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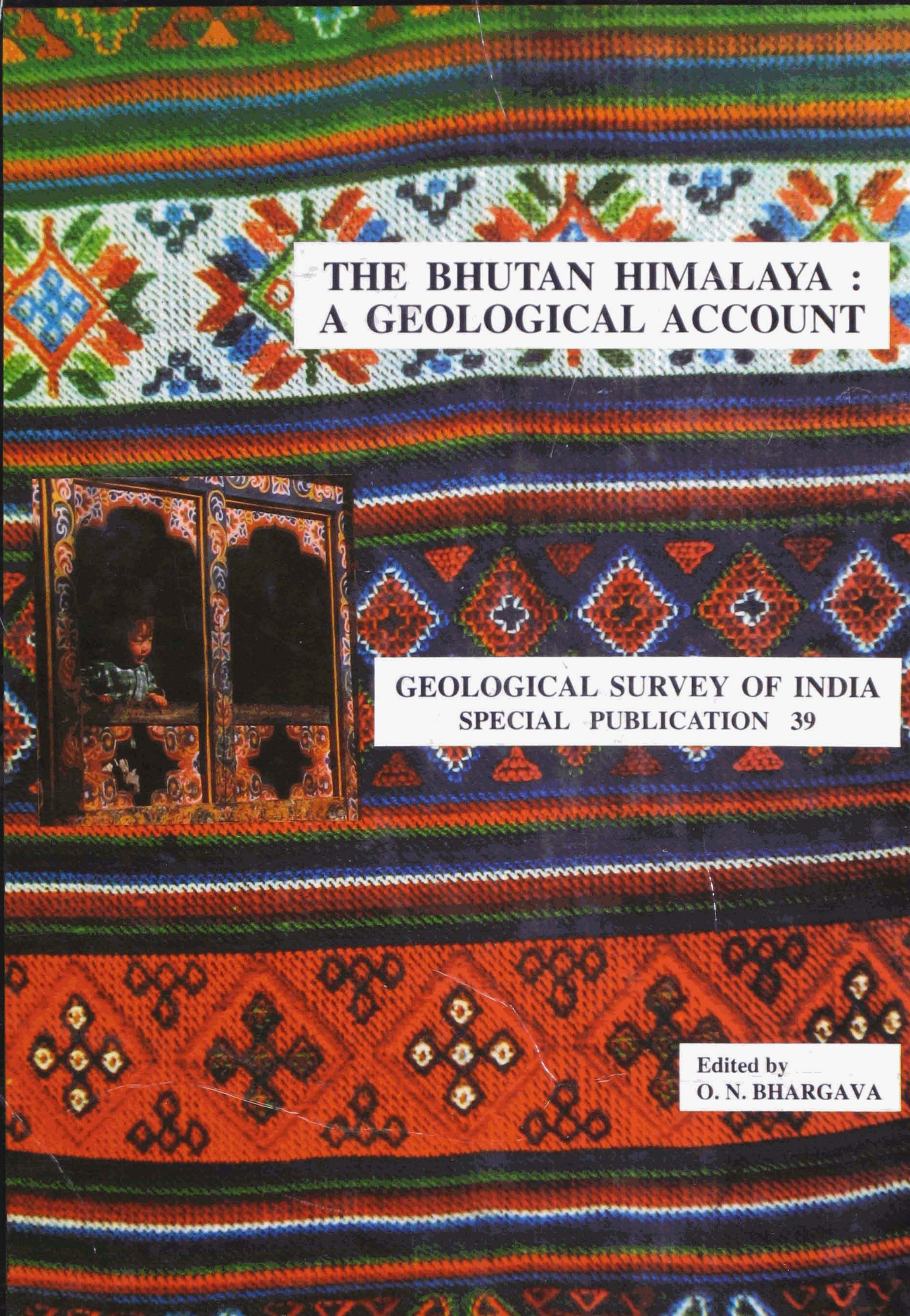

THE BHUTAN HIMALAYA : A GEOLOGICAL ACCOUNT

GEOLOGICAL SURVEY OF INDIA
SPECIAL PUBLICATION 39

Edited by
O. N. BHARGAVA

1995

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विषेश प्रकाशन 39

भारतीय भूवैज्ञानिक सर्वेक्षण

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GEOLOGICAL SURVEY OF INDIA

सम्पादक : ओ. एन. भार्गव

Edited by : O. N. BHARGAVA

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PREFACE

This Special Publication presents a synoptic and critical review of the existing geoscientific knowledge of the Bhutan Himalaya.

The section of Tectonostratigraphy brings out the regional description of all the formations exposed in Bhutan. An interesting feature of this contribution is the detailed description of Quaternary deposits of Bhutan. Though no detailed work was carried out during last few years in the Siwalik, Damuda, Setikhola and Diuri segments, the information contained in these chapters are based on previous unpublished work, with marginal additions. On the other hand, the Baxa, the Shumar, the Thimpu and the Tethyan chapters present new data. The present work necessitated defining a few new formations, viz. the Jaishidanda, the Singhi, the Deshichiling and the Quartzite. The first occurs as a tectonic scale below the Thimphu thrust sheet and the latter three form parts of the Tethyan succession developed over the Thimphu crystallines.

The chapter on the Granitic Rocks provides new petrochemical and geochronological data, which are very useful in regional correlation.

The Synthesis chapter presents the stratigraphic column, attempts correlation of various formations of the Bhutan Himalaya with the better known formations of the other parts of the Himalaya and provides a broad structural and metamorphic set-up. The chapter on Geological History presents an evolutionary model. In such an attempt certain generalisations become unavoidable.

Chapter on Mineral Resources briefly gives the grade and reserves of important mineral deposits of Bhutan.

It is expected that this write-up will fill the voids in the knowledge of the eastern Himalaya. It is hoped that the volume will provide useful geoscientific information to the future workers.

(D. B. Dimri)
Director General
Geological Survey of India

ACKNOWLEDGEMENTS

The idea of compiling the geology of Bhutan was conceived by B.D. Dungrakoti. However, before it could materialise, he was transferred and the mantle fell on me. At that time several contradictions and fallacies existed in the geology of Bhutan. There were three different geological maps, published by (i) Geological Survey of India, (ii) Prof. A. Gansser and (iii) ESCAP (UN). Besides many areas lacked cogent map pattern.

Thus mapping and detailed traverses were organised in all the crucial sections, the result of which is the present new and revised version of the Bhutan Geology. This revision with field work restricted to critical sections during 1993 and 1994 has been possible only due to sound edifice provided by previous workers, whose efforts were ably guided by S.P. Nautiyal (1960-63), B. Laskar (1963-69), P. Kar (1969-74), A.R. Gokul (1974-80), C.P. Vohra (1980-85), B.S. Jangpangi (1985-87) and B.D. Dungrakoti (1988-1992).

Dr. D.K. Paul and Dr. M. Ramakrishnan took keen interest in this write-up, the former arranged for quick geochemical and isotopic studies. Discussions with Dr. S.K. Acharyya, K.K. Ray, Sibdas Ghosh and Dr. S.K. Ray were always educative, refreshing and inspiring.

B.P. Rishi in NAA Lab, Pune and I.B. Ghosh, S. Singh, A.K. Sanyal, S.K. Bhaduri and A. Mondal in Chemical Laboratories, Central Headquarters and Eastern Region were kind enough to analyse various samples on priority.

Colleagues in the Royal Government of Bhutan gave ample and unstinted support to the Geological Survey of India field parties and arranged for various facilities. A special mention may be made of Dorji Wangda and Thinlay Dorji, the latter was also associated with the mapping in Ha district. Dr. T.C.A. Raghavan, the then First Secretary, Indian Embassy, Thimphu evinced keen interest in the present work.

First draft of the manuscript was typed by Dr. J.U. Rao. Final typing was ably and painstakingly performed by S. Mukhopadhyay. Chandra Shekhar and Prasanta Chakraborty drew final drawings and maps. S. Singanenjam and T.K. Pyne meticulously perused the final manuscript.

This write-up has been possible due to a great sacrifice on part of my wife Malti. Despite her serious illness at Chandigarh, she kept on encouraging and inspiring me to stay back at Samtse and complete this book.

This book is published with the kind permission of the Royal Government of Bhutan and the Director General, Geological Survey of India.

O. N. B

THE BHUTAN HIMALAYA : A GEOLOGICAL ACCOUNT

CONTENTS

1. INTRODUCTION

1. INTRODUCTION

O.N. Bhargava

The land-locked mountainous kingdom of Bhutan (Fig.1.1) constitutes an important segment in the geology of the Eastern Himalaya. It is flanked in south-west, south and east respectively by the states of Sikkim, West Bengal-Assam and Arunachal Pradesh of India and in north by Tibet of China. Bhutan is believed to have derived its name from Sanskrit word *"Bhu-uttan or Bhot-ant"*. The former means sudden rise in elevation, while the latter conveys end of Tibet (Anon, 1979). For locals the name of this fabulous country is Druk Yul --- *Land of the Thunder Dragon.*

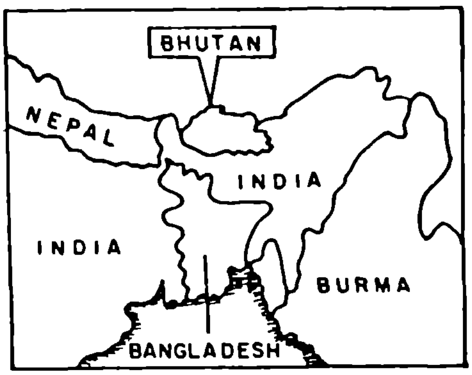

Fig.1.1 Geographical location of Bhutan.

Bhutan having an area of about 46,000 sq km supports a population of 0.6 million. The people of Bhutan come from three stocks. Sharchops, mainly inhabiting the eastern part of the country are the earliest settlers, Ngalongs are of Tibetan descent, predominantly living in west Bhutan and the Nepalese, chiefly confined to the southern part, settled in Bhutan towards the end of the last century.

Thimphu (Fig.1.2), the capital of Bhutan is connected with International Airport Paro by a 52km road. It is linked with the plains of India by Jaigaon-Phuntsholing State Lam-2 (Lam = road). The 550km long Thimphu-Tashigang (SL-1) road is the most important highway in Bhutan which passes through Wangdiphodrang, Tongsa, Bumthang and Mongar. This trunk road is connected with the plain of India through Samdrup Jongkhar-Tashigang road (SL-3), Geylegphug-Shemgang-Tongsa road (SL-4) and Sarbhang-Chirang-Wangdiphodrang road (SL-5). Barring Gasa, all other district headquarters are connected with the State Lams by several branch roads. Since long Punakha, Paro (Fig. 1.3-1.4) and Bumthang have remained the seats of cultural activities. The interior villages are far flung, neat and have beautifully painted houses built of stone, clay and wood. The district administrations and so also the central administration at Thimphu are housed in castle-like buildings known as dzongs (Fig.1.5-1.14). These afford an excellent example of exquisite Bhutanese architecture.

The altitude of the terrain controls the climatic pattern which varies from hot humid summer, heavy monsoon to pleasant winters in south, pleasant summer, normal monsoon to moderately severe cold during winters in middle part and pleasant summer, meagre monsoon and severe cold in northern most and higher altitude terrain. The hills in southern and middle parts rise upto an elevation of 3500m and support a thick forest cover. Bonsun, bamboo, panisaj, chilaune, champ, chikrase, magnolias and orchids are common in the southern foothills. At higher elevation rhododendron, birch, oak, pine, fir, spruce blue pine, hemlock, cyprus and junipers constitute the forests. Altitude above 4500m is mostly barren except for dwarf rhododendron, miniature azolea, iris, poppies and certain herbs.

Wild life is rich in Bhutan. The southern forests, where the Manas Sanctuary is also situated, are inhabited by elephant, tiger, buffalo, bison, rhinoceros, deer and golden langur. Amongst birds, egrets, cormorants, wood pecker and hornbills are common. The Inner Himalayan zone abounds in wild boar, bear, sambar, laughing thrush, ward's trogon, rufousnecked hornbills, myzorin, patridge, fowl and pigeon. In high altitude terrain burket, musk deer, takin, bharal, Himalayan bear and snow leopard are encountered.


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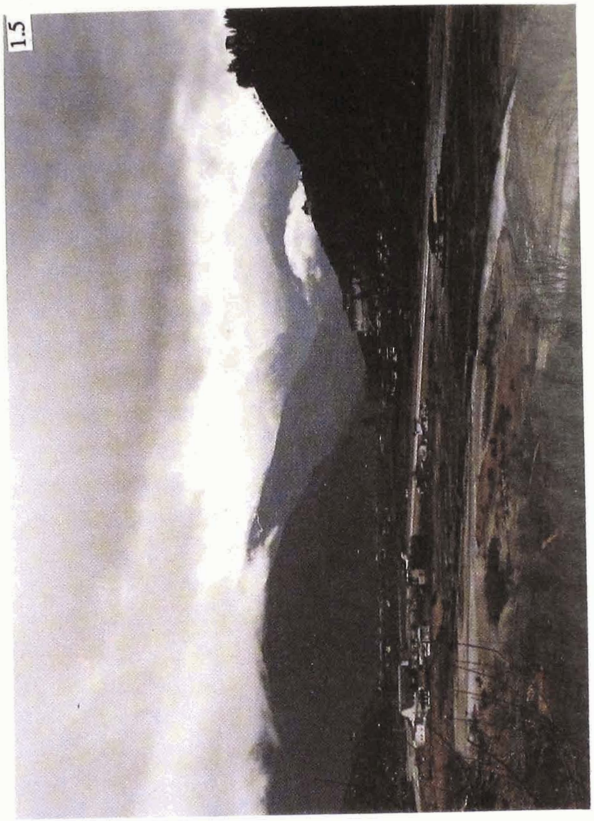
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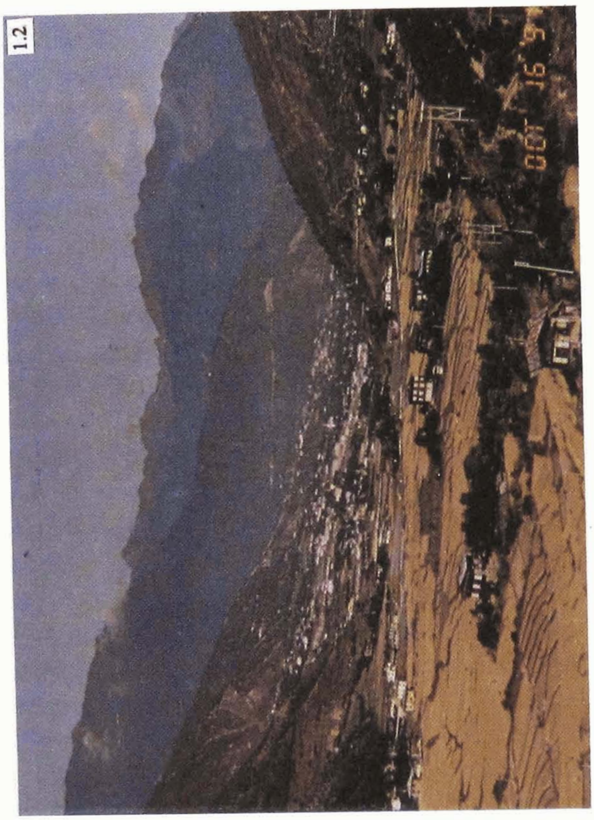

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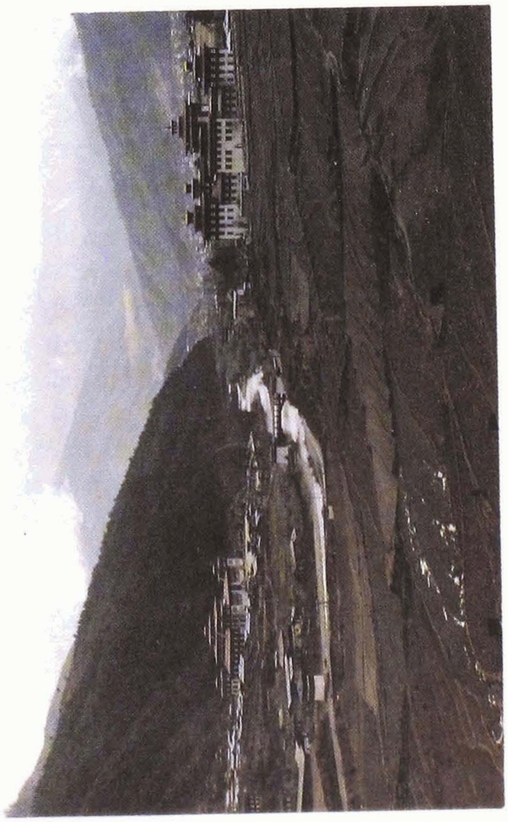
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Table 1.1 : Attributes of principal hotsprings and a few cold springs of Bhutan

Locality	Bhurkhola Cold Spring	Lodrai-Tatapani	Lodrai Cold Spring	Raongri	Tintali-Jiti River	Gasa-1	Gasa-2	Gasa-6	Ratey Pond	Tatapani-Bhurkhola	Rate Khola right bank	Lodrai Hot Spring	Chhephu Thermal	Chhephu Cold Spring
pH	7.2	8.1	7.8	7.7	7.7	7.9	8.1	6.6	8.1	8.9	8.1	7.6	8.7	8.3
Sp.cond. at 25°C	170	881	1359	239	202	8814	8921	6584	255	1859	138	855	377	175
CO_3^-(mg/l)	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	2.0	1.0
HCO_3^-(mg/l)	51	167	122	55	94	2008	2144	1826	129	11	64	163	83	71
Cl^-(mg/l)	6	18	54	8	9	1840	1920	1263	4	22	5	36	51	12
F^-(mg/l)	0.3	0.6	0.8	0.2	0.3	4.0	4.0	4.0	0.4	8.0	0.2	0.6	20	4.0
SO_4^-(mg/l)	34	284	450	57	7	38	35	54	NIL	892	NIL	253	30	10
Total hardness (As $CaCO_3^-$(mg/l)	72	268	314	100	82	176	158	448	116	518	68	252	10	44
Ca^{++}(mg/l)	26	89	92	34	26	25	17	140	40	205	21	88	4	14
Mg^{++}(mg/l)	2	11	20	3	4	28	28	23	4	2	4	8	NIL	2
Na^+(mg/l)	5	70	135	7	7	1700	1810	1230	8	220	3	67	71	24
K^+(mg/l)	2	21	21	5	6	220	220	120	3	4	2	21	1	1
SiO_2(mg/l)	Trace	Trace	5.0	10.0	9.0	35.0	35.0	29.0	23.0	3.0	4.0	1.0	32.0	24.0
Boron(mg/l)	Trace	1.0	1.0	Trace	Trace	61.0	61.0	41.0	1.0	1.0	Trace	1.0	1.0	1.0
TDS(mg/l)	113	680	1011	178	120	5295	5570	3973	174	1485	101	625	260	146

The Bhutan Himalaya is endowed with several hot springs. The attributes of principal hot springs are listed in Table-1.1. the thermal discharges are, in general, feebly alkaline to alkaline with pH of 7.2-8.9. The discharges of Bhurkhola-Lodrai springs are characterised by comparatively high sulphate and total dissolved solid contents. The Gasa spring is richer in hydro-carbonic acid, chlorine, soda, potash, boron and total dissolved solids.

Like other sectors of the Himalaya, the Bhutan Himalaya can also be divided into physiographic sub-divisions of the Siwalik Hills, the Lesser Himalaya and the Higher Himalaya where topography is essentially controlled by geological formations. As would be evident in the following pages, the Siwalik Group is only locally developed and the Lesser Himalayan formations below the Thimphu Thrust Sheet are highly attenuated and tectonically telescoped. As a result the Siwalik hills are only discretely developed and the topography corresponding to the Lesser Himalayan terrain of western and central Himalaya is present only as a narrow zone. In most part specially where the Siwalik Group is absent, the hills abruptly rise from the plains of India and physiography, beyond a narrow zone of the Lesser Himalaya near the foothills, is rugged and comparable with that of the Higher Himalaya of the western Himalaya (Fig. 1.15). The highest terrain which is abode of several glaciers is located in the northern most part of Bhutan. Chomulhari (7326m), Masang Kang (6710m), Fig.1.16), Kula Kangri (7537m), Kanker Phunsum (7561m) and number of unnamed peaks dot the northern Bhutan in Gasa and Punakha districts. Tremo Wagye and Monlakarchung are important passes between Bhutan and Tibet.

Save the Dragme *Chu*, which flows in south-westerly direction, all other rivers in general have a southerly course. These rivers emerging through the steep gradient of Bhutan when meet the Indian Plains, abruptly lose the velocity resulting in heavy sedimentation (Fig.1.17). The main rivers of Bhutan from west to east are the Amo *Chu*, the Ha-Paro-Wang *Chu*, the Sankosh, the Mangde *Chu*-Bumthang *Chu*, the Manas, the Kuru *Chu*, the Borari and the Dhansri. Of these, the Kuru *Chu* is an antecedent river. The Mo *Chu*, Pho *Chu*, tributaries of the Sankosh and Mangde *Chu*, Bumthang *Chu*, Kuru *Chu* and Dragme *Chu* - important tributaries of the Manas river have `U' shaped valleys in their upper reaches, showing imprint of earlier glaciation. These valleys, where become narrow, possibly show the limit of the Quaternary glaciation. This limit in general is at an elevation of 3000m. The average height of the Mangde *Chu* and the Bumthang river beds located in between E longitudes 90° and 91° is higher as compared to those of the Sankosh in the West and the Kuru-Drangme *Chu* in the east. Similarly the average altitude of the Wang *Chu* river bed is higher as compared to the beds of the adjoining valleys. These blocks seem to be sort of uplands of which the former supports the Black Mountain area. All the rivers when meet the plains braid and meander. Drainage density is poor in northern Bhutan constituted of the granitoid gneiss, moderate in central Bhutan made up crystallines and low grade metasediments and high in western, eastern and southern parts of Bhutan comprising sedimentaries and low grade metasedimentaries.

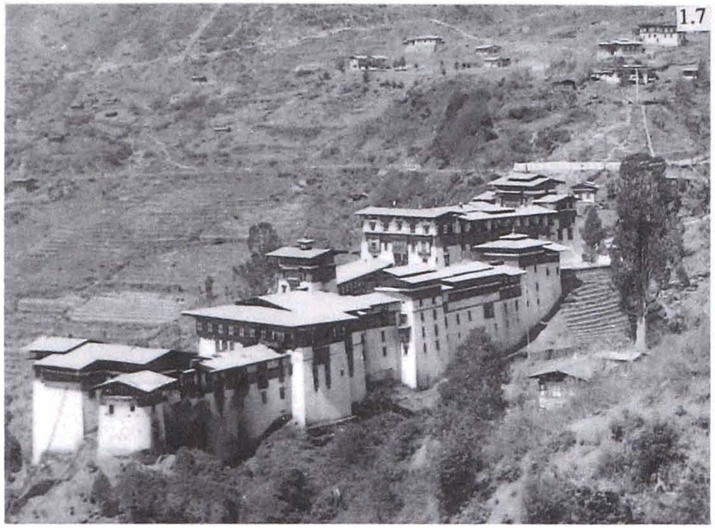
Perpetual snow line in Bhutan is roughly above 5,000m altitude, which is also the abode of glaciers. Glaciated valleys and glacial polish are present in the area south of Singye Dzong, the Wang *Chu* north of Cari Compa, and the Ha valley, NW of Ha Dzong.

The Lunana glacier (Fig.1.18) was examined by the Geological Survey of India in 1973, 1984 and 1986 mainly to assess the environmental hazard posed by the Lunana glacial lake (Fig. 1.19-1.20). There are four main glaciers in the vicinity of the lake. The average width and length of the main glacier are about 500m and 1.25km

Explanation of Fig.s 1.2 - 1.5

Fig.1.2 Thimphu, Capital of Bhutan, located in a broad valley. Fig.1.3 Punakha Dzong situated in a river bed. Fig.1.4 A view of wide Paro Valley. Fig.1.5 A view of Tashichhodzong and SAARC buildings in Thimphu.


1.6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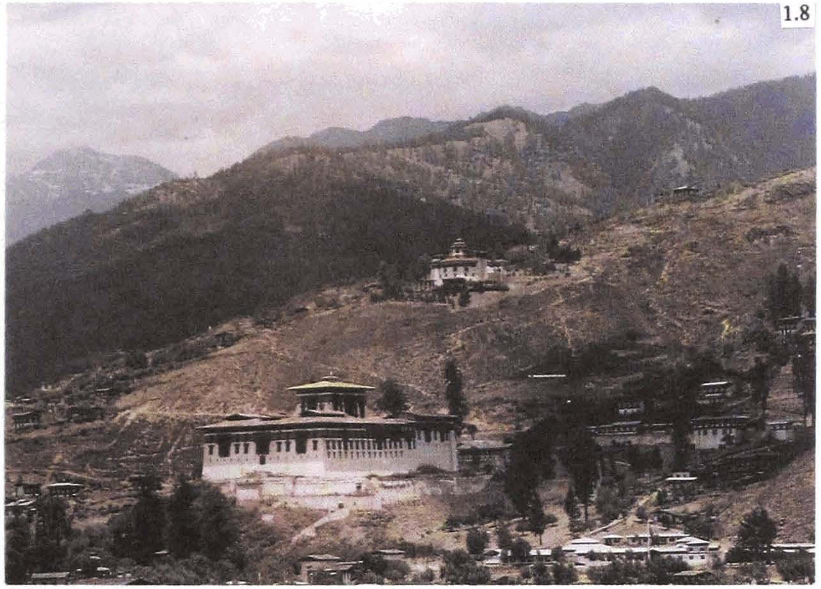
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respectively. The tongue of feeder glaciers directly descends into the lake. The valley walls of the glacier are steep with slope gradient of 55^{o} to 70^{o}. Along the longitudinal section over a distance of 750m the glacier shows a gradient of 7^{o} from snout upto head-wall beyond which it is inclined at 55^{o} to 90^{o}. The glacier besides precipitation in form of snow is also replenished by avalanches. The ablation zone is covered by morainic cover and is dotted by morainic humps -- formed possibly due to differential melting of ice underneath. The accumulation zone is devoid of any morainic cover. Criss-cross patterned small crevaces are present along the headwall of the glacier. Accumulation and ablation ratio is approximately 1:1. The average glacial movement determined by limited observation is 17cm/day.

An account of glacial lakes of Bhutan is given by Gansser (1983). The Lunana lake according to Gansser (1983) poses an environmental hazard to the habitation down stream of the lake. Sharma *et al*., (1986) ruled out the possibility of a sudden spill over of enough water mass from lake causing damage to the Punakha Dzong (Fig.1.3) in immediate future due to high level flood. However, they recommended periodic monitoring of the area. One of the glacial lakes burst in first week of October, 1994.

The first geological information pertaining to Bhutan came from Godwin-Austin (1868) in connection with mineral assessment. He was followed by Mallet (1875) and Pilgrim (1906). Lahiri (1941) provided details of the foot-hill geology especially of his `Buxa Series'. The geological investigations got an impetus after 1961 when the Geological Survey of India (Fig. 1.21-22) set up a unit at Samtse (old spelling Samchi). Results of the early geological survey were published by Nautiyal *et al*, (1964). This was followed by a crisp account of Bhutan geology by Gansser (1964). Jangpangi (1974, 1978) and Jangpangi *et al*, (1975) dealt in detail the regional geology of parts of Bhutan. Yet another detailed account of the Bhutan geology was provided by Gansser (1983). Local details of the Lingshi basin, Tang *Chu* and Black Mountain areas have been provided by Ganesan *et al*, (1978), Mamgain and Roy (1989) and Chaturvedi *et al*, (1983) respectively.

After Nautiyal *et al*, (1964), except for the publication of a geological map (Anon, 1984) no attempt has been made to synthesise divergent views contained in numerous unpublished reports of the Geological Survey of India. The emphasis had shifted to mineral exploration. The results of mineral investigations have been summarised by ESCAP (Anon, 1991) under United Nations in an Atlas of Mineral Resources of Bhutan along with a map.

Thick forest cover, paucity of outcrops, poor communications (Fig.1.23-24) and dearth of even camp sites impose severe constraints on mapping. The detailed geological mapping thus remained confined mainly to accessible sections. In 1993 and 1994 detailed traverses and mapping of selected areas were undertaken to reconcile various contradictory views and remove anomalies in the published geological map (Anon, 1984, 1991). The field investigations were followed by petrological, petrochemical, geochronological and palaeontological studies. The present publication incorporates results of the aforementioned studies. We do not claim to have solved all the geological problems of the Bhutan Himalaya, but we are certainly in a position to provide answer to some of them, furnish details of many formations and formulate right questions for posterity to answer.

Explanation of Figs. 1.6 - 1.9

Fig.1.6 A close up of the SAARC buildings. Fig.1.7 A view of Tongsa Dzong. Fig.1.8 A view of Paro Dzong. Fig.1.9 A view of Paro Museum (Photo P.R. Golani).

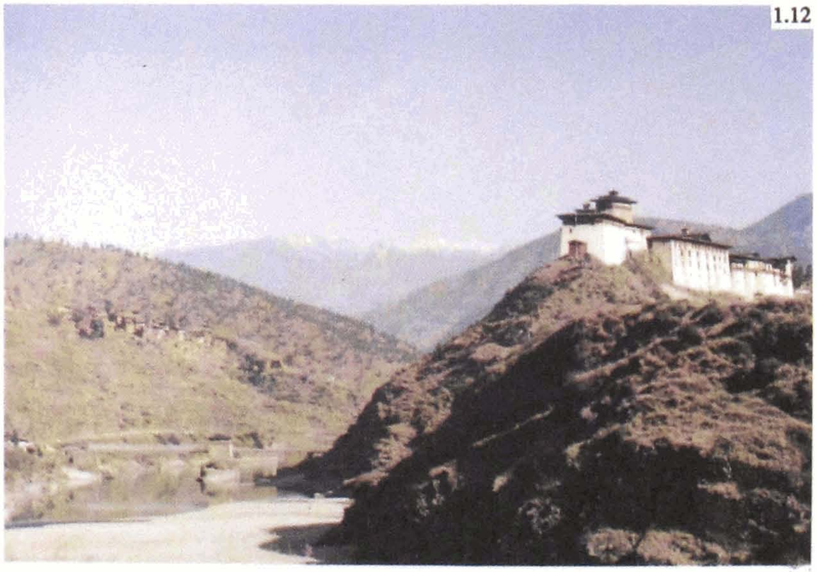
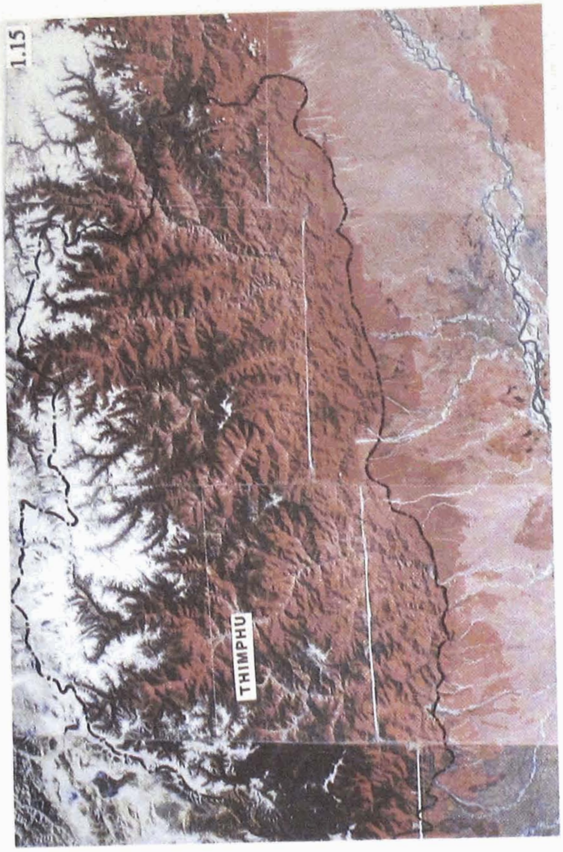


Fig. 1.10 : A distant view of Shemgang (Photo S.K. Tangri). 1.11 : A view of Shemgang Dzong. 1.12 : A view of Wangdi Dzong. 1.13 : Kurje Temple, Bumthang.



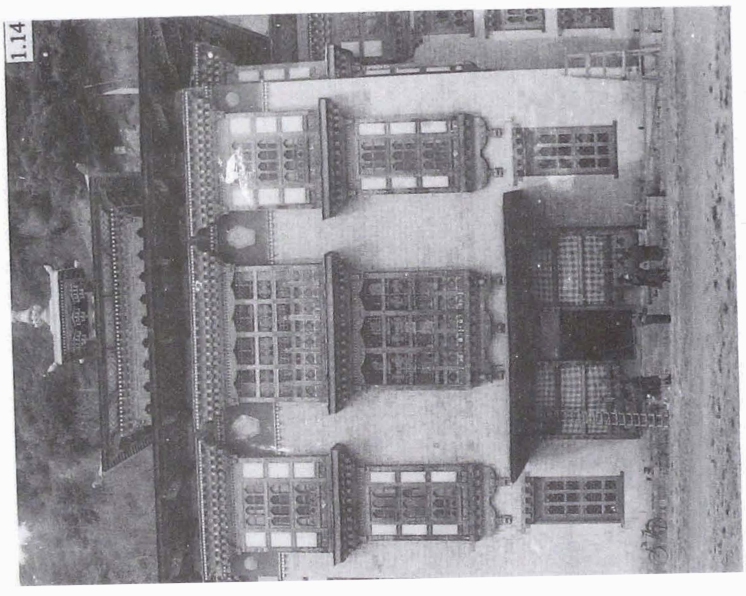


Fig. 1.14 Kurje Temple, Bumthang. Fig.1.15 Uncontrolled FCC Mosaic of Bhutan. International boundary approximate. Fig.1.16 A view of Masang Kang.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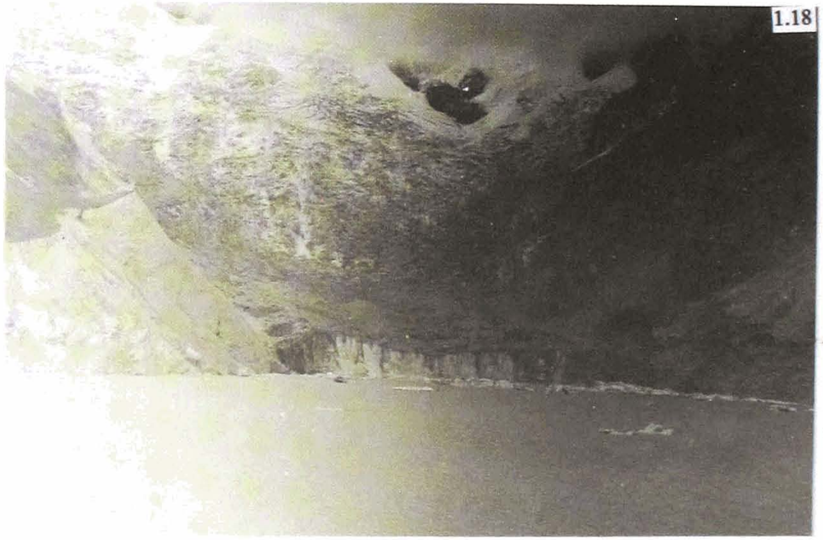
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Explanation of Figs. 1.17 - 1.20

Fig.1.17 During heavy rain and consequent sedimentation, a temporary hut got submerged upto a height of one metre. Fig.1.18-20 Views of Lunana Lake (Photo A.R. Sharma).

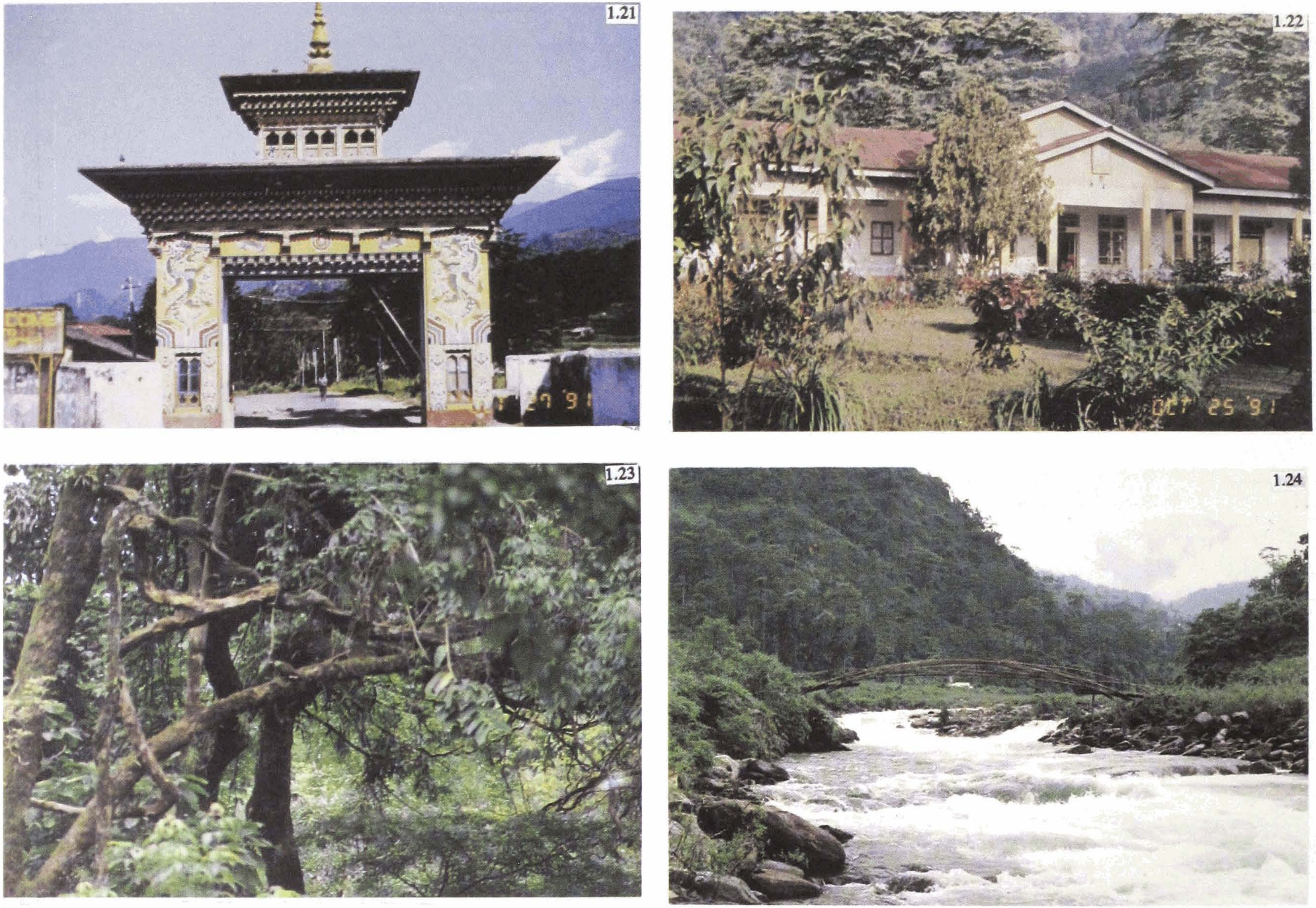

Fig. 1.21 : Samtse Gate. 1.22 : GSI Office at Samtse. 1.23 : Thick forest in a part of Bhutan (Photo Ashutosh Joshi). 1.24 : A primitive bridge on the Jiti river (Photo Ashutosh Joshi).

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2. GEOLOGY OF BHUTAN - A SYNOPTIC VIEW

2. GEOLOGY OF BHUTAN - A SYNOPTIC VIEW

O.N. Bhargava

2.1 TECTONO-STRATIGRAPHY

Based on rock types and tectonic style, the Bhutan Himalaya can be broadly divided into two geological zones : below and above the Thimphu Thrust.

Below the Thimphu Thrust Sheet, largely unfossiliferous Lesser Himalayan formations are present. The Lesser Himalayan sequences, so well developed as distinct tectonic belts in the western Himalaya, have been reduced to a narrow width in the Bhutan Himalaya. The reduction in width is due to more southward translation of the Thimphu Thrust Sheet and tremendous tectonic telescoping suffered by the Lesser Himalayan rocks. The intense tectonics has completely disrupted the original stratigraphic order of these unfossiliferous sequences. No single approach seems to help restoring the stratigraphic order rendered chaotic by tectonics (Table 2.1).

The Thimphu Group has also been referred to as the Takhtsang Gneiss by Gansser (1983) on the plea that the town Thimphu is not situated exactly on the Thimphu `Series' of Nautiyal *et al*, (1964) and that Takhtsang is a better section. We beg to disagree with Gansser (1983). Thimphu is very much situated over the gneiss of the Thimphu Group. Takhtsang certainly exposes excellent section of higher grade metamorphic gneiss but it is different in all respects from the gneiss exposed at Thimphu.The name Thimphu Group is thus retained with the Takhtsang Formation as one of its sub-divisions (see Golani in this volume).

A new formation named after Jaishidanda has been proposed in this write-up (see Dasgupta in this volume). The sequence classified under the Jaishidanda Formation was earlier mapped by different workers as part of either the Thimphu Group or of the Shumar Formation. Dasgupta (this volume) finds this formation distinct from both, hence the new name. B.D. Dungrakoti however, considers the creation of this formation unnecessary.

The Shumar has been used synonymously with the Daling by Gansser (1983). Dasgupta's mapping reveals that the Daling as defined recently (Acharyya, 1989, Ray, 1989) is much too different from the Shumar Formation and the former includes equivalents possibly of the Baxa

Table 2.1 - Tectono-stratigraphic order of superposition in the Bhutan Himalaya

Tethyan succession	Conglomerate, shale, siltstone, sandstone, limestone, volcanics.
--------- Unconformity ---------	
Thimphu Group	Gneiss, migmatite, amphibolite and high grade metasediments.
-------- Thimphu Thrust -------	
Jaishidanda Formation	Biotite-garnet+staurolite schist with tectonic slivers of granite gneiss.
-------- Jaishidanda Thrust -------	
Shumar Formation	Quartzite, phyllite and chlorite-mica schist, Barsong limestone, a few tectonic slivers of granite gneiss in lower part.
-------- Shumar Thrust --------	
Diuri Formation	Diamictite, phyllite, quartzite.
--------- Unconformity ? - locally tectonised --------	
Baxa Group	Gritty feldspathic quartzite, limestone, dolomite, quartzite, conglomerate, slate, quartzite, phyllite, tectonic scales of Permian Setikhola Formation.
-------- Baxa Thrust --------	
Damuda Subgroup	Sandstone, siltstone, shale, coal beds.
-------- MBT --------	
Siwalik Group	Sandstone, siltstone, shale, clay, conglomerate.
-------- Fault --------	
Quaternary succession	Sand, conglomerate, silt, clay.

Group and Jaishidanda Formation also. Though it is conceded that a large part of the Daling is equivalent of the Shumar, due to subtle differences enumerated above, it is preferred to retain the term Shumar in the present write-up.

Gansser (1983) considered the Thungsing Formation indistinguishable from the Shumar Formation, while in the geological map published by the GSI (Anon, 1984), the Thungsing Formation is considered to form the oldest unit of the 'Baxa' Group. There is also a difference of opinion about the geographical extension of the Thungsing Formation in Bhutan. According to earlier geological map (Anon, 1984), it extends throughout the entire length of Bhutan, whereas ESCAP map (Anon, 1991) shows it confined to the Eastern Bhutan only. The present work suggests that the Thungsing Formation in lithology and finer details of metamorphism is quite distinct from the Shumar Formation and it forms a part of the Baxa Group. Tangri critically examines this problem in the present volume.

The Thungsing Formation is reported to grade into the Diuri Formation, which has been considered as part of the Gondwana sequence by several workers. In the Samdrup Jongkhar Section, the Diuri Formation is not only devoid of fossils but also lacks bioturbation, yet in the Setikhola section the Diuri-like conglomerate is associated with beds yielding Permian marine fossils (Joshi, 1989). Tangri (this volume) studied the Diuri as well as the conglomerate associated with the Permian fossils and has interesting points to make.

The Baxa in recent publications has also been spelt as Buxa. Mallet (1875) originally spelt this sequence as Baxa, which has also been adopted in the Lexicon of Indian Stratigraphy. Thus as suggested by Srikantia and Bhargava (1982) and Gansser (1983) Baxa has a precedence over Buxa. The Baxa has been accorded a group status and divided into three formations(Anon, 1984). Tangri (this volume) re-evaluates this grouping.

The coal-bearing Damuda Subgroup in the Eastern Bhutan is fossiliferous and divisible into two units. It has been reviewed by Lakshminarayana in this volume. The marine equivalent of the Damuda has been designated as the Setikhola Formation (Joshi, *et al*, 1990) after the Setikhola where this formation encloses marine fossils. Marine fossils have also been reported from the Deothang section (Damuda Subgroup) by Acharyya (1978). Identical looking sequences in the western Bhutan, though unfossiliferous have also been mapped as the Setikhola Formation (Anon, 1991). The Setikhola Formation is described in this volume by Joshi.

The Siwalik Group in Bhutan has narrow outcrop width and along strike it is discretely developed. Lakshminarayana (this volume) has been able to classify the Siwalik sequence into three broad sub-divisions and establish sedimentary cycles.

The so called Tethyan sequence occurs over the Thimphu Group in four isolated synclinoria, viz., Lingshi, Gurpola, Black Mountain, Sakteng and one north of the Lunana lake. The Black Mountain and Sakteng sequences rest over the Sure Formation, while the Lingshi and Gurpola sequences occur over the Takhtsang Formation. Of all the Tethyan sequences in the Himalaya, the Black Mountain succession is nearest to the Peninsular Shield area.

On the Tethyan side also the stratigraphic picture is not too clear and many controversies do exist. The Chekha Formation of Nautiyal *et al*, (1964) was redesignated as the Mao Khola Group, divisible into the Harachu and Tirkhola Formations. Present work suggests that there is no distinct difference between these two formations and also changing name from Chekha to Mao Khola was uncalled for. The name Chekha has thus been restored in this publication.

The quartzite and conglomerate referred to as the Nake Chu Formation, occur at several tectono-stratigraphic levels within the Chekha Formation. It would be interesting to find if they belong to same stratigraphic level and repeated due to folding or represent different stratigraphic levels. The sequence overlying the Chekha-Nake

Chu Formations was classified under the Black Mountain Group. From the basal most Maneting Formation of this group, Chaturvedi *et al*, (1983), reported mid-late Ordovician fossils. Mamgain and Roy (1989) from this very sequence have recorded lingulellid fossils of early Cambrian age and suggested a stratigraphic inversion in the Black Mountain area. However, there are two more possibilities; (i) the identifications of fossil collection of Chaturvedi *et al*, (1983) are possibly not conclusive and the entire sequence may be really Cambrian, or (ii) there is a major unconformity within the Maneting Formation. The overlying Wachi La Formation is largely unfossiliferous while the upper most Tang Chu Formation of the Black Mountain Group has been found to be a mixture of Palaeozoic Ripakha and Pe Chu Formations (Devonian-Carboniferous) and late Mesozoic Beli Formation. Mamgain and Roy (1989), redesignated it as the Tangchu Formation (it should have been a group instead) under which they still classified Ripakha, Beli and Pe Chu Formations of diverse ages which are also separated by major hiatus. These formations of different ages and separated by unconformities cannot be classified under one group.

In the Lingshi sector, the Tethyan sequence comprises Barishong and Shodug Formations (Ganesan *et al*, 1978) supposedly of Silurian to early Carboniferous and middle Carboniferous to Permian ages respectively. The younger sequence in this basin is known as the Lingshi Group divisible on the basis of fresh water, fresh water-marine and marine fossils into the Mo Chu, Chebesa and Ngile La Formations, (Ganesan *et al*, 1978). Tangri and Pande (this volume) attempt to answer many of these points.

In the above description, the Paro Formation does not find a mention. The name Paro 'Series' was suggested by Nautiyal *et al*, (1964) for a metasedimentary sequence occurring below the Thimphu Group. The Paro 'Series' though lumped with the Thimphu Group (Nautiyal *et al*, 1964) had tectono-stratigraphic connotation i.e., its position below the Thimphu gneiss. Gansser (1983), however, used this term for several metasedimentary sequences regardless of their tectono-stratigraphic position. During recent surveys the Paro Formation *sensu-stricto* has been found to be an extension of the Shumar and the Jaishidanda Formations exposed in the tectonic windows below the Thimphu Thrust Sheet at Paro, Chukha and Sambe Dzong, Duna Dzong and Getta Dzong (Dasgupta, this volume). The sequences designated by Gansser (1983) as Paro other than those mentioned above, occur at different tectonic levels and according to present mapping form part of the Thimphu Group (Naspe Formation of Golani). The name Paro in the present write-up, therefore, has been dropped. B.D. Dungrakoti, however, opines that the Paro could be retained for rocks exposed in the windows.

Fig. 2.1 Two levels of terrace along the Kirung *Ri* at Nganglam

There are no direct evidences to assign any age to unfossiliferous sequences or even to determine their relative order of superposition. Even the Tethyan, Damuda Subgroup and Siwalik sequences are sporadically fossiliferous and defy precise age fixation.

2.2 STRUCTURE

Structurally the Bhutan Himalaya presents an extremely complicated picture. Each formation is not only thrust bound but is also traversed by subthrusts. The southern most tectonic belts show maximum imbrications and constitute a schuppen zone, though the horizontal translation involved seems to be limited and deformational history simple. The northern tectonic belts (i.e., Shumar and Thimphu Thrust Sheets) apparently seem to have simple regional structure but have suffered large scale horizontal translation and show a complicated deformational history. In contrast to the western Himalaya, the Tethyan rocks in the Bhutan Himalaya seem to be involved in complicated deformation. An attempt is made to reconstruct deformational history and also provide broad structural set-up of the Bhutan Himalaya. There are wide spread evidences of neo-tectonics in Bhutan which also find a mention in this volume (see Synthesis).

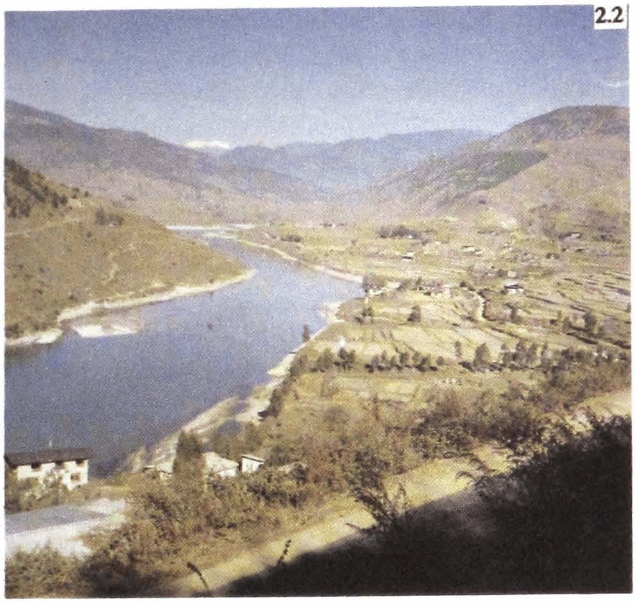

Fig. 2.2 Unpaired terraces along the broad Ama Chu, Wangdiphodrang

2.3 METAMORPHISM

The rocks in the Bhutan Himalaya show metamorphism varying from anchigrade to higher amphibolite-granulite (?) facies. Almost every tectonic belt is characterised by a distinct metamorphic facies. Polymetamorphic characters are apparent specially in the rocks of the Jaishidanda Formation and the Thimphu Group. It may not be possible to provide time connotation to these metamorphic episodes but some inter-relationship vis-a-vis deformation can be established (see Synthesis).

2.4 GEOMORPHOLOGY

The Bhutan Himalaya offers a fascinating geomorphological study. However, the area is too vast and our observations being of restricted nature, only a generalised account of geomorphology is possible. Abrupt rise in altitude from the plains is the most conspicuous feature of the Bhutan Himalaya. Pediment zone in Bhutan has restricted development. Three levels of river terraces (Fig. 2.1) are commonly found. The terraces are generally unpaired (Fig. 2.2) and locally paired. The denudational hills are low lying in the foot hills, moderate to high in the Lesser Himalaya and high in the northern Higher Himalaya.

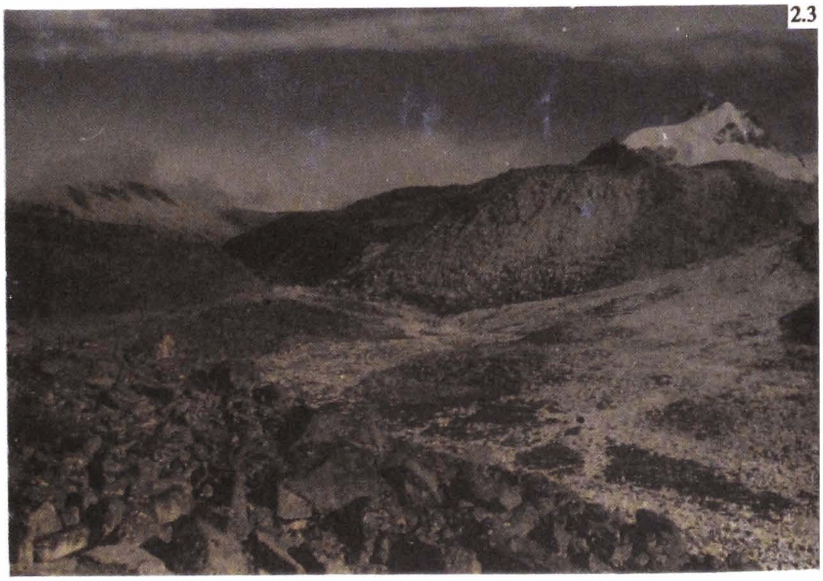

Fig. 2.3 Moraines in Lunana area.

True glacial deposits are found around the glaciers as various kinds of moraines (Fig. 2.3).

An attempt has been made towards the end of this write-up to harmonize various divergent views and interpret and synthesise the geological history of the Bhutan Himalaya. Such a synthesis based on limited data, cannot be final; hopefully it is an improvement on the existing knowledge on the Bhutan geology.

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3. TECTONOSTRATIGRAPHY

3.1 QUATERNARY SEDIMENTS

T. Laskar

The main spread of the Quaternary Sediments is found south of Bhutan in Indian plains. Within the Bhutan territory, the Quaternary successions are of limited extent. These belong to following categories.

(1) Glacial, (2) Glacio-fluvial, (3) Fluvial, (4) Lacustrine and (5) Residual soils.

3.1.1

Fig. 3.1.1 Moraines in the Ha Valley.

3.1.1 Glacial deposits

True glacial sediments are present only along the present day glaciers as surface, lateral, median and terminal moraines (Fig.3.1.1). These deposits comprise ill-sorted sub-angular to sub-rounded diamictons embedded in silty to clayey matrix. Though the matrix vs. clasts percentage is highly variable, the diamictites are by and large matrix supported. The faceting and glacial striations are rather rare. Locally drumlins made of finer clastics are also observed.

3.1.2 Glacio-fluvial deposits

Glacio-fluvial sediments are mainly found downstream of the existing glaciers (Fig.3.1.2). Though along the turbulent streams the glacial erratics/diamictons have been carried quite far from the glaciers as outwash, in most of the cases the glacio-fluvial deposits are confined to the vicinity of the glaciers. These comprise

3.1.2

Fig. 3.1.2 Glacio-fluvial deposits, Bumthang.

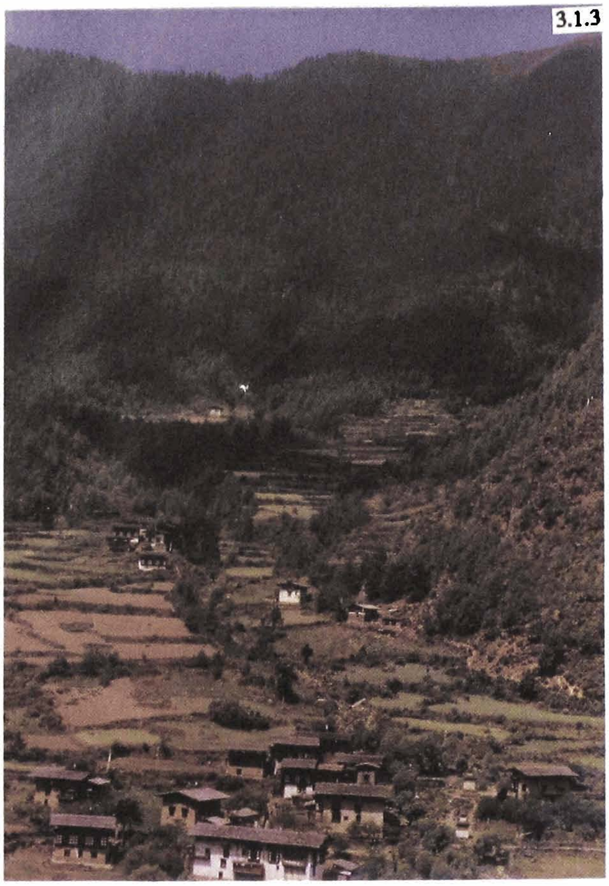
3.1.3

Fig. 3.1.3 Fan deposit supporting habitation in the Ha Valley.

subrounded to rather rounded clasts varying in size from pebble to boulders embedded in a clayey-sandy matrix. Where large ill-sorted clasts are absent, it is difficult to distinguish fluvio-glacial sediments from the fluvial deposits.

3.1.3 Fluvial and fan deposits

The fluvial deposits occur as terraces at different heights on either side of the present day valleys. Fan deposits are extensively developed throughout the foot-hills, which are reworked by rivers during floods; these locally occur in Higher Himalaya also (Fig.3.1.3).

The fluvial deposits in most sections represent alternate beds of coarser and finer (sand size) clastics of variable thickness (Fig.3.1.4). The coarser clastic layers are both clast and matrix supported. The clasts are well rounded (Fig.3.1.5), well sorted and where pebble dominated show pebble imbrication (Fig.3.1.6). Within these, locally occur fine silty and clayey layers (Fig.3.1.7-3.1.8).

The alternation of coarser and finer sand either indicates annual seasonal variation i.e. coarser representing material transportated by the turbulent streams during monsoon and deposition due to loss of energy of these streams during the lean season. The finer sediments represent medium energy streams during which this material also sieved through the boulders and cobbles to provide matrix to the coarser layer. Alternatively finer and coarser fractions may be function of tectonic activity. Coarser element representing upliftment of the catchment area whose gradual levelling restorated supply of the finer clastics.

About 2000m thick conglomeratic sequence, designated as the Diklai Boulder Bed was considered as upper

3.1.4

Fig. 3.1.4 Fluvial deposit in Bumthang area.

most part of the Siwalik Group by Jangpangi, (1974). The Diklai sequence comprises diamictite,

Fig. 3.1.5 Coarser clastics in fluvial sediments in Bumthang area.

conglomeratic sandstone, argillaceous sandstone and silty claystone. The diamictite is constituted of rounded pebble, cobble and boulders, mainly of quartzite in an areno-argillaceous matrix. Carbonised wood and ill-preserved dicot leaf impressions are common in silty clay matrix. This sequence, almost horizontal and undeformed, rests over folded and faulted Siwalik Group rocks, between Jiabor *Nadi* and Janapani *Nadi* in eastern Bhutan. In the present write-up it is regarded to be a post-Siwalik sequence deposited after the deformation of the Siwalik (cf. Acharyya, 1994). The Diklai Boulder Bed possibly represents a fan deposit of Quaternary age which was partially reworked by axial drainage.

The silty-clayey layers present in the fluvial sequence are interpreted to represent local ponding of the river due to landslide/blockades. The erosion of the landslide restored the course of the river and also the sedimentation of the coarser sediments.

3.1.4 Lacustrine deposits

The lacustrine deposits in the Bhutan Himalaya are found around the lakes and also interbedded with fluvial cycles. Those occurring in the present day lake basin are mainly fine grained sediments while away from the fringes of the lakes towards upslope they pass into fluvial, glacial and/or fan deposits.

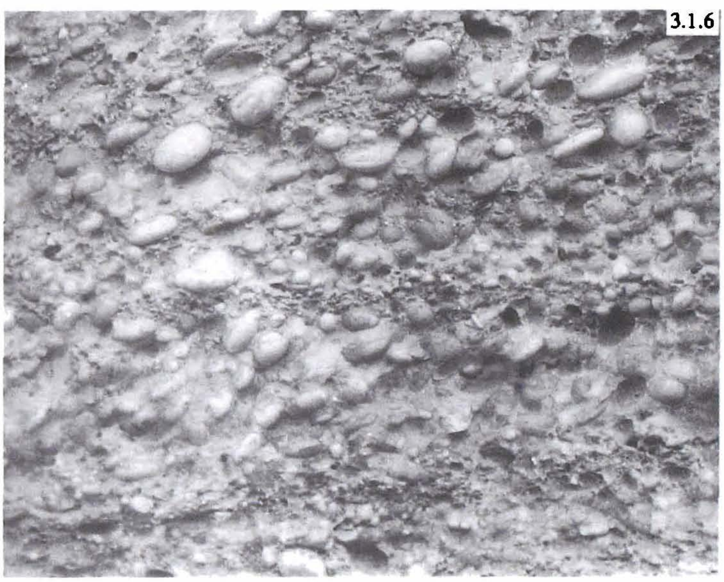

Fig. 3.1.6 Well sorted pebbles - cobbles in a fluvial sequence, Bumthang area.

The lacustrine deposits associated with the riverine sequence are both restricted and also extensively developed. The former represent short and local damming of the river while the latter is due to large landslides which dammed the rivers. The larger slides obviously required greater span of time to get eroded; the broad terraces are mainly due to lakes formed by such slides. These deposits, as in recent lake sediments, upslope pass into coarser clastic deposits. Erosion of landslide which restored the river flow also led to reworking of the lake and fan sediments.

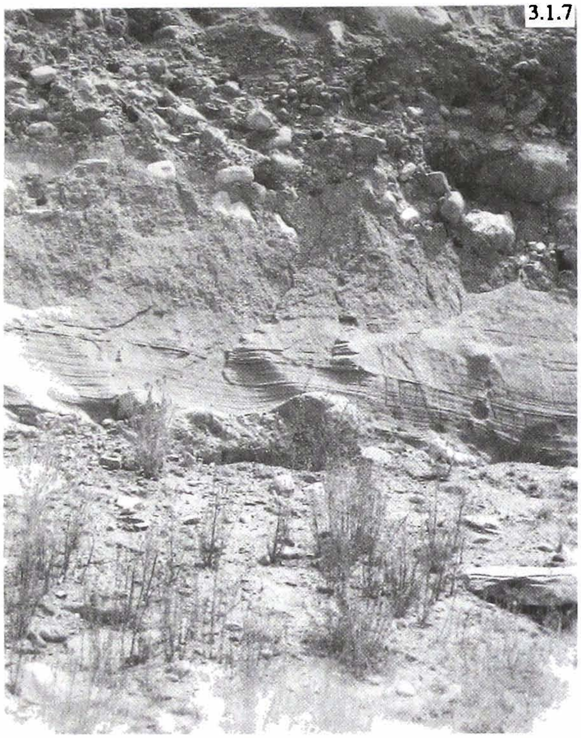

Fig. 3.1.7 Rhythmic lacustrine clay in a flivial sequence, Bumthang area.

Fig.3.1.8 Close-up of the above.

3.1.5 Residual soil

Locally residual soil is developed in the Bhutan Himalaya. The residual soil is specially conspicuous over marble bearing rocks near Paro, Lobesa and Punakha area.

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3.2 SIWALIK GROUP

G. Lakshminarayana and Bhagwan Singh

A molassic sequence of the Neogene age named after the Siwalik Hills is developed through out the length of the Himalaya. Rich in vertebrate fossils, the Siwalik Group shows excellent development in the Western Himalaya. However, east of Hardwar (Garhwal foothills), the Siwalik Group rocks are poor in fossil contents. In Bhutan, the sediments of the Siwalik Group are not only poorly fossiliferous but are also discretely developed. All along the foot-hills of Bhutan, these sediments form a scarp against the Indian plains.

The Siwalik Group in Bhutan was first studied by Godwin-Austin (1868), who also discovered an elephant molar. He was followed by Mallet (1875), Pilgrim (1906), Heim and Gansser (1939), Lahiri (1941), Nautiyal *et al,* (1964), Jangpangi (1974), Biswas *et al,* (1979), and Agarwal *et al,* (1991).

Crocodilus teeth (Dhaundial and Awasthi, 1981), lamellibranch and gastropod impressions (Rao and Murthy, 1968) and dicot leaf impressions are known from the Siwalik Group of

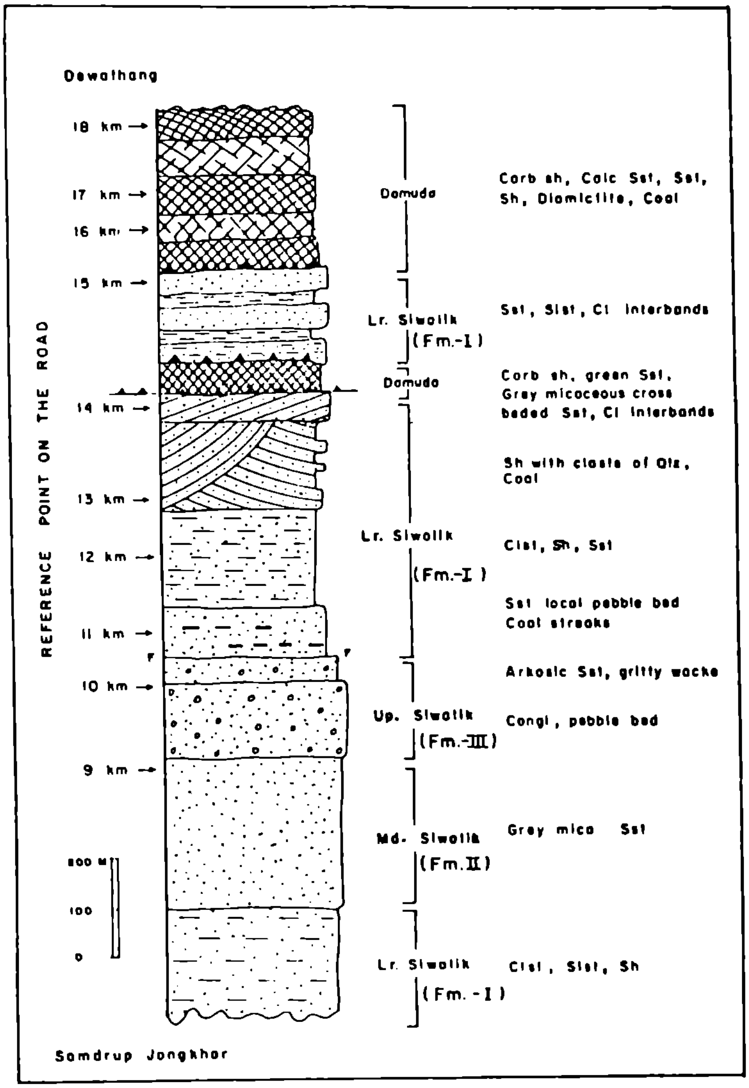

Fig. 3.2.1a Generalised tectono-stratigraphic sequence of the Siwalik Group between Samdrup Jongkhar and Deothang.

Bhutan. Limited record of fauna in Bhutan, at least in part, could be due to lack of intensive search.

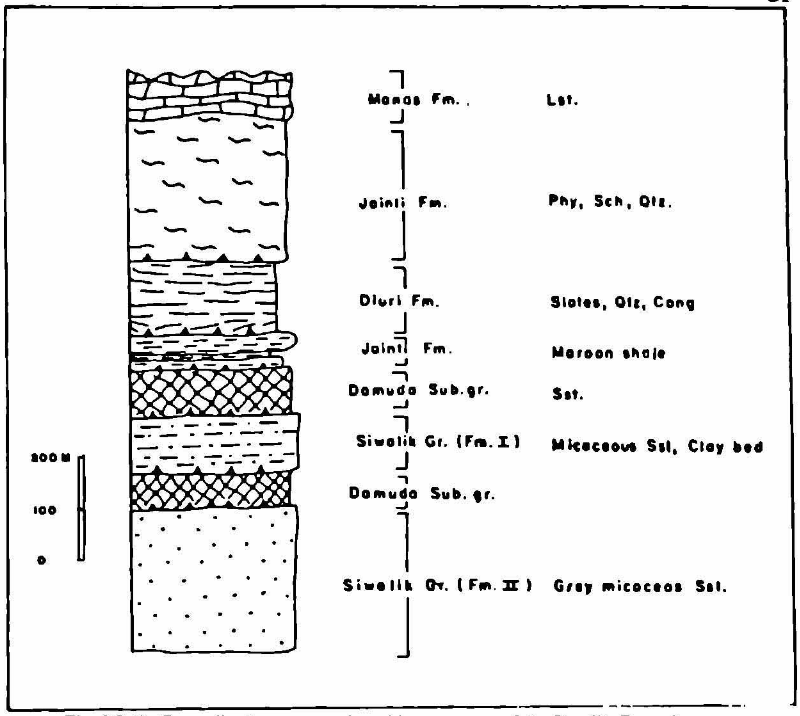

Fig. 3.2.1b Generalised tectonostratigraphic sequence of the Siwalik Group in Nganglam-Gachari section.

The Siwalik Group bound by the Indian plains in south and variously by the Damuda Subgroup and Baxa Group along well defined tectonic planes in north, is divisible into three

Fig. 3.2.2 Alternating units of shale-clay and fine grained sandstone in Formation-I, Samdrup Jongkhar area.

Fig. 3.2.4 Syndepositional fault in Formation-I, Samdrup Jongkhar.

formations. Nautiyal *et al,* (1964) conventionally designated them as `Lower, Middle and Upper Siwalik', whereas Acharyya (1994) following Biswas *et al,* (1979) classified the Siwalik Group into Formation-I, Formation-II and Formation-III. The Diklai Boulder Bed of Jangpangi (1974) rests over the folded Siwalik Group rocks along an unconformity. This sequence thus is of Quaternary age and has been separated from the Siwalik Group (Acharyya, 1994).

Lithological Details

A generalised sequence of the Siwalik Group is presented in Fig. 3.2.1a-b. In Eastern

Bhutan in Samdrup Jongkhar-Deothang section, all the three formations are exposed, whereas towards west mostly lower and middle subdivisions are developed.

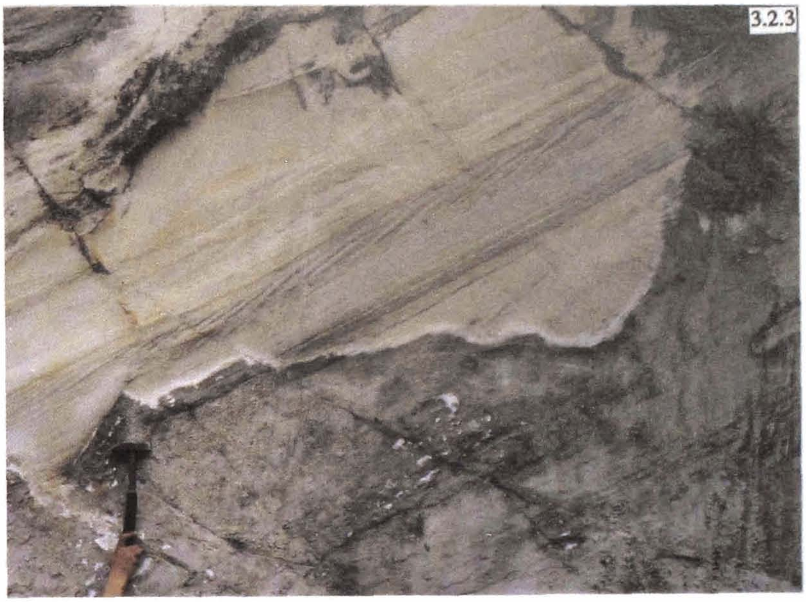

Fig. 3.2.3 Small scale tabular cross-stratification in sandstone (Formation-I), Samdrup Jongkhar area.

Formation - I This formation is well exposed in Dirang, Pagladiyo, Danag, Matunga, Jibar, Chamrang, Manas and Sankosh sections. Its thickness in Samdrup Jongkhar area is about 1000m (Joshi, 1989) and 1200m in Nganglam stretch.

The Formation-I comprises dark grey, greenish grey light brown clay/shale and fine grained sandstone repeated in alternate cycles (Fig.3.2.2) with local calcareous nodules and pockets and lenses of light brown lignite mainly in clay layers. The thickness of fine grained sandstone increases in each succeeding cycle. The sandstone is made up of lithic fragments, quartz, feldspar in a clayey to micaceous (biotite) matrix. Garnet, zircon, ilmenite, tourmaline and magnetite consitute the heavy minerals.

Small scale cross-bedding, ripple drift cross-bedding and tabular cross-bedding (Fig.3.2.3) are preserved in the sandstone. Slumps and faults, possibly of syn-sedimentation origin, are present in the Formation-I of the Samdrup Jongkhar section (Fig. 3.2.4).

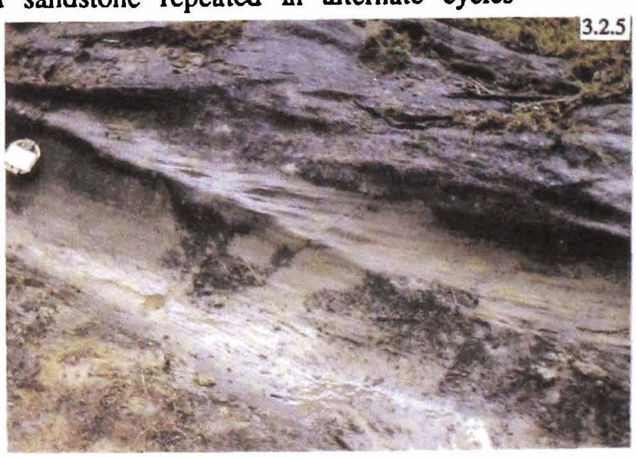

Fig. 3.2.5 Wedge-shaped cross-bedding in Formation-II, Samdrup Jongkhar section.

Leaf impressions of *Gangifera* sp., *Shorea* sp., *Cinnamomum* sp. and *Psilidium* sp., are known from this formation (Sinha, 1974). The microfloral elements include *Cyathidites, Polypodia-ceasporites, Marosullites* sp., *Tricolpites* sp., *Palmaepothenites, Polypodisporites* and *Leptolepidites* sp.

Fig. 3.2.6 Horizontal bed lamination, Formation-II, Samdrup ongkhar section.

Formation - II Conformably overlying the Formation-I, the Formation-II ranges in thickness from 200m to 1000m. It is exposed in all the sections of Bhutan where the Siwalik Group is developed. It is constituted of medium to coarse grained greenish grey to grey, salt and pepper textured medium to thickly bedded sandstone, conglomeratic sandstone, and lenses of conglomerates and shale.

The sandstone is made up of quartz, feldspar and rock fragments of quartzite and phyllite in a clayey to calcareous matrix. Garnet, tourmaline, zircon and opaques occur as heavy minerals. Conglomeratic sandstone contains moderately well sorted, two to six centimetre size pebbles of quartzite, dolomite, limestone, grey feldspathic quartzite, and a few rare clasts of biotite gneiss and granite. The conglomeratic lenses are identical in composition. Lenses of grey clay (40cm-60cm) also occur within the sandstone.

Horizontal lamination, tabular and wedged-shaped cross-bedding and small to large channel scours are present in the sandstone beds (Fig. 3.2.5-7). The channel scours are gently wavy and show a concentration of reworked clasts (Fig.3.2.8). The size of clasts in basal part of the sequence is smaller (about 10 cm) as compared to upper part (300cm). Reworked coal-clasts (few millimetres to four centimetres) also occur within the sandstone (Fig.3.2.9). These coal clasts differ from light brown lignite of the Siwalik in having vitreous lustre. Powdered coal occurs along thin laminae of fossil beds. Generalised lithofacies of Formation-II are shown in Fig. 3.2.10.

Crocodilus sp. is known from the calcareous sandstone of the Formation-II (Dhaundiyal and Awasthi, 1981). Fossil wood and leaf impressions are preserved in clay beds. In eastern sector occur

Fig. 3.2.7 Channel scour, Formation-II, Samdrup Jongkhar

irregular calcareous nodules which possibly represent a partially paleo-pedogenised surface.

Fig. 3.2.8 Close-up of above.

Formation - III This formation rests conformably over the Formation-II and is well developed (600m-800m) in Raidak, Darranga, Matunga, Jaibar and Lakshmi sections. It is absent in Eastern Bhutan. The Formation-III is constituted of boulder conglomerate, grey conglomeratic sandstone and sandstone and local lensoidal beds of siltstone and shale. The conglomerate is matrix as well as clast-supported and shows moderately well to poorly sorted clasts of quartzite, gneiss and granite. The size of clasts mainly varies from pebble to cobble. The thickness of conglomerate bed varies from three metres to 30m. The clasts in the conglomerate bed

Fig. 3.2.9 Coal clast in sandstone.

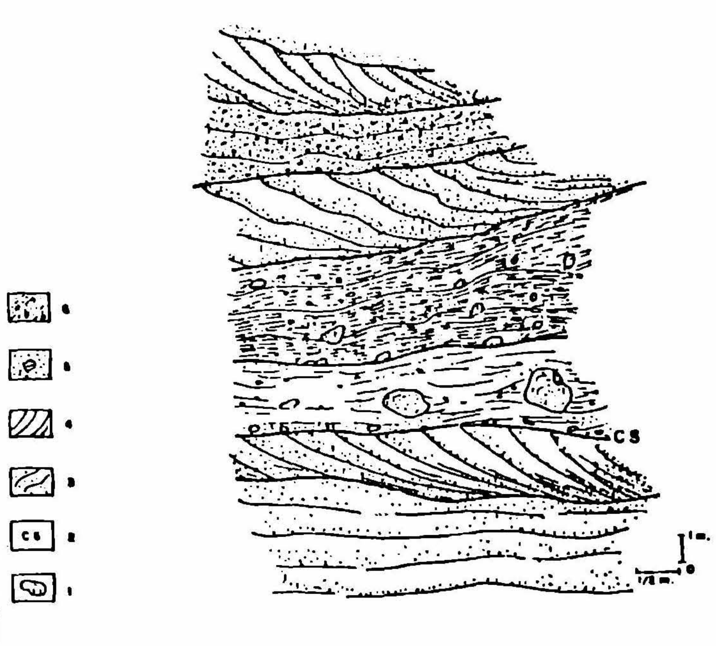

Fig. 3.2.10 Generalised lithofacies succession in the Formation-II, in Samdrup Jongkhar-Deothang section : 1. Intraformational sandstone clast, 2. Channel scour, 3. Sst. - Horizontal lamination, 4. Sst. -Tabular cross-bedding, 5. Massive Sst., 6. Conglomeratic Sst.

occurring in the basal part of the sequence are aligned parallel to the bedding. The sandstone is wacke type and shows clasts of quartzite, gneiss, granite, schist, phyllite, in a biotite-rich micaceous matrix. The heavy minerals are represented by kyanite, sillimanite, rutile and zircon. Locally the conglomerate shows channeled characters.

Biswas *et al*, (1979) reported lateral gradation of Formation-II into the Formation-III in the Ranga Khunda-Khurdi and Sankosh sections. Intercalated contact between the Formation-I and Formation-II is also observed between Kalapani and Janapani rivers.

The three formations of the Siwalik Group have been correlated by Acharyya (1994) with the Gish clay, Geabdat Sandstone and Parbu Grit - Murti Boulder Bed of Darjeeling and Dafla, Subansiri and Kimin Formations of Arunachal respectively.

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3.3 DAMUDA SUBGROUP

G. Lakshminarayana

The Gondwana sediments in Bhutan were initially surveyed by Pilgrim (1906). Subsequently Jangpangi (1974) carried out detailed mapping and reported several coal occurrences. He indicated a number of dolomite beds in upper part of his 'Gondwana'. Subsequent workers, however, did not classify dolomite-bearing sequence within the Gondwana Supergroup. Gokul (1981) divided the Gondwana sequence into (a) lower coal bearing and (b) upper non-coal bearing.

in basal and upper parts respectively is alike and can be classified under Damuda Subgroup. The Damuda Subgroup extends from the Deo *Nadi* in west to the Leshang *Ri* in east over a distance of about 65km.

Good exposures of the Damuda Subgroup, as defined here, are observed in Bhangtar, Diglai, Chamrang, Kalapani, Niwai, Nagarkhola, Gerua and Dimala Khola sections with best exposures

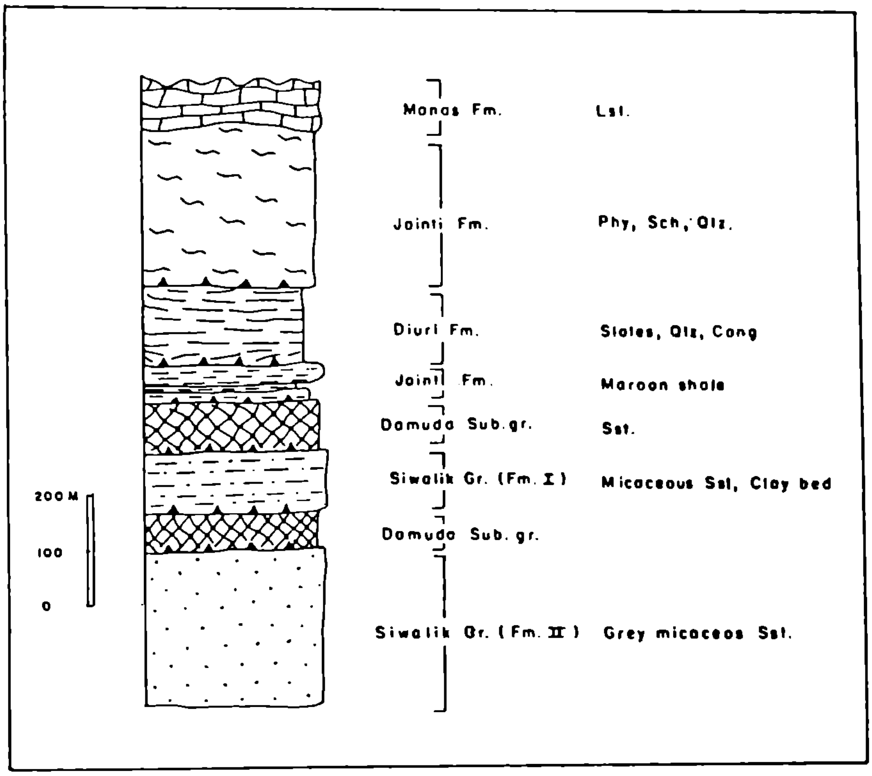

Fig. 3.3.1 Generalised tectono- stratigraphic column showing levels of the Damuda Subgroup in the Nganglam section.

A sequence of feldspathic sandstone, siltstone, shale, coal lenses with plant fossils, exposed in the foot-hills of Eastern Bhutan was designated earlier as the Damuda Formation. Sinha (1974) later correlated this sequence with the Barakar and Barren Measures Formations of the Gondwana Supergroup. The entire sequence except for the presence and absence of coal beds

along the Bor *Nadi*.

The lower and upper contacts of the Damuda Subgroup are delineated by thrusts. To the south exists the Siwalik Group along the Main Boundary Thrust, while to the north occurs the Duiri Formation or the Baxa Group, also along a thrust.

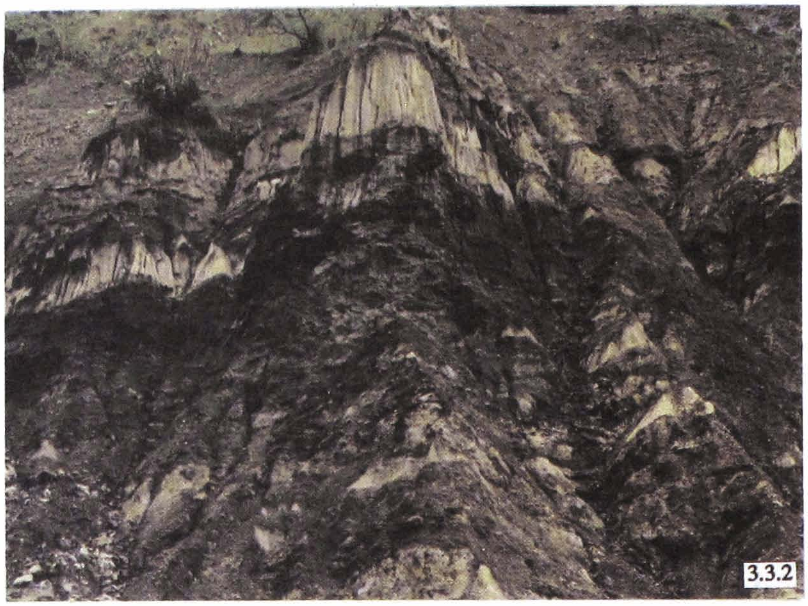

Fig. 3.3.2 Upward fining cyclotherms of coal showing pinch and swell structure, Damuda Subgroup. Loc. Bhangtar.

Lithological Details

The Damuda Subgroup comprises feldspathic sandstone, siltstone, shale, carbonaceous shale and coal. The lithounits are lenticular in nature and are arranged in upward fining cycles (Fig. 3.3.1-2). Sandstone is friable to weakly indurated, off-white to greyish white, locally light brown and made up of medium to coarse subangular and moderately sorted grains of quartz, feldspar (mainly potash), mica, garnet, zircon, apatite and opaques. Locally occur iron concretions which on weathred surface impart limonitic coating to the rock. Sandstone shows tabular cross-bedding.

Fig. 3.3.3 Splitting of coal seam. Loc. Genual.

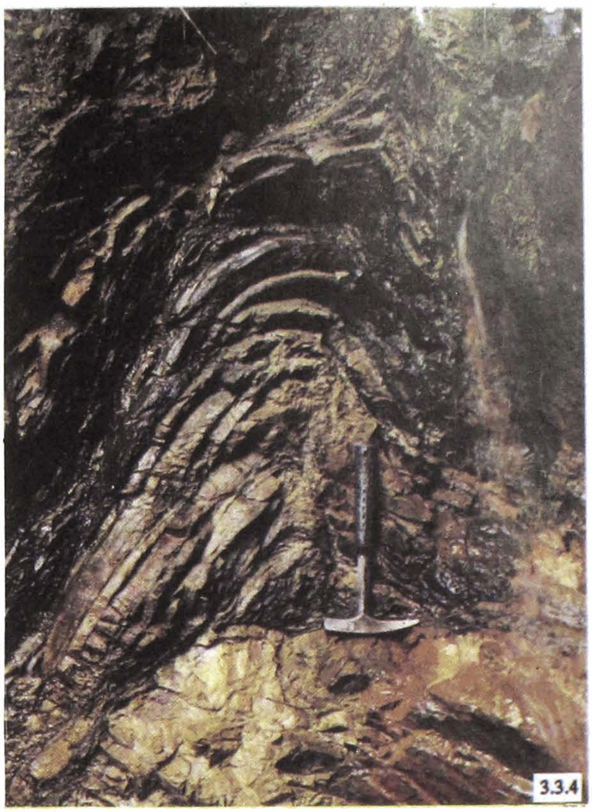

Fig. 3.3.4 Folded coal seam. Loc. Genual.

A fairly detailed study of the coal beds has been carried out in the Bhutan Himalaya. It occurs as one metre to four metres thick lensoidal bodies characterised by splitting (Fig. 3.3.3), pinching and swelling - both along and across the strike (Fig.3.3.2). The maximum strike length of coal bands is usually between 50m to 600m. Number of coal bands in the sequence vary from four to 34. Absence of any marker horizon renders the coal seam correlation difficult even in the adjoining blocks. Coal seams are folded (Fig.3.3.4) and faulted and highly disturbed (Fig.3.3.5). Coal is powdery, flaky and commonly occurs as crumpled lumps.

Palynomorphs found in the coal beds (Banerjee *et al*, 1986) are summarised in Table-3.3.1. Bhutan coals are dominated by non-striate dissacate *Scheuringi pollenites* assemblage having resemblance with the palynomorph assemblage of the Middle Barakar Formation.

The upper part of the sequence has higher percentage of argillaceous component in the form of grey shale, carbonaceous shale/slate/phyllite. These occur interspersed with dark grey compact sandstone. This unit has yielded *Glossopteris* sp., *Gangamopteris* sp., *Vertebraria* sp., and *Schizoneura* sp. (Guha Sarkar and Rao, 1968).

Sinha (1974) correlated the basal coal-bearing part of the sequence with the Barakar Formation and upper non-coaly with the Barren Measure Formation. In Deothang section the marine facies are intercalated with the Damuda Subgroup from which Acharyya (1978) reported fenestellid bryozoa and gastropods.

The coal shows low moisture of <1.76% but the coal cores show moisture values of 3.16%. The ash content is upto 48.7% which increases substantially in the younger seams. The volatile content (on a Pure Coal basis) ranges from 23.38% to 41.02%. The sulfur content is less than 0.61%. The coals are non-coking. Detailed studies on Bhutan Coal analysis by CFRI (1984) is furnished in Table-3.3.2.

Table 3.3.2 : A summary of Proximate analysis of Bhutan Coal.

Moisture	Ash	Volatile Matter	At 60% R.H. and 40^{o}C		Caking Index
			Fixed Carbon	Calorific value	
1.1 to 3.0%	18.2 to 52%	23.3 to 26.2%	37 to 47%	4960 to 5790	5 to 8

Low moisture content in Bhutan coal is a conspicuous feature which is due to tectonisation, deformation and subaerial weathering.

Partial Chemical analysis shows that coal contains C = 81.29 to 84.04%, M = 4.58 to 5.21% and S = 0.57 to 0.61%.

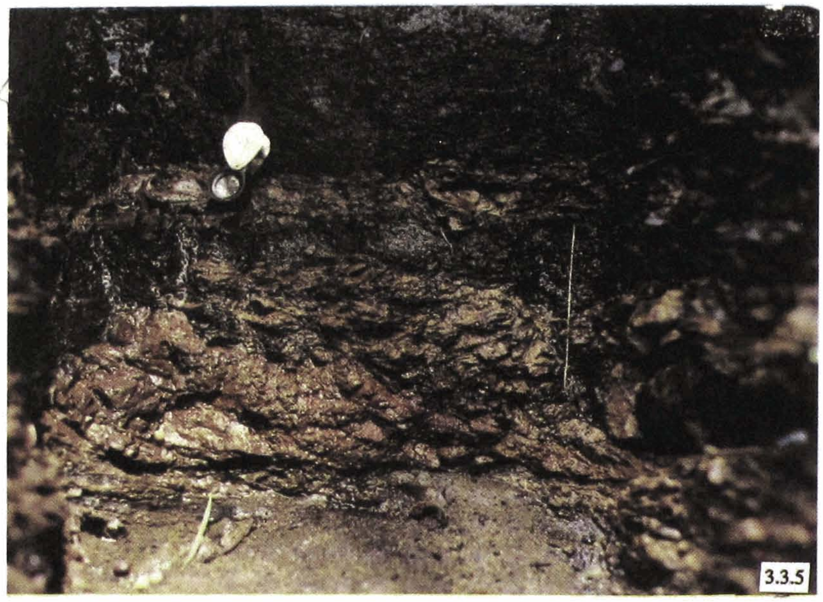

Fig.3.3.5 Crushed coal. Loc. Bhangtar

The trace element abundance in the coal of the Bhangtar are detailed in Table-3.3.3. Trace elements derived from organic source (Cu, Mo, In, Vs, B) are low, while those from inorganic source (Mn, Ni, V, Ba, Cr) are relatively higher.

exinite content varies from 4.3 to 11.7%. Of the exinite group of macerals sporinite is abundant and represented by tenvis spores. Due to high exinite content there is enrichment of volatiles and hydrogen in the coals. Among the inertenite group of macerals, fusinite is dominant which is represented by brilliant white coloured degralofusinil and yellowish white coloured pyrofusinite. Reflectance measurements (Av. R_o% in Oil) of Bhutan coals show small variation between 0.66% and 0.74% with V-shaped distributions confined between V_5 and V_7. Based on oil reflectance studies the rank of coal is metalignitous to hypobituminous type (Pareek, 1990).

TABLE - 3.3.3 : Trace elements (in ppm) in coal samples from Bhangtar area, Bhutan. (after Pareek, 1990)

Sample No. and Seam	Sn	Pb	Cu	Ni	Co	Mo	V	Mn	Ag	Ga	In	Nb	La	Y	Yb	Ba	Cr	B	Ge	Ash (%)
6BH IX	10	20	20	35	10	-	250	130	1	30	10	70	200	120	30	10	140	80	-	66.71
5BH VII	10	70	40	100	15	-	300	120	1	30	10	70	150	130	30	10	160	70	-	35.95
3BH V	-	-	5	10	-	-	10	10	1	-	-	20	50	10	20	20	10	-	-	35.28
2BH IV	10	50	40	300	70	30	300	700	1	150	10	50	600	250	120	10	250	80	120	10.82
1BH IV	-	30	30	70	30	5	200	20	1	30	-	50	50	40	15	-	50	40	10	20.63
7BH Borehole Core	-	-	10	10	10	-	50	30	1	10	-	20	70	30	20	-	50	40	-	46.91
Average composition (Aver. of 6)	5	38	30	120	30	9	200	210	1	52	2	50	212	108	45	10	117	50	32	-

Sr and Zr not determined.

The maceral composition of coals worked out by Pareek (1990) shows vitrinite (9 to 47%), eximnite (1 to 5%), inertenite (15 to 55%), while the mineral and shaly matter varies from 8 to 58%. Microlitho type composition is also evident. Bhutan coals are low in exinite and inertenite. Vitrinite content increases in the younger seams.

The vitrinite grains are usually light to dark grey, small, often crushed and found to be intimately assosciated with mineral matter. The

The massive tectonic shearing effects on the coal is also well revealed under microscope by frequent presence of typical microfolding and other compressional structures. Mineral matter includes quartz, chalcedony, siderite, ankerite, pyrite and galena. Kaolinite forms integral part of viri-inertenite.

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3.4 SETIKHOLA FORMATION

Ashutosh Joshi

An areno-argillaceous sequence enclosing Permian marine fossil was discovered by Joshi (1989) in the Sankosh valley of Bhutan. After its type section, this sequence was designated as the Setikhola Formation (Joshi *et al*, 1990). Prior to this report, Permian marine fossils in the Lesser Himalaya of Bhutan were reported from the Deothang area (Acharyya, 1978). Though unfossiliferous in larger parts, the Setikhola Formation is more or less continuous throughout the length of the Bhutan Himalaya.

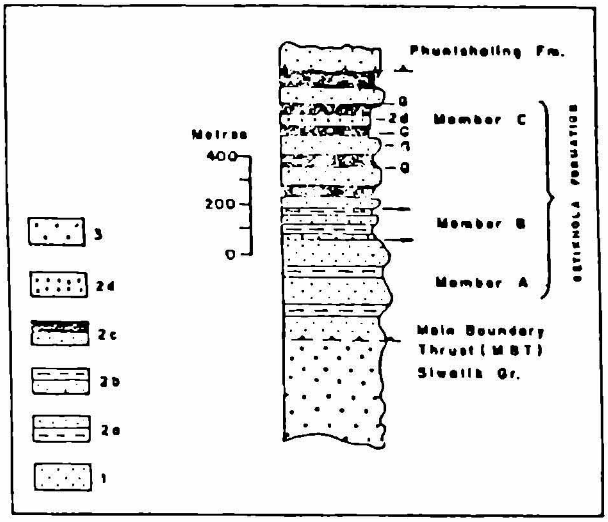

Fig. 3.4.1 Lithocolumn of the Setikhola Formation. 1. Coarse cross-bedded sandstone, 2a. Maroon sandstone and shale, 2b. Black grey, green shale and calcareous sandstone, 2c. Carbonaceous nodular shale and calcareous sandstone. 2d. diamictite, 3. Pink sandstone, G. shale/slate fossil level.

Contact Relationship

The Setikhola Formation, folded into tight to open folds with easterly plunge, rests over the Siwalik Group rocks along the Main Boundary Thrust. The rocks of the Baxa Group resting over the Setikhola Formation along another thrust show northeasterly plunging folds.

