sp.) are either known from a little deeper section of the undisputed uppermost Permian beds (*Claraia*) or the immediate forerunners of these species are quite unknown in the underlying undisputed uppermost Permian due to facial variations. So, the occurrence of these faunas in the *Otoceras woodwardi* Zone is most probably a facies-controlled event. Certainly it is difficult to say so is '*Triassic*' bivalves, if the immediately forerunners of these are unknown from the underlying undisputed topmost Permian beds due to facial changes. Biostratigraphy has to be based on phylomorphogenetic lines and not on the facies-controlled occurrence of some species. So, in fact the *Otoceras woodwardi* Zone has in its lower part a Permian fauna without the presence of Triassic elements. The first Triassic elements (e.g., *Anchignathodus parvus*† is at the conodonts) appears in the younger horizons. Even these are in fact the last elements of Upper Palaeozoic groups that straddle the Permian-Triassic boundary. *Anchignathodus* is frequently found in the Upper Carboniferous and Permian and is a very conservative genus. Some new species and even genera evolved from the long-ranging *A. minutus* border the Permian-Triassic boundary and these conodonts disappear near the top of the *Ophiceras commune* Zone which has been considered to demarcate the Permian-Triassic boundary by Newell (in : Logan and Hills, 1973). No Triassic faunal elements were reported from the *Otoceras* (*Julfotoceras*) *concavum* Zone. Even the 'Triassic' bivalves (with the exception of *Claraia*) are unknown from this zone that has yielded quite typical Upper Permian condont and brachiopod faunas.

During the last few years some authors have placed both the *Otoceras*-bearing beds as well as the Otoceras (*Julfotoceras*) *concavum* and *Otoceras woodwardi* Zones into the Upper Permian (Bhatt, 1979; Gupta, 1982; Bando *et al.*, 1980; Foster, 1982; Kozur, 1972, 1973, 1974, 1977*a*, *b*, 1980; Newell, 1973, 1978; Waterhouse, 1973, 1976*a*, *b*, 1979; Waterhouse and Gupta, 1975). Other workers continue to place the *Otoceras concavum* and *Otoceras woodwardi* Zones (and some authors even all *Otoceras*-bearing beds) into the Triassic (e.g., Nakazawa *et al.*, 1980; Tozer, 1979; Zhao *et al.*, 1981). However, in those sections where *Otoceras* is not found, the time equivalent of these beds has generally been considered equivalent of the beds corresponding to the *Otoceras woodwardi* Zone. This is evident from the fact that the topmost zone of the Changhsingian (unnamed zone by Zhao *et al.* (1978)) with *Pseudogastrioceras* (the last goniatite genus), a lot of Permian brachiopods and other Permian elements was classified by all the workers into the topmost Permian until Zhao *et al.* (1981) reported the occurrence of *Otoceras* in these beds.

Two arguments generally used in support of the Triassic age of the *Otoceras*-bearing beds are :

(*a*) Zhao *et al.* (1981) wrote that the *Otoceras* fauna cannot be contemporaneous with the *Paratirolites* beds of Transcaucasia, because no *Otoceras* was found in the South Chinese Changhsingian. This opinion may stem from different taxonomic views. In our opinion (see also Bando *et al.*, 1980) *Julfotoceras* Bando is a subgenus of *Otoceras* Griesbach. But *Otoceras* (*Julfotoceras*) *tarazi* (Bando) appears first in the topmost Dzhulfian and disappears a little below the top of the Dorashamian. Therefore, the *Otoceras*-bearing beds are time-equivalents of the Dorashamian, but reach a little higher than the topmost Dorashamian *Paratirolites* Zone (see Kozur, 1980; Bando *et al.*, 1980). The question of the age of the *Otoceras* fauna is more or less a taxonomic one—the problem of the taxonomic position of *Julfotoceras*. If *Julfotoceras* is an independent genus, then also *Otoceras* (*Julfotoceras*) *concavum* must belong to the genus. In that case, the first *Otoceras* would begin above the *O.* (*J.*) *concavum* Zone.

(*b*) Tozer (1979) restudied the two specimens of *Otoceras* cf. *woodwardi* from the Lower Triassic of China from the beds above the Changhsingian as defined by Zhao *et al.* (1978). According to Tozer (1979), South China is the first place in the world, where a Changhsingian fauna is followed by an *Otoceras* fauna

†In the multielement taxonomy *Hindeodus parvus*.

that must therefore be younger than the topmost Permian Changhsingian. We cannot follow this conclusion for two reasons : (i) in all sections of South China without or only with a minor gap at the Permian-Triassic boundary the topmost Changhsingian is followed by *Ophiceras* faunas without *Otoceras*; (ii) the two specimens of *Otoceras* cf. *woodwardi* reported by Hsu (1937) are very imperfect questionable specimens and even the exact horizon from which they were collected is not known with certainty till today.

In the section with *Otoceras* cf. *woodwardi* the two topmost zones of the Changhsingian, i.e., the *Rotodiscoceras asiaticum* Zone and the unnamed zone *sensu* Zhao *et al.* (1978) are missing. Theoretically, the two very imperfact specimens of *Otoceras* (if at all they belong to *Otoceras*) could be reworked. According to a written communication of Prof. K. Nakazawa, Kyoto (Japan) the ammonoid material published by Hsu (1937) was restudied by Chinese ammonoid specialists. They found that the two specimens of *Otoceras* cf. *woodwardi* reported by Hsu (1937) belong to *Koninckites* and occur about 40m above the base of the Triassic. According to Chen *et al.* (1982), the so-called '*Otoceras* beds' in the suburbs of Nanjing are in reality beds with *Koninckites* and *Paranorites*. As such it can be inferred that there is no *Otoceras* above the Changhsingian in South China as postulated by Zhao *et al.* (1978).

Kozur (1980) predicted the occurrence of *Otoceras woodwardi* and *Otoceras* (*Julfotoceras*) *concavum* in the transitional beds and in the unnamed topmost Changhsingian ammonoid zone (*sensu* Zhao *et al.*, 1978). The *Otoceras* (*Julfotoceras*) *concavum* fauna may be even present in deeper parts of the Upper Changhsingian. These assumptions of Kozur were proved true when Zhao *et al.* (1981) recorded the find of *Otoceras* together with *Glyptophiceras*, *Xenodiscus* (= *Hypophiceras*) and *Pseudogastrioceras* (!) alongwith *Claraia* (?) sp. and a large number of Permian brachiopods. This is in fact the first record of *Otoceras* in South China and this genus has not been found in the Lower Triassic rocks but occurs in the topmost Changhsingian as propounded by Zhao *et al.* (1978).

As predicted by Kozur (1972-80) all time-equivalents of *Otoceras*-bearing beds will be placed into the Upper Permian if *Otoceras* were not present, because all the other faunal elements are clearly Permian. In that eventuality, when *Otoceras*—the last representative of the Upper Permian superfamily Otoceratacea—would be found, this fauna will be placed into the Triassic. Exactly this happened now with the uppermost (unnamed) ammonoid zone of the Changhsingian as defined by Zhao *et al.* (1978). After the finding of *Otoceras* this zone has been replaced from the topmost Changhsingian and assigned to the basal Triassic age by Zhao *et al.* (1981), in spite of the rich Upper Permian fauna and flora found associated with it.

Before discussing the Permian character of the *Otoceras*-bearing beds it may be appropriate to remark briefly on the Dorashamian and Changhsingian Stages of China. This problem has been discussed in detail by Kozur (in press).

