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# An Introduction to the Geological Map of the Area between Hunza and Baltistan, Karakoram-Kohistan-Ladakh-Himalaya Region, Northern Pakistan
## (Scale 1:150,000)

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## Abstract

These notes introduce a new geological map at 1:150,000 scale of the mountainous zone adjoining the regions of Hunza and Baltistan in the north-western Himalayan syntaxis, Pakistan (Fig. 1). It covers approximately 13,000 km$^2$ and includes the central granitoid belt and the southern metasedimentary complex of the Karakoram range, volcano-sedimentary and igneous formations of the Kohistan and Ladakh island-arc units, and the northern tip of the gneissic and granitic Himalayan spur.

The description of each fully illustrated formation is followed by a comparative presentation of the metamorphic and structural evolution of the major units, underlining similarities of their recent development.

The notes also comprise a lexicon of about a hundred geological formations/units, plutons, and the main tectonic lines of the map.

**Key words**: Geological map, Karakoram, Kohistan, Ladakh, Himalaya, Pakistan

## Introduction

THE area covered by the present map (in pocket) is located on the right bank (north) of the Indus River, along the watershed of two of its major tributaries: the Hunza River to the west, and the Shigar River to the east (Fig. 2 and annex. 6). It covers some of the main glaciers of the Karakoram such as the Biafo, Hispar, and Chogo Lungma that form some of the most mountainous and rugged regions of the planet (Fig. 2, Table 1). However, communication means have greatly improved since the exploratory times. These include beside other developments, the building of the Karakoram Highway (KKH) and the road to Skardu in the seventies, the creation of numerous breath-taking dirt roads, and the almost regular flights to Gilgit and Skardu. Field work was mainly carried out by the authors (Annex. 1) in 1986 (Biafo-Hispar, PLF), 1987 (Distaghil, AP), during two scientific expeditions of the Club Alpin Français, and from 1991 to 1998, with contributions of U. Pognante and P. Benna in 1991 (Turmik valley, PLF), and F. Rolfo, Y. Lemennicier, B. Lombardo and P. Pertusati in 1993 (Chogo Lungma area, PLF and AP). Following data processing problems, this map, initially ready in 1998, has only been printed in 2001 through the courtesy and participation of the Geological Survey of Pakistan. It has thus been possible to make it more precise and complete it in its eastern part using additional field data acquired during 1998 and 1999 by one of the authors (AP) with the help of Yann Rolland, Stéphane Guillot and Gweltaz Mahéo. In addition, three theses and a geological map of the Chogo Lungma glacier have been presented (Rolfo, 1994; Lemennicier, 1996; Rolfo et al., 1994; Rolland, 2000). The present text is the English translation from the authors' original manuscript in French.

Previous geological mapping started with preliminary traverse mapping at 1:500,000 scale

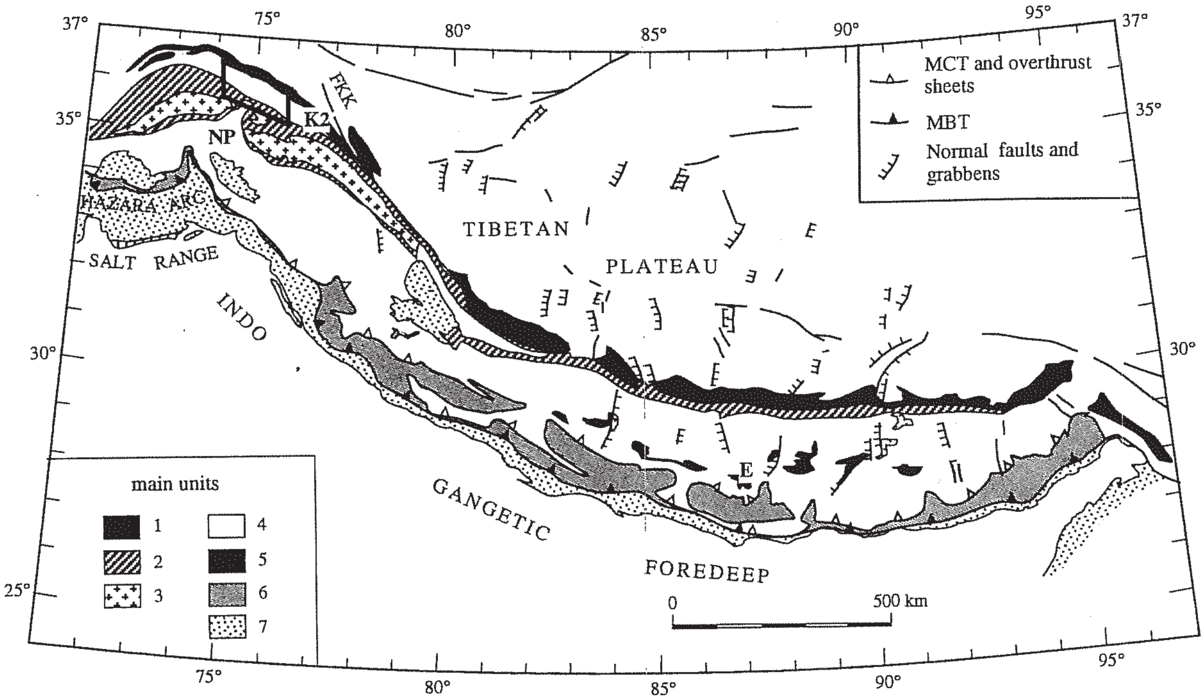



FIG. 1. Himalaya sketch map (modified from Seeber and Pêcher, 1998). Tectonic units are 1: TransHimalaya plutons (Cretaceous); 2: Kohistan and Ladakh Arc (Cretaceous), Indus Suture flysch and ophiolites (Cretaceous), Indus molasse (Eocene); 3: Karakoram plutons (Cretaceous); 4: Tethyan basement and sedimentary series (Indian platform and outer margin, Paleozoic to Eocene); 5: Leucogranites (Miocene); 6: Lesser Himalaya sediments (Proterozoic to Eocene); 7: Siwalik molasses (late Eocene to present) and Intra-mountainous basins (Pliocene and Quaternary). Area covered by the present Hunza-Baltistan map is located, between Nanga-Parbat (NP) and K2 summits.

*Carte schématique de l'Himalaya (d'après Seeber et Pêcher, 1998, modifié). Les unités tectoniques sont 1: plutons du Transhimalaya; 2: Arc volcanique du Kohistan-Ladakh (Crétacé), flyschs et ophiolites de la suture de l'Indus (Crétacé), molasse de l'Indus (Eocène); 3: Plutons du Karakoram (Crétacé à Miocène); 4: Substratum téthysien et séries sédimentaires (plate-forme et marge indienne, Paléozoïque à Eocène); 5: Leucogranites (Miocène); 6: Sédiments du Moyen Himalaya (Protérozoïque à Eocène); 6: Molasse des Siwaliks et du Gange (Eocène terminal à actuel) et bassins intramontagneux (Pliocène-Quaternaire). La zone couverte par la présente carte Hunza-Baltistan est délimitée, entre les sommets du Nanga-Parbat (NP) et du K2.*

along the Indus and Hunza valleys, by an Australian-Pakistan team during the summer of 1951 (Ivanac et al., 1956). Mapping was mainly contributed by Italian teams led by Ardito Desio, since the 1929 Duke of Spoleto's expedition (Desio, 1964; Zanettin, 1964; Desio & Zanettin, 1970; Casnedi, 1979; Desio et al., 1985), and by Austrian teams working on the eastern Karakoram (Gattinger, 1961, with a 1:1,000,000 general map and a detailed coloured block-diagram from Skardu to Gasherbrum), the western Karakoram and Hindu Kush (Gamerith, 1976 & 1979).

The pioneer work of H.J. Schneider (1957, 1960) recognised without naming them the five main geological zones of Kohistan, Shyok suture, Karakoram metamorphic complex, axial batholith and northern sedimentary Karakoram. Gattinger (1961) in the Shigar-Braldu region, distinguished an older metamorphic and granitization phase cut by the younger plutonic body of the Baltoro granite. Detailed studies and mapping of limited sectors have been performed in the PhD thesis of Hanson on the Shigar valley (Hanson 1986 & 1989), and in the Master's thesis of Verplanck on the Stak valley


FIG. 2. Main rivers and reliefs in the mapped area. Light gray and medium gray area bounded by the 5000 m and 6000 m contours respectively. All the more than 6000 m and 7000 m peaks have been reported.

*Principales rivières et zones hautes dans la zone cartographiée. Les plages gris clair et gris sombre sont limitées respectivement par les courbes 5000 et 6000 m. Tous les sommets de plus de 6000 m et plus de 7000 m ont été reportés.*

(Verplanck, 1987); they have been incorporated for the regions that we have not visited. A few geological sketch maps at smaller scales have also been helpful in the W and SW border sectors of the present map, in particular those of Pudsey (1986) in the Chalt region, Butler et al. (1992) in the upper Phuparash valley, and Gamerith (1976 & 1979) north of Gilgit. In addition, a geological map of North Karakoram from the Chapursan valley to the Shimshal pass at a scale of 1:150,000, has recently been published (Zanchi & Gaetani, 1994). The two

TABLE 1. Highest mountains of the map (adapted from Neate, 1989).

| Map Rank | Name | Height in metre | Geological unit | Pakistan Rank | World Rank |
|---|---|---|---|---|---|
| 1 | Distaghil | 7885 | Karakoram | 8 | 22 |
| 2 | Kunyang Chhish | 7852 | Karakoram | 9 | 25 |
| 3 | Rakaposhi | 7788 | Kohistan | 11 | 29 |
| 4 | Batura I | 7785 | Karakoram | 12 | 30 |
| 5 | Batura II | 7762 | Karakoram | 13 | 32 |
| 6 | Batura III | 7729 | Karakoram | 16 | 39 |
| 7 | Trivor | 7720 | Karakoram | 17 | 36 |
| 8 | Distaghil E | 7696 | Karakoram | 20 | 48 |
| 9 | Shispar | 7619 | Karakoram | 23 | 59 |
| 10 | Batura IV | 7592 | Karakoram | 25 | 62 |
| 11 | Yazghil dome | 7559 | Karakoram | 26 | 66 |
| 12 | Batura V | 7531 | Karakoram | 28 | 74 |
| 13 | Pumari Chhish | 7492 | Karakoram | 30 | 80 |
| 14 | Pasu | 7478 | Karakoram | 34 | 87 |
| 15 | Malubiting W | 7452 | Kohistan | 36 | 90 |
| 16 | Haramosh | 7406 | Himalaya | 41 | 104 |
| 17 | Batura VI | 7400 | Karakoram | 44 | 107 |
| 18 | Ultar I | 7388 | Karakoram | 48 | 112 |
| 19 | Pumari Chhish SE | 7350 | Karakoram | 56 | 133 |
| 20 | Mohmil Sar | 7342 | Karakoram | 59 | 137 |
| 21 | Duanasir | 7329 | Karakoram | 64 | 143 |
| 22 | Malubiting central | 7291 | Kohistan | 77 | 162 |
| 23 | Baintha Brakk (Ogre) | 7285 | Karakoram | 79 | 164 |
| 24 | Diran | 7266 | Kohistan | 87 | 176 |
| 25 | Hachinder Chhish | 7163 | Karakoram | 95 | 221 |
| 26 | Latok 1 | 7145 | Karakoram | 99 | 231 |
| 27 | Kampire Dior | 7143 | Karakoram | 100 | 232 |
| 28 | Latok 2 | 7106 | Karakoram | 103 | 252 |
| 29 | Ghenta | 7090 | Karakoram | 111 | 265 |
| 30 | Spantik (Golden peak) | 7027 | Karakoram | 124 | 304 |
| 31 | Sangemarmar | circa 7000 | Karakoram | 129 | 321 |
| 32 | Laila | 6986 | Himalaya | 132 | |

compilation maps by Searle (1991) and Searle & Khan (1996) have been of limited use, because of their compilational nature. A recent map at 1:750,000 (Tahirkheli, 1996) gives the general geological framework of the region. A preliminary presentation of the 800 km$^2$ of the Chogo Lungma to Turmik area, covering the eastern part of the map, has already been published (Le Fort et al., 1995).

The present map is a direct continuation and overlaps the eastern half of the Zanchi & Gaetani (1994) map, at the same scale, but on a revised topography. In the field, we have used enlarged copies of the available toposheets: the 1:250,000 map of the Swiss foundation for alpine research (1990), the 1:150,000 sketch map of the Hispar glacier by Bullock-Workman & Workman (1900 & 1908), the 1:100,000 map of the Chogo Lungma glacier by Kick (1964), the 1:100,000 Italian maps for the Turmik and Stak valleys (Lombardi, 1957). However, for sheets no. E3 and F3 we have enlarged the 1:253,440 map of Shipton's 1939 expedition (Mott, 1950), for sheets no. D4 and D5 in Stak valley we have reduced Lombardi's map (1957), for sheets no. D4 and E4 along the Chogo Lungma glacier we have reduced Kick's map (1964), and for sheet no. G4 we have enlarged the Swiss map (1990). The accuracy of these base maps, except for the outstanding Shipton's one (Mott, 1950), is not always good and sometimes irreconcilable from one to another;

some of the original maps have thus necessitated approximate corrections in the absence of reliable detailed documents.

We have had access to a limited number of SPOT satellite scenes, unfortunately covered with too much fresh snow at high altitude (197-277, 4-7-1990; 198-278, 15-9-1990). A splendid USGS Landsat MSS colour image coverage came out in 1997: a satellite image of the whole of Pakistan at a scale of 1:2,000,000 (number I-2587-A) and seven sheets at 1:500,000 scale, of which map I-2587-C covers the concerned region. We have used it for control and help in the most remote sections.

Names and altitudes usually follow those of the local topographic sheets and compiled mostly from aerial surveys with limited ground checks. Only in a few cases, more common spellings have been retained, and when useful, additional names have been borrowed, from the Swiss map (1990), or from the trekking guides of Shaw and Shaw (1993) and Mock & O'Neil (1996). However, local names given by the maps are hardly satisfying and seldom reflect the exact denomination and local pronunciation (cf. Skyhawk's work in the Hispar basin).

Even in a country of such relief (Fig. 2, Table 1) and of such arid climate, the contrast between different formations is not always obvious in the landscape, so that it remains difficult to relate actual observations. Nevertheless, we feel that most of the contours drawn in plain line using outcrop observation, landscape extrapolation, and satellite imagery, are reasonably reliable.

## Geological Framework

The area comprised in the map groups the three major units of the Himalayan collision zone (Fig. 1): the Karakoram mountain range, the Kohistan-Ladakh island-arc, and the Nanga-Parbat-Haramosh massif, NW protruding end of the Himalayan mountain range (Tahirkheli, 1996).

### *The Karakoram mountain range*

The Karakoram mountain range is built on Peri-Gondwanian continental crust rifted away from Gondwana during Late Palaeozoic, and accreted to the southern Eurasian margin during the upper Mesozoic (Gaetani et al., 1990). It is bounded to the south by the Shyok suture or Main Karakoram Thrust (Tahirkheli et al., 1979); whereas to the north, the limit, less conspicuous, lies along the Tas Kupruk zone of Kafarskyi & Abdullah (1976) and its eastward prolongation, associated with alkaline femic volcanics (Gaetani et al., 1996; Zanchi et al., 1997) that may represent the Palaeo-Tethyan suture, separating Karakoram from Hindu Kush-Pamir. Following Gansser (1964), the Karakoram unit is usually subdivided into three main parallel sub-units, from north to south:

1. The northern sedimentary belt

The northern sedimentary belt is made up of a pile of thrust sheets (Zanchi & Gaetani, 1994). The most complete succession consists of a 5 to 7 km thick pile of sediments, discordant on a pre-Ordovician crystalline basement (Le Fort et al., 1994), and extending mostly under marine conditions up to the earliest Cretaceous. Local marine Upper Cretaceous sediments are followed by very discontinuous continental deposits (Zanchi & Gaetani, 1994). Isolated plutons intrude these sediments; they form a composite group of metaluminous and peraluminous granitoids, of mid-Cretaceous age (Debon et al., 1996). Metamorphism usually remains very weak, except around the granitoid intrusions mentioned above or at the contact with the following batholith:

2. The Karakoram batholith

The Karakoram batholith or central plutonic belt (frequently named "axial batholith" after the axial zone IV of Schneider, 1957). It covers about 30% of the range. Four intrusive episodes have so far been recognised in it: a large mid-Cretaceous alkaline, sub-alkaline, and calc-alkaline set of plutons (Koz Sar, Darkot Pass, and Hunza plutonic units), a minor Eocene episode of gabbro, adamellites and granites (Batura plutonic unit), a Miocene sub-alkaline episode mainly represented by the Baltoro granite;

3. The southern metamorphic belt

The southern metamorphic belt as the northern sub-unit, it is also predominantly made up of sedimentary series, but the metamorphism accompanying the polyphased deformation usually reaches the amphibolite grade facies, and even, locally, the granulite one (Rolland, 2000, 2001b). The least metamorphosed areas lie to the west and to the east, outside of this map. To the west, in the region of Darkot, Permian (Hayden, 1915; Dickins, 1952; Ivanac et al., 1956) and Triassic (Le Fort & Gaetani, 1998) fossiliferous beds have been discovered. To the east, in the Thalle valley region, Ordovician fossiliferous limestones have recently been found (Rolland & Pêcher, 1999; Rolland et al., 2001a). The southern metamorphic belt also contains bodies of orthogneiss of very varied dimension, the largest ones forming dome structures within the metasedimentary formations. Finally, the belt is also intruded by a limited number of small Mio-Pliocene plutonic bodies, usually leucocratic and granitic (Hasanabad, Nagar, Sumayar), but also alkaline in the case of the Hemasil syenite.

Of these three sub units, only the two southern ones lie within the area covered by the present map.

*The Kohistan-Ladakh unit*

The Kohistan-Ladakh unit formed of the two large areas stretching on both sides of the Nanga Parbat-Haramosh massif, is attributed to a large section of an oceanic island arc, since the pioneer work of Tahirkheli (1979) and Tahirkheli et al. (1979). The island arc is usually considered to result from the north-dipping subduction of the Tethys oceanic floor during the northwards drift of the Indo-Pak continental plate. Khan T. et al. (1994) and Treloar et al. (1996) have identified back-arc formations in the northern part of Kohistan. Rolland et al. (2000, 2001) have shown that this back-arc basin extended eastward in Ladakh, with geochemical signatures suggesting the eastward progressive implication of the Asian continental margin. This back-arc zone forms the greater part of the reworked and sliced terrains of the Shyok suture. Recently, on poorly convincing geochemical arguments, Khan A. et al. (1997) have suggested a south-dipping subduction zone during most of Cretaceous times, until collision with Karakoram.

The Kohistan-Ladakh unit may provide the most complete exposed section of an arc crust, from its upper mantle base to its subaerial volcanics (Tahirkheli et al., 1979). A revised lithostratigraphy of the volcanic and sedimentary formations of the Kohistan arc have been propounded by Treloar et al. (1996) and help them to pinpoint the four major phases of magmatism, linked to extension phases that they date as Middle and Late Cretaceous, Eocene, and Oligo-Miocene. The two first phases have been deformed and the plutonics orthogneissified. Up till now, the equivalence between Ladakh and Kohistan was broadly assumed and based on large scale correlation. We have mapped the uninterrupted connection between Kohistan and Ladakh for the first time, and showed the remarkable continuity of the meta-sedimentary horizons.

*The Himalayan unit*

The Himalayan unit is represented by the north-south promontory of the Nanga Parbat-Haramosh massif. Culminating at 8,125 m south of the map, it consists of a wide variety of high grade gneisses in which Madin (1986) has distinguished a large western anticlinorial area of orthogneisses, the Iskere gneisses, covered by a thick succession of meta-volcanic and meta-sedimentary para-gneisses, called the Shengus gneisses. However, due to their intrication, the "basement-cover" relationship remains debatable. Ages obtained by Chamberlain et al. (1991), Zeitler et al. (1989, 1993), Schneider et al. (1999a, 1999c) and also Treloar et al. (2000 a & b) show the complexity of the evolution of the zone in which an old Precambrian magmatism and metamorphism have been largely obliterated by the Himalayan thermal evolution probably starting before 40 Ma, culminating around 20 Ma, but continuing up to recent Neogene.

## Description of the Formations

*Quaternary formations*

The development of Quaternary formations around the glaciated areas as in the valleys is properly remarkable, being very diversified and very extensive. However, Quaternary formations form a world by itself, and it was beyond the scope of this work to give full justice to it. We have only made rough distinctions, trying to represent approximately the extension of the Quaternary in the areas that we have surveyed, especially around the places where the Quaternary formations tend to mask major contacts and/or evidences.

**F**: we have grouped fluviatile and lacustrine **alluvium** (Fig. 3). **Fz**: recent alluvium; major River beds and lowest terraces are distinguished when possible. **Fy**: stands for older and generally higher terraces often covered by irrigated cultivation; they are particularly well represented in Hunza, Gilgit, Shigar, and eastern Indus (Skardu) valleys. **Fx**: highest terraces, mapped on the left bank of the Gilgit River and along the Indus where they may lie more than 1200 m above the present level of the River (Thhwar and Rondu).

Special mention may be made of the Skardu basin in which the Late Cenozoic molasse sediments of the Bunthang sequence (**FyB**) reach approximately 1300 m (Cronin, 1989, Cronin et al., 1989). They comprise, above a basal discordant sandstone (around 50 m), a lower mudstone (around 300 m), middle fanglomerates (around 350 m), and an upper sandstone and mudstone sequence at the top (around 500 m). The sedimentological and paleomagnetic studies show that the flow structures are oriented to the NW, as nowadays, and that the sequence was deposited between 3.2 and 0.73 Ma, resulting from the damming of the Indus valley by the rapid uplift of the Nanga Parbat-Haramosh crystalline massif (ibid).

**J**: torrential fans, either active, or stabilised and covered by vegetation and culture. Some of them stretch on several square km (Gilgit fan, and fans of the Shigar valley)(see Derbyshire and Owen, 1990).

**Ez** and **Ey**: recent and old **screes** and **eluvial deposits**, only mapped when covering large slopes. Some major landslides have also been distinguished; some of them, such as on the left bank of the Shigar River, concern almost entire mountain slopes.

**G**: main **moraine** deposits. **Gx**: recent moraines; **Gy**: older moraines often covered by vegetation and cut by the recent streams. Eight glacial phases including three major ones, have been recognised in the Hunza valley by Derbyshire et al. (1984), Owen & Derbyshire (1989) and Derbyshire & Owen (1997), from the widespread Shanoz stage of earliest Pleistocene age, to the minor historical Pasu II stage. Huge glaciers (Fig. 4) occupied all the major valleys, including the Hunza, Gilgit, and Indus valleys down to Sazin-Shatial area, leaving behind many large till deposits (Desio & Orombelli, 1971; Burgisser et al., 1982; Shroder et al., 1989). The indurated Jalipur tillites along the Indus, downstream of the Hunza confluence, represent an early glaciation younger than 1 to 2 Ma (Shroder et al., 1989). In the region of Skardu, relics of a diamictite formation outcrop in the city and at the base of the Bunthang sequence. This Skardu (Karpochi) till (**GyK**) has been studied by Owen (1988) and Cronin et al. (1989) and could have been deposited during the Shanoz stage. **GyH**: humocky moraine, distinguished downstream from Skardu. The present day ice coverage is about minimum.

**D**: **sand dune**, most recent in the large Shigar and Indus valleys.

**Landslides**, rockslide, debris flows and avalanches are numerous all across the mapped area (see Hewitt, 1998), either actual or linked to the glacial retreat. They greatly contribute to the morphology of the valleys. Only some of the main ones have been drawn, for instance left bank of the Basha valley.

It is to be noted that, even nowadays, Quaternary deposits only come second to the extraordinary development of glaciated areas. A rough estimate of the area of the glaciers shows that they cover around 30% of the mapped zone. The glaciers have shown considerable fluctuations, including major advance around the turn of the century (Pasu II stage) and general retreat starting in the 1930's as mentioned by the international Karakoram project study (Goudie et al., 1984) in the Hunza area. The snow line ranges from 5100 to 5600

FIG. 3. Quaternary terraces: **A:** View downstream of the Shigar valley from the Goslo pass (on the path from Hemasil to the Ganto La). The Mango Gusar range lies in the background; the black spur to the left corresponds to the Dasu dome; the Chutrun limestones form the foreground cliff. The "Shigar lineament" follows the main Basha and Shigar valleys. The large Quaternary filling of the valley results from the damming of the Indus, downstream, by the fast rising Himalayan crystallines of the Nanga Parbat-Haramosh massif (PLF slide **OF70**, 30/5/92, 3520 m of elevation, oriented to the SE). **B:** View upstream the Indus valley from the road to Khaltaro. Between the Khaltaro and Phuparash rivers (the latter hidden on the left, joining the main Indus river in the Sassi turn), remnants of a high terrace, about 400m above the Indus stream. The Raikot fault approximately follows here the Khaltaro river, then the Indus left bank, at the right border of the picture (AP slide **95.7.9**, 8/9/95, 1890m, oriented South). **C:** View of the remains of an older terrace lying on the left bank of the Gilgit river, south of Dainyor, at least some 600 m above the present level of the river. In the background, summit of the Bilchar Dobani (6,143 m). Seen from the KKH, 13 km east of Gilgit (PLF slide **QB64**, 27/6/96, 1525 m of elevation, 65 mm lens, oriented N 60° E).

*Terrasses quaternaires: **A:** Vue vers l'aval de la vallée de la Shigar depuis le col de Goslo (sur le chemin menant d'Hemasil au Ganto La). En arrière plan, le chaînon du Mango Gusar; l'éperon sur la gauche, entre la Basha et la Braldu (masquée derrière correspond à la bordure ouest du Dôme de Dassu; tout le premier plan correspond aux calcaires de Chutrun. Le "linéament de la Shigar" suit les vallées de la Basha et de la Shigar. Le large remplissage quaternaire de la vallée (terrasses inférieures et plaine d'inondation actuelle) résulte du barrage de l'Indus derrière l'éperon Nanga-Parbat-Haramosh, en rapide surrection (photo PLF **OF70**, 30/5/92, prise à 3520 m d'altitude, orientée au SE). **B:** Vue vers l'amont de l'Indus depuis la piste de Khaltaro. Entre les torrents de Khaltaro et de Phuparash (ce dernier masqué dans la vallée à gauche de la photo, et rejoignant l'Indus dans le coude de Sassi), reste d'une terrasse environ 400m au dessus du lit de l'Indus. La faille quaternaire de Raikhot suit à peu près la rivière de Khaltaro, au premier plan, puis la rive gauche de l'Indus, en bordure droite de la photo (photo AP **95.7.9**, 8/9/95, 1890m, orientée sud). **C:** Vue des restes d'une terrasse ancienne, en rive gauche de la rivière Gilgit (au sud de Dainyor), environ 600 m au dessus du lit de l'Indus. A l'arrière plan, sommet du Bilchar Dobani (6.143 m). Vue prise de la KKH, 13 km à l'est de Gilgit (photo PLF **QB64**, 27/6/96, 1525 m, orientée N 60° E).*

m (ibid).

*: **hot springs**, the region presents many hot springs in all units. We have shown the major ones on the map.

*Karakoram*

1. Intrusive rocks

a. The isolated young bodies

γN, the **Hasanabad and Nagar granites** (Figs. 5 and 6, Annex. 3-1) are lenticular stocks that outcrop at the confluence of Hasanabad and Hunza valleys, and along the lower Hispar valley respectively. They have been studied and dated by Le Fort et al. (1983), Debon et al. (1987), Crawford & Searle (1992, 1993). They consist of muscovite, garnet, ± tourmaline, ± beryl granite with an heterogeneous grain size. The lenticular bodies outcrop for around a kilometre in length for 100 to 200 m in thickness, and are roughly concordant with the surrounding gneisses.

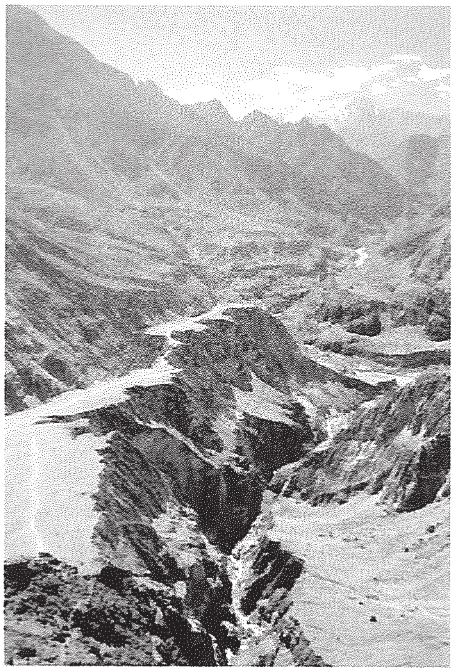
The Hasanabad body essentially consists of medium-grained granite with a porphyritic tendency, mesocratic, bearing two micas and garnet. It is orthogneissified and very much foliated. Heterogeneous, it contains biotitic schlieren and presents clear-coloured banding parallel to the foliation, itself concordant with the foliation of the country-rock. Enclaves, mainly meta-sedimentary, are often oblique on the foliation. The whole body is criss-crossed by numerous 2M ± T aplites and pegmatites. In addition, it is cut by many E-W north-dipping normal faults.

The Nagar granite is essentially (80%) made up of a very leucocratic Mu-Gr bearing aplite. The garnet from Nagar contains 76% almandine for 16% spessartine (Crawford & Searle, 1993). It is crosscut by numerous dykes of pegmatite (20%), irregular in direction, attitude, and thickness. Pegmatites usually have a blurred contact with the leucogranite. They underline contacts with country-rocks and septa of country-rocks.

Chemically (Annex. 3-1), the two granites are very similar adamellites.

A sample from Nagar (KK110*, Annex. 4) have been analysed for K-Ar (Debon et al., 1987); the whole rock and muscovite have yielded 14.4 and 2.7 Ma respectively, whilst a muscovite of a pegmatite sample has yielded a

A OF70



B 95.7.9

C QB64

K-Ar age of 5.6 Ma.

γS, the **Sumayar granite** is an elliptical body cut by the Sumayar River valley. It is made up of an homogeneous two-micas, tourmaline ± garnet ± beryl medium-grained leucogranite (adamellite), some 4 km in diameter, little deformed, intruding the surrounding pelitic and calc-silicate-bearing Karakoram metasediments where it develops a small (50 m) contact aureole (Crawford & Searle, 1992 & 1993). The biotite is usually included in the flakes of muscovite, a characteristic often met in the High Himalayan plutons (Le Fort, 1981). Garnets are 61% almandine in the pluton core and 65% spessartine in the pluton rim (Crawford & Searle, 1993).

Chemically (Annex. 3-1), the granite is also an adamellite.

U-Pb dating of zircon and uraninite has yielded an age of 9.2 ± 0.1 Ma, whereas xenotime intergrown with zircon have yielded an apparently younger age of 8.55 ± 0.15 Ma

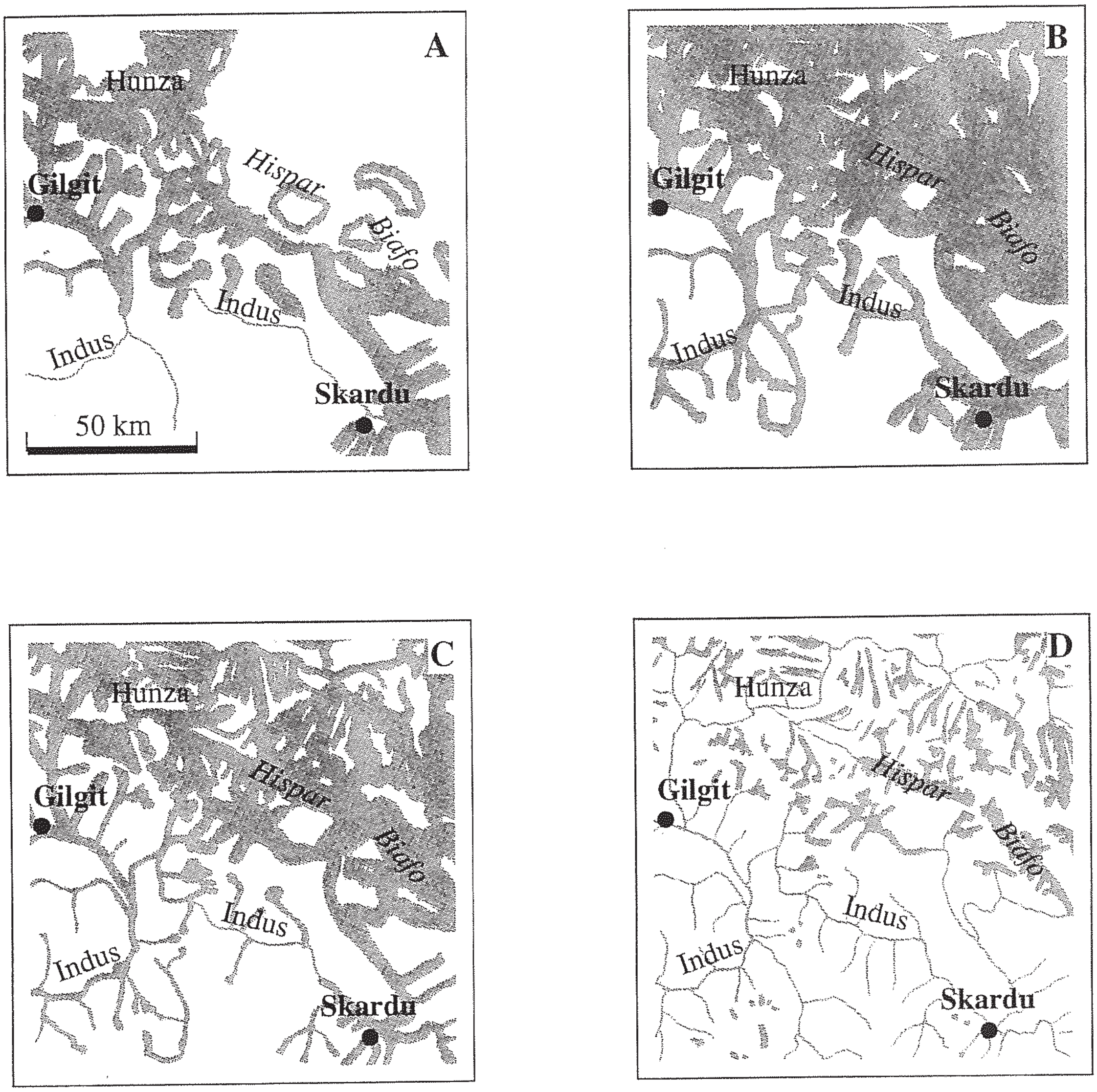



FIG. 4. Extents of Quaternary glaciations in Gilgit-Skardu area (modified from Derbyshire and Owen, 1997). **A:** Shanoz phase, poorly constrained (till around 4000 m), undated. **B:** Yunz phase (till between 3000 m and 3650 m), around 140,000 BP. **C:** Borit Jheel phase (tills up to 3000m), around 60,000 BP. **D:** present.

*Extension des glaciations quaternaires dans la zone Gilgit-Skardu (Derbyshire et Owen, 1997, modifié).* ***A:*** *phase Shanoz, d'extension mal définie (dépôts vers 4000 m), non datée.* ***B:*** *phase Yunz (dépôts entre 3000 m et 3650 m), datée à environ 140 000 B.P.* ***C:*** *phase Yunz (dépôts jusqu'à 3000 m), datée à environ 60 000 B.P.* ***D:*** *aujourd'hui.*

(Fraser et al., 1998). These ages are close to around 10 Ma U-Pb age obtained by Schneider et al. (1999a) on the Himalayan Phuparash granite located 30 km more to the south.

σH, the **Hemasil syenite**, discovered in 1992, is a small rounded massif located on the right bank of the Basha valley, NE of the Hemasil village; preliminary descriptions have been published by Le Fort et al. (1995) and Lemennicier (1996). Covering some 10 km$^2$, it forms the heart of a domal structure slightly elongated in a N140° direction. It is a syntectonic massif, with a magmatic foliation, even in the central part of the pluton, concordant with the regional tectono-metamorphic cleavage. At the border of the pluton, ductile shear planes develop. It has a gneissic aspect at the outcrop scale. Microscopically, it shows a

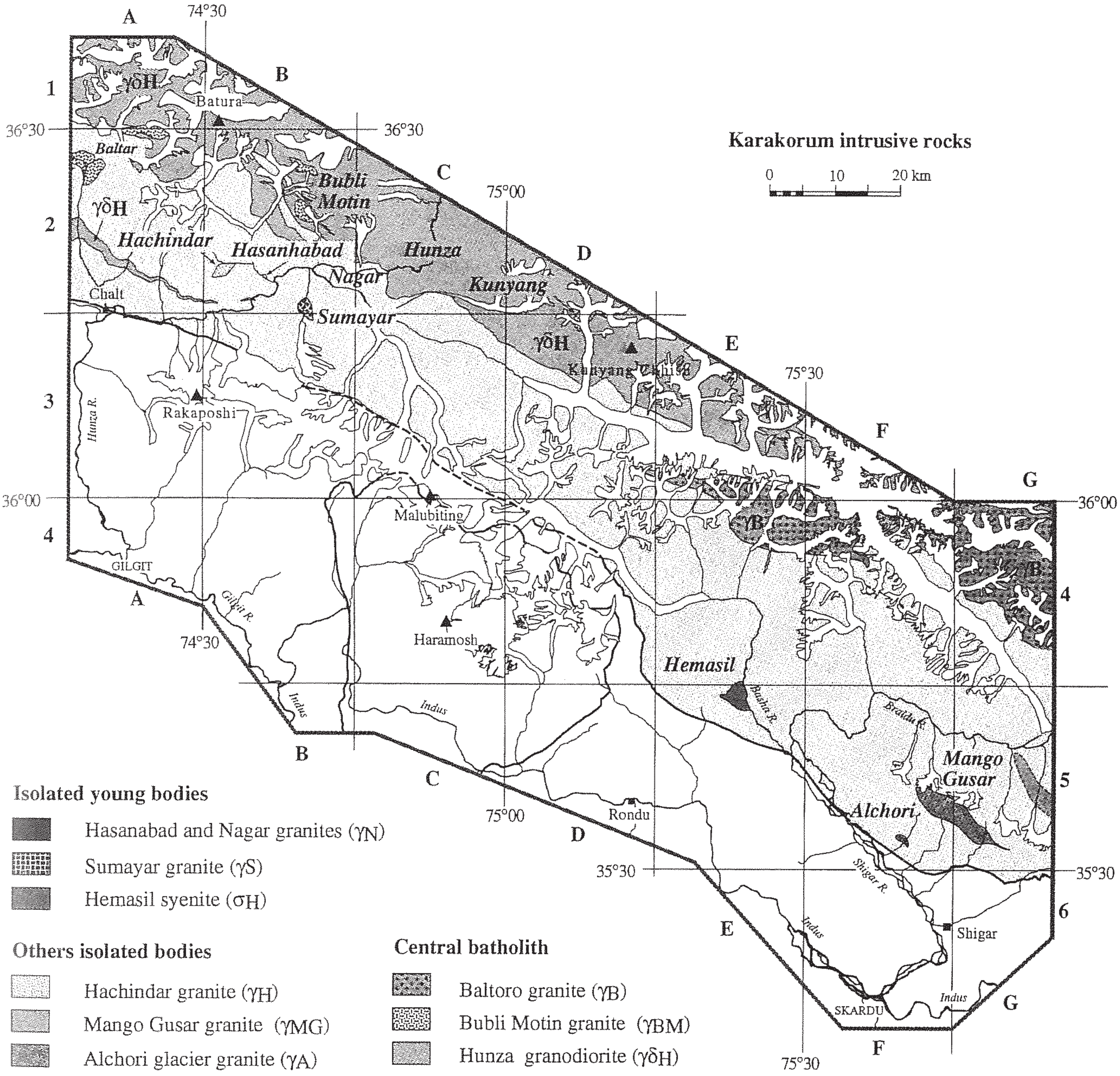
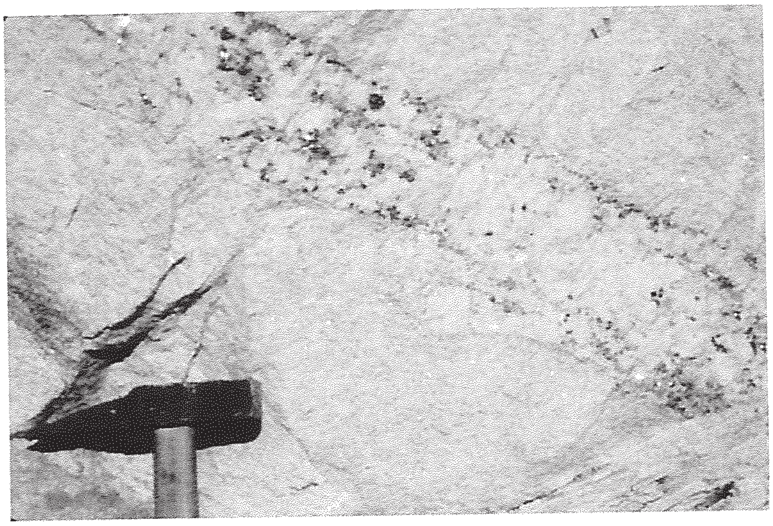



FIG. 5. The main plutonic bodies mapped in Karakoram. **1:** Hasanabad and Nagar granites; **2:** Sumayar granite; **3:** Hemasil syenite; **4:** Hachindar granite; **5:** Mango Gusar granite; **6:** Alchori granite; **7:** Baltoro granite; **8:** Bubli Motin granite (Baltar area, Bubli Motin peak, Kunyang glacier); **9:** Hunza granodiorite. Note two modifications between this figure and the main map: (i) The Mango Gusar granite, for which we were having no field data in 1998, is not drawn in the main map; its approximate contours Figure 6 are from new data by Y. Rolland. (ii) The Alchori granite, a granite sheet probably very similar to the Mango Gusar granite, has been indexed as the Mango Gusar granite (γMG); it has been distinguished here above and in the explanatory notes.

