ITALIAN EXPEDITIONS TO THE KARAKORUM (K²) AND HINDU KUSH

Prof. ARDITO DESIO Leader

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E. J. BRILL - LEIDEN
ITALIAN EXPEDITIONS TO THE KARAKORUM ($K^2$) AND HINDU KUSH

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III - Geology - Petrology

Volume 2°

GEOLOGY OF THE BALTORO BASIN

by

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E. J. BRILL - LEIDEN
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The expedition to the Karakorum range which, during the summer of 1954 conquered K2 (8611 m) — the second highest peak in the world — had, according to Italian tradition, a scientific as well as a mountaineering objective.

Besides the actual ascent, the programme of the expedition included research and study on the Geography, Geophysics, Geology, Anthropology and Ethnography of the area. Also, a small collection of specimens of local flora and fauna from elevated heights was occasionally made.

The expedition was carried out in three campaigns. A preliminary reconnaissance was made by Professor A. Desio with a guide (Mr. R. Cassin), during the summer of 1953. The main stage followed in 1954 and lasted six months: it was carried out by an Italian team of five scientists (Professors Paolo Graziosi, Antonio Marussi, Bruno Zanettin, Ardito Desio and Dr. Guido Pagani, the physician of the expedition), eleven climbers and a photographer; a medical officer (Colonel Dr. M. Ata Ullah) and an assistant surveyor (Bad Shah Jan of the Survey of Pakistan), both from Pakistan, also joined the staff.

The scientific research was continued in the 1955 campaign which lasted about three months. The team this time consisted of three Italian scientists (Paolo Graziosi, Antonio Marussi and Ardito Desio) and three Pakistani assistants (Dr. N. M. Khan of the Geological Survey, Mr. M. Azizullah of the Survey of Pakistan, and Mr. Javed, a student at the University of Lahore).

The territory examined during the first campaign is to be found between the upper course of the Indus river, from Skardu as far west as the Stak valley, and the principal ridge of the Karakorum to the north. However, some reconnaissance was carried out westwards as far as Hunza and Gilgit and eastwards as far as Bagicha. The territory covered in 1955 lies between the Gilgit area and Chitral.

A new scientific campaign was organized by Professor Desio during the summer of 1961 in order to explore geologically the Wakhan territory, lying between the Hindu Kush and the Pamirs, and to extend eastwards the geophysical observations. The leader was accompanied by Professor Marussi and two assistants (Dr. Giorgio Pasquarè and Dr. Ercole Martina) and by an Afghanistan geologist (Mr. Afruddin).
Whereas the geophysical programme was carried out in its entirety, the geological one was reduced to the survey of Central Badakhshan, for the expedition was not allowed to cover Wakhan.

In order to complete the geological research over an area which had been omitted from the itineraries of previous expeditions and to clear up a number of unsolved problems of its stratigraphical geology, Prof. Desio, accompanied by two assistants (Dr. Ercole Martina and Dr. Roberto Galimberti) organized in 1962 a further campaign to the Western Karakorum. The territory covered this time is to be found between the Chogo Lungma and the Sosbun glaciers, and the upper valley of the Hunza river.

* * *

The present volume concerns the geological and petrographical results obtained by the 1954 expedition into the basin of the Baltoro glacier. The same area had been geologically surveyed by me during the Italian expedition to Karakorum in 1929 and again during my expedition in 1953.

During the expedition in 1954 Professor B. Zanettin had not only to carry out studies on the petrology and geology of the Stak, Tourmik and Shigar valleys in order to complete and draw up the preliminary results of my previous journeys, but had also to collaborate with me in the geological survey of the Baltoro basin. One of Zanettin's special tasks was the petrological investigation on the plutonic and metamorphic rocks of that area.

According to the general plan of the expedition the scientific team should have been working in the above mentioned valley during the climbing assault on K2, and the two scientists, Prof. A. Marussi and Prof. B. Zanettin and the topographer, Captain G. Lombardi, should have been transferred from their work field to the Baltoro area at the end of the climbing activity.

On July 31 two of the climbers of the expedition, A. Compagnoni and L. Lacedelli, reached the top of K2, and a week later the return of the climbing party began. The first successful stage of the expedition was at an end.

In the meantime the scientists and the topographer were anxiously waiting to know what had happened on K2, but the greater part of my messages entrusted to the porters did not reach their destination. On July 17 Professor Zanettin arrived at the base camp and told me about the situation of the scientific team. He also announced that his colleagues would be arriving after some weeks. On August 18 the whole scientific team was assembled on the Baltoro glacier, but only for a few days: on August 23 I left the Baltoro glacier for Askole with Zanettin. A week later I
said goodbye to Zanettin who left for Italy, and continued alone my scientific investi-
gations throughout the Biafo and Hispar glaciers as far as Hunza valley, and reached Gilgit on September 18.

The results of Zanettin's studies in the Stak, Turmik and Shigar area are con-
tained in the first volume of part III of the scientific records of my expeditions; those of Marussi in the volume (part II) devoted to Geophysics; the maps surveyed by Lombardi in the Baltoro basin complete this volume as topographic base of the geological maps of the Baltoro basin and the K², and are included at the end.

As I have said, the present volume deals with the geological and petrological results obtained by the 1953-1954 expeditions into the Baltoro basin, combined with the data collected by me during the 1929 expedition, under the leadership of the Duke of Spoleto.

**

I am indebted to Professor Robert Scholten of the Pennsylvania State Uni-
versity and to Professor Charles Blackburn for the translation and the linguistic revision of the manuscript of the present volume.

I like to thank also Doctor G. Francalanci, photogeologist, who collaborated with me in the tectonic interpretation of K² massif, and Marcus Schmuck and Walter Bonatti, famous climbers, who collected some interesting rock specimens on the tops of Falchan Kangri (Broad Peak, 8051 m) and Gasherbrum (7925 m) giving the possibility to the authors of this volume to know the precise geolithological compo-
sition of the summits of the two mountains.

Before concluding this preface, I should like to thank Professor Zanettin for his effective and diligent collaboration during the expedition of 1954 and afterwards in Italy. I also wish to thank the Italian National Research Council which financed my scientific expeditions to the Karakorum and Hindu Kush, and contributed also to the publication of the present volume.

Ardito Desio
Fig. 1 – Orographic sketch-map of the Karakorum range (the Baltoro area is limited by the red line).
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I. INTRODUCTION


The basin of the Baltoro glacier (fig. 2) lies on the south side of the Karakorum chain, to the south west of the highest ridge. It is bounded to the north by the basins of the Shaksgam river and its tributary the Sarpo Laggo, to the east by the basins of the Urdok, Siachen, and Kondus glaciers, to the south by the basins of the Kabery, Chogolisa, Gondokhoro, Masherbrum, and Chingkhang glaciers, and to the west by the basins of the Dumordo river and the Panmah glacier.

The highest peak of the Karakorum chain, K2 (8611 m), is situated on the watershed between the Indus basin, of which the Baltoro glacier is a tributary, and the Tarim basin. Three other peaks with elevations above 8000 metres rise to the south of K2: the two Gasherbrums, I (8068 m, Hidden Peak) and II (8035 m), and Falchan Kangri (8051 m, Broad Peak).

The Baltoro basin lies between longitudes 76°04' and 76°46' east, and latitudes 35°35' and 35°56' north. Its elevation is between 3500 and 8611 metres above sea level.

The principal valley of the Baltoro glacier (pl. I) trends in a general east-west direction, while the prevailing trends of the tributary valleys are northwest-southeast and north-south. The main valley lies nearer to the southern watershed than to the northern, so that the tributaries entering from the north are usually longer than those entering from the south.

The perimeter of the Baltoro basin is 212 km long, 118 km of which coincide with the main watershed of the Karakorum chain, between the Indus and the Tarim basins.

The maximum length of the basin, in an east-west direction, between Sia Kangry and the peak to the south of the glacier front, is about 57 km. The maximum width, between the peak rising to 7026 m in the Skyang Kangri massif and the ridge representing the southern watershed of the Vigne glacier, is 38 km.
Fig. 2 – Orographic sketch-map of the Baltoro basin.
The whole basin lies above 3586 m, and more than half of it is covered by ice.

The perimeter of the Baltoro basin is composed of three mountain chains, two of which are nearly parallel, lying in an east-west direction, and which are linked at their eastern ends by a third chain. The northern chain, 50 km long, is part of the Karakorum, and is here called the Mustagh chain, after the pass that crosses it. The southern chain is called the Masherbrum chain, after its highest peak, and is 60 km in length, while the third is called the Gasherbrum chain, and is 44 km long.

The length of the glacier is 53 km when measured along the main ice-stream between the Chogolisa saddle and the end of the glacier. If measured from the Skyang-la, at the head of the Godwin Austen glacier, it is 57 km long.

According to S. G. Burrard (1933) the name Baltoro comes from the Tibetan, dpal-gtor-po, meaning spreader of abundance.

Local names within the basin were given by explorers, and confusion has arisen in identification, with the result that one feature has sometimes been mistaken for another (A. Desio, 1936).

The most important place-names are shown in the sketch-map (fig. 2), for ease of reference.

Many other names, in the Balti language and often given by the native porters, had to be added to the names existing before the 1954 expedition. In many cases we have translated the original place-names given by previous explorers from English to Balti. Thus Chogolisa Kangri corresponds to Bride peak, Skyang Kangri to Staircase, Falchan Kangri to Broad peak etc.

It is common knowledge that the highest peak, K², is so named after the symbol given to it by Colonel Montgomery in 1856 when its elevation was first measured from a distance. The letter K is the first letter of the word Karakorum, while 2 is the serial number of the peaks which he measured.

Since this name is in everyday use, because of the publicity given to the mountain when it was climbed and subsequently conquered in 1954, there seems no reason to change it.

Among the various names given to this mountain, Godwin Austen was once the most widely used, but it was not the first name given, and there is no particular reason to maintain it. During the 1954 expedition the porters used the name Chogo-ri, which in Balti means great mountain.
2. Previous Work.

The first geological information on the basin of the Baltoro glacier probably dates back to 1867, and is supplied by A. M. Verchère. He did not visit the region, but used information obtained from H. H. Godwin Austen and from some samples supplied by E. C. Ryall.

A geological cross-section of the Masherbrum peak, compiled from this information, includes the two slopes of the Baltoro valley. According to Verchère the right slope is composed of granite, the left one of gneiss, micaschist, sandy shales and coarse slate, pale dolomitic limestone and pale ochre-coloured limestone. The latter rock is probably the parent of the Silurian Sphaeronites limestone found at the south side of the Masherbrum.

On the geological map of the "Western Himalayan and Afghan Mountain" (scale 1:1,000,000) an area corresponding, in the key, to "metamorphic in general" occurs on the northern side of the Masherbrum, on the left side of the Baltoro valley. An area of "Granite" is indicated on the opposite side of the valley, towards the Eastern Muztagh Pass. Two areas of "Silurian (fossiliferous) Limestone and Shale" are indicated on the southern side of the Masherbrum and to the north-west of the Muztagh pass. This information is too important to be omitted, and will be further discussed in the chapter on the geology of the lower Baltoro valley.

A more detailed account of the geology of the basin is given by R. Lydekker (1883).

According to this author the whole of the Baltoro basin is composed of "granitoid gneiss" and "central gneiss", while crystalline schists of the "Supra-Kuling" series, with saccharoidal limestone and gneiss, ascribed to either the Triassic or the Jurassic, only crop out at the foot of the glacier. No petrographic observations were made on the rocks from the moraine at the foot of the glacier—such observations would have shown that other rocks besides "granitoid gneiss" occur in the basin—which leads us to believe that Lydekker did not penetrate very far into the Biaho valley.

Data given by Bonney and Raisin (1894), though exclusively petrographic, is far superior to that presented by the first two authors. This data refers to the Conway collection (1892), consisting of 74 samples, five taken downstream from the Baltoro, and the others in the Baltoro glacier basin. Among the rocks collected, mention must be made here of the granites, syenites and diorites, micaschists, quartz and calcareous conglomerate, and quartz sandstone.
Some of the samples were not defined, while others were not fully determined. Most of the samples came from the Crystal Peak and from the Baltoro Kangri (Golden Throne) which, as will be shown further on, are geologically rather peculiar. To the list of samples, accompanied by some descriptive notes which are often incomplete, the authors added a very short account of the geographical distribution of the rocks.

Although based on a relatively poor number of samples Novarese's study (1912) of the geology of the Baltoro basin is of interest. A sample of biotite-gneiss from Mount Chogolisa (Bride Peak) is accurately described, and mention is made of serpentine and vein quartz. The sedimentary rocks collected on the floating moraines were put by Novarese into two groups, «one made up of schists and essentially siliceous aragonite, the other formed of limestones, dolomites, and various breccias».

Novarese's descriptive list is followed by a short account of the possible geological distribution of the rocks and their topographic distribution, and an attempt at a reconstruction of the geology of the Baltoro basin.

Further information on the geology of the Baltoro basin did not appear for some thirty years. However, in 1930 A. Desio published two preliminary papers dealing with research carried out in 1929 during the Italian Geographical Expedition to the Karakorum range, under the direction of the Duke of Spoleto.

The first of these preliminary papers (Desio, 1930 a) gives both a general account and an account of the itineraries. The events of the journey and the geographical and geological observations on the Baltoro basin are reported, for the first time from direct observations. The distribution of the various rock types is reported, including the gneiss and granites downstream from Concordia. The geology of the highest peaks, such as K2, Falchan Kangri, Gasherbrums, etc., is briefly indicated, as well as the presence of Permian fossiliferous limestone with neoschwagerines, pelecypoda, gasteropoda and corals. The fossils were later studied and illustrated by A. Silvestri (1934), who demonstrated their Carboniferous age.

These two papers (Desio, 1930a; Silvestri, 1934) are rarely quoted by later authors, whereas a later paper of Desio (1930b), much shorter than the first and written in English, is often cited. Even after the publication of the official volume on the 1929 expedition (Desio and Savoia Aosta, 1936) the short paper by Desio was still the most quoted account.

Four years later, in one of the volumes of the scientific reports of De Filippi's expedition, G. Dainelli (1934) gave a brief account of the geology of
the Baltoro basin. The data are a repetition of those given by previous workers, and chiefly those of A. Desio in his 1930 paper.

Dainelli attempted to correlate the data on the Baltoro basin with that on the Siachen basin (p. 572-573, 578, 588) but came to erroneous conclusions, as will be shown further on. He attributed the multi-coloured conglomerates and other associated red and yellow rocks of the Upper Baltoro basin to the Ordovician, after comparing them with similar rocks of the Spiti and of the Kizil pass. It will be shown later that the latter are in fact part of a older complex, and are totally disconnected with those of the Baltoro basin.

Dainelli also suggests that the Devonian, as well as the Silurian, occurs in the basin, but again this is incorrect, as will be shown later.

These time-stratigraphic interpretations are of course incorporated in the tectonic interpretation, summarised in a profile (p. 992).

The geographic report of the 1929 Italian expedition to the Karakorum range was published two years later, in 1936. Due to financial difficulties this report had been delayed in publication for a few years. It contains some chapters on the geology of the region, by A. Desio, and these are the only chapters available, since the following volumes, which were to be devoted to the geology of the region, were not issued, again for financial reasons.

The first geological map of the Baltoro basin was published in this volume. It was surveyed on the scale of 1:100 000 using the topographical map prepared from the survey by the Duke of Abruzzi’s expedition in 1909, and, where this map is incomplete, on the scale of 1:300 000 using Conway’s map of 1892.

For the first time the distribution of, and relationship between, the main rock types of the region are given in this map.

The geology is given in some detail in about fifteen pages illustrated with several profiles and stratigraphic columns. Previous workers had not covered the basin, but had based their geological interpretations on samples collected from the moraines by explorers. For this reason the map represents a great step forward in the geological interpretation of the basin.

The description of the geology of the Baltoro basin, written more than twenty five years ago, will not be summarised here, but it is necessary to present the geological sketch-map published in 1936, even though several amendments have to be made (fig. 3). Later authors either forgot the existance of the Italian work, or made use of it without mentioning it.

A short summary of the geology of the Balto basin, based on Desio’s work, was published by G. O. Dyhrenfurth in 1939, but contained no further information other than that already reported.
Fig. 3 – First geological sketch-map of the Baltoro basin surveyed by A. Desio in 1929 (Desio, 1936).
During the Second World War and the following years no further publications on the Baltoro appeared. The first post-war expedition which covered the region of the Baltoro glacier was that led by C. Houston in 1953. Among the explorers was a geologist, Art Gilkey, who unfortunately died during an attempt on K2, and left no scientific report.

The following year A. Desio returned to the Baltoro basin, collected new information, and began a geological survey on the scale of 1 : 75 000 using the topographical maps prepared from the survey by the 1929 expedition. Since Desio was engaged in the organisation and direction of the 1954 expedition, he was not able to write a complete scientific report of the new work. It was also necessary to carry out petrological and palaeontological studies on the collected samples before any detailed reports could be given.

Some preliminary reports were however published, chiefly in collaboration with B. Zanettin and other workers. These notes will be briefly summarized here, since the various problems outlined in them will be dealt with in more detail in this volume.

The first report (A. Desio and M.B. Cita, 1955) contained a description of samples taken from some of the moraines of the Upper Baltoro and of the southwestern glaciers of Falchan Kangri (Broad Peak), where Desio had found fossiliferous limestone pebbles containing Permian Schwagerinae.

General accounts of the territory covered by the 1953 and 1954 expeditions were presented at the International Geological Congress in Mexico (1956), but the report, compiled by A. Desio and B. Zanettin and containing a small scale geological map, was not published separately until 1968. Other reports by the same authors briefly illustrate the various rocks constituting the Baltoro basin (1957a) and the geology of K2 (1957b), and contain greater petrographic detail than previous papers.

C. Viterbo and B. Zanettin (1959) gave an account of the chemistry and petrography of some lamprophyre dykes of the Upper Baltoro basin. A. Desio and A. Marussi (1960) published a paper on the geotectonics of the Karakorum granite batholiths (including those of the Baltoro) and the distribution of the batholiths in the Karakorum and Hindu Kush ranges.

A small volume by T.E. Gattinger, published in 1961, deals with a wider territory than that considered here. However, at least a dozen pages are devoted to the geology of the Baltoro basin. Mention must be made here of the descriptions of the rock samples collected by the expedition. Most of the 45 samples listed come from the Gasherbrums ridge, but it is not stated whether they were collected from the moraines or from in situ rock. It is very strange
that the author did not mention any samples of granite taken from the Baltoro, since this is the most common rock-type found within the basin.

The geological information will be referred to further on, but only that dealing with the Baltoro basin (1).

Enclosed in GATTINGER’s volume is a geological map of the Gasherbrums group on a scale of 1 : 83,000, and a series of block-diagrams depicting nearly the whole of the Baltoro basin. For the most part they are a product of the author’s imagination. GATTINGER does not appear to know the previous work sufficiently well, since he does not incorporate it in his accounts (DESIO, 1963 a). Further remarks on this work by GATTINGER appear in the geological descriptions of the Baltoro.

The most recent work dealing with the Karakorum range, and in which the Baltoro basin is only occasionally mentioned, is A. GANSSER’S interesting book on the geology of the Himalayas (1964). GANSSER’S knowledge of Karakorum was gathered from previous papers and volumes, but unfortunately the author did not take sufficient care in the choice of his sources, since he gives credit to some unreliable papers such as that of GATTINGER. We shall not comment on the whole chapter on the Karakorum, since we are only dealing with the Baltoro basin. Comparison of the geological interpretation of the Karakorum range on GANSSER’S geological map of the Himalayas with DESIO’s more detailed geological map of the Western Karakorum (1964) or, better, with the content of the present work, shows the many discrepancies which exist in GANSSER’S interpretation due to the unreliable data on which it was founded.

With reference to the geology of the Baltoro basin some inaccuracies must be recorded.

The black shales and schists of the Upper Baltoro have never been found to contain *Fenestella* of Carboniferous age by DESIO (p. 31). *Fenestella* is however found in an arenaceous shale from the upper basin of the Panmah glacier. The Baltoro black shales and slates are unfossiliferous, as will be shown later, but they probably belong to the Lower Carboniferous as they can be correlated with the Singhie Shale of Shaksgam valley (DESIO, 1963).

Secondly, the black shales, i.e. the Singhie Shale of the Shaksgam valley and Aghil range, do not contain «conglomeratic horizons, and reddish schists» with some «grey and black limestones». The paper cited of DESIO (1960a) deals

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(1) Geological problems concerning the whole Karakorum range will be dealt with in the last volume on the geology of the Karakorum and Hindu Kush. It will be firstly necessary to report the geological information collected by DESIO’s expeditions in other parts of the territory in the following volumes of the present series.
with the Karakorum granite batholith; conglomerate, schists, and limestone are not mentioned in this paper. It may be summised that GANSSER intended to refer to the Urdok Conglomerate and Chikchi-ri Shales (DESIO, 1963) which in fact belong to the Upper and (?) Middle Triassic, and not to the Carboniferous. Thus no acceptable conclusions can be drawn from this data.

It is unfortunate that in such a valuable book on the geology of the Himalayas the chapter on the Karakorum should contain such inaccuracies, especially since the author had better sources of information at his disposal.


If serious difficulties are encountered in the geological survey of high mountains, the survey of the Baltoro basin which, as we have stated, lies between 3500 m and 8611 m, may be considered to be a kind of riddle that the geologist is required to solve. The most accessible paths are provided by glaciers, huge glaciers, flowing along the bottoms of valleys, with their backs covered by many pit-falls for the unwary explorer. A blanket of boulders and rocks, covered by snow, hides the ice and the huge crevasses. The sides of the valleys are very steep, steeper than those in the Alps, and usually coated in ice and snow. To cross the glacier, in order to inspect the rocks on the other side, you are often obliged to spend more than one day, and when you reach the edge of the glacier you are menaced by rock or ice falls and avalanches, many of which, commencing at the highest peaks, cross the valley from one side to the other.

Above 5000 m the outcrops are small and scattered here and there, and it is usually impossible to reach them. Due to the blinding reflection of the sun on the ice you are obliged to wear very dark glasses the whole of the day, and this makes it difficult to distinguish the colours of the rocks and thus determine their nature. So you are obliged to collect samples from the talus under the cliff faces, or to follow the floating moraines as far as their origins to determine where the rocks have come from.

Then there is the extreme variability of the weather. Cloudless days are rare during the summer, and even on such days the high peaks are often capped for many hours by snow clouds. Snow falls frequently during the summer, so that the geologist must stop his field work, often for many days, since the new snow covers the few rock outcrops.
Under such conditions the geologist must continue his work, often forced to remain in his small tent, for many months, hastily cooking and eating the simple and monotonous food, isolated from the world.

4. Subdivision of the Territory into Geological Zones.

As the Baltoro basin is not a geological but a hydrological unit it is necessary, for practical reasons, to subdivide the territory into geological zones (fig. 4). The basin can be regionally divided into three geological zones, based on the preponderant outcropping rock types: 1. low-grade metasedimentary sequence, 2. metamorphic complex, 3. granite batholith.

The granite batholith covers a far wider area than the other geologic unities of the Baltoro basin, and is also lithologically the least heterogeneous. Its emplacement has interrupted the continuity of the other formations, and in its vicinity the normal sedimentary facies disappear. The latter are never
in direct contact with the granite body, but are always separated from it by a zone of metamorphic rocks.

In the following chapters the sedimentary rocks will be described first since these provide the best documentation for reconstructing the geological history of the territory.

Unfortunately these sedimentary rocks cover a relatively small area of the Baltoro basin, and constitute very steep and high mountains, so that detailed research of this stratigraphic sequence is virtually impossible. These mountains occur in the eastern chain, and include all the highest peaks of the Karakorum except K2 itself: the Falchan Kangri and the two Gasherbrums, all with peaks rising to over 8000 m from bases at 4500 m.

The metamorphic complex is most widespread in the northeastern sector, but it also occurs in other, smaller, areas along the borders of the granite batholith.

A small, isolated, igneous body, essentially dioritic, crops out within the area occupied by the sedimentary sequence, between the Falchan Kangri and the two eastern peaks of Gasherbrums.
II. THE LOW-GRADE METASEDIMENTARY AREA

1. Introduction.

Besides the low-grade metasedimentary rocks it is necessary to include in this chapter descriptions of markedly higher grade metamorphic rocks which are obviously derived from the sedimentary sequence.

In the Baltoro basin completely unmetamorphosed sedimentary rocks are scarce. Even samples that yielded the best fossils (fusulinids) ranged in metamorphic grade from virtually unmetamorphosed compact limestone, comparable with that of the same age from the Shaksgam valley, to true, white, marbles which contain recognizable fossils.

It would thus have been impossible to divide all the metamorphic rocks into lithostratigraphic units corresponding to the prevailing sedimentary facies.

In fact, the weakly metamorphosed sedimentary rocks, since they are more abundant than the unmetamorphosed ones, prove to be the most useful in reconstructing and dating the stratigraphical sequence.

The low-grade metasedimentary rocks of the eastern Baltoro basin lie in a fairly well defined area between the Falchan Kangri to the north and the Baltoro Kangri to the south.

Apart from this area the sequence only occurs on a few spurs of the Khal-khal ridge. The rest of the basin, at least where it is not covered by ice, is underlain by intensely metamorphosed rocks and igneous rocks.

Within the Baltoro basin it is impossible to find a good stratigraphic section in which the complete sedimentary sequence is exposed. The best partial sections are generally inaccessible, and many of them are in part covered by ice, so that it is little possibility of even studying them from a distance.

Added to these difficulties are the tectonic complications and often intense metamorphism, making our reconstruction a very difficult, if not sometimes impossible problem.

Thus, our account will necessarily be rather fragmentary. We shall,
however, attempt to put in some order and also co-ordinate the few data which we have at our disposal.

The lithostratigraphic units to be described in the following sections are listed below, thus giving the reader a summary of the low-grade metasedimentary sequence of the Baltoro basin (1):

7. Khalkhal Sandstone: green and red sandstone with interbedded conglomerate, of the Khalkhal valley and Falchan Kangri. Cretaceous;


5. (Bdongo-la complex?): black, compact, laminated limestone with crushed belemnoid (?) remains, of the Gasherbrums. Jurassic;

4. Aghil Limestone: grey fossiliferous limestone with large, crushed bivalve remains, of the Gasherbrums. Triassic and Lower Jurassic (??);

3. Urdok Conglomerate and Chikchi-ri Shale: calcareous, multi-coloured conglomerate and/or black, brown, green and red arenaceous shales, and green schist with interbedded limestone. Middle and Upper Triassic;

2. Shaksgam Formation: white, grey, waxy and crystalline, often fossiliferous limestone with fusulinids, corals and unidentifiable fossil remains, interbedded with a few beds of black shales and slates, of Falchan Kangri and Gasherbrums range. Permian and Upper Carboniferous;


Other sedimentary units may well occur and be discovered within the Baltoro basin, besides those mentioned above. It must be emphasised that the list includes only the present state of knowledge of the sequence.

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(1) We want to point out that in order to distinguish the names of the rocks, as lithotypes, from the names of the rocks used (in composition with local names) for calling the lithostratigraphic units (formations), we use the small letter in the first case, the capital in the second case.

We say, for instance, Khalkhal Sandstone, when we want to refer to the Khalkhal formation which is composed not only of sandstone, but also of conglomerate etc.; but we write Khalkhal sandstone when we want to point out the sandstone of the Khalkhal formation. An other example: \( K^a \) Gneiss is a formation name which include augen gneiss, granite gneiss and strips of paragneiss included in the preceding rocks; \( K^a \) gneiss is the porphyroblastic gneiss only.

We emphasize that frequently our formations are not sufficiently well defined in order to be considered formal formations for which the capital must be used; but they are real formations even if they lack, for instance, a detailed type-section. The possibility of getting a complete description of a new formation is very rare owing to the difficulty of approaching and climbing the slopes and for the extensive cover of ice.
The formations will now be described in more detail, according to geographic regions defined by the mountains: the Khalkhal range, the Falchan Kangri (Broad Peak), the Gasherbrums and the Baltoro Kangri (Golden Throne).

2. Northern Spur of the Khalkhal Ridge.

The basin of the Savoia glacier is separated from the basin of the Khalkhal glacier by this spur (pl. II). Both these glaciers are tributaries of the Godwin Austen glacier.

Geological research of this spur has been limited to its eastern end, where it forms, over a distance of about two and a half kilometres, the eastern slope of the Godwin Austen glacier basin. However, distant observations of the whole spur, which is about 6 km long, were made from this point.

![Geological section across the southern confluence spur of the Savoia valley](from Desio's field book).

Ks Khalkhal Sandstone, Sc Savoia Limestone, m moraine.

The sedimentary sequence, sensibly metamorphosed, begins on the lower part of the spur at the confluence of the Savoia glacier with the Godwin Austen glacier (fig. 5). A thick sequence of black micaschists, predominantly composed of biotite and muscovite, with garnet and andalusite, forming the south-western part of the Savoia glacier basin, is overlain by the following rocks:

a) at the base, a whitish calcareous conglomeratic complex;
b) a green phyllitic arenaceous complex passing southwards and westwards into a higher grade metamorphic facies which forms the northern side and the head of the Khalkhal glacier valley.

We shall call the complex a) the Savoia Limestone, and complex b) the Khalkhal Sandstone. These two complexes may represent two formations.

The southern side of the same valley is composed of the calcareous slatey complex of the Doksam ridge (Marble peak) which will be described later. The latter sedimentary series constitutes the core of a faulted syncline with a roughly southeast strike.

We shall now examine in more detail the composition of the two rock units.

On the lower part of the spur at the confluence of the Savoia glacier with the Godwin Austen glacier, the sedimentary sequence, composed of calcareous conglomerate and including breccias, shows a distinct layering dipping to the south-west at 60° (fig. 6 and pl. XIV fig. 2).

The base of the sequence is composed of:

1) A yellowish-grey, compact, sometimes weakly schistose limestone containing a few fragments of a dark-grey calcareous rock and of crystalline limestone. It sometimes shows a lamellar bedding and arenaceous texture (54 PD-63, -64) (1). It contains small cubic crystals of pyrite.

This limestone grades upwards, with more and more frequent intercalations, into:

2) multi-coloured, yellowish and grey conglomerate and breccia, made up of more or less rounded but often flattened and sometimes angular pebbles varying in size from 100 to 5 mm in diameter.

The pebbles are composed of various rock types, among which were noted black, grey, white and yellowish compact limestones, some of which are semi-crystalline, greyish-white, waxy limestones, and a blackish, calcareous, fine-grained breccia. The abundant cement is usually of a calcitic nature, but sometimes has an arenaceous composition, and contains numerous small cubic crystals of mica (54 PD-65, -66, -67, -141).

The multi-coloured conglomerate sometimes shows distinct rock-cleavage and contains small cubic crystals of pyrite (2-3 mm sides) scattered throughout the rock. The conglomerate is sometimes considerably brecciated.

(1) The serial numbers in brackets refer to the samples. See the petrographic description of the specimens at the end of the text of this volume.
The total visible thickness of the two combined rock units is at least one hundred metres. At this locality the lower beds of the calcareous formation are not visible, but they can be seen on the opposite side of the valley of the Godwin Austen glacier, that is, on the western side of the Falchan Khangri. These will be mentioned later.

The conglomerate is overlain by:

3) bright, reddish-grey, laminated phyllitic calc-schists with silky surfaces, and containing some calcareous intercalations (54 PD-69). This unit is only a few metres thick and marks the gradation into the overlying formation, composed of:

4) phyllitic calcareous sandstone and green and red arenaceous sericitic phyllite, with some conglomerate intercalations containing bright calcareous and calc-schist fragments.

According to B. ZANETTIN (1), the phyllitic sandstone (54 PD-68) appears under the microscope to be composed of bands with irregular strike and thickness and containing sericite and chlorite in close association, alternating with thicker bands of quartz and calcite. Sometimes the former, and sometimes the latter, prevail.

The matrix of the arenaceous phyllite (54 PZ-142) is composed of a fine quartz, sericite and chlorite aggregate. Numerous medium-sized quartz grains occur in this matrix, surrounded by the fine aggregate. The matrix sometimes includes a prismatic mineral, now altered to sericite, which may have been a plagioclase. Calcite, often localised in the fractures of the rock, and epidote, are also present, but in small quantities.

These arenaceous beds are well exposed on the same spur, and reach a thickness of at least 200 m, until they disappear under the ice which covers the mountain slope.

The same arenaceous rocks occur in the spur which separates the Savoia glacier from the Khalkhal glacier, as can be seen from the green colour of the rock and from the samples collected from the debris covering the foot of the walls bordering the Godwin Austen glacier to the west (fig. 6). At this locality the thickness of this formation must be over 800 m.

In the debris, besides the phyllitic sandstone and arenaceous phyllite, we also collected samples of other rocks; among them ZANETTIN identified

(1) More detailed descriptions of samples are contained in the petrographic description of the specimens.
quartzofeldspathic blastomylonitic gneiss (54 PZ-145) and fine biotite gneiss with feldspar porphyroblasts (54 PZ-144). The former are closely connected with the phyllitic sandstone, as can be seen from ZANETTIN’s petrographic description (1).

Fig. 6 – Geological view of the Khalkhal ridge from the Godwin Austen Glacier (Desio).
1 Black micaschist with andalusite; 2 G. P. sequence; 3 Savoia Limestone with conglomerate; 4 Khalkhal Sandstone.

The gradational relationships between the two gneisses, and the first gneiss with the phyllitic sandstone, show that the same arenaceous complex has undergone more and more intense metamorphism from north-east to south-west as the granite body is approached.

At the head of the large and deep valley of the Khalkhal glacier and, further westwards, in the valley of the Younghusband glacier, the rocks grade into those of the metamorphic belt surrounding the Baltoro granite batholith.

(2) See Petrographic Description of the Specimens, p. 264.
3. Falchan Kangri.

a) INTRODUCTION.

The Falchan Kangri (once Broad Peak, 8051 m), the third highest peak of the Karakorum range, stands between the Godwin Austen glacier, to the west, and the North Gasherbrum glacier, to the east (fig. 7). Northwards, it ends in the upper valley of the Godwin Austen glacier, just in front of the south-east face of K2.

From the west, the summit of the mountain has a dome-shaped form truncated towards the lower Godwin Austen glacier by steep walls. The highest ridge is divided into three main peaks of which the southern is the highest (pl. III fig. 2 and pl. IV).

The east side of the Falchan Kangri descends steeply to the North Gasherbrum glacier (Shaksgam basin) (pl. III fig. 1). We take as the southern limit of the mountain the Falchan-la, the lowest saddle of the ridge joining the Falchan Kangri to the Gasherbrum. Northwards, the limit of the Falchan Kangri is taken at a saddle at the head of the Kharut glacier, a tributary of the Godwin Austen glacier.

Of the highest mountains of the Baltoro basin the geology of the Falchan Kangri is perhaps the easiest to investigate, because of the favourable configuration of its western side, which overlooks the Godwin Austen glacier, and because of the lithology of its rocks which are characterised by distinct and various colours, some of which can be recognized from a distance.

The study of this massif was chiefly facilitated by observation of the rock outcrops from a short distance, and by study of the few samples of country rock collected in place and a number of erratics gathered from the moraines of the glaciers on the western side of the mountain. Taking into account the relatively short length of the glaciers, it was a fairly easy task to identify the origin of the morainic materials and hence to deduce the geology of the western side.

Further data, confirming the geological interpretation, were provided by valuable rock fragments which MARCUS SCHMUK, leader of the 1957 Austrian expedition to Falchan Kangri, kindly sent us when we were writing this chapter. These fragments will be further mentioned later on.

The surface covered by ice is far greater on the northern side of the massif; however, we were able to collect samples of rock in situ as well as from
Fig. 7 – Orographic sketch-map of Falchan Kangri ridge.
the talus, so that it has been easy to identify the origin of the latter. For the eastern side of the mountain, which belongs to the hydrographical basin of the Yarkand river and which dominates the North Gasherbrum glacier with its very high ice-encrusted flanks, we only possess data collected by A. Desio during the Duke of Spoleto's expedition in 1929.

b) Previous knowledge.

We do not wish to dwell on the preceding geological work, but it must be recorded that we owe to V. Novarese the first, though brief, petrographic study of rocks from this area collected by the 1909 expedition led by the Duke of Abruzzi. On page 75 a "moraine with calcareous elements, collected along the walls of the Broad (Peak)" is recorded. The following pages contain descriptions of various types of limestone, but it is not stated which ones come from the Falchan Kangri group. Further on, the author records that "limestone is predominant in the upper portion of Broad... The basal schists are seen to crop out at the foot of these mountains...". Further on, the author poses questions about the age and attitude of these schists, but does not succeed in giving answers.

The first geological data on rocks directly collected in situ is that published in two preliminary reports by A. Desio (1930a, b). Among other things these reports announce the great extent of limestone, one of the main rocks constituting the Falchan Kangri and record the finding of limestone containing Permo-Carboniferous Neoschwagerinae in the moraine of the glaciers coming from this massif.

The description which was published in 1936 in the official volume of the 1929 expedition of the Duke of Spoleto is more detailed, and gives an outline of the geological constitution of the massif. A stratigraphic series reconstructed on the northern side of the mountain is also reported. Among the data collected at that time, but which cannot be confirmed as the samples were lost, is the presence of gypsum. This is actually a white, polverulent, autoclastic limestone. We will not report here the description published in 1936. However, it must be recorded that the geological information contained in G. O. Dyhrenfurth's work (1939) was compiled on the basis of the above mentioned publication. Later (1961), T. E. Gattinger also wrote on the same massif.

Gattinger's conception of the geological constitution of the Falchan Kangri is chiefly expressed in his geological map and block-diagram. According to him the mountain massif is for the most part composed of a) "Schwarze Schiefer u. Phyllite, b) Kalkschiefer u. Kalkphyllite, c) Hellgelbe bis weissliche dichte Kalke, and d) Granite, teilweise wergreist". Two thin bands of "Schwarze mergelige Hagenkalke" and one of "Bänderkalke u. Bänderdolomite" are supposed to outcrop at the top of the eastern slopes.

The block-diagram indicates that the massif is underlain by an anticlinal structure with an approximately east-west axis and that a suite of tectonic disturbance lines ("beobachtete Störungslinien") occur in the middle and upper portion of the mountain.

It is perhaps needless to criticize Gattinger's work at this point. The geological data to be given in the following pages, drawn from direct observations and based on samples collected in situ, sufficiently demonstrate the groundlessness of this work. I would
only like to refer to some of the more salient mistakes. For instance, there are no granites in the Falchan Kangri, though according to GATTINGER a considerable portion of the north-west side of the mountain is composed of this rock.

Other non-existent, smaller granite outcrops are indicated by GATTINGER in the South Falchan Kangri glacier and West Gasherbrum glacier basins.

The southwestern side of the Falchan Kangri, which he indicates to be underlain by "Schwarze Schiefer u. Phyllite" is, on the contrary, mostly underlain by diorite. GATTINGER does not even mention this rock, even though it constitutes such a considerable portion of this side.

According to GATTINGER, the long southwestern spur of the Falchan Kangri is underlain by the black slate; on the contrary it is mostly composed of green arenaceous schist of the Khalkhal formation.

The summit of Falchan Kangri is not composed of Schwarze mergelige Lagenkalke of "Permo - Karbone Kalk-Dolomite" but of Cretaceous Khalkhal sandstone and conglomerate, etc.

If one compares GATTINGER's map with DESIO's first geological drawing of 1929, on a much reduced scale (DESIO 1936), the same mistakes in GATTINGER's work can be observed. No mention is made of this drawing in GATTINGER's work. One also wonders how GATTINGER, who did not collect even one rock sample from the Falchan Kangri, was able to produce such a relatively detailed geological map.

The consequences of these facts have already been mentioned.

b) GEOLOGICAL DESCRIPTION.

The beds which occur in the spur of the above described Khalkhal ridge, cross from the western to the eastern side of the valley of the Godwin Austen glacier.

The rocks of the calcareous conglomeratic formations of the Savoia glacier and Khalkhal ridge constitute a large portion of the western side of the Falchan Kangri, outcropping between the big ridge descending from Falchan I North and the southern glacier of Falchan Kangri.

Two main faults affect the beds, some of which might be repeated. Other faults, difficult to observe from a distance, cross the mountain, as will be shown later. However, the basement underlying the sedimentary formations was observed by us on the north-western rocky spur of Falchan Kangri, around which the Godwin Austen glacier passes in an elbow shape (small saddle, 4960 m high). This basement is a metamorphic complex, mainly composed of gneiss, which appears to be tectonically separated from the sedimentary rocks. It is thus impossible to determine stratigraphical relationships between the gneisses and the sedimentary sequence.
On the western side of Falchan Kangri, at an altitude of about 5000 m, several samples were collected from the talus descending from the walls of the above mentioned spur. Studies by B. Zanettin have shown them to be:

54 PD-60 *Porphyroblastic plagioclase gneiss*;
54 PD-61 *Garnetiferous biotite parascist. «Black slate» type*;
54 PD-62 *Porphyroblastic quartz-feldspathic arenaceous gneiss*.

On the small saddle at the base of the western spur of Falchan Kangri we also collected:
54 PD-70 *Plagioclase porphyroblast-bearing fine-grained biotite gneiss*. Similar to the «K² gneiss»;
54 PD-71 *Pegmatitic dyke* in the schists; near the edges metasomatic feldspar has been introduced.

The schistosity dips south-southeastward at 50°, and the following upward sequence is observed (fig. 8):

1) black garnetiferous biotite parascist (54 PD-61), more than 250 m thick;
2) plagioclase porphyroblast-bearing fine-grained biotite gneiss (54 PD-70);
3) grey-green quartz-feldspar gneiss (54 PD-62): the combined thickness of units 2 and 3 is about 160 m;
4) black biotite paraschist, about 50 m thick;
5) light, grey-green quartz-feldspar gneiss (very thick).

Pegmatitic dykes cross this sequence.

The section between the small saddle at 4960 m and the northern bank of the glacier to the north-northwest of Falchan Kangri is probably between 600-700 m thick. The sequence continues upwards as gneisses similar to those of layers 2 and 5. The last one probably forms a considerable portion of the top of Falchan II North, and underlies the sedimentary sequence. From a distance they are light-green in colour, differing from the colour of the other gneisses. They can thus be identified with rocks fragments of the same colour to be found in the talus.

The previously described Savoia and Khalkhal sedimentary formations are continued, from north to south, along the eastern side of the Godwin Austen glacier. A fault locally severing the metamorphic from the sedimentary rocks can be seen from a distance (pl. III fig. 2). On the southern side of the small valley of the North-northwestern Falchan glacier.

The rock crossed by the fault comprises the wall of the left bank of the above mentioned valley near its outlet. This wall is made up of fine-grained biotite gneiss with plagioclase porphyroblasts, similar to the «K² gneiss» in which occur huge fragments of grey compact limestone forming a sort of cyclopic breccia (fig. 9). A fault plane lies above this breccia; the plane of the fault being marked by a friction breccia composed of fragments of basement gneiss and limestone fragments from the overthrusted beds.

Overlying the fault plane is a formation of grey, strongly laminated, calc-schist crossed by numerous calcite veins. The schistosity dips south-south-east at an angle of 50°.
Along the western slopes of Falchan Kangri a rather thick sequence of calc-schist and lamellar limestone occurs (pl. V), containing, towards the south, thin beds of yellowish and grey limestone forming a group of beds several tens of metres thick, on the right side of the small valley of the north-west Falchan glacier near to its outlet. On the opposite side of the valley the calc-schist and flaggy limestone are intensely folded. The same formation continues southwards.

![Geological section across the outlet of the valley of the North-west Falchan Glacier](image)

Fig. 10 – *Geological section across the outlet of the valley of the North-west Falchan Glacier* (from Desio's field book).

Sc calc-schist and l limestone of the Savoia formation.

The attitude of the beds of calc-schist and limestone on both sides of the valley of the North-west Falchan glacier near its lowest end is very irregular, as can be seen in the drawing (fig. 10).

Two samples, one of grey limestone (54 PZ-149) and one of whitish limestone (54 PZ-149/a), were collected *in situ* near our camp, close to the eastern edge of the Godwin Austen glacier, between the northwestern and western glaciers of Falchan Kangri, and have been summarily examined and described by M. B. Cita (Desio and Cita, 1955).

The grey limestone, which becomes almost blackish when wet, is very pure and finely brecciated, but compact, and cut by fractures filled with secondary calcite. The white limestone is very pure, saccharoidal and crystalline, with a uniform texture, and rather faint, grey spots irregularly distributed in the ground-mass. Examination under the microscope shows that none of these samples contain organic remains.

Further south, in the long rock spur on the left side of the Godwin Austen glacier, the contact of the calc-schists and the previously mentioned yellowish and grey limestone with a complex composed for the most part of sericitic sandstone occurs. These rocks are not very different from those of the Khalkhal formation, but are finer grained. A sample (54 PZ-150) of these
light green phyllites, collected in situ on the west-southwest side of Falchan Kangri, near our camp, was examined by B. Zanettin who found it to be very similar to samples 54 PZ-142 and -143, from the Khalkhal ridge, but differs in that, under the microscope, it is seen to be more schistose. The schistosity planes are discordant with the bedding planes.

All these observations confirm the continuation of the Khalkhal formation along the eastern side of the valley of the Godwin Austen glacier. The contact between the Savoia Limestone and the arenaceous complex appears to be normal, whilst two faults, parallel to the bedding planes, can be seen in the previously-mentioned calcareous-schistose sequence (fig. 11).

Fig. 11 – Geological section along the western spur of Falchan Kangri between the South-west Falchan Glacier and the West Falchan Glacier (from Desio's field book).
Ks Khalkhal Sandstone, Sc Savoia Limestone, x fault.

The southern end of the same spur, which flanks the southwestern glacier of Falchan Kangri, is entirely composed of slate and green sandstone, whilst on the opposite spur, on the left side of the glacier, a sequence of light-coloured marbles followed by black slates, quite similar to the Marble peak sequence, crops out.

Observations made, from a distance, of the highest slopes of Falchan Kangri, and with the help of samples collected from the moraines of the glaciers flowing from these slopes, have yielded further data on the geological structure of the massif. The view taken from a photograph (fig. 12) gives a synthesis of the direct observations, and will be referred to in the following description. Above the gneissic formation of the northern side of Falchan II North, can be recognised, from the bottom upwards:

(1) quartzo-calcareous sandstone and green phyllitic slates, of the same types as those of the Khalkhal formation, which seem to constitute the rock faces descending from the southern side of Falchan II North as far as the sad-
Fig. 12 – Geological structure of the north-west side of Falchan Kangri (Desio).

β: baltorite (red), Ks Khalkhal Sandstone (pink), Sc Savoia Limestone (red vertical lines), Ι grey limestone ( Permian?), Fg Falchan Gneiss, Kg* Kg* Gneiss, glaciers (white), faults (red lines). 1 quartzo-calcareous sandstone and green phyllitic slates; 2 red breccia and conglomerate; 3 light grey or greenish rock with intercalations of blackish schistose rock; 4 grey thin-bedded limestone with few thin arenaceous beds associated with grey veined limestone; 5 green quartzo-calcareous sandstones and green and red breccia; 6 Grey calc-schist and thin undulating limestone beds.

dle between this and Falchan I North. The contact with the metamorphic formation is probably tectonic.

(2) Red breccia, grading into conglomerate with arenaceous cement: the pebbles and angular fragments of the breccia are composed of crystalline limestone and a red arenaceous, or clayey-arenaceous, rock (54 PD-76) (1).

The breccia and red conglomerate can easily be placed in the Falchan Kangri sequence, since it can be clearly distinguished, due to its characteristic colour, on the southern side of the saddle separating Falchan I North from Falchan II North.

Overlying the conglomerate can be distinguished:

(1) These samples were collected on the underlying glaciers. Description and place of origin is given later and in the Petrographic Description of the Specimens, p. 235.
(3) several metres of light-grey or greenish rock, probably of arenaceous-type, with intercalations of a blackish schistose rock which cannot be firmly identified among the samples collected from the moraines of the underlying glacier.

(4) Grey, thin-bedded limestone (54 PD-73), with a few thin, slightly arenaceous beds, associated with compact, grey, veined limestone, often containing crystals of pyrite and, more rarely, chalcopyrite and hematite.

Numerous blocks of such rocks can be seen in the central portion of the North-northwest Falchan glacier associated with white and dark grey sub-crystalline limestone, with «black slates», with green-grey quartz-feldspar gneiss, and with red and green conglomerate. The presence of morainic blocks composed of strongly brecciated limestone, or autoclastic breccia, similar to a mylonite, confirms the existence of a fault at the base of the limestone layer and of another fault crossing this layer diagonally. These faults can be clearly seen from the Godwin Austen glacier (pl. III fig. 2). The limestone besides outcropping on the northern side of Falchan I North, where it forms a bed about 40 metres thick, crops out more extensively on the south-eastern side of the head of the North-northwestern Falchan glacier. The outcrop is triangular in shape, with a maximum thickness of almost 200 m, but narrowing eastwards and westwards due to faulting (1).

Above the limestone can be distinguished:

(5) green, well-bedded rocks, with a few red-coloured intercalations, whose nature may easily be deduce from the morainic blocks scattered on the North-northwest Falchan glacier. These rocks are green quartzo-calcareous sandstones, similar to sample 54 PD-75, associated with green and red-green breccias (29 KD-52).

The floating moraines of the North-northwest Falchan glacier contain, on the right side, black biotite schist, grey and whitish limestones, and gneiss similar to the «K\(^2\) gneiss», most of which derive from the northern side of the valley, whilst towards the centre the grey and whitish limestones and red conglomerate are more frequent. Fragments of «baltorite» also occur in this central position (2).

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(1) The thickness was calculated using photographs taken with a telescopic lens with reference to quoted points, and available data on inclination of beds, and must be considered approximate.

(2) We prefer to maintain the term «baltorite» for the lampophyric dyke rocks of the high Baltoro, even though its use in this connection has been criticized. Even though chemical and petrographic study of some samples of these rocks by C. Viterbo and B. Zanettin show them to be vogesite and minette, it is often impossible to collect samples from the many dykes of this type that occur here and there throughout the region, so that the collective term is more useful here.
Numerous samples were collected from the moraines of the glacier descending from the saddle between the Falchan I North and Falchan II North peaks, but some of them were unfortunately lost by the porters.

The following are the remaining samples:

54 PD-72. Pyroxene minette. From the right moraine of the North-northwest Falchan glacier.

Fig. 13 – Sample 54 PD-76 of multi-coloured conglomerate (Khalkhal Sandstone) from Falchan Kangri (3/4 of the natural size).


54 PD-73/2. Grey brecciated limestone. From the same locality. Brecciated limestone or microcrystalline calcareous breccia with grey and black fragments, of somewhat aspect, containing a thin, elongate, reticulate structure, perhaps of organic origin.

54 PD-75. Green calcareous arenite. From the same locality. Not very different from samples 54 PZ-142 and -143, and especially 54 PD-68, all from the Savoia formation, and which have already been referred to. However, the present sandstone is more calcareous and less compact.

54 PD-76. Multi-coloured breccia with red cement, grading into conglomerate (fig. 13). From the same locality. Breccia of prevalingly red colour with red, calcareous-arena-
ceous cement, sometimes so coarse-grained that the cement itself passes into breccia. The included fragments are predominantly angular, but some are rounded, and they vary in size from a fist down to the grain size of the arenaceous cement. The breccia fragments are prevalently waxy, grey and white limestone, white semicrystalline limestone, reddish sandstone, and reddish, arenaceous schist.

Samples 54 PD-77 to 54 PD-86 were lost by the porters. We can, however, remember the names written on the labels. All the samples were collected from the same moraine of the North-northwest Falchan glacier, except for samples 54 PD-78 and -79:

54 PD-77. *Friction breccia* (calcareous).
54 PD-78. *Micaceous gneiss*, including blocks of limestone. From the left side of the valley of the North-northwest Falchan glacier.
54 PD-79. *Limestone*, included in the gneiss. From the same locality.
54 PD-80. *Conglomerate with green arenaceous cement.*
54 PD-81. *Siderite vein.*
54 PD-82. *Calc-schist.*
54 PD-83. *Light-coloured limestone.*
54 PD-84. *Grey limestone.*
54 PD-85. *Green conglomeratic sandstone.*
54 PD-86. *Greenish quartzite* (probably green calcareous arenite).

It should be noted in connection with the last sample that the same field-name, «greenish quartzite», is also given on the label to sample 54 PD-75, already mentioned, which in thin section has been identified as «green calcareous arenite». It is very probable that sample 54 PD-86 is of the same type.

In addition to the above-mentioned samples, mention must be made of two samples collected by *DESIO* from the moraine of the same North-northwest Falchan glacier, on 21st May, 1929.

They are: 29 KD-52. *Red and dark-green breccia* with green, more or less coarse-grained, arenaceous cement. The breccia fragments vary in size from a fist down to the grain-size of the cement, and are both partly angular and partly rounded. They are composed of red sandstone, brown quartzitic sandstone, and white waxy limestone.
29 KD-104. *Dark-grey «baltorite».*

The stratigraphic sequence of the ridge of Falchan Kangri, interrupted by the fault, continues southwards with the sandstone and red conglomerate layer 5, while below them occur K\(^2\) gneiss and black biotite-schist of the Falchan gneissic formation. The Falchan I North peak is composed of the former, sedimentary, rocks. This peak shows, at about one hundred metres from the top, on the north side, a forty metre thick intercalation of whitish rock which is probably a limestone similar to the underlying one. A fault plane could possibly run at the bottom of the intercalation. The top of the dome of Falchan Kangri is composed of green sandstone and conglomerate, chiefly on its northern side. On the highest crest of the mountain, reddish
and yellowish sandstone and conglomerate occur. The latter may represent a (transgression?) conglomerate located at the base of the overlying formation.

Near to the major summit, to the south, the arenaceous-conglomeratic sequence seems to be overlain by a light-coloured schistose rock which, from a distance, appears to be referable to the grey calc-schist with intercalated thin beds of compact yellowish limestone. Alternatively, it could be correlatable with sample I b mentioned just below.

The geologic composition of the top of the Falchan Kangri dome is also indicated by some rock fragments collected in place and kindly sent to us by M. SCHMUCK, together with some others collected near his Camp I during his successful expedition to Falchan Kangri (1).

The samples are as follows:

I. Broad Peak — 7.6. 1957, 5800 m. Collected near Camp 1st (2 small samples);
   (a) multi-coloured conglomerate with liver-red, arenaceous, schistose cement, with very flattened, small pebbles of white and reddish, waxy, subcrystalline limestone;
   (b) variegated white and red, waxy subcrystalline limestone, crossed by many calcite veinlets.

II. Broad Peak — collected north of the 1st camp, 5800 m. The Broad Peak, on its western flank, is crossed by black veins of this rock, several metres wide, which are inclined upwards from left to right.
   Blackish «baltorite», rich in black mica.

III. Broad Peak — 7.6.1957, 8030-8047 m. (5 small samples). The two rock types are:
   (a) grey sandstones, very similar to those of the Khalkhal formation;
   (b) whitish arenaceous rock, deeply weathered, composed of grains of feldspar and quartz, and dark minerals perhaps derived from biotite.

The most interesting of SCHMUCK's samples are the last ones, because they were collected between the northern pre-summit and the major summit of Falchan Kangri. Both the rock specimens without any doubt belong to the Khalkhal formation.

(6) Grey calc-schist associated with thin undulating limestone beds crop out — as has been already recorded — further below, on the slopes of the mountain and dip south-westward at about 50°. These rocks also constitute the spur separating the North-northwestern from the North-western Falchan glaciers. Some dark «baltorite» dykes can also be seen here.

(1) We are very grateful to M. SCHMUCK for these samples.
The thickness of the thin yellowish limestone beds intercalated in the calc-schist increases southwards.

The same rocks constitute the morainic blocks of the North-west Falchan glacier. The blocks are of grey calc-schist and green sandstone grading into red-green conglomerate and breccias associated with grey and light-coloured limestone which is often brecciated and veined with calcite. The limestone is the prevailing rock type.

Under the ice-wall which marks the edge of the over-hanging ice-plate beneath the saddle between Falchan Kangri and Falchan I North, occurs a sequence of dark rocks. Some of them appear to be green sandstone, some blackish and dark grey limestone, and some «baltorite» dykes of which numerous blocks can be seen in the above-mentioned moraine.

Further down on the southern side of the deep valley of the North-northwestern Falchan glacier, some samples were collected by M. Schmuck, as has already been stated. Two samples (Ia and Ib) from the neighbourhood of his Camp I are particularly interesting. The first one (Ia) corresponds perfectly to our sample 54 PD-76; the second (Ib) is very similar to the pebbles of the conglomerate mentioned above.

The other sample (II) collected 50 m to the north of the 1st camp, is of «baltorite». It is also written on the label that the veins are inclined upwards from left to right. This means they dip approximately northwards with high inclination. The «baltorite» corresponds very well to our sample 29 KD-104, studied by P. Comucci (1938, p. 79).

The floating moraine of the South Falchan glacier collects material from the three main ice-flows coming from the north-northeast, northeast, and east. Only the first two descend from the Falchan Kangri massif; the third is partly supplied by the nevè-fields of the Falchan Kangri, and partly by those of the Gasherbrum ridge, if we consider the Falchan-la (6500 m) to be the marker between the two groups. In the left moraine of the glacier, materials from the Gasherbrum ridge are mixed. The right moraine is mainly composed of white and grey marble with which are associated numerous fragments of grey and white limestones and, less frequently, grey, black, and rose-coloured waxy limestones, and flesh-red, green, and yellow calcareous breccias, sometimes brightly variegated. Red conglomerate blocks occasionally occur, as well as fragments of grey gneiss, fine-grained grey diorite, and sericitic schists.

Towards the central portion of the moraine diorite blocks become more and more numerous, until they become prevalent along the axis of the glacier.
Proceeding towards the left side of the glacier, grey and yellowish limestones, associated with diorite and "baltorite", become prevalent. The morainic material of the left flank is essentially composed of black biotite schist and marbles similar to those of the Marble Peak.

The samples collected in 1929 and 1954, and which were examined in part by B. Zanettin and in part by M. B. Cita, F. Villa, and A. Desio, are as follows:

54 PZ-153  Fossiliferous limestone. South Falchan glacier, left moraine. Compact, pure, waxy, biogenic white limestone with light grey spots. Among the white areas in relief, some show roundish forms of evidently organic origin (algae?).

To this sample four more are to be added, collected in 1929 by A. Desio at the same locality. They are:

29 KD-118  Grey and whitish subcrystalline limestones. Moraine at the outlet of the south-southwestern valley of Falchan Kangri. Several fragments from two types of limestone, one grey and one whitish.

   (a) The grey limestone is compact and rather dark in colour, with small white spots of calcite of probable organic origin. It is also crossed by a narrow calcite vein.

   (b) The whitish limestone possesses a more decidedly crystalline texture, is pale grey to rose coloured, and is dotted with dark minerals. It appears to grade into a calciphyre and to represent a considerably metamorphosed facies of the preceding rock.

29 KD-582  Dark grey biogenic limestone. From the same locality. Microcrystalline limestone with dark, small, rounded masses of 3-5 mm diameter, in a grey ground mass dotted with white bioclastic spots. Microscopic examination by F. Villa led to the identification of organic remains of foraminifera, including, probably, Neoschwagerinae. The sample, analogous to others from the Baltoro basin, is Permian in age.

29 KD-583  Grey, compact limestones. From the same locality. These include two types, one light grey and the other dark grey. The light grey limestones show a decidedly crystalline texture. Within the light grey material are dark, shaded areas, of various sizes and shapes, sometimes roundish and of probable organic origin. The dark grey limestone (black when wet) is compact and contains small, rounded, white calcite areas, probably representing calcitized fossils remains. The limestone is not very different from sample 29 KD-582.

29 KD-584  Dark grey, compact limestone. From the same locality. Dark grey, compact limestone with traces of schistosity. Within the dark material are numerous white areas of calcite that, without any doubt, are derived from organic remains, perhaps of small brachiopods. It is very similar to sample 29 KD-583/b.

54 PZ-156  Calciphyre with tremolite and serpentine. Moraine of the South Falchan glacier. The sample is composed of differing, subparallel bands: one type is light-coloured or slightly pale green, and calcitic; the other type is very dark green in colour, compact, and contains coarser, pale green serpentine acicules. Under the microscope the different bands appear to be prevalently constituted of tremolite, serpentine, magnetite, and calcite.

54 PZ-155/a  Contact between pyroxene-amphibole hornfels and serpentine. From the
same locality. The sample shows a contact between hornfels similar to that of sample 54 PZ-155 and a band containing serpentine.

54 PZ-155 *Pyroxene-amphibole hornfels, with epidote.* From the same locality. The rock shows a contact facies with the diorite of the type seen in sample 54 PZ-154. The igneous rock grades into the hornfels and is sharply separated from it by a band of serpentine (54 PZ-155/a).

54 PZ-154 *Biotite-pyroxene diorite, with potash feldspar.* From the moraine of the Southern Falchan glacier. The rock is of uniform medium-fine grain-size.

29 KD-581 *Greenish-grey, medium-grained augen gneiss.* From the same locality.

29 KD-49 *Green porphyrite (1).* From the same locality. According to P. Comucci's sample label.

In general, rocks definitely ascribed to the Savoia formation cannot be recognised in these samples, whereas, as will be shown later, some of the limestones can be compared to those of the Permian sequence of the Gasherbrum range.

Some of the limestones have been metamorphosed to calciphyre and hornfels by the intrusion of diorite, which produced a contact metamorphic aureole. The distribution of diorite outcrops on the southwestern side of the mountain can be seen from the end of the South Falchan glacier, as can be seen in

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(1) According to some authors: porphyritic andesite.
FALCHAN KANGRI

figs. 14-16. The diorite underlies all of the ridge of the Falchan-tso, outcropping here and there as satellite masses in the northern branches of the South Falchan glacier. But the main mass, as will be seen later, is located further south in the Gasherbrum ridge.

A more difficult problem is the identification of the outcrops of the various limestone types. The microfossils yielded by some samples (29 KD-582), and their close affinities with the limestone of the Gasherbrum ridge show them to be of Permian age. Others have been more or less metamorphosed by the diorite, so that identification of outcrops at a distance is difficult.

Fig. 15 - Geological view of the south ridge of Falchan Kangri between Falchan-tso and Falchan-la (Desio).

F8 Falchan quartz-diorite; Ks Khalkhal Sandstone; SI Savoia Limestone; PI Permian Limestone and marble (M).

The rocks of the right-hand moraine originate from the north branch of the glacier. This branch collected debris from the walls of the highest Falchan Kangri ridge and from the long spur which divides the glacier from the main Godwin Austen glacier. Rocks fragments of the Savoia and Khalkhal formations, such as grey limestone, red conglomerate, sericite-schist and also perhaps a multi-coloured breccia (unless this is a tectonic breccia), come
from the northern walls of the spur. The gneiss sample must also come from the upper part of the spur and belong to the Falchan Gneiss formation.

The wall at the head of the glacier basin is composed of grey and yellowish Permian limestone (Shaksgam Formation) or Savoia Limestone (fig. 15), and perhaps red conglomerate, while the long spur dividing the north branch from the south branch of the South-west Falchan glacier is composed of white and grey marbles intersected by massive outcrops of diorite. The parallel spur to the south has a similar composition to the preceding one, and frag-

![Geological view of Falchan-la between Falchan Kangri and Gasherbrum IV (Desio).](image)

Fig. 16 - Geological view of Falchan-la between Falchan Kangri and Gasherbrum IV (Desio).

$F$ Falchan quartz-diorite, $Pm$ Permian limestone.

ments of such rocks, particularly diorite, are numerous in the central part of the floating moraine of the South Falchan glacier. This part of the moraine, however, also collects debris from the basin of the main ice-stream of the glacier. Quartz-diorite blocks are concentrated along the axis of the glacier since they are supplied not only by the above mentioned spurs, but also by the large diorite outcrop at the crest between the Falchan-la and Gasherbrum peaks. At the head of the valley of the main branch of the South Falchan glacier, however, between Falchan-la and Falchan-tso, the rock is much lighter in colour and is also stratified (fig. 16). This outcrop must have supplied the morainic blocks of grey and yellowish limestones, some of which are fossiliferous, belonging to the Permian calcareous sequence. Blocks of «baltorite » indicate that dykes of this rock outcrop at the crest.

The left side of the moraine of the South Falchan glacier collects debris falling from the south wall of the glacier basin, that is, from the west spur of
the Gasherbrum IV. This will be referred to in the next section, dealing with the Gasherbrums. The outcrops of Comucci's "green porphyrite" were not identified. The serpentinite and hornfels lie close to one another in situ; we collected one sample (54 PZ-155/a) containing both rock types. These rocks come from the contact with the diorite body. The serpentinite form the outermost part of the thin aureole of calc-silicate hornfelses. Since the diorite body crops out extensively within the basin of the South Falchan glacier, we were unable to determine precisely the origin of the serpentinite fragments.