Zhao *et al.* (1978) considered within the Changhsingian of South China all ammonoid zones above the *Pseudostephanites-Tapashanites* Zones as younger than the Dorashamian. All other authors regarded the whole Changhsingian as time-equivalent of the Dorashamian.

The new conodont data published by Wang and Wang (1981) and Zhao *et al.* (1981) show that the reality lies between these two opinions, but near to the view point of Zhao *et al.* (1978). According to Kozur (1980), the presence of *Iranites-Phisonites* Zone of South China was never proven there and this has been recently confirmed by Zhao *et al.* (1981). These workers have placed the boundary between the Lower and Upper Changhsingian Stage as lying between the *Tapashanites-Pseudostephanites* Zone (Lower Changhsingian) and the *Pseudotirolites-Pleuronodoceras* Zone. The upper part of the Lower Changhsingian is characterized by the *Gonodella carinata* Clark (= *Neogondolella subcarinata changxingensis* Wang and Wang).† The last representatives of *Gondolella subcarinata elongata* (Wang and Wang) occur there in association with this species. This conodont fauna is quite the same as the one found in the topmost parts of the Upper Dorashamian *Paratirolites* beds.

The conodont fauna from the Upper Changhsingian is characterized by the presence of *Gondolella carinata*, *G. subcarinata subcarinata*, *Anchignathodus minutus*, *A. parvus*, but without *Gondolella subcarinata elongata*. This conodont assemblage is different from the conodont fauna known from the topmost Dorashamian. It is restricted to the 2 m thick 'unfossiliferous' beds (without macrofauna) lying above the *Paratirolites* beds and below the

†This synonymy is of little significance in stratigraphy, because Wang and Wang (1981) reported '*Neogondolella*' *subcarinata changxingensis* in all sections always occurring together with *Gondolella carinata* that begins quite in the same level as '*Neogondolella*' *subcarinata changxingensis*.

TABLE 1—CONODONT RANGES IN THE TOPMOST PERMIAN AND LOWERMOST TRIASSIC OF SOUTH CHINA AND TRANSCAUCASIA. ALSO THE RANGE OF THE *HOLLINELLA TINGI* FAUNA (OSTRACODA) IS INDICATED (UPPER RANGE UNKNOWN UNTIL NOW)

Proposed subdivision				*South China*		*Transcaucasia*	
Series	Stage	Substage			*Hollinella tingi*, *Isarcicella isarcica*, *Anchignathodus parvus*, *Gondolella carinata*, *Gondolella subc. subcarinata*, *Gondolella subc. elongata*		*Hollinella tingi*, *Isarcicella isarcica*, *Anchignathodus parvus*, *Gondolella carinata*, *G. subcarinata subcarinata*, *G. orientalis*, *G. subcarinata elongata*
Lower Triassic	Brahmanian	Gandarian Ellesmerian			*Ophiceras* + *Claraia wangi*		*Claraia*, *Ophiceras*
Upper Permian	Changhsingian	Upper Changhsingian	Gangetian	Changhsingian Upper	*Unnamed zone* *Totodiscoceras zone* *Pseudotirolites Pleuronodoceras Zone*		No macrofauna
				Changhsingian Lower	*Pseudostephanites-Tapashanites Zone*	Dorashamian	*Paratirolites fauna* *Shevyrevties-Iranites fauna*
		Lower Changhsingian	Dorashamian		?*Shevyrevites* fauna		*Phisonites* fauna

TABLE 2—RANGES OF CONODONTS AND *HOLLINELLA TINGI* IN THE *O. WOODWARDI* AND *O. (J.) CONCAVUM* ZONES IN THE HIMALAYA

System	*Substage*	*Ammonaid Zone*	*Hollinella tingi*, *Isarcicella isarcica*, *Anchignathodus parvus*, *Gondolella carinata*, *G. subcarinata subcarinata*, *G. orientalis*
Triassic	Ellesmerian	*Ophiceras tibeticum*	
Upper Permian		*Octoceras woodwardi*	
		Octoceras (Julfotoceras) concavum	

Triassic ammonoid-bearing beds with *Ophiceras* in the Transcaucasian sections (including the type section of the Dorashamian). These beds were until now classified as part of the Triassic exclusively on lithostratigraphical grounds. According to the conodont faunas found within these beds they are undoubtedly time-equivalents of the Upper Changhsingian.

Unlike the Changhsingian of South China, *Gondolella orientalis* is present (with few specimens) both in the Dorashamian and in the post-Dorashamian/pre-Triassic conodont fauna of Transcaucasia, NW Iran and Abadeh (Central Iran).

These conodont finds show that the Dorashamian is older than the Upper Changhsingian and it should be regarded as Lower substage of the Changhsingian. The post-Dorashamian strata classified here as part of the Upper Changhsingian are by no means Triassic in age. This is in fact the youngest rich marine Upper Permian fauna of the world as pointed out by Zhao *et al.* (1978).

The conodont fauna of the Upper Changhsingian perfectly coincide with the conodont fauna of the *Otoceras woodwardi* Zone. *Isarcicella isarcica*, the world-wide guide form for the lowermost Triassic makes its appearance immediately above the Changhsingian (as defined by Zhao *et al.* (1978)) and immediately above the *Otoceras woodwardi* Zone (but not immediately above the *Paratirolites* fauna of the topmost Dorashamian). Above the topmost Dorashamian is found in all the sections a conodont fauna with *Anchignathodus minutus*, *A. parvus*, *Gondolella carinata*, *G. subcarinata subcarinata* and rare *G. orientalis*—the conodont fauna which is exactly similar to the conodont fauna known from the Upper Changhsingian and the *Otoceras woodwardi* Zone. *Isarcicella isarcica* is found occuring in beds yielding *Ophiceras* fauna. This conodont succession can be traced from Transcaucasia through NW Iran until the Abadeh region of Central Iran.

On the basis of our data about the faunal succession in the Permian-Triassic boundary beds of Transcaucasia, NW Iran, Central Iran and in the Himalaya as well as on tbe basis of the recently published paleontological results about the faunal and floral succession in South China the following conclusions could be drawn :

(i) Together with the last *Otoceras* the last goniatites ammonoids (*Pseudogastrioceras*) occur in the unnamed ammonoid zone of the topmost Changhsingian in association with other Permian ammonoids (*Episageceras*, *Xenodiscus*). Even *Otoceras* is a Permian-type ammonoid. The first most primitive Triassic ammonoids (*Ophiceras*) makes its appearance in the *Otoceras woodwardi* Zone, but is still quite absent in the *Otoceras* (*Julfotoceras*) *concavum* Zone. The occurrence of ophiceratids in the Upper Permian of New Zealand (Waterhouse, 1973) shows that *Ophiceras* has to be assigned to the faunal elements that straddle the Permian-Triassic boundary.

(ii) The conodont fauna of the *Otoceras woodwardi* Zone with *Anchignathodus minutus*, *A. parvus*, *Gondolella subcarinata subcarinata*, *G. carinata*, *G. orientalis* corresponds to the conodont fauna of the Upper Changhsingian of South China or at least to its upper part. *Isarcicella isarcica* makes its appearance immediately above the last occurrence of *Otoceras* and immediately above the top of the unnamed ammonoid zone of the topmost Changhsingian. Between the conodont fauna of the topmost Dorashamian and the first appearance of *Isarcicella isarcica* there is still the conodont fauna of the topmost Changhsingian even in the type area of the Dorashamian.