*Les principaux plutons cartographiés au Karakoram. **1:** granites de Hasanabad et Nagar; **2:** granite de Sumayar; **3:** syénite d'Hemasil; **4:** granite d'Hachindar; **5:** granite du Mango Gusar; **6:** granite d'Alchori; **7:** granite du Baltoro; **8:** granite de Bubli Motin (région de Baltar, pic de Bubli Motin, glacier de Kunyang); **9:** granodiorite de Hunza. Noter deux modifications entre cette figure et la carte : (i) le granite du Mango Gusar, pour lequel nous n'avions aucunes données fiables de terrain en 1998, n'apparaît pas sur la carte; son contour approximatif sur la figure provient de données inédites de Y. Rolland, qui l'a recoupé dans la vallée nord du Skoro La. (ii) Le granite d'Alchori, vraisemblablement très similaire au granite du Mango Gusar, avait été noté sur la carte comme s'il s'agissait du même granite; il a été distingué tant sur la figure que dans cette notice explicative.*



JZ19

FIG. 6. Karakoram intrusive rocks: isolated young bodies. Outcrop of the fine-grained Nagar two-mica + garnet leucogranitic slab cut by abundant (around 20%) muscovite and tourmaline-bearing pegmatitic dykes. Located near the suspended bridge over the Hispar river, leading to Nagar village. Sample KK110, that has yielded a 14.4 Ma age by K-Ar on whole rock, comes from this outcrop (PLF slide **JZ19**, 26/11/82, around 2300 m of elevation).

*Intrusifs du Karakoram, corps jeunes isolés. Affleurement de la lame de leucogranite à grain fin de Nagar. Le granite, à deux micas + grenat, est recoupé par de nombreuses (20% de la roche) pegmatites à muscovite - tourmaline. Près du pont sur la rivière Hispar, sur la route de Nagar. L'échantillon KK110, qui a été daté par K-Ar sur roche totale à 14,4 Ma, provient de cet affleurement (photo PLF **JZ19**, 26/11/82, vers 2300 m d'altitude).*

magmatic texture with oligoclase-microcline-green biotite- sphene ± hornblende and some relict pyroxene. Lemennicier (1996) has distinguished two samples, bearing magmatic epidote and located in the NE (group I, Annex. 3-2), from the rest of the pluton where secondary epidote forms by alteration of the plagioclase (group II, Annex. 3-2). In the northern part, at the contact with the limestones that underline the structure, a darker layer results from phenitisation, with crystallisation of calcite into the syenitic assemblage. At the southern contact, a screen of amphibolite is intercalated between the syenite and the Chutrun limestone.

Mineralogically (chemical compositions of minerals in Lemennicier, 1996), the abundant K-feldspar is a slightly albitic microcline ($Ab_{16}$), variably perthitic. Plagioclase is an unzoned oligoclase ($An_{24}$ to $An_{18}$). The biotite is green, Fe- and Mn-rich. Poikilitic anhedral amphibole, pleochroic from blue-green to yellowish green, is a ferropargasite, rather K-rich. The calcic amphibole from the southern screen is a magnesian hastingsite. Muscovite is only abundant in the border facies. Epidote is Fe-rich. No crystal or relic of feldspathoid has been found.

Chemically, 9 samples have been analysed for major and trace elements and 7 for REE (Lemennicier, 1996). The major elements (Annex. 3-2) confirm the undersaturated syenitic nature of the rock; the ferriferous trend already noted at the mineralogical level is met again with the whole rock composition. The REE patterns, relatively heterogeneous, present a strong enrichment in LREE (Fig. 7). The convex pattern of samples from Group I, bearing primary epidote, differentiates them from th concave pattern of Group II samples Lemennicier (1996) suggests that enrichment i MREE and Y of Group I samples result fror epidote and apatite addition. The enrichment c Group II samples in U, Th, Zr, Hf, Pb as well a slightly higher initial Sr isotopic ratio woul result from crustal contamination.

Isotopically, five samples have been analyse by H. Lapierre for Rb-Sr and Nd-Sm systen

(Lemennicier et al., 1996). No isochron age could be obtained. The samples seem to derive by partial fusion from an enriched mantle. The differences observed in the $^{143}Nd/^{144}Nd$ initial ratio calculated for 10 Ma, and their negative correlation with the Th content, can be explained by assimilation-fractional crystallisation process, the parts of the magma closest to the border being enriched in Th (Fig. 8). In addition, high temperature reaction with the surrounding marbles have disturbed the Rb-Sr system. $^{40}Ar$-$^{39}Ar$ dating by I. Villa (Villa et al., 1996a) of a biotite from the core and an amphibole from the surrounding screen of amphibolite has yielded Plio-Pleistocene cooling ages of 3.7 to 4.0 and 7 to 7.7 Ma respectively. The amphibole age gives an upper limit to emplacement and doming of the syenite, and implies a minimum average cooling rate of 75°C/Ma.

b. The central plutonic belt (also called "Axial Batholith")

The central plutonic belt crops out along the northern part of the studied area. South of the main belt, several smaller plutonic bodies are connected with it. Altogether, four major plutonic units have been recognised in this belt: the Hunza granodiorite, the Darkot and Ghamubar porphyritic granites, the Batura granite, and the Baltoro granite. All but the Batura unit are at some extent represented on the map.

γ**B**, the **Baltoro granite** (Desio, 1963 a & b, 1964; Desio & Zanettin, 1970; Desio et al., 1985; Debon et al., 1986; Parrish & Tirrul, 1989; Searle et al., 1989; Schärer et al., 1990; Searle, 1991) only appears to the NE of the map (Fig. 5) where it forms a thin elongated wedge starting from the Kero Lungma basin. The Baltoro is one of the largest plutonic bodies of the Karakoram, extending eastward for more than 100 km. We have observed it in the Biafo glacier and in the upper Berelter valley (Fig. 9).

In the Biafo glacier region, the granite overlies the metasedimentary formations with a 30° NE dipping contact well visible cutting the left bank ridge, below the granitic summits of Dongbar (6,282 m) and Chaunpisha (5,361 m). Where it comes closer to the Biafo glacier, the contact of the granite with the surrounding

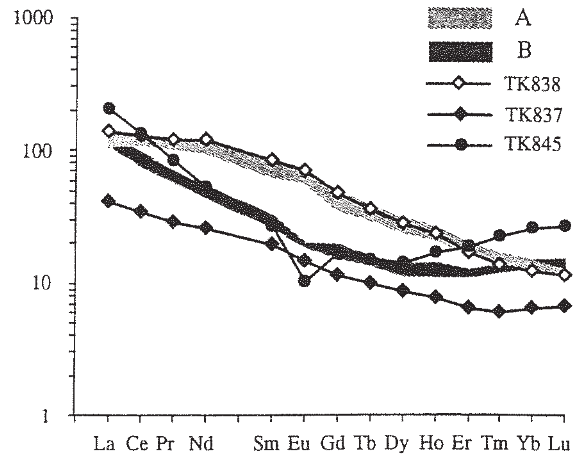



FIG. 7. REE plots for Hemasil syenite. REE are normalised to chondritic values of Evensen et al. (1978). Light grey (A): samples TK836 and TK839 of group 1 (see text), and lamprophyre TK838. Dark grey (B): samples TK480, TK835, TK837 and TK841 of group 2. TK845 is a zircon rich sample.

*Terres Rares dans la syénite d'Hémasil. Diagramme normalisé aux chondrites (valeurs d'Evensen et al., 1978). Gris clair (A): champ pour le groupe 1 (TK836, TK839 et lamprophyre TK838). Gris sombre (B): champ pour le groupe 2 (TK480, TK835, TK837 et TK841). TK845 est un échantillon plus riche en zircon que les autres.*

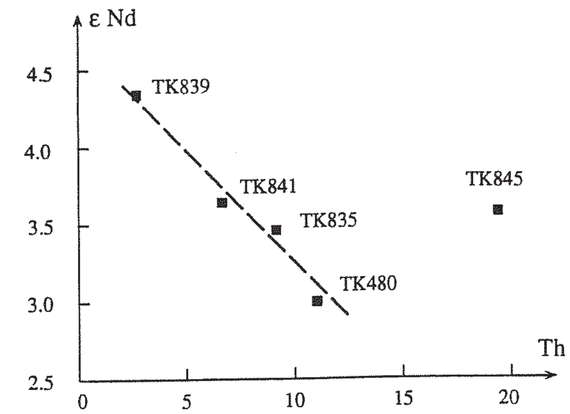



FIG. 8. Diagram εNd v. Th for Hemasil syenite. Sample TK845, from the pluton margin, has suffered crustal contamination and lies out of the correlation trend defined by the other samples (for those samples, correlation coefficient r = 0.987).

*Diagramme εNd v. Th pour la syénite d'Hémasil. L'échantillon TK845 provient de la bordure du pluton. Hors de la tendance définie par les autres échantillons, il montre les traces d'une contamination crustale Pour les autres échantillons, le coefficient de corrélation r vaut 0.987.*

FIG. 9. Some aspects of the Baltoro granite: **A** - View of the upper Biafo glacier and of the towers and cliffs of its left bank made up of Baltoro granite. At the base of the cliff in the centre and in the shade to the right (see photo C), a screen of dark schists, sort of intermediate floor within the granite, is clearly visible (PLF slide **LT17**, 26/7/86, at 4580 m of elevation). **B** - Typical outcrop of two-mica + garnet-bearing Baltoro granite on the left bank of the upper Biafo glacier, close to the junction with the Sim Gang glacier. The granite has a rough foliation and a porphyritic tendency (PLF slide **LS33**, 21/7/86, at 4565 m of elevation). **C** - The screen of schist in the middle of the Baltoro granite seen on the spur outcropping to the south of the Hispar pass. The granite underneath, to the right, is completely shattered (PLF slide **LT38**, 27/7/86, at 4630 m of elevation, tele-lens, view looking north). **D** - Eastwards looking view of the Sokha Glacier, upper Berelter valley. Left (north) of the central pass and needles, the main Sosbun Brakk tower (6063 m) is entirely made of Baltoro granite. South of it, formations with the strong steep fabric are gneisses and marbles (Baintha marbles), also present in the foreground shadowed outcrops (AP slide **92.6.27**, 25/5/92, around 3640m of elevation, close to the Solu and Sokha glacier junction).

*Quelques aspects du granite du Baltoro: **A** - Tours et falaises en granite du Baltoro, en rive gauche du haut glacier du Biafo. A la base de la falaise centrale et dans l'éperon à l'ombre à droite (celui de la photo C), on voit un écran de schistes sombres, sorte de plancher intermédiaire dans le granite (photo PLF **LT17**, 26/7/86, à 4580 m d'altitude). **B** - Affleurement de granite du Baltoro typique, à 2 micas - grenat, en rive gauche du haut glacier du Biafo, prés de la jonction du glacier de Sim Gang. Le granite montre une foliation frustre et a une tendance porphyroïde (photo PLF **LS33**, 21/7/86, à 4565 m d'altitude). **C** - L'écran de schiste du milieu du granite du Baltoro, vu sur l'éperon affleurant au sud du col d'Hispar. Le granite sous-jacent aux schistes est complètement fracturé (photo PLF **LT38**, 27/7/86, à 4630 m d'altitude, téléobjectif, vue vers le nord). **D** - Vue vers l'est du glacier de Sokha, haute vallée de la Berelter. A gauche (nord) du col et des aiguilles centrales, la tour principale du Sosbun Brakk (6063 m) est faite entièrement de granite de Baltoro. Plus au sud, les formations montrant une forte fabrique verticale sont des gneiss et des marbres (marbres de Baintha), affleurant aussi dans le versant à l'ombre au premier plan (photo AP **92.6.27**, 25/5/92, vers 3640m d'altitude, près de la jonction des glaciers Solu et Sokha).*

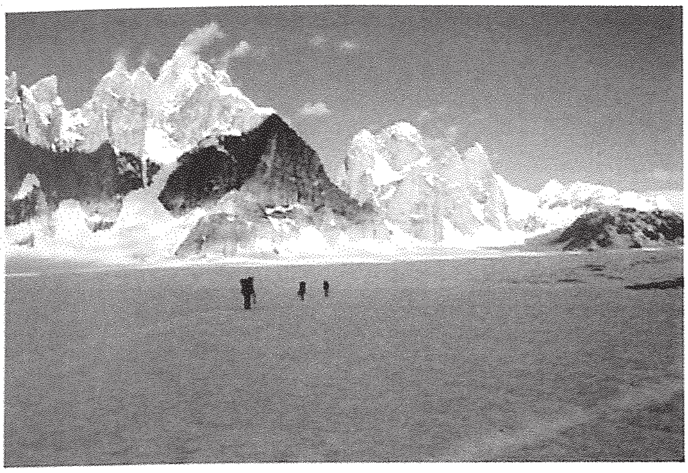
migmatitic paragneisses has been already rapidly described by Desio (1963b) and Desio et al. (1985, plate IV). They noted the increasing abundance of veins and dykes of granite crosscutting the paragneisses of their Dumordo formation, but spoke of a "passage to migmatites and thereafter to massive granite". Actually, the "migmatites" are deformed gneisses, including true migmatites, that are intruded by a very dense network of granitic to pegmatitic dykes surrounding the granite pluton for more than a kilometre. The "agmatites" of Desio only correspond to a gigantic zone of injection that can be followed on both sides of the glacier for more than 10 km along the contact.

We visited the contact on the left bank above Baintha at an altitude of around 4,500 m, where the injected zone of dominantly migmatitic paragneiss is separated from the dominantly granite zone with numerous xenoliths of gneisses by a 6 m thick band of rusty and schistose gneissic mixture. The granite overlies the folded gneisses with a planar contact more or less parallel to the foliation of the gneisses, dipping around 30° to 50° to the NNE. The xenoliths and schlieren within the granite reach all sizes between a few centimetres and several hundred metres; they are generally surrounded by a leucocratic rim of pegmatite.

The granite itself in this zone is made up of quartz, K-feldspar, faintly zoned oligoclase (from a maximum of An 31 in the core to a minimum of An 19 at the rim, often slightly oscillatory), muscovite, biotite, ± garnet. These garnet compositions compare to those obtained by Searle et al. (1989): almandine (55-76%) and sometimes spessartine (8-40%)-rich. The granite presents abundant myrmekites.

Chemically (Annex. 3-1), it is composed of adamellites with a sub-alkaline tendency.

Upstream the Biafo glacier, the Baltoro granite outcrops on both banks for a few hundred metres of height, apparently forming an antiform at the base of the injected migmatitic gneisses; this structure has been already mentioned by Desio (Fig. 5 of Desio et al., 1985). The granite is here, loaded with numerous dissected enclaves of gneiss, schlieren, bands of two mica-garnet schist, and quartzitic streaks; calcsilicate enclaves have not been met with certainty. Actually, this small granite dome probably corresponds to a large injected slab of Baltoro granite within its gneiss



A LT17

B LS33

C LT38

D 92.6.27

and schist floor. However, the entire structure that the Biafo glacier crosscuts, resembles a pluri-kilometric xenolith floating at the floor of the Baltoro pluton and thoroughly dissected by the granitic magma.

This structure remains true near the junction with the Sim Gang glacier and the Snow Lake, on both banks of the Biafo, where large rafts of sillimanite-bearing migmatitic gneisses float within the granite, at the base of the outcrops, forming a sort of disrupted screen that may not lie far above the floor of the pluton (Fig. 9C). In the upper catchment zone of the Biafo glacier, on the left bank, the gneisses are folded at all scale by NW-SE post-metamorphic folds plunging gently to the NW. Part of the injected granite dykes are folded by these folds. The contact with the granite, crosscutting these folds, is sharp. The granite is coarse-grained and usually contains two micas ± garnet. Successive generations of granitic material can often be recognised. The two mica-garnet pegmatitic dykes seldom bear tourmaline.

In the upper Berelter valley, the Solu granitoid, almost non deformed, is intrusive into the metasedimentary formations. Within the granite, one can follow the prolongation of limestone horizons from the sedimentary country rock (Fig. 9D). These limestone inclusions can be traced for more than ten kilometres north of the southern limit of the granite. The contact with the country rocks has not been observed, although the granite sends a swarm of dykes into it.

The granite has been dated on zircons of the Baltoro glacier, by U-Pb method, at 21-25 Ma (Parrish & Tirrul, 1989); two U-Pb monazite ages have also been obtained at 17 and 19 Ma (ibid). K-Ar and $^{40}Ar$-$^{39}Ar$ cooling ages between 11.8 and 5.25 Ma (Searle et al., 1989) have also been obtained on micas and 9 Ma on K-feldspar (Debon et al., 1986; Searle et al., 1989; Schärer et al., 1990; Searle, 1991).

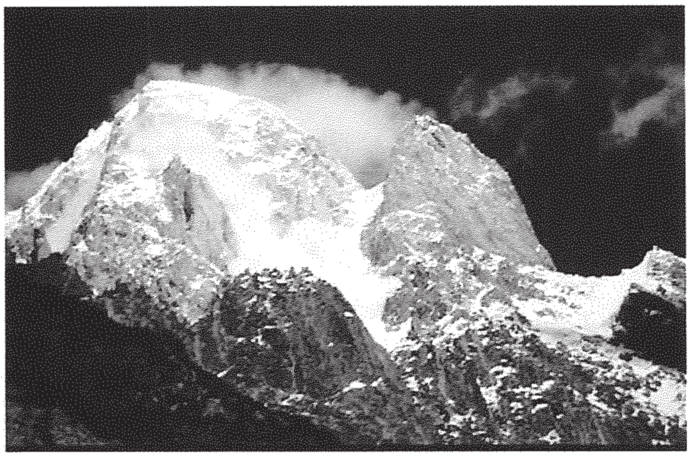
γMG, the "**Mango Gusar pluton**", lying south of the batholith, has been mentioned by Gattinger (1961), Zanettin (1964), and Searle (1991). It partly outcrops on the present map, but we have not been able to visit it. This two-mica granite-granodiorite, described either as an orthogneiss (Gattinger), a gneissic granite (Zanettin), or as non-foliated (Searle), has yielded a U-Pb zircon age of 37.0 ± 0.8 Ma, and a K-Ar muscovite cooling age (his table 8.1) of 22.0 ± 1.0 Ma (R. Parrish in Searle, 1991). According to Searle, this Oligocene pluton would post-date all major deformations of south Karakoram, possibly including the MKT (ibid, his Fig. 9.4). As Searle gives to it a variable shape (cf Fig. 9.2 Vs 9.3, ibid), and sometimes represents it as intrusive into the folded para-gneisses, but other times draws it with completely faulted contacts (Searle, 1991 on the 1:250,000 attached map; Searle et al., 1996), the area would deserve a detailed mapping and complementary study.

**γA, Alchori glacier granite**, We have only met this two-mica granite on blocks in the Alchori torrential fan (see analysis of SK 307*, Annex. 3-1). It forms the entire crest of the small valley and extends southward to the Skoro La valley where it has recently been observed in place (Y. Rolland, personal communication, 1997). The granite is oriented and locally orthogneissified close to its contact. Another slab, quite alike, occurs at the eastern limit of the map, on the left bank of the Thalle valley. The Mango Gusar granite (see below) probably forms a similar occurrence.

**γBM,** porphyritic granites of the **Bubli Motin type**. These granites form circular masses of kilometre-size that have a sharp contact with the surrounding plutonic unit of the central belt that they intrude, most generally the Hunza granodiorite (Fig. 5). In the area covered by the map, we have observed at least four of them, from west to east, the granitic masses of: Baltar and Toltar (that are likely to extend in the Shittibar valley, where blocks of the same granite have been found), Bubli Motin (considered as typical), and Kunyang glacier. Three of them are carved out by the erosion and cut by major glacial valleys, whereas the Bubli Motin one, who gets its name after a slender needle also called "Lady Finger", stands in high and spectacular relief (Fig. 10).

In Baltar, the porphyritic granite contains euhedral K-feldspar crystals ("dents de cheval") up to 7 cm long, but usually 1 by 3 cm; the granite is foliated and the K-feldspars are arranged parallel. It is biotite ± muscovite-bearing and includes numerous biotite-rich schlierens.

Detailed work in the Kunyang glacier valley has revealed the presence of a kilometre-size pod of porphyritic biotite granite. It is made up of porphyritic adamellites associated with undeformed Bi ± Amf granodiorite, called the "Trivor pluton" by Debon (1995). Its subalkaline and ferriferous chemical characteristics (Annex. 3) remind of the Batura



A PZ22

B 95.2.9

FIG. 10. The Bubli Motin granite: **A:** View of the Hunza peak (6270 m, left) and Bubli Motin needle (circa 6000 m, right) from the left bank of the Shispar glacier. Both peaks are carved in the circular pluton of Bubli Motin porphyritic granite. Note the avalanche crumbling down the Hunza peak (PLF slide **PZ22**, 7/6/96, 3265 m of elevation, tele-lens, oriented N 105° E). **B:** Porphyritic biotite granite (adamellites) of Bubli Motin type, junction of the Kukuar and Baltar valleys (AP slide **95.2.9**, 26/8/95, around 2470 m of elevation, left bank of the Kunyang glacier).

*Le granite de Bubli Motin: **A:** Vue du pic de Hunza (6270m, à gauche) et de l'aiguille de Bubli Motin (environ 6000m, à droite) depuis la rive gauche du glacier de Shispar. Les deux pics sont taillés dans le granite porphyroïde de Bubli Motin. On voit une avalanche en train de descendre du pic de Hunza (photo PLF **PZ22**, 7/6/96, 3265 m d'altitude, téléobjectif, prise vers N105° E). **B:** Granite porphyroïde biotitique (adamellite) de type Bubli Motin, bloc d'un écroulement à la jonction des vallées de Kukuar et de Baltar (photo AP **95.2.9**, 26/8/95, vers 2470 m d'altitude, rive gauche du glacier de Kunyang).*

association. However, according to Debon, the REE patterns are typical of the Hunza plutonism and should therefore be linked with the latter rather than with the Paleogene Batura. More to the east, the three following glaciers (Pumari Kish, Jutmaru, and Khanibasar) also carry voluminous boulders of similar porphyritic biotite granite, with similar chemical composition. Part of them come from the south face of the Kunyang Kish - Pumari Kish range that Searle (1991, p. 114 & Figs. 6.9 and 6.10) mistakenly reports as being made of a "massive, pale, leucogranitic pluton". But the exact extension of this porphyritic mass, possibly related to the Batura plutonic episode, has not been mapped.

Chemically the Bubli Motin granites (Bubli Motin and Trivor, Annex. 3-3) are subleucocratic adamellites, or granodiorites, having a subalkaline tendency.

The Paleocene to Eocene **Batura unit** (Debon et al., 1987; Debon, 1995), restricted to the northern part of the belt, outcrops a few km to the north of the present map (Zanchi & Gaetani, 1994). We have looked, without success, for outliers and/or morainic boulders of it, on the southern side of the Batura wall. Dispersed boulders of gabbro met in the moraines of the Toltar glacier could however be related to those associated with the Kuk pluton of the Batura unit (Zanchi & Gaetani, 1994). However, as already noted by Debon (1995), the Bubli Motin granite has a major elements composition very much alike that of the Batura granite.

**γδH**, the **Hunza granodiorite** or **Hunza plutonic unit** (Le Fort et al., 1983; Debon et al., 1987; Crawford & Searle, 1992, 1993) is the largest one. It extends for 250 km at least between the valley of Karambar and the glacier of Chiantar, west of the mapped area, to the Muztagh Tower, east of the mapped area. On the present map, it forms the major part of the northern granitoid belt. North of the map (Zanchi & Gaetani, 1994), the northern contact of the Hunza granodiorite is intrusive into the north-Karakoram sediments. The granodiorite is made up of foliated medium-grained rocks, dominantly granodioritic in composition, containing biotite (contrarily to the statement of Searle, 1991, p.123) and, usually, amphibole with occurrence of residual clinopyroxene. The broad zonation observed by Debon & Khan (1996) in the Karambar valley, west of the map, with darker and more amphibole-rich rocks toward the middle part of the section, is also encountered in the western part of our area (Bar to Bualtar-Toltar valleys). The rock has been deformed from mild fracturation accompanied by chloritisation ± epidotitisation to a thorough ortho-gneissification and recrystallisation under upper amphibolite-grade conditions estimated at 580 - 640°C and 5 ± 0.5 kbar (Debon et al., 1987). The strong deformation and metamorphism seem to be characteristic of the southern and central portion of the unit.

In all the western part of the map, this highly deformed and metamorphosed zone is separated from the northern epimetamorphic portion by a steeply dipping lineament underlined by intensely folded and squeezed marble. The axes of the folds that we could observe from the distance on the right bank of the higher part of the Toltar glacier (Fig. 11A) seem to be plunging at high angle. This lineament has been followed eastward up to the Hunza valley, where it is marked, just north of the KKH bridge of Shishkat (between Chamangul and Bulchi Das) by large septa and lenses of marble showing skarn reactions at their border. There it roughly underlines the limit between the southern more amphibolic and more deformed facies where the foliation dips to the north, and the northern more biotitic and less deformed facies where the foliation dips to the south (cf Fig. 6 in Debon et al., 1987). Altogether, this Shiskhat lineament seems to have already existed when the granodiorite was emplaced and to have been further reworked during the main deformation with a strong strike-slip component.

East of the Hunza valley, the granodiorite has been met only sporadically along sections worked out on right bank tributaries of the Hispar valley (Garesa, Kunyang, Jutmaru, and Khani Basa mainly). The rock, hornblende- and/or biotite-bearing, is often strongly foliated, typically at N120°E, S75°. The easternmost outcrop visited on this map lies at the confluence of the Sim Gang glacier with the Snow Lake, on the northern spur. In fact, the Hunza granodiorite does not "wedge out west of Snow Lake" as written by Searle (1991, p. 119), but continues east of the latter towards the Muztag Tower. On the outcrop east of Snow Lake, the foliated granodiorite has a porphyritic tendency, bears rounded quartz, large K-feldspar, euhedral centimetric strongly zoned andesine (from An 61 in some cores to An 32 at the rim), and nests of millimetric biotite; it presents abundant microgranular, meta-sedimentary, and micaceous enclaves. The foliation of the granodiorite is crosscut by a dense network of two mica-garnet-tourmaline metric aplo-pegmatitic dykes (up to 30% in volume), where the decimetre-long muscovite is palmate and the tourmaline euhedral up to a few centimetre-long.

To the south of the main unit, several kilometre-thick slab of a deformed granodiorite similar to that of Hunza, crop out on the northern side of the middle Hunza valley. We have mapped two main bands: (i) one (Ultar band), some 20 km long, crosses the lower Ultar valley, the Hasanabad valley and probably joins the main batholith in the uppermost Muchiohul (Muchuhar) glacier, and (ii) a second one (Hindi band), crossing the Bar valley, stretches and thins westward for more than 30 km, cutting the Mayon and Shilimbar valleys, and reaching the Hunza valley, east of Hindi (Tashot). In the vicinity of their contact with the KMC, as in the thinner part of the bands, the granodiorite is often strongly orthogneissified and resembles the orthogneissic bands described below (γδζ). In the prolongation of the Hindi band, numerous small slabs of the same material are interfoliated in the isoclinally folded metasedimentary formation around the Bualtar glacier and on the left bank of the Barpu glacier. On the right bank of the Barpu glacier, the two small massifs of orthogneiss (Barpu Giram and Rash Lake) could actually be lenses of the same set of highly deformed Hunza granodiorite. More to the east, in the Chogo Lungma basin, some of the orthogneisses have a composition very similar to that of the Hunza granodiorite. The best studied example is the Bukpun dome (Lemennicier, 1996; see also below) on the left bank of the Chogo Lungma glacier. Another dome, cut by the lower Biafo glacier, shows a core of foliated garnet-bearing Hunza-type granodiorite just north of Namla on the right bank. This discontinuous 150 km long belt of granodioritic orthogneiss could either be an independent plutonic lineament or, more likely, the reworked highly folded extension of the main mass of Hunza granodiorite. From this point of view, the naming of the batholith as "axial" does not reflect its actual structural setting.

Chemically (Annex. 3-3), our new analyses confirm the calc-alkaline cafemic association, with compositions ranging from gabbro-monzogabbro to adamellite for the most clear-coloured samples, the majority being normative Bi + Hb ± Px bearing granodiorites.

The crystallisation age of the granodiorite has been determined by U-Pb method on zircons, at 95 + 4/-6 Ma (Le Fort et al., 1983), and recently at 105.7 ± 0.5 (Fraser et al., 1998). An eight points whole rock Rb-Sr isochron at 97 ± 17 (2σ Ma with a rather high Sr initial ratio of 0.7097 has been obtained by Debon et al. (1987). Numerous cooling ages have also been obtained (Debon et al., 1987; Treloar et al., 1989, Ogasawara et al., 1994, Debon et al., 1996), largely reflecting the intrusion of innumerable pegmatitic dykes throughout the pluton (see below).

**θ, gabbro boulders**. On two occasions, we have observed boulders of gabbro without retrieving exactly their origin: (i) on the surface moraine of the Toltar glacier where they seem to come from the crest of the upper left bank, and (ii) in the Chukutens alluvial fan (right bank of the Barpu glacier) coming from the Hispar-Barpu crest.

c. The dykes

The Karakoram at some places is really criss-crossed by granitic dykes of aplitic, granitic, and pegmatitic material. In particular, the Hunza granodiorite in the Hunza section shows a remarkably dense network of leucocratic dykes (Fig. 12A), forming up to 40% of the total mass of the rock in some outcrops (Desio & Martina, 1972; Debon et al., 1987; Searle, 1991; Crawford & Searle, 1993). They usually contain, in addition to quartz and two feldspars, Bi, Mu, Gr, and T.

K-Ar cooling ages on the micas from the pegmatitic dykes of Hunza range between 16.9 and 2.7 Ma for Debon et al. (1987), and 24 to 4 Ma (Searle et al., 1989; Treloar et al., 1989). The zircon, monazite and uraninite of a garnet-biotite pegmatitic dyke intruding the gneiss and marble south of the pluton in the Hunza valley, has recently been dated by U-Pb method at 35.3 ± 0.4 Ma (Fraser et al., 1998).

**Gem-bearing pegmatites**. Karakoram has been known for a long time to contain a wealth of gemstones (e.g. Middlemiss & Prashad, 1918; Okrush et al., 1976; Gübelin, 1982; Kazmi et al., 1985; Kazmi & O'Donoghue, 1990). These

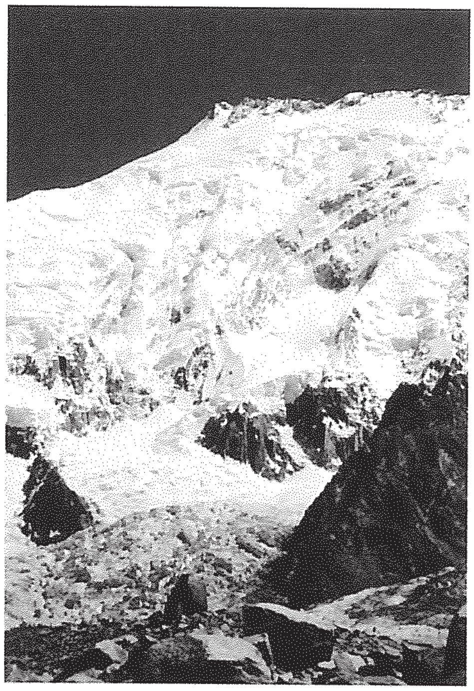
FIG. 11. The Hunza granodiorite plutonic unit: **A:** The needles of folded marble squeezed in the Hunza granodiorite on the right bank of the upper Toltar glacier. Marbles can be followed discontinuously eastwards, crossing the ridge joining the Hachindar and Batura summits (photo A) (PLF slide **PN65**, 27/8/95, 3905 m of elevation, tele-lens, oriented N 345° E). **B:** View of the southern slope of the Distaghil Sar (7885 m, summit is just outside the northern map edge), at the head of the Kunyang glacier, looking towards north. The large icy slope of the Distaghil Sar is made up of Hunza granite and granodiorite (AP slide **88.3.34**, 24/7/88, around 5350 m of elevation, above Kunyang glacier, on the road to south ridge of the Distaghil). **C:** Outcrop of biotite-bearing foliated Hunza granodiorite with a porphyritic tendency. The outcrop lies at the junction between the Sim Gang glacier and the Snow Lake (geochemical sample BH77) (PLF slide **LS73**, 23/7/86, at 4660 m of elevation). **D**: Block of banded granodiorite lying along the KKH downstream from Gulmit. The banding mimics oblique bedding and is displaced by later pegmatitic veinlets (PLF slide **KB51**, 8/12/82, around 2540 m of elevation). **E:** Outcrop of an E-W gabbroic dyke, around 3 m-thick, loaded with breccia clasts of varied nature. The clasts may be decimetre- to metre-long and be made up of the surrounding Hunza granodiorite, of microgranular material, of sedimentary material (quartzite, marble), etc. Located on the left bank of the Hunza, upstream from Gulmit (PLF slide **JY55**, 24/11/82, around 2550 m of elevation).

*L'unité plutonique de la granodiorite de Hunza: **A:** Les aiguilles de marbre plissé et pincé dans la granodiorite de Hunza, en rive droite du haut glacier de Toltar. Ces calcaires se poursuivent de manière discontinue vers l'est, passant l'arête entre les sommets de Hachindar et de Batura (voir photo A) (photo PLF **PN65**, 27/8/95, 3905 m d'altitude, téléobjectif, orientée vers N345° E). **B:** Vue du versant sud du Distagil Sar (7885m, juste au nord de la limite de la carte), au fond du glacier du Kunyang. Ce sommet est formé de granite et granodiorite de Hunza, affleurant çà et là dans le grand versant glaciaire. (photo AP **88.3.34**, 27/7/88, vers 5350 d'altitude, au dessus du glacier de Kunyang, en montant vers l'arête sud du Distagil). **C:** Affleurement de granodiorite de Hunza. Faciès à biotite, à tendance porphyroïde, folié. L'affleurement se situe à la jonction du glacier de Sim Gang et du Snow Lake (échantillon géochimique BH77) ) (photo PLF **LS73**, 23/7/86, à 4660 m d'altitude). **D:** Bloc de granodiorite rubanée, au bord de la KKH en aval de Gulmit. Le rubanement mime des stratifications obliques et est déplacé par les petites veines pegmatitiques tardives (photo PLF **KB51**, 8/12/82, vers 2540 m d'altitude). **E:** Affleurement d'un filon gabbroïque est-ouest, d'environ 3 m de puissance, rempli de fragments brêchiques de nature variée. Les fragments sont décimétriques à métriques et faits de la granodiorite encaissante, de matériel microgrenu, de matériel sédimentaire (quartzites, marbres), etc. Affleurement situé en rive gauche de la Hunza, en amont de Gulmit (photo PLF **JY55**, 24/11/82, vers 2550 m d'altitude).*

precious and semi-precious gems have been mainly mined out from various pegmatitic dykes that can be schematically divided into three groups:

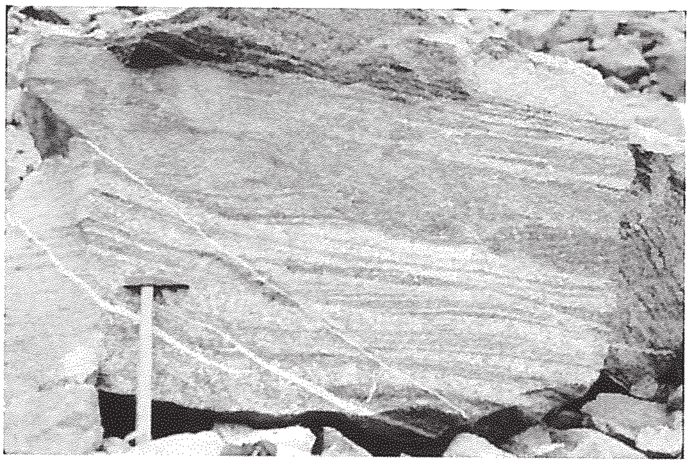
- pegmatites intrusive into orthogneisses. The best occurrences lie in the Dassu dome and contain the assemblage Q-Kf-Mu-topaz-aquamarine±T±Bi (cf Middlemiss & Prashad, 1918; Kazmi et al., 1985; Kazmi & O'Donoghue, 1990). Other places are also actively mined locally, such as near the village of Doko for Q-Kf-Mu-T-aquamarine±topaz±Gr bearing pegmatites in the migmatitic gneisses of the Mangol Bluk dome, or downstream the village of Zil where hundred metres long Q-Kf-Mu-Bi-T±Gr bearing pegmatites cutting the Zil gneiss are also searched for aquamarine and topaz;
- pegmatites intrusive into the marbles of the Karakoram Metamorphic Complex (Fig. 12B), well known for bearing ruby and sapphire, red to blue spinel, and deep pistachio green pargasite (Okrush et al., 1976; Kazmi & O'Donoghue, 1990). Not less than 40 other minerals have been identified (Okrush et al., 1976). They are, in alphabetical order: actinolite, apatite, augite, anorthite, biotite, bornite, calcite, cassiterite, chlorite, chondroclite, chromium diopside, dolomite, epidote, fuchsite, garnet, graphite, hematite, hornblende, jasper, limonite, magnetite, margarite, microcline, muscovite, orthoclase, pargasite, phlogopite, plagioclase, pyrite, pyrrhotite, quartz, rutile, scheelite, sphene, spinel, staurolite, talc, tourmaline, wollastonite, zircon. The reserve of corundum was estimated at 1.3 to $5 \times 10^6$ carats (ibid);
- pegmatites intrusive into the gneiss and schist of the Karakoram Metamorphic Complex. The best occurrences are those of Dassu, in the micaschists surrounding the Dassu orthogneiss, and that of Chumar Bakar lying in the upper reaches of the Sumayar valley, on the crest between the Silkiang and Bualtar glaciers where exceptional large-size aquamarine crystals have been mined out (Voillot, 1995).