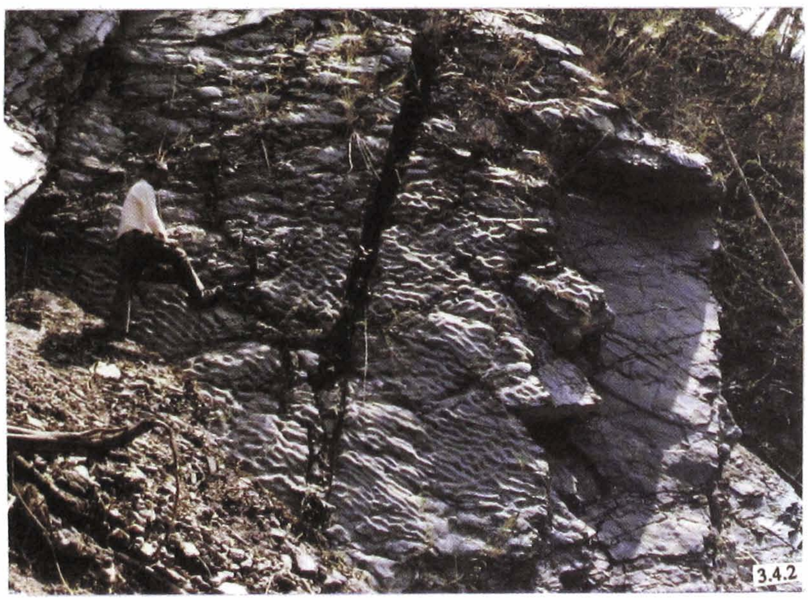

Fig. 3.4.2 Interference ripple marks in Member A. Loc. Kharsan *khola*.

Lithological Details

The Setikhola Formation comprises three members named A, B and C (Fig.3.4.1). These three members have gradational contacts with each other.

Fig. 3.4.3 Load casts in Member A. Loc. Kharsan *khola*.

Member A : This member comprises 400m thick pink, maroon, white and sporadically green well bedded sandstone with maroon and rare greenish shale. Red beds are the most dominant unit in this member. The sandstone commonly contains clasts of shale and granules of jasper and exhibit cross-stratification. The sandstone of this member falls in both the wacke and arenite classes. The quartzarenite contains an appreciable amount of zircon which is commonly concentrated along laminae. The quartzwacke consists of fine to coarse-grained, poorly sorted quartz and exhibits authigenic overgrowth. The shale constitutes dense and opaque paste of iron oxide with little sericite and clay minerals. The sandstone shows asymmetric and interference ripple marks (Fig.3.4.2), cross-bedding, mud cracks, worm tracks, wrinkle marks, load casts (Fig.3.4.3), flute casts, sandstone dikes (Fig. 3.4.4), flame structure and bioturbations (Fig. 3.4.5) indicating beach to mudflat environment of deposition.

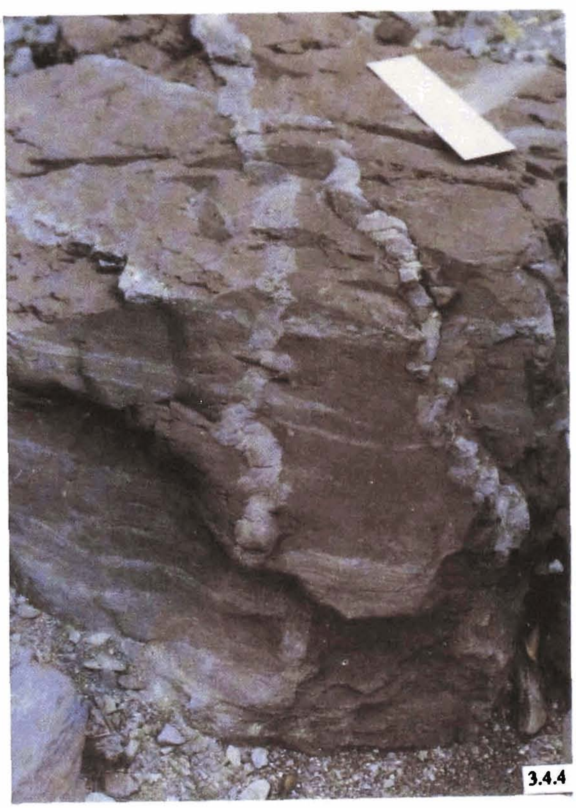

Fig. 3.4.4 Sandstone dikes in Member A. Loc. Kharsan *khola*.

Member B : About 140m thick sequence made up of rhythmically interbedded carbonaceous black, grey and greenish shale and calcareous quartzwacke characterise this member. The greenish grey to grey calcareous sandstone is thinly bedded and has rusty brown laminae. It also occurs as small boudins and lenses within the shale. Calcite as thin veins and as cement has imparted calcareous nature to the rock. Siderite occurs in partly altered state. The lithounits of the Member B display asymmetric and interference ripple marks, cross-bedding, mud cracks, worm tracks, channel fills, sandstone dikes and slump folds suggesting deposition in a semi-isolated basin.

Member C : This member is constituted of a 550m thick sequence of thickly bedded dirty white to grey sandstone, carbonaceous shale and diamictite. The medium to fine-grained locally coarse sandstone is generally calcareous. Sandstone often occurs as boudins and lenses within the shale. The carbonaceous shale contains nodules some of which are calcareous. A diamictite bed of 25m thickness is exposed 190m below the top of this member (Fig.3.4.1). It contains clasts of different sizes and shapes mainly of quartz, carbonate and a few pelitic rocks in a clayey matrix. Almost all the grains of quartz exhibit authigenic growth. Plagioclase, zircon and tourmaline form accessory minerals. In rocks lacking carbonate cement, matrix is formed by sericite, mica, rare flakes of chlorite and clay minerals. In some rocks matrix forms about 40% of the rock by volume. In some sections proportion of carbonate cement is high and such rocks grade into sandy limestone. In one thin section oolite with quartz nucleus has been recorded. In some rocks, quartz clastics are of silt grade and can be classified as calcareous siltstone. Locally non-calcareous sandstone displays brecciated texture with poor sorting and angular clasts set in a siliceous, micaceous and clayey matrix having resemblance with greywacke. Pyrite (?) as spherical opaque is invariably present.

Black carbonaceous shale under microscope shows dominantly dark carbonaceous matter with a few flakes of muscovite. The nodular rock shows calcite in a nearly opaque matrix. Calcareous sandstone of this member shows cross-stratification. The lithological assemblage suggests a reducing environment under lagoonal conditions.

Fig. 3.4.5 Bioturbation in Member A. Loc. Kharsan *khola*.

Four fossiliferous levels have been identified in this member (Fig. 3.4.1). Fossils occur either in nodules or in clusters. The nodules are spherical to oblate and are compact. Many of the nodules bear fossil impressions on the surface but it is the core that invariably contains well preserved fossils along with pyrite disseminations. In sandstone, the fossils occur as clustered and recrystallised shells. Recrystallisation has destroyed preservation and obscured the morphological details. The following forms have been reported from this member (Joshi *et al*, 1990).

Neospirifer cf. fasciger (Keyscrling), *Neospirifer sp.*, *Orthotetes sp.*, *Trigonotreta sp.*, *Platyteichum sp.*, *Protoretepora cf. ampla* Lonsdale, *Waagenoconcha cf. vagans* (Reed), *Waagenoconcha cf. humboldti* (d'Orbigny), *Waageneconcha sp.*

The faunal assemblage of the Member C indicates an early Permian age. Equivalent marine sequences of Permian age are also known from the foothills of Garhwal, Nepal, Darjeeling, Sikkim and Arunachal Pradesh. In the last mentioned sector the Garu Formation (Singh, 1978a, 1978b, 1978c, 1983) in Arunachal Pradesh tectonically overlying the Siwalik Group has lithological resemblance with the rocks of the Setikhola Formation. The Member C of the Setikhola Formation is correlatable with the Bomte Member of the Garu Formation on the basis of comparable lithology and fossil assemblage. However, the equivalent of the overlying Sikki Abu Member of the Garu Formation is not recorded in the Sankosh and Raidak valleys but similar sequence in eastern Bhutan is known as the Diuri Formation (Jangpangi 1974, 1978). The ash-green and the calcareous shales of the Bichom Group containing bryozoa, lamellibranch and brachiopod fossils are correlatable with the Rangit Pebble-slates of Sikkim and have been assigned a probable Carboniferous to Permo-Carboniferous age (Anon, 1974; Raja Rao, 1981).

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3.5 BAXA GROUP

S.K. Tangri

A thick sequence of dolomite, quartzite and shale was designated by Mallet (1875) as the `Baxa Series' after the famous `Buxa Fort' in western Duars (near Central southwestern Bhutan). Pilgrim (1906) classified it as a part of his `Purana' sequence. A more detailed account and classification of the Baxa succession in the type area was provided by Lahiri (1941), who changed its spelling to `Buxa'. However, in this write-up the original spelling `Baxa' is being used. In recent years, Nautiyal *et al*, (1964), Acharyya (1966, 1969, 1974, 1978), Bhattacharjee (1969), Jangpangi (1974, 1978, 1980, 1989), Sinha-Roy (1972), Ray (1976), Guha Sarkar (1979), Sen Gupta and Raina (1977, 1978, 1980), Chaturvedi and Reddy (1977), Chaturvedi and Mishra (1979) and Ray and Ganesan (1983) have contributed to the understanding of this significant stratigraphic unit. The present work based on examination of a number of stratigraphic sections of the Baxa Group reinterprets and synthesises earlier published as well as unpublished data and attempts to present a cogent and comprehensive picture of this group, after reconciling various incongruities in the existing knowledge (Table 3.5.1).

The Baxa Group -- main repository of dolomite and limestone in Bhutan, outcrops all along the length of the Bhutan Himalaya (Fig.3.5.1) as a metasedimentary belt of thickness

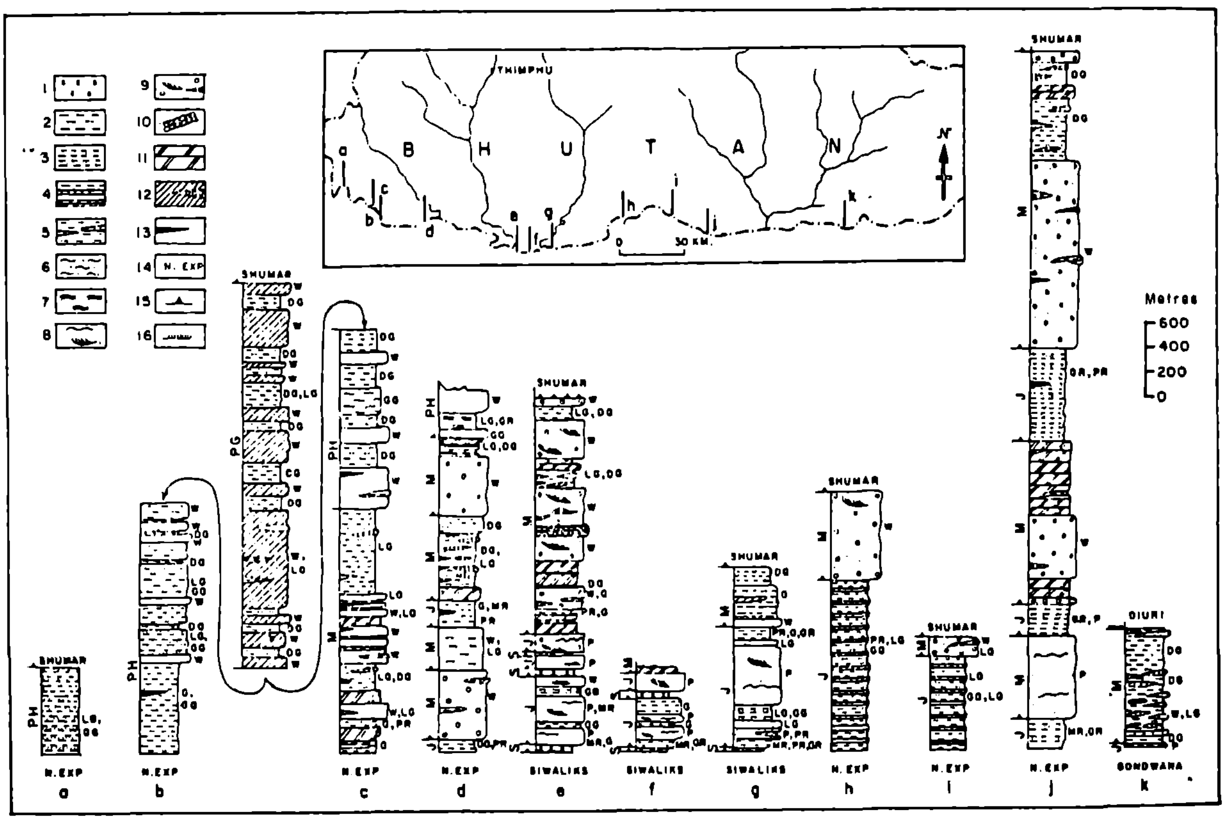


Fig. 3.5.2 Tectonostratigraphic lithosequence exposed along various visually measured sections. Inset map shows locations of sections studied. 1. Slickensided carb phyllite, light to brownish grey quartzite, local conglomerate, 2. Phyllite, 3. Phyllite with minor quartzite, 4. Phyllite, siltstone with little quartzite, 5. Phyllite with quartzite/limestone - dolomite, 6. Talcose phyllite, 7. Schist, 8. Cross-bedded ripple marked quartzite, 9. Gritty, locally feldspathic cross-bedded quartzite, local conglomerate, 10. Conglomerate, 11. Dolomite, 12. Dolomite with intercalated minor quartzite, phyllite, 13. Basic sills, 14. No exposure zone, 15. Thrusted contact, 16. Faulted contact. On the right side of the column : G = Grey,, LG = Light grey, DG = Dark grey, GG = Greenish grey, P = Pink, PR = Purple, MR = Maroon, GR = Green, W = White. On the left side of the column : S = Setikhola Formation with/without Diuri Formation, J = Jaintí Formation, M = Manas Formation, PH = Phuntsholing Formation, PG = Pangsari Formation.

Table 3.5.1 : DIFFERENT NOMENCLATURE/CLASSIFICATION ALONG WITH LITHOASSEMBLAGE PROPOSED FOR THE BAXA SEQUENCE OF BHUTAN

Mallet (1875)	Lahiri (1941)	Nautiyal (1964)	Jangpangi (1974,1978)	Acharyya (1974)	Guha Sarkar (1979)	Chaturvedi and Reddy (1977)	Gansser (1983)	Anon (1984)
Baxa Series	**Buxa Stage**	**Baxa Series**	**Phuntsholing-Buxa Group**	**Buxa Group**	**Baxa Group**	**Buxa Group**	**Baxa Formation**	**Buxa Group**
Dolomite, shale and quartzite	Dolostone, quartzite (Jainti), quartz-schists, chlorite schists and phyllites. **Sinchula Stage** Quartzites and quartzitic schists.	Massive dolomite, dark slate, limestone, quartzite, feldspathic sandstone, Diuri boulder beds. **Phuntsholing Series** Purple-green phyllites, quartzites, conglomerates, thick carbonaceous phyllites with basic sills.	b) **Buxa Formation** Dolomite, limestone, white quartzite and dark grey slates. a) **Phuntsholing Formation** Sombre, bluish and green phyllites and white, grey and pinkish quartzites traversed by basic sills.	b) **Jainti Formation** Quartzite and dolomite with minor slate. a) **Sinchula Formation** Thick bedded quartzite, slate and phyllite.	Dolomite with thin interbedded carbonaceous slate. **Phuntsholing Group** Purple slate; phyllite; quartzite.	**Sinchula Formation** Greenish grey quartz-sericite phyllite with quartzites. Thin basic sills and dolomite. White massive quartzite, sericite quartzite, quartz-sericite phyllite. Interbanded phyllite, quartzite. **Jainti Formation** Cream, purple calcareous quartzite; variegated quartzite; thin talc, grey phyllite/slate. White, light green quartzite; thin chlorite phyllite, oligomictic conglomerate. Grey phyllite; carbonaceous phyllite, slate with thin limestone, variegated phyllite. Grey dolomite, carb.phyllite. Gritty quartzite, conglomerate. Greenish grey greasy slate, phyllite; green purple, grey phyllite; limestone, grey minor purple dolomite.	Dolomites, limestones, calcareous shales and locally gypsum which begins with basal quartzite (Jainti quartzite of Lahiri, 1941).	c) **Manas Formation** Dolomite, quartzite and carbon phyllite. b) **Phuntsholing Formation** Green to greenish grey phyllite purple phyllite and carbon phyllite with thin interbands of green and/or purple quartzite; thin impersistent pebbly horizons. a) **Thungsing Formation** A feldspathic and highly gritty quartzite with pebbly and conglomeratic bands and thin intercalation of grey slate, phyllite, minor marble and metavolcanic.

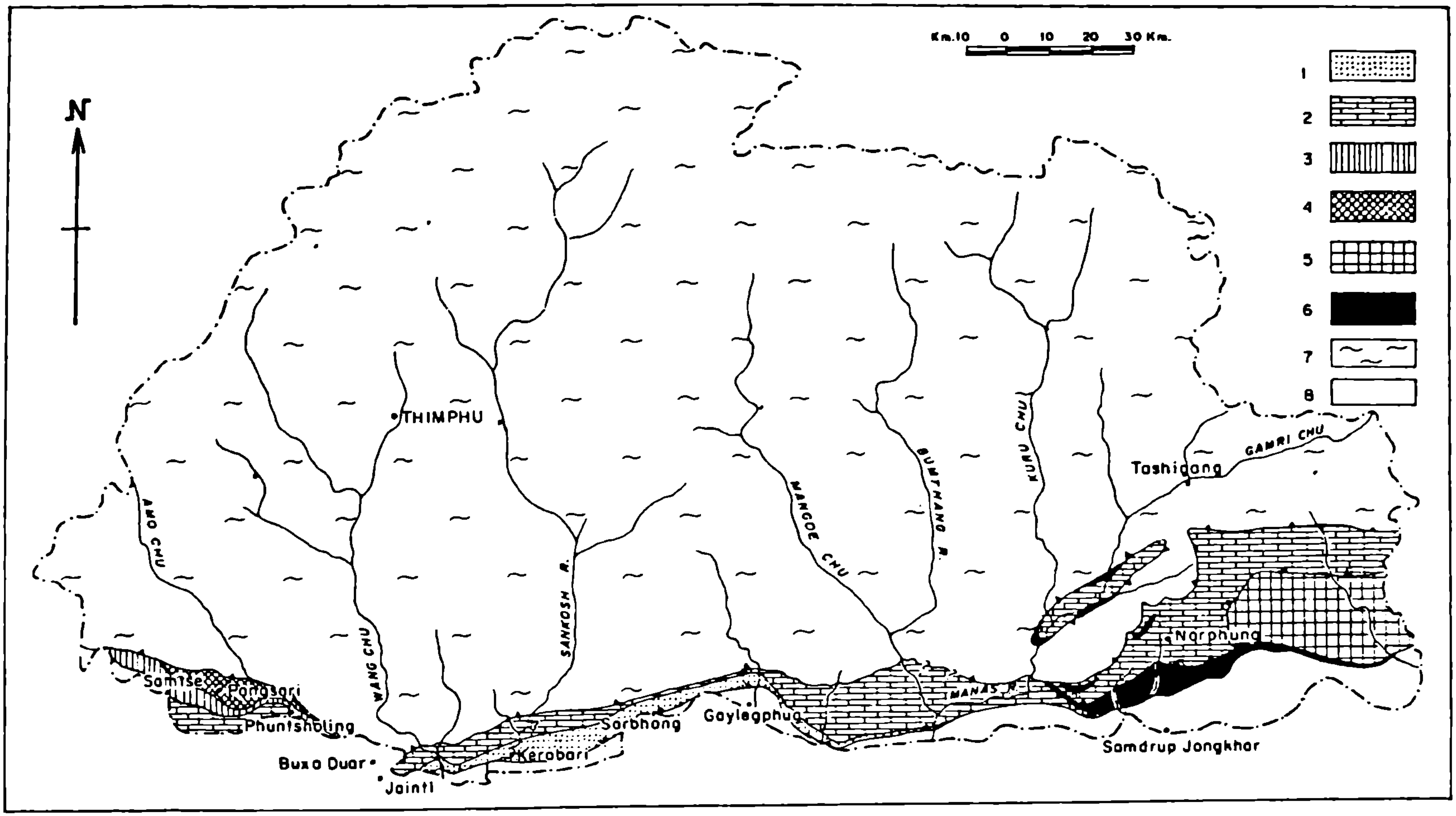


Fig. 3.5.1 Geological map of the Bhutan foot-hills showing spatial distribution of different formations of the Baxa Group. 1 - 4. Baxa Group 1. Jainti Formation, 2. Manas Formation, 3. Phuntsholing Formation, 4. Pangsari Formation, 5. Baxa Group with slivers of Shumar Formation and granite gneiss, 6. Diuri Formation, 7. Shumar, Jaishidanda Formations, Thimphu Group with Tethyan cover, 8. Setikhola Formation and Siwalik Group.

ranging from the maximum of 16,000m in the Kanamakra, Kakulang river sections to about 1,500m in the Jaldhaka river section. Within the Baxa Group (Fig.3.5.2e) locally occur a few thin tectonic slivers of the Setikhola Formation with or without the diamictites of the Diuri Formation. A few thrust wedges of the Baxa rocks in turn have been recorded within the over-riding Shumar Thrust Sheet (Jangpangi, 1974).

Contact Relationship

It is tectonically sandwiched dominantly between the Shumar Formation in the north and the Setikhola Formation (and its equivalents) or the Siwalik Group in the south. Its lower contact with the Siwalik Group/Setikhola Formation is defined by the Main Boundary Thrust (MBT), while the upper contact for major part of the length is delimited by the Shumar Thrust. The Baxa Group in a few sections is overlain by the Diuri Formation along an unconformity.

Classification

Broadly, the Baxa Group comprises pink-buff-white, locally gritty to conglomeratic quartzite; meta-siltstone; greenish grey- green-maroon- purple- light to dark grey, locally pyritous phyllite/phyllitic slate; grey to yellowish white (cream) dolomite, limestone and minor basic intrusives.

Majority of the workers subsequent to Mallet (1875) recognised two distinct litho-suites in the Baxa Group viz., a lower carbonate-free and the upper carbonate-rich. However, several differences existed in the details of the two litho-assemblages and their relative stratigraphic positions as given by various authors (Table-3.5.1). The scope of Baxa Group was later broadened (Anon, 1984) to include the Thungsing Formation of Jangpangi (1974) and accordingly it was classified into three formations viz., the Thungsing, Phuntsholing and Manas Formations in ascending order of superposition. Bhattacharya *et al*, (1992) though retained this three fold classification of the Baxa Group yet assigned a supra-Manas Formation status to the Thungsing Formation. Acharyya *et al*, (1975) also indirectly referred to the Thungsing Quartzites of Narphung area as the `Buxa Quartzite'. The present work based on observation along several visually measured sections (Fig.3.5.2) spread across the Bhutan foot-hills, indicates that the lithosequence hitherto classified as the Baxa Group, represents a composite thrust sheet. Though due to the unfossiliferous nature and intense tectonisation it is difficult to reconstruct the original lithostratigraphy of the Baxa Group, yet four distinct lithopacks occupying fixed structural levels all through the Baxa belt have been identified. These lithopacks have been assigned formational status. Few of these formations show normal stratigraphic contacts. Their tectonostratigraphic order of superposition is given below.

Pangsari Formation		White to cream, fine grained arenaceous dolomite; subordinate grey-green, locally talcose phyllite and white, light grey, fine to medium grained sporadically calcareous quartzite - locally pebbly to conglomeratic with clasts of jasper, red quartzite
Phuntsholing Formation		Alternating sequence of white-light grey fine to medium grained quartzite; light to dark grey, green, greenish grey phyllite, phyllitic slate; rare carbonate.
Manas Formation		Intercalated sequence of white - grey, fine to medium grained, locally gritty/pebbly to conglomeratic quartzite containing clasts of jasper and red quartzite; grey-rare creamish grey dolomite; light to dark grey phyllitic slate, impersistent thin limestone horizons.
Jainti Formation	Member B	Pink subordinte white, fine to medium grained quartzite locally gritty/pebbly containing clasts of jasper; thin partings of maroon-purple-green-grey phyllite.
	Member A	Maroon-purple, green-grey phyllie; metasiltstone and quartzite.

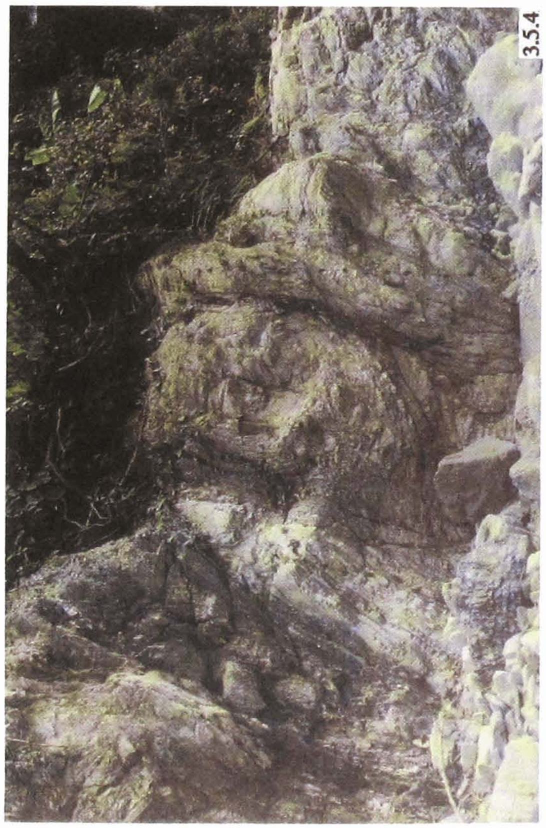
Explanation of Figrues. 3.5.3a-b, 3.5.4, 3.5.5

Fig.3.5.3a,b Mesoscopic tight to isoclinal overturned folds in Baxa rocks. West of Phuntsholing. a. photograph. b. sketch of a. Fig. 3.5.4 Tight folds associated with conspicuous slip planes in the Manas Quartzite. Loc. Titi *khola*. Fig. 3.5.5 Sharp contact of carbonaceous phyllite (Setikhola Formation) with quartzite-slate sequence (Jainti Formation). Note a small tectonic wedge of carbonaceous phyllite (II) within the quartzite. Loc. Raidak valley near confluence with Sakua *nala*.

3.5.3b

3.5.5

3.5.3a



3.5.4

The internal stratigraphy of these formations has been complicated by the presence of a number of tight to isoclinal, overturned folds (Fig.3.5.3,4) and north dipping reverse faults/thrusts.

The wide variation recorded in the individual thickness of these units is perhaps partly sedimentologic and partly tectonic. In the eastern Bhutan due to intense deformation, possibly the basement gneiss has been interleaved with the Baxa sequence as tectonic slivers (cf. Sen Gupta and Raina, 1980). The gneiss has yielded an age of ca 1421Ma with initial Sr87/Sr86 ratio at 0.7262 (Sen Gupta and Raina, 1980). Picture of this area is, however, far from clear.

Type Area

Though the Baxa Group was named after `Buxa Fort' in western Duars, this area exposes only an attenuated succession and it is the Titi section which preserves its more complete sequence (Mallet, 1875). Acharyya (1974) suggested that the sections exposed along the Jainti and Raidak rivers and the one along the Baxa Duar-Sinchula track may be treated as the reference sections. Jangpangi (1980) opined that the valley of Dhigurn *Ri*, a tributary of the Gong *Ri* may be regarded as the type area of the Baxa Group. The present author finds that no single section exposes good section of all the formations. The Titi *khola* section followed by the track to north of Thunuwa and the Sankosh River section expose composite type sections of the Baxa Group.

The visually measured tectonostratigraphic lithosequence of the Baxa Group exposed in various sections spaced across the Bhutan foot-hills are depicted in Fig. 3.5.2a-k.

Lithological Details

Detailed description of various formations of the Baxa Group is given below.

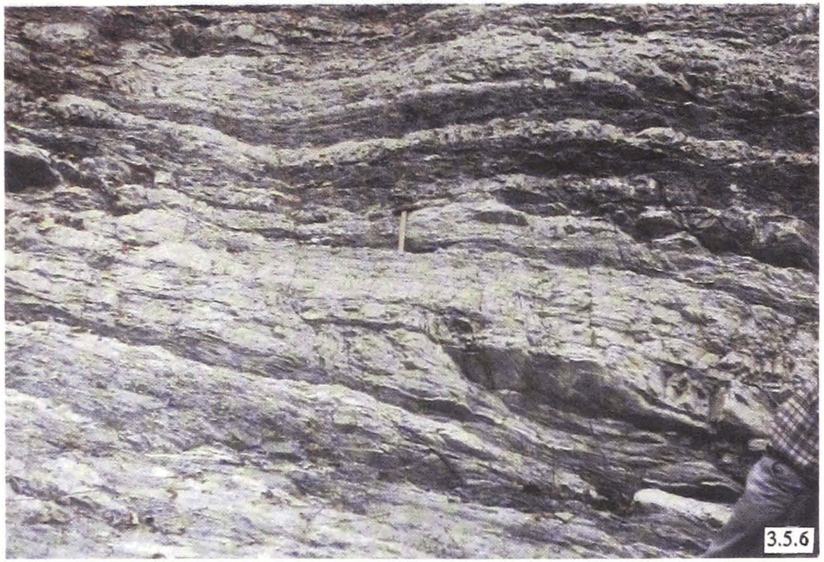
Jainti Formation : The name `Jainti Quartzite' was first proposed by Lahiri (1941) for the quartzites constituting the lower segment of his `Buxa Stage'. Acharyya (1974) followed by Chaturvedi and Reddy (1977) included the dolomite, variegated phyllite, slate and quartz-pebble bearing quartzite and conglomerate within it and termed it as the `Jainti Formation'. The red facies dominated variegated argillo-arenaceous sequence of this unit was classified as part of the Phuntsholing `Series'/Formation/`Group' by Nautiyal *et al*, (1964), Jangpangi (1974), Guha Sarkar (1979) and Anon (1984, 1992). It was christined as the `Gobarkunda Formation' by Ray and Ganesan (1983), who assigned it a Palaeocene-Eocene age.

In the present work the term `Jainti Formation' is being redefined to include exclusively the red facies dominated argillo-arenaceous lithosequence constituting the basal part of the Baxa Group. It is extensively developed in the central Bhutan foot-hills. The Sankosh valley near Kerabari exposes its best section. The Jainti Formation is also well exposed in the Jainti, Raidak, Kalikhola and Kanamakra river sections. Limited development of this formation is recorded in the Titi *khola*, Nganglam-Chengkhari road and along Richong *Ri*, north of Sarjung in the eastern Bhutan (Sen Gupta and Raina, 1977).

The lower contact of the Jainti Formation with the rocks of the Siwalik Group or the Setikhola Formation (or its equivalent) is defined by the MBT. Along this thrust at places, due to imbrication a few thin (20-90m) tectonic slivers of the Setikhola Formation with or without the Diuri diamictites have been emplaced within its basal part (Fig.3.5.2e,f & 3.5.5). The MBT zone is marked by intense shearing and mylonitisation of the rocks. An ironstone band in the Maure area reported to be part of the Siwalik Group (Mishra, 1985), may in fact be an imbricated Jainti lithotope within the Siwalik rocks along the MBT thrust zone. The upper contact of this formation

Explanation of Figures 3.5.6 - 3.5.9

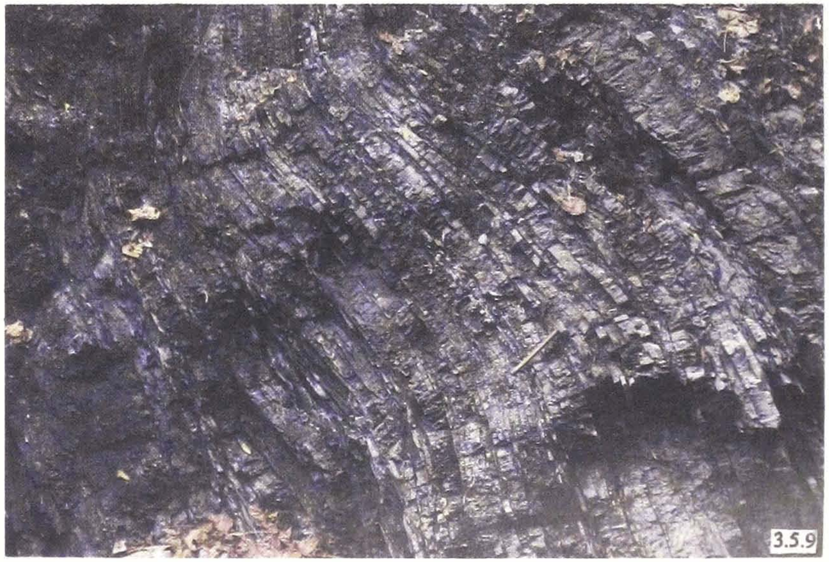
Fig.3.5.6 & 7 Variegated thin bedded phyllite-meta-siltstone-quartzite sequence. Jainti Formation (Member A). Note local uneven-continuous bedding in quartzite (Q) Fig.3.5.7. Loc. Titi *khola*. Fig. 3.5.8 Quartzite-phyllite Rhythmite. Jainti Formation (Member B). Loc. Khorsan *khola*. Fig. 3.5.9 Thin bedded flaggy pink quartzite with purple phyllitic slate partings. Jainti Formation (Member B). Loc. Khorsan *khola*.



3.5.6

3.5.7

3.5.8



3.5.9

with the Manas Formation though at places looks normal stratigraphic, may represent a local sediment-ologic break as suggested by i) a sudden change in the sedimentary facies, ii) occurrence of the Manas sediments over different lithounits of the Jainti Formation and iii) presence of well laminated, subrounded pebbles of the characteristic pink quartzite-jasper of the Jainti Formation within the quartzite/conglomerate of the younger Manas Formation. However, till a conclusive evidence of a sedimentary break at this level is found, the Jainti Formation may be retained as a formation within the Baxa Group. Locally (e.g. the Sarbhang *khola* section) the Jainti-Manas contact is tectonised along which an appreciable thickness of the former formation has been eliminated.

The fact that the clasts of the rocks of this formation are present in the quartzite/ conglomerate of the younger Manas, Phuntsholing and 'Pangsari' Formations, confirms that the Jainti Formation is stratigraphically the oldest unit of the Baxa Group which moved over the tectonic basement of the Diuri-Setikhola sequence.

The Jainti Formation is readily identifiable in the field by predominantly red, brightly variegated rocks, comprising quartzite - locally gritty; meta-siltstone; phyllite and rare thin carbonate beds. This formation can be divided into two members, viz., Member A and Member B. The Member A comprises chiefly variegated phyllite, siltstone and subordinate quartzite. The Member B is composed of a thick monotonous sequence of pink - purple, subordinate buff and white quartzite. The excellent development of the Member A is seen in the Kali *khola*, Sankosh and Sarbhang *khola* sections (Fig.3.5.1). Attenuated sequences of this member are exposed in the Titi, Khanabharti *khola*, Kanamakra river and Nganglam-Chengkhari road sections. It consists of brightly variegated phyllite/phyllitic slate in alternating maroon- purple- green- grey colours (Fig.3.5.6,7) in the lower part, which gets restricted to grey- green- purple and rare monotonous light grey shades in the upper parts. Under microscope the maroon slate is locally silty and shows alternating iron-rich and poor bands (Fig.3.5.13). The phyllite/phyllitic slate is often thinly (0.3-15cm) interstratified with siltstone or fine grained quartzite of the same colour (Fig.3.5.6,7) and contains a few thin concordant basic bodies. This sequence preserves a variety of shallow water deposition sedimentary structures viz., mud draped bedding, ripple marks, mud cracks, load casts and rafted mud chips. In the Raidak, Kali *khola* and Sankosh sections the repeated occurrence of thick pink-purple quartzites alternating with thick argillite dominated sequences (Fig.3.5.2e,f,g) is possibly due to tectonics.

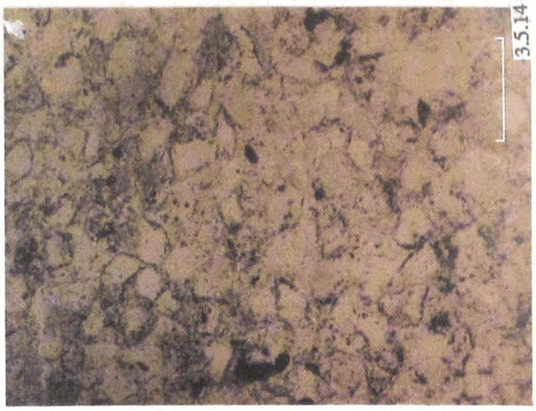
The Member B is extensively exposed in the Raidak, Kali *khola* and Sankosh river sections and further east, it is tectonically eliminated in the Sarbhang-Chirang and Gaylegphug-Tongsa road sections, only to reappear in the Kanamakra section (Fig.3.5.1). Similar pink quartzite is also recorded from the Dhigum *Ri* (Jangpangi, 1974), Jhiri *Chu* and Dangana area (Bhattacharya *et al*, 1992). This quartzite is not exposed west of the Baxa Duar area.

The quartzite is dominantly thin to medium bedded (3-35cm) (Fig.3.5.9,12), locally calcareous, fine to medium grained and preserves cross (Fig.3.5.11), graded, mud-draped beddings, ripple marks (Fig.3.5.12), synaeresis mud cracks, load casts, small-scale channel scours and rare rafted mud-chips (Fig.3.5.10). Bedding is dominantly even parallel and subordinate uneven continuous type. Local development of rhythmites is also recorded (Fig.3.5.8). The cross-bedding is dominantly grouped, but is locally solitary, small to medium scaled (3-25cm), low angled (15^{o}-20^{o})

Explanation of Figures 3.5.10 - 3.5.14

Fig. 3.5.10 Cross-bedded pink quartzite with rip-up mud chip clasts along the main bedding (A) and the cross-set laminae (B). Jainti Formation (Member B). Loc. Jamduar *nala*. Fig. 3.5.11 Grouped, medium scale, low angle trough type cross-bedding in quartzite. Jainti Formation (Member B). Loc. Jamduar *nala*. Fig. 3.5.12 Thin to medium bedded, rippled (arrow) quartzite. Jainti Formation (Member B). Loc. Seti *khola*. Fig. 3.5.13 Alternating iron-rich and poor layers in phyllitic slate. Jainti Formation (Member A). Bar length 0.5mm. Fig. 3.5.14 Quartzite with moderately sorted subangular framework grains and ferruginous cement. Jainti Formation (Member B). Bar length 0.5mm.

3.5.11



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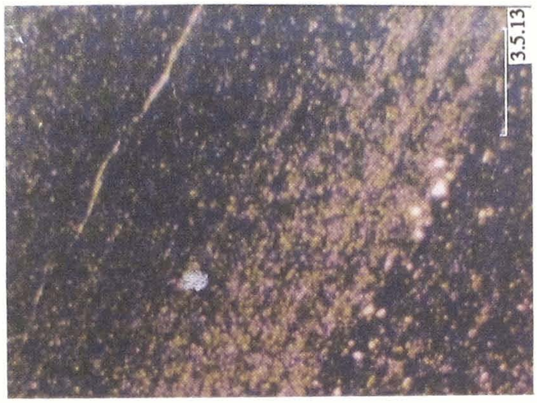

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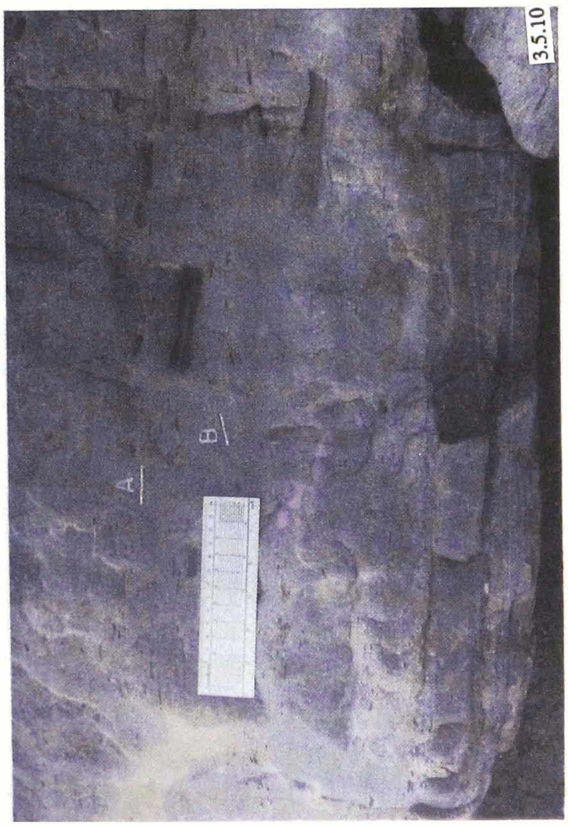


3.5.10

3.5.12

tabular and trough type. Sporadically cross-bedding with mud draped, cross-set laminae or containing rafted mud-chips is recorded (Fig.3.5.10). The ripple marks are generally longitudinal, asymmetrical current type with pointed and locally with rounded crests oscillation type ripples marks have also been recorded by Acharyya (1974). The Ripple Index ranges from five to 10 with wavelength and amplitude varying from two to seven centimetres and from 0.2cm to one centimetre respectively. The cross-bedding and ripple marks indicate palaeocurrent direction ranging between N10°E and N50°W. The quartzite locally contains thin impersistent beds and lenses of gritty quartzite-conglomerate containing the subangular jasper clasts. The red colouration of the quartzite is due to the ferruginous cement in them (Fig.3.5.14).

The carbonates represented by impersistent thin (0.5-15m) beds of grey-pink, massive, fine grained dolomite occur interstratified with the quartzite of the Member B.

The complete lithoassemblage of the Jainti Formation may be correlatable with a part of the Reyang Formation (Ray, 1976) of the Darjeeling Himalaya.

Manas Formation : Conspicuous by rich-carbonate content, it is the most characteristic lithostratigraphic unit of the Baxa Group. Earlier this marker carbonate bearing lithosuccession was variedly classified as the Baxa Stage/Series/Formation/Group by Lahiri (1941), Nautiyal (1974), Jangpangi (1974) and Guha Sarkar (1979) respectively and as part of the Jainti Formation by Acharyya (1974) (Table-3.5.1). The term Manas Formation was first used in a brochure (Anon, 1984) as comprising dolomite, quartzite and carbon phyllite in which dolomite formed the most important lithounit. It was named after the river Manas, where the various lithounits of this formation are best developed. In the present study, the term is being retained with the modification to include also the Thungsing Formation of Jangpangi (1974).

The Manas Formation has been traced east of the Chamurchi *khola* all through the length of the Bhutan Himalaya (Fig.3.5.1). It nestles majority of the carbonate deposits of Bhutan. Beside the type Manas river section, its excellent development is noticed in the Raidak valley, Titi, Sukti and Khanabharti *khola* sections. Locally (e.g., Sarbhang-Chirang and Gaylegphug-Tongsa road sections, Fig.3.5.2h,i) the Manas Formation is represented by quartzite unit only.

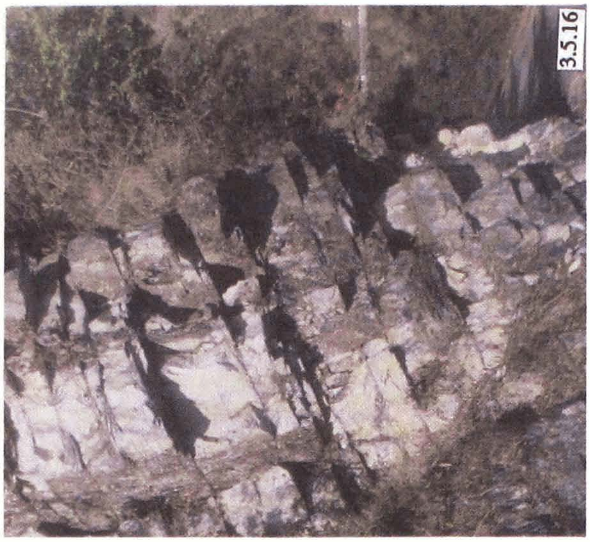
The Manas Formation overlies the Jainti Formation along an unconformable?/thrusted contact and in turn is overlain by the Phuntsholing Formation along a gradational contact.

The Manas Formation is represented principally by the quartzite- carbonate (dolomite) sediments interstratified with argillite-carbonate (dolomite and limestone) rocks.

The quartzite is dominantly white to light grey, thin to medium bedded (Fig.3.5.16,17), fine to coarse and locally gritty to pebbly with characteristic clasts of red quartzite and jasper. It locally preserves solitary, small to medium scale, low angled, cross-bedding (Fig.3.5.15,17) and longitudinal assymetrical current ripples. The palaeocurrent direction recorded is in N10°W to N65°W direction. Impersistent beds to lenses of red quartzite-jasper clast bearing polymictic conglomerate (Fig.3.5.18,25) varying in thickness from 0.15m to 25m are sporadically present. The conglomerate is generally unstratified (Fig.3.5.18), ill to moderate sorted and clast supported. The clasts are composed of subangular to subrounded pebbles to boulders of white-grey-pink-green fine grained quartzite, chert, vein quartz, grey siltstone-slate and jasper, held in a dominantly arenaceous but locally silty to argillaceous matrix.

Explanation of Figures 3.5.15 - 3.5.18

Fig. 3.5.15 Grouped, low angled trough type cross-bedding in the quartzite. Note large scale cross-bedding (A) followed upwards by medium scale cross-beds (B). Manas Formation. Loc. Raidak valley, north of Piping. Fig. 3.5.16 White, medium bedded quartzite. Manas Formation. Loc. North of Narphung. Fig. 3.5.17 Large scale, low angled tabular type cross-bedding in quartzite. Manas Formation. Loc. North of Narphung. Fig. 3.5.18 Unstratified, ill-sorted, clast supported polymictic conglomerate. Manas Formation. Loc. Raidak valley, north of Piping.


3.5.16


3.5.17


3.5.15
A
B


3.5.18

Some of the quartzite clasts including those of the pink quartzite exhibit well preserved laminations (Fig.3.5.25), suggesting that these were well lithified before erosion. The pebble-matrix ratio of the conglomerate varies from 80:20 to 90:10. The largest quartzite clast measures 40cm. The nature of the conglomerate suggests that it possibly represents lag deposits, marking local unconformities.

The quartzite of the Manas Formation is fine to medium grained, moderately sorted comprising subangular to subrounded grains of quartz (85-95%), feldspar (2-15%) - plagioclase, microcline, orthoclase and rock fragments (0-2%) with little argillaceous matrix (3-7%) present as thin film around grain boundaries (Fig.3.5.23). Locally the sericitisation of feldspar grains (Fig.3.5.22) and deformation of silty slate clasts (Fig.3.5.21) form secondary matrix, raising the overall matrix content of the rock. Siliceous cement forms 10-20% of the rock. Authigenic growth over quartz grains (Fig.3.5.20,22) has led to planar contacts between the enlarged grains. Largely the quartzite exhibits cataclastic mortar, mylonitic (Fig.3.5.24a-d) texture indicating the intense deformation suffered by them. Development of proto-mylonite (Fig.3.5.24a,b) to blasto-mylonite (Fig.3.5.24c) with recrystallisation of quartz is recorded. Preservation of original sedimentary texture in such rocks is rare. The quartzite can be classified under subarkose-arkose to quartzarenite.

The thick quartzite sequence of eastern Bhutan hitherto classified as the Thungsing Formation (Jangpangi, 1974), represents the continuity of the quartzites of the Manas Formation only. The evidences suggestive of this conclusion include :

i) Compositional similarity of the quartzites of the Manas and Thungsing Formations. Quartzite in both the formations is subarkose-arkose to subordinate quartzarenite, and is locally gritty/pebbly to conglomeratic containing diagnostic red-pink quartzite clasts.

ii) Both the formations exhibit similar low grade metamorphism.

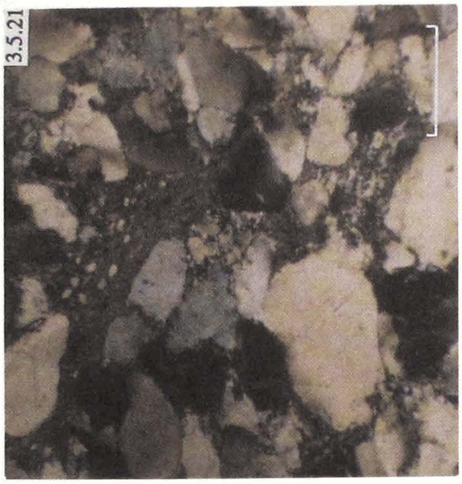
iii) In the area east of Narphung the Thungsing Quartzite overlies the Baxa dolomite, a stratigraphic setting identical to that in the Manas Formation.

The uniform composition, dominant cataclastic-mylonitic texture and the folds (Fig.3.5.4) preserved in the quartzite occurring at different structural levels in the Manas Formation suggests that this repetition is possibly tectonic. However, till the strike mapping of the quartzite establishes such an interpretation, the separation of quartzite as a distinct formation is not justified.

The other characteristic lithocomponent of the Manas Formation is the thin to thick (4-600m) interstratified horizons of dolomite (Fig.3.5.2c-g & j). These have been delineated from the Khanabharti *khola* in the west, through the Pagli-Titi area to Kalesor Danda, west of Phuntsholing. Further east it reappears after a gap of about 28km in the Jainti, Raidak, Kali *khola* river sections and continues further through Dhanese, Kakulang area to the type Manas valley where the dolomite is extensively developed. The dolomite is predominantly light to dark grey, locally yellowish white, fine grained, massive, highly fractured and commonly contains thin (0.3-30cm) chert beds (Fig.3.5.26) and rare thin intercalated carbonaceous phyllite/slate. However, in Kalesor Danda area the carbonaceous phyllite intercalation measure 200m (Chaturvedi and Reddy, 1977). Locally the dolomite encloses autoclastic conglomerate (Fig.3.5.27) and breccia, latter commonly filled by secondary carbonates (Fig.3.5.28).

Explanation of Figures 3.5.19 - 3.5.23

Fig. 3.5.19 Silty phyllite showing prominent alignment of phyllosilicate. Phuntsholing Formation. X-nicols. Bar length 0.5mm. Fig. 3.5.20 Authigenic growth of quartz in quartzite. Manas Formation. X-nicols. Bar length 0.5mm.Fig. 3.5.21 Secondary matrix formed by deformed silty slate clasts (S) in quartzite. Manas Formation. X-nicols. Bar length 0.5mm. Fig. 3.5.22 Secondary matrix formed by sericitisation of feldspar clasts (F) in quartzite. Manas Formation. X-nicols. Bar length 0.5mm. Fig. 3.5.23 Moderately sorted detrital grains of quartz and microcline in quartzite. Note authigenic growth over quartz grain (Q). Manas Formation. X-nicols. Bar length 0.1mm.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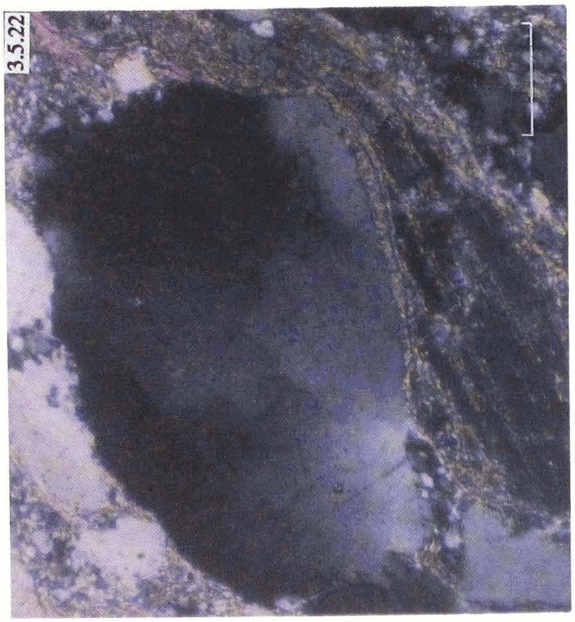

3.5.22

Petrographically the dolomite is pseudosparitic, containing a few free floating detrital quartz grains and rare pyrite. The concentration of these quartz grains into thin layers defines the bedding. Sporadically the dolomite shows silicification (Fig.3.5.30).

Locally the dolomite contains stromatolites (Fig.3.5.29). Raha and Das (1989) identified the *Jurusania* fm., *Tungussia* fm., *Gymnosolen* fm. and *Columnocollenia* stromatolite assemblage of upper Riphean - Vendian age from these dolomites. Recently oncolites have also been reported from the dolomites of this formation exposed in the Nganglam area (personal communication, A.K. Moitra).

A characteristic feature of the dolomite is its fairly consistent chemical composition (Guha Sarkar, 1979). The dolomite is of flux grade, and is being exploited at Khanabharti *khola*, Pagli and Hathipotha areas. Locally the Manas dolomite contains minor galena and sphalerite mineralisation in Ratepani area.

The argillite-carbonate suite is chiefly represented by light to dark grey, locally pyritous phyllitic slate, containing lenticular beds of limestone and dolomite and white to light grey, fine grained quartzite. The limestone is dominantly grey, fine grained thinly bedded. It is being mined as a raw material for the cement industry.

The lithoassemblage of the Manas Formation is correlatable with that of the 'Buxa' Subgroup of the Darjeeling Himalaya (Ray, 1976).

Phuntsholing Formation : The name 'Phuntsholing Series' was first proposed by Nautiyal *et al*, (1964) for a succession of purple phyllite, quartzite, siliceous limestone with epidiorite sills exposed north of Phuntsholing and interpreted to form basal part of the Baxa sequence. Jangpangi (1974) and Anon (1984) assigned it a formational status and included in it the 'Jainti Quartzite' and associated phyllite of Lahiri (1941). In the present study, this formation is being retained exclusively for a grey-greenish grey-green phyllite, phyllitic quartzite sequence with rare carbonates, intercalated with thick white-light grey fine to medium grained, locally gritty quartzite sequence exposed to the north of Phuntsholing town. The observation made along the Jiti, Chamurchi, Khanabharti, Titi and Torsa river and Phuntsholing-Thimphu road sections during the present work indicates that contrary to the contention of Nautiyal *et al*, (1964), Jangpangi (1974) and Anon (1984), this formation occupies a supra-Manas Formation level.

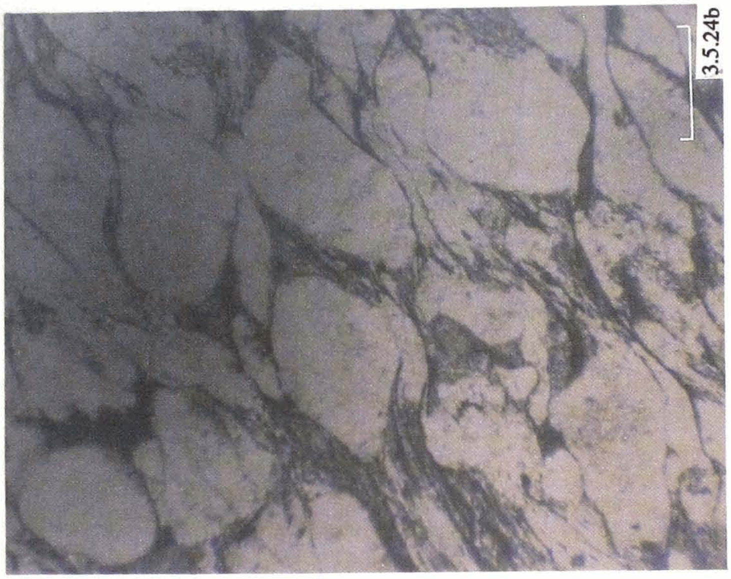
Beside the type section described by Nautiyal *et al*, (1964), along the Phuntsholing-Thimphu road, good sections of this formation are exposed along the Chamurchi and Khanabharti *khola* sections (Fig. 3.5.2b,c). East of the type area the continuity of the Phuntsholing Formation can be traced upto the Raidak river beyond which it is possibly tectonically overlapped by the Shumar Thrust Sheet (Fig. 3.5.1). Westward, skirting the Torsa river loop, through Lorikha-Khanabharti-Samtse area it continues upto the Jaldhaka river.

The quartzite and phyllite of this sequence are somewhat akin to those of the underlying Manas Formation. Under microscope the phyllite is seen to contain 5-10% silt size subangular detrital quartz grains and show prominent alignment of phyllosilicates (Fig.3.5.19). Limestone in the Phuntsholing Formation is light grey, thinly bedded and fine grained (e.g. one kilometre south of the Khanabharti peak .1275).

Pangsari Formation : This newly proposed formation resting conformably over the Manas Formation is the youngest stratigraphic unit of the Baxa Group, denoting a thick sequence of dominantly yellowish white (cream), locally pink and buff coloured dolomite interstratified with subordinate white to light grey, locally calcareous quartzite and grey-green locally talcose phyllite, exposed to the north of Lorikha and Khanabharti.

Explanation of figures 3.5.24a - d

Fig.3.5.24a-d Different varieties of mylonites in the quartzites of the Manas Formation. 3.5.24a,c,d. -- X-nicols. Bar length 0.5mm in b, c, d and 0.1mm in a.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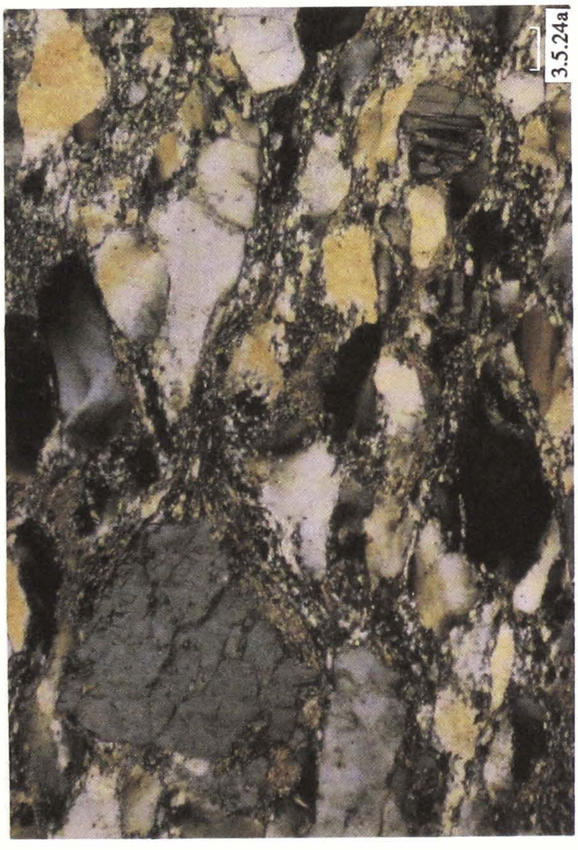
3.5.24d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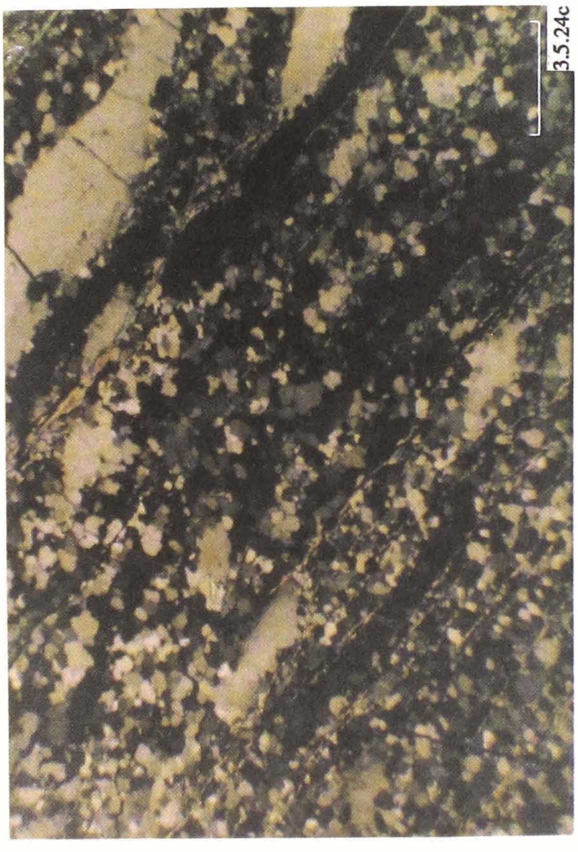

3.5.24c

This unit identified as 'Calcareous Quartzite' of the Jainti Formation by Chaturvedi and Reddy (1977) was mapped as a part of the Samchi Series by Nautiyal *et al*, (1964) and of the Phuntsholing Formation by Jangpangi (1978) and Anon (1984, 1991).

This characteristic lithosequence exposed as a thick lenticular body in the west-central Bhutan (Fig.3.5.1) is named after a small village Pangsari, about 1.5km east of the area's highest peak .1938 (about 10km ENE of Samtse) where it is excellently exposed. The Pangsari Formation has a maximum thickness of about 2,400m in the Khanabharti-Dorkha track (Fig.3.5.2c), which is also its type section. Good sections of this formation are also exposed along the Chamurchi *khola* and Lorikha-Thunuwa track. East of the type section the thickness of this formation gradually reduces to about 800m near Pa *Chu* village. Further southeast, at about two kilometre southeast of Resum, it pinches to reappear as thin intercalation near the MBT in the Pana river section. The Pangsari Formation is not exposed east of the Pana river. Though not mapped, but in its westward continuity this formation seems to pinch out between the Diana and Dipu river sections (cf. Sen Gupta and Raina, 1978).

The Pangsari Formation conformably rests over the Phuntsholing Formation along a sharp contact and in turn is tectonically succeeded by the Shumar Formation. The increased southward translation of the Shumar Thrust Sheet has caused tectonic elimination of the Pangsari Formation along a major length of the Bhutan Himalaya.

Thick cream-buff-pink, fine grained, thinly bedded dolomite with partings to thin bands of light grey-green, locally calcareous and rare talcose phyllite constitute the characterisitic lithology of the formation. Locally the dolomite bears a variegated, thinly banded look (Fig.3.5.31). It is fine grained, pseudosparitic, containing 15-20% free floating, moderately to poorly sorted, subrounded quartz grains, the bigger grains being better rounded (Fig.3.5.32). Sporadically the quartz grains show authigenic growth. The quartz is in inequillibrium with the carbonate matrix, resulting in the latter corroding the former (Fig.3.5.33).

The interstratified quartzite is white to light grey, fine to medium grained, locally calcareous, subarkose to quartzarenite type. It is locally gritty, pebbly to conglomeratic with diagnostic clasts of pink-red quartzite and jasper(?) similar to the quartzite of the underlying Phuntsholing and Manas Formations. The quartzite of the Pangsari Formation commonly exhibits cataclastic-mylonitic fabric indicating highly tectonised state of this quartzite as well. The thickness of individual interstratified quartzite horizon ranges from less than a metre to 100m (e.g. north of Gaharigaon). The proportion of phyllite increases towards the upper part of the formation where it contains as much as 200m thick horizons of phyllite (Fig.3.5.2c).

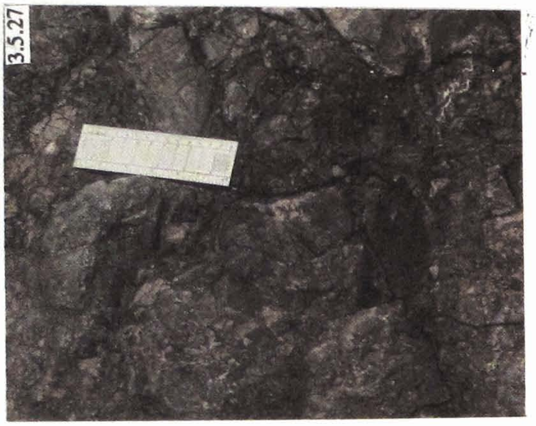
Bhattacharjee (1969) reported a few thin (upto one metre) beds of oolite bearing calcareous quartzites from the Torsa valley, which possibly belong to the present Pangsari Formation. The oolites are undeformed, calcareous, spherical to elliptical, ranging in size from 0.75mm to one millimetre (Bhattacharjee, 1969).

Along the Pa *Chu* and Phuntsholing-Thimphu road sections, the Pangsari Formation is tectonically overlain by a grey, greenish grey phyllite sequence with subordinate carbonate and haematite quartzite bands. This sequence though mapped as a part of the Shumar Formation bears close resemblance with the Baxa Group and may infact be its tectonic slice in the former pack.

Heavy Mineral Assemblage : Analysis of 21 quartzite samples from different levels of the Baxa

Explanation of figures 3.5.25 - 3.5.30

Fig. 3.5.25 Moderately sorted, clast supported polymictic conglomerate. Note cross-bedded quartzite clast (Q). Manas Formation. Loc. Khanabharti *khola*. Fig. 3.5.26 Dolomite intercalated with chert beds. Manas Formation. Loc. Raidak valley near Piping. Fig. 3.5.27 Autoclastic conglomerate in dolomite. Manas Formation. Loc. Raidak valley downstream of Piping. Fig. 3.5.28 Brecciated dolomite filled by secondary carbonate. Manas Formation. Loc. Upper reaches of Seti *khola*. Fig. 3.5.29 Stromatolites in a dolomite boulder. Manas Formation. Loc. Titi *khola*. Fig. 3.5.30 Pseudosparitic dolomite showing silicification. Manas Formation. X-nicols. Bar length 0.5mm.



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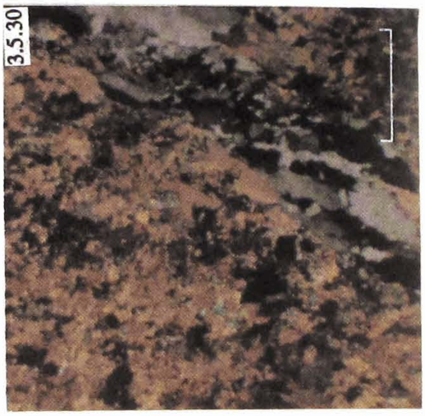

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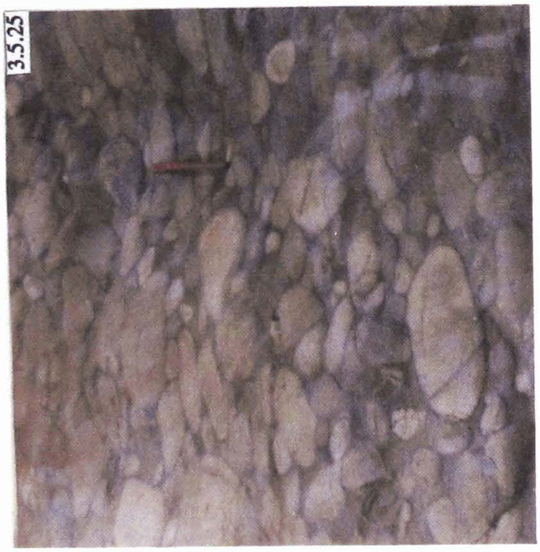


3.5.25

3.5.28

lithopack spread along the entire length of the Bhutan Himalaya yielded the following heavy minerals :

> Iron opaques- ilmenite- titanite- garnet- rutile- zircon- hornblende+ tourmaline+ sphene+ chlorite+ biotite+ tremolite+ spinel+ anatase.

The total heavy mineral weight percentage ranges from 0.02 to 2.68 with an average of 0.52%. Fig.3.5.34 presents the average relative proportion of the different heavy minerals.

Age : Age of the Baxa Group is highly controversial. Ages ranging from Precambrian to Triassic have been assigned to this group on the basis of lithological correlation with the stratigraphic units of other parts of the Himalaya. Mallet (1875), Nautiyal *et al*, (1964) and Guha Sarkar (1979) suggested a Permo-Triassic age for the Baxa rocks and correlated them with the Krol Group of the western Himalaya. The Krol sequence now has been found to represent a late Precambrian age. Lahiri (1941) on the basis of presence of `Banded iron ores' and metamorphosed nature of the Baxa rocks assigned it a Precambrian age. O'Rourke (1962), however, considered the Himalayan iron ores broadly of Permo-Carboniferous age. Sinha-Roy (1972) based on feeble to moderate metamorphism, unfossiliferous nature and occurrence of stromatolites assigned a Precambrian age to the Baxa rocks. Acharyya (1974) suggested that the stunted columnar and wavy stromatolites in the Baxa carbonate may not indicate a Precambrian age. Considering the apparent intercalated relationship between the Baxa and Rangit Pebble Slate, Acharyya (1976) assigned a Carboniferous-Devonian age to the Baxa rocks which was later revised to Riphean age (Acharyya, 1983). Jangpangi (1974) correlated the Baxa sediments with the characteristic orthoquartzite-carbonate suites of other parts of the Himalaya and assigned it a Precambrian to Lower Palaeozoic age. Raha and Das (1989) on the basis of stromatolite assemblage of the Baxa Group assigned it an upper Riphean-Vendian age.

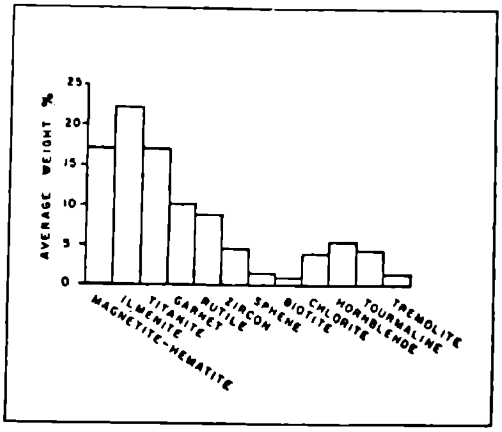


Fig. 3.5.34 Bar diagram showing average weight percentage of heavy minerals in the Baxa Group.

Acknowledgement

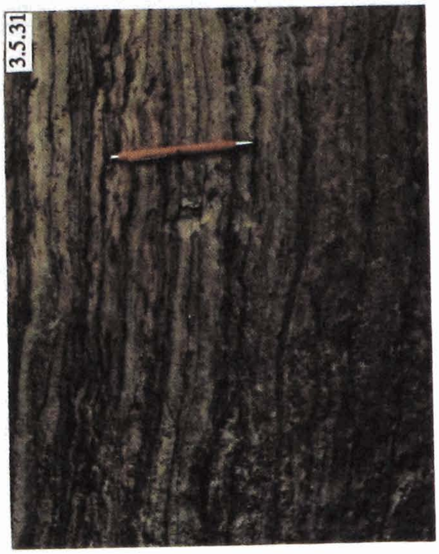
Sincere thanks are due to Dr. O.N. Bhargava for his overall guidance during the course of the project and critically reviewing the manuscript that led to significant improvements in the interpretation and presentation of the data.

Geological details provided by Dr. Joginder Singh and D.D. Raju (Khanabharti-Dorkha section), Dr. A.K. Chaudhary (Raidak and Sankosh river sections), Dr. P.R. Golani, Dr. Joginder Singh, A.C. Pande (Sarbhang-Chirang road section) and Dr. S. Dasgupta (Nganglam-Kirung area) are gratefully acknowledged.

Heavy mineral analysis was performed by Dr. A.N. Singh.

Explanation of Figures 3.5.31 - 3.5.33

Fig. 3.5.31 Thin bedded, white-pink arenaceous dolomite with green-grey phyllite partings. Pangsari Formation. Loc. Upstream of Doya *khola*. Fig. 3.5.32 Dolomite with ill-sorted quartz grains. Pangsari Formation. X-nicols. Bar length 0.5mm. Fig. 3.5.33 Quartz grains corroded by the carbonate matrix. Pangsari Formation. X-nicols. Bar length 0.5mm.



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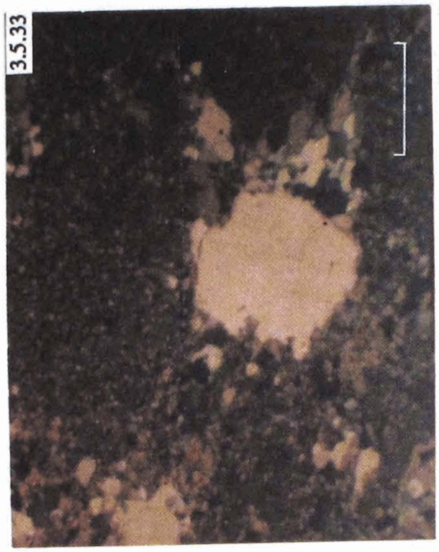

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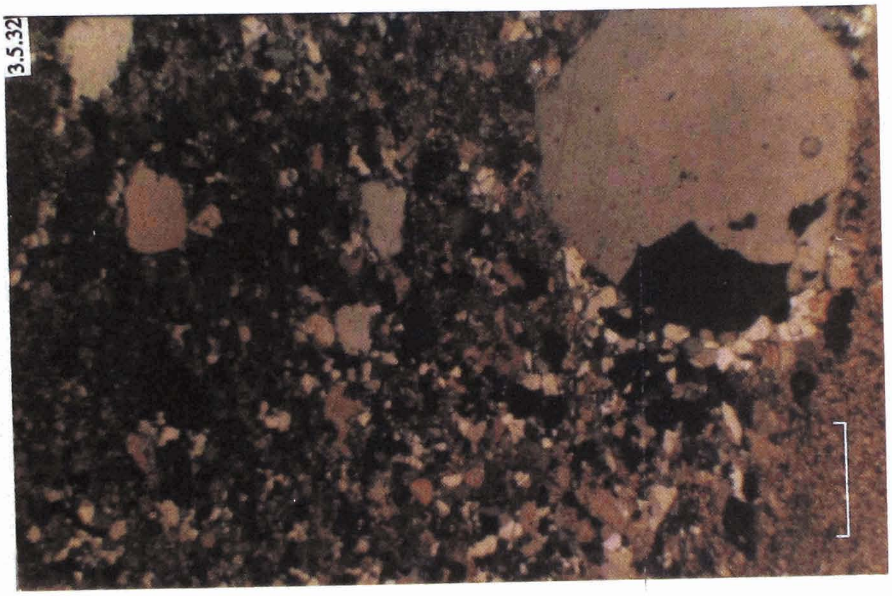

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3.6 DIURI FORMATION

S.K. Tangri

Named after the Diu *Ri* valley, a distinctive sequence of pebbly-cobbly rarely bouldary, phyllitic slate was designated as the Diuri Boulder Bed and classified as a part of the Baxa Group (Nautiyal *et al*, 1964). Jangpangi (1974) formally named it as the 'Diuri Boulder Slate Formation', which was abbreviated to 'Diuri Formation' by Gansser (1983).

The principal development of the Diuri Formation is confined to the southeastern Bhutan where it is exposed as an east-west trending belt of variable thickness between the Manas river in the west and the Dhansiri in the east (Fig.3.5.1). The Diuri Formation exhibits maximum development in the type section and also along the Samdrup Jongkhar-Tashigong road. In the latter area it is disposed into a major ENE-WSW trending, partly faulted syncline. In the southern limb of the aforementioned syncline, the thickness of the Diuri Formation is about 2500m (Jangpangi, 1974). With gradual reduction in thickness eastward, the Diuri Formation pinches out in the Borila *nadi* section, only to reappear as a thin band in the Jhumo *Ri* section. This formation is also preserved in the core of the syncline south of Khar and continues to a little northeast of Yangle Gompa. In the Dangana area the sediments of the Diuri Formation overlie the violet-purple quartzite of the Jainti Formation and are exposed in a tectonic window (Bhattacharya, *et al*, 1992). Beside these, a few thin isolated outcrops of the Diuri Formation occur in association with the rocks of the Setikhola Formation in western Bhutan foot-hills. In these sections the Diuri Formation occurs as tectonic slivers within the Jainti Formation of the Baxa Group. Joshi *et al*, (1990) considered the conglomerate of the Diuri Formation as an integral part of the Setikhola Formation, in the latter's type section.

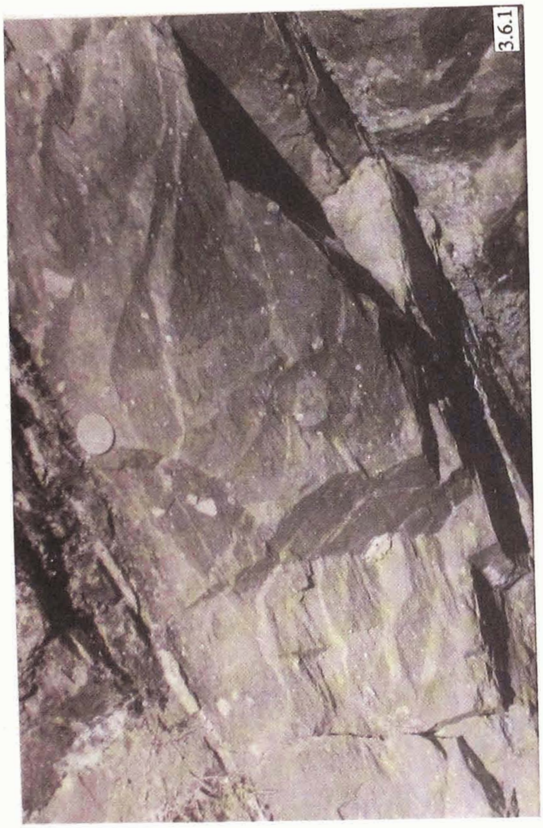
Contact Relationship

Stratigraphically the Diuri Formation overlies the thick quartzites of the Manas Formation earlier designated as the Thungsing Formation (e.g., northeast of Yangle Gompa and in the Shekpassing area) and the purple quartzites of the Jainti Formation (e.g. Dangana area), suggesting a possible unconformity. Acharyya *et al*, (1975) considered the contact between the Diuri Formation and the Buxa Quartzite in the Deothang-Narphung road section to be gradational.

Along major part of its length the Diuri Formation is tectonically bounded between the Baxa Group in the north and the Damuda Subgroup/Setikhola Formation and in rare cases even the Siwalik Group in the south. In the Nganglam area it is sandwiched within the Baxa succession. In the Kulamanti area and in the Gong Ri-Jhiri Chu window zones the Diuri diamictite overlies the Baxa sequence and is underlain by the Shumar rocks.

Lithological Details

The Diuri Formation comprises essentially a monotonous sequence of dark grey to earthy green, predominantly unstratified, ill-sorted, gritty to cobbly, sporadically bouldery, and pyritous phyllitic wacke slates (diamictites) (Fig.3.6.1), interstratified with subordinate non-pebbly slate/phyllite, siltstone, conglomerate (Fig.3.6.2-4) and rare fine grained quartzite. The plus sand size clast fraction of the diamictite in general constitutes 7% to 10% of the rock. But locally the percentage increases to grade into a conglomerate. The coarser clastics are represented by subangular to subrounded clasts of white-light grey sporadically buff fine grained arenite, vein quartz, light-dark grey-earthy green slate, light-dark grey dolomite, limestone and rare granitoid and pegmatite. The diamictite/ conglomerate exhibits wide variation in the population of dolomite clasts (5%-50%) (Fig.3.6.2). Beside the silt-sand size fraction, the clasts exist in three distinct size modes viz., 0.2 to 1.50cm; 1.51 to 5cm and >5cm, in almost constant ratio of 60:5:1 (Fig.3.6.3). The size of the largest boulder recorded is 25cm. The bigger clasts exhibit comparative higher roundness and sphericity



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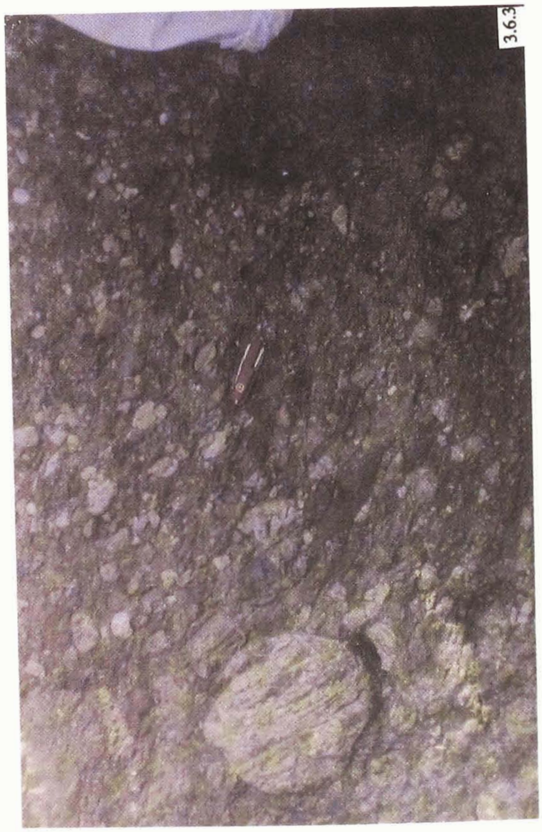
3.6.2



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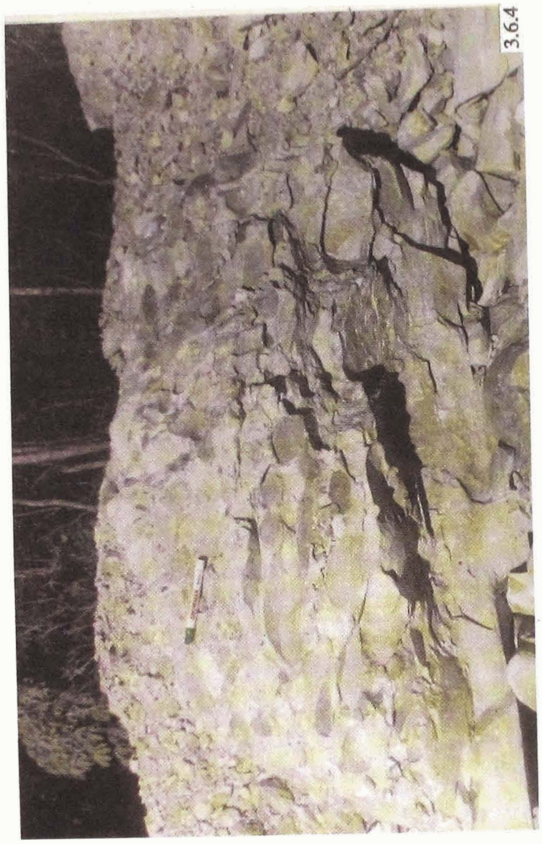


3.6.4

(Fig.3.6.2,3). Locally the diamictite contains small (0.2-4cm), dominantly lensoidal, limonitic material filled cavities, which possibly are due to weathering of ferruginous slate/dolomite clasts.

Though largely the Diuri Formation is devoid of sedimentary structures an isolated instance of dropstone-like structure has been recorded, near 31km stone on the Samdrup Jongkhar-Tashigang road.

Under microscope the matrix of the diamictite has an appearance of arenaceous sericite phyllite containing ill-sorted, subangular to subrounded silt-sand sized floating clasts (Fig.3.6.5-8). The clast fraction constitutes 15%-30% of the matrix and comprises quartz (70%-80%), feldspar (5%-15%) -- microcline (Fig.3.6.7), orthoclase, plagioclase (Fig.3.6.6,7), perthite and lithic fragments (15%-20%) -- fine grained quartzite (Fig.3.6.5), siltstone, slate (Fig.3.6.5), dolomite and rare granitoid (Fig.3.6.6). Feldspar clasts are commonly sericitised. Locally the rock contains thin flattened lensoidal aggregates of calcite. Common development of pressure shadows around bigger clasts with local crystallisation of carbonates in the shadow zones is noticed (Fig.3.6.8).

The diamictite gradationally passes into non-pebbly slate and siltstone. The quartzite is dominantly white to green, medium bedded, fine grained and locally exhibits medium to large scale, solitary, low angled, trough type cross-bedding indicating palaeocurrent in N5^{o}E to N15^{o}W direction.

In most sections, base of the Diuri Formation is marked by a 20-60m thick, polymictic conglomerate (Fig.3.6.4). It consists of subangular to subrounded pebbles-boulders of white - light-dark grey fine grained quartzite, dark grey-earthy green slate, light-dark grey dolomite and limestone, held in an arenaceous, locally feldspathic matrix. The clast to matrix ratio varies from 65:35 to 80:20 with the size of the largest clast being 30cm. This conglomerate is distinct from that of the Baxa Group by the presence of dolomite-limestone clasts and absence of pink quartzite clasts. The conglomerate at the base of the Diuri Formation might possibly be a lag marking commencement of the Diuri sedimentation after a sedimentalogic break.

Analysis of five samples yielded following heavy minerals in the Diuri Formation.

Iron opaques- ilmenite- titanite- garnet- rutile-zircon- sphene- hornblende-tourmaline± chlorite± biotite.

While the total heavy mineral weight percentage ranges from 0.08% to 0.35%, the average relative proportion of the different heavy minerals is shown in fig.3.6.9.

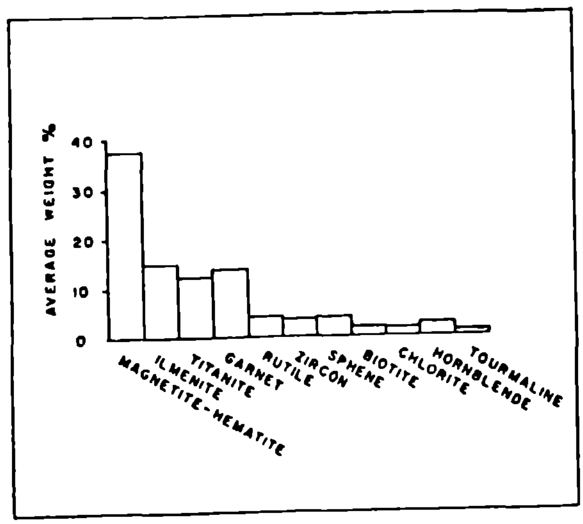
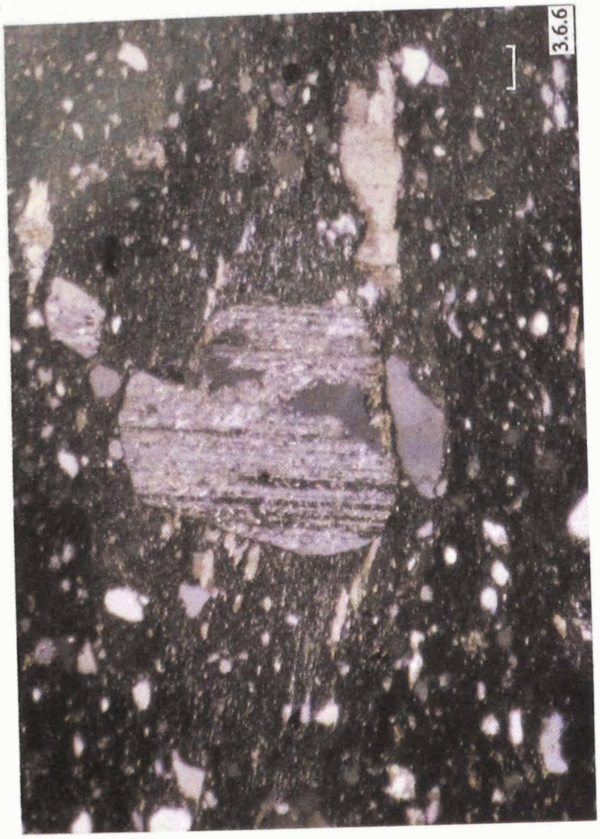


Fig. 3.6.9 Bar diagram showing average weight percentage of heavy minerals in Diuri Formation.

Age : Due to unfossiliferous nature it is difficult to assign any specific age to the Diuri Formation. Jangpangi (1974, 1978) assigned a Permian age to

Explanation of Figures 3.6.1 - 3.6.4

Fig.3.6.1 Earthy green, pebbly phyllitic slate. Diuri Formation. Loc. Samdrup Jongkhar-Tashigong road, near 31km stone.Fig.3.6.2,3 Conglomerate rich in dolomite clasts showing distribution pattern of different size clasts. Note higher sphericity-roundness of bigger clasts. Diuri Formation.Loc. Kharpodang *Ri*, northwest of Chowki. Fig. 3.6.4 Basal Diuri Conglomerate. Loc. Near Yangle Gompa.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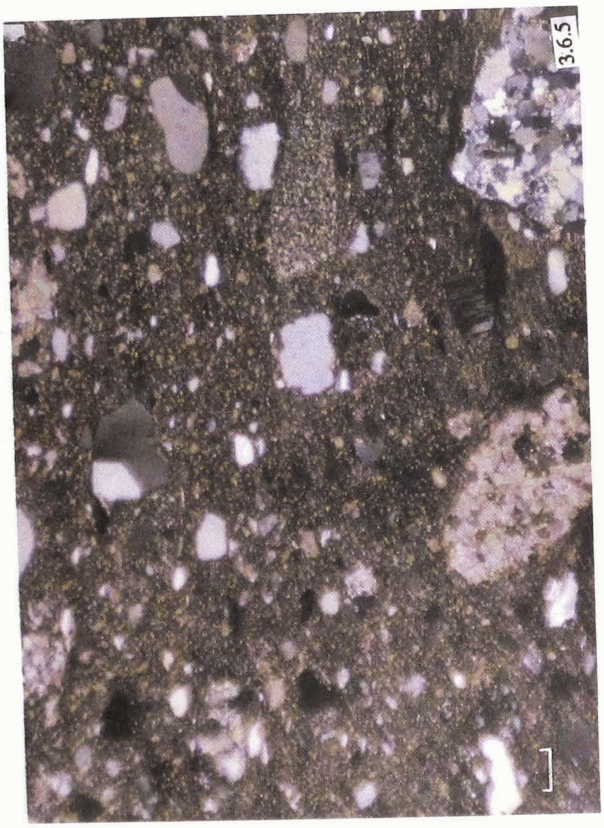
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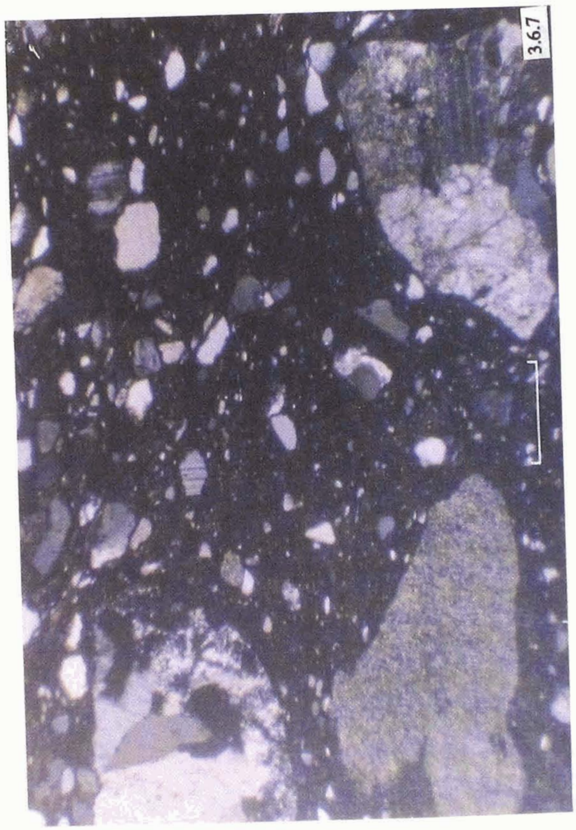
3.6.7

the Diuri Formation. It has also been equated with the Rangit Pebble Slates of the adjoining Darjeeling-Sikkim and Arunachal Himalaya (Acharyya, 1978), which have yielded early Permian marine fossils (Acharyya *et al*, 1975). Singh (1992), however, opined that the diamictites of the type section and those found associated with the Setikhola Formation as also the ones exposed in the Nganglam-Mikuri section are different. The present work, however, finds that all the above mentioned conglomerates are lithologically alike.

The present author opines that the common association of the Diuri Formation with the Permian Setikhola sediments suggests a close stratigraphic relationship between these two sequences. This postulation is supported by the presence of an identical pebbly slate/diamictite unit i.e., the Shodug Formation of the Permian age in the Tethyan succession of northwestern Bhutan. The present author thus is in agreement with the age assignment suggested earlier by Jangpangi (1974, 1978) and Acharyya (1978).

Acknowledgement

Special thanks to Dr. O.N. Bhargava for critically reviewing the text and useful discussions. Geological details provided by Dr. S. Dasgupta about the Nganglam-Dichhiling area are gratefully acknowledged.

Heavy mineral analysis was performed by Dr. A.N. Singh.

Explanation of Figures 3.6.5 - 3.6.8

Fig. 3.6.5 Quartz (Q), feldspar (F), quartzite (Qt), slate (S), dolomite (D), clasts in diamictite. Diuri Formation. X-nicols. Bar length 0.1mm. Fig.3.6.6 Subangular clasts of feldspar in diamictite. Diuri Formation. X-nicols. Bar length 0.1mm. Fig. 3.6.7 Granitoid (G), carbonate (C), microcline (M), plagioclase (P) clasts in diamictite. Note subangular to subrounded ill-sorted clast population. Diuri Formation. X-nicols. Bar length 0.5mm. Fig.3.6.8 Pressure shadow around a bigger clast. Note development of carbonate in the pressure shadow. Diuri Formation. X-nicols. Bar length 0.5mm.

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3.7 SHUMAR FORMATION

S. Dasgupta

A sequence of metasedimentary rocks, constituted mainly of phyllite (with rare lenses of gypsum), slate, limestone, flaggy and massive quartzite in Nangkur-Shumar area of eastern Bhutan was designated as the Shumar `Series' by Nautiyal *et al*, (1964). This litho-package occurs along the upper tectonic level of the Lesser Himalayan metasedimentary belt south of the crystalline thrust sheet of the Thimphu `Formation' (Nautiyal *et al*, 1964). The Shumar `Series' has been found to be synonymous with the Samchi `Series' (Nautiyal *et al*, 1964; Guha Sarkar and Singh Gaur, 1963; Singh and Krishna Murthy, 1963), exposed between the Manas and the Jaldhaka rivers and the Umling Quartzite (Sayeed, 1966) of the Kuru Chu valley. The Shumar `Series' redesignated as the Shumar Formation (Jangpangi, 1974) extends throughout the length of the Lesser Himalaya in Bhutan (Fig.3.7.1). Gansser (1983) used the nomenclature `Daling-Shumar Group' to avoid the different local names as well as to indicate Shumar's equivalence with the well known Daling rocks of the Darjeeling Himalaya (Sen Gupta and Raina, 1978). Roy *et al*, (1989) have also assigned a group status to Shumar litho-package. There are wide lithological variations within the sequence of the Shumar Formation. Individual litho-units of this formation do not have a regional spatial extension and at best can be designated as members. Thus, raising Shumar to a group level is unwarranted. No where full succession of the Shumar Formation is preserved. Hence, the succession presented here has been reconstructed by piecing different sections.