(iii) Fusulinids are until now unknown in beds with *Otoceras*. But all these beds have an ostracode fauna that is a little brachyhaline (not quite euhaline). In such facies fusulinids are never present. Because fusulinids are still present in the higher parts of the Upper Changhsingian, where *Archignathodus parvus* is already present they must be also present in the beds considered time-equivalents of the *Otoceras woodwardi* Zone, because *A. parvus* evolved from *A. minutus* not earlier than in the middle part of the *Otoceras woodwardi* Zone.

In this connection it may be interesting to remark that Brogio Loriga *et al.* (1981) reported fusulinids from the lower part of the Tesero horizon (that is generally equated with *Otoceras woodwardi* Zone) of the Southern Alps. Fusulinids like *Staffella*, *Nankinella*, *Sichotenella* and *Reichelina* as well as the Permian calcarous algae *Permocalculus*, *Mizzia* and *Epimastopora* have been recorded by these writers. The algae may be reworked from the underlying Bellerophon Limestone which is rich in calcarous algae. As fusulinids are rare in the Bellerophon Limestone reworking of these from the Bellerophon Limestone may be excluded.

(iv) In the lowermost part of the Dolomite Unit of the Salt Range (Narmia section) time-equivalents of the *Otoceras woodwardi* Zone and probably also of the *Otoceras* (*Julfotoceras*) *concavum* Zones are present.

Tayyab *et al.* (1981) on the basis of boron content investigations have suggested that the facies of these beds must have not been quite euhaline at this time. In spite of this fact, the presence of *Reichelina* has been noticed within these beds. According to Tayyab *et al.* (1981) the sedimentological data does not support the idea that the fusulinids found within this unit were reworked.

The typical Upper Permian small foraminifera (*Geinitzina*, etc.) still occur in the *Otoceras woodwardi* Zone and not in beds younger than these.

(v) The occurrence of trilobites has not been recorded from the *Otoceras*-bearing beds until now. The absence of trilobite may be facies-controlled. Tribolites are found in the beds corresponding to *Rotodiscoceras asiaticum* Zone with *Anchignathodus parvus* and other conodonts typical of the *Otoceras woodwardi* Zone. Therefore it is possible that trilobites may still be present in beds which are time-equivalents of the *Otoceras woodwardi* Zone.

(vi) The large number of Permian brachiopods (13 species belonging to 8 genera) are known to occur in beds near the top of the *Otoceras woodwardi* Zone, and these disappear in the beds younger than those belonging to *Otoceras woodwardi* Zone.

(vii) The *Hollinella tingi* ostracode fauna which is characteristic for the basal Triassic of South China, Hungary and Yugoslavia appears exactly alongwith the first appearance of *Isarciella isarcica* in the beds immediately above the top of the unnamed ammonoid zone of the topmost Changhsingian as defined by Zhao *et al.* (1978).

(viii) The typical Permian plants (association of the Cathaysia province with *Gigantopteris*, *Lobatannularia* and *Annularia*) occurs still in the *Otoceras*-bearing beds and these flora disappear immediately above the beds marked with the first appearance of the *Hollinella tingi* and *Isarcicella isarcica* faunas.

(ix) The sporomorphs of the *Otoceras*-bearing beds in South China have still Upper Permian characters. The sporomorphs from the beds with the *Hollinella tingi* fauna lying immediately above the top of the *Otoceras*-bearing beds have a typical Mesozoic character. Foster (1979) has placed the sporomorph association of the *Otoceras woodwardi* Zone (*Protohaploxypinus microcorpus* association) into the Upper Permian. Similar associations are also known to occur in Australia.

(x) The Lamellibrachiata found within the *Otoceras woodwardi* Zone have Triassic characters. With the exception of *Claraia* they are strongly facies-controlled and have no forerunner in the immediately underlying euhaline marine undisputed Upper Permian beds. *Claraia* is known to occur in the topmost part of the undisputed Upper Permian.

CONCLUSION

With the help of conodonts (first appearance of *Isarcicella isarcica*) and ostracodes (first appearance of the *Hollinella tingi* fauna) the top of the *Otoceras woodwardi* Zone can be traced in the whole Northern Hemisphere. These conodont and ostracode faunas appear immediately above the last occurrence of the genus *Otoceras*, but they can be found also in beds without any macrofossils. The brachiopods recorded from the *Otoceras woodwardi* Zone support Permian affinities of this zone.

On the basis of the Permian character of the micro-and macrofaunas as well as floras from the *Otoceras*-bearing beds we propose that the Permian-Triassic boundary lies at the top of the *Otoceras woodwardi* Zone that coincides with the top of the unnamed uppermost ammonoid zone of the Changhsingian *sensu* Zhao *et al.* (1978).

The Permian-Triassic boundary at the base of the *Otoceras woodwardi* or *Otoceras* (*Julfotoceras*) *concavum* Zones would only be an 'academic boundary' applicable only to those areas where *Otoceras* is present (fewer than 5% of the Permian-Triassic boundary beds).

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One of us (HK) is grateful to Prof. H. Mostler, Director of the Institute of Geology and Palaeontology, Innsbruck University, Innsbruck, Austria. He gave us the microfossils from the NW Iranian, Central Iranian, and other Iranian Permian-Triassic boundary sections. Prof. K. Nakazawa, Kyoto, Prof. Wang, Zhio-hao, and Prof. Wang, Zhen-chuan sent the newest micro-palaeontological and ammonoid data from the Permian-Triassic boundary beds of South China to one of us (HK) for which we are grateful to them.

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First Record of Fossil Ophiuroids from the Upper Triassic Rocks of Kashmir Himalaya

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THE PAPER deals with the taxonomy and biostratigraphic implications of two nearly complete ophiuroids along with a number of fragmentary specimens. The present specimens are recorded from the Upper Triassic limestone exposed in northern Pir Panjal flank, near Munda (33°32′48″ : 5°12′44″). The ophiuroids (one of which CAS Cat. No. *1824* is complete and the other CAS Cat. No. *1826* is nearly complete) can be related to *Geocoma carinata* which has been reported from the Lower Jurassic rocks of the famous Solenhofen quarries of Southern Germany (Bavaria).

The find of nearly complete ophiuroids from the fine-grained lithographic limestone, gives additional information on the lithology, palaeoecology and environment of the deposition of these beds. At present, the palaeontological data suggests an Upper Triassic age for the sequence exposed in Pir Panjal Range. Although admittedly the evidence at present is meagre but the specimens are sufficiently well-preserved to assign them to *Geocoma*.

Earlier Hazra and Prasad (1962) also reported the occurrence of Triassic rocks from this area. According to these workers, the Triassic limestone is mainly unfossiliferous except for some corals and crinoid stems, which are very difficult to extract. Upper Triassic rocks in the Pir Panjal Range, near Quazigund have been reported by Kapoor and Bando (1974). According to them the flaggy shale containing *Claraia* spp. marks the beginning of the Lower Triassic. These shales were earlier classified as part of the Zewan formation by Hazra and Prasad (1962). Upper Triassic limestone is mostly barren of mega-fossils but there are occasional layers of 10-20 cm thick, rich in *Spiriferina stracheyi* and *Spiriferina haueri* (Kapoor and Bando, 1974). Uppal *et al.* (1981) reported the occurrence of fish remains from the Zewan Formation exposed in Pir Panjal Range near Jawahar Tunnel.

SIRATIGRAPHY OF THE AREA

The following stratigraphic sequence is exposed in the northern ridges of Pir Panjal near Munda :

Sub Recent—Recent	:	Sand, loam and blue clay interbedded with few bands of conglonerates
(?) Jurassic	:	Unfossiliferous limestone, quartzite and shale
Triassic	:	Massive, hard and compact, grey and pale-coloured limestone with few bands of coralline and crinoid-bearing limestone
Zewan Formation	:	Buff-coloured limestone associated with *Eurydesma* cf. *E. cordatum*, with occasional bands of shale.