The tectonics of the Falchan Kangri will now be described. As can be seen from the fig. 17, two principal dislocation systems can be distinguished. One system is more or less parallel to the bedding planes and is
represented by overthrust surfaces whose importance is difficult to determine. One of these surfaces separates the sedimentary formations from the metamorphic ones, and a layer of Permian (?) limestone is included between the metamorphic rocks and the Khalkhal arenaceous formation. Probably the whole upper portion of the Falchan Kangri, composed of Khalkhal Sandstone, is overthrust on the Permian Limestone, and is thus affected by a system of numerous fractures and faults.

The Savoia Limestone, together with a strip of Khalkhal Sandstone, constitutes the western side of the Falchan Kangri and lies in a large, inclined blanket on the older metamorphic and sedimentary formations. It is not clear whether they are part of the same overthrust mass, or whether they constitute an independant overthrust mass. The presence of the ice blanket and the obviously complicated tectonics make a precise analysis impossible. The structure is probably that of an overthrust mass, anticlinal in shape, with the axis of the fold occuring high up on the western side of the mountain (fig. 17). Two younger east-west faults cross all the previously mentioned formations and tectonic planes. They are both reverse faults, the northern one with a relatively minor throw, and the southern one with a throw of some hundreds of metres.

Much of the southern and central part of the Falchan Kangri is occupied by the diorite body, which cross-cuts the sedimentary formations and is therefore younger than them. The diorite also cross-cuts and is younger than the Khalkhal Sandstone occurring in the highest parts of the Falchan Kangri. The major dislocations described above, do not affect the diorite body, though

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Fig. 18 – System of the most recent faults across Falchan Kangri (Desio).
to the south the contact of the diorite with the Gasherbrum limestone is probably due to a more recent fault.

A system of numerous, less important faults crosses the Falchan Kangri massif with a general east-west or east-northeast trend. These faults are easily seen in the field from Concordia (fig. 18). The faults that can be seen on the main crest of the Falchan Kangri proceed downwards along the southern slope of the mountain and cross the long western spur dividing the South Falchan Kangri glacier from the Godwin Austen glacier. As previously stated (pag. 35), this spur is composed of Savoia and Khalkhal formations of Cretaceous age, so that the faults must be more recent than Cretaceous. But some of the small faults also cross the diorite mass which, as we will see later, is more recent than the above mentioned formation. The age of this fault system must therefore be late Tertiary.


a) INTRODUCTION.

The Gasherbrum ridge, like that of Falchan Kangri, is one of the highest in the Karakorum. The ridge includes two peaks rising to over 8000 m: Gasherbrum I, also known as Hidden Peak (8068 m), and Gasherbrum II (8035 m). The Gasherbrum ridge lies between the valleys of the Upper Baltoro and the Abruzzi glaciers on the south-west side, and the valleys of the North Gasherbrum glacier, the Sgan glacier and the Urdok glacier on the north-east side. It is separated from the Falchan Kangri by the Falchan-la (fig. 7), and from the Sia Kangri by the Urdok-la. If the considerable altitude and the difficulty in climbing did not make the investigation practically impossible, the ridge would be ideal for a sedimentary stratigraphical study, being nearly completely composed of unmetamorphosed sedimentary rocks some of which are even fossiliferous.

Due to the shorter time spent in the Gasherbrum ridge the geological work is less detailed than that carried out in the Falchan Kangri.

(b) PREVIOUS KNOWLEDGE.

The first geological information on this mountain was given by T. G. Bonney and C. A. Raisin (1894).

These authors gave a short account of some specimens collected by Conway's expedition from the moraines of the Gasherbrum glaciers (pp. 58-59, 62 and 73). No fur-
ther indication of localities was given. Sample 247 is «a brownish-stained, dull, compact felspathic grit»; sample 277c was classified as «an impure limestone» characterised by «a finely laminated, rather compact pale brownish rock»; finally, samples 248 and 249 are recorded as reddish «dull, earthy limestone».

Another short report on the geology of this range was given by V. Novarese (1912 b), in which he examined the samples collected by the Duke of Abruzzi's 1909 expedition. Novarese refers to a «large moraine with calcareous fragments, with multi-coloured breccias and aragonite of various colours, predominantly wine-red, sloping down from the Hidden Peak and southern spurs of the Gasherbrum». On page 77, we read: «Limestones predominate in the upper part of the Broad and Gasherbrum; the schistose basement crops out at the foot of these mountains along the whole left flank of the Godwin Austen glacier and, eastwards, a little way along the Upper Baltoro, almost as far as the Mitre».

Indeed, until 1929, little was known on the geological composition of this ridge. The first information on rock samples collected in situ was given by A. Desio in two preliminary reports in 1930. In these reports we read that «the enormous group of mountains (Gasherbrum and Falchan Kangri) is almost entirely composed of grey and black limestone, occasionally assuming a schistose character and bearing fossils» of Permocarboniferous age.

According to G. Dainelli (1934, p. 993), within the south-west slope of the Gasherbrum, a «probable» Silurian-Devonian formation, overlain by Upper Paleozoic rocks, crops out. The tectonic position of the above formation is represented by a syncline. More precisely Dainelli writes: «The same syncline (of the Upper Siachen) with Upper Paleozoic core must be present on the south slope of the Gasherbrum, within the Upper Baltoro».

Later (1936), the geological structure of the ridge was widely given in more detail by A. Desio in the official volume of the 1929 expedition led by the Duke of Spoleto.

Note was made of limestone with Permian Neoschwagerinae, limestone with pelocypods which was ascribed to a probably Triassic age, and black limestone with Jurassic fossils (belemnoids ?). Other rocks, such as calcareous breccias, red schist, marbles, quartzites, black slate, diorites etc. were described. A few of these samples were collected in situ, and the rest from the moraines of the glaciers sloping down from the mountain. Some geological sections, one of which crossed the anticline of Gasherbrum I (Hidden Peak), and a short description of the tectonics, follows. This was the first concrete information on the geology of the Gasherbrums. Following this publication, very scanty information was published on the geological structure of the Gasherbrums. A short list of the rock samples which must have been collected from the moraines of the Abruzzi and Baltoro glaciers, and thus came from the Gasherbrums, is to be found in a book by G. O. Dyhrenfurth (1939 pp. 54-55). However, the origin of the rock types is not mentioned. They correspond to types which had previously been discussed by A. Desio, and included «black limestone (with Aulacoceras ?)» which had previously been mentioned by the same author. Only one other sample, «a limburgite (basalt)», was recorded, collected by Neltner on the south spur of Gasherbrum I. It presumably corresponds to our «baltorite».

Considering that the members of the expedition stayed rather a long time on the Abruzzi glacier and also penetrated the basin of the South Gasherbrum glacier, it can be
assumed that they were not particularly interested in the geology, but, like almost all the members of the subsequent expeditions, were only interested in conquering the mountains.

No further information on the tectonics of the Gasherbrums was forthcoming from this expedition. Of the subsequent expeditions, the only one among whose members was a geologist was the Austrian expedition led by F. Moravec to Gasherbrum II. The geological results were illustrated by T. E. Gattinger (1961), who devoted a section to the Gasherbrums (from page 74 to page 81), as well as a geological panorama, a part of a geological map at the scale of about 1:83,000, and part of a geological block-diagram. Descriptions of 45 rock samples were carried out by H. Scharbert: however, no precise information is given on the localities from which the rocks were collected, so that the data lose some of their importance.

Before summarising the report of T. E. Gattinger mention must be made of several mistakes and gaps in the author's knowledge of the geological bibliography. Firstly, Gattinger credits (p. 85) the discovery of limestones with Neoschwagerina craticulifera, to G. O. Dyhrenfurth whereas this author (1939, p. 54) only summarised Desio's work of 1930 and 1936, in which such data are repeatedly reported together with other data of the same kind. Secondly, T. E. Gattinger ignores all publication on the Baltoro region by Italian geologists after 1936. His bibliography is limited almost exclusively to works written in German, thus failing to take into account the fact that most workers who dealt with the geology of the region published their works either in Italian or English.

Had he cared to read such reports, he would certainly have avoided publishing such mistaken information, and giving tectonic interpretations which are merely products of his imagination. It is not worth while to discuss this work in detail especially since it has already been criticised and reviewed by one of us (Desio, 1963 a). Therefore, we will only add some remarks on his geological map of the Gasherbrums, which must be considered as a detailed map due to its large scale (about 1:83,000).

The northern half of Gasherbrum IV is not made up of "mittelgraue schichtige Kalke, teilweise dolomitisch", but of quartz diorite. The lithostratigraphic classification of limestone of the Permo-Carboniferous sequence into five units differing in age is also imaginary.

On the southeast side of the Gasherbrum, Gattinger's map shows a wide outcrop (2 × 4 km) of "basische Ganggesteine, postplozän", isolated within the ice, but indicated to extend in a far wider area under the ice. The only dyke rocks to be quoted in H. Scharbert's list are minette and augitic kersantite. It seems strange that these rocks should constitute such extensive masses: they were not seen by A. Desio when he was in the area. He did, however, notice some rather narrow dykes of a basic rock which had been called "baltorite" by P. Comucci.

Two samples of porphyrite were collected by A. Desio in 1929 from a floating moraine of the Upper Baltoro glacier, which possibly originated from the head of the Abruzzi valley. We will return to this subject later.

The attribution of three layers of clastic rocks, one to the Lower Triassic, on the grounds of supposed similarity to the Alpine Werfen, and the others to the Lower Tertiary, is not supported by any valid evidence.
The errors in Gattenger's map involving the east side of the Gasherbrum range will not be listed here: suffice it is to say that this side was only seen from a distance by Gattenger, who did not check the material from the moraines.

As a consequence of the above mistakes the tectonic interpretation is also false. The sample list is of a certain interest, since it was compiled by a well-qualified petrologist.

c) GEOLOGICAL DESCRIPTION.

As has already been stated, the Gasherbrum range extends from the Falchan-lā in the north to the Urdok-lā in the south. The south branch of the South Falchan glacier separates the western side of the range from the Falchan Kangri.

The composition of the blocks in the moraines of this glacier is of great interest and in particular those of the left-hand moraine which is chiefly supplied by the Gasherbrum IV (pl. VI). This moraine is prevalently composed of quartz diorite and different kinds of limestone which have already been recorded. Near the Falchan-lā the contact can be seen between the limestone, which is probably Permian, and the quartz diorite, which composes the rest of the spur and also the east portion of the west spur ending on the peak 6925 m high (fig. 16).

The composition of this spur, which separates the South Falchan glacier from the West Gasherbrum glacier, is of particular interest. Near the eastern edge the black slates appear, dipping southwest with varying inclinations (maximum 50°).

Below the black slates, grey and whitish limestones, with intercalations of calcareous schists and other black slates, crop out to the south, as can be observed from the opposite side of the valley of the Godwin Austen glacier.

The principal black slates are overlain by a sedimentary complex of grey and white limestones, most of which are markedly crystalline. These constitute the small ridge forming the western edge of the spur and up to the highest point, at 5393 m. Further east the spur is crossed by a belt of sericitic arenaceous schists, some fragments of which are visible on the right floating moraine of the South-west Gasherbrum glacier, as will be later mentioned.

This schist band, included between the black slates to the west, and marble to the east (the latter in direct contact with the quartz diorite), is limited to the south by a fault, and is the direct continuation of the beds of the Khalkhal formation. These beds, crossing the valley of the Godwin Austen glacier, compose the great ridge rising at the confluence of the South Falchan glacier with the Godwin Austen glacier, as already mentioned. Its thickness is considerably reduced, probably due to the same fault. That the same schist band crosses the whole western spur of Gasherbrum IV is
verified by the presence of some fragments of sericitic arenaceous schist in the right moraine of the West Gasherbrum glacier.

We are now at Gasherbrum IV, the mountain peak rising behind the West Gasherbrum glacier. The west wall of Gasherbrum IV is visibly cut by a vertical plane (fault?) marking the contact of two very different rocks, a dark one to the north, and a light one to the south (pl. VI). There is no doubt about the nature of these rocks. The first one is a quartz diorite, numerous samples of which may be collected in the central moraine of the South Falchan glacier and in the right moraine of the West Gasherbrum glacier, while the second one is a limestone (fig. 19).

In the latter moraine, white and grey compact limestones, white marble, tabular-bedded grey and black limestones and white-veined sericitic and chloritic schists are associated with the quartz diorite (one sample contained alternating bands of schists and limestone).

W. Bonatti, who conquered the Gasherbrum IV in 1958 (1), collected some samples confirming our interpretation.

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(1) We thank W. Bonatti for his small, but valuable, collection of rocks.
The samples collected by W. Bonatti and studied by Zanettin are the following:

No. 1 *From the eastern crest of the Gasherbrum IV*. Blastocataclastic quartz diorite. Quartz and, in subordinate quantity, potash feldspar are associated with plagioclase and amphibole, the principal components.

The rock has evidently been affected by tectonic action. The quartz has undergone cataclasis, hornblende has been mechanically deformed and partially transformed, while plagioclases, partly fractured, have been largely transformed into sericite. Potash feldspar on the contrary, is perfectly clear, sometimes including much altered plagioclase, suggesting that crystallization, or recrystallization, of potash feldspar occurred later than the principal phase of deformation.

No. 2 *From the small saddle between the “granitic” and calcareous rocks on the eastern spur of Gasherbrum IV; sample of the “granitic” rock.*

Blastocataclastic quartz diorite. This rock is very similar to the previous sample (No. 1). It can be distinguished from the former by its stronger parallel structure and better state of preservation of the plagioclases. Traces of an original zoning in the plagioclases have been mostly obliterated by a later process of homogenisation.

The rock may be defined as a blastocataclastic quartz diorite, locally rich in potash feldspar.

No. 3 *From the highest summit of Gasherbrum IV.* Calcareous breccia.

Numerous fragments, less than 1 mm to 1 cm in size, of a somewhat grey, waxy, strongly fractured limestone are included in a white calcareous matrix.

The rock is a calcareous mylonite, evidently connected with faulting.

The limestone fragments correspond to the grey compact limestone of Permian age outcropping in the same mountain.

No. 4 *From the end of the 700 m high ice-fall.* Waxy limestone.

Microcrystalline, greyish-white, waxy limestone, with a jagged fracture. The weathered surface is slightly yellowish.

The rock corresponds to sample 54 PZ-97 of K₂. A small fragment of greyish-white crystalline limestone with a brown weathering surface occurs with this limestone.

The quartz diorite should be correlatable with samples which we collected in the moraine of the South Gasherbrum glacier (54 PZ-154), but there are no structural analogies, and pyroxene diorite, so common in the sample we collected, is lacking in the samples collected by W. Bonatti.

The calcareous mylonite, evidently connected with faulting, contains limestone fragments corresponding to the grey limestones which are to be found in the moraines of the West Gasherbrum glacier.

The composition of the moraines of the West Gasherbrum glacier at its terminal end, near the confluence with the Upper Baltoro, will now be described.

Near the right flank, white compact limestone fragments predominate, associated with white marbles, grey and blackish foliated limestones, black
slate, sericitic and chloritic schists interbedded with limestone, diorite, and "baltorite". All these rocks come from the spur which separates the South Falchan glacier from the West Gasherbrum glacier, as has already been mentioned. Some hematite blocks are present among the materials composing this moraine. From the right side of the moraine towards its centre the quartz diorite fragments become more and more frequent until, at the centre, they are far more prevalent than the other rock types, of which various limestone types are most frequent.

Crossing towards the left side, the limestones become more and more numerous, until they exceed the other rock types.

The origins of the above listed rocks are relatively easy to identify. White marbles and limestone come mostly from the north-east slope of the peak at 5393 m. The sericitic and chloritic schists with interbedded limestone are visible in the narrow gap of the west spur of Gasherbrum IV, below the peak at 6218 m. They belong to the Khalkhal (and Savoia) formation and can be correlated with the larger outcrops of the south-west spur of Falchan Kangri.

The schist outcrop within the gap is limited by a fault which, to the east, eliminates the formation. The numerous blocks of quartz diorite come from the large outcrop of this rock composing the west spur of Gasherbrum IV culminating on the peak at 6925 m. This outcrop also supplies many blocks of quartz diorite to the moraines of the south Falchan glacier (fig. 19).

The limestones found in the left moraine of the West Gasherbrum glacier confirm that the whole eastern slope of the basin is composed of these rocks. But there are different types of limestone and it is difficult to distinguish the source of each. The Gasherbrum IV is probably composed of light-coloured, thick-bedded Triassic limestone (Aghil Limestone), and the Gasherbrum V and its west spur of grey and yellowish limestone of the Shaksgam Formation (Permian and Upper Carboniferous), and containing minor interbedded dark slates (fig. 20).

The peak at 5603 m, on the east side of the confluence of the West Gasherbrum glacier, is composed of grey and yellowish limestones, which are rather different from those of the opposite side. The same grey limestone, with a yellowish weathering surface, composes the left spur of the confluence of the South Gasherbrum glacier with the Upper Baltoro glacier, and also the mountain standing above it. The beds dip at 55° to the south-southwest.

These limestones overlie black slates and dark sandstone and extend towards Gasherbrum V (7321 m), of which they compose the top. It must be mentioned that in this group the limestones become more crystalline south-
westwards, though they retain evidence of their organic origin in the com-
pletely calcified fossil remains.

![Geological section across the crest from Gasherbrum IV to Gasherbrum V (Desio).](image)

**Fig. 20** - *Geological section across the crest from Gasherbrum IV to Gasherbrum V (Desio).*

8 quartz-diorite, Al Aghil Limestone, Sh+1 dark shales and slates with limestone intercalations, Sh black slates.

The south-western slope of Gasherbrum V is composed of black slates with some arenaceous intercalations, generally dipping northwards at 45°. Near the top of the peak at 6103 m (Chochordin crest), a suite of overturned folds occurs in these slates (fig. 21).

A sample of slate (54 PZ-163) which was collected in situ, shows the following characteristics.

54 PZ-163. **Black slate.** Very dark schistose rock, easily splitting in thin slabs. The surfaces of the slabs are feebly rippled.

Under the microscope the schistosity is made evident by an alternation of light and dark bands, which depends on the carbonaceous content.

![Overturned fold on the Chochordin crest](image)

**Fig. 21** - *Overturned fold on the Chochordin crest (from Desio's field book).*

The mineralogical composition is very simple. Quartz is contained under the shape of grains crushed along the schistosity planes; phengite is in tiny laminae; chlorite is mostly lenticular. Then there are albite, iron oxide and rutile. Laminae of light phyllosilicates are very rare but sufficiently well developed. The rock is always fine-grained with the exception of the quartz grains which are larger. Also the shape of such grains is more round than those of the other minerals.
Another sample (29 KD-208) was collected in situ by A. Desio at the western edge of the spur culminating at 5632 m. It was examined by P. Comucci (1938, p. 187) and classified as a minute black-brown quartzite.

Between the limestone at the top of the Gasherbrum V and the black slates there occurs a sequence of mostly white or light-grey limestone separated by intercalations of black shales (?). In the lower part the beds are dipping at 45°-50°, but steepen upwards, until, at the summit ridge of the mountain, they become almost vertical (fig. 22).

Fig. 22 — Geological section across the southern spur of Gasherbrum V (from Desio’s field-book). I grey and white limestone, dl dark limestone of the Shaksgam Formation; sh black and dark slates with sandstone intercalations, x fault.

The materials carried by small glaciers flowing down from the south-western side of the Gasherbrum V and forming the moraine of the right bank of the Upper Baltoro glacier yielded some interesting data on the geological composition of this slope of the Gasherbrum ridge. It is useful to report here the list of samples.

54 PZ-157 Light-grey fossiliferous limestone; saccharoidal with jagged fracture, on the weathering surfaces plentiful, small, dark, roundish sections of foraminifera occur. Some of these are large Fusulinidae while, among other fossils, fragments of bryozoans and organic traces of uncertain origin can be distinguished. Ca CO₃ 93%, Ca Mg (CO₃)₂ 4%.

54 PZ-158 Fairly dark grey, fossiliferous, very compact limestone somewhat similar to that of sample 54 PZ-159. In addition to some oolite the rock contains some indeterminable remains of pelecypods. (Ca CO₃ 97.3%).

54 PZ-159. Fairly dark grey, very compact oolitic limestone with irregular fracture and a characteristic spotted aspect due to the presence of numerous small, black, roundish masses of one to three millimetres in diameter. At first sight these can be mistaken for fossils but microscopic examination by M. B. Cita (1955) has shown them to be calcareous ooliths.

54 PZ-160. White, almost pure, fossiliferous crystalline limestone, like marble, with many fossils.
On a broken surface the rock is seen to be a saccharoidal limestone, with small roundish Fusulinids, among which R. Ciry and M. Amiot (1965) identified *Hemigordiopsis renzi* Reichel of the Lower Permian. Some of the fossils are, however, more evident on the slightly yellow weathered surfaces than on the fresh surfaces.

Other foraminifera, smaller in size and with calcareous instead of arenaceous test, are contained in the rock. According to M. B. Cita (1955) these are *Miliolidae*, most of them belonging to the genus *Quinqueloculina*.

54 PZ-161. *Blackish limestone*, with a distinct aspect, in hand specimen, due to the presence of numerous elongate white masses, irregularly roundish or oval in section, which appear to be fossils: the nature of these masses is, however, uncertain.

The sample contains some remains of cylindrical corals 3 to 5 mm in diameter, which are completely calcitized (fig. 23).

54 PZ-162. *Blackish, very compact, fossiliferous limestone* characterised by the presence of large, white, curvilinear tracks. (Ca CO₃ 97.3%).

![Fig. 23 – Blackish limestone with calcified corals from the right moraine of the Upper Baltoro Glacier (sample 54 PZ-161). (3/4 of the original size).](image)

The rock contains numerous remains of large bivalves, many of which are crushed and indeterminable (fig. 24). They are, however, identical to those of the dark grey fossiliferous limestones of the Siachen basin (fig. 34), which were referred to the Upper Triassic (Norian) by C. F. Parona (1933).

More numerous specimens were collected in 1929 by A. Desio near Camp V (see fig. 27) of the expedition of that year. They were taken from the floating moraine coming from the southwest spur of the peak at 6103 m and also from the debris of the southern spurs of the Chochoardin. The specimens are as follows:
29 KD-116, 117. *Quartz-amphibole diorite*, indicated on the label as “eruptive rock, crossing the limestone”. After Desio’s field book this rock outcrops on the south spur of Gasherbrum V (fig. 25), but probably also elsewhere. We emphasize that the samples were collected on the moraine, and not *in situ*; therefore it is not excluded that the green rock of the dyke can be the same porphyrite of the sample 29 KD-230/0.

Fig. 24 – *Norian fossiliferous limestone (Aghil Limestone)* (3/4 of the original size).
A. From the right floating moraine of the Upper Baltoro Glacier (sample 54 PZ-162). B. From the floating moraine of the Upper Siachen Glacier (coll. Dainelli).

29 KD-230. *Dark grey «baltorite».*
29 KD-230/0. *Normal porphyrite*, a little weathered.
29 KD-119. *Saccharoidal marble*, greenish-white due to the presence of epidote.
29 KD-120. *Lemon-yellow, microcrystalline, veined limestone.*
29 KD-196. *White-blue limestone*, microcrystalline, with a crust of white quartz.
29 KD-249. *Grey marble*, slightly schistose due to dynamic metamorphism, containing fusulinids which have been deformed by stretching. According to A. Silvestri (1943) the linguiform bodies should represent *Neoschwagerina* specimens.
29 KD-250, 252. Slightly grey marble containing fossils identified by R. Ciry and M. Amiot (1965) as *Hemigordiopsis renzi* Reichel of the Lower Permian.

29 KD-571. *Oölitic limestone* with both light and dark coloured oölites associated with indeterminable organic remains. Very similar to the limestone of sample 29 KD-574, though not as laminated as that one.

29 KD-572. *Calcareous conglomerate* with generally rounded fragments of a pinky-white crystalline limestone varying in size from a walnut to a hazel-nut and cemented by a blackish arenaceous matrix.

29 KD-573. *Grey waxy limestone* containing assimilated fragments of black limestone. The grey limestone is rich in fossil remains, which include tubular and slightly flattened (?) belemnoids, and crushed valves of pelecypods (see sample 29 KD-577).

![Fig. 25 – Dyke of igneous rock (vv) within the limestones of the south slope of Gasherbrum V (from Desio's field book). (Symbols like in the fig. 22).](image)

29 KD-574. *Black, compact, fossiliferous, slightly waxy limestone* containing indeterminable remains of gastropods (?) and calcified brachiopods.

29 KD-575. *Grey biogenic limestone* with small dark spots which appear to be semi-oblitiated organic remains (foraminifera?).

29 KD-576. *Whitish, microcrystalline, slightly marly and schistose limestone*. According to F. Villa, this rock contains microscopic fossil remains of *Hemigordius* sp., *Miliolidae* and algae. This limestone is similar to the Permian limestone of the Shaksgam valley (camp near the front of the Staghar glacier).

29 KD-577. *Black compact laminated limestone*, containing a crushed belemnoid rostrum (fig. 26).

29 KD-578. *Grey, compact, schistose, limestone*, with black spots, microcrystalline areas and marly films; frequent calcite veins. Contains organic remains recrystallized into calcite; these, according to F. Villa, are foraminifera and probably *Hemigordius* sp., *Neoschwagerina* sp., and *Miliolidae*. 
In general we can recognize among the limestones of the Gasherbrum V the presence of:

a) a Permian formation which is mostly represented by more or less crystalline limestones, most of which are white or light grey in colour, often contain oölitic structures, and contain microfossils.

b) Dark grey limestones, rich in big pelecypod valves, mostly crushed. As has already been mentioned they correspond both in lithofacies and biofacies to some limestones of the basin of the Siachen glacier (1). C. F. Parona (1933), on the basis of the identification of several species of *Megalodon* attributed these limestones to the Norian (fig. 24).

c) Other limestones, black and mostly schistose, might perhaps be attributed to the Jurassic (or Cretaceous?) due to the presence of remains which may be belemnite’s rostrums. However, this possible Jurassic age can not be verified due to the poor preservation of the fossils. Even the mutual stratigraphical position of various types of limestones, fragments of which were collected in the moraines, are not clear. It can only be noted that yellowish weathering grey limestone, alternating with black slates, constitutes the lower part of the sequence and probably represents the passage-beds between the black shales and the Permian fossiliferous limestone.

![Fig. 26 – Black laminated limestone with belemnoid's rostrum, from the floating moraine near the camp V of Desio’s journey in the Upper Baltoro Glacier, 1929 (sample 29 KD-577). (3/4 of the original size).](image)

(1) We have analized the CaCO₃ and CaMg(CO₃)₂ content of the exteriorly similar fossiliferous samples collected in the Upper Baltoro and Upper Siachen and we have obtained the following results. Baltoro: CaCO₃ 97.3% (two samples), Siachen 95.2%, 96.2%. In the Siachen basin the dolomite, with 70% of CaMg(CO₃)₂, is more common than in the Upper Baltoro where not one of the analized samples was a real dolomite.
The presence of fossiliferous marble is perhaps unusual, but similar rock-types have been observed elsewhere (1). The Permian limestones were no doubt thermally metamorphosed at the time of intrusion of outliers of the quartz diorite body, now mostly hidden under the glaciers. The lithology of the diorite samples was determined by B. ZANETTIN (p. 215).

We also believe that the Triassic limestones underwent intensive crushing, but were not metamorphosed.

Fig. 27 – The position of the camps during Desio's 1929 journey on the Upper Baltoro.

The calcareous conglomerate of the moraine may be derived from outcrops of the Urdok Conglomerate, which is much more common in the basin of the Abruzzi glacier (see below).

The waxy limestone with inclusions of fragments of black limestone containing belemnoid remains is also rather puzzling. This black limestone is similar to the Jurassic limestones of Shaksgam valley (Bdongo-la sequence), and if it is in fact of Jurassic age, then the waxy limestone should be younger (Cretaceous?). We are not sure that all the rocks collected near Camp V of the 1929 expedition (fig. 27) originated from Gasherbrum V and the Chochordin. Some blocks may have come from the Abruzzi valley.

The main limestone mass overlies the sequence mentioned above, composing the whole of the main ridge of the Gasherbrum range which connects Gasherbrum IV with Gasherbrum I. We will return later to these rocks.

Before continuing with the stratigraphical reconstruction we will report here the other data which were collected on the east portion of the range.

Northward dipping black shales and dark sandstone (1) compose the whole south-west side of the Chochordin (7003 m, pl. VII-VIII) with the exception of the southern end of the right-hand side of the confluence (4992 m a.s.l.) of the Abruzzi glacier with the Upper Baltoro glacier. This southern end is composed of yellowish foliated limestone in faulted contact with the black shales of the Chochordin (fig. 28). This limestone is similar to that of the Savoia formation outcropping on the western side of the Falchan Kangri; it does not belong to the Permian, but probably to the Cretaceous sequence.

In 1929 A. DESIO penetrated the Abruzzi glacier as far as the Conway saddle and collected some samples from the scanty moraines.

Camp VI of the 1929 expedition was located on the moraine, at a height

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(1) According to Gattinger (1961), quartz conglomerate is also present.
of 4990 m close to the south spur of the Chochordin peak on the outlet of the Abruzzi valley (fig. 27).

The samples collected at this locality are listed below.

29 KD-253. *Grey schistose, crystalline limestone*; dotted with light-coloured spots, and oval, elongate, blackish spots. Most of these spots are to be attributed to fusulinids, among which those with banded structure, according to Silvestri may be identified as *Neoschwagerina craticulifera* (Schwager).

Those of elongate form may be identified as *Schwagerinae*. Very rare, fan-shaped, organic remains may be identified as colonies of bryozoans (Silvestri, 1934).

29 KD-159/1. *Blackish-grey, compact “baltorite”.*

29 KD-159/2. *Grey, very compact, ragged siliceous limestone.*

29 KD-159/3. *Red, limey, arenaceous silty rock*, slightly schistose, including small rounded grains of white quartz and of dark grey limestone. Very similar to 54 PZ-165 (p. 57).


29 KD-254. *White limestone* with included elongate, angular fragments of blackish limestone, some millimetres in width. Many large calcareous oölites are present in the white limestone. Very similar to sample 54 PZ-159 (p. 47).

The samples originate from the north side and the head of the Abruzzi valley.

Proceeding upstream another collection was made on the moraines of the South Gasherbrum glacier, the lowest right tributary of the Abruzzi glacier.

The right-hand lateral moraine is largely composed both of blocks of black limestone veined with calcite, and of compact, greyish-white limestone and black, slightly schistose limestone, and rarer blocks of quartz diorite and black slates.

These rocks originate from the west walls of the glacier basin, that is the east slope of Chochordin, Gasherbrum V and Gasherbrum IV.

Probably between the last two peaks a faulted contact runs between the Permian and the Norian limestones. On the south-east slope of Chochordin the bedding of the Permian limestone with dark shales intercalations (Shaksgam Formation) is inflected but nearly vertical, except on the foot where the bedding dips south-southwest with an angle of about 45° (pl. VIII).

The blocks of quartz diorite derive from the walls of Gasherbrum IV where there are large outcrops (fig. 71), but the same or similar rock is present also on the other lateral moraine and thus another outcrop, not yet known, must exist within the east branch of the basin of the South Gasherbrum glacier.
The left-hand lateral moraine contains the same rocks as the right-hand moraine, as well as huge grey and red calcareous breccia blocks, yellowish arenaceous limestone, red schistose-arenaceous limestone and some fragments of the above mentioned dioritic rock.

In this moraine the grey limestone predominates while the black limestones are less frequent than in the other moraine. The breccia blocks came down from the west side of Gasherbrum I, where they can be seen to outcrop from the outlet of the South Gasherbrum valley.

As can easily be seen from the photograph (pl. IX), the South Gasherbrum glacier collects the talus from the principal ridge of the Gasherbrums and of its southern spurs. It can thus be confirmed that the ridge is almost completely composed of limestones.

Part of this limestone is definitely Permian, as demonstrated by the presence of *Neoschwagerinae*, but the other part has not yielded any determinable fossils and may be of more recent age.

In this connection, it is necessary to take into consideration the grey and red calcareous breccia and conglomerate outcrops on the western side of Gasherbrum I, which is the source of the large blocks scattered within the left moraine of the South Gasherbrum glacier. These breccias and conglomerates are of the same type as those which were observed by DESIO in the basin of the Urdok glacier (Urdok Conglomerate: DESIO, 1963b), where they occur abundantly. They are also of the same type as those which, in the Shaksgam valley and in the Siachen basin, mark the base of the thick Mesozoic calcareous dolomitic sequence transgressively overlying the Permian portion of the Shaksgam Formation (DESIO, 1963b). The grey and red breccias of the upper Urdok valley cannot be continually followed so as to join those of the western side of Gasherbrum I. However, the outcrops are no more than five kilometres apart, while the distance from the Siachen outcrops is shorter still.

The red and yellowish arenaceous limestones of the moraine of the South Gasherbrum glacier, probably are associated *in situ* with the conglomerate and are to be compared with the rocks of the Chikchi-ri Formation of the Shaksgam valley (DESIO, 1963b), or with the similarly coloured limestone overlying the conglomerate.

Few samples of rock were collected within the Abruzzi valley upstream of the South Gasherbrum glacier since the surface of the main glacier was nearly clean. Only some blocks of limestone and few of a dioritic rock and of a green porphyrite (?) were observed downstream of the Camp VII located on the centre of the valley (fig. 27).
The origin of these rocks must be located upstream of Camp VII, i.e. on the head of the Abruzzi valley and within the basins of the northern tributaries of the Abruzzi glacier. Of the same origin are also the samples collected near Camp VI, listed above (p. 54).

As we have seen, the greatest part of the samples belong to rocks of the Permian formation of the Shaksgam valley.

Some data on the geological composition of the Abruzzi valley (and Baltoro Kangri) may also be drawn from a small group of samples which were selected by us in 1954 when we crossed the Upper Baltoro glacier from north to south about at the level of Camp V of the 1929 expedition, namely between the south-western slopes of Gasherbrum V and little upstream of the upper confluence edge of the Vigne glacier (pl. X fig. 1).

From Desio's field book we report here a short description of the rocks and the cross-section of the glacier (fig. 29).

Fig. 29 – Topographic section across the Upper Baltoro Glacier and his moraines.

« Crossing from the right to the left side of the Upper Baltoro, we meet the fossiliferous limestone moraine, corresponding to the right-hand floating lateral moraine (moraine 1 of the fig. 29), then a moraine running parallel to this composed of white and yellowish limestone, some dark-grey fossiliferous limestone, « baltorite », and some fragments of green sericitic schist (moraine 1 bis of fig. 29). We then cross a strip of ice pinnacles, after which occurs one of the median moraines, where we placed the « High Baltoro Camp ». This moraine (2) is composed of red and yellow schistose silty rocks, multi-coloured calcareous conglomerates with red or yellow cement, yellow limestone, and greenish medium-grained sandstone, while black slate and dark grey limestone occur rarely.

This strip is succeeded by another strip of ice pinnacles; then we cross a median moraine which is almost entirely composed of black slate (moraine 3). This moraine is composed of two parallel ridges which are separated by a small valley. The left ridge (3 bis) is not only composed of black slate, but also of red calcareous breccia, multi-coloured calcareous conglomerate, red marl, and lilac and greenish sericitic schist.
Farther on, towards the left edge, we cross a strip of ice pinnacles then another morainic ridge (moraine 4), composed entirely of black slate on the right side, and of rocks analogous to those of moraine 2 on the left side. This ridge is succeeded by another strip of pinnacles and then the left-hand moraine 5 which was not examined by us.

The materials composing moraines 1, 1 bis, and 2 come from the north side of the Abruzzi valley i.e. from the Gasherbrum ridge; those composing 3 and 3 bis, from the head of the Abruzzi glacier valley, namely from the Conway saddle, the Sia Kangri and the Urdok Kangri. The 3 bis possibly came from the north side of the Baltoro Kangri. The moraines all seem to start from the west side of the Baltoro Kangri, except ridge 5 and perhaps even part of ridge 4. This last moraine carries materials from the southern side of the Baltoro Kangri and Chogolisa ice-fall. Only the left-hand moraine 5 is composed of materials coming from the Chogolisa Kangri, to be mentioned later.

A short petrographic description of the samples collected during the crossing is given below.

54 PZ-165. Liver-red coloured, schistose, limey, slightly ragged slate. In thin section the rock is seen to be constituted of very fine, homogeneous grains. The depth of colour of the rock varies in irregular bands, being most intense where quartz is abundant in small crystals.

54 PZ-166. Dark grey pyroxene-garnet vogesite with biotite.

54 PZ-167, 168. Liver-red coloured, schistose breccia-conglomerate, containing white limestone fragments, some rounded, some angular and elongated during crushing. The cement is siliceous, schistose, intensely red-coloured fine-grained, and homogeneous; it is comparable with 54 PZ-165.

54 PZ-169. Liver-red coloured argillaceous slate (24 calcimetric units). In thin section the rock shows a distinctly parallel texture. Frequently broken, very large crystals of calcite are distributed in a very fine-grained, reddish, ochre-coloured matrix.

Now we are in a position to infer some of the principal features of the geological constitution of the upper part of the Abruzzi valley, upstream of the South Gasherbrum glacier. The rock fragments of the moraines 1, 1 bis and 2 are similar to those of the moraines of the South Gasherbrum glacier (p. 54). They belong to the Aghil Limestone, Urdok Conglomerate, Chikchi-ri Formation and Shaksgam Formation (Desio 1963b). The green sericitic schist, which was not previously mentioned, seems to be one of the rocks of the Chikchi-ri Formation. The black slates of the moraine 3 probably come from the Conway saddle buried below the ice and they are responsible of such depression. Southwards these rocks is followed by multi-coloured clastic
rocks of the moraine 3 bis which come from the head of the Abruzzi valley, on the south side of Conway saddle, and north side of Baltoro Kangri (1).

We will later examine the origin of the rocks fragments of the southern moraines of the Upper Baltoro glacier (4 and 5).

We can proceed now to yield other information collected during Desio's exploration of the upper Abruzzi valley and the ascent to the Conway saddle (6000 m).

Desio wrote in his field book of 1929: «The right side (of the valley of the Abruzzi glacier), between the glaciers descending north-west and south of Gasherbrum I (Margang and Zbwa glaciers) consists of limestone, the beds of which are folded into an anticline with a north-northwest axis, but on the foot of the same slope the beds plunge steeply southward.

The spur between the two glaciers of the higher part of the valley is

(1) The representation of the different formations outcropping at the head of this basin is idealized on the geological map of Baltoro basin enclosed in this volume.
composed of limestones which are part of the eastern limb of this anticline.

We can add that this limb is also folded in a smaller anticline which is
evident on the flanks of the valley of the Margang glacier (fig. 30).

Further on the author added: «Generally speaking, the whole of Ga-
sherbrum I is composed of light-coloured limestones, folded under the shape
of an anticline and disturbed by secondary folds and faults (fig. 31).

Limestones also compose the west spur of Sia Kangri in which the bed-
ding almost vertical, though slightly undulating (fig. 32) which divides the
upper Abruzzi valley into two parts (pl. XI) and continues a long way beyond
the Conway saddle. The mountains east of the saddle are also composed of
limestone for the most part, but rarely it emerge from beneath the large mantle
of ice ».

From the Conway saddle it was easy to see not only Gasherbrum I (pl. XII-
XIII) but also the ridge of the Urdok Kangri, towering between the Abruzzi and
Urdok valleys. The whole ridge appeared to be composed of Upper Triassic

![Fig. 31](image1)  — The anticline of Gasherbrum I
(from Desio's sketch taken from the
Conway saddle).

![Fig. 32](image2)  — Desio's field sketch of the west
side of Sia Kangri.

limestone (Aghil Limestone), and Permian limestone. The latter composes
the upper portion of the spurs between Urdok Kangri and Sia Kangri.

About the tectonics, we remark that the suite of formations represented
by the rocks composing the moraines of the Upper Baltoro glacier reported
above, is not a regular suite. The normal position of the black slates within
the local stratigraphy is at the base of the series. In the moraines the black
slates are repeated and they lay in contact with multi-coloured clastic forma-
tions which belong to a much more recent stratigraphic units. From this
situation we can infer the presence of some faults at the head of the Abruzzi
valley and on north-west side of Baltoro Kangri.
The Gattinger’s stratigraphy (1961) of the side of Gasherbrum I (see his geological map) probably is to interpretate as follow on the light of our investigations:

The «Kalkschiefer u. Kalkphyllite» are dark shales of the upper Shakgam Formation; the «Quarzschiefer u. Quarzphyllite, röltich u. grünlich, den alpinen W erfener Schiefer sehr ähnlich, mit Konglomerateinlagerungen» together with «Bunte serie: Rote Konglomerate, dunkelgraue Sandschiefer etc., and also Graue Conglomerate» are the Chikchi-ri Shales and the Urdok Conglomerate (Middle and Upper Triassic) overlying the Shaksgam Formation (Upper Carboniferous and Permian) and underlying the Aghil Limestone (Upper Triassic and Lower Jurassic). The sequence is disturbed by some faults, but probably is not so tectonically complicated as on Gattinger’s geological map with the object of explaining some contacts between rock of supposedly very different age.

On the same geological map, as we have already mentioned (p. 41), a large outcrop of basic dyke rock is indicated on the north wall of the head of the Abruzzi valley. These are probably sills of porphyrite, similar to those within the Permian and Triassic sequence of the Shaksgam valley, or a small diorite body.

Fragments of such rocks were observed downstream Camp VIII but as they have not been gathered, we are not able to give a precise classification. In this regard we recall here two samples, one of pyroxene porphyrite (29 KD-218) and one of normal porphyrite (29 KD-194/2), collected by Desio from the floating moraine near Camp VIII of the 1929 expedition. As we will see (pag. 62), the samples originate from Baltoro Kangri, but they may have come from the Abruzzi valley. We do not agree with Gattinger’s views about the breadth of the outcrop, as has already been stated (p. 41).

Among the types of dyke rocks collected on the moraines coming from the head of the Abruzzi valley we record also the «baltorite» which possibly should compose the above mentioned outcrop, but we have never seen large outcrops of such rock which is a typical dyke rock. Moreover some «baltorite» dykes are present within the north flank of the same valley.

5. Baltoro Kangri.

a) INTRODUCTION.

The Baltoro Kangri (Golden Throne), 7312 m high, lies at the head of the Upper Baltoro valley, rising between the Conway saddle and the Chogolisa saddle (pl. X).

Geological information on this mountain, which is smaller and lower than those previously described, is scarce due to an extensive ice blanket.
The country rock outcrops for the most part along the west side and gives rise to a number of moraines which unite to form one of the median moraines of the Upper Baltoro glacier. These moraines give us some idea of the geology of Baltoro Kangri. The structure is exposed on the west slope of this mountain.

We are indebted to W. M. Conway for some important data on this mountain, drawn from the samples examined by T. G. Bonney and C. A. Raisin (1894), some of which were collected in situ during the ascent to the Pioneer peak, and some from the moraines lying at the foot of the peak.

We do not think it necessary to report here all the data which were published by Conway, but will briefly mention them when necessary, referring the reader to the original work.

The Duke of Abruzzi also collected several samples from the mountain, which were examined by V. Novarese (1912 b) and illustrated in some colour plates, but were not described in detail.

G. Dainelli (1934, p. 587) tried to give a stratigraphic interpretation to those samples. «We have seen that within the upper Baltoro glacier, he writes, and specially within the Golden Throne, widely crops out the formation composed by multi-coloured conglomerate and red quartzitic sandstone, which I think can represent the Lower Ordovician».

The first description of the geological structure of the Baltoro Kangri is due to A. Desio (1936) who in 1929 also gathered some samples coming from this mountain and interpreted the tectonics. We will discuss such data later.

Also T. E. Gattinger (1961) gives some information on the geology of Baltoro Kangri and an interpretative picture (1).

We can record here that five samples collected from the moraines coming from this mountain and studied by H. Scharbert belong only to quartz phyllite (our “black slates”).

In the preceding section we have mentioned the rocks of the moraines coming from the Baltoro Kangri (p. 57). The morainic ridge 4, which starts from the west wall of this mountain, on the north side is composed by black slates, on the south side by livered and yellow argillaceous slate, green sandstone, multi-coloured calcareous conglomerate, calcareous breccia and conglomerate with yellow or red cement, few samples of dark grey limestone.

Some interesting data was given by T. G. Bonney and C. A. Raisin (1894), drawn from materials and data collected by Conway: «The right bank of the Throne Glacier (give) * phyllite, * argillite, * limestone (these three being associated), * slate, and a * limestone breccia (this, however, might be a fault product). From the left bank of

(1) He announces also that the Sia Kangri (Queen Mary of Bullock-Workmann) was newly named « Austria Peak », but no valid reason exists for such a change of a good topographical name.
the same glacier (whether “in situ” is uncertain) a fine-grained gneiss, a granite, and a
dolomite (the last is said also to occur in Golden Throne). The strike in the mountains
by the glacier is said to be 70° S. of E.S.E. (dip about vertical), and this continues all
along the valley. The moraine starting from the western foot of Golden Throne
affords sandstone, grits, and calcareous grits (both schistose), limestones, and dolomite,
and the peculiar felstones described above. Mr. Conway states that the last named
occur on the mountain and appear to form bands in the schistose grits. On the Pioneer
Peak (1) the first point of the arête reached yielded schistose grits, one of which (a purple
specimen, with small pebbles) occurred again at the second peak striking 5° E. of S., and
dipping 35° to the east. It is evident that a considerable mass of sedimentary rock must
be folded from Gasherbrum to Golden Throne».

Asterisked samples were collected in situ.

We know that conglomerates with red cement crop out along the ridge of the Pioneer
Peak, namely on the ridge rising from the glacier lying to the southwest of the peak. The
bedding dips eastwards. In reality, the composition and tectonic structure can be only
indistinctly seen on the western walls of the mountain.

The great variety of rocks composing the Baltoro Kangri can be deduced also from the
information given above on the composition of the morainic materials from the Upper
Baltoro glacier (p. 57).

b) North, West and South Slopes of Baltoro Kangri.

The moraine 3 bis (half black slates, half multi-coloured clastic rocks) is
composed of rocks coming from the north-west corner of Baltoro Kangri, the
moraine 4 (north side of black slates, south side of red and yellow schistose silty
rock, multi-coloured calcareous breccia and conglomerate, yellow limestone,
greenish sandstone) come from the west slope of Baltoro Kangri. We notice
a repetition of black slates and multi-coloured clastic rocks which lead us to
infer the presence of faults on the rock in situ.

Additional information are yielded by three samples collected near Camp
VIII of the 1929 expedition.

These samples are the following:

29 KD-194/1. Dark grey clastic limestone with large elliptic oölites.
29 KD-194/2. Normal porphyrite. (This name is written on the label by Comucci).
rock,” (Comucci, 1938).

The Camp VIII was placed on a median moraine of Upper Baltoro gla-
cier coming from the north-west side of Baltoro Kangri. It is possible that

(1) According to W. M. Conway the Pioneer Peak is about 800 yards (732 m) south-west of
the summit of Baltoro Kangri.
the samples originate from the Abruzzi valley as we have already said (p. 60).

Some other data on the geological composition of the Baltoro Kangri may be gathered from direct observation of the walls of the west side (pl. X fig. 2). Well layered light-coloured rocks, seemingly calcareous, crop out in slightly inclined and curved layers forming a wide syncline. Northwards, these limestones are sharply inflected against a fault plane which seemingly trends east-west bringing them into contact with a southward-dipping, blackish-coloured, thin-layered sequence. This sequence appears to be composed of slates, which overlie another sequence of thick beds, light in colour and probably calcareous, with a similar southwards dip (fig. 33).

Further north there should be three other faults, dividing the mountain into three main blocks composed of very dark rocks. The northern block may be completely composed of black slates, while the southern one may contain a thick bed of limestone intercalated within the slates. Rocks of the red clayey-arenaceous-conglomeratic formation overlie the light-coloured limestones. This can be seen also from the remarks of Conway, but it should also continue northwards, since rocks of the same type are gathered by the floating moraines of the Abruzzi glacier, as has already been mentioned.

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**Fig. 33 — Geological structure of the west wall of Baltoro Kangri (Desio). (See pl. X fig. 2).**

sh red shale and conglomerate, Pl Permian limestone (Shaksgam Formation), Bsl black slates.
We cannot add much further direct information on the geology of the west wall of this mountain, since a great part of it is covered by a thick mantle of ice.

The geological constitution of the south side of Baltoro Kangri can be revealed by the data referred by Bonney & Raisin (1894) about the samples collected by Conway during his climb to Pioneer peak, and by some geological data of the 1929 Italian expedition.

A. Desio noted in his 1929 field account that the right-hand moraine of the ice-flow sloping down from the Chogolisa saddle, which gathers the talus from the southern side of Baltoro Kangri, is composed, in order of decreasing abundance, of yellowish grey calc-dolomitic schist and black slate, the red clayey-arenaceous-conglomeratic sequence, grey compact limestone and finally green and pinkish garnetiferous micaschist.

Most of these rocks were collected also by Conway’s expedition along the way to Pioneer peak.

In addition to this information we report another list of samples collected by Desio near Camp IX (Concordia) of the 1909 expedition.

After Desio’s field observation the starting point of the moraine of Camp IX is situated on the foot of Chogolisa ice-fall. The moraine gather the debris falling from the south side of Baltoro Kangri and probably fragments removed from the rocky bottom of the ice-fall.

29 KD-194/01. Tuffaceous porphyrite.
29 KD-194/02. Dark grey clastic limestone with large oölite ellipsoid-shaped, and towered shells of small gastropods.
29 KD-201/1. White-greenish clastic sericitic quartzite with small pebbles of red argillaceous schist and some strips of green material crossed by thin veins of calcite.
29 KD-198. Redish clastic quartzite.
29 KD-204. Grey-green clastic quartzite with red strips.
29 KD-185/1. Light-grey schistose sandstone with few small pebbles of white limestone and fragments of a red arenaceous rock included.
29 KD-199/1. Schistose conglomerate-breccia similar to sample 29 KD-201/2 but with bigger elements of grey limestone.
29 KD-210/1. Schistose micaceous calcareous breccia with whitish and grey elements.
29 KD-199/2. Red-purple schistose conglomerate rich in arenaceous cement containing fragments of chloritic rock. The elements of the conglomerate vary in size from 0.3 to 3 cm. The elements are composed of white, light-grey, dark-grey and blakish, mostly crystalline, limestone.
29 KD-203/1. Multi-coloured schistose conglomerate with red arenaceous cement and flattened (crushed) elements of white, greenish and grey marble.
29 KD-203/2. *Liver-red schistose conglomerate* similar to 54 PZ-168.

29 KD-185/2. *Black slate.*

This list suggest some comments.

We have compared the samples of Camp IX with those of north-west side of Falchan Kangri and specially with the samples collected by Desio in Chitral during his 1955 expedition and we have discovered a striking similarity. We have particularly remarked the identity between the rocks of Camp IX and those of the Dundi Gal sequence, near Drosh. But within the Dundi Gal sequence *Orbitolina* limestone belonging to the Lower Cretaceous (Desio, 1957) is included, so that we have no doubt that the rocks of the moraine of Camp IX come from a Cretaceous formation outcropping on the south side of Baltoro Kangri.

Regarding the origin of Camp IX samples we have sure evidence in the presence of those types of rocks along the way to Pioneer peak (1) as was stated in the reports of the Conway’s 1892 expedition (Bonney & Raisin, 1894).

We have no information on the stratigraphy and tectonics of the Cretaceous rocks of the Baltoro Kangri, but the proximity of a similar formation in the Falchan Kangri led us to infer analogous composition of the stratigraphic sequence. Regarding the tectonics of the south side of the Baltoro Kangri we can assume a similar feature to that which is exposed on the north-west side of the mountain.

Among the rocks of the moraines coming from the west side of the Baltoro Kangri and the Abruzzi basin we have to record multi-coloured breccia and conglomerate. There is a noteworthy variety of rocks; some of them look like the conglomerate of the south side of Baltoro Kangri. We have referred the conglomerate and breccia of the above mentioned area to the Triassic Urdok Conglomerate which crops out on the opposite side of the watershed. But we cannot exclude the presence of samples of Cretaceous conglomerate among the rock debris of the above mentioned moraines on account of the similarity of the two formations. In addition we have to remember that further southward, on the foot of the Chogolisa ice fall, occur meta-sedimentary and higher grade metamorphic formations heralding the granitic body which is partly exposed along the north side of Chogolisa peak (Bride peak).

The boundary between the two formations probably occurs under the ice flow of the Kondus saddle. M. Conway indicated the presence of gneiss, perhaps in situ, on the left side of the «Throne glacier»; that is the flow which,

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(1) Regarding the topographical position of Pioneer peak see p. 62, foot note.
in the map of the same author, is seen to flow down to the southwest from the Baltoro Kangri.

c) **East Slope of Baltoro Kangri.**

Before leaving this mountain we have to mention some geological data on the upper Kondus valley, deduced from some samples collected by C. Calciati (1914). The head the Kondus valley is located on the east side of Baltoro Kangri and of the Conway saddle; the Chogolisa saddle crosses the divide of the Baltoro and Kondus basins.

The samples collected by Calciati from the moraines of the Kondus glacier, were examined by A. Roccati (1915). The list of the rocks is as follows:

- a) biotite granite, porphyritic biotite granite, pegmatite;
- b) porphyry;
- c) biotite gneiss, muscovite-albite gneiss, fine-grained gneiss;
- d) fine-grained micaschist, phyllite;
- e) pyroxenite;
- f) graphitic slate, black slate, red-purple slate;
- g) anagenite (metamorphosed quartz conglomerate), breccia with quartz-sideritic cement, calcareous breccia;
- h) calcareous arenite;
- i) very abundant calcareous rocks.

Unfortunately we do not know the topographical distribution of the samples; nevertheless we can try to give an interpretation of this rough list of rocks in the light of our knowledge on the opposite side of the ridge.

The presence of biotite granite in the Kondus valley testifies that the Baltoro batholith continues to the east of Chogolisa Kangri, where the most eastern outcrop occurs. Probably in the Kondus valley the superficial extension of the Baltoro batholith is very reduced: in fact only one sample of granite was collected there by Calciati. Other rocks, like gneiss, micaschist etc., are the rocks of the metamorphic belt surrounding the granite batholith and those forming its roof. Certainly the metamorphic belt running along the south slope of the Upper Baltoro valley, with south-east strike, enters the Kondus valley, where we find also the thick horizon of black slates which form the basement of the sedimentary sequence.

We have much information on this sequence deduced from Calciati's collection of rocks studied by Roccati. Firstly we must record the metamorphosed conglomerate represented by several samples which have been descri-
bed by ROCCATI (p. 49) «The rock must have supported a strong lamination which produced a certain schistosity with bright and specular, or finely striated surfaces of joints; analogously the pebbles and the fragments are crushed and stretched in the direction of the schistosity.

The cement which connect the pebbles and fragments is partly of siliceous nature, and partly with the appearance of a micaceous mineral... contaminated by ochraceous pigment which give to the mass an intense red or purple colour..... The particules bound by the cement have different size (until 2-3 cm of the maximum diameter) and various shapes, partly angular, partly rounded as they had been submitted to a long floating. They are prevailingly composed of quartz of milky, yellowish, purple and red colour, but frequently it is contaminated by ochra pigment which colours the mass; others are composed of white, granular or compact and greenish quartzite, or with the appearance of red diasper; finally others correspond to metamorphic black and green schists ». Among the rocks of the pebbles, the limestone and dolomite are the most common.

The red slate is described by ROCCATI (p. 49-50) as a rock of similar origin of the preceding one, but composed of a micaceous metamorphic mineral strongly contaminated by red ochra pigment of the same nature of the cement of the conglomerate.

The two preceding rocks are the most characteristic lithotypes which were collected on the floating moraines of the Upper Baltoro glacier.

There are two types of conglomerates which can be compared with those of the Kondus valley: the Urdok Conglomerate, of Triassic age, and the conglomerate of the Khalkhal Sandstone, of Cretaceous age (p. 27). Not having had the possibility of examining the samples, which were lost, we are not in a position to decide, but we may assume that both conglomerates are present among the samples collected by CALCIATI.

After 1929 DESIO’s investigation, the Urdok Conglomerate crops out in the upper Urdok valley, which is close to the upper Kondus valley. Other rocks of the CALCIATI’s collection are also present into the Urdok valley, like porphyry, biotite gneiss, red and black slates, calcareous breccias, limestone and dolomite.

The stratigraphical position of the Urdok Conglomerate is well defined in the Shaksgam valley (DESIO, 1963b). The conglomerate overlies the upper beds of the Shaksgam Formation (Upper Paleozoic), with, or without, the intercalation of the Chikchi-ri Shales, and it is overlain by the limestone and dolomite of the Aghil Limestone (Upper Triassic and Lower Jurassic ages).
A sentence of ROCCATI's report (p. 51) confirms the presence in the examined collection of the Urdok Conglomerate. ROCCATI write: «... the same sequence was surveyed also by CALCIATI in the Kon dus valley, where thick calcareous beds overlay "anagenites" and schists... ».

However the east slope of the Baltoro Kangri forms the west side of the upper Kon dus valley and as the formations which compose this mountain strike prevailingly west-east, we assume we may find similar rocks on both sides (west and east) of the Baltoro Kangri and fragments of them not only on the Upper Baltoro glacier — as we have seen — but also on the upper Kon dus glacier.

Among the conglomerates described by ROCCATI we recognize also fragments of the Cretaceous conglomerate, (Khalkhal Sandstone) which are present on the Upper Baltoro moraines (camp IX of 1929 expedition).

Summarizing the preceding knowledge, we may assume that on the east slope of the Baltoro Kangri the whole geological series of the Upper Baltoro valley, crops out that is: Baltoro black slates, Shaksgam Formation, Chikchi-ri Shales and Urdok Conglomerate, Aghil Limestone, Khalkhal Sandstone. Moreover, on the south-east corner of the same mountain crops out the passage belt from the black slate to the granite, represented by a sequence of metamorphic rocks like gneiss and micaschist.

6. The Low-grade Metasedimentary Sequence.

a) INTRODUCTION.

The low-grade metasedimentary formations of the Baltoro basin, considered in a wider sense (page 13), are limited to the eastern part of the basin, as we saw in the preceding pages. They are associated with higher grade metamorphic and igneous formations and occupy a very limited area when compared with the areas underlain by igneous and high-grade metamorphic rocks of the Baltoro. This area is briefly called the «sedimentary zone».

From the descriptive sections of the previous chapter it is easy to see that the outcrops of sedimentary rocks are very scattered, making it difficult to distinguish the different formations one from another and to delimit them on the map. This task is made even more difficult by the inaccessibility of the slopes and the extensive cover of ice. The lithostratigraphical sequences
of each formation exposed on these slopes are very scarce, and for the present they must be reconstructed from observations at a distance and on the basis of the samples collected from the talus and the moraines. It will certainly be some years before any other methods of mapping these formations are available, so that we must reconstruct the stratigraphical sequences in the best way possible with the data at present in our hands.

In Desio's report of 1963, some «formations» peculiar to the Baltoro basin were briefly described. In this chapter they will be placed in stratigraphical order, and compared with formations occurring in nearby territories.

We may begin by listing the different lithostratigraphical units more or less briefly mentioned in the descriptive sections. In a tentative chronological order they are, from the top to the bottom, the following:

(7) Khalkhal Sandstone: green and red sandstone with conglomerate interbedded of the Khalkhal valley and the Falchan Kangri (Cretaceous);
(6) Savoia Limestone: light grey-yellowish limestone thin bedded, with phyllitic calc-schist intercalations of the spur between the Savoia and Godwin Austen glaciers and the Falchan Kangri (Cretaceous);
(5) Bdongo-la complex (?): black, compact laminated limestone with crushed belemnoid (?) remains, of the Gasherbrums (Jurassic);
(4) Aghil Limestone: grey fossiliferous limestone with remains of large crushed bivalves, of the Gasherbrums (Triassic and Lower Jurassic?);
(3) Urdok Conglomerate and Chikchi-ri Shale: calcareous, multi-coloured conglomerate and breccia and/or black, brown, green and red arenaceous shales, and green schist with thin limestone interbeds (Middle and Upper Triassic);
(2) Shaksgam Formation: white, grey, waxy, compact and crystalline, often fossiliferous, limestones with fusulinids, corals, and unidentifiable fossil remains belonging to the Permian, of the Falchan Kangri and the Gasherbrums. Some beds of black shales or slates are often intercalated within the limestone beds (Permian and Upper Carboniferous);
(1) Baltoro black slates, with sandstone intercalations (Singhie Shale, Lower Carboniferous).

We must emphasise that the seven lithostratigraphical units listed are not necessarily the only ones existing in the sedimentary zone of the Baltoro basin. Others may be distinguished at a future time with more detailed and complete field research than we were able to carry out. Some of them grade laterally one to another.

We will now examine these units in detail.
b) Khalkhal Sandstone.

A thick arenaceous series with conglomeratic, mostly green, intercalations, overlies the Savoia formation. At the confluence of the Savoia glacier the two formations are separated by beds of red-violet arenaceous slate.

It was not possible to survey a type-section in detail, but the lithological composition of the formation is rather uniform.

As inferred from the preceding descriptions (p. 15-30) there is an alternation of fine-grained calcareous arenite, mostly green, sometimes also reddish, grading to phyllitic sandstone and arenaceous phyllite with intercalated conglomerate and breccia beds. In these conglomerates and breccias, predominantly calcareous fragments are included in a red or greenish arenaceous cement.

Layers of white, green or yellow limestone are also intercalated.

On the Khalkhal ridge the phyllitic rock types prevail while on the Falchan Kangri the most arenaceous-conglomeratic ones are dominant.

There is no doubt that it is the same formation, which crosses the Godwin Austen valley from west to east.

This is verified by the petrography of samples taken from either side of the valley. According to investigations of B. Zanettin, samples 54 PD-68, 54 PZ-141, -142, -143 from the western side correspond to sample 54 PZ-150 from the eastern side. The thickness of this formation is greater than 800 m, but cannot be determined to any greater accuracy.

The passage to the underlying formation, the Savoia Limestone, is marked by the presence of a layer of reddish slate, but the uppermost beds of the Khalkhal Sandstone have not been observed.

North of the summit of the Falchan Kangri the green sandstone seems to be overlain by whitish sandstone, perhaps grading into calc-schist, but we have no definite information on this matter.

Along the strike the Khalkhal Sandstone grades into quartzo-feldspathic blastomylonitic gneiss and biotite gneiss as the granite batholith is approached. These gneisses are the metamorphic facies of the Khalkhal Sandstone.

Khalkhal Sandstone forms most of the ridge between the Savoia and Khalkhal glaciers, and, on the eastern side of the Godwin Austen valley, it forms the southern part of the ridge limiting, on the west, the glaciers that come down from the western side of Falchan Kangri. It also occurs between two faults on the ridge descending from Gasherbrum IV on its western side.

Further east, it outcrops on the right side of the West Gasherbrum glacier. Much of the same formation forms the dome at the summit of Falchan
Kangri. It extends down the western side of the mountain, without reaching the bottom of the valley. We could not accurately measure the thickness of the Khalkhal formation, but estimate it as being of the order of 1500 m.

None of the collected samples of Khalkhal Sandstone contain recognisable fossils, though vague markings occur in the calcareous pebbles of the conglomerate. It is thus necessary to compare the formation with accurately dated formations of nearby territories.

Further westwards, a formation very similar to the Khalkhal Sandstone, and described by A. Desio (1959), accompanies the *Orbitolina* limestone with corals and rudists of Yasin.

The green and red sandstone of Yasin does not show any visible trace of metamorphism, but it has characters of tuffaceous sandstone and tuff connected with extrusive manifestations of porphyritic type. Some of the Falchan Kangri sandstone probably has such an origin. The conglomerates with arenaceous cement and calcareous pebbles are no different from those of the Cretaceous formation cropping out, for instance, between Tangai and Gupis, west of Yasin, and elsewhere in Chitral.

Without doubt the Khalkhal Sandstone and Yasin formation are equivalent, so that the sandstone is of Aptian age.

We have now to deal with an other conglomerate outcropping on the Baltoro Kangri. It is a calcareous conglomerate, passing into breccia, with a red arenaceous cement, associated with red and yellow sandstone and siltstone made up of the same material as the cement. Sometimes the conglomerate is markedly metamorphic.

Some of the calcareous pebbles of the conglomerate contain traces of organic remains that we could not decipher. Since no fossils have been found which might date the conglomerate, we tried to compare the samples collected here with the ones of other petrographically similar outcrops.

As we have already hinted, the greatest affinities were noticed with the conglomerates of the Dundi Gal series, near Drosh, in Chitral (Desio, 1959). These conglomerates overlie limestone with *Orbitolina* and rudists belonging to the Albian. Another comparable rock is that of sample 55 PD-18, from Dundi Gal, composed of a piece of whitish, waxy limestone pebble to which a patch of red sandstone is adhering. It is identical to sample 29 KD-34 collected from a moraine of the Upper Baltoro valley coming from the southern side of the Baltoro Kangri, towards the Chogolisa saddle.

At Dundi Gal this type of conglomerate grades into a very thick, red and green conglomerate that is no different from ones underlying, further west...
(at Yasin for instance), the fossiliferous bed containing *Orbitolina* and rudists, referred to the Aptian (DESILO, 1959).