Besides, the Shumar Formation, exposed south of the Thimphu Thrust Sheet in the Lesser Himalayan belt, a similar metasedimentary sequence crops out in west-central Bhutan occupying a considerable aerial extent around Paro, Sambe Dzong, Getta Dzong, Duna Dzong and Chukha. Out of these the largest one is present around Paro-Ha-Bunakha-Simtokha areas and was named as the Paro `Series' by Nautiyal *et al*, (1964). According to them a distinct thrust

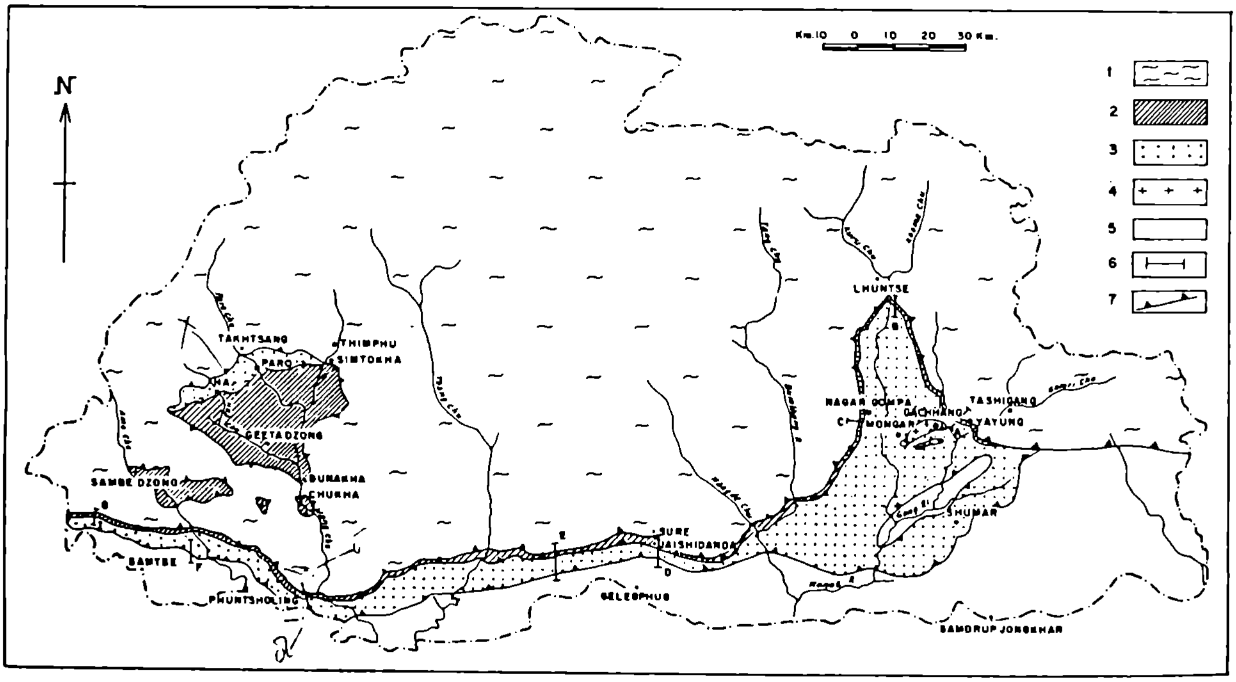


Fig.3.7.1 Generalised geological sketch map showing disposition of the Shumar and Jaishidanda Formations in Bhutan. 1. Thimphu Gr., 2. Jaishidanda Fm., 3. Shumar Fm., 4. Granitic slivers, 5. Baxa Gr., Diuri and Setikhola Fms., Siwalik Gr. (undifferentiated). 6. Sections measured, 7. Thrust.

separates the overlying granitoid gneisses of the Thimphu `Formation' from the underlying metasedimentary package of the `Paro Series', exposed in window `zones' in the above mentioned areas. Though Nautiyal *et al*, (1964) identified the Paro metasedimentary package as a separate stratigraphic and tectonic entity, they still considered it as a sub-unit of the Thimphu Formation. Jangpangi (1978) considered the Paro sequence as the metamorphosed equivalents of the Buxa/Phuntsholing and the Shumar Formations, exposed in tectonic windows. Gansser (1983) refuted this correlation of the Paro metasediments with the Lesser Himalayan rocks. His views are rather contradictory. In his geological map Gansser (1983) shows the Thimphu `Formation' to be thrusted over the Paro metasediments along its northern as well as along southern margins, south of Chapcha, yet in the text (Gansser, 1983; p.73 & 75) the northern contact of the Paro metasediments with the overlying Thimphu (Taksang) gneiss is described as gradational. The Paro (metasediments) Formation of Gansser (1983) in fact indiscriminately includes sequences exposed at different tectono-stratigraphic levels - viz., (a) tectonically below the Thimphu Group, (b) interstratified within the Thimphu Group and (c) those resting stratigraphically above the Thimphu Group. The last one has yielded fossils. These `Paro Sequences' represent three different stratigraphic entities and have to be considered separately.

Recent traverses, photo geological studies as well as re-evaluation of the previous mapping report unambiguously suggest that the metasediments at Paro, Sambe Dzong, Getta Dzong, Duna Dzong and Chukha areas are exposed in tectonic windows along the Wang *Chu*, Paro *Chu*, Ha *Chu* and Amo *Chu* valleys on subthrust sides of the Thimphu Thrust Sheet. On the basis of identical tectono-stratigraphic position (Fig.3.7.2), gross lithological assemblage and grade of metamorphism the metasedimentary package of the Paro Formation of the Ha and Paro sections are found to be the northern extention of the Shumar Formation; while those of the Wang *Chu* and Amo *Chu* represent the Jaishidanda Formation (discussed later).

Type Section

Shumar-Kharungla area of the eastern Bhutan exposes the best section of the Shumar Formation. Another excellent section is also observed in the Kuru *Chu* valley. In the former area it occupies the core of a NE-SW trending regional synform sandwiched inbetween corresponding antiforms. In the latter area it occupies the core of N-S trending Kuru half window. Well developed sections can also be observed between Yayung-Seri *Chu* and Mongar-Nagar Gompa areas along the Tashigang-Bumthang road.

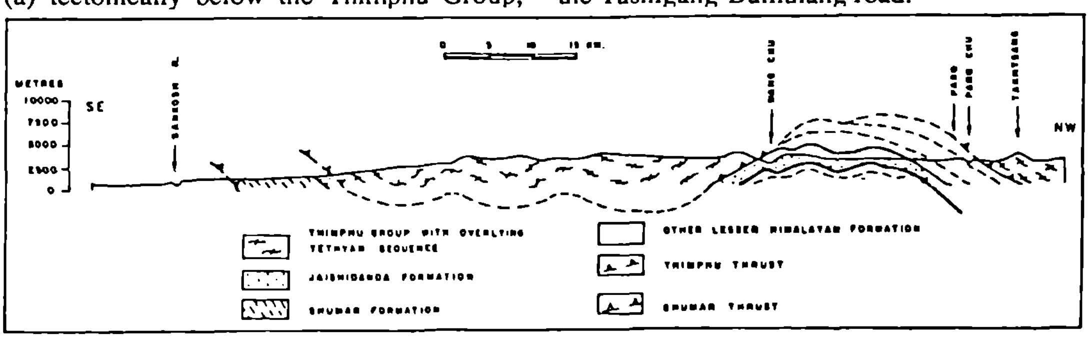


Fig.3.7.2 Geological section between Sankosh and Paro showing extension of the Shumar and Jaishidanda Formations on subthrust side of the Thimphu Thrust Sheet from foot-hills to the Paro window.

Lithological Details

Broadly the Shumar Formation comprises an alternating sequence of quartzite and phyllite/mica schist with impersistent bands of carbonate and lenses of gypsum. Basic sills are common mainly towards the upper part of the sequence. Concordant sheet-like bodies of mylonitised granite gneiss are present at different levels within the sequence, particularly towards the basal part (Table-3.7.1).

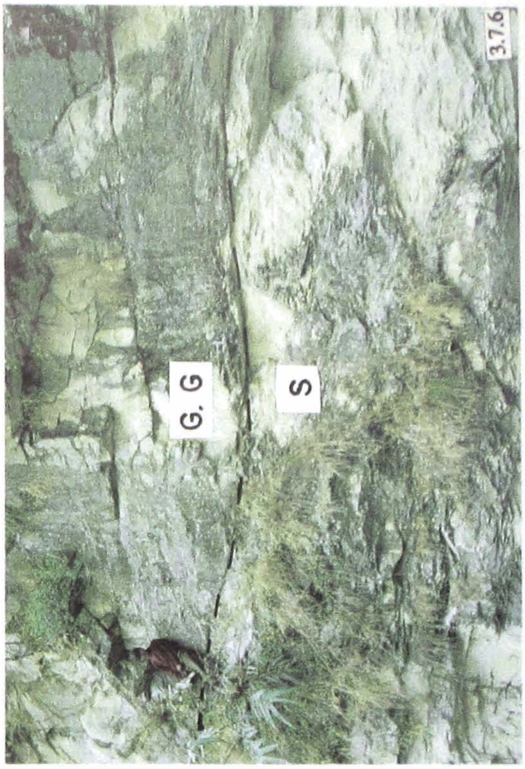
Table 3.7.1 : Lithological succession of the Shumar Formation in the Kuru *Chu* valley and Shumar-Kharungla area of Eastern Bhutan.

	Kuru *Chu* valley (after Jangpangi, 1974)		Shumar-Kharungla area (after Ray and Razdan, 1975, Ray, 1978)
AUCHHHO AREA	Phyllite, schist, limestone and flaggy quartzite with granite gneiss.	KHARUNGLA AREA	Greenish and greyish phyllite often with . carbonaceous impurities
	Quartzite.		Flaggy, greenish, micaceous, well jointed quartzite.
	--------- Chhimung Ri fault ----------		Grey carbonaceous phyllite with lenses of limestone
	Phyllite, flaggy quartzite, limestone, dark grey slate, gypsum bed, basic sill and Chhimung Ri gneiss.		Foliated and jointed flaggy quartzite with occasional magnetite rich bands. Brown and grey coloured phyllite, sporadically carbonaceous and with lenses of grey limestone
	Quartzite, thick, massive, locally gritty and sericitic.		
THANGRUNG AREA	Phyllite and quartzite with thin basic rock and granite gneiss of Gachhang and Marsing areas	SHUMAR AREA	Foliated, bedded and jointed, flaggy, white quartzite grading into mica schist
	Quartzite with minor phyllite		
	Phyllite with minor quartzite		
	----------- Thangrung fault ----------		Greenish chlorite phyllite and chlorite muscovite quartzite with lenses of crystalline limestone
	Quartzite		
	---------- Kharungla-Damkar fault ----------		Phyllite, slate, limestone, quartzite and gypsum bed in the Shumar area.
	Quartzite and phyllite		

Phyllite/mica schist which forms a main bulk of the sequence is fine grained, commonly grey to greenish and locally khaki coloured and well foliated. However, sporadically due to enrichment of carbonaceous matter it attains dark grey hues. Locally laminations, defined by alternating quartzose and phyllosilicate rich layers, are well preserved. Essential mineral constituents of pelites are muscovite/sericite, quartz, chlorite and opaques. Common accessories include tourmaline, apatite and feldspar. Towards the upper part of the sequence within this unit appear biotite, the fine grained phyllosilicates become coarser and as a result phyllite passes into mica schist. Polygonization of larger quartz grains and formation of small strain-free grains are common, particularly in the vicinity of the mylonitised granite gneiss and upper and lower contacts of the Shumar Formation. Phyllonitic rocks exist, specially along the lower contact of this formation. Vein quartz is wide spread within this unit notably towards the upper and basal parts of the sequence.

The quartzite of this formation is commonly fine grained, white to greyish white, thin to medium bedded and well jointed. Colour banding, defining the bedding, is conspicuous and is invariably associated with a bedding joint. The concentration of phyllosilicate minerals along layers as well the bedding joints imparts a flaggy nature to the rock (Fig.3.7.3).


3.7.4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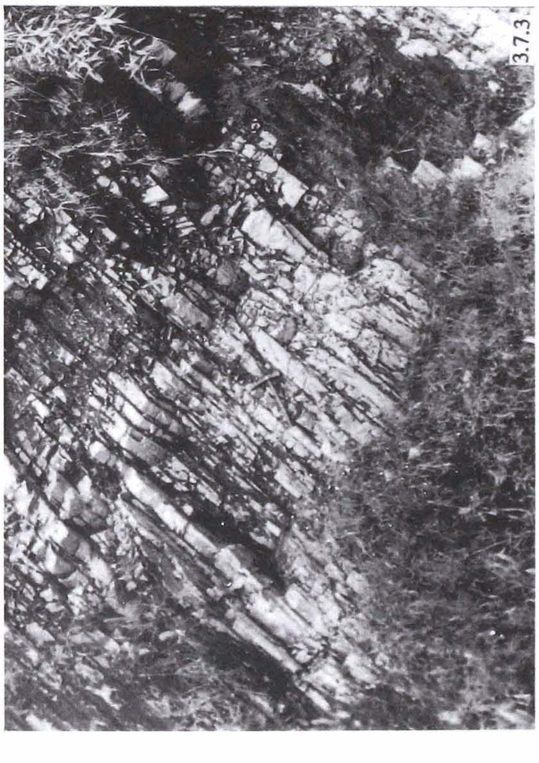
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3.7.5

Locally the quartzite is almost devoid of phyllosilicate minerals with inconspicuously developed bedding, imparting a massive look to the litho-unit. The dominant minerals in the quartzite are quartz, muscovite/sericite with rare chlorite and biotite. Accessories include feldspar, tourmaline and opaques. With the increase in proportion of phyllosilicate minerals, the quartzite grades into micaceous quartzite. Strong post-crystalline deformational effects, mainly represented by undulose extinction, deformation lamellae and strain shadows are common within the larger quartz grains. These larger grains are frequently replaced by small, strain-free, recrystallised grains imparting a blastomylonitic texture. Locally conglomeratic/gritty zones occur within the quartzite. At places, the conglomerate is autoclastic in nature (e.g. near Kheri Gompa, Thongsa and Mongar) and is made up of white quartzite pebbles set in a quartzose matrix. Northwest of Moshi, massive hematite rich bands, with restricted spatial extension, are associated with the quartzite. Except isolated occurrence of solitary cross-bedding with low angle truncation (Fig.3.7.4), no other well preserved sedimentary structure is observed within the quartzite unit.

Carbonate unit in the Shumar Formation is mainly represented by fine grained, thinly bedded grey to greyish white coloured limestone. However, in some sections well crystallised marble is also present (e.g. Rong Ri, Paro and Ha). Colour banding is conspicuous and at many places it is due to concentration of carbonaceous dirt. Main mineralogical constituents of the limestone are carbonate, quartz and sericite/muscovite. In the impure zones hornblende, actinotite tremolite, epidote and quartz, form the main constituents of the calc-silicate rocks. In general the carbonate unit occurs as bands and lenses of various dimensions within the pelites and exhibits gradational and inter-fingering relationship (e.g. Tashigang-Mongar road, west of Yayung). This intimate relation between phyllite/mica schist and limestone possibly led the previous workers to consider the carbonate as part of the Shumar Formation. However, Pantic *et al*, (1981) from a calcareous band, interlayered with mica schist in the upper part of the Shumar Formation at Barsong reported palynomorphs of Jurassic age. These authors considered this carbonate band as tectonic sliver of the younger sediments within a Precambrian metasedimentary millieu. Incidence of base metal mineralisation, dominantly Cu and rarely Pb-Zn, associated with carbonate unit, is known from several localities (e.g. Gomchu, Moshi, Bungthing etc.)

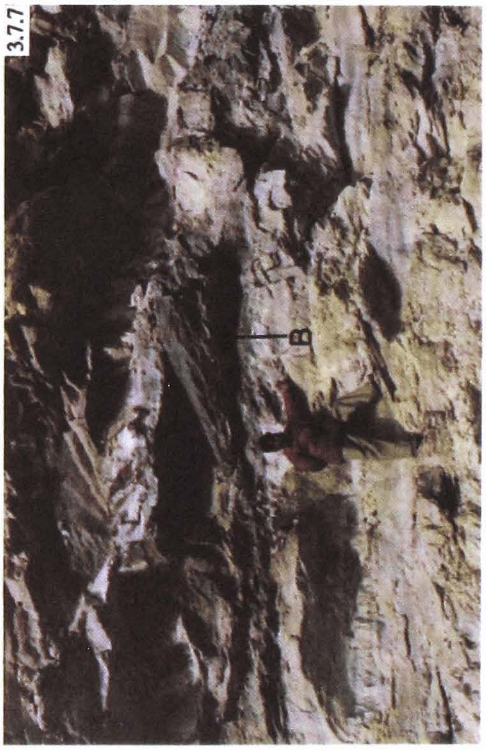
Basic rocks of the Shumar Formation are medium to coarse grained, dark green and dioritic/doleritic. They are constituted of hornblende, plagioclase, subordinate quartz and rare relict pyroxene grains. The basic rock occurs as concordant sill-like body with a sharp contact with the adjoining country rocks (Fig.3.7.5). Concordant as well as foliated nature of the sills points towards an early tectonic emplacement of these rocks.

Several thin, concordant, sheet-like bodies of mylonitised granite gneiss are found in the Kuru *Chu* valley within the mica schist of the Shumar Formation at different levels. Thickness of these bodies varies from 50m to several kilometres. Among these the mappable granite bodies are known as Gachhang, Chhimung Ri and Mursing Granites. Besides, minor occurrences of deformed granite gneiss are seen in section between Gedu-Dhamtari area within the mica schist. Further west in Suntalakha road, a thin metaconglomerate bed is found to be associated with the deformed granite gneiss.

These granite gneiss bodies exhibit sharp and highly sheared contact with the enveloping mica schist (Fig.3.7.6). No thermal effect and apophyses are observed within the adjoining country rock. Phyllonitic rocks have developed within the Shumar Formation along the contact

Explanation of Figures 3.7.3 - 3.7.6

Fig.3.7.3 Well developed bedding joints, imparting a flaggy nature to the quartzite of the Shumar Formation. In Gaylegphug-Sure Section. Fig.3.7.4 Tabular cross-bedding with low angle truncation in the quartzite of the Shumar Formation, Seri *Chu* area. Fig.3.7.5 Basic sill in the Shumar Formation, east of Seri *Chu*.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3.7.9


3.7.10

with the granite gneisses. Near the vicinity of the granite gneisses, basic rocks within the Shumar Formation have been rendered highly schistose (Fig.3.7.7).

All the granite gneiss bodies are highly deformed and exhibit mylonitic texture. The dominant minerals in the granite gneiss are quartz and perthite. K-feldspar and plagioclase are rare. Feldspar grains are commonly clouded due to alteration. Common mafic mineral is biotite which is present as tiny flakes, forming thin laminae parallel to the mylonitic foliation which is continuous with the schistosity of the enveloping metasediments. Muscovite/sericite is present as cluster of tiny flakes, some of which appear to have formed by the alteration of feldspar. Accessories include tourmaline and opaques. In a few samples carbonate grains are present. All the samples invariably show effect of intense post-crystalline deformation. Quartz occurs as fine grains in the ground mass and rarely as porphyroclasts which are partially or totally replaced by mosaic of fine, polygonal recrystallised grains. Larger quartz grains show undulose extinction and strain shadows and highly elongated parallel to mylonitic foliation. Feldspar and perthite grains are mainly present as porphyroclasts which commonly exhibit undulose extinction, tapering deformation twin lamellae, micro-faulting and fracturing. Perthitic intergrowth are commonly `flame' type and sporadically `banded' or `lamellar' type. The predominance of perthite grains and rarity of K-feldspar grains probably suggest that most of the K-feldspar grains exsolve albite forming perthite during the advance stage of plastic deformation (cf. Bard, 1987). At places, recrystallised quartz grains are found within the fractures of the feldspar grains. The larger feldspar/perthite grains constitute augens which exhibit asymmetric pressure trails. In some thin sections S-C fabrics are observed (Fig.3.7.8).

Locally larger feldspar and tourmaline (Fig.3.7.9) grains exhibit book-shelf sliding texture. With increasing intensity of deformation the number and sizes of the augen gets reduced, as a result protomylonite of a comparatively low strain zone passes into mylonite in a high strain zone. Sporadically the granite attains phyllonitic appearance, particularly along the margin. In such cases it becomes difficult to differentiate granite phyllonite from adjoining phyllonitic schist of the enveloping metasediments which show apparently a diffused contact. At places, banded mylonitic rocks, exhibiting fluxion banding (Fig.3.7.10) are found.

Important Sections of the Shumar Formation

The lithological variations and details of the Shumar Formation in various sections are given bellow.

Kuru *Chu* and Shumar-Kharungla section : Both in the Kuru *Chu* valley and Shumar-Kharungla area the full sequence of the Shumar Formation is not developed and there is a variation in thickness from one section to another due to lateral facies change as well as due to regional folding. In the Shumar area the lower most unit is a thick quartzite band which can be physically traced in the adjoining Kuru *Chu* valley, and thus can be used as a marker bed to broadly correlate the two well exposed sections. From the Nanong in the Shumar area, this lower most band extends northwest upto Bamshing where from it swings westerly towards Chhiya. Due to faulting, the outcrop is repeated further north. With an antiformal flexure it veers around the Gachhang Granite and extends upto south of Mongar in the Kuru *Chu* valley where still deeper succession of the Shumar Formation is exposed. In both the sections gypsum bed is present (Table-3.7.1). However, the Kuru *Chu* section is characterised by the presence of several concordant sheets of mylonitised granite gneiss.

Explanation of Figures 3.7.7 - 3.7.10

Fig.3.7.7 Highly schistose basic rock in the Shumar Formation near granite gneiss contact. Seri *Chu* valley. Fig.3.7.8 S-C fabric developed within the Gachhang Granite. bar 0.1mm. Fig.3.7.9 Book-shelf sliding texture in the Gachhang Granite. X-nicols, bar. 0.1mm. Fig.3.7.10 Fluxion banding in banded mylonites of the Gachhang Granite. X-nicols, bar. 0.2mm.

In the Kuru *Chu* antiformal flexure, exposed in the Kuru *Chu*-Seri *Chu* valley, litho-units constituting the upper part of the Shumar Formation have been studied in detail in three different sections (Fig.3.7.1), viz., (i) Yayung-Seri Chu section (eastern limb), (ii) Lhuntsi section (axial zone) and (iii) Lingmethang-Nagar Gompa section (western limb). In all these three sections, though widely separated, a broad correlation of the litho-package can be made (Fig. 3.7.11).

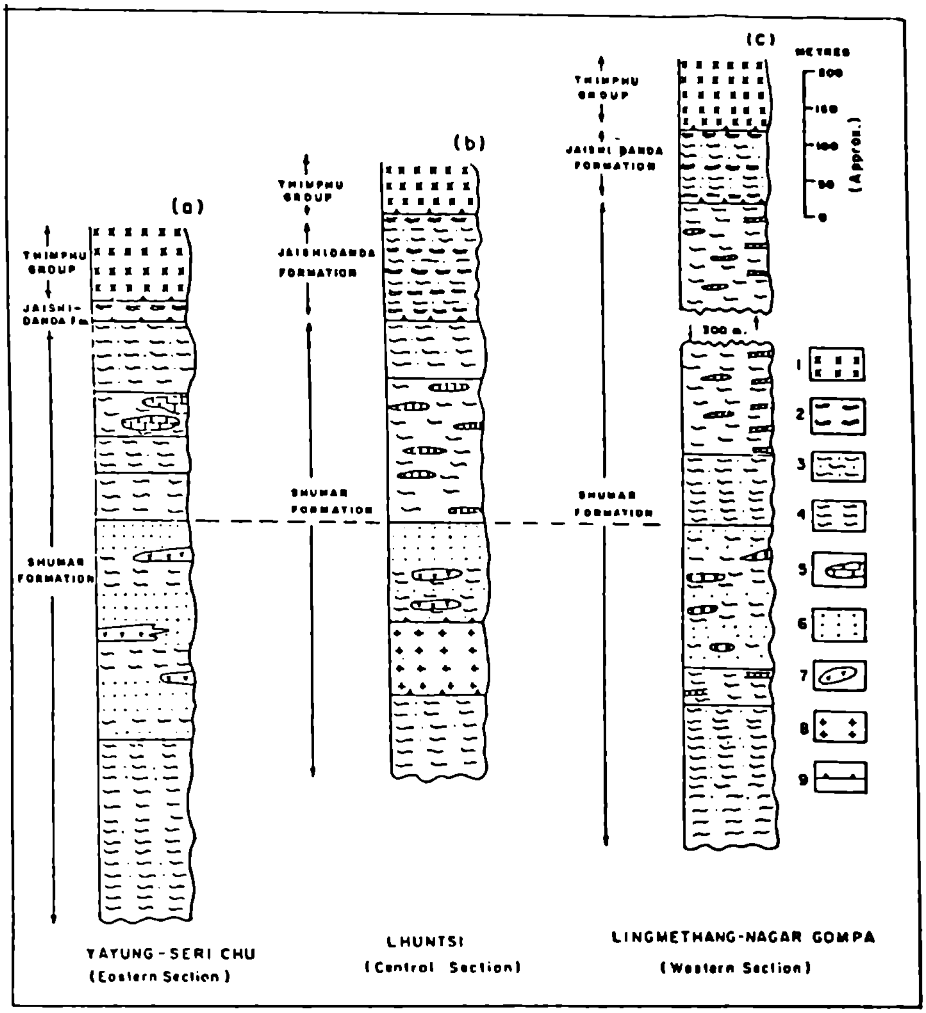

Fig.3.7.11 Lithologic details of the Shumar Formation in Yayung-Seri *Chu*, Lingmethang-Nagar Gompa and Lhuntsi Sections.
1. Granite gneiss - (Thimphu Group), 2. Garnetiferous mica schist, 3. Thinly bedded micaceous quartzite, 4. Mica schist/phyllite, 5. Carbonate rock, 6. Medium bedded quartzite, 7. Metabasic sill, 8. Mylonitised granite gneiss, 9. Thrust.

A study of the sequences in the afore mentioned sections (Fig.3.7.11) reveals that the upper part of the Shumar Formation is chiefly constituted of an alternating sequence of phyllite/mica schist and quartzite with impersistent bands of carbonate and few basic sills. The entire sequence can be divided into the following members.

Member F	:	Thinly bedded, medium to fine grained, greyish white, micaceous quartzite.
Member E	:	Mica schist with impersistent bands of carbonate and common quartz veins.
Member D	:	Thinly bedded, micaceous quartzite and mica schist/phyllite.

Member C	Interlayered sequence of fine grained, white to greyish white, medium bedded quartzite and phyllite with basic sills.
Member B	Phyllite with impersistent bands of carbonate.
Member A	Interlayered sequence of phyllite and thinly bedded, micaceous quartzite.

The Member F is better developed in the eastern Yayung-Seri *Chu* section as compared to the central Lhuntsi section whereas it is absent in Lingmethang-Nagar Gompa section (Fig.3.7.11). The Member E is well developed in the western part, with the thickness of the carbonate bands varying from 10-20m in the eastern section and one metre or even less in the central and western sections. The Member D is present in eastern and western sections but is absent in the central part. The quartzitic unit being thick in this member can be separated out in the eastern section; on the other hand in the western section the quartzite is thinly interstratified with the phyllitic unit. The Member C is ubiquitous but with a variable thickness. In the central section below the Member C exists a concordant sheet-like body of mylonitised granite gneiss. Similar deformed granite gneiss (discussed later) crops out in the still lower part of the Shumar Formation in Gachhang, Mursing and Chhimung *Ri* areas. The Member B is present in the western part only. Within the Member A occur tabular cross-bedding with low angle truncation (Fig.3.7.4) which is locally deformed (Fig.3.7.12).

Kanamakra Section : The Shumar Formation which is considerably thick in the Kuru *Chu* section, gradually becomes thin towards southwest beyond Mangde *Chu* valley. In Kanamakra river section it attains a thickness of about 1500m and is mainly represented by an alternating sequence of grey to greenish grey phyllite/mica schist and fine to medium grained, light grey, micaceous quartzite. Occasionally 10-20cm thick lenses of marble bands, particularly towards the upper part of the sequence, are present. A few basic sills are associated with the arenaceous unit. In this section the litho-package of the Shumar Formation is underlain and overlain by the Baxa and Jaishidanda Formations respectively.

Fig.3.7.12 Deformed cross-bedding in the quartzite of the Shumar Formation, Seri *Chu* area.

Lodrai-Sure and Sarbhang-Chirang Section : The litho-column of the Shumar Formation of the Rong *Ri* valley along the Lodrai-Sure road and in the Sarbhang *Khola* and the Loring *Khola* valleys along the Sarbhang-Chirang road are presented in

Fig.3.7.13a, b. In both these sections the lithopackages are broadly correlatable with some minor variations. The lower and middle parts are dominated by argillaceous and arenaceous sediments respectively. In the Sarbhang-Dhara *Chu* section (Fig.3.7.13b) the upper part of the Shumar Formation is dominated by mica schist with prominent quartzite bands which are occasionally gritty. Thin carbonate intercalations (1m or less) are observed towards the upper part, upper most part as well as towards the lower part of the sequence. The carbonate bands of the lower calcareous unit attain considerable thickness (7-30m) towards west on the right bank of the Rong *Ri* valley where deposits of chemical grade limestone/marble have been located. In this section (Fig.3.7.13a) gritty/conglomeratic layers within the quartzite are confined to basal and middle parts.

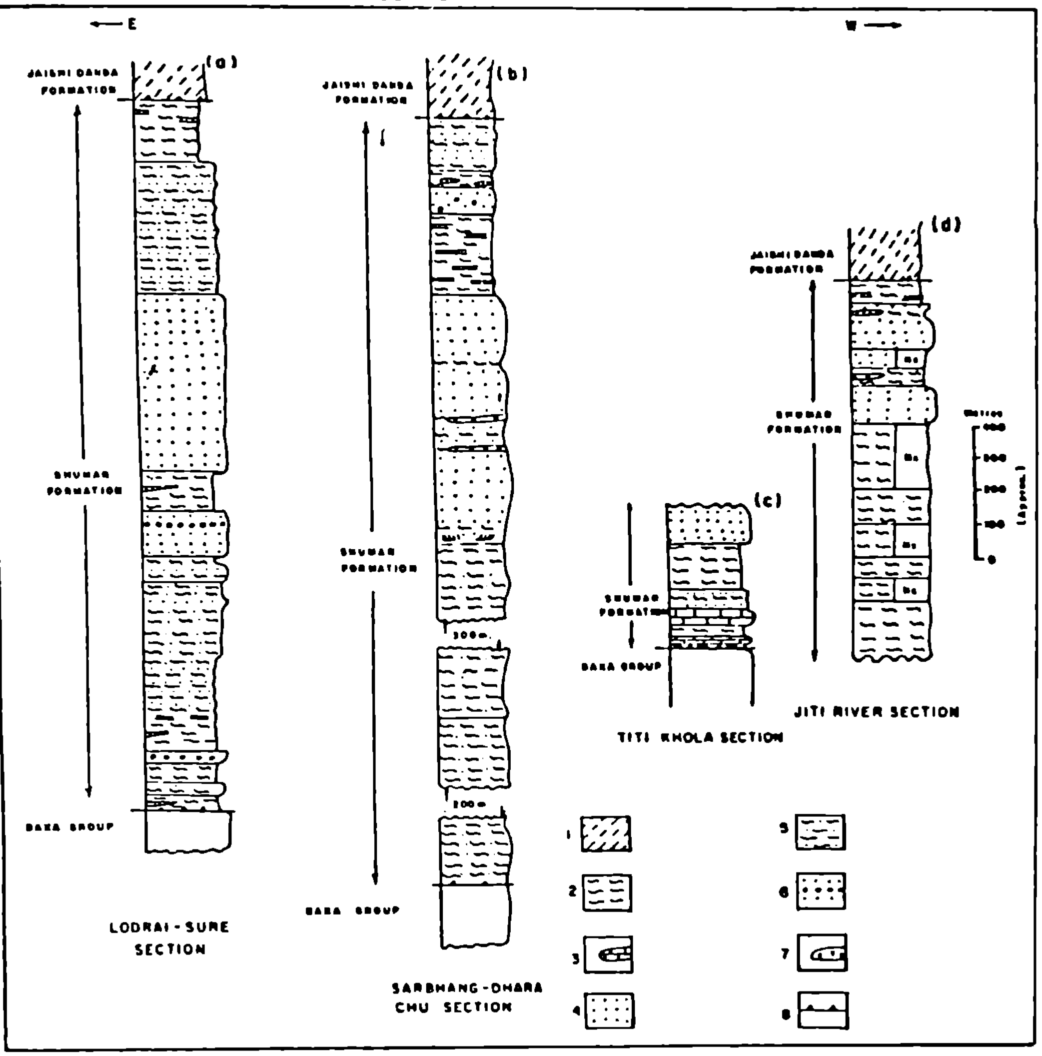

Fig.3.7.13a-d Lithocolumns of the Shumar Formation in different sections. 1. Jaishidanda Formation, 2. Mica schist/phyllite, 3. Carbonate, 4. Quartzite, 5. Micaceous quartzite, 6. Gritty-conglomeratic rock, 7. Metabasic sill, 8. Thrust.

In the Lodrai-Sure section (Fig.3.7.13a) the upper part of the sequence is also dominated by mica schist but with thin intercalations of quartzite. In this section thin carbonate bands (3-7cm) are found within the mica schist/phyllite along the

West of the above described sections, between the Sankosh and the Torsa rivers, the Shumar Formation lies over the gritty, commonly feldspathic grey phyllitic quartzite of the Baxa Group. In this area the basal part of the Shumar

Formation is represented by highly tectonised grey to greenish grey, sericite-chlorite schist with minor bands of grey, fine grained, thinly bedded micaceous quartzite. This basal unit grades upward into a thick, white to grey, medium to thinly bedded quartzitic unit with thin basic sills. Further north the upper part of the succession shows an intercalatory sequence of quartzite and mica schist which is topped by the rocks of the Jaishidanda Formation.

Titi *Khola* Section : In the western part between the Torsa and the Jaldhaka rivers, rock sequences are poorly exposed. In the Titi *Khola*, the Shumar Formation lies above a thick sequence of gritty quartzite of the Baxa Group. It commences with a thin horizon of laminated, light grey phyllite unit followed upward by two prominent bands (20m and 40m) of fine grained, thinly bedded, light grey carbonate unit, intervened by a phyllite horizon (Fig.3.7.13c)). Further north, the sequence becomes dominantly phyllitic which passes upward into an arenaceous unit. According to Sen Gupta and Raina (1978) the arenaceous unit is enormously thick and in this section grades upward into a predominantly argillite unit with intercalatory minor carbonate and quartzite, succeeded by the Jaishidanda Formation.

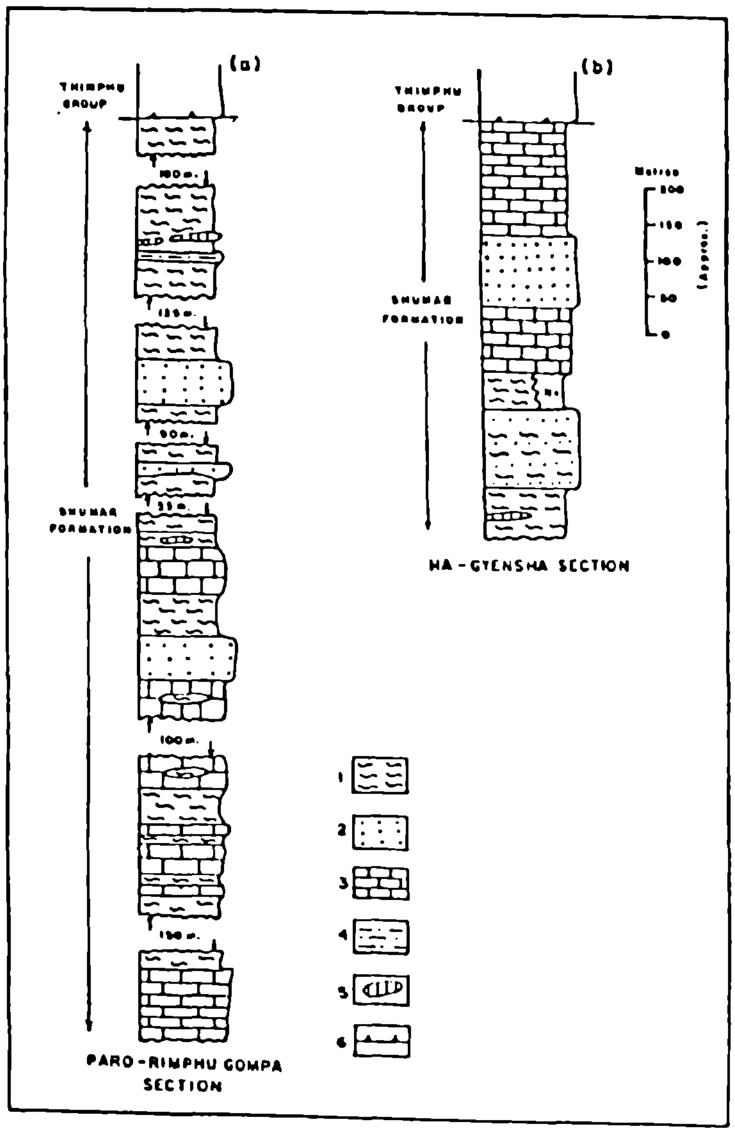

Fig.3.7.14a-b Details of the Shumar Formation in Paro (a) and Ha (b) areas. 1. Mica schist, 2. Quartzite, 3. Carbonate rock, 4. Garnetiferous calc-silicate rock. 5. Calc-silicate rock, 6. Thrust.

Jiti river Section : In the western most part along the Jiti river (Fig.3.7.13d) the lower part of the sequence is represented by poorly exposed, laminated, light grey to greenish grey phyllite within which the prominent carbonate bands of the Titi *Khola* section are absent. This phyllitic sequence is followed upwards by a quartzite dominated unit with thin intercalation of mica schist/phyllite and basic sills. The top part of this sequence is represented by mica schist with thin carbonate layers. The lower contact of the Shumar Formation in this section could not be delineated due to absence of marker gritty/conglomeratic quartzite of the Thungsing Formation.

Paro-Ha Section : As stated earlier, the northern extension of the Shumar Formation is found around Paro and Ha areas within the window zone (Plate-1). In these areas also the litho-package is mainly represented by an alternate sequence of quartzite and mica schist with prominent carbonate bands of considerable thickness (Fig. 3.7.14). Rare thin bands of calc-silicate rocks are found in this sequence. In the Chilai La area considerably thick graphite schist occurs towards the upper part of the sequence.

Contact Relation

Throughout the Lesser Himalaya, the rocks of the Shumar Formation are overlain by the lithounits belonging to the Jaishidanda Formation. However, within the 'window' zone of the Paro and the Ha areas, it is overlain by rocks of the Thimphu Group (Fig.3.7.14a, b). The exact contact between the Jaishidanda and the Shumar Formations is mostly covered; but where exposed (e.g., Yayung, Nagar Gompa and south of Dhara *Chu*) it is sharp. Along this contact evidences of intense mylonitisation are found, particularly within the rocks of the overlying Jaishidanda Formation which as discussed later, exhibit a higher grade of metamorphism than the underlying Shumar Formation. The occurrence of mylonitised rocks and higher grade of metamorphism of the Jaisidanda Formation points to a thrusted nature of the contact between these two formations. The Thimphu Group after tectonically transgressing over the Jaishidanda Formation directly rests over the Shumar Formation in the window zone along a major thrust.

In most of the sections, the Shumar Formation is underlain by the gritty, commonly feldspathic quartzite of the Baxa Group (Fig.3.7.13). In Chhiya-Moshi area along the Jiri *Chu* valley rocks of the Baxa Group and the Diuri Formation occur directly below the Shumar Formation (Ray *et al*, 1989). Occurrence of the Shumar Formation over different formations suggests a tectonic discordance along the basal contact of the Shumar Formation. This conclusion is corroborated by the presence of tectonic wedges of the Baxa rocks along the basal part of the Shumar Formation (Ray *et al*, 1989; Jangpangi, 1974). These wedges are interpreted to represent footwall elements, tectonically incorporated within the overlying Shumar Formation during its forward propagation (Ray *et al*, 1989). In the Lodrai-Sure section, the basal quartzite unit of the Shumar Formation is highly sheared and associated with thin bands of carbon phyllite. The quartzite exhibits blastomylonitic texture (Fig.3.7.15). In Tashigang section, south of Moshi well developed mylonitic texture is present within the Thungsing Formation (Fig.3.7.16). All these evidences indicate a thrusted nature of lower contact of the Shumar Formation.

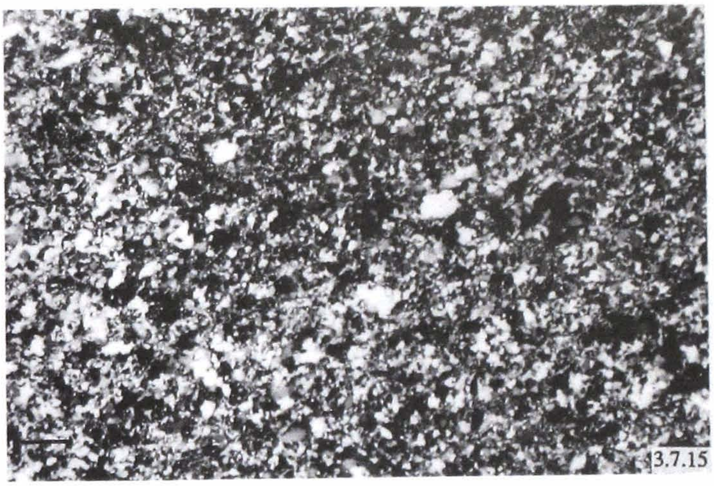
3.7.15

Fig. 3.7.15 Blastomylonite developed in the basal part of the Shumar Formation, north of Lodrai; X nicol, bar length 0.1mm.

Discussions

The Shumar Formation has maximum thickness in the east; towards west the thickness considerably thins down. The variation in thickness from east to west can be attributed to sedimentary or tectonic pinching. Regionally the thickness of all the Lesser Himalayan formations tapers from east to west and so also the more southward advancement of the Thimphu Thrust Sheet. Hence, in the present author's opinion it is the impact of the Thimphu Thrust Sheet that caused the tectonic pinching and consequent reduction in the thickness of the formaion.

In the western most sector between the Torsa and the Jaldhaka rivers the maximum southward advancement of the Thimphu Thrust Sheet has resulted in tectonic telescoping and imbrications within the Lesser Himalayan formations which have been thrown into schuppen zone. In some sections these complications coupled with poor exposures render delineation of the lower limit of the Shumar Formation difficult and have led to diverse opinions (Nautiyal *et al.* 1964; Sen Gupta and Raina, 1978). However, the synthesis of the data collected by the present author during the recent studies and also analysis of the earlier work points that the broad sequence of the Shumar Formation extends from east to the west and is overlain and underlain by rocks of the Jaishidanda Formation and the Baxa Group respectively.

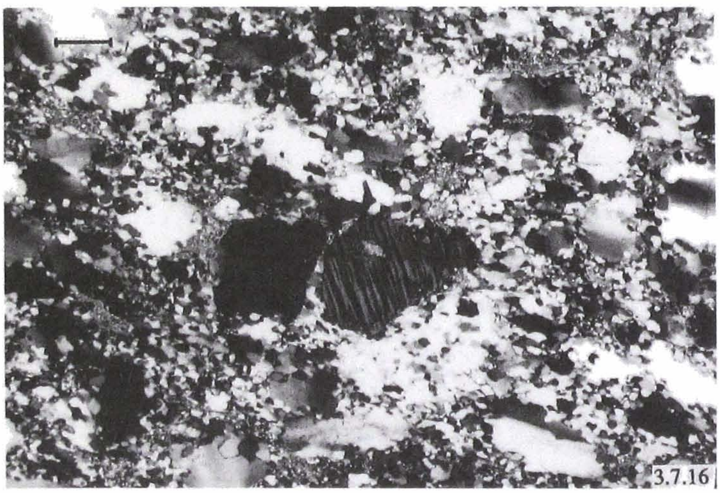

Fig. 3.7.16 Mylonitic texture within the quartzite of the Thungsing Formation. X-nicols. bar 0.1mm, Moshi.

Study of several sections reveals the following characteristic feature of the Shumar Formations.

(1) The Shumar Formation can broadly be divided into three parts ; (a) lower part dominated by phyllite and muscovite-chlorite schist with intercalatory quartzite and occasional calcareous zones, (b) middle part mainly represented by quartzite with minor mica schist intercalations and basic sills and (c) upper part mainly comprising the mica schist with interbands of quartzite with frequent carbonate beds.

(2) The sparsely developed conglomeratic/ gritty lenses within the Shumar Formation are oligomictic type and sporadically autoclastic in nature.

(3) Incidence of base metal mineralisation is mainly of copper and rarely of lead-zinc.

(4) Besides bedding, the rare sedimentary structure is solitary type cross-bedding.

(5) The mylonitised granite gneisses within the Shumar Formation are considered as tectonic slivers of the footwall elements, accreted during it's forward propagation (Ray *et al*, 1989). The concordant sheet-like bodies of the granite gneiss exhibit sharp contact with the enveloping mica schist of the Shumar Formation. The sharpness of the contact, highly mylonitised nature, absence of any contact effect as well as of granite apophyses within the adjoining schist confirms that these granite gneisses represent tectonically emplaced slivers within the Shumar Formation.

(6) Gypsum beds, reported only from Shumar and Kuru *Chu* valley areas, are lenticular bodies which occur at different levels particularly within the upper part of the sequence. The presence of the gypsum beds at different levels as well as their restricted occurrence in a small part of the belt, make it rather difficult to consider

them as part of the Shumar Formation. The alternative that they too are tectonically emplaced wedges may be considered.

Considering the litho-assemblages and tectono-stratigraphic position, the Shumar Formation can be correlated with the Garubathan Formation of the Sikkim-Darjeeling area. Like the former, the latter is also characterised by the incidence of Cu-Pb-Zn mineralisation as well as by the occurrence of mylonitised granite gneisses. Sen Gupta and Raina (1978) correlated the Lesser Himalayan litho-assemblage below the Thimphu 'Formation' between the Torsa and Jaldhaka rivers with that of the Daling/Baxa Groups, assuming the rocks of the area to be in strike continuation of rocks of the Buxa Duar and the Daling *Chu*. Correlation of the Shumar Formation with that of Daling Group has also been favoured by several workers (Nautiyal *et al*, 1964; Guha Sarkar, 1979; Gansser, 1983). Jangpangi (1989), Ray (1989) and Acharyya (1989) considered the Shumar Formation same as the Garubathan Formation of the Darjeeling-Sikkim Himalaya. The Garubathan Formation is further correlated with the Tenga Formation of Arunachal Pradesh (Acharyya, 1989).

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3.8 JAISHIDANDA FORMATION

S. Dasgupta

In the east from Shumar-Kuru *Chu* sector to the west in Torsa-Jaldhaka sector, an almost persistent package of metasedimentary rocks, constituted of garnetiferous mica schist with intercalations of micaceous quartzite, rare carbonate bands and occasional lenses of carbonaceous schist, occurs below the Thimphu Group (Fig.3.7.1). Difference of opinion prevails among the earlier workers about the status of this litho-package. Some of the workers considered this litho-package as part of the overlying Thimphu Group (Jangpangi, 1974; Sen Gupta and Raina, 1978; Trichal and Jayaram, 1989), while others included this sequence within the underlying Shumar Formation (Guha Sarkar, 1979; Ray *et al*, 1989). The present study suggests that lithologically this metasedimentary package is broadly akin to the rocks of the underlying Shumar Formation. However, the distinct metamorphic and deformational (mylonitised) nature as well as persistent regional occurrence at a particular tectono-stratigraphic level (Fig. 3.7.1), led to differentiate this litho-package from the underlying and overlying formations. Hence, a formational status is accorded to this litho-package which is being designated as the Jaishidanda Formation after the Jaishidanda village where it shows best development.

Besides being exposed along the sub-thrust side of the Thimphu Group in the Lesser Himalayan belt, a metasedimentary sequence similar to that of the Jaishidanda Formation crops out in the west-central Bhutan over a considerable aerial extent within the window zones around Bunakha-Simtokha, Sambe Dzong, Getta Dzong, Duna Dzong and Chukha along the Wang *Chu* and Amo *Chu* valleys (Fig.3.7.2). The earlier as well as the present views about the status of the metasedimentary sequence below the Thimphu Group in the window zones have been discussed in Chapter 3.7.

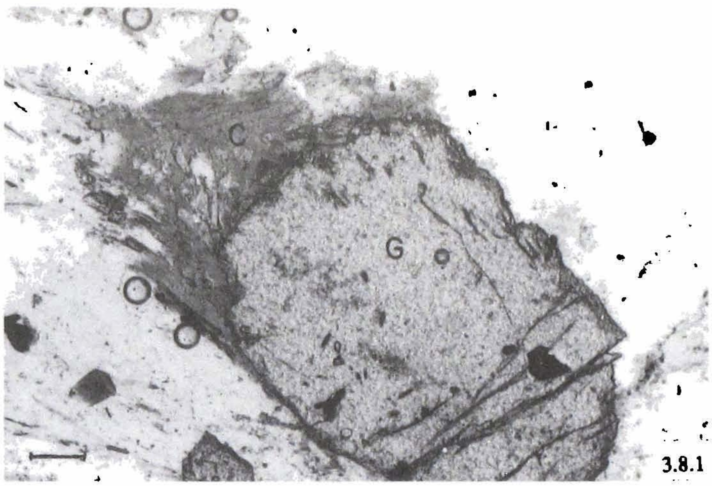

Fig. 3.8.1 Chlorite (C) formed along the peripheral part of garnet porphyroblast (G) with little irregularly oriented inclusions, within the garnetiferous mica schist of the Jaishidanda Formation; bar length 0.05mm; Near Yayung village.

Fig. 3.8.2 Garnet (G) and Staurolite (S) grains within the garnetiferous mica schist of the Jaishidanda Formation; bar length 0.2mm; Near Yayung village.

Type Section

The type section of the Jaishidanda Formation is exposed east and south-east of the Jaishidanda village along the Rong *Ri* valley and Geylegphug-Tongsa road (between 24-27km stone). Another well developed section can be studied on the Sarbhang-Chirang road (21-23km stone). Besides, this formation can be seen in several other sections out of which the Kuru *Chu*, Wang *Chu* and Jiti river sections are worth mentioning.

Lithological Details

The Jaishidanda Formation is mainly constituted of garnetiferous mica schist with intercalations of micaceous quartzite. Occasionally thin lenses of carbonaceous schist are also present. Carbonate and calc-silicate bands are found only in a few sections. Concordant sheet-like bodies of mylonitised granite gneiss are common within this sequence.

Garnetiferous mica schist which forms the main bulk of the sequence is medium to coarse grained, light to dark grey and well foliated. Frequently this litho-unit is found to be highly sheared, imparting a phyllonitic appearance to the rock. At many places, development of S-C fabric is discernible even in hand specimen. Quartz veins, commonly in the form of sigmoidal lenticles, frequently traverse this unit. In some areas (e.g. south of Sure, west of Lobanakha and Sheme Gompa) kyanite is sporadically associated with quartz veins. The main mineral constituents of the mica schist are quartz, muscovite, biotite and garnet. Muscovite flakes are commonly larger in size and more abundant compared to biotite. Elongation of phyllosilicate minerals mainly defines the schistosity, however, in some samples irregularly oriented phyllosilicate flakes are also present. Chlorite is rare and is mainly present as irregular patches, particularly along the peripheral part of the garnet grains (Fig.3.8.1). Rare staurolite grains are present (Fig.3.8.2).

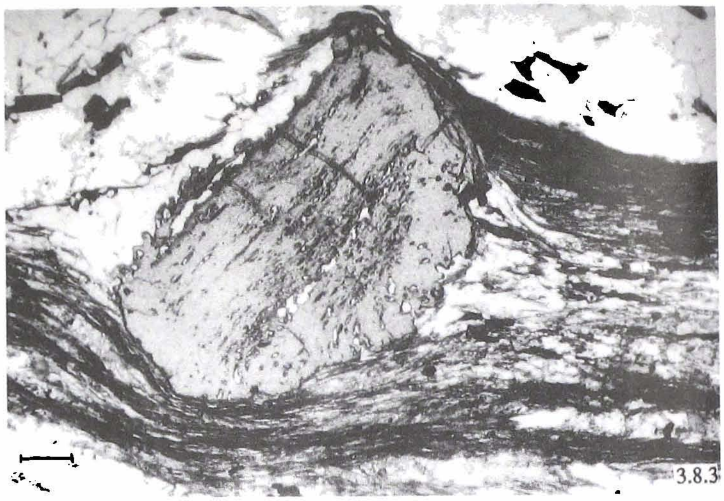

Fig. 3.8.3 Garnet porphyroblast with linear inclusion trail, making an angle with the outer schistosity; garnetiferous mica schist of the Jaishidanda Formation; bar length 0.05mm; Near Jaishidanda village.

Accessories include apatite, tourmaline and opaques with rare feldspar grains. Within the mica schist, garnet commonly occurs as porphyroblasts and rarely as smaller grains. Some of the garnet

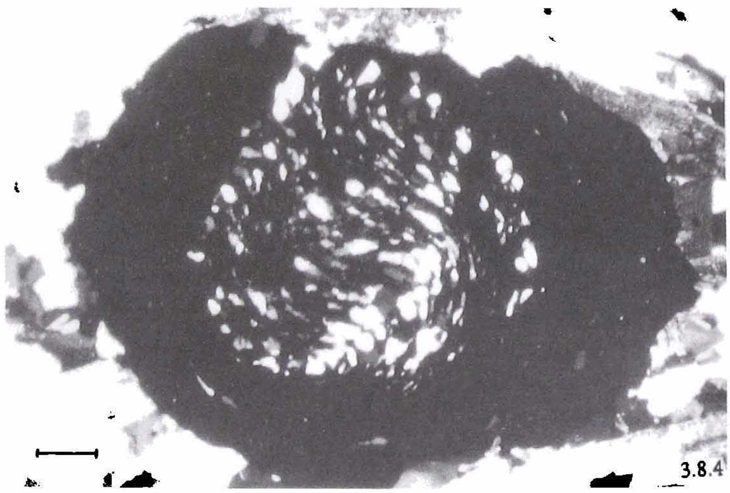

Fig. 3.8.4 Garnet porphyroblast with sigmoidal inclusion trail; from garnetiferous mica schist of the Jaishidanda Formation; bar length 0.05mm; x nicol; from Bunakha area.

porphyroblasts contain no or little oriented inclusions (Fig.3.8.1), while in others, inclusions commonly exhibit different trail patterns

(Fig.3.8.3-6). Some of these grains have inclusion-rich core and almost inclusion-free outer rim (Fig.3.8.7). The details of the micro-textural features of the garnet grains and their temporal relation with respect to the deformational history are discussed in the Chapter 5.3. At a few places thin (1m or even less) concordant amphibolite bodies are found within the mica schist.

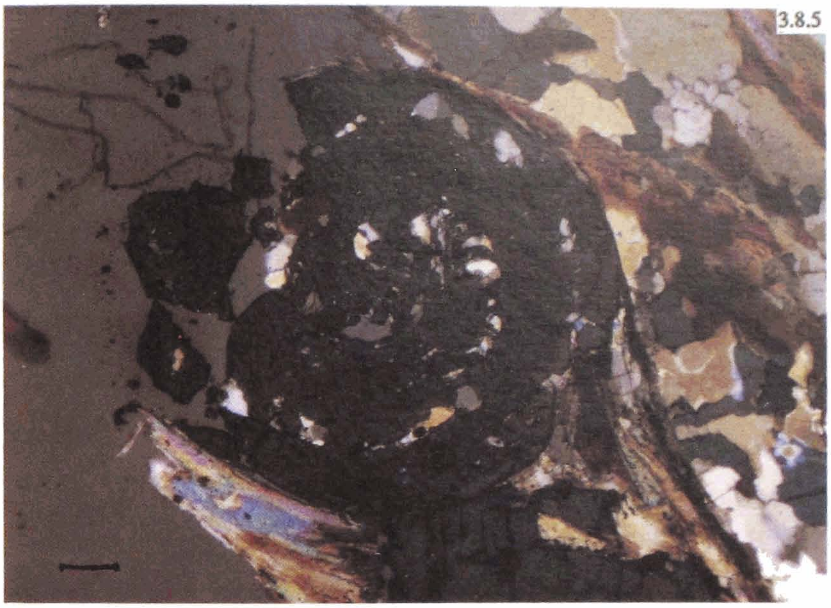

Fig. 3.8.5 Garnet porphyroblast with double spiral inclusion trail; from garnetiferous mica schist of the Jaishidanda Formation; bar length 0.05mm; partially x nicol; from Bunakha area.

Micaceous quartzite commonly occurs as intercalatory bands within the garnetiferous mica schist. The quartzite is medium grained, greyish white and thinly bedded. Colour bands, defining the bedding, are conspicuous and commonly associated with bedding joints. Rare occurrence of solitary cross-bedding is observed. The dominant mineral constituents are quartz, muscovite and comparatively rare biotite. Accessories include tourmaline and opaques. However, within the calcareous zone in addition, carbonate and epidote grains are found. With the increase in phyllosilicate component, this quartzitic unit commonly grades into mica schist.

Close association of carbonate and calc-silicate units is common and the former is mainly represented by medium to coarse grained, thinly bedded grey to greyish white coloured limestone/ marble. Well developed colour bands are particularly observed around Chapcha and Gidakom areas. In Tamchhey Gompa area in the Paro *Chu* valley, lenticular bodies of yellow marble are found within grey to greyish white variety. Occasionally within the impure zones banding is defined by alternation of carbonate and

Fig. 3.8.6 Garnet porphyroblast with simple spiral inclusion trail; from garnetiferous mica schist of the Jaishidanda Formation; bar length 0.05mm; partially x nicol; from Bunakha area.

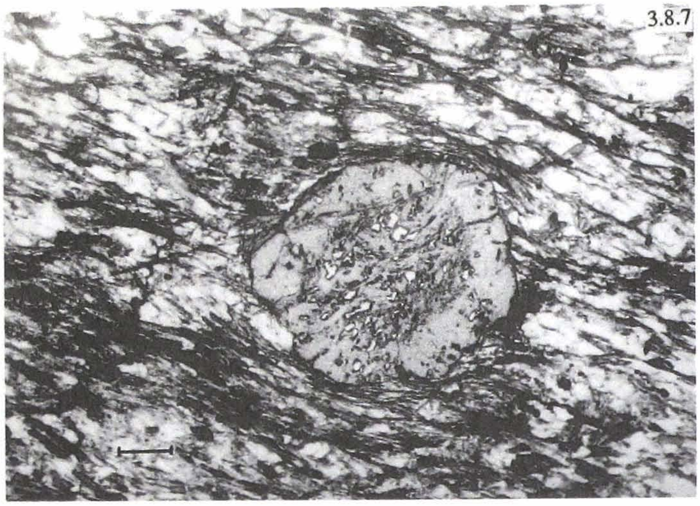

Fig. 3.8.7 Garnet porphyroblast with inclusion-rich core and almost inclusion-free outer rim, within the garnetiferous mica schist of the Jaishidanda Formation; bar length 0.1mm; near Yayung village.

hornblende-epidote rich layers. Main mineralogical constituents of the limestone/marble are carbonate and little quartz with a few muscovite flakes. Biotite is rare. Accessories include apatite and opaques. Incidence of base metal (mainly Pb-Zn) associated with the carbonate unit is known from several localities (e.g. Gidakom, Jemina and Genekha). Within the calc-silicate unit colour banding is excellently developed. This banding is defined commonly by amphibole and carbonate quartz rich layers. However, at places epidote as well as garnet (grossular variety) form rich layers and thin lenticular pockets. Dominant minerals are tremolite/actinolite, epidote, biotite, carbonate and quartz. Incidence of tungsten and copper mineralisation is found in Bhur*khola* and Dholpani areas within the calc-silicate rocks.

Concordant, sheet-like bodies of mylonitised granite gneiss are common within this formation. Thickness of these bodies generally varies between 5m-50m. However north of Chuzom (confluence between the Paro *Chu* and the Wang *Chu*) one such body attains a thickness of about 100m. The granite gneiss exhibits sharp and highly sheared contact with the enveloping garnetiferous mica schist (Fig.3.8.8). No thermal effect and apophyses are observed within the adjoining country rocks. Phyllonitic rock is almost invariably present along the contact of these gneisses. At several localities, particularly along the Lodrai-Sure and Sarbhang-Dhara *Chu* sections, a distinct reduction in size and number of augen related to the intensity of deformation is found towards the margin of the granite bodies. In other words the granite with protomylonitic texture gradually becomes mylonitic towards its margin.

The granite gneiss is highly deformed and is protomylonitic to mylonitic type. The dominant minerals are quartz, K-feldspar, plagioclase, muscovite and biotite. Epidote, apatite, tourmaline and opaques constitute the main bulk of the accessories. Occasionally larger feldspar grains

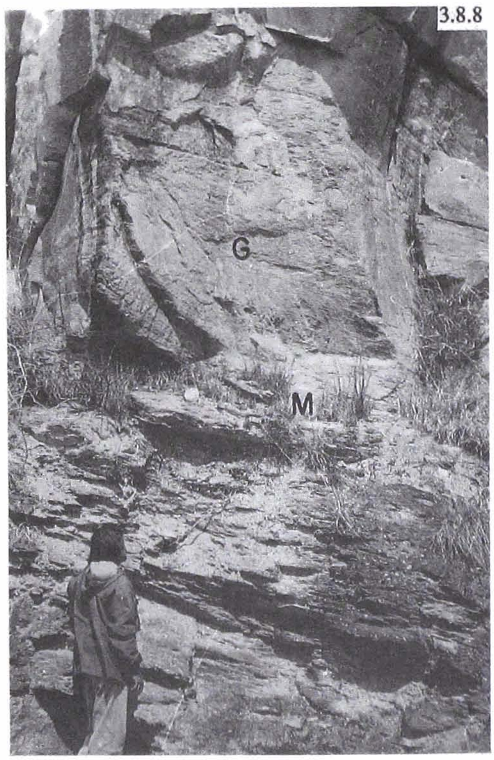

Fig. 3.8.8 Sharp contact between the granite gneiss (G) and the enveloping garnetiferous mica schist (M) of the Jaishidanda Formation; south of Pareen village in the Wang *Chu* valley.

exhibit myrmekitic intergrowth. Effect of strong post crystalline deformation is indicated by strain shadows, undulose extinction and replacement of larger quartz grains by small, strain free grains. In some sections bands of small, strain free grains alternate with comparatively larger quartz grains which are invariably elongated parallel to the mylonitic foliation. Porphyroclasts, defining augen, are commonly made up of aggregate or single feldspar grains which are set in a fine grained quartzo-feldspathic ground mass. Asymmetric pressure trails are commonly found around the augen. The lithological variation and the local details of the Jaishidanda Formation in important sections are given below.

In the Kuru *Chu*-Seri *Chu* valleys of the eastern section the Jaishidanda Formation has been studied at (i) Yayung-Seri *Chu*, (ii) Lhuntsi and (iii) Lingmethang-Nagar Gompa sections (Fig.3.8.9), where the thickness is considerably reduced compared to the western sectors. In the Lhuntsi section this formation attains a thickness of about 150m, while in Lingmethang-Nagar Gompa and Yayung-Seri *Chu* sections the thickness is 100m and 25m respectively. In all the

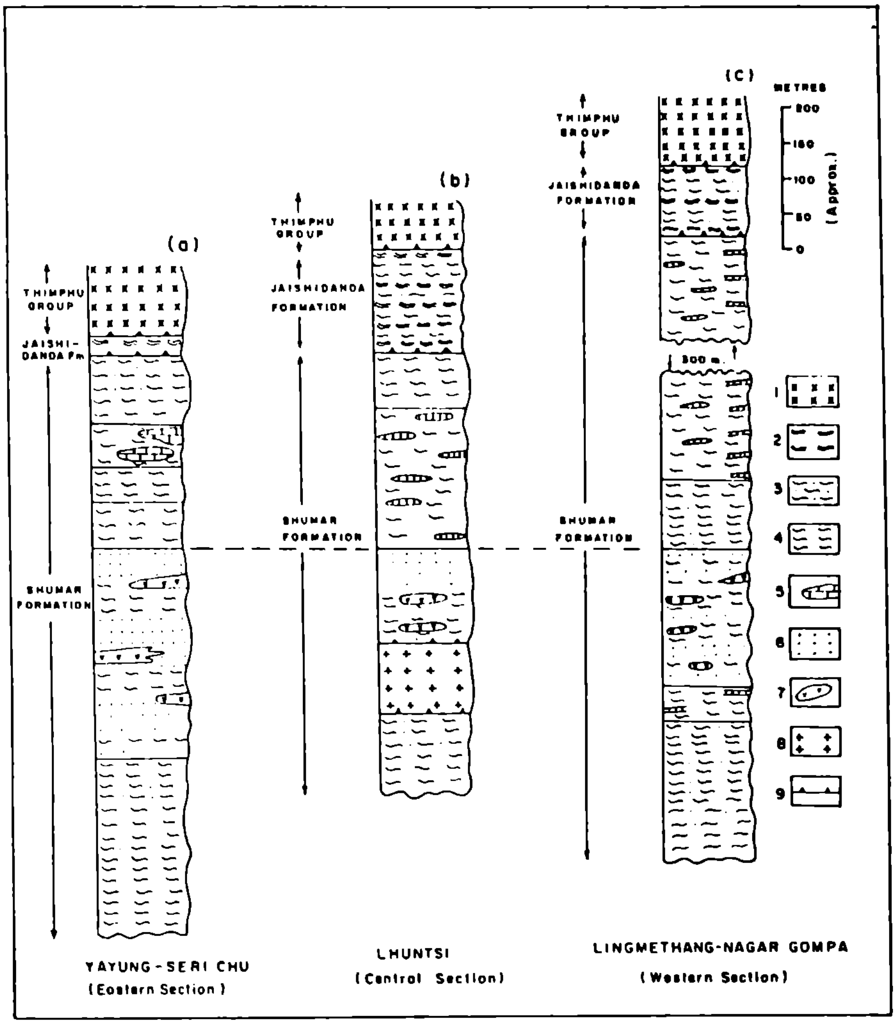

Fig. 3.8.9 Lithological details of the Jaishidanda Formation along with the overlying and underlying Thimphu Group and Shumar Formation respectively. 1. Granite gneiss, 2. Garnetiferous mica schist, 3. Thinly bedded micaceous quartzite, 4. Mica schist/phyllite, 5. Carbonate rock, 6. Medium bedded quartzite, 7. Meta-basic sill, 8. Mylonitised granite gneiss, 9. Thrust.

three sections the Jaishidanda Formation is represented by garnetiferous mica schist with intercalations of micaceous quartzite.

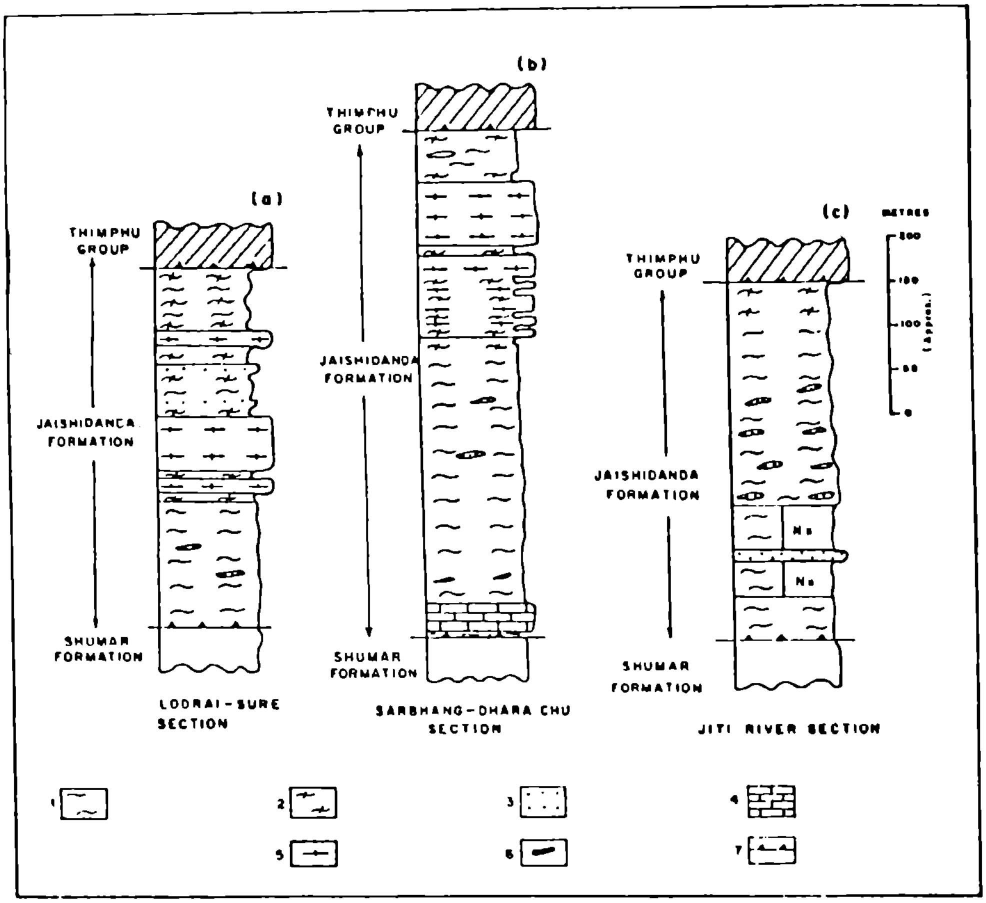

Fig. 3.8.10 Lithological details of the Jaishidanda Formation in different sections. 1. Garnetiferous mica schist, 2. Phyllonite, 3. Micaceous quartzite, 4. Carbonate rock, 5. Mylonitised granite gneiss, 6. Carbonaceous schist, 7. Thrust.

Towards west in the Mangde *Chu* valley, the presence of this formation is reported by Guha Sarkar (1979) according to whom the garnetiferous mica schist is intensely sheared as compared to the underlying rocks of the Shumar Formation. Garnet with `snow-ball' texture are observed within this litho-package.

In the south-central Bhutan, south-east of Jaishidanda village (type area) along Lodrai-Sure road and in Sarbhang *Khola* and Loring *Khola* valleys along the Sarbhang-Chirang road litho-columns of the Jaishidanda Formation have recently been studied in detail (Fig.3.8.10). In both the sections the litho-packages are broadly similar and are characterised by common presence of phyllonite and thin concordant sheet-like bodies of mylonitised granite gneiss (Fig. 3.8.11). In Lodrai-Sure section (Fig.3.8.10a) the Jaishidanda Formation attains a thickness of about 400m, while in Sarbhang-Dhara *Chu* section (Fig.3.8.10b) the thickness is around 550m. In the latter section a thick carbonate band crops out along the basal part of this litho-package. Similar litho-package with bands of mylonitised granite gneiss is also present in the intervening Bhur *Khola*-Dholpani area where calc-silicate and carbonate bands are present (Trichal and Jayaram, 1989). Incidence of tungsten and copper mineralisations, associated with the rocks of this formation are known from this area.

Further west between the Sankosh and the Jaldhaka rivers, just below the Thimphu Group, Singh and Krishna Murthy (1963) have traced a similar 150-500m thick litho-package, constituted

Fig. 3.8.11 Sharp contact between the granite gneiss (G) and the enveloping garnetiferous mica schist (M) of the Jaishidanda Formation; between 24-23km stone along Lodrai-Sure road.

of medium to coarse grained, dark grey garnetiferous mica schist with subordinate intercalations of grey, thinly bedded micaceous quartzite. They have also reported frequent development of mylonitic rocks from this sequence.

From the south-western most sector, between the Torsa and the Jaldhaka rivers also identical litho-package is reported (Sen Gupta and Raina, 1978). In the Jiti river section (Fig.3.8.10c) the Jaishidanda Formation is represented by garnetiferous mica schist with subordinate intercalations of micaceous quartzite. Phyllonitic rocks are developed in the upper part of the sequence. The thickness of this sequence is around 400m.

As mentioned earlier, the northern extension of the Jaishidanda Formation is found within the window zones around Bunakha-Simtokha, Getta Dzong, Duna Dzong, Sambe Dzong and Chukha areas. The litho-package exposed between Chuzom and Simtokha (Fig.3.8.12) resembles that of the above described Lesser Himalayan sections and is also characterised by the frequent presence of phyllonite, concordant bands of mylonitised granite gneiss and incidence of base metal mineralisation. However, unlike its Lesser Himalayan counterparts, considerable thickness of carbonate and calc-silicate bands are present in this section. Similar metasedimentary assemblage, constituting mainly of garnetiferous mica schist with intercalatory micaceous quartzite, carbonate and calc-silicate rocks are reported by Sahai (1964) from the window zones around the remaining areas also.

Contact Relations

Rocks of the Jaishidanda Formation are overlain by the litho-units of the Thimphu Group. The

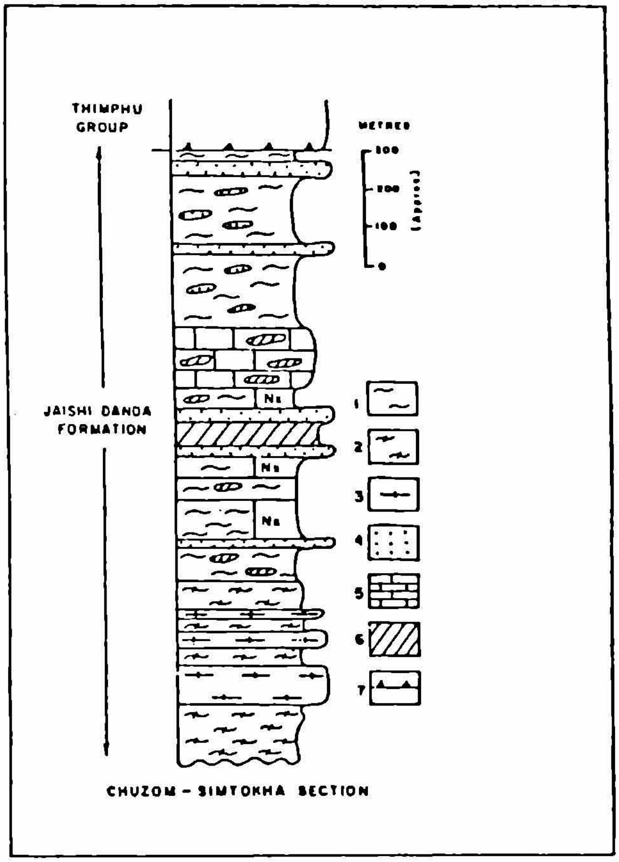

Fig. 3.8.12 Lithological details of the Jaishidanda Formation along Wang *Chu*-Paro *Chu* confluence to Simtokha section. 1. Garnetiferous mica schist, 2. Phyllonite, 3. Mylonitised granite gneiss, 4. Micaceous quartzite, 5. Carbonate rock, 6. Calc-silicate rock, 7. Thrust.

exact contact between the Jaishidanda Formation and the Thimphu Group seen only in a few sections (e.g. Yayung, Chumithangka and Taktechu areas) is sharp (Fig.3.8.13-14). Jangpangi (1974) and Guha Sarkar (1979) reported highly tectonised rock units along this contact. Sen Gupta and Raina, (1978) and Singh and Krishna Murthy, (1963) reported occurrence of thin discontinuous bands of augen gneiss, found to be protomylonite along the basal part of the Thimphu Group. During the present study thin bands of mylonitic/phyllonitic rocks have been located in the Kuru *Chu*-Seri *Chu* area as well as in the Lodrai-Sure, Sarbhang-Dhara *Chu* and Jiti river sections (Fig.3.8.9-10). There is a sharp change in the grade of metamorphism across the Jaishidanda-Thimphu contact. The mineral assemblage within the underlying Jaishidanda Formation represents considerably lower grade of metamorphism compared to the immediately overlying Thimphu Group. All these evidences point to a thrusted nature of the contact between the Jaishidanda Formation and the Thimphu Group. Earlier workers (Nautiyal *et al*, 1964; Jangpangi, 1974; Gansser, 1983; Ray *et al*, 1989) have also expressed similar views.

The Jaishidanda Formation is underlain by the rocks of the Shumar Formation along a thrusted contact.

Discussion

The thickness of the Jaishidanda Formation varies in different sections of the Lesser Himalaya. Its maximum thickness is exposed within the window zone around Bunakha-Chapcha-Simtokha areas. The reduction in thickness in the Lesser Himalaya might have been caused due to tectonic telescoping.

Carbonate facies in the Jaishidanda Formation is dominant within the sequence of the window zones as compared to the sequence exposed in the Lesser Himalaya where it is restricted to the Bhurkhola and adjoining sections. This probably indicates that the package of the window sections represents relatively deeper water facies compared to the Lesser Himalayan sequence.

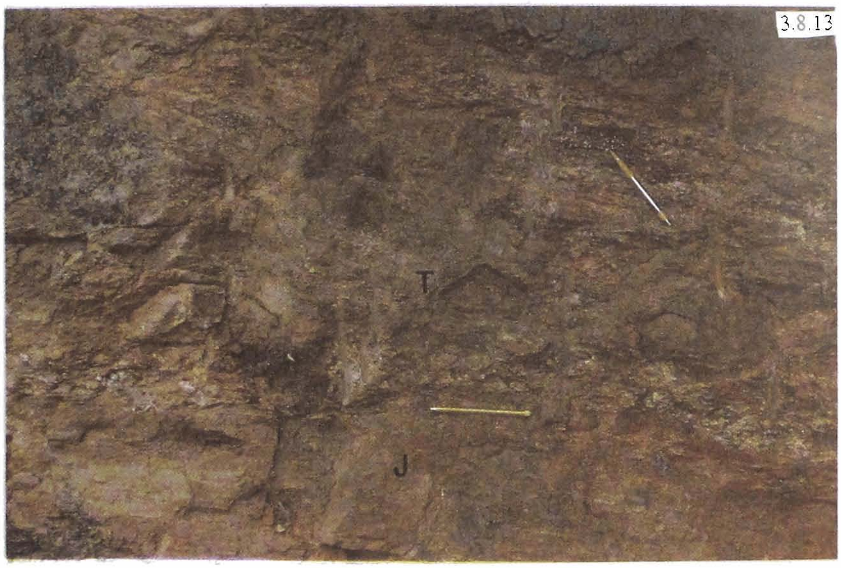

Fig. 3.8.13 Sharp contact between the granitoid gneiss (T) of the Thimphu Group and micaceous quartzite (J) of the Jaishidanda Formation. Near Chumithangka in Rong *Chu* valley.

The sequence of the Jaishidanda Formation is characterised by the incidence of tungsten and base metal mineralisation, commonly of Pb-Zn and rarely of Cu. Both in the Lesser Himalaya as well as in window sections, frequent presence of phyllonite and concordant sheet-like bodies of mylonitised granite gneiss is noted. The gneiss exhibits sharp contact with enveloping mica schist of the Jaishidanda Formation. The sharp contact, highly mylonitised nature and absence of any contact effect within the adjoining mica schist suggests the gneiss bodies to be tectonically emplaced slivers within the metasedimentary package of the Jaishidanda Formation.

The highly tectonised nature of the rock units, presence of several tectonic slivers of granite gneiss and the higher grade of metamorphism compared to the underlying overlies the topmost level of the Garubathan Formation and underlies the gneissic formation of Sikkim Group in the Darjeeling-Sikkim Himalaya (Acharyya, 1989). Considering the tectono-

Fig. 3.8.14 Sharp contact between the granitoid gneiss (T) of the Thimphu Group and the intercalatory sequence of garnetiferous mica schist and quartzite of the Jaishidanda Formation (J). On the road section near Taktechu.

Shumar Formation indicate that the Jaishidanda Formation represent either an allochthonus mass tectonically brought on to its present position or a litho-package of the tectonic imbrication zone, developed along the Thimphu Thrust.

A persistent belt of litho-package, constituted of mylonitic granite gneiss and phyllonitic schist stratigraphic position as well as gross lithology, intense deformation and grade of metamorphism, the Jaishidanda Formation may be correlated with the afore-said package forming part of the Chunthang Subgroup (cf. Ray, 1989) of the Darjeeling-Sikkim Himalaya.

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3.9 THIMPHU GROUP

P.R. Golani

Crystalline rocks comprising garnet, kyanite, sillimanite paragneiss, schist and flaggy quartzite with basic and igneous intrusions, occurring as a thrust sheet were described by Nautiyal *et al*, (1964) as the Thimphu Series after the capital of Bhutan. Subsequently the term `Series' was replaced by formation by Jangpangi (1978). Gansser (1983) preferred to describe the Central Crystallines as Frontal Crystalline thrust masses and Northern Crystalline units. In the present write-up, the crystalline rocks are referred to as the Thimphu Group. Its formations have been delineated on the basis of sections visited by the present author and the details available in various reports.

northern crystalline units by Gansser, 1983) and (2) sequence of coarsely crystalline marbles, calc-silicate rocks interstratified with garnetiferous mica schists and quartzite referred to as the Paro `Group' of rocks. Despite its distinct tectonic and stratigraphic status recognised first by Nautiyal *et al*, (1964), the Paro rocks were tentatively grouped with the Thimphu sequence. Subsequent studies by Jangpangi (1978) indicated that the Paro rocks could be a metamorphosed anologue of the Baxa Group. Based on the structural, lithological and metamorphic aspects, these rocks have been interpreted to be extension of the Shumar Formation below the Thimphu Thrust Sheet, now exposed in the windows (Dasgupta *et al*, 1994). Gansser (1983) extended this term to

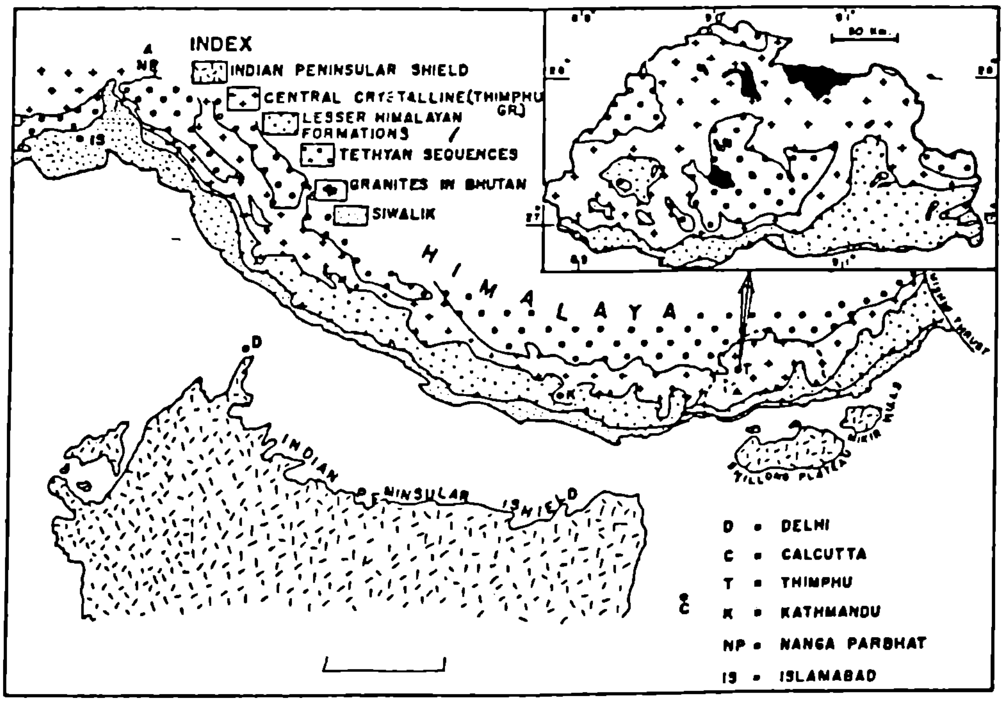


Fig.3.9.1 Generalised geological map of Bhutan Himalaya, showing spatial distribution of the Thimphu Group.

Lithostratigraphic Subdivisions

The crystalline rocks have been generally divided into two groups (1) Gneiss dominated Thimphu Formation *sensu stricto* - Thimphu Series of Nautiyal *et al*, (1964) (= frontal and various types of metasediments occurring within and above the gneiss with little stratigraphic relevance. From his Paro `rocks' of the Black Mountain, fossils have been recovered (Chaturvedi *et al*, 1983). In the present write-up thus only the gneiss and the intimately associated high grade schist are considered to constitute the Thimphu Group.

Gansser (1983) though did not delineate on map, made metamorphic distinction within the gneisses when he used the term Takhtsang for sillimanite bearing biotite garnet-muscovite gneiss in central and northern Bhutan to differentiate it from other gneisses. However, he emphasised more on the presence of sillimanite rather than disappearance of muscovite (Gansser, 1983, pp.98-99) which signifies attainment of the sillimanite facies of metamorphism.

Distribution Pattern

The crystalline rocks of the Thimphu Group occupy a wide expanse covering about two third of the total area of Bhutan (Fig.3.9.1).

Between the Wang *Chu* and Amo *Chu* sections and further to the west, the Thimphu Thrust Sheet has moved far too south close to the Indian Shield, thereby reducing the width of the Lesser Himalayan metasediments to about 10km in certain sections (e.g. Phuntsholing-Kamji and Geylegphug-Sure stretches). East of Geylegphug, the contact between the metasediments and crystallines has receded about 70km towards north due to deep erosion of crystallines along the Kuru dome. Further east, the Thimphu Group extends into Arunachal Pradesh.

Contact Relationship

The Thimphu Group has been identified as an allochthonous mass that has been thrusted over the little metamorphosed metasediments of the Lesser Himalaya (Nautiyal *et al*, 1964).

The thrust along which the crystallines have moved is designated as the Thimphu Thrust (= Main Central Thrust) in Bhutan. It is believed to demarcate the southern limit of the Thimphu Group. The detailed studies of various sections viz. Phuntsholing-Kamji, Sarbhang-Chirang, Geylegphug-Sure and Samdrup Jongkhar-Tashigang reveal that the Thimphu Thrust is not a single sharp tectonic plane. Several tectonic slices of deformed granite and gneiss which occur at different structural levels could be the manifestation of this thrust system. The lower contact of the Thimphu Group is placed at locales where the gneiss occurs in overwhelmingly large proportions. In the section between the Wang *Chu* and Torsa and also to the further west, augen gneiss (protomylonitic) occurs as impersistent layers upto 150m thick in the immediate north of the Thimphu Thrust.

In contrast to the lower tectonic contact marked by the Thimphu Thrust, its upper contact is demarcated by the overlying low grade metasedimentary rocks referred to as the Chekha Formation. The contact between rocks of the Thimphu Group and the Chekha Formation is variously interpreted as conformable (Jangpangi, 1978), disconformable and unconformable (Guha Sarkar, 1979). In the Black Mountain region, Chaturvedi *et al*, (1983) considered biotite porphyroblast bearing rocks of the Chekha Formation to grade downward into the Thimphu Group. A disconformable contact is reported from the south-west of Shemgang near Chaplekhola, near the confluence of the Buri *Chu* and the Sankosh River, on Chirang-Wangdi Phodrang road and also near Bachham in the north of Tashigang.

Unconformable nature of contact between the Thimphu Group and the Chekha Formation is reported in the lower reaches of the Mangde *Chu* valley near Zurfai village where basal conglomerate bed of the Chekha Formation overlies the biotite gneiss of the Thimphu Group (Guha Sarkar, 1979). The metamorphic discordance between the Thimphu and the Chekha rocks is evident in the Chekha type locality where sillimanite-garnet bearing gneiss (Takhtsang gneisses of Gansser, 1983) is overlain by biotite porphyroblast bearing phyllite and quartzite of the Chekha Formation. This metamorphic gap is pronounced in Gurpola area in northern Bumthang, where muscovite-free sillimanite-garnet±spinel bearing gneiss is overlain by the Chekha quartzose phyllite. Regionally the Thimphu Group has been found to have a disconformable relationship with the overlying Chekha Formation. This disconformable contact has been locally tectonised in Samte-Cholling section as a result biotite gneiss rides over the Chekha rocks along a reverse fault (Guha Sarkar, 1979). About two kilometers north-east of Shemgang, a 20m thick mylonitised slice of biotite gneiss occurs within the biotite porphyroblast bearing phyllite of the Chekha Formation.

The Takhtsang and Naspe Formations are separated from each other by the Takhtsang Thrust which has been identified at Khakthang, Chephu and Takhtsang in the Chomkha *Chu*, Mo *Chu* and Paro *Chu* sections. Similar setting exists at Tashiyangtse and probably also in the immediate north of Lhuntshi. The thrust zone is wide at Chephu and Tashiyangtse while at Khakthang it is represented by 100m thick zone of granite gneiss phyllonite. The contact between the Naspe Formation and the underlying Sure Formation is generally concealed. These formations have regional persistence.

Table 3.9.1 : Lithostratigraphic subdivisions of the Thimphu Group

Takhtsang Formation	Biotite granite gneisses. A true migmatitic sequence characterised by frequent occurrence of sillimanite-garnet in the biotite gneiss occurring in the northern Bhutan. Subordinate layers of muscovite gneiss.
---------------------- Takhtsang Thrust ----------------------	
Naspe Formation	A graphite bearing metapelite-marble lithopack with or without gneiss.
Sure Formation	A two mica granite gneiss dominated lithoassemblage widespread in central and southern Bhutan with medium to high grade schist often containing garnet and kyanite. Sillimanite is rare.

Based on the present surveys in the upper catchment areas of the Ha, Paro, Mo and Chamkha rivers and information available in various reports dealing with the Central Crystallines, the Thimphu Group in the present work has been divided into Sure, Naspe and Takhtsang Formations (Table 3.9.1). There is a perceptible increase in the metamorphic grade from south to north.

Sure Formation : A sequence of granite gneiss and schist constituting the basal part of the Thimphu Group has been delineated as the Sure

Fig.3.9.2 Granitoid gneiss of the Sure Formation (right half) tectonically juxtaposed with the rocks of the Jaishidanda Formation (left half). Near Yayung village, the Tashigang-Seri *Chu* road.

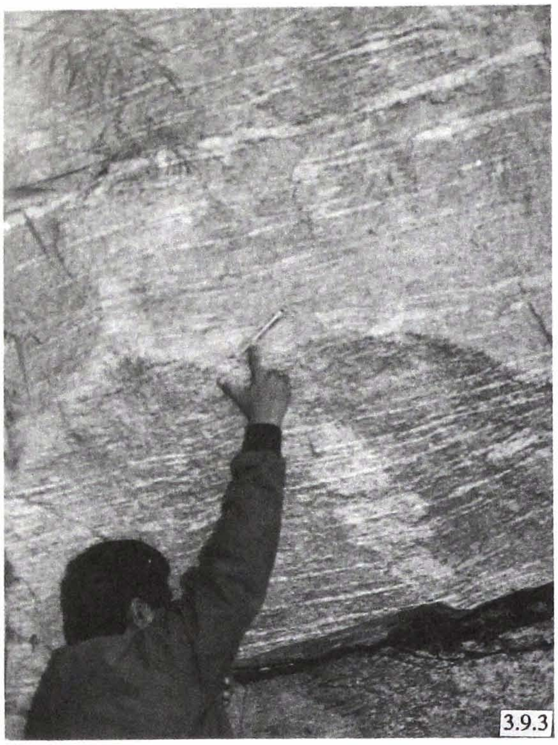


Fig. 3.9.3 Granitoid gneiss of the Sure Formation from the type locality.

Formation after a village situated in the Sarbhang district. The basal part of this formation is marked by the Thimphu Thrust. Of all the three subdivisions of the Thimphu Group, the Sure Formation is by far the most widespread. In Geylegphug-Shemgang road section, the Sure Formation commences with the gneiss tectonically juxtaposed with the garnet mica schist of the Jaishidanda Formation (Fig. 3.9.2). The Sure Formation forming a massif crops out near type locality (Fig.3.9.3).

The total gneissic component in the Sure Formation amounts to 60 percent. A considerable thickness of schist, constituting 40 percent of the total package in the type locality occurs immediately north of Sure in Samkhera area (Fig.3.9.4). In other sections schist forms a minor proportion. In Chaple *khola* area the schists is overlain by augen gneiss.

The Sure gneiss is a two-mica granite gneiss which locally shows migmatitic structures (e.g., between Loring *khola* bridge and Dhare *Chu*). In general mafic component is subordinate while muscovite is conspicuous in the Sure Gneiss. Garnet is sporadically developed. The augen gneiss occurs at higher structural levels and shows feldspar porphyroblasts upto 1.5 centimetres in longer dimension. Biotite content in this rock is a little more than in granite gneiss exposed at Sure village. In Samkhera area only a few outcrops of schist are present, most of the area shows no exposure. The schist band in this section is thicker than those of eastern and western frontal belt sections of Bhutan. A prominent leucocratic tourmaline granite occurs in the Sure Formation at about 1.5km south of Sure. Sillimanite is reported from Samkhera area and also from a little east in Khomsar area in the Chamkha *Chu* valley (Guha Sarkar, 1979). The schist of the type Sure Formation differs from the tectonically underlying schist of the Jaishidanda Formation

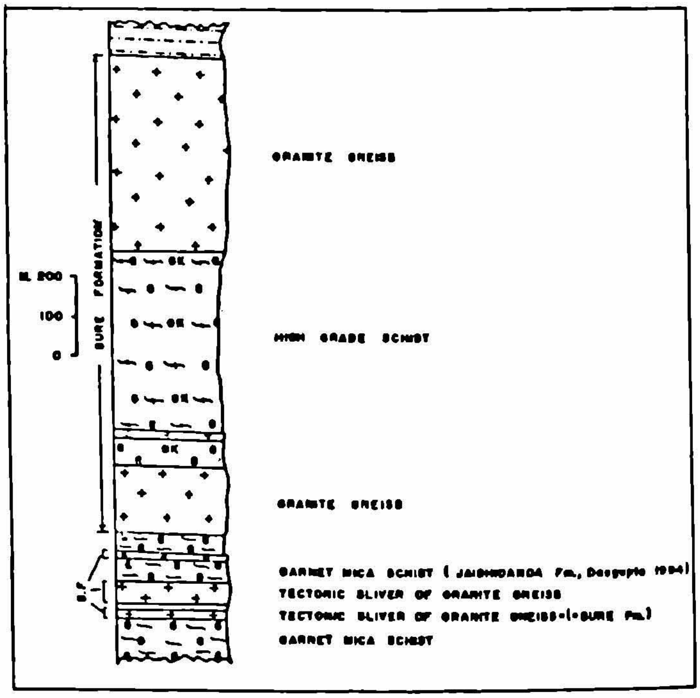


Fig.3.9.4 Litho-column of the Sure Formation, exposed in Sure-Samkhera area.

in having profuse granite-pegmatite intrusions

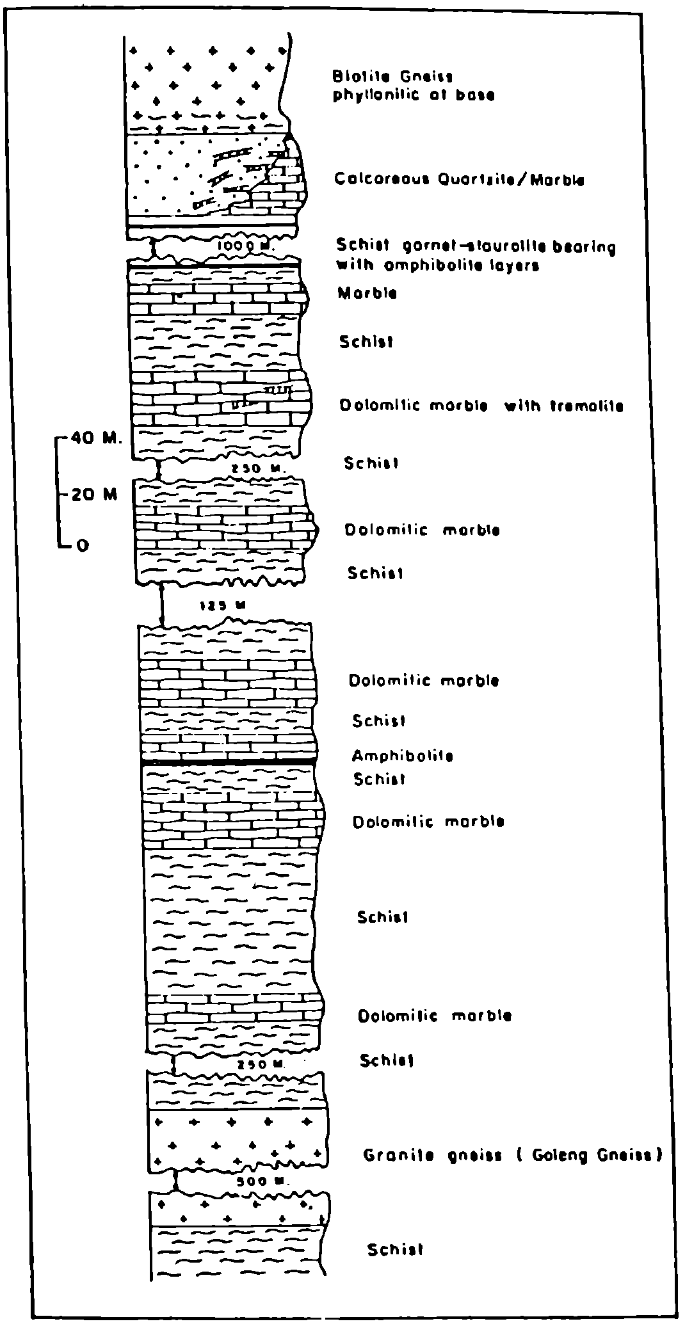


Fig.3.9.5 Litho-column of the Naspe Formation along Chomkha *Chu* valley, between Goleng and Khakthang.

apart from containing high grade minerals like kyanite and rare sillimanite. Besides the type locality, the high grade schist of the Sure Formation contains kyanite and sillimanite in the area east of Tashigang. As a rule kyanite is more widespread in the Sure Formation than sillimanite. Where these two high grade minerals are absent, the Sure schist is little different from the garnetiferous mica schists of the Jaishidanda Formation.