——————————Reversed fault——————————

Panjal Traps

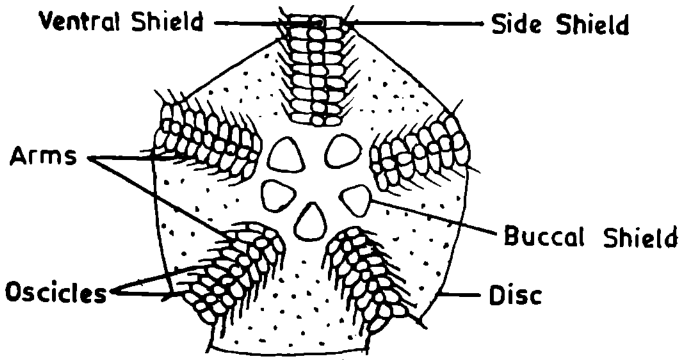

Figure 1. Hand sketch of *Geocoma* sp. showing different morphological features × 3.

SYSTEMATIC DESCRIPTION

Phylum	:	Echinodermata
Subphylum	;	Asterozoa Zittel, 1895
Class	;	Stelleroidea Lamarck, 1816
Subclass	:	Ophiuroidea Gray, 1840
Order	:	Ophiurida Müller and Troschel, 1840
Suborder	;	Chilophiurina Matsumoto, 1915
Family	;	Ophiuridae Lyman, 1865
Subfamily	:	Ophiurinae Lyman, 1865
Genus	:	*Geocoma* d' Orbigny, 1850

Geocoma sp.

The arms of the present specimen are well-differentiated from the central oral disc. They are long, tapering and flexible, with terminal ends deflected in clockwise direction. The disc is pentagonal in shape and covered with thick plates, buccal shields robust, large and reach almost to the centre of the disc. Genital and dental papillae are indistinct as calcitic plates have undergone recrystallization. The arms show the presence of well-developed oscicles as in *Geocoma carinata* with all elements fully developed. A median groove is prominent on the lower side of all the arms. Figure 1 shows the hand sketch of the present specimen.

REMARKS

Complete fossil ophiuroids are poorly represented in the Indian record. There are few reports of the occurrence of isolated and assorted ophiuroid oscicles found during the micro-palaeontological investigations of the Mesozoic and Cenozoic beds exposed along the Peninsular coast of India. By the Lower Jurassic time ophiuroids had become fairly common and are usually found in euxinic to lagoonal low energy environments. The present occu-

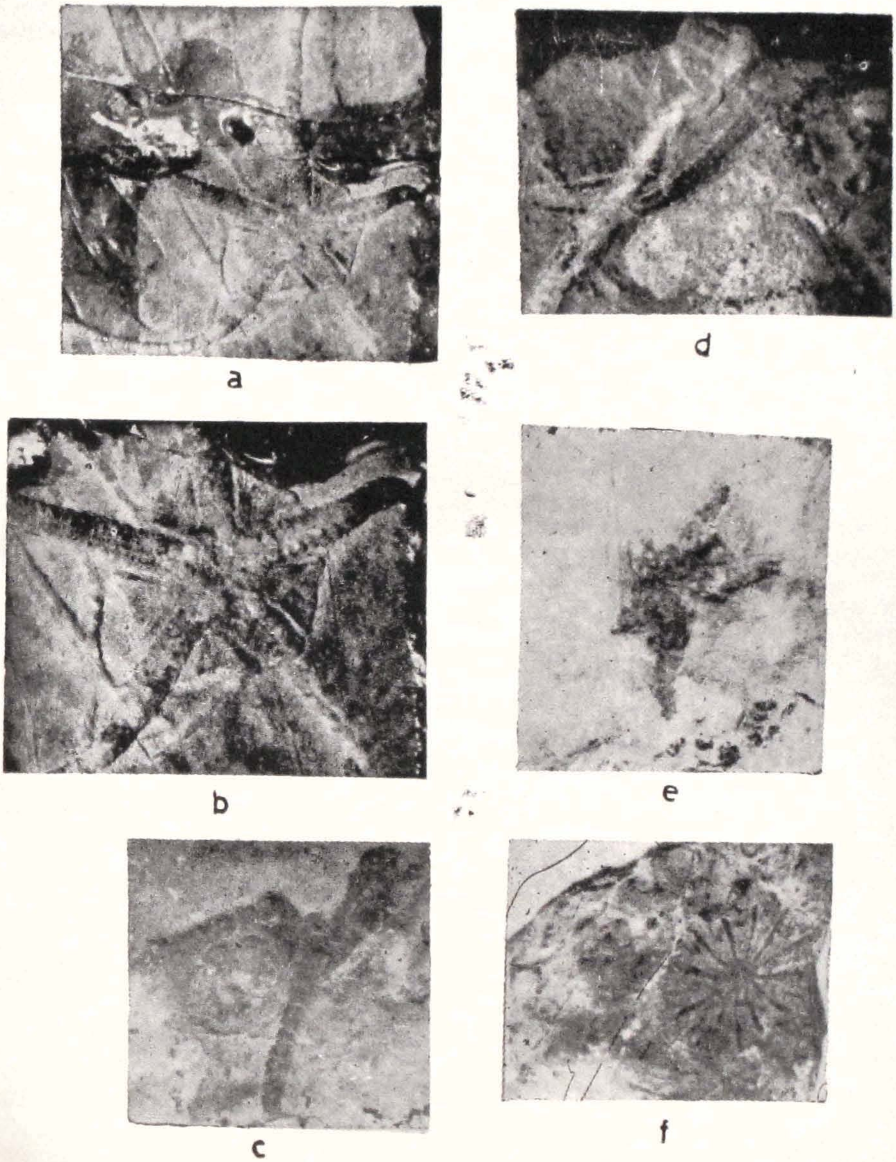

Figure 2. *a* CASG Cat. No. F 1824 Oral view of *Geocoma* sp.— 3. *b*. CASG Cat. No. F 1824 Enlarged view of 'a' × 5. *c*. CASG Cat. No. F 1825 *Geocoma* sp. ×3. *d*, CASG Cat. No. F 1826 Nearly complete specimen of *Geocoma* sp. × 4. *e*. CASG Cat. No. F 1827 Broken part of *Geocoma* sp. × 2,5. *f*. CASG Cat. No. F 1828 *Montlivaltia* sp. × 3.

rrence of ophiuroids is also from the same palaeoecological conditions. The limestone from which the present specimens have been found appear to be deposited in lagoonal, low energy conditions. No other diagnostic fossils are found associated with the ophiuroid remains except for some corals assignable to *Montlivaltia* sp. (Fig. 2f) The age of the Pir Panjal ophiuroid-bearing limestones can only be precisely determined when the temporal distributions of Tethyan realm Mesozoic ophiuroids is better known.

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Some of the Biostratigraphical Aspects of the Indus Formation, Ladakh Region

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ABSTRACT

Ten biostratigraphic zones, namely zones I-X (in ascending order), based on faunal and floral evidences have been delineated for the Indus Formation (Lr. Cretaceous-Lr. Eocene) of the Ladakh region. Zone I has been ascribed a Lower Cretaceous age, zone II a Middle to an Upper Cretaceous age, zone III a Palaeocene age, and zones IV to X a Lower Eocene age. The upper part of the Indus Formation (zones III to X) can be correlated with the Subathu Formation of the Jammu, Himachal and Garhwal regions and Lower Cenozoic Formations in Pakistan.