Still in Chitral, between Dundi Gal and Ashereth, but also elsewhere, green quartz porphyrite (55 PD-23) is associated with conglomerate. Blocks of pyroxenic porphyrite (29 KD-218) are also associated with the samples of conglomerate of Baltoro Kangri collected in 1929 near the VIII camp by A. DESIO (DESILO, 1936) and studied by P. COMUCCI (1938, p. 162). This association makes our interpretation more probable.

In Chitral there is another horizon of calcareous conglomerate that is found extensively in the Reshun territory. This calcareous conglomerate, with brown and red cement, unconformably overlies the limestone of Aptian age containing *Orbitolina* and rudists. Some of its pebbles contain fragments of rudists, so that it has been, until now, ascribed to the Tertiary.

We think this to be unlikely especially if the conglomerate and the red and yellow sandstone of the Baltoro Kangri are to be identified with these conglomerates rather than with those of the Cretaceous, mentioned above. Those of the Baltoro Kangri show petrographical affinities with the types at Dundi Gal, where Tertiary conglomerate is lacking; thus we can conclude that the Baltoro Kangri conglomerate is to correlate with the conglomerate of the Khalkhal formation with which it presents great affinity.

If now we take into consideration the sedimentological character of the Yasin and Khalkhal formations we have no doubt that they represent a Cretaceous *Flysch* facies.

c) SAVOIA LIMESTONE.

A continuous, standard, sequence of this formation is unknown. One short sequence, which we carefully examined in the field, crops out on the lower slopes at the confluence of the Savoia glacier with the Godwin Austen glacier.

Other data was obtained on the opposite side of the Godwin Austen valley, that is, on the western sides of Falchan Kangri, where field investigations were also made. The sequence quoted on pages 15 and 25, drawn up from the data obtained from this locality, constitutes a good basis for identifying Savoia Limestone. The sequence can be summarised from the top to the bottom as follows:

(3) Phyllitic, bright, grey-reddish calc-schist with some limestone intercalations, some metres thick.

(2) Conglomerate and multi-coloured breccias, grey and yellow in colour, composed of mostly flattened fragments of variable size composed of
yellowish, white, and black compact limestone, greyish-white, waxy and semi-crystalline, limestone, and blackish calcareous breccia. The cement is mostly calcitic, but it sometimes takes on a calcareous-arenaceous composition and a more or less marked schistosity. Thickness more than one hundred metres.

(1) Compact, light, grey-yellowish limestone, sometimes slightly schistose, containing small pebbles and scattered fragments of dark grey limestone. It sometimes has lamellar bedding and a slightly arenaceous texture. Visible thickness about 50 m.

This unit is certainly much thicker, but is in faulted contact with "black slates" at this locality.

On the opposite side of the Godwin Austen valley another unit of the Savoia Limestone occurs, lying below those mentioned above. The passage layers of the Savoia Limestone to the Khalkhal Sandstone, to be described further on, are visible on the left side of the Godwin Austen valley, exactly in front of the Khalkhal glacier valley.

Below them, on the western side of the Falchan Kangri, occur yellowish limestones and a light-coloured calcareous conglomerate, similar to that of the opposite side of the valley. These are underlain by grey and yellow limestones, in rather massive beds, with some conglomeratic layers, followed by very thick, grey calc-schists with thin layers of yellow limestone intercalated.

Were it not for faults and folds that disturb the limestone and calc-schist series, its thickness could be up to a thousand metres, so that the whole Savoia formation could be up to 1500 m in thickness.

It is not possible to state whether the limestone of the high valley of the North-northwest Falchan glacier belongs to this formation or not, because it is involved in a fault system that isolates it from the others.

The same considerations are valid for the limestone partially forming the southern and western sides of the Falchan-tso, of which samples were collected on the moraines of the southern glacier of Falchan Kangri. These will be considered further on. Rocks belonging to the Savoia Limestone were also collected on the Upper Baltoro glacier.

We must now find some way of determining the geological age of this formation.

As we saw above (p. 25), none of the samples of Savoia Limestone yielded definable fossils. Also, the position of the formation in the local stratigraphical series is not clear. We only know that it underlies the arenaceous series of the Khalkhal and is in contact with the black slates of the valley of the Savoia glacier.
A comparison between the lithological types of the Savoia Limestone and those of the Cretaceous series of Chitral, a number of sections of which A. Desio surveyed in 1955 (Desio, 1959), show so many affinities between these formations that we can consider them equivalent.

The limestone of samples 54 PZ-63 and -66 from the lower confluence of the Savoia glacier with the Godwin Austen glacier is very similar to the grey-yellowish compact limestone of sample 54 PD-67/2 of the Cretaceous series, which contains Orbitolina, from Mount Nal, near Reshun. The presence of small pyrite cubes in both samples 54 PD-66 and 55 PD-67/2 strengthens this analogy.

Phyllitic, reddish calc-schist of sample 54 PD-69 from the Savoia Limestone is very similar to the reddish phyllitic calc-schist of sample 55 PD-22/1 coming from Kalkhatok, and of Cretaceous age.

Very strong analogies are noticeable in the Cretaceous limestones of the Yasin series in the Gilgit territory (Desio, 1959).

Further eastwards there are not only analogies but also a real identity. Calcareous breccias and yellowish limestone with pebbles of dark limestone, similar to the ones of the Savoia Formation, were found by De Filippi's expedition near the snout of the north branch of the Rimu glacier, in a small fossiliferous outcrop of Senonian age (Dainelli, 1933).

A comparison between the samples coming from the Savoia and the Rimu glaciers showed their identity and, since it is a rather uncommon lithological type, there are no doubts about the equivalence of the two formations.

However the analogies between the Savoia Limestone and those of the Cretaceous outcropping to the west and east of it become greater when we not only compare the different types of limestone with one another, but when, we also consider that a series of green arenaceous-conglomeratic layers belonging to the Khalkhal Sandstone is found both above the limestone of the Savoia formation and above the Orbitolina Cretaceous limestone of Yasin and Dundi Gal (Drosh).

Fossils were not found in the Savoia series since they were probably destroyed by an incipient metamorphism, but in many of the limestone samples there are traces of organic remains.

As mentioned above, the calcareous formation of the Savoia crosses to the opposite side of the Godwin Austen valley, where it forms a large part of the western side of the Falchan Kangri.

But here other limestones crop out, mostly belonging to a Permian formation. In the field, when the sequence is disturbed by folds and faults, it
is difficult to distinguish one from the other, especially when we do not have definite lithostratigraphic standard for each formation. For this reason it is possible that we have attributed, on the geological map, some limestone outcrops of the Permian sequence to the Savoia sequence, and vice versa.

d) **Bdongo-la Complex (?)**

This name was given by A. Desio, in an as yet unpublished volume on Shaksgam valley, to a layered complex, probably of formation status, represented by yellow marly sandstone and black limestone with corals and ammonites of the Upper Jurassic (Desio and Fantini, 1960), outcropping in a small saddle, called Bdongo-la, of the Shaksgam valley (1).

The same complex probably occurs in the Aghil range where Jurassic rocks were discovered by K. Mason (1928).

In the Baltoro basin there are only a few traces of the Bdongo-la complex, in some samples of black laminated limestone with remains of belemnoids (29 KD-577) coming from the Gasherbrums range (see p. 51). Other samples contain fossiliferous remains which may be belemnoids and corals belonging to this Jurassic complex, but the uncertainty is greater. The hypothesis of the presence of Jurassic rocks in the Gasherbrum range was set forth in 1936 report by A. Desio.

It is also of interest that the outcrop of Bdongo-la complex in the Shaksgam valley seems to occur on the extension of the tectonic axes of the Gasherbrum ridge. Nothing can be said on the thickness and extent of the Bdongo-la complex in the Gasherbrum ridge.

(e) **Aghil Limestone.**

Many samples of fossiliferous limestone have been taken from the Gasherbrum ridge, and mainly from Gasherbrum I. They are more or less dolomitic, compact, varying in colour from grey to black, and correspond perfectly to some lithological types occurring extensively on the southwest side of the Shaksgam valley, on the ridge marking the watershed between the Shaksgam basin and the Siachen glacier (Desio, 1963 b). The fossils contained in this limestone could not be determined, but a careful comparison between the samples collected in the moraines of the Upper Baltoro glacier and the Abruzzi glacier with the fossiliferous *Megalodon* limestone of the moraines of the Sia—

(1) See Desio's geological map at the scale of 1:500,000 (1964 b).
chen glacier (p. 49) showed them to be identical both as regards their lithofacies and their biofacies.

The outcrop of this formation can be traced continuously from the Teram Kangri-Urdok Kangri ridge to the Gasherbrum I ridge (1), and so this ridge must be composed of the Aghil Limestone. As we have already said on page 51 this limestone is well stratified, in rather thick layers, in the same manner as that occurring on the north-eastern side of the Shaksgam valley.

The Aghil Limestone was ascribed to the Middle and Upper Triassic-Lower Jurassic (?) in the Shaksgam basin by Desio in 1963 and there is no reason why the rocks ascribed to the same formation in the Baltoro basin should not be of the same age.

**f) Urdok Conglomerate and Chikchi-ri Shales.**

At the base of the calcareous Aghil formation in the Shaksgam valley there often occurs a calcareous, multi-coloured conglomerate named Urdok Conglomerate, that was ascribed to the Upper Triassic (A. Desio, 1963 b) on the basis of its stratigraphical position.

This conglomerate, in some places more than a hundred metres thick, occurs extensively in the high basin of the Urdok glacier, on the eastern side of Gasherbrum I, and also in the basin of the Siachen glacier.

The calcareous conglomerate of the upper Abruzzi glacier, descending from the southern side of the Urdok Kangri, is petrographically similar to this Urdok Conglomerate.

The stratigraphical position of these conglomerates in comparison with the Aghil Limestone in the Gasherbrum I is not clear, but their topographical position, close to each other, gives some confirmation of their stratigraphical relationship.

In the Shaksgam valley, below the Urdok Conglomerate, which usually occurs at the bottom of the Aghil Limestone, a sequence crops out of black, brown, green and sometimes red, arenaceous shales and green schists, with thin interbeds of limestone.

These strata, which are intercalated between the Aghil Limestone and the Shaksgam Formation, were named Chikchi-ri Shales (Desio, 1963 b) and referred to the Middle and Upper Triassic.

In this valley, where the Urdok Conglomerate is lacking the Aghil

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(1) See Desio's geological map at the scale of 1:500,000 (1964 b).
Limestone directly overlies red shale. If this shale is not equivalent to the Chikchi-ri Shales, then it substitutes for the Urdok Conglomerate.

Multi-coloured schists with conglomerate intercalations were indicated to occur on the south slope of the Gasherbrum ridge by T. E. GATTINGER (1961), and referred to the Triassic. It is possible that they belong to the Chikchi-ri and Urdok formations.

g) SHAKSGAM FORMATION.

A. DESIO (1963 b) attempted to define the Shaksgam Formation in the following manner: «Brown to black and grey limestone and shaley marl associated with beds of brown and yellowish quartz sandstone. Some light-coloured beds are generally very fossiliferous. The most frequent fossils are: Brachiopods of the genus Productu, Pelecypods, Bryozoans, Corals, Crinoids, and Foraminifera (mostly Parafusulina) ».

A great number of samples collected in the moraines, mainly coming from the Gasherbrum range, are referrable to these lithologic types. The limestone has yielded microscopic fossils which certainly belong to the Permian. They are mainly Hemigordiopsis renzi Reichel, a species generally ascribed to the Upper Darvasian (Lower Permian) (CIRY and AMIOT, 1965).

Even though we were unable to survey any rock sequences on the Gasherbrum ridge, the presence in the moraine of the above mentioned lithologic types and the later observations, quoted in the descriptive pages, allow us to identify the Shaksgam Formation (1) on the southern side of the Gasherbrum ridge.

As in the Shaksgam valley, the formation is characterised by the presence of calcareous units, prevalent in the upper part of the formation, and of dark shaley levels becoming more frequent and abundant in the lower part, in association with arenaceous lithologic types.

The same distribution of lithologic types occurs on the southern side of the Gasherbrum, though with a noteworthy peculiarity: from east to west the metamorphic facies become more and more prevalent in contrast to those of normal sedimentary facies.

We shall deal with the metamorphic facies of the Shaksgam Formation in the chapter on the metamorphic formations (p. 177).

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(1) Other Permian and Carboniferous fossils from the same formation collected in Shaksgam valley by Desio during his 1929 exploration are described in the IV-I volume of the present scientific reports.
The extent of the Shaksgam Formation in the Baltoro basin is not yet fully known. The normal sedimentary facies is rather extensive in the Gasherbrum ridge and it is present in the Falchan Kangri. It is also possible that the beds of well-stratified limestone occurring along the ridge linking the two groups, and visible from a distance, belong to this formation.

We do not have enough information to determine the thickness, but it seems to be over 600 m.

h) BALTORO BLACK SLATES.

At the base of the Shaksgam Formation in the Baltoro basin one often comes across a complex of black slates in which more or less coarse-grained arenaceous strata are intercalated (I). They are mainly dark rocks of pelitic and psammitic type that were loosely called «scisti neri» during our field survey, owing to the impossibility of recognising their real nature in the field. Different rocks were temporarily associated under the name «scisti neri», such as fine-grained biotite paragneiss, biotite-graphite phyllite, phyllitic micaschist, etc., that could well belong to different stratigraphic horizons. These will be dealt with in the following chapter (p. 86).

The most complete series of black slates of the Baltoro basin is exposed within the Upper Baltoro valley on the southwest slope of the Chochordin. Here the thickness may be estimated as more than a thousand metres.

Under the name of black shales or slates, both in the Shaksgam valley and in the Upper Baltoro basin, there is a rather thick formation of black shales and slates with sandstone intercalations. In the Baltoro basin it is generally more decidedly metamorphosed (black slate, arenaceous slate, and quartzite). The identification of Baltoro «scisti neri» with the Shaksgam Singhie Shale is based not only on the lithological affinity, but also on the stratigraphical position in comparison with the preceding formation ascribed to the Upper Carboniferous and Permian on palaeontological grounds.

For such reasons we can ascribe the black shales and slates of the Upper Baltoro basin to the Singhie Shale and to the Lower Carboniferous.

The grade of metamorphism of the Singhie Shale increases not only from east to west, as we saw in the Shaksgam Formation, but also from north-east to south-west, that is, from the right side to the left side of the Upper Baltoro valley.

(I) According to GATTINGER (1961), also lenses of quartz conglomerate.
We have no precise data on the thickness of this formation due to the incomplete nature of our survey and to the presence of many tectonic disturbances. We think, however, that it may be over a thousand metres thick. If it is this thick, then we can consider the Baltoro black shales and slates to be the oldest formation occurring both in the Baltoro basin and in the Shaksgam valley.

This formation will again be considered when we discuss the stratigraphy of the metamorphic formations (p. 180). But from now we can express our opinion that under the sedimentological point of view the Singhie Shale and the Baltoro black slates with the arenaceous intercalations represent a *graywacke* facies of the Upper Paleozoic.
III. THE METAMORPHIC AREA

A. K² MASSIF AND ITS SURROUNDINGS.

1. Introduction.

The difficulties encountered in the reconstruction of the geologic sequence of the metamorphic rocks are the same as, if not greater than, those encountered in the reconstruction of the sedimentary rock sequence: lack of outcrop, inaccessibility of outcrop, and intense tectonic disturbance.

In addition we must also try to distinguish the different types of metamorphism suffered by the rocks of the Baltoro basin.

The rocks constituting this metamorphic area are mainly gneisses with big feldspar crystals, including more or less large strips of sedimentary formations. These rocks constitute the so-called «Baltoro metamorphic peribatholithic belt», lying between the Baltoro granite batholith and the zone of low-grade metasedimentary formations.

The K² massif and its spurs lies outside this peribatholithic belt. It constitutes a different zone from the preceding ones, both geologically and topographically, so that we shall describe it separately. We shall begin with the upper basin of the Godwin Austen glacier because of the greater variety of lithologic types outcropping there.

2. General Petrographic Characters of the Upper Valley of the Godwin Austen Glacier.

In the upper basin of the Godwin Austen glacier pelitic rocks of very variable crystallinity crop out.

The types with lower crystallinity are represented by granitic phyllite, while the coarse-grained types are granitic gneisses with big feldspar individuals.
The following lithologic types were distinguished *in situ*:

a) arenaceous gneiss, b) biotite paraschist (divided into graphitic biotite phyllite and fine-grained biotite paragneiss), c) porphyroblastic gneiss (divided into augen gneiss and granitic gneiss). (a + b = Falchang gneiss; c = K² gneiss).

The general petrographic characters of each of these types are given below, and the aplitic and pegmatitic dykes, which cross the porphyroblastic gneiss in great number, are also described.

Rocks of other type also crop out within the surveyed area: marls, calc-schists, calciphyres, conglomerates, etc.

a) ARENACEOUS GNEISS.

This name is given to pale, very compact rocks, lacking in micaceous minerals, and slightly schistose, clearly derived from the metamorphism of arenaceous sediments. With increase in micaceous minerals, and mainly biotite, these rocks pass into biotite paraschists or more or less porphyroblastic biotite paragneiss, with which they are generally associated. Facies rich in muscovite are much rarer (54 PD-44).

The mineralogical composition is very simple: *plagioclase* with a composition of 30% An, *quartz*, and *potash feldspar* (sometimes a *microcline* with pronounced crosshatched twinning, sometimes an untwinned variety) in equidimensional crystals and in equal amounts occur in granoblastic aggregates; *biotite* and *muscovite*, the latter often poikiloblastic, are scarce and generally sub-oriented, though some lie across the schistosity planes (54 PD-5). Common additional minerals are *epidote* and occasional *apatite*.

More frequent than these uniform grained rocks are those with a rather porphyroblastic texture (54 PD-30, -31, -62). Under the microscope it is possible to see that coarser-grained feldspars (plagioclase with a composition of 25-32% An and microcline perthite) include other matrix minerals, especially quartz and biotite. In other cases quartz includes small feldspar individuals.
TABLE 1

Psammitic gneiss; near the K*b Base Camp, on the moraine (54 PD-31)

CHEMICAL COMPOSITION

(Analyst: T. Zulian)

<table>
<thead>
<tr>
<th>Element</th>
<th>Psammitic gneiss</th>
<th>Adamellite type (granitic magmas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>70.84%</td>
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<tr>
<td>TiO₂</td>
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<tr>
<td>P₂O₅</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
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<td>Fe₂O₃</td>
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</tr>
<tr>
<td>FeO</td>
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</tr>
<tr>
<td>MnO</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>2.89</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>3.34</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
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<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>4.02</td>
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</tr>
<tr>
<td>H₂O⁺</td>
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<td></td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.02</td>
<td></td>
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<tr>
<td>Water</td>
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NIGGLI's values

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<th>Fm</th>
<th>C</th>
<th>Alk</th>
<th>K</th>
<th>Mg</th>
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<tr>
<td>Psammitic gneiss</td>
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<td>35.3</td>
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Basis

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<th>Equivalent Norm</th>
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<tr>
<td>Ne</td>
<td>19.2</td>
<td>Or = 23.7</td>
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<td>Cal</td>
<td>5.7</td>
<td>Ab = 32.0</td>
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<td>Cs</td>
<td>1.9</td>
<td>An = 9.5</td>
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<td>Fs</td>
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<td>Wo = 2.5</td>
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<td>Fo</td>
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<td>Fa</td>
<td>1.1</td>
<td>Hy = 1.3</td>
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<tr>
<td>Ru</td>
<td>0.1</td>
<td>Mt = 0.2</td>
</tr>
<tr>
<td>Cp</td>
<td>0.3</td>
<td>Ru = 0.1</td>
</tr>
</tbody>
</table>

Equivalent Norm

Q = 22.4%
In table 1 the analytical data of one typical psammitic gneiss with weakly developed porphyroblastsis (54 PD-31) are given.

It is not always easy to distinguish in situ the true arenaceous gneiss from the quartz-feldspar gneiss derived by recrystallization of strongly cataclastic granitic gneiss (54 PD-105). Under the microscope identification is easy not only due to the structural characteristics, but also due to the strong sericitization of plagioclase that, when it is definable, shows a markedly more albitic composition (up to 10% An) than plagioclase of the arenaceous gneiss.

In the table 3 the analytical data of a gneiss with large feldspar porphyroblasts (54 PD-33) is given.

b) Biotitic Paragranite.

The above mentioned rocks were grouped in the field under the general term «black slates», due to their dark, almost black, colour, together with their marked schistosity. In fact they are a group of rocks made up of petrographically well distinguishable types, and particularly of biotite-graphite phyllite, fine-grained paragneiss, and phyllitic micaschist. All these metamorphic rocks were derived from arenaceous to clayey sediments of rather constant composition.

The most common type is graphite-biotite phyllite, which is blackish, and very fine-grained (54 PD-21). These rocks are exclusively composed of quartz, an oligoclase-andesine plagioclase (28% An), and very fine grained biotite lamellae with red pleochroism. Tourmaline often occurs in addition.

Dynamic action has produced an undulating schistose structure, with small, twisted folds, and many shear-planes. Graphite is often located along these surfaces. Other rocks which look very similar in hand specimen contain large amounts of sericite and chlorite, the latter probably coming from transformation of biotite (54 PD-90).

In table 2 the analytical data for one of these phyllites (54 PD-21) is given.

With increase in the size and amount of micaceous minerals these pass into phyllitic micaschists that are distinguished from the carbonaceous phyllites by the presence of well-defined biotite bands, and subordinate muscovite bands, alternating with narrower quartz and plagioclase (about 25% An) bands.

Garnet can also be present, and sometimes some small sillimanite needles (54 PD-39).

In a few cases (54 PD-107, -108) these garnet-bearing schists have the characteristics of thermal metamorphic rocks due to the appearance of large andalusite poikiloblasts.

The porphyroblastic development of minerals referable to rather high
TABLE 2

Graphitic biotite-phyllite; near the \( K^2 \) Base Camp, on the moraine (54 PD-21)

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

<table>
<thead>
<tr>
<th></th>
<th>SiO(_2)</th>
<th>TiO(_2)</th>
<th>P(_2)O(_5)</th>
<th>Al(_2)O(_3)</th>
<th>Fe(_2)O(_3)</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na(_2)O</th>
<th>K(_2)O</th>
<th>H(_2)O(^+)</th>
<th>H(_2)O(^-)</th>
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</thead>
<tbody>
<tr>
<td>Graphitic biotite-phyllite</td>
<td>62.19%</td>
<td>0.83</td>
<td>0.42</td>
<td>16.21</td>
<td>0.53</td>
<td>5.59</td>
<td>0.08</td>
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<tr>
<td>Opdalitic type</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Normal quartzdioritic type</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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NIGGLI's values

<table>
<thead>
<tr>
<th></th>
<th>si</th>
<th>al</th>
<th>fm</th>
<th>c</th>
<th>alk</th>
<th>k</th>
<th>mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphitic biotite-phyllite</td>
<td>214</td>
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<td>34.0</td>
<td>13.4</td>
<td>19.0</td>
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<td>0.49</td>
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<td></td>
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<tr>
<td>(granitic magmas)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal quartzdioritic type</td>
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<td></td>
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Basis

<table>
<thead>
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<th>Basis</th>
<th>Equivalent Norm</th>
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<tbody>
<tr>
<td>Q</td>
<td>Q = 43.4</td>
</tr>
<tr>
<td>Kp</td>
<td>L = 40.2</td>
</tr>
<tr>
<td>Ne</td>
<td>M = 15.0</td>
</tr>
<tr>
<td>Cal</td>
<td>M' = 16.4</td>
</tr>
<tr>
<td>Sp</td>
<td>( \pi ) = 0.23</td>
</tr>
<tr>
<td>Fs</td>
<td>( \mu ) = 0.45</td>
</tr>
<tr>
<td>Fo</td>
<td>( \gamma ) = —</td>
</tr>
<tr>
<td>Fa</td>
<td>( \alpha ) = 3.03</td>
</tr>
<tr>
<td>Ru</td>
<td></td>
</tr>
<tr>
<td>Cp</td>
<td></td>
</tr>
</tbody>
</table>

| Q     | 11.2%   |
| Or    |         |
| Ab    | 31.6    |
| An    | 15.5    |
| En    | 7.7     |
| Hy    | 8.4     |
| Cord  | 3.7     |
| Mt    | 0.6     |
| Ru    | 0.6     |
| Cp    | 0.8     |
metamorphic conditions, such as garnet and andalusite, and the appearance of sillimanite, though exceptional, seems to contradict the development of fine-grained phyllites and phyllitic micaschists. Under the microscope these rocks always show a «hornfelsic habit».

This «hornfelsic habit» is more marked in the fine-grained biotite paragneiss. Even though the grain-size is still rather fine, the rock is more compact and the colour has become a grey-violet.

The granoblastic aggregate of these rocks is composed of quartz and feldspar. The composition of the plagioclase varies in the different samples between 18-20% An (54 PD-87, -96) and 40% An (54 PD-6).

Potash feldspar is scarce or lacking. The quantity of biotite is also smaller; it appears as iso-oriented lamellae within the granoblastic aggregate.

Among the additional minerals tourmaline is predominant, while epidote, sphene, graphite, iron oxides, apatite, and zircon also occur. Samples containing garnet are scarce (54 PD-61).

Sometimes within these paragneisses are bands or lenses with a more developed grain-size (54 PD-6, -17a, -96). With this increase in grain-size the amount of biotite further decreases, and the first porphyroblastic development of feldspars occurs. Feldspars often include biotite lamellae in the process of transformation. Fractures in the plagioclases are filled with potash feldspar. Such facies with larger grains can be considered as passage types into rocks of the porphyroblastic gneiss group.

The chemical analysis given in table 3 is of one of the typical facies of fine-grained biotite paragneiss (54 PD-6).

c) Porphyroblastic gneiss.

Under this general name we have grouped all rocks in which the feldspar porphyroblasts are numerous enough to impart a macroscopically distinguishable augen structure to the rocks. This group also includes rocks fundamentally similar to the paragneisses described as fine-grained biotite paragneiss, or arenaceous gneiss, but containing many feldspar porphyroblasts, either small or large (augen gneiss), and rocks of general coarser grain-size and a poorer schistosity (granite gneiss), and in which the derivation from sedimentary rocks is not perceptible.

In this group are associated rocks of very different aspect, since they are always associated in the field, and grade from one to another due to the gradual porphyroblastic development of feldspars without substantial changes in the total rock composition.
TABLE 3
Fine-grained biotite paragneiss; on the right lateral moraine of the De Filippi Glacier
(54 PD-6)

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

<p>| | | | | |</p>
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<th></th>
<th></th>
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<th></th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>68.62%</td>
<td>MgO</td>
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<td></td>
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<tr>
<td>TiO₂</td>
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<td>CaO</td>
<td>2.18</td>
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<tr>
<td>P₂O₅</td>
<td>0.14</td>
<td>Na₂O</td>
<td>1.88</td>
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<tr>
<td>Al₂O₃</td>
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<td>K₂O</td>
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<tr>
<td>Fe₂O₃</td>
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<td>H₂O⁺</td>
<td>1.98</td>
<td></td>
</tr>
<tr>
<td>FeO</td>
<td>3.03</td>
<td>H₂O⁻</td>
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<tr>
<td>MnO</td>
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NIGGLI's values

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<tr>
<th></th>
<th>si</th>
<th>al</th>
<th>fm</th>
<th>c</th>
<th>alk</th>
<th>k</th>
<th>mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine-grained biotite paragneiss</td>
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Basis

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<td>Cal</td>
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</tr>
<tr>
<td>Sp</td>
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<td>Fo</td>
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<td>Fa</td>
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<td>Ru</td>
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<td>Cp</td>
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<thead>
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<td>M</td>
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<td>M'</td>
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<table>
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<tr>
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<td>Ab</td>
<td>17.5</td>
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<tr>
<td>An</td>
<td>10.4</td>
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<tr>
<td>En</td>
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<tr>
<td>Hy</td>
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<td>Mt</td>
<td>0.3</td>
</tr>
<tr>
<td>Cord</td>
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</tr>
<tr>
<td>Ru</td>
<td>0.6</td>
</tr>
<tr>
<td>Cp</td>
<td>0.3</td>
</tr>
</tbody>
</table>
d) **Augen gneiss.**

The most common facies of augen gneiss is represented by a pelitic, biotitic rock, with a ground mass of variable but usually fine-grain size, and varying in colour from dark to violet. The plagioclase porphyroblasts may be roundish or prismatic in form. The roundish porphyroblasts are usually smaller than the prismatic ones. The latter can reach considerable dimensions. Some facies have only small porphyroblasts (54 PD-22, -22a), but more frequently both small and large porphyroblasts occur in the same rocks. With increase in size of these feldspar porphyroblasts there is usually a concomitant increase in grain-size of the matrix, but exceptions to this rule are rather frequent.

During our survey we gave these gneisses the name «K₂ gneiss ». Other gneisses, poor in biotite, occur within the K₂ gneiss and are clearly visible due to their lighter colour and their much less evident augen structure. They will be described further on as porphyroblastic quartz-feldspar gneisses. Dark and light gneisses can alternate in rapid succession (54 PD-38, -38a) and it is then possible to see the passage from one to another due to gradual decrease in biotite.

Under the microscope the fundamental texture of the biotitic augen gneiss (K₂ gneiss, 54 PD-22, -24, -27, -38, -41, -48, -49, -59, -60, -70, 54 PZ-144) appears as clearly as in the field: large feldspar individuals occur in a dark matrix corresponding in composition and habit to biotitic paragneiss. These feldspars have displaced the pelitic bands of the matrix during their growth.

The ground mass is composed of a granoblastic aggregate of quartz and feldspar in which biotite occurs in iso-oriented but isolated laminae either gathered in elongate lenses or in bands, due to their abundance.

With biotite, generally of reddish colour and sometimes transformed into chlorite (54 PD-27, -41, -48, -49, -98) muscovite is also present in small quantities and sometimes limited to the parts of the matrix in direct contact with the feldspar porphyroblasts (54 PD-22, -22a).

Facies rich in muscovite (54 PD-49) and also those completely lacking in it (54 PD-38) are scarce.

The main differences in the matrix of the different facies of the biotitic gneisses are ascribable to the different quantitative relations between potash feldspar and plagioclase and also the different amounts of biotite and the various degrees of crystallinity of the ground mass.

**Potash feldspar** is generally scarce in the matrix (54 PD-22, -49, -70), or only locally abundant due to very irregular distribution (54 PD-27). Though
it is usually in subordinate quantity in comparison with plagioclase it is seldom absent (54 PD-48). Plagioclase varies in composition from 30% An to 40% An. In a few cases both feldspars are scarce (54 PD-49) or lacking (54 PD-48) in the matrix, so that it is, in this latter case, made up of quartz and biotite, sometimes with muscovite and chlorite.

Tourmaline, graphite, iron oxides, sphene, apatite, epidote, orthite, zircon, calcite, and sometimes amphibole can be present as additional minerals.

Feldspar porphyroblasts, often randomly oriented with respect to the schistosity of the rock, developed within the more or less fine-grained pelitic matrix. They are dominantly represented by plagioclase while potash feldspar porphyroblasts occur in subordinate quantity.

The quantity of large potash feldspar (often microcline) crystals often seems to vary with the degree of porphyroblasticity of the rocks.

In the fine-grained facies it can be very scarce (54 PD-24, -38, -59) or completely lacking (54 PD-22, -48, -49, -70), while it is more frequent in the facies containing large feldspar crystals. This variation is not related to variations in the chemical composition of the rock.

The composition of the plagioclase porphyroblasts is unaffected by the variation in amount of porphyroblastic potash feldspar. It is always unzoned and is generally an andesine (40% An on the average, varying from 35% An to 45% An).

Plagioclase is generally prismatic, while potash feldspar, even when present in larger individuals than the plagioclase, occurs in anhedral, roundish porphyroblasts. Where plagioclase and potash feldspar are in contact myrmekitic associations are sometimes developed, and plagioclase is often substituted by microcline.

The feldspar porphyroblasts of these rocks almost always contain numerous inclusions.

The included minerals are the same as those of the matrix, together with feldspars, and also white mica (partly derived from the transformation of biotite). More seldom, apatite and epidote are also present. Generally, both feldspars contain these inclusions, but plagioclase may also be devoid of inclusions, usually when they have well-developed prismatic forms (54 PD-27).

The large feldspar individuals are commonly fractured.

Three samples of augen biotitic gneiss were chemically analysed, two (54 PD-70, -38) containing small porphyroblasts, mainly of plagioclase, the other (54 PD-24) containing large individuals of both plagioclase and potash feldspar. The analytical data are given in tables 4, 5, 6.
TABLE 4

Biotite augen gneiss; *the lower portion of the western spur of Falchan Kangri* (54 PD-70)

**CHEMICAL COMPOSITION**

(Analyst: B. Zanettin)

<p>| | | | | | | |</p>
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<thead>
<tr>
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<tbody>
<tr>
<td>SiO₂</td>
<td>65.25%</td>
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<tr>
<td>TiO₂</td>
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<td>CaO</td>
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<td>K₂O</td>
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<td>H₂O⁺</td>
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<td>FeO</td>
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<td>H₂O⁻</td>
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NigglI's values

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<td>32</td>
<td>32</td>
<td>18</td>
<td>18</td>
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<tr>
<td><em>Normal quartzdioritic type</em></td>
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<td>32</td>
<td>31</td>
<td>19</td>
<td>18</td>
<td>0.25</td>
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**Basis**

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<td>Or</td>
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<td>M = 13.1</td>
<td>Ab</td>
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<tr>
<td>Cal</td>
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<td>M' = 14.2</td>
<td>An</td>
<td>16.5</td>
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<tr>
<td>Sp</td>
<td>3.1</td>
<td>π = 0.27</td>
<td>En</td>
<td>6.0</td>
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<tr>
<td>Fs</td>
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<td>μ = 0.45</td>
<td>Hy</td>
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<tr>
<td>Fo</td>
<td>4.5</td>
<td>γ = —</td>
<td>Cord</td>
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<tr>
<td>Fa</td>
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<td>α = 5.55</td>
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<td>Ru</td>
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TABLE 5

Biotite augen gneiss; near the Kg Base Camp, on the moraine (54 PD-38)

CHEMICAL COMPOSITION

(Analyst: T. Zulian)

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NIGGLI'S values

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<th>alk</th>
<th>k</th>
<th>mg</th>
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<td>32.3</td>
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<td>Normal quartzdioritic type</td>
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<td>31</td>
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<td>18</td>
<td>0.25</td>
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Basis

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<td>50.5</td>
<td>Q</td>
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<td>Kp</td>
<td>8.9</td>
<td>L</td>
<td>36.7</td>
<td>Or</td>
<td>14.9</td>
</tr>
<tr>
<td>Ne</td>
<td>18.7</td>
<td>M</td>
<td>12.2</td>
<td>Ab</td>
<td>31.2</td>
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<td>M'</td>
<td>12.7</td>
<td>An</td>
<td>15.1</td>
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<td>π</td>
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<td>Wo</td>
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<td>μ</td>
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<td>En</td>
<td>11.1</td>
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<td>Fo</td>
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<td>γ</td>
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<td>Hy</td>
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<td>Fa</td>
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<td>α</td>
<td>6.40</td>
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<td>Cp</td>
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<td>Cp</td>
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</table>
### TABLE 6

Biotite augen gneiss with large feldspathic porphyroblasts; near the K2 Base Camp, on the moraine (54 PD-24)

**CHEMICAL COMPOSITION**

(Analyst: B. Zanettin)

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition (%)</th>
<th>Element</th>
<th>Composition (%)</th>
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</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>69.63%</td>
<td>MgO</td>
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<tr>
<td>TiO₂</td>
<td>0.59</td>
<td>CaO</td>
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<td>P₂O₅</td>
<td>0.51</td>
<td>Na₂O</td>
<td>4.00</td>
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<tr>
<td>Al₂O₃</td>
<td>15.08</td>
<td>K₂O</td>
<td>2.64</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.19</td>
<td>H₂O⁺</td>
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<td>FeO</td>
<td>2.75</td>
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\[100.73\]

**Nigglı's values**

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<th>mg</th>
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<tr>
<td>Biotite augen gneiss</td>
<td>318</td>
<td>40.6</td>
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<td>14.0</td>
<td>25.4</td>
<td>0.30</td>
<td>0.43</td>
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<tr>
<td><strong>Farsunditic type</strong> (granodioritic magmas)</td>
<td>300</td>
<td>42</td>
<td>20</td>
<td>15</td>
<td>23</td>
<td>0.25</td>
<td>0.40</td>
</tr>
<tr>
<td><strong>Leucoquartzdioritic type</strong> (trondhjemitic magmas)</td>
<td>300</td>
<td>42</td>
<td>17.5</td>
<td>13</td>
<td>27.5</td>
<td>0.25</td>
<td>0.40</td>
</tr>
<tr>
<td><strong>Adamellitic type</strong> (granitic magmas)</td>
<td>300</td>
<td>37.5</td>
<td>22.5</td>
<td>13.5</td>
<td>26.5</td>
<td>0.45</td>
<td>0.30</td>
</tr>
</tbody>
</table>

**Basis**

| Q  | 53.2  | Q  = 53.2 | Q  = 24.2% |
| Kp | 9.5   | L  = 38.1 | Or  = 15.9 |
| Ne | 21.8  | M  = 7.3  | Ab  = 36.4 |
| Cal| 6.8   | M' = 8.7  | An  = 11.3 |
| Sp | 2.5   | τ  = 0.18 | Cord = 4.6 |
| Fs | 0.2   | μ  = 0.27 | En  = 1.7 |
| Fo | 1.3   | γ  = —    | Hy  = 4.3 |
| Fa | 3.3   | α  = 9.58 | Mt  = 0.2 |
| Ru | 0.4   |         | Ru  = 0.4 |
| Cp | 1.0   |         | Cp  = 1.0 |

**Equivalent Norm**
General features analogous to the ones above described for the darker, biotitic facies of the augen gneiss are also present in the light-coloured quartz-feldspar gneisses, which are poor in biotite and micaceous components in general (54 PD-33, -38a, -40, -49; 54 PZ-144, -145).

The analytical data of two light augen gneiss (54 PD-38a, -33) are given in the tables 7, 8.

The porphyroblastic structure is less marked because the minerals of the matrix are larger than those of the biotitic facies, and the porphyroblasts (among which quartz, as well as feldspars, sometimes occur) are rather small.

Besides the abundance of quartz and lack of biotite, the distinctive feature of these gneisses is the prevalence of potash feldspar over plagioclase, a prevalence noticeable both among feldspars of the matrix and among the porphyroblasts. The latter are sometimes composed of potash feldspar alone (microcline, microcline perthite). The composition of the plagioclase (both in the granoblasts and in the porphyroblasts) corresponds to that of andesine, as in the biotitic augen gneiss. Plagioclase is often turbid and earthy, while potash feldspar is clear.

Evident structural analogies with biotitic augen gneiss are also seen in amphibolitic augen gneiss (54 PD-7, -23, -102, -103) which is locally associated with it.

In this also, the porphyroblasts are represented by plagioclase, with numerous potash feldspar individuals. Porphyroblasts of hornblende also occur. Unlike common augen gneiss, plagioclase may here be rhythmically zoned, while potash feldspar may include, besides biotite and quartz, plenty of small plagioclase crystals. In the matrix, potash feldspar is more abundant than plagioclase and amphibole is present in the same quantity as biotite. In spite of its abundance, hornblende is never in direct contact with feldspar porphyroblasts, as biotite occurs between them. Biotite must come, partially at least, from transformation of amphibole. In other cases hornblende may convert to amphibole of the tremolite-actinolite series. Some bands in the matrix are completely composed of quartz.

Among the additional minerals, sphene and waxy epidote occur.

e) Granite gneiss.

In these rocks (54 PD-1, -2, -18, -26, -32, -34, -50, -93, -94) recrystallisation is more marked than in the augen gneisses. Feldspar crystals constitute most of the rock and can be up to many centimetres in size. With increase in size of the porphyroblasts the matrix minerals also become larger. These
### TABLE 7

Light augen gneiss; *near the Kp Base Camp, on the moraine (54 PD-38 a)*

**CHEMICAL COMPOSITION**

(Analyst: T. Zulian)

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<tbody>
<tr>
<td>SiO₂</td>
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**NIGGLI's values**

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<td>0.34</td>
<td>0.84</td>
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<td><em>Natronrapakiwititc type</em></td>
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<td></td>
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<tr>
<td>(trondhjemetic magmas)</td>
<td>340</td>
<td>42</td>
<td>20</td>
<td>8</td>
<td>30</td>
<td>0.25</td>
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**Basis**

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<td>Q</td>
<td>50.9</td>
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<tr>
<td>Kp</td>
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**Equivalent Norm**

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<td>Ab</td>
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<td></td>
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<td>An</td>
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<td></td>
<td></td>
<td>6.0%</td>
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<tr>
<td>Wo</td>
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<td>1.3</td>
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<td>0.3</td>
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TABLE 8

Light augen gneiss; near the K² Base Camp, on the moraine (54 PD-33)

CHEMICAL COMPOSITION

(Analyst: T. Zulian)

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minerals occur in smaller and smaller areas occurring between the large feldspar individuals. These rocks look like porphyritic granites, or rather porphyroblastic granite gneiss, for their general structure is still laminar, even if less marked than in augen gneiss.

The rock is almost uniform in grain-size, so that it is not possible to clearly distinguish between the minerals of the matrix and the porphyroblasts (54 PD-94).

In these rocks the mineralogical composition is similar to that of augen gneiss, except for the increase in the quantity of feldspar and the decrease of biotite. The matrix is still prevalently composed of quartz, biotite, and feldspars. Plagioclase generally prevails over potash feldspar (54 PD-1, -2, -18, -26), but occasionally (54 PD-50, -93) potash feldspar is dominant.

Feldspar is often very scarce in the matrix. Plagioclase of the matrix varies in composition between 20 and 25% An. It is of note that its composition always agrees with that of the porphyroblasts.

Porphyroblasts are always represented both by plagioclase and by potash feldspar (microperthite, microcline perthite), in which first the former (54 PD-1, -2, -18, -50) and second the latter (54 PD-26, -32, -34, -94) prevail. In these rocks also, though to a less marked extent than in the augen gneiss, plagioclase tends to take on a regular form, while potash feldspar is always anhedral and often takes on roundish forms. Here also, biotite lamellae and quartz granules are commonly included in the porphyroblasts.

At the contact between the two different types of feldspar, myrmekitic associations are frequently developed.

Potash feldspar frequently substitutes for plagioclase, and plagioclase may also be included in potash feldspar in the form of irregular strips.

The large plagioclase individuals, sometimes slightly zoned (54 PD-50), are generally of a much more sodic composition than the porphyroblasts in the augen gneiss. The most calcic types (25-28% An) were found in rocks whose structure is more similar to that of augen gneiss (54 PD-1, -50, -93). In rocks with a less prominent laminar texture, that is in real granite gneiss, the composition is less than 20-22% An (54 PD-2, -26, -34). These latter plagioclases often correspond to antiperthitic associations, rich in laths or microcline patches.

It should be especially noted that in almost all the granite gneisses, smaller plagioclases, sometimes partially sericitised, with a composition of 32-35% An, are included in large plagioclases with a composition of 20-22% An. Sometimes (54 PD-2) the included individual has a more calcic central part and
a more turbid periphery, both of which are well defined. The peripheral part is also much more calcic than the host plagioclase.

The chemical analyses were made on two typical samples of granite gneiss, one more biotitic and with a more abundant matrix (54 PD-1), the other lighter, rich in feldspar and with more uniform structure (54 PD-2). The data are given in tables 9, 10.

TABLE 9

Granodioritic gneiss; *below the southern wall of K*2, *at a height of about 5000 m* (54 PD-1)

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

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<th>63.19%</th>
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<td>P₂O₅</td>
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<td>α   = 4.69</td>
<td>α   = 4.69</td>
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TABLE 10
Granitic gneiss; below the southern wall of Kz, at a height of about 5000 m (54 PD-2)

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

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Yosemitgranitic type
(leucogranitic magmas)

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f) Other types of Schists.

Briefly noted here is the presence of actinolite schists (54 PD-25, 54 PZ-148), found only in the moraine and whose relations with the paraschists and the above gneisses are not known. They are prevailingly constituted of acicular amphibole of the tremolite-actinolite series, locally associated with biotite, or talc and sphene. Quartz, plagioclase with a composition of 35% An (that is of analogous composition to plagioclases of porphyroblastic gneiss), and potash feldspar may be present in the amphibole aggregate in the form of small crystals, or constitute lenses or sialic patches.

g) Aplitic and Pegmatitic Layers.

Porphyroblastic gneisses, mainly of the granitic type, are intersected by a network of sialic layers and veins of pegmatites and aplites. It often happens that the pegmatitic or the aplitic characters of one of these layers is connected with the size of the layer, and there is often a passage from one to another.

The contacts with the enclosing rocks, often rather sharp in the field, are gradual under the microscope. A good example is given by a small vein a few centimetres thick (54 PD-46) made up of an aggregate of quartz, potash feldspar, and muscovite, in individuals of medium grain-size, in the outer parts, and of large quartz crystals towards the centre. The vein occurs in an augen gneiss composed of quartz, plagioclase, and biotite, and lacking in potash feldspar. The passage from the enclosing rock shows a gradual decrease and disappearance of biotite and plagioclase and concomitant appearance and increase of potash feldspar and muscovite, accompanied by a marked increase in the grain-size.

A typical aplite (54 PD-3) is composed of medium-grained perthite individuals (and microcline perthite), albite-oligoclase with a composition of 10-12% An, including quartz granules, and small imbricated granules of quartz occurring in patches or bands.

Others (54 PD-95) are richer in quartz and plagioclase (15-20% An) and contain biotite with long axes lying parallel to biotite in the enclosing gneiss.

Characteristic pegmatites (54 PD-13, -71, -106) are composed of perthite and microcline perthite in very large individuals of bright grey colour (mounstone). Other minerals occur between the perthites. They are sometimes represented only by quartz, but more often by quartz, very sodic plagioclases, and muscovite. More seldom, biotite occurs. Some larger perthite patches are composed of different crystals that have grown together, so as to include the other minerals close to their edges.
Pegmatites with analogous characters may contain large *muscovite* plates (54 PD-4), or large *tourmaline* crystals (54 PD-28). Others contain a rather calcic *plagioclase* with a composition of 30% An (54 PD-29). Some of these layers are very cataclastic and blastomylonitic.

A gneissose pegmatitic rock (54 PD-14) contains long, thin quartz bands alternating with bands composed of a medium-fine grained aggregate of *quartz*, *albite* *plagioclase*, and *potash feldspar* in which big microperthite individuals are developed.

Also in this rock, concordant veins, very rich in epidote, sphene, apatite, calcite, sericite, and chlorite, are included. Some amphibole is also associated with them. These veins may represent schist included in the pegmatite.

**h) Lamprophyric Dykes.**

The above rocks are also crossed by mafic dykes. These lamprophyric rocks possess particular mineralogic and chemical characters (1), with which we shall deal in detail in another part of the present volume. At this point it is sufficient to note that they are classifiable as minette and vogesite with very high potash content.

3. **Summa-ri (Savoia Ridge).**

The Summa-ri stands on the western side of the Savoia glacier valley, between the pass at 6840 m and the peak at 7170 m of the Khalkhal ridge.

Its long axis lies in a north-south direction, and it rises to a maximum height of 7263 m. At the southern end occurs a saddle coated with ice (that could be named *Summa-la*) (pl. XIV fig. 1).

We have no direct information on the geology of this ridge, but observations from a distance, together with investigation of some rock samples taken from the right-hand floating moraine of the Savoia glacier, give us some preliminary information.

This moraine is almost entirely composed of black *biotite-muscovite micaschist* containing garnet and andalusite that often occur in big nodules that look like fossils (54 PD-107, -108). Along with this rock a few fragments of augen gneiss (K² gneiss) occur.

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(1) For more detailed information see C. Viterbo and B. Zanettin (1958-59).
This moraine gathers the talus falling from the eastern wall of Summa-ri and probably also from the ridge between it and the Savoia saddle.

Since no other rock type was found in the right-hand moraine of the Savoia glacier we are led to believe that the wall of the Savoia ridge, between Summa-la, the Khalkhal ridge on one side, and Summa-ri, on the other side, is made up of black mica schists with garnet and andalusite, and of augen gneiss.

The presence of andalusite in a pelitic rock would suggest the proximity of an igneous body. Such a body, however, does not seem to crop out in the Savoia glacier basin since fragments of plutonic rocks are lacking in the moraine.

Either these rocks are hidden by the ice or they crop out beyond the summit of the Savoia ridge, either in the high basin of the Younghusband glacier or that of the South Chongtar glacier. Igneous rocks derived from such a body were not found in the moraines of the first of these two glaciers. They may, however, occur in those of the second glacier.

4. **K² Massif.**

   a) **Introduction.**

   The K² peak (8611 m) is a gigantic isolated pyramid of gneissic rock rising about 3600 m above its base, which lies 5000 m above sea level (pl. XV).

   The six sides of the mountain face to the north-northeast, east, south-southeast, south-southwest, west, and north-north-west. The ridges are well defined from the crest down to 7500 m, while below this height some of them branch out into a number of spurs. The number of faces of the mountain thus increases towards its base.

   On the north-northeast side of K², at an altitude of 7000–7500 m, is a shoulder covered by an ice blanket with precipitous walls descending on either side. Above the shoulder the peak rises as another smaller pyramid (pl. XVII). The north slope is a tremendous wall, so that, viewed from this side, the top of the mountain appears very slender (pl. XX fig. 2).

   The divide between the basins of the Indus and Yarkand rivers runs across the top of K², but only the two northern slopes belong to the Yarkand basin.

   The pyramid of K² is connected with the main Karakorum range by two ridges, one oriented in a northwest direction and ending at the Savoia saddle, and the other in an east-northeast direction, towards the Skyang Kangri (7544 m), and, further eastwards, the Skyang-la (6233 m). The Godwin Austen
glacier flows from the Skyang-la, grazing the foot of the southeast slope of K². The Savoia glacier flows from the Savoia saddle grazing the foot of the eastern slope and joining the Godwin Austen glacier at the end of the south-southwest spur (Angelus spur). The two slopes of the north side of K² are grazed by the K² glacier towards the north-west and by the Sughet glacier towards the north-east (pl. XX fig. 2).

The K² peak is largely covered by ice, which flows for the most part into the Godwin Austen glacier which is divided into two main branches, the Savoia glacier and the De Filippi glacier. Other branches are very steep, and smaller than the preceding ones, and have independent glaciers.

Except on the west side of the mountain the country rock is very poorly exposed and usually occurs where the slope is too steep to support the ice cap. However, the walls are also often coated with snow, so that, even during the summer, clean rock surfaces are reduced. Snow falls frequently during the summer and the mountain is rarely free from clouds. Under such condition, favourable occasions for geological inspection of the rock slopes from a distance are very few and of short duration.

During our four month stay at the base camp and the camps along the Abruzzi spur of the 1954 expedition to K², we were able here and there to directly examine the rock and to devote many hours to inspection from a distance by means of powerful binoculars, but our inspection was essentially limited to the south and south-east slope (1).

In spite of the above mentioned difficulties, by the employment of all the means at our disposal, we trust that our effort has been repaid by some appreciable results (see «Geological map of K²» at the end of this volume). Our investigation on the structure of K² has been made easier by the photogeological interpretation of the photographs taken by F. Lombardi for the photogrammetrical survey of K². This was undertaken by G. Francalanci, to whom we are indebted for a preliminary structural sketch-map and cross-sections of the peak.

For the purposes of the geological description of K² we shall divide the group into four slopes, instead of six: the south slope, the east slope, the north slope, and the west slope. The ridges dividing the four slopes are, descending

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(1) It may perhaps seem surprising that during such a long time relatively few samples of country rock were collected, particularly along the Abruzzi ridge. But it must be made clear that the only geologist present on the spot during the climbing period was A. Desio who was also the leader of the expedition. His duties were so heavy at this time that he was obliged to forego any geological investigations. The climbers were unable to collect any rock samples.
from the top: for the south slope, the Angelus ridge; for the east slope, the Abruzzi spur, and the one ending at the gap at 6526 m, opening at the head of the Marpophong glacier; the north slope of the mountain stands to the north of the watershed ridge; the west slope is between the ridge leading to the Savoia saddle (6666 m) and the Angelus peak, as drawn in fig. 34.

Fig. 34 - $K^2$ massif and its orographic branches.

b) Previous Knowledge.

The first information on the geology of $K^2$ probably dates back to 1883, and is due to R. Lydekker. It is the result of an extrapolation, or rather an induction, for the author did not visit the Baltoro glacier, and perhaps never saw $K^2$ either.

However, on page 315 he says: «granitoid, frequently porphyritic, central gneiss, seems to form the whole of this part of the great Muztagh, or Karakorum range, and also the enormous peak of the second highest known mountain in the world ($K^2 = 28,265$ feet) The granitoid gneiss of this district is the same as the lowest gneiss of Rondu...».

W. M. Conway, who explored the Baltoro glacier in 1892, and here and there collected some rock samples, does not mention the geological constitution of $K^2$. V. Novarese (1911 a, b) refers to the geology of $K^2$ with the help of samples collected by F. De Filippi, a member of the Duke of Abruzzi’s expedition to Karakorum in 1909. On page 75 Novarese quotes the different moraines of the Baltoro described by De Filippi and among these he mentions a «median moraine coming from the southern and western
faces of $K^2$, prevalently composed of granites and crystalline schists, with scanty fragments of limestone.

No sample of that moraine was collected, so that the information, though interesting, cannot be documented. Further on in the same report Novarese again mentions the geological structure of $K^2$. He says: «in the upper Godwin Austen glacier, the limit between the gneiss and the formations of the Palaeo-Mesozoic series must run south of the Windy Gap, because the Staircase is composed of light grey, coarse-grained gneiss. The base of the highest peak of the region, $K^2$, according to the data of the various expeditions, should be composed of granite or light granitoid gneiss. But various photographs taken from the south, the east, and the west show a very distinct bedding dipping not very steeply, from 15° to 20°, in the terminal pyramid. It is probably an analogous gneiss to that of the Bride Peak (1). Godwin Austen, who noticed it in the photographs taken by the Italian expedition, is inclined to consider the stratified top of $K^2$ to be more recent than the granitic base. I cannot agree without reserve with this opinion of the renowned and learned explorer. The simple occurrence of an overlying unit, in such a dislocated region, is not enough evidence upon which to state the relative age of the formations, especially since the granite could be intrusive.»

It is evident that these are mere inductions. Following that expedition, nobody approached $K^2$ until 1929, when a small patrol of the Duke of Spoleto's expedition reached the slopes of the mountain.

A. Desio, who led that patrol, referred to the geology of the mountain in two reports of 1930. In the first one he says that: «the commanding pyramid of $K^2$ is composed of well stratified banks of gneiss, occasionally foliated, the same as occur on the southern slope between the De Filippi and Savoia glaciers.

Granite dykes cross-cut the gneiss. Also the snow-clad top of the huge mountain must be composed of light-coloured gneiss, a hypothesis that I found to be supported by the appearance of the rocks in situ and by the nature of the talus carried down by the glaciers.» No more than this is said in the second report, while a more detailed description is to be found in the official report of the same expedition (1936, p. 269-270). This description is based on the petrographic study by P. Comucci (1938) of the samples collected by A. Desio from the moraines. The $K^2$ peak is considered to be substantially composed of plagioclase gneiss with dykes and sills of granite.

Later geological information on $K^2$ is of secondary importance, since it was taken from the above mentioned works. Nevertheless, we must point out an observation by N. A. Beljaewski contained in a small paper on the geology of Karakorum (1947). He says that all the intrusive rocks of the Karakorum belong to the Pre-Cambrian and Cymmerian intrusive phases, and that the Pre-Cambrian intrusions of $K^2$ are made up of biotitic-amphibolitic orthogneis. This chronological classification of the igneous rocks of our region must have been suggested to the author by the information given in previous publications.

New data were published in 1957 by A. Desio and B. Zanettin in a short report on the Baltoro basin, in which the geological composition of $K^2$ is mentioned. Another

(1) Described as «biotite gneiss» by Novarese.
report of the same year by the same authors is devoted to K², and is accompanied by geological cross-sections. These will be mentioned later in the chapter.

In the geological report of T. G. GATTINGER (1961, p. 69) the author states that K² is composed of "granite", identical to the axial granite of Karakorum (see coloured block-diagram appended to the book). GATTINGER ignored our geological report on K² published in French four years earlier, in a widespread geological record (DESIO and ZANETTIN, 1957 b).

Fig. 35 – The geological structure of the south wall of K² (according to Desio and Francalanci). Sl Savoia Limestone, G.P.s Gilkey-Puchoz sequence, Fg Falchan Gneiss (grey), K²g K² Gneiss.

c) SOUTH SLOPE.

We shall begin the description of the geological composition of K² on the south slope, for we obtained most of our information and samples on this side of the mountain (fig. 35 and the geological map at the end of this volume).

The southwest ridge of K² descends in a series of steps towards a deep
gap which was called the Negrotto saddle by the Duke of Abruzzi's expedition of 1909.

Further to the south-west a massive spur rises, culminating in the white top of the Angelus (6855 m) which is divided into two branches, one of them directed westwards, the other at first south-southeastwards, then bending south and finally south-east. The first of the two branches extends towards the Savoia glacier and the second towards the right bank of the Goldwin Austen glacier, between the De Filippi and Savoia glaciers.

Towards the Godwin Austen glacier the southern branch is divided into many small spurs, the southernmost of which has at its end the Puchoz tomb and the Gilkey memorial (pl. XIV fig. 2).

Most of the samples that we collected in situ or in the talus immediately below the wall came from the foot of the southern branch (fig. 36).

![Map of the area with labels and sample locations.](image)

Fig. 36 – Distribution of the samples collected during the 1954 expedition on the south foot of K2.

The northern edge of the confluence between the Savoia and Godwin Austen glaciers is formed of an alternating sequence of rocks of different nature (porphyroblastic gneiss, biotitic paraschists, calc-schists, pegmatites etc.) all affected by intense tectonic disturbances. They almost always appear cataclasised or mylonitised. The alternating sequence of these rocks gives the complex a striped appearance, with subvertical light and dark bands, generally trending north-east (fig. 37).
The prevailing lithologic type is a *porphyroblastic gneiss* more or less rich in biotite and generally strongly laminated (54 PD-18).

The surfaces of intense tectonic movement are blackish, and quartz appears to be segregated in elongate lenses. In some cases the dynamic action was so strong that the rock looks like a compact *feldspathic quartzite* (54 PD-105).

It is possible that some of the rocks that, in the field, we called laminated sandstone (54 PD-17), or metamorphic products of original arenaceous rocks, are in fact derived by the blastomylonitization of porphyroblastic gneiss.

In this extreme part of the south slope of K² *graphitic fine-grained biotitic paragneiss* is also found (54 PD-17a). It is very similar to that cropping out widely on the left side of the high basin of the Godwin Austen glacier.

The carbonate rocks (54 PD-19, -20, -21a, -104) contain thin irregular bands or dark, carbonaceous stringers (fig. 38). The most impure parts have

Fig. 37 – *Geological view of Angelus Peak and the outlet of the Savoia Valley* (Desio, Francalanci). Ks Khalkhal Sandstone; G.P.s. Gilkey-Puchoz sequence; Bsl black slates and micaschist (grey); Fg Falchan Gneiss; K²g K²Gneiss; —— fault.
a schistose texture, while the purest parts, which are white, are never crystalline, but, on the contrary, are very fine-grained and crumble between the fingers.

In this area *pegmatite*, with well-developed crystals and always blastomylonitic, is also frequent and mostly conformable with the other rocks of the sequence. One particular dyke (54 PD-106), injected into limestone, is characterised by the presence of large, grey, iridescent perthite (moonstone) crystals.

Where the eastern wall of the Gilkey-Puchoz spur turns to the southwest, a gneissic rock appears (54 PD-102). It looks like a quartz diorite with orientated texture. Under the microscope the rock appears similar to the common porphyroblastic gneisses found in this area, but it differs from them in the abundant amphibole (both as a component of the matrix and as porphyroblasts) and chlorite present.

This *amphibolic porphyroblastic gneiss* constitutes a band about fifty metres thick. Immediately south of the principal outcrop, and divided from it by a band of biotitic porphyroblastic gneiss, these amphibolic intensely cataclastic...
rocks appear again (54 PD-103). They are followed by a layer of calcareous rocks (54 PD-104).

Judging from the rocks noted and collected at the foot of the walls, the part of the slope lying between the Gilkey-Puchoz spur and the De Filippi glacier is principally composed of porphyroblastic gneiss, including both *augen gneiss* (54 PD-93) and *granite gneiss* (54 PD-2, -94), the latter being more prevalent.

There is no sharp division between the two types of gneiss even if locally the passage is rapid. The variation within this gneissic formation is related to the quantity and distribution of biotite.

Where granitic types prevail, dark mica is irregularly distributed. At one point it may be concentrated in rather thick stripes, while at another it is so scarce as to make the schistosity of the rock just perceptible.

With this gneiss a few much darker and fine-grained lenses of *biotitic paragneiss* are present (54 PD-96). Compared to the analogous paragneiss present in the basin of the Godwin Austen glacier, it shows, in some parts, a more marked crystallinity. The whole of the gneissic complex is crossed by aplitic and, more seldom, pegmatitic veins.

The aplitic facies sometimes contain a schistosity conformable with the country rock and include short stripes rich in biotite (54 PD-3, -95). The pegmatite (54 PD-4) may contain muscovite or biotite in large individuals, sometimes gathered into rather thick piles.

Carbonate rocks also appear on this part of the southern slope of K2. They are composed of *arenaceous limestone* (54 PD-97, -99) in which quartz, as well as being uniformly distributed within the calcite aggregate, occurs in bands and thin lenses. Lamprophyric dykes, corresponding to *pyroxene minette* (54 PD-100) are also present, and cross-cut all the other rocks.

Rocks substantially analogous to those mentioned above come from the De Filippi glacier. Near the edge marking the confluence with the Godwin Austen glacier, on the right-hand lateral moraine, typical fine-grained *biotitic paragneiss* (54 PD-6) and *arenaceous gneiss* (54 PD-5) were collected.

From the opposite, left-hand edge of the confluence *arenaceous gneiss* (54 PD-8), *perthitic pegmatite* (54 PD-13), and *porphyroblastic gneiss* rich in amphibole and biotite (54 PD-7) were collected.

The latter rocks, here occurring very extensively, show macro- and microscopic characters very similar to those already mentioned for the layers outcropping north of the Gilkey-Puchoz memorial (54 PD-102).

A *pyroxenic-epidote calciphyre* comes from the same area (54 PD-16). It should be pointed out that this was the only sample we collected of a meta-
morphite with calcium silicates derived from impure carbonate rocks. The material from the moraine underlying the left corner of the confluence of the De Filippi glacier comes from the spurs occurring towards the upper part of the De Filippi glacier. Carbonate rocks are represented by calc-schists of high crystallinity and locally rich in phlogopite (54 PD-9), grey and white coarse-grained marble (54 PD-10), which sometimes contain phlogopite (54 PD-12), or epidote (54 PD-11).

These carbonaceous rocks may be crossed by pegmatite, or be associated with them in some way, because a pegmatitic gneiss (54 PD-14) collected here includes conformable lenses rich in epidote, sphene, calcite, and amphibole, probably derived from transformation of calc-schist included in sialic rocks.

Lamprophyric dyke rocks are also represented, and a sample collected here corresponds to a pyroxene-biotite vogesite with amphibole (54 PD-15).

The floating debris of the moraine near to and upstream from the K² Base Camp supplies further information on the frequency of the above-mentioned lithologic types in the wall underlying the Abruzzi spur and extending to the summit of K².

Augen gneiss prevails over other rocks. The porphyroblasts are well developed in a matrix rich in biotite (54 PD-22, -22a, -24, -27, -38, -41). Often closely associated are lighter, less porphyroblastic rocks, corresponding to arenaceous gneiss (54 PD-30, -31, -33, -38a, -40). Other types occurring less frequently, though well represented, are granite gneiss (54 PD-26, -32, -35, -37, -42, -47, -47a, -51), graphitic phyllite (54 PD-21, -39), and sometimes biotite paragneiss, and pegmatite (54 PD-28, -29, -45, -46). The latter is sometimes deformed and laminated.

Among the less common types are amphibolic porphyroblastic gneiss (54 PD-23), actinolite schist (54 PD-25, 54 PZ-148) and the usual lamprophyre dykes (54 PD-52, -53, -54, PZ-146, -147).

Summing up the observations on the south slopes of K² we can make the following remarks:

a) The most common rock type is porphyroblastic gneiss, among which augen gneiss prevails. The most granite-like gneiss occurs for the most part on the walls west of the De Filippi glacier.

b) The carbonate rocks are rather frequent on the Gilkey-Puchoz spur and on the walls east of the end of the De Filippi glacier.