Naspe Formation: Map compiled by Gansser (1983) conveys an impression that the supposedly high grade metasediments in the 'Central Crystallines' referred to as the Paro type metasediments or Paro Formation are quite widespread in Bhutan. Subsequent detailed mapping by the Geological Survey of India revealed that the Paro type metasediments of Gansser (1983) encompass a wide spectrum of rocks ranging from anchimetamorphosed sandstone to high grade pelitic schist and gneiss which occur at different tectonic and stratigraphic levels. Some of the rocks grouped in the Paro Formation include banded and augen gneiss as exposed near Lhuntshi Dzong in the Kuru *Chu* valley. To ward off such inconsistencies the Naspe Formation is adopted after Lakshminarayana and Singh (1993) for the metapelite-dominated schist horizon within the Thimphu Group.

The Naspe Formation comprises a thick interlayered sequence of kyanite, staurolite-bearing garnetiferous mica schist - commonly graphitic and impure dolomite marble, the former being in overwhelming proportion. The metasediments occur north of Byakar Dzong, between Goleng and Khakthang in the Chomkha *Chu* valley. The staurolite-garnet graphitic schist which is the characteristic lithology, constitutes the foundation rock of the Naspe Monastery after which this formation was first named (Lakshminarayana and Singh, 1993). Kyanite occurs in muscovite rich portions of the schist. The carbonate component, though conspicuous, forms only 10 percent of the formation (Fig.3.9.5). Minor impersistent quartzite bands are exposed east of Naglakhang. Thin layers of amphibolite occur at different tectonic levels within the Naspe Formation.

The lower contact of the Naspe Formation is concealed under the river terrace while the upper contact at Khakthang with the sillimanite bearing biotite gneiss is well exposed. About 100m thick granite phyllonite at the base of the high grade gneiss indicates extensive shearing. The evidence of shearing in the rocks of the Naspe Formation starts appearing just north of the Naspe Monastery section. The pronounced shearing coupled with the occurrence of sillimanite-garnet bearing high grade gneiss over relatively low grade staurolite-garnet mica schist suggests existence of a thrust named as the Takhtsang Thrust.

The staurolite-garnet schist first appears near Treshling village. The best exposures of this schist are present only at a few places e.g. Naglakhang section near Dumphie and at the Naspe Monastery. The contact between the schist and the marble is well exposed at hillock located between Naglakhang and Samgling overlooking the eastern bank of the Chomkha *Chu*. In this section staurolite-garnet-biotite-muscocvite schist grades into impure calcareous schist and marble. In other sections a physiographic depression immediately above the carbonate band marks the contact zone.

Garnet and staurolite are ubiquitously developed in the Naspe Formation with biotite and muscovite as common constituents. Kyanite associated with the muscovite rich zone is recorded at several localities, the most notable being the western bank of the Chomkha *Chu* in the west of Naglakhang. The graphitic schist is exposed east of Naglakhang. The concentration of garnet and staurolite differs from place to place. The profuse development of staurolite is observed in the exposures which form foundation rock of the Naspe Monastery. In some samples graphite inclusions are concentrated as bands within the staurolite porphyroblast (Fig.3.9.6).

A few chemical analyses of staurolite-garnet schist from Naspe area show that the bulk rock composition is high in alumina and iron. One sample (NSUP-1) contains anomalously high amount of manganese. The fixed carbon content of two samples of graphite bearing schist from Naglakhang is 6.95 and 4.65 percent. Table 3.9.2 gives chemical composition of different rock types of the Naspe Formation.

Petrographic studies reveal that the schist band consists of a varied mineral assemblage. The following co-existing mineral phases could be recognised.

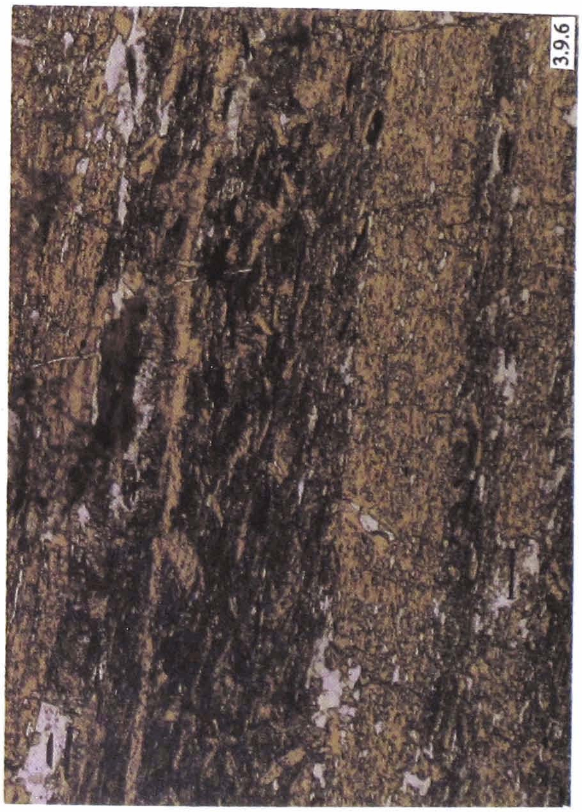
1) Quartz+ kyanite+ muscovite+ biotite+ garnet+ opaques

Table 3.9.2 : Chemical composition of different rock types of the Naspe Formation

Sample No.	NSUP-1	NSK-1	BS-20	BS-15	N-1	NSK-2	BS-14
SiO_2	44.60	52.00	67.30	75.80	6.00	4.02	3.00
TiO_2	0.48	1.34	1.44	1.50	0.14	0.06	0.09
Al_2O_3	16.35	24.22	11.56	6.37	0.00	0.00	0.00
Fe_2O_3	12.79	4.79	5.21	5.81	0.00	0.00	0.00
FeO	8.46	5.94	2.34	4.86	0.00	0.00	0.00
MnO	7.65	0.20	0.09	0.18	0.02	0.00	0.00
CaO	4.50	0.67	0.49	0.54	29.48	30.56	30.86
MgO	1.12	1.72	1.17	0.59	21.32	1.22	21.02
Na_2O	0.13	1.04	0.35	0.10	0.16	0.12	0.09
K_2O	0.06	4.24	1.75	0.07	0.26	0.30	0.06
$+H_2O$	2.78	0.78	0.18	1.88	-	-	-
$-H_2O$	0.14	0.02	0.06	0.04	-	-	-
P_2O_5	0.04	0.03	0.10	0.10	0.04	0.02	0.03
L.O.I.	-	-	-	-	41.84	43.08	44.26
C	-	-	6.95	4.65	-	-	-


3.9.7


3.9.9


3.9.6


3.9.8

2) Quartz+ biotite+ muscovite+ garnet+ staurolite+ carbonaceous matter+ opaque

3) Quartz+ biotite+ muscovite+ garnet+ opaque

The staurolite is developed in the form of bands (Fig.3.9.7) as well as discrete zoned grains (Fig.3.9.7). There are two types of staurolite. The early formed ones are conspicuously sieved. In such grains the inclusion trails (Si) are aligned in conformity with the preferred dimensional orientation displayed by the phyllosilicates of the matrix (Fig.3.9.8) indicating late tectonic development. Certain grains display sigmoidal inclusion trails (Fig.3.9.9). Locally staurolite grains show pressure shadow zones represented by beared growth of mica. Pronouncedly sieved staurolite appears as skeletal grains studded with muscovite, biotite and opaques. The other type of staurolite occurs as well developed inclusion-free crystals which commonly cut across the schistosity (Fig.3.9.10). Zoning is common particularly when developed in graphitic schist (Fig.3.9.7). Garnet occurs in two habits, with inclusion as well as inclusions-free (Fig.3.9.11). In some thin sections inclusions are confined to the central part while the rim is clear indicating development of garnet in two stages. Textural relations between garnet and staurolite in graphitic schist of Naglakhang area suggests that the garnet development pre-dates the formation of staurolite (Fig.3.9.12). Kyanite occurs as porphyroblasts in the muscovite-rich schists. Individual crystals are as long as three centimetres. Graphite generally occurs as fine dust. Muscovite and biotite define foliation in the rock.

Marble occurs interlayered with the staurolite-garnet schist. In all, eight marble bands of variable thickness could be noted between Treshling and Khakthang along the Chomkha *Chu*. Individual bands are eight to 22m thick with best exposures at the cliff face of the hillock between Naglakhang and Sangling and at Sapchithang. The marble is cream coloured with grain size around one millimetre and is commonly tremolitic as observed at Sapchithang along the track leading to Naspe. Tremolite crystals are as long as four centimetres. Chemical analyses of three samples indicate that the marble is dolomitic in nature. Silica is generally low except in the topmost layer near Khakthang where it is more akin to a calcareous quartzite than to a siliceous marble.

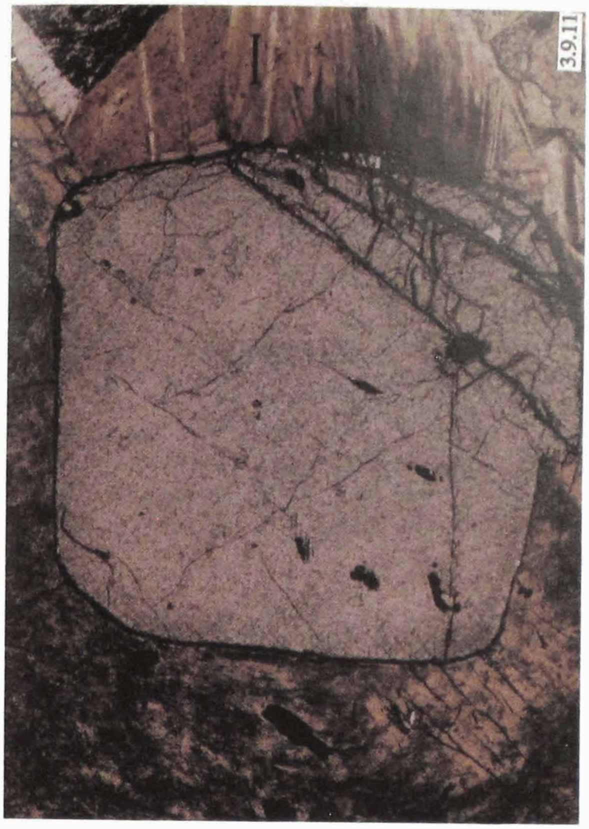
Amphibolite in the Naspe Formation occurs as concordant layers in the metapelitic schist and dolomite. The thickness of each amphibolite body rarely exceeds a few metres. At Naspe Monastery it is only two metres thick while along Naspe-Kole *La* track it occurs as bouldery outcrops giving impression of a slightly thicker body underneath.

Paro metasediments of Gansser (1983) of Bumthang area form part of the presently defined Naspe Formation.

Takhtsang Formation : Name Takhtsang for this sequence is retained after Gansser (1964) who differentiated sillimanite bearing high grade gneiss and schist (the Takhtsang gneiss) from the remaining relatively low grade gneiss (the Chasilakha, Sure and Tashigang gneisses), Nautiyal *et al*, (1964) used the term Thimphu Series for gneisses and schist of identical geological setting and metamorphic status. This term is, however, not found suitable as it can be confused with the Thimphu Group. It may be mentioned that a better section of the Takhtsang Formation is exposed along the Chomkha *Chu* valley. The lithocolumn of the Takhtsang Formation is shown in Fig. 3.9.13. Characteristically this formation is constituted of garnet-sillimanite biotite gneiss largely devoid of muscovite. Muscovite, where present, represents retrogression and/or neomineralisation. Gansser (1983) marked tectonic contact at the locale of

Explanation of Figures 3.9.6 - 3.9.9

Fig.3.9.6 Graphite inclusion-rich (dark) bands defining compositional layering within staurolite porphyroblast of Naspe Formation. Bar length 0.1mm. Fig.3.9.7 Zoned staurolite porphyroblast of Naspe Formation; Note graphite inclusion-rich core and almost inclusion-free rim. Bar length 0.1mm. Fig.3.9.8 Staurolite porphyroblast of Naspe Formation; Note straight inclusion trail developed in continuity with the outer schistosity; Bar length 0.1mm. Fig.3.9.9 Staurolite porphyroblast with sigmoidal inclusion trail, Naspe Formation. Bar length 0.1mm.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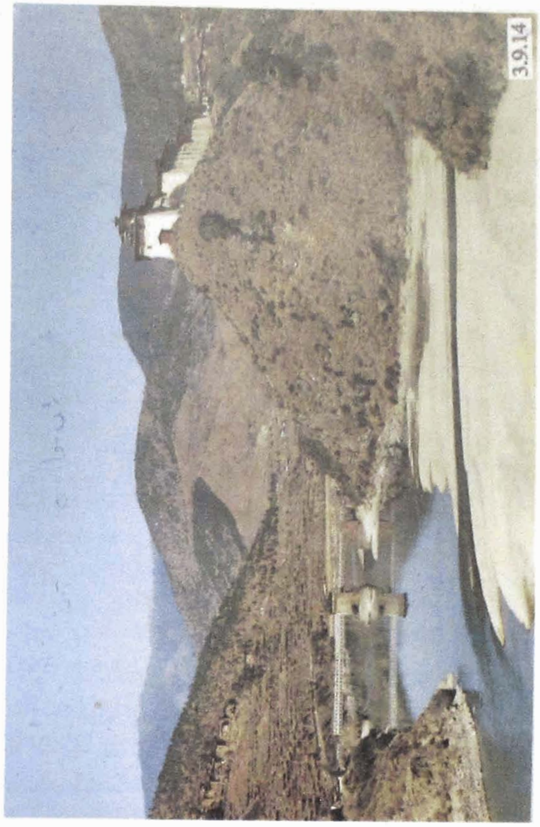

3.9.14


3.9.10


3.9.12

garnetiferous amphibolite between sillimanite bearing gneiss and metasediments.

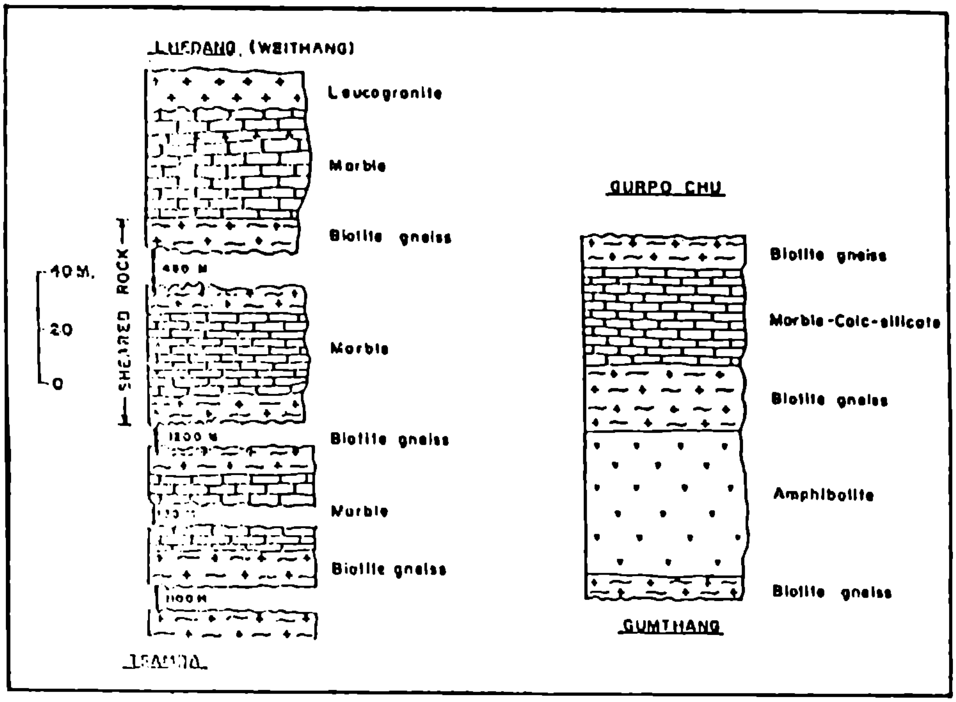


Fig.3.9.13 Litho-column of the Takhtsang Formation from Lhedang-Tsamba and Gurpo *Chu*-Gumthang sections.

Reference sections of the Thimphu Group

Paucity of exposures and inadequate accessibility restrict fieldwork to selected river valleys. This is particularly so in northern and far western sectors of Bhutan which are constituted of the Thimphu Group rocks. The following sections therefore, deal with the Wang *Chu*, Paro *Chu*, Mo *Chu* (Sankosh), Chomkha *Chu*, Kuru *Chu* and Gamri *Chu*-Kolong *Chu* valleys which are easily accessible and expose the Thimphu Group.

Mo *Chu* Section : The rocks belonging to the Sure Formation are exposed between the Loring *Khola* in south and Buri *Chu* in north along the Sarbhang-Chirang-Wangdiphodrang road, partly along the Sankosh (Mo *Chu*) river. Near Loring *Khola* garnetiferous mica schist contains as many as three slivers of deformed granite gneiss below the thick streaky and augen gneiss, the base of which is regarded to mark the lower contact of the Sure Formation. The upper contact of this formation is well exposed near the Buri *Chu*-Mo *Chu* confluence where augen gneiss is overlain by mica-schist of the Chekha Formation with sharp disconformable contact. The intervening tract between Dhupi Danda and Chirang as well as little further north is underlain by a dominantly garnetiferous mica schist with subordinate amount of gneiss. In this area the Sure Formation is profusely intruded by pegmatite and granite. The gross lithologic package of the Sure Formation in the Loring-Buri *Chu* section is comparable to that of the Sure type locality. The stretch between the Mo *Chu*-Kame *Chu* confluence area north of the Chekha outlier is occupied mainly by the biotite gneiss. The southerly dipping Chekha quartzite overlies the gneiss near the Kame *Chu*. The contact zone is intensely intruded by tourmaline

Explanation of Figures 3.9.10 - 3.9.12 & 3.9.14

Fig.3.9.10 Outer schistosity abutting against the staurolite porphyroblast, Naspe Formation. Bar length 0.1mm. Fig.3.9.11 Inclusion-free garnet porphyroblast with bearded growth of phyllosilicate in the pressure shadow zone, Naspe Formation. Bar length 0.1mm. Fig.3.9.12 Garnet almost totally included within staurolite, Naspe Formation. Bar length 0.1mm. Fig.3.9.14 Calc-gneiss of the Sure Formation forming the foundation of Wangdiphodrang Dzong and also eastern abutment of the Sankosh bridge.

bearing leucogranite.

The lithologic monotony of the biotite gneiss is broken by a 150m thick N-S trending calc-gneiss band occurring at the western bank of the Mo *Chu* and below the Wangdiphodrang Dzong (Fig.3.9.14). The band can be traced in north upto Lobesa paralleling the course of the Mo *Chu*. From Lobesa onward, it can be followed discontinuously at least upto south of Thinlegang. The gneiss is well banded, actinolite-bearing and contains garnets as big as three centimetres in diameter. A 20m thick quartzite is exposed north of Wangdiphodrang on the eastern bank of the Mo *Chu*. The quartzite is thoroughly recrystallised and contains appreciable quantity of magnetite. This particular area and also the tract lying immediate to the south of Lobesa is capped by red colour residual soil.

Metasedimentary rocks also occur immediately east of Punakha in the Shenga Rong *Chu* valley where mappable calc-silicate rocks and calcareous quartzite underlie the gneiss. North of Lobesa a prominent band of marble extends between Tala and Olakha. The gneiss overlying the metasedimentary patches contains muscovite, biotite and garnet apart from the main quartzo-feldspathic ingradients. Size of garnet varies from one millimetre to about one centimetre. Coarse grained amphibolite as large lenticles within the biotite gneiss are exposed between Thinlegang and Lobesa and also at Srigang and Rim *Chu*. In the latter locality it occurs as impersistent band in the area immediate south of the Rim *Chu* stream. The amphibolite contains garnet having a diameter of about three centimetres. Skarnoids are observed near Olakha, Punakha and Rim *Chu*. Megascopically the skarnoid consists of diopside, feldspar, garnet, quartz, calcite and some opaque minerals. At Rim *Chu*, garnet in some of the long skarnoid boudins constitutes as much as 70 percent of volume, the remaining part is mostly made up of diopside and calcite. Garnets separated from amphibolite, granite gneiss, mica-schist and skarnoid from Punakha area were analysed and compared with those associated with the Bhurkhola tungsten deposit (Table 3.9.3). The first three analyses show almandine-rich garnets while the one from Punakha is closely comparable to the grossularite-rich variety of Bhurkhola.

The litho-package of the Sure Formation between Kame *Chu*-Wangdiphodrang to little north of Punakha contains a few additional metasedimentary patches around Punakha area. Further to the north of the Rim *Chu*, biotite gneiss is migmatitic, banded (Figs. 3.9.15-16) and sillimanite-bearing, yet still underlying the calc-silicate-sillimanite biotite schist of the Naspe Formation. Such relationship in the Mo *Chu* section indicates that the metamorphic grades cross cut the formational boundaries of the Naspe and Sure Formations.

The metasedimentary pack at the Chephu belonging to the Naspe Formation is about 100m thick in the Koma *Chu* section. Calc-silicate-diopside marble, sillimanite-biotite schist, biotite gneiss and granitic intrusions constitute 60, 25, five and 10 percent of the litho-pack respectively (Fig.3.9.17). Graphite bearing sillimanite biotite schist occurs as small lenticular pockets. The talc-silicate occurring at the lower structural levels contains pyrite, sphalerite and galena in the Kame *Chu* river bed. Several sulphurous hotsprings are located in this calc-silicate band. The biotite gneiss occurs only in patches. The sillimanite biotite schist is commonly feldspathised. Tourmaline is invariably a substantial component of this rock. It shows a highly preferred dimensional orientation paralleling schistosity in the rock. The carbonate fraction in the upper structural levels is represented by coarse diopside marble. Calc-silicates are relatively rare in the upper part of the Koma *Chu* section.

Sillimanite-garnet bearing gneiss belonging to the Takhtsang Formation occurs above the rocks of the Naspe Formation in Chephu-Gasa-Konia-Laya tract. The gneiss occurs as discontinuous sheets due to injection of granitic gneiss material which itself shows development of crude foliation. In rare cases gneissosity is developed and evidence of post-crystalline deformation is also noticed in the rock. Beyond Konia younger garnet bearing granite and gneiss form an inextricable mixture.

Table 3.9.3 : Chemical composition of the Garnets of Mo *Chu* and Bhurkhola Section

Wt (%)	TKB/1G/91	TKB/2G/91	TKB/3G/91	TKB/4G/91	TKB/5G/91
SiO_2	53.45	55.60	47.75	45.50	53.96
TiO_2	1.28	0.10	0.44	0.24	0.44
Al_2O_3	14.74	15.41	17.42	15.74	14.74
Fe_2O_3	0.40	8.36	6.10	0.40	2.53
FeO	19.08	9.00	15.84	18.72	10.44
MnO	0.34	3.06	1.21	1.76	1.56
CaO	3.39	0.95	5.93	11.76	12.63
MgO	4.09	0.91	2.42	0.95	0.82
Na_2O	0.27	0.93	0.18	0.19	0.66
K_2O	0.25	1.17	0.44	1.23	0.52
$+H_2O$	0.54	2.24	0.74	0.30	0.10
$-H_2O$	1.26	1.44	0.88	0.46	0.30
P_2O_5	0.60	0.50	0.30	0.30	0.30
CO_2	-	-	-	2.17	0.60

1G. Garnet from amphibolite near Bothokha village, 2G. Garnet from granite gneiss near Helesa village, 3G. Garnet from mica schist near Punakha, 4G. Garnet from Skarn near Punakha and 5G. Garnet from Bhurkhola Tungsten deposit near Geylegphug.

Central Bhutan: The Geylegphug-Sure road and the Chomkha *Chu* section in the north of Bumthang expose the best section of the Thimphu Group. The type sections of the Sure and Naspe Formations are exposed along this transect. The Takhtsang Formation occurring in the upper reaches of the Chomkha *Chu* comprises the most varied and thick litho-assemblage of high grade gneiss, marble and amphibolite. Unlike the type Takhtsang Monastery section, the gneiss of this section is K-feldspar bearing and the early formed muscovite is absent in the mineral assemblages.

Apart from the type locality, the rocks belonging to the Sure Formation are exposed in the Tongsa-Bumthang area in Central Bhutan. They are mainly two mica granite gneiss with frequent occurrence of garnet-kyanite bearing schist intercalations. The gneiss of this section rests over the low grade rocks of the Tethyan affinity along a reverse fault (Guha Sarkar, 1979). About 20m thick slice of mylonitised gneiss occurs within the biotite porphyroblast bearing schist.

The high grade gneiss occurring in the stretch between Khakthang and Lhedang constitutes the most well developed section of the Takhtsang Formation. Other lithologic units include marble and less commonly amphibolite. Biotite gneiss is the most dominant rock type occurring between Khakthang and Tsamba. Barring a small stretch of migmatites near Saduksum and Gumthang, the gneiss is more or less uniform in composition. The lower part of the gneiss about one kilometre north of Khakthang shows kyanite-mica-garnet schist which contains clear white translucent crystals of kyanite. Staurolite bearing assemblages are totally missing in the milieu of biotite gneiss. First megascopically identifiable sheaths of sillimanite appear at about one kilometre north-west of Saduksum along the Chomkha *Chu* track. Sillimanite occurs in the garnet-biotite schist and more commonly as constituent of garnet-biotite gneiss. The schist occurs as discontinuous bands which imperceptibly passes into sillimanite bearing gneiss. The best development of garnet-sillimanite bearing assemblages is between Chamdur to Lugchen *La* and also near Lungsipang. The rock from these localities shows the following mineral assemblage :

quartz+ feldspar+ plagioclase+ sillimanite+ garnet+ biotite+ opaques.

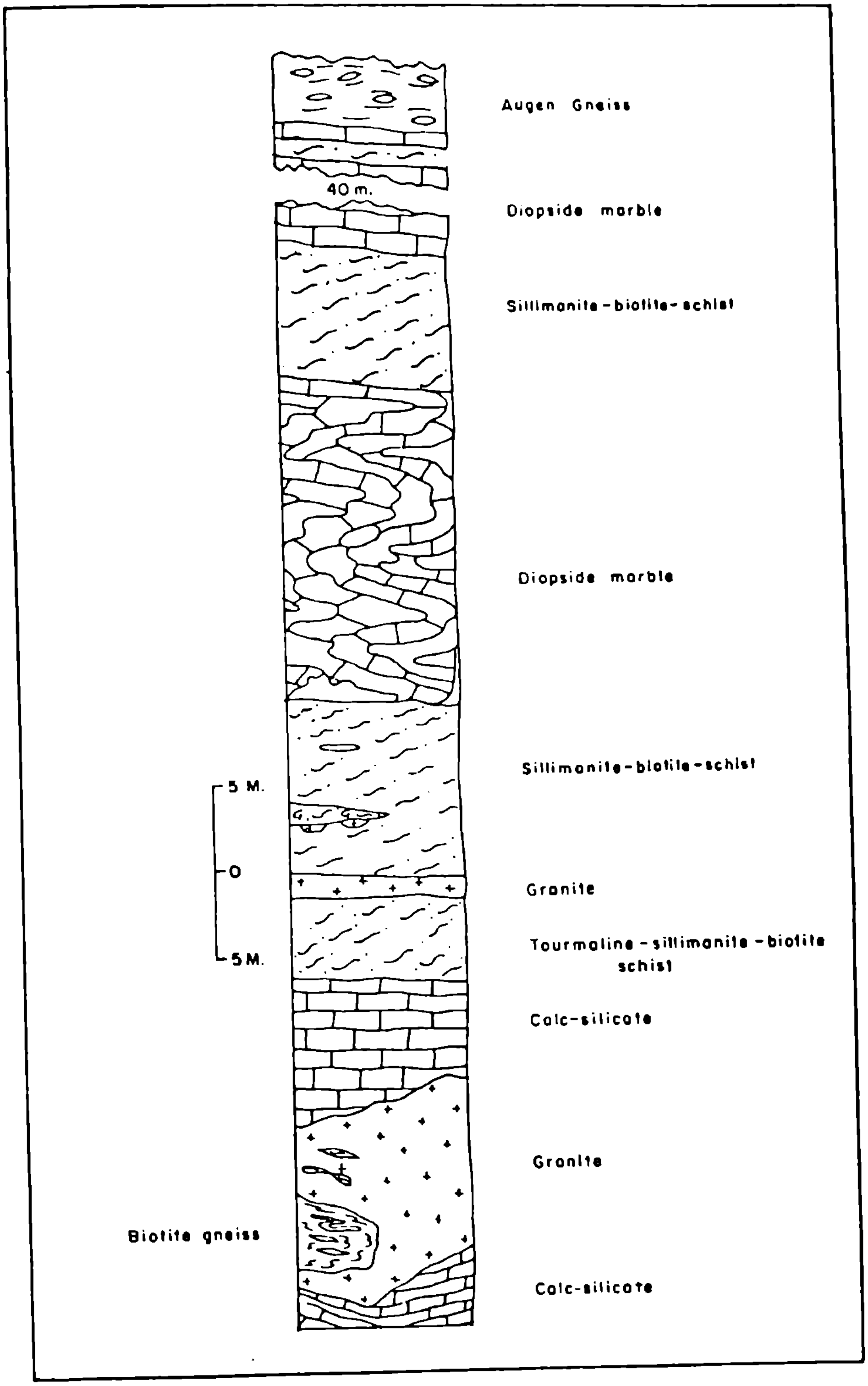


Fig.3.9.17 Litho-column of Naspe Formation in Koma *Chu* section.

Similar rocks collected from Gurpola show presence of spinel in addition to the above mineral assemblage. The assemblage is typically free from the early formed muscovite phase. However, coarse grained muscovite, distinctly later than the peak metamorphic assemblages is locally developed in the rocks. Being close to the shear zone, the Gurpola specimens show evidence of retrogression. Garnet shows marginal granulation, lenticular shape (Fig.3.9.18) and rare alteration to chlorite. Sillimanite occurs as sheaths (Fig.3.9.19) and as fibrolitic mat (Fig.3.9.20) in quartz in the gneiss. The spinel-bearing assemblages from the adjoining eastern part of the present area are interpreted by Swapp and Hollister (1991) as metamorphic reactions at temperatures exceeding 700°C.

The other components of the Takhtsang Formation in the Chomkha *Chu* valley are three marble bands which occur interbanded with the biotite gneiss between Tsamba and the Point .4066m in the river bed. A 150m thick band occurs at Tsamba (Fig. 3.9.13). The marble contains partings of sillimanite biotite gneiss and amphibolite. The other two bands of siliceous marble occur structurally above the Tsamba marble. All the marble bands thin out towards east and only one could be recorded in the Gurpo *Chu* section (Fig.3.9.13). Megascopically the marble is well banded light grey to white with considerable grain size variation. The general size of equant grains is one millimetre across the diameter. Calc-silicate component is usually low when compared with the bands occurring near Konia in the Mo *Chu* valley at comparable structural levels. Partial chemical analysis of one sample collected from the Melunghi *Chu* valley shows CaO 44.73%, MgO 0.28%, SiO_2 9.44%, Al_2O_3 6.32%, FeO 1.85% and K_2O 1.20%. The marble exposed in the river bed at 4066m contains little muscovite which imparts fissility to the rock. A pyrite nodule was observed at this locality. At Dhilirap *Chu*-Chomkha *Chu* confluence and in the Melunghi *Chu* valley, the siliceous marble shows development of wollastonite in the close proximity

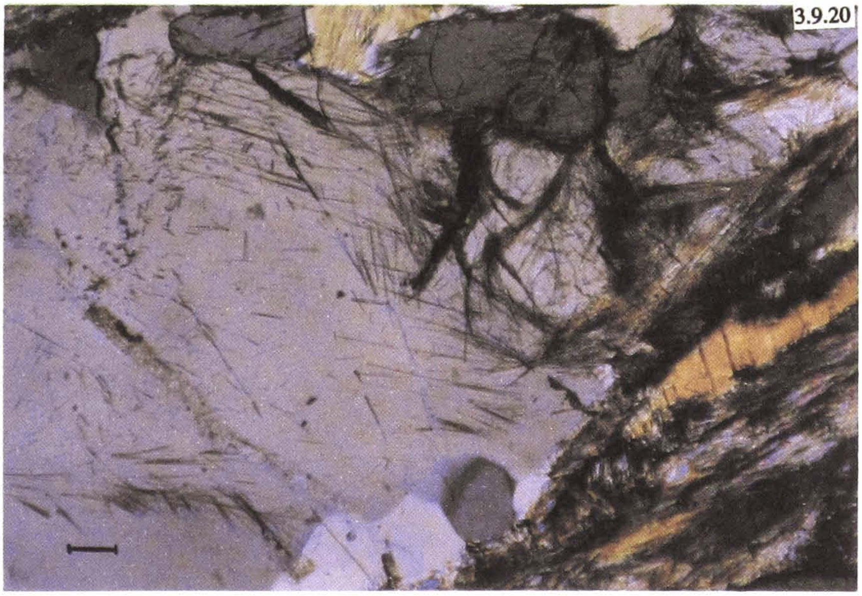
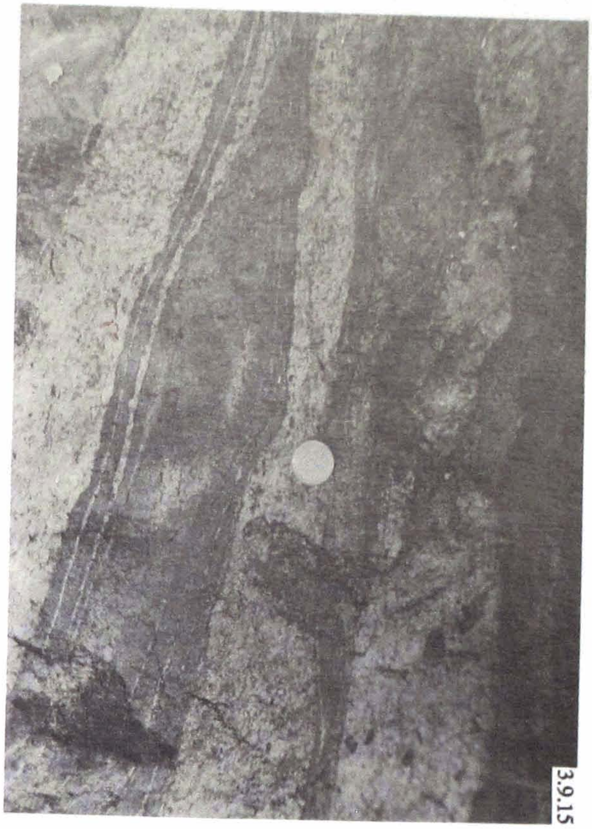


Fig.3.9.20 Quartz showing fibrolite mat in Takhtsang Formation near Gurpo *La*, partially crossed. Bar length 0.05mm.

Explanation of Figures 3.9.15 - 3.9.16 & 3.9.18 - 3.9.19

Fig.3.9.15 Banded migmatitic gneiss, Sure Formation. 3km north of Rim *Chu*. Fig.3.9.16 Stromatic migmatite, developed within the Sure Formation, North of Rim *Chu*. Fig.3.9.18 Streched garnet and quartz in sheared sillimanite-garnet bearing gneiss of the Takhtsang Formation. Partially crossed. Bar length 0.1mm. Fig.3.9.19 Sillimanite occurring as discrete sheath in gneiss, also seen garnet and quartz; Takhtsang Formation near Gurpo *La*. Partially crossed. Bar length 0.05mm.

3.9.18



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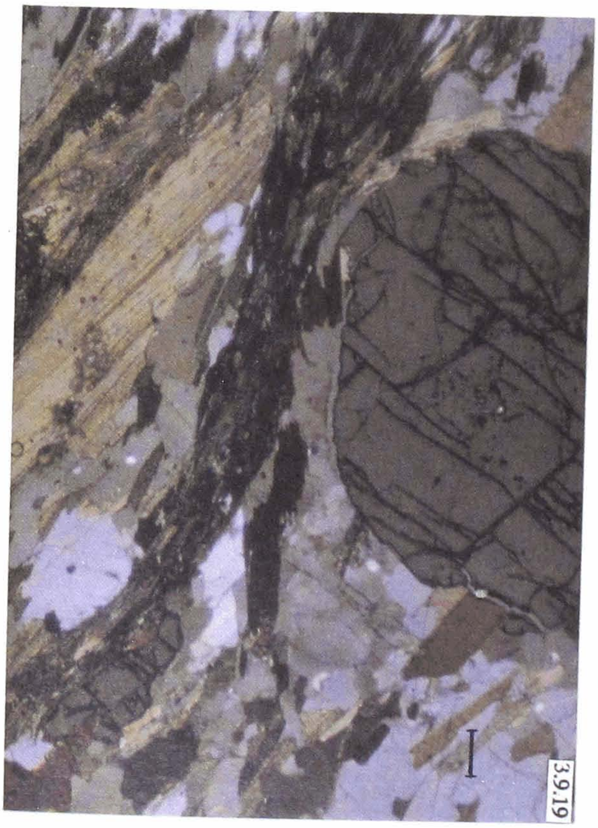

3.9.19

3.9.16

to the granitic intrusions (Fig.3.9.21). Vesuvianite has also been reported by Gansser (1983) from the Melunghi *Chu* valley. Sporadic scheelite grains occur in the contact metamorphic zones.

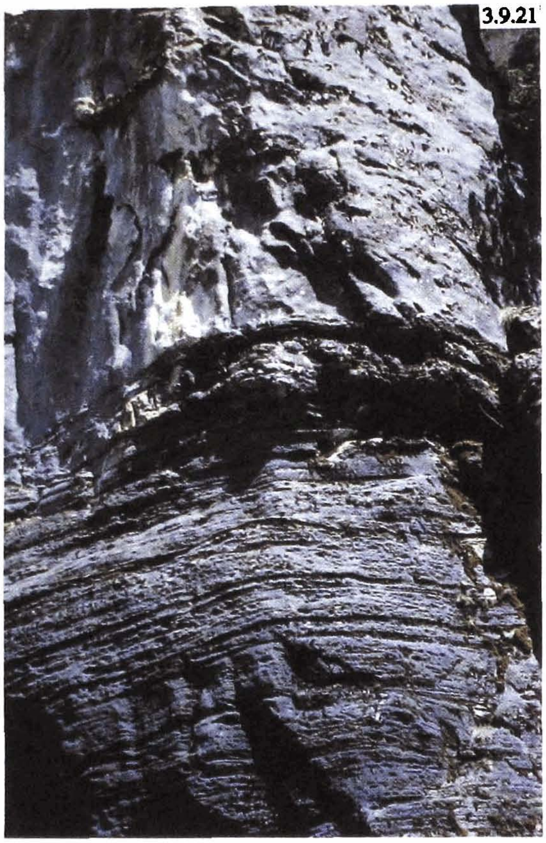

Fig.3.9.21 Monlakarchung Granite intrusive in the marble band in Dhilirap *Chu* section.

Thin layers of amphibolite are more common in the Takhtsang Formation exposed in north of Khakthang than in granitic gneiss of the Sure Formation in the Bumthang Dzong area. The individual amphibolite bodies vary in thickness from 50cm to 50m, exposed about three kilometres north of Gumthang on the eastern bank of the Gurpo *Chu* stream. It is foliated and made up of mostly subidioblastic to idioblastic grains of hornblende and garnet with opaques constituting the main accessory. Locally plagioclase is also a common mineral.

Eastern Bhutan : The Thimphu Group is well exposed in the Kuru *Chu* valley. The contact between the gneiss and quartz-garnetiferous mica schist of the Shumar-Jaishidanda Formations is exposed near Minji. The two mica granite gneiss constituting bulk of the Sure Formation is exposed between Minji and Lhuntshi Dzong. Besides the gneiss, garnet, kyanite-mica schist and quartzite are the other important lithologic units. Granite gneiss, pelitic schist and quartzite occur in about 70, 20 and 10 percent proportion respectively in the Sure Formation.

The gneiss exposed south of the Lhuntshi Dzong is of two types; biotite gneiss and leucocratic granite gneiss. The former occurs as impersistent band within the leucogneiss. The latter is quartz-rich and contains pod-shaped clusters of tourmaline. The biotite gneiss shows sporadic development of feldspar augen. Outcrops of the garnet, kyanite-mica schist are poor. It is exposed to the immediate south of the Lhuntshi Dzong. Quartzite occurs as 25m to 30m thick bands within the gneiss. It is thoroughly recrystallised and is made up of muscovite, biotite and opaques.

The schist of the Naspe Formation from the type locality extends to the east in the Kuru *Chu* valley passing through the Tang *Chu* where it is best developed. The schist component constitutes about 90 percent of the total lithopack, the remaining lithologic units are marble and quartzite. The schist contains garnet and kyanite. Garnet in the schist occurs as idioblastic crystals exhibiting poikiloblastic texture. It shows S-shaped trails of inclusions mainly of quartz commonly with streaks of opaque ores. Kyanite occurs as colourless to bluish grey broad tabular crystals which are bent near the garnet porphyroblasts. Graphite occurs as lenticular bands intercalated with mica schist. The thickness of individual bands ranges from two to six metres. The bands are traceable upto 300m strike length. The non-carbonate fraction ranges from 13 to 16 percent. Quartzite in the Naspe Formation is ferruginous, a thin band of banded hematite quartzite is also recorded near Gangzur.

Biotite gneiss crops out north of Thimyul. Sillimanite and garnet are the common constituents of the gneiss of the Takhtsang Formation. Several marble bands having strike lengths from two to five kilometres with thickness

Fig.3.9.22 Migmatites of the Thimphu Group, Tashigang area.

rarely exceeding 30m occur within the high grade gneiss. Beyond Pemathang the rocks are mostly granite gneiss profusely intruded by veins of pegmatite. The gneiss is devoid of marble and calc-silicate rocks and has, therefore, been mapped separately in the Mo *Chu* and Ha *Chu* sections.

In Tashigang area, the Sure type gneiss is represented by granite gneiss, augen gneiss and streaky gneiss. The latter two varieties are laterally impersistent and represent tectonically induced textural variants. The streaky gneiss is found along the Shumar-Thimphu contact in the area west of Nagar Gompa and Yayung. A well foliated leucocratic granite gneiss component is present within the biotite granitoid gneiss in the area west of Tashigang. It could probably be related to the migmatites (Fig.3.9.22). The main constituents of the Tashigang gneiss are quartz, K-feldspar and plagioclase. Muscovite and biotite occur in equal proportions. Accessories include tourmaline, epidote, apatite and opaques. Garnet when present shows quartz inclusions.

The thicker schist band of the Naspe Formation in the Kuru *Chu* valley thins out in the east and in the Tashigang-Tashiyangtse section it is inconspicuous. High grade gneiss is copiously permeated by granitic activity in this section. A thrust represented by an extensive zone of mylonitisation is well exposed immediately east of the Tashiyangtse Dzong. It possibly demarcates the contact between the thin schist band of the Naspe Formation and the overlying gneiss.

Wang *Chu* Section : The crystalline expanse of the Thimphu Group swings to the south-west from the Mo *Chu* valley and occupies the entire Thimphu township area. The best exposures are at about one kimoleter north-west of the Dichhencholing, the administrative Headquarter of the Royal Government of Bhutan and on way to Cari

Fig.3.9.23 Shear zone developed in Takhtsang gneiss. Quarry, NW of Tashichho Dzong, Thimphu.

Gompa. South of Thimphu, the exposures exist upto little north of the Simtokha Dzong. In this section the two mica granite gneiss of the Sure


3.9.24

Fig.3.9.24 Migmatites of Takhtsang Formation, location same as Fig. 3.9.23.

Formation is tectonically overlain by migmatite and garnet-sillimanite biotite gneiss and schist of the Takhtsang Formation without the staurolite-kyanite schist lithology of the Naspe Formation. The contact between the two is marked by the Takhtsang Thrust which passes through the Thimphu township. Discrete shear zones also occur in the migmatite-garnet-sillimanite biotite gneiss in the immediate north-west of the Dichhencholing in a quarry face (Fig.3.9.23).

The two-mica biotite gneiss of the Sure Formation occupies a small stretch between Thimphu and Simtokha. They reappear in Bunakha-Chukha and Chasilakha areas in the Wang *Chu* valley. Exposures are poor in the former area. However, in Bunakha and Chasilakha areas the gneiss is well banded and shows preponderance of biotite over muscovite. Gansser (1983) reported kyanite and fibrolitic sillimanite associated with biotite in the gneiss which occurs to the north of Chasilakha. In the south, the discontinuous band of augen gneiss ranging in thickness from 20m to 150m occur in close proximity to the Thimphu Thrust. The size of the augen varies from one to six centimetres. The augen consists of orthoclase crystals which are occasionally zoned. Matrix is invariably retrograded and comprises biotite, chlorite and sericite.

The migmatites and biotite-sillimanite-garnet gneiss first appear near Dichhencholing. The migmatites show deformed quartzo-feldspathic aggregates in a milieu of mafic rich paleosome when observed in a plane at right angle to the direction of stretching lineation (Fig.3.9.24). The biotite-sillimanite-garnet gneiss occurs as discontinuous bands within the migmatites. Abutments of the traditional Bhutanese bridge near Cari Gompa are made up of sillimanite bearing gneiss. Sillimanite aggregates at this locality exceed two centimetres.

Paro-Ha *Chu* Section : The two-mica granite gneiss of the Sure Formation thins down in the Paro Valley and in the Paro-Takhtsang-Drukye section it is only 200m thick. The gneiss in this section shows distinct size reduction and S-C fabric at places. Sheaths of sillimanite occur aligned parallel to the shear plane. The biotite-sillimanite-garnet gneiss of the type section first appears at about two kilometres south of the Takhtsang Monastery. The high grade gneiss of this locality comprises a lithopack of biotite-sillimanite-garnet gneiss intercalated with the leucogneiss and augen gneiss, as seen in the Drukye Dzong area.

Petrographically the Takhtsang gneiss consists of quartz, feldspar, biotite, fibrolitic sillimanite, garnet and opaques. Muscovite present in this rock clearly post-dates this peak metamorphic assemblage. The presence of muscovite has thus limited significance while characterising the petrography of the Takhtsang gneiss (cf. Gansser, 1983).

In the Ha *Chu* valley Sure Formation is not recognisable. The sillimanite-biotite gneiss of the Takhtsang Formation occurs as impersistent bands with the leucocratic granite gneiss along the

Fig.3.9.25 Leuco-granites within biotite granitoid gneiss, Ha *Chu* valley.

northern tributary of the Ha *Chu*. Further west only leucogneiss with some biotite and augen gneiss is exposed in the Ha *La*-Jule *La* areas. At the Ha *La*, the leucogneiss occurs as deformed bands within the migmatitic biotite gneiss (Fig.3.9.25). The most notable feature of the gneissic terrain west of Damthang is the near absence of garnet in the migmatitic biotite gneiss and leucogneiss. The garnet could be observed in the biotite gneiss only at a locality about eight kilometers south of Khundugang.

Petrographically the Takhtsang gneiss comprises quartz, plagioclase, K-feldspar, biotite and fibrolitic sillimanite. Muscovite occurs as small grains cross cutting well developed shear fabric. Quartz occurs as stretched lenticular ribbons. The sillimanite needles outline tight microscopic folds. Feldspar is also stretched, indicating development of this mylonitic fabric.

The leucogneiss comprises quartz, plagioclase and K-feldspar as the main minerals. Green and brown biotite is the main mafic mineral. Later biotite and muscovite cross cutting the earlier fabric are developed in some rocks. Muscovite forms very coarse flakes and also appears to rim the later formed biotite. Tourmaline is also a later addition to the mineral assemblage. The significant feature is the frequent occurrence of anastomosing veins showing mortar texture in virtually all the rock specimens collected from the west of the Jule *La*. The evidence of post-crystalline deformation in leucogneiss is also recorded in the upper reaches of the Mo *Chu* valley which indicates that this gneiss is distinctly older to the two-mica granite of the Moulakarchung and Gurpo *La* areas. This is one of the reasons for including these gneisses into the Takhtsang Formation.

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3.10 TETHYAN SEQUENCE

S.K. Tangri and A.C. Pande

In conformity with the geological configuration of the Himalaya in the adjoining countries of India and Nepal, the Bhutan segment also is characterised by the presence of a fossiliferous late Precambrian-Phanerozoic sedimentary sequence over the `Central Crystalline Rocks. This low to anchimetamorphosed rock sequence though of peri-Gondwana affinity has been referred to in the geological literature as the Tethyan succession. This Tethyan lithopack, riding over the Central Crystallines has been variedly translated southward over the Lesser Himalayan sequences. The Central Bhutan preserves the southernmost occurrence of the Tethyan rocks in the entire Himalayan Belt.

In the Bhutan Himalaya, the Tethyan rocks are exposed in four isolated sectors (Fig.3.10.1) viz., (i) Northern Higher Himalayan ranges, skirting Bhutan-China border (near Masakang, Toma La, Gorpu La, Bodu La and in the upper reaches of the Kuru *Chu* river system), (ii) near Tremo La and Lingshi in the west, (iii) Tang *Chu*-Black Mountain sector in the central and (iv) Sakteng-Mira sector in the east. The first two successions are southern extension of the Tethyan rocks of Tibet, while the latter two form independent occurrences.

The earliest reference to the Tethyan rocks in Bhutan was made by Hayden (1907) who indicated a possible extension of the Chumbi valley Tethyan succession into the Tremo La and Chomolhari areas. Subsequent contributions to the Tethyan succession were made by Nautiyal *et al*, (1964) and Gansser (1964). Detailed work in the Lingshi sector was carried out by Ganesan *et al*, (1978, 1982) and that in the Tang *Chu*-Black Mountain by Chaturvedi *et al*, (1983 a, b) and Passayat and Das (1976, 1977, 1984). The present work compiles and reinterprets earlier work in light of mapping and detailed observations made in a few crucial sections of the Black Mountain-Tang *Chu* sector by the present authors. Geological information of the Lingshi sector (Fig.3.10.1) is mainly after Ganesan *et al*, (1978, 1982) and Ganesan and Bose (1982).

Earlier workers (Gansser, 1983, Jangpangi, 1978, Ganesan and Bose, 1982, Chaturvedi *et al*, 1983a) have referred to these isolated occurrences of the Tethyan succession as independent basins. In view of highly comparable lithology and fossil contents the Tethyan sequences of all the above enumerated sectors in the present work are regarded to be part of the same basin, now separated due to folding and subsequent erosion along structural highs. The Tethyan sequences are preserved in synformal cores in the aforementioned sectors. The easternmost Sakteng sector exposes an early Palaeozoic succession, the other regions towards the west preserve progressively younger sequences. In the Black Mountain area the sequence ranges upto Early Carboniferous, in the Pe *Chu*-Tang *Chu* (Fig. 3.10.2), Lingshi valley, Masakang and Toma La regions the sequence ranges upto Cretaceous and further to the west Eocene rocks (Dzongbuk Shales) are known in the Kampa section of southern Tibet.

Since these sectors were mapped by different workers, varied lithostratigraphic classifications were proposed. Whereas well defined lithostratigraphic classifications exist in one area, these have been mixed up in other. The present work endeavours to sort out such anomalies. Though with the help of detailed descriptions of previous workers, possible mix-up of formations could be identified in earlier classifications, yet due to limited field observations delineation of such formations on map has not been feasible. In such cases we have worked out the anatomy of mixed-up terms but still retained old lithostratigraphic names in map and also in the text. The lithostratigraphy of the Tethyan sequence followed in this work is furnished in Fig.3.10.3. Description of various lithostratigraphic divisions is given below.

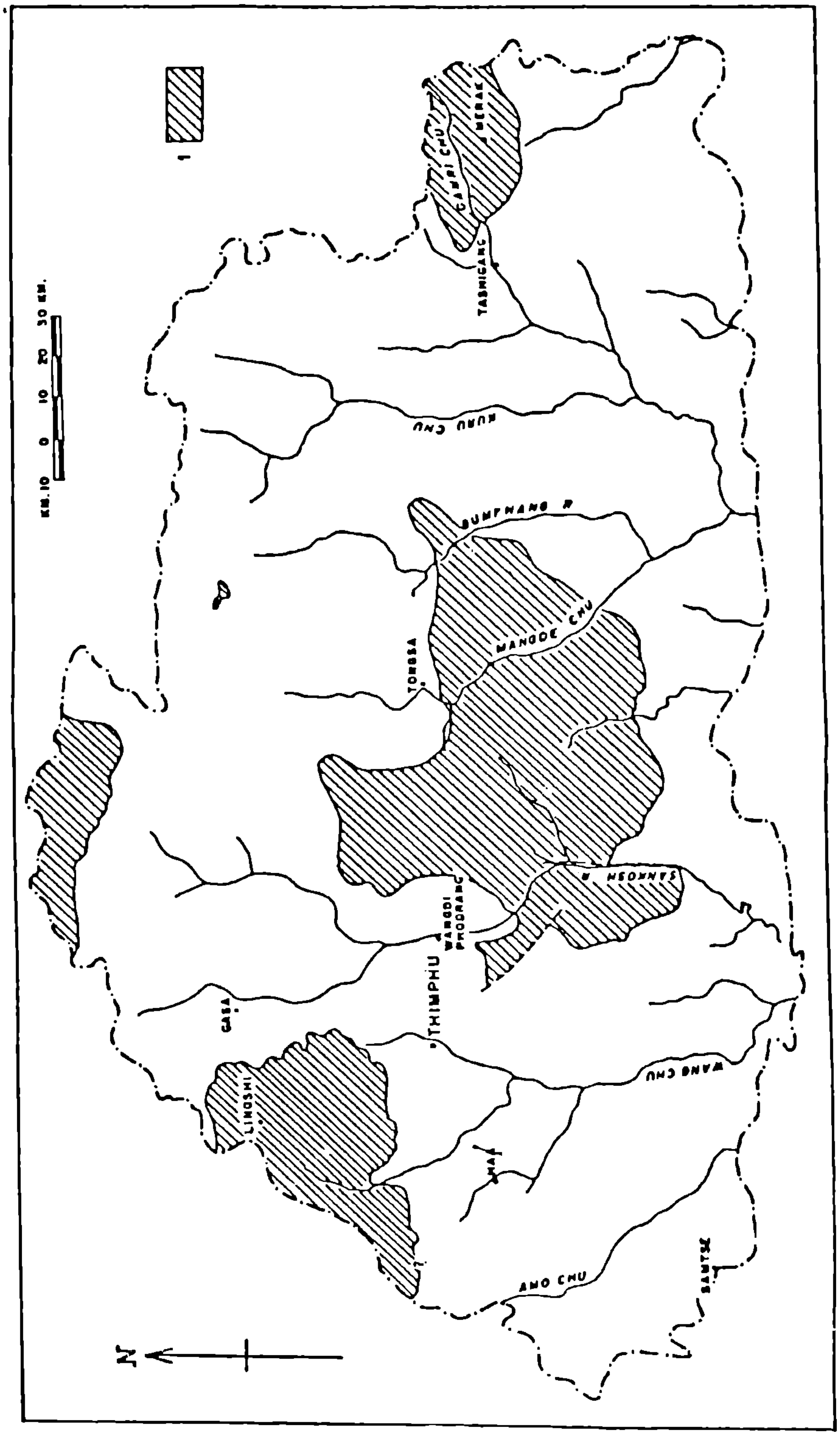


Fig.3.10.1 - Map showing distribution of the (1) Tethyan sequence in the Bhutan Himalaya.

A PANORMIC VIEW OF TANG-CHU NORTHERN RANGE

Fig.3.10.2 - Panoramic view of the northern Tangchu ranges.

Table-3.10.1 : DIFFERENT NOMENCLATURE/CLASSIFICATION ALONG WITH LITHOASSEMBLAGE PROPOSED FOR THE CHEKHA SEQUENCE OF BHUTAN

Nautiyal *et al*, (1964)	Pushkar Singh (1967)	Jangpangi (1965*, 1978)					Ganesan *et al*, (1978)	Gansser (1983)	Chaturvedi *et al*, (1983)	Pasayat & Das (1984)
CHEKHA SERIES	CHEKHA SERIES	C H E K H A F O R M A T I O N					CHEKHA FORMATION	CHEKHA FORMATION	MAOKHOLA GROUP	GONGKHOLA GROUP
		Chekha area	Linghshi area	Chendebji area*	Tirkhola area	Shamgong Dzong area				
Biotite porphyroblast sericite schists, quartzite, crystalline pink and fissile limestone, intruded by granite veins.	- White brownish massive quartzite, conglomerate. - Grey phyllite and quartzite with incipient development of biotite porphyroblasts. - Schist with biotite porphyroblast. - Quartz biotite schist. - Upper crystalline limestone. Calcareous quartzite and schist with biotite porphyroblasts. - Green, purple, grey phyllite, quartzite. - Lower crystalline limestone with graphitic, garnetiferous schist. - Garnetiferous schist & flaggy quartzite.	- Phyllite, slate & quartzite. - Crystalline limestone, slate & phyllite. - Biotite porphyroblastic schist & quartzite. - Crystalline limestone & phyllite. - Garnet, biotite schist and quartzite.	- Phyllite & slate. - Crystalline limestone & phyllite. FAULT - Calcsilicate, marble rocks of Barishong Dzong area.	- Quartzite (white brownish massive and sericitic near base), at times conglomeratic. - Dark grey, carbonaceous schistose rock, Budhi type schist in lower part. - Quartz biotite schist with quartzite. - Crystalline limestone. - Schist and quartzite, locally with Budhi type schist. - Crystalline limestone with garnetiferous schist.	- Quartzite with thin phyllite & limestone. - Phyllite with quartzite. THRUST - Quartzite. - Dark grey sericite phyllite. - Porphyroblastic schist (Budhi type) with quartzite. - Greenish grey schist. - Brownish grey quartzite, garnetiferous mica schist and limestone.	- Quartzite and phyllite, thick in Shamgong Dzong area. - Porphyroblastic schist and quartzite. - Phyllitic schist. - Garnetiferous mica schist with quartzite.	Grey and greenish grey phyllite & quartzitic phyllite with occasional lenticular limestone. Intruded by tourmaline muscovite granite.	Garnetiferous mica schists, biotite porphyroblast schist, grey-greenish grey phyllites, marbles, calc-schists & subordinate quartzite. At places the carbonate facies of the Chekha (Dando Gompa carbonate facies) becomes dominant. Intruded by tourmaline granite.	<u>Trikhola Fm.</u> - Dark grey carbonaceous phyllite and slate with grey quartz-sericite phyllite. - Thickly bedded subgreywacke, arkosic quartzite and grey micaceous quartzite, argillaceous interbands with biotite porphyroblasts. - Brown, buff calcareous quartzite with thin limestone bands. - Thickly bedded subgreywacke, arkosic quartzite, micaceous quartzite with thin phyllite schist interbeds. <u>Hara Chu Fm.</u> Calcareous phyllite with impure crystalline limestone, marble and thin subgreywacke beds.	<u>Rimtigang Chu Fm.</u> Limestone. <u>Rongpani Fm.</u> Phyllite-quartzite sequence. <u>Dodhre Fm.</u> Orthoquartzite conglomerate. <u>Birgaon Fm.</u> Carbonaceous phyllite schist.

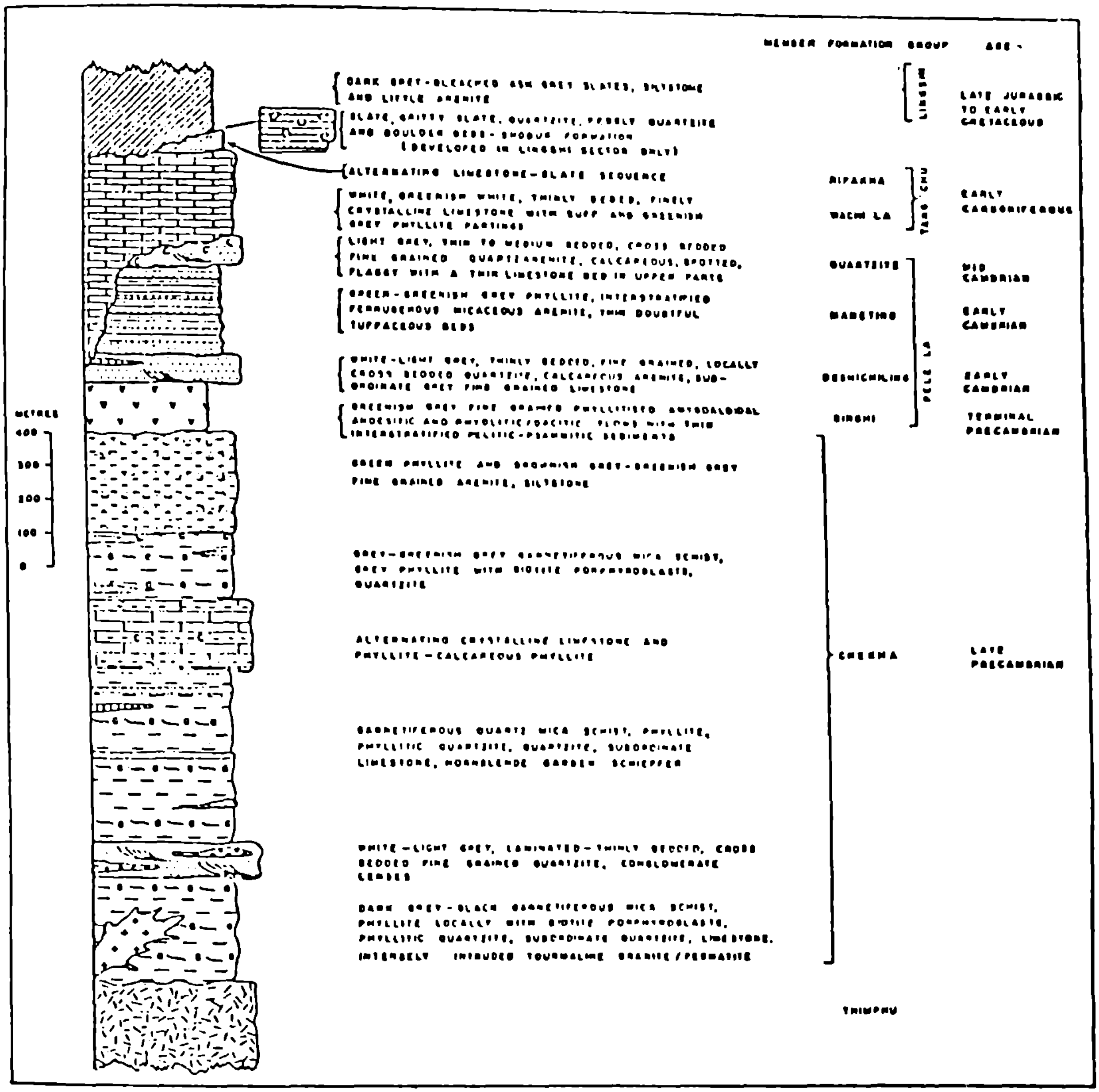


Fig.3.10.3 Generalised lithostratigraphy of the Tethyan sequence in Bhutan.

Chekha Formation

The name Chekha 'Series' was suggested by Nautiyal *et al*, (1964) after a village in the upper Paro valley for an argillo-arenaceous sequence resting above the 'Thimphu Gneissic Complex'. This formation in the Black Mountain area was referred to as Gongkhola Group (Passayat and Das, 1977, 1984) and also as the Mao Khola Group (Chaturvedi *et al*, 1983a). In the type section, only a limited sequence of the Chekha Formation is available; better sections are exposed along the eastern spur of the Black Mountain range. In the absence of precise definition, various workers included different lithounits in their Chekha Formation' (Table 3.10.1). The subdivisions Hara Chu Formation and the Tirkhola Formation of the Mao Khola Group (=Chekha) of Chaturvedi, *et al*, (1983a) were found untenable during recent mapping.

In the present work, the term Chekha Formation due to its priority has thus been retained. It is defined as an argillo-arenaceous sequence containing subordinate limestone, that rests over the high grade migmatitic gneisses of the Thimphu Group. The Chekha Formation towards top is delimited by the volcanics of the Singhi Formation, where these volcanics are absent, the Chekha Formation is succeeded by the younger Deshichiling or Maneting Formation.

The contact between the Chekha Formation and the Thimphu Group has been regarded as tectonic (Nautiyal *et al*, 1964, Singh, 1967), gradational (Jangpangi, 1978, Ganesan *et al*, 1978; Passayat and Dass, 1984, Gansser, 1964, 1983 and Chaturvedi *et al*, 1983a) and unconformable (Guha Sarkar, 1979).

The Thimphu Group includes sillimanite-bearing migmatitic gneiss while the overlying Chekha Formation at the maximum includes garnet and biotite bearing schist. Thus there is an abrupt and major metamorphic break in between these two sequences, which also show a sharp contact in the Buri *Chu*, Pe *Chu* and Sangsing La sections. The contact between the Thimphu Group and the Chekha Formation is, therefore, regarded as unconformable. This contact in several sections has been tectonised (e.g. Chendebji, Gorpu La sections) and in many sections masked by granitic intrusion and also partly diffused by Tertiary metamorphism. The upper contact of the Chekha Formation with the Singhi Volcanics/Deshichiling Formation and/or Maneting Formation is also unconformable.

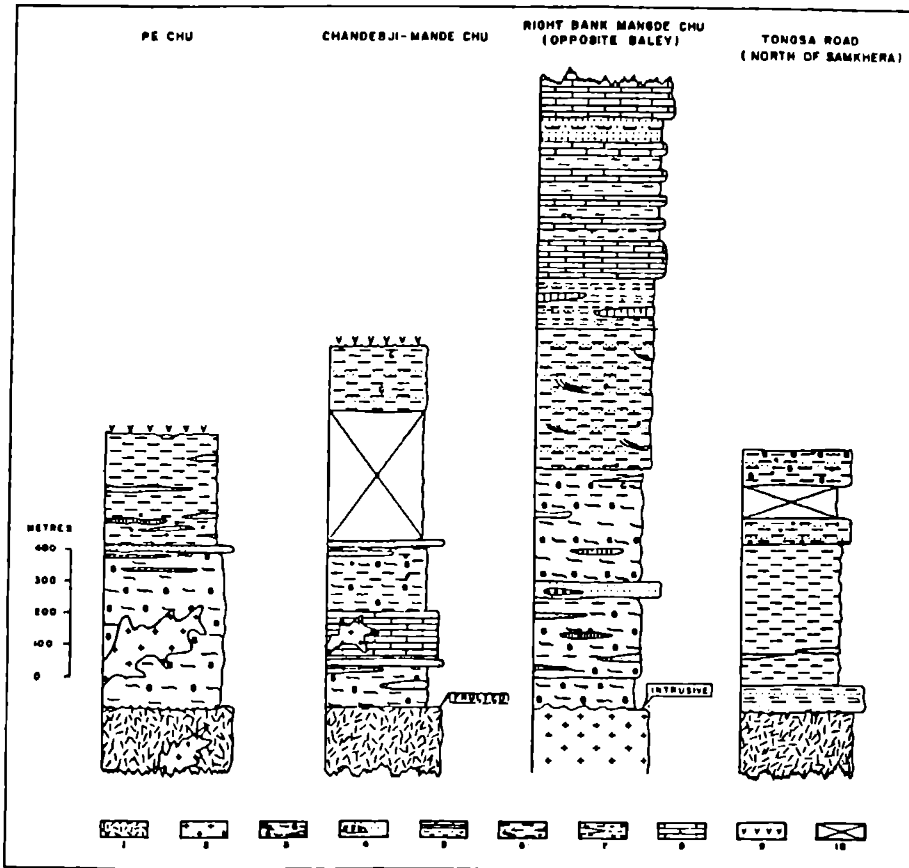


Fig.3.10.4 Generalised succession of the Chekha Formation along visually measured sections. (Right bank Mangde *Chu* section, partly measured partly reconstructed after details/working sheet of Pasayat and Das, 1976). 1. Thimphu Group, 2. Leucogranite, 3. Garnetiferous mica schist with quartzite, limestone interbeds, 4. Quartzite with conglomerate lenses, 5. Alternating phyllite/mica schists - crystalline limestone, 6. Laminated to thinly bedded phyllitic quartzite (sporadically cross-bedded) and quartzose schists (occasionally pyritous), 7. Alternating phyllitic quartzite - mica schist sequence with limestone lenses, 8. Crystalline limestone, 9. Singhi Formation, 10. No exposure zone.

The Chekha Formation comprises grey to greenish grey phyllite, garnetiferous mica schist, quartzose mica schist with frequent biotite-porphyroblasts, quartzitic phyllite, quartzite, limestone, hornblende garben schieffer and conglomerate in decreasing order of abundance. The biotite porphyroblasts contain straight inclusions of quartz that are in continuation with the dominant schistosity of the rock (Fig.3.10.5) pointing to their post-kinematic (F_1) origin. The garnet porphyroblasts have commonly developed across the dominant foliation and also contain straight inclusions of quartz (Fig.3.10.6). The biotite porphyroblast bearing schist has been compared with the Budhi schist of Garbyang section in the Kumaon Himalaya (Gansser, 1964, 1983). The Chekha Formation in the Lingshi

Table-3.10.2 : Major and trace element and normative composition of Singhi Volcanic rocks.
(SiO_2 to LOI values in percent and Cu to Sc in ppm)

Sample No./ Element	V2	V5	V6	V7	V8	V11	V12	V14	V16	V17	V18	V23	V24	Arithmetic Mean	Standard Deviation
SiO_2	57.35	57.22	58.00	59.60	58.15	53.02	54.79	57.60	54.10	55.71	56.05	62.72	59.61	57.22	2.59
TiO_2	1.14	1.19	0.95	1.28	0.90	0.85	0.95	1.04	0.71	1.00	0.71	0.38	1.04	0.93	0.24
Al_2O_3	22.52	17.00	15.50	16.80	17.52	15.40	14.67	16.90	14.93	16.88	14.54	17.18	16.61	16.65	2.04
Fe_2O_3	4.64	3.03	2.82	2.68	2.64	2.17	2.16	2.19	2.51	1.99	1.90	2.87	2.66	2.64	0.70
FeO	3.07	3.28	3.43	4.00	4.79	4.43	4.86	4.78	4.14	4.28	4.43	4.50	4.43	4.19	0.59
MgO	1.50	1.62	1.77	1.52	1.66	3.20	1.80	1.66	1.84	1.52	1.84	1.60	1.66	1.78	0.44
CaO	0.90	6.89	8.08	5.89	5.10	9.82	9.04	6.20	9.12	6.14	9.05	3.11	5.12	6.50	2.59
Na_2O	0.91	1.14	1.25	0.90	1.04	1.20	1.08	1.16	1.16	0.97	0.85	0.74	1.12	1.04	0.15
K_2O	4.69	3.44	2.80	2.94	3.12	3.14	1.67	3.00	2.44	3.15	3.00	3.87	2.89	3.17	0.58
MnO	0.02	0.05	0.06	0.05	0.06	0.09	0.07	0.07	0.08	0.06	0.07	0.02	0.06	0.06	0.0004
P_2O_5	0.08	0.15	0.04	0.04	0.15	0.04	0.06	0.04	0.10	0.08	0.02	0.02	0.04	0.07	0.04
LOI*	2.99	5.00	5.40	4.00	4.82	6.46	7.85	5.27	9.03	7.99	7.64	2.72	4.65	5.68	1.98
Total	99.81	100.02	100.10	99.70	99.95	99.82	100.00	99.91	100.15	99.77	100.10	99.73	99.89	99.92	0.15
Mg No.	27.60	27.85	28.70	22.85	21.32	36.00	22.40	21.32	25.79	21.71	24.47	21.71	22.63	24.95	4.24
Cu	30.00	100.00	150.00	95.00	95.00	115.00	60.00	155.00	125.00	45.00	220.00	50.00	170.00		
Zn	190.00	110.00	160.00	225.00	240.00	180.00	190.00	230.00	205.00	260.00	190.00	100.00	180.00		
Mo	6.00	8.00	9.00	7.00	7.00	6.00	6.00	6.00	12.00	8.00	7.00	7.00	7.00		
Ni	35.00	25.00	30.00	25.00	25.00	35.00	30.00	50.00	35.00	35.00	40.00	35.00	35.00		
Co	15.00	9.30	9.00	12.00	10.00	12.00	12.00	9.00	11.00	15.00	13.00	15.00	13.00		
Ba	2600.00	2200.00	1300.00	1200.00	1100.00	1000.00	850.00	900.00	800.00	1400.00	900.00	1450.00	1250.00		
Cr	129.00	97.00	68.00	76.00	65.00	74.00	69.00	80.00	62.00	95.00	72.00	88.00	106.00		
Rb	140.00	100.00	70.00	110.00	70.00	110.00	80.00	90.00	70.00	100.00	80.00	120.00	100.00		
Sr	190.00	410.00	310.00	300.00	250.00	330.00	380.00	290.00	910.00	1000.00	350.00	190.00	270.00		
Hf	8.90	5.50	4.80	5.00	5.00	4.80	2.10	4.00	3.70	5.00	3.00	15.00	5.10		
Ta	4.00	1.60	1.30	0.90	1.90	0.61	1.50	2.60	0.40	2.00	1.20	1.10	2.80		
Th	37.00	25.00	21.00	25.00	20.00	23.00	20.00	21.00	21.00	25.00	21.00	33.00	26.00		
Sc	28.00	19.00	13.00	15.00	14.00	16.00	13.00	16.00	13.00	19.00	15.00	16.00	16.00		
Zr	580	308	252	296	202	186	160	186	257	259	169	595	251		
Nb	63	28	33	47	24	12	24	24	13	23	13	36	33		
Y	200	115	48	90	67	48	52	51	51	65	38	90	75		
NORMS															
Q	28.10	21.03	22.16	28.13	25.78	11.30	19.00	22.47	18.80	22.54	20.32	32.07	27.92	23.12	5.46
C	15.01	0.00	0.00	1.59	3.70	0.00	0.00	0.60	0.00	0.98	0.00	6.36	2.55	2.37	4.25
Or	28.69	21.40	17.48	18.16	19.39	19.88	17.12	18.73	15.83	20.28	19.17	23.60	17.93	19.82	3.32
Pl	12.05	42.92	41.19	38.22	34.82	40.19	39.54	42.60	41.86	41.66	36.97	22.25	36.35	36.20	9.06
Hy	8.96	6.01	3.43	7.21	10.49	5.02	3.29	10.06	3.41	9.22	3.08	12.11	9.21	7.04	3.17
Mt	3.96	4.11	3.75	4.06	3.66	3.37	3.40	3.36	3.52	3.14	2.98	2.81	3.87	5.84	8.29
Il	2.24	2.38	1.91	2.54	1.80	1.73	1.96	2.09	1.48	2.07	1.46	0.74	2.07	1.88	0.47

*Loss on ignition of sample at 950°C; includes $-H_2O$.

Table-3.10.3 : Rare earth element data (in ppm) of the Singhi Volcanic rocks (Normalising values used in element ratio calculations are from Sun and McDonough, 1989)

Sample No./ Element	V2	V5	V6	V7	V8	V11	V12	V14	V16	V17	V18	V23	V24
La	97.00	66.00	54.00	53.00	47.00	48.00	44.00	52.00	50.00	47.00	49.00	76.00	59.00
Ce	186.00	128.00	111.00	111.00	106.00	112.00	98.00	115.00	112.00	100.00	100.00	170.00	118.00
Nd	79.00	60.00	52.00	52.00	51.00	54.00	49.00	54.00	54.00	50.00	49.00	79.00	57.00
Sm	16.00	9.70	7.90	8.00	7.70	8.20	6.50	7.70	7.70	7.50	7.20	12.00	8.80
Eu	2.70	1.50	1.20	1.30	1.00	1.30	1.10	1.20	1.10	1.10	1.20	1.70	1.40
Tb	1.50	1.10	0.51	0.50	0.50	0.40	0.55	0.57	0.72	0.73	0.55	0.68	0.49
Yb	5.20	2.70	1.20	1.90	1.40	1.20	1.50	2.20	1.70	2.40	1.00	1.70	1.40
Lu	0.77	0.30	0.15	0.30	0.20	0.16	0.18	0.35	0.22	0.32	0.13	0.18	0.17
REE	388.17	269.30	227.96	228.00	214.80	225.26	200.83	230.02	227.44	209.05	208.08	341.26	246.26
RATIO													
(La/Ce)N	1.36	1.35	1.27	1.24	1.16	1.12	1.17	1.18	1.16	1.23	1.28	1.17	1.30
(La/Nd)N	2.38	2.13	2.01	1.97	1.78	1.72	1.74	1.86	1.79	1.82	1.94	1.86	2.00
(La/Sm)N	3.82	4.28	4.30	4.17	3.84	3.68	4.26	4.25	4.09	3.94	4.28	3.99	4.22
(Ce/Nd)N	1.75	1.58	1.58	1.58	1.54	1.54	1.549	1.58	1.54	1.48	1.52	1.60	1.54
(Ce/Yb)N	9.26	12.27	23.93	15.13	19.60	24.14	16.91	13.53	17.05	10.79	25.88	25.87	21.82
(Tb/Yb)N	1.27	1.80	1.87	1.16	1.58	1.47	1.62	1.14	1.87	1.34	2.42	1.77	1.55

sector is continuation of the Khongbu Series (Hayden, 1907) of the Chumbi valley and correlatable with the Everest Pelite (Gansser, 1964).

The rocks of the Chekha Formation are intruded by basic rocks - metamorphosed to amphibolite, tourmaline granite, pegmatite veins (locally containing beryl) and thin quartz veins.

The Chekha Formation in the Lingshi sector is exposed towards south and southwest upto the Ha valley, in eastern, northern and northwestern parts it has been tectonically eliminated. In the Tang *Chu*-Black Mountain and Sakteng areas it is extensively developed. A generalised succession commences with a thick sequence of grey, greenish grey, garnetiferous mica schist with biotite porphyroblasts. The sequence is intensively intruded by tourmaline granite-pegmatite and quartz veins. It is followed upward by a greyish white to white fine grained quartzarenite sequence that locally is cross-bedded and contains oligomictic conglomerate lenses. It is succeeded in turn by a garnetiferous mica schist, quartzose mica schist, schistose quartzite lithopack which becomes gradually more quartzose in the upper level. This lithopack characteristically contains prolific thin impersistent bands (0.5-30cm) of garnetiferous hornblende garben schieffer. The quartzite is grey, laminated to thinly bedded and commonly exhibits low angle truncation and tabular cross-bedding. West of Sankosh river-Hara *Chu* confluence, a few interstratified quartzarenite beds show hommocky cross-bedding. These sediments also exhibit common development of the biotite porphyroblasts. It is succeeded by a thinly interstratified sequence of crystalline limestone and phyllite/schist. Occasionaly the succession contains upto 150m thick white to greyish white, fine to medium grained crystalline limestone bands - e.g. the Chendebji limestone band. This lithosuccession is followed by grey, frequently thinly (0.2-3cm) bedded phyllite/schist-siltstone sequence which also locally contains the garnet and biotite porphyroblasts. In the upper parts it contains a few white to grey fine grained quartzarenite beds. Locally (e.g. Dechi Faka village) the Chekha Formation, in its upper part contains a thinly interlaminated sequence of green phyllite and brownish grey to greenish grey fine grained arenite and siltstone. A generalised succesion of the Chekha Formation in various sections is presented in Fig.3.10.4.

PELE LA GROUP

It is a newly constituted stratigraphic unit named after the famous pass `Pele La' on the Wangdi Phodrang-Tongsa road, around which two of its formations are developed. It corresponds to a part of erstwhile Chekha Formation, Mao Khola Group and the Black Mountain Group of Chaturvedi *et al*, (1983a). The creation of this new group has been necessitated by the recognition of a thick volcanic suite above the Chekha succession (Tangri *et al*, 1994).

The Pele La Group overlies the Chekha Formation along a major unconformity, manifested by a thick volcanic suite at its base. The upper contact of the Pele La Group with the Tang Chu Group is also unconformable.

The Pele La Group constitutes (i) Singhi Formation, (ii) Deshichiling Formation (iii) Maneting Formation and (iv) Quartzite Formation (Fig.3.10.7).

Singhi Formation

This basal stratigraphic unit of the Pele La Group is named after Singhi village in the Pe *Chu* valley. The Singhi Formation shows best section along the irrigation channel on the right bank of the Pe *Chu*, about 1.5km south of the Sha Slate Mine Guest House and about six kilometers SW of Chendebji.

In earlier maps (Chaturvedi *et al*, 1983a, b; Anon, 1983, 1991) this formation formed part of the Tirkhola Formation (present authors' Chekha Formation) over which it has now been found to rest unconformably. The Singhi Formation forms a narrow WNW-ESE trending linear belt, extending from west of village Singhi to Rachau in the east. Further east of Rachau, it attains a NW-SE trend and is exposed SSE of Nobding along the water divide between the Tang *Chu* and Nake *Chu* valleys. Due to paucity of outcrops, coupled with its possible thinning towards the south, it has not been delineated in the southern sectors of the basin. Another outcrop of this formation has been delineated intermittently over a distance of about 500m in the area SW of Chendebji.

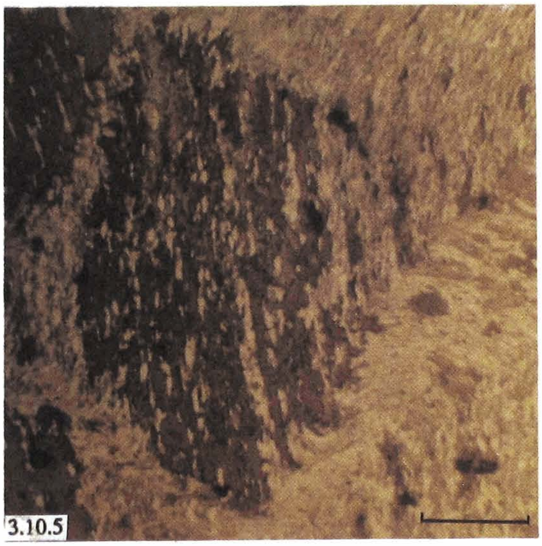


Fig.3.10.5 Porphyroblast of biotite containing straight inclusions of quartz in continuation with the schistosity. Chekha Formation. Bar length 0.5mm.

In the upper Ha Valley, west of Khandugang peak, a similar volcanic suite overlies a thin (approx.50m) quartzite sequence of the Chekha Formation (Dasgupta and Golani, 1994).

Volcanics of the Singhi-Rachau-Nobding Area

The Singhi Formation in this stretch comprises greenish grey to light grey, dominantly laminated, aphyric, commonly amygdaloidal basic flows and pyroclastics (Fig.3.10.8), now metamorphosed to pyritous phyllite. The amygdules (Fig.3.10.9) are commonly filled with quartz, chlorophaeite and calcite, which are mostly concentrated along the top of individual flows. The amygdules have been stretched due to deformation. Towards base, the volcanic flows are intercalated with a few thin (0.02-2m) very fine grained arenaceous intertrappean beds (Fig.3.10.10). The volcanic flows, pyroclastics and intertrappeans largely occur in cycles in the following ascending order : volcanic flow -- pyroclastics -- intertrappeans. A small outcrop about 100m short of 14km stone along the Chuzomsa - Sha Slate Mine road preserves two such complete cycles. The pyroclastics are represented by silty phyllite containing <1mm to 9mm size deep green volcanic clasts (Fig.3.10.8). The volcanic suite except for variable density of amygdule/vesicle has consistent megascopic characters and is devoid of crustal or mantle xenoliths. Fine quartz veins parallel as well as across the foliation/primary lamination of volcanics are common.

Microscopically the phyllitised volcanics are dominantly represented by pyritous, calcareous quartz-sericite-chlorite phyllite, whose foliation is defined by parallel aligned phyllosilicates and elongated quartz grains. Coarse calcite generally occurs concentrated in layers.

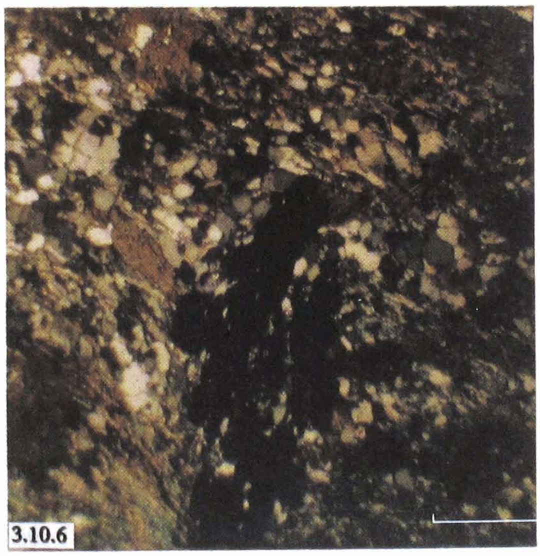


Fig.3.10.6 Poikilitic garnet porphyroblast developed across the dominant foliation, containing inclusions of quartz. X nicols. Bar length 0.5mm.

In general the Singhi Volcanics are characterised by 53-62% SiO_2, high Al_2O_3 (14-23%), K_2O (2.44-4.69%) and low TiO_2 (0.38-1.28%), Na_2O (0.74-1.25%) and P_2O_5 (0.02-0.15%) contents (Table 3.10.2). K_2O abundance is consistently more than twice that of the Na_2O. Volcanics of the Singhi Formation (Table 3.10.2) are quartz normative in nature (q=11.3-32.07%); in a few cases corundum normative is also decipherable.

The major and trace element chemistry suggests an evolved character of the volcanic suite which is also corroborated by their low Ni abundance and Mg Numbers. The Mg No. ranges from 21.32 to 36 with majority of them lying between 21 and 26. The Solidification Index of the suite also exhibits a wide variation from 10.13 to 22.63, though dominantly the values range between 12.52 and 15.31, indicating an andesitic affinity.

Fig.3.10.8 Polished slab showing volcanic pyroclastics, concentrated in layers. Singhi Formation. Bar length 7mm.

All the samples of the Singhi Volcanics fall under Basaltic-andesite and Andesite fields in Total Alkali-Silica (TAS) diagram (Fig.3.10.11a) conforming to potassium type (Le Maitre 1984). The andesitic classification is also confirmed by the Triaxial plot (Fig.3.10.11b) of FeO + Fe_2O_3 + 1/2 (MgO+CaO) versus Al_2O_3/SiO_2 and Na_2O+K_2O after Church (1975).

The K_2O-SiO_2 plot (Fig.3.10.12a) places the Singhi Volcanics into the High-K Calc-alkaline-Shoshonite Series. The Al_2O_3 versus Normative plagioclase plot (Fig.3.10.12b) (Irvine and Baragar, 1971) which are relatively immune to the alkali loss, identify ten out the thirteen samples of the Singhi Formation as belonging to the Calc-alkaline Series. The Calc-alkaline-Shashonite affinity of the present suite is also supported by the Chondrite normalised REE abundance pattern (Fig.3.10.13) and the Th/Yb-Ta/Yb plot (Fig.3.10.14a) of the Singhi Volcanics.

All the samples of the volcanics indicate REE enrichment from about 142-313 x chondrite for La and about 4-24 x Chondrite for Lu (Table 3.10.3). The chondrite normalised REE abundance pattern (Fig.3.10.13) exhibits a strong LREE enrichment with (Ce/Yb)N ratio ranging between 9.26 and 25.88, and a comparatively much less fractionated HREE with (Tb/Yb)N ratio varying from 1.14 to 2.42. The REE abundance pattern shows an affinity with that of a High K-Calc-alkaline Magma Series, thus corroborating the inference drawn regarding the calc-alkaline nature of the Singhi Volcanics on the basis of major element chemistry.

The Normal Mid-Oceanic Ridge Basalt (NMORB) normalised trace element spiderdiagram (Pearce, 1983) of the Singhi Volcanic suite (Fig.3.10.15) has a spiked character with K, Rb, Ba and Th showing great enrichment and a distinct depletion of Ta-Nb and P. Besides, the Ce and Sm contents exhibit an enrichment with respect to their NMORB concentration. This pattern resembles that of a subduction related High K-Calc-alkaline basalt.

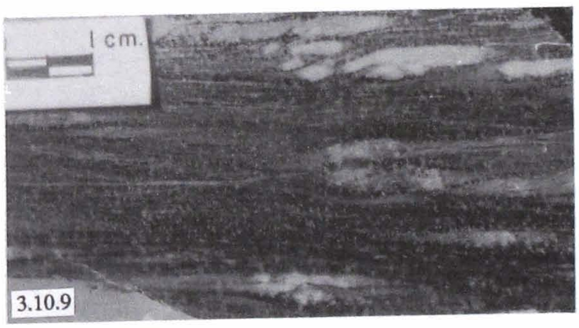


Fig.3.10.9 Polished slab of andesite showing tectonically stretched quartz - filled amygdules.

The subduction related characteristics of the Singhi Volcanics are also substantiated by the Th/Yb vs. Ta/Yb, (Fig.3.10.14a) and Th-Hf-Ta (Fig. 3.10.14b) tectonomagmatic discrimination

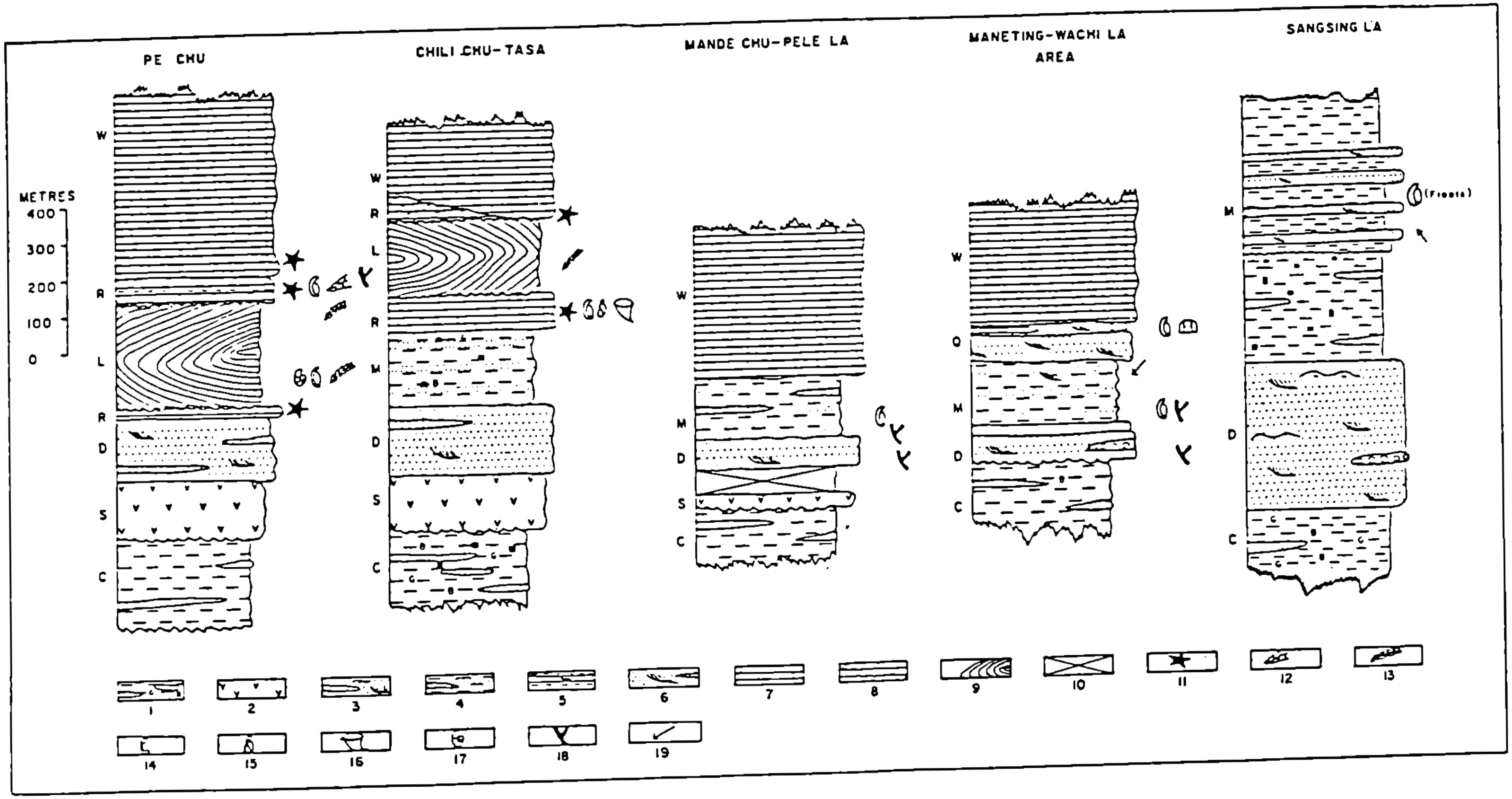


Fig.3.10.7 - Generalised post-Chekha lithosuccession along a few visually measured sections in Black Mountain-Tang *Chu* sector. 1. Phyllite/schist locally garnet, biotite porphyroblast bearing, pyritous with thin quartzite, limestone interbands, 2. Pyllitised amygdaloidal andesitic flows, pyroclastic, 3. Fine grained quartzite cross-bedded, ripple-drift laminated with subordinate limestone and local oligomictic conglomerate, 4. Phyllite locally pyritous and containing biotite porphyroblasts interstratified with quartzwacke and ferruginous micaceous arenite and local limestone, 5. Lithology at '4' alternating with thick quartzarenite, 6. Quartzarenite locally cross-bedded, calcareous with a limestone band in the upper part, 7. Thinly bedded limestone with phyllite partings, 8. Alternate limestone-slate, 9. Slate-siltstone, 10. No exposure zone, 11. Crinoid ossicle, 12. *Fenestella*, 13. Plant fossils, 14. Brachiopod, 15. Gastropod, 16. Coral, 17. Ammonoid, 18. Trace fossils, 19. Palaeocurrent. C = Chekha Formation, S = Singhi Formation, D = Deshichiling Formation, M = Maneting Formation, Q = Quartzite Formation, R = Ripakha Formation, W = Wachila Formation, L = Lingshi Group.

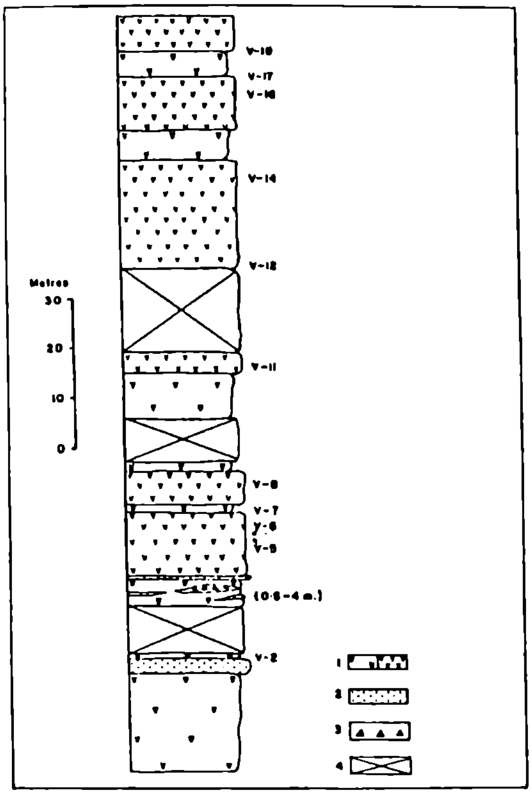


Fig.3.10.10 Lithostratigraphic section of the Singhi Formation xposed along the irrigation canal on the right bank of Pe *Chu*. 1. Grey, greenish grey phyllitised sparsely/densely amygdaloidal/vesiculer flows, 2. Fine grained arenaceous intertrappean bed, 3. Pyroclastic, 4. No exposure zone. Numbers on right represent geochemical sample numbers.

diagrams (after Wood, 1980, Pearce, 1983 and Thompson *et al*, 1980 respectively). On the former diagram the Singhi Volcanics plot in the Lower left Th-rich part of the "Subduction related volcanics" field, whereas on the Th/Yb vs. Ta/Yb plot, they fall dominantly near the "active continental margin field (only two out of the thirteen samples plot within the said field).