INTRODUCTION

THE GEOLOGY of the Indus Formation of the Ladakh region has been studied amongst others by Lydekker (1880, 1883), Dainelli (1933-35), De Terra (1935), and recently by Gansser (1964), Gupta and Kumar (1975), Shankar *et. al.* (1976), Shah *et al.* (1976), Pal and Mathur (1977), Fuchs (1977), Frank *et al.* (1977), Pal *et al.* (1978), Sharma and Kumar (1978), and Pal *et al.* (1980). Although some of the biostratigraphic aspects of the Indus Formation have been touched upon by Gupta *et al.* (1970), Pande and Tewari (1969), Shankar *et al.* (1976), and Srikantia and Bhargava (1978), no comprehensive biostratigraphic zonation has been attempted so far. The biostratigraphy of the Cretaceous-Eocene succession in Pakistan and Afghanistan, on the other hand, is fairly well-established through the pioneering works of Blanford (1879), Vredenburg (1909), Davies (1930), Gee (1944), Eames (1952 *a, b*), and Nagappa (1959). This can be attributed mainly because of the difficult terrain and is also due to the failure on the part of different workers to recognise the correct stratigraphic relationship amongst different rock units. It is now realised by the present workers (Pal *et al.*, 1978 and Pal *et al.*, 1980) that an elongated orthogeosyncline was divided by a miogeosynclinal ridge into two furrows forming miogeosyncline in the northern part and eugeosyncline in the southern one. The Indus Formation is a flysch-type deposit which was laid down in the miogeosyncline, and the Dras Formation was deposited concomitantly in the eugeosyncline which abounds in volcanic activity. The Indus Formation shows cyclic sedimentation and consists of shales, conglomerates, sandstones, and at places limestones. The aim of this paper is to attempt a zonation in the Indus Formation of the Ladakh region.

BIOSTRATIGRAPHIC INVESTIGATIONS

(a) Previous Investigations

The Indus Formation has been assigned an age ranging from Lower Cretaceous to Middle Eocene mainly on the basis of foraminifera. Its lower age limit as Lower Cretaceous is fixed due to the occurrence of *Orbitolina pileus* Fossa Mancini, *O.* cf. *parma* Fossa Mancini, *O.* cf. *discoidea* Gras (Tewari *et al.*, 1970). The upper age limit of the Indus Formation as Middle Eocene is based on the reported occurrence of *Nummulites beammonti* d'Archiac and Haime. Pande *et al.* (1969) gave the following stratigraphic sequence (in ascending order) to the Indus Formation from Likir to Lamayuru : (1) Green and purple shales, (2) Dark grey limestone containing *Orbitolina kashmirica, O. pileus,* and *O. parma,* (3) Green and purple shales, (4) Grey and purple siliceous bands of cherts containing *Globigerina* spp. and planktonic forms. Ravi Shanker *et al.* (1976) recognised Samdo Formation of Cretaceous age in the southern part covering Dras, Kargil, and Samdo areas. In the northern part covering Nyoma, Mahe, and Khalsi, they recognise two formations, namely Lower Indus Formation (=Samdo Formation) and Upper Indus Formation of Palaeocene (Danian) to Middle Eocene (Lutetian) age. They demarcated four zones in these Formations (in ascending order) : (i) characterized by *Orbitolina* sp. (foraminifer); *Cytherella* sp. and *Protocytherella* sp. (ostracodes); *Cenomanellia* sp. and *Damasia* sp. (gastropods); and algae (Albian-Cenomanian); (ii) characterized by *Protocytherella* sp. (ostracode); *Gyrodes* sp. (gastropod); *Pinna* sp. (bivalve) (Coniacian to Santolian); (iii) *Globotruncana* sp. (foraminifer); *Hoplitoplacenteceroas* sp. (ammonite); *Belanophyllia* sp. (anthozoan); *Turritella* sp. (gastropod); radiolarian, algae, and bivalave (Companian to Maestrichtian), and (iv) characterized by *Nummulites beaumonti, Assilina* sp., and *Discocyclina* sp. (foraminifers); *Belanophyllia* sp. (anthozoan); bivalve and algae (Danian-Lutetian).

(b) Present Investigations

During the course of biostratigraphic investigations in the four areas, namely (*a*) Miru, (*b*) Matho-Marchlange, (*c*) Kunda La, and (*d*) Nimmu (Figs. 1-5), the authors encountered a rich assemblage comprising molluscs and foraminifers besides the occurrence of algae and corals. Out of these areas, Kunda La area has been designatied as the type area where a fairly complete and fossiliferous stratigraphic sequence is exposed. Biostratigraphcal study indicates that the distribution of various taxa belonging to different groups of fossils has immense stratigraphic value. As a result of a detailed study, ten zones, namely I to X (in ascending order), were delineated on the basis of faunal and floral evidences. Zone VII has been subdivided into three subzones, namely VII*a*, VII*b*, and VII*c* (in ascending order)—Zone I is of Lower Cretaceous age, zone II of Middle to Upper Cretaceous age, zone III of Palaeocene age, and zones IV to X of Lower Eocene age. Not all the zones and subzones are present

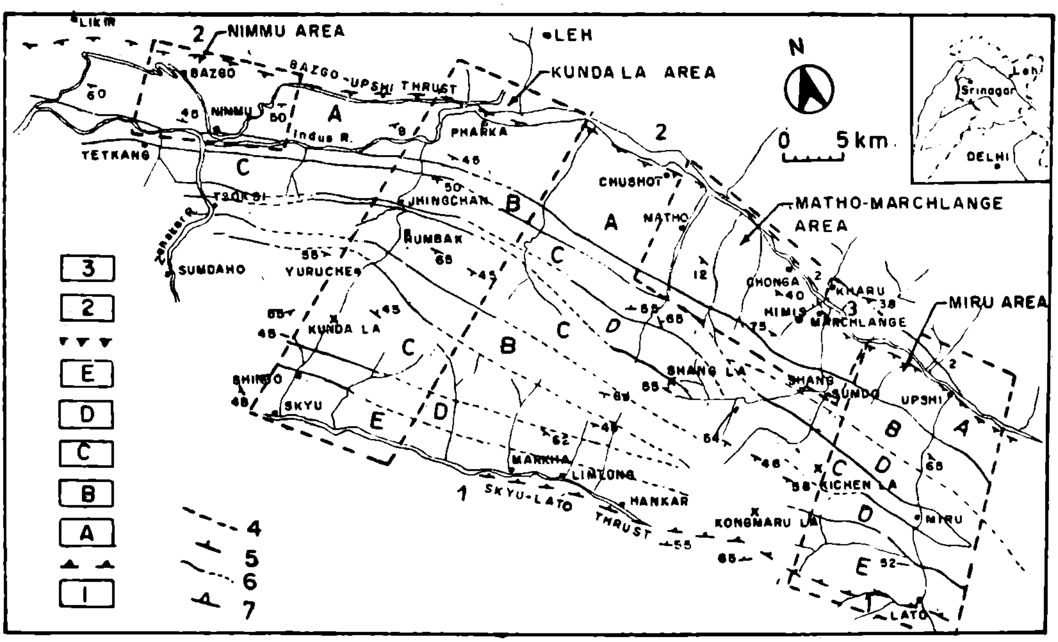

Figure 1. Geological map of the Indus Formation, Central Ladakh showing areas studied (Based on Pal *et al.*, 1978). 1—Permo-Triassic sediments; A to E—Members of the the Indus Formation; 2—Ladakh Batholith; 3—Karroo Formation; 4—Fault; 5—Bedding; 6—Lithostratigraphic contact, certain, inferred; 7—Foliation.