**A** PN65



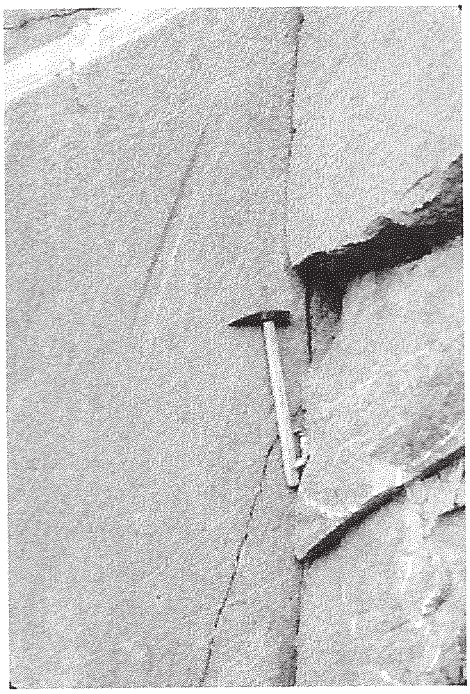
**B** 88.3.34

**C** LS73



**D** KB51

**E** JY55



F JY17

G LT79

FIG. 11 (continued). **F:** Outcrop along the KKH of homogeneous Hunza granodiorite strongly orthogneissifiec the amphibolite facies. The foliation, dipping around 60° to the NE, is underlined by stretched microgranular encla\ and cut by two micas and garnet bearing-pegmatite (PLF slide **JY17**, 23/11/82, around 2400 m of elevation). **G:** B: of tightly folded marble, calc-schist, and black schists within the Hunza granodiorite. This band seen on the left banl the Khani Basa glacier (right bank tributary to the Hispar glacier) can be followed along most of the northern side of Hispar glacier, even cutting the upper Snow Lake (PLF slide **LT79**, 28/7/86, at 4720 m of elevation, tele-lens, v looking north-east).

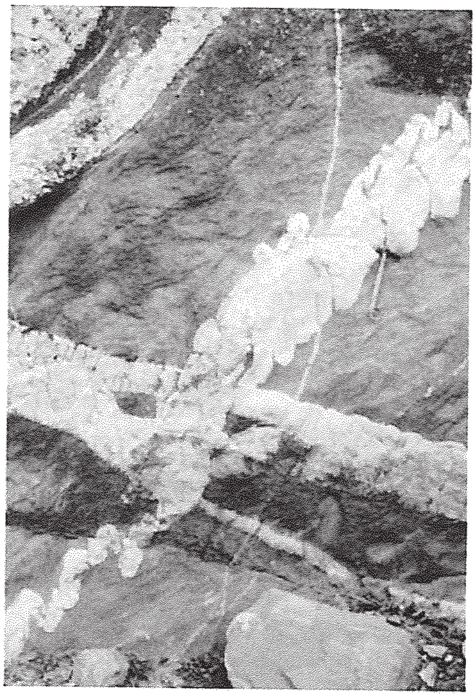
*F: Affleurement au bord de la KKH de granodiorite de Hunza homogène, fortement orthogneissifiée dans le fa amphibolite. La foliation, plongeant d'environ 60° vers le NE, est soulignée par des enclaves microgrenues aplatie: recoupée par des pegmatites à 2 micas-grenat (photo PLF **JY17**, 23/11/82, vers 2400 m d'altitude). **G:** Bande marbres, calcschistes et schistes noirs dans la granodiorite de Hunza. Cette bande, ici en rive gauche du glacie Khani Basar (tributaire rive droite du glacier d'Hispar) peut se suivre presque tout le long du versant nord du gla d'Hispar, traversant même le haut du Snow Lake (photo PLF **LT79**, 28/7/86, à 4720 m d'altitude, téléobjectif, p vers le nord-est).*

between the Silkiang and Bualtar glaciers where exceptional large-size aquamarine crystals have been mined out (Voillot, 1995).

A remarkable and unique **gabbroic dyke** (Fig. 11E) has been observed to cut the Hunza granodiorite and its foliation on the left bank of the Hunza section, opposite to the confluence of the Gulmit glacier outlet (Debon & Le Fort, 1982). The around 3 m thick dyke is E-W oriented and dips 60° to the south. The gabbroic matrix presenting 1 cm large euhedral hornblende crystals, contains ca 50% of both rounded and angular enclaves of very varied nature, decimetric to metric in size. The enclaves include dominant fine-grai microgranular material, pieces of surrounding Hunza granodiorite, me sedimentary material (mostly quartzitic, sometimes also, calcareous), and one block foliated aplite. The presence of metasedimentary enclaves brought up by gabbroic magma probably implies that Hunza granodiorite rests on top of the sa metasedimentary formations on which it been thrust southward.

2. KK metamorphic complex

The Karakoram metamorphic complex f defined by Desio (1963a & 1964) covers



**A** JY71

**B** JZ28

FIG. 12. Karakoram pegmatites and gemstones: **A:** Typical example of varied pegmatitic dykes crosscutting the Hunza granodiorite and its foliation. The ptygmatitic aspect of the latest dyke contrasts with the parallel aspect of the older ones. Outcrop along the KKH on the left bank of the Hunza river (PLF slide JY71, 25/11/82, around 2450 m of elevation). **B**: View across the Hunza river of the Khushi ruby mine, opened at the base of a thick pile of marbles from the Hispar Sar group on the right bank of the river. The marbles are interbedded with dark-coloured amphibolite levels affected by boudinage (PLF slide JZ28, 26/11/82, around 2400 m of elevation, 205 mm tele-lens).

*Pegmatites et gemmes du Karakoram:* ***A:*** *Exemple typique de filons pegmatitiques, ici recoupant la granodiorite de Hunza et sa foliation. L'aspect ptygmatitique de la pegmatite la plus tardive contraste avec l'aspect non plissé de la pegmatite la plus ancienne. Affleurement en bordure de la KKH, en rive gauche de la Hunza (photo PLF JY71, 25/11/82, vers 2450 m d'altitude).* ***B:*** *Vue d'une rive à l'autre de la Hunza de la mine de rubis de Khushi, creusée à la base d'une épaisse bande de marbres du groupe de Hispar Sar, en rive droite de la rivière. Les marbres sont interfoliés avec des amphibolites (niveaux sombres) boudinées (photo PLF JZ28, 26/11/82, vers 2400 m d'altitude, téléobjectif).*

entire zone between the central granitic belt to the north (Fig. 13) and the contact with the Kohistan-Ladakh formations to the south. It can be schematically subdivided into two sub-units: the gneissic domes representing the back-bone of the structure, and the metasedimentary formations lying north and south of them (Le Fort et al., 1995).

Searle (1991) groups all rocks south of the Karakoram batholith in his "Karakoram metamorphic complex" (also named "Karakoram metamorphic series" on his Fig. 9.2), subdivided into metasedimentary formations (the Hushe complex, Dumordo, Ganchen, and Askole amphibolite units), and metaplutonites (in the Hushe complex, and Dassu gneiss). As stated by Searle (1991), the insufficient sedimentological and palae-ontological controls prevent from a clear definition of the various entities.

The magmatic rocks intruding the KMC have been dealt with in a previous section concerning the plutonic rocks.

a. Orthogneisses

Within the KMC occur numerous elongated bodies of orthogneiss (Figs. 14 and 15), varying largely in size (from a few metres to several kilometres), shape (from thin continuous bands to globular domes), and composition (from granitic to granodioritic and tonalitic, and even syenitic). We will describe some of the largest entities forming more or less complex domes in Baltistan, and mention some characteristics of the occurrences in Hunza, considering their geochemistry and affinities to the other plutonic bodies, especially those from the axial belt.

The relationship between the orthogneiss and the metasedimentary formations is not always clear as their contact is a preferential zone of ductile deformation. However:

(i) in the western part of the Bukpun dome, near the Kilwuri Gans glacier, the orthogneiss cuts the metasedimentary formations and develops a contact metamorphism as shown by the presence of retromorphosed chiastolitic andalusite (see below);

(ii) the Arelter elongated body, forms an individualised dome intrusive into an amphibolitic layer north of the Ganchen peak;

(iii) the Dassu dome clearly sends out a swarm of orthogneissified granitic dykes into the surrounding metasedimentary formations. All three bodies are gneissified by the main tectonometamorphic events.

The domes are massively composed of orthogneiss with a few occurrences of paragneiss. The metamorphic grade is always high and often contrasts with that of the metasedimentary surrounding formations, with a sharp transition. In addition to the domes, orthogneisses can be found as intercalations within the metasedimentary formations (Shiskin, Moraine, Bolocho), and as so folded with them (cf infra Fig. 40 A). In the mapped area, three main gneissic domes are individualised: the Dassu gneiss dome (Desio, 1964; Desio et al. 1985; Bertrand et al., 1988; Allen and Chamberlain, 1991) extending across the entire Braldu valley and studied again recently by Y. Rolland and G. Mahéo, the Mangol Bluk or Basha dome essentially cropping out in the large bend of the Basha valley, and the Bukpun dome west of Arendu, that shows a migmatitic core well exposed at the entrance of Kero Lungma. The small dome of Arelter, mantled by amphibolitic levels, shows the sam[e] petrographic and deformational characteristics; new data from the Hoh Lumba valley (S. Guillo[t] and G. Mahéo) show that it extends eastwar[d] may be up to the Biafo glacier.

**γζD, the Dassu dome**, is one of the olde[st] recognised mass of orthogneiss (Desio, 1963a [&] 1964). At Dassu itself, one may distinguish [a] matrix of migmatitic leucocratic orthogneisse[s] Bi ± Mu ± Gr-bearing, with sinuou[s] discontinuous bands of biotite schi[st] interfoliated every 20 to 30 cm (Fig. 15C[)] larger interfoliated bands of fine-grained gre[y] gneiss may represent former aplitic dyke[s] Granitic specks result from the constriction [of] partially molten levels of the migmatitic gneis[s] they align along a conspicuous lineatio[n] sometimes forming veinlets axial plane [to] centimetre-long folds. The whole rock [is] crosscut by numerous pegmatitic dykes, Mu-T[o] Bi-bearing.

Westward, along the Shigar valley, t[he] orthogneisses are quite heterogeneous. T[he]

**A** LU65

**B** 93.9.2

FIG. 13. Karakoram metamorphic complex, general view: **A:** View of the upper Hispar glacier and Hispar pass (5151 m). The slopes of the left bank are built up in the formations of the Karakoram Metamorphic Complex, made up of dominant metasedimentary material (including some marble horizons) and minor orthogneiss. The distance to the pass is approximately 30 km (PLF slide LU65, 31/7/86, at 4130 m of elevation, tele-lens). **B:** View of the medium segment of the Chogo Lungma glacier, looking to north-west. In the central part of the photo, the tributary Kiwuri Glacier, and the Kurumal pasture, at the junction between Kiwuri and Chogo Lungma glaciers. Farther east (on the right), the Shing Kuru pastures. Massive outcrops above Shing Kuru are made of the Bukpun felsic gneiss and orthogneiss, whereas above and west of Kurumal limestones and metapelitic alternations are clearly seen. In the foreground, the right bank of the Chogo Lungma glacier is formed by the Greenstone complex, with lenses of limestones, probably corresponding to olistholiths in the MKT zone (AP slide 93-9-2, 9/8/93, around 4550 m of elevation, right bank ridge of the Remendok glacier).

*A: Vue du glacier supérieur d'Hispar et du col d'Hispar (5151 m). Les pentes de la rive gauche (à droite de la photo) sont faites de matériel sédimentaire prédominant (avec quelques horizons de marbre) et d'orthogneiss appartenant au Complexe Métamorphique du Karakoram. La distance jusqu'au col est d'environ 30 km (photo PLF LU65, 31/7/86, à 4130 m d'altitude, téléobjectif).* ***B:*** *Vue de la partie médiane du glacier du Chogo Lungma, vers le nord-ouest. Dans la partie centrale de la photo, le glacier affluent de Kiwuri, et l'alpage de Khurumal, à l'angle du glacier du Kiwuri et du Chogo Lungma. Plus à l'est (à droite), les pâturages de Shing Kuru. Les affleurements massifs au dessus sont dans les gneiss feldspathiques et orthogneiss de Bukpun, tandis qu'à l'ouest et au dessus de Khurumal on voit bien les alternances de calcaires et de métapélites. au premier plan, la rive droite du Chogo Lungma est creusée dans le Complexe de roches vertes, avec des lentilles de calcaires en olistholite (zone du MKT) (photo AP 93.9.2, 9/8/93, vers 4550 m d'altitude, arête rive droite du glacier de Remendok).*

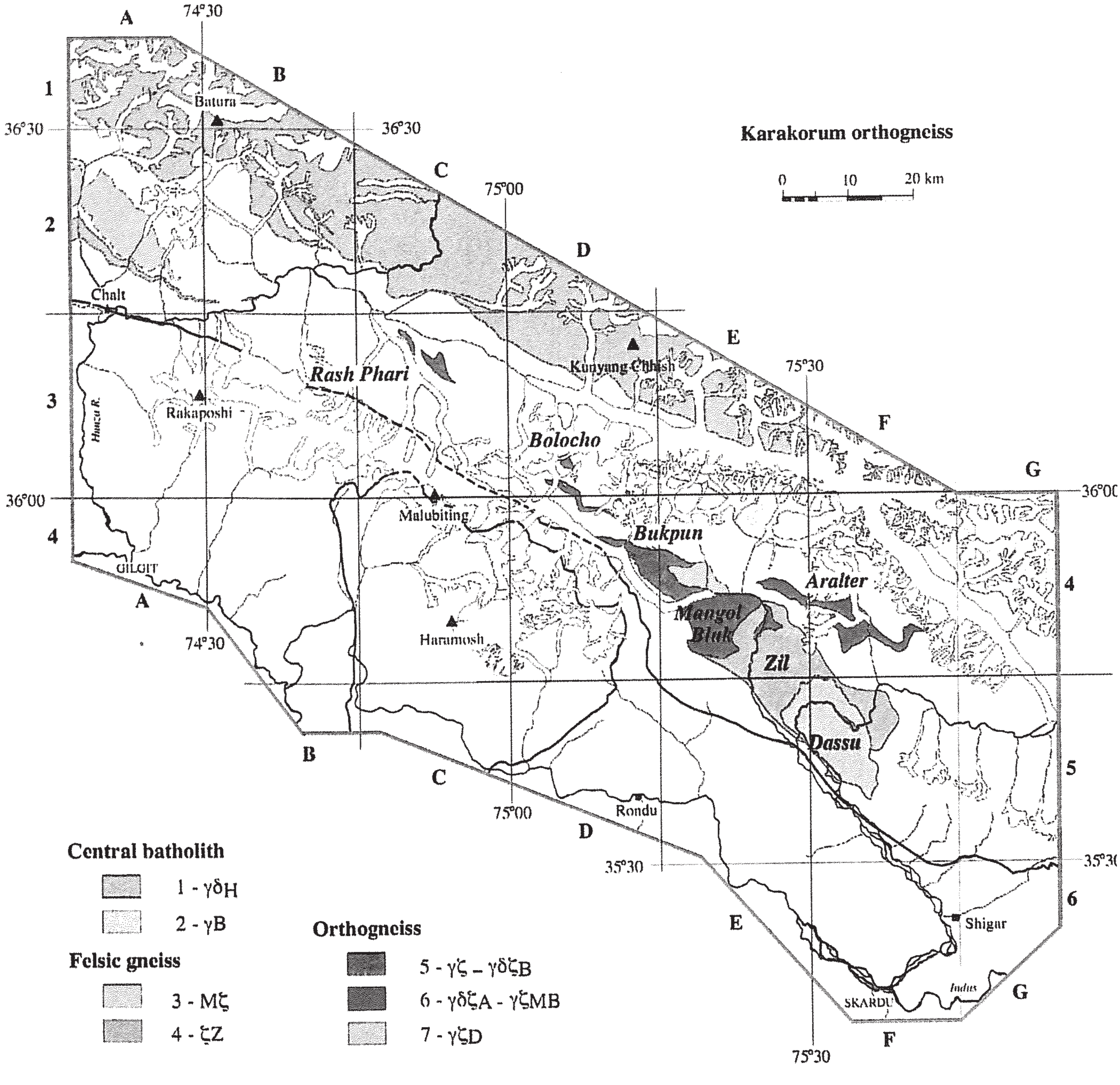



FIG. 14. Sketch map of the Karakoram orthogneiss: Colours for the orthogneiss refer to their chemical affinities either with the Hunza (predominantly granodioritic) or Baltoro (leucogranite) plutons (see Fig. 20). Central batholith: (1) Hunza and (2) Baltoro granites; felsic gneiss: (3) migmatitic gneiss of Bola Das valley and Arendu area, (4) Zil felsic gneiss, predominantly orthogneissic; massive orthogneiss: (5) interfoliated Rash Phari, Bolocho and Moraine lenses (possibly metamorphosed sills of Hunza granodiorite), Bukpun orthogneiss, (6) Mangol Bluk and Arelter orthogneiss (chemically similar to Baltoro granite, and as it, regionally trending west-east ), (7) Dassu and Goyungo orthogneiss, chemically different from Hunza as well as Baltoro granite.

*Carte schématique des orthogneiss du Karakoram: Les couleurs choisies pour les orthogneiss rappellent leur affinité chimique avec les granitoïdes de Hunza (surtout des granodiorites) ou du Baltoro (leucogranite) (voir Fig. 20). Batholite central: (1) massifs de Hunza et (2) du Baltoro; gneiss felsiques: (3) migmatites de la région de Bola Das et d'Arendu, (4) gneiss felsiques (en grande partie des orthogneiss) de Zil; orthogneiss massifs: (5) lentilles interfoliées de Rash Phari et de la région des glaciers Bolocho et Moraine (probablement des sills de granite et granodiorite de Hunza métamorphisés), orthogneiss de Bukpun, (6) orthogneiss du Mangol Bluk et d'Arelter (chimiquement proches du granite du Baltoro et dessinant comme lui un alignement ouest-est), (7) orthogneiss de Dassu et de Goyungo, chimiquement assez différents de Hunza comme du Baltoro.*

most leucocratic (such as SK290, analysis Annex 3-4) are very migmatitic and bear two-micas, garnet and tourmaline; they contain masses of strongly foliated Bi-Amf-Gr orthogneiss, not unlike those from Bukpun. These gneisses present abundant small shear zones that have been later cut by Bi-T pegmatites. The more mesocratic gneisses contain biotite and hornblende with a plagioclase up to An60; Hanson (1986) even mentions the presence of orthopyroxene in one sample from the mouth of the Braldu River. Metasedimentary enclaves include schists, calcsilicate rocks, and marbles.

**Goyungo gneiss**: eastward, in the gorges carved out by the Braldu, the ortho-gneiss (Fig. 15E) becomes an augen-gneiss with euhedral K-spar up to 7 cm; there, the garnet is also frequent, and in one place at least, north of Goyungo, we have met kyanite crystals forming a mineral lineation, retrogressed into sillimanite-fibrolite. The contact with the surrounding biotite-rich and sillimanite-bearing paragneiss, more or less parallel to the foliation, is underlined by a banded two-mica pegmatite, several metres-thick. More banded two-mica tourmaline aplo-pegmatitic dykes follow for some 70 m within the paragneiss; in the landscape, they form hectometric clear-coloured boudins.

The whole of the Dassu dome is famous for its gem-bearing pegmatites. Kazmi et al. (1985) have described their mineralogy that includes albite, muscovite and lepidolite, black tourmaline, almandine-spessartine garnet, pale-blue aquamarine up to 16 cm long, pale yellowish-green emerald, pale pink fluorapatite, topaz, and very rare apple-green hydroxyl-herderite [CaBe(PO4)(OH)], all mostly of gem quality. Late pegmatites include Q-FK-Mu-T-Chl bearing dykes in which the very green chlorite is extremely fine-grained, powdery.

Chemically (Annex. 3), the gneiss has a mesocratic peraluminous granitic composition, and the alumino-cafemic association is ferriferous and remarkably quartz-rich. Th and Zr are abundant. The single analysis given in Hanson (1986, p. 40), may represent a granodioritic inclusion, as mentioned above.

Age-wise, Hanson (1986, p.55) mentions a U-Pb inheritance of at least 1 Ga in zircons from the Dassu gneiss. This is the only indication ofthe age of the source. An $^{40}$Ar-$^{39}$Ar plateau age on a biotite from a garnet-sillimanite bearing sample is given as 7.3 ± 0.2 Ma in the text, but 8.0 ± 0.2 Ma in the corresponding figure (Searle, 1991, p. 213-214), the same biotite yielding 7.1 ± 0.28 Ma by K-Ar, another biotite from another sample yielding a K-Ar age of 4.69 ± 0.19 Ma (ibid & Searle et al., 1989). Two young U-Pb monazite ages (6.8 ± 0.2 Ma and 6.7 ± 0.5 Ma) have been obtained by Smith et al. (1992) on two samples of schist east of the Dassu dome, likely to represent the age of the latest peak of amphibolite-grade metamorphism. These Pliocene cooling ages point out to the recent exhumation of the dome.

Altogether, the Dassu orthogneiss resembles very much the Iskere orthogneiss from the Nanga Parbat-Haramosh basement gneisses. This akinness may not be fortuitous. The Gondwana basement was probably quite uniform before its splitting in two fragments during Palaeozoic times. The northern fragment corresponded to the Karakoram, Lhasa block, and Afghan central mountains present units (South Tibetan block), whilst the southern fragment corresponded to the Himalayan domain (Indo-Pakistani block). After a long isolated evolution, the two fragments after collision, are again in the vicinity of each other, with similar portions of the old basement. This of course implies that the age of crystallisation of the Dassu protolith is old, and it would single it out of the other south-Karakoram domes, likely to be Cretaceous for most of them.

**γζMB,** the **Mangol Bluk or Basha dome,** a large one covering more than 150 km$^2$, extends on both sides of the valley from Arendu to Niesolo. It is composed of orthogneiss (Figs. 14 and 15E), sometimes containing large septa of paragneiss, both strongly structured by a phase of isoclinal folds preceding the doming phase doming (Lemennicier, 1993, Fig. 13). The orthogneiss also contains large intrafoliated bands of massive Bi-bearing amphibolite, up to 2 m thick and several hundred metres-long, that probably represent old mafic dykes, gneissified

FIG. 15. Karakoram orthogneiss: **A:** View of the Mangol Bluk (Basha) dome from the left bank of the Basha valle Note the strong rigging lineation framing the dome (PLF slide **OE36**, 24/5/92, 3010 m of elevation). **B:** Small dome orthogneissified granodiorite and surrounding metasediments, outcropping on the right bank of the Biafo glaci upstream from the Namla settlement (PLF slide **LR47**, 17/7/86, at 3550 m of elevation, looking at N 242° E). **C:** Das migmatitic orthogneiss, biotite-muscovite-garnet bearing, with sinuous discontinuous bands of biotite schlierens. Lim of the late cuspate folds are crosscut by leucocratic lenses of mobilisates, formed during the late dome exhumati processes. Outcrops just beside the Dassu guest house (AP slide **95.5.35**, 11/9/95, around 2245 m of elevation). Outcrop of Dassu porphyroid orthogneiss (Goyungo orthogneiss). Outcrop in the main lens, making a small dome the Askole road. Several other sills of the same material are visible higher up in the slope, in the cliffs left bank of t Braldu river. Road from Dassu to Askole, about 5 km east of Dassu (AP slide **95.8.2**, 11/9/95, around 2300 m elevation). **E:** Outcrop of Mangol Bluk (Basha) orthogneiss. The section is perpendicular to the foliation, and alm perpendicular to the lineation. It is why it shows nearly no dissimetry in the shape of the eyes of K-feldspar. Outcr east of Bisil, left bank of the Basha (PLF slide **OE83**, 26/5/92, 2950 m of elevation).

*Orthogneiss du Karakoram:* ***A:*** *Vue du dôme du Mangol Bluk* (Basha), *depuis la rive gauche de la vallée de la Basl Notez la structure en piliers du dôme, due à la forte linéation d'étirement (photo PLF* ***OE36****, 24/5/92, 3010 d'altitude).* ***B:*** *Petit dôme fait de granodiorite orthogneissifiée au coeur et de métasédiments à l'extérieur, en r droite du glacier du Biafo, en amont de l'alpage de Namla (photo PLF* ***LR47****, 17/7/86, à 3550 m d'altitude, prise v N242° E).* ***C:*** *Orthogneiss de Dassu, migmatisé, à biotite-muscovite-grenat, avec des schlierens biotitiques discontin Les flancs des plis tardifs sont recoupés par des lentilles de mobilisat leucocrate, formées pendant l'exhumation tard du dôme. Affleurement juste à côté de la maison d'hôte de Dassu (photo AP* ***95.5.35****, 11/9/95, vers 2245 m d'altituc* ***D:*** *Affleurement des faciès homogènes porphyroïdes du dôme de Dassu (gneiss de Goyungo). Affleurement dans lentille principale, dessinant un petit dôme recoupé par la route d'Askole. D'autres sills du même granite sont visib plus haut dans les falaises en rive gauche de la Braldu. Route de Dassu à Askole, environ 5 km à l'est de Dassu (ph AP* ***95.8.2****, 11/9/95, environ 2300 m d'altitude).* ***E:*** *Affleurement des orthogneiss du Mangol Bluk* (Basha). *La sect est perpendiculaire à la foliation et presque perpendiculaire à la linéation. Pour cette section particulière, les y feldspathiques sont très symétriques. Affleurement à l'est de Bisil, rive gauche de la Basha (photo PLF* ***OE83****, 26/5/ 2950 m d'altitude).*

with the gneiss; the best examples are exposed between Bisil and Murtswa, and south of Arendu, right bank of the Tippur Gans valley. The orthogneiss is a two–micas±garnet ±tourmaline leucocratic granite with a fine-grained to augen texture.

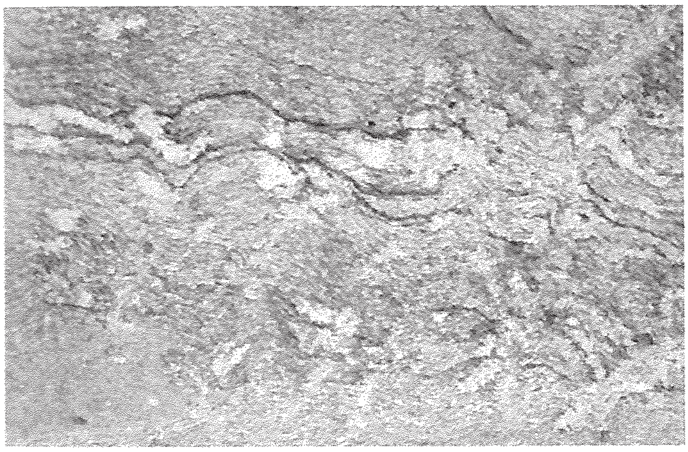
Chemically (Annex. 3-4), the orthogneiss is dominantly made up of leucocratic to sub-leucocratic granite, with some adamellite and granodiorite. The different samples collected form an alumino-cafemic association, more or less peraluminous, ferriferous, with a sub-alkaline affinity. Usually enriched in LREE, they present a strong negative anomaly in Eu. Concerning the trace elements, compared to the lower crust composition, the Basha orthogneiss is depleted in Ba, Sr, Ti and enriched in Rb, Th and U (see Lemennicier, 1996 for more details). All these characteristics point out to a crustal genesis by anatexis and are not unlike that of the Baltoro granite cropping out some 10km to the north.

**γδζB,** the **Bukpun dome**, is an elongated dome of 20 x 5 km, outcropping on the left bank of the Chogo Lungma and culminating at the Bukpun peak (5,441 m) (Figs. 14 and 15 Near the settlement of Kurumal, it is obvic that the original granitoid was intrusive into metasedimentary formations of the KMC, wh shadows of chiastolitic andalousite represent trace of the contact metamorphism in aluminous schists. North of Arendu, granitoid seems to be also intrusive in Arendu migmatitic formation. The Bupk gneiss has a quite varied appearance: leucocr to mesocratic, with two-micas or biotite alo fine-grained to coarse-grained, and sometir with augens. Microgranular enclaves are rat frequent, and lenticular septa of amphibolite garnet micaschist also occur. The foliatio very strong, underlined by the micas sometimes also by quartz ribbons.

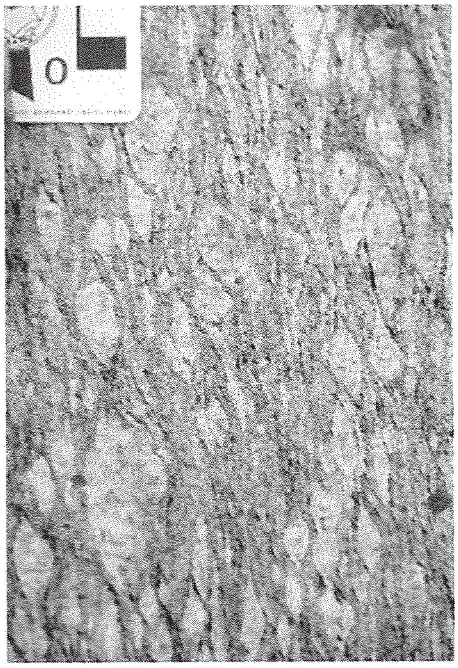
The chemical characteristics (Annex. 3-4 the analysed gneiss samples are homogene (Lemennicier, 1996). They are ma granodiorites extending from qua monzodiorites and tonalites to adamelli ranging from slightly metaluminous to slig peraluminous, and forming a calc-alka association with a normal (Mg/Mg+Fe) ra

**A** OE36

**B** LR47

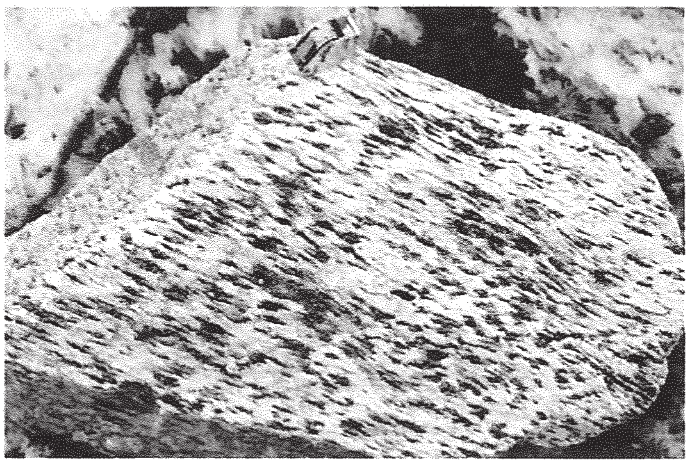


**C** 95.5.35

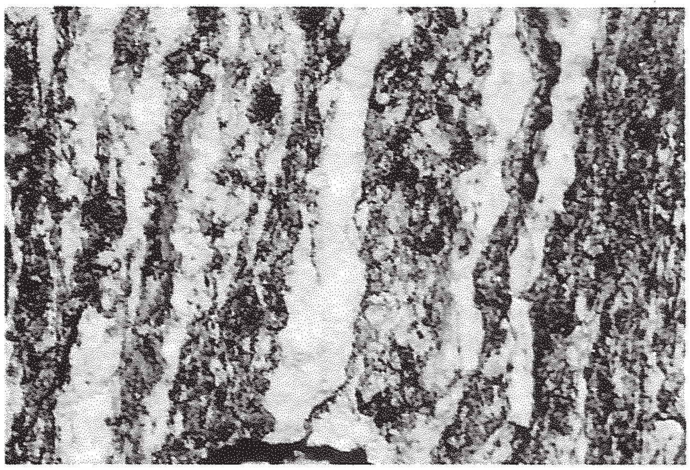


**D** 95.8.2

**E** OE83



F 0C31



G PE93

FIG. 15 (continued). **F** - Bukpun orthogneiss, boulder of "leopard" facies. The rock is strongly foliated and li
Left bank of the Chogo Lungma glacier valley (PLF slide **OC31**, 17/5/92, 3250 m of elevation, scale given by th
**G** - Boulder of biotite and garnet-bearing slightly migmatised orthogneiss originating from the Rash Phari body.
of the right lateral slope of the Barpu glacier (PLF slide **PE93**, 17/7/94, 3020 m of elevation, macro-lens).

*F - Orthogneiss de Bukpun, bloc de faciès "léopard". La roche a une forte fabrique planaire + linéaire. Rive*
*de la vallée du Chogo Lungma (photo PLF **OC31**, 17/5/92, 3250 m d'altitude, échelle donnée par la loupe). G*
*d'orthogneiss à biotite-grenat en provenance des affleurements du Rash Phari. Eboulis de la pente rive dr*
*glacier de Barpu (photo PLF **PE93**, 17/7/94, 3020 m d'altitude).*

They are enriched in LREE with a $La/Yb_N$ ratio of 9 to 51, and a small Eu anomaly (Eu/Eu* from 0.76 to 1.09). All these characteristics are very similar to those of the Cretaceous Hunza and Ghamubar plutons (Debon et al., 1987) with which we suggest a common origin and age.

**γδζA,** the **Arelter dome** is a large lens-shaped body whose western part has been studied by Lemennicier (1996) in the Arelter valley (Fig. 14). New data (Guillot & Mahéo, 1998) show that the body extends eastwa
least up to the Hoh Lumba-Biafo divide,
of Hoh Bluk, with a thick slab, elor
N120°, and made up of granitic orthognei
the Arelter valley, it forms the heart of
vergent anticline and has undergone two d
tectonometamorphic events: an early isc
folding followed by doming. The rock cc
of oligoclase, K-feldspar, quartz, biotit
muscovite, with sphene and allanite as acc

phases. Microstructurally it shows a granoblastic structure with pervasive recrystallization. A late deformation produces extinction bands in the quartz and small fractures in the feldspars. Geochemically (Annex. 3-4), it is a very homogeneous grano-diorite, slightly peraluminous, corresponding to an alumino-cafemic association, subalkaline, and sodic, typically magnesian. The 5 Ma obtained by $^{40}Ar$-$^{39}Ar$ method on a muscovite represents cooling after the doming event (Villa et al., 1996).

γζ, **other masses of orthogneiss** include:

- kilometre-size elongated massifs, such as that of the Rash lake (Figs. 14 and 15G), between Barpu glacier and Hispar valley, and that of the Moraine-Bolocho glaciers;
- hectometre-size bands that stripe the KMC and that we have met particularly along the Sumayar valley, and the Bualtar, Barpu, Hispar, Moraine and Bolocho glaciers;
- stray boulders from unvisited outcrops, such as those in Chukutens, on the right bank of the Barpu glacier.

All these masses are foliated and folded with the paragneisses and schists of the KMC. On the west-central part of the map, they draw a discontinuous strip more than 50 km long, that probably represents the deformed prolongation of the batholith southern outliers described above (the Hindi or Nasirabad plutonic strip).

The orthogneiss outcrops of the Bolocho valley are the only ones to have been studied chemically in some detail (Annex. 3-4). Their geochemical characteristics very much recall those of the Hunza plutonic unit, to which they are probably related, in a similar way to the orthogneiss of the Bukpun dome.