Volcanics of the Chendebji Area : The outcrops SW of Chendebji comprise a sequence of acid volcanics. These were discovered by the present authors after the conclusion of the main work. Though the petrochemical and isotopic analysis are still underway, in view of the significance of this discovery a passing reference to this suite is being made here. The volcanics are represented by dirty white to cream coloured, fine to medium grained dominantly porphyritic dacitic/rhyolitic flows. In all six flows ranging in thickness from one metre to about 22 metres were logged. These are separated by three to 35m thick, laminated to thinly bedded light grey-white, phyllite-siltstone sequence, which exhibits sporadic development of the biotite and rare garnet porphyroblasts. Some of the flows bear a streaky look. Under microscope the porphyritic variety comprises dominantly euhedral to subhedral phenocrysts of plagioclase, quartz and sporadically of perthite set in a fine grained groundmass material made up of subhedral quartz, plagioclase and biotite with sphene and apatite in accessory amount. The quartz phenocrysts show occasional bipyramidal shape. The perthitic phenocrysts in rare cases have a reaction rim.

The argillo-arenaceous Chekha Formation, the clastic intertrappean beds in the Singhi Formation and the quartzarenite-limestone succession of the overlying Deshichiling Formation exhibiting low angle truncation and flaser bedding, indicate shallow near-shore palaeo-environment. Shallow basinal environment at the time of Singhi volcanicity is also evident by the

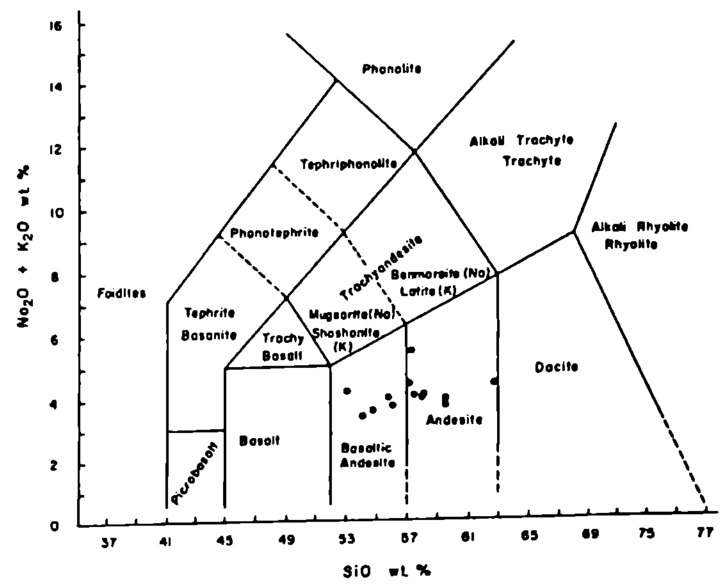


Fig.3.10.11a. Rock classification plots for Singhi Volcanic rocks (Pe *Chu* section).
a) Total alkali-silica diagram after Maitre (1984).

high density of the vesicles and absence of the pillow structures in the volcanics.

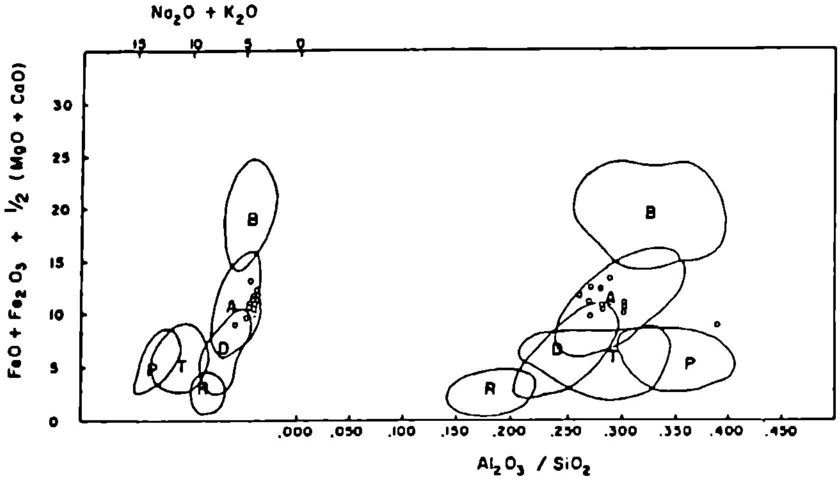


Fig. 3.10.11b. Rock classification plots for Singhi Volcanic rocks (Pe *Chu* section). Triaxial plot of $FeO + Fe_2O_3$ + 1/2(MgO+CaO) versus Al_2O_3/SiO_2 and Na_2O+K_2O, after Church (1975); = Basalt, R = Rhyolite, A = Andesite, T = Trachyte, D = Dacite, P = Phonolite; latter designated rock types are positioned near Daly's (1933) averages.

These bimodal volcanics denote a major geological event, having a significant bearing on the evolution of the Tethyan basin. The stratigraphic position of the volcanic suite, just above the unfossiliferous Chekha Formation and below the Deshchiling-Maneting Formations containing ?Precambrian-Cambrian ichno-fossil assemblage and early Cambrian brachiopods suggests it to be a possible terminal Precambrian event, equivalent of which have been recorded from many parts of the world.

Deshichiling Formation

Named after Deshichiling Gompa (Tangri and Pande, 1994) this formation is exposed along the irrigation channel on the right bank of the Pe *Chu* (Fig.3.10.16) about 1.25km south of the Sha Slate Mine Guest House. From the Pe *Chu* valley in the west, it extends as a linear belt upto Nobding in east, where it has greater outcrop width due to a series of folds. It is also exposed all along the higher reaches of the northern Black Mountain range.

The Deshichiling Formation represents a marker bed of supra-volcanic arenite dominated sequence. The arenite of this formation were also referred to by Chaturvedi *et al*, (1983a) as the Nake Chu Formation which as stated earlier was assigned an Ordovician age. The present Deshichiling Formation is distinct from the Chekha Formation and is older than Ordovician. Thus to avoid confusion with a well known name having specific stratigraphic position, a new name has been suggested.

The Deshichiling Formation consists of light grey, greyish white, buff to brown, dominantly thin (0.2-10cm), rarely medium (upto 30cm) bedded, fine grained quartzite with thin partings (0.1-3cm) of buff, greenish grey rare pyritous phyllite

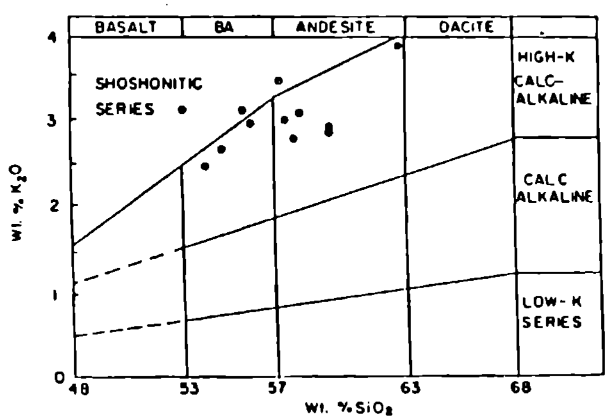


Fig.3.10.12a. Magmatic identification plots for the Singhi Volcanic ocks (Pe *Chu* section). (Wt. %) K_2O-SiO_2 (after BVSP-1981).

and thin (0.1-10cm) laminations/beds of greyish white, fine grained limestone, calcareous quartzite and local oligomictic conglomerate in the basal part of the sequence. Southeast of Nobding, thin (0.1-1.5m) beds of greyish white, fine grained limestone are present in the upper part of the sequence. The arenites exhibit cross-bedding, low angle truncation and flaser bedding. The cross-bedding is dominantly grouped, small to medium scale, low angled (15° to 20°) trough type (Fig.3.10.17,18). North of Samkhera along the Geylegphug-Shamgang road the quartzite sequence comprises 40-90cm thick cycles (Fig.3.10.18) in which medium scale cross-bedded units (height 15-25cm) are overlain gradually by smaller scale cross beds, which at places are topped by ripple drift laminated to even parallel laminated units or a thin argillaceous bed. Channel fill structures upto a width of six metres and thickness of 1.5m have been recorded. The

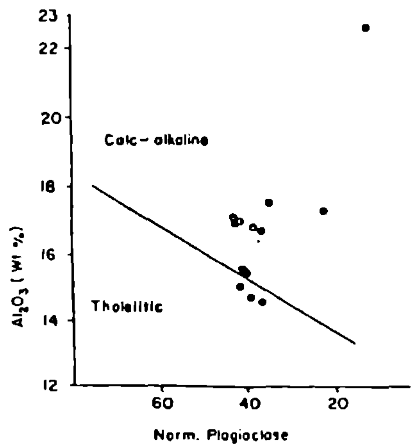


Fig. 3.10.12b. (Wt. %) Al_2O_3-Normative plagioclase, field boundaries of Bowen *et al*, (1986).

quartzite locally contains 0.1-7m thick impersistent beds to lenses of clast supported oligomictic conglomerate (Fig.3.10.19,20) composed of moderate to well sorted, subangular to subrounded pebble to cobble of white, light grey quartzite and vein quartz set in a quartzitic matrix. In the Tintibi area the pebbles in the conglomerate exhibit intense tectonic stretching (Fig.3.10.20,21). The conglomerate horizons occur at different stratigraphic levels.

From the section east of Mane Ting, near the bifurcation of the tracks for Chendebji and Wachi La and from the Mande *Chu* valley, the quartzarenite of the Deshichiling Formation has yielded a rich concentration of ichnofossil *Planolites* (Fig.3.10.22). This is the earliest sign of life in the Tethyan sequence of Bhutan.

The simple ichno-assemblage of *Planolites* and absence of any body fossils in the entire sequence may indicate a latest Precambrian age for the Deshichiling Formation. Such an age interpretation is also supported by the occurrence of early Cambrian trace fossils and primitive phosphatic lingullid brachiopods in the overlying Maneting Formation.

Maneting Formation

The name Maneting was originally proposed by Chaturvedi *et al*, (1983) for a thick fossiliferous siliciclastic sequence overlying quartzitic and conglomeratic Nake Chu Formation.

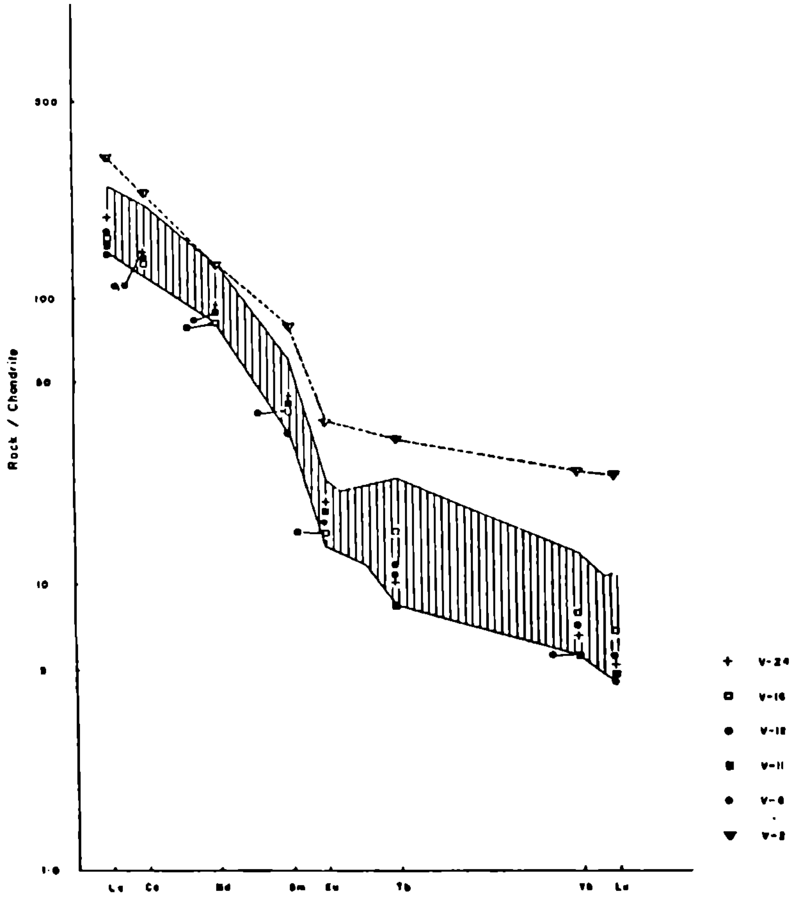
Chaturvedi *et al*, (1983a) divided the Maneting Formation into eight members (viz. A to H) in which the sequence from Members A to F is largely argillo-arenaceous and that of G and H is arenaceous.

Since the lithological distinction is marked and the two individual units being mappable, the present authors have restricted the term `Maneting Formation' for the lower argillo-arenaceous sequence (i.e. upto Member `F' of Chaturvedi *et al*, 1983).

The Maneting Formation overlies the Deshichiling Formation along a gradational contact. The Maneting hill, where it is best exposed, lends its name to the formation. Its outcrops also cover a large expanse of the higher reaches of the northern Black Mountain range, including the Pele La section. In the southern part it commonly occupies the cores of tight synclines. Possibly due to the absence of marker Singhi Volcanics or easily distinguishable Deshichiling quartzite in certain sections, the Maneting Formation has not been differentiated by earlier workers from the underlying Chekha Formation (e.g. northwest of Shemegong in Anon, 1984, 1991).

The Maneting Formation comprises a monotonous (rhythmic) sequence of green to greenish grey, laminated phyllite interstratified with thin (0.5-3cm) beds of greenish grey, earthy green, fine grained quartz wacke, brown fine grained micaceous, ferruginous arenite, quartzarenite and sporadic thin (0.2-3cm) beds of grey fine grained limestone. The sequence becomes dominantly silty towards the top and exhibits low angle truncation, flaser, mud draped bedding (Fig.3.10.23), small scale ripple

Fig.3.10.13 Chondrite normalised REE abundance pattern of the Singhi Volcanics (Pe *Chu* section). Vertical lines indicate the range of Chondrite normalised REE pattern of 12 samples of the Singhi Volcanics. The pattern of sample V-2 is shown separately. The symbols denote concentration of different REE in a few representative samples. Normalising values after Sun and McDonough (1989).



lamination and occasional small to medium scale (5-10cm) solitary low angled tabular cross-bedding. Southeast of the Maneting Hill along the track to Wachi La, the thin horizon of light grey, pitted, silty volcanogenic rock has been identified in the basal part of the sequence. It probably corresponds to the light buff coloured phyllitic meta-volcanic flows and tuff (Member-D) of the Maneting Formation of Chaturvedi *et al*, (1983a). However, no such lithotope could be located in the Pele La and Sangsing La sections. Paraconglomerate and minor andesitic lava and tuff beds have been reported from this stratigraphic unit from the Gongkhola-Nobji *Chu* valley area (Bandyopadhyay and Gupta, 1990).

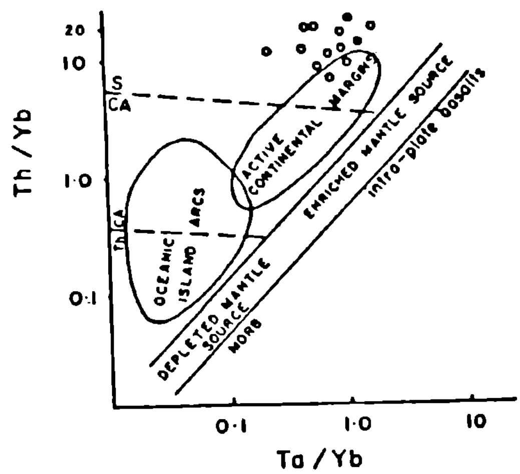


Fig.3.10.14a. Tectonomagmatic discrimination diagrams of the Singhi Volcanics (Pe *Chu* section). a) Th/Yb-Ta/Yb plot (after Pearce, 1983). Th = Tholeiitic, CA = Calc-alkaline, S = Shoshonite fields.

The Maneting Formation has yielded a rich assemblage of trace and body fossils. The ichnofossils collected from the base of the formation exposed in the Mangde *Chu* include

Planolites and *Cochlichnus* (Figs.3.10.24,25). A little above the trace fossil-bearing horizon, appear thin (0.2-2cm) richly fossiliferous, dominantly brown, sporadically greenish grey arenite beds at several stratigraphic levels. These

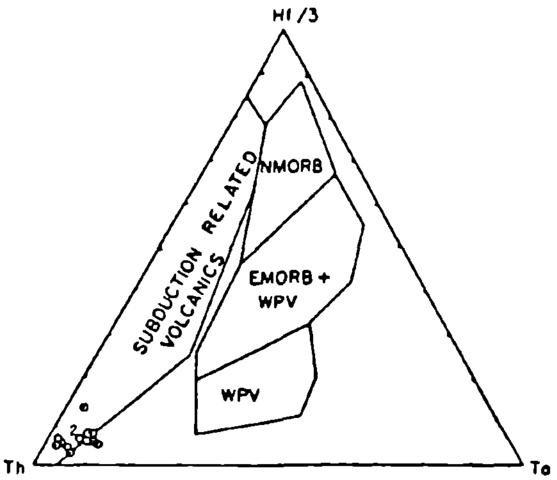


Fig.3.10.14b. Tectonomagmatic discrimination diagrms of the Singhi Volcanics (Pe *Chu* section). Th-Hf-Ta diagram (after Wood, 1980). NMORB, EMORB = Normal and enriched ocean ridge basalt respectively, WPV = Within plate volcanics.

fossiliferous beds contain rich concentration of comminuted as well as whole shells of brachiopod *Lingulella* (Fig.3.10.26) possibly as tempestite layers (Fig. 3.10.27). In the Maneting Hill area, though due to the paucity of exposures it is difficult to construct an exact lithocolumn, yet the following possible sequence of ichno-assemblage could be made out.

(e) *Monomorphichnus* (Fig.3.10.28)

(d) *Didymaulichnus* (Fig.3.10.29)

(c) *Phycodes pedum*, *Arenicolites*, *Helminthopsis* (Figs. 3.10.30-32), *Palaeophycus*.

(b) *Gordia* (Fig.3.10.33),

(a) *Planolites* (Fig.3.10.24).

Following Crimes (1994), the Precambrian-Cambrian boundary can be located between horizons b and c. In the upper stratigraphic levels of this formation, beside the trace fossils lingulellid bearing horizons (similar to the ones found in the Mande *Chu* area) also appear. In the Pele La section, the trace fossils are confined only to the basal 15m of the succession. The lingulellid fossils appear about 30m above the trace fossil

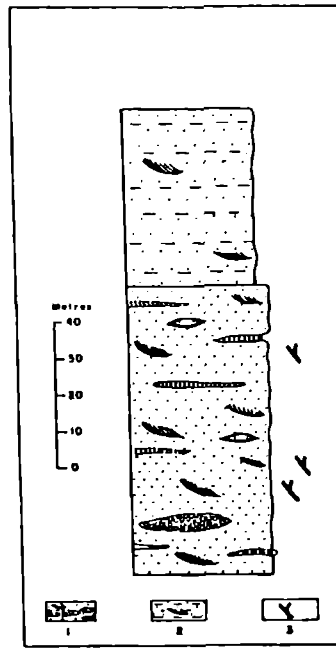


Fig.3.10.16 Synthesised lithostratigraphic section of the Deshichiling Formation. 1. Grey-white thin to medium bedded quartzite with cross and flaser bedding, local limestone and oligomictic conglomerate intercalations, 2. Thinly bedded buff-greyish white flaggy quartzite, occasional cross-bedding, thin phyllite partings, 3. Trace fossils.

level. In the Sangsing La section, also a few boulders containing rich concentration of lingulellid shells have been recorded.

Chaturvedi *et al*, (1983a) reported the following body fossils from the Maneting Formation :

Brachiopod	*Glossella* sp., *Lingulella* sp.
Lamellibranch	*Ctenodonta* sp., *Palaeoneilo* sp.

The body fossils together with the ichnofossils suggest an early Cambrian age for the redefined Maneting Formation.

Quartzite Formation

This new proposed stratigraphic unit, named after its distinctive lithology, gradationally overlies

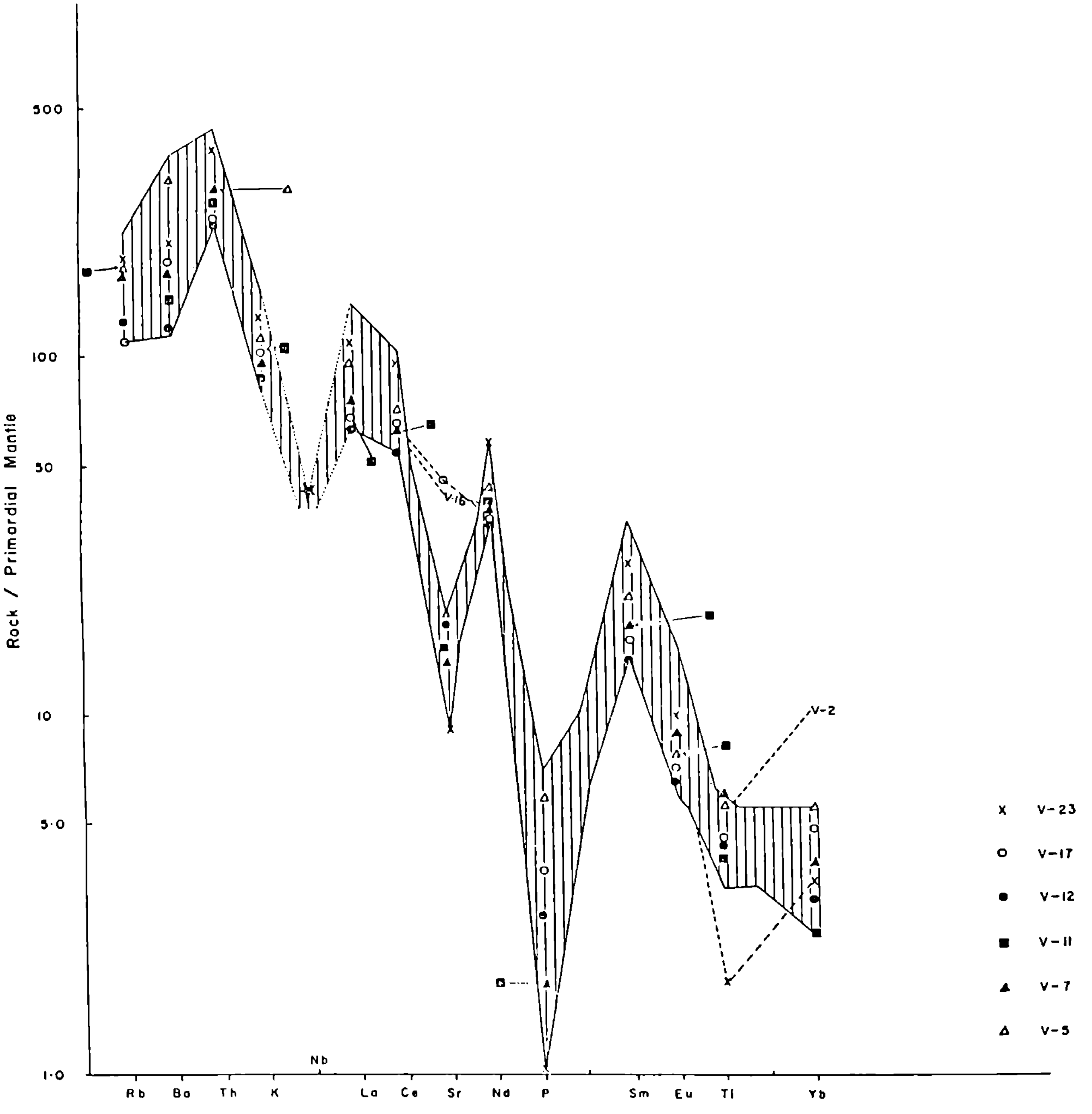


Fig.3.10.15 - NMORB normalised trace element pattern of the Singhi Volcanics (Pe *Chu* section) (after Pearce, 1983). Vertical lines indicate the range of NMORB normalised trace element pattern. Symbols denote the abundance of element in a few representative samples. (Normalising values after Sun and McDonough, 1989).

the Maneting Formation. By virtue of its characteristic lithology and rich faunal content, the Quartzite Formation constitutes a marker unit in the area. It is best exposed as a distinct band in the higher reaches of the Wachi La-Black Mountain ranges. In the areas further to the north, it has

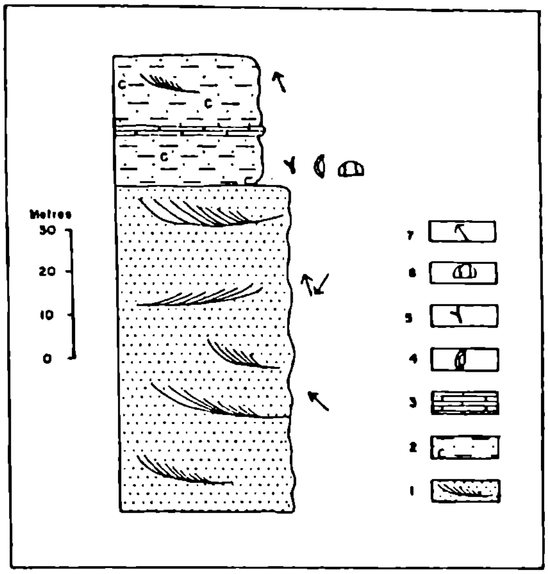


Fig.3.10.34 Lithostratigraphic section of the Quartzite Formation, Maneting-Wachi La area. 1. Cross-bedded quartzite, 2. Quartzite locally calcareous and cross-bedded with thin phyllite interbeds, 3. Limestone, 4. Brachiopod, 5. Trace fossils, 6. Trilobite, 7. Palaeocurrent.

possibly been overlapped by the Wachi La Formation. Since no locality name exists nearby it has been named after its distinct lithology. It corresponds to the Member G and H of the Maneting Formation of Chaturvedi *et al*, (1983a).

The Quartzite Formation (Fig.3.10.34) consists of a basal 75m thick sequence of light grey, thin to medium bedded (5-15cm) fine grained quartzarenite showing medium scale, low angle tabular cross-bedding. It is topped by an approximately 30m thick horizon of richly fossiliferous, spotted, greyish white, brown on weathered surface, fine grained, locally calcareous flaggy sandstone with thin partings of greenish grey calcareous phyllite and a thin (1.5m) white crystalline limestone bed (Fig. 3.10.35). The arenite of upper part sporadically exhibits, medium scale low angled cross-bedding (Fig. 3.10.35). The moulds of body fossils are invariably limonitised and ill-preserved (Figs.3.10.36-41).

The fossils recorded by Chaturvedi *et al*, (1983a) from this formation (=Member G and H of their Maneting Formation) include *Orthis* sp., *Strophomena* sp., *Laptaena* sp., *Rafinesquina* sp., *Cratera* (?), a few trilobites, and ill-preserved fenestellid bryozoans. It was assigned a possible Ordovician age. Contrary to that the present authors have collected trilobite fossils identified as kaolishaniids or pagodiids which have an age range of middle to late-Late Cambrian (written communication Prof. J.A. Talent to ONB).

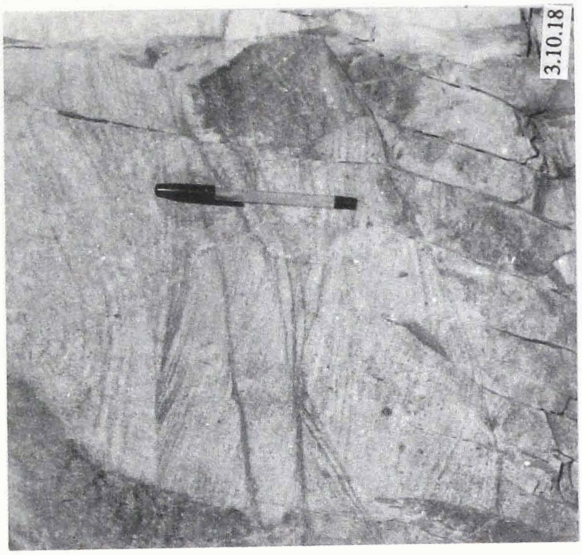
Thus considering the gradational relationship of this formation with the underlying Maneting Formation and the trilobites collected from it, a middle Cambrian age is being assigned to this formation.

TANG CHU GROUP

The name Tang Chu Series was suggested almost simultaneously by Nautiyal *et al*, (1964) and Gansser (1964). The former assigned a 'Lower Palaeozoic' age and the latter a 'Silurian-Devonian' age, which was later restricted to late Devonian (Termier and Gansser, 1974). Singh (1973) redesignated it as the Tang Chu Formation and suggested a Permo-Carboniferous age, which was followed by Sen (1975) and Jangpangi (1978). Datta (1975) proposed a three fold lithostratigraphic classification of the Tang Chu Formation. Chaturvedi *et al*, (1983a) assigned a Devonian to Lower Carboniferous age to the Tang Chu Formation. Roy and Ghosh (1988) reported the first plant fossil assemblage from the middle member of Dutta (1975) and accordingly assigned a Devonian-Lower Cretaceous age to the Tang Chu Formation.

Explanation of Figures 3.10.17 - 3.10.21

Fig.3.10.17 Trough cross-bedded unit overlain by thinly laminated unit showing low angle truncation in quartzite, Deshichiling Formation. North of Samkhera, Gaylegphug-Tongsa road. Fig.3.10.18 Upword decrease in the size of the trough cross-beds in quartzite, Deshichiling Formation. North of Samkhera, Gaylegphug-Tongsa road. Fig.3.10.19 Moderaterly sorted clast supported oligomictic conglomerate. Deshichiling Formation. East of Gangti Gompa, Phubjika valley. Fig.3.10.20-21 Tectonic stretching of pebbles in conglomerate, Deshichiling Formation. 1.5km west of Dak Phey on Tongsa road.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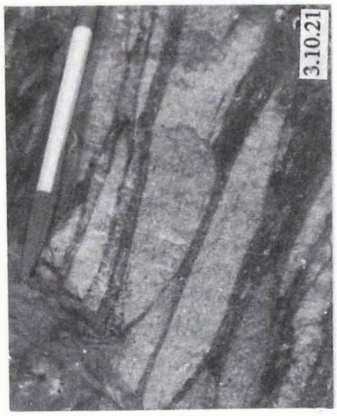
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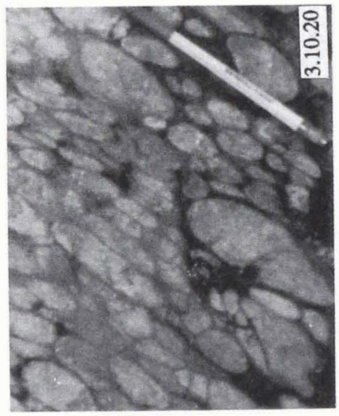
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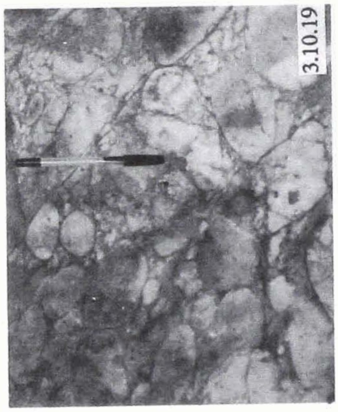
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Mamgain and Roy (1989) upgraded the Tang Chu Formation to a group level and divided it into Pe Chu, Ripakha and Beli Formations. The last named formation being of Jurassic-Early Cretaceous age was separated from the Lower Carboniferous Ripakha Formation by a major unconformity. The 'Beli Formation', therefore, has been separated from the Tang Chu Group in the present work. In ascending stratigraphic order it is subdivided into the Wachi La and Ripakha Formations. The Tang Chu Group is recognised in Tang *Chu*-Black Mountain section only. In the Lingshi sector its broad equivalent is designated as the Barishong Formation.

Wachi La Formation

This name was suggested by Chaturvedi *et al*, (1983a), for a carbonate dominant sequence exposed around the Wachi La in the Black Mountain area. It was separated from the thick carbonate sequence of the Tang Chu Series/Formation (Nautiyal *et al*, 1964; Gansser, 1964; Jangpangi, 1978) exposed in the Pe *Chu* and Tang *Chu* valleys (Chaturvedi *et al*, 1983a). However the present work establishes the continuity of the rocks of the Wachi La Formation into those of the Pe Chu Formation of the Tang Chu Group of Mamgain and Roy (1989). The name Pe Chu, thus is being dropped in favour of the Wachi La Formation which has a precedence.

Outcrops of the Wachi La Formation occur extensively along the crestal part of the Black Mountain range around the Wachi La and in the higher reaches of the upper Tang *Chu* and Nika *Chu* valleys. It rests over the Quartzite Formation (Fig.3.10.7) in the type section, over the Maneting Formation in the Tang *Chu* and Pele La sections and over the Deshichiling Formation in the Pe *Chu* section, showing a regional transgressive contact signifying an unconformity, which possibly has also acted as a tectonic plane.

The Wachi La Formation in the type area is represented by a thick (+250m) sequence of white to greenish white, thinly bedded (Fig.3.10.42), fine grained, crystalline limestone, dolomitic limestone with buff and common greenish grey calcareous phyllite partings and occasional thin beds of calcareous brown flaggy quartzite. The phyllite is comparatively more abundant in the basal part.

The sporadic crinoid ossicles are the only fossils recorded from this formation. In the absence of diagnostic fauna, no definite age can be assigned to the Wachi La Formation. However, considering its gradational contact with the overlying Ripakha Formation which preserves early Carboniferous fauna, late Devonian-early Carboniferous age may be assigned to this unit.

Ripakha Formation

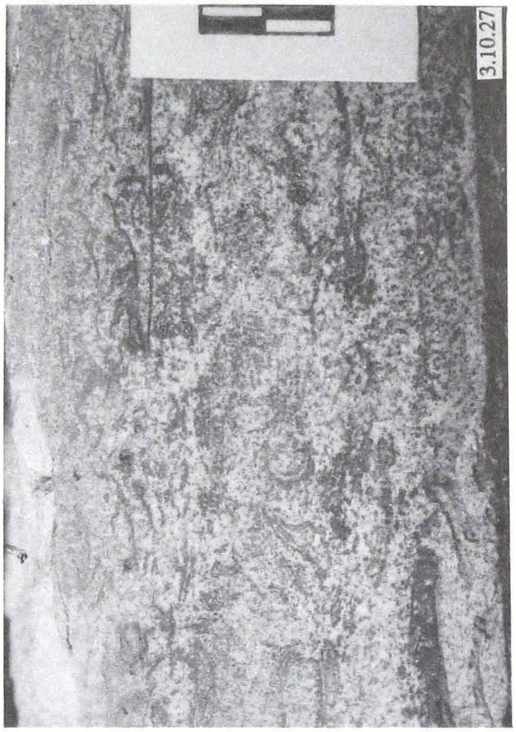
This formation was introduced by Mamgain and Roy (1989) after Ripakha settlement on the left bank of the Pe *Chu* where it is best exposed. Its occurrence in the remaining Black Mountain-Tang *Chu* sector is patchy. Its presence in the Tang *Chu* valley west of Kobja is indicated by boulders of this formation. The Wachi La Formation with gradual increase in the proportion of shale/phyllite and the fossil contents passes into the Ripakha Formation.

The Ripakha Formation comprises a richly fossiliferous coarsely interstratified sequence of thin bedded limestone, dolomite and shale/slate (Fig.3.10.43). Limestone/dolomite is grey, fine grained, crystalline and full of crinoid ossicles. The intercalated shale/slate is dark grey, brown, commonly ferruginous and crowded with *Fenestella* which is more common towards the upper part of the formation. The petrography of a few representative carbonate samples spanning the stratigraphic thickness of the formation indicated the presence of (i) recrystallised mudstone, (ii) recrystallised bioclastic mudstone, (iii) recrystallised moderately sorted, faintly laminated bioclastic packstone-wackstone (Fig.3.10.44, 45).

Explanation of Figures 3.10.22 - 3.10.24 & 3.10.26-3.10.27

Fig.3.10.22 *Planolites*, Deshichiling Formation. East of Maneting. Fig.3.10.23 Flaser, mud-draped bedding. Maneting Formation. Maneting Hill. Fig.3.10.24 *Planolites*, Note cross over. Maneting Formation. 1.25km NNW of Dechhi Faka. Left bank of Mande *Chu*. Fig.3.10.26 Ill-preserved shells of lingulellids. Maneting Formation. Bar scale 1cm. Right bank of Mande *Chu*. Fig.3.10.27 Tempestite layer. Maneting Formation. Bar scale 1cm. 1.5km NW of Dechhi Faka. Right bank of Mande *Chu*.


3.10.24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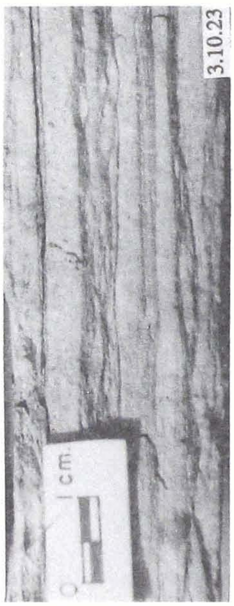
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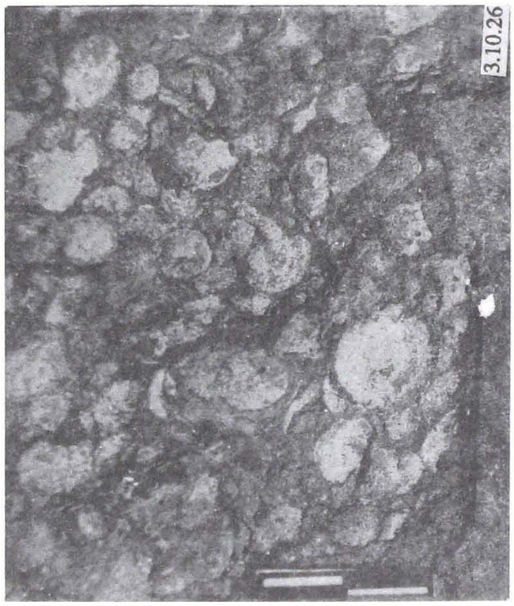
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Mamgain and Roy (1989) reported following fossils from the Ripakha Formation.

Bryozoa	*Fenestella* cf., *F. plebeia* Mccox., *Fenestella* sp., *Protoretepora* cf. *ampla Lonsd.*
Brachiopod	*Stenoscisina* (=*Camerophoria*) sp., *Hemiplethorhynchus* sp. *Dielasma* sp., *Neospirifer* sp., *Unispirifer* sp.
Lamellibranch	*Aviculopecten* cf., A. *middlemissi* Diener.
Crinoid fragments.	

In addition, Gansser (1983) makes a mention of atrypids. Beside these, the argillaceous layers preserve abundant trail, track and burrnow structures. On the basis of above fossil assemblage Lower Carboniferous age has been assinged to the formation.

Barishong Formation

This name was suggested by Ganesan *et al*, (1978) for a carbonate dominated sequence exposed in the Lingshi sector near Barishong village. Though it is a broad equivalent of the Tang Chu Group, presumably some formations of the Pele La Group have been mixed up with this formation.

West of Chekha village Ganesan *et al*, (1978) described a gradational contact between the Chekha Formation and the Barishong Formation. However as mentioned earlier Dasgupta and Golani (1994) in the same sector have recorded a volcanic suite about 50m above the Thimphu-Chekha contact from the upper Ha valley.

In eastern Lingshi sector and Yam La section the Barishong Formation directly rests over the migmatites of the Thimphu Group. In the western part, the Jhang Gothang Fault brings the Barishong Formation in direct contact with rocks of the Thimphu Group.

The Barishong Formation in the basal part is a 100-150m thick succession of white saccharoidal quartzarenite with interbands of calcareous quartzite. It is succeeded upwards by a thick interstratified sequence of bluish grey limestone, whitish grey marble, phyllitic limestone, calcareous quartzite and subordinate greenish grey calcareous phyllite. In the upper part of the formation the carbonate rocks are less recrystallised, fine grained and contain small irregular patches and lenses of dolomite. The detailed lithosuccession of the Barishong Formation exposed along the Thimphu *Chu* is shown in Fig.3.10.46.

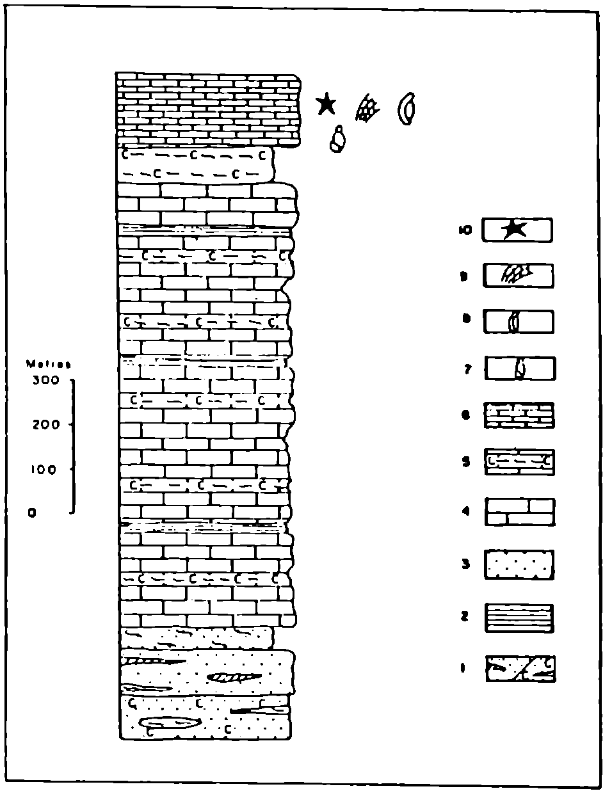
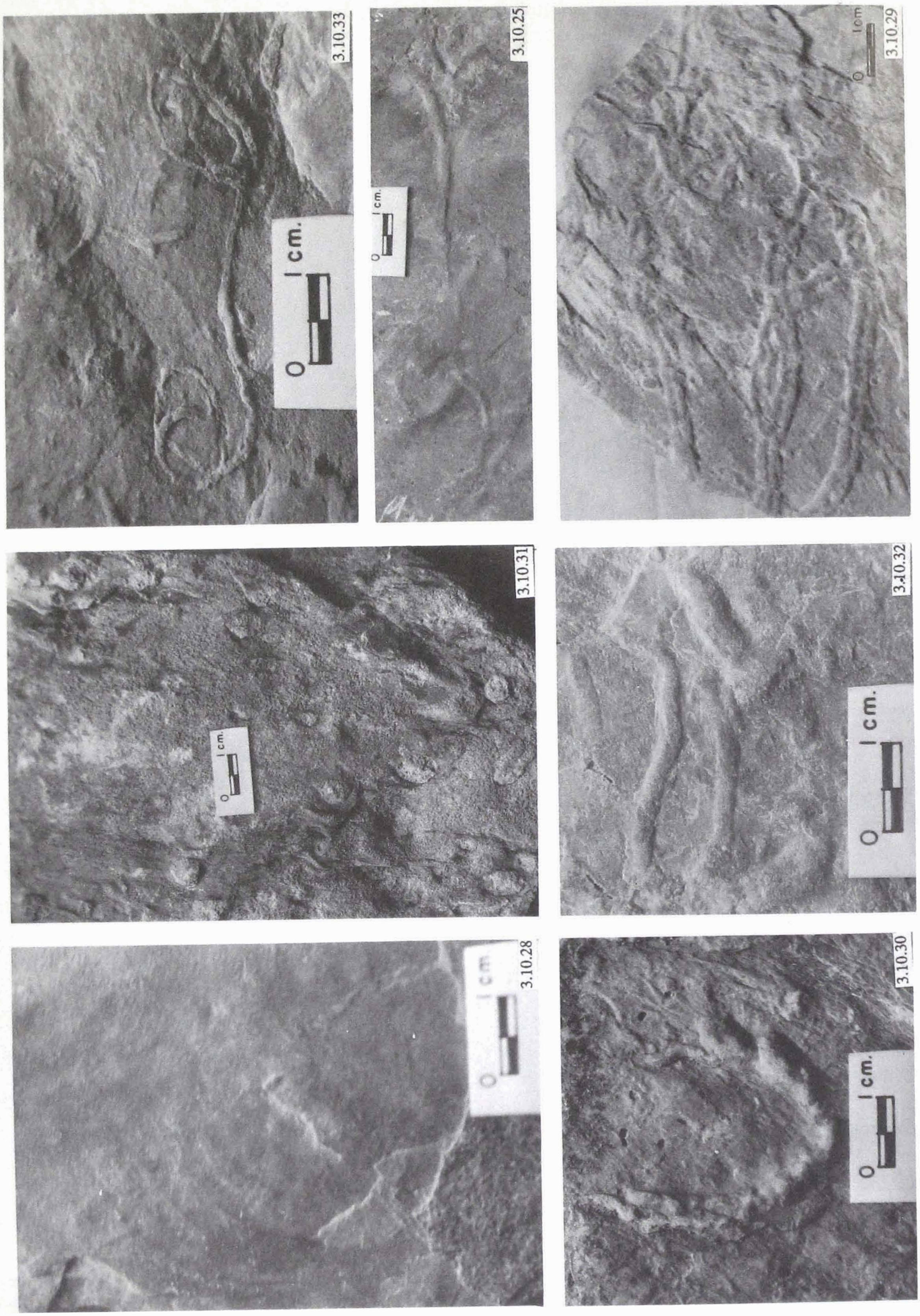


Fig.3.10.46 Lithostratigraphic column of the Barishong Formation, along Thimphu *Chu* (reconstructed after Ganesan *et al*,1978). 1. Quartzite/ calcareous quartzite with limestone, phyllite partings, 2. Shale/slate, 3. Quartzite, 4. Lower grey limestone, 5. Calcareous phyllite, 6. Platy limestone, 7. Gastropod, 8. Brachiopod, 9. Bryozoa, 10. Crinoid ossicle.

Explanation of Figures 3.10.25 & 3.10.28 - 3.10.33

Fig.3.10.25 *Cochlichnus*, Maneting Formation. Maneting Hill. Fig.3.10.28 *Monomorphichnus*. Maneting Formation. 2km south of Hill .4136. Fig.3.10.29 *Didymaulichnus*. dislodged specimen. Maneting Formation. 1.5km SW of Maneting Hutment. Fig.3.10.30 *Phycodes pedum* - dislodged specimen. Maneting Formation. Maneting Hill. Fig.3.10.31 *Arenicolites* - dislodged specimen. Maneting Formation. Maneting Hill. Fig.3.10.32 *Helminthopsis*. Maneting Formation. 2km south of .4136. Fig.3.10.33 *Gordia* - dislodged specimen. 1.5km SW of Maneting Hutments.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In the Dishi-Lamilekha section, the basal part of this formation is represented by pink and green calcareous phyllites and argillaceous limestone. This facies in its strike continuity in the Basingthang *Chu*, becomes more calcareous and less argillaceous. Similar pink argillaceous limestone and phyllite are exposed on the western side of the Say *Chu* anticline in the Chekha-Chomigom La section.

The upper part of this formation comprises flaggy to platy limestone. It contains a rich faunal assemblage. The fossils reported in upper part by Ganesan *et al*, (1978) are :

Brachiopod	*Marginifera* sp., *Spirifer* sp., *Productus* sp., *Syringothiris* sp., *Camarophoria* sp.
Coral	*Favosites* (?) sp.
Bryozoa	*Fenestella* sp., *Polypora* sp., *Dogaddanella* sp., *Rhombopora* sp.
Echinoderm	*Blastoides*, mostly columns with calyx fragments, crinoid stems and theca fragments, mostly of Camerata type (?).

The middle and basal parts of the Barishong Formation are poor in fossils. The fossils recorded include a few crinoidal stems, corals, gatropods (?*Spanionema* sp.) and bivalves.

In the basal part of the Barishong Formation sequences resembling the Nake Chu-Maneting Formations have been identified (Anon, 1984), which are possibly referable to the Deshichiling and Maneting Formations of the present authors. The overlying sequence of bluish grey limestone, white marble, phyllitic limestone and calcareous quartzite is reminisent of the Wachi La and Ripakha Formations. Thus the Barishong Formation seems to represent a mix up of various formations (viz. Deshichiling, Maneting, Wachi La and Ripakha Formations). Since it has not been possible to map these formations separately, the term Barishong has been retained in the present work. Unless the stratigraphic picture is clear, it is hazardous to assign any lower age limit to this formation. Ganesan *et al*, (1978), however, assigned a middle-upper Devonian to Carboniferous age to the Barishong Formation.

At a number of places, Barishong sediments in the basal part are intensively intruded by tourmaline granite. Along the south wall of the Chomolhari range the Chung La tourmaline

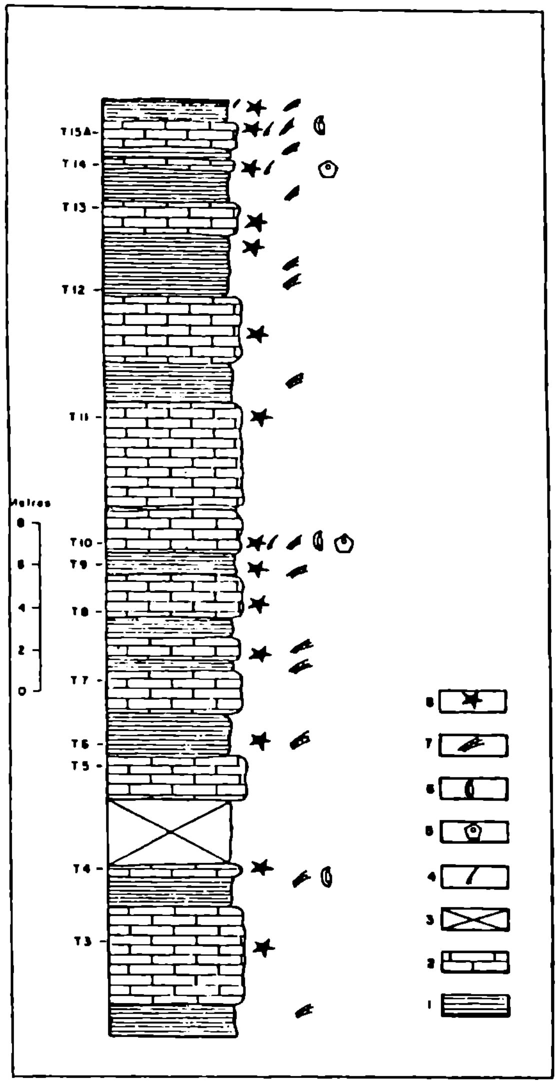
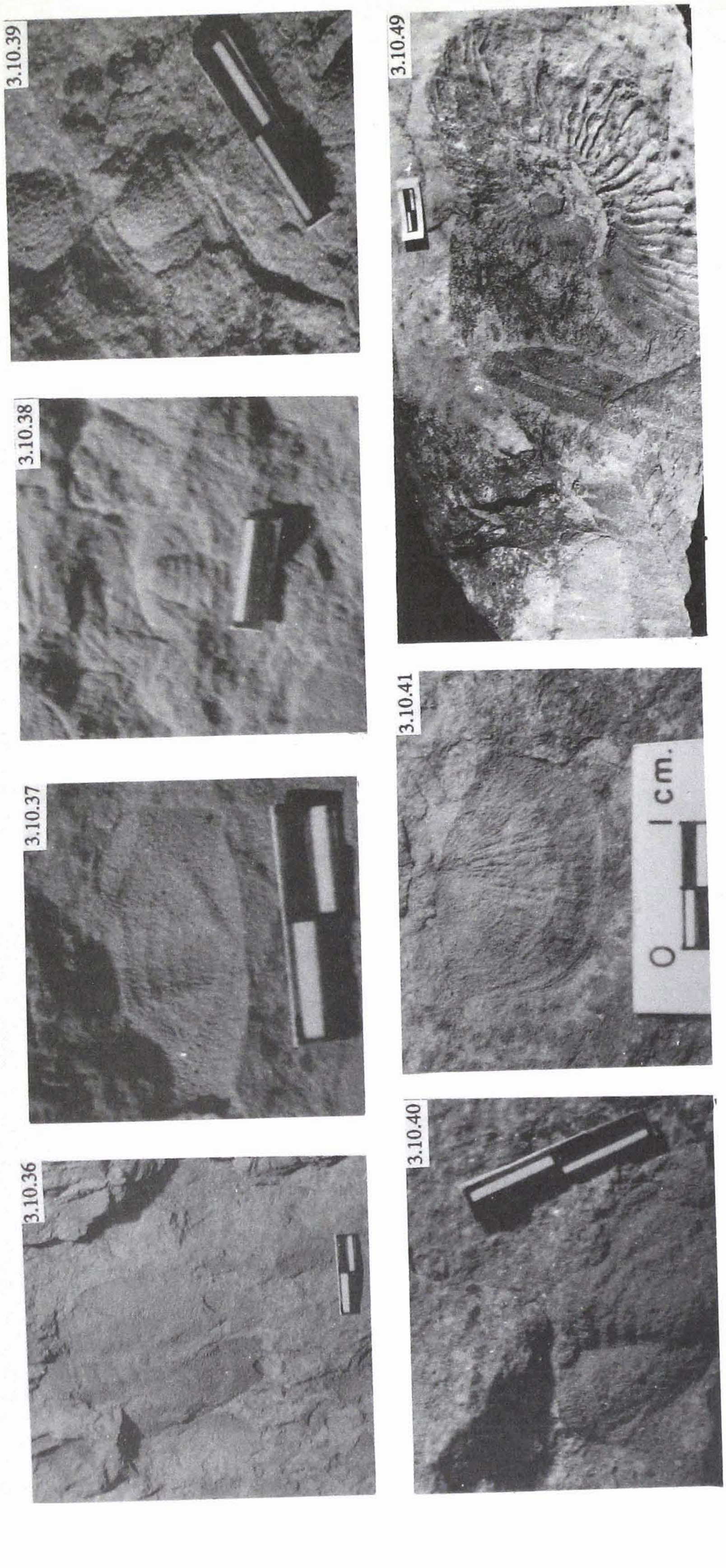


Fig.3.10.43 Lithostratigraphic column of the Ripakha Formation, left bank of the Pe *Chu* Valley. 1. Grey-greenish grey, brown shale/slate, 2. Limestone with dolomite, 3. No exposure zone, 4. Echinoid spine, 5. Echinodermal plate, 6. Brachiopod, 7. Bryozoan, 8. Crinoid ossicle.

Explanation of Figures 3.10.36 - 3.10.41 & 3.10.49

Fig.3.10.36-40 Trilobite remains. Quartzite Formation. Bar sc' 1cm. 3km SSE of Hill .4136. Fig.3.10.41 Brachiopod impression. Quartzite Formation. 3km SSE of Hill .4136. Fig.3.10.49 Cephalopod and *Ptilophyl*... in slaty shale. Lingshi Group. Bar scale 1mm. Left bank of Pe *Chu*. Opposite Sha Slate Mine Guest House.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0
1 cm.
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granite has profusely intruded into the carbonates of the Barishong Formation. These intrusions are dominantly in the form of sills, and have caused recrystallisation of the carbonate.

Shodug Formation

This formation was first identified as 'Shodug Series' by Nautiyal *et al*, (1964) for a distinct lithopack of thinly bedded limestone and slates pebble conglomerate lying unconformably over the carbonate of the 'Chekha Series' in the Shodug area in the Thimphu *Chu*. Gansser (1964) used the term 'Greywacke Formation' for this sequence. Ganesan *et al*, (1978) designated it as Shodug Formation. This formation is developed only in the Lingshi sector. The Shodug Formation is well exposed in the Shodug Zumb and Yele La sections. It rests unconformably over the Barishong Formation. The contact is locally tectonised, causing shearing of the pebbles (Ganesan *et al*, 1978).

The Shodug Formation comprises a thin horizon of grey pyritous shale/slate at the base followed upward by an intercalated sequence of greenish grey to olive green diamictite, local cross-bedded quartzite, bluish grey slate and occasional gritty calcarenite (Fig.3.10.47). The most characteristic lithology of this formation is the diamictite which consists of ill-sorted, unevenly distributed, subangular to subrounded, clasts of vein quartz, white, grey and green quartzite, light grey to bluish grey slate, grey phyllite and sporadically of quartz-mica schist and fine grained granite, held in a grey to greenish grey silty to sandy matrix. The clast matrix ratio ranges from 20:80 to 30:70. The clasts dominantly are in the size range of two to five centimetres but a few layers are dominated by granule size clasts. In bouldery slates, angular boulders (22-24cm) of quartzite admixed with smaller clasts (3-5cm) of limestone occur embedded in the matrix. The argillaceous matrix contains ill-sorted grains of quartz and feldspar and fine carbonaceous matter. The diamictites occur interlayered with 0.5-2m bands/lenticles of non-pebbly slate and white to buff fine grained ferruginous quartzite. In the eastern part of the Lingshi sector, the diamictites are not conspicuous (Ganesan *et al*, 1978). Gansser (1964, 1983) opined that the pebbly horizons of the Shodug Formation are quite akin to the Blaini tillites, thus suggesting their correlation.

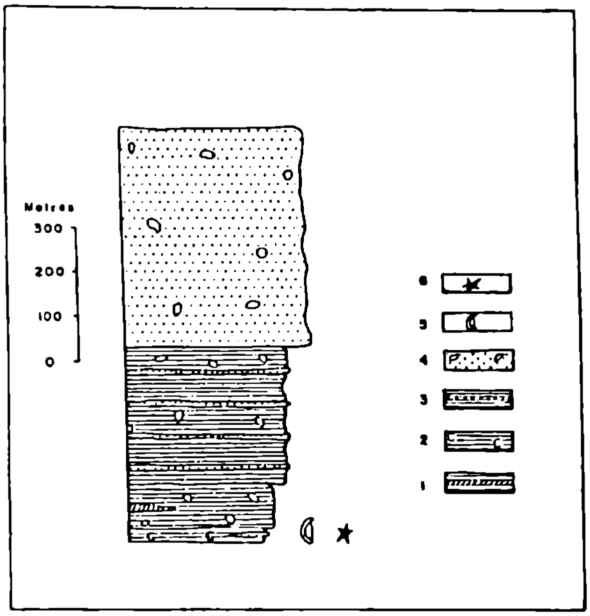


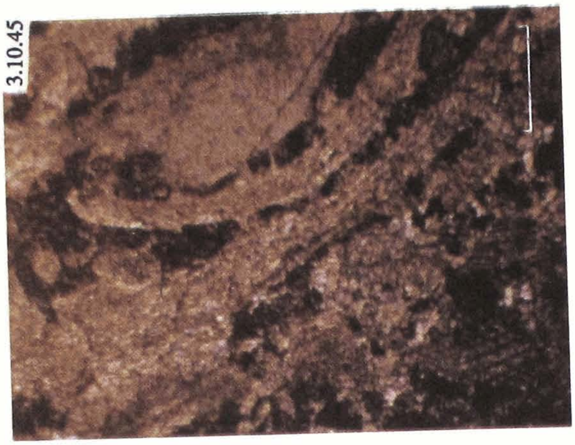
Fig.3.10.47 Lithostratigraphic column of the Shodug Formation, in the type area (reconstructed after Ganesan *et al*, 1978). 1. Slate with calcarenite bed, 2. Calcareous non-pebbly slate, 3. Pebbly/non-pebbly slate with white gritty quartzite beds, 4. Thinly bedded pebbly sandstone, 5. Brachiopod, 6. Crinoid ossicle.

Only the basal most shale horizon of the Shodug Formation is fossiliferous, whereas the diamictite-quartzite sequence is devoid of them. The fossils reported from the formation by Ganesan *et al*, (1978) are :

Brachiopod	*Spirifer nitensis* Dien., *S. lydekrii* Dien., *Productus* sp., *P.cora*, *Marginifera himalayenses*, *Ambikella sahni*, *Ingerella*, *Camobell* sp., *Derbia* sp., *Syringothyris* sp., *Camorophoria* sp. and *Terebratula* sp.
Bryozoa	*Fenestella* sp., *Polypora* sp., *Rhombopora* sp. and a number of unidentified forms.

Explanation of Figures 3.10.42, 3.10.44 - 3.10.45 & 3.10.35

Fig.3.10.35 Limestone bed, overlain by low angle cross-bedded areni[illegible] unit Quartzite Formation. Loc. 3km SSE of .4136. Fig.3.10.42 Thinly bedded limestone. Wachi La Formation. 2.25km WNW of Wachi La. Fig.3.10.44 Recrystallised crinoidal packstone. Ripakha Formation. Bar length 0.5mm. Left bank of Pe *Chu* near Ripakha. Fig.3.10.45 Recrystallised whole fossil packstone. Ripakha Formation. Bar length 0.5mm. Left bank of Pe *Chu*, near Ripakha.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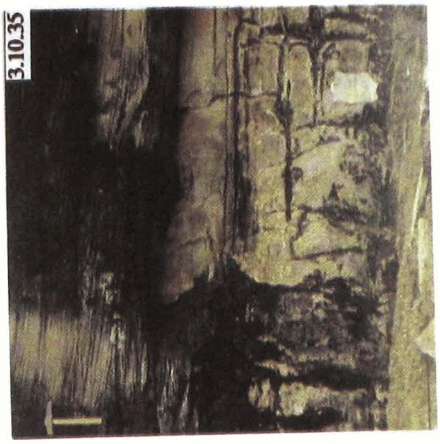
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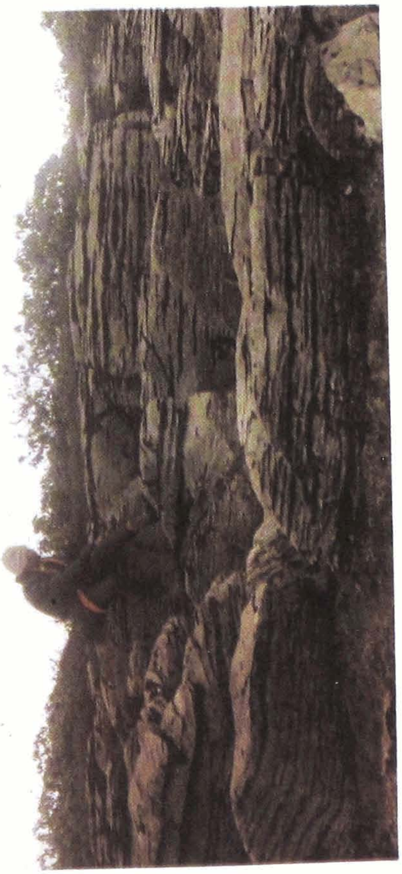

Echinoderms mostly crinoids stems.

In addition certain unidentifiable gastropods, lamellibranchs and corals and worm tracks have also been recorded from this formation. This fossil assemblage suggests a Carboniferous to late Permian age for the Shodug Formation.

The basal most shaly part forms a horizon which is distinct from the underlying carbonate dominated Barishong Formation and the overlying diamictitic sequence. The shale unit in future work, if found to be regionally developed, be separated to constitute an independent formation.

LINGSHI GROUP

The sequence classified under the present Lingshi Group was recognised for the first time by Nautiyal *et al*, (1964) as the Lingshi and Yale La Series in the Lingshi sector. Ganesan *et al*, (1978) first designated it as the Lingshi Formation comprising a basal fresh water and an upper marine lithofacies. Later he (Ganesan and Bose, 1982) raised it to a group level and divided it into three formations which in ascending order of superposition are (i) Mo Chu Formation, (ii) Chebesa Formation and (iii) Ngile La Formation. The sequence identical in lithology and age has been referred to as the Beli Formation (Mamgain and Roy, 1989) in the Tang *Chu*-Black Mountain sector (Fig.3.10.7), where it occurs in the cores of three overturned synforms. The name Beli is thus superfluous and is being dropped.

The Lingshi Group rocks rest over the Shodug and the Ripakha Formations in the Lingshi and Tang *Chu*-Black Mountain sections respectively, along an unconformity. Its northern contact with the Ripakha Formation in the Tang *Chu* valley is in the form of a thrust along which the Ripakha Formation has ridden over the Linghshi Group rocks. A description of the various formations of the Lingshi Group is given below.

Mo Chu Formation

The Mo Chu Formation is exposed in the southern and eastern parts of the Lingshi synform and is best developed in the Yale La-Lingshi and Lingshi-Laya sections (Fig.3.10.48). It comprises a 300-350m thick sequence of greenish grey to light grey, laminated fine grained quartzite and interbedded slates. The sequence contains a rich floral assemblage which is interstratified with a few thin beds containing cephalopods. Plant fossils reported by Ganesan and Bose, (1982) from the formation include;

Pachypteris cf. *indica* (Oldham and Morris), Bose and Roy, *Ptilophyllum acutifolium* Morris; *Elatocladus jabalpurensis* (Fiestmantel) Halle; *Pagiophyllum* sp. and *Coniferocaulon* cf. *rajmahalense* Gupta.

This floral assemblage resembles that from the Upper Gondwana sediments of the Satpura basin and Kachchh, thus suggesting a middle to late Jurassic age for the Mo Chu Formation (Ganesan and Bose, 1982). According to Ganesan *et al*, (1978) this sequence represents fresh water environment of deposition.

Chebesa Formation

The Chebesa Formation represents a 1500-2000m thick sedimentary sequence, that conformbaly overlies the Mo Chu Formation. It is predominantly developed in the central and west-central parts of the Lingshi sector. The Chebesa Formation consists chiefly of a fossiliferous, monotonous succession of dark carbonaceous and pyritous slate, olive green and grey shale and minor greenish arenite. Within the slate commonly occur small non-calcareous silty nodules, which locally enclose fossils as nucleus. The basal part of the sequence contains a few thin (1-10cm) beds of carbonaceous shale/slate which have yielded remains of *Ptilophyllum* sp. (Ganesan *et al*, 1978). The Chebesa Formation according to Ganesan *et al*, (1978) comprises essentially marine sediments. The fossil assemblage (Ganesan *et al*, 1978) recorded from the formation includes :

Lamellibranch	*Aucella spitiensis*; *Nucula spitiensis*, *Nuculana* sp. (*Kibberianna*?); *Ilomomya tibetica* (?).
Brachiopod	*Rhynchonella* sp.
Cephalopod	Perisphinctid forms with bifurcating and trifurcating ribs, smooth and

	distantly ribbed body chamber. *Neocomites* sp., *Kalianella* sp., *Odontodiscus* sp.
Crinoid	*Calliptychoceros* sp. Crinoidal stems.
Gastropod	Unidentified small, coiled conical casts of apex portion.

The carbonaceous shale beds of the basal part of the formation have yielded :

Cycadophyta	*Ptilophyllum acutifolium* var. *maximus*, *P. acutifolium* var. *tennarium*.

The above fossil assemblage indicates late Jurassic age for the Chebesa Formation (Ganesan *et al*, 1978).

Ngile La Formation

The rocks grouped under this formation were earlier classified under the Yale La Series (Nautiyal *et al*, (1964). Since only Shodug Formation is exposed at the Yale La, Ganesan *et al*, (1978) argued that the usage of term 'Yale La' for the Cretaceous rocks would be misleading and thus proposed the name Ngile La Formation for these sediments. The Ngile Formation rests over the Chebesa Formation along a gradational contact. This formation comprises dark carbonaceous shale, buff-brown-olive green, bleached locally nodular shale/slate, and thin beds of quartzitic sandstone. Following fossil assemblage has been recorded from this formation (Ganesan *et al*, 1978).

Cephalopod	*Callyptychoceraus* sp. *Neocomite* (?) sp. *Kalianella* (?) sp. *Odontodiscoceros* (?) sp. *Hoplites* sp. *Prohystoceras* (?) *Mortoniceras* sp.(?) *Heteroceras* sp. (?)
Lamellibranch	*Venericardita* (*Cardita beaumonti* ?) sp.

While the lower horizons are rich in Berriasellidae Neocomitinae, Tollina forms, the middle horizon is dominated by Hoplitina ammonites.

These fossils resemble those of the Beleminite Beds of Salt Range and indicate an age range from Valaginian to Tithonian (Ganesan *et al*, 1978).

The fossils reported by Mamgain and Roy (1989) from the Lingshi Group of the Tang *Chu* Valley are :

Ptilophyllum acutifolium, P. *cutchense*; *Gymnoplites* cf. *simplex Holcodiscus* sp.

Possibly from this sequence only Hanny (in Gansser, 1983) reported negative of *Parajuvavites* of Norian age.

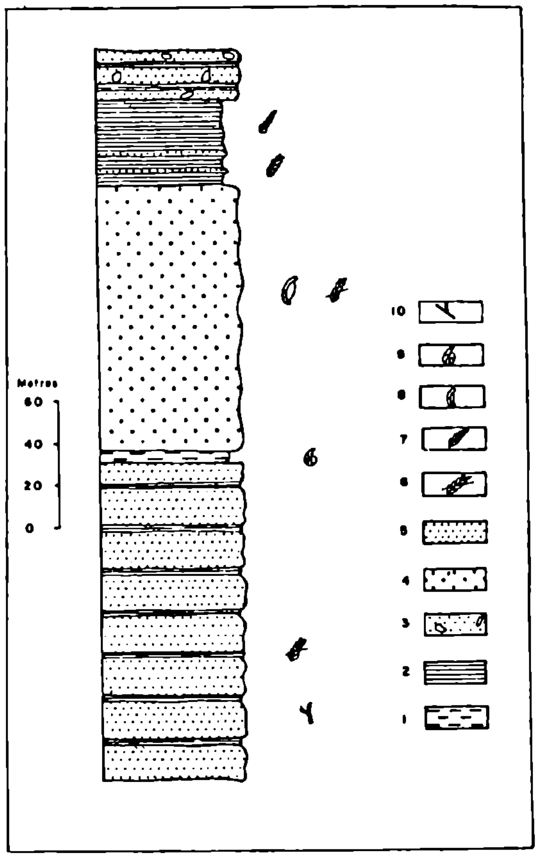

Fig.3.10.48 Lithostratigraphic column of the 'Mo Chu' Formation, Linghsi-Laya area (reconstructed after Ganesan *et al*, 1978). 1. Bleached slate, 2. Shale/slate, 3. Quartzite commonly gritty/pebbly, 4. Sandstone, 5. Laminated quartzite, 6. Fragmentary plant fossils, 7. Plant fossils, 8. Brachiopod, 9. Ammonoid, 10. Trace fossil.

The above lithostratigraphic classification of the Lingshi Group into three formations is based on interpreted fresh water and marine environments and not on distinct lithology. Such an approach could be misleading in view of discovery of plant fossils and cephalopod on same bedding plane by the present authors in the Pe *Chu* valley (Fig.3.10.49). However, we leave refinement of the classification of the `Lingshi Group' to posterity after more detailed field work.

Northern Higher Himalayan Tethyan Belt

The crestal part of the Northern Higher Himalayan ranges of Bhutan exposes a thick succession of the Tethyan sediments. Owing to inhospitable climatic and terrain conditions, the geological knowledge of these areas is limited mainly to a few traverses of Gansser (1964, 1983) and a few geoscientists of the Geological Survey of India.

These Tethyan sediments recorded at Toma La, north of the Masang Kang Mountain, north of Lunana, at Gorpu La in the upper Chomkha *Chu* valley, at Bodu La and in the upper Kuru *Chu* valley represent the southern edge of the wide Kampa Dzong `basin' of Tibet. The best section of this belt was studied at Toma La by Gansser (1983), who gave the following lithostratigraphic succession :

h) Crinoidal limestones, grey nodulour fossiliferous limestone and thick bedded dolomitic limestone. (crinoids, fragments of brachiopod shells and of a nautiloid ? algal remains.)

g) Well bedded dark limestones and graphitic slates, nodulus, yellow and dark grey mottled calcareous and dolomitic siltstones.

f) Dolomitic claystone with a band composed of irregularly arranged dolomitic clay pellets within a dark claystone matrix.

e) Dark and white banded, fine grained marbles and calc-arenites. (Doubtful fossils of ostracodes, molluscs, brachiopods, echinoderm and primitive arenaceous foraminifers).

d) Black biotite greywacke with larger biotite phenocrysts (without sieve inclusions).

c) Muscovite bearing quartzite (20m).

b) Well bedded yellow marbles.

a) Calc-schists to schistose-nodulose calc-silicates.

------- Conformable (but in detail irregular) -------

Migmatitic and partly granitised gneiss.

Gansser, (1983) assigned a tentative Silurian to Devonian age to the upper part of the Toma La limestones.

In the high ranges occurring to the north of Lunana, Gansser (1983) reported presence of banded calc-silicates alternating with tourmaline granite sills, overlying the migmatitic gneisses. These in turn are succeeded by dark bands of graphitic slates and grey thick bedded fine grained banded marbles.

Golani *et al*, (1994) reported a low grade metasedimentary sequence of probable Tethyan affinity at Gurpo La in the upper reaches of the Chomkha *Chu*. In this section a sequence of quartz-chlorite-biotite schist and impure argillaceous quartzite overlies the spinel-bearing sillimanite-garnet-biotite gneiss and schists along a major sheared contact.

Further in the east, at the Bodu La and in the Upper Kuru *Chu* river system east of the Kula Kangri range, the Tethyan sediments are represented by a thick sequence of well bedded black slates, which are akin to the black biotite slates of the Toma La section.

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4. THE GRANITIC ROCKS

4. THE GRANITIC ROCKS

Amitabha Sarkar and S. Dasgupta

The granitic rocks in the Bhutan Himalaya occupy a sizeable terrain. These rocks are preponderant in the Thimphu Group and are of minor occurrences in the Lesser Himalayan and Tethyan sequences (Fig.4.1). The granitic rocks can be broadly grouped in the following categories.

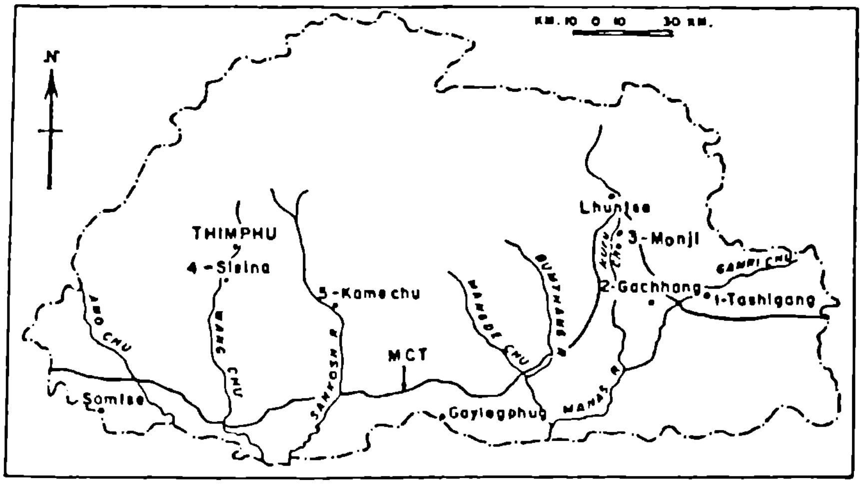

Fig.4.1 Map showing location of the granite samples ; 1 - Tashigang, 2 - Gachhang, 3 - Monji, 4 - Sisina, 5 - Kame *Chu* (For geological details see Plate-I).

4.1 Thimphu Granitic gneiss and related migmatites.

4.2 Tectonic slivers of the granitic gneiss within the Shumar and Jaishidanda Formations and in the Baxa Group.

4.3 Leucocratic granitic rocks intrusive in the Thimphu Group and the Tethyan sequence.

In the present study the petrochemical and isotopic data for some of the granitic suites of the Bhutan Himalaya were collected and critically evaluated.

Under the petrochemical studies a total of 46 major element analyses were carried out by X-ray Fluorescence Spectrometry. FeO was determined by conventional wet chemical method. Rb, Sr contents and Rb/Sr ratio were determined by X-ray Fluorescence method on a fully computerised PW 1400 equipment.

For geochronological studies Sr was extracted following conventional Ion Exchange Chromatography. Sr isotopic ratios were measured using an automated VG 54R single collector Thermal Ionisation Mass Spectrometer. The uncertainty of individual run precision (generally better than 0.60%) was used for computation of isochron age data. $^{87}Rb/^{86}Rb$ ratios were computed from Rb/Sr ratios. Rb/Sr ratios were determined on pressed pellets using an automated PW 1400 X-ray Fluorescence Spectrometer. Precision of $^{87}Rb/^{86}Rb$ determination is about 2%. For the linear regression of isochron the programme of York (1969) was used. All uncertainties are quoted at 2 levels and ^{87}Rb decay constant used is $1.42 \times 10^{-11} a^{-1}$. The procedure of Sarkar *et al*, (1990) was followed for Rb-Sr isotopic analysis.

The petrochemical data following Petro *et al*, (1979), have been used to interpret tectonic status of the granitic rocks. In this exercise mean values of Differentiation Index of Thorton and Tuttle (1965), weight percent CaO and total alkalis (Na_2O+K_2O), CaO/Na_2O+K_2O and FeO^t/FeO^t+MgO ratios in the SiO_2 interval 70-75% of a particular suite (Petro *et al*, 1979) have been chiefly utilised to compare with those of the granitic rocks of the Bhutan Himalaya. Closeness of the mean values of parameters with those of `type' compressional and `type' extensional suites have been considered for inferring the tectonic set-up of granitoid generation.

4.1. THIMPHU GRANITIC GNEISS AND RELATED MIGMATITES

4.1.A Mode of Occurrence :

The granitic rocks of the Thimphu Group are mainly represented by medium to coarse grained, well-foliated leuco- to mesocratic biotite granite. The principal textural variants are : (i) homogeneous gneissic granite, (ii) augen gneiss and (iii) streaky gneiss (locally banded). The first variant is spatially most dominant while the latter two commonly occur as linear impersistent bodies, particularly along the sole of the Thimphu Thrust Sheet.

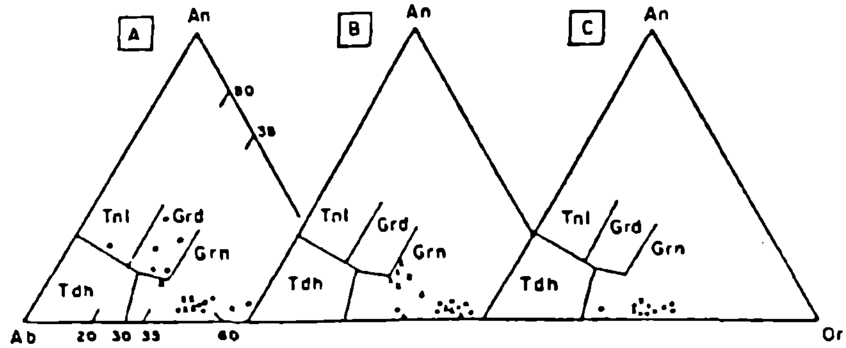

Fig. 4.2 Normative An-Ab-Or ternery diagram (after O'Connor, 1985) (fields modified by Barker, 1976). Abbreviations for different fields : Tnl - Tonalite, Grd - Granodiorite, Grn - Granite, Tdh - Trondhjemite. Symbols : A. Solid circles : Tashigang suite, Crosses : Sure suite. B. Solid circle : Gachhang suite. Crosses : Sisina suite, solid triangle : Monji suite. C. Solid circle : Kame *Chu* suite, Cross : Plot of average leucogranite, Bhutan (Gansser, 1983).

The gneiss commonly shows migmatite zones. Following Mehnert (1968), the dominant migmatitic structures in these zones can be termed as phlebitic (vein-type injection gneiss), stromatic (banded gneiss), schlierric and nebulitic (in the diatexites of migmatitic zones). These occur in

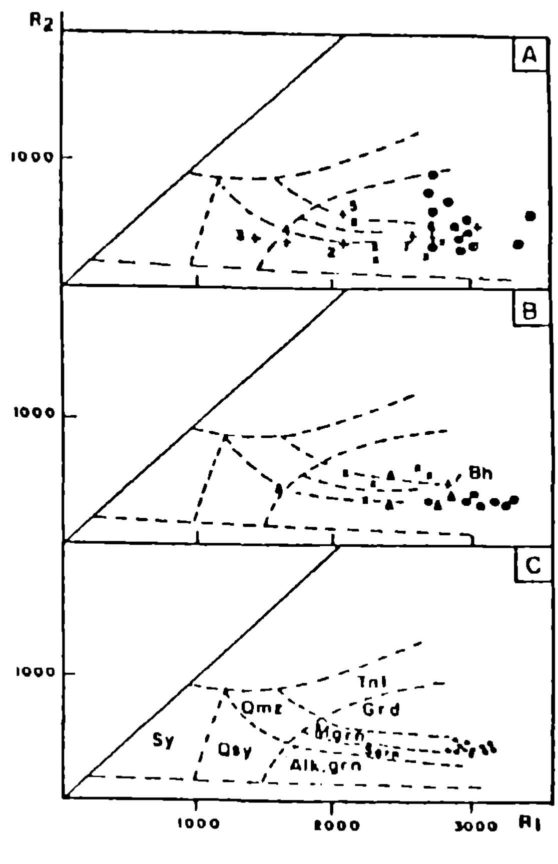

Fig. 4.3 R1-R2 diagram (after De La Roche *et al*, 1980) showing plots for Bhutan granitoids. Symbols in A, B and C are as in fig.4.2. Plus signs signify plots of average granitic rocks from 1. Chimakothi, 2. Dagana, 3. Pamla, 4. Takhtsang, 5. Gedu, 6. Ha, 7. Masangkang (sources of data as in Table 4.2).
R1 parameter = 4Si-11 (Na+K)-2(Fe+Ti).
R2 parameter = 6Ca+2Mg+Al.

intimate association with supracrustal high grade schists (biotite± muscovite ± garnet ± sillimanite± kyanite) and other metasediments (calc-silicate and marble) which also occur as xenoliths. Several xenoliths along margins show granitisation resulting in the development of injection gneiss. Rare metabasic enclaves are also known (Gansser, 1983). Sizeable bodies of hornblende-bearing quartz-dioritic rocks occur in close proximity of the granitic gneiss in the Tashigang area, presumably as cognate xenoliths ('congeneric inclusions' of Didier *et al*, 1982). The contact zone between the granite gneiss and the dioritic rocks in the Tashigang area is marked by the development of mafic-rich banded (stromatic) gneiss.

homogeneous gneissic granite of a low-strain zone commonly grades into augen and streaky gneiss in a high-strain zone.

The granitic gneiss is mainly composed of quartz, plagioclase, K-feldspar and biotite (±muscovite). Granitic gneiss from the Tashigang and Ha areas in addition also contains hornblende. Garnet is locally common. Accessories include epidote, apatite, tourmaline, opaque minerals, zircon and rare allanite. In general, the granite gneiss of the Takhtsang Formation exhibits higher grade mineral assemblage compared to that of the Sure Formation. The spatial variation in lithology and mineral assemblages of the gneisses of the Thimphu Group has already been discussed under Chapter 3.9.

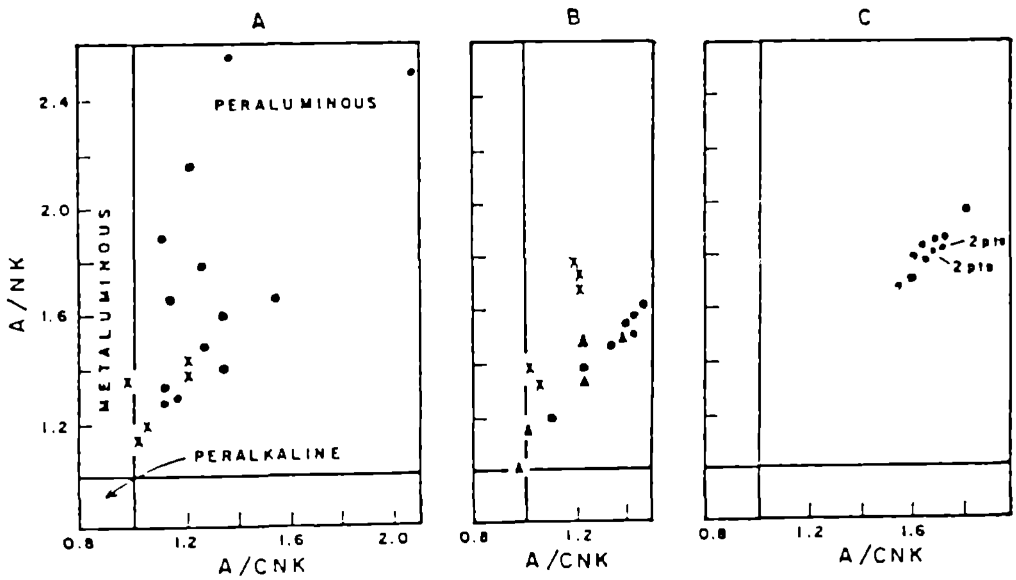

Fig. 4.4 A/CNK versus A/NK plots for Bhutan granitoids. Symbols in A, B and C are as in Fig.4.2A, 4.2B and 4.2C respectively.

The homogeneous gneissic granite displays well-foliated but little distorted hypidiomorphic granular fabric, with the development of penetrative mylonitic foliation the rock has been largely changed into the augen and streaky gneiss. A reduction in overall grain size is perceptible from little deformed homogeneous gneissic granite to the mylonitised gneiss. Based on the relative proportion of porphyroclasts, the augen and streaky gneisses can be termed as proto-mylonite and mylonite respectively. Variation in texture and fabric of the gneiss of the Thimphu Group is due to difference in the intensity of strai Thus,

The effects of strain, prominently noticeable in augen and streaky gneisses, are manifested by undulose extinction, strain shadows and ribbon-banding in quartz, bending of cleavages and twin lamellae in biotite and plagioclase respectively. In some samples of highly deformed streaky gneiss, bands of recrystallised quartz grains having replaced coarser quartz grains alternate with fine grained phyllosilicate-rich bands giving rise to a finely banded fabric. In the augen gneiss, augen are mainly composed of feldspar grains and exhibit

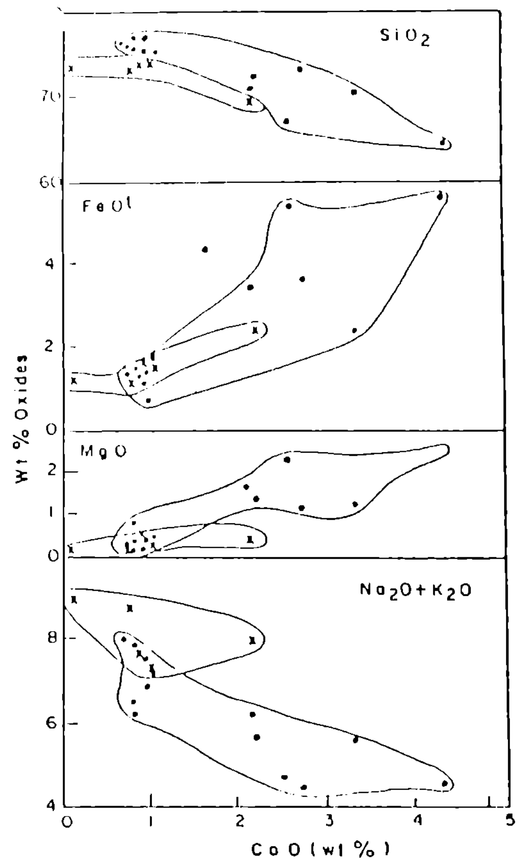

Fig.4.6 Variation of SiO_2, FeO^t, MgO and Na_2O+K_2O with CaO in the Tashigang (solid circles) and Sure (crosses) suites.

deformational features like undulose extinction and micro-faulting/fracturing.

4.1.B Petrochemistry : Major element data for 13 samples of the Tashigang and five of Sure suites are presented in Table 4.1. Earlier petrochemical studies on the Thimphu Gneiss' were mainly confined to the western, southern and northern sectors (Table 4.2).

Except for one sample which falls in the tonalite field, the Tashigang rocks fall in the granodiorite-granite fields (Fig.4.2A) in the normative An-Ab-Or diagram (after O'Connor, 1965, modified by Barker, 1976). The plots for the Sure suite are restricted within the granite field (Fig.4.2A). On the classification grid based on cationic parameters in terms of mineralogical components (R1-R2 diagram after De La Roche *et al*, 1980), the Tashigang rocks fall in the granodiorite-granite fields and the Sure samples in the monzogranite-syenogranite- alkali granite fields (Fig.4.3A). Fig.4.3.B shows plots of average major element data from other sectors of the Thimphu gneiss (data source in Table 4.2).

Barring one sample, granitic gneisses from the Tashigang and Sure areas are corundum normative (mostly within 0.5-4.92%) and peraluminous (A/CNK≥1, mostly within 0.99-1.55) (Table 4.1 and Fig.4.4A). The unusually high normative corundum (8.45%) and A/CNK ratio (2.07) in sample TC-2 (Table 4.1) is due to the presence of aluminous minerals like sillimanite, garnet and tourmaline -- the first two presumably as xenocrysts. In the A{Al-(Na+K+2Ca)} and B(Fe+Mg+Ti) binary diagram (after Debon and Le fort, 1983), the leucocratic variants of the Tashigang suite (with less than 10% dark

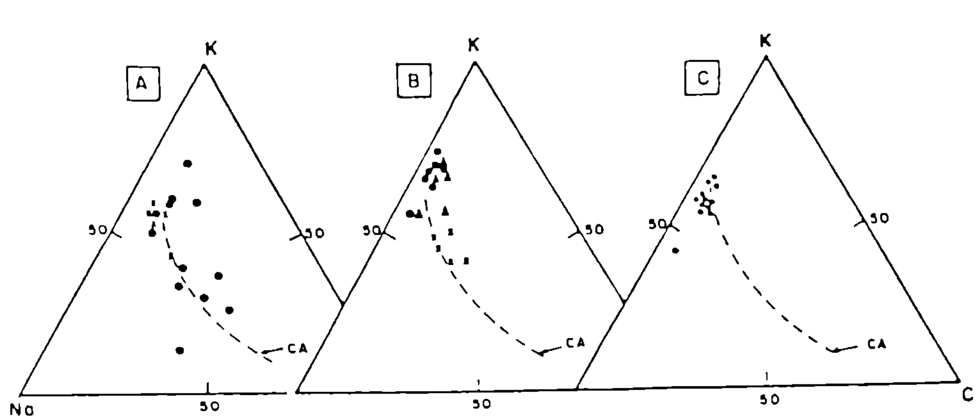

Fig. 4.7 K-Na-Ca diagram showing the classic calc-alkaline trend (after Barker and Arth, 1976) and plots for Bhutan granitoids. A. Tashigang (solid circles) and Sure (crosses). B. Gachhang (solid circles), Sisina (crosses) and Monji (solid triangles).

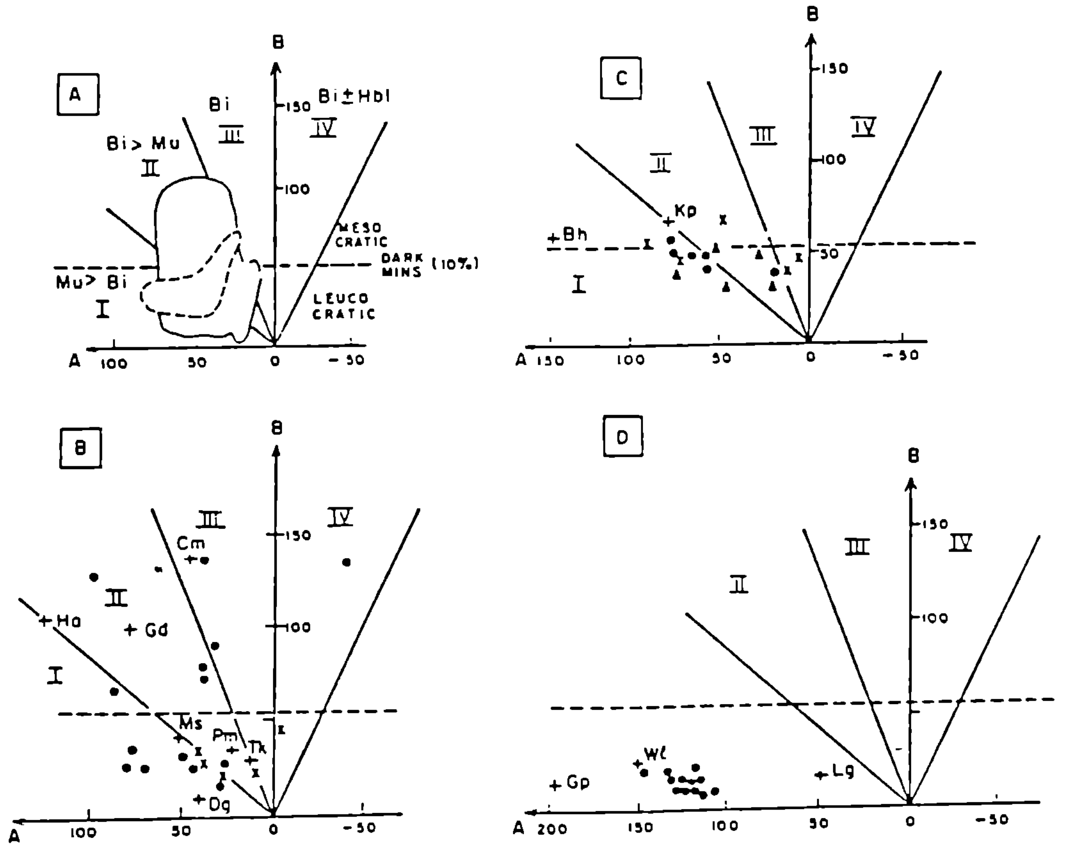

Fig. 4.5 (A) {Al-(Na+K+2Ca)}-B(Fe+Mg+Ti) diagram after Debon and Le Fort (1983) showing various peraluminous (I, II and III) and one metaluminous field (IV) and various minerals considered to be diagnostic for each field (Mu - muscovite, Bi - biotite, Hbl - hornblende. Field enclosed by solid line : field for Lesser and Higher Himalayan granitoids of Tibet and Nepal field enclosed by dotted line, field for leucogranitic rocks of Tibet and Nepal Himalaya. (B) Plots for Tashigang (solid circles) and Sure (crosses). (C) Plots for Gachhang (solid circles), Sisina (crosses) and Monji (solid triangle). (D) Kame *Chu* leucogranite.

Table 4.1 : Major element analyses of the biotite granitoid gneiss of the Thimphu Group from eastern and south-central sectors (Data in Wt %)

Sl.No. Sample No.	1 TC-1	2 TC-2	3 TC-4	4 TC-5	5 TC-6	6 TC-11	7 TC-7	8 TC-12	9 TC-13	10 TC-14	11 TC-1	12 TC-2	13 TC-3	14 TC-8	15 TC-9	16 TC-10	17 TC-11	18 TC-12
SiO_2	64.30	66.65	76.70	70.80	70.05	75.60	72.20	76.05	75.00	75.05	73.10	76.00	76.80	73.59	73.45	73.98	73.94	69.79
TiO_2	0.68	0.63	0.27	0.68	0.52	0.21	0.56	0.28	0.28	0.17	0.56	0.28	0.22	0.12	0.12	0.13	0.14	0.28
Al_2O_3	15.99	16.32	12.52	14.03	16.05	12.99	13.98	12.75	14.05	13.54	13.04	13.88	13.04	13.32	13.63	13.51	13.82	14.81
Fe_2O_3	0.16	0.31	0.17	0.53	0.30	0.01	0.01	0.22	0.01	0.16	0.12	0.60	0.01	1.02	0.89	0.81	0.77	1.18
FeO	5.49	5.04	1.26	2.97	2.07	1.44	2.70	1.17	1.17	1.62	3.53	0.72	0.63	0.36	0.45	0.81	0.90	1.35
MnO	0.12	0.11	0.02	0.04	0.02	0.02	0.04	0.01	0.05	0.05	0.05	0.04	0.01	0.07	0.05	0.07	0.07	0.06
CaO	4.32	2.55	0.77	2.13	3.34	0.79	2.20	0.68	0.92	0.98	2.73	0.78	0.93	0.71	0.75	1.00	0.88	2.16
MgO	2.49	2.34	0.63	1.65	1.22	0.22	1.42	0.17	0.33	0.34	1.16	0.18	0.16	0.10	0.10	0.29	0.47	0.43
Na_2O	2.33	2.74	1.62	3.19	4.50	3.12	3.24	2.44	2.53	2.57	2.12	2.93	3.13	3.66	3.86	3.09	3.31	4.14
K_2O	2.29	1.97	4.89	3.04	1.14	4.78	2.46	5.53.	4.37	4.64	2.39	3.35	4.42	5.32	4.96	4.23	4.31	3.94
P_2O_5	0.20	0.13	0.07	0.12	0.14	0.10	0.36	0.09	0.08	0.12	0.10	0.30	0.05	0.11	0.10	0.11	0.11	0.04
LOI	0.80	0.86	0.71	0.46	0.40	0.36	0.46	0.33	0.44	0.48	0.70	0.66	0.24	0.51	0.51	0.50	0.55	0.54
K_2O/Na_2O	0.81	0.72	3.02	0.95	0.25	1.53	0.76	2.23	1.73	1.81	1.13	1.14	1.41	1.45	1.29	1.37	1.30	0.95
K_2O/Na_2O+K_2O	0.84	0.54	0.12	0.34	0.59	0.10	0.39	0.09	0.13	0.14	0.61	0.12	0.12	0.08	0.09	0.14	0.12	0.27
A/CNK (molar)	1.17	2.07	1.35	1.15	1.12	1.13	1.26	1.16	1.35	1.26	1.21	1.55	1.13	1.03	1.06	1.20	1.21	0.99
A/NK	2.53	2.46	1.57	1.64	1.86	1.26	1.75	1.27	1.58	1.46	2.14	1.64	1.31	1.13	1.16	1.40	1.37	1.34
Norm.C	2.29	8.45	3.21	1.89	1.66	1.50	2.85	1.72	3.67	2.78	2.22	4.92	1.53	0.50	0.77	2.27	2.37	-
FeO^t/FeO^t+MgO	0.69	0.70	0.69	0.68	0.66	0.87	0.66	0.89	0.78	0.84	0.76	0.88	0.80	0.93	0.93	0.84	0.77	0.85

1-13 Granite gneiss of the Tashigang suite (Tashigang-Nagargompa)
14-18 Granite gneiss of the Sure suite.