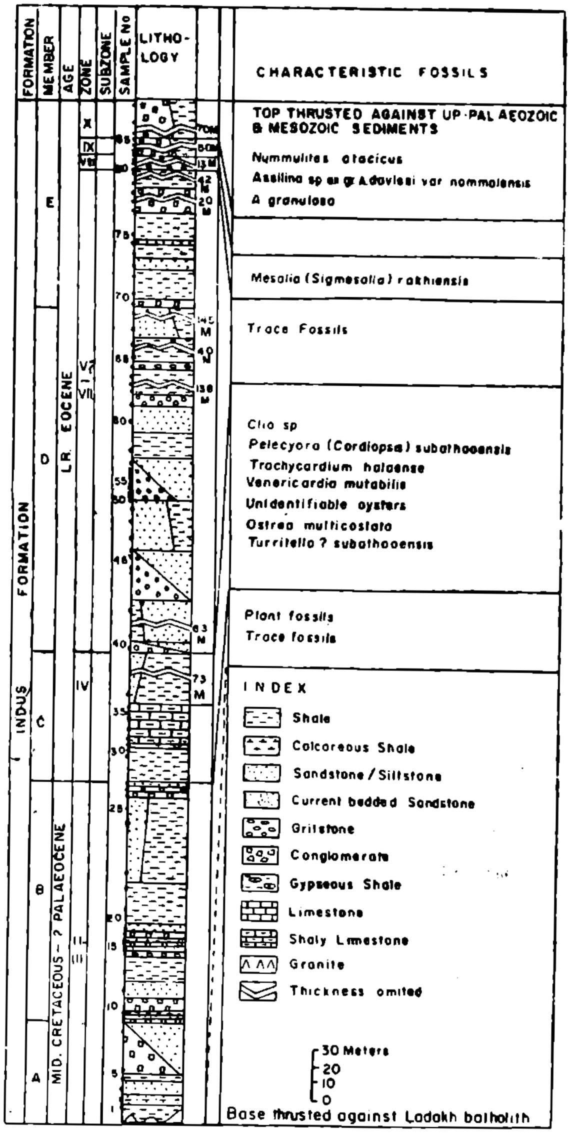

Figure 2. Biostratigraphic succession of the Indus Formation in the Miru area.

in all the areas mainly because of the fact that the lower contact of the Indus Formation has thrust contact with the Ladakh Granite and the upper contact also abuts against Permo-Triassic sediments along a thrust. However, these zones can be traced in all these areas which indicates their great utility in solving various stratigraphical problems in this tectonically disturbed region. Table 1 summarises the characteristics of various zones and sub-zones :

TABLE 1

Permo-Triassic sediments SOUTH

Skyu-Lato Thrust

LR. EOCENE

(10) *Assilina granulosa* Zone (zone X) : Besides the zonal fossil, the zone contains *Assilina* sp. ex gr. *A. daviesi* var. *nammalensis*, and *Nummulites atacicus*.

(9) Barren Zone (zone IX) : This zone is characterized by its general unfossiliferous nature.

(8) *Turritella* (?) *subathooensis* Zone (zone VIII) : In addition to the zonal fossil, the zone abounds in *Pelecyora* (*Cardiopsis*) *subathooensis* and oysters.

(7) *Nummulites* sp, ex gr. *N. obtusus* Zone (zone VIII)

(iii) Miliolids Subzone (subzone VII*c*): *Nummulites atacicus*, *Discocyclina ramaraoi* and algae occur in addition to the zonal and subzonal taxa.

(ii) *Venericardia mutabilis* Subzone (subzone VII*b*) :

(i) *Fasciolites oblonga* Subzone (subzone VII*a*) : Besides containing the zonal and subzonal taxa, the subzone has yielded *Discocycling ramaraoi*, *Nummulites atacicus*, *N. mamilla*, *N.* sp. I Mathur, *Assilina* sp. ex gr. *A. daviesi* var *nammalensis*, and *A. laminosa*.

(6) *Ostrea* Zone (zone VI) : Besides the zonal fossil, the zone also contains 'Turritellids?', *Venericardia mutabilis* and *Peleeyora* (*Cordiopsis*) *subathooensis*.

(5) *Assilina* sp. ex gr. *A. daviesi* var. *nammalensis* Zone (zone V) : In addition to the zonal taxon, the zone also contains *Assilina granulosa* Form A, *Nummulites atacicus*, and *N. mamilla*.

(4) *Clio* Zone (zone IV) : Characterized by the occurrence of *Clio* sp. and *Trachycardium halaense*.

PALAEOCENE

(3) *Pitar-Costacallista* Zone (zone III) : Characterized by the occurrence of *Pitar* (*Calipitaria*) *carteri* and *Costacallista semilunaris*.

MID. TO UP. CRETACEOUS

(2) Plant fossils Zone (zone II) : Contains abundantly plant fossils.

LR. CRETACEOUS

(1) *Orbitolina* Zone (zone I) : Characterized by the occurrence of *Orbitolina Parma*, *O. discoidea*, '*Hippurites*' spp., and oysters.

Bazgo-Upshi Thrust

Ladakh Batolith of Pre-Tertiary age with unconformably overlying continental Kargil and Karroo Formation of Mio-Pliocene age.

NORTH

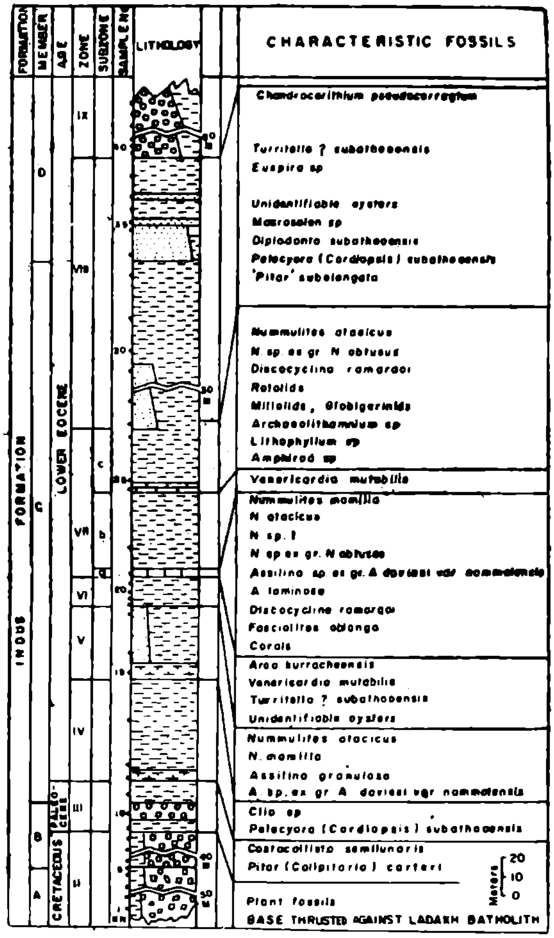

Figure 3. Biostratigraphic succession of the Indus Formation in the Kunda La area.