From the stratigraphic point of view the complex of strata containing carbonate rocks on the south slope of K² is rather interesting. As in the
preceding pages we were not able to survey a valid series, but were able to
recognise that this bedded complex is well differentiated from the other rock
associations of the whole of the south slope of K². We will return to this que-
stion in an other section, and will only mention here that we have called this
complex the *Gilkey-Puchoz spur calcareous sequence*, or shortly *G. P. sequence*.

**d) East Slope.**

As we have already said, very few samples were collected from the southern
slopes of the mountain. This was due to the fact that both the upper
Godwin Austen glacier and the Savoia glacier are almost completely lacking
in moraines, and the small rocky outcrops of the mountain are unapproachable.

Three samples were collected *in situ*. From the foot of the Abruzzi spur
a sample of *porphyroblastic gneiss* (54 PD-49) was collected and analogous rocks
were collected above this at 5580 m near the first camp (54 PD-48). This
sample is an *augen gneiss* with feldspathic porphyroblasts of different size,
but lighter-coloured rocks are also present.

These are poor in biotite and more homogeneous in grain-size, and cor-
respond to passage types between augen and granite gneisses (54 PD-50). The
latter occurs as lenses in the preceding rock.

In his field notes relating to the above samples, A. DESIO states: «The
rocks composing the Abruzzi spur, between the 1st and 2nd camp (6095 m
a.s.l.) are dominantly greenish gneiss distributed round the 1st camp (54
PD-48), associated with black slates (biotitic paragneiss) and grey gneiss, and
sometimes augen gneiss, and accompanied by many lenses of granite (granite
gneiss) forming the longest bands.

Observing from the talus-cone of the 1st camp, the rocky crest which li-
mits this cone to the west (downstream) we see a fold in the gneissic layers
like the one in the figure (fig. 39). There is a sort of knee-fold formed by the
above mentioned rocks.

Considering the trend of the layers, the same lithologic composition could
extend up to about 7000 m a.s.l. along the Abruzzi spur; that is, up to the
7th camp of K². Further down, on the crest east of the 1st camp (5580 m), we
noticed an alternation of grey gneiss (among which also occurred augen gneiss)
with fine-grained blackish, arenaceous (?) gneiss and whitish quartzite (pl. XVI
fig. 2).

White calc-schists should also be present in this series, since we found
a fragment of this rock is the talus.

Between the above mentioned crest and that of the 1st camp, passes
a contact between an essentially gneissic sequence and a more varied one, with limestone and quartzite (?), that seems to underlie the first.

To this information we can add the presence of white marble fragments at the foot of the spur descending from the east-southeast crest and ending at 5847 m a.s.l. These fragments probably belong to the country rock.

In the floating moraine immediately below are present, in decreasing order of abundance, «black slates» and $K^2$ gneiss, followed by compact white and grey limestone, calc-schists of the same colour, grey gneiss, pegmatite and aplite, grey quartzite with a reddish weathered surface, and «baltorite». The moraine is probably fed by the talus falling from the wall interrupting the roof glacier of the «shoulder» of $K^2$, but perhaps also by Skyang Kangri, with which we will deal later.

![Geological section across the ridge to the west of 1st camp $K^2$ (from Desio's field book).](image)

Taking into account the trend of the gneissic layers, it is probable that the $K^2$ gneiss and the «black slates», the predominant components of the above moraine, form the walls lying under the shoulder of $K^2$.

In further support of this interpretation we quote some information taken directly from the field note-book of A. DESIO: «$K^2$ seen from the Windy Gap (Skyang-la), presents an apparently uniform geological composition, and seems to be composed of the same rocks of the $K^2$ gneiss series, more or less injected with granitic material.

The gneissic layering is well marked as far as the top, apparently dipping to the east-northeast at $25^0$. Only in the lower part of the mountain do
greater irregularities appear, where the gneissose bands seem to slope down steeply and rather irregularly in different direction (pl. XVII).

The summit or $K^2$ seems to possess the most regular structure, so that the attitude of the beds does not differ appreciably from north to south, where the rock sticks out from the terminal ice-dome». This trend of the layering is clearly visible in fig. 40 and in the plate XVIII.

Fig. 40 - The bedded structure of the $K^2$ Gneiss in the upper pyramid of $K^2$ (Desio).
(Grey colour, Falchan Gneiss).

Between the 4th camp at 6412 m and the 5th camp at 6678 m a.s.l., on the Abruzzi spur, a white rock crops out in a wall cut in a sort of gap (Bill chimney). It could be a marble layer intercalated in the «black slates» and $K^2$ gneiss.

Fragments of this rock are visible at the foot of the frozen gully running down the western side of the Abruzzi spur.

Marble also seems to outcrop on the eastern side of the summit pyramid of $K^2$. But we have no proof of this; the supposition comes from observations made from below with powerful binoculars.

Some photographs of the summit of $K^2$ give us further geological information.
On the left side of one photograph (pl. XIX fig. 1) can be seen a heterogeneous sequence of well-banded rocks composed of white, grey, and black strata which repeatedly alternate. Four white bands are visible in the photograph and seem to be included between black bands.

From our experience of the appearance of rocks of the $K^2$ massif we assume that the white bands are composed of limestone, or probably marble, the black ones of «black slates», and the grey ones of gneiss ($K^2$ gneiss). The regularity of the banding suggests that the rocks are of sedimentary origin. This sequence can be compared with the calcareous sequence of the southern wall of Black Peak, near the Gilkey-Puchoz memorial.

Another photograph (pl. XIX fig. 2) includes the same view as the first one, but is more extensive, so that a great part of the summit of $K^2$ can be seen, which, though covered by ice, is composed of a similar rock sequence.

Fig. 41 – Faults below the top of $K^2$, from the south (Desio).
The third photograph (pl. XVIII) shows the whole summit of K², with the calcareous belt extending to the left along the rocky wall below the larger ice fall. Upwards, a gully divides the calcareous belt from the rocks of the top which seem to be different from the preceding ones. A vertical fault extends into the gully (fig. 41), so that the calcareous sequence regularly overlies the K² gneiss of the upper Abruzzi ridge, but is separated from the K² gneiss of the top by the vertical fault.

The rocky crest extending from the K² shoulder to the saddle at the head of the Marpophong glacier (Marpophong gap) is analogous in geological composition to that of the east slope of K² (XX fig. 1). However, the rock appears darker either due to more frequent intercalations of fine-grained darker biotitic paragneiss, or, more likely, due to the presence of Falchan gneiss. From the trend of the layering it is unlikely that the geological composition of this crest changes markedly. The rocks of the crest are probably the same as those forming the lower portion of the eastern slope of K².

In general we can say that the upper eastern slope of K², above 6500 m, is constituted of porphyroblastic gneiss, sometimes very laminated, and that the lower slopes are composed of Falchan gneiss.

Near the south foot of the east slope calcareous rocks again appear, and, as at the northeastern end, there is a passage from Falchan gneiss to «black slates». Numerous granite gneiss bands are included within this gneiss.

The layers prevailingly dip north-eastwards, the dip increasing from the shoulder to the foot of K², and decreasing from the shoulder to the top. From the shoulder downwards the layers are folded into a knee-shaped anticline, as seen in fig. 39.

e) North Slope.

The north slope of K² is the least known, due to the difficult approach and the great distance from the arterial high ways and airports. The little geological data we have comes from observations made by A. Desio on the North K² glacier in 1929 and the aeroplane flight of 1954.

The North K² glacier carries morainic materials that for the most part come from the northern side of the mountain.

The two main feeder branches lap the foot of the north-east and northwest walls of the huge pyramid (pl. XX fig. 2), joining at the north end of the crest that divides the north slope of K² into two faces. The glacier then continues in a north-northwest direction.

The moraine contains greenish porphyroblastic gneiss, K² gneiss, pro-
bably similar to the gneiss of sample 54 PD-48, and « black slates » accompanied by some scarce white marble blocks (1).

The two faces of the north slope of $K^2$ must be composed of rather homogeneous gneiss. From a distance the schistosity planes can hardly be seen. However, on the northeast face the gneiss bands seem to dip towards the northwest.

Some data on the attitude of the banding can be drawn from the photographs taken during the photogrammatic survey of the Savoia glacier.

As can be seen in fig. 42, on the northwest face of $K^2$ the bending has a flat trend immediately below the top of $K^2$, while below this they seem to have an anticlinal form, with the axis plunging to the southwest. The folding is also cut by some faults. These few data are the only information we have on the north slope of $K^2$.

f) West Slope.

The geological information on the west slope mainly refers to distant observations and to data drawn by G. FRANCALANCI from the photographs

(1) The samples collected here were lost when one of the bearers emptied the case in which they were contained to use for his personal effects. (Information from Desio's field notes).
of F. Lombardi taken for photogrammetrical purposes. The latter are the most interesting, since they also give an idea of the tectonics.

The lithological composition of the western slope is no different from that of the neighbouring southern and northern slopes. Viewed from a distance the rock is identical both in colour and layering and is continuous from one slope to another. Unfortunately floating moraines are lacking on the left-hand side of the Savoia glacier, and the right-hand side moraines come from the Summa-ri ridge.

From the direct observations and the stereoscopic investigation of the photographs we can consider the west slope to be prevailingly composed of grey and greenish rather massive gneiss, and often an augen gneiss (K² gneiss), associated with granite gneiss. This is confirmed by the rather massive nature of the rocks and their rather light and uniform colour (pl. XXI).

According to G. Francalanci, on the western spur of the Angelus (6855 m) an outcrop of lighter-coloured rocks, well distinguishable in the photograph, occurs (pl. XXII fig. 1).

These rocks have a strange appearance and seem to be an agmatite. The slope is composed of K² Gneiss and Falchan Gneiss and is crossed by an irregular lens of white matter including blocks and fragments of different shape and size, composed of a grey and black rocks (Falchan Gneiss?). The outcrop is very fractioned by the ice blanket, so that the relationship between the supposed agmatite and the gneiss is not clear.

The eastern portion of this spur, like the end of the western spur of K², is composed of dark rocks, not very schistose, so that we think it could be Falchan Gneiss rather than «black slates». The crest joining the K² pyramid to the Savoia saddle is of analogous composition.

The contact between K² Gneiss and Falchan Gneiss to the southeast of the Savoia saddle, seems to be a vertical fault (fig. 42).

The tectonics will be discussed in the next section.

g) TECTONICS.

A brief description of the structure of the great pyramid of K² was given in a preliminary note in 1956, and was compiled chiefly on the basis of field observations.

Following this, petrographic study of the samples collected on the northern and eastern slopes of the mountain was completed by B. Zanettin. The many photographs taken by F. Lombardi, topographer of the 1954 expedition, on the east, south, and west sides, for the survey of the topographic map
of $K^2$ at a scale of $1:12$ 500, have been submitted to an accurate stereoscopic analysis by G. FRANCALANCI. These studies, as well as the numerous observations collected in situ during the climbing of $K^2$, partly by the naked eye and partly with good binoculars, have brought to light several new pieces of information. On the basis of these we were able to take a new step in the understanding of the geological structure of the mountain.

It can be seen from the structural sketch drawn by G. FRANCALANCI, and from the geological map of $K^2$ of A. DESIO that two different types of dislocations are present, namely faults and folds (see the geological and tectonic maps of $K^2$ at the end of this volume).

**Faults.** The faults form a close network in which two principal systems can be easily distinguished, intersecting one another at right angles. The north-trending system consists of longer, perhaps also more significant, faults. For practical reasons we have numbered them from east to west, writing the symbol N (north) after each progressional number.

It seems that the most continuous fault is the one intersecting $K^2$ slightly east of the top, from the north to the south side, dividing the mountain into two principal, slightly different, blocks. We have marked it 2N. It is visible by naked eye from the Godwin Austen glacier (fig. 41) and we have already mentioned it in a preliminary paper (DESIO and ZANETTIN, 1957 b). Near to the top it puts the $K^2$ gneiss in contact with a thin strip of limestone (G. P. sequence).

Further downwards, to the south, it separates the limestones from the $K^2$ Gneiss. The fault 3N seems to be much shorter than the preceding one, and northwards dies out against the faults of the system at right angles to it (E system). The fault 5N runs along the northwest side of $K^2$, and seems to estinguish southwards under the ice of the Negrotto glacier. In this direction we see that faults 8 N and 9 N passe to the west of the Black Peak, but we do not have (on account of a large cover of ice) sufficient data to know whether it continues further north, on the east side of the Angelus, to where $K^2$ Gneiss comes in contact with Falchan Gneiss. Such an extension did not appear obvious from the stereoscopic examination of the photographs. An other fault (7N) crosses the ridge between the northwest outlier of $K^2$ and the Savoia saddle.

The last fault of the same system i. e. the fault 1N crosses the ridge from $K^2$ to the Skyang Kangri, passing to the west of the Marpophang glacier. This fault puts the Falchan Gneiss (west) in contact with the «black slates ».

As has been shown in the geological sections (fig. 43) all these faults are
vertical or steeply inclined. The throws cannot be calculated, due to lack of stratigraphical data that could be used for reference.

The faults of the system striking east-west, that is, perpendicular or almost perpendicular to the preceding one, seem to be more discontinuous. Most of the recognizable faults of this system are included between fault 2N and fault 4N. These are faults 2E, 3E, 4E, 5E, 7E, 8E, which do not strike exactly east-west but somewhat to the east-northeast.

Fig. 43 A.B. - Geological sections across $K^2$ (according to DESIO and FRANCALANCI’s interpretation of LOMBARDI’s stereoscopic photographs).

G.P.s G.P. sequence, $K^g$, K$^g$ Gneiss, Fg FalchanGneiss, x faults (Scale 1 : 75,000).

It seems that at least some of the above mentioned faults stop against those of system N, though 3E and 4E pass beyond fault 2N. However, 1E extends beyond 4N, perhaps ending against 5N.

Two other faults (9E and 10E) belong to the same system. These run
along the northern side of the Angelus, passing to the south of the Negrotto saddle. Eastwards they probably end against 4N, while westwards they disappear under the Savoia glacier. On the north side of the valley of the Negrotto glacier there seems to lie a fault belonging to system E which has been indicated as 6E.

As can be seen in the section (fig. 43) the faults of system E also have steeply inclined planes.

Finally, two more faults should be recorded, which have a different strike from those mentioned above. These have been called 1NE and 1SE and cross the Abruzzi spur, the first with a north-northeast strike and the second with a south-east strike. In both instances the strikes and inclinations of the fault planes are even more variable than those of the two preceding systems. In connection with these two systems, it has to be emphasised that while the faults of system N generally intersect the trend of the bedding perpendicularly or almost perpendicularly, those of system E generally strike more or less parallel with it.

The faults recorded here may be surveyed in the field and, chiefly, by stereoscopic analysis of the photograms.

But, if we consider the large ice cover of K², it can easily be imagined that other faults may exist under the ice. However, due to the steepness of the sides of the mountain, outcropping rocks are present here and there at almost all localities. For this reason the identified faults should represent the large majority of the principal faults present.

A few observations should be made on the relative ages of the above mentioned systems of faults. Firstly, faults belonging to the same system are of the same age.

In this connection, an examination of the relationships between the two systems shown in the geologic map of K² shows that the faults of system E are mostly interrupted against the faults of system N. This would suggest that the latter may have developed prior to the former system. Faults of system E would have developed inside blocks formed previously, that is, bounded by faults of system N. If this was the case for some of the faults of system E, such as 1E and 5E, others, such as 3E and 4E (and perhaps also 7E) crossed faults of system N, such as 2N.

In our geological map other faults of system E are interpreted as being displaced by the faults of system N. For example, where a fault disappears under the ice we can imagine that it continues for a while; if on its way it is crossed by a perpendicular fault, an interruption is naturally suggested.
To conclude, it cannot as a rule be proven that the faults of system N displace those of system E.

A further observation may give us some information for judging the relative ages of the two systems. The faults of system E lie parallel to the strike of the beds, while the faults of system N are mostly transverse to this direction. In such cases, transverse faults are commonly the most recent, the others having been caused by the same stresses as those which caused the folding. This last proof seems to be much more valid, so that we are led to consider the fault system N to be more recent than system E.

**Folds.** In our preliminary notes (Desio and Zanettin, 1957 b), we suggested the presence of an anticline occurring in the eastern half of $K^2$. The fold is well exposed in the lower half of the Abruzzi spur, and shown in the sketch of fig. 39. The axis of the fold has a northward trend and runs approx-
imately slightly to the east of the «shoulder» of K². The fold is crossed by fault 1NE, which does not seem to cause any essential modifications to its configuration.

It is followed to the west by a weak syncline, whose axis trends north and which seems to die out north of the fault 1NE, where beds show a continuous eastward dip.

On the southern side of the mountain the bedded structure is inflected slightly, producing a broad anticline which is cut almost symmetrically by faults 2N and 3N (fig. 43, section A). But southward, the axis of the anticline bends westward until it is parallel to the preceding syncline, and meets the southern prolongation of the 3N fault. Further west the bends do not show any recognizable folds, being intersected by the network of previously described faults. But, west of the fault 4N, an asymmetrical fold verging westwards is well seen on some of the photographs (pl. XXI), and shown in fig. 44. This figure has been drawn on the basis of FRANCLANCY's interpretation.

The axis of the fold has an approximately northward trend. To the south the fold is cut by faults 9E and 10E, but it cannot be said whether it is displaced by these faults. A faulted anticline seems to occur on Black Peak with north-northwest trend, but shows no visible relationship with the preceding one.

The anticline of Black Peak is followed westwards by a syncline with northward trend, the trace of which can be seen in the south-west buttress of the Angelus.

The trend of all the folds mentioned above is close to the north direction, the maximum deviation from this direction being less than 25° and can be seen on the southwest corner of the K² massif.

But on this side of the mountain (more precisely on the south spur of the Angelus) FRANCLANCY identified a truncated anticline with west-east trend, that is perpendicular to the Black Peak anticline.

Another similar fold, with north-east trend, crosses the north-west corner of K².

We have thus briefly recorded the principal inflections of the banding, which may be qualified as folds. In fact they are fragments of folds truncated in two perpendicular directions by fault planes.

Thus, K² is a mosaic of faulted blocks with a prevailing north-south or north-northwest direction, within which the rocks are gently folded.

The main dislocation line is the fault running near the top of K², and designated as 2N (fig. 41).
We may make some suggestions on the chronological relationships between folds and faults. The folds and the faults of system E are generally parallel, so that they may be approximatively of the same age, and so developed during the tectogenesis of the region.

The information gathered on the age of the rocks which constitute the K' massif (p. 139) suggests that some deformation of the rock masses constituting this great mountain occurred during the Hercynian orogeny. The sedimentary formations may have undergone a primary folding and a longitudinal faulting during the late events of the Hercynian tectogenic cycle.

During the Alpine orogeny a few faults were reactivated. This block, already made rigid during the previous folding, was repeatedly fractured in a prevailing north-south direction. It was later submitted to a granitisation process which, after consolidation, made the block more and more rigid, until it eventually fractured into large rocky blocks, as previously recorded.

5. The Skyang Kangri Massif.

The massif of Skyang Kangri (Staircase Peak, 7544 m) stands between the narrow saddle opening at the head of the Marpophon glacier and the Skyang-la (Windy Gap, 6233 m). Skyang Kangri has a squat shape with an upper terrace covered with ice and cut in every direction by high rocky walls mostly coated with ice (pl. XXII fig. 2). To this massif an irregular rocky crest is linked to the southeast, ending at Skyang-la. Westwards it is cut by another wall descending to the small saddle opening at the head of the Marpophong glacier.

The preceding geological information on this rocky massif was very scarce, the only information until this time being due to A. Desio (1936). He mentioned the light colour of the mountain when viewed from the Godwin Austen glacier, and argued that it could be granite or limestone, but was more inclined to the latter interpretation.

The observations we gathered later were taken from the upper Godwin Austen glacier and the Skyang-la. As we were able to judge at short distance, the western part of the massif is made up of compact and subcrystalline yellowish or grey limestone, and also of white limestone with dark veins, in vertical layers with a small layer of red rock, apparently schistose, intercalated (fig. 45). We found some samples of limestone in the right-hand floating moraine of the upper Godwin Austen glacier. They may originate from the Skyang Kangri,
but we did not follow the morainic debris as far as the peak. No samples of the red rock were present in the moraine.

Judging from its appearance, the limestone of the Skyang Kangri shows some similarities with the Permian limestones of the Gasherbrum ridge: these limestones are compact, and grey or yellowish in colour. In the Gasherbrum ridge we have not seen red slate interbedded in the limestone, but it occurs in the sequence of Shaksgam valley.

The attribution of the Skyang Kangri limestone to the Shaksgam Formation is supported by the similarity of the Skyang Kangri blocks to the rocks outcropping below the front of the Sarpo Laggo glacier which is relatively close to the Skyang Kangri. The left wall of the Sarpo Laggo valley is composed of grey limestone containing Permian fusulinids, while, during the 1929 expedition, A. Desio observed among the debris fragments of red shale and multi-coloured conglomerate. This rock association seems to belong to the Urdok Conglomerate, overlying the Shaksgam Formation. We know that the Urdok Conglomerate can be substituted by red shale of the Chikchi-ri formation. Thus, within the Skyang Kangri we should have the following sequence from bottom to top: Permian limestone, red shale, Aghil Limestone.

Another possible comparison can be made with the limestone of the Savoia formation within which we have sometimes seen red rocks. Nevertheless the
first hypothesis seems more acceptable than the second one, due to the very close position of the Skyang Kangri to the Permian rocks of the Shaksgam valley and the trend of the beds.

A dark rock, not well defined but very similar when seen from a distance to the blackish biotite-tourmaline paragneiss forming the small crest near Skyang-la, occurs to the west of and in contact with the Skyang Kangri limestone. Eastwards, the Skyang Kangri limestone is cut by a fault and comes into contact with grey gneiss and blackish biotite paragneiss. The small crest, just emerging from the ice, descending to the Skyang-la from Skyang Kangri (pl. XXIII fig. 1), is composed of fine-grained blackish tourmaline-biotite paragneiss (54 PD-87).

Many pegmatite and aplite dykes are included in the gneiss.

In general the calcareous rocks forming the western part of Skyang Kangri represent a tectonic inclusion in the predominantly gneissic complex of K2. Information on the tectonics was gathered not only in the field, but also from the stereoscopic investigation by FRANCALANCI of the photographs taken for photogrammetric purposes. As can be seen in one photograph (pl. XXIII fig. 2) and in the sketch (fig. 45), an anticlinal structure occurs in the rocky wall under the eastern summit, but it appears to be placed between two subvertical faults. Westwards the gneiss seems to be slightly folded into

Fig. 46 – The anticline of Skyang-la (Desio).
Bsl black states, Fg Falchan Gneiss.
an anticline, while eastwards there is a syncline plunging south-westwards.

The latter contains the northern limb of another anticline with its core near Skyang-la (fig. 46), and its southern limb of the crest running towards Falchan Kangri.

We shall deal with this crest in the next section.

6. The Crest between Skyang-la and Falchan Kangri.

In general this crest is oriented north-east, but has a very irregular trend and from it many short spurs branch to both east and west. Along this crest runs the watershed between the basin of the Baltoro glacier (tributary of the Indus river) and the basins of the Skyang glacier and North Gasherbrum glacier, tributary of the Shaksgam river.

This crest may be considered to run from Skyang-la to the gap at the head of the Kharut glacier. This gap may be called the Kharut gap. Further westwards the Falchan Kangri rises.

The only previous geological information on this crest was that due to A. Desio. It was published in 1936 in the volume on the Duke of Spoleto’s expedition of 1929, and notes the presence of black shales, gneiss, and limestone.

We do not have much new data, but what we do have does give further information.

The small ridge south of Skyang-la (fig. 46), is composed of fine-grained biotite paragneiss, mostly black or very dark, crossed by pegmatite and aplite dykes, sometimes many metres thick. We also noticed a lamprophyric dyke of pyroxene minette (54 PD-89). The layering, near the saddle, dips to the south-west at $45^\circ$.

The crest has an analogous geological composition as far as the Sella saddle (6180 m), but the banding dips south-eastwards so that it appears that between Skyang-la and this saddle the core of an anticline occurs. This core approximately follows the western slopes of the crest (pl. XXIV).

Above the biotite gneiss (Falchan Gneiss) of the eastern limb of this anticline, on the crest forming the head of the Kharut glacier, white and black striped marble appear. A series of faults displaces the marble (fig. 47). The latter are quite evident due to their light colour, so that they stand out from the blackish gneiss (pl. XXIII fig. 2).

Below the Sella saddle, at about 5700 m, we collected in the talus three samples, one of multi-coloured brecciated limestone (54 PD-92), one of grey
calcaceous schist with a yellow weathered surface (54 PD-91), and one of arenaceous sericite-chlorite schist with the appearance of black slate.

This summarizes the present state of information on this crest. Further west occurs the Falchan Kangri which we dealt with in another section.

![Geological sketch of the crest between the Sella saddle and Falchan Kangri (Desio)](See plate XXIII fig. 2).

M Marble, Fg Falchan Gneiss, --- faults.

7. Petrogenesis of the Upper Valley of Godwin Austen Glacier.

a) Introduction.

Metamorphic rocks exposed in the upper basin of the Godwin Austen glacier show both low crystallinity (graphitic phyllites) and high crystallinity (granitic gneiss), with all the intermediate gradations (biotitic and arenaceous paragneiss, augen gneiss with small and big porphyroblasts).

The fundamental petrologic problem of this part of the Karakorum deals with the genesis of the porphyroblastic gneiss. Observations in situ and petrographic study of the material collected allow us to say that the porphyroblastic gneiss must have been formed through progressive transformation of biotitic and arenaceous paragneiss. We shall try to show the fundamental points on which our conclusion is based.
b) Relations between Lithological Types.

Far from the outcrop area of porphyroblastic gneiss (that is, in the highest part of the left slope of Godwin Austen valley) paraschists make up a homogeneous formation, here and there, for example, at Skyang-la crossed by aplitic-pegmatitic veins and dykes analogous to the ones intersecting the gneissic formations of Falchan Kangri and K\(^2\). The porphyroblastic gneiss appears in the paraschists in the area of the Falchan Kangri massif, and becomes more and more abundant as one approaches K\(^2\), until it prevails over the other rocks; however it never becomes the exclusive rock, but is always associated with big or small bands of paraschist.

As to the spatial relations among the different lithologic types making up the paraschist-porphyroblastic gneiss complex, the rule is the indeterminate or gradual nature of the passages between them and the irregularity of the outcrops of the porphyroblastic facies. In a broad sense, however, it may be said that the zone of paraschists (from Skyang-la to Sella saddle) is followed by a zone rather rich in augen gneiss with small feldspathic porphyroblasts (Falchan Kangri), and this in turn by another with bigger porphyroblasts, and finally by another in which granitoid gneiss prevails (walls west of De Filippi glacier). Thus, in a spatial sense, the increasingly porphyroblastic gneiss would represent a transition between the paraschists and the granitoid gneisses.

It is possible to recognize megascopically the progressive structural modifications through which the transformation of paraschist into granitoid gneiss takes place.

The passage between successive lithologic types, beginning with the less metamorphic ones (biotitic-graphitic phyllites), occurs at first through a general increase in the grain size of the matrix (biotite paragneiss), followed by the appearance of small feldspar porphyroblasts in the matrix, which progressively increase in number and size with consequent decrease (augen gneiss) and eventual disappearance (granitoid gneiss) of the matrix itself.

c) Petrographic Investigation.

The petrographic investigation, besides confirming that the feldspathic porphyroblasts of the augen gneiss develop themselves in a ground mass corresponding to the matrix of the biotitic paragneiss, allowed us to follow in detail the course of the mineralogical and structural transformations.

The simplest transformations are the ones leading to the formation of granitoid gneiss from arenaceous gneiss. The latter, as stated previously, is essentially made up of plagioclase with 30% An, quartz, and potash-feldspar,
and contains small quantities of biotite and muscovite; in other words it already has a mineralogical association of a granitic type. Upon mere recrystallization of these minerals there is a general increase in the grain size of the rock, resulting in a light gneiss with indistinct porphyroblastic structure (in these cases, in fact, feldspars seldom have a very marked development).

Of the two feldspars present here, potash-feldspar, specifically microcline-perthite, tends to form the most developed crystals, mainly in the most advanced metamorphic facies.

On the whole, the porphyroblastic development of these rocks of arenaceous origin appears later than that of the rocks of pelitic-arenaceous origin, as is evident in the common occurrences of thick intercalated bands of biotitic and arenaceous gneiss (54 PD-38, -38a).

The transformations of paragneiss of pelitic-psammitic origin are more complex. The facies of lower crystallinity representing these gneisses in this area are biotitic-graphitic phyllites rich in quartz, plagioclase (20-30% An) and biotite in very small crystals.

In a more advanced phase (biotitic paragneiss), the same minerals occur in better developed crystals of more or less equidimensional shape.

In addition to recrystallization, transformations also begins at this stage, as proved by the presence of a new mineral, potash-feldspar, formed at the expense of biotite (which is scarcer and more discretely confined to lamellae in paragneiss than in the phyllites) and by the highest medium An-content of plagioclase. At a certain point in this process, feldspathic porphyroblasts begin to form at many points in the rock. They are fed by the small granoblasts of the matrix, as well as through the above transformations (augen gneiss).

The first porphyroblasts coming into evidence are plagioclases, generally corresponding to andesine with 40% An, and hence more calcic than the earlier ones in the matrix. Only when plagioclases reach a certain size, the first potash-feldspar porphyroblasts begin to appear; later they grow more quickly than the plagioclases.

In some rocks the porphyroblastic development of feldspars happens in the order indicated, but in other cases the appearance of the two feldspars may be quite simultaneous.

Probably, the appearance of the big crystals of potash-feldspar is most rapid when the quantity of potash-feldspar granoblasts in the matrix is large.

The formation of porphyroblasts occurs according to the process of crystallization by concretion and substitution, as shown by the bending of the schistose beds caused by their increase and by the fact that they generally
include the minerals of the matrix (quartz and biotite). As transformation and recrystallization proceed, the matrix disappears completely, with consequent lessening of the schistose texture.

At this point significant new phenomena occur, which, with the others, make the granitoid gneiss appear. Plagioclase which, in augen gneiss, corresponds to andesine (35-40% An), corresponds in granitoid gneiss to oligoclase (20-22% An). The passage between the two lithological types is in some places very abrupt, obscuring the fact that the granitoid gneiss represents a transformation product from the augen gneiss.

The finding of rocks with mineralogical and structural characteristics (plagioclase with 25-29% An) intermediate between the two types of gneiss, and the observation that in many granitoid gneisses small crystals of andesinic plagioclase are present, show that granitoid gneiss genetically depends on augen gneiss.

It is noteworthy, even if not sufficiently controlled, that in some granitoid gneisses potash-feldspar substitutes and myrmekitizes the partly sericitized andesinic plagioclase which does not seem to happen with oligoclasic plagioclase (antiperthite).

d) Chemical Composition.

The chemical composition of several members of the paraschist-granitoid gneiss series was determined in order to determine whether the transformations described in the preceding sections occur with or without variations in composition.

For this purpose we took a biotitic-graphitic phyllite (54 PD-21) and a biotitic paragneiss (54 PD-6) as representatives of the lower metamorphic members of the metamorphic series, the former being the most common type. In addition we took two biotitic augen gneisses (one with fine porphyroblasts, 54 PD-70, the other with large feldspar crystals, 54 PD-24), and two granitic gneisses, one biotitic and with an abundant and rather fine matrix (54 PD-1), the other richer in feldspar and with a more homogeneous texture (54 PD-2).

The weight per cent values obtained by the chemical analyses are quoted in table II.
### TABLE 11

THE K² GNEISSES

ANALYSED ROCKS

<table>
<thead>
<tr>
<th>Locality</th>
<th>Petrographic classification</th>
<th>Chemical classification according to Niggli's magmatic types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. - Near the K² Base Camp, on the moraine.</td>
<td>Graphitic biotite-phylite (&quot;dark schists&quot;) (54 PD-21).</td>
<td>Between the granitic opdalitic type and the normal quartzdioritic type.</td>
</tr>
<tr>
<td>3. - Near the K² Base Camp, on the moraine.</td>
<td>Psammitic gneiss (54 PD-31).</td>
<td>Granitic adamellitic type.</td>
</tr>
<tr>
<td>4. - The lower part of the western spur of Falchan Kangry.</td>
<td>Biotite-augengneiss with small plagioclase porphyroblasts (54 PD-70).</td>
<td>Between the granitic opdalitic type and the normal quartzdioritic type.</td>
</tr>
<tr>
<td>5. - Near the K² Base Camp, on the moraine.</td>
<td>Biotite-augengneiss with small plagioclase porphyroblasts (54 PD-38).</td>
<td>Normal quartzdioritic type.</td>
</tr>
<tr>
<td>6. - Near the K² Base Camp, on the moraine.</td>
<td>Biotite-augengneiss with large feldspars porphyroblasts (54 PD-24).</td>
<td>Between the granodioritic farsunditic, the trondhjemitic leucquartzdioritic and the granitic adamellitic types.</td>
</tr>
<tr>
<td>7. - Near the K² Base Camp, on the moraine.</td>
<td>Light augengneiss (54 PD-33).</td>
<td>Between the rapakiwitic and granosyenitic types and the trondhjemitic natronrapakiwitic type.</td>
</tr>
<tr>
<td>8. - Near the K² Base Camp, on the moraine.</td>
<td>Light augengneiss (interbedded with biotite-augengneiss) (54 PD-38 a).</td>
<td>Trondhjemitic natronrapakiwitic type.</td>
</tr>
<tr>
<td>9. - Below the southern wall of K², at a height of about 5000 m.</td>
<td>Granodioritic gneiss (54 PD-1).</td>
<td>Between the normal granodioritic type and the tasnagranitic type.</td>
</tr>
<tr>
<td>10. - Below the southern wall of K², at a height of about 5000 m.</td>
<td>Granitic gneiss slightly schistose (54 PD-2).</td>
<td>Between the yosemitigranitic type and the rapakiwitic type.</td>
</tr>
</tbody>
</table>
(TABLE 11 - Continued)

CHEMICAL COMPOSITION

ANALYSED ROCKS

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>62.19%</td>
<td>68.62%</td>
<td>70.84%</td>
<td>65.25%</td>
<td>67.86%</td>
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<tr>
<td>TiO₂</td>
<td>0.83</td>
<td>0.65</td>
<td>0.16</td>
<td>0.66</td>
<td>0.36</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.42</td>
<td>0.14</td>
<td>0.14</td>
<td>0.28</td>
<td>0.16</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>16.21</td>
<td>13.55</td>
<td>13.75</td>
<td>15.45</td>
<td>13.78</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.53</td>
<td>0.26</td>
<td>0.18</td>
<td>0.27</td>
<td>0.22</td>
</tr>
<tr>
<td>FeO</td>
<td>5.59</td>
<td>3.03</td>
<td>0.95</td>
<td>4.25</td>
<td>2.48</td>
</tr>
<tr>
<td>MnO</td>
<td>0.08</td>
<td>0.07</td>
<td>n.d.</td>
<td>0.08</td>
<td>n.d.</td>
</tr>
<tr>
<td>MgO</td>
<td>3.27</td>
<td>2.31</td>
<td>2.89</td>
<td>2.85</td>
<td>3.94</td>
</tr>
<tr>
<td>CaO</td>
<td>2.57</td>
<td>2.18</td>
<td>3.34</td>
<td>3.58</td>
<td>3.77</td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.49</td>
<td>1.88</td>
<td>3.58</td>
<td>2.96</td>
<td>3.43</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.34</td>
<td>5.02</td>
<td>4.02</td>
<td>2.60</td>
<td>2.46</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>2.15</td>
<td>1.98</td>
<td>0.89</td>
<td>1.54</td>
<td>1.49</td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.08</td>
<td>0.06</td>
<td>0.02</td>
<td>0.03</td>
<td>0.07</td>
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<tr>
<td></td>
<td>100.75</td>
<td>99.75</td>
<td>100.56</td>
<td>99.80</td>
<td>100.12</td>
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<table>
<thead>
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</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>69.63%</td>
<td>70.95%</td>
<td>71.94%</td>
<td>63.19%</td>
<td>71.50%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.59</td>
<td>0.21</td>
<td>0.15</td>
<td>0.87</td>
<td>0.42</td>
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<tr>
<td>P₂O₅</td>
<td>0.51</td>
<td>0.13</td>
<td>0.13</td>
<td>0.66</td>
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<tr>
<td>Al₂O₃</td>
<td>15.08</td>
<td>13.46</td>
<td>13.89</td>
<td>17.20</td>
<td>14.06</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.19</td>
<td>0.18</td>
<td>0.02</td>
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<td>0.17</td>
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<tr>
<td>FeO</td>
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<tr>
<td>MnO</td>
<td>0.05</td>
<td>n.d.</td>
<td>n.d.</td>
<td>0.07</td>
<td>0.06</td>
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<tr>
<td>MgO</td>
<td>1.25</td>
<td>2.15</td>
<td>2.62</td>
<td>1.92</td>
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<tr>
<td>CaO</td>
<td>2.87</td>
<td>2.10</td>
<td>2.04</td>
<td>3.29</td>
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<tr>
<td>Na₂O</td>
<td>4.00</td>
<td>3.42</td>
<td>4.66</td>
<td>4.05</td>
<td>3.48</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.64</td>
<td>4.71</td>
<td>3.69</td>
<td>3.26</td>
<td>4.16</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>1.12</td>
<td>1.20</td>
<td>0.73</td>
<td>1.14</td>
<td>0.67</td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.05</td>
<td>0.05</td>
<td>0.02</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>100.73</td>
<td>100.08</td>
<td>100.68</td>
<td>100.44</td>
<td>100.23</td>
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</table>
**Niggl'i's values**

<table>
<thead>
<tr>
<th>K²</th>
<th>Analysed Rocks</th>
<th>Si</th>
<th>Al</th>
<th>Fm</th>
<th>C</th>
<th>Alk</th>
<th>K</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Graphitic biotite-phyllite</td>
<td>214</td>
<td>33.0</td>
<td>34.0</td>
<td>13.4</td>
<td>19.0</td>
<td>0.38</td>
<td>0.49</td>
</tr>
<tr>
<td>2.</td>
<td>Biotite-paragneiss</td>
<td>318</td>
<td>37.0</td>
<td>28.8</td>
<td>10.8</td>
<td>23.4</td>
<td>0.64</td>
<td>0.55</td>
</tr>
<tr>
<td>3.</td>
<td>Psammitic gneiss</td>
<td>308</td>
<td>35.3</td>
<td>22.8</td>
<td>15.6</td>
<td>26.3</td>
<td>0.42</td>
<td>0.82</td>
</tr>
<tr>
<td>4.</td>
<td>Biotite-augengneiss</td>
<td>255</td>
<td>35.6</td>
<td>31.6</td>
<td>15.0</td>
<td>17.8</td>
<td>0.37</td>
<td>0.52</td>
</tr>
<tr>
<td>5.</td>
<td>Biotite-augengneiss</td>
<td>270</td>
<td>32.3</td>
<td>32.3</td>
<td>16.0</td>
<td>19.4</td>
<td>0.32</td>
<td>0.72</td>
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<tr>
<td>6.</td>
<td>Biotite-augengneiss</td>
<td>318</td>
<td>40.6</td>
<td>20.0</td>
<td>14.0</td>
<td>25.4</td>
<td>0.30</td>
<td>0.43</td>
</tr>
<tr>
<td>7.</td>
<td>Light augengneiss</td>
<td>336</td>
<td>37.6</td>
<td>21.5</td>
<td>10.7</td>
<td>30.2</td>
<td>0.47</td>
<td>0.70</td>
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<tr>
<td>8.</td>
<td>Light augengneiss</td>
<td>329</td>
<td>37.4</td>
<td>21.2</td>
<td>10.0</td>
<td>31.4</td>
<td>0.34</td>
<td>0.84</td>
</tr>
<tr>
<td>9.</td>
<td>Granodioritic gneiss</td>
<td>240</td>
<td>38.4</td>
<td>25.6</td>
<td>13.4</td>
<td>22.6</td>
<td>0.34</td>
<td>0.42</td>
</tr>
<tr>
<td>10.</td>
<td>Granitic gneiss</td>
<td>359</td>
<td>41.5</td>
<td>18.2</td>
<td>10.1</td>
<td>30.2</td>
<td>0.44</td>
<td>0.39</td>
</tr>
</tbody>
</table>

**Niggl'i's magmatic types**

Granitic magmas:
- **Adamellite type**
  - Si 300
  - Al 37.5
  - Fm 22.5
  - C 13.5
  - Alk 26.5
  - K 0.45
  - Mg 0.3

- **Opdalite type**
  - Si 225
  - Al 32
  - Fm 32
  - C 18
  - Alk 18
  - K 0.45
  - Mg 0.45

- **Tasnagranitic type**
  - Si 300
  - Al 36
  - Fm 28
  - C 9
  - Alk 27
  - K 0.45
  - Mg 0.35

Quartzdioritic magmas:
- **Normal quartzdioritic type**
  - Si 225
  - Al 32
  - Fm 31
  - C 19
  - Alk 18
  - K 0.25
  - Mg 0.45

Granodioritic magmas:
- **Normal granodioritic type**
  - Si 280
  - Al 39
  - Fm 22
  - C 17
  - Alk 22
  - K 0.45
  - Mg 0.40

- **Farsunditic type**
  - Si 300
  - Al 42
  - Fm 20
  - C 15
  - Alk 23
  - K 0.25
  - Mg 0.40

Trondhjemitic magmas:
- **Leucoquartzdioritic type**
  - Si 300
  - Al 42
  - Fm 17.5
  - C 13
  - Alk 27.5
  - K 0.25
  - Mg 0.40

- **Natronrapakiwitic type**
  - Si 340
  - Al 42
  - Fm 20
  - C 8
  - Alk 30
  - K 0.25
  - Mg 0.3

Leucogranitic magmas:
- **Yosemitgranitic type**
  - Si 350
  - Al 43
  - Fm 14
  - C 13
  - Alk 30
  - K 0.45
  - Mg 0.30

Leucosyenitgranitic magmas:
- **Rapakiwitic type**
  - Si 350
  - Al 41
  - Fm 18
  - C 9
  - Alk 32
  - K 0.45
  - Mg 0.3

- **Granosienitic type**
  - Si 260
  - Al 39
  - Fm 18
  - C 11
  - Alk 32
  - K 0.45
  - Mg 0.3
Comparing the compositions of the different samples, the most marked differences are found between those representing the initial, low-metamorphic members of the metamorphic series that is, between the phyllite and the paragneiss.

Of the two metasediments, the phyllite have the lower SiO$_2$ content (62.19% against 68.62%) and the higher Al$_2$O$_3$ content (16.21% against 13.55%). The sum of alkali is the same in the two rocks, but whereas in the phyllite Na$_2$O and K$_2$O are equal, potash strongly prevails over soda in the paragneiss. Aside from the above differences, their substantial analogy in composition is shown by the fact that both of them are comparable to the granitic magmas of NIGGLI.

In particular, paragneiss coincides very well with the tasnagranitic type and phyllite with the opdalitic type. The latter rock can also be put near the normal quartzdioritic type of the quartzdioritic magmas from which, however, it differs in that the value of $c$ (13.3) is lower than the minimum required (15).

The differences between the two augen gneisses examined are less marked than between the two lower-grade parametamorphic rocks with which they show certain analogies. Specifically, the composition of the two augen gneiss is between that of the two metasediments.

The fine augen gneiss has "Niggli values" similar to the opdalitic type of granitic magmas and the normal quartzdioritic type of quartzdioritic magmas, as is the case with the biotitic-graphitic phyllite.

Owing to the low values of $fm$ and $k$ the gneiss with more highly developed porphyroblasts does not show strict correspondence with the granitic magma types, although it is near the adamellitic type, but is equivalent both to the farsunditic type of granodioritic magmas and to the leuco-quartzdioritic type of the trondhjemitic magmas.

The composition of the granitoid gneiss, with its rather abundant matrix, is not very different from that of the four rocks mentioned above.

Its "Niggli values" correspond well to those of the normal granodioritic type (analogous to the gneiss with large porphyroblasts), but they could also belong to the tasnagranitic type (analogous to the biotitic paragneiss).

The lighter granitoid gneiss, poor in biotite, is more obviously different from the other rocks examined, mainly on account of its higher content of SiO$_2$ (71.50%) and its low content in mafic oxides.

The differences are expressed in "Niggli values" that present a correspondence both with the rapakiwitic type of the leucosyenitic-granitic magmas, and with the yosemitic-granitic type of the leucogranitic magmas.
In order to have a complete picture of the chemistry of the rocks belonging to the K2 Gneiss formation, we also examined two samples of arenaceous gneiss, one quite uniformly fine-grained (54 PD-31), the other with coarser grains and marked porphyroblastic texture (54 PD-33). In addition, we performed two chemical analyses on a single sample formed by alternating dark (biotitic porphyroblastic gneiss) and light (arenaceous gneiss) bands. One analysis was made of the light band (54 PD-38a) and the other of the dark band (54 PD-38).

The data quoted in table 11 show that the two arenaceous gneisses (54 PD-33 and -38a) have a composition similar to that of the granitoid gneiss analyzed; the first one corresponds to the rapakiwitic type of the leucosyenitic-granitic magmas, the second owing to the different value of $k$ to the natron rapakiwitic type of the trondhjemitic magmas.

The third arenaceous gneiss (54 PD-31) is different from the others in its higher value of $c$ (15 instead of 10). It belongs to the adamellitic type of the granitic magma.

The augen gneiss (54 PD-38) bands intercalated with arenaceous gneiss are quite similar to the other augen gneisses (normal quartzdioritic type).

e) Petrogenesis.

The data presented above confirm the genetic hypothesis set forth at the beginning of this chapter, that is that the porphyroblastic gneisses cropping out in the K2 area are the product of mineralogic and structural transformations produced at the expense of the biotitic and arenaceous metasediments which form the prevailing lithologic types on the upper branch of the Godwin Austen glacier.

The above transformations are mainly isochemical (1) because all the mineralogic components present in the porphyroblastic gneisses are potentially present also in paraschists, as we can see by the analogy of the standard mineralogical composition of the examined rocks (table 11).

It must be pointed out that the last statement may be applied with confidence to the augen gneiss, but is not so sure for granitic gneiss. In fact although the latter has a chemical composition rather similar to arenaceous gneiss, it cannot have been directly derived from it through simple structural transformation. Arenaceous gneiss, in fact, forms well defined rectilinear layers, intercalated within the prevailing biotitic paraschist, whereas the out-

(1) In some preliminary notes (B. Zanettin 1957; A. Desio and B. Zanettin, 1957 b) we set forth the hypothesis that these gneisses were formed by metasomatic granitization of paraschist, intending to finish our investigation before giving a definite judgement.
crops of granitoid gneiss have rather irregular forms, demonstrating only a coarse banding.

Looking for a solution of this problem the fundamental petrographic characteristic distinguishing augen gneiss from granitic gneiss must be kept in mind: the former has andesinic plagioclase, the latter oligoclasic plagioclase. It shows that the transformation augen gneiss $\rightarrow$ granitic gneiss occurs through a remarkable change of the metamorphic conditions.

As granitic gneiss tends to a massive texture we can argue that the new metamorphic conditions give the matter a greater mobility. Thus, we can set forth the hypothesis that in this more advanced phase of the process a homogeneization of the parent materials (arenaceous gneiss and augen gneiss) occurs.

It is more likely, however, that substances coming from outside the system are also involved, so that the process, which at first is merely metamorphic, would become metamorphic-metasomatic.

The existence of rocks structurally and mineralogically transitional between augen gneiss and granitic gneiss and the regular presence of andesinic plagioclase remains in these rocks guarantee, in every case, that granitic gneiss was formed at the expense of augen (and arenaceous) gneiss.

The sequence of the transformations paraschist $\rightarrow$ granitoid gneiss must have been characterized by a more and more marked mobility of the matter: beginning with the simple recrystallization of phyllitic paraschists it continued with the formation of porphyroblasts, entailing migration of ions over greater distances, and ended with the introduction, though moderate, of extraneous substances (metasomatism).

On the whole the process can be considered as a case of isochemical granitisation.

As to the causes of the above transformations, they are surely related to the granitic batholith of Baltoro. This one, as we shall say further on (page 206), is considered by us to be the product of the injection of an anatectic magma into the rocks overlying the anatexis area. Probably, an anatectic process occurred at a certain depth below the area of $K^2$. The rocks now exposed perhaps suffered a simple recrystallization process by the fluids coming from the anatectic area below. According to the intensity of their duration, or to the nature of the action of these fluids, the different gneiss types described above would have been produced.

Even if we recognize in situ a coarse banding of the relatively more transformed rocks, we must remember that the intensity of the transformations is
very changeable, even in places near to each other. The paraschist strips present in the areas where porphyroblastic gneiss prevails, can be considered portions of rocks that escaped the catalytic or metasomatic action of the « granitising » fluids.

The $K^2$ gneiss formed in this manner was in the end injected with veins and dykes of the anatectic aplitic and pegmatitic magmas formed in the zone below.


In the preceding paragraph we tried to explain the origin of the metamorphic rocks of the $K^2$ massif and of the upper valley of Godwin Austen glacier.

We must give now a stratigraphic interpretation of the sedimentary rocks from which the present parametamorphic ones are derived.

On the south slope of $K^2$ a group of rocks is particularly evident for its colour, which is lighter than the common colour of the slope, and for its mineralogical composition. We are dealing with a complex of calcareous rocks included and intercalated within the prevailing porphyroblastic gneiss. The calcareous rocks are white and grey marbles ($54 \text{ PD-10, -11, -12, -47}$), calciphyre ($54 \text{ PD-16}$), calc-schists ($54 \text{ PD-9, -37, -42}$), and limestone ($54 \text{ PD-47, -99}$), which may be more or less schistose ($54 \text{ PD-19, -21, -35, -91}$) and brecciated ($54 \text{ PD-51, -92}$). Such rocks are not very widely exposed in the upper valley of Godwin Austen glacier. They are localized on the south slope of Black Peak, on the south side of the lower valley of De Filippi glacier, on the east side of the Abruzzi spur, and on the south-east foot of $K^2$, always in small outcrops, mostly scarcely emerging from the ice. Another outcrop of such rocks probably exists, just below and east of the summit of $K^2$, and still another, more extensive, on the west slope of Angelus peak (page 110).

We were not able to survey detailed and complete sequences within such calcareous complexes. On the Gilkey-Puchoz spur the sequence may be approximately as follows:

a) porphyroblastic gneiss (augen gneiss+granitoid gneiss), with lenses of biotitic paragneiss,

b) laminated sandstone,

c) fine-grained graphitic biotitic paragneiss,
d) soft calcareous rock with black irregular beds of carbonaceous trails,
e) porphyroblastic amphibole gneiss,
f) limestone,
g) porphyroblastic gneiss.

In the outcrop of the confluence of De Filippi glacier white and grey marbles are more widely distributed. Other rocks present in the calcareous sequence of the south slope of K^2 are: fine grained sandstone, chlorite schist, biotite-chlorite gneiss, feldspathic gneiss with amphibole and chlorite, etc.

We do not know the stratigraphic relations between the above-mentioned sequences of rocks. The outcrops are, in fact, separated by large ice fields and crossed by faults which prevent of reconstruction the actual sequence. Probably we are dealing with different levels of an extensive calcareous sequence. In any case, we can assume that the calcareous sequence of K^2 represents a geological formation, as yet poorly known (see p. 110) which we will call *Gilkey-Puchoz spur calcareous sequence* or shortly *G. P. calcareous sequence* (1). This sequence is typically composed of marbles and metamorphic limestones associated with metamorphic sandstone, chlorite and amphibolitic schists, and fine-grained graphitic gneiss. The calcareous rocks alternate with gneissic rocks and their thickness is of the order of tens rather than hundreds of metres.

Now we should ask ourselves whether the limestones which crop out farther upstream, on the group of the Skyang Kangri and on the crest which forms the head of the Kharut glacier, belong to the same formation. From this last locality, some samples composed of compact limestones (54 PD-92), calcareous schists (54 PD-91), and black arenaceous sericite-chlorite schists have been collected; in addition, white marbles are distributed along that crest.

The white marbles rank directly behind the «black slates» in predominance. These «black slates» are the same rocks which compose, together with other rocks, the north-west flank of the Falchan Kangri, which we already know (p. 23) by the name *Falchan Gneiss*.

Besides these rocks, others have been collected from the same outcrop on the left moraine of the Godwin Austen glacier at an altitude of about 5000 m. These include zoned arenaceous schist (54 PD-43), muscovite micaschist (54 PD-44), grey compact limestone (54 PD-47), in addition to fine biotitic gneiss with feldspar porphyroblasts (54 PD-46), and dyke rocks (pegmatite).

(1) The name «formation» cannot be used because we know neither a well-defined series, nor the stratigraphic position of the local sequence.
On the whole the lower part of the group of rocks of the Kharut crest represents the "black slates" with a passage to the facies of Falchan gneiss.

The marbles overlying the black slates can be compared with the limestone of the Shaksgam Formation overlying the black shales of the Singhie formation in the Shaksgam valley. This correlation remains hypothetical because of insufficient lithostratigraphic data, but we did not find a sequence bearing greater similarity to that of the Kharut crest. Perhaps the Kharut sequence offers some remote similarity with the G. P. sequence, which also contains chlorite schists, but the thickness of the marble beds is lower in the latter sequence and some different types of rocks are also represented, which are lacking in the Kharut crest. For that reason we favour the first correlation.

We should now consider the calcareous outcrop of the Skyang Kangri, from which we could not collect samples: we could only examine it by binocular at a short distance. We seem to have recognized in these calcareous beds substantial differences with respect to the previous ones. Their thickness is much greater, and their colour seems to be different: from a distance, they seem to be yellowish. Furthermore, these limestones are intercalated with a bed of a red rock, seemingly a shale, which does not appear in the other outcrops, nor in the floating moraines of the Godwin Austen glacier. All considered, it does not seem that we are dealing with the same formation which contains the calcareous units that crop out in the valley of the Godwin Austen glacier. As has been already mentioned (p. 124), the Skyang Kangri limestone can be compared preferably with the Permian, or possible Triassic, limestones of the Shaksgam valley.

With regard to the other rock sequences of the valley of the Godwin Austen glacier, the stratigraphic data at our disposal, though scanty, permit further specification.

The "black slates" of the Savoia valley can be correlated with the "black slates" of the Sarpo Laggo valley, whereas the "black slates" of the Skyang-la lie nearly in continuity with the black shales of the Shaksgam valley. We can conclude that the "black slates" of the Godwin Austen basin represent the beds which link the "black slates" of the Sarpo Laggo valley to the black shales of the Shaksgam valley, specifically, those which have already been called *Singhie Shale* (Desio 1963 b).

With respect to the stratigraphic relationships between black slates and Falchan Gneiss, in addition to the lateral change from one formation into the other observed along the upper valley of the Godwin Austen glacier, which proves the equivalence of the two formations, there is also a set of petrographic
tests already mentioned in a precedent section. The same can be said about the stratigraphic relationships between black slates, Falchan gneiss and K² gneiss, so that it is sufficient to establish the age of one formation – or, rather, of the pre-metamorphic rocks – in order to date to the others as well.

B. THE PERIBATHOLITHIC METAMORPHIC BELT

1. Introduction.

The granitic batholith of the Baltoro is surrounded on three sides by an irregular belt of metamorphic rocks which possess different facies in accordance with the nature and texture of the rocks from which they are derived and with the greater or lesser distance from the igneous body. The contact between the granite and the metamorphic rocks is in part clean, in part indeterminate. In both instances this limit enters the basin of the Baltoro to the north, near the East Muztagh glacier, crosses diagonally, at an angle of about 30°, the Baltoro valley, which is oriented east-west, reaching the Mitre peak and continuing along the south-west side of the valley of the Upper Baltoro glacier (see the Baltoro geologic map). On the opposite side of the batholith the contact lies near the crest of the Masherbrum, on the Biarchedi massif, continuing from there towards the valley of the Vigne glacier. The trend is about east-southeast. As has already been mentioned, the batholith dips to the south-east below a mantle of originally sedimentary rocks.

In the preceding paragraphs we have emphasized that augen gneiss and granitoid gneiss of K² constitute an « island » of marked crystallinity, surrounded by formations of a low metamorphic grade. We have expressed the opinion that this crystallinity may be connected with the greatest petrogenetic events that affected the rocks of the Baltoro basin: the formation of the granite batholith.

Now we shall consider the rocks which are in direct contact with the batholith. First of all, it has to be recorded that all of the country-rock presents a more developed crystallinity than the metamorphic rocks cropping out very far from the granitic body. But, aside from this common characteristic, clear petrographic and textural differences can be noticed between the country-rock outcropping north of the granitic body and those outcropping south or at the top of the batholith.

At the north-easterly contact of the batholith (right side of the Baltoro) gneissic rocks are visible, in part similar in aspect and petrographic character to
the porphyroblastic gneiss of K²; at the south-easterly contact (basin of Vigne glacier), however, schists affected by thermal metamorphism may be seen.

Also, it must be emphasized that along the right side of Baltoro the peribatholithic belt is very thick and that the contact surfaces between granite and country-rock are essentially conformable, whereas in the Vigne glacier basin the thermally metamorphosed belt presents modest thickness and non-conformable contacts.

In a following section, devoted to the petrogenesis of the Baltoro granite (p. 205), we shall try to explain the difference between the geologic and petrographic features along the two sides of the batholith.

We shall first illustrate the geological conditions and the petrographic character of the country-rock south of the batholith and then those to the north.

2. Chogolisa Kangri and Vigne Glacier Valley.

a) Introduction.

The Chogolisa Kangri (pl. XXV fig. 1), which is also known in the old literature with the name of Bride Peak, rises almost isolated between the Chogolisa icefall and the Vigne glacier. The main peak is characteristic for its horizontally truncated summit and for its extensive ice-mantle. This can be observed from Concordia and from the lower Godwin Austen glacier.

The highest summit reaches 7654 m; only one spur extends from it with a northward direction. A deep saddle which was named by us Vigne-la, separates that spur from the relatively isolated peak 6802 m high, which has been called by us Vigne peak. It is from this peak that a long, northward spur branches out, which separates the Vigne glacier from the Upper Baltoro glacier.

The Vigne glacier makes an arch with a north-east concavity, and is flanked in the opposite direction by a long crest which forms the left side of the valley. North-westward rises the Naating crest, which terminates south-eastward in the Mitre peak. The Mitre's eastern spurs delimit three small glaciers, which are left tributaries of the Vigne glacier. The largest of these (the southern one) has been called by us West Vigne glacier.

(b) Previous Knowledge.

The first geological knowledge regarding the Chogolisa Kangri was provided by V. Novarese (1912 b), who examined the samples collected by the expedition of the Duke of Abruzzi of 1909. A sample of biotitic gneiss, of dark colour, studied by Novarese, was collected in situ by the Duke of Abruzzi at an altitude of 7498 m a.s.l. Novarese
described this sample in some detail but we shall summarize his description here. The rock is a fine-grained, lineated, flaggy, biotitic gneiss. Under the microscope it is made up of quartz, feldspar, biotite and amphibole (actinolite); other, less frequent, minerals are: sphene, zircon, apatite and calcite. The mica prevails in quantity over the amphibole; quartz and feldspar grains are equidimensional. The texture of the rock is granoblastic, characteristic of the metamorphic rocks near the contact with the granite, but in thin sections no contact minerals have been found.

Other geological information comes from A. Desio (1936). According to this author, the massif of the Chogolisa Kangri is constituted to a great extent by granite, granitoid gneiss and dark biotitic gneiss. At the base of the slope, towards the Baltoro, lies a belt of black slates; thick beds of gneiss, and perhaps of limestone, are intercalated within the upper levels. The same author also gives data on the Mitre peak: «Here can be clearly seen the interbeds of yellowish-white crystalline limestone in the schistose sequence formed by black phyllite, chloritic schist, micaceous gneiss and dark calc-schist». This schistose sequence is in contact with the granite.

According to T. E. Gattinger (1961, table 4), who did not bother to read the earlier reports, the Mitre peak is supposedly composed of blak slate and phyllite cut by big granite dykes. Also, the uppermost part of the peak, towards the Baltoro, is said to be composed of granite. As is clear from the above cited data, what was previously known was much more exact than what was published by Gattinger.

c) Features of the Thermally Metamorphosed Rocks.

In the basin of the Vigne glacier the rocks in contact with the granite of the batholith, composing its roof, are everywhere more or less intensely thermally metamorphosed. They represent different lithological types, according to the different nature of the original rocks from which they were derived.

The most common types are the ones which are derived from pelitic or pelitic-psammitic rocks, more or less rich in quartz. They are represented by hornfelses of different metamorphic degree: biotite hornfels (54 PZ-193), biotite-andalusite-hornfels (54 PZ-191), biotite-andalusite-sillimanite hornfels (54 PZ-190), and biotite-sillimanite hornfels (54 PZ-180, -188, -203).

The biotite shows the typical reddish-brown pleochroism which generally distinguishes the thermally developed iron-magnesian micas; it is commonly associated with muscovite, with which it may be intergrown. In a few rocks, micas are distributed in single individual crystals within the other minerals; in other rocks they form sub-parallel bands.

Andalusite is locally present in large crystals bounded by aggregates of sericite and muscovite; more commonly it is present in extremely poikiloblastic, almost skeletal, individuals. The characteristic pink pleochroism is visible only in well developed crystals. In a few instances the andalusite has been directly converted into sillimanite.
Sillimanite, in very thin needles distributed in spots or tufts, is generally formed at the expense of muscovite and also of biotite. Usually, the new formation of sillimanite is preceded by the appearance of spots constituted of fine aggregates with the aspect of sericite or talc. Small crystals of sillimanite may be directly developed at the edges of muscovite crystals.

Also tourmaline is rather common in pelitic contact rocks.

In addition to the above-mentioned minerals of thermal origin, quartz and an oligoclase-plagioclase (about 15-25% An) occur, commonly in abundance, in all of these hornfelses. These two minerals become most abundant in the rocks derived from more strongly arenaceous sediments. In these rocks, the thermal metamorphism causes the appearance of dark, rounded spots in a pale ground mass. This consists of the accumulation of biotitic lamellae, or, more commonly, of needles of sillimanite (54 PZ-203).

Hornfelses richer in quartz, but in places very poor in plagioclase (54 PZ-198 - 199), locally form layers of fairly considerable thickness; but more normally they constitute thin beds intercalated with more argillaceous sediments or, more rarely, with green schists rich in actinolite (54 PZ-200).

Also associated with these « normal » types of pelitic hornfels, are schists possessing an unusual mineral association; for example, a few dark rocks, strongly biotitic and showing a clear schistose structure, have been found next to the granite mass (54 PZ-183). The fundamental minerals are represented by the above-mentioned reddish biotite, segregated in thick lamellae, and also by garnet and quartz, either in lenses or in isolated large individuals, and by bytownite. This last mineral also represents a product of recent formation, as indicated by the evident poikiloblastesis (resulting from the inclusion of small individuals of quartz of various shapes) which in places is so strong that it locally causes skeletal individuals. Rocks of such type would be formed through metamorphism of pelitic-carbonatic sediments.

Contact metamorphic rocks such as marbles, calciphyres and calcsilicate hornfelses derived from pure and impure sediments, are common but are restricted to the mouth of the Vigne glacier. A few banded hornfelses (54 PZ-182) have been produced by the metamorphism of a close alternation of thin beds of different compositions: bands of marble, quartzite and quartz marls, are interbedded with beds composed of a minute aggregate of biotite-epidote-amphibole-pyroxene, in which the different minerals are present in variable quantities, together with calcite and quartz. The thin beds originally constituted of clayey sandstones have been changed into biotitic hornfelses.

Within the contact aureole, together with the above-mentioned rocks, are
also basic schists, generally corresponding to amphibolites more or less rich in biotite (54 PZ-185, -187, -189, -192, -194, -195). Generally, they do not appear much different from certain orthoschists of the amphibolitic formation exposed west of the Baltoro, in the Braldu valley; but sometimes the former can be distinguished on account of reddish-brown spots caused by the concentration of biotite lamellae. This is the only evidence of a process of thermal metamorphism undergone by the amphibolitic rocks. The fundamental mineral components are: plagioclase, hornblende and biotite, whereas quartz may be scanty in some types and abundant in others. The textural character is not very uniform. A few medium-grained rocks (54 PZ-194) or coarse-grained rocks (54 PZ-189) present a uniform texture, with the various components developed in equal size, whereas in other instances we can notice differences in grain size between the femic minerals and the sialic minerals, as well as between different parts of the same rock. The schistose texture, always well visible to the naked eye, appears attenuated if examined under the microscope.

The plagioclases of the basic schists possess variable compositions in each sample collected, generally varying between 20% and 40% An. The single individuals are unzoned and almost equidimensional. Only a few rocks form exceptions to this fact; in some (54 PZ-187) rare large plagioclase porphyroblasts are developed; others (54 PZ-192) appear to consist even megascopically of an alternation of irregular femic and sialic bands; in the latter the plagioclases, together with quartz, are present in large crystals, whereas elsewhere, plagioclase, or plagioclase and quartz, constitute a rather minute granoblastic aggregate.