Table 4.2 : Major element analyses of the biotite granitoid gneiss of the Thimphu Group from western and northern Bhutan (Data in Wt %)

Sl.No. 1 Location	1(2) Chimakotha	2(5) Dagana	3(2) Pamla	4(2) Takhtsang	5 Gedu	6 Ha	7(3) Masangkang
SiO_2	71.92	73.11	68.56	71.02	67.70	69.79	72.50
TiO_2	0.92	0.08	0.16	0.16	0.43	0.71	0.20
Al_2O_3	12.56	16.21	16.72	15.70	15.86	15.34	14.90
Fe_2O_3	2.43	0.55	0.78	0.43	1.49	2.54	0.80
FeO	5.31	-	2.16	1.67	3.96	3.96	1.60
MnO	0.04	-	0.06	0.01	0.09	0.02	0.04
CaO	1.76	0.39	0.84	0.62	2.22	0.64	1.30
MgO	1.38	0.09	0.01	0.21	1.27	0.92	0.40
Na_2O	2.90	6.86	4.49	4.69	3.28	1.15	3.30
K_2O	2.12	1.99	6.20	5.75	4.74	5.48	4.20
P_2O_5	0.08	0.26	0.20	0.27	0.25	0.10	0.14
LOI	0.25	0.38	0.56	0.19	0.30	0.56	0.90
K_2O/Na_2O	0.73	0.29	1.38	1.23	1.45	4.77	1.27
CaO/Na_2O+K_2O	0.35	0.04	0.08	0.06	0.28	0.10	0.17
A/CNK (molar)	1.24	1.20	1.10	0.89	1.13	1.72	1.24
A/NK (molar)	1.78	1.21	1.91	0.91	1.51	1.96	1.49
FeO^t/FeO^t+MgO	0.85	0.84	1.00	0.91	0.81	0.87	0.85

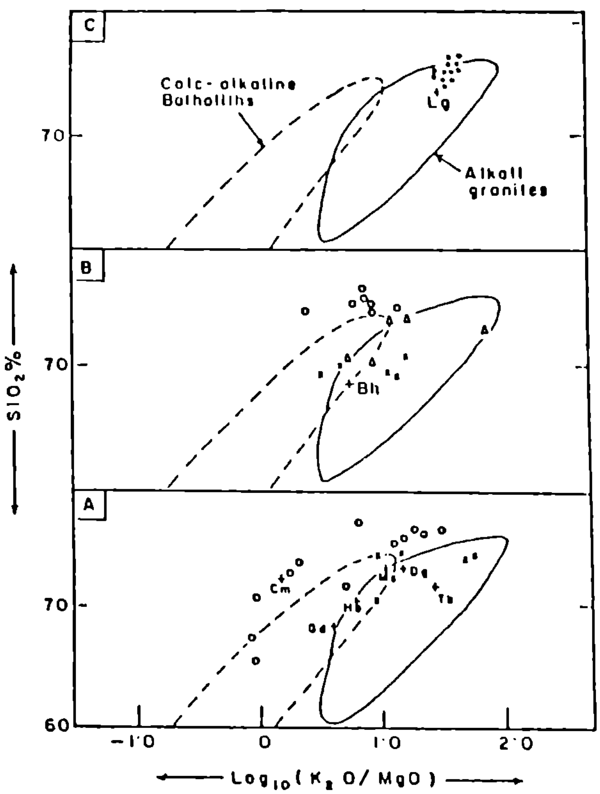

Fig. 4.8 $Log_{10}(K_2O/MgO)$ versus SiO_2 diagram showing fields for granitoids in calc-alkaline batholiths and alkali granites (after Rogers and Greenberg, 1981). A. Tashigang (solid circles) and Sure (crosses). Plus symbols denote plots of average from Cm - Chimakothi, Gd - Gedu, Ha - Ha, Tk - Takhtsang, Dg - Dagana and Ms - Masangkang (data sources as in Table 4.2). B. Gachhang (solid circles), Sisina (crosses) and Monji (solid triangles) suites. C. Kame *Chu* leucogranite (solid circle) and average leucogranite from Bhutan (plus) (after Gansser, 1983).

minerals) fall mostly in field I of the peraluminous domain and the mesocratic variants (with 10% dark minerals) plot in fields II and III of the peraluminous domain (Fig.4.5B). An overall increase in the degree of peraluminosity with increasing felsic mineral contents is thus evident in the suite. Compared to granitoid associations of the Lesser and Higher Trans Himalaya of Tibet and Nepal, the Tashigang suite exhibits similar range in A parameter (Alumina index) but a larger range in B parameter, the latter implying presence of mafic rich variants (Fig.4.5A and B).

Save one sample which falls in the metaluminous field close to metaluminous/ peraluminous field boundary, the Sure gneiss falls in fields II and III of the peraluminous domain in the A-B diagram (Fig.4.5B). The Sure suite has a restricted range in B parameter reflecting its leucocratic granitic composition.

The granodiorite-granite suite of Tashigang shows perceptible systematic variation in major element chemistry as revealed by plots of SiO_2, FeO^t, MgO and Na_2O+K_2O against CaO. Despite some scatter, the positive correlation of FeO^t, MgO and inverse correlation of SiO_2 and total alkalis with CaO are evident (Fig.4.6). Systematic variations in major element chemistry are also displayed by the Sure gneiss samples, albeit on a smaller scale as compared to the Tashigang suite (Fig.4.6). Such variations in major element chemistry imply role of crystallisation differentiation processes in the evolution of the Tashigang and Sure suites. Comparable differentiation trends have also been recorded in the Masangkang granitoids of the Thimphu Group (Gansser, 1983).

Distinct calc-alkaline affinities of the Tashigang and Sure suites are revealed in the K-

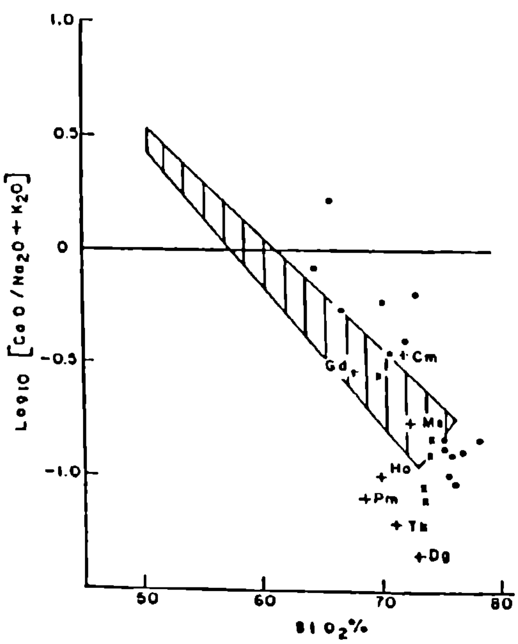

Fig. 4.9 SiO_2 versus $log_{10}(CaO/Na_2O+K_2O)$ diagram showing field for calc-alkaline andesites with calc-alkali index between 56-61 (calc-alkali). Index SiO_2% range over which where CaO/Na_2O+K_2O ratio becomes 1(Log of which is 0). Solid circles (Tashigang suite). Crosses (Sure suite) and the plus symbols denote plots of average from other areas of the Thimphu gneissic complex. Abbreviations of areas are as in Fig.4.8.

Na-Ca ternary diagram (Fig.4.7, after Barker and Arth, 1976). In the SiO_2 versus log

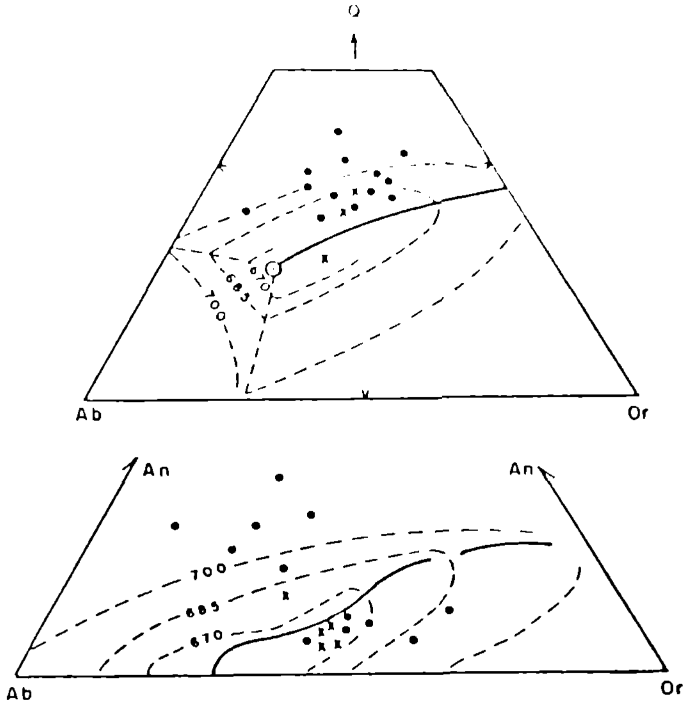

Fig. 4.10 Normative Q-Ab-Or and An-Ab-Or diagram showing plots of Tashigang (solid circles) and Sure suites (crosses). The projections for cotectic minimum and cotectic line at 5KbPH_2O and related isotherms are shown along with projection of cotectic minimum at 2KbPH_2O (after Winkler, 1976).

$_{10}(K_2O)/MgO)$ diagram, most samples of the Tashigang suite fall along but marginally outside the typical calc-alkaline field boundary (Fig.4.7A), defined by Rogers and Greenberg (1981).

Such dispersion of data points, reflects relatively more siliceous but K-deficient composition of the Tashigang rocks compared to calc-alkaline rocks in batholiths. The progressive increase in K_2O/MgO ratio with concomitant increase in SiO_2 suggesting fractionation is depicted by the Tashigang suite (Fig. 4.8A). In the SiO_2 versus log10 (K_2O/MgO) diagram, Sure suite rocks fall in both calc-alkaline and alkali granite fields. Thimphu gneisses of the Gedu, Ha, Masangkang areas plot in the calc-alkaline field and those from Takhtsang and Dagana in the alkali field (Fig. 4.8A).

The log $_{10}(CaO)Na_2O+K_2O)$ versus SiO_2 diagram (after Brown, 1982) reveals the calcic to calc-alkalic affinity to the Tashigang suite (Fig.4.9). The Sure suite is calc-alkalic to alkali-calcic. The calc-alkalic affinity of the Gedu, Masangkang suites and alkali-calcic affinity of the Ha, Pamla, Takhtsang and Dagana suites are also apparent (Fig.4.9).

The Q-Ab-Or relationships of the Tashigang and Sure suites are compared in Fig.4.10 with experimental results in the haplogranite system after Winkler, (1971). The normative compositions of the Tashigang and Sure rocks are mainly located in the zone of low temperature

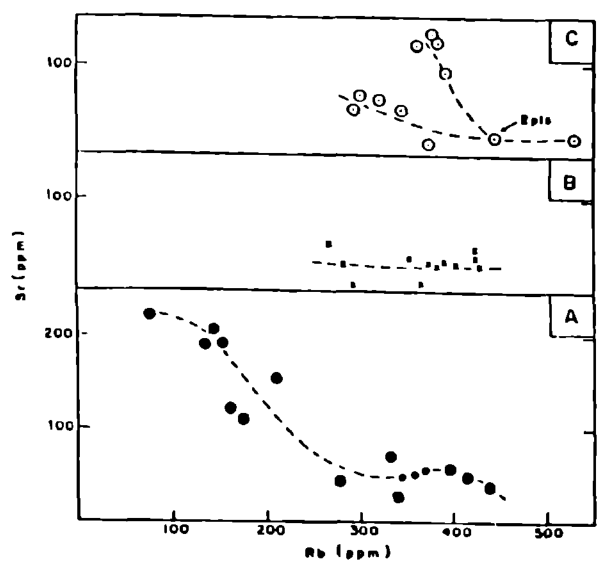

Fig. 4.11 Rb-Sr variation diagram. A. Tashigang suite, B. Gachhang suite and C. Kame *Chu* suite.

melts very close to the cotectic minimum at 2KbPH_2O and the corresponding cotectic line. The cotectic line represents the equilibrium quartz-plagioclase-alkali feldspar-liquid and

Table 4.3 : Major element analyses of deformed granite gneisses from Bhutan Himalaya (Data in Wt %)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Within Jaishidanda Formation (Sisina)					Within Shumar Formation (Gachhang)							(Monji)				
	DG-1	DG-2	DG-3	DG-4	DG-5	G-1	G-2	G-3	G-4	G-5	G-9	G-11	ML-11	ML-12	ML-14	ML-15	ML-16
SiO_2	69.40	69.06	70.67	68.98	70.29	74.90	75.20	75.75	76.20	74.35	74.50	75.05	70.38	70.38	73.03	73.94	74.02
TiO_2	0.31	0.34	0.24	0.29	0.30	0.27	0.27	0.31	0.31	0.37	0.37	0.37	0.39	0.48	0.12	0.12	0.16
Al_2O_3	15.01	15.80	14.50	15.49	15.61	12.52	12.79	12.52	12.26	13.43	13.59	12.92	14.30	15.59	12.97	13.31	14.16
Fe_2O_3	1.33	0.97	1.20	1.49	1.61	0.26	0.48	0.16	0.36	0.21	0.51	0.31	1.12	0.76	1.36	0.89	1.29
FeO	1.26	1.98	1.08	1.08	1.17	1.44	1.17	2.16	1.80	2.16	1.26	2.34	0.81	0.81	0.72	0.81	0.81
MnO	0.05	0.07	0.05	0.06	0.07	0.02	0.02	0.02	0.02	0.02	0.01	0.04	0.02	0.10	0.01	0.10	0.01
CaO	2.07	2.39	1.56	2.03	2.12	0.55	0.33	0.62	0.53	0.53	0.42	0.50	0.80	1.35	0.34	0.54	0.54
MgO	0.41	1.15	0.30	0.36	0.73	0.46	0.71	0.62	0.64	0.62	1.53	0.69	0.71	0.98	0.10	0.32	0.50
Na_2O	3.53	3.10	3.76	4.02	3.19	2.54	1.93	1.97	2.16	1.92	3.04	2.12	4.75	3.08	2.51	2.51	2.30
K_2O	4.71	3.57	4.49	4.38	3.54	5.86	5.63	4.42	4.42	5.05	3.64	4.26	5.95	5.01	6.57	5.38	5.26
P_2O_5	0.03	0.06	0.05	0.04	0.06	0.10	0.10	0.12	0.10	0.08	0.08	0.10	0.39	0.10	0.12	0.09	0.09
LOI	0.60	0.32	0.66	0.45	0.42	0.76	0.98	1.00	0.78	0.24	1.08	0.90	0.50	0.78	0.91	0.63	0.95
K_2O/Na_2O	1.33	1.15	1.19	1.09	1.11	2.31	2.92	2.24	2.05	2.63	1.20	2.01	1.25	1.63	2.62	2.14	2.29
CaO/Na_2O+K_2O	0.25	0.36	0.19	0.24	0.32	0.07	0.04	0.10	0.08	0.08	0.60	0.08	0.08	0.17	0.04	0.06	0.07
A/CNK (molar)	1.03	1.20	1.06	1.22	1.22	1.11	1.33	1.41	1.35	1.43	1.43	1.47	0.97	1.23	1.12	1.24	1.38
A/NK (molar)	1.38	1.76	1.32	1.70	1.72	1.19	1.38	1.56	1.47	1.56	1.52	1.60	1.00	1.48	1.15	1.34	1.48
Norm. C	0.40	2.62	0.78	2.80	2.80	1.23	3.16	3.65	3.19	4.03	4.07	4.15	-	2.88	1.41	2.59	3.72
FeO^t/FeO^t+MgO	0.86	0.71	0.88	0.87	0.78	0.78	0.69	0.79	0.77	0.79	0.53	0.79	0.72	0.60	0.95	0.83	0.80

1-5 Granite gneiss of Sisina area.
6-12 Granite gneiss of Gachhang area.
13-17 Granite gneiss of Monji (Kuru *Chu* valley)

Table 4.4 : Major emement analyses of Kame *Chu* Leucogranite (Data in Wt%)

Sl.No.	1	2	3	4	5	6	7	8	9	10	11	12
Sample No.	KG-1	KG-2	KG-3	KG-4	KG-5	KG-6	KG-7	KG-8	KG-9	KG-10	KG-11	KG-12
SiO_2	75.17	75.71	74.84	75.03	74.34	73.73	73.52	75.87	74.62	74.32	74.24	73.90
TiO_2	0.05	0.03	0.05	0.02	0.10	0.11	0.12	0.01	0.01	0.01	0.01	0.06
Al_2O_3	15.63	16.09	15.85	15.67	16.40	17.08	17.46	15.79	15.96	15.93	16.10	16.67
Fe_2O_3	0.71	0.67	0.58	0.50	0.65	0.89	0.65	0.38	0.25	0.34	0.30	0.50
FeO	0.18	0.09	0.27	0.18	0.36	0.18	0.45	0.27	0.36	0.36	0.45	0.27
MnO	0.01	0.01	0.01	0.10	0.01	0.02	0.02	0.01	0.01	0.06	0.05	0.01
CaO	0.54	0.48	0.54	0.53	0.59	0.57	0.53	0.36	0.39	0.35	0.37	0.43
MgO	0.10	0.10	0.10	0.11	0.10	0.10	0.11	0.10	0.10	0.10	0.10	0.10
Na_2O	2.46	2.41	2.37	3.12	3.12	3.05	2.77	2.76	2.91	3.86	2.91	3.08
K_2O	4.29	4.44	4.35	3.98	3.87	3.92	4.01	4.02	3.97	2.94	3.94	3.89
P_2O_5	0.09	0.07	0.11	0.15	0.12	0.13	0.12	0.06	0.07	0.07	0.08	0.11
LOI	0.47	0.27	0.50	0.23	0.50	0.59	0.68	0.53	0.54	0.39	0.26	0.46
K_2O/Na_2O	1.74	1.84	1.84	1.28	1.24	1.29	1.45	1.46	1.36	0.76	1.35	1.26
CaO/Na_2O+K_2O	0.08	0.07	0.08	0.08	0.08	0.08	0.08	0.05	0.06	0.05	0.05	0.06
A/CNK (molar)	1.65	1.70	1.70	1.56	1.62	1.71	1.82	1.68	1.66	1.59	1.69	1.70
A/NK (molar)	1.80	1.83	1.84	1.66	1.76	1.84	1.96	1.78	1.76	1.67	1.78	1.80
Norm C	6.17	6.61	6.52	5.62	6.29	7.09	7.88	6.39	6.33	5.93	6.56	6.84
FeO^t/FeO^t+MgO	0.89	0.87	0.89	0.85	0.91	0.91	0.91	0.86	0.86	0.87	0.88	0.88

vapour. The granodioritic rocks of the Tashigang suite lie marginally away from the cotectic line probably in the higher temperature region of the cotectic surface quartz-plagioclase-liquid-vapour. These observations imply that crystallisation of the Tashigang and Sure suites began with plagioclase and quartz followed by K-feldspar. This order of crystallisation is borne out by plots in the normative An-Ab-Or diagram as well (Fig. 4.10).

regarding the relative role of two major processes, viz., partial melting and crystallisation differentiation in the evolution of the rock suite (Hanson, 1978). In a granitic system, Sr has a much larger bulk distribution coefficient (D)(D>>1) compared to Rb(D<<1). In Fig.4.11A, Rb vs. Sr plots of the Tashigang suite show relatively wide systematic variation of Sr implying the dominant role of crystallisation differentiation

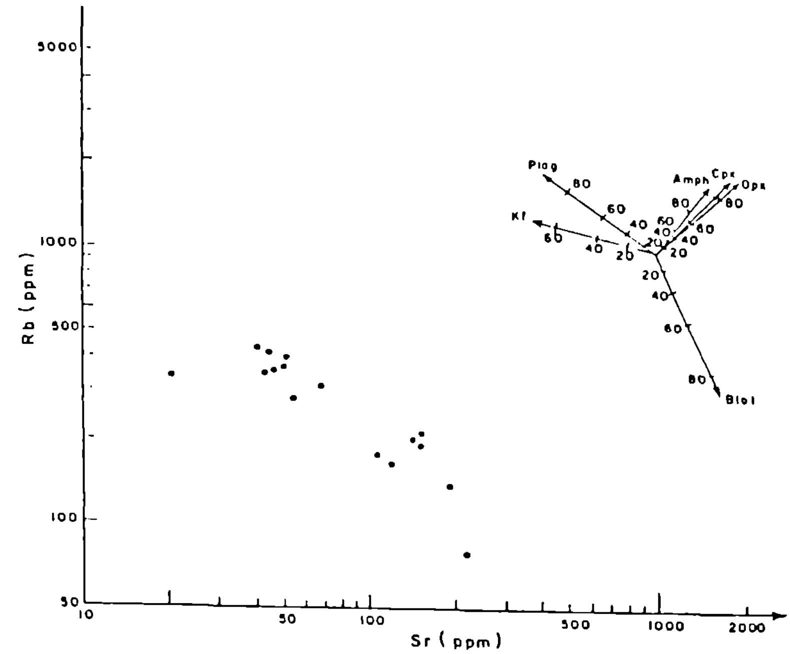

Fig. 4.12 Rb-Sr variation diagram for the Tashigang suite compared with vectors which indicate the change in composition of granitic melts as a result of fractional crystallisation of the different phases (Kf - K-feldspar, Plag - Plagioclase, Amph - amphibole, Cpx - clinopyroxene, Opx - orthopyroxene, Biot - Biotite). Figures indicate percentage of crystal removed (after Walsh *et al*, 1979).

The range of Rb, Sr contents and Rb/Sr ratios in 16 samples of Tashigang suite is given below :

	Range	Mean
Rb(ppm)	78-436	272
Sr(ppm)	43-221	101
Rb/Sr	0.35-16.33	5.23
(Mostly within 0.35-10.14 barring one sample)		

Compared to average low-Ca granite (Rb 170ppm, Sr 100ppm, Turekian and Wedepohl, 1961), the Tashigang suite is distinctly Rb enriched (mean Rb content 272ppm). The K/Rb ratio for five samples of the Tashigang suite ranges between 119-134, with an average value of 125.

Variation pattern of Rb and Sr contents in a cogenetic granitoid suite provides an indication

processes in the evolution of the rock suite (cf. Hanson, 1978). This is supported by major element variations as well. Comparison with established fractionation vectors reveals that the Rb and Sr variations in the Tashigang suite are mainly due to fractionation of three phases, viz., plagioclase, K-feldspar and biotite (Fig.4.12).

4.1.C Geochronology : Seven whole-rock samples of the Tashigang suite define a well fitted Rb-Sr isochron corresponding to an age of 524 ± 8 Ma with an initial $^{87}Sr/^{86}Sr$ ratio (^{I}Sr) of 0.71237±47 (2) and with MSWD 1.73 (Fig. 4.13). The age date is interpreted to mark the emplacement event of the Tashigang suite. The relatively high ^{I}Sr (0.71237) of the suite suggests contribution from crustal sources. Table 4.6 reveals that the rocks with lower Sr absolute abundance have the highest $^{87}Sr/^{86}Sr$ ratio whereas the rocks with higher Sr abundances have

Table 4.5 : Average major element analytical data (wt%) for granite rock of Bhutan Himalaya (Figures in paranthesis are standard deviation)

	1	2	3	4	5	6	7	8	9	10	11
	Thimphu Gneises				Deformed Gneiss			Leucogranites			
	Tashigang	Sure	Sisina	Gachhang	Monji	Bh	Kp	Kame Chu	Gophula	W. Lunana	
SiO_2	72.95 (4.00)	72.95 (1.78)	69.68 (0.76)	75.14 (0.66)	72.35 (1.84)	68.34	72.54	74.61 (0.75)	73.46	71.97	72.80
TiO_2	0.11 (0.11)	0.16 (0.07)	0.30 (0.04)	0.32 (0.05)	0.25 (0.17)	0.58	0.04	0.05 (0.04)	0.12	0.18	0.11
Al_2O_3	14.01 (1.30)	13.82 (0.58)	15.30 (0.50)	12.87 (0.49)	14.07 (1.02)	18.47	13.42	16.22 (0.58)	14.87	15.56	15.12
Fe_2O	0.20 (0.19)	0.93 (0.17)	1.33 (0.25)	0.33 (0.13)	1.09 (0.26)	1.64	0.70	0.54 (0.19)	0.86	-	0.26
FeO	2.29 (1.55)	0.77 (0.40)	1.31 (0.38)	1.76 (0.48)	0.79 (0.04)	0.73	2.91	0.29 (0.11)	-	1.45	0.67
MnO	0.05 (0.04)	0.06 (0.01)	0.06 (0.01)	0.02 (0.08)	0.05 (0.05)	0.09	0.02	0.02 (0.02)	0.02	0.04	0.03
CaO	1.78 (1.20)	1.10 (0.61)	2.03 (0.30)	0.50 (0.10)	0.71 (0.39)	0.57	0.99	0.47 (0.09)	0.71	0.82	0.79
MgO	0.95 (0.83	0.23 (0.18)	0.59 (0.36)	0.75 (0.35)	0.50 (0.36)	0.85	1.00	0.09 (0.03)	0.05	0.12	0.14
Na_2O	2.84 (0.68)	3.61 (0.42)	3.52 (0.39)	2.24 (0.41)	3.03 (1.00)	3.18	1.66	2.90 (0.41)	4.06	3.56	3.71
K_2O	3.48 (1.37)	4.55 (0.57)	4.14 (0.55)	4.75 (0.79)	5.63 (0.63)	4.51	4.52	3.97 (0.38)	4.78	5.28	4.67
P_2O_5	0.14 (0.09)	0.09 (0.03)	0.05 (0.01)	0.10 (0.01)	0.16 (0.13)	-	0.18	0.10 (0.03)	0.09	0.07	0.15
LOI	0.53 (0.19)	0.52 (0.02)	0.49 (0.14)	0.82 (0.28)	0.75 (0.19)	-	1.59	0.45 (0.14)	1.00	0.86	0.85
K_2O/Na_2O	1.28	1.27	1.17	2.19	1.99	1.42	1.49	1.41	1.26	1.48	1.26
CaO/Na_2O+K_2O	0.32	0.14	0.27	0.15	0.55	0.07	0.76	0.07	0.08	0.09	0.09
A/CNK (molar)	1.30	1.10	1.15	1.36	1.19	-	1.49	1.67	1.15	1.21	1.23
A/NK (molar)	1.73	1.28	1.58	1.47	1.29	-	1.76	1.79	1.25	1.34	1.35
FeO^t/FeO^t+MgO	0.76	0.86	0.82	0.73	0.78	0.75	0.79	0.88	0.94	0.93	0.87

the lowest $^{87}Sr/^{86}Sr$ ratio. Such a relationship suggests that the melt underwent contamination with high $^{87}Sr/^{86}Sr$ ratio and low Sr abundance material of crustal origin.

Table 4.6 : Rb-Sr Isotopic Data

Sl.No.	Sample No.	Rb (ppm)	Sr (ppm)	$^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr$+2
Tashigang					
1.	CCT/2	145	204	2.059	0.72740 ± 0.00015
2.	TC/1	152	191	2.312	0.72981 ± 0.00014
3.	CCT/7	214	153	4.062	0.74312 ± 0.00023
4.	CCT/6	334	69	14.231	0.82008 ± 0.00040
5.	CCT/15	364	51	20.975	0.86814 ± 0.00020
6.	CCT/16	357	48	21.867	0.87505 ± 0.00020
7.	CCT/12	350	45	22.885	0.88258 ± 0.00040
Gachhang					
8.	GCG/9	271	54	15.219	1.22067 ± 0.00080
9.	GCG/2	380	39	30.161	1.42162 ± 0.00030
10.	GCG/7	390	36	33.885	1.54000 ± 0.00050
11.	GCG/6	409	33	38.861	1.57820 ± 0.00010
12.	GCG/11	458	33	44.024	1.68700 ± 0.00020

The age of the Tashigang granodiorite-granite gneiss (524±8 Ma) is closely comparable to that of the Bhurkhola granitic gneiss (Rb-Sr whole rock isochron age 508±15 Ma, Chowdhury

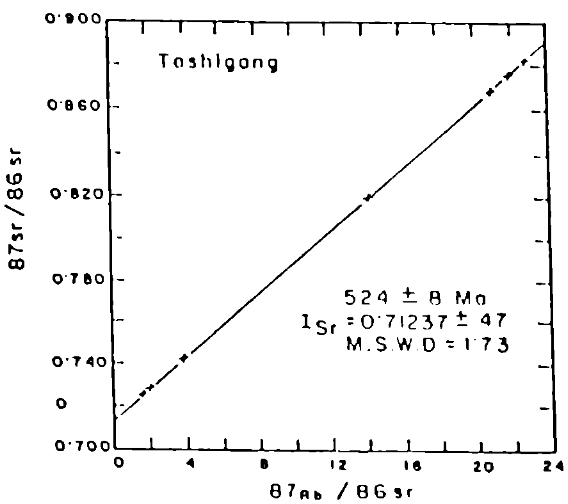

Fig. 4.13 Rb-Sr isochron diagram for the Tashigang suite.

and Bhalla, 1988), which occurs within the Jaishidanda Formation of the Lesser Himalaya of Bhutan. The Tashigang suite is distinctly older than the Masangkang pluton of the Bhutan Himalaya (Rb-Sr whole rock isochron age 369 ± 5 Ma), ISr = 0.715, Gansser, 1983).

Emplacement events of granitoids in the Himalayan orogen principally belong to five broad temporal groups, viz.,

Early Proterozoic	(ca. 2300-1800 Ma)
Middle Proterozoic	(1600 - 1000 Ma)
Late Proterozoic-Palaeozoic	(700 - 400 Ma)
Late Palaeozoic-Late Mesozoic	(300 - 100 Ma)
Cainozoic	(65 - 20 Ma)

Of the above noted temporal groups, the Early Palaeozoic and younger granitoids (400-600 Ma) mainly occur within the Main Central Thrust Sheet and its equivalents. Table 4.8 lists available isotopic age data for the Early Palaeozoic granitoids from different sectors of the Himalayan orogen. Fig.4.14 reveals that more than 90% of the granitoids (40 out of 43, Table 4.8) have ages within a rather restricted time interval between 450-570 Ma (Cambrian-Ordovician). The ISr of these granitic rocks is mostly high and about 75% range between 0.708-0.724 with a mean of about 0.716±0.015 (1) (Table 4.7). Such intermediate to high ISr values imply variable involvement of crustal sources and the large range of variation of ISr within a rather restricted time interval signifies variability in both nature and age of crustal protoliths.

4.1.D Tectonic Status : In Tashigang suite barring low alkali level, principally due to deficiency in K_2O, all other parameters point to distinct compressional millieu (Table 4.9). This is

Table 4.7 : Isotopic ages[1] of granitic rocks in the Himalaya Orogen related to Lower Palaeozoic Event

Sl. No.	Rock type/area	Age (Ma)[2]	I_{Sr}[3]	Reference
	J & K Himalaya			
1.	Hant granite, Baramulla	489+20	0.7170+12	Rao *et al*, (1990)
2.	Kangan granite	470+11	0.7216+23	Trivedi *et al*, (1984)
3.	Doda granite, Pranu	496+21	-	Kwatra *et al*, (1987)
4.	Granite gneiss, Thathri	499+57	0.7020+114	Kwatra *et al*, (1987)
5.	Pologonkala granite	487+25	0.7154+67	Trivedi *et al*, (1986)
6.	Karzok granite	487+14	0.7113+36	Trivedi *et al*, (1986)
7.	Nimaling granite	460+8 (U-Pb/Zir)	-	Stutz and Thoni (1987)
	Himachal Himalaya			
8.	Central gneisses, Rohtang pass-Manali	601+9(581)	0.7113+7	Mehta (1977)
9.	Migmatitic gneisses, Kulu	518+8(500)	0.7190+7	Mehta (1977)
10.	Mandi granite	564+12(545)	0.7019+15	Mehta (1977)
11.	Biotite granite, Sarangi and Runga Thach	467+45	0.719	Bhanot *et al*, (1979)
12.	Mandi granite	518+100(500)	0.7189	Jager *et al*, (1971)
13.	Jispa granodiorite, South Lahul	495+16(509)	0.720+2	Frank *et al*, (1977)
14.	Budatoli granite	501+38	0.732+5	Singh *et al* (1993)
15.	Rakcham granite	495+50	-	Sharma *et al*, (1983)
16.	Granite gneiss, Kiksar	567+22	0.704	Kwatra *et al*, (1987)
17.	Akpa (Rakcham granite)	477+29	0.7201	Kwatra (1986) in Thakur (1992)
18.	Chazur granite	530+40	0.7326	Kwatra (1986) in Thakur (1992)
19.	Kinnaur Kailash granite	675+70	-	Sharma (1983)
20.	Quartz diorite, Kuwa	414 (K-Ar)	-	Sinha and Bagdasarian (1977)
	U.P. Himalaya			
21.	Ranikhet granite	485+55	0.756+25	Pandey (1981) in Singh *et al*, (1993)
22.	Granite-granodiorite, Champawat-Almora	560+20	0.7109+13	Trivedi *et al*, (1984)
23.	Granite gneiss, Tawaghat	453+26	0.741	Singh *et al*, (1986)
	Arunachal Himalaya			
24.	Deed granite	500+19	0.7201+13	Bhalla *et al*, (1994)
25.	Tamen gneiss	486+65	0.7142+65	Bhalla *et al*, (1994)
26.	Hornblende gneiss, Sela	481+23	0.7194+10	Dikshitulu *et al*, (1995)
	Bhutan Himalaya			
27.	Granite gneiss, Bhurkhola	508+15	0.7088+35	Chowdhury and Bhalla (1988)
28.	Granodiorite-granite gneiss, Tashigang	524+8	0.71237+47	This work
	Tibet Himalaya			
29.	Kangmar granite gneiss, South Tibet	485+6	0.7186+18	Wang *et al*, (1981) in Debon *et al*, (1986)
30.	Kangmar granite gneiss, South Tibet	484+14	0.7140+12	Debon *et al*, (1986)

Table 4.7 (Contd.)

Sl. No.	Rock type/area	Age (Ma)[2]	ISr[3]	References
31.	Kangmar granite gneiss, South Tibet	434.7+37.3	0.7207+9	Jin and Xu in Debon *et al*, (1986)
32.	Kangmar granite gneiss, South Tibet	562+4 (U-Pb/Zir)	-	Scharer *et al*, (1986)
	Nepal Himalaya			
33.	Migmatitic orthogneiss, Dudh Kosi valley	550+16	0.7283+6	Ferrera *et al*, (1983)
34.	Augen gneiss, Formation III, Tibetal crystalline slab, Central Nepal	517+62	0.7097+120	Le Fort *et al*, (1983)
35.	Paragneiss, Lhotse, Mt. Everest region	449+56	0.7236+30	Ferrera *et al*, (1983)
36.	Palung granite	486+10	0.720	Beckinsale in Mitchell (1981)
37.	Simchar granite	i) 466+40 ii)511+55	0.7205+16 0.7085+48	Le Fort *et al*, (1983) in Debon *et al*, (1986)
38.	Palung+Simchar granite	493+11	0.7106+31	Le Fort *et al*, (1983)
39.	Barun migmatite, Eastern Nepal	525+20	0.7372+31	Kai (1981)
40.	Barun+Irkhua gneisses, Eastern Nepal	512+20	0.7234+13	Kai (1981)
	Punjab Himalaya			
41.	Manserah granite pluton	516+16	0.7189+6	Le Fort *et al*, (1980)
42.	Lower Swat granites	515 (39Ar/40Ar)	-	Shams (1983)
43.	Shengus gneiss, Nanga Parvat area	400-500 (U/Th-Pb-Zir)	-	Seitler *et al*, (1989)

1. Rb-Sr whole rock isochron ages unless otherwise mentioned. Apparent ages based on single sample (assuming initial 87Sr/86Sr ratio) have not been compiled. 2. Age data within paranthesis are based on old Rb decay constant. 3. Initial 87Sr/86Sr ratio.

supported by calc-alkalic affinity of the suite established earlier. However, alkali deficiency or enrichment is quite common in granitic rocks of compressional regime and may be related to depth of melt generation and/or nature of protolith (cf. Petro *et al*, 1979).

The Sure suite shows distinct affinity to extensional milieu.

iv) Presence of biotite and hornblende as major mafic minerals.

v) Presence of migmatitic zones (aureoles) around enclaves.

vi) Distinct peraluminous nature with degree of alumina saturation increasing in the felsic variants.

Table 4.8 : 1000-1300 Ma old granitic rocks of the Himalayan Orogen[1]

Sl.No.	Rock type/area	Age (Ma)[2]	ISr3	Reference
1.	Deformed granite gneiss, Brijranigad, Bhilangana valley, Tehri dt., UP	1276+12	0.82	Bhattacharyya *et al*, (1982)
2.	Deformed granite gneisses, Ingedinala, Bhilangana valley, Tehri dt., UP	1139+12	1.10	Bhattacharyya *et al*, (1982)
3.	Bandal granite, Kulu, Himachal Pradesh	1263+100 (1220)	-	Bhanot *et al*, (1976)
4.	Grey granite, Amritpur, Kumaon, UP	1110+131	0.74+12	Singh *et al*, (1986)
5.	Granite, Gwaldam-Dangoli area, Baijnath crystallines, Kumaon, UP	1307+79	0.793+17	Pandey *et al*, (1980)
6.	Granite gneisses, Gwaldam-Dangoli area, Baijnath crystallines, Kumaon, UP	1175+120	0.749+8	Pandey *et al*, (1980)
7.	Chor granite, Himachal Pradesh	1000 (K-Ar)	-	Dixit (1977)
8.	Deformed granite gneiss, Kangpar, Bhutan	1012	0.7617	Sinha-Roy and Sen Gupta (1986)
9.	Deformed granite gneiss, Gachhang, Bhutan	1109+125	0.97565+0.04672	Present study

1. Mostly Rb-Sr whole rock isochron ages except Sl.No.7. Apparent ages based on assumed initial $^{87}Sr/^{86}Sr$ ratios are not copiled. 2. Figures in paranthesis indicate age based on old decay constant of ^{87}Rb. 3. ISr = initial $^{87}Sr/^{86}Sr$ ratio.

Table 4.9 : Comparison of mean values of petrochemical parameters in the Silica Range 70-75%

Rock suite	D.I.	CaO	Total alkalies	CaO/Na_2O+K_2O	FeO/FeO^t+MgO
'Type' Extensional[1]	88.9, 92 (=90)	0.86, 1.24 (<1.25	8.57, 8.43 (>8)	0.15, 0.10 (<0.15)	0.91, 0.93 (>0.90)
'Type' Compressional[1]	83.1, 83.3 (83)	2.40, 2.22 (>2.00)	6.71, 6.94 (7)	0.38, 0.34 (>0.30)	0.79, 0.83 (<0.80)
Tashigang	81	2.26	5.20	0.41	0.71
Sure	92	0.84	8.19	0.11	0.87
Sisina	85	1.84	7.49	0.26	0.83
Gachhang	89	0.50	7.35	0.25	0.70
Monji	91	0.71	8.94	0.08	0.78
Kame *Chu*	90	0.47	6.87	0.07	0.89

4.1.E Petrogenesis : Significant petrological aspects of the Tashigang suite pertinent to its genesis are :

i) Granodiorite-granite (minor tonalite) association with appreciable presence of mesocratic variants.

ii) Close spatial association with hornblende-bearing dioritic rocks.

vii) Regular and systematic major element and Rb, Sr variations symptomatic of crystallisation differentiation processes.

viii) Distinct calcic to calc-alkaline affinity but perceptibly SiO_2 enriched and alkali deficient compared to typical calc-alkaline granitoids.

ix) Moderately high ISr(0.7124) with the evidence that the melt underwent contamination with low Sr, high $^{87}Sr/^{86}Sr$ crustal material.

x) Possible generation in a compressional tectonic milieu.

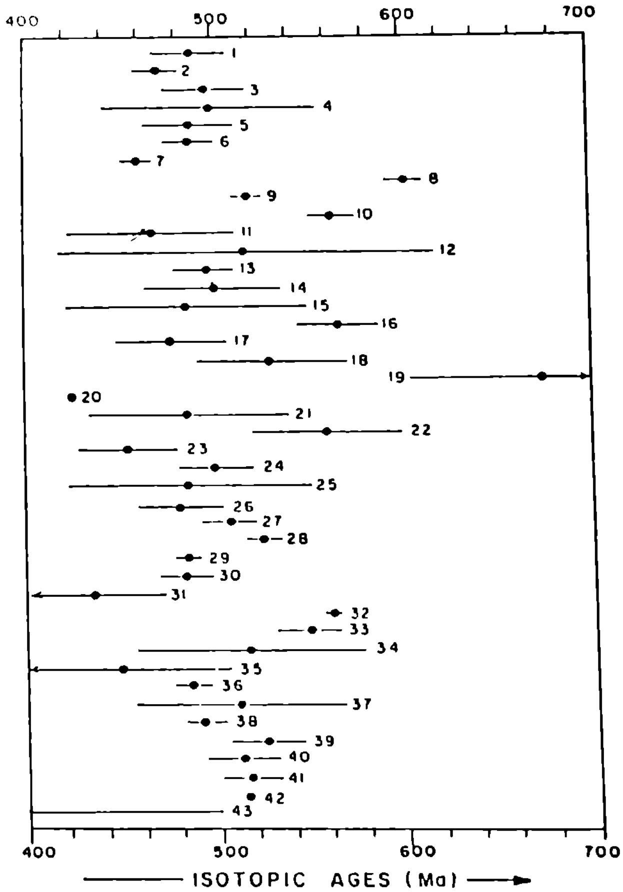

Fig.4.14 Graphical representation of available isotopic ages of Early Palaeozoic granitoids from the Himalayan orogen (data sources in Table 4.7). Solid circles represent ages and the attached bars indicate limits of uncertainity.

In the Na_2O vs. K_2O diagram, the Tashigang samples show affinity with I-type granitoids (Fig.4.15). In fact, barring distinct peraluminous nature, relatively high SiO_2 content of the felsic variants, relative dominance of metasedimentary xenoliths and relatively high ^{I}Sr (0.7124), all the petrological attributes of the Tashigang suite listed above conform to I-type granitoids. However, peraluminous nature itself is no unequivocal indicator of S-type affinity (cf. Miller, 1985). ^{I}Sr of many I-type granitoids have values comparable to Tashigang suite (e.g. 0.715 for some I-type granites of Massif Central, France, Didier *et al*, 1982). Several distinct I-type Late-Proterozoic-Palaeozoic granite plutons of East Khasi Hills, Meghalaya plateau, share several characteristics of the Tashigang suite viz. mixed xenolith population, presence of biotite and absence of muscovite and close spatial association with hornblende-bearing dioritic rocks and relatively high ^{I}Sr (ranging from 0.7095-0.7149)(Ghosh *et al*, 1991). However, in sharp contrast to the Tashigang suite, the Meghalaya granitoids are distinctly metaluminous (A/CNK≤1.05), Sr enriched (365-432ppm) and have lower Rb/Sr ratios (0.71-1.38) (Ghosh *et al*, 1991).

Plots of Na_2O/Al_2O_3 vs. K_2O/Al_2O_3 (after Garrels and Mackenzie, 1971) for the Tashigang suite imply a hybrid protolith (Fig.4.16A).

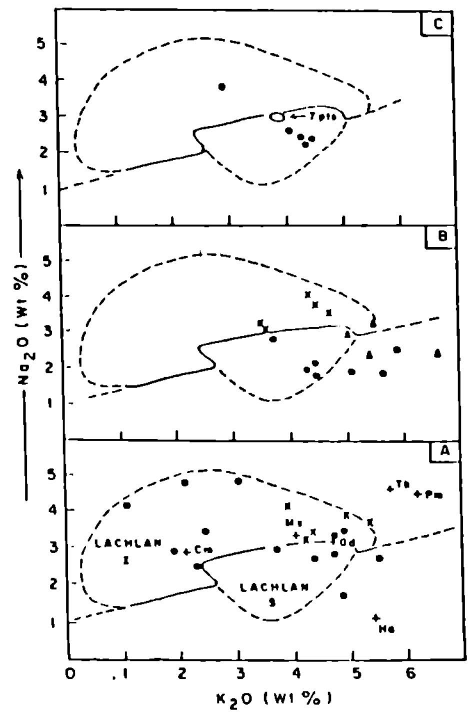

Fig. 4.15 Na_2O-K_2O diagram showing fields for type I and S granites from Australia (White and Chappal, 1983). A. Tashigang (solid circles), Sure (crosses). Plus symbols denote average data from other areas (abbreviations of areas are as in fig. 4.8). B. Sisina (crosses), Monji (solid triangles) and Gachhang (solid circles). C. Kame *Chu* suite.

Relatively high levels of silica in the felsic members, presence of xenoliths of pelitic rocks and xenocrysts of high grade metamorphic minerals (garnet, sillimanite), consistent peraluminous nature with alumina saturation index increasing in the late felsic rocks suggest involvement of sedimentary/metasedimentary

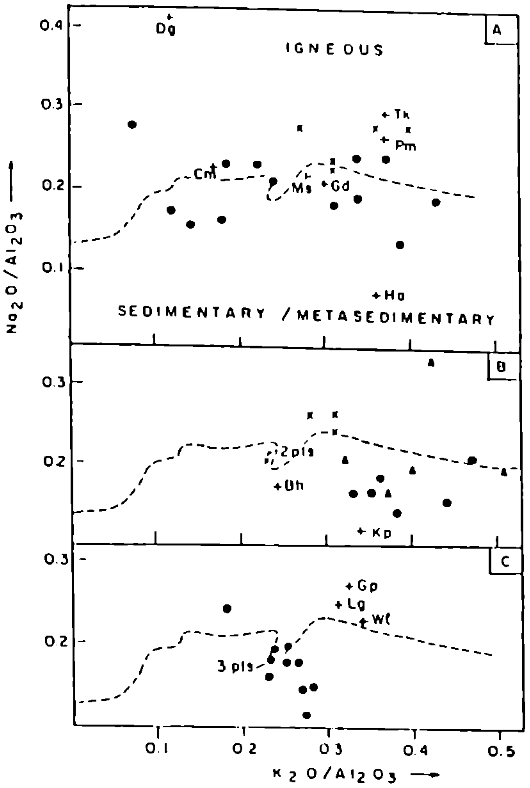

Fig. 4.16 Na_2O/Al_2O_3-K_2O/Al_2O_3 diagram showing igneous and sedimentary/metasedimentary fields (after Garrels and Mackanzie, 1971). Symbols in A, B and C are in Fig. 4.20).

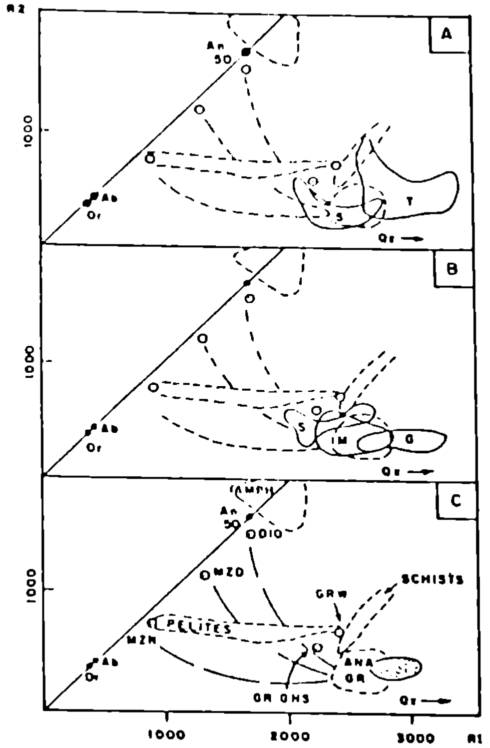

Fig. 4.17 R1-R2 diagram showing partial melting/fractional crystallisation vectors. Fields for various protoliths are shown (pelites, schists, GRW - graywacke, Gr.GNS - Granite gneiss, AMPH - amphibolite). End member mineral components : Ab - albite, Or - orthoclase and Qtz - quartz. Field of typical crystally derived anatectic granite is shown (ANA Gr.). Location of other rocks (DIC - diorite, MZD - monzodiorite, MZN - Monzonite) (After Batchelor and Bowden, 1985). A.T - Tashigang suite, S - Sure suite, B. G - Gachhang suite, M - Monji suite, S - Sisina suite, C. Dotted field - Kame Chu leucogranites. R1 = 4Si-11(Na+K)-2(Fe+Ti). R2 = 6Ca+2Mg+Al.

sources. In the R1-R2 diagram, the field of Tashigang rocks towards the felsic end reveals a broad splay towards quartz-rich compositions overlapping with the field of largely crustally derived anatectically generated granites (Fig.4.17).

The various petrological attributes of the Tashigang suite are explained by crystallisation differentiation of a hybrid melt generated by intermingling of an intermediate magma (quartz-dioritic or dioritic) with felsic liquids generated by simultaneous anatexis of crustal sedimentary/metasedimentary protoliths. The generation of the intermediate magma obviously requires a mantle connection. Removal of calcic plagioclase and amphibole from a tholeiitic basalt may lead to generation of an intermediate dioritic melt, which may be variably contaminated with concomitantly generated crustal melts due to cushioning of mafic melts at depth. For K-deficient calc-alkaline granitoids in a compressional tectonic milieu such as the Tashigang suite, such a mode of generation is favoured (cf. Batchelor and Bowden, 1985).

Sure Suite : The Sure gneiss is biotite-bearing metaluminous to peraluminous alkali-calcic type generated in an extensional tectonic milieu. The plots of the Sure rocks in the Na_2O-K_2O and Na_2O/Al_2O_3-K_2O/Al_2O_3 diagrams imply a mixed protolith (Fig.4.15A and 4.15.B). In the R1-R2 diagram, the rocks show considerable overlap with the field of anatectic granitoids (Fig.4.22).

4.2 TECTONIC SLIVERS OF GRANITIC GNEISS IN THE JAISHIDANDA AND SHUMAR FORMATIONS AND BAXA GROUP

Granitic gneiss within the Shumar and Jaishidanda Formations and the Baxa Group invariably occur as sheet-like bodies (see Chapters 3.7 and 3.8). Within the Baxa Group sequence, granitic gneiss slivers are known from Kangpar (Sinha-Roy and Sen Gupta, 1986) and east of Narphung areas.

The concordant sheet-like geometry, highly deformed and mylonitised nature, sharp contact with enveloping low-grade metasediments with total lack of contact effect suggest these bodies to be tectonically emplaced wedges (slivers). These were possible plucked from the basement over which the corresponding thrust sheet was translated (cf. Sinha-Roy and Sen Gupta, 1986; Roy *et al*, 1989).

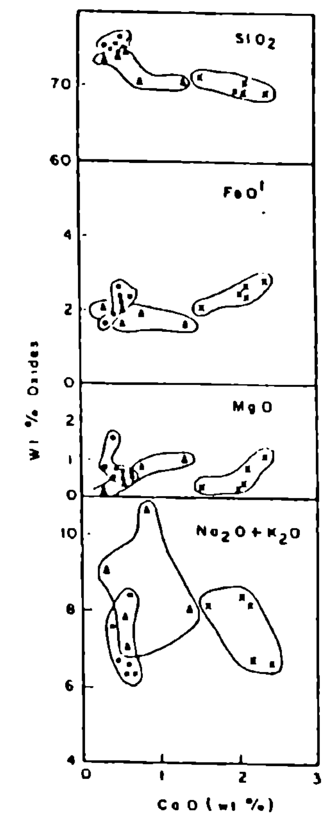

Fig. 4.18 Variation diagram of the Sisina (crosses), Monji (solid triangles) and Gachhang suites (solid circles).

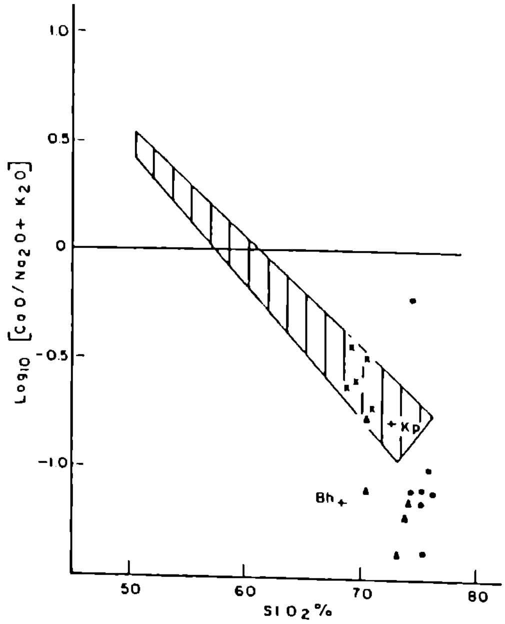

Fig. 4.19 SiO_2 vs. $\log_{10}(CaO/Na_2O+K_2O)$ diagram (after Brown, 1982) showing plots for Sisina (crosses), Monji (solid triangles) and Gachhang suites (solid circles). BH and KP - average granite gneiss from Bhurkhola and Kangpar areas of Bhutan. Other explanations as in Fig. 4.9.

4.2.A Mode of Occurrence

Mylonitised granite gneiss within the garnetiferous mica-schist of the Jaishidanda Formation is recorded from Lodrai-Sure, Bhurkhola, Sarbhang-Dhara *Chu* and Phuntsholing sections. Thickness of individual body varies between less than five metres and 50m, the largest body having a thickness of about 100m occurs around Sisina (north of Wang *Chu*-Paro *Chu* confluence). The granitic gneiss slivers are invariably interleaved with phyllonitic schists (Figs.3.8.10 & 3.8.12) with a sharp contact (Figs.3.8.8 & 3.8.11). The granitic texture in these rocks has been almost completely obliterated by plastic deformation and dynamic recrystallisation. Texturally the rocks are represented by protomylonite, augen gneiss and mylonite. At several localities, particularly along Lodrai-Sure and Sarbhang-Dhara *Chu* sections, there is a reduction in size and number of porphyroclasts (augen), related to intensity of deformation, from centre to margin of the granite slivers. The dominant mineral constituents of the rock are quartz, K-feldspar, plagioclase, muscovite and biotite. Accessories include epidote, apatite, tourmaline and opaques. The details of the textural features have been discussed in Chapter 3.8.

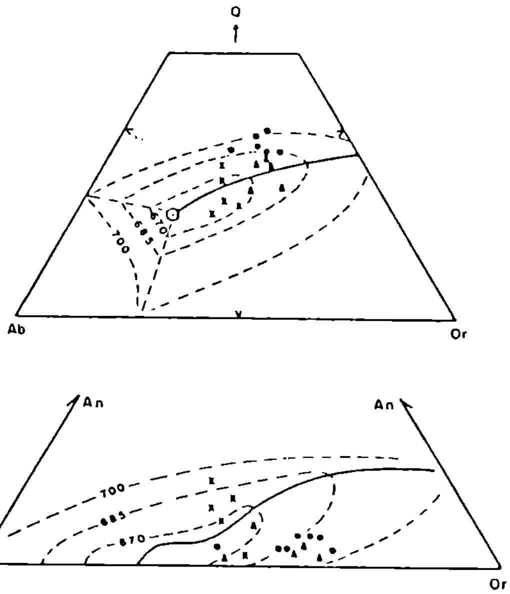

Fig. 4.20 Normative Q-Ab-Or and An-Ab-Or diagram showing plots for Sisina (crosses), Monji (solid triangles) and Gachhang (solid circles). Other explanations as in Fig. 4.10.

Within the Shumar Formation, several splintery and sheet-like masses of mylonitised granite gneiss of variable dimensions occur at different tectonic levels. Spatially, these masses are restricted to within the Kuru *Chu*-Seri *Chu* river valleys. South of Monji, Kuru *Chu* valley, splinters of granite gneiss vary in thickness from 10m to 50m. Mappable bodies of such granite gneiss are known as Gachhang, Chimung Ri and Murshing granites. In the Gachhang area, the granite gneiss attains a maximum thickness of about five kilometres.

These granitic rocks have highly deformed mylonitic nature (see Dasgupta, Chapter 3.7). The rocks are subleucocratic and principally composed of quartz, perthitic K-feldspar, plagioclase and biotite. Tiny flakes of muscovite and sericite occur in clusters. Accessories include tourmaline and opaque oxides.

4.2.B Petrochemistry : Major elements for five samples of Sisina, seven of Gachhang and five from Monji suites were determined (Table 4.3).

Sisina gneiss, occurring within the Jaishidanda Formation, plot in the granite field close to granodiorite-granite field boundary in the normative An-Ab-Or ternery diagram (Fig.4.2.B). In the R1-R2 diagram, these, however, occupy granodiorite-monzogranite-syenogranite fields (Fig.4.3.B). The rocks are corundum normative (0.4-2.81%) and marginally peraluminous (A/CNK = 1.03-1.22)(Table 4.3 and Figs.4.4B & 4.5C). Despite limited number of samples, systematic increase of SiO_2, Na_2O+K_2O and decrease of FeO^t and MgO with decreasing CaO in the Sisina suite is an unambiguous (Fig.4.18) effect of fractionation.

In the K-Na-Ca diagram, the Sisina rocks cluster along Calc-alkali trend (Fig.4.7.B). In the SiO_2 vs. $\log_{10}(K_2O/MgO)$ diagram, the Sisina rocks plot in both calc-alkalic and alkali granite fields (Fig.4.8.B). However, $\log_{10}$ (CaO/ Na_2O+ K_2O) vs. SiO_2 relations point to a distinct calc-alkaline affinity of the suite (Fig.4.19).

Table 4.0 : Rb and Sr ranges and ratios in Gachhang, Brijranije and Kangpar samples.

	Gachhang (13 samples		Brijraniga-Ingedinala (25 samples)		Kangpar* (6 samples)	
	Range	Means	Range	Means	Range	Means
Rb(ppm)	271-458	377	101-574	431	300-416	367
Sr(ppm)	10-54	34	5-55	19	33-96	60
Rb/Sr	5.02-36.90	13.59	3.35-107	34.09		6.93

* Data from Sinha-Roy and Sen Gupta (1986)

Chowdhury and Bhalla (1988) considered Bhurkhola gneiss as a component of the Thimphu Group. The present studies, suggest that the Bhurkhola gneiss occurs as tectonic slice within the garnetiferous mica schists of the Jaishidanda Formation. Deformed gneiss of the Sisina and

Bhurkhola, though located wide apart, occur as tectonic wedges within the Jaishidanda Formation. The Bhurkhola gneiss has higher Al_2O_3 content, K_2O/Na_2O, A/CNK ratio and lower CaO and CaO/Na_2O+K_2O ratios (Table 4.5, Nos. 3 & 6) reflecting inherent inhomogeneity of the basement complex from which tectonic wedges were derived.

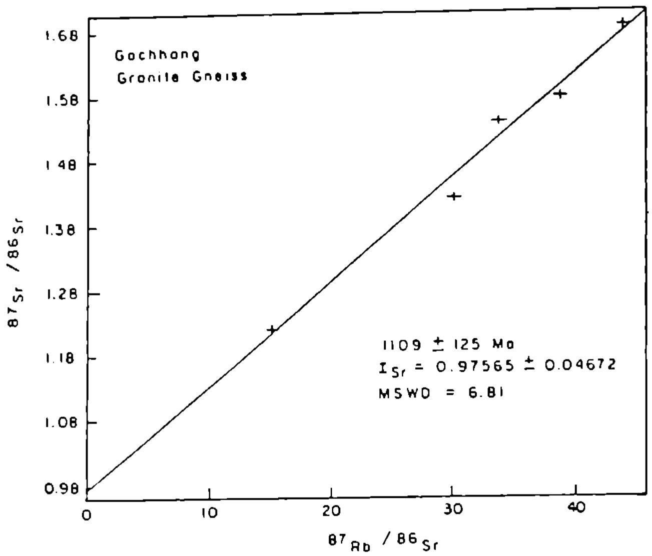

Fig. 4.21 Rb-Sr isochron diagram for the Gachhang gneiss.

Samples of deformed gneiss from the Gachhang and Monji suite, plot in the granite field in the normative An-Ab-Or ternery and monzogranite-syenogranite-alkali granite fields in the R1-R2 diagrams (Figs.4.2B & 4.3B). However, Gachhang gneiss shows marginally higher SiO_2 and lower Al_2O_3 contents compared to the Monji gneiss (Table 4.5, Nos. 4 & 5). Gachhang suite is uniformly corundum-normative (c 1.23-4.15%) and peraluminous (A/CNK = 1.11-1.47) whereas the Monji suite, though largely peraluminous includes metaluminous components also (normative corundum 0.3.92, A/CNK = 0.97-1.38)(Table 4.3, Figs. 4.4B & 4.5C).

Despite limited data points, Monji gneiss reveals perceptible systematic variation in major element chemistry reflected in inverse correlation of SiO_2, FeO^t and MgO with CaO (Fig.4.18). Lack of correlation between total alkalis with lime contents is noteworthy in the Monji samples. Gachhang gneiss, however, does not show any such systematic variation pattern and tends to plot in irregular clusters. It, however, shows remarkable variation of total alkalis within a rather restricted lime content (Fig. 4.18).

In the K-Na-Ca diagram, the granitic gneisses of Gachhang and Monji cluster at the potassic and of the calc-alkaline trend (Fig.4.7B). In the $\log_{10}(K_2O/MgO)$ vs. SiO_2 diagram, the Gachhang samples plot just beyond the calc-alkaline field indicating their higher SiO_2 levels compared to calc-alkaline granitoids (Fig.4.8B). The Monji samples, however, mostly fall in the alkali granite field (Fig.4.8B). CaO/Na_2O+K_2O vs. SiO_2 relations, however, point to the alkali-calcic nature of both the Gachhang and Monji suites (Fig.4.19).

On normative Q-Ab-Or and An-Ab-Or plots, samples of the Sisina suite plot essentially in the low temperature region of the Q-Ab-Or haplogranite system close to the cotectic minimum at $2KbPH_2O$ (Fig.4.20). Distribution of data points of the Sisina suite in the Q-Ab-Or and An-Ab-Or suggests relatively early crystallisation of plagioclase followed by quartz and K-feldspar. The Gachhang and Monji samples (Fig.4.20) are characterised by relatively lower Ab/Or ratio and plot in the low temperature region close to the cotectic minimum at $1KbPH_2O$ (the 1Kb cotectic minimum is not shown in fig. to avoid cluttering). These pressure estimates imply crystallisation of these suites at shallow depths. It may be noted that for the Kangpar gneiss occurring as tectonic sliver in the Baxa Group, Sinha-Roy and Sen Gupta (1986) inferred a similar pressure estimate ($1KbPH_2O$).

The range of Rb, Sr contents and Rb/Sr ratios of 13 samples of Gachhang granite gneiss is given below and compared with those of Kangpar granite gneiss and sheared granite gneisses of Brijraniga-Ingedinala area, Bhilangana valley, UP, (Bhattacharyya *et al*, 1982).

Compared to the average low-Ca granite (Rb 170ppm, Sr 100ppm; Turekian and Wedepohl, 1961), the Gachhang granite gneiss is highly enriched in Rb (377ppm) and depleted in Sr (34ppm). The suite has a rather wide range in Rb/Sr ratio (5.02-36.90) and a conspicuously high mean Rb/Sr ratio (13.59). The average Rb content of the Gachhang granite gneiss (377ppm) is similar to that of the Kangpar granite gneiss (367ppm) but its mean Sr content (34ppm) is distinctly lower than that of the Kangpar suite.

Plot of Rb vs. Sr for the Gachhang suite reveals little variation of Sr (with bulk distribution co-efficient D>>1 in granitic systems) with Rb contents (Fig.4.11B). This implies dominant role of partial melting processes in the evolution of the Gachhang suite.

4.2.C Geochronology : Five whole rock samples of deformed gneiss from the Gachhang area define a Rb-Sr isochron corresponding to an age of 1109±125 Ma with an extremely high ^{I}Sr (0.97565±0.04672) and high MSWD (6.81)(Table 4.6 and Fig.4.21). The extremely high ^{I}Sr of the suite implies derivation of the suite from radiogenic ^{87}Sr enriched crustal sources, thus the age data is interpreted to approximate the time of anatectic generation of the suite from crustal protoliths.

The high MSWD (6.81) of the best fit line clearly indicates that scatter of the data points (Fig.4.21) cannot be ascribed to experimental errors alone. Partial open system behaviour of Rb and Sr after the generation of the rock suite has played a role. The strong penetrative deformation/thrusting during Cainozoic Himalayan Orogeny might have contributed to small scale disturbances in the Rb-Sr isotopic systematics of the Gachhang suite. Thoni (1988) recorded comparable disturbances in the Rb-Sr systematics of the mylonitised gneisses associated with basement nappes in Eastern Alps.

The age of the Gachhang gneiss (1109±125 Ma) is comparable to 1012 Ma age of the deformed gneisses of the Kangpar area, which occur as a basement wedge within the Baxa Group rocks (Sinha-Roy and Sen Gupta, 1986). Table 4.9 lists several ages of granitic rocks within the age bracket 1000-1300 Ma from the Himalayan Orogen. The age and ^{I}Sr of the deformed granite gneisses of Gachhang are closely comparable to those of the deformed and mylonitised granite gneiss of Ingedinala area of UP Himalaya (1139±46 Ma, ^{I}Sr = 1.10)(Table 4.8, Nos. 2 & 9).

Table 4.8 shows that the 1000-1300 Ma old granitic gneisses of the Himalayan orogen are characterised by extremely high ^{I}Sr ranging from 0.741-1.10. This consistent geochemical feature among 1000-1300 Ma old granitoids signifies major tectonothermal event leading to widespread crustal anatexis during this period. During 1000±200 Ma period marked major tectonothermal event took place in Eastern and Central Indian Precambrian shield areas, with widespread crustal anatexis and generation of typical S-type granitic rocks (Sarkar *et al*, 1989; 1990). The contemporanity of identical events in the Himalaya and Peninsular shield is conspicuous.

4.2.D Tectonic Status : D.I and FeO^t/ FeO^t+MgO ratios of the Sisina suite are closely comparable to those of `type' compressional suites. CaO, total alkali content and CaO/$Na_2O$+$K_2O$ ratios have intermediate values between `type' compressional and `type' extensional suites. The combined deviations in CaO and total alkalis (and consequently on CaO/Na_2O+K_2O ratio) may be due to protolith character. Thus this suite may belong to compressional regime in view of strong calc-alkaline affinity as revealed from CaO/Na_2O+K_2O vs. SiO_2 relations (Fig.4.19). The Gachhang suite lacks specific signatures, hence difficult to classify.

The Manji suite, barring relatively lower FeO^t/FeO^t+MgO ratio, shows remaining parameters suggestive of extensional milieu.

4.2.E Petrogenesis : Sisina suite gneiss is two-mica bearing (biotite+muscovite), marginally peraluminous, distinctly calc-alkaline granodiorite-monzogranite-syenogranite suite presumably generated in a compressional tectonic millieu. A mixed protolith is implied for the suite in the Na_2O-K_2O and Na_2O/Al_2O3-K_2O/Al_2O_3

diagrams (Figs.4.15 & 4.16). Partial melting of a mixed protolith can explain the distribution of data points in the R1-R2 diagram (Fig.4.17).

Gachhang suite gneiss also represents a two-mica bearing (muscovite+biotite), syenogranite-alkali granitic suite with distinct peraluminous stamp and alkali-calcic affinity. Lack of systematic variation in major element chemistry, except marked variation of total alkalies within a restricted range of lime content, is a marked feature of the suite. This feature implies (i) S-type affinity (cf. Miller, 1985) and (ii) evolution of the suite principally by partial melting processes. The signature of partial melting is also evident in the Rb-Sr variation pattern of the suite (Fig.4.11B). In the Na_2O-K_2O diagram, the Gachhang gneiss occupies S-type field (Fig.4.15) and in the Na_2O/ Al_2O_3-K_2O/Al_2O_3 diagram, a sedimentary/ metasedimentary protolith is clearly indicated (Fig.4.16B). In the R1-R2 diagram, the suite is located close to the field of anatectic granites and the plots form an elongated field along Or-Qtz tie line (Fig.4.17B). The suite is highly depleted in Sr and enriched in Rb and has very high Rb/Sr ratios. The unusually high ^{I}Sr(0.976) of the suite is a clear indication of derivation from highly reworked and ^{87}Sr enriched upper crustal sources. The mean 34ppm Sr content of the suite is comparable to 20ppm that of sandstones (Mason, 1966). In the (Fe_2O_3+MgO) - Na_2O-K_2O ternery plot (after Blatt *et al*, 1980), the Gachhang granite gneiss falls in the field of potassic sandstones. Partial melting of a K and Rb-enriched, Ca-poor sedimentary protolith appears to be the process for the generation of the Gachhang suite.

Monji Suite : Essentially represents a marginally peraluminous alkali-calcic monzogranite-syenogranite association with an affinity to extensional tectonic millieu. The S-type affinity of the suite is obvious from Na_2O-K_2O and Na_2O/ Al_2O_3 vs. K_2O/Al_2O_3 diagrams (Figs.4.15B & 4.16B). In the R1-R2 diagram, field of Monji rocks overlaps with crustally derived anatectic granite field (Fig.4.17). Thus Monji suite is interpreted to represent an anatectically derived S-type granite.

4.3 LEUCOGRANITES

4.3.A Mode of Occurrences : This type of granite is localised within the lithopackage constituting the Thimphu Group and the overlying Tethyan sequence. The larger bodies of leucogranites designated as Monlakarchung, Gophu La-Lunana and Chamolhari granites are located mainly in northern Bhutan. Mappable plutons of leucogranite are also known from Gonju La in the north and the Kame *Chu* and Nobding areas in central Bhutan. In the Kame *Chu* and Nobding areas, leucogranitic rocks have invaded the Tethyan sequence. Incidence of tungsten mineralisation is observed within the rocks of the Tethyan sequence in close vicinity of the granite plutons.

Leucogranitic rocks from Chomolhari area in the west to Bumthang in central Bhutan were studied by Gansser (1983). Those of Gophu La and Lunana areas were examined by Castelli and Lombardo (1988). The present study was mainly restricted to the Kame *Chu* area (Wangdiphodrang district). Petrological and mineralogical composition of all these granite bodies is strikingly similar.

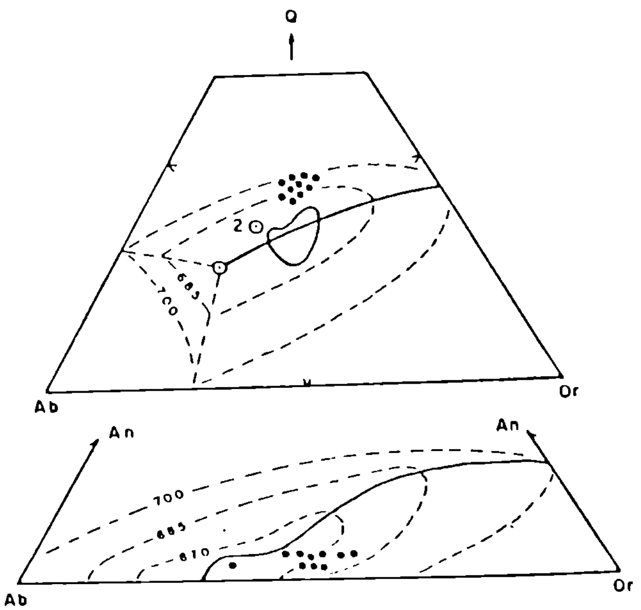

Fig. 4.22 Normative Q-Ab-Or and An-Ab-Or diagram showing plots for the Kame *Chu* suite. Field of Gophula-Western Lunana granitoids (Castelli and Lombardo, 1988) is shown. Other explanations as in Fig. 4.10.

The Kame *Chu* pluton comprises medium to coarse grained, massive, leucocratic granitic rocks of near homogeneous mineral assemblages. This granite pluton has invaded the rocks of the Chekha Formation. Along the Wangdiphodrang-Pinsha road section, the intrusive relation is unambiguous due to presence of (i) huge metasedimentary enclaves within the granite (ii) veins and apophyses of the granitic rocks within the enveloping metasediments.

The dominant mineral constituents of the Kame *Chu* granite are quartz, K-feldspar and plagioclase. Main phyllosilicate minerals include muscovite and biotite, the former invariably dominating over the latter. Some of the samples are even biotite free. Tourmaline is ubiquitous. Other accessories include apatite, garnet and opaque minerals.

4.3.B Petrochemistry : Major element data for 12 samples of the Kame *Chu* granite suite (Table 4.4) fall in the granite field in the An-Ab-Or ternary (Fig.4.2C) and in the monzogranite-syenogranite fields in the R1-R2 diagrams (Fig.4.3C). The rocks are distinctly peraluminous and typified by consistently high values of normative corundum (5.62-7.88%) and A/CNK ratios (1.56-1.82) (Table 4.4, Figs.4.4C & 4.5D). In the A-B diagram (Fig.4.5D), all the samples of the Kame *Chu* granite suite are restricted within field I reflecting highest degree of alumina saturation and cluster along a typical sub horizontal trend parallel to X axis (A parameter) -- a feature considered to be diagnostic of the Higher Himalayan leucogranites (Debon and Le Fort, 1986). Distribution of the data points in the An-Ab-Or and K-Na-Ca diagrams suggests limited variation of potash and soda contents with a near constant level of lime abundance (Figs.4.2C & 4.7C). Variation of K_2O/MgO ratio with SiO_2 in these rocks are similar to alkali granite suites (Fig.4.8C). However, the total alkali content of the rocks (mean 6.87%, Table 4.5, No.8) is conspicuously lower than that of average low-Ca granite (8.54%, Turekian and Wedepahal, 1961). Compared to other leucogranitic rocks of the Bhutan Himalaya, the Kame *Chu* suite rocks are deficient in CaO, Na_2O, K_2O but have higher SiO_2 and Al_2O_3 contents (Table 4.5, 4.11).

In the normative Q-Ab-Or ternary diagram, the Kame *Chu* leucogranites define a cluster close to the cotectic minimum at $2KbP_{H_2O}$ and the corresponding cotectic line (not shown in fig. for clarity) and between 700-685° isotherms. In the normative An-Ab-Or ternery diagram, the data points lie bounded by low temperature isotherms in the K-feldspar field (Fig.4.22). These minimum estimates of pressure and temperature for the Kame *Chu* granite suite are comparable to those reported for the Gophula and west Lunana granites of the Bhutan Himalaya (Castelli and Lombardo, 1988).

Rock suite	Rb(ppm)		Sr(ppm)		Rb/Sr		K/Rb	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Kame *Chu* (n=12)	293-530	382	15-139	68	2.7-25.4	10.32	62-123	89
Gophula[1] (n=14)	295-418	357	52-98	74	3.5-7.4	4.7	92.9-135-6	112
W. Lunana[1] (n=6)	364-514	394	54-128	98	3.4-6.7	4.0	73.3-136.3	114
Bhutan leucogranites[2] (n=17)	237-522	347	8-128	67	2.2-29.6	5.2	76.6-137.1	113

1 Castelli amd Lombardo (1988)

2 Dietrich and Gansser (1981)

Rb, Sr contents, Rb/Sr and K/Rb ratios of 12 samples of the Kame *Chu* leucogranites are given below and compared with those from other leucogranitic suites of Bhutan Himalaya.

It is seen from the above table that the Kame *Chu* leucogranites have Rb contents closely comparable to other leucogranite suites of the Bhutan Himalaya. However, it has higher mean Rb/Sr ratio and larger range of variation of Rb/Sr ratio. These features reflect greater variability of Sr in the Kame *Chu* suite compared to other suites. In the Rb-Sr diagram, the Kame *Chu* leucogranites show two distinct trends reflecting the presence of two distinct Sr populations (Fig.4.11C). Involvement of two distinct crustal sources with differing Sr abundance levels can thus be envisaged for the Kame *Chu* leucogranite suite. Castelli and Lombardo (1988) based on K/Rb vs. Sr variations inferred involvement of two distinct crustal sources for the Gophula and Western Lunana leucogranite suites also.

4.4.C Tectonic Status : The Kame *Chu* suite typically represents a lime and alkali-deficient extensional suite. This relatively low level of CaO and Na_2O+K_2O as discussed in foregoing pages distinguishes it from other leucogranitic suites of the Bhutan Himalaya. Other leucogranitic suites of the Bhutan Himalaya thus have values of parameters closely comparable to extensional suites. The lime and alkali deficiency of the Kame *Chu* suite may be related to protolith composition.

4.3.D Petrogenesis : The Kame *Chu* leucogranite is essentially muscovite (+biotite) bearing, highly peraluminous monzogranite-syenogranite suite generated in an extensional tectonic milieu. Distinct S-type affinity of the suite is reflected in the Potash-soda and alkali/alumina relations (Figs.4.15C & 4.16C). In the R1-R2 diagram, the suite defines a field overlapping the field of crustally derived anatectic granites (Fig.4.17C). The Rb-Sr variations in the suite, however, indicate two distinct sources. Partial melting of crustal protoliths (mainly sedimentary/metasedimentary) with differing Rb/Sr ratios can be envisaged for the generation of the Kame *Chu* suite.

DISCUSSION

The granitic gneiss of the Thimphu Group, comprises a wide spectrum of rock types of the granite-kindred. The available data indicate that there exists a complete spectrum from calcic through calc-alkaline to alkali-calcic granitoids (Fig.4.9). The individual occurrences have quite distinct petrological attributes and any broad generalisation can be misleading. The granitic gneiss of the Thimphu Group should be visualised as part of a highly reworked basement granite-gneiss complex with all its widely differing petrochemical and tectonic affinities.

Though not conclusive, the presence of both compressional and extensional granitic rock suites are indicated in the Thimphu Group. The obvious corollary is that the Thimphu Group includes both syn-orogenic and post-orogenic granitoids. The early Palaeozoic Tashigang suite has several attributes of an orogeny-related granitoid suite. Thus the generalisation that all the early Palaeozoic granitic rocks of the Himalaya are anorogenic (Debon *et al*, 1986) may need re-examination.

Le Fort *et al*, (1983) envisaged generation of the leucogranites in the Himalaya by partial melting of the Tibetan slab at the time of over thrusting during the Himalayan orogeny along the MCT implying a synorogenic setting. The Kame *Chu* leucogranite is massive and shows no textural evidence of deformation/ metamorphic recrystallisation. This leucogranite commonly cuts across the main structural grain of the host metasediments and therefore, represents an emplacement/generation event post-dating the main Himalayan orogeny. The evidence from Gophula and Western Lunana leucogranite plutons are equally corroborative (Castelli and Lombardo, 1988).

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5. SYNTHESIS

5.1 STRATIGRAPHY

O.N. Bhargava

5.1.1 Lesser Himalaya

Restoring original order of stratigraphic superposition to the tectonically mutilated unfossiliferous Lesser Himalayan sequences of the Bhutan Himalaya is a formidable exercise. With no direct clues available, recourse has been taken to indirect evidences. Relative grade of metamorphism of various sequences, together with their tectonic attributes and composition of clasts found in the conglomerates have been utilised to reconstruct the stratigraphic column of the Lesser Himalayan formations.

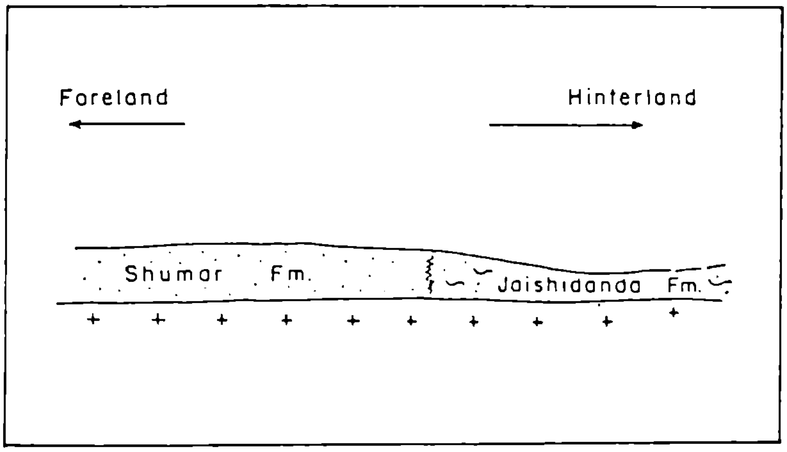

Fig. 5.1.1 Interpreted original stratigraphic position of the Jaishidanda and Shumar Formations.

Amongst all the Lesser Himalayan formations of Bhutan, the Jaishidanda Formation comprising quartzite, schist and marble shows highest grade of metamorphism-reaching upto garnet and rare staurolite zone. The metasediments of this formation enclose bands of mylonitic gneiss having sharp contact with country rock. No thermal effect is noticed in the enclosing rocks. Similar gneissic scales found in the Daling rocks (in part equivalent of the Jaishidanda Formation) have been considered to be the tectonic slivers of the basement (Sinha-Roy and Sen Gupta, 1986). For the gneiss occurring at different levels in the Shumar Formation, which included presently defined Jaishidanda Formation, Ray *et al*, (1989) also proposed that the gneiss slivers represent footwall tectonic-accretion of the basement gneiss. Following these authors and also on the basis of observations made during the present work by Dasgupta, it is suggested that the gneissic slivers in the Jaishidanda Formation represent imbricated basement which tectonically was incorporated during the translation of the Jaishidanda Thrust Sheet. This observation suggests that the Jaishidanda Formation, prior to its detachment, lay directly over a crystalline basement (Fig.5.1.1). In other words, no other formation existed in-between the Jaishidanda Formation and the basement. The Jaishidanda Formation is thus regarded as the oldest sequence in the Lesser Himalaya of Bhutan.

Apparently the Jaishidanda Formation, minus its grade of metamorphism, resembles the Shumar Formation, of which hitherto it was considered to be a part. The Shumar Formation also encloses tectonic slivers of gneiss (e.g. Gachhang Gneiss). The close lithologic resemblance between these two formations may suggest that the more metamorphosed Jaishidanda Formation possibly forms the basal part of the Shumar Formation. Alternatively, the Jaishidanda Formation could be a more metamorphosed facies variant of the Shumar Formation in hinterland which suffered greater depth of burial (Fig.5.1.1).

The gypsum and marble beds occurring in eastern Bhutan so far have been considered part of the Shumar Formation. The Shumar Formation, mainly made up of clean, low angle cross-bedded to sub-parallel bedded quartzite with subordinate chlorite phyllite and marble does not show any evidence of dessication and development of evaporite facies. Dasgupta (in this volume), therefore, rightly considers existence of gypsum in the Shumar Formation due to tectonic emplacement. The marble like-wise too, may not form part of the Shumar sequence.

In the eastern Bhutan (east of Narphung) along with carbonate rocks of the Manas Formation and maroon arenites of the Jainti Formation also occur bands of mylonite gneiss and white quartzite at different levels (Sen Gupta and Raina, 1978). Both, the gneiss and white quartzite are foreign to the Jainti Formation. The gneiss resembles tectonic slivers of basement found in the Shumar/Jaishidanda Formations while the white quartzite is comparable with that of the Shumar Formation (Fig.5.1.2). It is therefore, suggested that the strong deformation of the Baxa belt in this part of the Bhutan Himalaya, led to squeezing and tectonic emplacement of the basement in the Baxa sequence. The Shumar Formation as interpreted above since rests directly over the basement, could not have escaped the tectonic squeezing. The white quartzite bands in the Jainti Formation, thus are considered tectonic wedges of the Shumar Formation. The above synthesis implies that the Shumar Formation occurs sandwitched between the basement and the Baxa Group or in otherwords the Baxa Group is younger to the Shumar Formation.

There is a difference in degree of recrystallisation between the arenites of the Shumar Formation and the Baxa Group, former being more recrystallised. The quartzite of the Shumar Formation, specially in the middle part, is in general white and sporadically encloses sedimentary structures represented by high to low angled cross-bedding. The Jainti quartzite is red, grey, cross-bedded and mudcracked.

Thus besides difference in degree of recrystallisation, which may be a function of relative depth of burial, there is also a sharp difference in environment of deposition of these two formations. The metasediments of the Shumar Formation represent a low-energy subtidal environment of sedimentation, whereas Jainti Formation signifies supra-tidal palaeoenvironment. The Jainti Formation is followed up by the Manas Formation which comprises limestone, dolomite, slate, quartzite and also gritty quartzite.

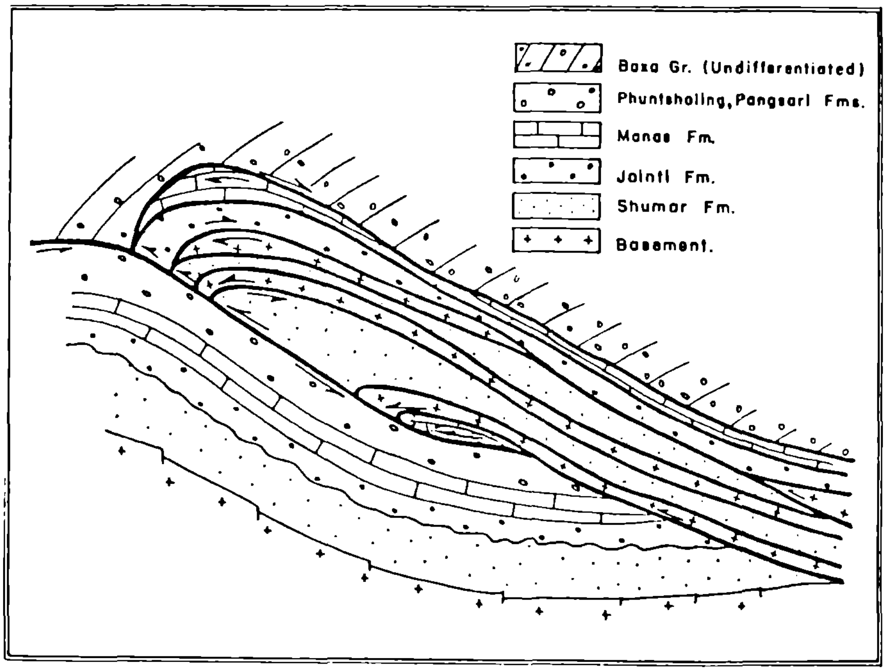

Fig. 5.1.2 Interpreted relationship of Shumar and Baxa sequences in south-eastern Bhutan.

These two dissimilar formations to account for subtle change in degree of their metamorphism and abrupt change in environment of deposition are interpreted to have an unconformable relationship. Several areas (e.g. Nunpani) occupied by the Baxa Group are dotted with saline springs, indicating existence of subsurface salt beds of evaporite facies. The gypsum at Kothakpa, possibly formed part of this evaporite facies as is evident from the intercalations of red shale, quartzite and dolomite associated with the gypsum in the Cherungri section. During the translation of the Shumar Formation over the tectonic basement of the Baxa Group (cf. Ray *et al*, 1989) the gypsum was tectonically emplaced in the Shumar Formation. Some of the marble bands in the Shumar Formation may also be tectonic slices.

Tangri (this volume) identifies four major subdivisions in the Baxa Group referable to the Jainti, Manas, Phuntsholing and Pangsari Formations in ascending order of superposition. The Jainti Formation is an argillaceous sequence in the basal part and arenaceous in the upper which shows a distinct hue of red-crimson colour. The quartzite of this formation shows synaeresis mud cracks, ripple marks, cross-bedding. Gypsum, now found within the Shumar Formation may have been part of the red facies of the Jainti Formation. The overlying Manas Formation encloses flux grade dolomite, cement grade limestone, quartzite, grit beds and slate/phyllite. The grit beds, which occur at various levels, besides others also contain clasts of red quartzite and jasper indicating that at least a part of the Jainti sequence formed positive area during the sedimentation of the Manas grits. These gritty beds and quartzite are highly comparable with those of the Thungsing Formation. Tangri (this volume), therefore, regards the erstwhile Thungsing Formation as an expanded form of the quartzite of the Manas Formation with depletion in carbonate contents. He thus logically groups the Thungsing sequence within the Manas Formation. However, a supra-Manas position of the Thungsing Formation in the type area militates against such an interpretation. Thus this classification shall have to be tested by detailed mapping. The Phuntsholing Formation hitherto considered older than the Manas Formation, has been found to rest over the latter in all the sections. The Phuntsholing Formation comprises an argillo-arenaceous sequence and is by and large devoid of carbonate beds. The overlying Pangsari Formation is made up of quartzite and off white cherty dolomite. The younger formations are developed in the western part; these successively get tectonically truncated towards east. The basal Jainti Formation is also sliced along a thrust towards east in the frontal part. It possibly makes an appearance in the squeezed core of an antiform east of Narphung. Extensive development of mylonite in the Baxa arenite suggests that each bedding plane is virtually a tectonic plane in this belt (cf. Auden, 1934). B.D. Dungrakoti is of the opinion that since Jainti and Phuntsholing sequences never occur together, they may be one and the same.

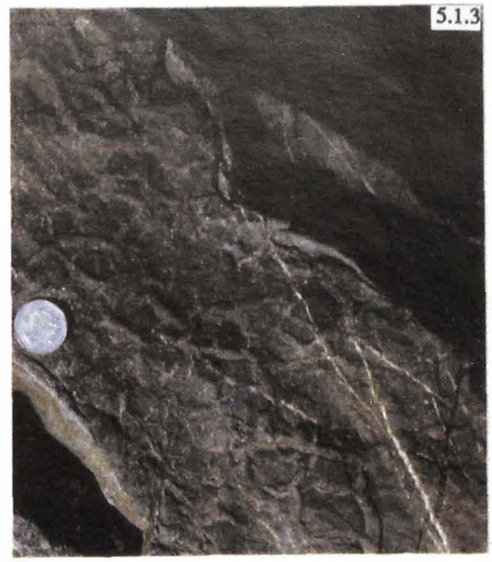

Fig. 5.1.3 Synaeresis mud cracks in the Jainti Quartzite, earlier mistaken for bioturbation. Loc. Kali *Khola* section (Photo Ashutosh Joshi).

The Diuri Formation along a normal stratigraphic contact rests above the arenaceous part of the Manas Formation (erstwhile Thungsing Formation) along the Samdrup Jongkhar-Tashigang road. The contact between these two formations is sharp. The Diuri Formation comprises pebbly phyllite, phyllite and local conglomerate. The red quartzite clasts disappear in the Diuri diamictite, whereas limestone clasts resembling the carbonates of the Manas Formation make appearance. The Diuri Formation, thus is considered younger than the Baxa Group. The sequence of the Diuri Formation in most of the sections commences with a clast supported conglomerate reminiscent of a lag marking beginning of a fresh cycle of sedimentation after a hiatus. Singh (1992) finds difference between the conglomeratic sequences along the Samdrup

Jongkhar-Tashigang road section, Mikuri-Dichling and at the Seti*khola*, the former according to him is foliated and latter two non-foliated. Tangri (this volume) finds both these conglomerates lithologically alike and associated with the Permian sediments.

Joshi (this volume) describes bioturbation from maroon sandstone and shale in the Seti *Khola* section and designates them as the Member A of the Permian Setikhola Formation. The structures described as bioturbation in the Members A and also possibly B (Josh *et al*, 1990), Fig.C) are infact synaresis mudcracks (Fig.5.1.3) and no evidence of biogenic activity is noticed in these members, though trace fossils do occur in part of the Member C. The maroon shale-sandstone represent a warm arid climate which is contrary to the cold/warm-humid climate which prevailed in the Indian subcontinent during early Permian i.e., at the time of deposition of the Setikhola Formation. The maroon mud-cracked sandstone/quartzite is unmistakably a part of the Jainti Formation. The true Setikhola Formation occurs as four tectonic scales within the Jainti sequence (Member C of Joshi *et al*, 1990). B.D. Dungrakoti, however, tends to agree with the model of Joshi *et al*, (1990).

In the eastern Bhutan, the Permian sequence which encloses coal in the Bhangtar area and also plant fossils has been referred to as the Gondwana/Damuda. Lakshminarayana (in this volume) follows the same nomenclature. The so called `Damuda' sediments have yielded marine fossils at Deothang (Acharyya, 1978). The whole sequence is more or less identical and no where any change from distinct fresh water facies to marine facies or vice versa can be established. The entire sequence thus seems to be marine and coal at Bhangtar may represent a deltaic or more likely lagoonal deposit. The terms Gondwana and/or Damuda which *sensu stricto* were used for the fresh water sediments deposited in the inland basin within the heart of the Indian plate, are, therefore, misnomers for a marine sequence occurring near the plate margin (cf. Jaikrishna *et al*, 1983). These Permian sediments can be more aptly labelled as the Setikhola Formation.

The marble at Barsong occurring within the Shumar Formation, is known to have yielded Jurassic palynomorphs (Pantic *et al*, 1981). This marble and also other carbonates occupying identical tectonostratigraphic positions were sent to the Birbal Sahni Institute of Palaeobotany (BSIP) for palynological studies. None of them, however, yielded any palynomorphs despite being treated by different methods. The BSIP failed to find any microflora even in rocks of the Manas, Setikhola, Tethyan, Jurassic and Siwalik of Bhutan (written communication Dr. S.C. Srivastava). Not much reliance, therefore, can be placed on such negative finds. The Jurassic limestone possibly represents a tightly infolded outlier signifying Jurassic marine incursion.

In the Deothang section, Acharyya (1994) recorded a boulder containing *Nummulites*. Subsequent efforts to locate *in situ* fossils proved futile. The Nummulitic bed, if present, in this section may occur either as a tectonic wedge along the Setikhola-Siwalik contact or as unconformable outlier over the Setikhola/ Thungsing/Diuri sequences.

The Siwalik Group sediments form the next stratigraphic unit, followed by the Diklai Boulder bed and Quaternary terraces.

Based on the above line of argument a stratigraphic column of the Lesser Himalayan formations of Bhutan is presented in Fig.5.1.4.

5.1.2 Tethyan Himalaya

In the Tethyan part based on the actual working sheets of the previous workers and traverses by Tangri and Pande in the northern part of the Black Mountain area, an attempt has been made to redraw the map to the extent possible. The Nake Chu Formation (now Deshichiling) south of Gongkhola is overlain by the fossiliferous Maneting Formation. The Maneting Formation north of the Nobji *Chu* seems to abut against the Chekha Formation. A fault, partially marked by earlier workers also, has been delineated to separate the Maneting Formation from the Chekha Formation.

In the Lingshi area perhaps there are some faulty fossil identifications and lumping of too many stratigraphic units under the Barishong Formation. This, as would be evident from the following discussion, has led to some contradictory stratigraphic interpretations.

follows the outcrop delineated by S. Dasgupta and S.A. Chore.