It is to be noted that zonal boundaries do not exactly coincide with the member boundaries of Pal and Mathur (1977). The lowermost member, namely member A, consists of red and green shaly flysch with subordinate conglomerate/limestone; member B comprises arenaceous flysch with subordinate shale; member C is composed of grey shaly flysch with subordinate shale; member D is characterized by red shaly flysch with subordinate sandstone/siltstone; and member E contains conglomerate flysch with subordinate sandstone/shale. Broadly speaking, zone I coincides with member A, zone II with member B, zones III to VII with member C, and zones VIII to X with members D and E. A brief description of various zones and subzones is given below.

(1) *Orbitolina Zone* (*zone I*)

This is the lowermost zone represented in this region. The base of this zone is nowhere exposed as the beds of this zone are in tectonic contact with the Ladakh Granite in the north. Lithologically, the zone is composed of red and green slates, conglomerates, sandstones, and subordinate limestones. There is a 40-m thick band of dark massive fossiliferous limestone exposed in the Khalsi area which has yielded *Orbitolina parma* Fossa Mancini, *O. discoidea* Gras, *O. pileus* Fossa Mancini, '*Hippurites*' sp. I, and '*Hippurites*' sp. II (Tewari *et al.*, 1970; Pal and Mathur, 1977). All these texa are restricted to this zone. The fossil assemblage indicates a Lower Cretaceous age

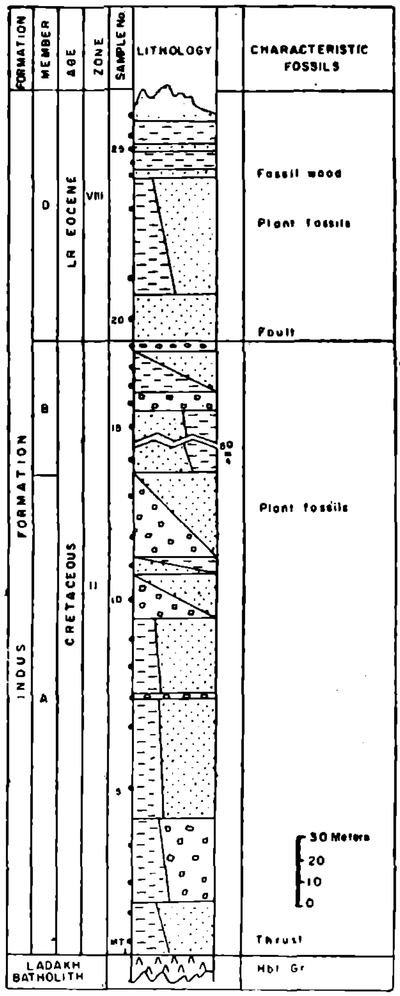

Figure 4. Biostratigraphic succession of the Indus Formation in the Matho-Marchlange area.

for this zone. A few unidentifiable taxa of oysters, cephalopods, gastropods, and smaller foraminifers were also recovered from this zone.

(2) *Plant fossils Zone* (*zone II*)

This zone is fossiliferous in all the four areas, namely Miru, Matho-Marchlange, Kunda La, and Nimmu. It is thickest in the Matho-Marchlange area where it attains a thickness of 280 metres. The zone is composed of red, green, grey, fine-to medium-grained sandstones, and conglomerates with intercalated shales. The shales are pyritic and gypseous in the Nimmu section. Graded-bedding, cross-bedding, mud cracks, and ripple marks are the most common sedimentary features which are observed in these rocks.

Rocks of this zone contain plants, trace fossils, and worm burrows. This zone has not yielded so far any characteristic fossil. However, on stratigraphic grounds, it has been assigned a Middle to an Upper Cretaceous age.

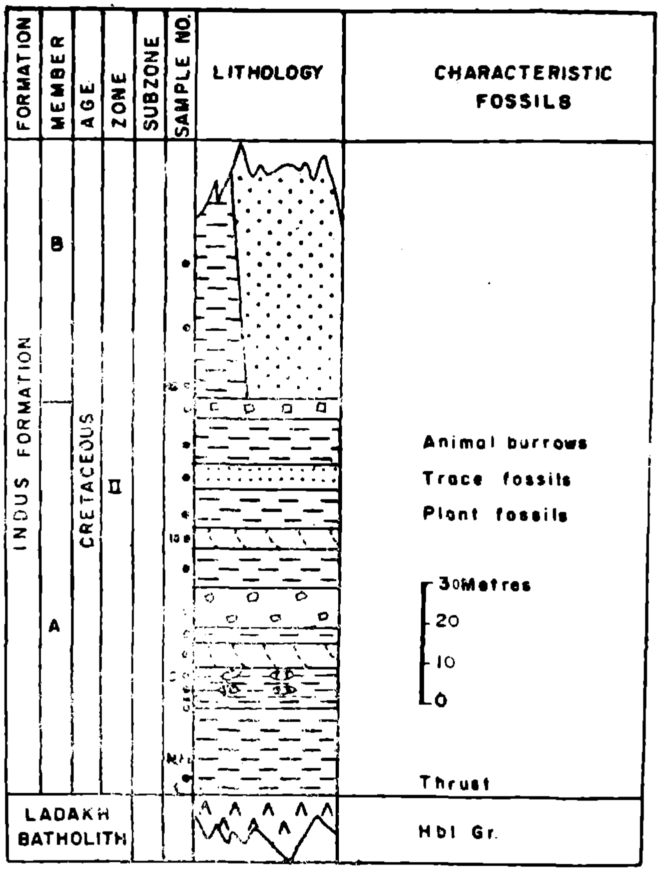

Fig. 5 BIOSTRATIGRAPHIC SUCCESSION OF THE INDUS FORMATION IN THE NIMMU AREA

(3) *Pitar-Constacallista Zone* (*zone III*)

This zone is exposed only in the Kunda La and Miru areas. In the former area, the zone is 28 metres in thickness and is composed of grey shales with a band of conglomerate in the middle. In the Miru area, the zone is comparatively thicker and attains a thickness of 50 metres. Rocks in this area comprise grey shales and sandstones which have yielded only trace fossils. *Pitar* (*Calipitaria*) *carteri* (d'Archiac and Haime) and *Costacallista semilunaris* (d'Archiac and Haime) occur in the Kunda La. The bivalve genera *Pitar* and *Costacallista* range from Palaeocene to Recent. Although none of these is a guide taxon, the stratigraphic position suggests that this zone may be of Palaeocene age.

(4) *Clio Zone* (*zone IV*)

This zone is fossiliferous in the Kunda La and Miru areas. In the former area, the zone is composed of a 55-metre thick bed of greenish grey shales which are calcareous at the bottom. In the latter area, the zone is represented by 144-metre thick sequence of grey shaly limestone, greenish grey shales and sandstones. This zone has yielded *Clio* sp. (pteropod); *Pseudomiltha vredenburgi* (Cossmann and Pissarro), *Pelecyora* (*Cordiopsis*) *subathoo-*

ensis (d'Archiac and Haime), *Trachycardium halaense* (d'Archiac and Haime), *Venericardia mutabilis* (d'Archiac and Haime), *Ostrea multicostata* Deshayes, and unidentifiable oysters (bivalves); *Turritella* (?) *subathooensis* d'Archiac and Haime (gastropod).

(5) *Assilina sp. ex gr. A. daviesi var. nammalensis Zone (zone V)*

This zone is fossiliferous only in the Kunda La area where it attains a thickness of 40 metres and is composed of alternations of greenish grey shales and sandstones, the latter being calcareous at the base. Conglomerates, sandstones, and shales in the Miru area have yielded only trace fossils and are probably homotaxial with the richly fossiliferous beds in the Kunda La area.