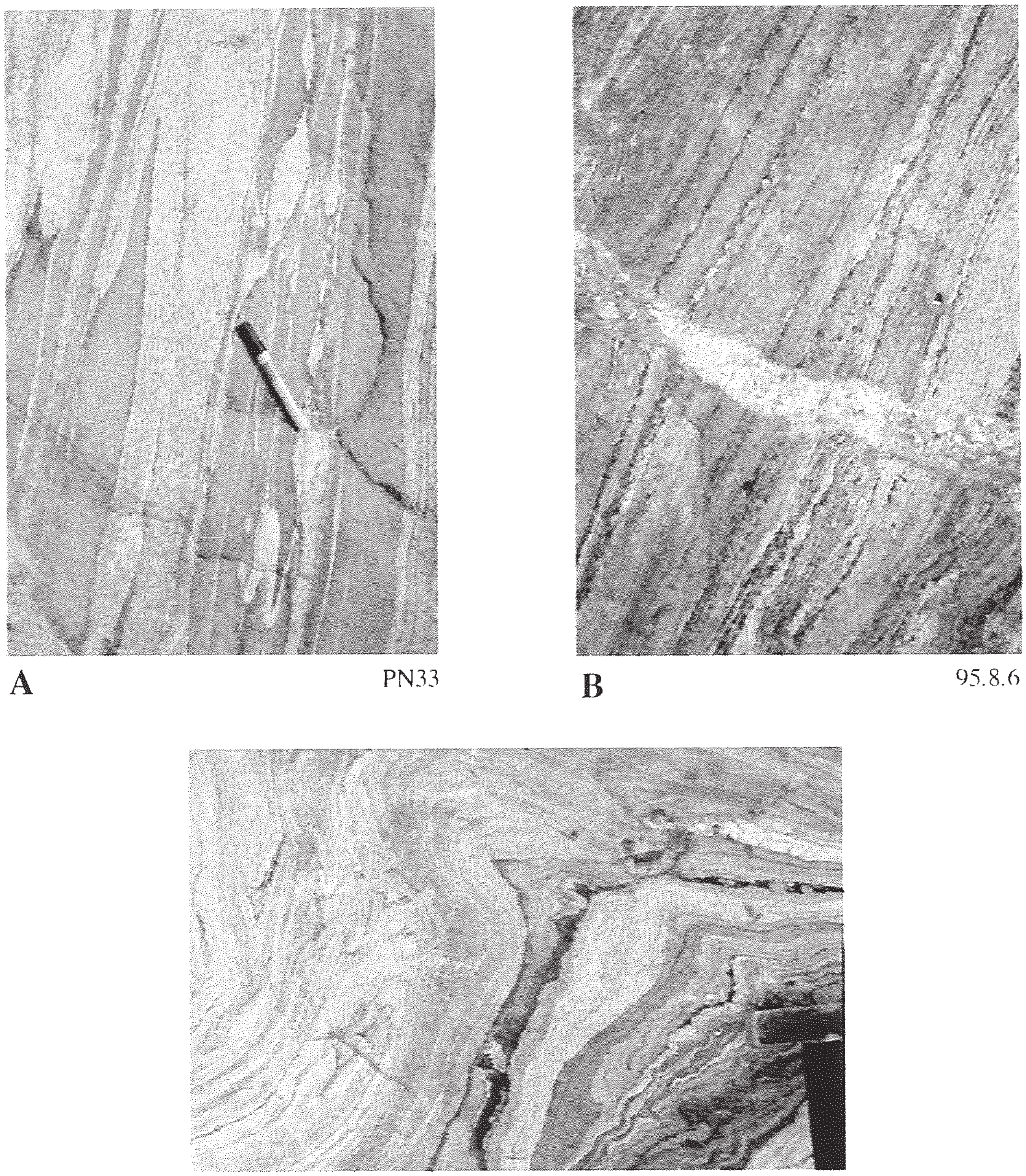
ζZ, the **Zil gneiss.** Surrounding the Mangol Bluk and Dassu orthogneissic domes, along the Basha and Braldu Rivers, outcrops a large patch of dominant orthogneiss with decimetric to hectometric intercalations of high-grade biotite and amphibole-rich paragneiss (Figs. 14 and 16). We have grouped these heterogeneous gneisses, sometimes migmatized, under the Zil gneissic formation. Desio (1964) and Desio et al. (1985) distinguish a "Ganchen Complex structurally interposed between the Dumordo Formation" (mostly equivalent to our KMC), "and the Dassu Gneiss" in the Basha area and to the east of it. Our Zil gneiss is part of this complex, but has a much smaller eastward and westward extension. It does not include the varied metasedimentary lithologies, marbles and associated paragneiss, that clearly pertain to the KMC.

The Zil formation (Fig. 16B) is highly deformed at all scale, including some kilometric isoclinal folds, sometimes visible in the landscape. For instance, numerous folds can be seen from the Ganchen summit down to the Basha River, as already noticed by Desio et al. (1985, pl. 1, fig. 2), who have also sketched the orthogneissic core (part of the Mangol Bluk orthogneiss) of one of them (ibid, pl. 1, fig. 1).

The aluminous paragneiss displays a first metamorphic paragenesis with Grt-St-Ky of HT-MP followed by a second metamorphic HT event underlined by the transformation of Ky into Sill. Allen and Chamberlain (1991) have estimated pressure and temperature of 4-10 kbar and 550-625°C. New estimates by Lemennicier et al. (1996) have yielded somewhat higher values of 6.1-7 kbar and 600-700 °C for the peak metamorphism of the second event.

On both sides of the Basha valley, all the gneissic formations are cut by late plurimetric pegmatitic dykes with a mild deformation and most generally a gentle dip. Such dyke swarms are particularly spectacular in the Braldu and Basha sections. In addition to quartz and feldspars they contain abundant giant muscovite, biotite, tourmaline, and more valuable beryl-aquamarine and topaz (see above).

Mζ, the **Arendu-Bola Das felsic gneiss and migmatite**. In the lower Kero Lungma valley, the left bank offers good outcrops of the migmatitic gneisses of Arendu (Fig. 14). The bulk of the rock is made up of a Bi-Gr gneiss containing interfoliated lenses of granitic mobilisate with conspicuous rims of restitic material. The gneisses contain local intercalations of pyroxene-amphibolitic or quartzitic levels. Muscovite is rare. The gneisses are often folded, sometimes tightly refolded (Fig. 16C), and cut by ptygmatitically folded dykes of granitic material. The two mica±tourmaline±garnet-bearing pegmatites are usually orthogneissified.



A PN33 B 95.8.6

C 92.5.8

FIG. 16. Bola Das valley and lower Chogo Lungma (Arendu) migmatites, Zil felsic gneiss: **A:** Coarse-grained granitic folded and stretched banding in fine-grained biotite gneiss of the Bola Das migmatites. Note the thin biotitic melanosome at the contact. The most leucocratic veins are ptygmatically folded (PLF slide **PN33**, 25/8/95, 2440 m of elevation, looking to the SE). **B:** Zil gneiss, east of the Dassu orthogneiss. An outcrop of layered quartzo-feldspathic gneiss, crosscut by a granitic lens. The dark levels are biotite+garnet rich (photo AP **95.8.6**, 11/9/95, left bank of Braldu, app. 1 km upstream the Foljo bridge, looking to N 110° E). **C:** Migmatites of the Chogo Lungma - Kero Lungma junction (Arendu migmatites). Boulder of a highly granitized gneiss, displaying refolded folds and several generations of mobilisates. Diffuse granitisation and biotite enriched restitic schlierens (AP slide **92.5.8**, 24/5/92, left bank of the Basha river, downstream Arendu).

*Migmatites de la vallée de Bola Das et du bas Chogo Lungma (Arendu), gneiss feldspathiques de Zil: **A:** Dans un affleurement des migmatites de Bola Das, rubanement marqué par les lits granitiques à gros grain, plissés et étirés. Noter les minces liserés de mélanosome au contact de ces lits. Les veines les plus leucocrates sont plissées de manière ptygmatitique (photo PLF **PN33**, 25/8/95, 2440 m d'altitude, vers le SE). **B:** Gneiss de Zil, à l'est de l'orthogneiss de Dassu. Affleurement de gneiss quartzo-feldspathique régulièrement lité et recoupé par une lentille granitique. Les niveaux sombres sont riches en biotite-grenat (photo AP **95.8.6**, 11/9/95, rive gauche de la Braldu, 1 km en amont du pont de Foljo, vers N 110° E). **C:** Migmatites de la confluence Chogo Lungma - Kero Lungma. Bloc d'un faciès montrant des plis repliés et des mobilisats de plusieurs génération. Granitisation diffuse abondante, et restites très riches en biotite (photo AP **92.5.8**, 24/5/92, rive gauche de la Basha, peu en aval d'Arendu).*

In the Bola Das section, north of Bar, the fine -grained biotitic gneisses present intercalations of rusty quartzites and calc-silicate horizons; they are thoroughly invaded by clear-coloured granitic material with a melanosome reaction rim at the contact (Fig. 16A). The whole mass looks quite heterogeneous and tectonised.

In the Arendu region, the migmatitic gneisses form a lenticular body, structurally underlying the Bukpun orthogneiss. East of the Kero Lungma valley, the metasedimentary formation of the KMC directly comes to rest on the migmatitic gneisses.

Although no age determination has been obtained, we believe that these gneisses could represent part of the Karakoram basement, analogous to the Chikar quartzite and migmatitic gneiss of N-Karakoram, intruded at the base of the Darkot glacier by the pre-Ordovician Ishkarwaz granite (Le Fort et al., 1994; Le Fort and Gaetani, 1998).

### b. Metasedimentary and metavolcanic formations of the Karakoram metamorphic complex (KMC)

The metasedimentary formations were originally named as the Dumordo group (or the Baltit group by Tahirkheli, 1982), of unknown age, and were described as a complex of metamorphic rocks dominated by crystalline limestones, rather in thick beds, interfoliated with calc-schists, schists, and gneisses (Desio, 1963a, 1979; Desio et al., 1985). In fact, they are composed of alternances of limestone, dolomite, quartzite, Bt-Mu-Q-Pl±Gr±St meta-pelites, with some conglomeratic layers, and rare amphibolitic horizons of basaltic composition (Figs. 17 and 18). Desio (1963a & 1979) and Desio et al. (1985) tried to distinguish the Dumordo from the Ganchen formation, the latter being less marble-rich, more amphibolitic and more gneissic. But the distinction is merely meaningless as both formations contain the same petrological horizons, and as the entire zone is actually thoroughly folded by isoclinal folds that mix everything. Thus the stratigraphy of the ensemble is impossible to assess, and it is more accurate to consider the whole metasedimentary unit as one broad formation.

Searle (1991) divides the KMC into a number of loose units, four of which concern the metasedimentary formations covered by the map: the Hushe complex, Dumordo, Ganchen, and Askole amphibolite units:

- the Hushe complex (Hushe gneiss on the 1991 map), defined in the Hushe valley, extends along the southern margin of the Karakoram formations. It is mainly made up of granodioritic to dioritic orthogneisses and amphibolitic material intercalated with thin bands of marble and psammitic metasediments. With their distinctive mafic composition they also single by their relatively old Jurassic age, loosely defined by a 145-150 Ma U-Pb zircon age from a deformed granodiorite, and two K-Ar hornblende ages of 208 ± 8 and 163 ± 7 Ma. In the area covered by the present map, Searle (1991) attributes to it a discontinuous band along the MKT, including the Skoro La region. But actually, in this area at least, there is no clear evidence for distinguishing the metasediments of the Hushe unit from the other metasediments;
- the Dumordo and Ganchen units are similar to the Dumordo formation and Ganchen gneiss of Desio (1963a, 1964, 1979), the difference between the two being merely a lesser abundance of marble in the latter. But actually, as said above, the distinction between the two is difficult to maintain;
- the Askole amphibolite unit, defined at Askole along the Braldu valley, is composed of interbanded dark-coloured amphibolites, marbles, and pelitic material. But there again, these lithologies cannot be separated from the other metasediments in which they are clearly interbanded over the entire area, especially well documented in the Askole (Braldu), Bolocho (Chogo Lungma) and Saret (Hunza) areas.

In a recent study of the formations outcropping at the eastern limit of the map (Askole-Skoro Lungma and Bauma Harel area) as well as immediately southeastward of it (Thalle valley), Rolland (Rolland et al., 2000) has been able to show that they were forming Precambrian to Middle Ordovician units composed of:

- a Precambrian basement, with a minimum Ar-Ar age of 650 Ma,
- sedimentary formations of plate-form type, overlying the basement, paleontologically dated

FIG. 17. Karakoram Metamorphic Complex, lithostratigraphy: **A:** Above the left bank of the Chogo Lungma glacier, east of the Moraine glacier, a section of the Karakoram Metamorphic Complex succession. The white levels are the Chogo Lungma limestones, interlayered with some black levels of amphibolites; variations of thickness in the amphibolitic levels are due to boudinage (and probably to initial variations) rather than to isoclinal folding. Between the marbles, the brownish levels are garnet rich metapelites and quartzite. The photo shows all the lower part of the Bolocho section (see Fig. 23), from the lower micashists up to the beginning of the Bolocho orthogneiss (forming the snowy upper part of the slope). In the background to the left, on the north-east ridge of the Spantik, the series are folded to vertical (AP slide **93.5.6**, 31/7/93, 3980 m of elevation, from the central part of the Chogo Lungma glacier, oriented N 335° E). **B:** View of the Spantik (Golden peak, 7028 m) from the Rash lake. The golden pillars are made up of vertical limestone horizons from the Chogo Lungma group of the Karakoram Metamorphic Complex (PLF slide **PF24**, 18/7/94, 4430 m of elevation, tele-lens, oriented N 150° E).

*Complexe métamorphique du Karakoram: **A:** En rive gauche du glacier du Chogo Lungma, dans le versant à l'est du débouché du glacier Moraine, une coupe de la succession métasédimentaire du Complexe Métamorphique du Karakoram. Les niveaux blancs, formant deux barres principales, correspondent aux calcaires (marbres) du groupe du Chogo Lungma. Les niveaux très sombres sont des amphibolites; leurs variations d'épaisseur sont dues plus à du boudinage (accentuant sans doutes des variations initiales) qu' à des plis isoclinaux. Entre les marbres, les formations brunâtres sont faites de micaschiste à grenat et de quartzite. La photo montre toute la partie inférieure de la coupe du glacier Moraine (Fig. 23), jusqu'aux orthogneiss de Bolocho (qui forment la partie supérieure de la pente, sous la neige). A l'arrière plan, sur l'arête nord-est du Spantik, la série est redressée à la verticale (photo AP **93.05.06**, 31/7/93, 3980 m d'altitude, depuis la partie centrale du glacier du Chogo Lungma, vers N 335° E). **B**: Le Spantik (le Golden Peak, 7028 m) vu du lac de Rash Phari. Les piliers dorés sont construits par les calcaires du groupe du Chogo Lungma (Complexe Métamorphique du Karakoram), redressés ici presqu' à la verticale (photo PLF **PF24**, 18/7/94, 4430 m d'altitude, téléobjectif, orientée vers N 150° E).*

Lower Ordovician by fossil findings (crinoids and graptolites), an age confirmed by $^{87}Sr/^{86}Sr$, $\delta^{13}C$ and $\delta^{18}O$ isotopic data (Rolland, personal communication) on marbles,

-a dismembered ophiolite, made up of metagabbros and metabasalts coated of ultramafites, lies above it. This unit (Masherbrum Complex of green rocks, Rolland et al., 2000) would extend northwestward into the Askole amphibolites.

Thus, taking into account, the difficulty to separate different formations, we have always tried to map the actual lithology met in the field: viz. marble, amphibolite, arenite, conglomerate, and represent it when large enough to draw it on the map.

**sKK, undifferentiated metasediments.** The metasedimentary formations are well exposed along the middle Hunza valley and the Barpu glacier valley, along most of the Hispar valley, on the left bank (northern side) of the Chogo Lungma and south of it in the Niamur valley, and along the Braldu valley and the lower part of the Biafo glacier. The bulk of the metasediments is made up of aluminous schists metamorphosed in the amphibolite-grade.

They have been strongly structured by at least two phases of deformation including a first south verging isoclinal folding with hectometre- to kilometre-size folds such as those on the left bank of the Baltar glacier, in the Hachindar valley, along the Moraine Glacier, in the Kero Lungma valley, and on the right bank of the Hispar one; the orthogneisses are involved in these folds (see below, Fig. 40; see also the "Ganchen fold" on the left bank of the Basha valley shown by Desio et al., 1985, plate 1, Fig. 1). The deformation and lack of good marker beds preclude retrieving the stratigraphy and original thickness of these formations.

**tKK, Shittinbar formation, predominantly terrigeneous**. On the western half of the map, we have distinguished the southern part of the KMC where a rather monotonous terrigeneous formation of dominant sandy and pelitic alternances (Fig. 19A) contrasts with the heterogeneous nature of the northern part.

**shK, Khusomik schist**. To the southeast of the map, in the upper Skoro and Bauma Harel valleys, in an area of lower metamorphic grade, we have individualized a sequence of dark pelitic schists intercalated with limestone and arenite. These schists and limestones are in direct prolongation of the series recognised by Rolland (2000) in the Thalle valley, dated Lower Palaeozoic, but are also in continuity

A 93.5.6

B PF24

with the Bauma Harel limestone horizons that have been dated Upper Cretaceous (see below). Their relationship with the other metasediments (sKK) remains unclear as they are tectonically intricated with other formations, including likely Kohistan material. Moreover, to the northwest, as the metamorphic grade increases, they become hardly distinguishable from the sKK metasediments. However, taking into account the structural continuity between the latter and the Khusomik formations, it is highly probable that they are largely made up of the same series.

**M, marble**. Some marble horizons show an astonishing continuity and can be followed all across the map from the right bank of the Hunza north of Chalt, to the left (north) bank of the Chogo Lungma, from there to the Braldu valley and Biafo glacier, and even to the left bank of the Shigar, underlining the main structures (Fig. 20). The limestones are usually marbles,

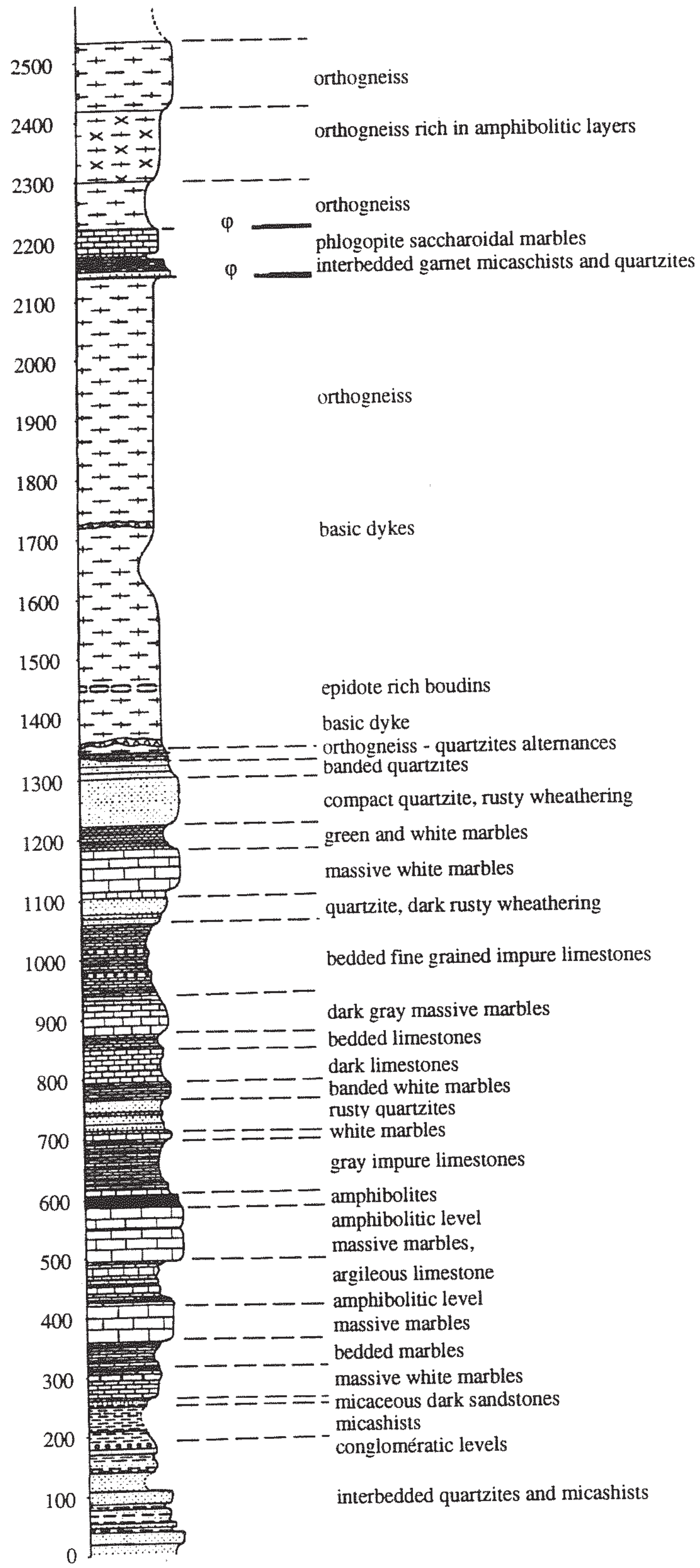



FIG. 18. Lithostratigraphic column of the Karakoram Metamorphic Complex series, left bank of the Moraine glacier. The natural section for the lower part of the log, up to the orthogneiss (Bolocho orthogneiss), can be seen on photo A, Fig. 22 (section by Y. Lemennicier, cf. Lemennicier, 1996, p.27).

*Log lithostratigraphique des formations métasédimentaires du Complexe Métamorphique du Karakoram, levé en rive gauche du glacier Moraine. Toute la partie basse de la série, jusqu'aux orthogneiss de Bolocho, est visible sur la photo A de la Fig. 22 (levé de Y. Lemennicier, cf. Lemennicier, 1996, p. 27).*

frequently saccharoid, more or less impure, and sometimes banded. We have not been able to separate the marbles into distinct formations because of the lack of systematic differences in composition. On the basis of their cartographic continuity and association with other rocks, it is possible to divide the marble horizons into three or four broad geographical groups, from south to north:

- the southern most group (**Chutrun** limestone; Matuntore limestone of Desio, 1963a) outcrops west of the Basha River, where it underlines the contact of the Karakoram metamorphic complex with the Greenstone Complex, and occasionally contains tremolite. North-westward, we have followed it in the Pakora valley where it is intensely folded, in the Niamur valley, and reaching the right bank of the Chogo Lungma glacier upstream from the Remendok confluence. More to the west, north-west of Remendok, the Chutrun limestone joins with hectometric lenses of marble, wrapped in schists; it could be interpreted as olistolitic remnants belonging to the MKT zone (see below the Shyok zone). West of the Bukpun dome anticlinorium, in the high reaches of the Chogo Lungma glacier, the Chutrun limestone probably joins the Chogo Lungma group of limestones;

- the **Chogo Lungma** group, particularly thick and well exposed in the area of the junction of the Bolocho and Chogo Lungma glaciers, but that can be followed from one end to the other of the map. The limestone horizons cut the Hunza valley near Tashot, warp around the Sumayar pluton, form the sheer pillars of the Spantik (7027 m, or Golden Throne, Fig. 17B), and after the Chogo Lungma left bank, make white stripes very visible on satellite picture across the Kero Lungma, Berelter, and Hoh Lumba valleys, joining from there through an unsurveyed zone the mouth of the Biafo glacier. In the middle Moraine glacier valley, they nourish the lateral moraine of the left bank tributary with huge blocks of white to greyish-blue intensely folded marble, often interbedded with amphibolitic horizons. In fact, these marbles are typically associated with levels of dark amphibolites (Figs. 17A, 19C and 19D), and they are often intensely folded by isoclinal ductile folds at various scale (see below). As described by Searle (1991, p. 206), the impure marbles at the mouth of the Biafo glacier contain diopside turning into scapolite, and forsteritic olivine; phlogopite is present in the magnesium marbles; both type of marbles are interbedded with calc-silicate layers containing the assemblage Di-Hb-Gr-Cc-Sph-Ep-Pl. The grossular-rich garnet has a compositional range of $Alm_{41-45}Py_{5-6}Gr_{44-50}Sp_{2-3}$ (ibid). At several localities, and particularly in the Moraine glacier, and around Namla on the right bank of the Biafo glacier, the marble acquires a very peculiar and characteristic acid green colour (Fig. 19E) apparently due to the presence of tremolite, as identified on sample TK 605 from the Moraine glacier by X-ray (F. Lhote, CRPG-CNRS, Nancy);

- more to the north, the **Baintha** group forms massive bands not far from the southern contact of the axial belt, sometimes even intruded by the granitoids as in Suru (upper Berelter valley) where they form elongated horizons within the granite. They cut the middle Biafo glacier near Baintha, and continue in direction towards the Marble Peak of the Baltoro near Concordia. Westward, they seem to join the Chogo Lungma group north of the Spantik, in a remote area where we have not done detailed investigations. From the satellite picture, the two groups seem to draw the two limbs of a multi-kilometre-size fold whose axis would plunge with a variable dip. Further west, the marbles outcropping on the right bank of the Barpu glacier, then crossing the Hunza River near Nagar, reaching the crest of the Hachindar valley, and finally forming continuous levels above Baltar, may be part of the same Baintha group.

- a fourth group, the **Hispar Sar** group runs along the right (north) bank of the Hispar glacier and across the Snow Lake for some 60 km. Tightly folded and very steeply dipping to the north, it is mainly associated with aluminous schists and quartzites. They are mainly in tectonic contact with the surrounding granodiorites of Hunza type, although we have observed a few intrusive contacts, for example on the left bank of the unnamed glacier, second east of Khanibasar. This last group of marbles has similar characteristics to the thick one

FIG. 19. Karakoram Metamorphic Complex, lithology: **A:** Shittinbar terrigenous formation, interbedding of metapelitic and quartzitic thin levels with some half-meter thick sandstone levels. Right bank of Bola Das river, bridge of Torbudo Das (AP slide **95.1.18**, 25/8/95, at 1980 m of elevation, looking west). **B:** Gastropod found by Y. Rolland in the green schist of Thalle, sample LL78 (PLF slide **QV99**, 4/9/97, macrolens). : Outcrop of banded marbles, left bank of Moraine glacier (northern tributary to the Chogo Lungma). The central boudined bed is made up of limestone, amphibolite and some thin quartzitic beds. This outcrop is in the upper part of the first massive marbles, little below the main amphibolitic level of the log of Fig. 23 (app. at level 570) (AP slide **93.6.36**, 4/8/93, at c. 4100 m of elevation, looking east). **D:** Outcrop of white marble, interbanded with dark-coloured amphibolite levels at the base and right bank of the Biafo glacier. Granitic dykes crosscut the layering and are themselves cut by pegmatites (PLF slide **LQ71**, 15/7/86, at 3125 m of elevation).

*A: Formation terrigène de Shittinbar, association de métapélites et de quartzites parfois à sulfures, avec des niveaux demi-métriques de grès. Rive droite de la rivière Bola Das, au pont de Torbudo Das (photo AP 95.1.18, 25/8/95, à 1980 m d'altitude, vers l'ouest).* ***B:*** *Gastéropode trouvé par Y. Rolland dans les schistes verts de Thalle, échantillon LL78 (PLF photo* ***QV99****, 4/9/97).* ***C:*** *Affleurement de marbres rubanés, rive gauche du glacier Moraine (tributaire rive gauche du Chogo Lungma). Le niveau central boudiné est fait de calcaire, d'amphibolite et de quelques minces niveaux quartzitiques. Cet affleurement se situe dans la partie supérieure de la première de marbres massifs du log de la Fig. 23, peu en dessous du niveau principal d'amphibolite (à peu près au niveau 570 du log) (photo AP* ***93.6.36****, 4/8/93, à env. 4100 m d'altitude, vers l'est).* ***D:*** *Affleurement de marbre blanc, interlité avec des niveaux sombres d'amphibolite, à la base et rive droite du glacier du Biafo. Des filons granitiques recoupent le litage, et sont eux mêmes recoupés par des pegmatites (photo PLF* ***LQ71****, 15/7/86, à 3125 m d'altitude).*

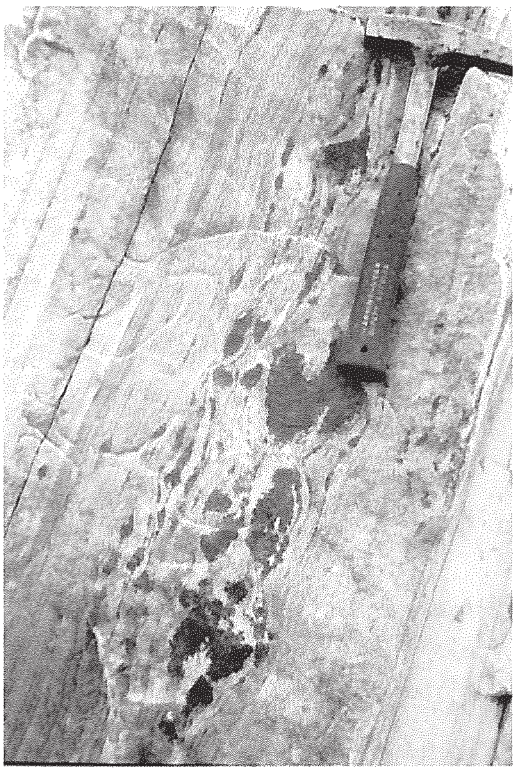
running through the Toltar glacier, and around the Sangemar Mar, cutting the Hunza valley south of the Hunza pluton, and reaching the right bank of the Hispar valley-glacier. In the section of the Hunza valley (the comprehensive Ganesh marbles of Tahirkheli, 1996), these marbles are associated with dark-coloured amphibolite layers. In the lower Hispar valley, some marble beds form boudins of calc-silicated material with Amf-Px-Ep within the pelitic schists and orthogneiss levels. It is in the 2 to 3 km thick marbles of the Hunza valley crosscut by pegmatites that have the famous corundum deposits (ruby and sapphire) (Fig. 12B).

Hanson (1986) found turitellid gastropod fossils in the upper Bauma Harel valley, just north of the MKT; they were tentatively ascribed to the Upper Cretaceous by Warren Allmon (ibid, p. 21). Despite thorough checks, none of the other marbles of the map has yielded any other fossiliferous remain. However, Verchère (1867, in Desio & Mancini, 1974) discovered, in samples collected by E.C. Ryal and passed to him by H.H. Godwin Austen, echinoderms (sphaeronites) likely of Silurian age. Desio & Mancini (1974) cast doubt on the credibility of the finding. However, recently, Rolland et al. (2000) have also found, in the Thalle valley just east of the present map, some Palaeozoic fossils (Fig. 19B, gastropod associated with lower Ordovician graptolites). The Bauma Harel and Thalle limestones, distant by about 20 km are very similar. The Thalle limestones can be followed to the northwest up to the upper Bauma Harel and Skoro La valleys (the northernmost limestone level shown on our map, south of the Skoro La Gans glacier). Due to metamorphism and high strain, it is difficult to assess if the discovery in the same zone of fossiliferous limestones of very different ages points out to the existence of a unique Mesozoic to Palaeozoic succession, unknown so far south of the central plutonic belt, or to a tectonic piling of units of varied origin.

**a, amphibolite**. Very dark amphibolite layers, from one to several tens of metre thick, are interbanded with thick marble horizons of the Chogo Lungma group (Figs. 17A and 19D, 19F). They are well exposed along the Karakoram Highway (in front of Ghammesar, not far from the southern contact of the Hunza granodiorite), in the area of the junction of the Bolocho and Chogo Lungma glaciers, in the Braldu valley near Askole, and at the mouth of the Biafo glacier. Other levels have been sampled and studied SE of this map, in the higher part of the Skoro Lungma valley and above Tasarpa Harel. Only the major amphibolite levels have been indicated on the map. The rock is made up almost entirely of

**A** 95.1.18

**B** QV99



**C** 93.6.36

**D** LQ71

green hornblende and opaque. Its composition varies from dioritic to that of a dark coloured gabbro (Annex. 3-7). It is noteworthy that in the Hunza valley these amphibolites are probably

E OX81

F PQ22

FIG. 19 (continued). **E:** Block of marble of the Chogo Lungma group, largely recrystallised in tremolite a determined by X Ray analysis by F. Lhote on this TK605 sample. Left lateral moraine of the Moraine glacier (PLF slid **OX81**, 3/8/93, 4490 m of elevation). **F:** Outcrop of biotite and amphibole banded gneiss affected by boudinage, and cu through by tourmaline-bearing pegmatitic dykes. Braldu valley (PLF slide **PQ22**, 11/9/95, 2430 m of elevation, 50 mn lens, oriented N 110° E).

*E: Bloc de marbre du groupe du Chogo Lungma, largement recristallisé en trémolite (déterminée aux RX par F. Lhote sur cet échantillon TK605). Moraine latérale rive gauche du glacier Moraine (photo PLF **OX81**, 3/8/93, à 4490 n d'altitude). F: Affleurement de gneiss amphiboliques et biotitiques rubanés, boudinés et recoupés par des veines e lentilles de pegmatites à tourmaline. Vallée de la Braldu (photo PLF **PQ22**, 11/9/95, 2430 m d'altitude, orientée vers N 110° E).*

the source for the chromium of the ruby, spinel, and chromium diopside that are found in the nearby marbles at the contact with the recent pegmatites.

**qz, quartzite**. The numerous quartzite and arenite layers are usually thin and more or less compact, sometimes alternating with micaschist, and quite difficult to follow in the landscape. Only the thickest ones have been represented on the map, such as along the KKH, SE of Hindi (Nasirabad), across the Bualtar and Miar glacier valleys, at the end of the Moraine glacier valley, at the lower end of the Niamur valley, and in the Berelter valley. Ripple-marks have bee observed in the Niamur and Naltoro valleys.

*The Shyok suture zone (MKT Zone)*

In the western part of the map, following th work of Pudsey (1986) in the Mayon area, w have individualised, South of the Karakoran metamorphic complex, a heterogeneous zone o volcanic to detrital formations, folded an metamorphosed in the greenschist to epidote amphibolite facies. These formations, typicall conglomerates associated with various types o

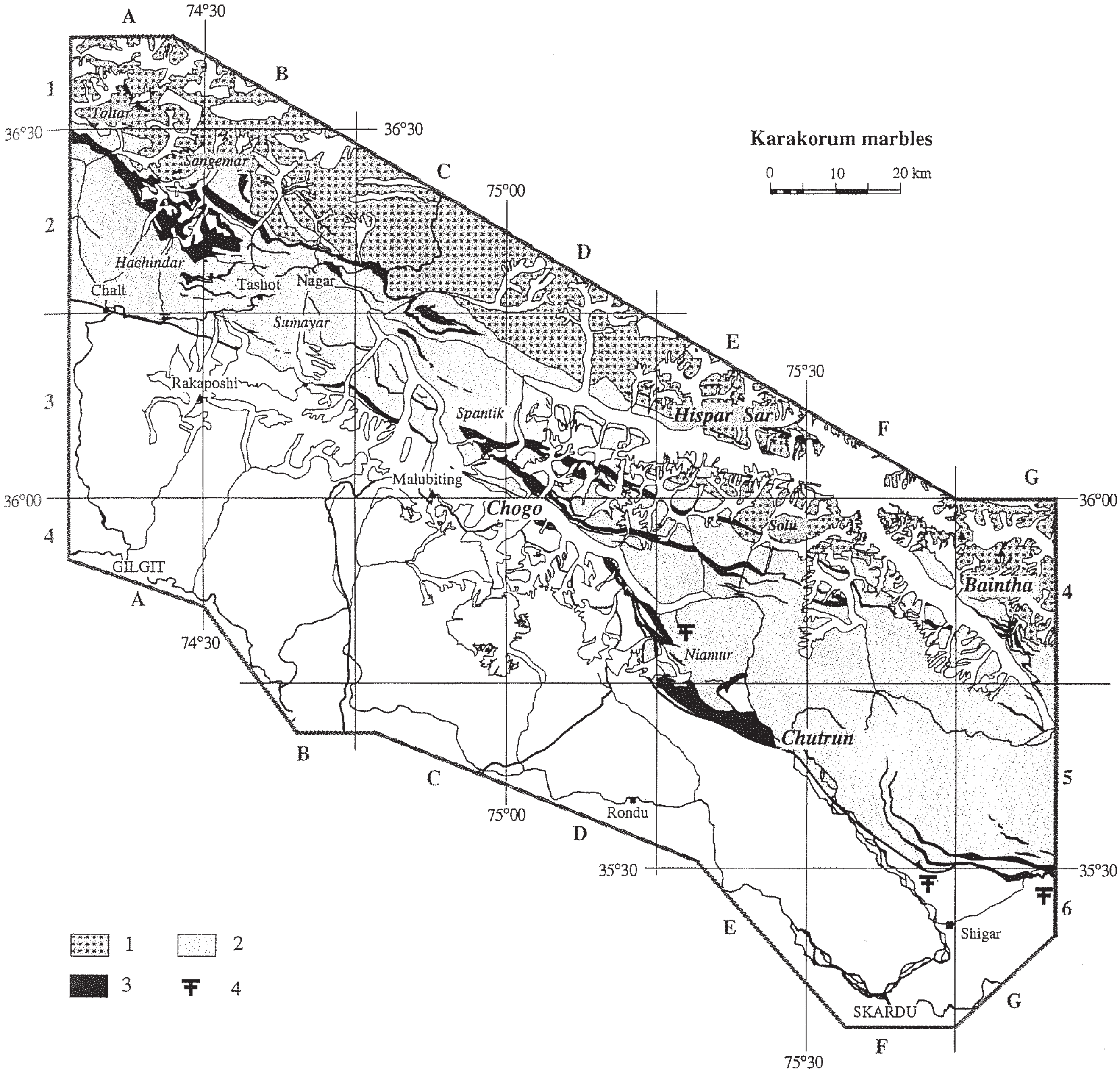



FIG. 20. The Karakoram marbles. (1) Axial batholith, (2) Karakoram metamorphic complex, (3) Karakoram marbles, and (4) the few area where fossils have been found.

*Carte des marbres du Karakoram. (1) batholite axial, (2) Complexe Métamorphique du Karakoram, (3) niveaux de marbres et (4) les quelques zones où des fossiles ont été trouvés.*

rocks having either Karakoram (terrigeneous metasediments as in the Spantik area), or KLIA affinities (diorite and amphibolite as in Mayon valley and Minapin glacier), represent the boundary between the continental crust of Karakoram and the oceanic crust of KLIA. They all pertain to the northern suture zone of Pudsey (1986), also called **Shyok suture zone** (in the Indian Ladakh, the suture separating the formations of the Ladakh arc from the Karakoram ones). In his zone, we have been able to map several more or less continuous formations, from north to south: the **Miar** polygenic sedimentary conglomerate, the

**Tagafari** limestone, the **Polan La** discontinuous lineament of serpentinised ultramafics, and the **Hapakund** polygenic volcano-sedimentary conglomerate and breccia. In a somewhat arbitrary way, in the western part of the map, we have chosen to put the northern boundary of the MKT zone at the northern limit of the Miar conglomerate, and the southern one at the MKT, underlined by the Polan La serpentinites.

South east of the mapped area, new field observations collected in 1997 and 1998 (Rolland et al., 2000) have evidenced, to the south of the MKT, a piling of tectonic scales made up of volcanic or volcano-sedimentary material, separated by serpentinised ultramafic bearing contacts. It is the **Bauma Harel mélange zone**, in which the volcanites often present pillow-lava structures. Here, the nature of the tectonic scales forming the Shyok suture zone reminds of the Ladakh arc and back-arc complex. For Rolland et al. (2000), the tuffaceous back-arc formations, not individualised on the map but outcropping underneath the tectonic scales in the Bauma Harel, down to the massive limestone level cutting across the valley east of Shigar, belong to the suture zone.

More to the east, outside of the map, quartzitic and limestone olistolithes occur in the same mélange zone (Rolland et al., 2000). The highly dislocated masses of limestone that outcrop on the right bank of the Chogo Lungma glacier between east and west Marpoh glaciers possibly represent part of an olistostrome outlining the Shyok suture (Fig. 21).

Finally, although we describe it here with the KLIA formations, most of the volcano-detrital series of Turmik, including conglomerates, more or less sheared limestone, and serpentinite lenses, may be considered to belong to the Shyok suture zone (Rolfo et al., 1997). Figure 22 presents a cartographic interpretation of the Shyok suture that takes into account the above assignments.