An analogous difference in plagioclase grains is, however, evident in all the rocks in which femic minerals are distributed in bands (54 PZ-185, -187). All plagioclase crystals include quartz-granules; moreover, quartz may be present only as inclusions in the plagioclase.

Amphibole is represented, in most cases, by hornblende, and is almost always combined with biotite. Amphiboles are often poikiloblastic and the sizes of crystals vary in each single instance, but are constant within the same sample. An exception is represented by those of a peculiar lithologic type (54 PZ-187) which is characterized by the presence of minute amphiboles, commonly acicular, and of well developed sialic minerals. Here, amphiboles accompany the minute plagioclase granoblasts, which form aggregates, in which individuals extinguish in slightly different positions arranged in patches and irregular bands. Where the minute granoblastic aggregate disappears and
larger plagioclase crystals are substituted instead, the amphiboles appear included within these crystals, or, more commonly, they themselves are large.

It often seems that a relationship between the dimensions of the amphibole and its composition exists, as the minute acicular crystals often present a weak pleochroism; thus they correspond to actinolite elements, whereas the well developed crystals are intensely pleochroic from green to blue-green. Biotite is abundant in all of these amphibolitic schists; it is usually closely combined with amphibole, but it may also appear in independent lamellae.

Among the accessory minerals, the most common are sphene, generally combined with iron oxides and iron-titanium oxides; epidote, locally in a manganese-bearing variety showing an intense violet pleochroism, and apatite. Also, calcite and chlorite may be present as secondary minerals.

In this section mention must be also made of some biotitic gneiss with plagioclase porphyroblasts (54 PZ-184). These rocks are uncommon and their presence is restricted to the contact-zone, yet they present no mineralogical or textural characteristics which could be indicator of thermal metamorphism.

The porphyroblastic development of plagioclases, as well as their composition (35% An), makes these rocks similar to the $K^2$ gneiss, all the more so as their macroscopic aspect does not much differ from the $K^2$ gneiss either. However, compared to the $K^2$ gneiss, the potash feldspar is very scanty and restricted to irregular patches which are included within the large plagioclase crystals.

Rocks not affected by thermal metamorphism are poorly represented in this area. They consist of black, fragile slates and of light and dark, scantily crystalline calc-schists and limestones.

d) The valley of the Vigne Glacier.

The country-rock exposed in this portion of Baltoro constitute the upper part of the metamorphic cover of the batholith. In fact, in the basin of the Vigne glacier, the granitic mass disappears gradually and irregularly, under its schistose cover.

The surface which delimits the batholith towards north-east, is strongly inclined to almost vertical; the surface which delimits it toward the south-west presents a more gentle inclination, on the whole, with an irregular course, as can be seen in the drawings presented later.

The Vigne basin was explored for the first time by B. Zanettin in 1954; thus there is no preceding geological information on this area except for the area of the mouth and
in particular of the group of the Mitre peak. The topography of the upper valley was also improved by the same author.

In a drawing of the Mitre peak, made by A. Desio in 1929 (Desio, 1936, p. 278) it is shown how the granitic rocks dip with a strong inclination under the country-rock; the latter are represented by a sequence of metamorphic rock (see p. 142).

We shall begin the geological description of the basin of the Vigne glacier with the Mitre peak up to the head of the glacier; subsequently we will describe the right side.

We started our observations at the foot of the northern flank of the Mitre peak (pl. XXVI), more precisely to the north of the top (that is, on the flank adjacent to the Baltoro glacier), not far from the granite contact.

The country-rock series is well exposed along one of the spurs perpendicular to the contact surface (fig. 48). The rocks farthest from the granitic mass consist of compact grey limestone (54 PZ-180). They are followed by «black slates» (54 PZ-181), well laminated, fragile, macroscopically identical to those which constitute the central «black moraine» of the Baltoro glacier. In these rocks, effects of thermal metamorphism are not visible. Contact metamorphism begins to appear in the limestones which follow the «black slates»; in fact, these are recrystallized, and a few layers show poor coherence, breaking down into granules. Thin dark bands are visible within the crystalline limestones; it was not possible to establish whether these are impure carbonatic rocks, or are thin interbedded «black slates».

The marble is followed by a thick dark layer, formed by biotitic
amphibolite (54 PZ-185, 187); biotite gneiss with plagioclase porphyroblasts (54 PZ-184); hornfelses with biotite in well developed lamellae; garnet-bytownite hornfelses (54 PD-183); and hornfelsic quartzite.

The sequence is continued by a thick bed of calc-schists changed into calciphyre and hornfels with calc silicates. Calciphyres with biotite, epidote, amphibole, pyroxene (54 PZ-182) alternate with thin beds of marble, quartzite, and biotitic hornfels, which crop out at a distance of about 100-150 m from the contact. All the rocks which constitute this innermost part of the metamorphic zone are distinguished by a characteristic reddish colour which

gradable decreases towards the outermost parts of the zone. This colour may be attributed in part to the change in colour undergone by rocks of pelitic origin subjected to thermal effects, but indubitably it is accentuated by the weathering of small crystals of pyrite which are scattered in the country-rock as well as in the granitic rocks immediatly adjacent to the contact.

It is on account of this colour that the contact zone may be distinguished from a distance.

The lithological types represented in proximity to the contact are for the most part biotite-andalusite hornfels and biotite-sillimanite hornfels (54-PZ-188, -190, -191), but amphibolites are also present (54 PZ-189).

In this part of the metamorphic aureole, the rocks are crossed by numerous sialic dykes, mostly pegmatitic, with sub-horizontal attitude.
The contact between dykes and country-rocks is very sharp. The sequence described above has a constant N 45° W direction, it is subvertical and has a generally north-east dip. The surface of contact with granite is roughly conformable with the country-rock, but, in detail, it appears non-conformable and rather variable, as shown in fig. 48-50.

On the opposite side of the Vigne glacier, on the spur between it and the Baltoro glacier, the contact between the granite and schists crops out again, showing the above-mentioned characteristics (fig. 49).

Here we could more clearly see, subhorizontal dykes of pegmatite, up to 4 or 5 m thick, which, starting from the granitic mass, penetrate for about a hundred metres or more into the country-rock.

No direct observations have been made on the country-rock farthest from the contact (which, extending south-eastwards, constitutes a part of the left side of the Upper Baltroro), but the materials collected in the moraine seem to indicate that at some distance from the contact the «black schists-limestones-calcschists» sequence (Mitre sequence) is followed by crystalline schistose quartzite and micaceous schists (1). Coming back to the zone of the Mitre Peak, we observe that the contact of schists and granite that can be seen from the Vigne glacier, i. e. from the east, lies slightly south of the eastern crest of the group (fig. 50). The course of the contact is very capricious and usually not well defined, as big and small bands of thermally metamorphosed reddish schists are included within the granite or intertongue with it. Also at a consi-

(1) These quartzite and micaceous schists might be the equivalent of quartzite and micaschist in the upper and middle basin of the Vigne glacier.
derable distance from the contact (700-800 m), reddish bands are visible in the light-grey granite; these bands may represent incompletely assimilated schists.

Near the mouth of the Vigne glacier a deep valley (1") opens on its left. The peaks at the head of the valley (fig. 51) consist of thermally metamorphosed reddish schists (biotite-andalusite hornfels and biotite amphibolite, 54 PZ-I-192), as could be deduced from materials collected from the moraine; the spurs bounding the valley on either side are in granite.

This condition is also repeated in the valley immediately upstream (2") where, however, the country-rock is restricted to the summit and to the southern portion of the head wall of the valley, showing a subvertical and irregular contact. The nature of the country-rock is indicated by the material which appears on the south-eastern side of the left-central moraine of the lower Vigne valley: they are quartz-schists and biotite-muscovite schists (ana-

![Figure 51](image_url)

**Fig. 51** - *West side of Vigne Valley: first secondary valley upstream the end of the glacier* (Zanettin).

logous to those carried into the Baltoro by the glacier that flows under the western wall of the Mitre peak).

The second deep valley is separated by a narrow ridge from the westernmost branch of the Vigne glacier which in this part is broad and flat. On this side appears the continuation of the contact mentioned above: the granite
mass dips steeply under the country-rock (fig. 52) which forms the whole wall at the head of the glacier. The granite crops out again at the base of the right wall of the western branch of the glacier, but it was not possible to follow the contact, as we did not go farther along this tributary of the Vigne glacier. For the same reason, precise information is lacking on the nature of the country-rock. In any case, it may be said that the wall at the head of the valley show a very dark colour, which could suggest biotite and amphibole-schists; the rocks overlying the granite mass on the right side are, however, light-coloured and show a clear stratification, thus indicating that they belong to the quartzite-micaschist sequence.

![Diagram of Valley of the West Vigne Glacier: north-east slope (Zanettin).](image)

The contact between granite and schists continues, in places rising, elsewhere falling along the wall in front of the lower and middle Vigne glacier; it is locally conformable, but in other places clearly nonconformable, with the schistosity of the country-rock. The latter are represented by quartzite and micaschist and have a south-southwesterly dip of about 20° (fig. 53).

Here we see the roof of the batholith; the contact cuts the wall obliquely and disappears at the elbow of the glacier.

On the left side of the upper basin of the Vigne, the poor outcrop, unreachable on account of the thick cover of snow (the Chogolisa peak is al-

1) Mention should be made that near the contact the exposed granite surfaces often show a reddish colour, similar to that of the country-rock, on account of the transformation of pyrite into limonite.
most wholly covered with ice) it composed again of quartzite and light-coloured micaschist, seldom biotitic, in which the effect of thermal metamorphism seems to be absent. This affirmation is based only on macroscopic observations carried out *in situ* on detrital material.
On the right side of the upper basin of the Vigne glacier, at the base of the southern wall of the peak culminating at 6851 m, the granite mass occurs again (fig. 54), overlain by the rocks of the quartzite-micaschist sequence. The contact between granite and schists rises as far as the spur occupying the inner part of the elbow of the glacier (fig. 55). Farther downstream, it descends, to disappear again under the ice at the base of the high crest which connects the point at 6851 m to that at 6674 m (fig. 56); still farther it rises again, presenting a very irregular course (fig. 57); here, the quartzite-micaschist sequence forms the southern limit of the previously mentioned granite outlier, which occurs at the mouth of the Vigne glacier (whereas to the north the granite is bounded by the contact with the «black schist-calcschist» sequence).

Also along this portion of the right side of the Vigne, schistose quartzites and micaschists are predominant (as can be deduced from the materials collected in the moraines), but almost always affected by thermal metamorphism.
In this instance, quartzites appear speckled on account of spots formed by sillimanite and sericite (54 PZ-203), and the micaschists are more clearly biotitic and contain sillimanite (fig. 58, 59).

In addition to these lithological types, *biotitic amphibolite* (54 PZ-194 -195), are also represented.
Characteristic are the banded rocks, formed by thin, regularly alternating quartzose and quartz-micaceous beds (fig. 60).

e) SOME DATA ON THE SOUTH SLOPE.

We are indebted to C. Calciati (1914) and A. Roccati (1915) for some data on the south slope of the Chogolisa Kangri and the crest between this
peak and the Biarchedi massif. Calciati collected some samples from the moraines of the Kabery glacier which drains the south slope of Chogolisa Kangri. Unfortunately we do not know the precise spot where the samples come from; the collections with the labels were destroyed during the 2nd World War and no precise information on this subject can be found in the reports of Calciati and Roccati. In any case, the list of rocks of the Kabery valley are the following:

a) biotite granite, porphyritic biotite granite, micaceous amphibole granite, two-micas granite, «jalomicte»;

b) quartz diorite with labradorite, micaceous microdiorite, quartz monzonite, quartz-pyroxene syenite;

c) porphyrite;

d) biotite gneiss, porphyritic biotite gneiss, granitic biotite gneiss, two-micas gneiss, muscovite-albite gneiss, fine-grained gneiss, micaceous pyroxene gneiss with cataclastic texture;

e) fine-grained micaschist;

Fig. 6o - The mountains surrounding the Mitre Glacier (Zanettin).
f) pyroxenite;
g) metamorphic sandstone with graphite.

Calcareous rocks are lacking.

On the basis of these incomplete and summary data we can try to interpret some geological pattern of the south slope of the Chogolisa Kangri. First, we have proof that the Baltoro granite batholith crops out on the south slope of Chogolisa in view of the presence of biotite granite and other varieties of granite known also within the Baltoro valley. The roof rocks of the batholith are also exposed on the same slope and they are represented by some types of biotite gneiss and particularly by the Vigne quartzite-micaschist sequence.

The latter is represented by the association of micaschist with metamorphic sandstone; the last rock obviously corresponds with the arenaceous quartzite of the Vigne valley.

Some of Calciati’s samples cannot be easily related to the lithotypes of the north slope of Chogolisa massif, for instance diorite and syenite. Nevertheless, it may be recalled that the former is known within the Upper Baltoro basin. However, with such poor data any tentative correlation is hazardous. We will return to these rocks later, as some of them are present also in the adjacent Kondus valley.


a) Introduction.

The great peak of Masherbrum rises above the mountain ridge bording the Baltoro basin to the south. Its pyramidal profile shows a truncated top on which a peculiar white cube is superposed reaching up to 7821 m. Such is the aspect of that high mountain, as viewed from the Baltoro glacier (pl. XXVII). Eastwards and westwards the ridge plunges rather rapidly and at lower elevation presents an indented profile marked by numerous saddles.

However from the Baltoro glacier only part of the ridge is visible where it forms the watershed between the Baltoro basin and that of Hushe, tributary of the Shayok river; the remainder is concealed behind high ridges alongside the glacier.

The orographical boundaries of the Masherbrum ridge may be defined as including, on the east, the Gondokhoro saddle (5480 m), and, on the west, a saddle of unknown altitude which lies at the head of the basin of the Liligo glacier.
The Biarchedi massif (6759 m, pl. XXVIII) rises between the Masherbrum and Gondokhoro saddles. The peak is dominated by a long spur separating the glacier of the same name from the Baltoro glacier. Other long spurs branch out from the main ridge of Masherbrum trending northwards. One of the longest and thinnest separates the Mundu from the Yermanendu glaciers. Both glaciers flow into the Baltoro glacier, upstream of Urdukas. Farther downstream a few minor glaciers come down, and still farther down the Liligo glacier on the bottom of a deep, arch-shaped valley (pl. XLII).

(b) Previous Knowledge.

The first geological information on the Masherbrum peak dates back to 1867, as mentioned at the beginning of this volume (p. 4). It has been reported by A. M. Verchère, who obtained it from Godwin Austen and from the examination of the samples collected by E. C. Ryall.

We can obtain some insight from a geological cross-section of the Masherbrum (fig. 61) made by Verchère with the aid of the information he received.

According to this section the northern slope of the Masherbrum is made by a sedimentary sequence composed of shales, limestone, and dolomite overlaying a basement of metamorphic rocks (gneiss and micaschist). Probably, the upper beds are made up of the same limestone which yielded Silurian fossils at the southern foot of the mountain. As we will see in the next pages, no sample of sedimentary rocks has ever been collected from the floating moraines of the glaciers draining the northern side of the mountain; thus Verchère's cross-section, at least insofar as the northern slope is concerned, cannot be trusted.

This conclusion may be supported by data reported by C. Calciati (1914), topographer of the Bullock-Workman expedition of 1911, who explored the southern slope of Masherbrum, and by A. Roccati (1915) who examined the samples collected by Calciati. These authors state that one of the samples “fallen from the top of the Masherbrum” is a pink biotite granite.
In a report on ascent of the Masherbrum ridge F. B. and W. H. Bullock Workman (1917) report that quartzite and black slates compose the ridge west of the Masherbrum Peak.

According to G. Dainelli (1934, p. 992), who published a geological cross-section of the Masherbrum peak, the upper part of the mountain is made of a syncline of Silurian-Devonian (probable) rocks regularly underlied by "crystalline schists". The supposed Silurian-Devonian rocks is represented, after Dainelli, by a "marble-quartzite" formation (ibid. p. 590); "the crystalline schists" are referred to a "pre-Silurian" age (ibid. p. 614).

Subsequent data by A. Desio (1936) are more precise. According to this author, the northern side of the massive pyramid of Masherbrum consists of granite and two micas-gneiss. He adds that the floating moraines of Mundu glacier carry only granite and gneiss pebbles to Baltoro; those of Yermanendu glacier carry also "black slates". Limestone found in one moraine on the left side of Baltoro glacier probably derive from the Upper Baltoro. The same author goes on to record that the northern wall of the Masherbrum presents a few horizontal black bands which are believed to be interbeds of biotite-gneiss. The samples collected by Desio were studied by P. Comucci (1938).

The most recent news on the Masherbrum range is contained in the memoir by T. E. Gattlinger (1961).

Leaving out details, the upper half of the Masherbrum, according to this author (p. 67), is composed of a "metamorphe Kalk Serie" (metamorphic calcareous series) underlain by other "Kalkschiefer" (calcareous shales), the two repeated several times on account of three fantastically piled up recumbent folds.

A further fold with a calcareous core, supposedly crosses the ridge farther south. The lower half of Masherbrum and of lateral ridges is supposedly composed of the underlying "Schwarze Schiefer and Phyllite" (black slate and phyllite) which gives way to granite in proximity of the Yermanendu glacier. A big lens of quartz-conglomerate is said to be included within the black slate and phyllite.

It has to be recorded that not a single rock sample from these mountains has been collected by Gattinger neither in situ, nor in the floating moraines; thus the entire geological description of Masherbrum in his memoir, is the product of his imagination: this will be better demonstrated in the discussion to follow (1).

c) Geological Description.

North side. Along the left side of Baltoro valley, downstream from the Mitre peak, the country rock crops out only on the ridges dividing at the head the glaciers flowing into the Baltoro glacier. No investigations have been made in situ; thus we can give only brief data.

Both sides of the glacier immediately west of the Mitre peak (Mitre glacier), are composed of granite, which — at the head of the valley — clearly dips beneath the country-rock (fig. 60). The latter belong to the series of

(1) See also p. 200.
quartzites-micaschists and are similar to those observed in the Vigne basin (1).

Likewise, the wall damming the valley of the Biarchedi glacier seems to be composed of schists, at least the part visible from the Baltoro glacier, but we did not succeed in identifying the contact with the granite. The granite constitutes either the right side, or left side of the valley of this glacier.

We have scant data also on the nature and location of the country-rock in the Masherbrum peak.

**TABLE 12**

Augen gneiss; northern side of Masherbrum (54 PZ-210)

<table>
<thead>
<tr>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Analyst: B. Zanettin)</td>
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</table>

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>H₂O⁺</th>
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<tr>
<td>70.04%</td>
<td>0.97</td>
<td>2.88</td>
<td>3.54</td>
<td>3.40</td>
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<tr>
<td>Al₂O₃</td>
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<td></td>
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<td>0.07</td>
<td></td>
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</tr>
</tbody>
</table>

NIGGLI’s values

<table>
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<tr>
<th>Augen gneiss from Masherbrum</th>
<th>326</th>
<th>42.4</th>
<th>17.1</th>
<th>14.4</th>
<th>26.1</th>
<th>0.39</th>
<th>0.40</th>
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<tbody>
<tr>
<td><em>Leucoquartzdioritic type</em></td>
<td>300</td>
<td>42</td>
<td>17.5</td>
<td>13</td>
<td>27.5</td>
<td>0.25</td>
<td>0.4</td>
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</table>

<table>
<thead>
<tr>
<th>Basis</th>
<th>Equivalent Norm</th>
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</thead>
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<td>Q</td>
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</tr>
<tr>
<td>Kp</td>
<td>12.2</td>
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<tr>
<td>Ne</td>
<td>19.3</td>
</tr>
<tr>
<td>Cal</td>
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<tr>
<td>Sp</td>
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<tr>
<td>Ru</td>
<td>0.3</td>
</tr>
<tr>
<td>Cp</td>
<td>0.4</td>
</tr>
</tbody>
</table>

(1) The peak which rises on the background of the valley would be the same as the one that appears in fig. 50, which can be seen from the Vigne glacier. In fig. 60 the north side is visible, only; in fig. 51, the east side.
Suffice it to record the presence of porphyroblastic gneiss (54 PZ-210-211) (table 12) which is similar to the $K^2$ gneiss, and the presence of agmatites with big components of banded biotite-gneiss and quartz diorite, all probably derived from the ridge separating the Yermanendu from the Mundu glaciers (1) (fig. 62).

Fig. 62 – Geological sketch of the Masherbrum peak from the Baltoro Glacier near the outlet of the Jermanendu Valley (Zanettin).

About the geological structure of the upper part of the Masherbrum pyramid we refer here to the result of our interpretation obtained by binocular from the Baltoro glacier and from the air during a flight around $K^2$, correlated with the samples collected from the moraines.

The top of the mountain is made up of a massive light rock, well exposed on the north wall just below the white ice die of the summit (pl. XXVII fig. 2); according C. Calciati and A. Roccati it is a pink biotite granite (2). The

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(1) See p. 200.
(2) See p. 157.
same rock, very much fissured along planes diping south at an angle of about 55° or more, makes up the highest crest south of the top and the upper part of the north-western spur. Below a dark rock crops out with the bedding apparently dipping gently south-eastwards; from a far it looks like the peri-batholithic plagioclase gneiss. The foot of the north-west spur is crossed by a fault trending approximately north-south (1). If we give credit to Workman's data, reported above, the ridge west of Masherbrum peak is made up of quartzite and black slate (2) the last rock probably belonging to the Vigne Quartzite, as we will see later.

At the base of the pyramid, the granite crops out again. On the northeast wall of the Masherbrum peak another schistose rock seems to be included; it is probably the Vigne sequence, but here we have no certain indications concerning the presence of this unit, which is more fully developed eastwards.

**South Side.** Until now we have not had occasion to visit the south side of the Masherbrum, but we have some data from previous explorers. The first report which supplies important data on this subject is the work by Verchère (1867), mentioned above.

In addition to the cross-section of the mountain (fig. 61), more detailed data are contained in the text (p. 47-48). We quote here Verchère's words because of the great importance of his information.

«Near the Mashabroom mountain (above 26,000 feet) the soil of the valleys between the spurs is to a great extent covered by glaciers; where not so covered, it is often an indurated clay strewed with debris of pale limestone a good deal worn and weathered, and with globular cystideae in very great abundance. Mr. Ryall, of the Great Trigonometrical Survey, gave me one of the pieces of limestone and some of the fossils. The limestone is an argillaceous dolomitic limestone, pale yellowish brown, with a few patches of pale blue, weathering like frosted glass, and resembling a good deal of the rock of the Weean and Kothair groups of carboniferous limestone.

The sphaeronites, however, point to a silurian epoch, these echinoderms having not been found as yet in formations posterior to the Wenlock limestone... The Mashabroom is stratified to its very summit, the beds being limestone and shales, dipping towards the S., at a moderate angle. This stratification is so well marked, that it can be distinctly noticed from a long way off. These sedimentary beds repose on metamorphich layers of mica-schist and gneiss.

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(1) It is not included in our geological map of the Baltoro basin.
(2) See p. 158 and plates XXVII and XXIX.
The limestone is extremely rich in magnesia, principally towards the base of the bed, where it passes into Steatite in patches (Austen).

After Godwin Austen's trip, the southern foot of the Masherbrum was reached by R. Lydekker (1881). Traveling up the Hushe valley he met « alternations of granitic and schistose gneiss » which continue « up to the watershed ». According to the same author « the lowest gneiss, forming the higher ridges and peaks, is of the primitive porphyritic type of Dars. Beds of the Rondu metamorphic limestone also occur among schistose gneiss near Hushi ». Lydekker's report makes no mention of the fossils illustrated by Verchère, or of fossils in general.

The presence of limestones among the rocks on the southern slope of the Masherbrum peak is recorded by C. Calciati (1914) and A. Roccati (1915). However, before referring the information supplied by these authors let us remember that another important piece of evidence regarding the geological constitution of the Masherbrum is represented by the sample of pink granite from the top of the peak, collected by Calciati in the Masherbrum valley, at the foot of the mountain.

We think it is useful to report the description of the rock made by Roccati (1915, p. 12).

« The mineralogical composition corresponds on the whole to biotite granite; the only difference being a light prevalence of plagioclase over orthoclase. In the latter, quartz inclusions are lacking and consequently so is the vermicular texture. Microcline is rare and plagioclase is represented by oligoclase which prevails with only Albite twinning. It has a pink colour, but under the microscope it is possible to see a remarkable alteration, consisting of kaolinization or production of secondary, finely fibrolamellar, micaceous minerals.

In addition, the rock shows a strong cataclastic structure (Mörtelstruktur or structure en mortier), so that the quartz and feldspar are finely crushed, but without interposition of matter between the fragments.

The mica, which is the common brown biotite, has likewise been subjected to the mechanical actions which involved the rock; only rarely does it occur as distinct laminae; more commonly the mineral is ground, or gathered into irregular spots. In this case the mica is almost entirely altered with production of limonite and of a green chloritic matter which does not react under polarized light.

Small hematite laminae and magnetite and pyrite grains are contained in the groundmass ». 
In both Calciati’s and Roccati’s reports we can find additional information about the south slope of the Masherbrum ridge, which is drained by the Masherbrum and Gondokhoro (or Chundugero) glaciers, both tributary to the Hushe river.

According to Roccati (1915 p. 61-62) the samples collected by Calciati in the Masherbrum valley have the following composition:

**Masherbrum Peak:**

a) pink biotite granite (top of the mountain), aplite;  
b) biotite gneiss.

**Moraine of Masherbrum Glacier:**

a) biotite granite;  
b) granitic biotite gneiss, porphyritic biotite gneiss, biotite gneiss, fine-grained gneiss, fine-grained micaschist;  
c) micaceous amphibolite, serpentine, chlorite schist, talc;  
d) metamorphic argilloschist with graphite (graphitic slate);  
e) abundant white and grey limestone (also crystalline variety with tremolite), dolomite.

The samples from the moraines of the Gondokhoro Glacier are the following:

a) biotite granite, pegmatite;  
b) biotite gneiss.

We have very little information on the topographic distribution of the rocks. The samples, which were kept in the collections of the mineralogical department of the Engineering School of Turin, were destroyed during the Second World War.

From the above mentioned data we can try to deduce a possible geological constitution of the south slope of the Masherbrum, in accordance with our knowledge on the neighbouring region (pl. XXIX).

From the rocks of the moraine of the Masherbrum Glacier listed above we can infer the possible occurrence of the Vigne quartzite-micaschist sequence (1) and the Ganchen Formation as well as the Baltoro Granite (Desio 1963 b). But we may also assume the presence of one or more Cretaceous formations on the northern slope of the lower Shigar valley. The association of micaceous amphibolite, with serpentine and chlorite schist recalls

(1) This sequence corresponds to the Nang Brok Quarzite of the Shigar valley as we will see later.
the Baumaharel Schist (Desio 1963 b), whereas the graphitic slate associated with limestone recalls the Skoro Lumba Slate.

However the question of the age of the limestones is much more obscure, as the only palaeontological evidence consists of the Silurian fossils mentioned by Verchère. To explain this, it would be reasonable to assume that a tectonic splinter of Silurian limestone is included in the prevailing Cretaceous formations. Nevertheless, some doubt arises about the true origin of the limestone specimens with well preserved Cystidea from Masherbrum. One is the absence of any of such unit insofar as it is known up till now; the other is the known mixing of labels of the fossils collected by Godwin Austen in Kashmir and particularly in the Shigar valley, close to the Masherbrum valley. Godwin Austen informs us of this himself, stating that some Carboniferous fossils were erroneously attributed as coming from Shigar valley (1). Only a new geological exploration of the Masherbrum valley can clear up this doubt.

We can proceed now to the northeastern branch of the Hushe valley, the Gondokhoro valley, where only biotite gneiss and pegmatite samples were collected from the moraines of the glaciers. We may assume that the basin of the Gondokhoro glacier, which drains the ridge between Masherbrum and Biarchedi is for the most part composed of biotite gneiss of the roof of the Baltoro batholith. The Masherbrum calcareous formation disappears east of the Masherbrum valley or bends southward. It seems that farther to the east, in the valley of the Kabery glacier, calcareous rocks are not present either, as we have already seen (p. 155).

4. Doksam Ridge.

This crest rises between the Kalkhal glacier and the Baltoro glacier and culminates at 6238 m a.s.l. (pl. XXX). A metre lower is the summit of False Crystal peak, so called because it was often mistaken for Crystal peak (5913 m), which is a lower, much more modest and less remarkable peak. This crest has a geological composition very different from the surrounding mountains and its aspect is different, specifically the contrast of colours of its summits, which are partly white, partly black and partly grey.

We have some in situ geological observations regarding the composition of this crest, published by T. G. Bonney and C. A. Raisin in 1894 and by

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(1) See H. H. Godwin Austen (1866).
A. Desio in 1936. A lithostratigraphic sequence was partially surveyed by A. Desio beneath Crystal Peak (1).

The sequence is as follows, from top to bottom (fig. 63):

4) Black arenaceous phyllite, many metres thick;
3) Interbanded marbles and ashgrey-coloured calc-schist, with some white stripes, about 500 m thick (2);
2) Quartziferous plagioclase gneiss with biotite (29 KD-162 and 181) and two-micas gneiss (29 KD-180), grey, with yellow-brownish weathered surfaces, associated with garnetiferous micaschists (29 KD-190 and grey-green chlorite-zoisite schist (29 KD-124).

The apparent thickness is about 300 m.

1) Grey and white banded marbles with frequent intraformational folding exposed for about 20 m.

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(1) The samples were studied lithologically by P. Comucci (1938).

(2) In the volume: "La Spedizione Geografica Italiana al Karakorum (1929)", published in 1936, on p. 268, the thickness is given erroneously as "cm 500" instead of 500 m.
Some further data on the geological composition of Crystal peak can be deduced from the samples collected by Conway's expedition in 1892 on the occasion of the ascent of that peak (T. G. Bonney and C. A. Raisin, 1894). Unfortunately we do not know the sequence of the samples taken from the slopes below the above-mentioned series up to the summit of Crystal peak.

In any case, samples of fine-grained gneiss, calcitic quartz-schist, dark mica-schist, dolomite and limestone (both crystalline), and fine-grained gneiss were collected in situ.

On the ascent to White Fan saddle, the following rocks were collected in situ: mica syenite; fine-grained, white, crystalline dolomite; greyish crystalline limestone apparently belonging to a mass of green rock (probably chlorite-zoisite-schist), in which are thin seams of noble serpentine. Halfway toward this saddle the strike is south-east, the dip being 70° south-west.

On the whole we can assume that an alternation of rocks similar to the underlying ones follows above level 4 and that the same sequence continues eastwards towards the White Fan saddle.

Also, the eastern portion of the Doksam ridge (Marble peak, Angle peak) is partly formed by white marbles, partly by dark to black schistose rocks, probably arenaceous phyllites like sample 29 KD-151 and by biotitic mica-schist and fine-grained gneiss.

Here the strata dip very steeply and make irregular folds that are well recognizable even at a distance (fig. 66) (1).

(1) The Conway expedition of 1892 reports a sample, probably of diorite or syenite, as coming from the Angle peak, near the confluence between the Godwin Austen glacier and the Baltoro glacier. During the 1953 expedition A. Desio was very close to this point and he did not see igneous rocks there.
Summing up we can say that Doksam crest is made up of a sequence of metamorphic rocks mainly represented by grey and white marbles and crystalline dolomite in rather massive strata, followed by chlorite-zoisite schist and black arenaceous phyllites associated with plagioclase gneiss and garnetiferous micaschist with quartzite intercalations.

Fig. 66 – Geological structure of the west Doksam crest (from Desio's field book).

M marble, Bs' dark slaty rocks included in the Doksam sequence, Bs black slates, x faults.

We do not know for certain the stratigraphic sequence of these beds, owing to the presence of recumbent folds and overthrusts (pl. XXXI) that could have caused repetitions of the same levels, giving the impression that they are regularly superposed one upon the other.

It seems possible to recognize the presence of at least two levels of marbles divided by a complex of chlorite-zoisite schists, gneiss and micaschist with quartzite intercalations. The association of micaschist with quartzite can recall the sequence of Vigne valley (p. 154).

Less clear is the position of the "black slates", which in some places occur at the top, elsewhere at the bottom of the sequence (pl XXXII). We will return later to this question.

It is without interest to report here GATTINGER's geological interpretation (1961) of the crest north-east of Biange. It is based only on observations from afar, without knowledge of the data collected in this range in situ by previous explorers.

(a) INTRODUCTION.

The Muztagh Tower is perhaps the most striking mountain in the Baltoro basin. It is characterised by twin peaks separated by a wide saddle, with a higher «tooth» at 7273 and a lower one at 6719 m (pl. XXXIII and XXXIV).

It rises near the head of the Younghusband glacier, between this glacier and the Chagaran glacier, a tributary of the Muztagh glacier (Baltoro basin) and the Moni glacier, tributary of the Sarpo Laggo glacier (Yarkand basin).

(b) PREVIOUS KNOWLEDGE.

Previous information on the geological composition of the Muztagh Tower is very scanty. A. Desio (1936) noted that much of the Tower seem to be composed of biotitic gneiss of blackish-grey colour intruded by granite dykes. The same gneiss would underlie the spur between the Younghusband glacier and the West Crystal glacier.

On the slopes of the mountain facing the Baltoro glacier the same author, during the 1929 expedition (A. Desio 1936, p. 267), observed a lens of white rock included in the porphyroblastic gneiss. It seemed to be a marble lens, and crosses the lower Biance valley in an east-southeast direction. A sample of bluish-white marble (29 KD-212) collected by A. Desio at the foot of the slope was examined by P. Comucci (1938). This author described the sample as follows: «Bluish-white marble. Calcite elements constitute a rather coarse-grained mosaic. Small transparent spheres with an amorphous core frequently occur; they are probably composed of amorphous silica and calcedony. Grains of a strongly birefringent mineral, which seems to be of pyroxenic type, occur less frequently».

The same outcrop of marble was observed by Conway's expedition and a sample (237 b) was also collected in situ. Bonney and Raisin described the sample as follows: «From the north bank of Baltoro glacier, near Storage Camp (strike 10°N of E, dip 85° southerly) much contorted, is a finely laminated white and grey, somewhat friable limestone, much resembling some of the crushed crystalline limestone of the Alps...».

With regard to the geology of the area surrounding the Tower, Desio (1936) recorded that the granites at the level of Gore (Biange) gradationally pass into quartz-biotite-plagioclase gneiss along a north-west trending contact line.

Gattinger's interpretation (1961) of the geology of the north-east crest of Biange is based entirely on distant observations, without knowledge of geological data collected in situ by previous explorers. The authors do not know of any further data on this area, other than their own preliminary reports, later then that mentioned above.

(c) GEOLOGICAL DESCRIPTION.

As has already been recorded in the introduction to this chapter (p. 140), the contact between granite and crystalline schists along the northern (right) side of the Baltoro valley is essentially conformable and the country-rocks show no effects of thermal metamorphism.
The contact with the granite body extends in outcrop from the Baltoro glacier to the west of the Biange locality (slightly more than one kilometre downstream from the outlet of the Younghusband glacier), and then trends to the north-west.

Rather fine-grained paragneiss, showing a homeoblastic structure (Biange Gneiss) (1), is found at the contact with the batholith; in this paragneiss the biotite is always aligned parallel to the schistosity and is uniformly distributed. Since the paragneiss lies almost parallel to the contact surface (dipping steeply to the north-east), it probably covers the granite body over a great distance; in fact, "biotite gneiss" has also been noted in the upper part of the Muztagh glacier (A. Desio, 1936, p. 266).

Up to about 100 m from the contact the biotite paragneiss is crossed, either conformably or unconformably, by numerous sialic pegmatitic and granitic dykes (54 PZ-170); the central parts of the dykes are sometimes very acidic. Stringers of schist are also included within the granite.

Numerous poeciloblastic muscovite laminae aligned transverse to the schistosity (54 PZ-171), occur in the rocks of this innermost belt.

Further from the contact, towards the mouth of the Younghusband glacier (pl. XXXIII), the fine-grained biotic paragneiss does not contain muscovite (54 PZ-174); this suggests that the development of white mica is connected with the genesis of the granites.

About 400-500 m downstream of the spur at the confluence of the Younghusband glacier the schistosity dips at a shallow angle, and the gneiss is porphyroblastic.

The conformable passage between the porphyroblastic gneiss and the fine-grained biotitic paragneiss, though rapid, shows some alternation. At the boundary between the two formations the paragneiss contains some lenses in which quartz and oligoclase (22-25% An; $\beta \geq \omega$) crystals have considerable dimensions. Extensive layers of fine-grained biotite schists, which under the microscope are seen to be analogous to those already described, occur within the porphyroblastic gneiss.

The porphyroblastic gneiss lying close to the fine-grained paragneiss is similar, both in texture and mineralogy, to some of the $K^2$ augen gneiss, from which it can be distinguished, however, by the absence, or very low amount, of potash feldspar.

Plagioclase porphyroblasts, with a composition of 30-35% An (of con-

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(1) See the Baltoro geological map at the end of this volume.
nuous variable composition from the centre to the periphery), and rich in biotite inclusions, are also present in this gneiss (54 PZ-173). At the mouth of the valley of the Younghusband glacier, along its right side, the gneiss is crossed by a considerable number of granitic-pegmatitic and pegmatitic dykes, most of which are sub-vertical; they may be up to 10-12 m in width.

The median moraine of the Younghusband glacier almost exclusively contains schistose and massive biotite-amphibole gneiss, and quartz diorite which includes dark biotitic or amphibolic stripes, or greenish nodules rich in actinolite and epidote.

The position of the passage between the augen gneiss similar to the K² gneiss and these more or less amphibole-rich rocks is probably adjacent to the zone intersected by pegmatitic dykes. The moraines at the foot of the south-east spur of the Muztagh Tower, and the spur itself (pl. XXXV fig. 1), are composed exclusively of these amphibolitic rocks. In places they look like intrusive rocks, being rich in femic nodules.

The few samples collected (54 PZ-176, -177, -177a) indicate that the rock is a biotite-amphibole gneiss with a granodioritic to tonalitic mineralogy. The plagioclases (35-48% An) are weakly zoned, and are extensively replaced by potash feldspar which isolates a few stripes; biotite and hornblende are often intergrown, and are associated with epidote and sphene. Orthite is common (54 PZ-175).

The chemical analysis of one of these samples (54 PZ-176, tab. 13) shows a composition analogous to that of the normal quartz dioritic type of Niggli.

More or less massive tonalitic gneiss, rich in dark amphibolitic nodules and spotted with idiomorphic plagioclase crystals, besides constituting most of the Muztagh Tower, also constitutes the lower part of the left side of the Younghusband valley and the slopes of the Baltoro valley below the peak at 5648 m between the outlet of the Younghusband valley and the Crystal peak.

Here the tonalitic gneiss clearly underlies biotite-muscovite paragneiss (54 PZ-179). These paragneisses are similar to the fine-grained paragneiss cropping out to the west of the Younghusband glacier (pl. XXXV fig. 2), at the contact with the granite batholith, though a correlation cannot be made since they differ in a few specific characters (abundant iron oxides; presence of types with large biotite and feldspar crystals).

The moraines of the Younghusband glacier also contain amphibolites composed of amphibole-biotite-clinozoisite bands (each one about a centimetre thick) alternating with quartz-labradorite bands (54 PZ-178), and gneisses containing colourless amphibole instead of green hornblende (54 PZ-175).
TABLE 13

Tonalite; southern wall of the Muztagh Tower (54 PZ-176)

CHEMICAL COMPOSITION
(Analyst: E. Callegari)

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>64.45%</td>
<td>MgO</td>
<td>2.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TiO₂</td>
<td>0.74</td>
<td>CaO</td>
<td>4.96</td>
<td></td>
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<td></td>
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<tr>
<td>P₂O₅</td>
<td>0.25</td>
<td>Na₂O</td>
<td>2.53</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>15.35</td>
<td>K₂O</td>
<td>2.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fe₂O₃</td>
<td>0.46</td>
<td>H₂O⁺</td>
<td>1.23</td>
<td></td>
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<tr>
<td>FeO</td>
<td>4.66</td>
<td>H₂O⁻</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>0.12</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

NIGGLI's values

<table>
<thead>
<tr>
<th></th>
<th>si</th>
<th>al</th>
<th>fm</th>
<th>c</th>
<th>alk</th>
<th>k</th>
<th>mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonalite from Muztagh Tower</td>
<td>238</td>
<td>33.4</td>
<td>31.4</td>
<td>19.6</td>
<td>15.6</td>
<td>0.42</td>
<td>0.49</td>
</tr>
<tr>
<td>Normal quartz dioritic type</td>
<td>225</td>
<td>32</td>
<td>31</td>
<td>19</td>
<td>18</td>
<td>0.25</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Basis

| Q  | 48.9 | Q = 48.9 | Q | 20.1 |
| Kp | 10.1 | L = 37.7 | Or | 16.8 |
| Ne | 13.9 | M = 13.4 | Ab | 23.2 |
| Cal | 13.7 | τ = 0.36 | An | 22.8 |
| Cs | 0.3  | μ = 0.48 | Wo | 0.4  |
| Fs | 0.5  | γ = 0.02 | En | 7.9  |
| Fo | 5.9  | α = 5.32 | Hy | 7.3  |
| Fa | 5.7  |          | Mt | 0.5  |
| Ru | 0.5  |          | Ru | 0.5  |
| Cp | 0.5  |          | Cp | 0.5  |

We have called the metamorphic «formation» composed of biotite-amphibole gneiss and amphibolite associated with tonalitic gneiss of the Muztagh Tower the Muztagh Tower gneiss since it represents a distinct lithostratigraphical unit.

Little information can be given on the lithology of the middle and upper parts of the Younghusband glacier, as exploration as far as the Moni-la was very rapid and the snow cover was almost complete.

Our field-notes state that after passing the ice-fall below the south-east crest of the Muztagh Tower and when we neared the left side at a height of 4600 m we observed, as well as the tonalitic gneiss, dark, compact, fine-grained biotitic schists.

At the head of the valley, north of the Moni-la the rocks cropping out
from the glacier are dark in colour and appear to be crossed by numerous sialic dykes. To the south of the pass (on the north side of the Muztagh Tower and the left side of the upper Moni glacier) the rock appears lighter in colour and might again be tonalitic gneiss. Insufficient information is available to say anything about the genesis of these tonalitic gneisses and their relationship with the surrounding formations, such as the granitic batholith of Baltoro, and the gneissic mass of $K^2$, between which the gneisses are included.

As already recorded at the beginning of this section (p. 168), a lens of white marble is included within the complex of porphyroblastic gneiss to the north-west of Biange.

THE PARAMETAMORPHIC FORMATIONS AND THEIR AGE

1. Introduction.

The preceding geologic-petrographic descriptions of the areas underlain by metamorphic rocks in the Baltoro basin indicate the difficulties encountered in grouping the lithotypes into formations and in correlating these formations.

The extensive ice cover and the intense tectonic deformation on the one hand, and the superimposition of different metamorphic events of different grade on the other, make such a co-ordination still more difficult and uncertain. However, an attempt of this kind must be made: we must also endeavour to put these formations in chronostratigraphical order, by correlating them with the low-grade metamorphic and unmetamorphosed formations of the surrounding areas.

These problems were mentioned in the preceding section, and provide a starting point for the present discussion.

2. Vigne Quartzite (1).

These light-coloured, fine-grained biotite-muscovite schists, and silky and silvery micaschists associated with whitish laminated arenaceous quartzites, are so called from the name of the glacier in whose valley they mostly crop out.

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(1) In Desio's Geological Map of the Western Karakorum (1964) this formations is called Vigne Gneiss; but the quartzite is the prevalent lithotype.
These rocks form the cover of the Baltoro batholith in the south-east portion of the Baltoro basin, where the contact dips to the south-east.

The highest peaks of the Chogolisa Kangri massif are composed of such rock types.

From this area the Vigne sequence extends even further to the west, around the head of the valley of the West Vigne glacier as far as the valley of the Naating glacier and the crest of Masherbrum.

Neither the sequence of lithologic types is known, nor the thickness of the formation. It does not crop out in any other part of the Baltoro basin, and cannot be correlated with any other formation within the basin. It can however, be compared with the Nang Brock Quartzite (Desio 1963b) which crops out along the north-east side of the Shigar valley, slightly below the Skoro-la (Zanettin, 1964b). This formation is composed of greyish arenaceous quartzite with thin intercalations of micaschists.

The Vigne Quartzite differs from this Nang Brock Quartzite in the more thick beds of micaschist. This may be easily explained by some differences in the lithological composition of the original sedimentary sequence. If this correlation is valid, an Eocene age is indicated for the Vigne Quartzite, in accordance with the Eocene age of the Nang Brock Quartzite.

Since the outcrops of the two formations are separated by a large area, relationships between them are not clear.


In our descriptive chapter two similar sequences of rocks, characterised by an alternation of limestone, quartzite, black slates, chlorite schist and amphibolite, or amphibole gneiss and chloritic gneiss, have been mentioned. They crop out on the Mitre peak and in the upper Godwin Austen valley.

The two sequences are lithologically similar but not identical. Nevertheless, the differences may be explained by the different types of metamorphic processes in which they have been involved. The Mitre sequence shows the effects of thermal metamorphism produced by the granite of the Baltoro batholith, which lies quite close to the calcareous sequence. The rocks in contact with the granite are andalusite and silliminite hornfelses, rocks peculiar to thermal metamorphism. The original sediments of the Mitre sequence, are clay, sandstone and limestone in alternating sequence. The G. P. calcareous sequence must have had the same original composition but it was affected by
a process of granitization which involved the whole K² area. The nearest outcrop of granite of the Baltoro batholith lies many miles to the south-west.

In conclusion we may consider the Mitre and G. P. sequence to probably belong to the same «formation»; on the Mitre peak the «formation» has been affected by thermal metamorphism, while on the Gilkey-Puchoz spur it has been affected by granitization.

We have now to examine the stratigraphic relationships between the Mitre (and G. P.) calcareous sequence and similar sequences of the Baltoro valley. A comparison will first be made with the Doksam sequence. The greatest difference lies in the thickness of the beds. In the Doksam ridge the calcareous rocks (marbles and calc-schists) are of the order of hundreds of metres, while those of the Mitre peak are of the order of tens of metres. Further, amphibolitic rocks are lacking in the marble and calc-schist sequence of the Doksam ridge. There is no stratigraphic and tectonic connection between the Doksam and the Mitre sequences. The large ice flow of the Baltoro, three kilometres wide, separates the Doksam ridge from the Mitre peak. The banding in the Mitre peak strikes south-east, which is approximately parallel to the banding trend on the opposite side of the Baltoro glacier. To the south-east of the Mitre peak lie the northern spurs of the Chogolisa Kangri, which are separated by the Upper Baltoro ice-stream from the Chochordin and Gasherbrum ridge. The geological composition and structure of the bottom of the valley is not known, but if we take into consideration the fact that south-eastwards, at the head of the Upper Baltoro valley, some faults occur on the west wall of the Baltoro Kangri, and Cretaceous deposits are enclosed between black slates, we may conclude that there is no direct stratigraphical connection between the opposite banks of the Upper Baltoro glacier. The same conclusion is valid for the Mitre peak and the Doksam ridge.

But a further suggestion may be made. On both flanks of the Upper Baltoro glacier occur black slates which appear to belong to the same formation. As we will see in the next section, the black slates are to be correlated with the black slates and shales of the Shaksgam valley (Singhie Shale). In this valley the black shales are overlain by the Shaksgam Formation with which we have correlated the Doksam sequence. However in the same valley the passage from one formation to the other is very gradual, so that below the thicker calcareous strata of Permian age an alternation of shaly rocks and limestone occurs, which is followed by the Singhie Shale.

On the north-east side of the Upper Baltoro valley, and particularly in the Chochordin ridge, approximately the same stratigraphical sequence is to be
The Upper Baltoro valley is apparently located on an anticlinal faulted structure, since on the right bank the bedding dips northwards, while on the left bank it dips south-eastwards (fig. 67), but the structure is complicated by two faults, between which occurs the squeezed syncline of the Baltoro Kangri. Thus, on the right bank, above the black slates, we find an alternation of fairly thin-bedded limestones and slaty rocks, followed upwards by thick limestone beds. On the opposite side of the Upper Baltoro valley the black slates are overlain by the south-east continuation of the Mitre sequence: calcareous rocks alternating with schistose rocks.

Is it possible to correlate these two sequences?

Some of the differences between the two sequences may easily be explained as being due to the effects of thermal metamorphism of the Baltoro batholith on the south side of the Upper Baltoro valley.

If this is so, the Mitre sequence should represent the metamorphic facies of the passage-beds between Singhie Shales and the Shaksgam Formation, and the Mitre sequence should be stratigraphically overlain by the Doksar sequence.

We cannot arrive at a conclusion because we have not surveyed a detailed stratigraphical sequence in the Chochordin massif. All our knowledge is derived from debris from the moraines and inspection of the slopes with binoculars. Nevertheless, it is important to note that no amphibolitic rock fragments, comparable to those of the Mitre sequence, were found among the morainic blocks at the foot of the Chochordin.

At this point it will be useful to compare the Mitre sequence with that of the region situated to the west of the Baltoro basin, and on which we have more detailed information.
It is difficult to find a similar sequence among the Cretaceous-Eocene formations of the Shigar valley (Zanettin, 1964), but undoubtedly there are many generic similarities.

No definite conclusions on these correlations may be reached at this stage, more detailed investigation of the Baltoro basin is needed to reach a solution.

4. Doksam Sequence.

The Doksam ridge, comprised of the False Crystal peak, the Crystal peak, and the Marble peak, is underlain by this metamorphic sequence.

No standard series of this sequence exists, due to its complex structure and to the difficult approach to the mountain. However, a lithological sequence under Crystal peak (p. 165) was surveyed, so that a fairly complete idea of the lithological composition of this series was obtained.

Crystalline dolomite and limestone, ash grey calc-schists with thick white stripes, and grey and white marbles, mostly banded and with frequent intraformational folding, are the dominant types. Intercalations include black slates, grey-green chlorite-zoisite schists, micaceous quartzites, garnetiferous micaschists, fine-grained biotite gneiss, plagioclase gneiss, etc. The latter rocks become more and more frequent towards the west, as the Baltoro batholith is approached.

It is obvious that this complex of marbles, slates and gneisses represents a marine sedimentary sequence, but the metamorphism has obliterated every trace of organic remains, so that the best dating indicators are lacking. The stratigraphic position of the complex with respect to the surrounding formations is uncertain, firstly because the Doksam ridge – being surrounded by ice on three sides – is isolated; secondly because the tectonic structure is very complex, and thirdly because field investigation has been very scanty. In spite of these difficulties, correlation may be attempted by tectonic and lithologic methods.

Along the southern side of the Doksam ridge the predominant strike is east-southeast (north-northeast dip); thus we should find their continuation in this direction. In this direction, beyond the Godwin Austen glacier – which at this point is two and a half kilometres wide – is the end of the west spur of Gasherbrum IV. The rocky peak of the spur culminates at 5393 m, and black slates, overlain by a banded marble apparently similar to those of the Marble peak, crop out at its base. Here the formations strike north-west so that, if we
imagine them continuing in this direction, we should find them just at the east end of the Doksam ridge.

On this basis, we could say that the Doksam sequence continues on the opposite bank of the Godwin Austen glacier and underlies the peak at 5393 m which rises at the end of the western spur of Gasherbrum IV. Also, the tectonic structures are analogous on either flank, with complicated folding of the calcareous sequence which probably overlies the black slates with tectonic unconformity.

From the lithologic point of view the chief difference seems to be the presence of a facies of less intense metamorphism along the eastern side, as compared with that on the western side of the glacier, where intensely metamorphosed rocks, such as gneisses, micaschists, etc., are present. As far as we know, these rock types are lacking along the eastern side (1).

The continuation of the Doksam sequence to the south-east, in the direction of strike, is found in the peak at 5603 m (fig. 19) which rises at the eastern edge of the West Gasherbrum glacier. This peak, as has already been recorded, is composed of grey and pale yellow limestones which continue eastwards in the Chochordin.

In the peak at 5603 m the beds have a north-west strike, which corresponds to those of the right flank of the West Gasherbrum glacier. This confirms their continuity on both sides of the glacier. Further east the grey and pale yellow limestones continue on the crests of Gasherbrum V, of Chochordin, and, even further, on the southern side of Gasherbrum I. These limestones, which are in part crystalline, yielded Permian fossils in clearly metamorphic rocks (p. 52).

To conclude, if our stratigraphic correlations are exact, the Doksam sequence would represent a more intensely metamorphic facies of the limestones, of the intercalated slates, and of the fossiliferous Permian formation (Shaksgam Formation) of the southern side of the Gasherbrums.

However also the green rocks of the Doksam sequence are lacking in similar sequence to the east of the Godwin Austen glacier and this fact does not depend on differences in the grade of metamorphism. This gap can be explained supposing that within the folds of the Doksam ridge, rocks of Khalkhal formation (Cretaceous) are involved. This formation crops out north-east of the peak 5603 m.

Thus, the presence in the Doksam sequence of micaceous quartzite and

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(1) No fragments of these rocks were found by us in the moraines derived from this spur.
garnetiferous micaschist, which recall a similar rock association (Vigne Quartzite), seems to confirm our hypothesis.

Another indirect proof can be found in the tectonics. The complicated structure of the Baltoro Kangri is situated along the main folding axis of the Upper Baltoro valley. This axis is directed north-west, and passes through the Doksam ridge which shows a similar complicated structure.

As we know, Cretaceous rocks are involved within the Baltoro Kangri folds. In other words both the Doksam ridge and the Baltoro Kangri are composed of strongly folded formations belonging to the Upper Paleozoic and Cretaceous. We do not know if under the ice cover of the Baltoro Kangri also the Vigne Quartzite is present.

If our hypothesis is correct, we can now try to explain the geological position of the beds of the peak 5603 m which seems to be the south-eastern continuation of those of the Doksam ridge.

The beds of the peak 5603 m are really the south-eastern continuation of those of the Doksam ridge but more precisely of the Marble peak, and not of the Crystal peak. In the first one, green rocks are lacking as in the peak 5603 m high which rises on the opposite side of the Baltoro glacier.

Now we can compare the Doksam sequence with other stratigraphic units of the surrounding areas.

In the region studied to the west of the Baltoro glacier the Dumordo Formation (DESIO, 1963 b) shows a stratigraphic sequence similar to that of the Doksam sequence. It is composed of white and grey well-bedded marble, intercalated with thick beds of grey and blackish, often garnetiferous, calc-schist, plagioclase-biotite gneiss, biotite-amphibole-garnet gneiss, garnetiferous micaschist and kyanite micaschist; but the age of this formation is still unknown.

Another formation comparable with the Doksam sequence is that cropping out at the head of the Panmah valley at the foot of the Skamri range. According to A. DESIO (1936 p. 159) the southern slope of the Skamri range is composed of a thick sequence of metamorphic limestone and marble, with black interbedded slates. The thickness of these slate intercalations increases downwards until they prevail over the limestone.

From the lower levels of this sequence very probably originates a fossiliferous sample of arenaceous shale containing *Fenestella* remnants, belonging to the Upper Paleozoic, which was collected among the rock-fragments of the floating moraine of the Panmah glacier, not far from the foot of the Skamri range.

Apart from the great thickness of the limestones of the Skamri range, the
Doksam sequence shows a remarkable similarity with the middle and lower levels of the Skamri sequence.

This correlation also agrees in age with the correlation of the Doksam sequence with the Shaksgam Formation of the Gasherbrum range.

Other limestone-rich formations, reminiscent of the Doksam sequence, are those of the Cretaceous-Eocene metamorphic complex of the Shigar valley. Amphibolitic rocks are widespread in these formations while, as far as we know, they are lacking in the Doksam sequence.

At the present state of knowledge, therefore, the greatest affinities with the Doksam sequence are to be found in the Permian Shaksgam Formation of the Upper Baltoro.

5. Biange Gneiss.

This name is given to a lithostratigraphic unit, essentially composed of fine-grained paragneiss, which is widespread on the south slope of the middle Baltoro valley, above Biange and Gore, and lies in contact with the granite of the Baltoro batholith.

This unit probably does not represent a true formation, but only a member of an unnamed formation.

The Biange Gneiss forms a belt which runs north-westwards from the mouth of the Biange valley up to the valley of the Chagaran glacier, and perhaps as far as the upper Muztagh valley.

The original sedimentary rock was an argillaceous shale which perhaps belonged to one of the shaly formations which have been examined previously (p. 69).

The Biange Gneiss grades laterally and more or less rapidly into the plagioclase gneiss of the peribatholithic belt.


Most of the Mustagh Tower is composed of an association of prevalently biotite-amphibole and tonalitic gneiss. Due to the large ice cover very little research was done in this region. Nevertheless, it was enough to ascertain that the above-mentioned rock association represents a lithostratigraphic unit, perhaps of formation order. We called this unit the Mustagh Tower Gneiss.
Other outcrops of this rock association within the Baltoro basin are unknown to us. Having so little petrographic data at our disposal, it is a difficult task to compare the Muztagh Tower Gneiss with other metamorphic formations of the Western Karakorum.

However, a rather similar rock complex crops out next to the Muztagh Tower, in the valley of the Sarpo Laggo glacier.

In the lower valley, which was geologically explored by Desio in 1929, a gneiss complex occurs. The lithotypes of this stratigraphic sequence are not exactly known because the samples collected within the valley were lost by the porters. However, we do have the field descriptions. According to these notes the «Sarpo Laggo series» should be composed of porphyroblastic biotite and amphibole gneiss with intercalations of amphibolite and metadiorites. The similarity between the two «formations» is thus very high, but, as we cannot make direct petrographical comparisons, we provisionally maintain the two names.

Data is lacking for the determination of the geological age of both «formations». Biotite and amphibole gneiss are, in fact, present in other metamorphic formations of the Central Karakorum, together with other lithotypes.


As noted previously, during the geological survey of the Baltoro basin we named all the schistose black or dark coloured metamorphic lithotypes «scisti neri» owing to the impossibility of making a correct petrographical classification in the field.

These rocks differ in metamorphic grade, as we have already noted (p. 78). The «scisti neri» of the north-east slope of the Upper Baltoro valley were assumed to be equivalent to the Singhie Shales of the Shaksgam valley (ibidem), due to their petrographical similarity to the great thickness of these rocks in both the Baltoro basin and in the Shaksgam valley, and to their stratigraphical position below the Permian fossiliferous limestone in both the Shaksgam valley and on the right hand slope of the Upper Baltoro valley.

Merely from the petrographical point of view, different lithotypes can be distinguished in the metamorphic «scisti neri» or «black slates»: a) biotitic-graphitic phyllite; b) phyllitic micaschist; c) biotite-muscovite micaschist; d) fine-grained biotitic paragneiss; e) hornfels and similar rocks.
It has already been noted that the sedimentary formation of the Singhie Shale in the Shaksgam valley increases in metamorphic grade from east to west. Westwards and southwards from the south slope of Chochordin, black shales grade into black slates as the plutonic rocks of the Baltoro batholith are approached. On the opposite flank of the Upper Baltoro glacier, along the north-east slope of the northern spur (6182 m) of Chogolisa Kangri, black slates extensively occur. They are separated from the granite by a narrow belt of Mitre calcareous rocks. Westwards, at the foot of the Doksam ridge, black slates support the calcareous sequence of the Marble and Crystal peaks; further to the west, slates grade into fine-grained gneiss. The granite batholith crops out a little to the west of these peaks.

We must now consider whether the black slates of the Upper Baltoro valley can be correlated with the black slates of the upper Godwin Austen valley, taking into account that no visible continuity exists between either outcrop. Petrographic affinities are of little significance in this instance, especially since we only possess a few samples. Stratigraphic evidence may, however, help in this case.

As has already been mentioned, the stratigraphic position of the black shales of the Upper Baltoro basin is defined by their position immediately below the Permian fossiliferous limestones; thus they may be correlated with the Singhie Shale of the Shaksgam valley which underlie the Shaksgam Formation.

In the upper valley of the Godwin Austen glacier, the black slates continue eastwards beyond the watershed. Along the upper basin of the Skyang glacier, the black shales of the Shaksgam valley occur almost as far as the Skyang-la. Due to an extensive ice cover, a direct connection between these outcrops is not possible; however, there is no reason to suppose that no connection exists. The black slates of the upper Godwin Austen basin can therefore be correlated with the Singhie Shale of the Shaksgam valley, as the black shales and slates of the Upper Baltoro basin. They should therefore be of Lower Carboniferous age.

Another argument supporting the thesis that these rocks are of the same formation, is that the black slates of the upper Godwin Austen basin underlie the marbles of the upper crest of the Kharut valley; these marbles seem to represent a metamorphic facies of the Permian limestones of the Shaksgam Formation.

Finally we must mention the "scisti neri" of the Savoia glacier basin. As stated in another section (p. 100), they are mainly biotite-muscovite micaschists with garnet and andalusite, and form a wide outcrop on the slopes of Summa-ri
which seems to be connected with the wide "scisti neri" zone of the Sarpo Laggo valley (DESIO, 1936).

This later complex of arenaceous black slates with intercalations of dark foliated gneiss is a very thick complex ascribed with some uncertainty to the Upper Palaeozoic (DESIO, 1963 b); it is connected to the Singhie Shale, of which it represents a more markedly metamorphic facies, probably similar to the «black slates» of the basin of the Savoia glacier.

In conclusion, we hope to have demonstrated that the black shales and slates of the Baltoro basin can be correlated with the black shales of the Singhie formation of the Shaksgam valley. From the chronostratigraphical point of view, the Baltoro black slates are of the same age as the Singhie Shale: that is, Lower Carboniferous.

8. Falchan Gneiss.

The name «Falchan Kangri gneiss» was given some years ago by A. DESIO (1963 b) to a complex of «black or dark-grey phyllitic paragneiss alternating with a light-coloured quartz-arenaceous gneiss» cropping out on the northern slope of Falchan Kangri. In following publications it was briefly called the Falchan Gneiss.

A small stratigraphical sequence surveyed on the western side of Falchan Kangri (fig. 13), forming the basement of the sedimentary formations, was quoted on page 23. The sequence is repeated below, numbered from top to bottom:

(5) light, grey-green, quartz-feldspar arenaceous gneiss (very thick),
(4) black biotite paraschist, about 50 m,
(3) grey-green, quartz-feldspar arenaceous gneiss. Levels 3 and 2 combined: about 160 m,
(2) fine-grained biotite-gneiss with plagioclase porphyroblasts (K² gneiss),
(1) black, garnetiferous biotite paraschist; more than 250 m thick.

The sequence continues upwards with gneisses similar to those of levels 2 and 5, and these latter gneisses probably form a considerable portion of the top of Falchan II North and may underlie the sedimentary sequence.

The sequence mentioned above has a total thickness of 600-700 m and is crossed by pegmatitic dykes. We have already demonstrated (p. 135 et seq.) that the rocks of the Falchan sequence are derived from pelitic and psam-
mitic sediments, transformed into gneisses by metamorphism. The upper level of this formation, in contact (faulted?) with the sedimentary series are unknown, because the composition was interpreted on the basis of rock fragments from the talus and from the colour of the rock in situ. The base of the formation is also unknown because level 1 disappears under the talus and ice.

The dip of the layering indicates that the Falchan Gneiss overlies the K^2 Gneiss, but the Godwin Austen glacier lies between the two nearest outcrops so that the mutual relationships between the two formations cannot be obtained. Petrographical evidence, given in a preceding chapter, suggests that the Falchan Gneiss is a lateral facies of the «black slates» of the upper basin of the Godwin Austen glacier and also a transitional facies between them and the K^2 Gneiss.

Other lithostratigraphical evidence supports this interpretation.

We previously correlated, on the basis of stratigraphic continuity, the «black slates» of the high basin of the Godwin Austen glacier with the Singhie Shale on the one hand, and with the slates of the Sarpo Laggo on the other. Both formations frequently contain arenaceous intercalations, and these are also present in the Falchan Gneiss.

Other than on the north slope of the Falchan Kangri, this formation is not known to outcrop in the Baltoro basin. A few outcrops of arenaceous phyllite, quartz-feldspar schist and arenaceous quartz-schist of the basin of the upper Hispar glacier belong to the same formation. «Black slates» and K^2 Gneiss are also present (DESIO, 1963c) in this area.


This name was given by A. DESIO (1936) to a greenish-grey plagioclase gneiss occurring on the south slope of K^2. The same name was later used on many occasions (1956, 1957a, 1957b, etc.) and recently DESIO (1963b) applied the name to one formation. So, while in a strict sense «K^2 gneiss» (1) includes two types of porphyroblastic gneiss, augen gneiss and granite gneiss, in a wider sense (2), as a formation, it also includes paraschists within the preceding rocks. It is difficult to estimate the thickness of the K^2 Gneiss because of the fracture system crossing K^2, but it may be over 2000 m.

---

(1) With small g.
(2) K^2 Gneiss, with capital G.
The K² Gneiss also occurs on the northern slope of the Karakorum chain in the Sarpo Laggo valley, and probably also on the north-east slope of the Aghil pass. Outcrops are also present in the valley of the North Gasherbrum glacier, in the Urdok glacier, and on the northern slope of the valley of the Hispar glacier: specimens of these rocks were collected by Desio on the moraines of those glaciers.