The fauna of the Kunda La area is represented by the characteristic Lower Eocene larger foraminiferal taxon, namely *Assilina granulosa* (d'Archiac) Form A. In addition to this, the zonal taxon, namely *Assilina* sp. ex gr. *A. daviesi* var. *nammalensis* Gill occurs in this zone besides containing *Nummulites atacicus* Leymerie and *N. mamilla* (Fichtel and Moll).

(6) *Ostrea Zone (zone VI)*

This zone is exposed in the Kunda La and Miru areas. It is fossiliferous in the Kunda La area where it is represented by a 15-metre thick bed of greenish grey shales. In the Miru area, greenish grey conglomerates, sandstones, and shales containing only trace fossils may be equivalent to the highly fossiliferous beds of the Kunda La area.

Besides the zonal fossil, *Pelecyora* (*Cordiopsis*) *subathooensis* (d'Archiac and Haime), *Venericardia mutabilis* (d'Archiac and Haime), and *Turritella*(?) *subathoogensis* d'Archiac and Haime also occur in this zone.

(7) *Nummulites sp. ex. gr. N. obtusus Zone (zone VII)*

This zone is exposed in the Kunda La and Miru areas. It is represented by red to green conglomerates, sandstones, and shales containing trace fossils in the Miru area. In Kunda La area, the zone is highly fossiliferous and is divisible into three subzones, namely VII*a*, and VII*b*, and VII*c* (in ascending order) which are outlined below:

(i) *Fasciolites oblonga Subzone (subzone VIIa)*

A 4-metre thick bed of grey limestone represents this subzone which has yielded *Nummulites* sp. ex gr. *N. obtusus* (Sowerby), *N. atacicus* Leymerie, *N. mamilla* (Fichtel and Moll), *Nummulites* sp. I Mathur, *Assilina* sp. ex gr. *A. daviesi* var. *nammalensis* Gill, *Discocyclina ramaraoi* Samanta, *Fasciolites oblonga* (d'Orbigny), and corals.

(ii) *Venericardia mutabilis Subzone (subzone VIIb)*

A 40-metre thick bed of greenish grey shales containing the zonal fossil *Venericardia mutabilis* (d'Archiac and Haime) represents this subzone.

(iii) *Miliolids Subzone (subzone VIIc)*

This subzone is composed of grey limestone at the base followed upwards by greenish-grey shales. The thickness of this subzone is 33 metres. It is highly fossiliferous and has yielded *Nummulites atacicus* Leymerie, *N.* sp. ex gr. *N. obtusus* (Sowerby), *Discocyclina ramaraoi* Samanta, rotalids, miliolids, and gobigerinids (foraminifers); *Archaeolithamnium* sp., *Lithophyllum* sp., and *Amphiroa* sp. (algae).

(8) *Turritella* (?) *subathooensis Zone (zone VIII)*

This zone is exposed in the Miru, Kunda La, and Matho-Marchlange areas. In the Miru area, the zone is represented by a 20-metre thick bed of greenish grey gritty bed followed upwards by a 58-metre thick sequence of conglomerates and shales. In the Kunda La area, the zone consists of red to green sandstones and shales and attains a thickness of 174 metres. The zone is richly fossiliferous in the Kunda La area. The fauna of this zone is represented by the zonal fossil *Turritella*(?) *subathooensis* d'Archiac and Haime. Besides this, the zone contains *Mesalia* (*Sigmesalia*) *rakhiensis* Eames, *Chondrocerithium pseudocorragtum* (d'Archiac and Haime), *Pseudomiltha vredenburgi* (Cossmann and Pissaro), *Pelecyora* (*Cordiopsis*) *subathooensis* (d'Archiac and Haime), '*Pitar*' *subelongata* (d'Archiac and Haime), unidentifiable oysters and *Diplodonta subathooensis* (d'Archiac and Haime). In the Matho-Marchlange area, the zone is composed of alternate sequence of red to green sandstones and shales which have yielded fossil wood and plants.

(9) *Barren Zone* (*zone IX*)

This zone is exposed in the Miru and Kunda La areas where it is represented by unfossiliferous red to green shales and conglomerates. Red facies is predominant in the Kunda La area while green facies dominate in the Miru area.

(10) *Assilina granulosa Zone* (*zone X*)

This zone is exposed only in the Miru area where it is represented by an alternate sequence of red and green shales and conglomerates. The zone is poorly fossiliferous and has yielded a few specimens of *Assilina granulosa* (d'Archiac) Form A, *A.* sp. ex gr. *A. daviesi* var. *nammalensis* Gill Form A, and *Nummulites atacicus* Leymerie Form A. The conglomerates of this zone have yielded fossils derived from older rocks.

AGE OF THE INDUS FORMATION

The occurrence of *Orbitolina pileus* Fossa Mancini, *O. kashmirica* Sahni and Sastry, and *O. discoidea* Gras in zone I suggests an Aptian to a Lower Cenomanian (Lower Cretaceous) age. The beds of zone I pass conformably into zone II which has not yielded any guide fossil. The beds of this zone have tentatively been assigned a Middle to an Upper Cretaceous age. Zone III has yielded *Pitar* (*Calipitaria*) *carteri* (d'Archiac and Haime) and *Costacallista semilunaris* (d'Archiac and Haime). Although none of these can be used as a guide fossil, no form renders inconsistent a Palaeocene age assignment to this zone. The fauna of this zone shows a close affinity with the Lower Cenozoic rocks of Pakistan and Kumaun Himalaya. *Costacallista semilunaris* has been reported from the Subathu Formation (Upper Palaeocene to Middle Eocene) of the Simla region, Kumaun Himalaya. *Pitar* (*Calipitaria*) *carteri* has been reported from Eocene rocks of Pakistan. The overlying zones, namely zones IV to VIII have yielded a large number of molluscan taxa. But only two species, namely *Trachycardium halaense* and *Pelecyora* (*Cordiopsis*) *subathooensis* seem to be characteristic of Lower Eocene. On the other hand, beds of zones V to X have yielded characteristic Lower Eocene larger foraminiferal species, namely *Assilina granulosa* and *A. laminosa* which have been recorded from the Subathu Formation of the Kumaun Himalaya (Mathur, 1978) Rajasthan, and Kutch in India and from several areas in Pakistan.

It is inferred that there existed two longitudinal basins running almost on northern and southern peripheries of the main Himalayan Ranges. A detailed paper on the correlation of the Indus Formation of the Ladakh region falling in the northern belt with the various Cretaceous-Eocene horizons in the southern belt will be published later while papers dealing with systematics, and age and affinity of the molluscan and foraminiferal fauna of the Indus Formation have been worked out (Mathur *et al.*, 1978*a*; Mathur *et al.*, 1978*b*). Some of the taxa which are common to the two basins include *Assilina granulosa*, *A. laminosa*, *A.* sp. ex gr. *A. daviesi* var. *nammalensis*, *Nummulites atacicus*, *E. mamilla*, *N.* sp. ex gr. *N. obtusus*, *Fasciolites oblonga* (foraminifers); *Ostrea multicostata*, *Venericardia mutabilis*, *Diplodonta subathooensis*, *Trachycardium halaense*, '*Pitar*' *subelongata*, *Costacallista semilunaris*, *Pelecyora* (*Cordiopsis*) *subathooensis*, and *Turritella*(?) *subathooensis* (molluscs).

It is, therefore, concluded that the Indus Formation of the Ladakh region ranges in age from Lower Cretaceous to Lower Eocene and shows affinity of its fauna with the Subathu Formation of the Himalaya and various Cretaceous-Eocene horizons in Pakistan.

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