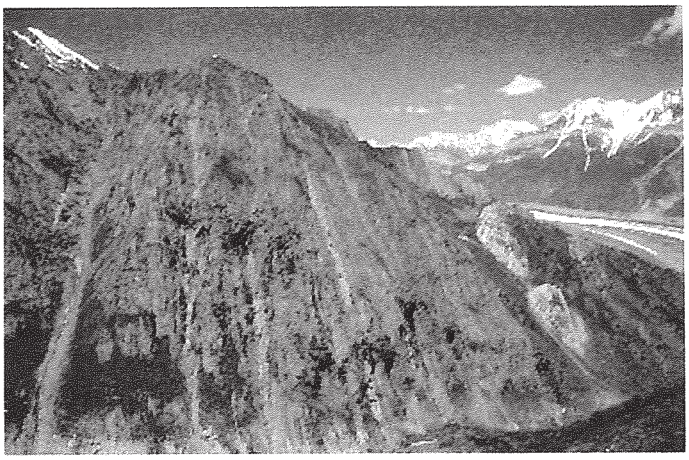
**cgM**, the **Miar conglomerate**, is a remarkably continuous polygenic sedimentary formation that stretches across the entire mapped area (Le Fort & Pêcher, 1995). It contains mainly ill-rounded pebbles of recrystallised quartz-arenite and limestone, reaching up to 50 cm in diameter (Figs. 23A and B). It is poorly sorted and the matrix is made up of limy sandstone. Volcanic contribution seems to increase progressively towards the south, as shown on the left bank of the Minapin glacier. Metamorphic or plutonic clasts have not been observed.

The observed outcrops and boulders include, from E to W:

- one or two horizons (a single folded horizon?) cutting the lower Bola Das valley just up from Chalt, between Chalt and Budelas,
- outcrops of the Mayon valley (Pudsey, 1986) that belong to the conspicuous band on the right bank of the Hunza River, cutting it at the bend just below the Minapin village. This band was already visited and mentioned by Hayden (1915),
- a thick band of massive outcrops crossing the Minapin glacier around its lower bend, and continuing to the east to form the Pheker peak (5,465 m),
- beautiful and large outcrops of the left bank of the Miar glacier, taken as type-locality,
- boulders from the upper moraines of the Chogo and Sumayar glaciers fed by the cliffs on the northern slopes of the Polan La,
- outcrops at the base of the ESE Spantik ridge,
- small outcrops on the left bank of the Chogo Lungma glacier between Bolocho and Arincho valleys,
- a series of outcrops on the left (northern) bank of the Turmik valley, in particular, 100 m thick north of the summer huts of Pakore,
- screes on the left bank of the valley up Tisar village,
- abundant boulders of polygenic volcanic conglomerates and breccias have also been transported by the Bualtar and Miar glaciers.

The thickness varies from a few metres - the formation may even lack in places - to more than a kilometre on the left bank of the Miar glacier. The total length of the most continuous horizon reaches some 60 km, from Chalt to the Chogo Lungma glacier. Towards the south, the Miar conglomerates often presents an increasing contribution of volcanic pebbles and tuffaceous material in the matrix. This has been

**A** 93.3.22



**B** 93.8.30

FIG. 21. The Shyok Suture Zone: **A:** From Sencho, view on the Chogo Lungma glacier and, some 40 km far away, the Spantik (7028 m). Right bank of the glacier, the spur facing the Shing Kuru settlement displays a continuous section of the Greenstone Complex strip pinched between the Himalayan gneiss, at south (left, below the background hanging glacier), and the Karakoram Metamorphic Complex, at north (on left bank of the Chogo Lungma). In the Greenstone Complex: at south, greenschists embedding dismantled limestones, at north (right) more massive limestones, prolongation via Niamur of the Chutrun limestones (slide AP **93.03.22**, 27/7/93, c. 3200 m of elevation). **B:** On the southern ridge of the Remendok valley, towards its northern side. The light clifts are made in the banded massive Pakora limestones. On the right, the huge limestone bloks in a schistose matrix seem to be olistholiths, underlaying the Shyok Suture Zone. Backside, left bank of the glacier, the Karakoram Metamorphic Complex, with its white marble levels (slide AP **93.8.30**, 9/8/93, 4100 m of elevation, looking N 255° E)

*La suture de Shyok: **A:** De Sencho, vue vers le glacier du Chogo Lungma et au fond le Spantik. Sur l'éperon au second plan, en rive droite du glacier (éperon faisant face à l'alpage de Shing Kuru), on peut voir une section complète du ruban de roches vertes et de calcaires de l'Arc, entre les gneiss de l'Himalaya, au sud (extrème gauche de la photo et sous le glacier suspendu, au fond), et le Complexe Métamorphique du Karakoram, au nord, en rive gauche du glacier. Dans le complexe de roche vertes, à gauche (sud) des schistes verts et des amphibolites emballant des calcaires démantelés, à droite (nord) des calcaires plus massifs, dans la prolongation des calcaires de Chutrun et de Niamur (photo AP **93.03.22**, 27/7/93, env. 3200 m d'altitude). **B:** De l'arête rive droite de la vallée de Remendok, vue sur son versant rive gauche. Les falaises claires sont taillées dans les calcaires rubanés massifs de Pakora. A droite, emballés dans une matrice de roches vertes, les blocs de calcaires clairs sont probablement des olistolites, marquant la suture de Shyok. En arrière-plan, en rive gauche du glacier, le Complexe Métamorphique du Karakoram, avec ses niveaux de marbres blancs (photo AP **93.8.30**, 9/8/93, 4100 m d'altitude, vers N 255° E).*

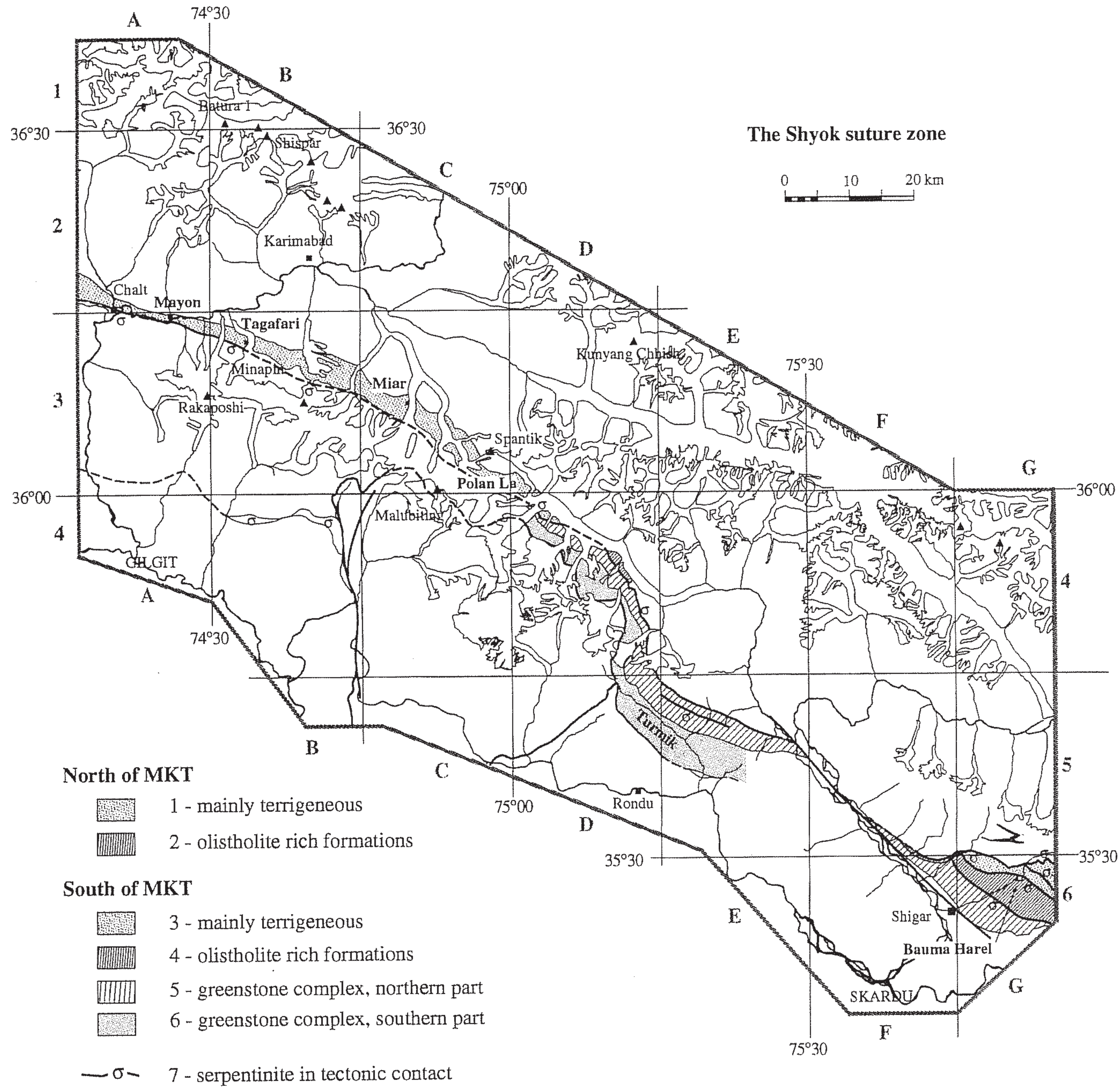



FIG. 22. Sketch map of the Formations belonging to the Shyok suture zone. This map, which takes into account recent works by Rolfo et al. (1997) or Rolland (2000), shows that the Shyok formations probably extend more than initialy indicated on the geological map, and include most or the Ladakh greenstone complex (Turmik and Bauma Harel area). They are made of mainly terrigeneous sediments, of olistholits rich formations, and of volcanic dominant formations; they outcrop as well North or South of the MKT, the commonly admitted boundary between Karakoram and Ladakh-Kohistan.

*Carte schématique des formations attribuables à la zone de suture de Shyok. Cette carte montre que les formations de la zone de suture sont sans doute plus étendues que représentées sur la carte géologique, englobant en particulier tout le complexe de roches vertes du Ladakh nord (cf Rolfo et al., 1997, zone de Turmik, et Rolland, 2000, zone de Bauma Harel). Elles comprennent des formations à dominante terrigène, des formations riches en olistholites et des formations à dominante volcanique; elles existent aussi bien au nord que au sud du MKT, accident normalement choisi comme limite entre le Karakoram et le Kohistan-Ladakh.*

particularly well observed in Minapin glacier area (both banks) as well as on the left bank of the Turmik valley, where such independent horizons of volcanic conglomerate occur (**cgv**). Some of the volcanic conglomerate horizons clearly occur south of the MKT (Polan La lineament); they form our **Hapakund** formation. These southern conglomerates, tuffs and volcanic breccias, the Hapakund conglomerate, have usually been considered to be part of the Greenstone complex of Tahirkheli & Jan (1979), Rakaposhi volcanic complex (Tahirkheli, 1982), or Turmik formation of Desio et al. (1985) (cf. Le Fort et al., 1995; Rolfo et al., 1997). However, from our study, we think that some of them at least may be part of the MKT zone, thus extending it south of the MKT itself. The Shyok zone actually appears to be a transition zone between the sedimentary formations of the KMC and the volcano-clastic ones of the Kohistan-Ladakh island arc.

The metamorphic imprint is mainly visible in the recrystallised sparitic carbonate pebbles. But also, at many places, metamorphic minerals including biotite and muscovite as well as epidote and an unidentified tabular mineral with a metallic shine, have crystallised, both in the matrix and in the clasts. In the more volcanic horizons, the metamorphic minerals include Pl-Chl-Act-Ep. The intensity of the deformation varies from place to place and may reach the formation of a penetrative cleavage. The pebbles are always deformed, flattened, the marble ones more than the arenitic ones. Systematic measurement of the axes of pebbles on several outcrops has yielded a flattening ratio around 3 (Fig. 24).

Interpretation of the depositional environment mainly results from the sedimentary features that occur profusely: steep cross-bedding, ill-sorted distribution of the clasts, poorly rounded pebbles and cobbles, especially the quartz-arenitic ones. They suggest a fan delta environment in a peri-volcanic region, and its derivation by erosion of a nearby sedimentary or very low-grade metasedimentary source.

Because of the lack of fossil remains in the clasts as well as in the matrix or in the surrounding formations, no precise age may be assigned to the Miar conglomerate. However, the lesser metamorphic and deformational imprints compared to the proximal Karakoram metamorphic or Greenstone complex formations, are arguments for a more recent deposition, post-Lower to Middle Cretaceous. Another way of considering the age of the Miar conglomerate is to compare it to other formations of known age, of similar nature and tectonic position. In fact, several conglomeratic formations have been described in northern Pakistan with like characteristics: the conglomerates of the Yasin group along the "northern" or Shyok suture (Ivanac et al., 1956; Desio, 1963a; Pudsey, 1986), the Hundur conglomerate cutting the Nialthi formation of the KMC, south of the batholithic unit of Ghamubar (Le Fort & Gaetani, 1998), the Reshun (Hayden, 1915; Calkins et al., 1981; Pudsey et al., 1985b; Gaetani et al., 1996; Gaetani, 1997; Le Fort & Gaetani, 1998) and Tupop (Gaetani et al., 1990a & 1993; Zanchi & Gaetani, 1994; Gaetani, 1997) conglomeratic formations lying just north of the Karakoram central batholith, and the Urdok conglomerate (Desio, 1963a; Gaetani et al., 1990b):

- In the lower part of the Yasin group, over 1 km thick sedimentary formations comprise volcano-lithic conglomerates associated with a large variety of Lower Cretaceous, mainly Barremian-Aptian, fossils that include foraminiferas, corals, and molluscs (Douvillé, 1926; Brunschweiler, 1956; Ivanac et al., 1956; Rossi Ronchetti & Mirelli, 1959; Eguchi, 1965; Ichikawa & Maeda, 1965). It is to be noted however that the Yasin group is overlying the Shamran formation, a succession of unmetamorphosed basaltic to rhyolitic volcanics, in which Treloar et al. (1989) have dated an hornblende andesite by $^{40}Ar$-$^{39}Ar$ at 58±1 Ma (Sullivan et al., 1993). Thus, either the relationship between the Yasin group and the Shamran volcanics has been overlooked, or the Yasin group maybe, at least in part, Eocene instead of Cretaceous, fossils being reworked. In the Asambar area (between Yasin and Karambar valleys, some 50 km west of Chalt), Pudsey (1986) describes some 500 m of conglomerate made up of volcanic and limestone moderately rounded pebbles and

FIG. 23. The Shyok Suture Zone: Miar conglomerate and Minapin formation: **A:** Boulder of polygenic mainly sedimentary conglomerate, the Miar conglomerate, containing pebbles of reddish limestone, arenitic limestone, arenite, and a few volcanic epidote-bearing clasts, with a limited amount of matrix. Some pebbles are deformed in contact with others, and there is a rough cleavage. Right lateral moraine of the Bualtar glacier (PLF slide **PE73**, 16/7/94, 2645 m of elevation). **B:** Boulder of banded conglomerate showing angular sedimentary clasts. Left lateral moraine of the Bualtar glacier (PLF slide **PH78**, 1/8/94, 2995 m of elevation). **C:** Boulder of Minapin quartz arenite showing sedimentary features of prodelta distributary channel deposit. Oblate penetrative pressure-solution cleavage well visible. Internal right bank lateral moraine of the Minapin glacier (PLF slide **PH12**, 28/7/94, 3395 m of elevation). **D:** Another boulder of quartz arenite showing slumps and small erosive channels (AP slide **94.05.08**, same location and date as C).

*A: Bloc d'un conglomérat polygénique surtout sédimentaire, le conglomérat de Miar. Galets de calcaires rougeâtres, de calcaire arénitique, d'arénite, et quelques fragments volcaniques à épidote, dans une matrice peu abondante. Clivage très frustre et galets peu ou pas déformés (quelques galets déformés au contact d'autres galets, quelques galets impréssionnés). Moraine latérale rive droite du glacier de Bualtar (photo PLF **PE73**, 16/7/94, 2645 m d'altitude). **B:** Bloc de conglomérat lité, à clastes sédimentaires anguleux. Moraine latérale rive gauche du glacier de Bualtar (photo PLF **PH78**, 1/8/94, 2995 m d'altitude). **C:** Bloc d'arénite quartzeuse de Minapin, montrant des figures de dépots de chenaux distributaires de prodelta. Schistosité oblique de pression-solution bien visible. Moraine latérale interne de la rive droite du glacier de Minapin (photo PLF **PH12**, 28/7/94, 3395 m d'altitude). **D:** Un autre bloc d'arénite quartzeuse montrant des figures de slump et des petits chenaux érosifs (photo AP **94.05.08**, même endroit et même date que C).*

cobbles; however, these conglomerates do not seem to represent a continuous formation, and the volcanic material associated seems to be quite abundant;

- The Hundur conglomerate forms a NE-SW oriented lenticular body cutting the Darkot valley. It can be traced eastwards, reaching the Ishkuman valley. It is made up of polygenic, poorly rounded, and ill-sorted pebbles of limestone, arenite, and minor slate, in a red purple, silty matrix. No volcanic pebble has been observed. A limestone pebble of the conglomerate contained Upper Early Permian fossil remains. It resembles the Reshun conglomerate (see below);

- The Reshun conglomerate, 140 to 1,500 m thick, contains clasts of Permian and Cretaceous (*Orbitolina*) fossil bearing limestone as well as a few clasts of granite. The Cretaceous age is thus only a minimum age;

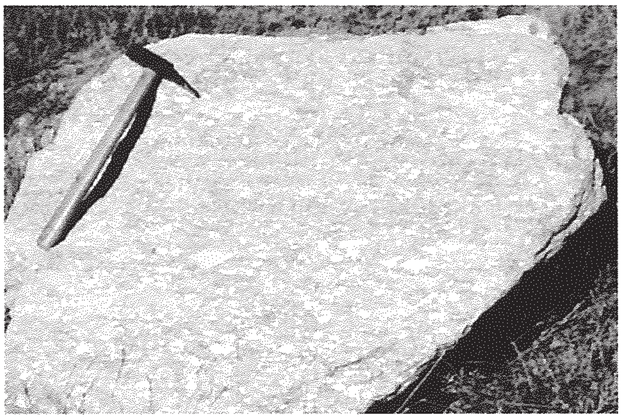
- The Tupop formation of northern Karakoram is a polymictic conglomerate lacking the *Orbitolina* pebbles of the Reshun, but overlain at one place by the pelagic Campanian Darband formation (Gaetani et al., 1993; Zanchi & Gaetani, 1994). Resting on all previous formations and sealing stacked thrust sheets with a strong angular unconformity, the Tupop conglomerate has been deposited in an alluvial to marine fan during late Lower to early Upper Cretaceous (Gaetani, 1997);

- the Urdok conglomerate of northern Karakoram, from a few tens of metres to more than 100 m thick, is made up of limestone pebbles, rounded to angular (Desio, 1963a). Its age remains unknown although Desio (1963a) spoke of an Upper Triassic age.

**Minapin arenite**. At the foot of the northern crest of the Diran a formation of quartz arenites shows beautiful sedimentary features of prodelta distributary channel deposit (graded bedding, climbing ripples, according to G. Allen, personal communication, 1998). It forms blocks in the internal right bank lateral moraine of the Minapin glacier (Figs. 23C and D). We have also found similar blocks on the surface moraine of the Yuna glacier, south of the Diran peak that would imply a larger extension of the MKT zone to the south, or the occurrence of this formation within the Kohistan arc.

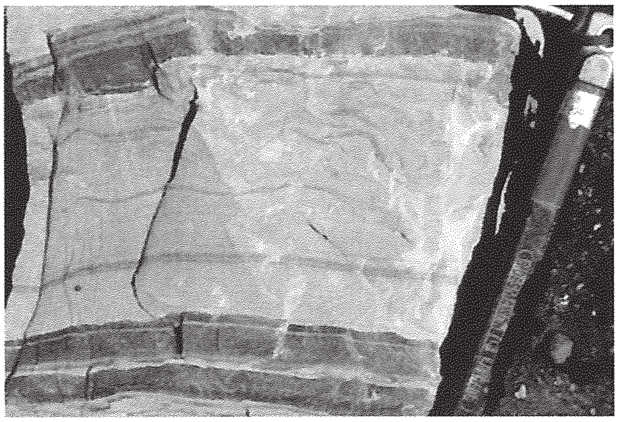
**mT**, the **Tagafari limestone**. In the vicinity of the southern boundary of the MKT zone, a continuous limestone horizon has been recognised in the landscape and followed on the satellite picture, from the Minapin glacier to the left bank of the upper Chogo Lungma glacier. Farther to the east, between east and west Marpoh glaciers, it could join with the possible olistostrome extension of the Chutrun limestone. Between Bualtar glacier and Sumayar valley, the Tagafari limestone remains quite inaccessible.

A PE73



B PH78

C PH12



D 94.5.8

In the type locality of the Minapin glacier, just north of Tagafari summer settlement, the section shows a ca. 100 m thick massive greenish epidote-amphibole bearing limestone; it is followed to the south by ca. 500 m of thinly banded alternances of reddish calcschists and arenitic schists. This calcareous formation is intercalated in extensive volcanic and volcanoclastic material, akin to that of the arc (Chalt formation, see below).

**o'P**, the **Polan La ultramafic lineament** (Fig. 25). South of the Miar conglomerate, there

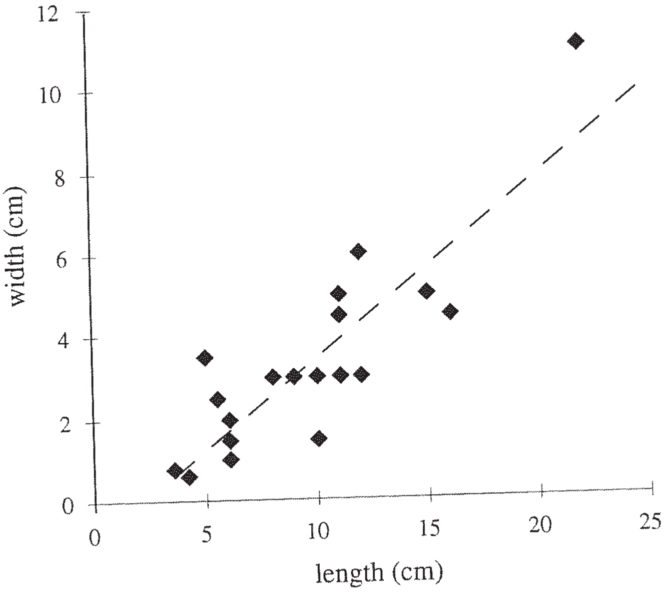



FIG. 24. Flattening rate for the pebbles of the Miar conglomerat, measurements made on an outcrop close to the path left bank of the Minapin glacier, at 2880 m of elevation.Section perpendicular to the cleavage and parallel to the stretching line. Average width/length ratio (slope of the best fitted line) is 0.44. Measurements in other locations lead aproximatively to the same width/length ratio.

*Exemple de valeurs d'aplatissement des galets pour le conglomérat de Miar. Mesures faites sur un affleurement près du chemin rive droite du glacier de Minapin, à 2880 m d'altitude. Section perpendiculaire à l'aplatissement et parallèle à la ligne d'étirement. Le rapport largeur/longueur moyen (pente de la droite de régression) vaut ici 0,44. Les mesures faites ailleurs montrent à peu près les mêmes rapports.*

is a marked lineament, underlined by discontinuous pods of serpentinized ultramafics that can be followed from the Hunza valley north of Chalt, to the left bank of the Shigar valley in Baltistan, along some 160 km. The serpentinite lenticular bodies have been observed at the following localities:

- just east of Chalt along the Karakoram highway (KKH), an outcrop mapped by Pudsey (1986),
- cutting the crest on the right bank of the Pisan glacier (Askoro pass),
- providing boulders on the right lateral moraine of the Minapin glacier, issued from the region of the pass leading to Bualtar valley, between the Sumayar and the Diran peaks,
- as big boulders on the Sumayar glacier, and on the left bank of the Chogo Lungma glacier, likely to originate from the Polan La (pass) between the Spantik and the Malubiting,
- as pebbles in the River bed of Burimis (a right bank tributary of the Chogo Lungma),
- as boulders in the River fan of Brag Zago or Blanzgo (a left bank tributary of the Turmik River). Zanettin (1964, p. 99) also mentions the presence of schistose conglomerate with a matrix rich in epidote upper in this valley;
- forming a 40 m thick lenticular band crossing the Pakora valley, north of the summer huts of Pakora,
- as two pods described and mapped by Hanson (1989) on the north-eastern slopes of the Shigar, along the Skoro and Bauma Harel valleys; they follow a tectonic contact (the MKT as mapped by Hanson, 1986) along which we have observed serpentinites in several other locations,
- underlining two other branches of the MKT, more to the south, on both sides of a large lens of volcanic material (Rolland et al., 2000).

Preserved ultramafics are very few, especially in place, and always altered with serpentine and talc. Deformation is shown by the presence of schistose ultramafics. Chemical

**A** 94.4.37

**B** PF25

FIG. 25. The MKT (South Karakoram Fault) and the Polan La lineament: **A:** The MKT zone in the western part of the Minapin glacier. The MKT runs probably little South (right) of the pass between the Sumayar (5020 m) and Pheker (5508 m) peaks to the North and the Diran Peak (7266 m) to the South. White levels in the pass correspond to the Tagafari limestones, and numerous boulders of serpentinized ultramafics, belonging to the Polan La lineament, are found in the right bank morraine of the Minapin glacier. North of the pass, brownish steep layers in the Pheker peak belong to the Miar conglomerate (AP slide **94.4.37**, 27/7/94, around 3500m of elevation, from the central morraine of the Minapin glacier). **B**: View of the Polan La from the Rash lake. The pass lies on the discontinuous ultramafic lineament of the MKT zone separating the Karakoram Metamorphic Complex to the North (left) from the Kohistan-Ladakh island arc to the South (right). (PLF slide **PF25**, 18/7/94, 4430 m of elevation, 210 mm polarised tele-lens, oriented to the SSE).

*A: La zone du MKT dans la partie ouest du glacier de Minapin. Le MKT passe sans doute un petit peu au sud (à droite) du col entre les pics de Sumayar (5020 m) et de Pheker (5508 m) au nord et le sommet du Diran (7266 m) au sud. Les niveaux blancs dans le col correspondent aux calcaires de Tagafari, et on trouve de nombreux blocs d'ultrabasites serpentinisées, appartenant au linéament du Polan La, dans la morraine latérale rive droite du glacier de Minapin. Au nord du col, les niveaux brunâtres très raides qui forment le sommet du Pheker sont les conglomérats de Miar (photo AP* ***94.4.37****, 27/7/94, vers 3500m d'altitude, vers l'ouest depuis la morraine centrale du glacier de Minapin).* ***B:*** *Vue du Polan La depuis le lac de Rash. Le col est situé sur le linéament discontinu d'ultrabasites qui jalonne le MKT, séparant le Complexe Métamorphique du Karakoram au nord (à gauche) de l'arc insulaire du Kohistan-Ladakh au sud (à droite) (photo PLF* ***PF25****, 18/7/94, 4430 m d'altitude, au téléobjectif, en regardant vers le SSE).*

analysis of two more or less serpentinized ultramafics are given Annex. 4.

**Bauma Harel mélange zone (svLK) and volcanites (vLK)**. East of the map, from the Skoro Lungma to the Thalle River, Rolland et al. (2000) have evidenced a piling of tectonic scales whose contacts are underlined with more or less continuous lenses of serpentinised ultramafics, prolonging the Polan La ultramafic lineament. A first group of tectonic scales (the "Northern group" of Rolland et al., 2000) is mainly composed of terrigenous formations deposited in a back-arc basin. For the upper scale (svLK), the lithology varies between argilaceous tuffs in the Skoro Lungma, and conglomerates containing volcanic and limestone pebbles more to the southeast. This scale overlies a sheared zone of ultramafics containing remains of andesitic basalts and basalts, with pillow lavas.

This zone in turn overlies a lower tectonic scale (vLK) presenting olistolitic formations, largely composed of blocks of limestone and blocks attaining a size of several hundred meters of pillow basalts; the matrix is tuffaceous or sometimes, conglomeratic. The lavas have a basaltic to andesitic basalt composition (cf. below Figs. 31 and 32, Annex. 3-7). Their trace element and REE geochemical study enables to distinguish between MORB-type lavas and lavas with an immature arc affinity (ibid).

Beneath the "Northern group", Rolland et al. (2000) evidence a "Southern group" mainly composed of volcanites and with no olistolithes. These lavas have characteristic Arc compositions. Northwestward, in the lower Bauma Harel valley, they pass laterally tuffaceous formations that have not been distinguished on the map of the Turmik Greenstone group.

## Conclusion

The formations described above, underline a broad lineament known as the Northern Suture, or the Shyok suture, or even the MKT zone. Apart from its eastern portion, on the left bank of the Shigar, where the thrusting structures become conspicuous, this lineament is almost vertical and rectilinear through the entire map. Actually, one has to distinguish the Shyok suture from the MKT, which is not a thrust but a very steep fault, and could better be named the Southern Karakoram Fault (SKF) (Pêcher & Le Fort, 1999). The MKT (SKF), mostly parallel to the tectonometamorphic orientation in the western part of the map (up to middle Chogo Lungma glacier), clearly cuts across tectonic and metamorphic structures more to the east. Its late activation has to be fairly young, definitely posterior to the metamorphic zonation (Smith, 1993; Rolland et al., 2000), and most likely contemporaneous to the end of the doming structuration known to be less than 10 Ma (Villa et al., 1996a & 1996b). In no way can the MKT (SKF) represent the original suture between Karakoram and Ladakh-Kohistan arc, bracketed between 102 and 85 Ma (Petterson & Windley, 1985), but only the trace of a recent reactivation of this suture.

### *Kohistan-Ladakh*

1. Intrusive rocks

Numerous plutons and dykes are intrusive into the different formations of the Kohistan-Ladakh unit. In Kohistan, Petterson & Windley (1985) have distinguished two sets of granitoids: the deformed ones, with a penetrative cleavage, and the undeformed ones. For these authors and others (Pudsey, 1986; Treloar et al., 2000) the distinction underlines the polyphased nature of the plutonism. They relate the deformation of the plutons to the collision of the Ladakh island arc with the northern continental margin along the Shyok suture, and use the absolute ages of the two types of plutons to bracket the age of the collision between 80 and 70 Ma.

The distinction between deformed and undeformed plutons probably remains valid for the less studied Ladakh. However, the use of such a criterion for dating the collision rises several questions: (i) the same pluton can be highly deformed, especially towards its border, while nearly undeformed in other parts; (ii) the deformational fabric of the surrounding metamorphic rock, which appears to be the same in LKIA and KMC, is probably much younger than the collision itself (e.g. Smith et al., 1994; Villa et al., 1996a & 1996b; Rolfo et al., 1997). Actually, we have not been able to find any clear field or map scale criteria to date the collision event.

In the portion covered by this map, the main plutons are, from northwest to southeast (Fig. 26):

- the Nomal leucotrondhjemite (Debon et al., 1987), cutting the lower Hunza valley (also called the Matum Das trondhjemite by Petterson & Windley, 1985),
- the N-Barti pluton extending from the Hunza to the Manu Gah valley (partly described by Kausar, 1991),
- the Barti, N- and S-Bilchar tonalite to granodiorite E-W lenticular plutons,
- the Gilgit granite opposite the town of Gilgit (Petterson & Windley, 1985),
- the plutonic complex of the left bank of the Gilgit valley with the Dainyor heterogeneous diorite,
- the Thhwar diorite (Twar diorite of Desio, 1963a, and Zanettin, 1964),
- the Skoyo tonalite (Skoyo gneiss of Desio, 1963a, and Zanettin, 1964),
- the plutonic complex of the Shigar valley that includes Tisar, Marshakala, Shigar village and Strongdokmo plutons (particularly described by Desio et al., 1964; Zanettin, 1964; Hanson, 1986).

In addition, two small plutonic bodies from the pinched zone north of the Himalayan spur have been distinguished in the Remendok valley: a leucotrondjhemite, and a granodiorite. Finally, swarms of granitic dykes intrude the Kohistan arc at its eastern edge (Petterson & Windley, 1985; George et al., 1993), and mafic dykes intrude in Kohistan and Ladakh (Hanson, 1986; Petterson and Windley, 1992).

As will be emphasised below, the LKIA is divided by the Dobani-Dasu ultramafic lineament (Pêcher & Le Fort, 1999). As shown in Table 2, there is a definite equivalence between the nature and sequence of plutonic bodies intruding Kohistan and Ladakh, especially to the south of the Dobani-Dasu ultramafics. We will follow the order of the table in our description of the different bodies.

**δJ Joring quartz-diorite** (non differentiated from the N Bagrot quartz monzodiorite noted τγδB on the map) is a small pluton that we know only from its boulders falling on both sides of the left bank crest of the Jaglot Gah (upstream from the village of Jaglot Gur, Hunza valley). We give it the local name of the alpine pasture located on its eastern slope. From the boulders examined, in particular at the summer settlement of Kulei, the rock is a medium-grained, little deformed amphibole-bearing diorite, somewhat altered by chloritisation and epidotisation. Under the microscope, the rock presents a rough foliation. The plagioclase forms aggregates of small crystals altered into thin laths of white mica and widespread epidote, the quartz makes clusters of crystals with wavering extinction, the bluish-green amphibole with a euhedral tendency is often zoned and twinned, with frequent core of biotite, the orange-brown biotite is scant and usually unaltered, epidote occurs in scattered grains with the amphibole and the biotite, sphene and opaque are accessory.

Chemically (Annex. 3-5), the analysis of one block taken to be representative of the boulders, is that of a dark-coloured magnesian quartz-diorite.

**mδD**, the **North Bagrot (Datocha) quartz-monzodiorite** forms a small pluton that extends mainly on the steep slope of the right bank of the upper Bagrot valley. The pluton is difficult of access and we have not been able to observe its contact with the surrounding Chalt formation that lies on the crest to the north and forms the slopes to the west, at the head of the Bari valley. To the east, the pluton probably crosses the Bagrot valley and outcrops in the gorges of the Khanegao valley, but we have not been able to control it. To the south, the pluton probably comes into contact with the Dobani-Dassu ultramafics and/or the Sinakkar volcano-sedimentary formation, but we could not check if it is a faulted or intrusive contact. In hand specimen (Fig. 27A), the rock is a rather coarse-grained amphibole- and biotite-bearing quartz-monzodiorite, hardly foliated, containing abundant microgranular, and few meta-sedimentary enclaves. It contains pods of medium-grained biotite-bearing granodiorite, showing abundant zoned plagioclase. Under the microscope, the abundant euhedral zoned

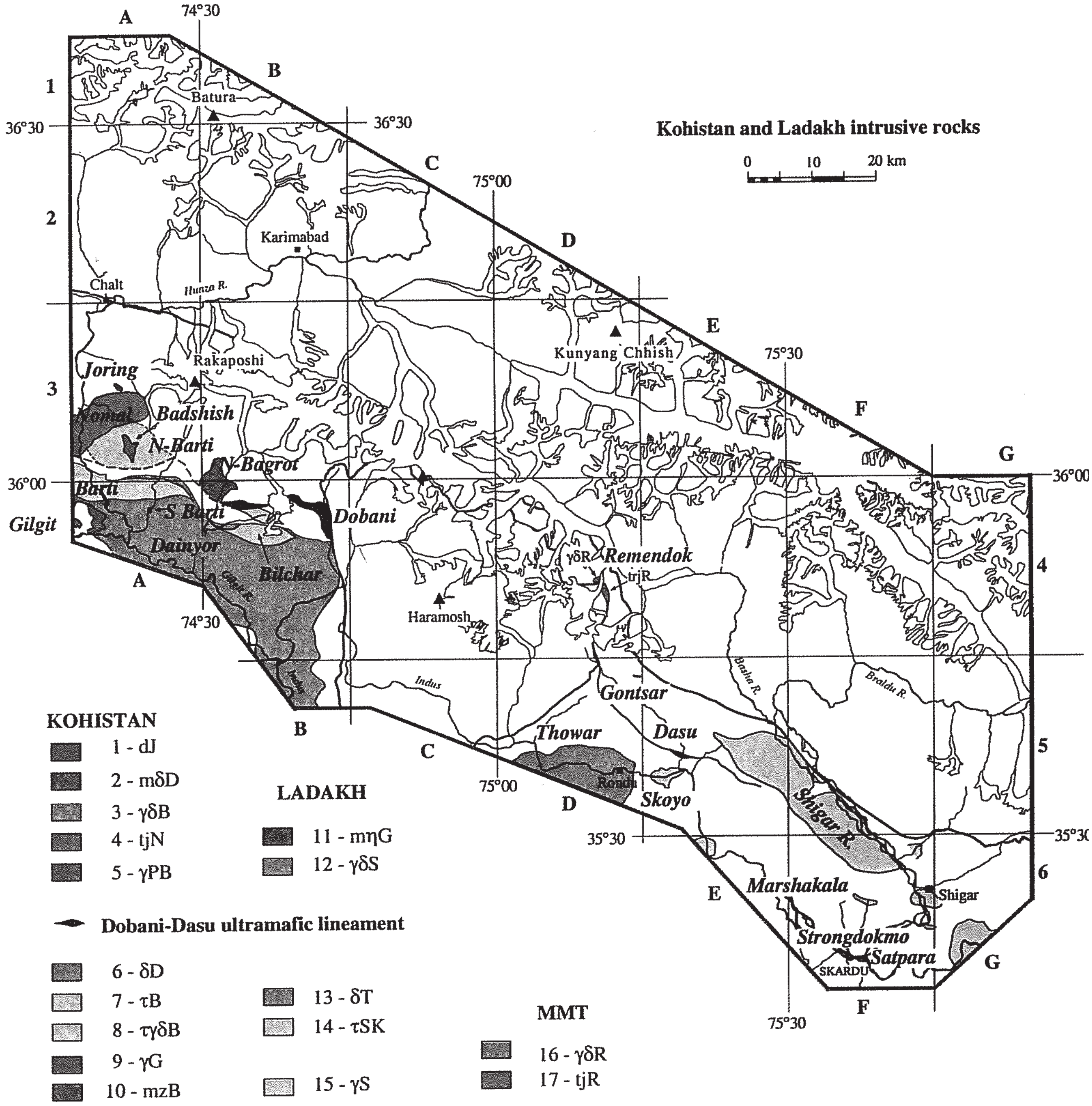



FIG. 26. Location map for the Kohistan and Ladakh intrusive rocks: Kohistan intrusive rocks: (1) Joring quartz diorite, (2) N-Bagrot quartz monzodiorite, (3) N-Barti tonalie to granodiorite, (4) Nomal trondjhemite, (5) Badshish porphyroid granite, (6) Dainyor diorite, (7) N- and S-Bilchar tonalites, (8) Barti tonalite and granodiorite, (9) Gilgit granite, (10) S-Barti monzonite. Ladakh intrusive rocks: (11) Gontsar monzogabbro, (12) Shigar indifferenciated complex, (13) Thhwar diorite, (14) Skoyo tonalite, (15) Satpara granite, tonalite and granodiorite. Intrusive rocks crosscutting the MMT: (16) Remendok granodiorite, (17) Remendok trondhjemite.