The Chekha Formation, hitherto considered as part of the Tethyan Palaeozoic succession, but now separated (Tangri and Pande, this volume) rests over the Thimphu Group. The Thimphu

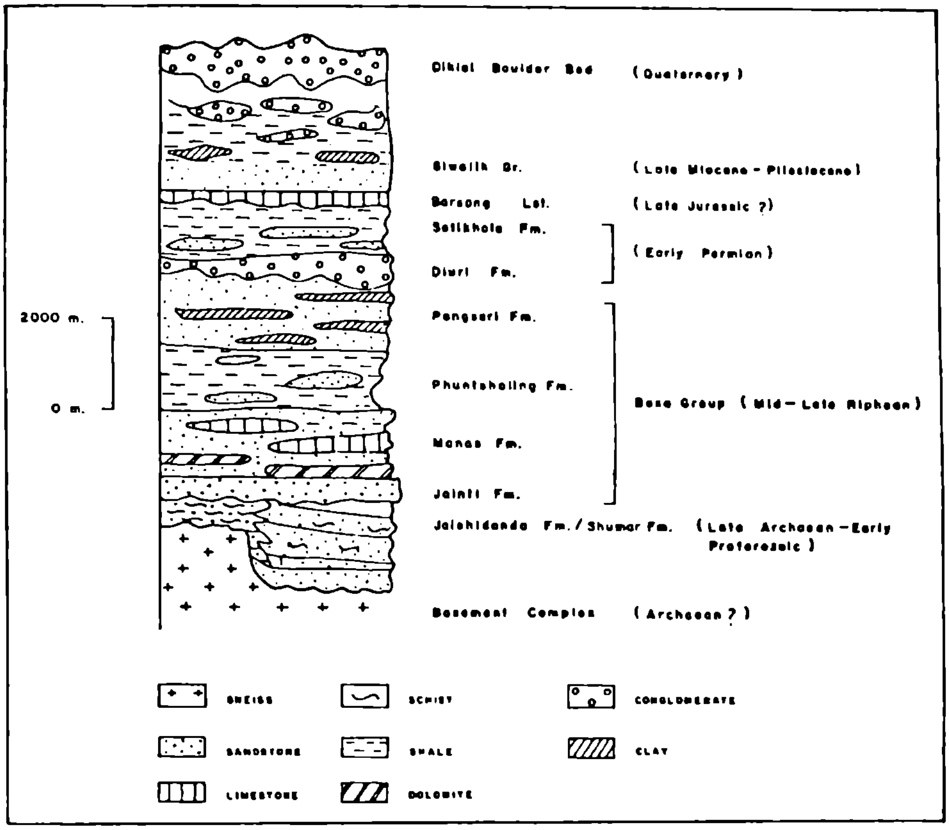

Fig. 5.1.4 Synthesised lithocolumn of the Lesser Himalayan formations of the Bhutan Himalaya.

The ages of several formations assigned earlier by Chaturvedi *et al*, (1983) have been modified due to discovery of diagnostic *in situ* body and trace fossils (Tangri and Pande, this volume).

The Thimphu Group is divisible into the Sure, Naspe and Takhtsang Formation (Golani, this volume). The Takhtsang Formation is considered to be a sub-nappe over the Naspe Formation. The actual outcrop pattern of the Naspe Formation, as mapped in March, 1995 by S. Dasgupta and S.A. Chore in eastern Bhutan has been found to be much different than the one depicted by P.R. Golani (Chapter 3.9). The main map in this book

Group is constituted of migmatites, whereas the rocks of the Chekha Formation display greenschist facies, thereby signifying a metamorphic break in between. The contact between the Thimphu Group and the Chekha Formation is thus regarded as unconformable, former having suffered a metamorphism prior to the deposition of the Chekha Formation. This contact in many sections has also been tectonised.

The 'Nake Chu Formation' mainly comprising quartzite and conglomerate was earlier assigned an Ordovician age. This formation is overlain by the Maneting Formation, which includes Precambrian-Cambrian tracefossils and lingulellids of early Cambrian age. The underlying quartzitic sequence thereby represents a latest Precambrian age. To avoid stratigraphic confusion name 'Deshichiling' has been proposed for this arenaceous sequence.

The Palaeozoic Tethyan succession commences with the Pele La Group divisible into the Singhi (volcanics), Deshichiling (quartzite, subordinate, phyllite and carbonate beds), Maneting (phyllite, quartzite local limestone) and Quartzite Formations. The Singhi Formation comprising volcanics, rests over the Chekha Formation in the Black Mountain-Tangchu Sector and over the Takhtsang Formation (Thimphu Group) in the Ha area of the Lingshi sector. The base of the Pele La Group, therefore, marks an unconformity.

The Singhi Volcanics are andesitic and acidic in character, hence have been favoured by Tangri and Pande (this volume) to indicate an island arc condition. The pyroclastic deposits, typical island arc sediment are conspicuous by their absence, thus Singhi Volcanics are regarded to signify continental rifting somewhat similar to Rio Grande Rift.

In the overlying Deshichiling Formation appears first trace fossil represented exclusively by *Planolites*.

The Maneting Formation as mapped earlier, included early Cambrian fossils in the basal part and Ordovician (?) forms in upper part (Chaturvedi *et al*, 1983). The so called Ordovician sequence has a sharp contact with the underlying sequence. In the present analysis, this part has been separated and the name Maneting is restricted to the underlying sequence. The newly defined Maneting Formation in basal part shows trace fossils mainly at two levels. The basal most level in the Pele La section includes *Planolites*, *Cochlichnus* and *Skolithos*, which may represent late Precambrian age (cf. Crimes, 1992). The upper level has yielded *Arenicolites*, *Gordia*, *Helminthopsis*, *Didymaulichnus*, *Paleophycus*, *Phycodes pedum*, *Planolites*, *Monomorphichnus* and *Rusophycus*. About 30m above the trace fossil horizon, in the Pele La section occur lingulellid fossils. The Maneting Formation is thus assigned a latest Precambrian to early Cambrian age, the Precambrian-Cambrian boundary being below the *Phycodes pedum* level (cf. Crimes, 1992, 1994, Crimes and Droser, 1992).

As no locality or peaks exist in the nearby area the overlying sequence has been designated as the Quartzite Formation by Tangri and Pande (this volume). This formation was reported to contain Ordovician fossils (Chaturvedi *et al*, 1983). This sequence has yielded trilobites. Photographs of these fossils were examined by John R. Laurie and Jake Shergold (written communication to ONB through John A. Talent) who identify them as kaolishaniids or pagodiids indicating a 'middle to late, Late Cambrian. The fossil identifications of Chaturvedi *et al*, (1983), therefore, become suspect. Since the sediments enclosing these trilobites rest over an early Cambrian sequence, a middle Cambrian age for the Quartzite Formation is advocated.

The Quartzite Formation is succeeded by the Tang Chu Group divisible into the Wachi La and Ripakha Formations. The Wachi La Formation comprises a crinoidal carbonate sequence with local phyllitic and quartzitic partings. It rests variously over the Deshichiling, Maneting and Quartzite Formations demonstrating a regional sedimentological discordance. It grades upwards into shale-carbonate sequence of the Ripakha Formation. The fossils in the Ripakha Formation include *Fenestella* sp., *Protoretepora* sp., *Aviculopecten* sp., *Neospirifer* sp., *Unispirifer* sp., *Dielasma* sp. and *Stenoscisina* sp and atrypides, indicating a late Devonian-early Carboniferous age.

Broad time equivalent of the Tang Chu Group in the Lingshi sector is the Barishong Formation. This formation is not well defined and possibly includes equivalents of the Deshichiling, Maneting, Quartzite, Wachi La and Ripakha Formations. There is also a mix-up of fauna as Ganesan *et al*, (1978) report *Marginifera* of late Permian age together with *Favosites* which is not known beyond Devonian.

In the Lingshi sector the Barishong Formation along an unconformity is overlain by the Shodug Formation which includes pyritous shale in the basal part and diamictitic sequence in the upper. The shaly part has yielded *Spirifer* sp., *Productus* sp., *Marginifera* sp., *Abmikella* sp., *Syringothyris* sp., *Camorophoria* sp., *Fenestella* sp., *Polypora* sp., *Rhombopora* sp. The fossil yielding sequence rests below a diamictite horizon. The upper Palaeozoic diamictite through out the Indian plate represents a late Carboniferous to early Permian age. *Marginefera* and *Abmikella* of late Permian reported by Ganesan *et al*, (1978) from a sequence below the diamictite hence are discordant with the regional lithostratigraphic set up. These fossil identification are thus regarded suspect.

Fig. 5.1.5 Cephalopod and *Ptilophyllum* occurring on the same bedding plane of Lingshi Formation. Loc. Sha Slate Mine area.

As suggested by Tangri and Pande (this volume) there is a strong case to separate the shaly part from the Shodug Formation to constitute a new formation. However, it can be accomplished only during a detailed remapping programme.

Though Singh (1967) reported Permian fossils from the Tang Chu area, subsequent workers failed to record any Permian elements. The presence of the Permian in the Bhutan Himalaya hence remains doubtful.

The Shodug Formation in the Lingshi sector and the Ripakha Formation in the Tang Chu sector are overlain along an unconformity by the Lingshi Group. *Daonella* indicating Ladinian age was reported by Nautiyal *et al*, (1964) from their Lingshi `Series' in Lingshi sector. From the same area Hanny (in Gansser, 1983) recovered a negative of *Parajuvavites* of Norain age. However, subsequently, Ganesan *et al*, (1978) did not mention any Triassic fauna from the Lingshi area and Permian was reportedly considered directly overlain by the Jurassic-Cretaceous Lingshi Group'. It is unlikely that identification of fossils of Triassic age both by Nautiyal *et al*, (1964) and Hanny (in Gansser, 1983) are erroneous. More likely is that Ganesan *et al*, (1978) missed the Triassic sequence in the Lingshi area. During the Triassic two main transgressions

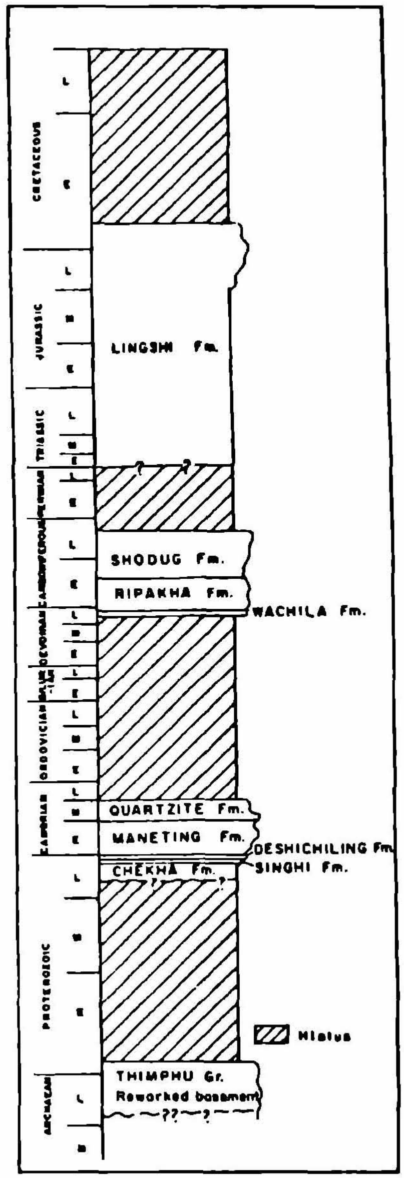

Fig. 5.1.6 Lithocolumn of the Tethyan sequence.

are known - early Triassic and Rhaetic (Bhargava, 1987). Since both Ladinian and Norian elements seem to be present, the Triassic sequence in the Lingshi sector, perhaps represents an early to late Triassic age which may form part of the Lingshi Formation. In this context, it is possible that identification of late Permian fossils by Ganesan *et al* (1978) is correct. Either Ganesan *et al*, (1978) examined an inverted sequence or there has been a mix-up of fossils of more than one stratigraphic level. The Triassic succession in the Lingshi sector is either poorly fossiliferous or has a patchy development to have been missed by Ganesan *et al* (1978). If the above surmise is correct, the Lingshi sequence may not be continuous, it is likely to have Permo-Triassic and upper Callovian sedimentologic breaks.

However, as the Lingshi sector was not visited during the present investigation it is neither advisable nor possible to arrive at definite conclusions. The question has to be left for posterity to answer. The Lingshi Group was divided by Ganesan *et al*, (1978) into the Mo Chu, Chebesa and Ngile La Formations. The basis of these subdivisions was preponderance of cephalopod or plant fossils indicating marine or fresh water palaeoenvironment. This basis of classification is subjective as the cephalopod and plant fossils are not only intimately associated but have been found to occur on the same bedding plane (Fig.5.1.5). The entire Lingshi Group, like other sequences on the Indian plate margins is considered marine (cf. Jai Krishna *et al*, 1983). The Lingshi thus may be relegated to a formational level and the Mo Chu, Chebesa and Ngile be referred as members. The Lingshi Formation encloses upper Gondwana flora, perisphenctids, *Gymnoplites* and *Holcodiscus* of Jurassic-Cretaceous age. Ganesan *et al*, (1978) also report *Cardita beaumonti* from the Lingshi Group. This specimen is still available in the GSI Museum at Samtse and does not compare with *Cardita*, hence need not be used for age fixation.

The stratigraphic column of the Tethyan succession is furnished in Fig.5.1.6.

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5.2 CORRELATION

O.N. Bhargava

5.2.1 Lesser Himalayan sequences

Though unfossiliferous, the Lesser Himalayan sequences in the western Himalaya could be assigned certain broad ages due to presence of a variety of stromatolites, availability of geochronological data of basic rocks and relatively lesser tectonic disturbance within each belt which still preserve the internal stratigraphy. The Bhutan Himalaya lacks these ingradients. To assign broad ages to the formations in Bhutan it is proposed to correlate the unfossiliferous sequences of the Bhutan Himalaya with those of the western Himalaya. As no other clues are available lithologic similarities, identical tectonic positions and palaeoclimatic manifestation with due emphasis on physical continuity seem to be the only criteria available. Correlation of rocks of such widely separated areas is obviously fraught with uncertainties and at best shall be tentative.

Jaishidanda Formation : This formation, occurs just below the Thimphu Thrust Sheet and encloses tectonic slivers of the basement gneiss. Towards west, this formation links up with the upper part of the Daling Group of the Darjeeling-Sikkim area which is also known to enclose the basement gneiss (Sinha-Roy and Sen Gupta, 1986). In Darjeeling-Sikkim area this unit, however, is a possible equivalent of the Chunthang Subgroup. Its equivalent in the Arunachal Himalaya has not been identified.

In the western Himalaya, the tectonic equivalent of the Jaishidanda Formation seems to be the Kulu Group Thrust Sheet (Sharma, 1977), occurring below the Vaikrita-Jutogh Thrust Sheets (Bhargava and Bassi, 1994). The Kulu Group comprises black, locally graphitic phyllite, quartzite and marmorised limestone, (Khamrada Formation), mylonite gneiss (Gahr Formation, also known as the Nirth-Baragaon gneiss) and mica schist-quartzite (Khokhan Formation). The Kulu Group, however, in most of the sections shows green schist metamorphism. The age of the Jaishidanda Formation, like that of the Kulu Group, is uncertain.

Shumar Formation : This formation towards west unites with the Garubathan Formation of the Daling Group sequence. Towards east in Arunachal Pradesh its equivalent is the Dirang Formation and the Bomdila Group, the later besides metasediments includes large tectonic enclaves of gneiss. Lithology, sedimentary structure and also tectonic position of the Shumar Formation above the Baxa Group, has a remarkable similarity with the Rampur Group of Himachal Pradesh (Sharma, 1977, Bhargava and Ameta, 1987) and Berinag Quartzite of Kumaon.

The Rampur-Berinag-Sanguri and Daling sequence, west of Bhutan and Bomdila Group, east of Bhutan bear uraninite and basemetal mineralisation. The basemetal mineralisation is also known in the Shumar Formation from Rimchu, Bungthing, Radi, etc. The tholeiitic flows found in the Sundernagar Group have geochemical signatures identical to those of tholeiites of the Rampur Group, both of which may be broadly co-eval. The main difference between the Rampur Group and the Shumar Formation is presence of thick tholeitic flows in the former and their absence in the latter. Infact there is a gradual reduction in the volume of basic rock from west to east, the change is more conspicuous east of Nainital.

The uraninite mineralisation in the Rampur Group was dated at 1200$\pm$40 Ma by Pb-U method (Narayan Das *et al*, 1979). Subsequently the tholeiitic volcanics associated with the Rampur Group indicated an age of 2540$\pm$9 Ma by Sm-Nd method. (Bhatt and Le Fort, 1992). The same age is advocated for the Shumar Formation.

Jainti Formation : As per stratigraphic interpretations attempted in this write up, the Jainti Formation occupies a position in-between the Shumar and the Manas Formations, being separated from the former by an unconformity. The infra-Manas position, and the lithologic assemblage of the Jainti Formation is highly comparable with that of the Ropri and Khaira

Formations of the Shali Group (Srikantia and Sharma, 1976) and Hurla Member of the Larji Formation (Sharma, 1977) of the western Himalaya and the Tenga Formation and also possibly the Miri Formation of the Arunachal Himalaya. In Darjeeling-Sikkim its equivalent is the Reyang Formation.

The red colour of the rocks indicates a palaeoclimatic control and can be taken to demarcate a time plane. Its other equivalent could be Saline beds of Salt Range, Saryu Valley Quartzite and Nagor Gypsum.

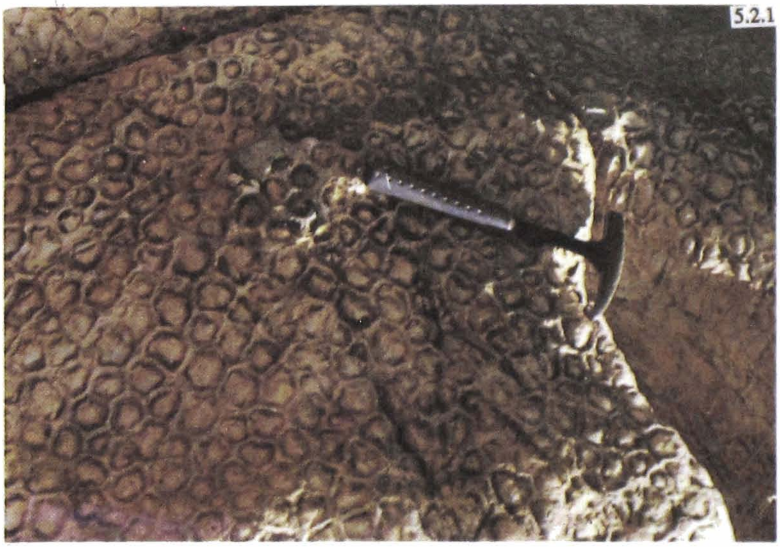


Figure 5.2.1 Stromatolite possibly *Boxonia* (rolled boulder) in the Labrang *Khola*, Photo Ashutosh Joshi.

Manas Formation : The Manas Formation encloses stromatolites (Fig.5.2.1), though their frequency as compared to that of the Shali-Deoban-Tejam-Pithoragarh and Krol sequences of the western Himalaya is much less. The stromatolites from the `Baxa Formation' reported by Raha and Sastry (1982) from the Darjeeling Himalaya are of early-middle Riphean age, while those from the Bhutan Himalaya are of Late Riphean-Vendian age (Raha and Das, 1989). It is unlikely that same sequence in adjoining sectors should have such widely separated ages. The Manas Formation is considered to be a broad equivalent of the Sirban- Shali- Deoban- Tejam-Pithoragarh-Nawakot and Dedza sequences, especially to their basal-middle parts. A late to middle Riphean age is thus considered to be more reasonable for this formation.

Phuntsholing and Pangsari Formation : These formations mainly represented by argillo-arenaceous and arenaceous-cherty dolomite sequences respectively may be equivalent of the upper parts of the Shali-Deoban-Calc- zones and possibly parts of the Simla and Jaunsar Groups.

Diuri Formation : Like any conglomerate, the Diuri Formation forms a conspicuous horizon in the eastern Bhutan. Its resemblance with the Blaini Formation of the western Himalaya was noticed by Nautiyal *et al*, (1964) and Gansser (1964, 1983). There are, however, differences from the Blaini Formation viz., (i) the orderly sequence found in the Blaini Formation is missing in the Diuri Formation and (ii) the characteristic limestone occurring at the top of the Blaini Formation too is lacking in the Diuri Formation. In the absence of fossils in the Diuri Formation, it is difficult to assign any age to this conglomeratic horizon. The absence of trace fossils and also bioturbation in a conglomeratic horizon also cannot be a decisive proof of a Precambrian age. Only indirect evidences thus can help. There are two stratigraphic levels at which conglomerate beds are developed in the Lesser Himalaya viz., Vendian (Blaini) and Late Carboniferous-Early Permian (Bijni). The Vendian (Blaini) conglomerate in the Lesser Himalaya, is not known, east of Nepal, whereas the late Paleozoic conglomerate is known from the Darjeeling-Sikkim and also Arunachal Himalaya. The Diuri Formation, thus considering the regional set-up, is likely to represent a late Palaeozoic age and an equivalent of the Bijni and Rangit Pebble Slates.

Setikhola Formation : The Setikhola Formation is mainly confined to the foot hill region. This formation encloses lenticular coal beds towards south and also Permian plant fossil. Towards north, at Deothang, it has yielded marine fossils of Permian age (Acharyya, 1978). The Setikhola Formation involved in a schuppen zone in type area encloses exclusively marine fauna (Joshi *et al*, 1990). The Setikhola Formation is a broad time equivalent of the Bijni Unit of the western Himalaya and the Rangit Pebble Bed of the Darjeeling Himalaya and the Bichom-Garu Fomation of the Arunachal Himalaya.

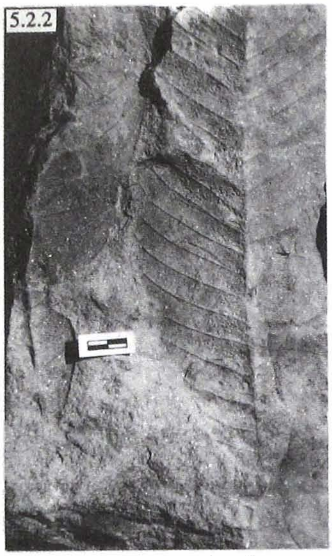
Barsong Limestone : Pantic *et al*, (1981) reported Jurassic palynomorph from these crystalline limestone. No Jurassic element in the Lesser Himalaya has been reported so far, though late Cretaceous fossils from the Nilkanth Formation (=Shell Limestone) are known in the western Himalaya. The Barsong Limestone in the Bhutan Himalaya, if really, of Jurassic age, is possibly a precursor to Cretaceous transgression in the Peninsula as well as in the Lesser Himalaya.

Siwalik Group : Though not many diagnostic fossils are known from the Siwalik Group of Bhutan, dicot leaf (Fig.5.2.2-3) and crocodile remains and intermitent physical continuity of these sediments from the western Himalaya leave little doubt about their broad correlation with the standard Siwalik sequence.

Correlation of Lesser Himalayan sequences of Bhutan is presented in Table 5.2.1.

5.2.2 Tethyan Sequences

The fossils in the Tethyan sequences of the Bhutan Himalaya are meagre and of these not many are age specific. It is therefore, not possible to fix exact ages of various formations - only broad age assignments are feasible. In reconstructing this broad stratigraphic frame work, various unconformable contacts signifying



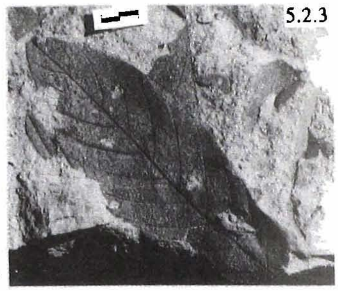


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Figure 5.2.2-3 Dicot leaf impressions in the Siwalik of Bhutan. Samdrup Jongkhar section.

standard transgressions and regressions have been utilised to correlate these with the transgressions and regressions identified in the Spiti (Bhargava and Bassi, 1995) on the presumption that such events are of regional magnitude.

Thimphu Group: This group forms the edifice of the Tethyan succession. The migmatitic gneiss in the Thimphu Group yielded a radiometric isochron age of ca 500 Ma by Rb-Sr method. The gneiss is not only migmatitic but also mylonitised, the radiometric age of this rock, therefore, may have little bearing on the exact age of the Thimphu Group. The tectonic position and infra-Tethyan stratigraphic position of the Thimphu Group makes it correlatable with the Vaikrita Group of the western Himalaya. In the Vaikrita Group, however, as compared to the Thimphu Group, insignificant amount of gneiss and migmatite are developed and the bulk of the sequence is made up of metasediments with intrusive granitoids of early Palaeozoic age. The Thimphu Group may thus be equivalent of the Rohtang Gneissic Complex of the Vaikrita Group. Its equivalent in the Darjeeling-Sikkim is the Darjeeling Crystallines and the Sela Group in Arunachal Pradesh.

Chekha Formation : The Chekha Formation comprising schist, quartzite, marble and diamictite

Table 5.2.1 : Correlation chart of the Lesser Himalayan formations of the Bhutan Himalaya

Age	Bhutan	Eastern Himalaya		Western Himalaya		
		Arunachal	Darjeeling-Sikkim	Kumaon-Garhwal	Himachal	Kashmir
Late Miocene Pliestocene	Siwalik Gr	Siwalik Gr.	Siwalik Gr.	Siwalik Gr.	Siwalik Gr.	Siwalik Gr.
Early Permian	Setikhola Fm Diuri Fm	Bichom-Garu Fm	Rangit Pebble Slate	Bijni Fm	-	-
Riphean	Baxa Gr	Dedza Fm, Tenga Fm	Baxa Gr.	Calc-zones of Tejam, Pithoragarh Deoban Gr.	Larji Gr., Shali Gr., Deoban Gr.	Sirban Gr.
Early Proterozoic ?	Shumar Fm & Jaishidanda Fm	Bomdila Gr. (with gneiss)/Dirang Fm.	Part of Daling	Berinag Qtz ?	Rampur Gr. Kulu Gr. ?	Kishtwar Qtz Extension of the Kulu Gr.

rests abruptly over the Thimphu Gneiss and in turn is unconformably overlain by the Pele La Group. The Dishchiling Formation of the Pele La Group encloses ichnofossils *Planolites*, indicating possibly a late Vendian age. The underlying Chekha Formation, therefore, is assigned a late Precambrian age, making it correlatable with the Chola Thatch Formation of the Himachal (Bhargava and Bassi, 1994), the Martoli Formation of the Kumaon Himalaya and the Machhal Formation of Kashmir.

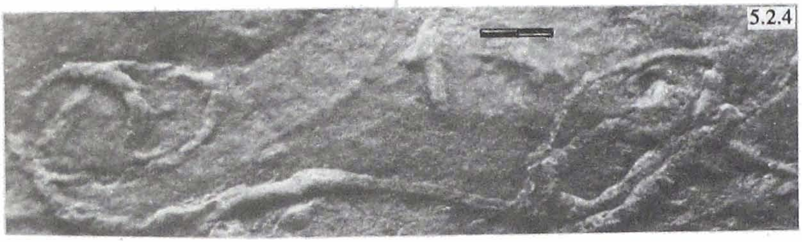


Fig.5.2.4 *Gordia*. Maneting Formation. Loc.1.5km SW of Maneting Hutments.

Pele La Group : This group comprises the Singhi (volcanics), Deshichiling (quartzite, phyllite and carbonate), Maneting (phyllite, quartzite, local carbonate and quartzite beds) and Quartzite Formations. The Singhi Formation comprising andesite, andesitic basalt and acid volcanics seems to mark a terminal Precambrian event and thus may be equivalent of the magnetite tuffs known from Kinnaur (Bassi and Chopra, 1984, Bhargava and Bassi, 1995) and lenticular flows known in the basal part of the Batal Formation (Bhargava and Bassi, 1994). In the Lesser Himalaya, the manifestation of terminal Precambrian volcanism occur possibly in the Earthy Siltstone Member - basal most unit of the Tal Group also. Its time equivalent may be the Khewra Trap in Salt Range and Bawdwin volcanics (Shon plateau) in Burma.

Fig.5.2.6 *Cochlichnus*. Maneting Formation. Loc. Maneting Hill.

Though the volcanics along the Precambrian-Cambrian boundary are well known from many parts of the world, in the Himalaya, save Bhutan, these are not mappable.

The Deshichiling Formation overlying the Singhi Volcanics except for ichnofossil *Planolites* is unfossiliferous, which possibly signifies a late Vendian age (cf. Crimes, 1992).

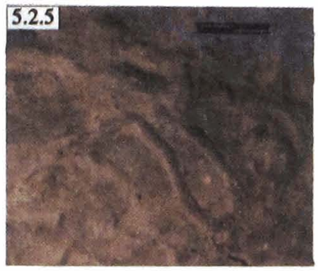


Fig.5.2.5 *Helminthopsis*. Maneting Formation. Loc. 2km south of Hill .4136.

The Maneting Formation, from its basal part has yielded a typical Precambrian-Cambrian trace fossil assemblage comprising *Arenicolites*, *Gordia* (Fig.5.2.4), *Helminthopsis* (Fig.5.2.5). The lower trace fossil horizon in the Pele La section includes *Planolites*, *Cochlichnus* (Fig.5.2.6) and *Skolithos*. The upper

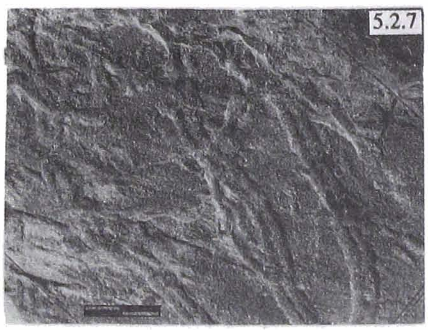


Fig.5.2.7 *Didymaulichnus*. Maneting Formation. Loc. 1.5km SW of Maneting Hutment.

level encloses a rich ichnofossil assemblage of *Didymaulichnus* (Fig.5.2.7), *Monomorphichnus*, *Phycodes pedum* (Fig.5.2.8), *Paleophycus*, *Planolites*, and *Skolithos*. The Precambrian-Cambrian boundary in this formation can be located below the *Phycodes pedum* level (cf. Crimes, 1992, 1994, Crimes and Droser, 1992). Approximately 30m above these trace fossils, in the Pele La section, occur lingulellid brachiopods. The Maneting Formation based on aforelisted fossil assemblage can be correlated with the Tal Group and the lower part of the Kunzam La Formation of Himachal Himalaya and the Rangmal Formation of Kashmir.

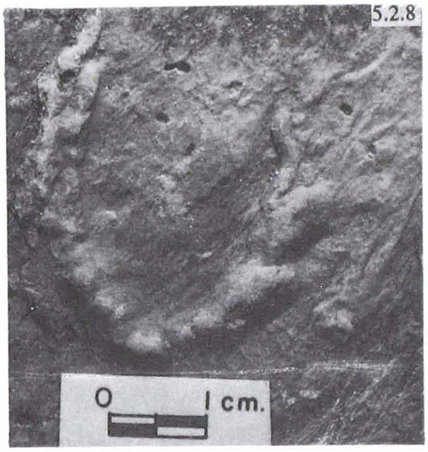


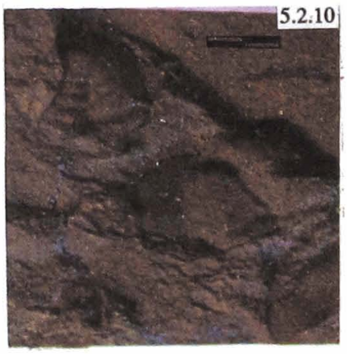
Fig.5.2.8 *Phycodes pedum*. Maneting Formation. Loc. Maneting Hill.

The arenaceous Quartzite Formation rests conformably but with sharp contact over the Maneting Formation. The Quartzite Formation encloses kaolishniids or pagodiids (Fig. 5.2.9-11) of middle to late Cambrian age. The Quartzite Formation thus is broadly correlatable with the upper part of the Kunzam La Formation of the Himachal and the Ralam Formation (?) of Kumaon and the Shumahal Formation of Kashmir (Bhargava and Bassi, 1995).

There was an extensive regression of sea during (a) early (Tal and Kumaon) (b) middle (Spiti-Zanskar) and (c) early-late Cambrian (Kashmir) which obliterated the Tethyan and the Lesser Himalayan basins respectively. The regression in the Bhutan Himalaya can be timed at middle to early late Cambrian. The Cambrian regression is commonly related to the Pan-African Orogeny, which also caused formation of the granitoids of this age (Le Fort *et al*, 1983).

Tang Chu Group : Comprising mainly a carbonate sequence, the Tang Chu Group rests unconformably over various formations of the Pele La Group. The basal Wachi La Formation except for crinoidal remains is unfossiliferous. From the conformably overlying Ripakha Formation, *Fenestella*, *Protoretipora*, *Stenoscisina*, *Dielesma*, *Neospirifer* and *Aviculopectin* of Carboniferous age have been recorded. In addition to these, Gansser (1983) reported athyrids of Devonian age. The lower age limit of the Tang Chu Group, therefore, can be placed within the late Devonian.

In Spiti-Kinnaur, two transgressive phases



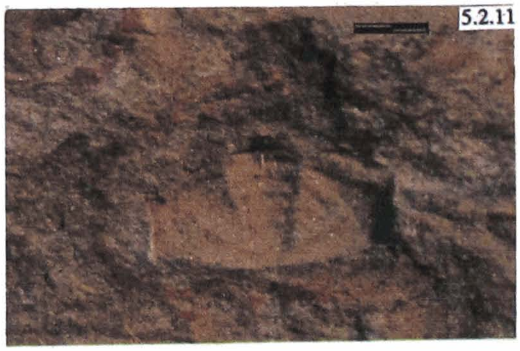


Fig.5.2.9-11 Remains of kaolishniids/pagodiids trilobites Quartzite Formation. Loc. 3km SSE of Hill .4136.

are decipherable during the Devonian viz., (i) at the base of the Muth Formation, middle Devonian (?) and (ii) at the base of the Lipak Formation, late Devonian (Bhargava and Bassi, 1995). The second event is more extensive which caused inundation of the positive terrain constituted of the Precambrian rocks. The sedimentation during this transgressive phase extended into early Carboniferous. The Tang Chu Group representing later transgressive phase can be aptly correlated with the Lipak Formation of late Devonian-Tournisian age (Bhargava and Bassi, 1995).

Barishong Formation : Due to stratigraphic mix up as discussed earlier, it is difficult to attempt correlation of the Barishong Formation with any single formation in the western Himalaya. Also the ages of fossils listed by Ganesan *et al*, (1978) are contradictory (i.e. *Marginifera* and *Favosites*). This formation however, seems to be a broad equivalent of the Pele La Group and Wachi La Formation.

Shodug Formation : The basal shaly part of the Shodug Formation has yielded *Ambikella*, *Marginifera*, *Spirifer nitensis*, *S. lydekari*, *Productus cora*, *Syringothyris*, *Fenestella*, *Polypora* and *Rhombopora* (Ganesan *et al*, 1978). Of these the *Marginifera*, *Spirifer nitensis* and *Ambikella* are mainly of late Permian age, whereas other fossils are long ranging or represent early Carboniferous age. The age of the Shaly bed, based on these fossils shall be early-late Permian and that of the overlying diamictitic sequence still younger.

Though the upper Palaeozoic diamictite deposit could be diachronous in a limited sense (Bhargava *et al*, 1985), a vast age difference between the diamictites of western and eastern Himalaya, which represent simultaneous significant event, is difficult to visualise. More likely is that identifications by Ganesan *et al*, (1978) of *Marginifera* and *Ambikella* in the Shodug Formation and of *Marginifera* in the Barishong Formation are tentative. In all probablities the shaly part of the Shodug Formation is an equivalent of the Visean Po Formation and Fenestella Shale of the Spiti and Kashmir areas respectively. The overlying diamictite shall correspond to the Pindabol Formation of Kashmir, Ganmachidam Formation of Spiti-Zanskar and Lachi Formation of Sikkim areas of late Carboniferous - early Permian age.

Lingshi Formation : This formation rests unconformably over the sediments of the Shodug Formation and the Tang Chu Group thus marking yet another transgressive phase. The Lingshi Formation has yielded upper Mesozoic flora of Gondwanic affinity comprising *Ptillophyllum acutifolium* var. *maximus*, *P. acutifolium* var. *tennarium*, *P. cutchensis*. The main marine fossils include *Callyptychoceras*, sp., *Kalianella* sp., *Hoplites*, *Gymnoplites* cf. *simplex* and *Holcodiscus* sp.

The entire sequence in the present work, like its time equivalent in Kachchh also (Jaikrishna *et al*, 1983), is considered to represent marine paleoenvironment. The Lingshi Formation is considered to range in age from Jurassic to Valangian-Tithonian (Ganesan *et al*, 1978). The report of *Cardita beaumonti* by Ganesan *et al*, (1978) is possibly a case of mis-identification. The transgression during this period, in the western Himalaya is marked by the Spiti Formation having Oxfordian as the lower and Valingian as the upper age limits (Jaikrishna, 1983; Bhargava and Bassi, 1995). The Lingshi Formation may also correspond to these age limits. However, *Daonella* (Nautiyal *et al*, 1964) and negative of a *Parajuvavitis* of Triasic age reported by Hanny (in Gansser, 1983) strike a discordant note. If these fossils can be relied upon, the Lignshi Formation has to include Triassic sequence in basal part and shall be an equivalent of Tso Lhamo Formation (Sikkim) and the Lilang Group and the Spiti Formation in Spiti. Regional correlation of various Tethyan formations of the Bhutan Himalaya is presented in Table 5.2.2.

Table 5.2.2 : Correlation chart of the Tethyan formations of the Bhutan Himalaya

Age	Bhutan	Western Himalaya			Eastern Himalaya
		Kumaon	Spiti-Zanskar	Kashmir	Sikkim
Late Jurassic/Early Cretaceous	Lingshi Fm.	Gungri Fm., Lilang Gr., Spiti and partly Giumal (?) Fms.	Gungri Fm., Lilang Gr., Spiti and partly Giumal (?) Fms.	Vihi Gr (?)	Tso Lhamo Fm.
Early-Late Carboniferous	Shodug Fm.	-	Po and Ganmachidam Fms.	Fenestella Sh and Pindabol Fm.	Lachi Fm.
Early Carboniferous (?)	Ripakha Fm.	Kali Fm.	Lipak Fm.	Syringothysis Lst., (Aishmuqam Fm)., Wazura Fm.	
Latest Devonian	Wachi La Fm.				
Middle Cambrian	Quartzite Fm.	Upper part of Martoli (?)	Kunzam La Fm.	Rangmal and Shumahal Fms.	
Early Cambrian	Maneting Fm.				
Terminal Precambrian	Deshichiling Fm.		Batal Fm with local flows		
	Singhi Fm.				
Precambrian	Chekha Fm.	Martoli Fm.	Chola Thach Fm.	Machhal Fm.	
	Thimphu Gr.	Vaikrita Gr.	Vaikrita Gr.	Salkhola Gr.	

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5.3 STRUCTURE AND METAMORPHISM

O.N. Bhargava and S. Dasgupta

5.3.1 STRUCTURE

Three tectonic planes extend throughout the length of the Himalaya. These from north to south are (i) Indus Suture, (ii) Main Central Thrust (MCT) and (iii) Main Boundary Thrust (MBT). In between the MBT and MCT, occur various belts of the the Lesser Himalayan formations, each one of which is thrust bound. The thrusts within the Lesser Himalayan sequences mostly related to thin-skinned tectonics, are commonly overlapped hence only of local extent. Though, the MBT like MBF (Main Boundary Fault) is also not a single thrust plane from west to east (Chaterji and Swami Nath, 1977), yet various thrust planes have been so designated, as each one of them separates the pre-Tertiary rocks from the Siwalik-Paleogene sequence.

In the Bhutan Himalaya, only the MBT and MCT are encountered. Sequence of the tectonic belts bound in between various thrusts as observed in Bhutan is schematically shown in Fig.5.3.1. The regional trend of these belts and

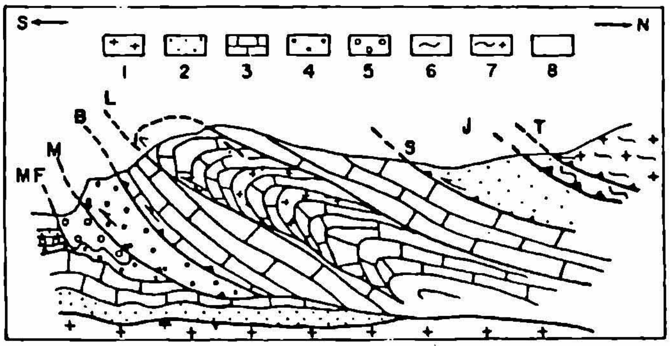


Fig. 5.3.1 Schematic section showing spatial distribution of different thrusts in the Bhutan Himalaya; MF=Main Frontal Thrust, M=Main Boundary Thrust, B=Baxa Thrust, L=Leap frog thrust, S=Shumar Thrust, J=Jaishidanda Thrust and MT=Thimphu Thrust (MCT). 1. Basement Gneiss, 2. Shumar Formation, 3. Baxa Group, 4. Setikhola Formation, 5. Siwalik Group, 6. Jaishidanda Formation, 7. Thimphu Group, 8. Alluvium.

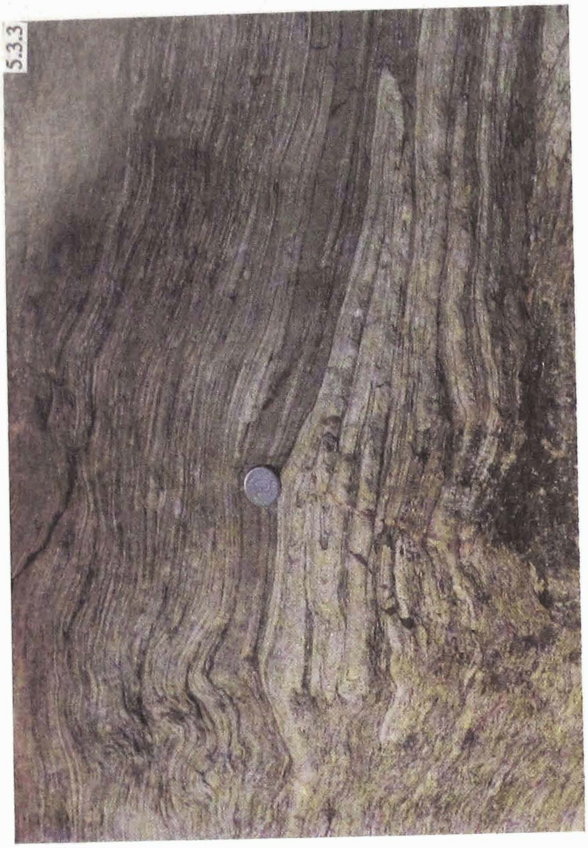
thrust varies from ENE-WSW to WNW-ESE with several conspicuous swings due to cross-folds. The tectonic belts and thrust sheets show identical deformation pattern. However, deformational fabrics of each belt exhibit different morphology due to variation in rheological properties and

Fig.5.3.6 Open type of F_2 fold within the granitoid gneiss of the Thimphu Group, Tashigang area.

depth of burial as well as intensity of bulk strain. A description of various deformational phases and associated fabrics is given in the following pages.

A. Folds and associated fabrics

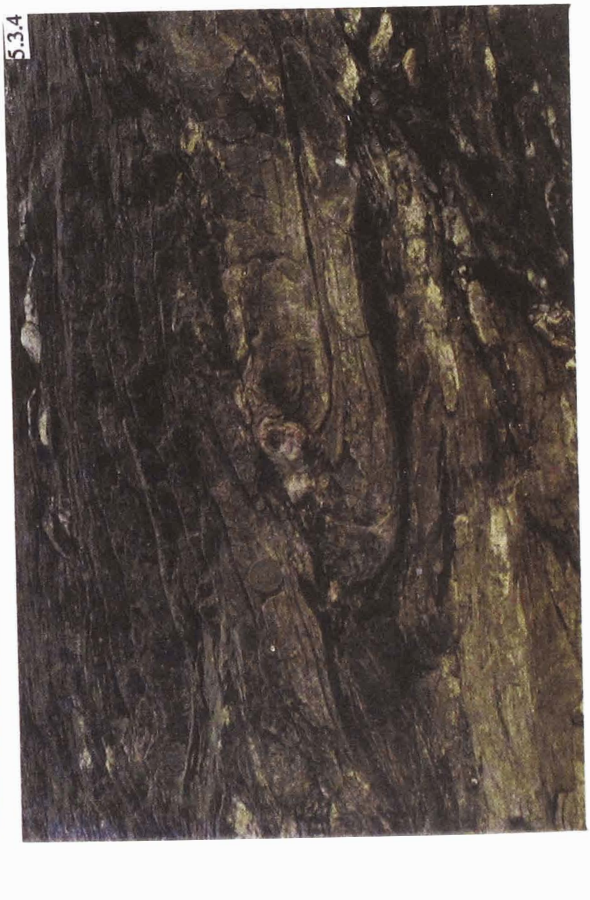
F_1 Folds : The earliest unambiguous folds save the Siwalik, are ubiquitous in the remaining formations and are generally E-W trending, tight to isoclinal with large amplitude to wave length ratio; these commonly attain reclined geometry. Sheath type folds are observed in the Shumar Formation (Ray, 1991). The F_1 folds are present only on microscopic to mesoscopic scales (Fig.5.3.2). During progressive deformation, at places, these folds are highly appressed, particularly in the vicinity of high strain zone, where adjoining fold limbs become inseparable (Fig.5.3.3). Slippage (Fig.5.3.4) parallel to axial plane has largely



5.3.3

5.3.5

5.3.2



5.3.4

obliterated the F_1 folds.

striping/intersection lineation, mineral lineation and pucker axis.

Fig. 5.3.7 Appressed F_2 fold within the Shumar Formation; Seri *Chu* area.

Though the above features are attributed to the first fold phase, there are indirect evidences of pre-F_1 deformation. As stated earlier, the Thimphu rocks suffered a pre-Chekha regional metamorphism and related deformation. The Tertiary deformation seems to have largely obliterated evidences of earlier fabrics.

F_2 folds : The F_2 folds have affected the bedding as well as the S_1 planes (Fig.5.3.5) and are commonly preserved in conjugate sets. These folds co-axial with F_1, are developed on mesoscopic as well as on regional scales and have determined the map pattern. These folds in general are open (Fig.5.3.5-6) having amplitudes-wave length ratio lesser than that of the F_1 folds. However, at many places these folds are also appressed (Fig.5.3.7)

The F_1 folds are associated with the most pervasive, axial planar fabric (S_1). The S_1 is parallel to the bedding except on hinges of the folds, where they intersect at high angles. The S_1 in the Shumar and Jaishidanda Formations, Thimphu Group, Chekha Formation and locally in the Baxa Group is represented by schistosity, while in the Manas-Sethikhola and Diuri Formations and post-Chekha Tethyan sequence, it is preserved as slaty cleavage. Near thrust/shear zones, the S_1 plane is represented by mylonitic foliation. Within these mylonitic rocks S-C fabric (Fig.3.7.8), asymmetric pressure trails, book-shelf sliding (Fig.3.7.9) and mica-fish have developed. The F_1 folds are interpreted to have been associated with a shear deformational regime during which the mylonites were also produced. These mylonites have been affected by the F_2 folds.

The linear fabrics related to the F_1 folding deformation are represented by

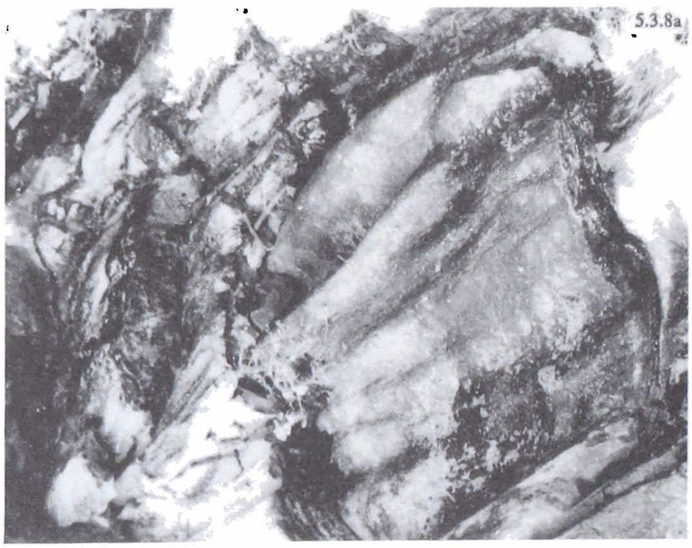


Fig. 5.3.8a En echelon F_2 folds with curvilinear axes within the granitoid gneiss of the Thimphu Group, Tongsa area. Photograph.

Explanation of Figures 5.3.2 - 5.3.5

Fig. 5.3.2 Mesoscopic F_1 fold within the Shumar formation; Seri *Chu* area. 5.3.3 Highly appressed F_1 fold within the Shumar Formation; Seri *Chu* area. 5.3.4 Slipage parallel to axial plane of F_1 fold within the Shumar Formation, Tintali area. 5.3.5 Open type of F_2 fold within the Shumar Formation, Tintali area.

and display geometry comparable to that of the F_1 folds. In some exposures F_2 folds exhibit curvilinear axis and en-echelon pattern (Fig.5.3.8a-b).

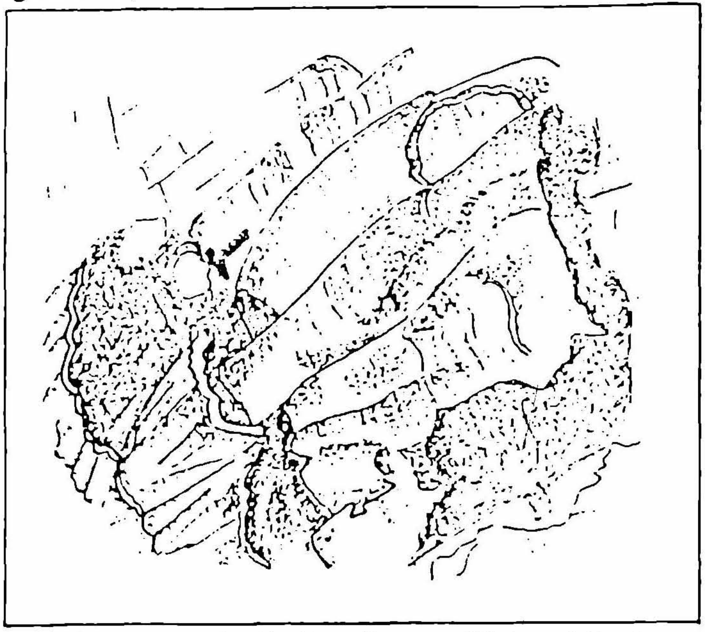


Fig.5.3.8b En echelon F_2 folds with curvilinear axes within the granitoid gneiss of the Thimphu Group; Tongsa area. Sketch of 5.3.8a.

The deformation associated with F_2 folds has produced axial planar fabric (S_2) in the form of crenulation cleavage (Fig.5.3.9). Locally S_2 plane is intensely developed and has completely transposed the S_1 planar fabric. The trend of S_2 cleavage is parallel to S_1, the former generally shows steeper angle of dip. The interference of F_2 with F_1 is well preserved in the Jaishidanda rocks (Fig.5.3.10).

The F_2 folds are decipherable in the Siwalik rocks, though no pervasive planar fabric in these rocks seems to have been formed.

F_3 folds : The last phase of deformation has produced N-S to NNE-SSW trending cross-warps (F_3 folds). These have modified the earlier folds. The F_3 folds are of regional dimensions and normally are not preserved on mesoscopic/outcrop scale. The superimposition of the F_3 folds over the F_2 folds is responsible for the swing in the regional strike of the rocks and also of the axial trace of the F_2 folds. Such superposition is sporadically observed on mesoscopic scale (Fig.5.3.11-13).

The F_3 folds are well developed in the Siwalik rocks also. The major folds of the area are listed in Table 5.3.1 and accordingly numbered and shown in Plate-1.

NE-SW strike in the western Himalaya and the N-S in the Eastern Himalaya have been interpreted as the extension of the Peninsular elements in the Himalaya (Auden, 1935, Jangpangi, 1974). The recent work, however, shows that these trends are by and large the result of cross-folds. However, as several Peninsular lineaments seem to find extension in the Himalaya, there is a possibility that the F_3 cross-folds, or even the F_2 folds were moulded by Precambrian basement structures which extended into the Himalaya (cf. Bhargava *et al*, 1991).

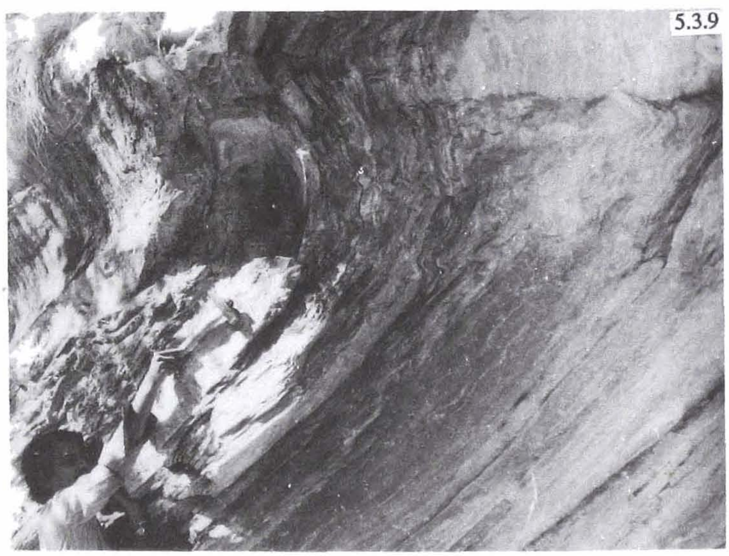


Fig. 5.3.9 Well developed crenulation cleavage, axial planar to F_2 folds within the Chekha Formation, Shemgang area.

B. Thrusts

Main Frontal Thrust : This thrust identified and so named by Nakata (1972) separates the Siwalik belt from the Quaternary Alluvium.

Table 5.3.1 : Disposition of major folds in Bhutan Himalaya

Fold phase	Antiforms	Synforms	Trend of Axial Trace	Remarks
F_2	I. Narphung	Ia Narphung	ENE-WSW	Baxa Group, Diuri Formation.
F_2	II. Gong Ri-Jiri Chu (window)	IIa Shumar	ENE-WSW	Shumar and DiuriFormations and Baxa Group.
F_2		III Sakteng	E-W	Chekha Formation and Thimphu Group.
F_2	IV. Manas-Jaldhaka	IVa Manas - Jaldhaka	E-W (southerly overturned)	Baxa Group.
F_2	V. Black Mountain - Tang Chu	Va Black Mountain - Tang chu	E-W (some are southerly overturned)	Thimphu Group and overlying Chekha Formation.
F_2 & F_3	VI. Paro (window)	VIa Bunakha	WNW-ESE and NNE-SSW	Thimphu Group, Shumar and Jaishidanda Formations (in Sambe Dzong only Thimphu Group and Jaishidanda Formation).
F_2	VII. Sambe Dzong (window)	VIIa Sambe Dzong	WNW-ESE	Thimphu Group and Jaishidanda Formation.
F_2	VIII. Duna Dzong and Chukha (window)		NW-SE	Thimphu Group and Jaishidanda Formation.
F_3	IX. Kuru Chu (half window)	IXa Gongkhola	N-S	Shumar, Jaishidanda Formations and Thimphu Group along with overlying Tethyan sequence. (The Gongkhola F_3 synform is not distinctly pronounced due to F_2 folds).
F_3	X. Sankosh		N-S	
F_2	-	XI Kobja	ENE-WSW	Tang Chu Group.
F_3(?)		XII Lingshi	NE-SW	Tethyan succession.

Fig. 5.3.10 Interference of F_2 with F_1 folds within the Jaishidanda Formation, Chapcha area.

The Siwalik sediments show F_2 and F_3 folds. The F_2 folds are open and overturned, in which the overturned limb has commonly sheared along reverse faults. These rocks mainly represent brittle deformation.

Fig. 5.3.11 F_2 folds (scale parallel to axial plane) refolded by F_3 warps (pen parallel to axial plane) within the Thimphu group, Tongsa area.

Main Boundary Thrust: This name is given to various thrust planes from west to east which have translated the Baxa and Setikhola sequences over the Siwalik rocks. The MBT on surface is a moderately inclined to high angled thrust plane dipping due north. It is considered to flatten at depth.

The tectonic belts which moved over the Siwalik parautochthon form schuppen zones, particularly in the vicinity of the MBT. The Setikhola Formation occurs as an imbricated belt within the Siwalik sequence near the MBT and away from it in the Setikhola section, it occurs as thin tectonic scales within the Baxa sequence (Fig.5.3.14).

Baxa Thrust : This thrust variously translates the Baxa tectonic belt over the Setikhola Formation. Where the Setikhola Formation has been tectonically overlapped, the Baxa belt rests directly over the Siwalik Group. The Baxa Group

Fig. 5.3.12 Tight, recumbent F_2 fold (in the upper part of the photograph) affected by open, upright F_3 wrap (in the lower part of the photograph) with axial plane fractures, within the Thimphu Group, Tongsa area.

rocks in the vicinity of the thrust have been intricately folded and also intimately involved in schuppen zone. The entire sequence shows extensive mylonitisation.

The tectonic scaling within the Sethikhola and Baxa sequence possibly represents a slow and protracted process in a brittle regime as may be evident by extensive development of mylonite in the low grade Baxa Group and the Setikhola Formation as well as by brecciation and fault gouge in the coal-belt of Bhangtar of eastern Bhutan.

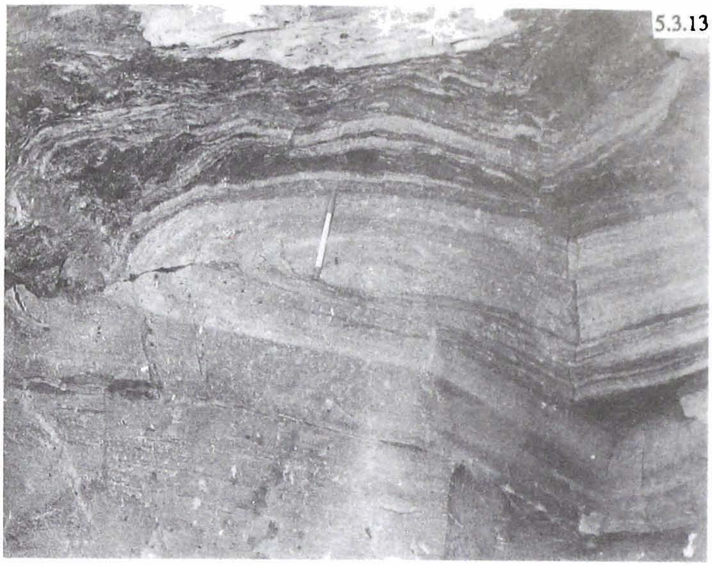


Fig. 5.3.13 Close-up view of the tight, recumbent F_2 fold (Fig.5.3.12) affected by F_3 wrap; Note F_3 puckers developed within the upper phyllosilicate rich band.

The restricted spatial occurrence, tectonic interlayering and overlapping of the low grade metasediments immediately underlying the Baxa belts probably indicate a limited translation of these belts along various thrusts from shallower depths. The tectonic imbrication possibly developed in response to up-dip movement of northern blocks due to the impact of Shumar-Jaishidanda-Thimphu Thrust Sheets.

Shumar Thrust: This thrust separates the Shumar Formation from the underlying sequences. Towards west it extends into the Sikkim-Darjeeling Himalaya. Towards east, SE of Tashigang, it is tectonically concealed under the Thimphu Thrust.

The Shumar Formation, comprising quartzite-phyllite sequence, also encloses concordant sheet-like bodies of granite gneiss at different tectono-stratigraphic levels. These granite gneiss bodies have been variously considered as intrusive (Jangpangi, 1978), thrust wedges (Jangpangi, 1974) splinters of basement granite (Sinha-Roy and Sen Gupta, 1986) and sub-thrust material incorporated during forward propagation of the Shumar Thrust Sheet (Ray *et al*, 1989). These gneissic bodies are highly deformed and exhibit a wide spectrum of mylonitic texture-protomylonite and augen gneiss being common rock types. They also show banded mylonite exhibiting fluxion banding. Asymmetric pressure trail, S-C fabric and book-shelf sliding texture are also observed. These granite gneiss bodies have sharp contact with the enveloping metasediments along which mylonite and phyllonite are commonly developed. In view of the characters described above, the granite-gneiss seems to represent tectonic slivers caught within the Shumar sequence along multiple thrusts during its propagation over its granitoid basement (Fig.5.3.15). The granite gneiss slivers are confined to the basal and upper parts of the Shumar Formation, whereas the middle part is relatively barren.

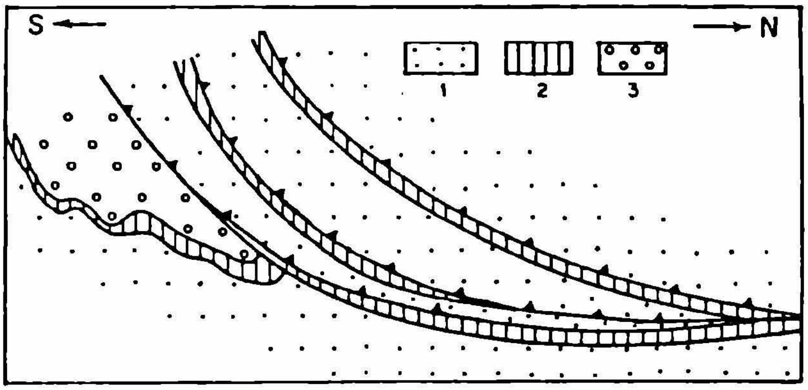


Fig. 5.3.14 Schematic section showing tectonic scaling between the Setikhola and Jaintu Formations in Setikhola section; 1. Jaintu Formation, 2. Setikhola Formation, 3. Siwalik Group.

The thin sheets of the Baxa rocks within the Shumar Formation have been similarly interpreted as thrust wedges (Jangpangi, 1974), or imbricate

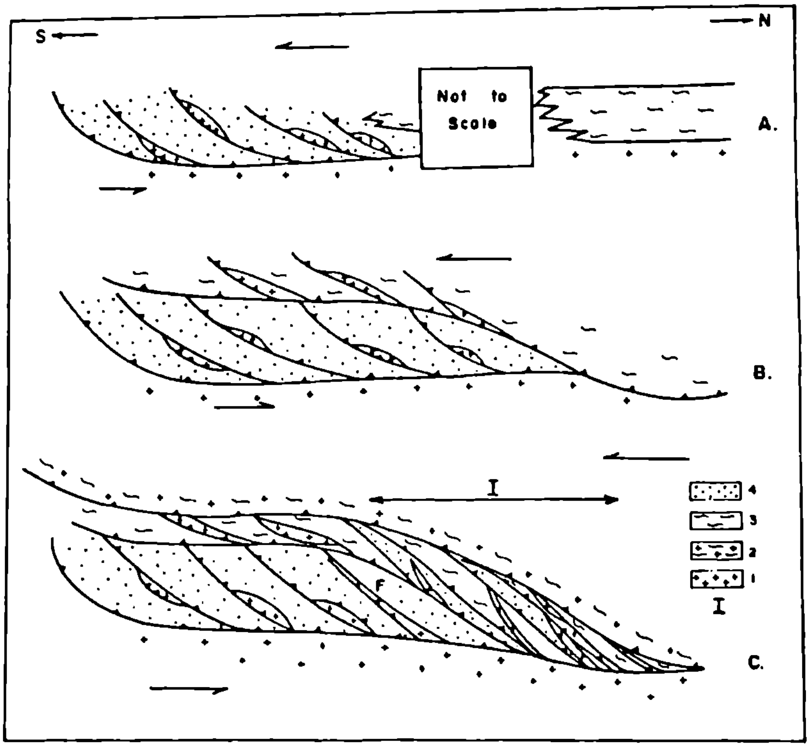


Fig. 5.3.15 Schematic diagram showing tectonic relation between Shumar and Jaishidanda Formations. A. Initiation of the Shumar Thrust Sheet, B. Initiation of the Jaishidanda Thrust Sheet, C. Emplacement of Thimphu Thrust Sheet and tectonic imbrication between Shumar and Jaishidanda Formations. 1. Basement Gneiss, 2. Thimphu Group, 3. Jaishidanda Formation, 4. Shumar Formation, I. Situation in the Paro Window.

blocks (Ray *et al*, 1989). The gypsum beds of eastern Bhutan and the crystalline limestone are possibly also tectonic slivers picked up from the Baxa rocks which formed part of the tectonic basement for the southward moving Shumar Thrust Sheet. The Shumar Formation thus traversed by multiple interconnected thrusts carrying basement slivers, represents a composite thrust sheet. Though not yet delineated on the map, the horses comprising stack of asymptotically arranged imbricate thrusts, bound by floor and roof thrust (e.g., Kamji road), are interpreted to be present in the Shumar composite thrust sheet (Fig.5.3.15). Ray *et al*, (1989) in the Norang-Chiya area described layer-cake sequence forming upper unit of the Shumar Thrust Sheet within which occur an antiform-synform within a forelimb thrust. The forelimb thrust is parallel to a ramp climb of the floor thrust. The Shumar Thrust cuts up the footwall stratigraphic sequence along this ramp (Ray *et al*, 1989).

In certain pre-to syn-thrust folds, inclination of the forelimbs has been directed towards shear direction and that of the back-limbs in the opposite direction (Ray, 1991). The progressive shearing, possibly during the thrust movement, caused shortening and buckling of forelimbs and stretching and attenuation of backlimbs. These folds indicate a shear sense of movement of the Shumar Thrust Sheet which generated and propogated under simple shear strain (Ray, 1991) in a ductile regime.

Jaishidanda Thrust : This thrust separates the Jaishidanda Formation from the underlying Shumar Formation. Towards west in the Sikkim-Darjeeling Himalaya, the Jaishidanda Thrust coincides with the contact between lithopackage of phyllonitic schist with mylonitic Lingtse Granite Gneiss and the Garubathan Formation. In east, SE of Tashigang, it is probably overlapped by the Thimphu Thrust Sheet.

Across the Jaishidanda Thrust, changes in metamorphic grade and deformation features are conspicuous. Whereas the Shumar Formation shows lower green schist facies, garnet with sporadic staurolite appears in the Jaishidanda Formation. The shearing and mylonitisation are more conspicuous in the rocks of the Jaishidanda Formation with an extensive development of S-C mylonites. The phyllonitic rocks in the Jaishidanda Formation are interleaved with thin lenticular, concordant sheet-like bodies of mylonitised granite gneiss. These sheets show sharp contacts with the enclosing metasediments. These granite gneiss bodies, like those in the Shumar Formation, are considered as basement slivers, tectonically incorporated, in the Jaishidanda Formation during its propagation from the root zone.

The Jaishidanda Thrust Sheet, though a much thinner pack as compared to the Shumar Thrust Sheet, also represents a composite thrust sheet. Due to intense shearing suffered by the metasediments of the Jaishidanda Formation, the mesoscopic folds, commonly observed in the Shumar Formation type area, have been largely obliterated in the Jaishidanda Formation. Much of shearing in the Jaishidanda Thrust Sheet could be due to its being sandwiched in between two major thrust sheets i.e., the Shumar and Thimphu. In view of extensive developments of S-C mylonite and other related characterisitic micro-textural features, the Jaishidanda Thrust Sheet seems to manifest a ductile shear regime.

The rocks of the Jaishidanda Formation were earlier mapped either as part of the Thimphu Formation or of the Shumar Formation. Considering the overall tectono-metamorphic features, this formation seems to represent either an individual thrust sheet with wedge of basement or a tectonic imbrication zone of the Shumar-Thimphu sequence developed along the sole of the Thimphu Thrust Sheet. In case of its being such an imbricate zone, one would expect a higher percentage of hanging wall element (i.e., Thimphu Group) than that of the foot-wall (Shumar Formation). On contrary the Jaishidanda Thrust Sheet is constituted predominantly of mica schist with minor granite gneiss sliver, hence the former interpretation is tentatively favoured.

Thimphu Thrust : This is the most unambiguous low angled thrust which has been recognised by most of the earlier workers (Nautiyal *et al*, 1964, Guha Sarkar, 1979, Ray *et al*, 1989). The Thimphu Thrust has translated the Thimphu Group over the Jaishidanda and the Shumar Formations.

An abrupt change in grade of metamorphism has been unequivocally recorded across the Thimphu Thrust. Besides metamorphic change, Gansser (1983) reported a sharp change in structural style also across the Thimphu Thrust plane. During the recent work, however, the dominant planar fabric was found to continue across the Thimphu Thrust, though there is a change in the morphology of the planar fabric. During the present studies the augen gneiss (Dutta and Sen, 1975, Sen Gupta and Raina, 1978) developed at the sole of the Thimphu Thrust Sheet is found to represent a mylonitic belt. Protomylonite, augen gneiss and mylonite have been recently recorded in the Kuru *Chu*-Seri *Chu* valleys, Lodrai-Sure sector, Sarbhang-Dhara *Chu* and Jiti river sections also. These rocks show S-C fabric and asymmetric pressure trails. The above evidences suggest formation and translation of the Thimphu Thrust sheet in a ductile shear regime.

There are numerous overturned and recumbent folds in the rocks of the Thimphu Group as well as in the overlying Tethyan succession. The convergence and asymmetry of all these folds indicate a southerly movement of the Thimphu Thrust Sheet.

The Thimphu Thrust Sheet though shows anomalous metamorphic grades is stratigraphically succeeded by the Tethyan succession. The thrust at the base of the Thimphu Group thus may be correlatable with the Main Central Thrust (cf. Bhargava and Bassi, 1994).

Another sub-thrust designated as the Takhtsang Thrust exists locally within the Thimphu Group. It brings the supposedly granulitic facies Takhtsang Formation to rest over the amphibolite facies Naspe and Sure Formations. This thrust identified only in a few sections of the Bhutan Himalaya, is characterised by incipient development of ductile shear zone.The deposition of the Tethyan sediments over the Sure as well as the Takhtsang Formations, suggests that the latter two formations possibly existed at the same elevation, at the time of marine transgression, to form a common basement for the Chekha Formation (Fig.5.3.16). In other words, the Takhtsang shear perhaps is of pre-Chekha age.

The Tethyan litho-pack due to differential movement during thrust propagation has been locally detached from its Thimphu basement along surficial thrust planes.

All the thrusts described above, save the MFT, have been folded along with the overlying

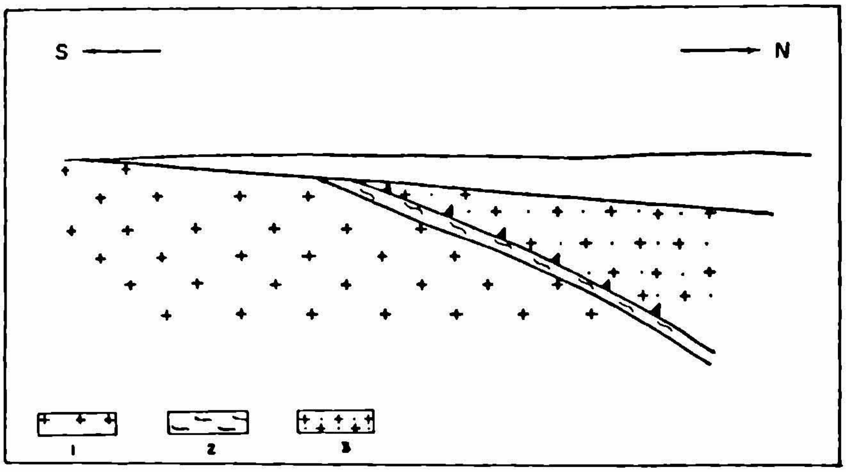


Fig. 5.3.16 Cartoon section to show probable positions of the Sure, Naspe and Takhtsang Formations at the time of deposition of the Chekha-Tethyan column. 1. Sure Fm., 2. Naspe Fm., 3. Takhtsang Fm.

The Tethyan sequence occurring over the Sure and the Takhtsang Formations, has also been translated along with the Thimphu Thrust Sheet.

sequences. The erosion of the thrust sheets, along the antiformal crestal zones has exposed the subthrust sequences along the Paro, Ha, Wang

Fig. 5.3.17a. NNE-SSW trending megascopic F_3 fold within the Jaishidanda Formation near Tamchhery Gompa in the Paro *Chu* valley. Photograph.

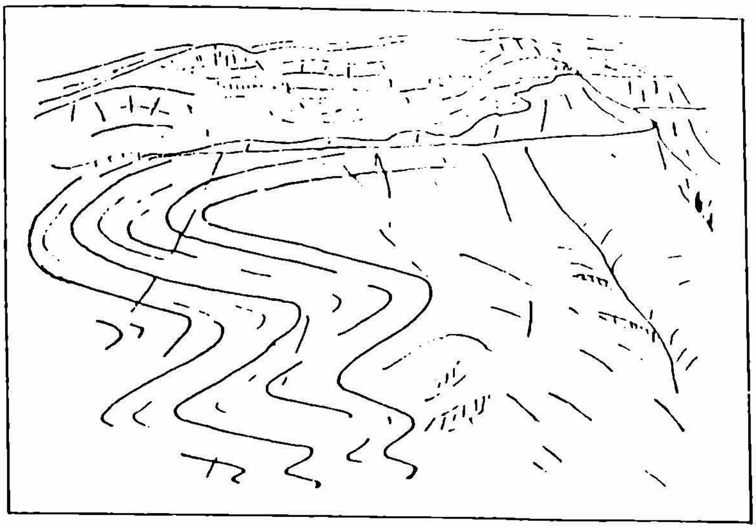


Fig. 5.3.17b.NNE-SSW trending megascopic F3 fold within the Jaishidanda Formation near Tamchhery Gompa in the Paro *Chu* valley. Sketch of 5.3.17a.

Chu, Amo *Chu*, Gong *Ri*-Jhiri *Chu* and Kuru rivers in the windows, the last area constitutes a half window. These windows are designated as the Paro, Sambe Dzong, Duna Dzong, Chukha and Gong Ri-Jhiri windows (Fig.3.7.1). The sequences exposed in the Paro, Sambe Dzong, Duna Dzong and Chukha windows were earlier classified under the Paro Formation (Anon, 1984). The work by one of us (SD) suggests that the sequences exposed in the windows are northward extension of the Shumar and Jaishidanda Formations (Fig.3.7.2). The thrust above these sequences in the windows represents the Thimphu Thrust (≡MCT). In the Gong Ri-Jhiri window, the Diuri and Baxa sequences are exposed.

The Kuru Chu half window represents third phase antiformal fold (Table-5.3.1). The Paro and Sambe Dzong windows represent a broad domal structure produced due to interference between WNW-ESE (Fig.5.3.17a-b) and NNE-SSW trending (Fig.5.3.18a-b) second and third phase antiformal folds respectively, while Duna Dzong and Chukha windows represent second phase antiformal folds only (Table-3.1). Among these, the Chukha antiform is found to be overturned towards south as a result near Taktechu, gneiss of the Thimphu Formation is overlain by the metasediments of the window zone.

In the Chukha, Sambe Dzong and Duna Dzong windows only the Jaishidanda Formation is exposed. In the Paro window, unlike foot-hill tectonic sequence, the Jaishidanda Formation is

Fig. 5.3.18a. NNE-SSW trending megascopic F3 fold within the Jaishidanda Formation near Tamchhery Gompa in the Paro *Chu* valley. Photograph. (Photo by S.K. Tangri).

overlain by the Shumar Formation. We suggest that in the Paro window, the Jaishidanda Thrust is of composite nature which resulted in anomalous tectonic relationship (Fig.5.3.1) between Jaishidanda and Shumar Formations. The exposure of the Jaishidanda-Shumar Formations in windows establishes a minimum horizontal translation of about 100km; comparable distance of translation has been computed in eastern Bhutan by Jangpangi (1974) for the Thimphu Thrust Sheet.

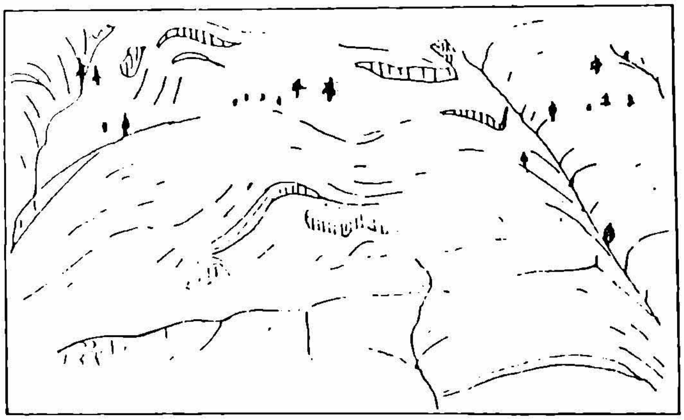


Fig. 5.3.18b. NNE-SSW trending megascopic F_3 fold within the Jaishidanda Formation near Tamchhery Gompa in the Paro *Chu* valley. Sketch of 5.3.18a.

C. Faults

Besides thrusts, there are several high angled faults in the Bhutan Himalaya. These faults in general have a E-W and N-S trends which are parallel to the axial traces of F_2 and F_3 folds respectively.

D. Temporal relationship of the structural elements

The S_1 schistosity formed during the first phase folds (F_1) grades into mylonitic foliation within the high strain zones. The S_1 schistosity and mylonitic foliation are co-planar with the thrust zone. The major phase of mylonitisation is regarded to be co-eval with the first phase of folding. The textural and structural features (kinematic indicator) developed within the mylonites indicate an up-dip movement of the northern block. The granite mylonites developed along the sole of the Thimphu Thrust sheet and also in the Shumar Thrust Sheet commonly display prominent down-dip mineral lineation defined by quartz-feldspar rods and elliptical aggregate of phyllosilicate minerals. The available structural evidences suggest a N-S direction of movement. The up-dip movement of the north block deduced from the textural and linear features is consistent with the overall direction of thrust propagation. The first phase folding is thus, considered to be syn-thrusting.

Fig. 5.3.19 Sinistral F_2 folds (section looking from east) within the Shumar Formation of the Tintali area.

Geometry and axial plane orientation of F_1 and F_2 folds are highly comparable. The asymmetry (Fig.5.3.19) and convergence of F_2 fold indicate an up-dip movement of northern blocks. Mesoscopic shear planes, axial planar to F_2 folds (Fig.5.3.20-21), indicate shear deformation regime similar to first phase folding. Similarly the forelimb folds developed on the limbs of the F_1 fold (Fig.5.3.22) point to a southerly movement. The above mentioned features suggest a similar bulk strain pattern during the first and second fold phases which were probably the earlier and later part of the same progressive deformational regime. The E-W oriented faults and local thrusts are considered to be syn-F_2.

Fig. 5.3.20 Mesoscopic shear plane, axial planar to F_2 folds, developed within the Jaishidanda Formation in the Paro *Chu* valley, near the Paro *Chu*-Wang *Chu* confluence.

The N-S trending F_3 cross-folds have affected the F_1 and F_2 folds and also the thrust planes. This is the last regional fold phase observed in the Bhutan Himalaya. It could also be the terminal phase of continuous deformation when the strain field had been rotated.

Some of the N-S sub-vertical faults seem to be continuation of faults/lineaments observed in the Peninsular part. These faults thus could be due to reactivation of pre-existing basement structures during F_3 folding. Some of the basement structures, though have exercised control on the formation of lineament in the Bhutan Himalaya have not found expression on surface in the form of displacement.

E. Structure of SE Bhutan

Scanty information is available for the SE Bhutan. In this area, in the deeper part of the Baxa parautochthon, occurs an interlayered sequence of carbonate-quartzite (=Baxa) recrystallised quartzite (Shumar ?) and mylonite gneiss. These units are folded in an E-W trending antiform with westerly plunge.

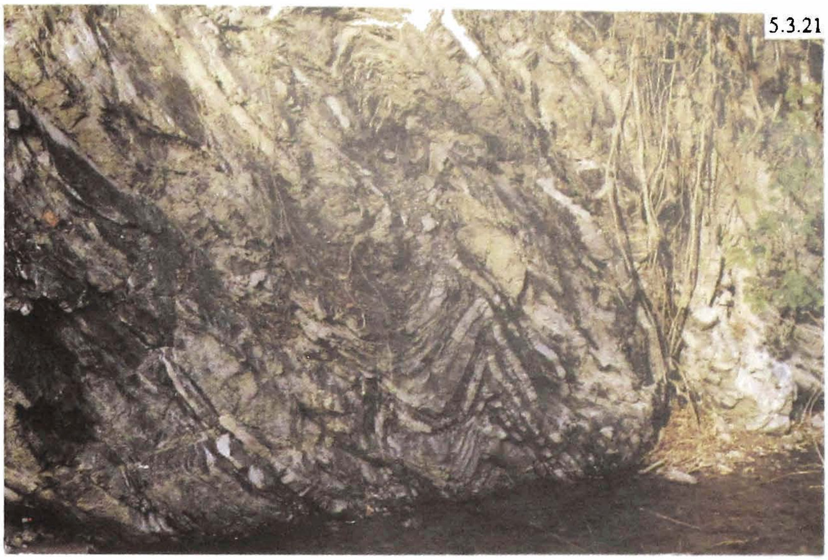
The carbonate-quartzite and granite-gneiss interlayered sequence possibly represents a tectonically affected basal part of the sequence along a leap-frog thrust(Fig. 5.3.1) which is of a much larger magnitude in the east where the succession translated along this thrust is designated as the Tenga Formation. However, we shall prefer to keep this interpretation open till detailed mapping substantiates such a model.

5.3.2 SEISMICITY AND NEOTECTONICS

Fig.5.3.23 shows the epicentres of the major earthquakes recorded in the Bhutan Himalaya and adjoining areas. Limited number of epicentres in Bhutan in our opinion is not due to its relative seismic stability, but due to dearth of data.

The epicentres in Bhutan are concentrated mainly in N-S alignment near 90°30' and 91°00' longitudes, where the Sankosh, Mangde *Chu* and Bumthang *Chu* have near straight courses. Also in the same alignment occur several epicentres in the Peninsular part. We are thus tempted to relate

Fig. 5.3.24 Folded terrace about 400m from Khasadrapchu on Gidakom road.



5.3.21

Fig. 5.3.21 Mesoscopic shear plane, associated with the F_2 folds, within the Shumar Formation. Tintali area.

these earthquakes to reactivation of major basement fractures which extend from Peninsular to the Himalayan part.

Evidences of neotectonic activity in the Bhutan Himalaya were first cited by Nakata (1972). These evidences were mainly restricted to the foot-hill region. During the present work evidences for neotectonic activities were encountered in several areas.

A. Direct Evidences

Folding and tilting of terraces

a) A gently folded anticline and a complimentary syncline are preserved in the Quaternary terrace about 200m from Khasadadrapchu along the road to Gidakom (Fig. 5.3.24). These folds are located near a fault along the Wang *Chu*.

5.3.22

Fig. 5.3.22 Fore-limb folds developed within the Shumar Formation. Ha area.

b) Tilted terraces were observed near Kali khola (Fig. 5.3.25). There are two sets of Quaternary sequence in this area. The earlier one is tilted at about 20^{o} angle, while the younger terrace which truncates the beds of earlier sequence, is horizontal. In the extension of the tilted terraces occurs a knick-point in the river.

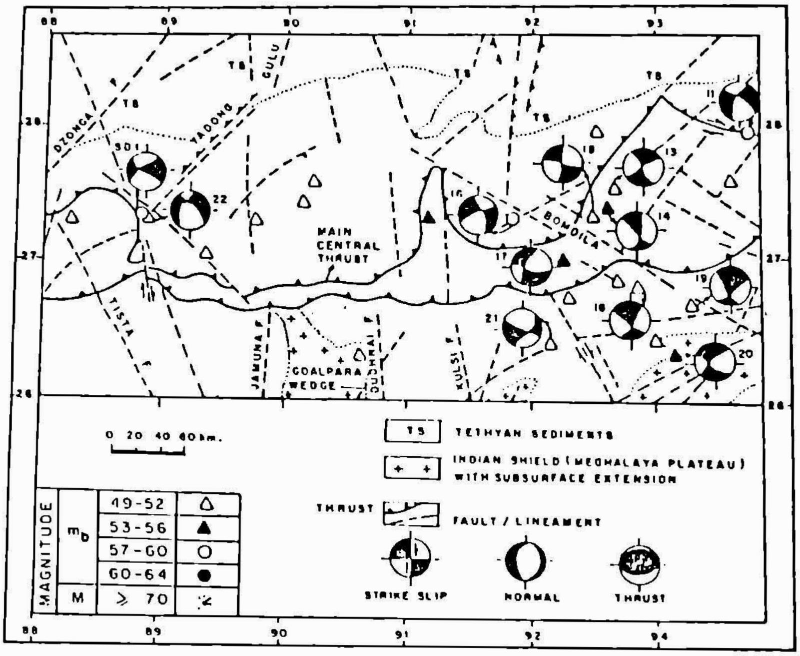


Fig. 5.3.23 Epicentres of major earthquakes in Bhutan and adjoining area (after Nandy and Dasgupta, 1991).

c) A limited movement of the Siwalik rocks along a low angled thrust plane was observed at the right bank of the Sankosh river, about 50m downstream of the confluence with the Jamduar *nala* (Fig. 5.3.26).

B. Indirect Evidences

Geomorphic evidences

a) **Scarp** : All along the Bhutan Himalaya the Siwalik rocks, and in their absence the pre-Tertiary rocks form a scarpment against the Indian plains (Fig.5.3.27-28).

b) **Triangular faceting** : All along the foot-hills triangular facetted hills indicating recent uplift are present.

c) **Occurrence of terraces** : River terraces occur much above the present river beds, indicating uplift during the Quaternary.

d) **Abandoned valleys** : Mostly the abandoned valleys are found in the foot hill region near to Indian plains. An excellent example is seen along Samtse-Sibsoo road near the Chamurchi bridge. In this part an abandoned valley exists immediately east of the bridge. This valley, further upstream (i.e., towards north) merges with the present valley. However, towards south (downstream) it forms a hanging valley. All along the western limit, the abandoned valley is bound by a conspicuous scarp in north constituted of hard rocks and in south of Quaternary fluvial terraces. This valley, it is suggested was abandoned due to faulting in the Quaternary-Holocene time.

Fig. 5.3.25 Tilted terrace near Kalikhola village ; note that the upper most terrace is horizontal.

Fig.5.3.26 Limited translation of the Siwalik rocks over the subrecent Quaternary. Right bank of Sankosh river, 50m downstream of Jamduar nala confluence. (Photo A.K. Chowdhury).

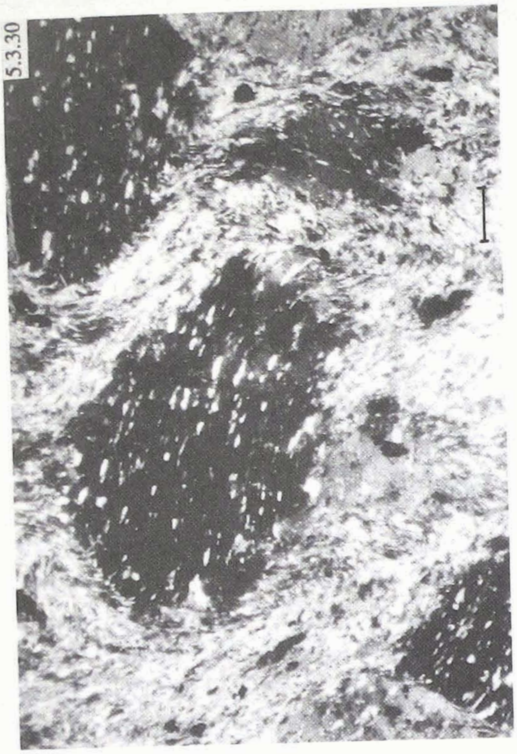
e) **Braided rivers** : The braiding of rivers is mostly observed in stretches traversed by faults, indicating fluvial response to tectonic movements (cf. Schumm, 1985).

f) **Lineament controlled drainage and earthquakes** : Several lineaments extend from the Peninsula to the Himalaya through the alluvial gaps separating these two terrains. The expression of these lineaments in alluvial stretches indicates their continued reactivation in the Quaternary time. Several rivers flow along these lineaments.

5.3.3 METAMORPHISM

The metamorphic scenario of the Bhutan Himalaya is closely comparable with other sectors of the Himalaya. Here too the litho-packages bearing imprints of higher grade of metamorphism occupy higher structural levels compared to the lower grade counter parts. The inverted sequence of metamorphism continues from the Lesser to Higher Himalayan sequence of the Thimphu

Fig. 5.3.27 A view from the Indian plains towards north showing abrupt rise of the Himalayan foot-hills range forming scarpment against the plains.


5.3.30


5.3.32


5.3.29


5.3.31

Group. The metamorphic grade becomes normal within the Tethyan package, overlying the Thimphu Group.

along a E-W trending belt. The Siwalik litho-pack is an almost unmetamorphosed within which incipient recrystallisation/rotation of mineral grains, sporadic weak alignment of quartz grains

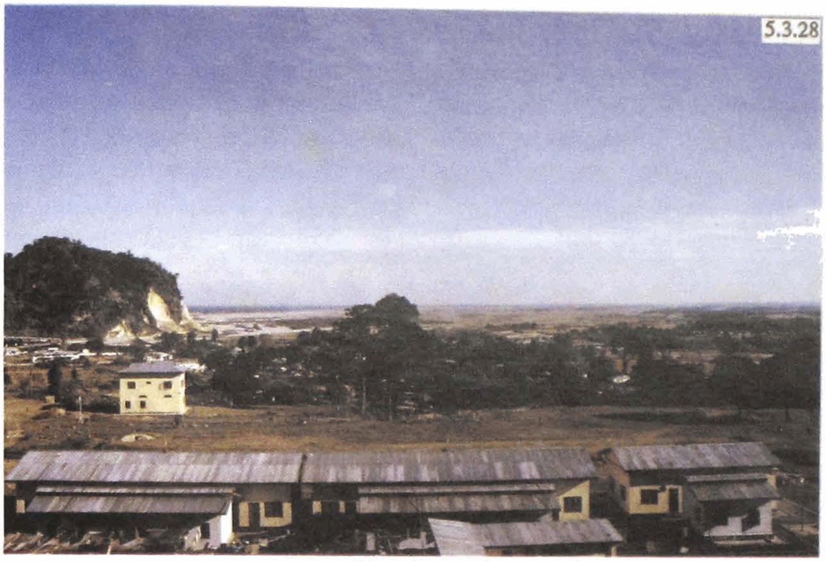


Fig. 5.3.28 Close-up view of the foot-hills range forming scarpment against the plains, Diaphom.

as well as development of discontinuous, dendritic type of cleavage, defined by concentration of fine opaque grains, have taken place in the vicinity of the Main Boundary Thrust.

The metamorphic history of this terrain has been rendered complicated due to large scale tectonic transportation of composite thrust sheets and stacking of different litho-packages with their inherent metamorphic imprints. Dearth of systematic data on regional variation of different mineral phases, their inter-relationship and geothermobarometry make deciphering of the evolutionary history of the P-T path particularly with reference to the mega-tectonics of corresponing tectonic belts difficult. Thus only a broad regional framework about the distribution of different index minerals and their relation with the deformation history is attempted here.

A. Distribution of different metamorphic minerals

Siwalik Belt : Along the lower most structural level the Siwalik Group of rocks are exposed

Setikhola Belt : North of the Main Boundary Fault/Thrust, occurs discontinuous patches of the Setikhola rocks. In these rocks development of a pervasive slaty cleavage is noticed which might have at least led to the development of some crystallisation of clay minerals. Tentatively these rocks can be considered to represent 'very low anchimetamorphic grade' package. Studies of clay mineral in metasediments and of reflectence in coal may help in precise determination of the metamorphic facies of this litho-package.

Baxa Belt : The Baxa Group which forms a major tectonic belt of the Lesser Himalaya rests

Explanation of Figures 5.3.29 - 5.3.32

5.3.29 Biotite porphyroblasts, cutting across S1 fabric, in the mica schist of the Chekha Formation. Bar length 0.1mm. 5.3.30 S_2 fabric wraps around biotite porphyroblasts in the mica schist of the Chekha Formation. X-nicols, bar length 0.1mm. 5.3.31 Garnet porphyroblast with spiral inclusion trial in the garnetiferous mica schist of the Jaishidanda Formation. Note outer schistosity deflects around garnet. Partially X-nicols, bar length 0.05mm. 5.3.32 Deflection of outer schistosity around garnet porphyroblast in the garnetiferous mica schist of Jaishidanda Formation. Bar length 0.05mm.

over the Setikhola rocks. Pervasive mineral fabric within this sequence is defined by the development mainly of clay minerals, individual grains of which are not resolvable under ordinary microscope. However, towards the upper part i.e., nearer to the Shumar Thrust, tiny flakes of sericite/muscovite and chlorite are observed in the Baxa rocks. At places, along the Shumar-Baxa contact development of coarse biotite flakes is also observed. Development of mylonite, specially within quartzitic units, is common within this belt. Plastic deformation, leading to recrystallisation of the quartz grains is common within the mylonite.

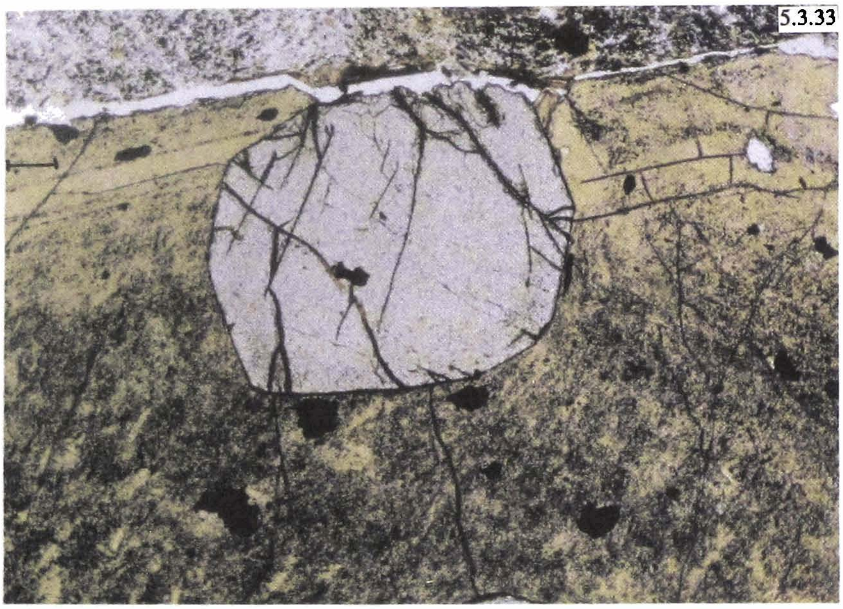


Fig. 5.3.33 Garnet included within staurolite in Naspe Formation. Bar length 0.1mm Photo P.R. Golani).

Shumar Belt : Occurring along the upper part of the Lesser Himalaya the pelitic rocks of the Shumar Formation commonly exhibit quartz+ muscovite/sericite+chlorite+opaque. Towards the upper part of the Shumar sequence biotite appears together with overall coarsening of the grain size of the rock units. Recrystallisation of quartz grains is common.

Jaishidanda Belt : It occupies the highest structural level of the Lesser Himalayan belt below the Thimphu Group. The rocks of the Jaishidanda Formation are characterised by quartz+ muscovite+ biotite+ Garnet± chlorite± staurolite±opaque. Within this sequence garnet and biotite are profusely developed. Staurolite is locally observed only under microscope. Coarsening of the grain size is evident in the vicinity of the Shumar-Jaishidanda contact.

Thimphu Belt : It exhibits typical amphibolite grade assemblage viz., Quartz+ K-feldspar+ plagioclase+ biotite± muscovite± staurolite± allumino- silicates± garnet± tourmaline. Accessories include apatite, zircon and opaques. A distinct variation in the mineral assemblages is observed within this group. The tectonically lower unit (Sure Formation) is characterised by the presence of muscovite, biotite, garnet, staurolite, kyanite and occasional sillimanite. Profuse development of garnet and staurolite is observed particularly within the metasedimentary sequence (Naspe Formation) exposed around Naspe. In the upper most unit (Takhtsang Formation) sillimanite (mostly as fibrolite) is more common and muscovite is absent in a few sections (see Chapter 3.9). From a few localities cordierite and spinel are also reported.

Tethyan Belt : The Tethyan rocks rest above the high grade sequence of the Thimphu Group. The basal most Chekha Formation exhibits mineral assemblage of garnet zone. Staurolite reported from this formation, however, could not be substantiated during the present studies. The most interesting feature of the Chekha Formation is the presence of biotite porphyroblasts which are comparatively of larger size than the biotite, muscovite and chlorite grains other wise present in the rock matrix. These porphyroblastic grains are irregularly oriented and invariably cut across the main schistosity. Towards the upper part of the Tethyan sequence the metamorphic grade gradually decreases to a 'very low grade' where individual phyllosilicate minerals are not resolvable under ordinary microscope.