In a preceding section (p. 135 et seq.) it was demonstrated that the K² gneiss represents an advanced stage of granitisation of the Baltoro black slates. Consequently the age of the original rocks is Lower Carboniferous.

But, as we have seen, beds of white marble are contained within the K² Gneiss. These marbles were derived from limestone intercalated in the black shale series. It is easy to explain such intercalations: in the Shaksgam valley the Singie Shales are overlain by an alternating sequence of black shales and fossiliferous limestones of the Upper Carboniferous and the Permian. The beds of marble contained within the K² Gneiss may represent the lowest beds of limestone of the Shaksgam Formation.

Later we will discuss the metamorphic processes which operated within the Baltoro region. It will firstly be necessary to consider the geology of the batholith.

D. STRATIGRAPHY OF THE METAMORPHIC FORMATIONS: SUMMARY AND CONCLUSIONS.

A synthesis of the partial conclusions of the preceding chapters enables us to give a summary of the whole stratigraphic sequence of the metamorphic formations outcropping within the Baltoro basin.

The sequence is as follows:

| Vigne Quartzite | Eocene (?) |
| Mitre and G. P. sequences | (Cretaceous ?) |
| Shaksgam Formation | Permian and Upper Carboniferous |
| Doksam sequence | |
| Biance Gneiss | Sarpo Laggo Gneiss |
| Muztagh Tower Gneiss | |
| Baltoro black slates | |
| Falchan Gneiss | Singie Shales |
| K² Gneiss | Lower Carboniferous |
A few comments must be added to this table.

Apart from the Vigne Quartzite, the uppermost beds belong to the Mitre and G. P. sequences of the Baltoro metamorphic formations; the age of these two is the most uncertain. Their lithological composition shows affinity with that of rocks of Cretaceous formations of the Shigar valley, while from the tectonic standpoint they seem to be connected with metamorphic facies of the Shaksgam Formation. For the moment the question remains undecided.

The Doksam sequence is referred to the Shaksgam Formation; but we have no precise information on its composition due to tectonic disturbances in the type-locality (Doksam ridge). It is possible that the Doksam member includes some Triassic beds which occur in the Gasherbrums to the east, and perhaps more recent formations.

The lower units of the Baltoro sequence are metamorphic formations equivalent to the Singhie Shale. This is the oldest formation of not only the Baltoro but also of the surrounding basins: the Upper Shaksgam, the Siachen, the Sarpo Laggo, the Panmah, etc. However, it is possible that rocks of Silurian age occur on the south slope of the Masherbrum peak, as discussed in a preceding section (p. 157).
IV. THE AXIAL BATHOLITH OF KARAKORUM IN THE BALTORO BASIN

1. Introduction.

The batholith underlying the main divide of the Karakorum chain extends about 500 km in a northwest-southeast direction, and further westwards describes an arc 200 km wide that assumes a northeast-southwest trend in Chitral territory. Both south and north of this batholith other minor igneous bodies crop out and lie parallel to the axial batholith, to which they can be connected, in part at least, in depth (1).

The Baltoro basin is crossed by the axial batholith over a distance of about 50 km with a southeast-northwest trend, between the Vigne glacier, the front of the Baltoro glacier, and the watershed between the Baltoro basin and the basin of the Panmah glacier.

More precisely, the northern contact of the batholith penetrates the northwest of the Baltoro basin through the East Muztagh pass, runs along the valley of the Chagaran glacier, a tributary of the Muztagh glacier, then bends south-eastwards, and then east-southeastwards, to reach the right-hand edge of the Baltoro glacier at the Biange locality, just downstream from the confluence with the Younghusband glacier (fig. 68 and 74).

Further to the south-east the northern limit of the batholith runs along the left side of the valley of the Upper Baltoro glacier as far as the northern flank of Chogolisa Kangri, where it is concealed by the ice. However, the batholith occurs further south-eastward, in the basin of the Siachen glacier, where the northern limit runs along the southern side of Teram Kangri.

The southern limit of the batholith, from the basin of the Panmah glacier, bends sharply south-southeastwards, running along the high crest which separates the Dumordo valley from the basin of the Tramgo and Uli Biaho glaciers and reaches the bottom of the Biaho valley at Paiu.

(1) See Desio's Geological Map of the Western Karakorum (1964 b).
From here it extends to the south-east, penetrating the upper valley of the Chingkang glacier, and runs south of the summit of Masherbrum peak. Further to the east the contact again enters the Baltoro basin in the Biarchedi massif, and then runs along the basin of the Vigne glacier. The contact then dips to the south-east, and its outcrops are smaller and irregular, until at Chogolisa Kangri it is concealed by the ice. But we know that the batholith crops out again in the upper valley of the Kondus glacier, to the south of the Chogolisa saddle, and, more extensively around the Bilafond glacier.

The average width of the batholith in the Baltoro basin is about 20 km. Due to the increasing height of the mountains from west to east and to the concomitant increase in ice cover, rocks of the batholith outcrop to a less and less extent in this direction, so that, as already noted, in the valley of the Vigne glacier it only crops out irregularly from the cover of metamorphic rocks or ice.

The petrographic composition of the batholith in the Baltoro basin is prevalently a biotitic granite, but to the north-west, beginning from the western end of the Panmah basin, granodiorite prevails.

Further to the north-west the Karakorum axial batholith is decidedly granodioritic in composition, both in the valley of the Biafo and Hispar glaciers (Desio, 1963 c), and within the upper basin of the Hunza river (Desio, Martina and Galimberti 1963).

South-eastwards the granitic composition of the axial batholith remains constant as far as the east end of the Karakorum range.
2. Previous Knowledge.

The oldest information on the granite of the Baltoro batholith is due to A. M. Verchère, H. H. Godwin Austen, R. Lydekker and W. M. Conway, the first explorers of the region.

In the report of A. M. Verchère (1867, p. 49) a cross-section of the middle Baltoro valley drawn by this author from information obtained by Ryall and Godwin Austen (see p. 157) correctly shows the northern slope of the valley to be composed of granite, while the opposite side, composed of a sequence of metamorphic schists and limestones, is also shown as granite. The investigations of Lydekker (1881) seem to be limited to the front of the Baltoro glacier. The author records the presence of a "a massive, lightcoloured, and frequently porphyritic gneiss, indistinguishable from granite". On the enclosed map, the whole lower and middle Baltoro basin is distinguished as being underlain by "older and Central gneiss".

The presence of granite is also mentioned by T. O. Bonney and G. A. Raisin (1894), who described the samples collected by Conway. One of the samples from in situ above Baltoro Camp, north of the valley, is porphyroblastic, showing a Carlsbad twin orthoclase. Only a little mica is present in this specimen, and in the following (278 and 279), from in situ, along the left bank of the lower portion of Baltoro glacier. Other samples of granite are mentioned by the same authors from the grey moraine of right side of Baltoro glacier, and from in situ at the angle where Piale joins Baltoro glacier. This is the first documentation of granite in the Baltoro basin.

No further information on this subject was obtained by the Duke of Abruzzi's expedition of 1909, while one sample of granite (granitite) collected by the De Filippi expedition of 1913-1914, near the front of the Baltoro glacier (Paiu), was described by P. Aloisi (1933).

A report issued by A. Desio in 1936 showed, for the first time, the limits of the Baltoro batholith, traced on a small-scale geological map, and the principal geological characters were described in summary form (p. 5). Very little information on the petrography of the granite is given and was mostly derived from the study of a few samples by P. Comucci (1938).

Various preliminary papers by the authors of the present work are listed in the bibliography at the end of this volume, and will not be dwelt upon here.

Among the more recent publications which contain at least some original data, mention must once more be made of the work of T. E. Gattinger (1961). In several places throughout the work the author describes the relationships between the granite (for which he gives no petrographic data since no sample was collected) and the country rocks.

Without dwelling on details, it will only be noted that Gattinger quotes "intrusive contacts" with the black slates of the middle Baltoro valley, with penetration of granite tongues into the slates. Remnants of micaschist and amphibolite are said to be contained within the granite, i.e. along the northern flank of the Baltoro valley between Lungka and the valley of the Uli Biaho, as well as on the Urdukas peaks. Of course, no proof or petrographic details are given.

(a) Introduction.

The Baltoro batholith is essentially composed of rocks of granitic type. Strongly differentiated rock types of sialic ( aplite and pegmatite) or mafic (diorite) composition or types structurally different from the granites, constitute a very minor fraction of the total volume of the batholith. Furthermore, they are always located at the margins of the batholith, so that the major part of the body is petrographically uniform.

(b) Granite.

Macroscopically the granites of the batholith are homogeneous throughout the area of outcrop. They are of rather fine and uniform grain size and only in the roof of the batholith, in the Vigne glacier area, do facies occur of slightly coarser grain size and occasionally with a microporphyrhetic structure. The quantitative relationships among the essential minerals, quartz, oligoclase, potash feldspar, and subordinate biotite and muscovite, are also uniform.

Microscopic observation, on the other hand, reveals some structural differences that enable us to distinguish between massive granites and gneissic granites.

The most regular massive structures appear in the granites of the Vigne glacier (54 PZ-202), mainly because plagioclase almost always shows a distinct idiomorphism.

This plagioclase generally shows rhythmic zoning. Its average composition corresponds to 20% An, but the cores of some crystals, which are very turbid due to the presence of alteration products and therefore difficult to determine, are probably somewhat calcic. Very often muscovite laminae are included within plagioclase, and this seems to be a common character among all the Baltoro granites. Inclusions of quartz and biotite are less common.

Quartz occurs in large areas, and sometimes includes biotite laminae.

Potash feldspar, generally microcline, is fairly uniformly distributed, and forms irregular areas with inhomogenous extinction.

Inclusions of plagioclase, quartz, and biotite crystals are always present in these areas.

Substitution and permeation of plagioclase by potash feldspar, and myrmekitic associations developed at the contact between the two feldspars, are common.
The substitution of zoned plagioclase by potash feldspar sometimes occurred in such a way that only a few inner zones have been substituted. This progressive substitution, zone by zone, may account for crystals of apparently zoned potash feldspar. Other potash feldspar individuals contain small inclusions arranged in such a way as to simulate zoning. These textures often occur in the granitic rocks of the Baltoro.

Occasionally, allotriomorphic areas occur, composed of oligoclase plagioclase with vague twinning and quartz crystals. Under high magnification the plagioclase is seen to be composed of many small sub-oriented individuals with margins slightly more sodic than the central parts.

Biotite is irregularly distributed in spots. Among the additional minerals are apatite, iron oxides, and zircon.

The granites of the eastern side of the lower Muztagh valley (54 PD-501) are very similar. These medium- to coarse-grained granites are composed of equidimensional individuals of oligoclase (20-25% An), potash feldspar, and quartz. Well developed laminae of biotite and muscovite are also present.

Apart from the micaceous minerals, only plagioclase shows a moderate tendency to idiomorphism. The plagioclases contain oriented inclusions of muscovite and quartz, and, more seldom, biotite. Potash feldspar includes prismatic plagioclase individuals and biotite.

Granites collected from the left moraine of the Baltoro glacier 3-4 km upstream from Urdukas and probably coming from the Masherbrum ridge, show a slightly oriented structure and some sign of a crystalloblastic texture (54 Pz-205, -206, -207). These features are visible with the naked eye. Biotite tends to be gathered into clusters, and small red garnets are also present.

Under the microscope it can be seen that plagioclase and potash feldspar assume larger dimensions, giving the rock a porphyritic aspect.

In the samples collected in the vicinity of Urdukas, in the central part of the Baltoro glacier (54 PD-Uz), and in the Chagaran glacier, a confluent of the Muztagh glacier (54 PD-Mu), the substitution of plagioclase by potash feldspar is very evident. The latter are sometimes turbid, due to the presence of small granules of iron oxide derived from the transformation of biotite into plagioclase. In fact biotite may still be present inside plagioclase, occurring as small laminae tending to lose their pleochroism and turning into chlorite. Muscovite inclusions are frequent and are often oriented within the plagioclase.

The first phase of the substitution of sodic-calcic feldspar by potash feldspar sometimes occurred without transformation or shifting of the inclusions so that they remain within the new mineral as inherited inclusions.
The substantial uniformity of the rocks of the batholith is confirmed by the chemical analyses (1) of three granites collected from various widely separated localities: one from the Vigne valley (54 PZ-202), where the contact of the batholith dips and disappears under the metamorphic cover; one from the southern slope of Baltoro, at Urdukas (54 PD-Uz); and the third from the northern side, in the lower Muztagh valley (54 PD-501).

### TABLE 14

**THE ROCKS OF THE BALTORO BATHOLITH**

**ANALYSED ROCKS**

<table>
<thead>
<tr>
<th>Locality</th>
<th>Petrographic classification</th>
<th>Chemical classification according to Niggli's magmatic types</th>
</tr>
</thead>
</table>

**CHEMICAL COMPOSITION**

<table>
<thead>
<tr>
<th>Analyst: B. Zanettin</th>
<th>Analyst: E. Callegari</th>
<th>Analyst: E. Callegari</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>SiO$_2$</td>
<td>70.93%</td>
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<td>0.03</td>
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<td>3.91</td>
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<td>K$_2$O</td>
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<td>H$_2$O$^+$</td>
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<td>H$_2$O$^-$</td>
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<td>0.02</td>
</tr>
<tr>
<td>99.59</td>
<td>99.73</td>
<td>100.35</td>
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</table>

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(1) The analyses are taken from E. CALLEGARI and B. ZANETTIN (1960). Further reference is made to this work for detailed information on the chemistry of rocks of the Baltoro basin.
TABLE 14 - (Continued)

NIGGLI'S values

<table>
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<tr>
<th>Baltoro analysed rocks</th>
<th>si</th>
<th>al</th>
<th>fm</th>
<th>c</th>
<th>alk</th>
<th>k</th>
<th>mg</th>
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</thead>
<tbody>
<tr>
<td>1. - Granite from Vigne glacier</td>
<td>358</td>
<td>44.9</td>
<td>11.1</td>
<td>9.9</td>
<td>34.1</td>
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<td>2. - Granite from Urdukas</td>
<td>396</td>
<td>47.9</td>
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<td>7.6</td>
<td>35.3</td>
<td>0.41</td>
<td>0.41</td>
</tr>
<tr>
<td>3. - Granite from the Muztagh valley</td>
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<td>47.3</td>
<td>7.3</td>
<td>9.2</td>
<td>36.2</td>
<td>0.37</td>
<td>0.37</td>
</tr>
</tbody>
</table>

NIGGLI's magmatic types

Leucogranitic magmas:

- Engadinitgranitic type: 380 43 13 8 36 0.5 0.25
- Aplitgranitic type: 460 47 8 5 40 0.45 0.25

Comparison of the analytical data of the table 14 shows that there are no important differences in chemical composition among the three samples. The principal difference occurs in the SiO$_2$ content, which varies between a minimum of 70.92% and a maximum of 73.36%. Na$_2$O and K$_2$O are present in almost equal quantities (≈ 4%) and this constancy is also evident in the value of the coefficient k of the magmatic formulae of NIGGLI (≈ 0.40).

Comparison of NIGGLI's values with the three samples shows them to belong to the leucogranitic group. They correspond to one or other of the 'types' into which the group is divided: the sample from the basin of the Vigne glacier corresponds to the engadinite granitic type, and the one collected in the lower Muztagh valley has intermediate chemistry between the aplite and engadinite granitic types.

(c) GRANITIC PORPHYRY.

A sample (54 PZ-201) of granitic porphyry comes from the right moraine of the lower Vigne glacier. However, nothing is known about the geological occurrence of these rocks. It can only be said that their matrix is composed of small quartz, plagioclase, and biotite crystals, within which quartz, oligoclase, potash feldspar, (sometimes microcline) and biotite phenocrysts occur.

Quartz phenocrysts are sometimes rounded and re-absorbed, while slightly zoned plagioclases sometimes have a narrow border of potash feldspar. Sometimes, potash feldspar, which may also include well preserved biotite lamellae, re-absorbs and substitutes small plagioclases. The larger biotite laminae are commonly surrounded by a very fine aggregate of biotite lamellae.

Apatite is common; a few large granules of sphene appear.
(d) APLITE AND PEGMATITE.

Peripheral differentiation is more frequent on the left side of the median Baltoro glacier, where it is joined by the Yermanendu glacier coming from the northern side of the Masherbrum. Here, aplite and pegmatite not only form layers in the granite mass and the country rock, but occur as masses which grade into normal granites. These granites include extensions of country rocks.

Fragments of *pegmatitic aplite* are common among the materials coming from the basin of the Yermanendu glacier. One of these (54 PZ-208) is particularly interesting because it contains three portions grading into one another. One portion, with autoallotriomorphic texture is medium fine-grained, and is made up of *quartz*, *plagioclase* with 10% An (and very turbid, due to inclusions of iron oxides), much-transformed *biotite*, and *muscovite*.

Another portion is coarse-grained and is rich in large crystals of *potash feldspar* (often *microperthite*) which sometimes include quartz and plagioclase.

A third portion composed of aggregates of *micropegmatitic* type is very common. This portion originated from the quartz-plagioclase aggregate by substitution of sodic-calcic feldspar by potash feldspar and the contemporaneous progressive deformation of quartz granules into small parallel lenses.

Aplitic bands alternate concordantly with schistose biotitic bands (54 PZ-209 a, p. 286).

The micaceous bands, composed of biotite, quartz, and plagioclase with 20-25% An are of coarser grain-size, and are completely lacking in potash feldspar.

The sialic bands are fine-grained and their composition varies with their thickness; the thin bands are quite lacking in potash feldspar, while it becomes more abundant in thicker bands.

Rocks of this type are crossed discordantly by pegmatitic dykes (54 PZ-209, p. 286). Their composition is not very different from the leucogranites of the batholith.

(e) DIORITE.

Large granitic fragments, including clots and mafic nodules of roughly dioritic composition, occur frequently at the mouth of the Yermanendu glacier and in the left moraine of the Baltoro.

A quartz diorite from this area (54 PZ-212, p. 287) is composed of well-twinned and homogeneous andesine *plagioclase* (35-40% An), *amphibole* (transitional between green hornblende and actinolite), *biotite*, and *quartz*. 
4. The Northern Side of the Baltoro Valley.

Detailed geological observations on this northern side were limited to the eastern edge of the batholith, specifically to the lower part of the Muztagh and Chagaran glacier valleys and to the nearby contact zone (Biange).

Here the sharp contact of the granitic body clearly dips under the schists of the country rock (dipping $40^\circ$ to the east-northeast).

Both the granites and the dark schists are crossed by many granitic and pegmatitic dykes, which are generally parallel to the contact surface but sometimes perpendicular to it.

These dykes penetrate many tens of metres into the country rocks and show sharp contacts or sometimes gradual contacts with them. They often contain large areas of foliated biotite or the biotite laminae may be distributed in a homogeneous way in the dyke rock, with an orientation sub-parallel to the schistosity planes of the country rocks.

One of these dykes ($54\ PZ-170$), injected into the schists ($54\ PZ-171$), corresponds to a coarse but variably grain-sized granite.

Plagioclase (oligoclase 25\% An), potash feldspar, and quartz are present in equidimensional individuals with isotropic distribution. Some of the micas, both light and dark, occur in sub-parallel planes. Plagioclase and alkali feldspar contain frequent inclusions of the other components, in a similar manner to the granite of the batholith. The present sample is distinguished from these granites by the total lack of zoning in the plagioclases.

West of the contact zone medium- or medium to coarse-grained granite occurs, corresponding to the most common types of the batholith.

A sample coming from the lower Muztagh valley ($54\ PD-501$) is of this kind. The chemical analysis (table 15) shows that it has a composition corresponding to a type intermediate between engadinite granite and aplite granite of NIGGLI'S leucogranitic magmas.

Ascending the Muztagh valley as far as the junction with the Chagaran glacier, medium grained granite of the most common type occurs.

Microscopic study of a sample ($54\ PD-Mu$) collected in the Chagaran glacier, 4450 m a.s.l., showed particularly evident substitution of plagioclase by potash feldspar.

In 1954 no other detailed observations on the granitic mass cropping out on the northern side of the Baltoro valley were made.


<table>
<thead>
<tr>
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<th>Analyst: E. Callegari</th>
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<td><strong>SiO₂</strong></td>
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<td><strong>P₂O₅</strong></td>
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**NigglI's values**

<table>
<thead>
<tr>
<th></th>
<th>si</th>
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<th>fm</th>
<th>c</th>
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<tbody>
<tr>
<td>Leucogranite from the</td>
<td>397</td>
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<td>9.2</td>
<td>36.2</td>
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<td>Muztagh valley</td>
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<tr>
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<td>47</td>
<td>8</td>
<td>5</td>
<td>40</td>
<td>0.45</td>
<td>0.25</td>
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<td>13</td>
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<td>0.5</td>
<td>0.25</td>
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<tr>
<td>(leucogranitic magmas)</td>
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**Equivalent Norm**

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<tr>
<td>Ne 23.6</td>
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<td>Cal 4.5</td>
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<td>Fo 0.1</td>
<td>γ = —</td>
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<td>Fa 1.2</td>
<td>α = 29.50</td>
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<tr>
<td>Ru 0.1</td>
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<tr>
<td>Cp 0.2</td>
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Geologists who previously visited this area also devote little attention to it in their accounts, no doubt because of the great homogeneity of the rocks of the batholith. They generally speak of granite without stating the place or origin of the samples collected.
The only definite information on this area is due to Desio (1936 pp. 264-267).

In his 1929 field book mention is made of granite with large crystals of orthoclase composing the lower slopes of the Baltoro valley just downstream from the junction with the Dunge glacier nearly as far as the junction with the Tramgo glacier. This rock type grades northwards into the common Baltoro granite. Near the mouth of the Dunge valley (pl. XXXVI fig. 2) the granite contains pink orthoclase, and porphyritic granite is common among the boulders of the floating moraine of the Dunge glacier.

The steep sides of the deep Tramgo valley are composed of a homogeneous granite which gives rise to some wonderful spires, such as Ainaablak (pl. XXXVI fig. 1) Tramgo Towers, etc. (pl. XXXVII and XXXVIII). The relatively uniform nature of the granite is visible on the walls and peaks as far as the head of the valley, and even into the basin of the Panmah glacier.

The structure of the granite changes in a north-east direction, within the upper basin of the Muztagh glacier. On the northern wall of the Karphogang the granite is striped with numerous lenses of banded gneiss, giving the appearance of an arterite (pl. XXXIX fig. 1).

A. Desio mentions the presence of granites with pink orthoclase «at the mouth of the Trango valley» and of pegmatitic layers «sometimes rich in large muscovite crystals and also containing pink garnet in different parts of the Trango basin, in the floating moraines of the Dunghe basin, and near Lopsang Bransa in the high basin of the Muztagh glacier».

The places of origin of granites with porphyritic structure «with big crystals of feldspar» are also quoted, but the later petrographic description by P. Comucci (1938, p. 102) of a sample collected by A. Desio at Lopsang Bransa makes it doubtful that this rock strictly belongs to the granitic batholith; it is petrographically analogous with a sample collected from the right moraine of the Chagaran glacier, in the Muztagh valley (54 PD-502), and we think it could be one of the granitic porphyroblastic gneisses appearing in the peribatholithic metamorphic band. Such an interpretation can hardly be extended to the «granites with porphyritic structure» noticed by A. Desio «about half a kilometre upstream from the confluence of the Uli Biaho, below the mouth of the Dunge valley» (pl. XXXVIII), in the central deep part of the Baltoro batholith. Since no samples collected in situ or detailed field observations are available it was not possible to make any statement on this subject.

It will be shown that a study of these areas would assist in the comprehension of the relationships between massive, homogeneous granites, porphyritic granites, and porphyroblastic gneisses.
5. The Southern Side of the Baltoro Valley.

The Baltoro batholith shows a great uniformity of rock types in the western and eastern areas, that is, in the Liligo area and in the Biarchedi - Vigne area, but, on the contrary, shows a great variability in the intermediate portion, corresponding to the area between Urdukas and the Yermanendu glacier.

In a later paragraph we will discuss the western peripheral part of the batholith downstream from the Baltoro glacier (near Paiu). Between the end of the glacier and Urdukas, three samples of granite were collected by W. M. CONWAY in 1892 and described by BONNEY and RAISIN (1894).

Investigations made by A. DESIO during the 1929 expedition and A. DESIO and B. ZANETTIN during the 1954 expedition show that this part of the valley is underlain by light-grey granite of medium-fine grain-size and «extraordinarily uniform» composition. The granite shows a very evident fracture system, simulating a layering, not only on the right side of the Baltoro valley but also along the whole left slopes, from Paiu as far as the Biarchedi massif (1). Narrow pegmatitic dykes cross cut the granitic rocks. Near the contact with the country rocks they are very abundant and decrease in number away from it. No preferential trend was noted for these dykes.

Most of the samples collected and studied come from Urdukas, and from the moraines carried by the Mundu and Yermanendu glaciers. In this area the rocks show the most lithological variation. Nevertheless, the prevailing rock type is granite, so that all the walls facing the Baltoro glacier are of granite (pl. XXXIX fig. 2).

Two samples collected by A. DESIO in 1929, at Urdukas (29 KD-10-11), and described as two-micas granite of the usual type (P. COMUCCI 1938, p. 101-102), are like the ones we collected near Urdukas (54 PD-UZ) and along the left moraine of the Baltoro, 3-4 km upstream from Urdukas (54 PZ-205, -206, -207). Chemical analysis (see table 16) of one of these samples (54 PD-UZ) shows it to correspond to the aplitgranitic type of the leucogranitic magmas of NIGGLI.

Two other samples from Urdukas collected by A. DESIO in 1929 (29 KD-43, -58) are described by P. COMUCCI (1938, p. 117-118) as small leucocratic dykes in a schistose rock «of which it also includes some fragments» and clas-

(1) See the paragraph on this subject at the page 204.
TABLE 16

Leucogranite; near Urdukas (54 PD-Uz)

CHEMICAL COMPOSITION

(Analyst: E. Callegari)

<p>| | | | | | |</p>
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<td>MnO</td>
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NIGGLI’s values

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<th></th>
<th>si</th>
<th>al</th>
<th>fm</th>
<th>c</th>
<th>alk</th>
<th>k</th>
<th>mg</th>
</tr>
</thead>
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<td>8</td>
<td>5</td>
<td>40</td>
<td>0.45</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Basis

| Q   | 55.8 | Q    | = 55.8 |
| Kp  | 15.4 | L    | = 39.9 |
| Ne  | 21.4 | M    | = 4.3  |
| Cal | 3.5  | π    | = 0.09 |
| Sp  | 2.0  | μ    | = 1    |
| Hz  | 1.1  | γ    | = 1    |
| Fs  | 0.1  | α    | = 20.37|
| Fa  | 0.8  |      |        |
| Ru  | 0.1  |      |        |
| Cp  | 0.2  |      |        |

Equivalent Norm

| Q   | 26.4 | Q    | = 26.4 |
| Or  | 25.0 | Ab   | = 25.0 |
| An  | 5.8  | Hy   | = 5.8 |
| Cord| 3.7  | Mt   | = 3.7 |
| Fe-Cord | 2.0 | Ru   | = 2.0 |
| Cp  | 0.2  | Ru   | = 0.2 |

sified as mica-quartz diorites. However, the mineralogical composition, and particularly the 20-27% An content of the plagioclases, leads us to believe that they could be the lighter beds of some banded gneisses shortly described (54 PZ-209a), and that are known to be present in the Urdukas zone.

We dealt with the constitution of the upper part of the Masherbrum peak (p. 160).

The prevailing rocks carried to the Baltoro from the Mundu and Yermannendu glaciers are also medium-grained or medium fine-grained granites some-
times containing small amounts of red garnet; but other lithological types are also important from this area:

(a) *pegmatite*, large bodies within and grading into the granite, and as dykes;

(b) *porphyroblastic granite gneiss*, often very similar to the $K^2$ gneiss, both in petrography (54 PZ-210, -211) and chemical composition (p. 159);

(c) *banded biotite gneiss* (54 PZ-209) with the appearance of arteritic migmatites, and composed of alternating very dark, narrow biotitic bands, and light bands of varying thickness.

These lithological types, which are similar to those seen in 1929 by A. Desio at Urdukas, are very often crossed by discordant aplitic-pegmatitic dykes, or included as strips within the granite;

(d) *quartz diorite* (54 PZ-212), schistose, more or less rich in amphibole, and may be associated with banded biotite gneiss (the field observations are not clear on this subject). The quartz diorites occur as large dark blocks included in, and showing sharp contact with fine-grained granite.

The chemical composition of the only sample collected is analogous to that of the normal *quartz diorite type* of the *quartz diorite magmas* of Niggli.

An agmatite of banded biotitic gneiss and quartz diorite occurs on the walls of the Masherbrum, on the flanks separating the Mundu and Yermanendu glaciers.

It is difficult to ascertain their correct position and also that of the granitic porphyroblastic gneiss.

For the above reasons we distinguish these gneisses from the granites of the batholith. The geological sketch (fig. 62) has been constructed from the observations made on the median moraine of the Baltoro.

Before ending the description of the south slope of lower Baltoro walley comment must be made on the Gattiner’s opinion that calcareous rocks crop out extensively in this area.

Limestone fragments are absent in these moraines carried by the Mundu glacier, but we cannot be as certain about those of the Yermanendu glacier (see p. 158).

If Gattiner’s interpretation were correct, the moraines of the Mundu glacier would contain many limestone fragments; but this is not so. This objection has already been raised by A. Desio (1963 a) in a recent note dealing with Gattiner’s work.
To the east of the Masherbrum, in the Biarchedi (pl. XL) and in the basin of the Vigne glacier, the granitic batholith is again lithologically homogeneous. Medium or medium fine-grained granite tends towards a porphyritic texture due to the development of feldspars. Differences in texture and lithology are negligible, and are noticeable only when samples collected in different places are compared.

Chemical analysis (54 PZ-202) shows these rocks to have a leucogranitic composition (aplite granite type of NIGGLI) (tab. 17).

### TABLE 17

Leucogranite; *Vigne glacier, on the moraine (54 PZ-202)*

**CHEMICAL COMPOSITION**

(Analyst: B. Zanettin)

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Analysis</th>
<th>Leucogranite from Vigne glacier</th>
<th>Engadinitgranitic type (leucogranitic magmas)</th>
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NIGGLI's values

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<td>11.1</td>
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**Basis**

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**Equivalent Norm**

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<th>Hy</th>
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</table>
Fragments of granite porphyry are present in the right-central moraine of the lower Vigne glacier. The floating moraines completely disappear upstream, so that it was impossible to determine the point of origin of these rocks. In a previous section we noticed that in the Vigne basin the granitic batholith dips under its cover (p. 150 and fig. 52). Although the country rocks at the northern contact of the batholith (in the area of the Mitre peak and on the opposite confluence edge between the Vigne and Baltoro glaciers) are crossed by many large pegmatitic dykes (fig. 49), the roof rocks do not seem to be affected by the same phenomenon.

6. The Relationship between the Baltoro Batholith and the Country Rocks near Paiu.

As we have already seen, the southern boundary of the granite batholith runs a little downstream from the front of the Baltoro glacier, close to the Paiu locality. Unfortunately, due to the burden of organisation, no detailed investigation could be carried out in this area during the 1954 expedition. Moreover, the samples collected near Paiu were lost by the porters. However, some observations were carried out by A. Desio during his 1953 expedition, and samples were collected near Paiu by previous explorers. W. M. Conway collected a granite sample in situ above the glacier front on the left side of the valley. T. G. Bonney and C. A. Raisin (1894, p. 224) described it as porphyritic, showing a Carlsbad twin of orthoclase. Only a little mica is present.

A sample was collected at Paiu by G. Dainelli in 1913 during the De Filippi expedition, and described by P. Aloisi (1932, p. 9) as a coarse-grained granite. «But», says Dainelli (1931, p. 711), «although it is the prevailing type, a slightly different granite type also appears». According to Aloisi, these granites correspond to biotite gneisses (p. 129) associated with two-mica and sillimanite gneiss (1) (p. 142), kinzigite gneiss (p. 149), and quartz-plagioclase gneiss with two micas and garnet (p. 166).

All these rocks were collected in the vicinity of the granite body, and are crossed throughout by granite dykes.

None of the properties described above suggest a thermal metamorphic

---

(1) This sillimanite type differs from the other rocks quoted here, in which plagioclase is an oligoclase with 20-25% An, in that the plagioclase is an andesine with 35% An.
origin but the author affirms that the texture and peculiar composition of the kinzigite, which «perhaps cannot be considered to be a proper kinzigite» should probably be ascribed to this types of metamorphism. If not, then the Paiu country-rocks differ from those of the Mitre peak and the Vigne valley which are characterised (as already recorded) by distinct thermal metamorphic properties.

Other observers agree in noticing that, near the western contact, massive granite passes into granitic gneiss with a slightly perceptible schistosity, and includes strips of metamorphic rocks.

A. Desio (1936, p. 263) noted that upstream from Paiu the metamorphic rocks give place to «porphyritic granites and granites that, together with granitic gneiss (with two micas), form the sides of the lower Baltoro valley».

From the 1954 field observations of the same author it appears that «the granitic rocks begin to crop out about fifty metres above the Paiu camp; they are fine-grained rocks with an indistinct schistosity containing slightly noticeable darkish strips and some strips of completely granitised schists».

The granite-schist contact runs from south-east to north-west, but also veers towards W 10°N, but is not always distinct, since dark bands, corresponding to partially granitised schists, are enclosed within the granite. The country-rocks are injected conformably by large and small granitic and pegmatitic dykes, so that the formation locally presents the aspect of a banded migmatite.

Further information on the contact zone between the granites and the metamorphic sequence can be found in the brief field notes made by A. Desio in 1953 (1).

«At the front of the Baltoro glacier, both sides of the valley are entirely underlain by granite of normal type.

On the left-hand side, the granite disappears near the outlet of the first small lateral valley descending into the Biaho valley (not the one descending near the glacier front); but on the right-hand side the contact occurs immediately downstream from Paiu. The contact is not visible along the caravan way, since an old moraine, some hundreds of metres thick, fills the bottom of the valley.

Where the rock emerges from beneath this moraine, augen gneiss and grey biotite gneiss occur both strongly injected; these are followed by a complex of schists and biotite gneiss, and amphibole gneiss with intercalations of garneti-
ferous micaschists. Calc-schist and grey and white marble follow these downstream.

Amphibole schists occur along the right side of the small valley below the Paiu Towers (pl. XLI). The schistosity dips towards the opposite side at about $30^\circ$, and, since that side is composed of granite, the schists seem to dip under the granite (fig. 69).

![Fig. 69 - The relationship between Baltoro granite (γ) and green schist and gneiss (Ggr) near Paiu (from Desio's field-book).]

The rocks mentioned above belong, on the whole, to the Ganchen Formation (Desio, 1963 b). Further west this is substituted by the Dumordo Formation, which is in contact with the granite batholith.

Near the front of the Panmah glacier the contact belt between the metamorphic rock and the granite seems to be similar to that at Paiu.

Near the contact the batholith is mostly composed of muscovite granite. This is in contact with micaschist and micaceous-garnetiferous amphibolite associated with garnet-bearing plagioclase-quartz gneiss. Marble and calc-schist containing mica and red garnet, are also present in the vicinity. Further south, white and grey marble of the Dumordo Formation occurs. The Ganchen Formation is reduced, due to a reverse fault which caused the lamination of the rocks and frequent twisting of beds.


We want to add some words on the striking of the joints of the Baltoro granite from which depend a peculiar mountains landscape on both sides of the middle and lower Baltoro valley. We did not devote particular investigation on this subject, but some data collected here and there offer a certain interest.

Two principal systems of joints are present: the principal system cuts the granite in big blocks which are occasionally feebly displaced; the secondary system produce a sharing in the granite simulating the strata of sedimentary
rocks. The first joint system strike north-east and dips approximatively north-west with an angle of $40^\circ \text{-} 50^\circ$.

The inclination of the joints increase from the outlet of the Dunge valley to the outlet of the Muztagh valley, but it lowers on the Biale crest where it is very gently inclined, and northward, where also the dip is north-northeast.

Similar conditions occur on the Chagaran ridge.

The principal joint system is also well developed on the south side of the Baltoro valley, between the Liligo and Mundu valleys (pl. XLII). Eastwards, the system is not very evident and locally seems to be substituted by joints with inverse dip.

Another important joint system, strike parallel to the precedent, and shear the granite with opposite dip and steeper inclination. The morphologic consequence is a peculiar fractionizing of the relief and the formation of an array of triangular shaped peaks set along the two sides of the lower Baltoro valley (pl. XLIII fig. 1). The net of lateral valleys and gorges complete the splitting up of the granitic body (pl. XLIII fig. 2).

The orientation of the secondary joints seems to be more variant than that of the precedent systems. Two systems of vertical joints, one perpendicular to the other, cross the peaks rising between the Uli Biaho and Tramgo valleys. Some spectacular granite spires and towers are the effect of such systems of joints (pl. XXXVI); but elsewhere the false bedding shows a different trend like on the north-east wall of the Muztagh glacier where the joints deep south-west, more downstream north-west, and to the east of the front of the Baltoro glacier, north-west.

What may be the interpretation of the jointing of the Baltoro batholith? If we compare the trend of the principal joint system with the direction of the axis of the batholith, we remark that the trend of the joints is nearly perpendicular to this axis, except in proximity of the northern border where it seems to strike nearly parallel and dip below the country rock.

The jointing can be produced either by the cooling process of the granite, or by an oriented orogenic pressure after the cooling, or by both. We are inclined to recognize a prevailing effect to the last orogenetic stress.


The reconstruction of events leading to the emplacement of the granitic batholith of Baltoro is particularly difficult because of the scarcity of observa-
tions made in the contact belt. We do have some data, and with these we shall try to construct a genetic hypothesis that is at least sound in a general way.

The data is substantially as follows.

In the east (Mitre peak and Vigne valley), where the upper part of the batholith is exposed, the contacts are sharp and the country rocks suffered contact metamorphism. The contact aureole is of moderate thickness and sometimes of not more than a few dozens of metres.

In the north-east (between the outlets of the Younghusband and Muztagh glaciers), on the northern side of the batholith, and in a deeper zone than the preceding one, the contacts with the country rocks are still sharp, but there is no sign of thermal metamorphism.

We were unable to determine the relationships between the massive granite and the schistose porphyroblastic rocks that border the batholith along its north-west edge with a belt of unknown thickness. Sometimes it appears that they are included within the batholith and pass gradationally into the normal granite. A spatial connection certainly exists between granite and porphyroblastic granitoid gneiss (though there seems to be an exception in the case of the K₂ gneiss).

The close petrographical and chemical analogies between the K₂ gneiss and peribatholithic granitoid gneiss allow us to ascribe a granitization genesis to the latter (either isochemical or allochemical, depending on the original composition of the granitized rocks).

In the axial zone of the chain at the proper depth and under the correct conditions, the granitization process would have begun. At the same time, granitic magmas could have been formed in the underlying zones, by anatexis. Great volumes of these magmas would have been injected into the overlying rocks, which themselves were involved to a decreasing extent in the anatexis or granitization process that produced the granitoid gneiss of the peribatholithic belt (and of the K₂ section). Such a hypothesis would explain why the contact surface with the country rocks, at first vague, becomes sharper and sharper with decreasing depth, until, where the country rocks were at lower pressure thermal metamorphic phenomena occur at the contact.

(a) Previous Hypotheses.

The problem of the geological age of the Baltoro granite is bound up with the wider problem of the age of the axial Karakorum batholith, of which the Baltoro granite is only a part.

We do not wish to consider the broad problem of the Himalayan granites but intend to limit our exposition as far as possible to the local problem of the Baltoro batholith. A. Desio has already dealt in the past with the age of Baltoro granite (Desio and Longinelli, 1961). Preceding authors had usually attempted to determine the age of the granitic masses of Karakorum, and had begun from the assumption that granites of different generations and age were characterised by different mineralogical associations and that igneous bodies with comparable associations belonged to the same emplacement and age.

Briefly reviewing the most recent interpretations it is noteworthy that P. Aloisi (1933) and G. Dainelli (1934) distinguished in the Karakorum and neighbouring regions three types of granites of different ages: a) indefinite type of granite, pre-Cambrian; b) biotite granite and two-micas granite, the most frequent ones being of pre-Cretaceous age and probably Upper Jurassic (Himalayan granite); c) mica-amphibole granite with associated diorite and basic rocks, of Senonian age (trans-Himalayan granite).

D. N. Wadia (1937) distinguished in Kashmir sensu lato three types of granites: a) biotite granite distributed from Kashmir to Assam (pre-Cretaceous); b) hornblende granite, less common, but similar in structure and composition to the biotite granite and of post-Cretaceous age (Eocene-Oligocene); c) tourmaliniferous granite, more recent than the previous two types, and into which it intrudes many dykes. Wadia considered it probable that the two Tertiary granites were formed by differentiation of the same originally homogeneous magma. He also mentions the granitic domes of Chitral, ascribing them to the Jurassic.

According to E. Norin (1946), three principal types of granites occur in the Karakorum and adjacent regions: a) biotite granite, post-Paleozoic and perhaps post-Triassic, but pre-Senonian; b) plagioclase granite of Cretaceous or lower Tertiary age; c) biotite-hornblende granite of Tertiary age.

According to P. Misch (1949), the three above mentioned types of granite exhibit remarkable affinities between one another, so that «one can hardly
speak of slightly different ages); in point of fact, they are considered to be syn-
genetic differentiations of the same magmatic process.

**Schneider** (1957), referring to the north-western part of Karakorum in
particularly, mentions, as constituting the axial portion of the range, granodioritic
masses (**Karakorum-Transhimalaya granite**) which form a heterogeneous plut-
on varying in composition from true **hornblende granodiorite** to **biotite granite**
with little or no hornblende. These intrusions are considered to be synor-
ogenic and of late Upper Cretaceous and early Tertiary age. The **aplitic gra-
nite** associated with tectonic disturbance of the region is considered to be post-
tectonic and post-Oligocene in age.

Only two of the age determinations quoted above were deduced from the
relationships between the igneous rocks and sedimentary rocks dated on palae-
ontological bases (**Dainelli and Wadia**).

More recently, as mentioned above, **Desio and Longinelli** attempted
to date the Baltoro granite geochemically. The results indicated a much more
recent age for the granite in comparison with previous estimations.

The entire Baltoro batholith was previously considered, for instance by
**P. Aloisi** and **G. Dainelli** (1934, p. 714), to be composed of «**Himalayan granite**», and consequently of Upper Jurassic age. This attribution was foun-
ded on the mineralogy of one sample of «**granitite**» collected near the end of
the Baltoro glacier. On this basis the whole axial batholith of Karakorum in
the same manner as the Ladak, Nun Kun (south-east Kashmir) and Qara Qash
(Kun Lun) batholiths on **Dainelli’s map** (1934, p. 714), are referred to as «**Hi-
malayan granite**», and thus of the same age.

**Dainelli** based his determination of the age of all these important gra-
nitic masses on the presence of pebbles of granite in a conglomerate of Se-
nonian age (idem., p. 748) cropping out near Himis (Upper Indus river). On
this basis the emplacement of the «**Himalayan granite**» was ascribed to the Up-
per Jurassic (p. 750). It is not easy to find concrete proof of the age of the
Himis granite in **Dainelli’s exposition**. In the table on page 73 the «**conglomer-
ates and granitic breccias with green cement with greenish sandstone len-
ses**» are included under the title «**Upper and medium Senonian (?)**», but evid-
ence of this age is not forthcoming.

In the local series there is a bed of hippuritic limestone but it is on the op-
posite side of **Dainelli’s supposed «syncline»**. Eocene fossils have not been
found in this locality: those collected **in situ** come from a site more than forty
kilometres away.

According to the author, Himis lies on the northern limb of the syncline
and is underlain by beds of Senonian age. The core of the syncline is supposed to be composed of Eocene beds. He correlated the outcrops of the northern limb with those of the southern limb where ophiolitic rocks also occur. The syncline is supposed to be complicated by secondary folds.

DAINELLI's tectonic interpretation is not convincing: many important dislocations, not recognized by DAINELLI, occur in the area so that his stratigraphic sequences of the Cretaceous-Eocene beds of the Ladak Indus valley are not acceptable. No geological section of the area around Himis is given. Those of Kalatze and Saspul are too distant to help to explain the problem, and they also do not seem acceptable because they are too dissimilar from the overall tectonic style of the region. According to DAINELLI (figs. 10, 11 and 12) it is made up of regular folds, with only a few bedding faults, whereas in fact it is intensively disrupted by faults and overthrusts.

De Terra (1935) also mentions the Senonian conglomerate of the Indus valley. In his scheme (p. 30) it appears at the base of the Indus flysch, ascribed to the Cretaceous, and further on (p. 55) he adds that «such a composition indicates a denudation process which followed the deposition of the Senonian Radiolite limestone, affecting both the granite of the neighbouring Ladak range and the Dras Volcanics south of it».

We are thus led to doubt the exact chronostratigraphy of the conglomerate with granite pebbles and, in consequence, the age of the Himis granite proposed by DAINELLI. Even if the Himis granite could be dated on a stratigraphical basis, it would not mean that all the granitic batholiths of the Karakorum and south-east Kashmir, and even the Qara Qash batholith (belonging, as already noted, to the Hercynian orogeny) must be of the same age simply because a small number of samples collected here and there belong to the «granitites» and biotitic granite group. As A. Desio has already pointed out (Desio, Tongiorgi and Ferrara, 1964) all these batholiths are of different composition and age; within one batholith the lithology varies from one point to another, and there is evidence to believe that the various phases are also of differing age.

A second chronostratigraphical determination of granitic masses, in a region rather near to Karakorum, has been attempted in the Burzil pass, on the western border of the Deosai plateau. The dating of this granite, which is a hornblende granite, and markedly different from the biotite granite, is due to D. N. Wadia (1937).

Near the Burzil Pass a Cretaceous volcanic series, containing limestone lenses, crops out.
In 1906 H. H. Hayden collected some fossils from the limestone, among which H. Douvillé (1926) recognised *Orbitolina bulgarica* of the Barremian.

Wadia at first ascribed the series of the Burzil pass to the Upper Palaeozoic (1934, p. 155) due to their analogy with the Panjal traps, but at a later date (1937), corrected this attribution on the basis of the fossils.

«The best preserved fossils in the limestone, writes Wadia, are *Orbitolina*, belonging to two or three species, besides other fragmentary foraminifera, corals, some doubtful impressions of ammonite shells, echinoids and bivalves.

The most interesting feature about this Cretaceous development in Kashmir is the intimate association of marine sediments with pyroclastic, volcanic, hypabyssal and plutonic rocks. Dykes, sills, and bosses of gabbro, pyroxenite, and serpentinite have invaded stratified tuffs, ash-beds and trap-flows, while hornblende granite has penetrated the whole series, the acid intrusions varying from thin veins to bosses several miles in diameter. Their intrusive relationships with tuffs containing pockets of *Orbitolina* limestone definitely dates the granite as post-Cretaceous.

It is highly probable that outlier strips of the Eocene, containing the foraminifera *Alveolina* and *Dictyoconoides* in a poor state of preservation, are involved in the folding of the Cretaceous in the Burzil valley». In Dras, these fossils have been identified in a thin band of limestone overlying a Cretaceous volcanic series of identical constitution to that of the Burzil pass.

The above facts, Wadia (1937) concluded, prove that the acid, basic and ultrabasic rocks are of «later age than the Cretaceous and are possibly post-Eocene. The relative age of the granite with respect to the gabbro suite is not yet certain, though it appears probable that the granite belongs to a later phase of injection».

E. H. Pascoe (1964) came to similar conclusions using the previous information on the Karakorum granites. He referred mainly to the hornblende granite, since he thinks it more probable that the biotite granites belong to an older intrusion. In this connection Pascoe says (p. 1435) that «at the confluence of the Indus and Shayok is a biotite granite without hornblende, traversed by a network of basic dykes and sills. The latter show metamorphism which, Auden suggests, may have been caused, not by the biotite granite which has every appearance of being the host rock, but by neighbouring hornblende granite. If it is not the case the biotite granite may be a variant of the hornblende granite which always contains a certain amount of biotite in addition to hornblende».

The chronological dating of the Burzil granite is confirmed by the presence
of strips of Dras volcanics (Cretaceous-Eocene) included in the hornblende granite of the Dras region (E. H. Pascoe, 1964). This granite is the direct continuation to the east of the granitic mass of the Burzil pass.

The igneous basic rocks (gabbrodiorite and tonalite) of the south side of the Shigar valley belong to the same types as the rocks of the Dras region and must also be referred to post-Cretaceous age (Zanettin, 1964).

(b) Present State of Knowledge.

As mentioned above, age determinations of the granitic rocks of Karakoram and the neighbouring regions, using geochemical methods, were made in the laboratory of Nuclear Geology at Pisa University, using samples collected by A. Desio. The results will be compared with those mentioned above.

The first age determination using the method of pleochroic haloes around biotite, was made in 1961 on three samples from the Baltoro basin, two of which were granite (54 PD-Uz and 54 PD-501) and the third a quartz diorite (54 PZ-154). The first two samples were respectively collected around Urdukas, and on the eastern slope of the Muztagh valley, not far from the junction with the Baltoro valley; the third was collected from a floating moraine of the southern glacier of Falchan Kangri, coming from an outcrop between Falchan Kangri and Gasherbrum IV.

The results of these determinations were published in a report by Desio and Longinelli (1961).

The granite sample from Urdukas was referred to the Pliocene, and that from Muztagh to the Oligocene. The more recent date may represent a metamorphic event.

The diorite sample does not belong to the Baltoro batholith, but to a smaller isolated body intruded into the sedimentary complex (Desio and Zanettin, 1957 a). It was dated as later than Oligocene.

As explained in a later report (Desio, Tongiorgi and Ferrara, 1964) the previous determinations had been obtained by the U/Pb method, using the Isola d’Elba (Italy) granodiorite for comparison; subsequently, new determinations were made on the Elba granodiorite, employing Rb/Sr and K/Ar methods, and different values were obtained. Considering the age of the Elba granodiorite (7 M.Y.) it would seem that the three samples from the Baltoro, including the granite from Urdukas (54 PD-Uz), have a more recent age.

These conclusions will be commented upon further on. Other determinations were made in the Pisa laboratory with the Rb/Sr method on other samples from the Baltoro basin. A biotite-muscovite paragneiss (54 PZ-172)
from the west of the Younghusband glacier, near the contact with the Baltoro granite, was dated at about 30 M.Y., that is Late Oligocene. According to Zanettin (p. 164) this datum can be interpreted as if the process of regional metamorphism in that time was practically concluded. An other sample of amphibole-sphene-epidote gneiss (54 PZ-176), collected from the floating moraine of the Younghusband glacier and coming from the south wall of the Muztagh Tower, is interpreted to be a product of a late acidic process connected with the formation of the granite batholith acting on a pre-existing rock of unknown age, was dated at 12.5 M.Y. (Pliocene). This is interpreted to indicate that the acidic process acted during the Pliocene. Two samples of granodiorite of the axial batholith, collected in the basins of the Biafo and Hispar glaciers, give us further data. One was collected from a moraine near Manho (54 PD-508) on the right bank of the Biafo glacier, and the other in the contiguous basin of the Hispar glacier, from the moraine of its confluent, the Khani Basa glacier (54 PD-527). These two localities are respectively 60 and 100 km west-northwest from Baltoro. The first sample gave an age of about 13 M.Y. (with some uncertainty), and the second, 24 M.Y. From the western continuation of the same batholith another granodiorite sample (62 PM-9), coming from the Hunza valley between Saret and Gulmit, about 58 km from the locality where sample 54 PD-527 was collected, gave an age of 8.6 M.Y.

The samples from the axial Karakorum batholith dated by the Rb/Sr method, yielded ages between 24 and 6-7 M.Y., that is from the beginning of the Miocene to the end of the Pliocene (B. M. Funnel, 1964). These ages cannot be assumed as definitive of the whole Karakorum batholith, but since no one sample gave an age older than Neogene and the process of regional metamorphism preceding the granitization was at this end in the late Oligocene, we can say that the axial batholith, for the most part, was consolidated during the Neogene. This conclusion does not agree with some data of the preceding section. However, the chronostratigraphical determinations mentioned above do not refer to the axial batholith of Karakorum, but to other granite and granodiorite bodies divided from the axial batholith by important dislocation lines and sedimentary complexes.

On the other hand, there is agreement with the few quantitative determinations of geological age of samples coming from other igneous bodies.

A quantitative chronological determination of the granodiorite of the Deosai plateau is given by a sample (62 PM-9) coming from the upper Satpura valley, near Skardu. The determination at the Pisa Laboratory, using the Rb/Sr
method, gave an age of 45 M.Y., i.e. Eocene, and near the limit between Middle and Upper Eocene (M. B. Funnel, 1964).

The hornblende granite of the Burzil pass which, according to the chronostratigraphical determination of Wadia is of post-Cretaceous age and «possibly post-Eocene», belongs to this same igneous body of the Deosai plateau.

The granite occurring near Himis, which, according to G. Dainelli, is of Upper Jurassic age, also belongs to the batholith of Deosai plateau which has been called «Ladakh batholith» by A. Desio (1964 c).

A quantitative determination, at the Pisa Laboratory, of the age of a granite pebble from the Himis conglomerate, using the Rb/Sr method, does not agree with this result. The age of this granite was found to be 38 M.Y., which according to Funnel (1964) corresponds to the end of the Eocene.

How can these different conclusions be reconciled? The geology of the Himis area is, as yet, unsolved. As we said above, we cannot agree with the tectonic interpretation, and consequently with the local stratigraphy, of G. Dainelli. It should be pointed out that the age of the Himis granite is similar to that obtained by the same geochemical method for the granodiorite of the upper Satpura valley.

According to A. Desio, both samples of granite belong to the Ladakh batholith, while the granodiorite from the Burzil pass, whose age was determined by Wadia from stratigraphical relationships, also belongs to the same batholith.

It is noteworthy that Wadia's conclusions agree with ours. It would seem, on the whole, that the Ladakh batholith began to be consolidated at the end of the Middle Eocene, while the Baltoro (axial) batholith was consolidated later, mostly between the Miocene and the Pliocene. Because of the scarcity of quantitative chronologic determinations available up to the present time, these conclusions must be considered quite provisory.

A further (stratigraphic) point must be considered in solving the problem of the age of the Baltoro granite: if the dating of some metasedimentary formations of Baltoro, the Vigne Quartzite discussed on page 173 is correct, then the Baltoro granite must be younger than Eocene, since it was responsible for metamorphism of these rocks.

All the preceding authors considered the tourmaline granite, outcropping mainly in the region to the west of Baltoro, to be the most recent of all the previously mentioned types. No samples of this granite have been collected by us in the Baltoro basin, but it belongs to the same period of igneous activity that is represented in our region by pegmatitic and aplitic injections ascribed to the end of the Pliocene.
V. SMALLER PLUTONIC BODIES

1. The Diorite of Falchan Kangri and Gasherbrums.

(a) INTRODUCTION.

The first information on the presence of diorite in the Gasherbrum ridge is contained in the volume of the Italian Expedition to the Karakorum, lead by the Duke of Spoleto, in 1929 (DESIo, 1936). On page 274 a sample of grey diorite is recorded among the fragments of the right lateral moraine of the south Gasherbrum glacier. Two other samples of amphibole-quartz diorite were collected at «Concordia» near the Camp V, and studied by P. COMucci (1938, p. 126). The sample was labelled «igneous rock intersecting the limestones». The location of the Camp V suggests that the samples originated from the Falchan-Gasherbrums range (fig. 27).

However more precise and detailed information is to be found in a paper by A. DESIo and B. ZANeTTIN (1957 a). Mention is made of the dioritic body of Falchan Kangri and Gasherbrum IV, and the lithology is deduced from the study of samples collected from the floating moraines of the glaciers south of Falchan Kangri and south-west of the Gasherbrum. The authors also discuss the petrogenesis and the lithological composition of the contact belt, characterized by the presence of hornfelsic calciphyre with tremolite and serpentine, samples of which were collected in these moraines.

T. E. GATTINGER in his work on the Baltoro basin (1961), ignores all this information. It is evident that he was not aware of the presence of the dioritic body. In his map (1:83 000), black slate and phyllite are indicated in its place.

(b) PETROGRAPHIC FEATURES.

On the left side of the lower Godwin Austen glacier, between Falchan Kangri (8051 m) and Gasherbrum IV (7925 m), quartz diorite, intruded into limestone and dolomite, are present.
In fact, great quantities of rocks of this type are transported by the South Falchan glacier and by the South-west Gasherbrum glacier.

Due to the marked differences in colour between intrusive rocks and country-rocks we were able to recognize the limits of the intrusive body from below, even though it was not possible to make observations in situ.

As can be seen in the accompanying geological map of the Baltoro basin, the diorite body seems to be composed of two wedge-shaped lobes with a common vertex and diverging in a south-east direction. The maximum extension of diorite outcrop corresponds with the saddle to the west of Gasherbrum IV.

Observations and samples collected by W. Bonatti in 1958, during the Italian Expedition to Gasherbrum IV, indicate that the diorite mass occurs extensively along the south-eastern side of Gasherbrum IV (fig. 71); it probably extends to the north of the summit and is connected with the western portion of the mass, delimited by us.

The quartz diorite of Falchan Kangri-Gasherbrum is uniformly medium fine-grained. One sample collected from the moraine of the South Falchan glacier (54 PZ-154) is composed of plagioclases, quartz, potash feldspar, pyroxene, biotite and amphibole. Plagioclases, always well twinned and idiomorphic, correspond to andesinic-labradorite (40-55% An). Both homogeneous and zoned individuals often with a core considerably richer in An (65%), may be present. Quartz is not uniformly distributed in the rock, but is concentrated in allotriomorphic patches, where it includes, and re-absorbs at the edges, plagioclase crystals. Potash feldspar, which is present in allotriomorphic patches, includes and variously substitutes the plagioclases. Myrmekite reaction products are often developed.

Femic minerals, especially pyroxenes and amphiboles, are lacking in idiomorphism. Individuals are often formed by the gathering of differently oriented portions. Pyroxene is a diopside-augite type, and is often transformed into actinolite at its edges. Amphibole is generally intergrown with biotite. Biotite, of a reddish colour, may be present in idiomorphic laminae. Sometimes it includes small individuals of pyroxene.

The variable texture of the rock indicates cataclastic and subsequent transformation and metasomatic substitution of sodic plagioclase, potash feldspar and quartz in a rock of probable gabbroic composition. Two samples from the south-eastern side of Gasherbrum IV, collected by W. Bonatti (58 PB-1, -2), though having undergone cataclasis and weathering, are very similar in composition to that mentioned above, but the femic components are almost exclusively represented by a green hornblende.
NIGGLI’S values calculated from the chemical analysis (table 18) of sample 54 PZ-154 show the rock to correspond at most to the normal dioritic type. However, due to the high value of $k$, the sample shows affinity with the tonalitic type of the quartz dioritic magmas.

**TABLE 18**

Diorite; *South Falchan glacier, on the moraine (54 PZ-154)*

**CHEMICAL COMPOSITION**

(Analyst: B. Zanettin)

<table>
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<tr>
<th></th>
<th>(\text{SiO}_2)</th>
<th>(\text{MgO})</th>
<th>(\text{CaO})</th>
<th>(\text{Na}_2\text{O})</th>
<th>(\text{Al}_2\text{O}_3)</th>
<th>(\text{K}_2\text{O})</th>
<th>(\text{H}_2\text{O}^+)</th>
<th>(\text{H}_2\text{O}^-)</th>
<th>(\text{MnO})</th>
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<tr>
<td></td>
<td>59.27%</td>
<td>4.07</td>
<td>5.91</td>
<td>2.60</td>
<td>15.37</td>
<td>2.82</td>
<td>2.14</td>
<td>0.20</td>
<td>0.11</td>
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</table>

NIGGLI’S values

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<th>(\text{al})</th>
<th>(\text{fm})</th>
<th>(\text{c})</th>
<th>(\text{alk})</th>
<th>(\text{k})</th>
<th>(\text{mg})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diorite from Falchan Kangri</td>
<td>191</td>
<td>29.3</td>
<td>36.3</td>
<td>20.5</td>
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**Basis**

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**Equivalent Norm**

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<td>(\text{Cp})</td>
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The contact between intrusive rocks and country rocks is sharp, and the latter are transformed by thermal metamorphism. Dolomitic rocks are transformed at the immediate contact into *pyroxene hornfelses*, which also contain
actinolite and clinozoisite (54 PD-155); towards the edges a zone may follow with tremolite, phlogopite, and green spinel, and then a thin serpentinose band formed by antigorite, chrysotile, and clinochlore (54 PZ-155a), sometimes accompanied by calcite and magnetite (54 PZ-156).

Apart from these metamorphic-metasomatic transformations, dolomitic rocks are weakly recrystallised.

Fig. 70 - Distribution of the quartz diorite outcrops between Falchan Kangri and Gasherbrum IV.  
1 Country rock, 2 Falchan quartz diorite.

(c) THE EXTENT OF THE QUARTZ DIORITE BODY.

The quartz diorite body stretches over a surface of about 36 km² between the south side of Falchan Kangri and the east side of Gasherbrum IV (fig. 70).
The outcrops are fractioned in many large dykes crossing the Permian-Triassic limestones. Near the contact with the diorite the limestones suffered the thermal metamorphism and were transformed into marble. The indented ridge of Falchan-tso is made up of metamorphosed limestone crossed by large dykes of quartz diorite and the same dioritic bodies continue south-westward under the ice of the West Falchan glacier. The dyke to the north of Falchan-tso seems to be limited northward by a fault which put the plutonic rock in contact with a sedimentary formation probably belonging to the Savoia Limestone, and eastwards probably to the Falchan Gneiss.

The crest dividing the West Falchan glacier from the South-west Falchan glacier is partly made up by quartz diorite (fig. 14) which probably stretches under the ice of the last glacier emerging from the ice as an island of rock. Also the crest between the South-west Falchan glacier and the West Falchan glacier is crossed by large dykes of quartz diorite included within the limestone or marble.

The largest mass of diorite crops out on the crest dividing the South Fal-
chan glacier from the West Gasherbrum glacier as far as the peak 6925 m high, and the same mass continues southward under the ice as far as the north side of Gasherbrum IV.

From the dioritic body other thick outliers stretch out toward the south and east slopes of the Gasherbrum IV entering the upper basin of the South Gasherbrum glacier (fig. 71). Specimens of quartz diorite were collected in the floating moraines of that glacier.

(d) GEOLOGICAL AGE.

It is obvious that the age of the dioritic intrusion of Falchan Kangri is later than those rocks affected by thermal metamorphism, but the age of these latter rocks has not been ascertained. Dolomitic limestones of Permian and Upper Triassic age are included in the metamorphic zone, and in proximity to the dioritic mass are represented by white and grey marbles. We do not know whether rocks of the Cretaceous formations, in which metamorphism is evident, have been affected by the thermal metamorphism.

Geochemical methods were employed to help solve the problem of age. The method of pleochroic haloes (DESIO and LONGINELLI, 1961) did not give any numerical data, though it did ascertain that the diorite is younger than the Baltoro granite, which is in turn younger than the granodiorite of the Island of Elba (Italy), which was consolidated 7 M.Y. ago.

The diorite seems to be thus of late Pliocene, taking into account that the Baltoro granite is, if not of the same age, younger than the granodiorite of the Island of Elba.

2. The Lamprophyric Dykes of Falchan Kangri and Gasherbrums.

(a) PETROGRAPHIC FEATURES.

While speaking about the formations cropping out on the two sides of the valley of the Godwin Austen glacier, on the west slope of Falchan Kangri, and on the right-hand slope of the Upper Baltoro valley, we often mentioned the presence of basic dykes of lamprophyric type that cross-cut the other rocks. These dykes are quite narrow, seldom more than one metre across, and very long, up to one kilometre and more.

They were first noticed in 1929 by A. DESIO (1936), at many of the localities mentioned above. The chemical-petrographic investigation by P. COMUCCI
(1937, 1938) of samples collected by A. Desio showed these rocks to possess such a peculiar composition that he called them with the new name of baltorite.

The same dyke rocks are mentioned by H. Scharbert (in T. E. Gattlinger 1961, p. 93), who carried out a petrographic examination of three samples collected by Gattlinger from the Gasherbrum. Two of them were classified as minette and the third as augite kersantite. The chemical composition and a short petrographical description of these dykes (C. Viterbo and B. Zanettin 1959) is given here because we consider them to be genetically dependent on the Falchan Kangri-Gasherbrums dioritic mass.

Accurate petrographical study of many samples collected in 1954 confirmed that these dyke rocks are lamprophyres, and, more exactly, minette and vogesite. At the same time it confirmed the peculiarity of these petrographic types.

A common feature of all the samples studied is the rapid variation in grain-size and mineralogical association from point to point within the rock. The sialic components are represented by potash feldspar which forms the groundmass of the rock, in large, welded, allotriomorph individuals. Fine-grained mafic minerals are included within these crystals.