*Carte de localisation des intrusifs du Kohistan-Ladakh: Intrusifs du Kohistan: (1) quartz diorite de Joring, (2) monzodiorite de N-Bagrot quartz, (3) tonalie à granodiorite de N-Barti, (4) trondjhemite de Nomal, (5) granite porphyroide de Badshish (6), diorite de Dainyor, (7) tonalites de N- et S-Bilchar, (8) tonalite et granodiorite de Barti, (9) granite de Gilgit, (10) monzonite de S-Barti. Intrusifs du Ladakh: (11) monzogabbro de Gontsar, (12) complexe indifférencié de Shigar, (13) diorite de Thhwar, (14) tonalite de Skoyo, (15) granite, tonalite et granodiorite de Satpara. Intrusif recoupant le MMT: (16) granodiorite de Remendok, (17) trondhjemite de Remendok.*

TABLE 2. Proposed equivalence between the different plutonic bodies in Kohistan and Ladakh, north and south of the ultrabasic screen of Dobani-Dassu, based on chemistry and structure.

| | | Kohistan | Ladakh | |
|---|---|---|---|---|
| **North** | dq<br>mzdq-ad | Joring ($\delta_J$ ) *<br>Datocha ($m\delta_D$) (and Naltar) | Marshakala ($\gamma\delta_S$)**<br>Strongdokmo La ($\gamma\delta_S$) **<br>Gontsar ? ($m\eta_G$) | d<br>d<br>go-mzgo |
| | to-gd | N Barti ($\tau\gamma\delta_B$) | Tisar ($\gamma\delta_S$)** | to |
| | trdj | Nomal ($tj_N$) | no known equivalent | |
| | gr? | Badshish ($\gamma p_B$) | no known equivalent | |
| | **UB** | **Dobani ($\sigma_D$)** | **Dasu ($\sigma_D$)** | **UB** |
| **South** | d-mzd/to | Dainyor ($\delta_D$) | Thhwar ($\delta_T$) | d-mzd |
| | to-gd | S-Barti ($mz_B$)<br>Bilchar N&S ($\tau_B$) | Skoyo (& Khomara) ($\tau_{SK}$) | to |
| | gr | Gilgit ($\gamma_G$) | Satpara ($\gamma_S$) | to-gr |
| | mz | S Barti ($mz_B$) | no known equivalent | |

** concerns a pluton initially grouped together with N Barti granodiorite ($\tau\gamma\delta_B$), and shown with the same colour and the same symbol on the map,*
*** concern bodies of the undifferentiated Shigar plutonic complex ($\gamma\delta_S$);*
*Second and fifth columns give the nomenclature of the plutons; abbreviations as in Fig. 26.*

plagioclase shows sericitization and saussuritization, the perthitic K-feldspar shows wavering extinction as does also the quartz, the olive-green euhedral amphibole and the dark-brown biotite, entangled with euhedral epidote, form disseminated nests. Corroded clino-pyroxene sometimes remains in the core of the amphibole. Opaques and euhedral crystals of sphene are abundant. Epidote is secondary on plagioclase (small crystals) and amphibole-biotite clusters (larger crystals). The quartz-monzodiorite mass is crosscut by a few decimetre-thick aplitic, and abundant metre-thick basic dykes steeply dipping to the SW. Besides faulting and cataclasis, the rock is apparently little deformed and would pertain to the "post-tectonic" group of plutons.

At first sight, the N Bagrot (Datocha) pluton resembles the Naltar pluton, located just west of our map, that outcrops along the dirt road leading to Naltar resort. Both appear to lie in a similar geological setting: just north of the Sinakkar volcano-sedimentary formation, amidst the Chalt formation.

Chemically (Annex. 3-5), we have analysed three samples, two of quartz-monzodiorite and one of the granodioritic pods, as well as one quartz-monzodiorite from the Naltar pluton. All samples are comparatively clear-coloured and magnesian.

**$\gamma\delta_S$, undifferentiated diorite to tonalite Shigar plutonic complex**. Along the right bank of the Shigar valley a great plutonic complex is exposed (Dainelli, 1934; Desio, 1964; Zanettin, 1964). It has been previously described as: Tisar tonalite, Chundupon gabbro-diorite, Twar diorite and Skoyo gneiss by Desio (1963a) and Desio et al. (1985), tonalite, gabbro-diorite and amphibole-gabbro by Zanettin (1964), Marshakala tonalite by Hanson (1986). The complex crosses the Shigar River towards the southeast where it forms in particular the Strongdokmo La complex (Hanson, 1986). Our observations, limited as for Zanettin (1964) to the foot of the outcrops and the debris flown out from the lateral valleys (including the Khomara valley to the west), as well as nine new chemical analyses, confirm that this plutonic complex is composed of several bodies of gabbroic, dioritic, granodioritic, tonalitic, and granitic composition. The analysed samples form an iron-rich cafemic association (Annex. 3). To the north, the tonalite is dominant whereas to the south, diorite is the dominant type with few gabbros and granites (Zanettin, 1964). Both are intrusive into the Askore formation and

FIG. 27. Kohistan and Ladakh intrusive rocks: **A:** Outcrop of dark-coloured N-Bagrot (Datocha) monzodiorite. Sample KL241 collected on the path up the right bank of the Bari stream, a right bank tributary to the Bagrot (PLF slide **RA81**, 11/4/98, 2525 m of elevation). **B**: N-Barti tonalite and Badshish granite: view of the granitoid needles soaring up on the crest between the Hunza and Manu Gah valleys. The peak to the left (5791 m) is made up of N-Barti tonalite, whereas the one to the right would correspond to the poorly known Badshish granite. View from the beginning of the dirt road to Jaglot on the left bank of the Hunza river (PLF slide **QB85**, 28/6/96, 1805 m of elevation, oriented N 116° E). **C:** Dobani-Dassu ultramafic lineament: view of the lower Turmik valley with the cultivated area around the village of Dasu and the whitish crumbling zone of the Dobani-Dassu ultramafic lineament (PLF slide **NP53**, 30/8/91, 2510 m of elevation, 50 mm lens, oriented N 330° E). **D:** Outcrop of Dainyor heterogeneous diorite reticulated with dark amphibole discontinuous lines. Left bank of the Bilchar valley between Bilchar and Hamaran villages (PLF slide **PZ77**, 13/6/96, 1960 m of elevation, 60 mm lens, oriented N 185° E). **E:** Slab of banded south Bilchar tonalite. The elongation of the microgranular enclaves give an idea of the stretching of the border of the pluton. Sample SK370 from the left bank of the Bilchar valley near Bilchar village (PLF slide **PZ97**, 14/6/96, 2160 m of elevation). **F:** Outcrop of foliated Nomal leucotrondhjemite and aplitic dyke cut by a dense network of parallel epidote-bearing veinlets that bleach the rock. Along the KKH (PLF slide **KA83**, 6/12/82, around 1700 m of elevation).

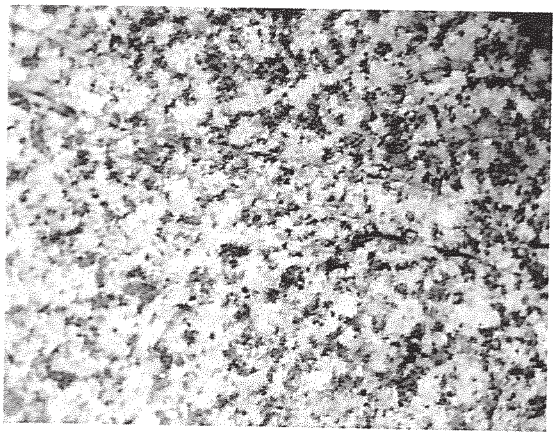
*Roches intrusives du Kohistan et du Ladakh: **A:** Affleurement de la monzodiorite sombre de N-Bagrot. Echantillon KL241 récolté sur le sentier qui remonte le torrent de Bari, un affluent rive droite du torrent de Bagrot (photo PLF **RA81**, 11/4/98, 2525 m d'altitude). **B**: Tonalite de N-Barti et granite de Badshish: vue des aiguilles de granite s'élevant sur la crête séparant les vallées de Hunza et de Manu Gah. Le pic de gauche (5791 m) est fait de tonalite de N-Barti, et celui de droite serait taillé dans le granite presqu'inconu de Badshish. Vue depuis le début de la mauvaise route joignant la KKH à Jaglot, en rive droite de la Hunza (photo PLF **QB85**, 28/6/96, 1805 m d'altitude, prise vers N 116° E). **C**: Linéament ultrabasique de Dobani-Dasu: vue de la basse vallée de Turmik avec les zones cultivées autour du village de Dasu et les arrachements blanchâtres dans les ultrabasites du linéament (photo PLF **NP53**, 30/8/91, 2510 m d'altitude, vers N 330° E). **D:** Affleurement dans la diorite hétérogène de Daynior, réticulée de filets discontinus sombres à amphibole. Rive gauche de la vallée de Bilchar, entre les villages de bilchar et de Hamaran villages (photo PLF **PZ77**, 13/6/96, 1960 m d'altitude, vers N 185° E). **E:** Dalle de tonalite de Bilchar foliée. L'étirement des enclaves microgrenues donne une idée de l'intensité de la déformation en bordure du pluton. A l'endroit de l'échantillon SK370, en rive gauche de la vallée de Bilchar, près du village de Bichar (photo PLF **PZ97**, 14/6/96, 2160 m d'altitude). **F:** Affleurement de la trondhjémite de Nomal recoupée par un filon aplitique, tous les deux foliés et recoupés par un réseau dense de veinules à épidote qui décolorent la roche (photo PLF **KA83**, 6/12/82, environ 1700 d'altitude).*

Greenstone Complex and seem to cut the contact between the two, although we have not been able to reach this far off point. Zanettin (1964 p. 141) also describes the contact metamorphism developed in the surrounding volcano-sedimentary rocks as in the xenoliths enclosed in the plutons. He mentions the occurrence of biotite-andalusite spotted slates, biotite-garnet schists, marbles, and a variety of calcic schists and hornfelses that may contain Ep, Act, Hb, Px, Sph, Wo and Gr.

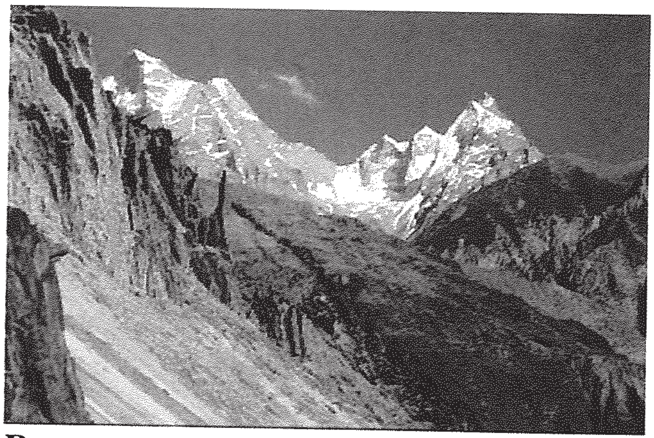
**$m\eta_G$, Gontsar monzogabbro**. A kilometre-thick body of gabbro intrusive into the meta-sedimentary and meta-volcanic formations of the Greenstone Complex. It outcrops along the valley of Gontsar, also called Matumber Lungma, a left bank tributary of the Turmik River. It is deformed on its border, but quite massive and isotropic in its central part. The contact with the surrounding formations is partly faulted. It is the only pluton that we have observed to intrude, in Ladakh, the Turmik formation (Greenstone complex). Chemically (Annex. 4, sample TK78), it has again a sub-alkaline tendency (monzogabbro).

**$\tau\gamma\delta_B$, N-Barti tonalite to granodiorite**.

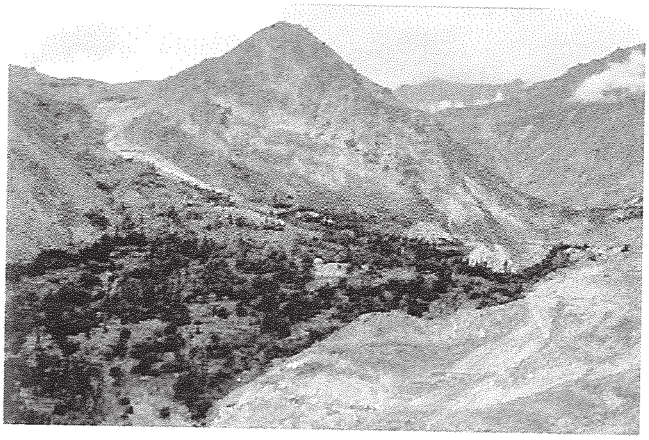
The N-Barti tonalite, also called Jutal quartz diorite (see Kausar, 1995) is well exposed to the north of Gilgit, in the lower Hunza valley, just reaching Jutal (Fig. 27B). It is a rather clear coloured heterogeneous tonalite to granodiorite. To the south, in the steep southern slope of the Badshish, it intrudes the Sinakkar volcano-sedimentary series, with a contact that we have not been able to reach but whose geometry seems to be complicated. To the north, at the level of the Hunza valley, it is separated from the Nomal trondjhemite by a screen of amphibolites, 100 to 200m thick. In the Manu Gah valley, we have met again this pluton, near its eastern termination. There again it is intrusive into the Sinakkar green rocks with a tectonised contact. Just downstream the hamlet of Barti (or Barit), close to the contact, the



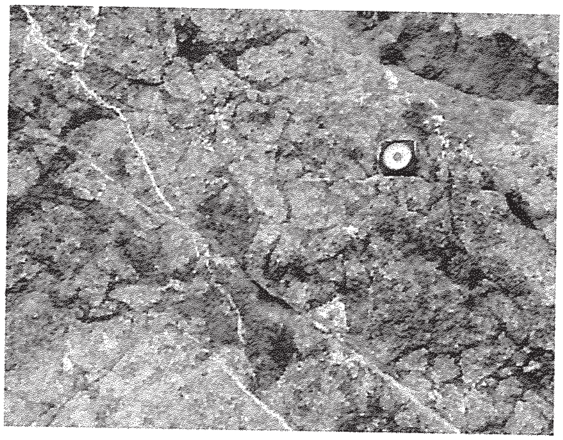
A RA81



B QB85



C NP53



D PZ77

E PZ97

KA83

F

granodiorite bears a conspicuous steep penetrative schistosity, parallel to the contact.

We only have a single analysis of this pluton, that of a sample collected in the ravine to the west of Barti. With an intermediate composition between a tonalite and a granodiorite (Annex. 3), it differs quite clearly from the N Bagrot monzodiorite, located on an eastern prolongation, in a similar structural position, as well as from the Nomal trondjhemite to its immediate north.

**tjN, Nomal trondjhemite**. Across the lower Hunza River, the Nomal pluton intrudes the Greenstone complex or Rakaposhi volcanics (Gamerith, 1976 &1979; Petterson & Windley, 1985; Coward et al., 1986; Kausar, 1991). The pluton has a rather bumpy shape, lying across the Hunza valley, but extending north-easterly into most of the Bartar valley and reaching the Jaglot Gah valley, where it seems not to cross to the right bank, at least at the level of the Birot glacier. According to Debon et al. (1987), it is made up of highly deformed and recrystallised rocks (Fig. 27F) with, usually, a clearly defined blasto-mylonitic schistosity. Its NNW orientation, mostly steeply dipping, remains relatively constant through the whole section along the KKH, but does not agree with the overall SW-NE elongation of the pluton. The grain size varies from fine to coarse, with a frequent microgranular porphyritic texture with conspicuous millimetric polycrystalline rounded quartz. Characteristic minerals include biotite, frequent epidote, rare amphibole, ± garnet, ± muscovite. There are few elongated microgranular and metasedimentary enclaves. It has a variable degree of hydrothermal alteration (Kausar, 1991). The pluton is thoroughly crosscut by metre- to several metre-thick basic dykes, the Jutal dykes of Petterson & Windley (1992) (see below).

Fifteen samples have been chemically analysed (ten from Debon et al., 1987, and five new samples; Annex. 3) that correspond to dominant peraluminous trondjhemite with subordinate metaluminous tonalite. Following the classification of Debon and Le Fort (1982 & 1988), these rocks correspond to a very typical alumino-cafemic and light-coloured tholeiitic association. The fairly low and flat REE pattern supports this tholeiitic character. The age of emplacement has been dated by Rb-Sr whole rock isochron at 102 ± 12 Ma with a very low initial Sr ratio of 0.7039 ± 0.0001 (Petterson & Windley, 1985). Two whole-rock-biotite pairs fit an isochron age of 30 ± 1 Ma with a rehomogenized initial Sr ratio of 0.7047; K-Ar dating on one of the pairs, yields cooling ages of 31 to 37 Ma (Debon et al., 1987),

**γpB, Badshisḥporphyroid granite.** Left bank of the Hunza valley, the crest between the Hunza and Mani Gah valleys is made of a tonalite (the N Barti tonalite) and a light coloured granite, apparently intrusive in the tonalite, and forming sharp needles on the crest (Fig 27B). This granite, entirely located in a remote and hard to reach area, is still very poorly known.

**σD**, The **Dobani-Dasu ultramafics.** In Ladakh, the contact between the Greenstone complex and the Askor amphibolite is underlined by a series of isolated pods and masses of serpentinised ultramafics (Fig. 27C), one of the major ones cutting the Turmik valley at Dasu (a frequent name in northern Pakistan, not to be confused with the Dassu village of the lower Braldu, type locality for the Dassu gneiss) (Le Fort et al., 1995). It has been followed eastward into the Komara valley where a kilometre-thick body of metaperidotite is wrapped in a shell of foliated serpentinite, interlayered with chlorite-talc-magnesite schist and albite epidote-tremolite-chlorite rodingite (Rolfo et al., 1997). Westward we have encountered blocks of serpentine in the Mala Kha Lungma valley (east of Dambudas), but they have not been found further north along the contact, especially in the section of the Askouber valley. Further to the north-west, besides ultrabasic rocks and calc-silicate fels that occur in lower Remendok valley, in a similar structural position, outcrops have not been met, but boulders of serpentinised material occur now and then.

However, in Kohistan, almost exactl symmetrical to the Dasu lenticular stripe squeezed against the northern end of the Raiko fault, we have discovered a similar stripe o serpentinised ultramafics that rises from th village of Khaltaro, follows the right (west bank of the Darchan River, crosses to the nortl of the Dobani peak (Bilchar Dobani of the Swis map, 6134 m) in the upper part of the Gutumi glacier, forms a large kilometric band on the northern side of the Bilchar valley, and finally thins out on the right bank of the Bagrot River between the villages of Datocha and Sinakkar. Further to the west, we have not found any remnant of it crossing the Dyor River, nor reaching the Hunza valley. It is likely, however, that the 25 km long strip of ultramafic rocks follows a tectonic lineament, at the northern edge of the Bilchar meta- volcano-sedimentary formation.

Following Rolfo et al. (1997) who studied the lineament in the Ladakh stripe (see the two analyses reported Annex. 4-B), the Dobani-Dasu metaperidotites are usually antigoritic serpentinites, which keep cumulitic textures, often with talc and magnesite. A screen of tremolite-talc-carbonate-epidote rodingite appears at the contact with the overlying volcano-sedimentary series. Two generations of olivine are described: the serpentinised magmatic one, and the newly grown metamorphic porphyroblastic one (Le Fort et al., 1995; Rolfo et al., 1997).

It is possible to consider these serpentinites as a part of the ophiolitic sole of the island arc as described near Dras (Ladakh, NW India) by Reuber (1989). Thus, contrarily to the remark of Petterson and Windley (1985), the Chalt-Turmik volcanics, with the Polan La lineament to the north and the Dobani- Dasu ultramafics to the south, compare well with the Dras volcanics that have tectonic mélanges on their northern and southern sides. This similarity is confirmed when comparing the chemistry of the lavas from Dras with those of the volcanites of the "Southern Group of the Shyok suture" (cf. infra Figs. 31 and 32), that outcrops on the map in the Bauma Harel region (vLK).

**$\delta_D$, Dainyor heterogeneous diorite**. The Dainyor (or Daniyor) (Fig. 27D) diorite covers a very large area (Fig. 26) between the lower Hunza River and the Raikot fault that constitutes its eastern boundary in the Khaltaro valley. It has been recognised at several localities and given different names, such as Shuta gabbro (Madin, 1986), or Daynior and Manu Gah monzonites (Kausar, 1991, 1995), but we prefer to name it after the highest (4358 m) summit of Dainyor (74° 28' 03" E, 35° 57' 43" N) and the village that lies just north of the Hunza-Gilgit confluence. It is a very heterogeneous pluton, for its mineralogical abundance as for its grain size. Actually, it contains many smaller magmatic bodies intruding into it with a tonalitic to monzonitic composition. The diorite is often deformed, orthogneissified. Usually the diorite is made up of a Q-Pl-Amf-Px±Bi assemblage. It contains both mafic microgranular, and metasedimentary or metavolcanic enclaves. The metasedimentary ones include biotite quartzites and less abundant calcsilicate ones. Some of the latest correspond to decimetric elliptical zoned boudins of former marbles, transformed into zoned skarns, with Pl-Gr-Cc rich cores with additional Cc, Cpx, and Amph zones from core to rim.

Chemically (Annex. 3-6), it is mainly composed of monzogabbros and gabbros, plus one sample of quartz-diorite, forming an iron-rich association.

**$\delta_T$, Thhwar heterogeneous diorite**. Across the Indus, east of the Stak valley, occurs a large mass of basic plutonic rocks, known as the Twar diorite (Desio, 1963a) or the Twar dioritic-noritic mass (Zanettin, 1964). This heterogeneous mass shows a remarkable variety of mineralogy, grain size, and chemical composition, very similar to the Dainyor heterogeneous diorite outcropping on the other side of the Haramosh Himalayan spur. It is made up of a very heterogeneous mass, presenting a large variety of grain size, mineralogy, and chemical composition. Locally, it can be very foliated; this is the case on its NW border where it may become difficult to distinguish between the amphibolites and the foliated diorite. The mineralogical composition, according to Zanettin (1964), includes andesine (An 40-50), clinopyroxene (hedenbergitic augite) or orthopyroxene (hypersthene) rimmed by amphibole (green hornblende) ± biotite, and secondary epidote.

To the east, it metamorphoses and assimilates amphibolite of the Askor formation, producing spectacular injection agmatites, and transforming several bands of marble into "calciphyres" and skarn-type rocks with Pl-Hb-Ep-Cc-Scp-Sph. The two major elements analyses given by Zanettin (1964) represent dioritic to monzodioritic material, relatively clear coloured with a strongly subalkaline magnesian trend. Analysis of a new sample (SK538, Annex. 3-6) corresponds on the contrary to a dark-coloured iron-rich gabbro very similar to the dark-coloured samples of the Dainyor diorite.

The hypersthene diorite, described by Zanettin (1964), near Tungas, is not outcropping along the bottom of the Indus valley. Only big boulders have been found on the right bank of the Indus, coming with a rockslide from higher up. It has a composition of a quartz-diorite, and could be part of the Thhwar heterogeneous diorite.

**τB, North and south Bilchar tonalite, Barti tonalite**. The Barti tonalite and the Bilchar tonalites have very similar settings and petrography. They form three E-W elongated lenses, the first one cutting through the lower Hunza and Manu Gahvalleys, the southern most of the two others cutting the Bilchar valley. These lenses are roughly pinched between the Dainyor diorite to the south, and the Sinakkar formation to the north. Close to the northern contact, the tonalites are sheared and orthogneissified, and the original intrusive contact is also deformed.

The rock, rather clear-coloured, with an epidote greenish shine, is usually foliated and contains abundant elongated and banded enclaves of dioritic material. In hand specimen, it is biotite and amphibole-bearing with rounded quartz crystals.

Chemically, two representative samples of the Bilchar tonalite, and two of the Barti tonalite have been analysed. They have a tonalitic to granodioritic composition, one of the sample (SK365) being very magnesian (Annex. 3-6).

**τSK, Skoyo tonalite.** Along the Indus, in the vicinity of the confluence with the Turmik River, a network of dykes intrudes the Askore amphibolites. It is related to a plutonic body exposed near Skoyo, previously named Skoyo gneiss (Desio, 1963a; Zanettin, 1964), that has a composition of a magnesian tonalite. The main petrographic type of the Skoyo tonalite is a mesocratic oriented rock consisting of oligoclase megacrysts in a ground mass of Q-Olg-Bi-Ep-Hb. The contact of the Skoyo meta-tonalite with the amphibolite is a thick "agmatite" screen which becomes progressively poorer in tonalite material towards the east, where it dies out in a thick sequence of epidote-biotite bearing amphibolitic gneisses: the Askor amphibolite. The dykes intruding the amphibolite are also tonalitic. They are deformed, being either transposed in the main foliation, or folded in a ptygmatitic way (that can affect plurimetric dykes). East of the Skoyo pluton, between Bayicha and the ridge south of Turmik, a large dyke of Bt-Mu leuco-granodiorite, concordant with the foliation of the amphibolites, can be observed.

Chemically, six samples of the Skoyo tonalite have been analysed (annex 3-6). They have a tonalitic composition, and are very magnesian.

**γG, Gilgit granite.** On the left (northern) side of the Gilgit valley, in front of Gilgit town, Petterson & Windley (1985) have described and dated a small pluton (<20 km²) of "undeformed" granite: the Gilgit granite. As we have little observed the pluton, we will largely use their observations and data.

North of Gilgit town, the slopes are very close to the roof of the pluton. There, the granite essentially consists of a swarm of decametre-large dykes following the foliation of the surrounding rocks, and anastomosing in numerous smaller dykes. These intrusive dykes often criss-cross the country rock, resulting in an agmatitic appearance. The country rock is made up of a mixture of meta-sedimentary (arenites with thin marble layers) and meta-igneous rocks (amphibolites), and presents a high-grade metamorphism with amphibole, pyroxene, and garnet, ± epidote. The amphibole at least has recrystallised in larger non-oriented crystals in the vicinity of the contact. The granite itself is a mesocratic, biotite-bearing, slightly porphyritic rock that contains, at least close to the contact, numerous elongated metasedimentary, and ovoid microgranular enclaves. There, the granite is deformed and presents a tectonic foliation partly synchronous to the epidotisation.

From the chemical analysis (Annex. 3, data from Petterson and Windley, 1991) the rock is a leuco-granite to -adamellite, slightly peraluminous and falling in the biotite field of the AB diagram, quartz-poor, with a normal Mg/(Mg+Fe) ratio. Trace elements present high LFS/HFS (e.g. Rb/Ti) and LREE/HREE (e.g. Ce/Yb) ratios that contrast with the early deformed plutons such as Nomal. A four points whole-rock Rb-Sr isochron has yielded a 54 ± 4 (2σ) Ma age with a low initial ratio of 0.7041 ± 0.00012.

**$\gamma_S$, Satpara tonalite and granite.** To the south and southwest of Skardu occurs a large complex of heterogeneous plutonic rocks, the " Deosai granodiorites and quartz-diorites" of Desio (1964) not so different from the Shigar plutonic complex, except for its geographic position. Just outside the southern limit of our map, the road leading to Satpara lake and the Deosai plateau cuts across metasedimentary and metavolcanic series apparently less metamorphosed than the Gilgit gneisses; along the section, they are intruded by a granite, clear-coloured, red-stained, fine-grained and undeformed: it is the Satpara granite, recognised by Debon & Bertrand (1984). They border on medium-grained enclave-rich granodiorites, that can be traced up to the Indus road, east of Skardu, having often darker facies.

We have gathered and analysed 3 samples from these plutonites (Annex. 3-6) belonging to the northern plutonic complex of the Deosai plateau. The Satpara granite itself is a fine-grained leucogranite, containing some chloritised biotite and small amounts of muscovite. Chemically it is a leucocratic syenogranite, biotite (and muscovite)-bearing, and presenting a normal Mg/(Fe+Mg) ratio. The two other samples are tonalites-granodiorites, with thick laths of euhedral biotite, that contains little amphibole, epidote and sphene. They present a somewhat magnesian trend.

**$mz_B$, S-Barti monzonite.** In the lower part of the Manu Gah valley occurs a small massif of monzonite, crosscutted by numerous basic dykes. It seems to partly correspond to the Gujar Das pluton of Kausar (1995), a pluton, which seems actually much wider than the small one that we have recognized and mapped.

It is a porphyroid monzonite, with large (up to 3cm) automorphous feldspar megacrysts in an often highly epidotitised matrix. We have analysed one sample (SK423), a iron-rich quartz-monzonite (Annex. 3, Table 3-6b).

$\gamma\delta_R$, the **Remendok granodiorite**. On the left (west) bank of the Remendok glacier, opposite to the Remendok trondjhemite, we have recognised a zone of glacier polished outcrops of granodioritic material. We have found boulders of similar material on the left bank moraines of the Chogo Lungma, probably originating from the right bank of the W-Marpho glacier. Petrographically, with its medium -grained size, amphibole and biotite, microgranular and metasedimentary enclaves, as well as chemically, it very much resembles the Hunza granodiorite from Karakoram. However, it lies very close to the Himalaya-Ladakh contact, and if identical in age and origin to the Hunza granodiorite, it testifies that the Ladakh-Karakoram suturing had already been achieved by 93 Ma.

**$tj_R$ the Remendok leucotrondhjemite**. It is a lenticular 4 by 1 km body, elongated N150°. Cropping out on the right (east) bank of the Remendok valley (Fig. 28), it is intrusive into the LKIA amphibolites as well as the HHC paragneisses, developing in both of them a network of dykes. The contact with the migmatised banded gneisses of the Himalaya is almost conformable with dykes interlayered within the gneisses. Thus the Remendok leucotrondhjemite seals the thrust contact of the Ladakh-Kohistan island arc over the HHC. It has suffered a late high temperature deformation in the presence of an aqueous fluid (Lemennicier, 1996).

The rock consists of quartz, K-feldspar, undulatory zoned oligoclase (An15 to 21), muscovite, epidote, biotite, ± garnet, with sphene and zircon as accessory phases. Microstructural deformation generally forms thin wavy bands of muscovite and epidote associated to granulated quartz and abundant myrmekite. Feldspar is generally undeformed.

TABLE 3. Tectono-stratigraphic succession and equivalence in KLIA.

| | **Kohistan** | **Ladakh** | **Nature** |
|---|---|---|---|
| North | Chalt | Turmik | Volc. & volc.-sed. |
| | **Dobani-** | **-Dassu** | ultramafic lineament |
| | Sinakkar | ? Turmik pro parte ? | Volc.-sed. |
| | Askore | Askore | volcanic |
| South | Gilgit | Katchura | detrital & sed |

**A** 0Z37

**B** OZ46

FIG. 28. Remendok leucotrondhjemite: **A:** View of the southern contact of the Remendok leucotrondhjemite with the Himalayan migmatitic gneisses, right bank of the Remendok glacier. The banded gneisses, to the right, dip almost conformably to the NNE (PLF slide **OZ37**, 9/8/93, 4065 m of elevation). **B:** Block of Remendok leucotrondhjemite showing the heterogeneity of the granitoid rock, especially in the grain size and the foliation (PLF slide **OZ46**, 9/8/93, 4015 m of elevation).

*A:- Vue du contact sud de la leucotrondhjemite de Remendok avec les gneiss migmatitiques himalayens, rive droite du glacier de Remendok. Les gneiss rubanés, à droite, pendent vers le NNE, presque parallèlement au contact (photo PLF* ***OZ37****, 9/8/93, 4065 m d'altitude).* ***B:*** *Bloc de leucotrondhjemite de Remendok montrant l'hétérogénéité de cette roche granitoïdique, tout particulièrement pour ce qui concerne la taille du grain et la foliation (photo PLF* ***OZ46****, 9/8/93, 4015 m d'altitude).*

Near the border of the pluton, shear bands with muscovite become more abundant (Villa et al., 1996a & 1996b).

Chemically, the six samples analysed, very homogeneous, have a composition of a leucocratic tonalite (Annex. 3-5, Table 3-5b).

Dating of this plutonic body would allow to put an upper limit on the movement of the Indus-Tsangpo suture to the NE of the fast rising Nanga Parbat-Haramosh massif. Two muscovites from the leucotrondhjemite have yielded $^{40}Ar$-$^{39}Ar$ ages of 8.2 and around 9.5 Ma (Villa et al., 1996). Such different values for samples of the same small massif may be related to the heterogeneous thrusting along the Himalaya-Ladakh boundary (ibid). Anyhow, they date the thrust movement at just before 9 Ma.

**acid dykes**. An exceptional quantity of dykes intrudes the KLIA, but the most spectacular area lies on the eastern edge of Kohistan, around the confluence of the Indus and Gilgit Rivers, where a dense network of varied dykes, mainly pegmatitic, forms probably not less than 30% of the total volume of rocks (Fig. 29). In fact, Petterson & Windley (1985) have distinguished one set of dykes as the "Indus confluence acid sheets" from the usually crosscutting "Parri acid sheets", located some 15 km more to the NW along the KKH. Both sets have a granitic to granodioritic composition (Annex. 4-B, samples SK364 et TK68) and contain quartz, plagioclase, alkali feldspar, biotite and/or muscovite,±epidote/clinozoisite (for Confluence set),±garnet (for Parri set) (George et al., 1993). Both are peraluminous but are easily distinguished on their Rb/Sr ratio, lower for the Confluence set (0.01-0.4) than for the Parri set (1-2) (Petterson & Windley, 1985). The first age dating of Confluence and Parri sets by Rb-Sr errorchrons at 34±14 and 29±8 Ma respectively (ibid), has been complemented by a new errorchron using four more samples from the Parri set, at 26.2±1.2 Ma with an initial Sr ratio of 0.7054 (George et al., 1993). Their Rb-Sr and Nd-Sm isotopic compositions are very similar to those of the arc derived magmas from KLIA, with Nd model ages from 500 to 700 Ma lying within the range of the Kohistan plutons (Petterson & Winley, 1992). Their setting and geochemistry suggest that they both originate from juvenile sources that may involve arc sediments to some extent, but preclude the participation of Indian crustal material (George et al., 1993).

**basic dykes**. Between Jutal and Chalt, in the lower Hunza valley, a suite of low-medium-K basalt to basaltic andesite intrudes the Nomal pluton and Rakaposhi Greenstone complex (Petterson & Windley, 1992). To the SE of these Jutal dykes, we have found similar dykes intruding the Dainyor diorite along the lower Manu Gah valley. The dykes, usually little deformed, crosscut the penetrative fabric of the Nomal and Dainyor plutonic rocks as well as folds of the Greenstone complex. Their orientation is compatible with NW-SE to N-S extension (ibid). The Hb-Bi-Pl rock, containing relict pyroxene, has been divided into two groups on the basis of its Hb/Pl content ratio and chemical composition (Petterson & Windley, 1992): a depleted D-type group has low concentrations in incompatible elements, and an enriched E-type group exhibits increasing incompatible element concentrations with increasing Zr (ibid). Both groups are cogenetic and would have originated by partial melting of the same mantle source with further low-pressure fractionation. They have yielded an average K-Ar age of 90 Ma (Treloar et al., 1989).

2. Volcanic and sedimentary rocks of Kohistan-Ladakh

In Kohistan, the Hunza valley section displays a set of beautifully exposed volcanic rocks, called the Chalt formation or Chalt volcanics (Desio, 1964; Petterson et al., 1990; Petterson & Windley, 1991). They present minor intercalations of volcano-sedimentary layers. Eastward, the proportion of volcano-sedimentary rocks increases and becomes predominant in Ladakh, where they form the "Greenstone complex", a term coined by Ivanac et al. (1956) in Kohistan, and used in our more restrictive meaning by Stauffer (1975), or Rolfo (1994) and Rolfo et al. (1997). In the Turmik and Askor valleys of Ladakh, it is possible to distinguish two main formations or groups of formations: i) the Turmik and Ganto-La formations (Desio, 1963a & 1964; Zanettin,

RB41

FIG. 29. Acidic dykes: The dense network of pegmatitic and granitic dykes seen around the Confluence of the Gilgit with the Indus river. View from the KKH looking at the left bank of the Gilgit river (PLF slide **RB41**, 14/4/98, around 1300 m of elevation, oriented towards the NE).

*Filons acides: Vue sur le réseau très dense de pegmatites, près de la confluence de l'Indus et de la rivière Gilgit, en regardant de la KKH vers la rive gauche de la rivière Gilgit (photo PLF* ***RB41****, 14/4/98, environ 1300 m d'altitude, prise vers le NE).*

1964; Desio et al., 1985); and ii) the Askor amphibolite formation, generally separated from the former one by the Dasu lensoid screen of serpentinised ultramafic (Dobani-Dasu formation). This distinction, well established in western Ladakh region, is valid also for Kohistan where the Chalt volcano-sedimentary formation in the north is separated from southern amphibolites by the Dobani serpentinised ultramafics (Table 3). However in Kohistan, we have observed a strip of volcano-sedimentary rocks, quite similar to part of the Turmik formation, but lying south of the Dobani ultramafics. We have mapped it as the Sinakkar formation, and will describe it separately. We will describe successively the two units.

Between Kohistan and Ladakh, in front of the NPHM, it is difficult to separate the Askor amphibolites from the largely dominant Chalt-Turmik formation. We have therefore grouped all formations of the thin band into a comprehensive northern volcanic and volcano-sedimentary Greenstone Complex. On the map, we have kept it undifferentiated from the Chalt-Turmik formation.

a. The volcanic and volcano-sedimentary complex of northern LKIA

The Chalt group in Kohistan, and the Turmik group in Ladakh, are essentially made up of volcanic and volcano-detrital rocks, interbedded with levels of limestone, relatively continuous or lenticular, with minor quartzite, and, locally, in the Pakora valley west of Tisar in Ladakh, with a thick lens of conglomerate. In this complex, we have distinguished:

- the Chalt formation in Kohistan, mainly volcanic, and its equivalent in Ladakh, the volcano-sedimentary formation of Turmik;
- limestones, abundant in Ladakh (Pakora and other limestones), fewer in Kohistan (limestones of the Rakhan Gali region);
- some formations of more local extension, such as the Pakora ultramafics, the Gontsar gabbro or the Pakora conglomerate, in Ladakh.

**vsC**, the **Chalt formation.** In Kohistan, the Chalt formation (Desio, 1964; also called Chalt volcanics, Petterson et al., 1990; Petterson & Windley, 1991; or Rakaposhi volcanics, Tahirkheli, 1982; Khan, 1991) forms a thick pile of volcanogenic material particularly well exposed along the section of the Karakoram Highway in lower Hunza valley, between Rahimabad and Chalt, where it attains an apparent thickness of some 4 km. It is composed of dominant layered amphibolites (Fig. 30D), chlorite-epidote schists, meta-tuffs with minor intercalations of calcschists and thin limestone bands. Deformed pillow lavas, amygdoidal flows and volcanic breccia are frequently recognised. Flattened pillow-lava structures are particularly spectacular between Garesh and Jaglot in the Hunza section (Fig. 30C). The composition of the volcanics range from basaltic andesite to andesite, dacite, and rhyolite (Tahirkheli, 1982). The metamorphic imprint is pervasive in the chlorite to epidote-amphibolite facies grade, with a tendency to increase from west to east.

We have analysed 11 new samples (8 from Chalt in Kohistan and 3 from Turmik in Ladakh, Annex. 3) that range from basalts and andesites through quartz-andesite to dacite (Fig. 31). Petterson and Windley (1991) on the basis of chemical composition and geochemical trend have shown the two-fold division of the Chalt volcanics in Kohistan:

- a group of high-Mg tholeiites with a tholeiitic or transitional tholeiitic/calc-alkaline differentiation trend, typical of a majority of samples collected from the Hunza valley. Together with a high MgO content between 15 and 6%, this group is characterised by a slight decrease in $Fe_2O_3$ and $TiO_2$ for increasing content of MgO;
- a group of andesites with a calc-alkaline differentiation trend, typical of the samples collected from the Ishkuman and Yasin valleys (west of our map) as well as a few samples from the Hunza valley. In this group, the low value of MgO (<6%) is accompanied by a strong increase in $Fe_2O_3$ and $TiO_2$ for increasing content of MgO.