B. Textural relation of crystallisation and deformation

Syntectonic recrystallisation of quartz grains is pronounced within all the litho-packages, except the Siwalik Group. There is a progressive change in quartz microstructures due to deformation under various temperature and strain rate conditions.

In the low strain zones the quartz grains show undulose extinction, sporadic deformation bands, weak elongation and feeble recrystallisation. In the domains of comparatively increased ductile deformation i.e., along the subsidiary thrusts (e.g., within the composite thrust sheets of the Shumar and Baxa packages), as well in the vicinity of the major thrusts (e.g., Shumar, Jaishidanda and Thimphu Thrusts), recrystallisation of quartz grains, particularly within the quartzose unit is pronounced. These zones are mainly characterised by the development of mylonite to protomylonite. In the zones of intense ductile deformation, i.e., along the major thrusts, pronounced recrystallisation is manifested by the presence of blastomylonite. Along the high strain zones, the deformation bands within the quartz grains are parallel to the mylonitic foliation which with increasing spatial distance from the main shear zone become angular. In most of the cases the mylonitic foliation is parallel to the S_1 fabric of the surrounding country rocks and hence, considered to be co-eval with F_1 folds.

Phyllosilicate minerals, mainly represented by muscovite, biotite and chlorite, are commonly aligned parallel to the S_1 foliation. In some sections, from Shumar and overlying sequence, the S_1 plane is microfolded with the development of an axial planar S_2 crenulation cleavage which is locally defined by chlorite and muscovite/sericite flakes. Within the upper part of the Shumar Formation and also in the Jaishidanda Formation and the Thimphu Group, sporadically irregular biotite flakes, exhibit cross-cutting relation with S_1 fabric. Within the Chekha Formation biotite porphyroblasts cut across the S_1 fabric (Fig.5.3.29). Some of these porphyroblasts exhibit-straight inclusion trails, defined mainly by quartz and opaque grains. In some sections the S_2 crenulation wraps around the biotite porphyroblasts (Fig.5.3.30). These evidences indicate that the recrystallisation of the phyllosilicates started in late-tectonic phase with the formation of S_1 fabric and continued thereafter also. Absence of opaques where chlorite is interlayered with biotite indicates prograde crystallisation of chlorite. However, in some samples of garnet, staurolite and kyanite zones, minor chlorite retrograded from garnet (Fig.3.8.1) and biotite is seen.

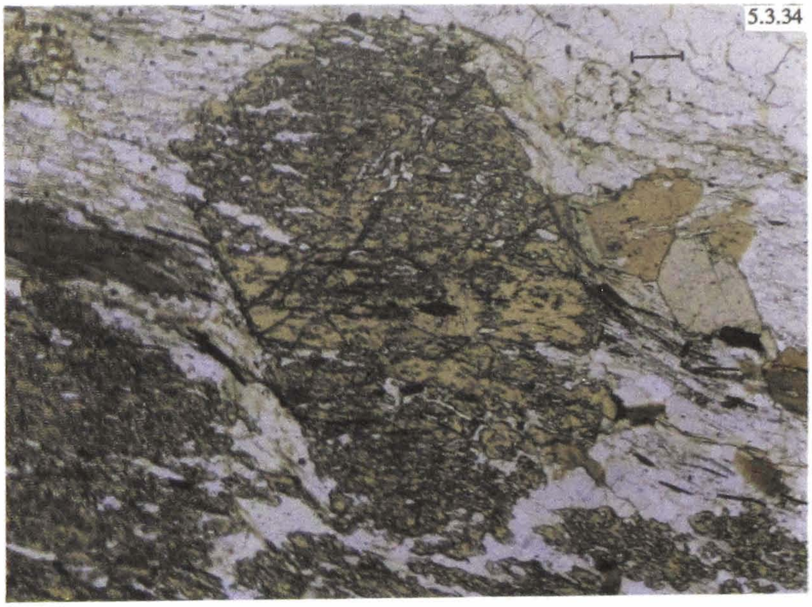


Fig. 5.3.34 Staurolite porphyroblast with inclusion trails which pass imperceptibly within the outer matrix, Naspe Formation. Bar length 0.1mm. (Photo P.R. Golani).

Garnet exhibits (a) inclusion-free euhedral to anhedral grains, (b) inclusion-rich core, surrounded by almost inclusion-free euhedral rims (Fig.3.8.7); some such grains in the core exhibit sigmoidal pattern of inlcusion trails (Fig. 3.8.4), (c) straight inclusion trails, continuous with the outer schistosity and (d) spiral (single and double type) inclusion trails (Fig.5.3.31 & 3.8.5-6). The outer schistosity is generally deflected around the garnet grains with aforementioned inclusion trails. Occasionally asymmetric pressure trails have developed around these grains. The inclusion trail patterns, deflection of outer schistosity (Fig. 5.3.32), and presence of asymmetric pressure trails around the grains suggest that these grains are syntectonic with the S_1 foliation, though at places their growth might have continued even later. These different trail patterns are considered to be result of rotation as well as incorporation of matrix material at different stages of later deformation. Garnet grain with inclusion-rich core (particularly with spiral and sygmoidal trails) and inclusion-free euhedral rims (Fig. 3.8.7) is considered to represent two-stages growth history. In some samples outer schistosity abuts against the inclusion free garnet grains, indicating an unequivocal post-tectonic formation with respect to the S_1 fabric. Within the Naspe Formation garnet grain is almost totally included in staurolite (Fig.5.3.31), pointing towards an earlier formational history of garnet compared to staurolite. From the central crystallines of the adjoining Sikkim-Darjeeling Himalaya Mohan *et al*, (1989) have described kyanite and staurolite as inclusion in garnet. Thus temporally garnet seems to have a protracted history of crystallisation; its crystallisation commenced prior to the formation of staurolite and kyanite and continued even after the formation of these two minerals.

In some of the staurolite grains, the central part is crowded with dusty graphitic material, while the rim is almost clear (Fig.3.9.7). At many places staurolite contains oriented inclusion trails of quartz and opaque, which pass imperceptibly within the surrounding matrix (Fig.5.3.34). Locally the inclusion trails, though continuous with the outer schistosity, form a broad sygmoidal pattern which lie at high angles with respect to S_1 (Fig.3.9.9). Euhedral staurolite grains, cutting across the schistosity are common (Fig.5.3.35). These textural features suggest that development of staurolite is post-tectonic with respect to the S_1 fabric. Some of the grains, however, show angularity between the inclusion trail and the S_1 fabric indicating rotation during later deformation. This observation contradicts the opinion of Swapp and Hollister (1991), who considered staurolite as a pre to synkinematic mineral.

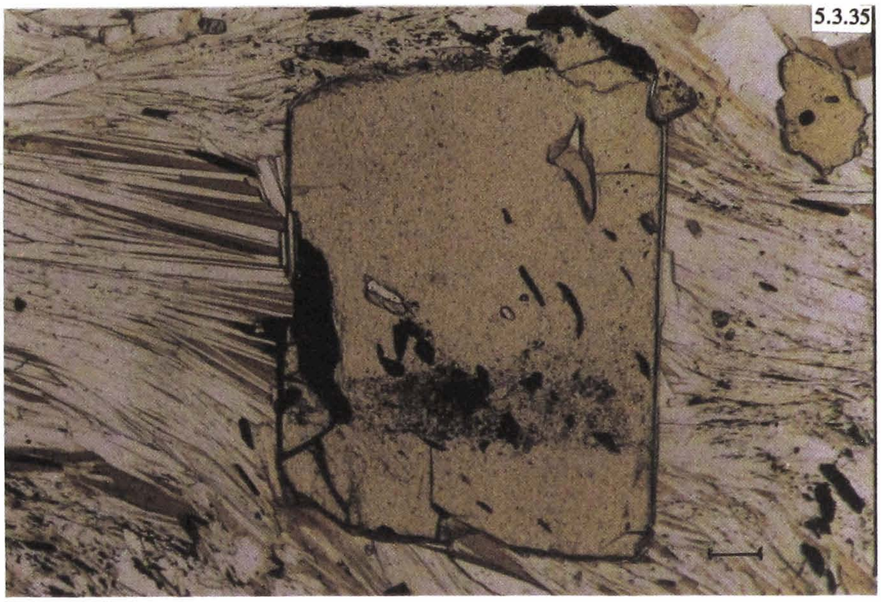


Fig. 5.3.35 Euhedral staurolite grain, cutting across the schistosity, Naspe Formation, Bar length 0.1mm. (Photo P.R. Golani).

Kyanite occurs parallel as well as oblique to the S_1 fabric with little internal deformation. Hence, kyanite is considered post-tectonic with respect to S_1 fabric. Sillimanite occurs as radiating needles but more commonly as fibrolite mat which is irregularly arranged (Fig.3.9.20) and rarely intergrown with biotite and muscovite, forming the S_1 fabric. In one sample fibrolite follows the micro-folded S_1 form. The above evidences suggest a pre-tectonic crystallisation of fibrolite with respect to the formation of the S_2 fabric.

The aforementioned observations suggest that the rocks of the Bhutan Himalaya bear imprints of at least two stages of prograde metamorphism. The garnet and phyllosilicate minerals started crystallising syntectonically with S_1 fabric and continued even during the formation of the S_2 fabric. On the other hand staurolite, kyanite and sillimanite crystallised probably during a static inter-kinematic phase between the development of S_1 and S_2 fabrics. Imprints of polyphase metamorphism from the adjoining parts of the Himalaya have already been recorded by several workers (Sinha-Roy, 1979; Banerjee *et al*, 1983; Mohan *et al*, 1989).

C. Discussion

The present study reveals that the mineral assemblages in the Sure and Naspe Formations indicate lower temperature and higher pressure regime as compared to that of the overlying Takhtsang Formation. This observation is also corroborated by geothermometric and geobarometric data (Swapp and Hollister, 1991) on the samples of the Tibetan slab which is equivalent of the Thimphu Group. However, presence of mineral assemblages, of pre-main pervasive fabric reported by Swapp and Hollister (1991) within the lower structural level rocks of the Thimphu Group could not be unequivocally proved during the present textural studies of the Sure and Naspe Formations.

Several models have been proposed to explain inverted metamorphic zones in the Himalaya. Some of the more discussed models are :

(1) Shear heating along major thrust planes (Arita, 1983; Graham and England, 1976; Ray, 1986).

(2) Over thrusting of exceptionally hot rock over cold rock (Bird, 1978) and hot rock over warm rock (Swapp and Hollister, 1991).

(3) Syn and post-metamorphic folding of isogrades (Frank *et al*, 1977; Harte and Dempster, 1987).

However, none of these models explains all the metamorphic anomalies, observed in a regional perspective.

In the Bhutan Himalaya in the vicinity particularly of the Shumar, Jaishidanda and Thimphu Thrusts, recrystallisation of mineral phases, relatable with the ductile deformation is seen. The thermal effect of shear heating alone, however, could not possibly account for such extensive regional changes in pressure-temperature regime. Several other workers (Inger and Harris, 1992; Mohan *et al*, 1989; Searle and Fryer, 1986), therefore, rightly doubted the applicability of this model to explain the metamorphic anomalies peculiar to the Himalaya.

The model proposed by Bird (1978) also does not explain the metamorphic inversion within the Thimphu Group, hence Swapp and Hollister (1991) conceived the existence of a thrust zone within the Thimphu Group above the Main Central Thrust (≡Thimphu Thrust) which brought `hot rock on the warm rock' rather than `hot rock on the cold rock'. These authors suggested that this thrust which brings higher grade rocks (of the Takhtsang Formation) over comparatively lower grade rocks (of the Sure and Naspe Formations) within the Thimphu Group, may pre-date the last motion of the MCT; both these thrust slabs subsequently were translated together along the MCT on to their present position. The model proposed by Swapp and Hollister (1991) thus accounts only for metamorphic anomalies observed in the Thimphu Group. The metamorphic history of the Bhutan Himalaya in totality remains unexplained.

The model postulating syn-to post-metamorphic bowing of the isogrades seems plausible for explaining the metamorphic anamolies over a major part, except within the Thimphu Group.

Distribution of metamorphic mineral assemblages exhibits a symmetric pattern, with metamorphism gradually decreasing at the higher as well as the lower tectonic levels with respect to the central axial zone of the Thimphu Group. In other words divergent metamorphic zones exist on either side of the axial zone of the Thimphu Group. The regional structural framework clearly depicts presence of south verging mega folds whose fore-limbs are commonly overturned along the Lesser Himalayan belt. Hence, considering the regional framework of the Bhutan Himalaya two stage model seems more plausible. (i) The model of Swapp and Hollister (1991), to explain initial stage of the evolutionary history, (ii) followed by south verging crustal scale folds with southerly overturned fore-limbs, which affected the lithological pile as well as the metamorphic isogrades.

There have been suggestions regarding the existence of pre-Tertiary metamorphic episode in the Himalaya (Mehta, 1976; Acharyya, 1979; Chakraborti, 1988; Bhargava and Bassi, 1994). In the light of the above following observations need critical evaluation :

a) Presence of granitoid components of ca 500 Ma age within the Thimphu Group. Similar ages are widely reported all over the Himalaya from sequences above the MCT.

(b) Between the Chekha Formation of late Precambrian age (Tangri and Pande, this volume) and the Thimphu Group there is a sharp change in metamorphic grade which probably reflects a disconformity between these two, and a pre-Chekha metamorphism of the Thimphu Group rocks.

(c) A shear zone at the base of the Takhtsang Formation exists in a few sections which separates it from the underlying Sure and Naspe Formations (Golani, this volume). Conclusive evidences to interpret it as a major dislocation plane are yet to be deduced. However, occurrences of the Chekha Formation over both the Sure and Takhtsang Formations implies that the latter two formations existed at same altitudinal level even at the time of Chekha deposition implying a pre-Chekha age to the thrust.

(d) Andesitic and (?) rhyolitic flows (Tangri and Pande, this volume) along the contact between the Chekha and the overlying Tethyan sequence (Cambrian and younger rocks) might have influenced the metamorphic history of this terrain during terminal Precambrian time.

Various data on metamorphism presently available preclude definite conclusion regarding the pre-Tertiary metamorphism.

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5.4 GEOLOGICAL HISTORY

O.N. Bhargava

According to the stratigraphic column of the Lesser Himalaya reconstructed in this write-up, the Jaishidanda-Shumar constitute the oldest metasedimentary sequences, below which occurs the basement gneissic complex. The Shumar Formation as discussed earlier is an equivalent of the Rampur-Berinag Groups of the western Himalaya. About 2500 Ma old meta-tholeiites (Bhatt and Forte, 1992) are associated with the Rampur Group which rests over the Jeori-Wangtu Gneissic Complex along a decoupled contact (Bhargava *et al*, 1991). Since the meta-tholeiites are neither associated with the sediments of island arc affinity nor with pelagic oceanic sediments, these were regarded to represent an intra-continental rifting (Bhargava *et al*, 1991). This rifting episode thinned the continental thrust and created a sedimentary basin over a gneissic complex which is considered to be an extension in the Himalaya of the peninsular Archean rocks. The Shumar basin forms the eastern continuation of the Rampur basin. According to the geophysical findings, the western Himalaya, east of Delhi-Hardwar Ridge, acquired denser oceanic crust (Sivaji *et al*, 1992) whereas the eastern Himalaya retained continental characteristics. Such an interpretation is also supported by the distribution of basic volcanics in the Rampur Group and its equivalents. The volcanics are conspicuous in the western Himalaya and nearly absent in the eastern part. In this Lesser Himalayan Rifted Basin (LHRB) were deposited the Rampur-Sundernagar, Berinag, Sanguri and Jaishidanda-Shumar sequences. This basin in Bhutan, as suggested by well sorted and clast-supported conglomerate sporadically developed in the basal part of the Shumar Formation could have been fluvial in initial stages. With the passage of time the basin deepened and became subtidal marine.

Around 2500 Ma rifting in northern Indian peninsula is also known to have occurred in the Archaean terrain of Rajasthan to form the Aravalli basin (Sinha-Roy, 1988) and possibly also in Bihar when the basin for the Singhbhum Group comprising volcano-sedimentary sequence was carved (Saha *et al*, 1988).

The trend of the rocks in Bihar are parallel to the eastern Himalayan ranges whereas the Aravalli ranges are athwart the Himalayan ranges. The Aravalli ranges, if extended further NE below the alluvium (known as Delhi Hardwar Ridge - DHR) shall hit the Himalaya east of Nainital at an obtuse angle (Fig.5.4.1). West and northwest of Nainital the strike of the Himalayan rocks and ranges is NW-SE, whereas east of Nainital it is E-W. The regional disposition of the NW-SE trending western Himalaya, E-W trending eastern Himalaya

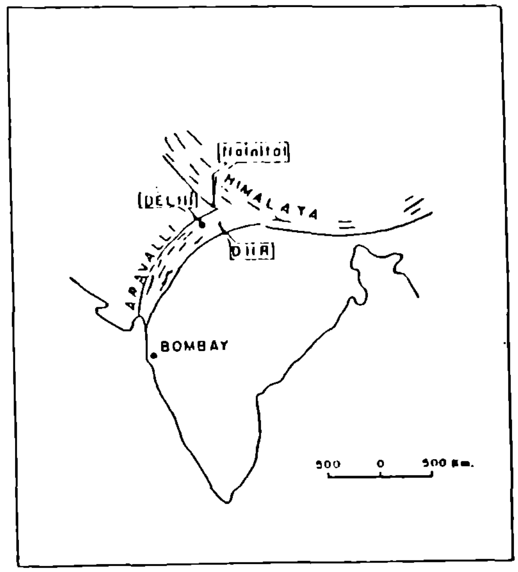

Fig. 5.4.1 The position of the Delhi-Hardwar Ridge (DHR) viz-a-vis eastern and western Himalaya.

and NE trending Aravalli which underwent simultaneous rifting suggests that these segments joined near Nainital and possibly formed a triple rift junction at ca 2500 Ma (Fig.5.4.2A). In this triple rift, the Aravalli part (Sychanthavong and Desai, 1977) and the Himalayan part west of DHR acquired denser crust of oceanic affinity (Shivaji *et al*, 1992), while the Himalayan arm east of DHR retained continental characteristics. These attributes indicate the intensity of rifting suffered by the three arms almost straddling the Archaean-Proterozoic boundary. The Himalayan rift,

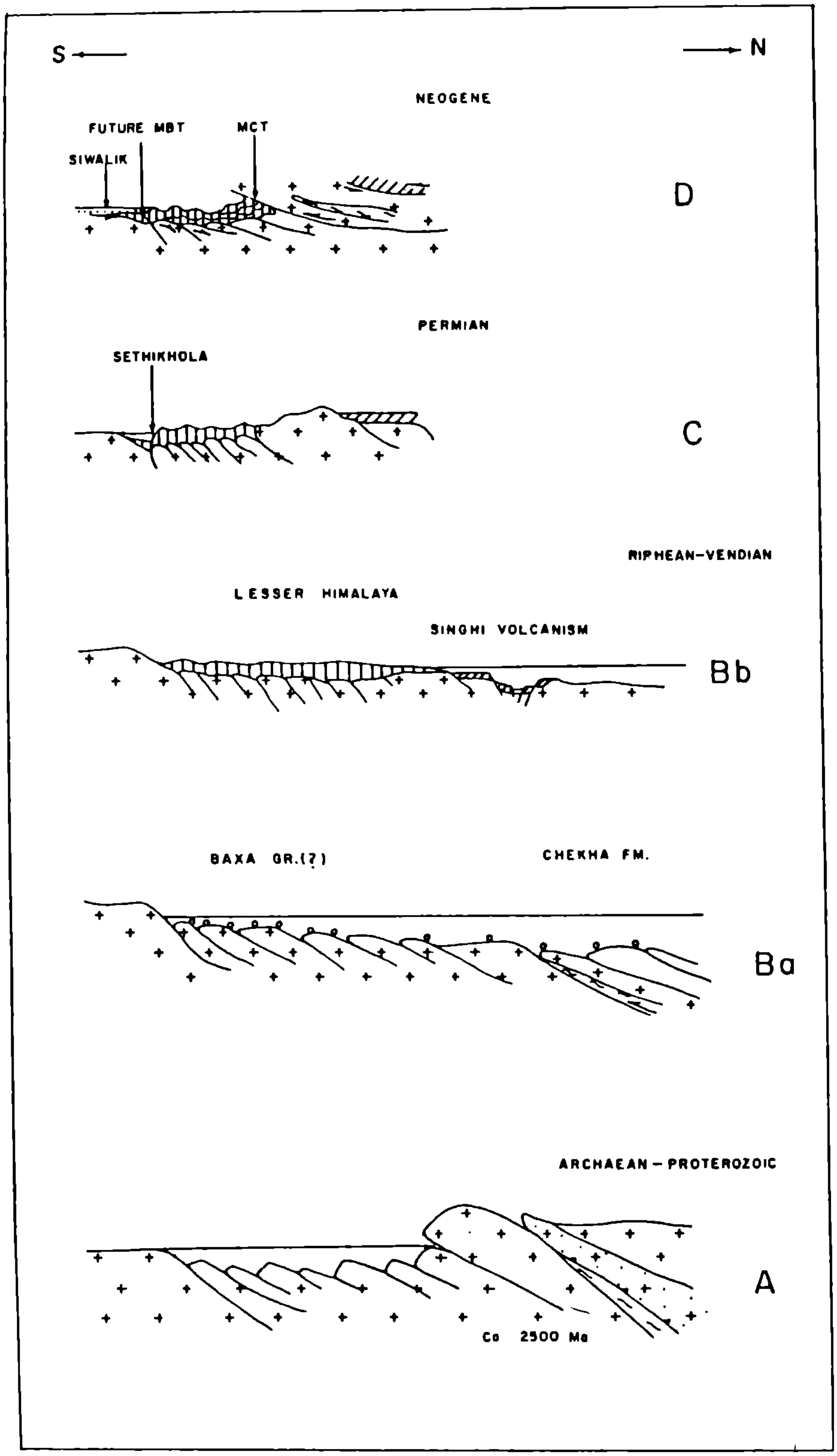

Fig. 5.4.2 Cartoon section to show the evolution of the Bhutan Himalaya. A. Rifted Basin of the Shumar Formation. Ba. Thungsing-Chekha basin. Bb. Renewed rifting leading to Singhi bi-modal volcanism. C. Permian basin bounded by two faults related to rifting. D. Initiation of thrust sheets - MCT possibly along the rift related fault.

thereafter remained more or less aborted, developed a passive margin and finally deformed during Himalayan orogeny.

After the deposition of the Jaishidanda-Shumar sediments, there was a regression of the sea and also perhaps a mild metamorphic event prior to the deposition of the Baxa sequence. The withdrawal of the sea and pre-Baxa metamorphism of the Shumar and equivalent sequences broadly coincide with the deformation of the Aravalli basin which occurred close to ca 1700 Ma (Sinha-Roy, 1988; Sharma, 1988).

Sometimes during the late Lower to Middle Riphean time there was an invasion of a shallow sea in the Himalaya in which the carbonate sequences of the Sirban, Shali, Deoban, Calc-zones of Tejam and Pithoragarh, Nawakot, Baxa and Tenga-Dedza were deposited. This basin in Bhutan was nearer to coast as is evident by the presence of suncracks (Fig.5.4.3), synaeresis mudcracks and stromatolites in the Baxa Group. This period witnessed warm and arid climate leading to the deposition of red quartzite and gypsum as a part of an evaporite sequence. The transgression of the Riphean sea in the Himalaya may be relatable to one of the diachronous rifting episodes of the Delhi basin which has been dated at 1300-1700 Ma on the basis of radiometric age of the metabasites (Volpe and Macdougal, 1990). The basin fluctuated from stable to somewhat unstable when carbonate and gritty-quartzite respectively were formed.

A transgression during Vendian probably extended to the Tethyan part ensuing the deposition of the Chekha sequence in a subtidal environment (Fig. 5.4.2Ba).

Followed by a minor hiatus of unknown time span, there seems to be a shallow rifting represented by the Singhi volcanics, in the late Vendian in the Tethyan part, whereas the Lesser Himalayan part remained passive (Fig. 5.4.2Bb). The Vendian rifting was possibly episodic as suggested by several levels of flows.

The latest Precambrian Singhi bimodal (?) Volcanics interstratified with clastic sequence pass into the Deshichiling Formation comprising fine grained quartzite, phyllite and fine grained limestone, latter being more common towards the stratigraphic top. The lithologic assemblage indicates a subtidal environment of deposition, with a tendency towards deepening in the later part of the basinal history. The Deshichiling Formation shows first sign of visible animal life in the form of *Planolites* (Fig.5.4.3).

In the early Cambrian, during the sedimentation of the Maneting Formation, the basin remained low energy subtidal wherein fine grained arenite, argillite and limestone beds were deposited. In the upper part of the Maneting Formation occurs a volcanic rock in the Black Mountain area. After the sedimentation of the early Cambrian Maneting and middle Cambrian Quartzite Formations, the Tethyan part witnessed withdrawal of sea. The corresponding regression in the western Lesser Himalaya occurred during early Cambrian, when the Tal basin was obliterated. In the Tethyan part of Spiti-Kinnaur, the regression took place during middle Cambrian and in Kashmir during early part of the late Cambrian. A major part of the late Cambrian is absent throughout the Himalaya. The extensive regression ranging from late Vendian to early-late Cambrian coincided with the Pan-African Orogeny. The late Vendian-early Palaeozoic seems to be a major and extensive event during which early Palaeozoic migmatites and granitoids were formed not only in the Himalaya but as far as Kerala. Ordovician, Silurian and a major part of the Devonian seem to be absent in Bhutan.

The Wachi La Formation, transgressing over older formations, signifies a late Devonian transgression. This event could be coeval with deepening of the Muth basin in its terminal phase (Bhargava and Bassi, 1995) which also resulted in inundation of Precambrian terrain by the Lipak sea in Phipuk area (Bhargava and Bassi, 1995) in the Spiti valley.

The fine grained quartzite with shale (now metamorphosed to phyllite) of the Wachi La Formation were laid in intertidal to subtidal environment. The same environment, with slight deepening continued during the sedimentation of the fine grained carbonates of the Ripakha Formation of early Carboniferous age. Subtidal seems to be the environment of deposition for the bryozoa and brachiopod bearing shale horizon occurring at the base of the Shodug Formation. In a strong regressive phase the basin shallowed, possibly accompanied by sharp uplift of the provenance. In this basin, accumulated the ill-sorted and matrix-rich diamictites of the Shodug Formation in late Carboniferous.

In the Lingshi area, the Barishong Formation, which perhaps represents a mix-up of more than one formation shows palaeoenvironment varying from intertidal to subtidal with doubtful lagoonal conditions. The sea withdrew from Lingshi and Black Mountain areas at the termination of the deposition of the Shodug and Barishong Formations respectively.

Fig. 5.4.3 Suncracks in the Jainti Formation, Loc. Seti *khola* (Photo Ashutosh Joshi).

Though Singh (1967), reported Permian horizon from the Tethyan part of Bhutan, no Permian fossils could be located during

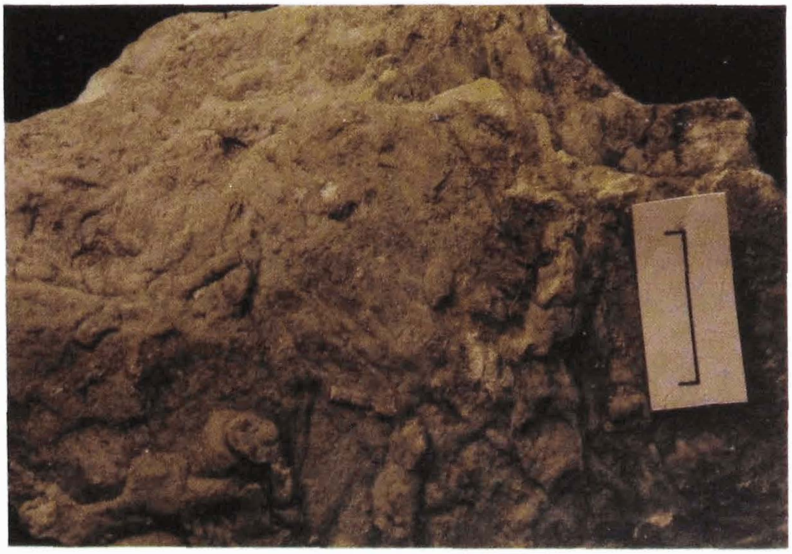

Fig. 5.4.4 *Planolites*, Deshichling Formation. Loc.

subsequent search. Since fossils (mainly *Fenestella* sp.) collected by Singh (1967), are not available for a re-examination, the Permian in the Tethyan part of Bhutan remains a suspect or, if developed, it must be in the form of small outcrops. However, definite early Permian marine sequence is known from the Lesser Himalaya of Bhutan. Marine Permian is also known from Arunachal, Sikkim, Darjeeling, Nepal and Garhwal. In all these areas, like Bhutan, the Permian is confined to the foot-hill region. Obviously there existed some major lineament in this region which opened during Permian to provide a seaway. Possibly, it could be due to reactivation of one of the faults defining the southern limit of the LHRB, originally formed ca 2500 Ma age (Fig. 5.4.2C). As the Permian facies of the Lesser Himalaya are more akin to those of the Peninsular sequences, a prolongation of the Narmada-Son sea which extended upto Brahmputra (Sen, 1991) is envisioned in the foot hill region of the Himalaya (Fig.5.4.5).

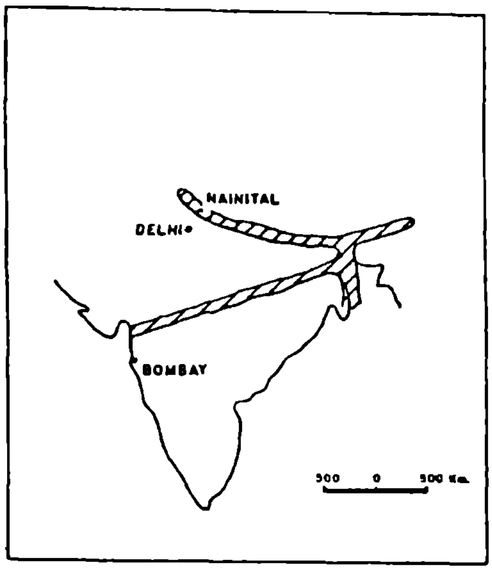

Fig. 5.4.5 Possible pattern of Permian sea in Peninsula and the Lesser Himalaya.

In the Bhutan Tethyan Himalaya there do not seem to be any definite evidences for Artkinsinian and/or Dzulfian transgressions which are well documented in the Spiti (Bhargava and Bassi, 1995). Fragmentary evidences exist for Triassic sequence in the Lingshi sector of Bhutan. The Triassic transgression in Bhutan possibly coincided with deepening and transgression recorded in the Spiti (Bhargava, 1987) at the base of the Mikin Formation (early Triassic).

The Barishong and Shodug Formations are succeeded unconformably by the Lingshi Formation of the Triassic(?)-Jurassic-early Cretaceous age. No definite lower age limit of the Lingshi Formation is known. However, taking cue from the regional set-up in the western Himalaya, the Lingshi basin possibly formed during early Triassic. The Lingshi basin during late Jurassic seems to be near-coast marine with local barred lagoonal conditions in which well preserved plant fragments came drifting from the adjacent land and cephalopods were tossed from the sea side during high tides/storms. The formation of the Barsong limestone in the Lesser Himalaya was also possibly related to this transgression. The Lingshi basin terminated in early Cretaceous. A major part of Cretaceous thus is absent in the Bhutan Himalaya.

Evidence of Eocene in Bhutan is only in the form of a limestone boulder containing *Nummulites* (Acharyya, 1994). The *in situ* outcrop of the Eocene has so far eluded the search. The Nummulitics in Bhutan may form a discontinuous narrow belt in the foot-hill region possibly between the Siwalik and the Setikhola sediments. The Paleocene-Eocene sea, like the Permian sea, invaded the foot-hill regions of the Himalaya, along an opening provided by some major lineaments. Perhaps these faults delimiting the LHRB in the south, were once again reactivated during Paleocene-Eocene time.

The deformation of the Tethyan and Lesser Himalayan sequences commenced with subduction of the Indian Plate, during late Cretaceous/Paleocene. After the collision, when the Indian Plate got locked due to buoyancy, other lineaments were activated along which the crystalline thrust sheets were translated towards the foreland. After the locking of the Indian plate along the Indus Suture, due to continued northward drift the next weak plane existing to the south of the Indus Suture got activated to form the MCT. Subsequently, the tectonic activity migrated to further south and along next weaker plane, the Jaishidanda Thrust Sheet was emplaced. As the granite gneiss of the Thimphu Group (Sure Formation) and those occurring within the Jaishidanda Formation as tectonic slivers have isochemical and isochronous attributes, it is suggested that during its propogation, the Jaishidanda Thrust Sheet incorporated tectonic slices from the overlying Sure granite gneiss. All the crystalline thrust sheets, throughout the Himalaya have their root zones north of the Lesser Himalayan sequences, i.e., the thrust at their bases seem to delimit the Lesser Himalayan basin in north/northeast. It is likely that faults binding the northern limit of the LHRB were reactivated during the Himalayan Orogeny along which the crystalline thrust sheets were propagated (Fig. 5.4.2D).

Collision and subduction, led to moderate rise of the Himalaya from which originated the southerly flowing streams mainly along structural grains. Initially the relief was low and streams lacked the present day turbulence as revealed by the fine grained sediments of the Lower Siwalik which were probably deposited in a shallow marginal sea (Basu *et al*, 1993). As the relief of the Himalaya increased due to rise and forward translation of thrust sheets accompanied by their unroofing, the rivers became more and more turbulent and carried coarser clastics, now preserved in fluvial middle and upper parts of the Siwalik Group. The sediments in the Middle and Upper Siwalik also include fluvially modified fan deposits and lacustrine beds formed due to ponding of palaeo-rivers. The Diklai Conglomerate represents post-Siwalik sedimentation. The last phases of deformation took place after the thrust sheets were emplaced as is evident from the extension of fold axes from the window rocks to the tectonic cover. As the last two phases of fold are clearly decipherable in the Siwalik Group, the deformation of the rocks seems to be post-Siwalik. As at many places, the folds in the Siwalik sediments truncate against the Main Boundary Thrust, the MBT is regarded to be either post-last fold or syn-last fold. The MBT traceable all along the Himalaya, seems to represent a reactivated old mega-lineament. Possibly, it was one of the faults delimiting the southern boundary of the LHRB which has been active from time to time throughout the geological history.

With the acquisition of height, the glaciers came to occupy the higher reaches and filled the then existing river valleys. As the glaciers descended to lower and warmer altitudes, they melted and from their snout emerged turbulent streams. The change in valley profile from U-shaped in upstream to V-shaped in down stream marks the lower limit of the Quaternary glaciation which is around 3000m msl in Bhutan.

As the climate warmed, the glaciers receded and their valleys were remodeled by the fluvial agencies. The change from U-shaped valley in higher reaches to V-shaped in lower reaches in the same profile reflects uplift and erosion of the Himalaya since last glaciation.

The last major tectonic movement seems to have taken place in the Holocene during which the Quaternary terraces at Khasadrapchu, Chalsa, Hathisar were folded/tilted. The neotectonics also brought about fluvial changes (e.g., raised abandoned channel near Samtse) and development of fault scarp all through the foot-hills. The tectonic plane between the alluvium and the older rocks has been termed as the Main Frontal Thrust (MFT).

The synthesis of the geology of Bhutan reveals following salient points.

1. The thickness of sediments in Bhutan Himalaya, as compared to their equivalents in the western Himalaya is much less. Though some reduction in thickness could be attributed to tectonic telescoping, much of it seems to be a depositional feature.

2. The crystalline thrust sheets in Bhutan are far more advanced towards the peninsula as compared to the western Himalaya.

3. The Lesser Himalayan belts in Bhutan are highly tectonised and telescoped.

4. Evidences of neotectonics in Bhutan are numerous and more spectacular.

Lesser thickness of sediments in the Bhutan Himalaya, as compared to the western Himalaya possibly indicates that the eastern Himalayan basin which had continental crustal characterisitcs (Shivaji *et al*, 1992) formed shallower part of the Himalayan basin in which limited sedimentation took place.

Perhaps due to lesser thickness accumulated, the Lesser Himalaya in Bhutan formed a depressed terrain of gentle relief, which greatly facilitated the southward advancement of the crystalline thrust sheets.

The peninsular shield of Assam is parallel and is in close proximity to the Bhutan Himalayan front. The Lesser Himalayan rocks seem to have been caught up in between the advancing crystalline thrust sheet and the rigid Assam shield in a vice-like grip and were squeezed to form fine thin skinned tectonic scales (Fig. 5.4.6).

The 1300-1000 Ma granitoids, not only in Bhutan, but all over the Himalaya (see Table 4.8) show conspicuously high initial Sr ratio. It may be worthwhile to undertake a project to find the cause of such a high initial Sr ratio in Middle Riphean granitoids of the Himalaya.

According to the tectonic evolutionary model suggested in the present write-up, following mineralisations can be expected in the Bhutan Himalaya.

1. Copper in the basement and also sediments of the Jaishidanda, Shumar and Maneting Formations (Zambian model).
2. Placer gold and uranium in the grit and conglomerate of the Jaishidanda and Shumar Formations and Baxa Group (Witwatersrand model) and also in the Siwalik Group. Gold in ironstones and BIF belonging to different Formations.
3. Lead-zinc-silver in the carbonates of the Jaishidanda and Shumar Formations and Baxa Group (Bleiberg model).

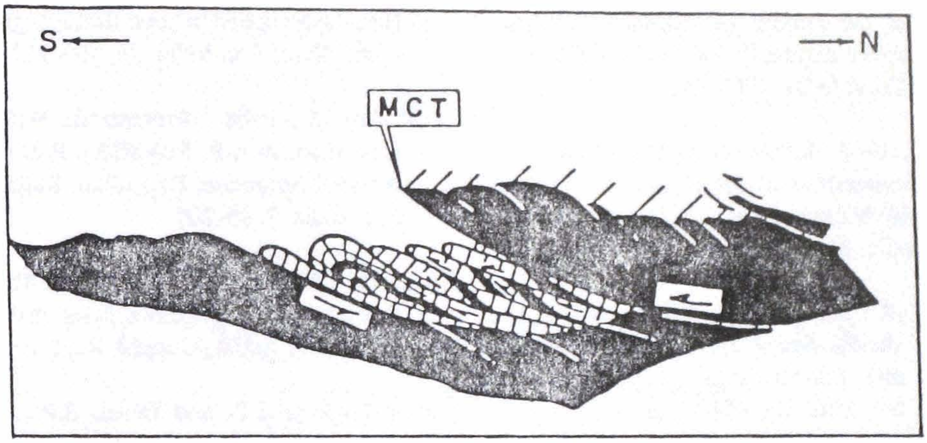

Fig.5.4.6 Cartoon to show tectonics of the Lesser Himalayan sequences controlled by Peninsular Shield and the Thimphu Thrust Sheet.

4. Phosphorite with stromatolitic carbonates of the Baxa Group and in comparatively deeper facies (subtidal) of the Setikhola Formation.
5. Evaporites in the Baxa Group.
6. Coal in shallower (lagoonal-deltaic) parts of the Setikhola Formation.
7. Tungsten in the skarnoids and tin and molybdenum in the vicinity of Palaeozoic and Tertiary leucogranites in the Thimphu Group, Jaishidanda and Chekha Formations.

Several such mineralisations and extensive limestone and low silica dolomite deposits have already been recorded in Bhutan (see chapter 6). The severe Himalayan Orogeny however, seems to have sheared many of these deposits rendering them small and discrete prospects.

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6. MINERAL RESOURCES - A COMPILATION

6. MINERAL RESOURCES - A COMPILATION

S.A. Chore

As compared to other sectors of the Himalaya, the Bhutan Himalaya seems to be better endowed with mineral resources. Besides the bedded deposits of limestone, dolomite, marble, gypsum, ferro-silicon grade quartzite, coal and slate, also occur deposits of copper, lead-zinc, tungsten, graphite and talc (Fig.6.1). At present only limestone (cement and chemical grade), dolomite, gypsum, quartzite, coal, marble and slate are being mined. With the improvement in communications and metallurgical process, the Gongkhola copper, Genekha lead-zinc, Chilaila graphite and Bhurkhola-Dholpani tungsten deposits may also become workable. Certain concept based investigations are under progress which may yield to new discoveries.

6.1. NON-FERROUS METALS

6.1.1 COPPER

6.1.1A GONGKHOLA AREA : The most important copper deposit located in the Gongkhola area, Tongsa district of central Bhutan was discovered by the Geological Survey of India (GSI) in 1976. The deposit is located at an aerial distance of about 40km from Geylegphug between altitude varying from 1700m to 2480m above msl. The area has to be approached by road upto Sure, beyond which a distance of 65km has to be trekked.

Copper mineralisation in the Gongkhola area, confined within the Tethyan rocks of the Black Mountain area, is in the form of chalcopyrite. The mineralisation occurs within the crystalline manganosiderite rock and quartzite belonging to the Maneting Formation. Mineralisation also occurs within the footwall quartzite associated with quartz-carbonate veins. There are two lodes viz., Lode-I and Lode-II. The Lode-I is in the manganosiderite band while the Lode-II is associated with thin quartz-carbonate veins within the footwall quartzite. These lodes are in the form of a network of veinlets and stringers, irregular fractures and breccia fillings and disseminations of chalcopyrite, pyrrhotite, pyrite and minor chalcocite. While chalcopyrite is the dominant ore mineral, in a few places, pyrrhotite dominates.

The Gongkhola copper prospect, for exploration work, was divided into four blocks, viz., the Western, Central, Eastern and Nobji *Chu* Blocks. The strike lengths of the mineralised zones in these blocks are 800m, 500m, 2100m and 200m respectively. The results of exploration by drilling in the Nobji Chu and Western Blocks were not encouraging. In the Central Block, the strike length of ore zone is 450m and lode width ranges from 0.5m to 5.08m. In the Eastern Block, the ore zone extends for a strike length of 1850m and its width ranges from one metre to 5.9m (rarely upto 12.29m). A few composite borehole samples from Eastern Block were analysed for gold. The gold value ranges from 0.20 ppm to 1.20 ppm. In the Central Block, borehole sample analysis shows high arsenic values of 1000 ppm to 2.67%.

The estimated copper ore reserves at cut-off grade of 1.0% are given in Table 6.1.1.

Table 6.1.1 : Reserves of copper ore in Gongkhola Eastern and Central Blocks

Block	Strike length of the lode (m)	Reserve (in million tonnes)	Grade of Cu (%)	Category of Reserves
Eastern	1850	1.8944	1.52	Probable (upto a depth of 120m; one metre stopping width)
Central	450	0.3493	1.50	Probable (upto a depth of 120m; one metre stopping width)

6.1.1B Other Occurrences : Copper mineralisation is also reported in the Shumar Formation from several places in Samtse, Sarpang and Tashigang districts. Detailed exploration by drilling was carried out in Bungthing area of

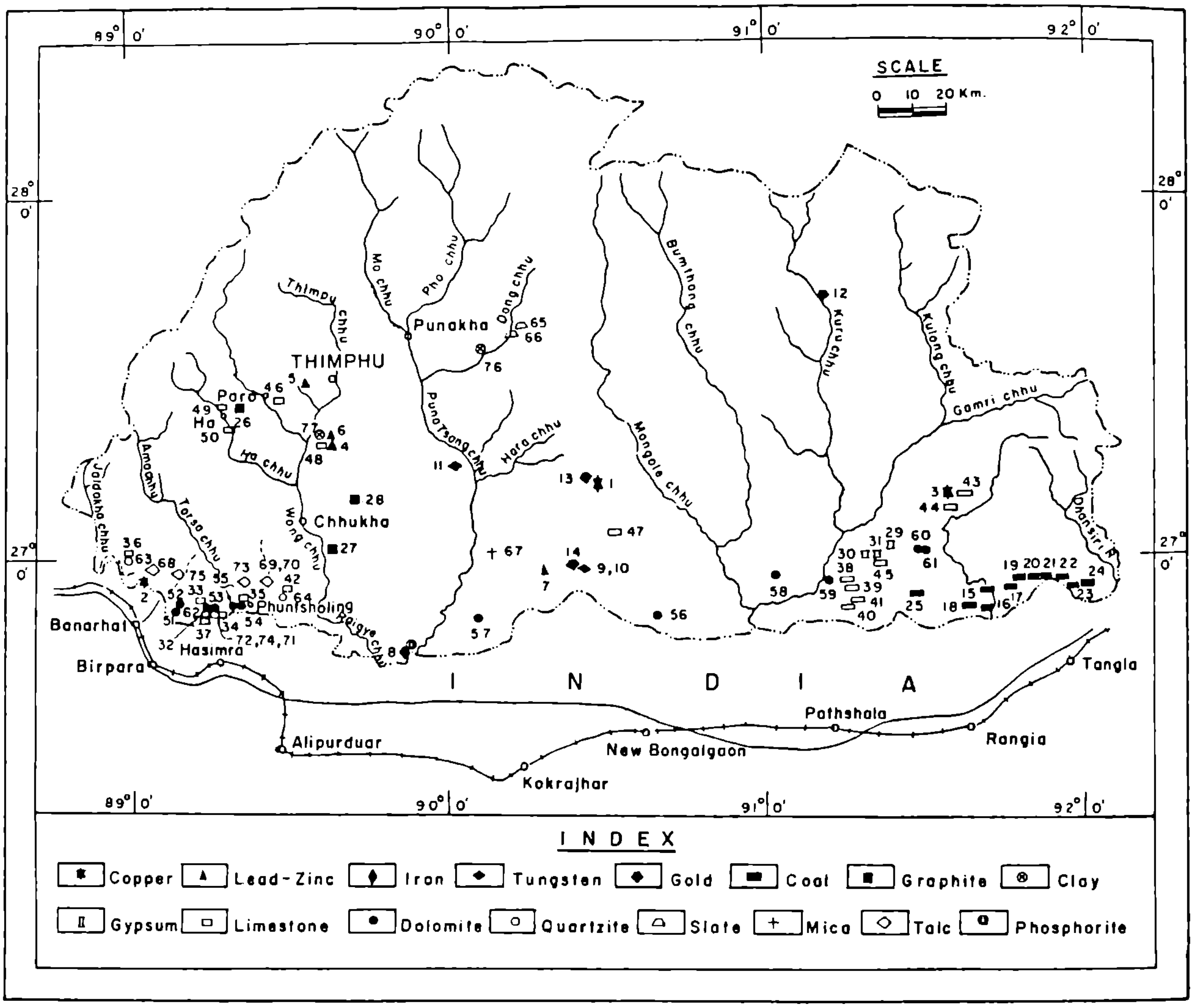


Fig. 6.1 Map showing mineral occurrences in Bhutan. Explanation of locations. 1. Gongkhola, 2. Bungthing, 3. Gomchu, 4. Genekha, 5. Jemena, 6. Chakula, 7. Ratepani, 8. Maure, 9. Dholpani, 10. Bhurkhola, 11. Pinsha, 12. Kuruchu, 13. Gongkhola, 14. Dholpani-Bhurkhola, 15. Jagartala, 16. Bhangtar, 17. Diglai Nadi, 18. Gerua-Dimala Khola, 19. Chamrang Nadi, 20. Kalapani Nadi, 21. Nunai Nadi, 22. Bhorila-Rash Ri, 23. Nagarkhola, 24. Khaurang-Leshing Ri, 25. Deothang, 26. Khepchishi Hill, 27. Donga, 28. Dapchasa-Dorjomsa, 29. Kothakpa, 30. Khar, 31. Uri Chu, 32. Pagli-Titi, 33. Khanabharti, 34. Haureekhola, 35. Kalesore, 36. Tintali, 37. Kalapani, 38. Marung Ri (Nganglam), 39. Kurung Ri (Nganglam), 40. Gachhari (Nganglam), 41. Kangrizhe (Nganglam), 42. Mirchang-Badena, 43. Rashong (Khaling), 44. Tokaphung, 45. Tshebar, 46. Khanku, 47. Rong Ri, 48. Genekha, 49. Haa-Wangcha, 50. Chilungkha, 51. Samtse-Rehti-Sarkitar, 52. Uttare, 53. Khanabharti-Pagli, 54. Titring-Kalesore, 55. Kalesore, 56. Kakulang, 57. Dhanese, 58. Manas, 59. Dechhiling, 60. Narphung, 61. Khandame, 62. Suktikhola, 63. Tintali, 64. Pedzekha Chu (Pasakha), 65. Bhel, 66. Kobja, 67. Chirang, 68. Pachu-Setikhola, 69. Khempa, 70. Thunuwa, 71. Pagli-Sarkitr, 72. Molabanse, 73. Lapchekha, 74. Suktikhola, 75. Budheni-Tin Doban, 76. Khelkha, 77. Wang Paon, 78. Maure-Kalikhola.

Samtse district and Gomchu area of Tashigang district. The mineralisation in both these areas, however, is uneconomic. Other minor occurrences of copper are known from Chunpatang, Athais *Khola* and Sundari *Khola* in Samtse district and Munga *Khola* and Tir *Khola* areas in Sarpang district.

6.1.2 LEAD-ZINC

6.1.2.A Genekha : An important lead-zinc deposit was discovered by the GSI in 1965 in the Romegang *Ri*, Chakula, Tashisekha in Genekha area of Thimphu district (Fig. 6.2). These deposits are situated at altitudes varying between 3000m and 3700m above msl and are approachable by a 20km mule cum foot track (previously a jeepable road, now in disuse) originating from Sisina, which is located at 145km stone along the Phuntsholing-Thimphu Highway.

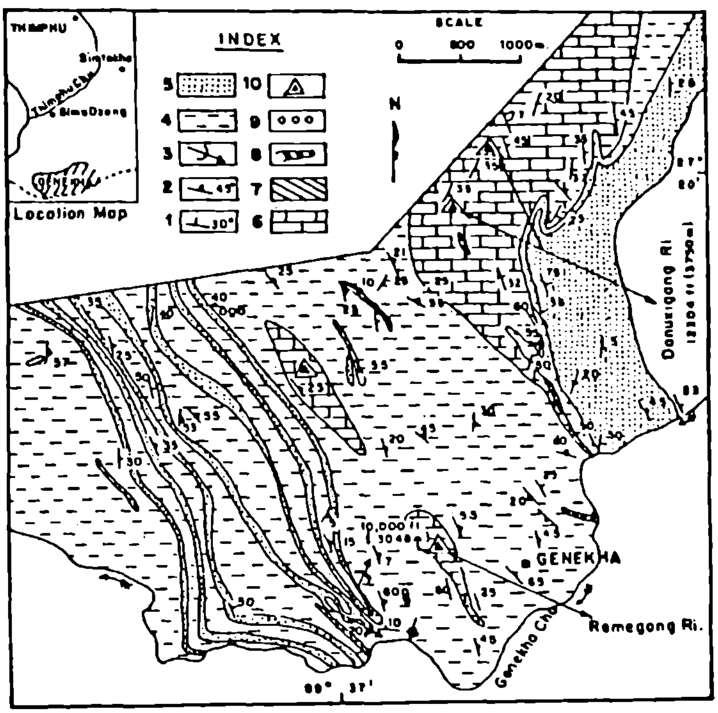


Fig. 6.2 Geological map showing location of lead-zinc mineralisation, Genekha area, Thimphu district (after Sengupta, 1972). 1. Dip and strike of bedding, 2. Dip and strike of foliation, 3. Minor fold axis, 4. Mica schist, 5. Quartzite, 6. Marble, 7. Calc-silicate, 8. Graphite schist, 9. Quartz vein, 10. Lead-zinc mineralisation.

The lead-zinc mineralisation in Genekha area occurs in the marble of the Jaishidanda Formation as thin concordant, tabular to lenticular and 'pod' like bodies, as disseminations, stringers and fracture fillings. The principal ore minerals are hemimorphite, zincite, galena, sphalerite, smithsonite and cerrussite. Subordinate amounts of pyrite, pyrrhotite, magnetite, chalcopyrite, franklinite, tetradymite, covellite and chalcocite are also present. The gangue minerals are calcite, dolomite, quartz, tremolite, barytes and mica. The mineralised zones are parallel to sub-parallel to the bedding plane of the host marble which is folded into a doubly plunging synform. The lead-zinc ore zones have been oxidised to varying degrees, both at surface and at depth.

Chakula deposit comprises eight ore zones which extend over a strike length of about 1100m. This deposit was explored in detail as a result in the Romegang *Ri* block, 11 lodes were demarcated in the top 100m to 130m thickness of marble. The width of the parting between the two adjacent lodes varies from five metres to 15m, out of these 11 lodes, only five have economic significance and occur within a depth range of 50m to 75m from surface with a strike length of 750m. Among all, the ore shoot in lode No.5 shows both strike and depth persistence with maximum width and grade.

The Mineral Exploration Corporation Ltd. conducted exploratory mining of the Chakula and Romegang *Ri* deposits by developing 366m of mine along two adits. 750m^3 material was mined from the exploratory mine and from 15 surface trenches. Two bulk samples of 100kg each of Romegang *Ri* ore were sent to the Hindustan Zinc Ltd. for bench scale studies. As per beneficiation tests, the extraction of metals from the oxidised lead-zinc ore of Genekha requires special metallurgical techniques. The reserves of Pb-Zn in Chakula and Romegang *Ri* are furnished in table 6.1.2.

6.1.2B Jemena Occurrence : The lead and zinc mineralisation in Jemena area of the Thimphu district was also explored in detail. In this area the lead-zinc mineralisation occurs in coarse grained limestone of the Jaishidanda Formation. The ore minerals are partially to completely oxidised at the surface as well as upto a depth of 10m. Based on the available exploration data, the Pb+Zn mineralisation in Jemena area appears to be of limited potential, though further work is required to assess its economic significance.

Table 6.1.2 : Pb+Zn Reserves in Chakula and Romegang *Ri* deposits

Area	Reserve (in million tonnes)	Average Grade			Category of Reserves
		Pb%	Zn%	Pb+Zn%	
Chakula deposit	3.116	1.03	6.33	7.36	Proved
Romegang *Ri* deposit	0.514	3.74	4.46	8.20	Probable
Total Reserves	**3.630**	**1.41**	**6.06**	**7.48**	

6.1.2.C Ratepani Occurrence : In Ratepani-Gombadara area of Sarpang district, primary lead and zinc sulphide mineralisation along with patchy occurrences of gossan have been found within highly brecciated and mylonitised dolomite of the Baxa Group. Primary sulphides i.e., galena and sphalerite occur as veins, stringers, disseminations and fracture fillings within the brecciated dark grey dolomite. Detailed investigation by drilling in Ratepani area is in progress to assess the potentiality of lead and zinc mineralisation.

6.2. FERROUS METALS

6.2.1 IRON

6.2.1.A Iron ore occurrences are rare in the Bhutan Himalaya. Small reserves of low grade iron ore are known near Maure along the left bank of the Sankosh river in Sarpang district (erstwhile Geylegphug district). Laminated iron ore bands were earlier mapped as a part of the Siwalik Group which now has been interpreted to be a part of the Setikhola Formation tectonically involved with the Siwalik Rocks. The iron ore bodies are bedded, hard, compact and massive. Iron content of the ore varies from 25% to 46% Fe. The inferred reserves of the two small ore bodies (East and Central Blocks) upto 50m depth is about 2.97 million tonnes. This low grade iron ore, if beneficiated, can be utilised locally for small scale industries.

6.2.2 TUNGSTEN

6.2.2.A Dholpani-Bhurkhola : Tungsten mineralisation in the Dholpani area in Sarpang district (erstwhile Geylegphug district) was discovered by the GSI in 1976. Subsequent field work in this district led to discovery of another occurrence of mineralised skarns in the Bhurkhola area.

Tungsten mineralisation in the Dholpani and Bhurkhola areas is in the form of disseminations of scheelite in calc-silicate (skarnoid) rocks (Fig.6.3). The skarnoid rock occurs as bands within the gneiss of the Jaishidanda Formation in proximity to the Thimphu Thrust (Main Central Thrust). In the Dholpani area, the mineralised rock is developed at the contact of marble with a tourmaline bearing granite.

Table 6.2.1 : Tungsten ore reserves in Dholpani and Bhurkhola areas.

Area	Strike length of mineralised skarn rock	Width of mineralisation (m)	Cut-off grade % WO_3	Reserve (million tonnes)	Grade % WO_3	Category	Remarks
Dholpani	430m	6.0m to 8.0m	i) 0.12 ii) 0.15 iii) 0.20	0.349 0.335 0.288	0.25	Probable under one metre stoping width	Reserves upto 75m depth
Bhurkhola (West)	570m	2.0m to 50.0m	0.20	3.00	0.22	Probable under one metre stoping width	Reserves upto 90m depth from surface.
Bhurkhola (East)	250m		0.20	0.29	0.26	Probable under one metre stoping width	Reserves upto 90m depth from surface.

Beneficiation test by the Indian Bureau of Mines, on a tungsten ore sample from the Dholpani area yielded three concentrates viz., (i) a high grade scheelite concentrate assaying 67.09% WO_3 suitable for use in tungsten carbide (ii) a low grade scheelite concentrate assaying 35.86% WO_3 suitable for the manufacture of ammonium para tungstate and (iii) a copper concentrate assaying 21.09% Cu suitable for copper smelting after blending with copper concentrate of low zinc content.

Estimated tungsten ore reserves of Dholpani and Bhurkhola areas are summarised in Table 6.2.1.

In Gurungkhola block of Bhurkhola area, gold mineralisation is also known.

6.2.2.B Pinsha-Pho *Chu* and Other Occurrences : Disseminations of scheelite are present in the calc-silicate rocks which occur as bands within the gneiss of the Thimphu Group and in the metasedimentary rocks tectonically underlying the Thimphu Group, in the Pho *Chu*, the Jarang *Chu* and the Chang *Chu* valleys in Punakha and Wangdiphodrang districts. The boulders of calc-silicate rocks occurring in the terrace sediments and the recent sediments of the Pho *Chu* river also show notable concentration of scheelite.

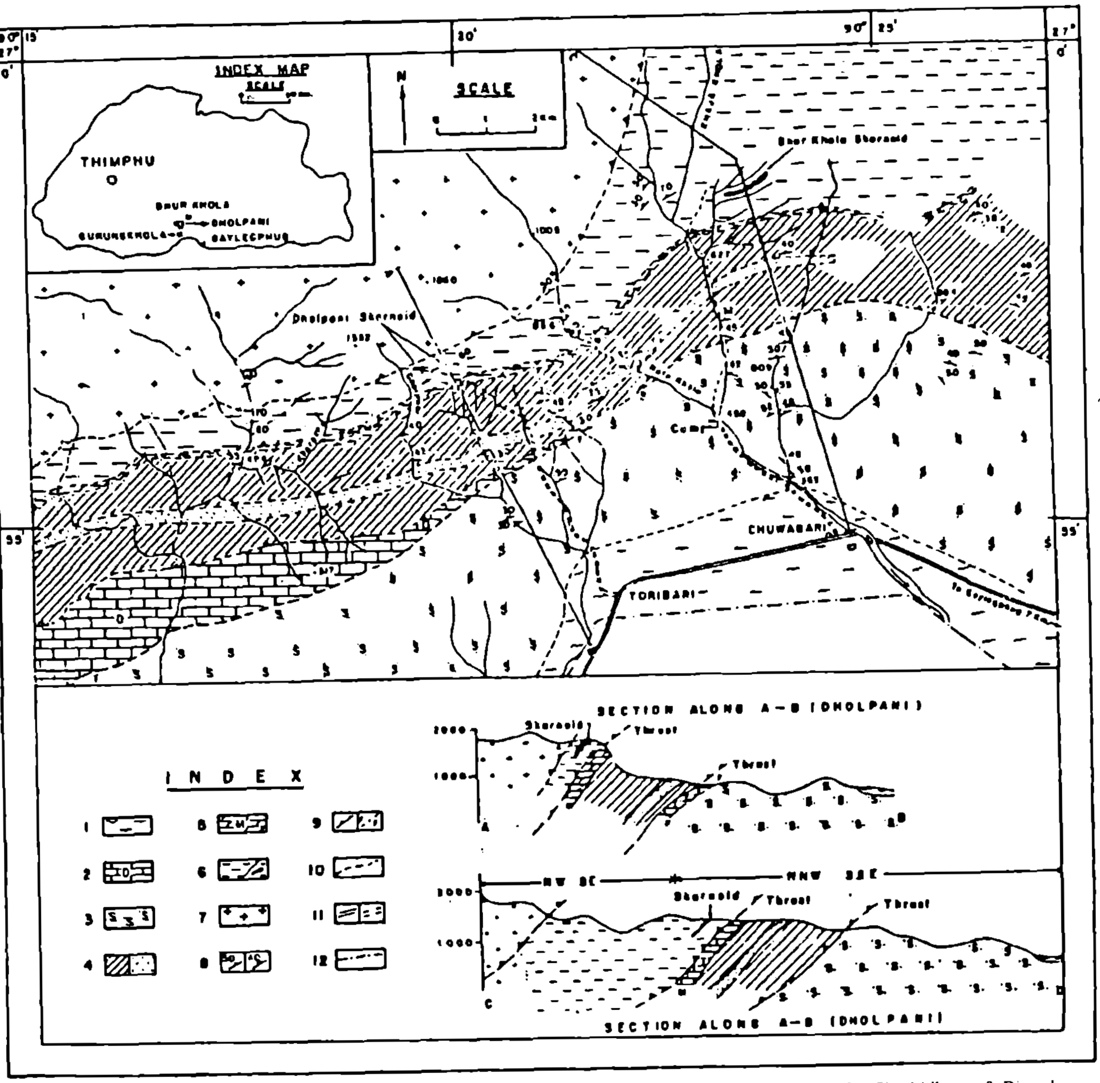


Fig. 6.3 Geological map showing tungsten mineralisation, Dholpani-Bhurkhola area, Sarpang district (after Shashidharan & Biswal, 1991).1. Alluvium/colluvium/talus, 2. Dark grey dolomite, (Manas Formation), 3. Variegated phyllite with quartzite (Phuntsholing Formation),4. Interbedded green phyllite and quartzite, 5. Marble (4-5 Shumar Formation), 6. Garnet-mica schist, gneissic bands, skarnoids with scheelite mineralisation (Jaishidanda Formation), 7. Granite gneiss (Sure Formation), 8. Strike and dip of bedding/foliation, 9. Thrust/fault, 10. Lithocontact, 11. Asphalt and unmetalled road, 12. Indo-Bhutan boundary.

In the Pinsha area (Wangdiphodrang district) scheelite mineralisation occurs in calc-silicate rocks of the Chekha Formation which forms the basal most part of the Tethyan sequence in Central Bhutan. Detailed investigation is in progress in this area to assess the potential of tungsten mineralisation.

6.3. PRECIOUS METALS

6.3.1 GOLD

A preliminary search for gold was carried out in a few selected areas. The results of these investigations are erratic and inconclusive.

6.3.1.A Gongkhola : A few composite borehole samples from Gongkhola copper prospect were analysed for gold which revealed a gold content of 0.20 ppm to 1.20 ppm in the Eastern Block while in the Central Block, high arsenic values of 1000 ppm to 2.67% have been reported.

6.3.1B Dholpani-Bhurkhola: In the Gurung *Khola* Block of the Bhurkhola area, gold mineralisation is associated with pyrite and chalcopyrite in the carbonaceous phyllite. Preliminary surface studies and 37 channel samples analysed 0.10 to 3.99 ppm Au by AAS.

6.3.1.C Kuru *Chu* : In fluvial sand and gravel deposits of the Kuru *Chu* in the Monji area of Lhuntsi district, widespread distribution of fine and flaky gold is reported. The gold values range from 0.001 to 0.25 g per1524 kg of sand.

6.4 NON-METALLIC MINERALS

6.4.1 COAL

6.4.1.A Bhangtar : Occurrences of coal along a 65km long belt in the foot-hills of Samdrup Jongkhar district in eastern Bhutan were discovered by the GSI in 1964, between the Deo *Nadi* in the west and the Leshang *Ri* in the east. These deposits are approachable by fair weather roads and foot-tracks.

Coal occurs as thin seams within the sandstone and shale mapped as the Damuda Subgroup. The thickness of most of the coal seams is less than two metres and the strike extent is less than 100m. Sporadically the seams measure upto five metres and extend more than 500m. The coal is highly crushed, sheared and tectonised, hence always occurs in a powdery or flaky form. The coal seams are commonly admixed with boudins of sandstone and shale. Lumpy coal is rare. The coal seams are traversed along and across by closely spaced faults and shear planes, resulting in frequent change in the trend of the seams.

The details of the coal seams of various areas and there reserves are presented in Table 6.4.1.

6.4.2 GRAPHITE

6.4.2.A Khepchishi Hill : The main occurrence of graphite in the Khepchishi hill of the Chilaila area, Ha district was discovered by the GSI in 1960. The deposit occurs at an altitude of about 3900m above msl and is approachable from Ha (26km), Paro (60km) and Thimphu (125km) via Chuzom by all weather metalled roads. Graphite is found within graphite schist and as concordant bands within quartzite, calcareous quartzite, calc-silicate rock and dolomite belonging to the Shumar Formation (Fig. 6.4). Graphite occurs as crypto-crystalline mass and flaky aggregate. There are three bands of graphite schist which merge into a single composite band near Latena spur and extends south-eastward into the Khepchisi peak. The composite band has a strike length of 1500m and a width of over 30m. Three individual bands extend over a strike length of about 250m; which are five to 10m thick. the Khepchisi Hill graphite deposit has been divided into five blocks (Blocks I to V). The Block-I in the north-western part of the deposit exposes two bands of graphite schist. The Block-II exposes three bands, which merge at Latena spur into a composite band. Blocks-III, IV and V expose the southern extension of the composite graphite schist band. The Block-IV is the most promising as regard to the reserve of graphite ore.

Pre-feasibility studies were conducted by Austrian Engineering Consultency Agency (AUSTROPLAN) for mining in the Khepchisi Graphite Prospect from February 1988 to May, 1988. The chemical analysis of graphite ore of Khepchisi hill is as follows :

Table 6.4.1 : Details of Coal Reserves in Bhutan

Sl. No.	Occurrence	No. of Coal seams	Thickness (m)	Strike length (m)	Dip. Extn. (m)	Reserve (Tonnes)	Reserve Category	Grade	Fuel Ratio	% Fixed Carbon	Status of investigation/Remarks
1.	Jagartala	38	0.70-2.80	15-150	30	103,000	Probable	Sub-bituminous	-	46.0	Detailed exploration by drilling completed.
2.	Bhangtar	5	6.50-12.30	236	50	98,000	Probable	Sub-bituminous	-	39.0-44.0	Detailed exploration by drilling completed
3.	Diglai Nadi	40	0.70-2.10	11-500	20	86,500	Possible	Sub-bituminous	2.05-2.67	52.5	Surface investigation
4.	Gerua-Dimala Khola	5	0.45-5.00	125-500	20	44,000	Probable	Sub-bituminous	-	30.6-41.7	Detailed exploration by drilling completed
5.	Chamrang Nadi	8	1.00-4.50	10-175	20	72,600	Possible	Sub-bituminous to Anthracitic	1.42-1.72	43.0	Surface investigation
6.	Kalapani Nadi	36	1.00-12.00	5-112	20	119,290	Possible	Sub-bituminous to bituminous	1.22-2.0	41.5	Surface investigation
7.	Nunai Nadi	4.	0.90-1.70	30	-	-	-	Sub-bituminous to Semianthracitic	2.76-5.69	-	Surface investigation, coal seamc are thin and impersistent
8.	Bhorila-Rash Ri	15	0.50-6.00	50-290	25	303,650	Possible	Sub-bituminous	-	40.1	Surface investigation
9.	Nagorkhola	5	1.00-2.50	17-60	30	52.000	Possible	Bituminous	1.0-2.0	41.0	Surface investigtion
10.	Khaurang-Leshing Ri	5	1.00-6.00	500	-	270,000	Possible	Bituminous to Anthracitic	-	-	Surface investigation
11.	Deothang	12	0.50-3.50	2250	-	-	-	Sub-bituminous	-	-	Surface investigation, coal seams are thin impersistent.
	Probable Reserves						245,000	metric tonnes			
	Possible Reserves						904,040	metric tonnes			
	Total known coal Reserves						**11,49,040**	**metric tonnes**	**Say**	**1.15**	**million tonnes**

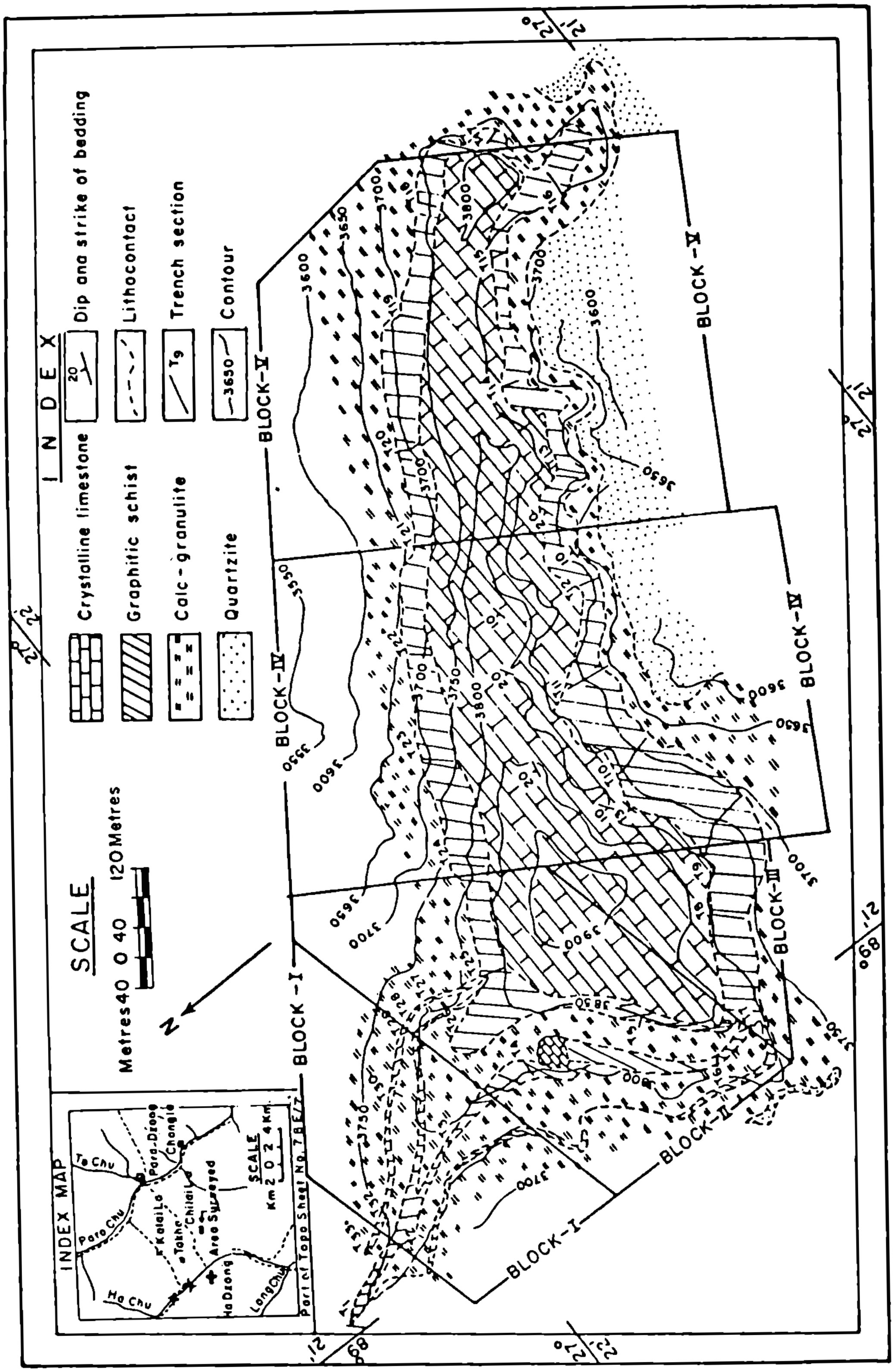


Fig.6.4 Geological map of the graphite deposit, Khepchishi Hill, Chilaila, Ha district (after Kanwar *et al.* 1985).

Non-carbonate carbon	: 10 to 25% (occasionally upto 28%)
Carbonate carbon	: Traces to 3%
Ash	: 70 to 85%.

The graphite ore of this prospect was subjected to beneficiation studies by National Metallurgical Ltd. (NML), Jamshedphur and Patna Estate Graphite Corporation, Orissa. The results of NML's beneficiation tests were not encouraging. The tests by Patna Estate Graphite Corporation indicated that graphite can be separated from impurities in -100 mesh. By using specially designed JETAIR Cells and after six cycles of floatation using HSD : Pine Oil : Xanthanates in 2 : 2 : 1 ratio (as frothers) and sodium silicate as collecting agents, about 95% of the beneficiated material containing more than 90% fixed carbon, 3% volatile material and 5% ash could be recovered.

The estimated block-wise reserves in Chilaila (Khepchisi Hill) area are given in Table 6.4.2.

Table 6.4.2 : Block-wise graphite reserve of Khepchishi Hill, Chilaila area

Block	Reserve of Graphite Ore (in million tonnes)	Category of Reserve	Overburden (in million tonnes)
I	0.24	Proved	0.84
II	5.89	Proved	5.94
III	5.70	Probable	8.13
IV	33.88	Probable	23.49
V	8.03	Inferred	5.52

6.4.2.B Donga, Depchasa and Other Occurrences : Graphite schist is also known from (i) Depchasa and Dorjomsa area east of Chimakothi, (ii) Donga area ESE of Takti *Chu*, (iii) at Duna (Dungna) area of Chukha district and (iii) the Jemena area in Thimphu district. These occurrences are associated with the gneiss of the Thimphu Group and the metasediments of the Jaishidanda Formation.

In the Donga area, two bands of graphite schist are exposed for a cumulative strike length of 600m. It underlies gneissic assemblage. About 0.22 million tonnes of graphite ore is estimated upto a depth of 20m down dip. Graphite ore from the Donga area shows non-carbonate carbon exceeding 18 percent.

In graphite schist from the Depchasa-Dorjomsa area, the average weighted percentage of the non-carbonate carbon is 14.62 with an average ash content of 84.0%.

In Duna (Dungna) area, graphite schist contains non-carbonate carbon ranging from 14.18 to 23.10%.

6.4.3 GYPSUM

6.4.3.A Kothakpa : Gypsum deposit was discovered by the GSI in Kothakpa area in eastern Bhutan in 1960. Kothakpa is approachable from Tselingkhor by a 25km fair-weather jeepable road. Tshelingkhor in turn is connected to Samdrup Jongkhar by a 70km road. The other occurrences of gypsum are Uri, Omsi *Ri*, Cherung *Ri*, Khar, Shali, Sakar Brak and Zeng *Ri*, which are located within short distances from Kothakpa.

Gypsum occurs in association with anhydrite as thick beds within the Shumar Formation which comprises dark grey slaty phyllite, calcareous quartzite, limestone and green phyllite. In general, the gypsum anhydrite bed occurs below an overburden averaging 25m constituted of green phyllite and talus material. Commonly the gypsum-rich zone lies above the anhydrite zone. Both gypsum and anhydrite are white to grey, massive to bedded and saccharoidal in texture. The gypsum-anhydrite beds have thin intercalations of calcareous phyllite and carbonates.

Various gypsum occurrences, their reserves and grades are given in Table 6.4.3

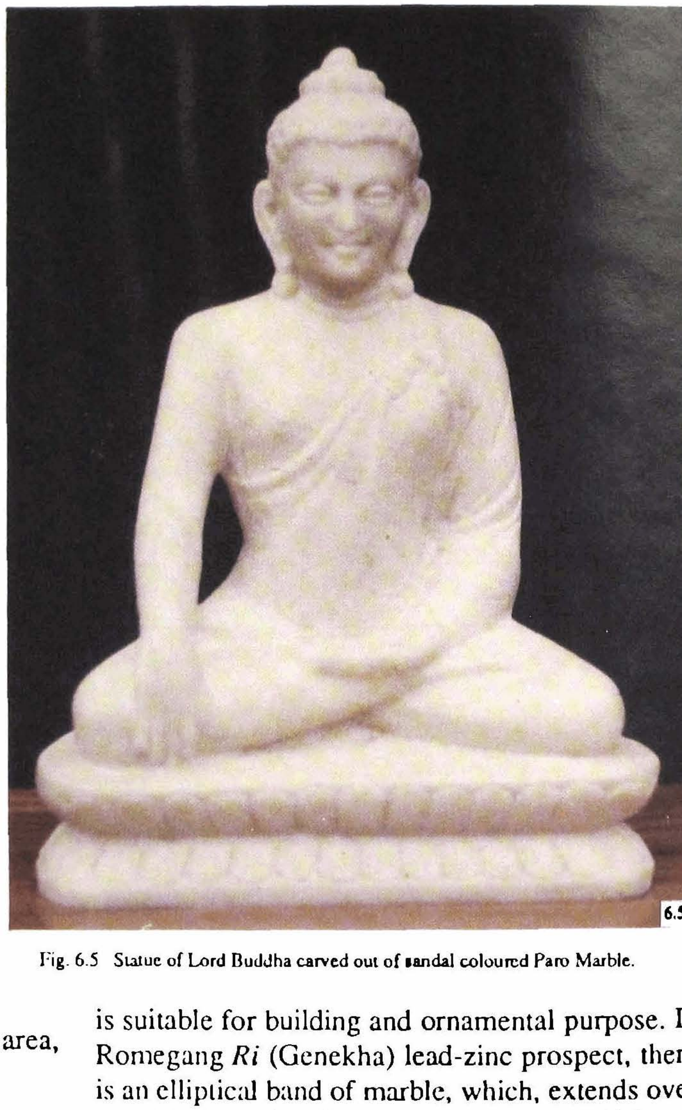
Table 6.4.3 : Reserves and grades of Gypsum deposits in various areas

Name of Deposit		Reserves (million tonnes)	Reserve Category	Grade (in %)			
				SO_3	Gypsum	Anhydrite	Impurities
Cherung *Ri*							
i)	with phyllite intercalations	69.036	Proved	33.86	48.67	18.90	18.63
ii	without phyllite	56.448	Proved	41.12	58.22	23.30	10.20
Uri		13.600	Inferred	-	91.63	1.26	-
Khar		0.034	Probable	-	87.87	1.28	-
Omsi *Ri*		8.830	Inferred	-	91.00	-	-

6.4.4 LIMESTONE

Limestone deposits are widespread in southern Bhutan. Several bands of limestone occur near Pagli-Titi, Kalesor, Khanabharti in south-western Bhutan and Tshebar and Nganglam areas in eastern Bhutan. These limestone deposits are easily approachable by all-weather jeepable roads which are connected to various railway stations in India. Besides these occurrences, crystalline limestone occurs at Mirchang-Badina (Tala area) and Khanku near Paro which are approachable by Phuntsholing-Thimphu/Paro Highways. Good quality limestone recently have also been located at Tokaphung, Tingtibi and Tiphu in eastern Bhutan and Suktikhola and Uttare in western Bhutan.

The details of all the important limestone deposits of Bhutan area presented in Table 6.4.4.



6.5

Fig. 6.5 Statue of Lord Buddha carved out of sandal coloured Paro Marble.

6.4.5 MARBLE

Marble is associated with the tectonostratigraphic belts of Baxa, Shumar, Thimphu and Tethyan Belt. Notable marble occurrences are at Pagli-Titi, Marung *Ri*, Khanabharti, Khanku, Paro, Bunakha-Chapcha, Mirchang-Tala area, Chilungkha (Ha) and Genekha.

At present, marble slabs are being quarried at Khanku. At Mirchang-Tala area, there are three marble bands which vary in strike length from 350m to 950m and with thickness varying between 30m and 80m. The marble is banded and is suitable for building and ornamental purpose. In Romegang *Ri* (Genekha) lead-zinc prospect, there is an elliptical band of marble, which, extends over a strike length of over 1150m with thickness ranging from 75m to 166m.

Finer varieties of Paro marble have been found to withstand chiselling and cutting by lathe for making various artefacts (Fig.6.5).

Table 6.4.4 : Details of limestone deposits of Bhutan

Location	Mode of Occurrence	Status of investigation	Reserves in million tonnes			Grade (in %)		Remarks
			Proved	Probable	Inferred	CaO	MgO	
Samtse District **Pagli-Titi Area**								
i) Pagli West `A'	Bedded limestone intercalated with phyllites. Baxa Group	Detailed exploration by drilling	6.040	-	-	44.81	2.42	Leased to PCAL for cement manufacture. Total reserves 7.23 million tonnes including marginal grade 43.77% CaO and 2.53% MgO
ii) Pagli Mine Extension	Bedded limestone intercalated with phyllites. Baxa Group	Detailed exploration by drilling	4.012	-	-	44.25	3.67	-
iii) Titi `A'	Bedded limestone intercalated with phyllites. Baxa Group	Detailed exploration by drilling	1.430	-	-	47.48	2.56	-
iv) Titi `B'	Bedded limestone intercalated with phyllites. Baxa Group	Detailed exploration by drilling	1.400	-	-	49.14	2.59	Out of this reserve 0.51 million tonnes is of chemical grade of >51.% CaO
v) Titi `C'	Bedded limestone intercalated with phyllites. Baxa Group	Detailed exploration by drilling	0.190	-	-	48.00	2.03	
vi) Bhavani Khola	Bedded limestone intercalated with phyllites. Baxa Group	Detailed exploration by drilling	0.710	-	-	44.25	3.89	
Khanabharti	Bedded limestone intercalated with slaty phyllite. Baxa Group	Surface investigation	-	-	0.260	45.30	3.66	
Haureekhola	Bedded limestone intercalated with slaty phyllite. Baxa Group	Detailed exploration by drilling	0.520	16.700	-	Cement Grade 51.85	1.66	Leased to BCCL
Kalesore	Bedded limestone intercalated with slaty phyllite. Baxa Group	Surface investigation	-	-	1.420	44.47	1.51	Out of this reserve 0.20 million tonnes is chemical grade with CaO 51.29% and MgO 1.23%.
Tintale	Bedded limestone interbanded with phyllite and quartzite. Shumar Formation	Surface investigation	-	-	0.380	50.51	2.93	-
Kalapani	Calc-tufa confined to low lying areas adjacent to Manas Formation. Baxa Group	Detailed exploration by drilling	-	1.073	-	44.83	2.63	-

Table 6.4.4 (Contd.)

Location	Mode of Occurrence	Status of investigation	Reserves in million tonnes			Grade (in %)		Remarks
			Proved	Probable	Inferred	CaO	MgO	
Samdrup Jongkhar District **Nganglam Area**								
i) Marung Ri North	Bedded limestone intercalated with phyllites and quartzite. Shumar Formation	Detailed exploration by drilling.	18.710	-	-	46.04	4.87	Leased to DCP Ltd., for use in the Cement Plant.
ii) Marung Ri South	Bedded limestone intercalated with phyllites and quartzite. Shumar Formation	Detailed exploration by drilling	22.630	-	-	49.02	3.71	Deposit explored by CCI Ltd.
iii) Kurung Ri	Bedded limestone intercalated with phyllite and quartzite. Baxa Group	Detailed exploration by drilling	0.400	-	-	47.41	0.74	20.41 million tonnes possible reserves estimated with CaO 42.45% and MgO 0.79%
iv) Gachhari	Bedded limestone intercalated with phyllite and quartzite. Baxa Group	Detailed exploration by drilling	1.090	-	-	33.83	2.64	To be blended with high grade limestone deposit of Marung Ri (South) Block.
v) Kangrizhe East & Central	Bedded limestone intercalated with phyllite and quartzite. Baxa Group	Detailed exploration by drilling	11.260	-	-	45.63	1.12	-
vi) Kangrizhe West Extension & North (Part)	Bedded limestone intercalated with phyllite and quartzite. Baxa Group	Detailed exploration by drilling	7.160	-	-	46.40	0.82	-
Chukha District								
Mirchang-Badena (Tala Area)	Crystalline limestone interbanded with garnetiferous mica schist and quartzite. Jaishidanda Formation	Detailed exploration by drilling	-	2.800	-	44.51	0.50 to 4.00	0.71 million tonnes of carbide grade limestone proved.
Tashigang District								
Rashong (Khaling)	Bedded crystalline limestone. Shumar Formation	Surface investigation	-	-	0.200	40.00 to 42.38	2.50 to 3.33	-

Table 6.4.4 (Contd.)

Location	Mode of Occurrence	Status of investigation	Reserves in million tonnes			Grade (in %)		Remarks
			Proved	Probable	Inferred	CaO	MgO	
Tokaphung	Bedded crystalline limestone. Shumar Formation	Surface investingation	-	-	30.000	45.00 to 50.00	2.00	-
Pemagatshel District								
Tshebar	Crystalline limestone intercalated with phyllite & quartzite. Shumar Formation	Detailed exploration by drilling in progress	-	1.600	-	46.77	1.02	-
Paro District								
Khanku	Crystalline limestone with mica-schist and quartzite. Shumar Formation	Detailed exploration by drilling	-	42.029	-	46.94	2.50	-
Sarpang District								
Rong Ri	Crystalline limestone inter-bedded with phyllite and quartzite. Shumar Formation	Detailed exploration by drilling in progress	1.940 1.190	-	-	50.35 51.00% Carbdide grade	2.52	Leased to BCCL
Thimphu District								
Genekha	Crystalline limestone hosting Pb+Zn ore. Shumar Formation	Detailed exploration by drilling	-	0.900	-	52.00	1.40	-
Ha District								
Ha Wangcha	Bedded crystalline limestone. Shumar Formation	Surface investigation and detailed exploration by drilling discontinued	-	5.000	-	52.00	2.00	-
Chilungkha	Bedded crystalline limestone. Shumar Formation	Detailed exploration by drilling	-	0.447	-	52.00 to 53.00	-	
			78.682	70.549	32.260			
Total known Limestone Reserves			**181.491 million tonnes**					

Table 6.4.5 : Details of dolomite deposits of Bhutan

Location	Mode of Occurrences	Status of investigation	Reserves (million tonnes)	Reserve Category	Grade	Remarks
Samchi-Rehti-Sarkitar	Bands of dolomite intercalated with slaty phyllite quartzite. Manas Formation. Baxa Group. Average thickness 200m. Strike length 9km	Surface investigation chip sample analysis	102.000	Inferred	20.00% MgO 30.00% CaO	-
Uarc- Deergaon	Bands of dolomite intercalated with slaty phyllite quartzite. Manas Formation. Baxa Group. Average thickness 50m. Strike length 8km.	Preliminry surface investigation	29.000	Inferred	20.50% MgO 30.00% CaO	-
Khanabharti North Pagli-Titi-Haurce	Bands of dolomite intercalated with slaty phyllite quartzite. Manas Formation. Baxa Group. Average thickness 250m. Strike length 16km.	Surface investigation & exploration by drilling on part of the area.	38.55 388.000	Proved Inferred	20.50% MgO 30.00% CaO	-
Titring-Kalesore North	Bands of dolomite intercalated with slaty phyllite quartzite. Manas Formation. Baxa Group. Average thickness 250m. Strike length 16km.	Surface investigation	529.00	Inferred	21.35% MgO 29.80% CaO	-
Kalesore	Four bands of grey dolomite with cumulative thickness of 330m. Strike length 5.25km.	Surface investigation systematic channel sampling. Exploration by drilling in south western part of Kalesore hill.	2500.00 5.58	Inferred Proved	21.14% MgO 29.73% CaO	-
Dhanse	Thick beds of dolomite interbanded with grey slates. Average thickness 80m. Strike length 700m.	Preliminary surface investigation	730.00	Inferred	20.95% MgO 28.78% CaO	-
Kakulang	Massive grey dolomite with calcite veins. Average thickness 200-800m. Strike length 32km.	Surface chip sampling	2900.00	Inferred	20.00% MgO 2.30% SiO_2	-

Table 6.4.5 (Contd.)

Location	Mode of Occurrence	Status of investigation	Reserves (million tonnes)	Reserve Category	Grade	Remarks
Manas	Very thick band of dolomite. Average thickneess 0.50 to 4.50km. Strike length 35 km	Preliminary random chip sampling	5985.000	Inferred	21.00% MgO	-
Dechhiling	Crystalline dolomite. Shumar Formation. Average width 2km. Strike length 20km	Preliminary random chip sampling.	2400.000	Inferred	21.00% MgO	-
Narphung	Two thickband of dolomite of Shumar Formation. Average width 750m. Strike length 9km	Preliminary random chip sampling.	135.000	Inferred	21.28% MgO 29.79% CaO	-
Khandame	Brown and dark grey varieties of dolomite. Average thickness 1.5km. Strike length 10km	Preliminary random chip sampling	281.000	Inferred	21.33% MgO	-
Suktikhola	Shumar Formation. Bands of dolomite with phyllite quartzite. Baxa Group.	Surface investigation and exploration by drilling.	7.2000	Proved	21.49% MgO 29.70% CaO	-
Total known reserves of dolomite			**51.33 15979.00**	**million tonnes (Proved) million tonnes (Inferred)**		

6.4.6 DOLOMITE

Bhutan has an enormous reserves of dolomite located all along the foot-hill region. Most of the dolomite deposits are approachable by fair-weather roads from India and from nearest road heads by foot-tracks. Largest of the dolomite deposits occur between the Manas River in the east and Samtse in the west, over a distance of more than 240km.

The dolomite deposits of Bhutan are restricted mainly to the southern part and occur as bands of various dimensions in the Manas Formation of the Baxa Group. Dolomite bands are intercalated with phyllite, slaty phyllite and quartzite. In some occurrences, dolomite grades into low grade limestone. The dolomite deposits have been explored mostly by surface investigation, chip/channel sampling and systematic geological mapping to trace the strike extensions. Exploration by drilling was carried out only on the Khanabharti, Pagli-Titi and Haureekhola deposits, along with investigation for cement grade limestone.

Summarised account of the dolomite occurrences in presented in Table 6.4.5.

6.4.7 QUARTZITE

Quartzite deposits of Tintali area in Samtse district and Pedzekha *Chu* (Pasakha area) in Chukha district were explored in detail by the Geological Survey of India for their suitability as a road material and in the manufacture of ferrosilicon and calcium silicide. The Tintali quartzite occurs as thickly bedded sequence with chlorite schist intercalations and epidiorite sills within the Shumar Formation. The quartzite deposit at the Pedzekha *Chu* area also occurs as thickly bedded sequence interbanded with micaceous quartzite and mica schist laminations.

Chemical parameters of both the quartzite deposits i.e., Tintali and Pedzekha *Chu* area broadly meet the requisite specification of the Bhutan Ferro-Alloy Limited for the manufacture of ferrosilicon and calcium silicide.

The reserves and grades of these quartzite deposits is as given in Table 6.4.6.

Table 6.4.6 : Detail of Ferro-Silicon grade Quartzite in Bhutan

Location	Mode of Occurrence	Status of Investigation	Reserves (million tonnes)	Category Reserves	Grade
Tintali					
Tintali (East)	Quartzite is coarse grained, snow-white to greenish/ greyish white, hard, well jointed.	Detailed surface sampling and exploratory drilling	0.890	Proved	97.52% SiO_2, 1.06% Al_2O_3 & 0.10% Fe_2O_3
Tintali (West)	Average thickness 4.0-42m	Detailed surface sampling and exploratory drilling	3.490	Proved	97.54% SiO_2, 1.06% Al_2O_3, 0.28% Fe_2O_3, 0.014% CaO & MgO 0.014%
Pedzekha Chu (Pasakha area)	Quartzite is white, medium to coarse grained and thickly bedded with regular joints. Av/thickness 60-70m, Strike length 1.5km	Detailed surface sampling and exploratory drilling	1.330	Proved	97.00-98.50% SiO_2, 0.80-1.40% Al_2O_3, 0.10-0.40% Fe_2O_3 upto 0.30% CaO and 0.01% P_2O_5
Total Reserves of Quartzite		5.710 million tonnes			

6.4.8 SLATE

: There are two major deposits of slate in Bhutan. These are at (i) Bhel (Bonsegeoma) and (ii) Kobja in Wangdiphodrang district. The Bhel and Kobja slates occur as thickly bedded deposits intercalated with clay and sandstone within the Tangchu Formation of the Tethyan sequence.

Based on surface investigations, reserves of 16 million cubic metres of good quality slate is indicated for the Bhel and Kobja areas upto a depth of 30 metres.

6.4.9 MICA : Mica-bearing pegmatite intrusives in the gneiss of the Thimphu Group have been demarcated in Chirang district at Lamedada, Damphu and Darechu. There are five mica bearing zones. Mica is in the form of books of variable dimensions. These mica books are of poor quality, highly strained and full of inclusions and stains.

6..4.10 TALC : A number of occurrences of talc are present in the foothill region of Bhutan. They extend from Samtse in the west to Sarbhang in a south-central Bhutan.

Talc occurs as thin lenses, films, pockets and bands associated with quartzite, phyllite and calcareous quartzite of the Baxa Group. The thickness of the talc bands varies from a few centimetres to about 40m.

The details of various talc occurrences and their reserves are furnished in Table 6.4.7.

6.4.11 CLAYS : There are two occurrences of clays in Bhutan viz., (i) at Khelkha in Wangdiphodrang district and (ii) at Wang Paon in Thimphu district. At Khelkha, clay occurs as a small lensoid body of about 50m long and 2m thick over the pegmatitic granite within the metasedimentaries of the Chekha Formation (basal part of Tethyan sequence). Detailed mapping and channel sampling found both its quantity and quality as insignificant.

The clay occurrence at Wang Paon near Sisina is in the form of tabular to lensoid body in association with the metapelites of Jaishidanda Formation (old Paro Formation). It is about 2400m long and 4m thick and has moderate plasticity. This clay occurrence may find use in ceramics and bricks industries and also as a drilling mud.

6.4.12 PHOSPHORITE AND RARE EARTH ELEMENTS

The only occurrence of phosphorite in Bhutan is reported from the Maure-Kalikhola area of Sarpang district. Phosphorite occurs as three detached isolated elongated bodies within the ironstone shale and carbonaceous phyllite. The mineralised ironstone shale is sandwiched between the thrusted contact of the Siwalik and Gondwana

Table 6.4.7 :

Location	Description of the Occurrence	Estimated Reserves (Tonnes)	Talc Grade	Remarks
Pa *Chu*-Seti *Khola*	Two lenses of talc, white, pale green & dark grey coloured with inclusions of quartzite, phyllite and dolomite. Average width 9.0m. Strike length 300m	1,10,000	Medium-high grade	Workable deposit
Khempa	White pale green talc foliated & grades into quartzite. Average Width 3.0-20.0m Strike length 7m-48m	12,500	Medium grade	-
Thunuwa	Four small lenses of talc. Average Width 5-40m. Strike length 30-70m	3,600	Low grade	-
Pagli-Sarkitar	Three small lenses of talc intercalated with quartzite and phyllite.		Low grade	-
Molabanse	Three small lenses of green to white schistose talc. Strike length upto 170m	5,300	Low medium grade	-
Lapchekha	Five lenses of grey and light green soapstone	4,200	Low grade	-
Sukti *Khola*	Small lenses of talc with quartzitic impurity	2,300	Low grade	-
Budheni-Tin Doban	Small lenses of talc highly impure & sheared	1,800	Low grade	-
Total known Reserves of Talc		139700 tonnes		

rocks. Systematic channel sampling in the area indicated that the P_2O_5 and Fe_2O_3 contents of the ironstone ranges from 2.10% to 10.80% and 8.70% to 81.66% respectively. The overall abundance of phosphorite in the ironstone is of little significance. However, systematic search for phosphorite occurrence of better grade is warranted along the Siwalik-Gondwana contact.

The ironstone bands of Maure-Kalikhola area also shows anomalous concentrations of Rare Earth Elements. Ten representative samples of ironstone band analysed have indicated a rich concentration of REE, with total REE content ranging from 2677.5ppm to 10289.5ppm. The elements La, Ce, Pr, Nd show great enrichment with respect to their crustal abundance. The REEs exhibit an overall increasing trend towards the stratigraphic top of the ironstone sequence. The high REE abundance in the ironstone bands is significant and warrants further investigation.

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