Phenocrysts are always mafic: biotite, pyroxene or amphibole. Biotite is always present. One or other or both of the other two minerals are always associated with, and sometimes exceed, the biotite. The mafic minerals are usually strongly zoned.

The central parts of the biotite crystals often correspond to phlogopite ($2V\alpha = 5-10^\circ$), and are very light in colour, while outer zones show rhythmic alternation of fairly intensely pleochroic biotite.

Pyroxenes generally have augitic cores, while the peripheries are composed of aegirinaugite and aegirine terms ($c : \gamma = 93-100^\circ$). The core may sometimes be composed of orthorhombic pyroxene.

The most common amphiboles are between common hornblende and kataborite (1) in composition. In the dykes rich in pyroxene and biotite, amphibole appears in small individuals of sodic composition, corresponding to riebeckite or varieties intermediate between riebeckite and arfvedsonite (2) in composition.

The chemical analyses of six lamprophyres (two of them collected by

(1) $N\beta//\gamma$; O.A.P. // (010); $c : \gamma = 25-51^\circ$; $2V\alpha = 60-78^\circ$; $\alpha =$ colourless or light greenish-yellow, $\beta =$ light violet-grey; $\gamma =$ almost colourless, or light green; strong dispersion.

(2) $N\gamma//\gamma$; O.A.P. // (010); $c : \gamma = 6-9^\circ$; $\alpha =$ bright green, $\beta =$ greenish-yellow, with blue tones; $\gamma =$ intense violet; very strong dispersion.
A. Desio in 1929, and four by us in 1954) are given in table 19. They show some characters which are not common in similar lamprophyres: very high values of K₂O (up to 10.13%) and low values of Al₂O₃ (with a minimum of 6.90%).

Comparison with NigglI magma types shows these rocks to have a moderate analogy with lamproitic magma and with the jiogoitic type of the shonkinitic magmas.

Our rocks correspond well, from the chemical and petrographical point of view, with a particular type of lamprophyre, named «prowersite» (1), and with some Alpine mafic dykes (2). In spite of its rarity, C. Viterbo and B. Zanettin (1959) concluded that this lithologic type corresponds to minette and vogesite very rich in potash, and for it they proposed the names K-minette and K-vogesite.

### TABLE 19

THE LAMPROPHYMES OF THE BALTORO BASIN

<table>
<thead>
<tr>
<th>Località</th>
<th>Petrographic classification</th>
<th>Chemical classification according to the NigglI's magmatic types</th>
</tr>
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<tbody>
<tr>
<td>1. - Near the confluence between the De Filippi and Godwin Austen glaciers, on the moraine.</td>
<td>Pyroxene-biotite vogesite with amphibole (54PD-15)</td>
<td>Between the melarkitic type (sommaitic magmas) and the yogoitic type (shonkinitic magmas).</td>
</tr>
<tr>
<td>2. - The south-western slope of Falchan Kangri.</td>
<td>Amphibole-biotite vogesite (54 PZ-151)</td>
<td>Between the murcialamproitic and the yogoit-lamproitic types (lamproitic magmas). Wyominglamproitic type (lamproitic magmas).</td>
</tr>
<tr>
<td>3. - Right side of the Godwin Austen glacier, on the moraine.</td>
<td>Amphibole vogesite (54 PZ-146)</td>
<td></td>
</tr>
<tr>
<td>4. - Skyang-la, at the height of 6233 m.</td>
<td>Pyroxene minette (54 PD-89)</td>
<td>jumillitic type (lamproitic magmas).</td>
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LAMPROPHYRIC DYKES

### Table 19 - (Continued)

**Chemical Composition**

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<td>C. Viterbo</td>
<td>C. Viterbo</td>
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**Nigglis's values**

*Baltoro analysed lamprophyres*

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**Nigglis's magmatic types**

Shonkinitic magmas:

*Yogoitic type* 145 22 40 20 18 0.5 0.55

Sommaitic magmas:

*Melarkitic type* 150 22 34 22 22 0.6 0.4

Lamproitic magmas:

*Murcialamproitic type* 140 17 52 13 18 0.6 0.75

*Yogoitlamproitic type* 140 19 41 19 21 0.8 0.7

*Wyominglamproitic type* 165 18 41 14 27 0.85 0.75

*Jumillitic type* 110 13 60 14 13 0.7 0.8
Since we consider the Baltoro «baltorite» to depend genetically on the diorite of the Falchan Kangri-Gasherbrums, it must be concluded that it is of the same age. Thus, we can interprete the «baltorite» as being a product of the last phase of basic igneous activity in the region, and to be of Quaternary age.

(b) Topographic distribution

The spread area of the «baltorite» dykes is principally restricted to the Falchan-Gasherbrum ridge and the average trend seems to be radially situated in respect to the diorite body. We are lacking in accurate field investigation, but the location of the samples collected here and there, integrated with some observed dykes, can supply the data for a preliminary sketch-map of the geographical distribution of such rock.

The list of the localities where the samples were collected and the dykes were observed is the following:

1. Pyroxene minette. At Skyang-la; altitude 6233 m (54 PZ-89).
2. Pyroxene vogesite. In the right-hand lateral moraine of the De Filippi Glacier, near the mouth (54 PD-15).
3. Amphibole minette. In the right-hand floating moraine of the Godwin Austen glacier, a little above the Base Camp. (54 PD-53).
4. Pyroxene minette. In the left-hand floating moraine of the Godwin Austen glacier, altitude approximately 5000 m (54 PD-52).
5. Pyroxene minette. In the left-hand floating moraine of the Godwin Austen glacier, altitude approximately 5050 m (54 PD-58).

7. *Pyroxene minette*. In the right hand moraine of the glacier that occupies the small valley lying between the first and second peak of Falchan Kangri (54 PD-72).

8. *Baltorite*. Dyke within the fine-bedded limestone between the NNW and NW Falchan glaciers (no sample) (fig. 72).

9. *Vogesite*. Veins on the west spur of Falchan Kangri at about 5800 m (according to SCHMUCK, 50 m north of I Camp.).

10. *Amphibole-biotite vogesite*. Towards the south-west of Falchan Kangri (54 PZ-151).

11. *Amphibole vogesite*. In the right-hand moraine of the Godwin Austen glacier, between the mouths of the Savoia and Khalkhal glaciers (54 PZ-146).

12. *Baltorite*. Dyke on the north wall of Marble Peak (no sample).

13. *Pyroxene-garnet vogesite*. In the middle moraine of the Upper Baltoro glacier (54 PZ-166).

15. « *Baltorite* ». Moraine close to the south spur of Chochordin peak (29 KD-159/1).


The origin of the last three specimens is not clearly known. On Gättinger’s geological map of Gasherbrum two basic dikes are indicated at the end of the south-southwest spur of Gasherbrum I, but a larger outcrop of the same rock is marked also at the head of the Abruzzi valley. In our opinion it deal with a different kind of rock (see p. 60).

An other dyke is indicated on the northern slope of the Baltoro Kangri.

From the above list and even more from the sketch-map (fig. 73) we have further confirmation of the connection existing between the « baltorite » dykes and the diorite body. We may also deduce that the minette seams to be more frequent than the vogesite and the pyroxenic minette more common than the amphibole minette, but the present data are very poor and thus it is impossible to reach an exact conclusion.
VI. REMARKS ON PETROGENIC PROCESSES
IN THE BALTORO AREA

After having described the various formations which make up this part of the Karakorum range, we shall attempt to explain concisely the petrologic processes (metamorphism, anatexis, magmatic crystallization) by which these formations have assumed their petrographic characters.

As already seen, the oldest formations cropping out in this region belong to the Lower Carboniferous (Baltoro black slates, Falchan Gneiss), and the youngest to the Cretaceous, or perhaps to the Eocene.

The first observation to be made is that the intensity of the regional metamorphism is not in relation to the age of the formations, but reaches its greatest values in the neighbourhood of the granite of the Baltoro batholith. Apart from the area of influence of the batholith, all the stratigraphic unities, (even the oldest ones, such as the Baltoro black slates of the Lower Carboniferous) are weakly affected by the metamorphism, which can be referred to the lower thermic level of the green schists facies. It is clear, therefore, that regional metamorphism and granite emplacement are strictly interdependent processes, likewise those of the area to the west of the Baltoro (B. ZANETTIN 1964): in that occasion we spoke of circumplutonic regional metamorphic aureole.

However, in our region it is possible to be more accurate regarding the relationship between granite and metamorphism. In the Upper Baltoro area, where the top of the batholith crops out, the rocks which form the roof are slightly metamorphic (passage from the green schists to the amphibolite facies), and in the neighbourhood of the contact with the granite these rocks underwent an intense thermal metamorphism which transformed them into hornfels (K-feldspar-cordierite hornfels facies). In the middle Baltoro the country rocks present a higher metamorphic grade (almandine-amphibolite facies) and show no evidence of thermal metamorphism. On the northern side of the granite mass gneiss with large oligoclase-andesine crystals are frequent. On the southern side porhyroblastic gneiss can still be observed (with large plagioclase and K-feldspar crystals) and frequent agmatites. On the lower Baltoro,
near Paiu, the country rocks are of a high metamorphic grade (sillimanite-almandine-orthoclase subfacies) and locally pass into banded migmatites.

This situation enables us to outline the processes which led to the emplacement of the granite and to the areal distribution of the regional metamorphism.

In the course of the Alpine orogenesis (which affected the formations described above, still unaffected by the metamorphism) in the deep parts (at least 6-7 kilobars) of the axial zone of the arising chain, the temperature rose progressively determining the genesis of regional metamorphic rocks of increasing grade and finally caused a rock melting and the appearance of migmatites with a varying quantity of neosoma, and different types of paleosoma according to the nature of the rocks affected by anatexis.

As always occurs during synkinematic anatetic process the distribution of the isograds had to vary with a certain continuity from the central and deepest parts of the axial zone towards the borders. Around the melted or partially melted parts (anatetic magma and migmatite) rocks with decreasing metamorphic grade should have been found.

Further, between the anatetic migmatite and the common regional metamorphic rocks could be interposed a band of irregular thickness made up of granitoid gneiss and porphyroblastic gneiss (characterised by the notable growth of plagioclase and K-feldspar crystals) originated by a process of isochemical granitization.

This zone of porphyroblastic gneiss (plagioclase 40% An) often appears crossed by aplitic and pegmatitic veins and dykes coming from the anatetic core. Locally this same zone is affected by an incipient anatexis leading to the formation of small granitic areas in which relics of andesine are included within the oligoclase crystals.

Later on all the overlying rocks of a decreasing metamorphic grade in ascending order were affected by a series of successive injections of anatetic magma, and these injections produced the formation of the Baltoro batholith.

Owing to the existing high pressure, the intrusion had no thermal effects in the lower part of the metamorphic sequence. On the other hand thermal effects are well evident and widespread at the top of the batholith, where the pressure at the moment of intrusion had to be of value low enough to permit the appearance of andalusite.

Once the relationship between regional metamorphism and anatexis is established, it may be said that this process did not only occur in strict spatial connection with the present granite batholith. In fact within rocks very slightly affected by metamorphism, an island of metamorphic rocks was recog-
nized in the $K^2$ area (accompanied by porphyroblastic gneiss and granitoid gneiss, injected by anatetic dykes).

Thus temperatures such as to cause local melting in rocks of suitable composition were even reached in the $K^2$ area. However, this process took place only under pressures lower than those affecting the axial zone of the range. The first effect of the increase of temperature in fact, caused the appearance of andalusite within the Carboniferous black slates. Further, the geothermal gradient must have been very high in the $K^2$ area, as the black slates rapidly grade into the products of the complete recrystallization of the same (granitoid gneiss by isochemical granitization) and into their incipient anatexis.

In the axial zone the metamorphic rocks belong to the Barrovian-type facies series, while those of the $K^2$ are to be attributed in part to a type of metamorphism of lower pressure.

With regard to the age of the processes described above, we recall that the radiometric measures ($\text{Rb/Sr}$) carried out on a biotitic paragneiss belonging to the country-rock of the batholith from the middle Baltoro ($54 \text{ PZ-172}$) furnished values of about 30 M.Y. It can be deduced that in the Late Oligocene the regional metamorphic process was substantially concluded.

If the above relation between metamorphism and anatexis can be taken as valid, then the same age must be also attributed to the genesis of the granitic magmas. The injection of these magmas took place later, at different times, as is indicated by the results of the dating carried out on samples of granite collected in various parts of the batholith, from which it appears that the crystallization of the magmas occurred during the Neogene (p. 212). It can therefore be affirmed that the Baltoro batholith is a composite mass.

Also the basic rocks, mainly diorites, injected within the dolomite of the Falchan Kangri are more or less contemporaneous with the Baltoro granite.

Finally, we mention that the great synkinematic, anatetic, magmatic cycle which already began during the Eocene, concludes in the Karakorum with the formation of the Baltoro batholith, and in the southernmost parts of the range (Deosai, Indus and Shigar valleys), with the emplacement of granites and diorites (hornblende granite of D. N. Wadia; trans-Himalayan granite of G. Dainelli etc.). As also in those zones a direct connection between metamorphism and genesis of the granite was observed (B. Zanettin, 1964 a), we can say that in the course of the formation of the Karakorum range similar processes took place repeatedly from south to north in the interval of time ranging from the Eocene to the Pliocene.
VII. THE TECTONIC STRUCTURE OF THE BALTORO BASIN

During the description of the different parts of the Baltoro basin we have already mentioned the most important tectonic structures of these areas. This data must now be co-ordinated and gathered together under one heading.

In this connection, it must first be recorded that the boundaries of the area under consideration do not coincide with those of one or more tectonic zones. If we look at the geological map of the Baltoro basin accompanying the present memoir, and that of the Western Karakorum (Desio, 1964), we can see that only half of the area of the basin, namely the north-easterly one, lies outside the batholith, which crosses the basin in a south-southeast direction.

The element dominating the structure of the Baltoro basin is this batholith, which, as has already been mentioned, is a small portion of the axial batholith of Karakorum. The batholith is geologically much younger than the formations of the Baltoro basin, and its emplacement strongly modified the pre-existing tectonic structures.

In the tectonic drawing (fig. 74), there seem to be very few folds compared with the number of fault lines, but this reflects in part the greater difficulties encountered in reconstructing the folds than in reconstructing the faults in a region where rock outcrop is very restricted and markedly fractioned by ice. In the case of faults, in fact, only a small face is needed to provide evidence of their presence.

It can also be added that the frequency of tectonic lineaments on the drawing is in part fictitious, since it reflects the accuracy of the field investigation, so that the map represents the present knowledge rather than the real structural conditions.

With these limitations let us begin with the faults.

Three prevalent fault orientations can be distinguished. The dominant system is oriented approximately along the meridial direction, while a second system trends more or less perpendicular to the first. These two systems are present on both K² and Falchan Kangri, while further southwards, in Gasher-
brums, a third, south-east trend seems to prevail: to the south, the faults of the first system tend to inflect, assuming this south-east trend.

It is important to note that this inflection occurs in the area lying nearest to the edge of the batholith which itself trends south-east, so that the inflection may be due to emplacement of the batholith.

As already remarked in the case of K², of the two systems of faults one is parallel and the other perpendicular to the prevalent trend of the bedding, and, consequently, to the axes of the folds. The same conclusions on the relative ages of the three systems which have been drawn in the K² area are also valid in the more general case.

The faults cut the region into blocks, so that the folds are discontinuous and difficult to distinguish when they are poorly exposed, due to the ice cover.

Near to the steeply inclined normal faults there is evidence of very low angled overthrusting. A few well-defined thrust planes, present in the Falchan Kangri, bring Cretaceous formations in contact with unmetamorphosed and metamorphosed Permian formations.
We have little information on the direction of thrusting. The thrust planes dip to the west or west-northwest which could suggest that thrusting came from these directions. Before coming to any conclusions on the subject, we must briefly consider the folds.

In the area of K², three anticlines have been recognised. The orientation of their axes is nearest to that of the N fault system (p. 121). An assumed anticline in the upper valley of the Godwin Austen glacier has a slightly different orientation, namely north-northeast. Between these anticlines lie some incomplete synclines with axes parallel to those of the anticlines.

On the south-west side of the K² massif a truncated anticline is oriented east-west, while another, oriented east-northeast, seems to be present to the north-west of K².

Starting from Falchan Kangri (fig. 17) and proceeding towards the south-east, three anticlines can be partially reconstructed; their axes are all oriented south-east, approximately parallel to the principal fault system. The axis of a intensely faulted anticline runs along the Falchan Kangri, while another runs along Gasherbrum I. The two folds may possibly be connected to one another.

Another anticline, recumbently folded and with its upper limb folded into a syncline (fig. 33), runs from the Baltoro Kangri to the Doksam peak. The shape of this anticline, which is overturned to north-east, suggests that thrusting came from the south-west.

The syncline which should be associated with folds mentioned above could not be reconstructed, due to the many faults which interrupt the continuity of these structures.

Finally, between this anticline and the batholith, along the Upper Baltoro valley runs a larger, probably folded and faulted anticline. The structure is hidden below the ice of the Upper Baltoro glacier but can be inferred from the tectonics of the Baltoro Kangri (p. 63) at the head of the ralley (fig. 68).

A rather pronounced change in orientation of the tectonic lineaments occurs between the area surrounding K² and the area lying further to the south. A strong disturbance line, separating the region into two blocks, probably occurs between these two areas, concealed by the ice. Of these two blocks, the one including K² seems to be more typical of the general tectonic features, since the dislocation axes of the block lying further to the south lie parallel to the main structural lines of this part of Karakorum (or of Aghil) and also to those of the axial batholith. Without extending these conclusions to the whole Karakorum region, we can, however, emphasize that in areas lying close to the northern
edge of the axial batholith the dislocation lines tend to be parallel to this edge, whereas further from the edge they are independent of this trend.

From a more general tectonic point of view, most of the Baltoro basin is included in the Muztagh Tectonic Zone of Desio (1965), which is bounded to the north by the Shayok Fault, and to the north-east partly by the Muztagh Fault, partly by the Upper Hunza Fault. The last two faults do not seem to be continuous, since two other faults are inserted between them. These two faults trend north-northwest, while the preceding ones trend north-west or west-northwest. The highest peaks, those of K2, Falchan Kangri and the Gasherbrums, rise from the Baltoro glacier between the north-northwest faults. Falchan Kangri and the Gasherbrums belong for the most part to the Aghil Tectonic Zone, while the K2 massif, with its north-northwest prolongation, appears to be a tectonically distinct and isolated body.
VIII. PETROGRAPHIC DESCRIPTION OF THE SPECIMENS

A. INTRODUCTION.

This appendix is devoted to supply a summary petrographic description of the samples collected here and there during the 1954 expedition to the Baltoro basin.

The extension of the petrographic descriptions is limited to supply only the necessary knowledge for a precise qualification of the different types of rocks composing the stratigraphic units of the Baltoro basin. Within the text more numerous types of rocks are mentioned, part of them collected by A. DESIO during the 1929 Italian expedition to the Karakorum, part by preceding explorers like W. M. CONWAY, H. H. GODWIN AUSTEN etc. As those samples have already been described in old reports, we have decided not to repeat such descriptions here. The reports are listed in the bibliography at the end of this volume.

We have to add that the description of the igneous and metamorphic rocks is made by B. ZANETTIN, and the description of the sedimentary rocks are made by A. DESIO.

The description of the samples is listed in numerical order with the same numbers of the labels accompanying the samples. Some numbers are lacking: they are the samples which were lost by porters during the march along the glacier. Fortunately they are very few. But also in these cases we have saved the matrix of the labels with the provisional names of the rocks used in field.

Finally, some numbers are lacking as they were omitted.

B. GODWIN AUSTEN GLACIER.

54 PD-1. – Biotite gneiss with porphyroblastic feldspars; at the foot of the south wall of K², altitude approximately 5000 m. (Analysed rock).
The rock is schistose and dark due to abundant biotite, and spotted with large feldspar crystals of both rounded and prismatic form, with their long axes usually aligned parallel to the schistosity.

Under the microscope the rock is seen to be prevalently of plagioclase, orthoclase, quartz and biotite.

The feldspars occur both as large individuals and as medium-sized constituents of the ground-mass. In both cases the plagioclase is either an oligoclase-andesine of composition 28%-30% An (indices between ε and ω of quartz; maximum angle of extinction of albite twins in the zone perpendicular to (010) = 10-12°), or, more often, an antiperthite. Inclusions of rounded quartz grains and biotite laminae are common in all cases.

The potash feldspar is a microperthite, and is less common than the plagioclase. Myrmekite and substitution textures occur at the contact of microperthite with plagioclase. In some cases quartz inclusions originally present in the plagioclase are found within the potash feldspar.

The ground mass is composed of quartz, plagioclase, biotite, and some orthoclase, all of medium grain-size.

Quartz also occurs as larger individuals possessing undulose extinction, arranged in parallel bands and sometimes containing inclusions of biotite and zircon.

Biotite occurs as well developed laminae, with frequent inclusions of zircon, and is associated with rare muscovite lamellae.

Apatite is relatively abundant, while epidote is scarce.

54 PD-2. – Biotite gneiss with porphyroblastic feldspar; at the foot of the south wall of $K^2$, altitude approximately 5000 m.

The rock, although similar to 54 PD-1, is lighter in colour due to the minor amount of biotite and the larger amount of feldspar. The latter occurs both as large porphyroblasts, sometimes aligned transversely to the weak planes of schistosity, and also in spots and irregular bands in association with other sialic minerals of medium grain-size.

Under the microscope the texture is seen to be similar to that of 54 PD-1; however, at many points the minerals of the ground mass assume larger dimensions, so that the porphyroblastic nature of the rock is less in evidence. That is to say the rock has a more uniform texture.

54 PD-3. – Aplitic gneiss stringer; at the foot of the south wall of $K^2$, altitude approximately 5000 m.
The rock shows aplitic texture, and is pale grey in colour, due to minute chlorite lamellae.

Feldspar and quartz are the dominant minerals, while chlorite occurs in minor amounts as small plates lacking a definite orientation.

Potash feldspar (perthite and microline perthite) and oligoclase albite of composition 10-12% An (na < ω of quartz; maximum angle of extinction of albite twins in the zone perpendicular to (010) = 9-10°) occur as individuals of medium grain-size and irregular form, including grains of quartz, and showing slight alteration.

Quartz occurs as smaller intergrown individuals, in rounded and lenticiform aggregates.

54 PD-4. – Pegmatite stringer; beneath the south wall of K², in the debris.

The rock is a pegmatite of large grain-size, rich in “books” of muscovite and containing slivers and lenticles of chlorite.

54 PD-5. – Fine-grained sialic arenaceous biotite gneiss; in the right lateral moraine of the De Filippi glacier, immediately under the corner of its confluence.

The light coloured ground mass of the rock is composed of sialic minerals of fine grain-size, and contains small isolated plates of biotite lacking any definite orientation though giving the rock a certain degree of schistosity.

The sialic minerals plagioclase, quartz and orthoclase (and microcline), are equidimensional, and show a characteristic metamorphic texture. The plagioclase is either fresh, of composition 25% An (nβ > ω), or altered to sericite and calcite, when it is then more sodic (nβ < ω).

Quartz and biotite inclusions in the feldspar are rarer than in the rocks previously described. In some cases large quartz individuals include small portions of feldspar and also smaller quartz grains of diverse orientation.

The biotite lamellae are sub-oriented, but are sometimes almost perpendicular to the schistosity. Muscovite is much rarer, and always poikiloblastic.

The rock is in a state of initial alteration.

Some grains of epidote, and scarce apatite, are present.

54 PD-6. – Fine-grained biotite gneiss; in the right lateral moraine of the De Filippi glacier. (Analysed rock).

The rock is compact, of grey-violet colour, and very fine grain-size. It shows a slight resemblance to a hornfels of pelitic type.
The rock is composed of minute granoblastic aggregates of quartz, andesine of composition 35-40% An, (nβ between ε and ω of quartz; angle of extinction of albite twins in the zone perpendicular to (010) = 20° approximately), and potash feldspar. Numerous isolated and iso-oriented biotite lamellae are uniformly distributed within this aggregate.

*Epidote, sphenite, graphite* and *iron-oxide* grains are common, while *apatite* and *zircon* are scarce.

Some bands are of larger grain-size, and this is accompanied by an increase in the amount of feldspar and sphene, and a marked diminution in that of biotite.

Rare feldspar crystals of larger grain-size (almost to be considered as porphyroblasts) include numerous unoriented biotite lamellae in various stages of transformation.

**54 PD-7.** Amphibole-biotite gneiss with feldspar porphyroblasts; *at the foot of the left-hand corner of the De Filippi glacier.*

The rock, which corresponds to a very common type in this locality, has a slight schistosity, is of dark grey colour, and is spotted with numerous relatively small feldspar porphyroblasts with rounded form. Concordant bands or veins of minute grain-size, of the thickness of a few millimetres to some centimetres are present.

Under the microscope, large individuals of *andesinic plagioclase* of approximate composition 40% An (angle of extinction of albite twins in the zone perpendicular to (010) = 18-22°) and rarer individuals of *potash feldspar*, are seen to be developed within a medium-grained matrix of quartz, potash feldspar, rarer plagioclase, green hornblende, and biotite. Grains of *epidote* and *sphene* are associated with the feric minerals. *Calcite* occurs in small amounts.

Although the amphibole may be as abundant as the biotite it only rarely comes in direct contact with the feldspar porphyroblasts; a border of biotite usually occurs between the amphibole and the feldspar, perhaps derived from the amphibole.

Many plates of biotite are included in the porphyroblasts, while hornblende inclusions are probably absent.

**54 PD-8.** Arenaceous gneiss; *left corner of the confluence between the De Filippi and the Godwin Austen glaciers.*

The rock is of medium-fine grain-size, and glistens, due to sericite aligned in the planes of schistosity. Biotite lamellae, though scarce, also occur. Quartz and feldspar grains are the major and almost exclusive constituents.
54 PD-9. — Calc-schist; in the moraine lying below the left-hand corner of the confluence of the De Filippi glacier.

This is a typical calc-schist, containing well developed yellowish mica, of phlogopite type.

54 PD-10. — Marble; in the moraine lying below the left-hand corner of the confluence of the De Filippi glacier.

The marble possesses a large grain-size, while fractures are filled with recent carbonate deposits.

54 PD-11. — Epidotic marble; in the moraine lying below the left-hand corner of the confluence of the De Filippi glacier.

The rock is striated and spotted with epidote aggregates of green to yellowish olive-green colour.

54 PD-12. — Phlogopitic marble; in the moraine lying below the left-hand corner of the confluence of the De Filippi glacier.

The sample is similar to 54 PD-10, but contains some phlogopite mica.

54 PD-13. — Perthitic pegmatite; on the left-hand corner of the confluence of the De Filippi glacier.

This is a typical feldspathic pegmatite, with green lamellar minerals occurring on irregular movement surfaces.

Under the microscope the rock is seen to be composed of very well developed perthite individuals, with much smaller aggregates of albitic plagioclase, a little quartz, and rare muscovite filling the interstices. Larger quartz individuals are independent of the plagioclase.

Numerous plagioclase and quartz individuals are included in the large perthite crystals.

The perthitic individuals have developed by accretion of crystals with diverse orientation, and have grown so as to enclose the other minerals.

54 PD-14. — Pegmatitic gneiss; in the moraine lying below the left-hand corner of the confluence of the De Filippi glacier.

Macroscopically this pegmatite is characterised by large, dark grey micro-perthite crystals distributed in a fine-grained, milky-white ground-mass.

The grain-size is smaller than that of sample 54 PD-13, while its texture is indicative of deformation. Quartz occurs in long, thin, sub-parallel bands,
bent and thinned to form lenticles, while between these bands a medium to medium-fine grained aggregate of quartz, albitic plagioclase, and potash feldspar occurs. The proportions of these three minerals varies from place to place.

Subparallel slivers and lenses, concordant with the schistosity of apatite, calcite, sericite chlorite, and also some amphibole, occur between these aggregates. These are probably derived from small strips of calcareous schist enclosed in the pegmatite.

Large individuals and aggregates of microperthite are developed here and there, and enclose crystals of plagioclase and quartz of the matrix. Development of these crystals appears to have been responsible for the displacement of the quartzose bands.

Aggregates of medium-grained plagioclase may represent an initial stage in the formation of plagioclase porphyroblasts.

54 PD-15. - Pyroxene vogesite; in the right lateral moraine of the de Filippi glacier, near the mouth. (Analysed rock).

The rock is dark grey in colour, and possesses a porphyritic texture due to the presence of femic minerals in a minute ground mass.

Under the microscope the ground-mass is seen to be composed of allotriomorphic areas of potash feldspar, within which the femic minerals, in crystals of various sizes, are included.

Potash feldspar is represented by both orthoclase and microcline. Plagioclase and quartz are rather scarce.

Biotite occurs in zoned phenocrysts. Generally the internal part is weakly pleochroic, while the external parts are strongly coloured.

The most abundant femic minerals are zoned pyroxenes, with augitic nuclei and aegirine-augite or aegirine borders (c : \( \gamma = 93-100^\circ \)). In some cases the nucleus is composed of rhombic pyroxene partially transformed to talc.

Amphiboles are scarcer and never occur as phenocrysts. They are sodic end-members, with composition between riebeckite and arfvedsonite (N\( \gamma / / y \); O.A.P. (010); c : \( \alpha = 6-9^\circ \)).

Apatite occurs in large elongate turbid crystals, around which the aegirine pyroxenes often occur in an aggregate.

(For a detailed description see C. Viterbo and B. Zanettin, 1959, p. 5).

54 PD-16. - Arenaceous calciphyre with pyroxene and clinozoisite; on the left-hand corner of the confluence of the De Filippi glacier.

The rock is compact and grey, and shows very subtle alternation of light
and dark bands, split apart in some points by thick quartz-feldspathic lenses.

Under the microscope the rock exhibits a cataclastic texture; there is a uniform distribution of various minerals of medium grain-size.

*Calcite* is prevalent, accompanied by *quartz* and *potash feldspar* grains.

Abundant *diopsidic pyroxene* and scarcer *clinozoisite* represent minerals of late genesis. The latter is abundant, or even dominant, near to a large lens of well-developed *quartz* and *potash feldspar* individuals. In this case it is associated with a tremolitic-actinolitic *amphibole* which is rare in other parts of the rock.

*Sphene* and *iron oxides* are also very common.

**54 PD-17.** – Fine-grained arenite; *left-hand corner of the confluence of the Savoia glacier, near to the monument to A. Gilkey and M. Puchoz.*

The rock is strongly laminated, of light grey colour, but dotted with numerous small dark minerals, perhaps biotite.

**54 PD-17a.** – Fine-grained biotite paragneiss; *left-hand corner of the confluence of the Savoia glacier, near to the monument to A. Gilkey and M. Puchoz.*

This rock is perfectly analogous to sample 54 PD-87 (Skyang-la, p. 000) and 54 PD-96 (east wall of the Black Peak).

**54 PD-18.** – Porphyroclastic mylonitic gneiss; *left-hand spur of the confluence of the Savoia glacier.*

The rock is dark, with blackish movement planes, indicative of diaphthoresis.

Under the microscope the rock is seen to be a gneiss analogous to types 54 PD-1-2, but transformed by dynamic and blastomylonitic action.

The rock is traversed by movement planes along which are deposited a darkish substance, perhaps iron oxide. The *quartz*, occuring in lenses composed of numerous elongate individuals with undulose extinction, is clear, while the feldspars of the ground mass are strongly altered to sericite and the biotite is altered to chlorite.

The original porphyroblasts are strongly cataclastic, while plagioclase twins are bent.

**54 PD-19.** – Schistose limestone; *left-hand spur of the confluence of the Savoia glacier.*
The rock is white and very fine-grained due to an intense cataclasis. Very thin irregular bands and dark slivers of carbonaceous material are traversed by laminations perpendicular to these bands.

54 PD-20. – Schistose limestone; *left-hand spur of the confluence of the Savoia glacier.*

This rock is analogous to sample 54 PD-19, but possesses only traces of carbonaceous material.

54 PD-21. – Biotitic carbonaceous phyllitic paraschist; *in the moraine, near to the K² Base Camp.* (Analysed rock).

This is a very fine-grained carbonaceous phyllite, and is evidently derived from an argillaceous to fine-grained arenaceous deposit, rich in organic matter. The rock is constituted of *quartz, sodic plagioclase* with a composition of 28% An, and very small *biotite* lamellae, occurring along refolded or sharply bent surfaces, typical of dynamic deformation. *Graphite* and *iron oxides* occur throughout the rock, and particularly along the frequent movement planes. *Tourmaline* occurs frequently, as in other analogous rocks of the Godwin Austen basin.

54 PD-21a. – Schistose marly limestone; *left-hand spur of the confluence of the Savoia glacier.*

The rock is similar to samples 54 PD-19 and -20.

54 PD-22 and -22a. – Biotitic muscovitic gneiss with plagioclase porphyroblasts; *in the moraine near the K² Base Camp.* (Analysed rock).

The rock is schistose with a dark, biotitic ground mass, is of medium grain-size and is spotted with numerous feldspar crystals of both lenticular and prismatic habit.

Under the microscope the feldspar porphyroblasts, represented exclusively or almost exclusively by plagioclase with a composition of 36-38% An (maximum angle of extinction of albite twins in the zone perpendicular to (010) = 18-20°), are seen to be set within a fine-grained quartz-muscovite-biotite matrix.

The force of crystallisation of the porphyroblasts has bent and compressed the schistosity. Numerous biotite and muscovite plates are included in the large plagioclases; these same minerals and also quartz are enclosed by the feldspars at their boundaries or fill plate fractures of the same porphyroblasts.
The matrix is analogous to sample 54 PD-21, that is to say of paraschist type, but of larger grain-size due to a more advanced stage of recrystallisation. The biotite is deep red in colour and often occurs in elongate lenses; around the porphyroblasts muscovite is more common and may originate, at least in part, by transformation of biotite.

Calcite is ubiquitous, evidently of late origin.

Plagioclases of the matrix are sometimes unaltered, while others show a well-defined central portion strongly altered to sericite and surrounded by an unaltered sodic rim. A little orthoclase is also present.

Among the accessory minerals sphene and apatite are widespread, while some beautiful crystals of orthite occur.

54 PD-23. – Amphibole biotite gneiss with feldspar porphyroblasts; in the moraine near to the K² Base Camp.

The rock is constituted of light-coloured quartz-feldspathic areas and irregularly distributed deep green areas, both of which contain a distinct schistosity, imparted by the alignment of the femic minerals and the distribution in irregular bands, slivers or lenses, of the sialic minerals.

Under the microscope the texture is seen to be similar to that already observed in the other porphyroblastic gneisses. The porphyroblasts are dominantly of plagioclase, with a composition of 32 - 36% An, \((\omega < n < \varepsilon)\) of quartz; maximum angle of extinction measured on albite twins in the zone perpendicular to \((010) = 15-18^\circ)\) and of potash feldspar. The plagioclases are often markedly zoned, with some rhythmic alternation, but with a border more sodic than the central part. Inclusions of biotite and rare grains of quartz are present, while para- and post-crystalline deformation is evident. Inclusions are more frequent in the large crystals of potash feldspar, in which plagioclases also occur.

In some areas the matrix is formed almost exclusively of quartz while at other points feldspars, and especially microcline, are abundant. Hornblende occurs in contorted and pinched-out bands, and is in the process of transformation to actinolite and tremolite, while co-existing biotite is partially altered to chlorite. Calcite, sphene, epidote and orthite also occur in these bands.

54 PD-24. – Biotite gneiss with feldspar porphyroblasts; in the moraine near to the K² Base Camp. (Analysed rock)

Larger feldspar porphyroblasts, up to 3 cm in length and rich in biotite inclusions, are developed in a compact biotite-rich schistose ground-mass spotted with feldspar porphyroblasts of medium grain size. This ground-mass
is similar to that of the other gneisses already described (54 PD-22). The texture is analogous to that of other samples of gneiss with feldspar porphyroblasts of this area (54-PD 1, 7, 22, etc.). In the portion observable under the microscope biotite is very scarce and often chloritised, and occurs as rather small, sub-parallel, isolated plates in the quartz-feldspathic aggregate. The quartz is often recrystallised in large united elements that constitute long sub-parallel bands including biotite.

The plagioclase, with a composition of 30% An, is slightly altered while potash feldspar is rarely altered.

Among the accessory minerals of the matrix are sphene, iron oxides, apatite, epidote, and zircon.

The feldspar porphyroblasts (with inclusions of biotite, quartz, post-crystalline deformation, etc.) are prevalently of plagioclase with a composition of 30% An, but potash feldspar is also common.

Myrmekitic associations are frequent.

54 PD-25. – Actinolite schist; in the moraine near to the K² Base Camp.

The rock is deep green in colour, irregularly schistose, and contains light mottled areas in the form of very flattened lenses.

Under the microscope it is seen to be constituted prevalently of an almost colourless amphibole of the tremolite-actinolite series, in individuals aligned for the most part in the plane of the schistosity, but sometimes variously bent and folded. Grains of potash feldspar are present in thin elongate lenses and mottled areas; quartz is much more scarce and plagioclase, with a composition of approximately 35% An, rarely occurs.

Minor quantities of biotite, talc, and sphene are associated with the amphibole.

54 PD-26. – Porphyroblastic granite gneiss; in the moraine near to the K² Base Camp.

In hand specimen the rock is seen to be a granite gneiss with porphyroblasts developed here and there.

Under the microscope numerous porphyroblasts of plagioclase, with a composition of approximately 20% An, and of microcline, are seen to be developed in a prevalently quartzose matrix of very variable grain-size.

The abundance of porphyroblasts, the relatively well-developed medium grain-size of the quartzose matrix, and the scarcity of biotite gives the rock a granitic aspect.
The *quartz* is in sutured granoblasts. The *biotite* is distributed in irregular fashion and appears to be intensely deformed.

A minute granulation of quartz and feldspar occurs along the healed movement planes.

Other minute granular aggregates of potash feldspar occur in well-defined areas in the pure quartz matrix.

**54 PD-27.** – Biotite gneiss with feldspar porphyroblasts; *in the moraine near to the K2 Base Camp*.

The rock contains a groundmass of variably coloured, sub-parallel bands. Biotite bands are dark, while lighter, green, bands alternate with them. From the fine grain-size and compact nature of the rock it is possible to say that it is intermediate between a biotitic paraschist and an arenaceous schist. Rounded or prismatic porphyroblasts, rarely assuming a notable size, are developed in this groundmass.

Under the microscope the matrix is seen to vary from biotitic to chloritic, which explains the difference in colour seen in the hand specimen; the micaeous minerals are neither very abundant, nor well-developed, and are always associated with notable quantities of *quartz, andesine* with a composition of 32% An, and *orthoclase*. The potash feldspar of the groundmass has a very irregular distribution, being abundant in one spot while scarce in another. Among the accessories *apatite* is common, some large grains of *epidote* occur, and *zircon* is relatively frequent.

Porphyroblasts of plagioclase and potash feldspar are developed in this fine-grained matrix.

The *plagioclases*, which are andesines with a composition of 40% An (nB a little lower or equal to ε of quartz; determinations on albite-Carlsbad twins, almost always show a well defined prismatic form, and are for the most part free from inclusions (with the exception of some crystals of apatite and alteration minerals), while the *orthoclase* (and microcline), which is much more scarce, has a rounded form, with ill-defined edges and includes very many grains of quartz, biotite, epidote, and apatite. Potash feldspar has reabsorbed the plagioclase at many points.

**54 PD-28.** – Tourmaline-bearing cataclastic blastomylonitic pegmatite; *in the moraine near to the K2 Base Camp*.

The rock, very rich in tourmaline, shows evidence of cataclasis.

It is constituted of porphyroblasts of *potash feldspar* and perthite, which
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include smaller individuals of altered plagioclase and quartz grains. The fractures are almost always filled with calcite, siderite, quartz, plagioclase, etc. Granoblastic aggregates of quartz, sodic plagioclase, orthoclase, and tourmaline are interposed between the well-developed individuals. These aggregates are evidently derived by recrystallisation following cataclasis.

Numerous, large, strongly fractured crystals of tourmaline occur, while at some points quartz occurs as large lenses.

Apatite is common.

54 PD-29. – Perlitic blastomylonitic pegmatite; in the moraine near to the K² Base Camp.

The rock is very similar to sample 54-PD-13 both in hand specimen and under the microscope.

Large individuals of perthite are prevalent. The fine grained portions of the rock derived by blastesis following intense cataclasis are constituted prevalently of a rather calcic plagioclase (30% An approximately) and various amounts of quartz.

Biotite is very rare, as inclusions in the orthoclase.

54 PD-30. – Quartz-feldspathic arenaceous schist; in the moraine near to the K² Base Camp.

The rock is very fine-grained and greenish in colour.

It is constituted of a granoblastic aggregate of quartz, plagioclase 28% An approximately, and potash feldspar, present in almost equal proportions. A few suboriented lamellae of muscovite and chlorite, and grains of epidote are also present.

Plagioclase and, more often, potash feldspar porphyroblasts of a medium grain-size are developed here and there. The other minerals of the matrix are included within the porphyroblasts.

54 PD-31. – Arenaceous schist with feldspar porphyroblasts; in the moraine near to the K² Base Camp.

The rock is compact and greenish with smaller, lighter spots of well-developed feldspars. Darker biotitic and chloritic bands, within which the feldspar porphyroblasts are more numerous and of larger size, alternate with this.

The groundmass is composed of quartz, plagioclase, and potash feldspar grains and a little biotite which is in part chloritised, while muscovite is absent. It is similar to sample 54 PD-30, but of larger grain-size.
Small porphyroblasts of potash feldspar (microcline perthite) and plagioclase with a composition of 32% An (measurements of albite-Carlsbad twins) are frequent; the former are rounded, while the plagioclase tends to assume a prismatic form. The inclusions are the same as those already cited of the other porphyroblastic rocks.

54 PD-32. – Blastomylonitic granite gneiss; in the moraine near to the K2 Base Camp.

This light-coloured, almost aplitic rock shows obvious planes of lamination, along which are disposed irregular, greenish, chloritic bands.

Under the microscope large porphyroblasts of potash feldspar and somewhat altered plagioclase are wrapped around by quartzose blastomylonitic aggregates. Chlorite occurs along the planes of movement in contorted and discontinuous slivers and irregular bands. Biotite is scarce and more or less transformed.

Epidote, apatite, calcite, and zircon occur as accessories.

54 PD-33. – Arenaceous schist with feldspar porphyroblasts; in the moraine near to the K2 Base Camp.

This rock is macroscopically very similar to sample 54 PD-31. However, the grain-size is larger in this sample.

In this rock both the quartz and the other minerals are aligned in a prevalent direction, giving rise to a distinct schistosity, due to recrystallisation successive to a tectonic deformation. The plagioclase is always earthy in colour, due to incipient alteration, while the potash feldspar is clear.

Porphyroblasts of quartz occur as well as those of feldspar.

Muscovite is rare, while the original narrow bands of biotite are now transformed to chlorite.

Rare clinzoisite grains are present.

54 PD-34. – Porphyroblastic epimetamorphic cataclastic granite gneiss; in the moraine near to the K2 Base Camp.

In hand specimen the rock resembles an aplitic granite with small quantities of femic minerals weakly oriented in subparallel planes.

Under the microscope are seen large fractured individuals of potash feldspar (orthoclase and microcline) and plagioclase with a composition of approximately 20% An (n, very near or scarcely larger than ω of quartz), and almost
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always sericitised; both feldspars include numerous quartz grains and rare chlorite lamellae.

The porphyroblasts constitute about 70% of the rock while minute aggregates of sutured quartz grow between them. Chlorite occurs in small amounts in mottles and short bands.

Muscovite, calcite, epidote, apatite, and zircon occur in accessory amounts.

54 PD-35. – Schistose limestone; *is the moraine near to the K2 Base Camp.*

The rock contains light and dark-grey slivers. With introduction of small amounts of mica this rock passes into a calc-schist.

54 PD-36. – White marble; *in the moraine near to the K2 Base Camp.*

54 PD-37. – Calc-schist; *in the moraine near to the K2 Base Camp.*

This calcareous rock contains laminations of alternating light-coloured crystalline bands and finer-grained, dark-grey, impure bands.

54 PD-38. – Fine-grained biotite gneiss with feldspar porphyroblasts; *in the moraine near to the K2 Base Camp.*

Two thin sections were prepared from the same sample from rock slices cut from two clearly distinct parallel bands. The first (54 PD-38a) has a dark, biotitic, fine-grained ground mass, and is identical to samples 54 PD-22, 22a, representative of the K2 gneiss. The other band (54 PD-38b) is more compact, much lighter in colour, and resembles some arenaceous schists already described (54 PD-31, -33), but differs in that thin, discontinuous biotitic lenses are developed in proximity to the other biotitic bands.

The dark portion is composed of minute grains of quartz and plagioclase with a composition of approximately 30% An or a little higher, and *potash feldspar* in subordinate quantities. Small plates of *biotite* are present in notable quantities. *Apatite* and *calcite* occur in accessory amounts.

Large individuals of *plagioclase* with a composition of 38% An (maximum angle of extinction of albite twins in the zone perpendicular to (010) = 20°; albite-Carlsbad twins) and rare individuals of *potash feldspar* are developed in the ground-mass. Both include quartz grains and biotite plates. Growth of these porphyroblasts has been independent of the schistosity of the rock and has displaced the schistose bands of the matrix.

The light portion possesses a matrix with a larger grain-size, with plagioclase in minor amount and very turbid due to alteration. Porphyroblasts are
rare and of smaller dimension that those in the dark portion, and are almost exclusively of potash feldspar.

54 PD-39. – Biotite-graphite-garnet paraschist; in the moraine near to the K² Base Camp.

The rock is markedly schistose and very black, with evident surfaces of lamination. It corresponds to a remarkably crystalline type of the so-called “black schist” of Godwin Austen valley.

The rock is composed of undulating and contorted bands of biotite and subordinate muscovite, alternating with thinner bands rich in quartz and plagioclases with a composition of approximately 20% An (n near or equal to 0 of quartz), which are sometimes twinned. Dark slivers and grains, probably of graphite, occur throughout, but especially in the micaceous bands.

Porphyroblasts of garnet are distributed throughout the rock in small amounts. At one point a few needles of sillimanite are present.

Apatite occurs in accessory amounts.

54 PD-40. – Banded arenaceous schist; in the moraine near to the K² Base Camp.

In this rock there is an alternation of light bands, of a clearly greenish colour, similar to samples 54 PD-31, 33, and of darker bands tending towards a violet-brown colour. An incipient schistosity lies approximately perpendicular to the original planes of stratification.

54 PD-41. – Fine-grained chloritic gneiss with feldspar porphyroblasts; in the moraine near to the K² Base Camp.

The ground mass is greenish, chloritic, and fine-grained. Feldspar porphyroblasts are irregularly distributed so that at some points they are virtually absent, while at others they are abundant enough to give the rock the appearance of a fine-grained granite gneiss.

54 PD-42. – Calc-schist; in the moraine near to the K² Base Camp.

This is a very fine-grained calc-schist, in which it is impossible to see the phyllosilicates in hand specimen.

54 PD-43. – Banded arenaceous schist; in the moraine near to the K² Base Camp.

The rock shows an alternation of light-coloured, almost white bands, and of grey bands, of very fine grain. Numerous fractures are filled with calcite and siderite.
54 PD-44. – Muscovite micaschist; *in the moraine above the K² Base Camp.*

The rock is a micaschist very rich in muscovite, and partially altered.

54 PD-45. – Cataclastic pegmatite; *in the moraine above the K² Base Camp.*

This pegmatite, containing large muscovite plates, shows strong cataclasis but possesses a considerable compactness, being clearly blastomylonitic.

54 PD-46. – Aplitic-pegmatitic stringer in the fine-grained biotite gneiss with feldspar porphyroblasts; *in the moraine above the K² Base Camp.*

A fine-grained biotite gneiss with porphyroblastic feldspars and very rich in mica, is concordantly cross-cut by a small quartz-rich stringer about 4 cm thick, and showing a clear contact.

Under the microscope one can observe the passage from the porphyroblastic gneiss (constituted of biotite, quartz, and plagioclase, in both small and large individuals) to the sialic stringer (composed of a medium to medium-large-grained aggregate of quartz and potash feldspar, with a little muscovite in the outer part, and large, sutured quartz grains in the central part). This passage is one of a progressive, irregular, diminution of biotite. Plagioclase disappears concomitantly with the disappearance of biotite, while grain-size increases rapidly, and muscovite and large quantities of potash feldspar appear.

The texture is markedly crystalloblastic throughout.

54 PD-47. – Grey limestone; *in the moraine above the K² Base Camp.*

This fine-grained limestone contains surfaces of movement.

54 PD-47a. – Grey marble; *in the moraine above the K² Base Camp.*

The rock is appreciably crystalline.

54 PD-48. – Porphyroblastic gneiss; *in the Abruzzi spur, near to Camp 1.*

The rock has a greenish colour and is strongly dotted with small feldspar porphyroblasts. It contains well-developed plagioclase porphyroblasts, all of which contain very minute sericite lamellae. The interstices between the plagioclases are occupied by medium-grained quartz granoblasts, and short bands of chlorite and a little sericite. The chlorite includes abundant iron oxides, sphene, and rutile.

Other chlorite fills fractures in the rock.

A tourmaline of yellowish colour is locally and abundantly present.
54 PD-49. – Fine-grained biotite-muscovite gneiss with plagioclase porphyroblasts; at the foot of the Abruzzi spur.

In hand specimen this rock is analogous to the other porphyroblastic biotitic rocks, and contains alternating light and dark bands.

Under the microscope can be seen wide quartzose-micaceous bands (quartz in sutured granoblasts, muscovite, biotite, and chlorite associated with abundant iron oxides) dotted by large porphyroblasts of plagioclase with a composition of 36-38% An (n, about equal to ε of quartz; maximum angle of extinction measured on albite twins in the zone perpendicular to (010) = 19°).

Small plagioclases and potash feldspars also occur in the groundmass.

A yellow pleochroic tourmaline is locally very abundant.

54 PD-50. – Porphyroblastic granite gneiss; at the foot of the Abruzzi spur.

In hand specimen the rock resembles a granite in which the biotite is sub-oriented.

It contains rather well-developed individuals of slightly zoned plagioclase with an internal composition of 35% An, and potash feldspar in minor quantity.

The plagioclases, which included quartz and biotite, tend to assume a regular prismatic form, while the potash feldspar is allotriomorphic, with ill-defined edges, and includes, as well as quartz and biotite, small plagioclase individuals.

Between the largest individuals is found a granoblastic and probably blastomylonitic aggregate of quartz and biotite, accompanied by variable amounts of feldspars. Potash feldspar occurs here and there, and especially along the planes of movement, in mottles and bands constituted almost exclusively of very minute grains associated with quartz.

54 PD-51. – Brecciated limestone with sulphide veins; in the moraine at the K² Base Camp.

This limestone, varying in colour from light grey to greenish grey, is crossed by sulphide veins and large calcite crystals.

54 PD-52. – Pyroxene minette; in the left-hand floating moraine of the Godwin Austen glacier, altitude approximately 5000 m.

54 PD-53. – Amphibole minette; right-hand moraine of the Godwin Austen glacier, a little above the Base Camp.

This stringer cross-cuts augen gneiss of the K² metamorphic complex. The rock is dark and fine-grained, with rare biotite phenocrysts.
As in the other lamprophyres, the groundmass is composed of potash feldspar.

Biotite occurs as zoned phenocrysts, while a minute mineral aggregate (about 80% of the total) of sodic amphiboles (riebeckite, arfvedsonite, katophorite, hornblende) is present.

Sphene and ilmenite are always abundant.

(For a detailed description see: C. Viterbo and B. Zanettin, 1959, p. 19).

54 PD-54. – Schistose calcareous arenite; in the left-hand floating moraine of the Godwin Austen glacier, altitude approximately 5000 m.

The rock, of liver-red colour, is brecciated and laminated, and shows glistening movement surfaces. It is similar to the red phyllitic calcareous arenite, 54 PD-69.

54 PD-55. – Conglomerate: in the left hand floating moraine of the Godwin Austen glacier, altitude approximately 5000 m.

The green cementing material of this conglomerate could correspond to a very fine-grained arenite. It contains light-coloured, decalcified, semi-crystalline angular elements which are essentially rose-coloured calcareous arenites of the same type as 54 PD-54.

54 PD-56. – Calcareous arenite; in the left-hand floating moraine of the Godwin Austen glacier, altitude approximately 5050 m.

The rock is very coarse-grained, of a decidedly green colour, and is constituted of quartz and feldspar grains cemented by calcite. These coarser bands alternate with others of finer grain.

54 PD-57. – Grey limestone; in the left-hand floating moraine of the Godwin Austen glacier, altitude approximately 5050 m.

The rock is semi-crystalline and is intersected by minute recemented fractures.

54 PD-58. – Pyroxene minette; in the left-hand floating moraine of the Godwin Austen glacier, altitude approximately 5050 m.

54 PD-59. – Fine-grained biotite gneiss with plagioclase porphyroblasts; in the left-hand floating moraine of the Godwin Austen glacier, altitude approximately 5000 m.
The rock is analogous to samples 54 PD-22, -22a and -38, and this is confirmed in thin-section. The matrix is fine-grained and consists of quartz, biotite, and a little hornblende, and, subordinately, calcite, orthite, sphene, apatite, and zircon.

The plagioclase porphyroblasts with a composition of approximately 35-40% An, and the rarer potash feldspar porphyroblasts, are of medium grain-size, and include quartz and biotite.

Their growth has displaced the bands of the original paraschist.

54 PD-60. – Porphyroblastic plagioclase gneiss; in the detritus of the west side of Falchan Kangri, altitude approximately 5000 m.

The rock is greenish in colour and contains irregularly dispersed plagioclase crystals of medium grain-size. It is similar to sample 54 PD-48.

This analogy is confirmed under the microscope; the most obvious difference is the smaller grain-size of the matrix, which wraps around the plagioclase porphyroblasts, and the presence of numerous lamination planes.

Some individuals of orthite are present.

54 PD-61. – Biotitic paraschist with garnet; in the detritus of the west side of Falchan Kangri, altitude approximately 5000 m.

This blackish, fine-grained, schistose rock closely corresponds to the average type of “black schist” of Godwin Austen. It could be considered as a type intermediate between samples 54 PD-6 and 39, but is perhaps more biotitic than these.

Under the microscope this rock is seen to correspond almost exactly to the matrix of the typical fine-grained biotitic gneiss with feldspar porphyroblasts, which is the most common facies of the “K₂ gneiss”.

54 PD-62. – Porphyroblastic quartz-feldspar gneiss; in the detritus of the west side of Falchan Kangri, altitude approximately 5000 m.

This rock, of grey to light greenish colour, is very similar to sample 54 PD-30. The small amount of sericite present gives to the rock a slight schistosity. A number of strong, parallel fractures cross-cut the planes of schistosity at a high angle.

The rock is composed essentially of granoblasts of quartz, potash feldspar and plagioclase with a composition of approximately 30% An, together with a little muscovite. The constituent minerals are fine-grained and uniform. A few porphyroblasts of microcline, inclosing quartz grains, are present.
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The fractures are filled with calcite, chlorite and epidote. Fluorite occurs associated with the calcite.

54 PD-63. – Fine grained calcareous conglomerate; right-hand spur of the confluence of the Savoia and Godwin Austen glaciers.

A few small, grey, rounded, calcareous pebbles are enclosed in a fine-grained limestone of pale yellow to red colour.

54 PD-64. – Calcareous conglomerate; right-hand spur of the confluence of the Savoia and Godwin Austen glaciers.

Rounded calcareous pebbles of both dark and light colour, and varying in size from 2 mm to 3 cm, are cemented by a fine-grained, greyish-white limestone.

54 PD-65. – Calcareous grey breccia; right-hand spur of the confluence of the Savoia and Godwin Austen glaciers.

It is not clear whether this is a calcareous breccia or a brecciated limestone.

54 PD-66. – Calcareous schistose conglomerate; right-hand spur of the confluence of the Savoia and Godwin Austen glaciers.

Crushed calcareous elements of tabular form are enclosed in a schistose calcareous matrix, containing sericite. Little cubes of pyrite frequently occur.

54 PD-67. – Multi-coloured calcareous breccia; right-hand spur of the confluence of the Savoia and Godwin Austen glaciers.

The rock is composed of green or reddish, schistose, calcareous fragments, and light yellow and grey calcareous areas.

54 PD-68. – Phyllitic calcareous arenite; right-hand spur of the Savoia and Godwin Austen glaciers.

The rock contains greenish areas, with very fine-grained mica, and elongate light coloured calcareous lenses.

The rock is constituted of sericite- and chlorite- rich bands, of irregular trend and thickness, in which the minerals are intimately associated, alternating with thicker bands of quartz and calcite in which one or the other mineral may be prevalent. The quartz grains are of variable size, but are never very large. Here and there the calcite occurs in mottles of well-developed crystals.
Sodic plagioclase, sometimes in perfect twins, epidote, and tourmaline occur in accessory amounts.

The mineral facies of this rock is similar to that of samples 54 PZ-142, -143 and -150.

54 PD-69. — Phyllitic calcareous arenite; right-hand spur of the confluence of the Savoia and Godwin Austen glaciers.

The rock is a fine-grained arenite, reddish in colour, laminated, and contains sericitic surfaces.

54 PD-70. — Fine-grained biotite gneiss with porphyroblastic plagioclase; in the little saddle at the base of the west spur of Falchan Kangri. (Analysed rock).

Both in hand specimen and under the microscope this rock is seen to be analogous to the prevalent type of the "K' gneiss" (54 PD-22, -22a, -38, and -59). The porphyroblasts are, however, exclusively of plagioclase with a composition of approximately 42% An (Albite-Carlsbad twins), while potash feldspar is very scarce even in the relatively well-developed crystalline matrix. Plagioclase of the matrix has a composition of 40% An.

Large individuals of orthite are present.

54 PD-71. — Pegmatite stringer; at the base of the west spur of Falchan Kangri.

A pegmatitic or aplitic-pegmatitic stringer of 6 to 7 cm thickness, containing grey perthite (moonstone) crystals, concordantly intrudes biotite paraschist containing rare, small, feldspar porphyroblasts.

54 PD-72. — Pyroxene minette; in the right-hand moraine of the glacier that occupies the small valley lying between the first and second peak of Falchan Kangri.

The rock has a porphyritic texture due to the presence of phenocrysts of biotite and apatite in a medium-grained ground-mass.

Biotite occurs both in large zoned crystals, and in aggregates of radially oriented plates.

Apatite is abundant enough to be a fundamental component of the rock.

Potash feldspar, together with a little very sodic plagioclase, forms vast areas of the ground-mass.

The femic minerals, among which pyroxene is most abundant, are almost totally altered to sericite, calcite, chlorite and amphibole. In marked contrast to this alteration of the femic minerals, the feldspars are very fresh.
54 PD-73/1. – Grey schistose limestone; in the moraine of the glacier flowing down between the first and second peaks of Falchan Kangri.

The rock is a grey to dark-grey slightly arenaceous, flaggy limestone, sometimes brecciated: it may be a calcareous breccia.

54 PD-73/2. – Grey brecciated limestone; in the moraine of the glacier flowing down between the first and second peaks of Falchan Kangri.

Brecciated limestone or microcrystalline calcareous breccia with grey and black fragments, containing a thin elongate, reticulate structure, perhaps of organic origin.

54 PD-74. – Grey limestone; in the moraine of the glacier flowing down between the first and second peaks of Falchan Kangri.

The same rock of the sample 54 PD-73/1, but without schistose texture.

54 PD-75. – Green calcareous arenite; in the moraine of the glacier flowing down between the first and second peaks of Falchan Kangri.

The rock has a reddish, arenaceous, and partially calcareous matrix, sometimes coarse enough to be a fine-grained breccia. It includes more or less crystalline calcareous fragments, and clear, grey, limestone fragments, and reddish, arenaceous or argillaceous fragments. It is not very different from samples 54 PZ-142 and -143, and especially 54 PD-68, all from the Savoia Formation, and which have already been referred to. However, the present sandstone is more calcareous and less compact.

54 PD-76. – Multi-coloured breccia with red cement, grading into conglomerate; in the moraine of the glacier flowing down between the first and second peaks of Falchan Kangri.

Breccia of prevalingly red colour with red, calcareous-arenaceous cement, sometimes so coarse-grained that the cement itself passes into breccia. The included fragments are predominantly angular, but some are rounded, and they vary in size from a fist down to the grain size of the cement. The breccia fragments are prevalently waxy, grey and white limestone, white semicrystalline limestone, reddish sandstone, and reddish, arenaceous schist.

54 PD-77 to 54 PD-86. – The samples were lost by the porters. All the samples were collected in the moraine of the glacier flowing down between the first and the second peaks of Falchan Kangri except for samples 54 PD-78
and -79 coming from the left side of the valley of the North-northwest Falchan glacier.

The names of the rocks written on the matrix of the labels are reported below.

54 PD-77. – Friction breccia (calcareous).

54 PD-78. – Micaceous gneiss including fragments of limestone.

54 PD-79. – Limestone, included in the gneiss.

54 PD-80. – Conglomerate with green arenaceous cement.

54 PD-81. – Siderite vein.

54 PD-82. – Calc-schist.

54 PD-83. – Light-coloured limestone.

54 PD-84. – Grey limestone.

54 PD-85. – Green conglomeratic sandstone.

54 PD-86. – Greenish quartzite (probably green calcareous sandstone).

54 PD-87. – Tourmaline-bearing biotite paragneiss; a little above Skyang-la, altitude approximately 6350 m.

The rock is schistose, dark, and fine-grained, analogous to the other “black schists” already described 54 PD-6 and -61. Here and there light coloured lenses are present in which feldspars are restricted to this and discontinuous micaceous bands.

Under the microscope the darker areas are seen to be composed of plagioclase with a composition of approximately 18-20% An, and of quartz, often separated from each other by very thin bands of tiny biotite plates.

The more sialic bands are characterised by an abundance of well-developed quartz and plagioclase with a composition 20% An, with the latter more prevalent, and by the presence of notable quantities of tourmaline, and larger biotite crystals.

Smaller tourmaline individuals are also found in the biotitic bands.
54 PD-88. – Acidic facies injected into the biotite paragneiss 54 PD-87; Skyang-la, altitude approximately 6230 m.

54 PD-89. – Pyroxene minette; at the Skyang-la, altitude approximately 6300 m. (Analysed rock).

The rock is analogous to the other lamprophyres, but is notably altered. The ground-mass is composed of potash feldspar in quantities less than that in the other lamprophyres, calcite aggregates, and minute crystals of pyroxene, biotite, and spinel. Phenocrysts of biotite and pyroxene stand out from this ground-mass, while the latter is mostly altered to calcite.

Some rounded chloritic areas seem to be derived from the alteration of garnets.

(For a detailed description see C. Viterbo and B. Zanettin, 1959, p. 22).

54 PD-90. – Sericitic chloritic carbonaceous phyllite; at the foot of the crest between Skyang-la and Sella Saddle, altitude approximately 5700 m.

The rock is black and compact, with prismatic jointing. The very fine-grained matrix is constituted of minute scales of sericite and mottles of chlorite. Quartz is present in grains of medium size, either as isolated individuals in the matrix, or united in small areas along with some chlorite.

Plagioclase occurs rarely as small individuals which are always altered. Graphite occurs in slivers and mottled areas and is minutely diffuse throughout the matrix in very fine grains.

Tourmaline and calcite occur as accessories.

54 PD-91. – Grey schistose limestone with yellowish weathered surface; at the foot of the crest between Skyang-la and Sella Saddle, altitude approximately 5700 m.

54 PD-92. – Brecciated limestone; at the foot of the crest between Skyang-la and Sella Saddle, altitude approximately 5700 m.

The rock varies in colour from point to point and is cross-cut by numerous fractures filled with a limonitic substance. Some pyrite crystals occur.

54 PD-93. – Biotite gneiss with feldspar porphyroblasts; east wall of K², under the Black Peak, in the detritus, altitude approximately 5000 m.

The rock is similar to the common “K² gneiss”, but the matrix crystallinity is much larger, while feldspar is strongly developed and in great abundance.
Under the microscope, corroborating the macroscopic evidence, one can see that the grain size of the various minerals is notably larger than that of the most common “K² gneiss”. Only small portions of the ground mass are of a relatively fine grain size, while the rest is recrystallised in large individuals.

Moreover, the quartz is a little more abundant and forms widespread areas.

The plagioclase, with a composition of approximately 25% An (Albite-Carlsbad twins) containing many drops of potash feldspar, sometimes includes minor plagioclase relicts with a composition of 35% An (Albite-ala twins) and partially sericitised.

The potash feldspar (microperthite) is almost absent in large areas of the rock, while it is very abundant in others, probably in ill-defined veins. At its contact with a more calcic plagioclasite, which is slightly sericitised, there is a myrmekitic association; this is not in evidence at the contact with the oligoclase.

54 PD-94. — Granite gneiss; in the detritus, at the foot of the east wall of the Black Peak, altitude approximately 5000 m.