Our 11 new analyses confirm these two trends, mostly tholeiitic or transitional for the Chalt samples (6 samples), and calc-alkaline for the Turmik samples (3 samples) and the remaining two Chalt samples, including the sample of dacite collected from the Minapin glacier. The relationship between $Fe_2O_3$ and $TiO_2$ on one hand, and MgO on the other, presents a broken trend around a MgO content of 6 to 7% (Fig. 32). For trace elements, the high-Mg samples have low concentrations that remain near constant through the range of major elements composition, and Petterson and Windley (1991) insist on their similarity with low-K tholeiitic andesites.

Unpublished data on samples collected in the Hunza valley (Picard, Kausar and Tahseenullah Khan, in prep.) confirm the interpretation and point out to the arc and back-arc environmental characteristics of the lavas. Petterson and Windley (1991) have suggested a Cretaceous age for the Chalt volcanics on the basis of their interweaving with the Albian- Aptian Orbitolina -bearing Yasin sediments (Pudsey et al., 1985a). These sediments however, are separated from the volcanics by the MKT and its stripe of ultramafic described above (Polan La lineament).

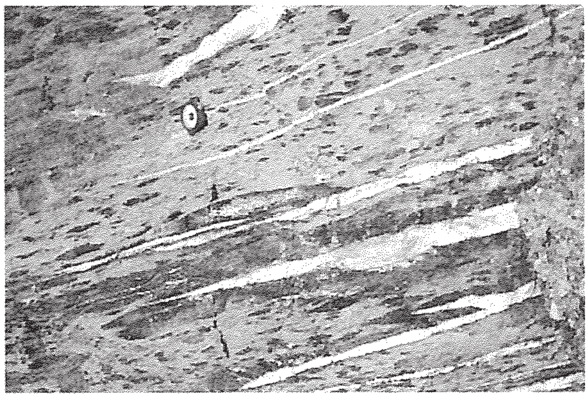
**vT**, the **Turmik Greenstone group: Turmik formation.** In Ladakh, the Turmik valley is carved in a thick volcano-sedimentary formation (Fig. 33), overlooked to the north by the bold Pakora limestone masses (Fig. 34). The formation is made up of alternances of green schists, containing calcite prisms several millimetres thick, minor amphibolite horizons, showing small pyrite grains, and rather rare quartzo-feldspathic conglomerate levels presenting centimetre large elements of amphibolite and green schist. A few stretched blocks of pillow-lava have also been observed.

North of the Pakora limestone, the Turmik formation (Desio, 1963a; Zanettin, 1964) seems to be made up of a tectonic collage of lenses of limestone, quartzite, micaschist, mylonitised biotitic gneiss, black shale, amphibolites, serpentinite, gabbro (the Gontsar gabbro described above), meta-conglomerate with basic elements, chlorite-schist and metabasite (Le Fort et al., 1995). Although these formations have not been recognised as such on the map, they most likely belong to the Shyok suture zone (Rolfo et al., 1997). They remind very much of the formations subsequently discovered (Rolland et al., 2000) and mapped between the Skoro valley and the region of Thalle (east of the map), and described above: a zone of volcano-detrital mélange (svLK), volcanics (vLK), and underlying lavas and tuffs of Bauma Harel. This mélange also reminds us of the olistolitic limestone formations outcropping on the right bank of the Chogo Lungma, albeit

**A** PY74

**B** 94.1.34

**C** QB89



**D** QB9

FIG. 30. Chalt formation: **A:** View of the Rakaposhi (7788 m) from the upper Shispar (Hasanabad) glacier. The mountain is carved in the Chalt volcano-sedimentary formation (PLF slide **PY74**, 5/6/96, around 3700 m of elevation, tele-lens, oriented around N 200° E). **B:** View of the Malubiting (7452 m, on left), Phupharash peaks (6785 m, top of the ridge right bank of the Miar glacier) and Miar peak (6785 m, on the right) from west of the Rash lake. All the high summits ridge is essentially carved in the Chalt meta-volcanic formation (AP slide **94.1.34**, 18/7/94, 3855 m of elevation, tele-lens, oriented N 175° E). **C:** View of stretched pillow-lavas from the Chalt formation. Road to Jaglot on the left bank of the Hunza river (PLF slide **QB89**, 28/6/96, around 1850 m of elevation, oriented to the NE). **D:** Banded amphibolites from the Chalt formation probably corresponding to the dismantling of a basaltic flow. Road to Jaglot on the left bank of the Hunza river (PLF slide **QB90**, 28/6/96, around 1860 m of elevation).

*Formation de Chalt: **A:** Vue du Rakaposhi (7788 m) depuis le haut glacier de Shispar (Hasanabad). La montagne est taillée dans les formations volcano-sédimentaires de Chalt (photo PLF **PY74**, 5/6/96, vers 3700 m d'altitude, téléobjectif, prise vers N 200° E). **B:** Vue du Malubiting (7452 m, à gauche), des pics de Phupharash (6785 m, sommet de l'arête rive droite du glacier de Miar) et du pic de Miar (6785 m, au fond à droite) depuis l'arête à l'ouest du lac de Rash. Toute la crête de haut sommets est faite des formations volcano-sédimentaires de Chalt (photo AP **94.1.34**, 18/7/94, 3855 m d'altitude, téléobjectif, vers N 175° E). **C:** Pillow-lavas étirés dans la formation de Chalt. Route de Jaglot, rive gauche de la rivière Hunza (photo PLF **QB89**, 28/6/96, environ 1850 m d'altitude, vers le NE). **D:** Amphibolites rubanées de la formation de Chalt, correspondant sans doute au démentèlement de coulées basaltiques. Route de Jaglot, rive gauche de la rivière Hunza (photo PLF **QB90**, 28/6/96, environ 1860 m d'altitude).*

north of the MKT, prolonging the Chutrun limestone (south Karakoram), and more metamorphosed (see Fig. 20).

In the higher Turmik valley, the volcanic material of the formation is dacitic to andesitic in composition. It includes massive flows, but, more often, a wide range of volcano-detritic rocks such as green quartzites, arenaceous schists, conglomeratic schists and conglomerates. In these detrital rocks, the volcanic material may compose either the matrix or the cement, or both.

The whole of the Turmik Greenstone group has been metamorphosed in the greenschist facies, with a typical paragenesis of quartz-plagioclase-muscovite-chlorite-biotite-epidote ± calcite (Rolfo, 1994; Rolfo et al., 1997).

**mP**, **Pakora limestone.** The Pakora limestone reaches a maximum thickness of about 2 km along the Pakora valley section, a left bank tributary to the Turmik, SW of the Ganto-La (not to be mistaken with the homonymous torrent flowing to the Basha near Tisar from the other side of the Ganto La). The mass of limestone has the shape of a very elongated lens. This lenticular shape is for most part of sedimentary origin, either reef limestone or exotic platform carbonate, or both; the tectonics only amplified the shape. It has yielded several fossiliferous occurrences:

- Early Cretaceous *Globotruncana* from the Tisar section (Matsushita & Huzita, 1965; Tahirkheli, 1982),
- post-Valanginian rudists in black limestone boulder from the left bank of the Pakora stream (Le Fort et al, 1992) (Fig. 34 B),
- *belemnite* remains and *echinoderm* fragments from the Tisar side (finding of the 1993 expedition by Y. Lemennicier and F. Rolfo, Lemennicier, 1996).

The Pakora limestone is a succession of different horizons of white massive marble, dark limestone, banded limestones (green and white). The foliation is usually strong and the *belemnites* show rotation structures. The Pakora limestone displays a good continuity, starting along the right bank of the Pakora valley flowing to Tisar, then forming the limestone needles of the Tisar Peak, just south of the Ganto La, and continuing along the northern slopes (left bank) of the upper Turmik valley; it seems to extend, much thinner, along the right bank of the Niamur glacier, then thickening again between Niamur and Remendok (Fig. 34 A), and finally disappearing around the east Haramosh second glacier. Variations in thickness probably result from conjunct initial sediment thickness variations and apparent thickening by isoclinal folding (hectometre-large isoclinal folding has actually been observed in the limestone mass of the Tisar peak).

In Kohistan, the limestones are much less abundant. Only few levels are thick enough to be traced and mapped. The thickest one, around 100 m, outcrops east and west of the Rakhan Gali pass in a large (kilometric) south-vergent isoclinal fold. Eastward, it can be discontinuously traced in the south face of the Phuparash peaks and forming the summital ridge of the Malubiting. Westward, it joins the upper Bagrot valley, above Bulche village. Altogether, this level extends for more than 30 km.

The calcaire de Pakora has been strongly déformé et métamorphisé. Métamorphique minerals include white mica et chloritoïde in calcaire, et kyanite in aluminous et carbonaceous schist intercalations (Rolfo, 1994).

**cgP**, **Pakora conglomerate.** As mentioned above, some conglomeratic horizons similar to the Miar conglomerate outcrop south of the MKT, and may also be linked to Shyok suture zone. The thickest horizon forms a more than 5 km long and more than 1.000 m thick lens, maximum on the right bank of the Pakora valley, located on the Tisar side (not to be mistaken with the Pakora summer pasture, across the Ganto La, where the Pakora limestone has been defined). This lens, juxtaposed to the north of the Pakora limestone, to which it is structurally and stratigraphically intimately associated, shows alternances of:

- beds of greywackes, 20 to 30 cm thick, rich in feldspars and lithic fragments, in a chloritic matrix,
- predominant and thicker conglomeratic beds, made up for 70% of flattened angular pebbles, that may reach 40 by 10 cm; they are mainly composed of white marble and grey limestone that remind of the Pakora limestone, and tonalites (around 20% of the pebbles), lying in a shaly matrix with chlorite and calcite. Towards their southern limit, close to the Shigar tonalitic massif, the breccias are richer in tonalites (up to almost 50 %) and basic volcanics.

**vsS, the Sinakkar formation**. In Kohistan, the Sinakkar formation extends for some 50 km as a narrow band of metamorphic volcano-sedimentary material to the south of the Dobani ultramafics, Chalt formation, and N-Barti and Nomal plutons. It has a variable width on the map as if it had been deformed in kilometre-scale boudins. At the type locality of Sinakkar, on the dirt road up the right bank of the Bagrot valley, the formation is made up of very fine-grained siliceous material, thinly banded in dark and clear-coloured alternances, associated with minor amounts of biotite and amphibole-biotite schist, and microconglomerate rare levels; the bedding is plunging around 70° to 190° E. We have observed the formation at several other places, particularly on both sides of the Hunza valley, and in the Bilchar valley. It includes a great variety of lithology such as:

- arenite, micaceous arenite, fine-grained quartzite, microconglomerate bearing clasts of rounded blue quartz, biotite- and muscovite-bearing microconglomeratic schist,
- versicolour schist, Bi and/or amphibole-bearing, iridescent talcschist, pale greenish calcschist,
- white, blue, and greenish marble, impure limestone, reddish veined calcareous arenite,
- fine-grained amphibolite, chlorite- and epidote-bearing prasinite with acicular amphibole, epidotised amphibolitic breccia, possible squeezed pillow-lava amphibolite, amphibolitic schist,
- massive sulfide occurrence, yellow sulfur-bearing pods, and rusty clusters.

Metamorphic minerals include chlorite, epidote, actinolite, biotite, and muscovite. Garnet and aluminium silicate have not been observed.

The Sinakkar resembles the Turmik formation of the Turmik valley by its lithology and mild metamorphic grade; it is, however, more varied, more deformed, and mineralised.

b. The Askor complex

The detailed mapping of this huge entity that covers a large part of Ladakh and some of Kohistan was not the aim of our survey. Outside from the narrow zone that surrounds the Nanga Parbat - Haramosh spur, we have only made quick traverses. The reading of Zanettin (1964), Hanson (1989), Verplanck (1987), Khan (1994), and Sullivan et al. (1993) is suggested for more information outside of this zone.

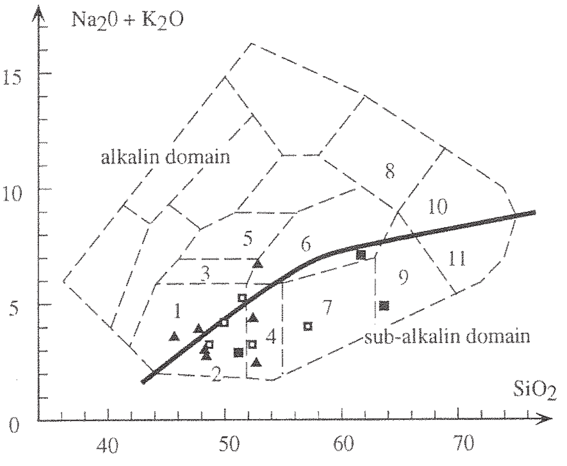
The complex is mainly made up of massive amphibolites where a few marble horizons underline the main structures and have been mapped.

**aA**, the **Askor amphibolite**. The Askor complex also referred to as Askor amphibolite (Zanettin, 1964; Rolfo, 1994) is mainly composed of banded gneisses with dominant amphibolites and amphibole bearing gneisses (Fig. 35), and less abundant biotite gneisses; it also contains horizons of marble and calc-schist. It is extensively intruded by granodioritic to dioritic and tonalitic plutons and dykes. At the contact with the tonalitic intrusion of the Indus-Turmik confluence (the Skoyo gneiss of Desio, 1963a; and Zanettin, 1964), amphibolites of the Askor complex are profusely intruded by tonalitic dykes that mimic an agmatite.

The Askor amphibolite is most commonly made up of fine-grained banded and schistose amphibolites with needle shaped amphiboles. It contains oligoclase (An 20-30) and green hornblende with scarce quartz and variable amount of epidote ± biotite, and sphene. Garnet and scapolite (mizzonite) often occur (Zanettin, 1964); rutile is frequent (Rolfo, 1994). A detailed study of the mineralogy and chemical composition of the minerals is given in Rolfo (1994, p. 39-67 and 109-119). Amphibole is calcic, varying from Al-tschermakite to Mg-hornblende; plagioclase is an oligoclase (An 19-30%); garnet is rich in almandine (61-70%) and pyrope (12-20%); biotite has an $X_{mg}$ ratio of 51 to 69; and epidote contains around 40% mole of zoisite.

PT estimates on two samples from Askober (garnet amphibolite) and lower Turmik valley (epidote amphibolite) yield contrasting values of 6.2 ± 0.5 kbar and 660 ± 75 °C for a fine-grained Hb-Pl-Ep-Q-Rt amphibolite, and 10.3 ± 0.4 kbar and 670 °C for a porphyroblastic Hb-Pl-Q-Gr-Ep-Bi amphibolite.

In Askober valley (right bank tributary of the upper Turmik River), decimetric to metric aplitic orthogneissified dykes are interfoliated with the amphibolite; they are metamorphosed with a muscovite-epidote-pyrite paragenesis. The amphibolite itself contains abundant volcanic breccia, metamorphosed in the amphibolite facies, with euhedral post-metamorphic hornblende.



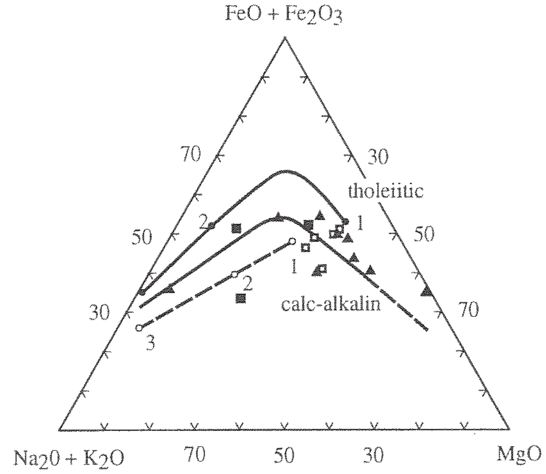




FIG. 31. Chalt and Turmik lavas: chemical classification. Analysis (sample number in brackets) given annex 3. Black triangles: Chalt (SK116, 126, 133, 193, 253, 263, 264, 391); black squares: Turmik (TK45, 48, 773); plain squares: Bauma-Harel (L140, 156, 157, 174, 199, given in Rolland, 2000).
Fields in the $Na_2O + K_2O$ v. $SiO_2$ diagram are for 1: alkali basalt, 2: sub-alkali basalt, 3: hawaiite, 4: andesitic basalt, 5: trachybasalt, 6: trachyandesite, 7:andesite, 8: trachyte, 9: dacite, 10: alkali rhyolite, 11: sub-alkali rhyolite. Trend lines in the $Fe_2O_3$+FeO - $Na_2O + K_2O$ - MgO triangle correspond to tholeiitic series and cal-alkali series. Black triangles: lavas from Chalt formation (SK116, 126, 132, 133,193, 253, 263, 264, 391), black squares: lavas from Turmik greenstones (TK45, 48, 773), plain squares: lavas from Shyok suture zone, Bauma Harel area (analyses L140, 156, 157, 174, 199, from Rolland, 2000).

*Laves de Chalt et Turmik: classification chimique. Les analyses (numéros entre parenthèses) sont données annexe 3. Triangles noirs: Chalt (SK116, 126, 133, 193, 253, 263, 264, 391); carrés noirs: Turmik (TK45, 48, 773); carrés vides: Bauma-Harel (L140, 156, 157, 174, 199, dans Rolland, 2000).*
*Les champs du diagramme $Na_2O + K_2O$ v. $SiO_2$ correspondent à 1: basalte alcalin, 2: basalte sub-alcalin, 3: hawaiite, 4: basalte andesitique, 5: trachy-basalte, 6: trachy-andeéite, 7:andésite, 8: trachyte, 9: dacite, 10: rhyolite alcaline, 11: rhyolite sub-alcaline. Les ligneés indiquées dans le triangle $Fe_2O_3$+FeO - $Na_2O + K_2O$ - MgO correspondent aux séries tholeiitiques et calco-alcalines. Triangles noirs: laves de la formation de Chalt (SK116, 126, 132, 133,193, 253, 263, 264, 391), carrés noirs: laves du complexe de roches vertes de Turmik (TK45, 48, 773), carrés vides: laves de la zone de suture de Shyok, dans la région de Bauma Harel (analyses L140, 156, 157, 174, 199, dans Rolland, 2000).*

In Kohistan, the Askor amphibolites form a large part of the left bank of the Maruk Gah valley, to the WNW of Khaltaro. There they are mainly formed of finely banded amphibolite, generally fine grained, containing interfoliated levels of carbonate + epidote, sometimes quite abundant. They also constitute xenoliths of various sizes within the Dainyor heterogeneous diorite.

Chemically, the Askor amphibolite has a rather homogeneous gabbroic to quartz-dioritic composition (Annex. 3-7). It has a very high content in dark minerals with variable metaluminous characteristics. Considered as awhole, the association has a clear subalkaline affinity and a rather magnesian trend. At first sight, the Askor amphibolite seems to resemble the Chalt-Turmik basalts and andesites, but, particularly in the QBF diagram (Annex. 3), the Askor samples plot on a subalkaline trend.

**mB, Boram marble**. In Ladakh, to the south, two large bands of crystalline limestone are well exposed along the Indus valley, south of Tungas where they climb along the Boram valley, with a total thickness of 400-500 m (Zanettin, 1964, who spells Burum). They can be traced

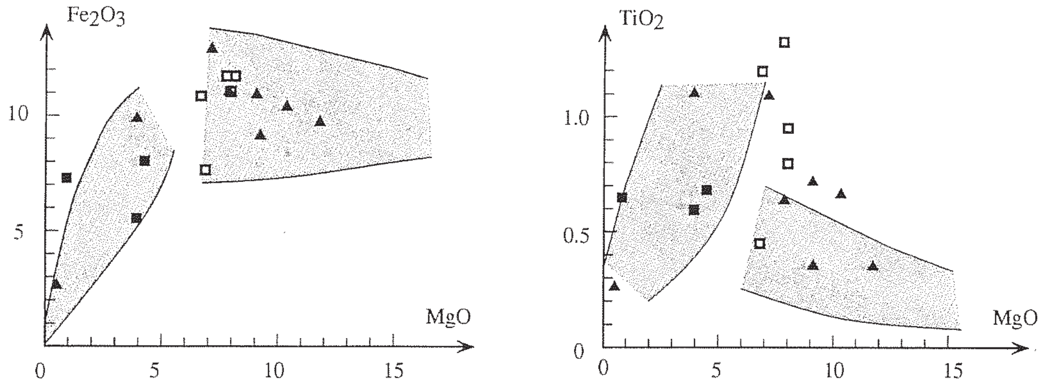



FIG. 32. $Fe_2O_3$ and $TiO_2$ v. MgO variations diagrams for the Chalt and Turmik volcanics. Analysis (sample number in brackets) given annex 3. Black triangles: lavas from Chalt formation (SK116, 126, 132, 133,193, 253, 263, 264, 391), black squares: lavas from Turmik greenstones (TK45, 48, 773), plain squares: lavas from Shyok suture zone, Bauma Harel area (analyses L140, 156, 157, 174, 199, from Rolland, 2000). Fields in gray correspond to calc-alkaline low-Mg and tholeiitic high-Mg samples given by Petterson and Windley (1991) for the Chalt volcanics.

*Diagrammes de variation $Fe_2O_3$ et $TiO_2$ v. MgO pour les volcanites de Chalt et de Turmik. Les analyses (numéros entre parenthèses) sont données annexe 3. Triangles noirs: laves de la formation de Chalt (SK116, 126, 132, 133,193, 253, 263, 264, 391), carrés noirs: laves du complexe de roches vertes de Turmik (TK45, 48, 773), carrés vides: laves de la zone de suture de Shyok, dans la région de Bauma Harel (analyses L140, 156, 157, 174, 199, dans Rolland, 2000). Les deux champs grisés correspondent aux domaines des échantillons de tendance calc-alcaline et Mg bas d'une part, et tholéiitique et Mg fort d'autre part définis par Petterson and Windley (1991) pour les volcanites de Chalt.*

eastward crossing the Katch Bore La and from there crossing again the Indus valley near Skoyo before they get assimilated by the Thhwar dioritic pluton. Eastward, folded in a large domal structure, they reach the almost inaccessible Indus-Shigar crest, from where they can be traced to the north around the B21 peak. These marbles seem to occur at the base of the formation, not far from the contact with the underlying (?) Katchura sillimanite bearing gneisses. This is comparable to the situation in Kohistan, south of our map, where the thick beds of crystalline limestone of the Telichi formation of Khan (1994) overlie the Gilgit paragneisses.

The contact of the Askor amphibolite with the Turmik Greenstone complex seems to be rather sharp between metasedimentary dominated horizons and amphibolitic material. However, no definite shear zone has been observed at the limit. The difference in grade of metamorphism between the two, from upper greenschist to epidote-amphibolite facies, remains the most conspicuous characteristic. It could mean that the contact corresponds to a transgressive deposition of sediments on already metamorphosed arc material.

Close to the contact with the HHC, we have made three detailed sections in the Askober, upper Turmik, and Remendok valleys. There, the Askor rocks are thinned to a few hundred metres - thick band of fine-grained amphibolites and gneiss. They display amphibolite, quartz-epidote hornblendites, biotite-epidote-rutile amphibolite, garnet-biotite amphibolite, 2 micas-epidote-garnet gneiss as the major petrographic types. In the Remendok valley, close to the leucotrondjhemitic intrusion, the amphibolites present strong dissymetric boudinage structures that indicate a top to the south stretching movement.

The Askor complex is probably not limited to the south by the Kachura formation or its eastern equivalent, the Gilgit formation of aluminous gneisses. As shown by Khan (1994), these may form a huge eroded anticlinorium.

c. ζG and ζK, the Gilgit-Katchura gneiss.

Kohistan and Ladakh each present a formation of aluminous gneisses and schists with minor intercalations of amphibolites, calc-silicate gneisses and marbles: the Gilgit formation (Khan M. et al., 1993; Khan T., 1994;

Khan T. et al., 1996) and the Katchura formation (Tahirkheli, 1982; Hanson, 1986 & 1989) respectively. They had been recognised in the Gilgit region by Hayden (1915), by Wadia (1932) who correlated them with the Salkhala of Himalaya, and by Ivanac et al. (1956) who included them in their Permo-Carboniferous Darkot group. Similar kyanite-bearing metapelitic gneisses have been described west of Kargil (Lemennicier, 1992).

The paragneisses, usually originated from pelitic to psammitic rocks, have a dark grey to purplish brown colour. They are metamorphosed in the amphibolite facies with garnet (Alm 58 to 83% according to Khan T., 1994), sillimanite and/or kyanite ± staurolite in the pelitic members, epidote, actinolite, zoisite, grossular and diopside in the calcic members. An occurrence of cordierite-garnet gneiss is mentioned by Hanson (1986) in the lower Shigar valley. The gneisses have undergone some migmatisation and are cut by numerous aplitic and pegmatitic dykes. They are intruded by several plutons such as the Dainyor heterogeneous diorite and Gilgit granite in Kohistan, and the Marshakala and Satpara plutons in Ladakh.

These paragneisses, located to the south, apparently underlie the Askor amphibolites in Ladakh. In Kohistan, they underlie the "Gashu-confluence volcanics". Khan T. et al. (1996) correlate these volcanics with the Chalt ones, whereas Treloar et al. (1996), adding geochemical criteria, consider them as underlying the Chalt volcanic group. For Khan T. et al. (1996), the contact between the Gilgit and Gashu-confluence formations observed in the Sai Nala valley (south of Parri) would be conformable and transitional. Therefore, Khan T. et al. (1996) as Treloar et al. (1996) suggest that the Gilgit gneiss is the lower more metamorphic formation of the threefold Mesozoic Jaglot group, derived from back-arc basin filling, and that it may be Jurassic (?). Rolland (2000 & 2001a) presents a similar hypothesis for the metasedimentary series found above the Ladakh batholith, in the region of the Largyap La, Indian Ladakh. Another possibility would be that the migmatitic gneisses of the Gilgit-Katchura formation represent remnants of an old continental crust incorporated at the northern edge of the Ladakh-Kohistan island-arc. This interpretation was already implicitly suggested by Wadia (1937) when he recognised them as part of his Salkhala sequence.

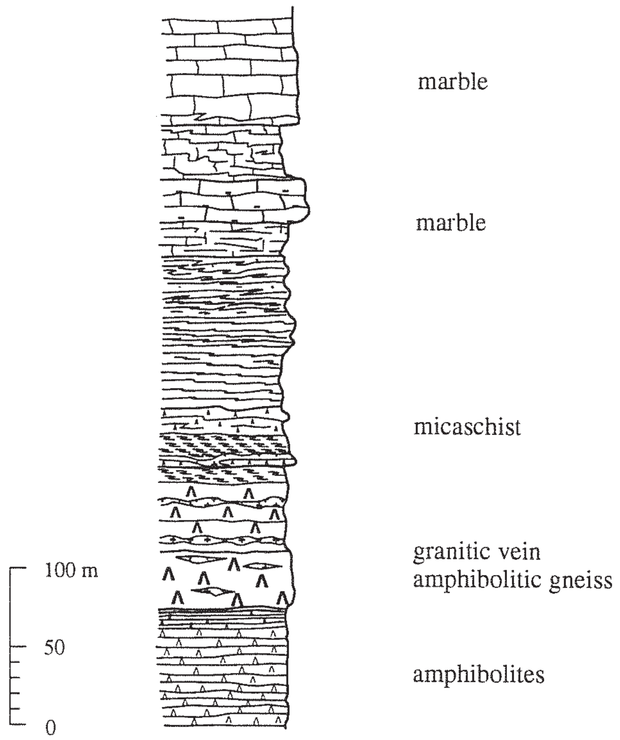



FIG. 33. Synthetic log of the lower part of the Turmik greenstone group. At the base, the amphibolitic gneiss belong already to the Askor amphibolite. The upper marbles are the Pakora limestones. From Le Fort et al., 1995.

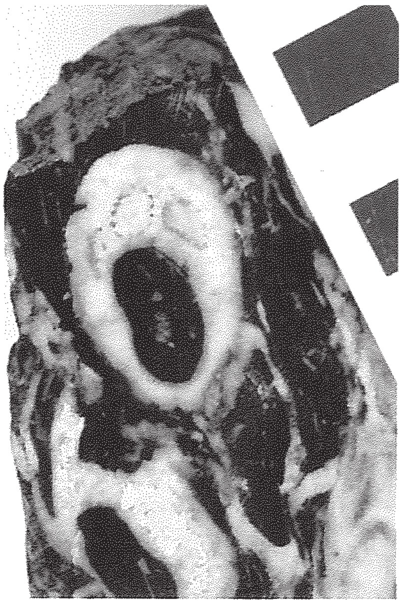
*Log synthétique de la partie inférieure du complexe de roches vertes de Turmik. A la base, les amphibolites appartiennent déjà aux amphibolites d'Askor. Les marbres supérieurs correspondent aux calcaires de Pakora. Figure extraite de Le Fort et al., 1995.*

**Sulphide and Sulphur mineralization**: In Kohistan, numerous sulphur and sulphide mineralizations are hosted by the volcanic-sedimentary formations of Sinakkar and Chalt. Kausar (1991) has studied some of the sulphide mineralization in which he has distinguished:

- porphyry copper at Barti (Manu Gah), and possibly Nomal, both in the Sinakkar fm, with chalcopyrite,

- volcanogenic massive sulphides (pyrite) at Jutial (lower Hunza), and probably at the beginning of the road to Jaglot, in the Chalt fm,

A 93.4.12



B OA14

FIG. 34. The Pakora limestones: **A:** Left side of the Burimis glacier made of a thick mass of Pakora limestones, regularly dipping around 70° N (photo AP **93.4.12**, 28/7/93, 4120 m of elevation, from the slopes right bank of the Burimis valley, looking N 230° E). **B**: Close up of a polished surface of a fossiliferous boulder of Pakora limestone. The white section corresponds to the shell of a post-Valanginian rudist (Le Fort et al., 1992). Sample TK26 from Pakora valley, a left bank tributary to the Turmik (PLF slide **OA14**, 3540 m of elevation, macro-lens).

*__A:__ En rive gauche du glacier de Burimis, passage de l'épaisse barre des calcaires massifs de Pakora, régulièrement pentés d'eniron 70° N (photo AP __93.4.12__, 28/7/93, 4120 m d'altitude, des pentes rive droite du vallon de Burimis vers N 230° E). __B:__ Vue rapprochée d'une surface sciée et polie d'un bloc de calcaire de Pakora fossilifère. La section blanche correspond à la cocquille d'un rudiste post-valanginien (Le Fort et al., 1992). Echantillon TK26, dans le vallon de Pakora, tributaire rive gauche de la vallée de Turmik (photo PLF __OA14__, 3540 m d'altitude).*

- and copper-iron skarn at Markoi (Manu Gah, opposite to Barti), in the Sinakkar fm, with pyrite and chalcopyrite.

All sulphide bearing-zones would have been deformed and metamorphosed after their emplacement, making difficult the identification of the primary hydrothermal mineralogy and structure (ibid). The sulphur isotopic composition of the sulphide from the studied prospects (Kausar, 1991; Ishihara et al., 1996) range from -7.1 to +3.6 per mil and are interpreted to be primarily of magmatic origin.

In addition, some sulphur deposits seem to have been produced in the Bagrot-Bilchar area, on both sides of the Sharain Gali in the Sinakkar fm, where the native sulphur crystals could have been deposited directly from recent hot spring activity.

*Himalaya*

In the region covered by the map, Himalayan plutonic rocks are essentially represented by the Iskere orthogneiss, part of the basement high-grade gneisses. Only one small intrusive pluton outcrops to the west: the Phuparash leucogranite. The famous laccoliths and pods of very recent leucogranite described in the Nanga Parbat region, such as the Tato pluton (1 Ma, Zeitler et al., 1993; Winslow et al., 1994) or the Mazeno Pass ones (U-Pb age of 1.4 Ma, Schneider et al., 1999a), have not been recognised here, but numerous dykes and pods of aplitic to granitic and pegmatitic material have a widespread scattered distribution. In addition, some areas of the Himalaya such as the Indus gorges, present numerous basic dykes.

1. Intrusive rocks

**γP,** the **Phuparash leucogranite**. This leucogranite forms a 9×2 km elongated body along the right bank of the Phuparash valley (a northern tributary to the Indus at Sassi), from the Phuparash glacier to the north, to the

**A** NQ53

**B** OZ4

FIG. 35. The Askor amphibolite: **A:** Boulder of finely banded amphibolite crosscut by a network of aplitic dykelets. Upper Askoubar valley, right bank tributary to the Turmik (PLF slide **NQ53**, 2/9/91, 3835 m of elevation). **B:** Outcrop of banded garnet-bearing Askor amphibolite showing boudinage and granitic pegmatoid patches dipping south at the knots (PLF slide **OZ4**, 9/8/93, 3585 m of elevation, oriented to the east).

*A: Bloc d'amphibolite finement rubanée, recoupée par un réseau de veinules aplitiques. Haute vallée d'Askobar, tributaire rive droite de la vallée de Turmik (photo PLF **NQ53**, 2/9/91, 3835 m d'altitude). B: Affleurement d'amphibolite d'Askor rubanée, àgrenat. L'amphibolite est boudinée, matériel granitique en inter-boudins, dans des lentilles irrégulières à pendage sud (photo LF **OZ4**, 9/8/93, 3585 m d'altitude, vers l'est).*

Darchan-Phuparash ridge to the south. It is highly dissected by a more than 1200 m deep cut of the valley. Former workers have named it Jutial granite (e.g., Butler et al., 1992; George et al., 1993), although it lies more than 2 km north of the village of Jutial. Actually, the Phuparash pluton is formed of two parts, a northern biotite-rich granite, and a southern two-micas ±

tourmaline, coarser-grained leucogranite (adamellite). The contact between the two parts has not been observed. The granite is little deformed although it lies very close to the northern tip of the Raikot-Sassi fault. Almost everywhere, the contact is intrusive into the surrounding Iskere orthogneiss, cutting across their syn-MMT mylonitic fabric. To the south, on the Darchan crest, it cuts into pelitic and calc-silicate-bearing gneisses. Numerous granite and pegmatite dykes cross-cut the country rocks (George et al., 1993).

It resembles many other High-Himalayan leucogranites but with distinctive high Th content (average 22 ppm) and extremely high $^{87}Sr/^{86}Sr$ ratios (from 0.8872 to 0.8920) (Butler et al., 1992). A muscovite-whole rock Rb-Sr dating has yielded 6.5 ± 0.04 Ma for one sample (George et al., 1993). Recent data by U-Pb on zircon, and Th-Pb on monazite have respectively yielded ages of 9.5 and 5.3 Ma (Schneider et al., 1999a). Whole-rock Nd- and Sr-isotope data for five samples give eSr and eNd calculated at 10 Ma between 1730 and 2609, and -24.3 and -26.3 respectively, compatible with an anatectic origin from the surrounding Nanga Parbat basement gneisses (George et al., 1995).

**The acid dykes and gem pegmatites.** Acid dykes are very abundant in all part of the Himalayan gneisses. They have attracted a limited number of studies, especially those containing gemstones. For instance, a detailed mapping of the pegmatites from the Shengus region has been published by Kazmi and O'Donoghue (1990); they mention the occurrence of aquamarine, tourmaline, moonstone, topaz, and beryl. It gives an excellent illustration of the density of the pegmatitic network in certain zones.

George et al. (1993) have sampled and studied a number of granitic dykes in selected areas of the NPHM, particularly W and SW of the Haramosh peak for the region covered by our map. Dominantly they are pegmatitic, heterogeneous, a few decimetres- to a few metres-thick, cross-cutting the metamorphic fabric of the country rocks. Very often, they are deformed, either in a ductile or in a cataclastic manner (Fig. 36B). They usually contain, in addition to quartz and feldspars, muscovite, biotite, schorl tourmaline, ± spessartine garnet; apatite, zircon, and monazite are usual accessory minerals. In addition, many dykes contain large and valuable gem crystals that the local population puts much energy to collect; among these gems: quartz, muscovite, garnet, kyanite, topaz, beryl and aquamarine, fluorite are the most common. However, because of the lack of knowledge and training of the gem hunters, many crystals are destroyed by inconsiderate blasting, many species unknown to them are not collected, and the original paragenesis and location is lost.

Recently, Laurs et al. (1998) have made a very detailed petrographic and mineralogical study of the pegmatites from the Stak valley, E of the Haramosh peak. The 1 to 5 m-thick pegmatites are located on the promontory south of the mouth of the Kothia glacier where they are mined for colour-zoned tourmaline crystals up to 10 cm in length. Tourmaline is an elbaite with black or dark-green base, grading into green, colourless, and locally, pink terminations (ibid). Together with these abundant elbaite crystals, crystals of albite, quartz, topaz, boron-rich muscovite, lepidolite, hambergite (Richards, 1996), and a large number of other and accessory minerals are mentioned by Laurs et al. (1998) (Table 4). The surrounding "flaser granite gneiss" shows up to 50 cm thick wall-rock alteration characterised by muscovitisation of biotite, tourmalinisation (schorl mainly), and local albitisation of oligoclase (ibid). Two $^{40}Ar$-$^{39}Ar$ plateau ages have been obtained on a muscovite from a gneiss and a lepidolite from a pegmatite of the mine yielding 5.80 ± 0.05 and 4.63 ± 0.12 Ma respectively.

In addition, a double emerald deposit, known as Khaltaro emerald deposit, has been mined in the NE sector of the NPHM (Lawrence et al., 1989; Kazmi et al., 1989; Laurs et al., 1996). It is located at around 4,500 m on the ridge between the archan and huparash valleys, in between the MMT, and the western contact of the Phuparash granite. The pegmatites cutting amphibolites, probably originate from the Phuparash granite, the Kohistan (?) amphibolites yielding the chromium. According to Kazmi et al. (1989), in addition to feldspar, quartz, micas, tourmaline, apatite, fluorite, and calcite, the two fertile pegmatites contain:

- amphibole, emerald, and rare goshenite for the first one, 5 by 3 m, cutting across biotite gneiss;
- emerald and goshenite for the second, 3 to 4 m thick, cutting across slivers of ultramafic rocks.

The emerald crystals, the only one in Pakistan to occur in pegmatitic veins, range commonly up to 3 cm in diameter. They have shown to contain actinolite, albite, calcite, chromite, and fluorite as mineral inclusions, a somewhat specific characteristic of the emeralds from Pakistan (Gübelin, 1989; Snee et al., 1989).

Dykes, in general, have a peraluminous composition, a high Rb/Sr ratio, and are depleted in High Field Strength elements such as Hf, Y, Zr, and REE (George et al., 1993). As for the Phuparash granite, the dykes have very high and heterogeneous $^{87}Sr/^{86}Sr$ initial ratios: from 0.79770 to 0.82659 for the five samples of the Haramosh region calculated at 10 Ma (ibid). Model Nd ages for the dykes of 2.4 to 2.6 Ga lie within the range obtained for the surrounding gneisses, supporting an origin by partial melting of the Himalayan basement gneisses, similar in this regard to the other Himalayan leucogranites (cf Le Fort et al., 1987; Le Fort, 1988).