This light-coloured rock, of granitoid type, contains frequent, irregular, subparallel bands of biotite.

Quartz, potash feldspar, plagioclase and biotite are well developed while the potash feldspar (microperthite) is porphyroblastic.

The plagioclase, with a composition of approximately 20% An, is very scarce in some parts of the rock and abundant in others. Both the feldspars include quartz grains and plates of biotite.

Biotite plates are also included in the largest quartz individuals.

Myrmekite is frequently developed, while apatite occurs in accessory amounts.

54 PD-95. — Aplitic-granitic gneiss; in the detritus, at the foot of the east wall of the Black Peak, altitude approximately 5000 m.

The section was cut from a concordant stringer in a biotite gneiss with feldspar porphyroblasts of the same type as sample 54 PD-93. There is a continuous, rapid passage from the stringer to the country-rock. The stringer is of rather small grain-size and contains a schistosity concordant with that of the surrounding gneiss, while short, dark, biotitic bands frequently occur.

Under the microscope the grain-size of the rock is seen to be relatively uniform, though feldspar is usually more developed.

The minerals present, in order of frequency, are quartz, plagioclase with a composition of 15 - 20% An, potash feldspar and biotite. The distribution
of potash feldspar follows a definite pattern, as it is mainly found in areas elongated along the schistosity of the rock.

54 PD-96. – Fine-grained biotite paragneiss; in the detritus, at the foot of the east wall of the Black Peak, altitude approximately 5000 m.

In hand specimen this rock is analogous to samples 54 PD-6, -39, -61, and -87. However, it contains more quartz and feldspar and, in some bands and lenses particularly rich in feldspar, is of somewhat larger grain-size. The essential components are quartz, plagioclase with a composition of approximately 18 - 20% An, and biotite; subordinate amounts of potash feldspar are present, often filling the numerous subparallel fractures in the plagioclases. Graphite is very common, but not as common as in the other analogous rocks.

54 PD-97. – Arenaceous limestone; at the foot of the east wall of the Black Peak, altitude approximately 5000 m.

This is a light-coloured, semicrystalline limestone with frequent small lenses of quartz. Under the microscope the quartz is seen to occur both in very compressed lenses or thin bands, and also in fine grains in the matrix, which is made of distinct crystals of calcite.

54 PD-98. – Chlorite schist with feldspar porphyroblasts; at the foot of the east wall of the Black Peak, altitude approximately 5000 m.

The rock possesses a greenish, fine-grained ground-mass, in which are developed feldspar porphyroblasts of various sizes distributed in an irregular manner. Under the microscope the schistose, medium to fine-grained matrix is seen to be constituted of calcite, chlorite, potash feldspar, quartz, plagioclase with a composition of approximately 35 - 40% An, and muscovite. If the calcite is primary, then the rock is an arenaceous calcschist. However, it was perhaps introduced at a late stage, since it also fills all the fractures of the rock. The porphyroblasts are almost always of potash feldspar (microcline, microclineperthite, and perthite); they are, for the most part, rounded and include numerous minerals of the ground mass. Plagioclase porphyroblasts are much more rare, with a composition of 38% An (measured on albite twins).
54 PD-99. – Semicrystalline limestone; at the foot of the east wall of the Black Peak, altitude approximately 5000 m.

This rock is analogous to sample 54 PD-97.

54 PD-100. – Pyroxenic minette; at the foot of the east wall of the Black Peak (K² massif).

*Potash feldspar* occurs in large, irregular individuals, which form the ground-mass and enclose all the other minerals.

Albitic plagioclase occurs, on the contrary, as smaller and more regular individuals.

The biotite is a very dark end-member (β and γ almost black), corresponding to lepidomelane. A diopside-augite pyroxene with aegirine-augite borders frequently occurs, while actinolite is scarce.

Apatite and sphene are relatively abundant.

54 PD-101. – Biotite-chlorite gneiss with feldspar porphyroblasts, with areas of aplite gneiss; at the foot of the east wall of the Black Peak, altitude approximately 5000 m, near the southern spur.

The rock has a dark greenish ground-mass, of medium grain-size, and is punctuated by the usual feldspar porphyroblasts, in this case antiperthite. At some points very light coloured, aplitic, rounded mottles occur in the rock.

Under the microscope one can see that the transition from the dark to the light part is by the rapid diminution and disappearance of biotite and chlorite, while the other minerals of the ground-mass, quartz, and plagioclase with a composition of 15 - 20% An, remain almost unaltered in their quantitative amount.

The grain-size seems to be larger in the micaceous than in the aplitic part.

*Potash feldspar* is always very scarce, filling the numerous fractures in the rock, and occurring in minor quantity between the various minerals; its introduction is, thus, post-tectonic. Para- and post-crystalline deformations are evident, the latter being predominant.

54 PD-102. – Quartzo-feldspathic gneiss with amphibole and chlorite; at the foot of the east wall of the Black Peak, near the southern spur, altitude approximately 5000 m.

The rock has a ground-mass of grey colour, punctuated by black amphibolic crystals, and light, feldspathic crystals, of which the latter are more well-developed.
Under the microscope the rock, composed essentially of quartz, potash feldspar and plagioclase, is seen to be of rather small grain-size and possesses a marked schistosity, determined by orientation of the femic minerals, amphibole and chlorite, and also by the slightly elongate form of the sialic minerals. The hornblende and a few feldspars are larger than the medium grain-size. 

_Sphene_ is fairly common, and also a few grains of orthite occur.

The feldspar porphyroblasts are mostly of plagioclase with a composition of 40 - 45% An (Albite-Carlsbad twins), while a few individuals of potash feldspar occur.

54 PD-103. – Cataclastic quartzo-feldspathic gneiss with amphibole and chlorite; at the foot of the east wall of the Black Peak, near to the southern corner, altitude approximately 5000 m.

The rock is a little different from sample 54 PD-102; the grain-size is slightly larger and the schistosity poorly developed.

The analogy with 54 PD-102 is revealed under the microscope. The same minerals are present, but of larger grain-size, while the feldspars and in particular the potash feldspar are notably larger and also very abundant.

The intense cataclasis of the rock is associated with frequent alteration of the plagioclases.

Some large orthite grains occur.

54 PD-104. – Grey hard limestone; at the foot of the east wall of the Black Peak, near to the southern corner, altitude approximately 5000 m.

54 PD-105. – Quartzo-feldspathic gneiss; at the foot of the east wall of the Black Peak, near to the south corner, altitude approximately 5000 m.

In hand-specimen the rock is recognised as rose-coloured arenaceous gneiss, with a few muscovite lamellae.

Under the microscope it is seen to consist of quartz, of plagioclase with a composition of approximately 8 - 10% An (ηγ < ω of quartz; maximum angles of extinction of albite twins in the zone perpendicular to (010) = 10 - 12°) and partially altered, and fresh potash feldspar. _Muscovite_ is scarce.

The most well-developed feldspar crystals enclose grains of quartz and muscovite plates.

_Zircon_ crystals are numerous.

The rock is possibly a partially recrystallised cataclastic granite gneiss.
54 PD-106. – Perthitic pegmatite; on the southern spur of K².

Large, grey, glistening crystals of perthite (moonstone) give the rock its distinctive character. Some areas consists exclusively of large crystals of microcline perthite and interstitial quartz.

This is a blastomylonitic pegmatite.

54 PD-107, -108. – Biotite-muscovite schist with garnet and andalusite; in the righthand moraine of the Savoia glacier, at the confluence with the Godwin Austen glacier.

The rock is blackish, fine-grained, and similar to the other “black schists”; however, large nodules occur on its surface.

It is constituted of very thin alternating bands of quartzose and quartzomicaceous character. A few individuals of plagioclase, with a composition of 22 - 23% An, are associated with the quartz.

Among the micaceous minerals biotite, and locally muscovite, is very abundant.

Garnets occur as beautiful idioblasts, while the growth of a few very well-developed poeciloblasts of andalusite has displaced the quartzo-micaceous bands.

54 PZ-141. – Calcareous schistose conglomerate; right-hand spur of the confluence of the Savoia and Godwin Austen glaciers.

The greyish, schistose matrix of this rock encloses small semicrystalline calcareous pebbles. The rock is similar to the sample 54 PD-64 but the pebbles are more angular and crushed.

54 PZ-142. – Chloritic-sericitic arenaceous phyllite; in the detritus, under the wall between the Savoia and Khalkhal glaciers, altitude 4800 m.

This very fine-grained, arenaceous, greenish rock is very similar to sample 54 PD-68.

Under the microscope the matrix is seen to be composed of a minute aggregate of quartz, chlorite, and sericite; in a few cases the latter is of larger size, passing into muscovite. The sericite often appears to pseudomorph another mineral which has almost totally disappeared and was perhaps plagioclase.

Along movement planes, chlorite is present in larger plates which are well oriented and give the rock a certain schistosity.

Numerous medium-grained quartz grains occur in the matrix. They sometimes include a prismatic mineral now totally altered to sericite, but which was perhaps a plagioclase.
Calcite, often localised in fractures in the rock, and epidote occur in minor quantities.

54 PZ-143. – Sericitic arenaceous schist; in the detritus under the wall between the Savoia and Khalkhal glaciers, altitude 4800 m.

The rock is identical to sample 54 PZ-142.

54 PZ-144. – Fine-grained biotite gneiss with feldspar porphyroblasts; in the detritus, between the mouths of the Savoia and Khalkhal glaciers.

The rock is analogous to the average type of "K² gneiss'. In the matrix, rich in quartz and feldspar, potash feldspar is abundant both in medium-size individuals and in thin capillary veinlets; they always occur between the quartz and the plagioclase grains, thus making it difficult to compare refractive indices. The plagioclases have a composition of approximately 40% An (maximum angles of extinction of albite twins in the zone perpendicular to (010) = 20° approximately).

Epidote in minor amounts and rare individuals of hornblende occur with the biotite. Inclusions of quartz, biotite, epidote, and a little amphibole occur in the plagioclase and potash feldspar porphyroblasts.

Sphene, orthite, and apatite occur as accessories.

54 PZ-145. – Quartzo-feldspathic blastomylonitic gneiss; in the detritus, between the mouths of the Savoia and Khalkhal glaciers.

In hand specimen the rock is recognized as an arenaceous gneiss of light green colour.

In thin-section it is noted that the ground-mass is clearly blastomylonitic and is constituted of minute, sutured quartz grains, accompanied by minor quantities of feldspar (especially potash feldspar), chlorite, sericite, orthite, and calcite.

Porphyroblasts of potash feldspar and plagioclase with a composition of approximately 35% An occur in the ground-mass. They show evidence of minor para- and post-crystalline deformation. Any microcline crystals are, on the contrary, undamaged by cataclasis, which indicates their late origin. The potash feldspar sometimes replaces the plagioclase.

54 PZ-146. – Amphibole vogesite; in the right-hand moraine of the Godwin Austen glacier, between the mouths of the Savoia and Khalkhal glaciers. (Analysed rock).
As in the other lamprophyres of the Baltoro, the potash feldspar occurs as large irregular individuals that, joined together, compose the ground-mass and enclose the other minerals. However, the phenocrysts are almost exclusively of amphibole and rare biotite plates.

The amphibole corresponds, for the most part, to intermediate terms of the common hornblende-katophorite series. A few sodic end-members (ribeckite-arfvedsonite) also occur.

(For a detailed description see: C. Viterbo and B. Zanettin, 1959, p. 15-17).

54 PZ-148. - Actinolite-biotite schist; in the moraine near the K² Base Camp.

The rock is compact and of light green colour, mottled with brownish areas.

Under the microscope the bulk of the rock is seen to be composed almost exclusively of actinolite, while the dark mottles are formed by the association of actinolite with a deep red biotite.

Quartz and plagioclase grains occur between the amphiboles, while in some sialic lenses quartz is associated with a minor amount of potash feldspar.

54 PZ-149. - Grey and light limestones; in the west-southwest slope of Falchan Kangri.

a) Sub-crystalline whitish limestone with calcitized traces of fossil organisms. Very similar to the sample 54 PZ-157; b) black, hard, bituminous limestone; c) grey limestone very similar to the type common on the left-hand moraine of the Upper Baltoro (Desio and Cita, 1955, n. 3).

54 PZ-150. - Sericitic arenaceous phyllite; on the west-southwest slope of Falchan Kangri.

This rock, of light green colour, is very similar to samples 54 PZ-142 and -143, but is more schistose.

54 PZ-151. - Amphibole vogesite; towards the south-west of the Falchan Kangri. (Analysed rock).

This dyke occurs in the calcareous rocks and contains, near to the contact, thin parallel bands of diverse compositions.

The potash feldspar occurs in small grains.

Amphiboles are the most frequent femic components and occur both in isolated crystals and in aggregates. In composition they are intermediate terms
hornblende-katophorite series. *Pyroxene* (diopside-augite) is more scarce, while *biotite*, though not abundant, always appears in phenocrysts or aggregates of plates. Sometimes a covering of very minute amphibole individuals surrounds these phenocrysts.

*Sphene* is very common.

Near to the contact with the limestones the rock is banded, each band being parallel to the contact and characterized by one femic mineral and the irregular distribution, or absence, of potash feldspar. These bands are as follows: a biotite band (with phlogopite); an amphibole band (hornblende-katophorite), with areas of microperthite and calcite; another amphibole band of larger grain-size and containing a little pyroxene (aegirine-augite) and sphene.

(For a detailed description see C. VITERBO and B. ZANETTIN, 1959, p. 12).

**54 PZ-152 and 153.** – Fossiliferous limestones; *in the moraine of the South Falchan glacier.*

Crystalline limestone from whitish to pale-grey in colour with dark spots strewed on the rock. On the weathered surface white reliefs rise from the bottom. The reliefs are round shaped and probably of organic origin (calcareous algae).

Under the microscope the rock appears a medium-grained aggregate of crystals of calcite. The organic structures are about completely obliterated.

**54 PZ-154.** – Biotite-pyroxene diorite, with potash feldspar; *in the moraine of the South Falchan glacier.* (Analysed rock).

The rock possesses a medium-fine, uniform grain-size. Some irregular, whitish areas are also visible.

Under the microscope the rock is seen to be composed of plagioclase, quartz, potash feldspar, pyroxene, biotite and amphibole.

The plagioclases are the only idiomorphic minerals present, though they show reabsorption phenomena at their edges. The composition varies between 40-55% An, while the cores have a composition of 65% An.

It is possible to distinguish both a regular zoning, due to increase in the Ab content with crystallisation, and a zoning due to late replacement of the calcic plagioclases by Ab-rich fluids.

In the latter case the zoning is limited to the edges of the crystals, and is more irregular, showing abrupt changes in composition. The replacement has possibly affected all of a particular individual, in an irregular manner, so as to preserve only some patches of the old plagioclase, or some “zones” (or
portions of “zones”) of zoned crystals, while all the remaining part has assumed a homogenous composition. The most advanced stage of replacement is seen in the areas where potash feldspar is present.

Late alteration is rare, and limited to the central parts of the plagioclase crystals.

The potash feldspar forms allotriomorphic areas in which plagioclases are included. These two minerals have often reacted to give myrmekitic associations. Areas of quartz also contain plagioclase inclusions.

With the exception of some biotite plates, the femic minerals do not show idiomorphism.

The pyroxene is a diopside-augite and is often altered, at the edges, to actinolitic amphibole. Other amphibole crystals, not associated with the pyroxene, are hornblendes with very weak pleochroism.

Pyroxene-amphibole and pyroxene-amphibole-biotite are often intimately associated. They are in part derived from the transformation of the pyroxene.

Among accessory minerals, apatite, zircon, epidote, and orthite are common.

54 PZ-155 and -155a. – Contact between pyroxene-amphibole hornfels and serpentinite; in the moraine of the South Falchan glacier.

The sample of the rock shows the distinct passage between the hornfels of sample 54 PZ-155 and a serpentinose band consisting almost exclusively of antigorite, with a minor amount of chrysotile, pennine and clinochlore, and with calcite almost always localised in veins.

At the contact with the serpentinose band the minerals of the hornfels are sometimes transformed to tremolite and phlogopite. A little green spinel is also present.

54 PZ-156 and -156a. – Calciphyre with tremolite and serpentine; in the moraine of the South Falchan glacier.

The rock is composed of various subparallel bands, one light-coloured, or slightly green, and carbonate-bearing, and another of very dark green colour, compact, and serpentinose. The latter is evidently more crystalline, containing acicular crystals of very light green colour.

The different bands are composed prevalently, from one place to another, of tremolite, serpentine, magnetite, or calcite.

The most well-developed band corresponds to a tremolite hornfels, containing prismatic, elongate individuals, occurring in aggregates.
The passage to the serpentinose zone is rapid, but it is possible to see some individuals of amphibole in rapid transformation; the transformation usually proceeds along the fractures and planes of cleavage. Among the transformation products is a red substance, prevalently of carbonates.

The serpentinose association is composed both of lamellar antigorite and of chrysotile in aggregates of very small fibrous, radiating crystals, or in ribbons, in which the fibres are oriented perpendicular to the length of the ribbon. The elongation of these individuals of serpentine is almost always positive, but individuals with negative elongation also occur.

Major or minor quantities of calcite and magnetite always accompany the serpentine, and become progressively more abundant in the more external part of the band.

With the disappearance of serpentine the magnetite also disappears, and only carbonates remain.

C. UPPER BALTORO GLACIER.

54 PZ-157. – Light-grey fossiliferous limestone; right floating moraine of the Upper Baltoro glacier.

Light-grey saccharoidal limestone with jagged fracture; on the weathered surfaces plentiful small dark roundish shells of foraminifera occur. On the fresh surface of the rock these fossils appear like dark bodies conferring to the rock a spotted appearance.

In thin section the rock appears as an aggregate of calcite crystals very irregularly distributed for the presence of numerous organic remains and darker arenaceous elements.

Some sections of large fusulinids are present. Within the shell one can distinguish a gradual replacement of the original arenaceous shell with microcrystalline calcite. Among other fossils, fragments of bryozoan and organic traces of uncertain origin can be distinguished. CaCO$_3$ 93%, Ca Mg (CO$_3$)$_2$ 4%. (DESIO and CITA 1955, n. 11).

54 PZ-158. – Fairly dark-grey, fossiliferous, very compact limestone; floating moraines of the Upper Baltoro glacier.

Beside some oölite, similar to that of sample 54 PZ-159, though less well-developed, the rock contains some indeterminable remains of pelecypods.

Calcimetric units 97.3 (DESIO and CITA 1955, n. 9).
54 PZ-159. – Fairly dark-grey, very compact oolitic limestone; floating moraines of the Upper Baltoro glacier.

This rock is characterized by its spotted appearance produced by the presence of numerous blackish, small, roundish bodies, of 1-3 mm in diameter with a little irregular shape which, at first sight, can be mistaken for fossils. Under the microscope they reveal their real nature, that is calcareous oolites. Beside the largest oolites easily distinguishable even by the naked eye, there are smaller ones composed of thin layers of calcite of different colour overlaing one another. The calcite crystals of the layers are extremely small. The most common shape of the oolites is roundish but some are oval.

The oolites are cemented by a crystalline matrix composed of coarse-grained calcite, but the oolites are the prevailing part of the rock. No traces of schistosity or organic content are present within the rock. (DESI and CITA 1955, n. 8).

54 PZ-160. – White fossiliferous crystalline limestone, like marble, with many fossils; floating moraines of the Upper Baltoro glacier.

Crystalline, almost pure limestone, very rich in fossils. On a broken surface the rock is seen to be as a saccharoidal marble containing many roundish bodies which are foraminifera shells. On the weathered surfaces the fossils assume a slightly yellow colour and they are more evident than on the fresh surfaces. In fact the tests are in relief on the surface of the cristalline rock and are visible to the naked eye as they have a diameter of 2-3 millimetres.

Under the microscope the rock is characterized by a rich organic content. The fossils are mostly represented by large fusulinids with arenaceous test which have a darker colour than the calcitic matrix. Among the fossils R. CIRY and M. AMIOT (1965) identified *Hemigordiopsis renzi* REICHEL of the Lower Permian.

Other foraminiferes, smaller in size and with calcareous instead of arenaceous tests, are contained in the rock. According to M. B. CITA (1955) these are Miliolididae, most of them belonging to the genus *Quinqueloculina*.

Calcimetric units: 84,6.

54 PZ-161. – Fossiliferous blackish limestone; right floating moraine of the Upper Baltoro glacier.

Limestone with a distinct aspect, in hand specimen, due to the presence of numerous elongated white masses, irregularly roundish or oval in section, which appear to be fossils: the nature of these masses however, is, uncertain.
DESCRIPTION OF THE SPECIMENS

The sample contain also remains of cylindrical corals from 3 to 5 mm in diameter, which are completely calcitized (fig. 23).
Calcimetric units: 100.

54 PZ-162. — Blackish, very compact, fossiliferous limestone; right floating moraine of the Upper Baltoro glacier.

Blackish, very compact, fossiliferous limestone characterized by the presence of large, white, curvilinear tracks. The rock contains numerous remains of large bivalves, many of which are crushed and indeterminable (fig. 24a). They are, however, identical to those of the dark grey fossiliferous limestone of Siachen basin (fig. 24b) which were referred to the Upper Triassic (Norian) by C. F. Parona (1933).
Calcimetric units 97.3.

54 PZ-163. — Black slate; on the south-west spur of the Chochordin. (In situ).

Very dark schistose rock, easily splitting in thin slabs. The surfaces are fleebly rippled.
Under the microscope the schistosity is made evident by an alternation of light and dark bands, which depend from the carbonaceous content.
The mineralogical composition is very simple. Quartz is contained as grains crushed along the schistosity planes; phengite is in tiny laminae; chlorite is mostly lenticular. There are also albite, iron oxide and rutile.
Laminae of light phyllosilicates are very rare but sufficiently well developed.
The rock is always fine-grained with the exception of the quartz grains which are larger. Also the shape of such grains is more round than those of the other minerals.

54 PZ-164. — Hematite; right-hand floating moraine of the Upper Baltoro glacier.

Black hematite with vesicular structure.

54 PZ-165. — Liver-red coloured, schistose, slightly ragged slate; floating moraine of the Upper Baltoro glacier.

In thin section the rock is seen to be constituted of very fine, homogeneous grains. The depth of color of the rock varies in irregular bands, and is most intense where quartz is abundant in small crystals.
Calcimetric units 23.9.
54 PZ-166. – Pyroxene-garnet vogesite, with biotite; in the middle moraine of the Upper Baltoro glacier.

The groundmass of the rock is constituted essentially of patches of potash feldspar in which all the other minerals are distributed. Albite (5-6% An) is also present, in small individuals.

Pyroxenes occur as individuals of very variable size and very diverse composition (augite, aegirine-augite, aegirine), while the zoning of these crystals is sometimes continuous and at other times recurring.

Biotite, in medium-size plates, is rather scarce.

The garnets are abundant enough to be considered as fundamental components of the rock. They usually occur as zoned phenocrysts varying in colour from reddish-brown to yellowish-red (andradite-rich mixture).

Apatite frequently occurs in long individuals.

(For a detailed description see C. Viterbo and B. Zanettin, 1959, p. 10).

54 PZ-167 -168. – Liver-red coloured conglomerate; in the floating moraines of the Upper Baltoro glacier.

Liver-red coloured conglomerate with schistose structure, composed of pebbles of white limestone with the size varying from few millimetres to some centimetres in the transversal direction; parallel to the schistosity the size is much larger. The prevailing shape is round but many elements are angular.

The cement is siliceous, schistose, intensely red-coloured, fine-grained and homogeneous. Calcimetric units: 38,6.

Under the microscope the rock shows a detritic texture. The calcite is frequent as medium-grained crystals; the largest grains are frequently fractured. No traces of fossils occur.

54 PZ-169. – Liver-red coloured argillaceous slate; floating moraines of the Upper Baltoro glacier.

In thin section the rock shows a distinctly parallel texture. Frequently broken large crystals of calcite are distributed in a very fine-grained, reddish, ochre-coloured matrix.

D. YOUNGHUSBAND GLACIER.

54 PZ-171. – Fine-grained biotite paragneiss; at about 50 m from the contact to the west of the confluence of the Younghusband glacier.
The rock has a marked schistosity, and is composed essentially of quartz, plagioclase and biotite. The composition of the plagioclases varies from grain to grain, with indices greater than, equal to, or lower than quartz, while the optic sign varies from negative to positive.

The biotite plates are always strongly oriented, while well-developed poikiloblasts of muscovite are often clearly discordant with respect to the schistosity. The latter are probably of new generation, due to contact metamorphism of the nearby granite body.

A little apatite and zircon are present, while tourmaline is rare.

54 PZ-172. – Biotite-muscovite paragneiss; to the west of the confluence of the Younghusband glacier, in the moraine that descends from the little valley near the contact.

The rock, both macro- and microscopically, is not very different from 54 PZ-171, which was collected near to the contact. However, it has a larger grain-size and the micas are less strongly oriented, yet still impart a distinct schistosity to the rock.

The constituent minerals are biotite, often altered to chlorite (pennine) and dotted with abundant iron oxides, muscovite, albite-oligoclase plagioclase (indices lower than $\omega$ of quartz, positive optic sign) sometimes altered to very fine sericite flakes, and quartz.

However, some quartz-plagioclase lenses are present, in which the plagioclases, with a composition of 22 - 25% $\text{An (np}_{5} \text{a})$, are in well-developed individuals which always lack alteration, and enclose quartz grains.

54 PZ-173. – Porphyroblastic plagioclase biotite gneiss; in the moraine of the little valley that descends near the contact, to the west of the Younghusband glacier.

The rock is constituted of oligoclase-andesine plagioclase, quartz, and biotite. Sphene, epidote, and apatite occur in accessory but abundant amounts, the former combined exclusively with biotite and the little muscovite present.

The biotite shows some orientation, but it is much more evident macroscopically than microscopically.

Plagioclases and quartz are developed in granoblasts, though the quartz may be found also in smaller elements associated with the biotitic bands. Quartz grains are often enclosed in the plagioclase.

Distinct fractures have bent some of the biotite plates, and have been
later healed with quartz, calcite, and chlorite. Concomitantly, biotite is altered to chlorite.

Large grains of tourmaline are rare.

The *plagioclases*, with a composition of 30 - 35% An, sometimes show a continuous variation in composition from the core to the periphery without the existence of noticeable zoning. They contain inclusions of biotite.

*Potash feldspar* occurs only in very small amounts, as myrmekite, developed here and there at the edges of the plagioclases.

The rock is remarkably analogous to the "K² gneiss".

54 PZ-174. – Biotite paragneiss; *between the contact with the batholith and the confluence of the Younghusband glacier*.

The rock is virtually analogous to the biotitic-muscovitic paragneiss 54 PZ-171 and in fact belongs to the same formation, separating the granite body from the coarse-grained feldspathic gneiss.

It differs only in the notably more minute grain-size and the total absence of muscovite.

Tourmaline and small grains of iron oxide occur quite frequently.

54 PZ-175. – Gneiss with actinolite, clinozoisite, sphene, and potash feldspar; *in the moraine under the crevasses of the Younghusband glacier*.

Strong orientation of prismatic-elongate actinolite crystals gives the rock a marked schistosity. It is of a finer grain-size than other gneiss from the wall of the Muztagh Tower.

The colourless *amphibole* occurs as distinct crystals, which often contain many, tiny, sialic inclusions.

*Clinozoisite* occurs in association with this amphibole, in isolated individuals with a texture that resembles that of myrmekite.

The *sphene* is also usually associated with the clinozoisite.

Sialic minerals include *potash feldspar*, both orthoclase and microcline, quartz and, subordinately, plagioclase; the latter, in the few determinations possible, seems to have indices a little higher than those of quartz.

Myrmekite associations at the edges of and also within the plagioclase are not very frequent. Rock fracture are filled with calcite. It does not appear probable that this rock was derived by metamorphism of an intrusive rock. It is more likely that feldspatic metasomatism of a potassic character (pegmatite, etc.) acted upon an amphibolitic paragneiss derived by metamorphism of a pre-existing calcareous rock (or calcarceous arenite). This would agree with
the observations in the field, where isolated individuals or strips of schistose materials of various types, including perhaps irregular calcareous facies, are seen to occur in the gneiss formation.

54 PZ-176. – Amphibolitic gneiss with sphene and epidote; under the crevasses of the Younghusband glacier; southern slope of the Muztagh Tower. The rock was derived by the action of a late acid phase on a pre-existing rock, of which the precise nature is not known.

The essential components are quartz, plagioclase which is sometimes zoned (46 - 47% An, mostly oligoclase-andesine), microcline, biotite, and green hornblende.

The orthoclase has partly replaced the old plagioclases, which sometimes occur in dismembered and isolated shreds. Myrmekite is often formed by reaction. Some of the plagioclase also seems to be of later generation (albite) and contains traces of curved foliation. Some of the quartz may also be of late generation, but this is unlikely.

Representative femic minerals are biotite and green hornblende accompanied by a substantial quantity of epidote and sphene.

54 PZ-177. – Biotitic amphibolitic gneiss with sphene and epidote; in the moraine under the crevasses of the Younghusband glacier.

The rock, which undoubtedly comes from the eastern wall of the Muztagh Tower, is very similar to 54 PZ-176, described above. However, the orientation of the coloured minerals is stronger, giving the rock a more pronounced schistosity.

Plagioclase has a composition of 35% An (albite-Carlsbad twins).

Myrmekite is very abundant, and perhaps indicates a late potassic metasomatism of the pre-existing gneiss.

Large orthite crystals with reddish pleochroism pass rapidly into a clinozoisitic epidote which encloses plates of biotite. Both the green amphibole and also some biotite plates have a poikiloblastic character.

54 PZ-178. – Epidote amphibolite; in the moraine of the Younghusband glacier, near the Muztagh Tower.

The rock is composed of bands of amphibole, biotite, clinozoisite and rare calcite, alternating with bands of quartz and quartz-labradorite. Calcic plagioclase is often associated with the clinozoisite or zoisite.

The bands are sharply bounded, and about 1 cm thick.
54 PZ-179. – Biotitic-muscovitic paragneiss with iron minerals; *left-hand moraine of the Younghusband glacier, near the confluence with the Baltoro glacier.*

The rock shows some analogy to those taken near the contact, to the west of the mouth of the Younghusband (samples 54 PZ-171, 172 and 174) despite the fact that their provenance is, with every probability, the high part of the left-hand slope of the Younghusband Glacier.

The micas are not well oriented throughout the sample. The fundamental components are biotite, muscovite associated with biotite, plagioclase, and quartz. The rock is dotted with iron minerals both of very fine grain and in more well-developed elements and sufficiently abundant to be an essential component. It is not known whether these are oxides or sulphides.

Tourmaline is quite abundant.

E. VIGNE GLACIER.

54 PZ-182. – Epidote-biotite-amphibole-pyroxene calciphyre, from the contact; *north-east wall of the Mitre Peak.*

The original rock was a quartzose-calcareous arenite containing thin quartzose-argillaceous, quartzose-calcareous or quartzose-marly bands, and quartzose beds.

The grain-size varies from point to point. Quartz is found both in aggregates of very small individuals and in large grains. The transformation is most evident in the beds of finest grain-size.

Besides the original constituents, quartz and calcite, notable quantities of brownish epidote with a very slight pleochroism and rare pyroxenes of diopsidic type \((c : \gamma = 40^\circ)\) occur; the amphibole is in the process of formation and is distributed in indefinite mottles within the epidotic aggregates, from which it is distinguishable by its deep green pleochroism.

Sphene is only locally abundant and is almost always combined with iron oxides. The original arenaceous-marly beds are now transformed to a quartzose-biotitic-epidotic hornfels dotted with abundant iron oxides. Very small muscovite lamellae are associated with these elements. The biotite is clearly of contact metamorphic origin. Epidote, unlike that in other parts of the rock, is almost perfectly formed.

54 PZ-183. – Garnetiferous-bytownitic hornfels; *north-east wall of the Mitre Peak.*
The rock is constituted of biotite, garnet, quartz and calcic plagioclase. Biotite occurs in large plates generated by contact metamorphism; the garnet also occurs in considerably large elements. Quartz occurs in large isolated elements, or constituting crushed lenses parallel to the schistosity of the rock.

This rock is characterised by the presence of numerous very calcic plagioclases, with a composition of 78% An (maximum angles of extinction on albite twins in the zone perpendicular to (010) = 48°, very high indices, high birefringence), always strongly poeciloblastic. Quartz occurs as small grains with a heterogeneous form, included in the plagioclases, giving rise to a micropegmatitic association.

54 PZ-184. – Biotitic gneiss with plagioclase porphyroblasts; north-east wall of the Mitre Peak.

The rock is constituted of biotite, quartz and plagioclase. Biotite is of contact metamorphic origin.

This sample is possibly typical, possessing a metamorphic structure and containing porphyroblasts of andesine plagioclase with a composition of 35% An. The latter enclose quartz, older plagioclases with various indices, and sometimes irregular mottles of potash feldspar. Orthite is present.

Since no clearly gneissic rock occurs within the formations far from the contacts, the porphyroblastic plagioclase was possibly formed by a mechanism analogous to that for the «K² gneiss», to which it is similar in hand specimen.

54 PZ-185. – Amphibole-biotite gneiss; north-east wall of the Mitre Peak.

This rock is similar to 54 PZ-192 and -194, but is more abundant in quartz, and contains regenerated biotite.

54 PZ-186. – Muscovite-biotite hornfelsic schist, with sillimanite; north-east wall of the Mitre Peak.

The rock is very similar to sample 54 PZ-203 taken from the right-hand moraine of the Vigne. The essential components are quartz, plagioclase, muscovite and biotite.

Quartz is much more abundant than plagioclase (with indices lying between ε and ω of quartz), while both are distributed in a rather uniform way. Muscovite and biotite, which are almost always present, are generally oriented. The former is most abundant, and frequently contains little, thin, needles
of sillimanite which either grow in from the edges of the crystals or occupy the central parts.

The sillimanite seems to be accompanied by sericite.
Some grains of apatite and epidote occur.

54 PZ-187. – Biotite-amphibole gneiss with epidote; north-east wall of the Mitre Peak.

Macroscopically the rock is distinctly schistose, while under the microscope the feric elements, biotite and amphibole accompanied by a small quantity of epidote, are seen to be randomly distributed.

**Amphibole** and **biotite** are often present, the amphibole is mostly a green hornblende, with very deep green pleochroism, but this sometimes passes into a lighter coloured, actinolitic amphibole, and sometimes to a completely colourless variety (perhaps tremolite). The amphibole is never present in distinct and well developed individuals, but either in poeciloblastic aggregates or, more often, in little crystals or grains dispersed between the other minerals.

**Epidote** and **apatite** are also quite common. Abundant iron oxides mottle the rock and are always more or less directly related to the feric elements.

The alteration or transformation of the amphibole seems to have been due to hydrothermal solutions infiltrating along pronounced fractures which are present in certain areas of the rock.

Among the sialic elements, an acid plagioclase (indices lower than $\omega$ of quartz) is prevalent, while quartz occur both in large elements and very minute grains and may be almost absent in some areas. The quartz is frequently reabsorbed and enclosed by the plagioclase which is, at least in part, of late generation.

54 PZ-188. – Arenaceous micaschist with biotite and sillimanite; north-east wall of the Mitre Peak.

On the whole this is very similar to the preceding sample (54 PZ-186), but differs in that the micaceous elements are much scarcer, so that the original quartzose arenaceous nature is clear. Plagioclase is also very scarce, while between the grains of quartz (which is by far the most prevalent mineral) one finds small allotriomorphic elements of orthoclase.

Sillimanite is formed from the muscovite.

54 PZ-189. – Coarse-grained amphibole-biotite gneiss; east wall of the Mitre Peak.
The rock is constituted of plagioclases, amphiboles and biotite, with which are associated small quantities of accessory elements (sphene and epidote). Green hornblende and biotite, which are almost always intergrown, are present in well-developed elements without a definite orientation (although in the thin-section basal sections prevail). The biotite is only idiomorphic when developed independently from hornblende.

Sphene is always united with iron oxides.

The sialic elements are represented only by plagioclases, quartz being absent.

**54 PZ-190.** – Biotite-andalusite-sillimanite hornfels; *at the east contact of Mitre Peak.*

**54 PZ-191.** – Biotite-andalusite gneissic hornfels with tourmaline; *at the east contact of Mitre Peak.*

The original gneissic texture, due to the orientation of the sialic minerals, quartz and plagioclase, and to the lamellar minerals, is still visible.

*Muscovite* plates, regenerated biotite, and chlorite spotted with iron oxides, are present in some bands in bundled aggregates without definite orientation, but are sparse in the bands constituted essentially of sialic minerals. The abundant sericite occurs, almost always, in well-developed mottles which are sometimes elongated parallel to the schistosity of the rock.

*Quartz* and *plagioclase* constitute irregular bands and lenses. The single individuals, for the most part of reduced dimensions, are often separated from each other by minute micaceous elements, or by a deep reddish substance which is probably limonitic and gives the rock outcropping near the contact a characteristic reddish colour (this is sometimes also seen in the igneous rocks and must therefore be of late infiltration).

*Andalusite* is abundant, in both clear and poeciloblastic crystals which are always bordered by a notable quantity of sericite and muscovite. The inclusions are represented by muscovite, biotite, quartz and iron oxides grains. At one point needles of sillimanite are developed from a bund of micas.

A yellowish or brownish-yellowish tourmaline, generally oriented perpendicular to the plane of the section, is abundant and often localised in certain areas.

**54 PZ-192.** – Amphibole-biotite gneiss; *in the left-hand moraine of the Vigne glacier, near to the contact.*
Except for some textural details this rock is very similar to 54 PZ-194 taken from the right-hand moraine of the Vigne.

The essential elements are plagioclases of medium acidity (indices sometimes inferior to ω of quartz, more often with values intermediate between ε and ω) and minor quantities of quartz, amphibole and biotite.

The amphibole, a green hornblende, occurs in elongate and sometimes acicular individuals. These are fairly well oriented along the planes of schistosity and shows good poeciloblastic texture. It is accompanied by biotite which probably formed by contact metamorphism.

Sphene is common and almost always combined with large iron oxide grains. Apatite grains are numerous. The epidote is a manganese variety of violet colour (see 54 PZ-194).

Calcite and chlorite are of late development.

The grain of the rock is clearly visible with the exception of some mottles constituted of a minute quartz aggregate and feldspar grains that are relicts of pre-existing texture.

It is clear that the large feldspars were formed (or grew) later than the quartz that is re-absorbed and isolated within them.

54 PZ-193. – Biotite-muscovite gneiss; right-hand moraine of the Vigne glacier.

Quartz and acid plagioclase constitute the sialic minerals present, while biotite and muscovite were regenerated by contact metamorphism.

Macroscopically the rock has a typical gneissose aspect, with light, prevalently feldspathic bands, alternating with dark, prevalently biotitic bands. Under the microscope the distinction between light and dark bands is not as clear because numerous small lamellae of biotite outline the plagioclase, in the light bands, so that there is naturally a diminution in the total content of the biotite in these bands.

In the dark bands, besides a finer grain size and perhaps as a consequence of this, the schistose texture is more evident. Also quartz seems to be more abundant.

The porphyroblasts are composed of albite (indices markedly lower than ω of quartz, maximum angles of extinction 160°), and are rather clear or contain very tiny sericite lamellae, usually distributed along the twin planes. Rounded, longish inclusions of quartz are very common, but some quartz seems to be of later generation than the plagioclase since it is found in narrow fractures accompanied by small quantities of calcite.
In other cases the quartz appears to be at least partially substituted by sodic feldspar.

*Biottite* is present both in medium-sized plates and in very small lamellae formed during contact metamorphism.

Alteration to chlorite is rare and localised at those points where late solutions responsible for the deposition of calcite managed to infiltrate.

*Muscovite* is much more rare and almost always associated with biotite.

54 **PZ-194.** – Amphibolitic gneiss with biotite; *in the right-hand moraine of the Vigne glacier.*

The schistose texture is due to the general orientation of the amphibole and associated biotite.

Under the microscope, the alternation of clear and dark bands seen in hand specimen is not seen, but irregular mottles, more or less rich is amphibole, constitute the rock.

Besides the green hornblende and biotite the other essential element, which is actually dominant, is a plagioclase with a composition of approximately 30-35% An (with indices usually between ε and ω of quartz, maximum angles of extinction on albite twins = 22°). Quartz is very scarce and for the most part included in the plagioclases.

A little apatite, manganese epidote, sphene and calcite occur.

54 **PZ-196.** – Biotite-muscovite micaschist; *in the right-hand moraine of the Vigne glacier.*

The two micas, and especially the biotite, are strongly oriented, and are almost always intergrown.

Among the sialic elements quartz is by far the dominant component, while plagioclase is in fact very rare. It is albitic and always in small turbid crystals.

Some epidote grains occur.

54 **PZ-201.** – Granite porphyry; *in the right-hand moraine of the Vigne glacier, about 4 km from the confluence with the Baltoro glacier.*

Numerous feldspar phenocrysts stand out in a matrix of greyish-white colour, while quartz phenocrysts are in general smaller. Small biotite lamellae are regularly distributed.

The ground-mass is microcrystalline. It is composed of minute quartz grains, longer, but not well-defined, plagioclases, and small biotite scales. *Apatite* and *calcite* are found in accessory quantities.
These same minerals, together with **potash feldspar**, also occur as phenocrysts.

The **quartz** occurs in rounded elements and is also sometimes reabsorbed in the typical manner for porphyries.

The **plagioclases**, of oligoclase type, are idiomorphic and clearly zoned; in some cases the extreme border is of potash feldspar.

The **potash feldspar** has, in some cases, re-absorbed and substituted the oligoclase.

The **potash feldspar** (sometimes microcline) may be in independent individuals or associated with plagioclases. It sometimes includes biotite.

Well-formed **biotite** plates have a periphery formed of minute scales, while sagenitic aggregates of rutile occur within the biotite.

**Apatite** is frequent while **orthite** is present in large grains.

54 **PZ-202.** – Leucogranite; in the right-hand moraine of the Vigne glacier, about 4 km from the confluence with the Baltoro glacier. (Analysed rock).

In hand-specimen this rock is very similar to the other facies of the Baltoro, but possesses a clearly larger grain size.

Although it is analogous in many ways to the other granite facies of the Baltoro (e.g., inclusions of pre-existing minerals in the potash feldspar) this rock differs in that it possesses a more regular texture.

Well-developed individuals of **quartz** sometimes include biotite plates, and cover widespread areas.

The **plagioclases** almost always show a distinct idiomorphism and are almost constantly zoned, usually rhythmically. Their median composition oscillates around 20% An, but some nuclei certainly possess a higher An content, and are sometimes notably higher. Often the central parts of the plagioclases are turbid, due to alteration products and also to the presence of a minute granular aggregate of iron oxides. Where the individual plagioclases are not idiomorphic, this is almost always attributable to substitution by potash feldspars, which in a few cases intimately compenetrates.

Inclusions of quartz and biotite are rare, while plates of muscovite are frequent and almost always randomly distributed.

The **potash feldspar** (often microcline) occurs as irregular allotriomorphic individuals with very varied dimensions. The largest sometimes contain many portions with different orientations and include numerous individuals of plagioclase, quartz and biotite. Substitution processes operating at the expense of the plagioclase are evident.
It is interesting that some potash feldspar individuals show a hint of zoning, or pseudo-zoning. Myrmekitic associations are frequent.

Some rare areas of plagioclase are present, including other plagioclase individuals and quartz with a chess-board form. Some plagioclase has a very irregular extinction, is spotted, and exhibits reabsorption of pre-existing plagioclases. Both plagioclases seem to possess very similar compositions, which makes the phenomenon rather difficult to understand.

Biotite is relatively abundant, but distributed in small areas. Apatite, iron oxides and zircon occur as accessories.

54 PZ-203. – Quartz-feldspathic hornfels with biotite and sillimanite; right-hand moraine of the Vigne glacier.

The rock is composed of quartz, oligoclase, and a little orthoclase, biotite, muscovite and sillimanite.

The plagioclase, which is sometimes a little turbid due to the presence of alteration products, corresponds to a mixture with a composition of approximately 25% An.

Biotite and muscovite, in about equal amounts, occur throughout the rock in plates derived by regeneration during contact metamorphism. The biotite, which is seldom chloritised, is abundant in some areas and rare in others.

The white mica is present in well-developed plates and in fine sericitic aggregates or in mottles or irregular festoons that outline, in certain areas, the sialic mineral grains. Numerous tiny needles of sillimanite are often developed from the sericite (sometimes they were derived directly from muscovite plates) and in some cases are entwined together to constitute most of the mottles or bundles.

These mottles form the “flowers” that are observable in hand specimen. Sillimanite also originates directly from biotite. Some zircon occurs.

F. GRANITE AND GRANITE GNEISS OF THE MIDDLE BALTORO VALLEY.

54 PD-Mu. – Leucogranite; in the floating moraine of the Chagaran glacier, tributary of the Muztagh glacier, altitude 4450 m.

The rock is a rather fine-grained and uniform granite, composed of quartz, plagioclase and potash feldspar, with small amounts of biotite and muscovite. The quartz and potash feldspar are allotriomorphic, while the plagioclase
Tends to be idiomorphic. The texture as a whole is transitional between that of a granite and a granite gneiss. Some plagioclase and potash feldspar crystals occur as phenocrysts, or porphyroblasts. The quartz individuals are aggregated in areas which are sometimes quite large. The plagioclases are almost always zoned, mostly rhythmically, and possess a variable internal composition of 20% An. They almost always include numerous quartz grains and plates of muscovite. The latter are sometimes poeciloblastic, and are usually oriented in definite planes within the host. Zircon inclusions sometimes occur.

The rock has a porphyroblastic texture due to the presence of a few well-developed feldspar individuals in a ground mass of medium-small grain-size. The ground mass is composed of quartz, plagioclase with a composition of about 20% An (ny = o of quartz; angles of extinction of albite twins in the zone perpendicular to (010) = 3-4°), and potash feldspar. The plagioclase are almost always turbid due to very minute black inclusions of iron oxides which remain from the transformation of biotite, some of which remain as inclusions. None of these three sialic minerals shows any tendency to idiomorphism.

Biotite is very scarce, while muscovite, other than that included in the plagioclase, is rare.

54 PD-Uz. - Gneissic leucogranite; near Urdukas, near the middle of the Baltoro glacier. (Analysed rock). The rock has a porphyroblastic texture due to the presence of a few well-developed feldspar individuals in a ground mass of medium-small grain-size.

Here and there large individuals of plagioclase and potash feldspar (microcline) are developed. Both are poeciloblastic, the first enclosing quartz, the second muscovite.
and the second enclosing quartz and plagioclase. The plagioclases include muscovite crystals which are often disposed in definite directions.

The potash feldspar sometimes encloses the plagioclase and after complete substitution inherits the inclusions of quartz, muscovite and iron oxides. The latter are sometimes distributed in such a way as to simulate a zoning in the potash feldspar.

_Biotite_ and _muscovite_ are rather scarce.

### 54 PZ-205. — Leucogranite; _in the left-hand moraine of the Baltoro glacier, 3-4 km upstream from Urdukas._

The rock corresponds, macroscopically, to a medium-grained granite with a rather gneissic texture, and containing biotite-rich mottles.

Some garnet is also visible.

Like the other granites described above (54 PD-Mu and -Uz) it is composed of quartz, _plagioclase_ with a composition of about 20% An, and _potash feldspar_.

The textures are also analogous. However, in this rock plagioclases, in some cases, appear included in quartzose areas. Also characteristic is a minute granulation of quartz, feldspar and muscovite lamellae occurring around the edges of larger crystals. Their presence can probably be described to cataclasis followed by recrystallization.

_Biotite_ is rather scarce and lacking in idiomorphism.

Some _garnet_ is also present.

### 54 PZ-206. — Leucogranite; _in the left-hand moraine of the Baltoro glacier, 3-4 km upstream from Urdukas._

In hand specimen the rock appears to be a light-coloured granite, containing small biotite plates while here and there more well-developed quartzose mottles are visible, and are usually distributed in a definite direction. Under the microscope the rock is seen to be analogous to sample 54 PZ-205; it differs however, in the presence of some notably more well-developed feldspar and quartz individuals, and so approaches, in texture, samples 54 PD-Mu and -Uz.

Large crystals of potash feldspar (often microcline) include both quartz and plagioclase, while large _plagioclases_ include both the potash feldspar and the other plagioclases, which have a more sodic composition. It is not clear whether the plagioclase has substituted for the potash feldspar, or vice versa. Also of relevance is the fact that these large plagioclase crystals, however regularly twinned, contain areas with notably diverse extinctions, as if complete
homogenisation of the individual was not achieved; generally the areas with greater birefringence occur as an aureole around the included minerals.

Some well-oriented muscovite inclusions within the plagioclases continue beyond the limits of one plagioclase and penetrate other plagioclase individuals with diverse orientation.

54 PZ-207. – Leucogranite with garnet; in the left-hand moraine of the Baltoro glacier, 3-4 km upstream from Urdukas.

The rock has a medium to medium-small grain-size and at some points biotite is clearly oriented. Small garnets of almandine type are very common.

Under the microscope the rock is seen to be very similar to sample 54 PZ-205; however, the very fine granulation of quartz, feldspar and biotite is lacking, while a subparallel trend of the biotite is fairly evident, even though some plates are disposed transversely to this trend.

A certain amount of muscovite accompanies the biotite.

54 PZ-208. – Pegmatitic aplite; in the left-hand moraine of the Baltoro, 3-4 km upstream from Urdukas.

The rock is a rather fine-grained pegmatite containing evident movement surfaces along which sericite is developed.

Under the microscope the rock is seen to be fundamentally of aplitic texture, containing grains of plagioclase with a composition of about 10% An, quartz, potash feldspar and muscovite. The feldspars, and especially the plagioclases, are turbid, due to the presence of minute grains of iron oxides and sericite, probably of epimetamorphic origin.

At some points wide areas of microperthite and micropegmatite are developed. Areas composed of plagioclases with a scarcely perceptible twinning and including numerous quartz grains are intimately associated with the micropegmatite. This is not a myrmekitic aggregate.

At some points plagioclases are in the process of transformation to orthoclase or microcline or aggregates of plagioclase, potash feldspar and quartz. In the latter the various potash feldspar grains have almost the same orientation. It is clear that the micropegmatitic areas are formed by progressive substitution of the plagioclase by the potash feldspar. Finally, these unite into an almost homogeneous single individual with numerous quartz inclusions aligned in a definite direction within the host.

In this rock the complete homogenization of the micropegmatitic areas is only rarely achieved.
The micropegmatites must thus form by a metasomatic process, while the quartz represents a relict of the pre-existing rock.

54 PZ-209 and -209a. – Pegmatite in contact with arteritic biotite schist; in the left-hand moraine of the Baltoro, 3-4 km upstream from Urdukas.

The sample, from which two thin-sections were cut, is composed of a typical coarse-grained pegmatite, with margins of smaller grain-size, of aplitic type. This stringer very clearly cross-cuts the arteritic migmatite composed of biotitic schistose bands alternating with subparallel sialic bands. Near the contact the stringer is rich in tiny garnets of almandine type.

Under the microscope the aplitic portion of the stringer (54 PZ-209) is seen to be very similar to the leucogranites of type 54 PZ-205. In this case some large quartz individuals include portions of potash feldspar and some biotite plates. Moreover, here and there one finds very large individuals of potash feldspar, of plagioclase and also of quartz.

The migmatitic biotite schist contains bands very rich in biotite alternating with quartzo-feldspathic bands in which the biotite is present as a few, small plates. In the most micaceous bands the components — biotite, quartz, and plagioclase with a composition of 20 - 25% An — have a large grain-size, while potash feldspar is practically absent, except where the pegmatite-aplite stringer is in direct contact with the schist.

The sialic bands have a smaller grain-size; moreover, notable quantities of potash feldspar are only present in thicker bands, while in the thinner ones this mineral is scarce enough to possibly consider it as accessory, or only a little more than accessory.

Apatite and zircon, but especially the former, are much more frequent in the biotitic bands than in the sialic ones.

54 PZ-210. – Porphyroblastic granite gneiss; in the left-hand moraine of the Baltoro glacier, about 3 km upstream from Urdukas. (Analysed rock).

In hand specimen the rock recalls some of the K² gneiss although in this case the orientation of the biotite is less evident. The rock is heterogeneous in composition; some portions are rich in biotite and contain medium-sized feldspars, while other portions, are essentially sialic due to the concentration of large feldspar porphyroblasts.

This rock is similar in some respects to the Baltoro granite described above, except for the greater abundance of femic minerals, essentially biotite.

There exist, however, notable differences in texture. In the interstices
between the well-developed crystals of plagioclase, with a composition of 30% An (nγ almost equal to ε of quartz; maximum angles of extinction of albite twins in the zone perpendicular to (010) = 120° approximately), of potash feldspar (microcline and microperthite) and of quartz, one finds minute associated individuals of plagioclase and quartz.

In the vicinity of the potash feldspar porphyroblasts the small plagioclase individuals begin the process of myrmekitisation of the plagioclases. Firstly, the various plagioclases include rounded grains of quartz; then, the many plagioclase individuals of the ground-mass accumulate into fan-shaped areas, with a homogenous composition, in which the form and disposition of the quartz is characteristic of a myrmekitic aggregate.

During the first stage of the process the plagioclases, with their quartz inclusions, are exactly similar to the poeciloblastic feldspars which are very common in the gneisses and granites of this region.

The biotite is present in well-developed plates.

Among the accessories, apatite and orthite are common.

54 PZ-211. – Porphyroblastic granite gneiss; in the left-hand moraine of the Baltoro glacier, 3 km upstream from Ursukas.

In hand specimen this rock seems to be completely analogous to sample 54 PZ-210. However, under the microscope it is seen to be a little richer in quartz and poorer in potash feldspar.

In terms of the texture, it is a transitional facies between the granite gneiss recorded above and the more common leucogranites of the Baltoro, since the plagioclase-quartz aggregate is here reduced to a few lenses or thin bands. The oriented disposition of the biotite is, on the whole, quite evident.

54 PZ-212. – Biotite-amphibole-quartz diorite; in the left-hand moraine of the Baltoro glacier, 3 km upstream from Ursukas.

The rock is very dark, with a medium to fine grain.

The principal constituents are plagioclases, amphiboles, biotite and quartz.

The plagioclases, corresponding to an andesinic mixture with a composition of 35-40% An (albite-Carlsbad twins), occur as perfectly fresh, more or less idiomorphic, well twinned, individuals of constant composition, with rare inclusions of quartz, biotite and amphibole.

The quartz is present in very minor quantities but is rather abundant for a rock so rich in femic minerals.
The amphibole is pleochroic in very light colours; it must correspond to an actinolite transitional towards green hornblende.

The biotite is associated with the amphibole; in some portions of the rock the plates show a certain subparallel disposition, not strong enough to be called a schistosity.

Among the accessory minerals apatite is very abundant, and sphene is also common.

54 PD-501. – Leucogranite; in the lower Muztagh glacier valley. (Analysed rock).

The rock is medium to medium-large grained and uniform, in contrast to other granitic rocks of the Baltoro (54 PD-Uz).

The three fundamental components, plagioclase, potash feldspar and quartz, are present as equidimensional individuals though only the plagioclases tend to assume true form. Mica also assumes notable dimensions, either in individuals or in aggregates.

The plagioclase, corresponding to an oligoclase mixture of about 25% An, almost always includes large muscovite plates which assume poeciloblastic form. Some cross-cutting muscovite plates disturb neighbouring plagioclase crystals with diverse orientation.

The muscovite inclusions are sometimes accompanied by very small carbonate crystals.

Inclusions of quartz are rare and are usually represented by large rounded grains. Among the inclusions, some beautiful elongate prisms of zircon are relatively common.

Potash feldspar is most irregular in form, and sometimes shows a faint net-like twinning. It possibly includes the same minerals as are found in the plagioclases, though it is usually either free of inclusions, or includes small plagioclases and biotite.

54 PD-502. – Porphyroblastic augen gneiss; in the right-hand moraine of the Chagaran glacier, tributary of the Muztagh glacier.

The rock contains large feldspar crystals, up to 4-5 cm in length, disposed in a random way in a biotitic quartz-feldspathic matrix of medium grainsize in which the various constituent minerals are distributed rather irregularly, but with a certain degree of orientation. The feldspar porphyroblasts contain numerous biotitic inclusions.
PETROGRAPHIC THIN SECTIONS

PLATE A

K² AREA

Graphite phyllite → biotite paragneiss → augen gneiss → granite gneiss series.

The six microphotographs show the fundamental lithotypes of the phyllite → granite gneiss series outcropping in the upper basin of the Godwin Austen glacier.

The first five terms of the series have very similar chemical composition, (corresponding to quartz-dioritic or granodioritic types of Niggli's classification) and are interpreted as the product of progressive mineralogical and textural transformation of pelitic sediments (isochronal granitization).

The enlargement of the six samples is the same (x 5,5; crossed nicols).

Fig. 1 – Graphite-biotite phyllite; on the moraine near the K² Base Camp (54 PD-21).

Quartz and plagioclase with a composition of 25-30°, An are the most common minerals of the rock. Very small biotite lamellae occur along refolded or sharply bent surfaces.

Fig. 2 – Fine grained biotite-gneiss; in the right hand lateral moraine of the De Filippi glacier (54 PD-6).

This rock exhibits coarser grain than that of the phyllite; also the plagioclase is more calcic (40°, An). At this stage of transformation potash feldspar appears.

Fig. 3 – Fine-grained biotite gneiss with porphyroblastic plagioclase; in the small saddle at the base of the west spur of Falchan Kangri (54 PD-70).

On the matrix (similar to the paragneiss shown in fig. 2) small porphyroblasts of plagioclase 40°, An occur. They include thin flakes of biotite and muscovite. The potash feldspar is present only in the matrix.

Fig. 4 – Biotite gneiss with feldspar porphyroblasts; in the moraine near the K² Base Camp (54 PD-24).

Only small portions of the rock are fine-grained. The feldspars (plagioclase 40°, An and K-feldspar) form well-developed crystals.
Fig. 1 – *Granite gneiss; at the foot of the south wall of K2, altitude approximately 5000 m (54 PD-1).*

The texture of the rock is still heterogeneous because of the presence of fine-grained patches of quartz and feldspar and of large crystals of microperthite, plagioclase 28-30\(^\circ\) An and biotite.

Fig. 2 – *Granite gneiss; at the foot of the south wall of K2, altitude approximately 5000 m (53 PD-2).*

The texture of the rock is more homogeneous and the biotite scarcer. The plagioclase, more sodic (25\(^\circ\) An), includes the remains of andesine plagioclase. The chemical composition of this rock is more sialic than other terms of the phyllite-granite gneiss series. It could represent the initial product of a local process of anatexis.

**BALTORO GRANITES**

Fig. 3 – *Granite; in the Chagaran glacier (Muztagh valley), altitude approximately 4450 m (54 PD-Mu)* (Crossed nicols; x 40).

The oligoclase crystals include small poikiloblastic muscovite lamellae. This is one of the most frequent features shown by the plagioclase of the Baltoro granites.

Fig. 4 – *Granite; in the Chagaran glacier (Muztagh valley), altitude approximately 4450 m (54 PD-Mu)* (Crossed nicols; x 40).

Clearly zoned crystal of potash feldspar. This is probably attributable to the variable content in Ab.
IX. BIBLIOGRAPHY


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PLATES
General view of the Baltoro glacier from Concordia. On the right side of the foreground the Godwin Austen glacier, on the left side the Upper Baltoro glacier.
View of the Khalkhal and Doksam ridges. On the right side of the foreground the confluence of the Suvon and Godwin Austen glaciers, on the left side of the background the confluence of the Godwin Austen and Baltoro glaciers.
The 

Fig. 1
View of the north-east slope of Falchan Kangri and the east side of the Falch Kangri-Gasherbrum ridg

Fig. 2
View of the north-west slope of Falchan Kangri.
The two glaciers are the North-west Falchan glacier (on the right side) and the North-northwest Falchan glacier.
View of the west side of Pachpan Kanya (8051 m).
Calc-schist of the Savoia Limestone, at the foot of the west slope of Falchan Kangri.
Gasherbrum IV and the outlet of the valley of the West Gasherbrum glacier, from Concordia.
Chochordin Peak (7003 m) on the left side, and Gasherbrum V (7321 m),
from the Conway saddle (6000 m).
The basin of the South Gasherbrum glacier. The principal peaks are composed of the white and grey Aghil Limestone. The slopes on the left and right sides are made up of black limestone and shales of the Shaksgam Formation.
Fig. 1 - *View of the Upper Baltoro glacier. Baltoro Kangri in the background.*

Fig. 2 *West slope of Baltoro Kangri.*
Fig. 1 - View of the head of the Abruzzi valley.

Fig. 2 - The Conway saddle (6000 m) from the Abruzzi glacier.
Gasherbrum I (8068 m) from the Conway Saddle (6000 m). See the attitude of the limestone beds of the Shaksgam and Aghil formations.
Outlet of the valley of the Savoia glacier.

On the right side the Gilkey-Puchoz spur, on the left side the contact between the Savoia Limestone and the Khalkhal Sandstone. (See fig. 6).

Summa-ri (7263 m) in the Savoia Glacier basin is mostly composed of micaschist with andalusite.

View of K3 (8611 m) and the base camp of the expedition at 5000 m above sea level.
Fig. 2
Bedded structure and jointing within the porphyroblastic gneiss (K² Gneiss) near the 2nd camp on the Abruzzi spur (right side).

The glacier below is the Godwin Austen glacier.
In the back-ground the Khalkhal ridge and the Marble peak.

PLATE XVI

Fig. 1
South-east slope of K² and Abruzzi spur (arrow).
The east slope of K2. Below the upper pyramid the ice-coated 'shoulder' of the mountain.
Fig. 1
The bedded structure of the rocks in the upper pyramid of $K^2$.
(From V. Sella photograph of 1909).

Fig. 2
The upper pyramid of $K^2$.
See geological details in the plate XIX.
Geological structure of the base of the upper pyramid of K2. The arrows point out the same rocky island as reference. (See also plate XVIII).
Fig. 1
The crest from $K^2$ to Marpophong-la.
On the left side the "shoulder" of $K^2$.

Fig. 2
The north wall of $K^2$
and the $K^2$ glacier in the foreground.
Fig. 1
Agmatite outcrop with acidic matrix at the foot of the western spur of the Angelus peak (K2 mass).

Fig. 2
View of Skyang Kangri (7544 m) from the upper Godwin Austen glacier. See the geology in fig. 45.
Fig. 1

View of Skyang-la (6233 m) from the upper Godwin Austen glacier.

Fig. 2

Sella saddle (6180 m) and the marble crest. (See fig. 47).
The upper valley of the Godwin-Auten glacier and the ridge to the south of Shyang-la from 4th camp K'.
PLATE XXV

Fig. 1
Chogolisa Kangri
from the north-east bank
of the Upper Baltoro glacier.

Fig. 2
Vigne valley
from the Abruzzi spur of
North side of Mitre peak where passes the contact between the granite (right side) and the metamorphic rocks. See fig. 48.
PLATE XXVII

Fig. 1
North side of Masherbrum (7821 m) from the Baltoro glacier.

Fig. 2
The summit of Masherbrum. Telephoto from the Baltoro glacier.
Masherbrum peak from west. On the right side the south slope of the ridge.
The Doksam ridge from the Baltoro glacier. On the left side the Fan valley and the False Crystal peak (6237 m).
Fig. 1
_The east slope of the White Fan valley._
Marble and dark schist show tectonic contacts.

Fig. 2
_Traces of overthrusts_ on the wall to the south of Crystal peak.
Fig. 1 - Tectonic contacts on the south side of Marble Peak.

Fig. 2
Marble Peak from Concordia.

Table XXXIII

Mustagh Tower (7273 m) made up of gneiss, and Dre glacier; on the foreground the ice pinnacles of the Younghusband glacier.
The upper part of the Muztagh Tower.
Fig. 1 - The valley of the Younghusband glacier.

Fig. 2 - The mountains to the west of the lower Younghusband glacier.
Fig. 1
The granite spire of Ainablak in the Trango valley.

Fig. 2
Wall of granite in the Dange valley.
Spires of granite in the lower Trango valley.
Fig. 1
The south wall of Karphogang made up of granite striped with lenses of gneiss.

Fig. 2
The south side of the Baltoro valley downstream Urdukas. Granitic landscape.

Plate XXXVIII

"Castles of granite in the northern side of the Baltoro valley and the outlet of the Dunge glacier.
On the left side the Tramgo Tower."
Bialetu massif from a slope east of Urdutas.
The small valley below the Pauu Towers (on the right side) where run the contact between the green schists (on the left side) and the Baltoro granite (on the right side).
The valley of the Litigo glacier and the set of parallel joints in the granite simulating the bedding.
Fig. 1 - Triangular shaped peaks in the lower valley of the Baltoro glacier.

Fig. 2 - Fractioning of granitic landscape: northern slope of the middle Baltoro valley.
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A. DESIO - C. FRANCALANCI

Tectonic sketch-map of K²

- Faults
- Anticlines
- Synclines
- Traces of layers
- Dip of layers
Stampato
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