**The basic dykes,** (Fig. 36C) are locally very abundant in the northern part of the NPHM, being either affected by boudinage or refolded in the metamorphic foliation, or clearly cutting across it. They have been studied in the Iskere region and in the Indus valley by Wheeler et al. (1995) and Treloar et al. (2000a), as well as south of the Gorophа La, in the higher Stak valley, by Pognante et al. (1993).

In the Indus valley, the least deformed basic dykes contain relicts of ophitic textures, with pyroxenes ringed by hornblende; the most deformed have turned into fine grained amphibolites containing hornblende and plagioclase, with some quartz, biotite and titanite ± garnet for some of them. Chemically (Treloar et al., 2000b), they are subalkaline basalts, saturated or oversaturated in silicon, slightly enriched in incompatible elements, presenting negative anomalies in Hf, P, Sr, Nb and Ba. The Nd model ages yield values of 1.6 to 1.8 Ga, whereas an errorchrone has given a 1.7 ± 0.2 Ga age. Unlike the Panjal volcanics, of Permian age and intraplate origin, they are most likely Middle-Proterozoic arc or oceanic ridge basalts.

The basic dykes from the higher Stak valley (Pognante et al., 1993), interfoliated in the surrounding gneisses, are characterised by a granulitic mineral composition with clino-pyroxene - plagioclase - garnet - quartz - kyanite - rutile ± hornblende ± biotite ± sphene ± calcite. This assemblage hardly presents any trace of re-equilibration during exhumation and cooling. Chemically, these metabasites are, contrarily to the previous ones, absolutely similar to the Panjal volcanics.

2. The Himalayan gneisses

The geology of the Himalayan Nanga Parbat - Haramosh massif has been described by Wadia (1932 & 1957), Misch (1949), Zanettin (1964), Coward et al. (1982a, 1982b, 1986), Coward (1985), Butler & Prior (1988), Chamberlain et al. (1989), Madin et al. (1989), Rehman and Majid (1989), Treloar et al. (1991), Butler et al. (1992), Pognante et al. (1993), Wheeler et al. (1995), Treloar et al. (1994), Wheeler et al. (1995), Geroge et al. (1996), Edwards et al. (1996, 2000), Foster et al. (1999), Treloar et al. (2000b).

The gneisses of the NPHM have been originally recognised as being the continuation of the High-Himalayan crystallines by Wadia (1932) who made them part of his Salkhala Precambrian sequence (Table 5). They consist of a series of migmatitic orthogneiss, the Iskere gneiss of Madin et al. (1989) and paragneiss, the Shengus gneiss (ibid), a somewhat unfortunate name as at Shengus itself, and eastward, up to Shun Nala, orthogneisses and paragneisses are intimately associated. We prefer the name of Stak La formation (the pass between Stak and Turmik valleys) where the paragneiss is well exposed in its diversity. Madin et al. (1989) add a formation of Haramosh schist (Table 5) that would correspond to the cover of the Shengus and Iskere basement gneiss, but the difference between his Shengus and Haramosh formation separated by the Baroluma fault, is not obvious. Finally, Butler et al. (1992) add a formation of

FIG. 36. Nanga Parbat-Haramosh massif: dykes and orthogneiss: **A:** Haramosh (7406 m) seen from the Stak La. The Kutiah glacier valley lies at the foot of the peak (PLF slide **NS9**, 6/9/91, 4495 m of elevation, oriented N 292° E). **B:** Ptygmatitic folding in a pegmatite intrusive in the Iskere gneiss. Boulder in the upper Darchan valley (PLF slide QA29, 10/6/96, 3455 m of elevation). **C:** Boulder of two micas-garnet-bearing Range Blok orthogneiss crosscut by an amphibole- garnet-bearing basic dyke similar to the dyke in which Pognante & al. (1993) found HP granulitic pargenesis. Sample TK146* from the Lecho valley, west of Stak La (PLF slide **NS35**, 6/9/91, 3705 m of elevation, macro-lens). **D:** Example of an outcrop of Iskere migmatised orthogneiss with leucosome and rims of melanosome cut by a tourmaline-bearing pegmatite on the road from Gilgit to Skardu, 15 km west of Shengus along the Indus river (PLF slide **QB3**, 25/6/96, around 1500 m of elevation).

*Massif du Nanga Parbat-Haramosh: filons et orthogneiss: **A:** L'Haramosh (7406 m) vu du Stak La. En avant du sommet, le glacier de Kothia (photo PLF **NS9**, 6/9/91, 4495 m d'altitude, orientée N 292° E). **B:** Pli ptygmatitique dans une pegmatite, intrusive dans les gneiss d'Iskere. Bloc dans la haute vallée de Darchan (photo PLF QA29, 10/6/96, 3455 m d'altitude). **C:** Bloc d'orthogneiss du Range Blok à 2 micas et grenat, recoupé par un filon basique à amphibole-grenat, semblable au filon basique dans lequel Pognante & al. (1993) on reconnu une paragénèse granulitique HP. Echantillon TK146* provenant de la vallée de Lecho, ouest du Stak La (photo PLF **NS35**, 6/9/91, 3705 m d'altitude). **D:** Affleurement d'orthogneiss d'Iskere migmatisé avec leucosome et mélanosome, recoupé par un filon de pegmatite à tourmaline. Au bord de la route de Gilgit à Skardou, 15 km à l'Ouest de Shengus, le long de l'Indus (photo PLF **QB3**, 25/6/96, vers 1500 m d'altitude).*

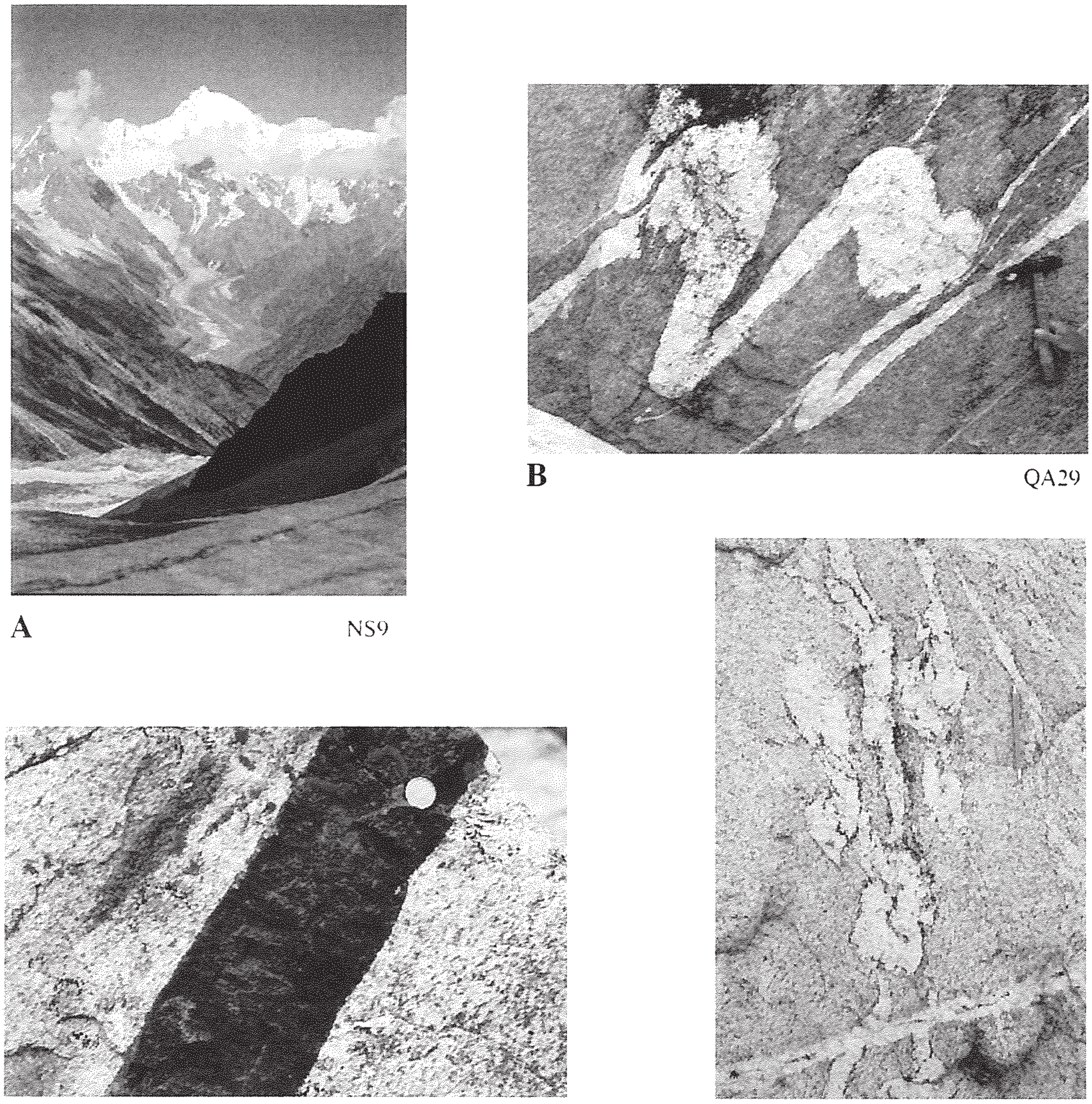
TABLE 4. Principal occurrence and characteristcs of minerals of pegmatites from Himalayan gneiss (after Laurs et al., 1998).

| Location | Host gneiss | Dating (Ma) | Method | Minerals | Accessory min. | Ref. |
|---|---|---|---|---|---|---|
| Dache | Iskere | no | | Ap, Aqm, Fl, Q, Gr, Srl, Tpz | | |
| Drot | Shengus (Stak) | 2.8 & 3.3 | Rb-Sr Ms | Aqm, Ap, Elb, Mrg, Q | Bry, Cst, Col, Gsh,Hlv, Hmb | George et al., 1993 |
| | Iskere | 5 to 8 | U-Pb Zr | Gr, Srl, Tpz | Hrd, Lpd, Pol, Spd Tap , Tnt, Ttn | Zeitler & Chamberlain, 1991 |
| Khaltaro | Stak | 9.1 | Ar-Ar Ms | Ap, Aqm, Em, Fl | Srl | Laurs et al., 1996 |
| Stak | Stak | 4.6 | Ar-Ar Ms | Ap, Elb, Fl, Q, Srl, Tpz | Col, Hmb, Lol, Lpd, M, Mrg, Zr | Laurs et al., 1998 |

"layered gneiss" that includes thick horizons of amphibolites and marbles in the NW corner of the NPHM. Actually, according to our observations in the upper Darchan and Rakhan Gali regions, the quartzo-feldspathic and biotitic layered gneisses correspond to Iskere orthogneiss blastomylonitised in the vicinity of the MMT shear zone. As for "the thick horizon of amphibolite and marbles", it only occurs in the Rakhan Gali region where it lies to the west and above the MMT, and belongs to Kohistan formations.

**ζoI**, the **Iskere gneiss** is predominantly a coarse-grained well foliated augen gneiss with two micas, and garnet often present. The foliation, easily traceable in the landscape, underlines the kilometre-size antiforms and synforms. The size and density of the K-feldspar augens are variable from one place tc the other, and the gneiss can be more or les: migmatized (Fig. 36D). Chemically (Annex. 3 8), the Iskere gneiss has a rather homogeneou: either tonalitic or granitic composition tha resembles that of the Dassu orthogneiss o Karakoram (see above).

Zeitler et al. (1989) dated the first zircons o the Iskere gneiss by U-Pb conventional and ior microprobe methods yielding upper Concordi intercepts of 1852 ± 14 Ma, and slightly mor than 1800 Ma, respectively. They showed th: the zircons had young overgrowths crystallise between 2.3 and 11 Ma. Treloar et al. (199 2000b) and Wheeler et al. (1995), using tl geometrical relationships between the date mafic dykes and the foliation of the gneis estimate that most of the metamorph



A NS9 B QA29 C NS35 D QB3

fabric of the gneiss, and consequently of the protolith, is older than 1.7 Ga.

ζoR, the **Range Blok orthogneiss** forms a small massif of homogeneous augen gneiss (see Fig. 36C), well exposed in the first gully on the left bank of the Gorópha valley, and in the cliffs of the right bank of the upper Stak valley where it also crosses to form small outcrops on the left bank. In the few places where we managed to observe the contact with the Stak La paragneiss, it is clearly intrusive, with dykes cutting the paragneiss and numerous enclaves of the paragneiss. The rock is a gneissified clear-coloured porphyritic granite with two micas and garnet, containing disseminated pods of tourmaline ("cocardes") and rather abundant elongated enclaves of microgranular and meta-sedimentary types. The matrix is generally medium-grained with disseminated centimetre-long K-feldspar crystals. The garnet is usually poekilitic, often forming ball-shaped nests surrounded by a quartzo-feldspathic aureole that

TABLE 5. Nomenclature of the Himalayan formations.

| This study | Wadia, 1932 Zanettin, 1964 | Misch, 1949 Tahirkheli, 1982 | Coward et al., 1982 | Madin, 1986 Madin, et al., 1989 | Butler, 1992 |
|---|---|---|---|---|---|
| (Chalt-Askor) | | | | Hanuchal Haramosh in part | Layered gn |
| Stak La p-gn | | | | Haramosh sch | |
| Stak La p-gn | Salkhala | Nanga Parbat | Precambrian | Shengus gn | Shengus |
| Range Blok o-gn | | | | | |
| Iskere o-gn | sequence | gneiss | basement | Iskere gn | Iskere |

*o-gn: orthogneiss, p-gn: paragneiss*

seems to be related to intrafoliated pegmatitic dykes. In some places, the Bi-Gr-T-bearing pegmatites are very abundant, invading most of the gneiss. The rock has been also intruded by later chlorite- and tourmaline-bearing quartzo-feldspathic veinlets that do not chloritize the biotite of the gneiss. Finally, the rock is cut metabasic dykes similar to those crosscutting the surrounding Stak La gneisses in which high pressure metamorphism has been recorded (Pognante et al., 1993).

Chemically it is made up of a leucocratic to sub-leucocratic aluminous granite, potassic and iron-rich (Annex. 3-8).

**ζS**, the **Stak La gneiss**. The eastern part of the Indus section has been classically described as composed of dominant paragneiss, called Stak migmatites (Desio, 1963a) or more recently, Shengus gneiss (Madin, 1986; Madin et al., 1989; Treloar et al., 1991), and even Haramosh schist (Madin et al., 1989). Actually, the Iskere orthogneiss remains largely predominant in the eastern part of the section, almost up to the MMT (east of Silbu).

Following from west to east the section along the Indus, paragneisses outcrop first, forming a 2 to 3 km wide band, just east of the Sassi-Raikot fault. They crop again between Shengus and the small valley of Jun Nala, where they are interfoliated with strips of orthogneiss and form the apparent heart of two antiformal domes, separated by the verticalised zone of the Baroluma Gah blastomylonites (Fig. 37D), oriented to the NNE. Finally, the same paragneisses are again met some 2 km west of the MMT; they expand towards the north in the Stak valley where one finds the best outcrops.

The Stak La gneisses (Fig. 37D) are composed of alternating metasedimentary and metavolcanic horizons including 2M-Gr-Ky pelitic gneisses, quartzitic levels, calschists and calcic gneisses, rare diopside-bearing marbles, amphibolitic schists and gneisses, amphibolites generally Gr-bearing. In the area of the pass, the most common assemblage (Q-Olg-Bi-Mu-Gt-Ky-Rt) shows very little re-equilibration (see the photomicrographs on Fig. 3 of Pognante et al., 1993). P-T estimates of the paragneiss gave a wide range of temperatures and pressures (510 to 700°C for 5 to 10 kbar, ibid). Greenschist-facies recrystallization only occur within a few tens of metres from the contact with the Turmik formation (MMT). Gneissified granitic material occurs profusely as interbanded granitic horizons and crosscutting aplo-pegmatitic dykes. Fine-grained metabasites, deriving from basaltic dykes, cut across the paragneiss (Pognante et al., 1993).

Several authors have considered the paragneiss as the Phanerozoic cover sequence of basement gneisses that include the Iskere ones; amphibolites have been equated to the Panjal volcanics of the High-Himalayan Tethyan series.

Thus, the age of the formation is not yet precisely established: U-Pb ion-microprobe analysis of zircons from the Stak La gneiss (called Shengus gneiss by the authors) yielded a complicated history probably revealing Archean (around 2500 Ma) inherited components incorporated during a circa 500 Ma crystallisation (Zeitler et al., 1989).

## Metamorphic and Structural Evolution

All the large structural units of the map present a polyphased tectono-metamorphic evolution. One observes:

- older structures (pre-Miocene), certainly already polyphased, that correspond to the main metamorphic fabric of the rocks. Their age is still poorly established, variable from one block to the other, and interpretations of authors often differ,
- very recent structures: it concerns an east-west alignment of structural domes (Fig. 38), that can be followed from the mouth of the Biafo glacier, in Karakoram, up to the NW extremity of NPHM, and that cuts across the major contacts of MKT- Shyok suture and MMT.

*The pre-dome structures and metamorphism*

Let us first recall what is known from northern Karakoram before dealing with the three major units of the map.

1. Northern Karakoram

In north Karakoram, Zanchi (1993) and Zanchi and Gritti (1996) have recognised and described three main tectonic phases: i) north vergent folds, ii) south-vergent thrusts, and iii) left-lateral wrench faults. The north-vergent structures of north Karakoram, overriding late-Cretaceous sediments, and locally accompanied by low-grade metamorphism in lower Shimshal valley, are intruded by the Kuk pluton of Paleocene age (Debon, 1995); they are also sliced by north-dipping south-vergent thrusts, occurring in particular along the contact between the Axial belt and its sedimentary cover, probably involving the Batura granitoids of Eocene age (Zanchi, 1993). The youngest dated marine sediments of Karakoram are those of the Darband formation of Campanian age (Gaetani et al., 1993). Consequently, there is little stratigraphic control on the Tertiary ages of deformation events in Karakoram.

As for the composite group of isolated plutons that intrudes the folded sedimentary cover, it is essentially of Cretaceous age: 121-84 Ma (Treloar et al., 1989; Ogasawara et al., 1984; Debon et al., 1996), and thus helps little in dating the Tertiary deformation evolution.

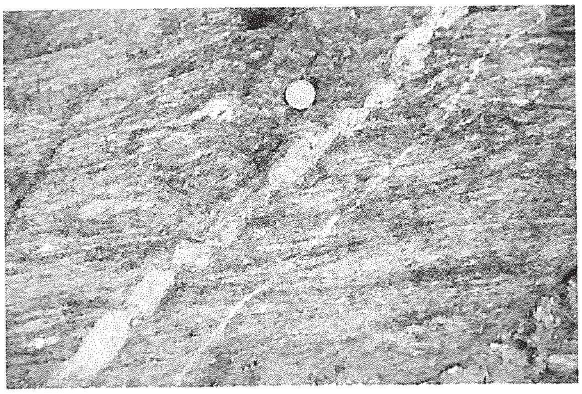
2. Southern Karakoram

All along the metamorphic complex of southern Karakoram, in spite of a strong metamorphic imprint, the lithological contacts remain the most conspicuous planes at landscape scale. For instance, one can easily follow the interleaving of white limestone, brownish metapelites, and black metabasalts (cf. Fig.17A), across the entire map, from the Bola Das valley to the west, to the Basha valley or the Biafo glacier to the east. At outcrop scale, the main tectonic fabric is the metamorphic foliation, associated to a lineation (mineral, intersection, or stretching lineation, the last one being often less distinct). Based on the systematic measurement of foliations, two structural domains emerge (Figs. 38 and 39):

- from Bar to Arendu and the higher Biafo glacier, the foliation is very regularly oriented at N115°E, its average dip increasing from approximately 45°N close to the Karakoram axial zone to nearly vertical close to the MKT. This fabric vanishes to the north, but clearly affects the southern part of the axial granites, the 95 Ma old Hunza granodiorite (Le Fort et al., 1983), in the Hunza valley, as well as the 21 Ma Baltoro granite (Parrish and Tirrul, 1989), in the Biafo glacier area,
- southeast of Arendu, the metamorphic foliation looses regularity, outlining dome structures characteristic of the zone (see below).

The predominant tectonic marker in the southern Karakoram is the metamorphic foliation, which is the axial surface of isoclinal folds at various scales, folding together both metasediments and sills of granitoid rocks (Fig 40A). They are NE-SW folds overturned to the south. The right bank of the Moraine glacier displays pluri-hectometric folds with a very steep axial plunge (Fig. 40B); their interpretation is difficult: they could either indicate the vertical extrusion of the southern edge of Karakoram, or the ductile strike-slip of the northern limit of the Shyok zone, a strike-slip with no convincing marker at outcrop scale, but required by the kinematic reconstitution of the zone (Seeber and Pêcher, 1998).

Along the Hunza section, Broughton et al. (1985) have shown that the metamorphic isogrades display an apparent reverse order. They interpret this disposition as resulting from the southward thrusting of the central batholith



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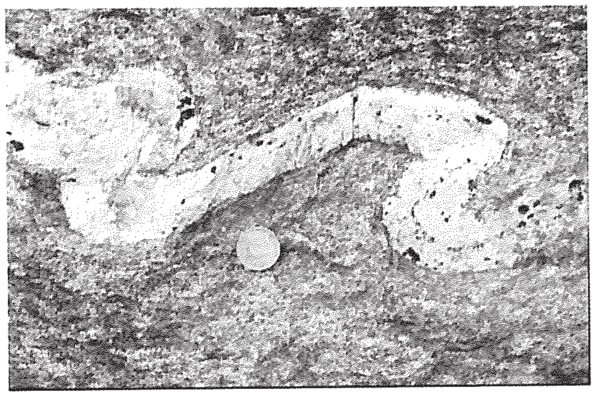

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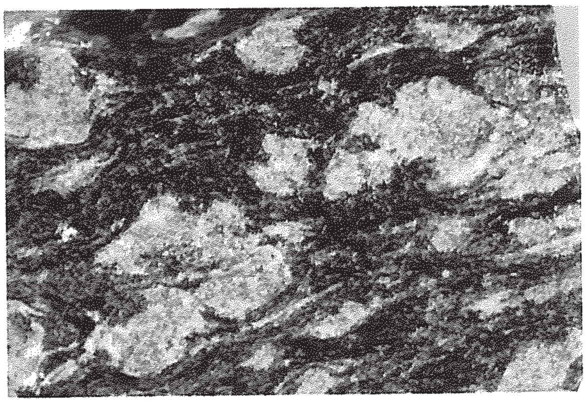

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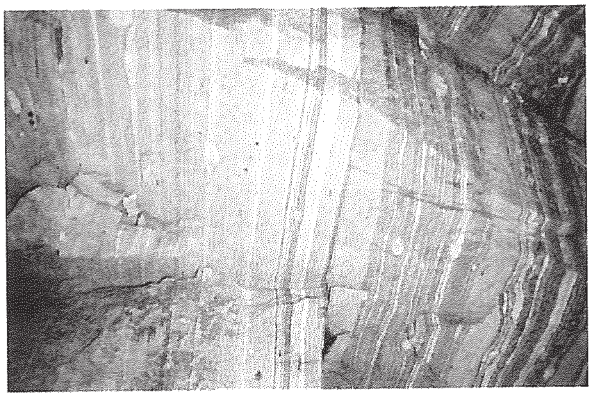

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FIG. 37. Nanga Parbat-Haramosh massif: Stak La gneiss: **A:** Outcrop of migmatitic Stak La gneiss crosscut by a sheared muscovite-tourmaline-bearing pegmatite. Left bank of the Stak La valley (PLF slide **NS85**, 9/9/91, 2880 m of elevation, oriented N 95° E). **B:** Boulder of Stak La biotite gneiss crosscut by a ptygmatically folded tourmaline-bearing pegmatite. The tourmaline crystals are prismatic and lie perpendicular to the walls of the dyke. Lecho valley, west of Stak La (PLF slide **NS33**, 6/9/91, 3755 m of elevation). **C:** Polished section of a garnet-rich boulder of Stak La gneiss. Sample TK84* from the upper Turmik valley La (PLF slide **OA16**, 3920 m of elevation). **D:** Outcrop of ultramylonites, Indus road, on the Spur left bank of the Baroluma Gah. The Barolunma fault itself is a late and minor accident, which does not disturb much the geometry of the previous syn-metamorphic contacts. But farther East in the same area, several blastomylonitic layers, refolded in the latest syn-metamorphic folds, can be observed, at the junction of two main domal structures. In this part of the Indus section, the Stak La type paragneiss predominate; nevertheless, on this outcrop, mylonites seem to rather derive from Shengus type orthogneiss. Mylonitic foliation striking approximatively N 30° E. (AP slide **96.12.19**, 17/10/96, less than 1 km South-East of the Baroluma river, looking north).

*Massif du Nanga Parbat-Haramosh: gneiss du Stak La:* ***A:*** *Affleurement de gneiss migmatitique du Stak La, recoupés par une pegmatite déformée à muscovite - tourmaline. Rive gauche de la vallée du Stak La (photo PLF* ***NS85****, 9/9/91, 2880 m d'altitude, orientée N 95° E).* ***B:*** *Bloc de gneiss biotitique du Stak La recoupé par une pegmatite à tourmaline dessinant des plis ptygmatitiques. Les cristaux de tourmaline sont prismatiques et dirigés perpendiculairement aux épontes de la pegmatite. Vallée de Lecho, à l'ouest du Stak La (photo PLF* ***NS33****, 6/9/91, 3755 m d'altitude).* ***C:*** *Galet de gneiss du Stak La riche en grenat, scié et poli. Echantillon TK84 provenant de la haute vallée de Turmik (photo PLF* ***OA16****, 3920 m d'altitude).* ***D:*** *Affleurement de blastomylonites, route de l'Indus, sur l'éperon rive gauche de la Baroluma Gah. La faille de la Baroluma Gah est un accident tardif assez peu important, qui ne semble pas correspondre ici à un fort décalage des gneiss de part et d'autres. Par contre, dans cette zone, à l'est de la faille, il existe plusieurs bandes d'épaisseur variable de blastomylonites, repliées dans les plis syn-métamorphiques les plus tardifs. Elles marquent une zone de contact importante, à la limite de deux dômes structuraux. Dans cette partie de la coupe de l'Indus, les paragneiss du Stak La sont prédominants; néanmoins, sur l'affleurement photographié ici, les mylonites semblent plutôt dériver d'anciens orthogneiss (photo AP* ***96.12.19****, 17/10/96, vers le nord).*

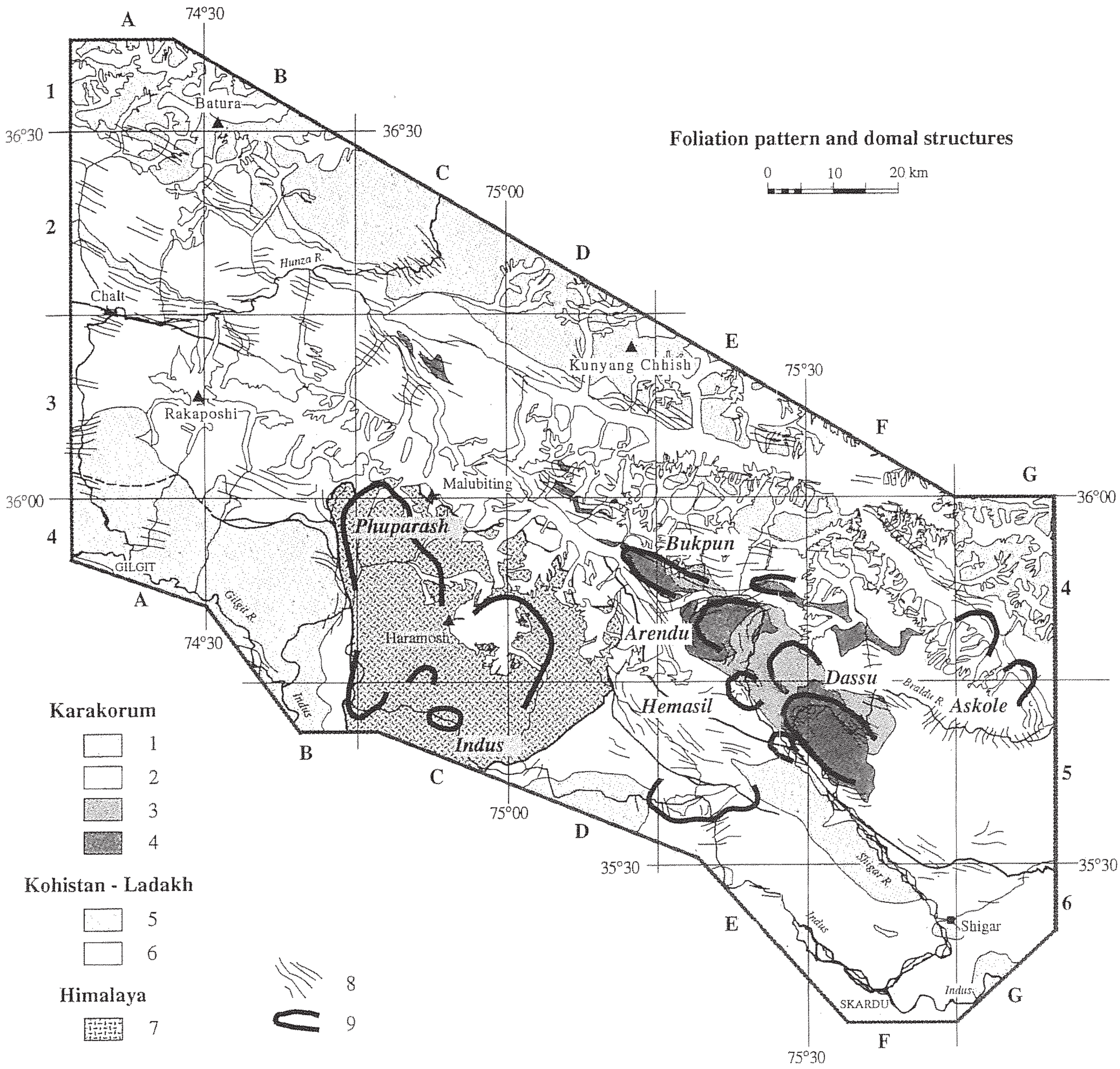
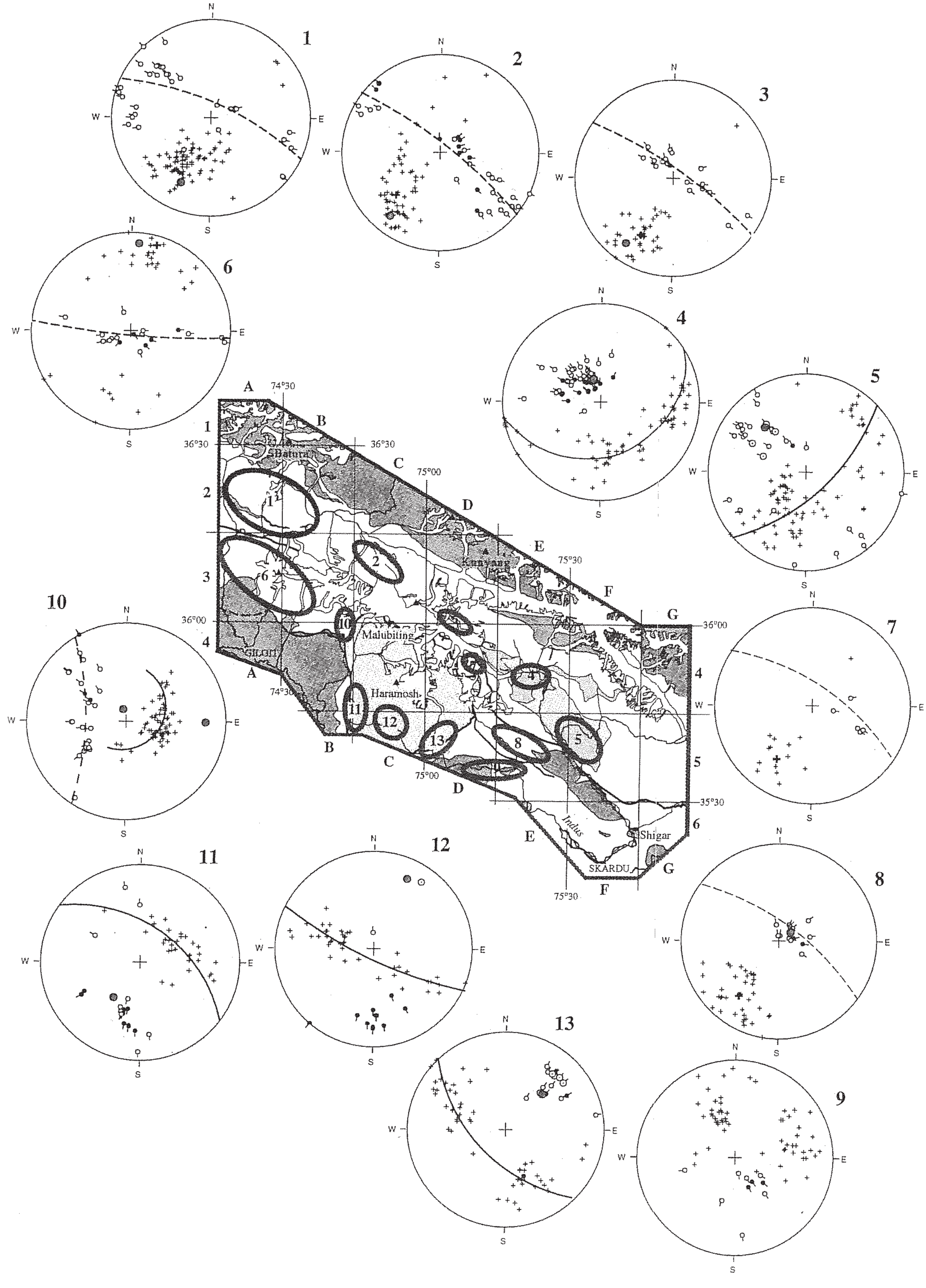



FIG. 38. The foliation pattern and the main domal structures. The map shows the general orientation of the metamorphic foliation, linked to M1 metamorphism (see text): in the western and central part of the map, its regular NW-SE orientation reflect the early thickening tectonic (south west vergent isoclinal folding evolving by place in thrust or nappe stacking); in the eastern part, the foliation is disrupted by the late M2 doming. Main lithological formations: in Karakoram 1: plutonic rocks, 2: metasediments, 3: felsic gneiss and migmatites, 4: orthogneiss; in Kohistan-Ladakh 5: plutonic rocks, 6: metasediments and metavolcanics; in Himalaya 7: undifferentiated gneisses. Tectonic pattern marked by 8: foliation trace, 9: domes shape.

*Les trajectoires de foliation et les principales structures en dôme. La carte montre l'orientation générale de la foliation métamorphique, associée aux phases de métamorphisme M1 (voir texte): dans les parties ouest et centrale de la carte, son orientation régulière NO-SE reflète l'épaississement tectonique précoce (plis isoclinaux à vergence sud-ouest évoluant par endroit en chevauchements ou nappes); dans la partie est, la foliation est redéformée par le doming tardif M2. Principales formations lithologiques: au Karakoram 1: roches plutoniques, 2: métasédiments, 3: gneiss feldspathiques et migmatiques, 4: orthogneiss; au Kohistan-Ladakh 5: roches plutoniques, 6: métasédiments et métavolcanites; en Himalaya 7: gneiss indifférenciés. La structure est marquée par 8: trajectoires de la foliation métamorphique, 9: forme schématique des dômes.*

FIG. 39. Orientation of the structural markers in southern Karakoram (diagrams and area labelled 1 to 5), in the northern Kohistan-Ladakh series (diagrams 6 to 9), and in the Himalayan (Haramosh) spur (diagrams 10 to 13) (from Pêcher and Le Fort, 1999, modified). Geological formations: dark gray for Karakoram and Kohistan-Ladakh plutonic rocks, light gray for Himalayan gneiss and Karakoram felsic gneiss, medium gray for Karakoram orthogneiss. Wulff stereonets, lower hemispher. Symbols are common to all the diagrams. Cross: metamorphic foliation; plain circles: axis of syn-metamorphic folds and bedding-foliation intersection lineations ("B" lineations); black circles: stretching lineation; circles with a dot at center: axis of post-metamorphic folds. Thick cross: calculated best plane for the foliation; gray circle: pole of the calculated best great circle, for a girdle type distribution of values, or pole of the best small circle, for a small circle (conical) type distribution. Plain best circle: best great (or small) circle calculated using the foliation data (evidence post metamorphic folding). Dotted circles: best great (or small) circle calculated using the synmetamorphic folds axis and intersection lineations. Orientations are given by plunge (or dip) value and plunge (or dip) direction (for instance, a line 56-26 means a line plunging of 56° in the direction 26° E). **Diagrams 1 to 3:** southern Karakoram, away from the eastern domes area. Foliation regularly oriented, but lineations, often with high values plunges, scattered along a plane (a great circle), close to the foliation best value. Best great circles and best foliation plane respectively oriented 56-26 and 72-24 (diagram 1), 64-46 and 79-38 (diagram 2), 68-29 and 78-35 (diagram 3). **Diagrams 4 and 5:** north-western ending of the Arendu and Dassu orthogneissic domes. Foliation deformed by the doming process and irregularly scattered. Scattering best fitted either using a small circle (conical fold, diagram 4) or by a great circle (cylindrical fold, diagram 5). In both case, axis plunging to north-west (viz. 63-161 and 27-137). The former lineation is rotated towards the dome axis. In the Arendu dome, a strong ductile stretching lineation, underlined by M2 metamorphic minerals, is observed. **Diagrams 6 to 8:** pattern observed in the Kohistan-Ladakh greenstone complex, very similar to the one observed in South Karakoram (diagrams 1 to 3). B-lineations, usually steep plunging, scattered in the foliation plane (diagram 6, best great circle at 84-196, and best foliation plane 84-185). In area 7 and 8 (Ladakh formations in zone unaffected by late doming), lineations also steeply plunging (thin great circle: cyclographic trace of the calculated best foliation planes, respectively 67-33 and 70-36 for diagrams 7 and 8). **Diagram 9:** a domal structure observed in Ladakh formations, along the Indus valley, South of the Turmik valley. Foliation very irregularly scattered, in a non cylindrical neither conical structure. **Diagrams 10 to 12:** domal structures in the Himalaya. The bulk shape of the northern terminaison of the NPHM spur corresponds to a large dome, made of the juxtaposition of several smaller domes/folds (two are cut by the Indus road, west and east of Shengus village: diagrams 12 and 13). In the Rakhan pass area (diagram 10), foliation at the northwest end of the main dome drawing an approximatively conical fold, with an axis at 76-346; former lineations dispersed along a small circle, centered at 26-91. In the Indus valley (diagrams 11 and 12), foliation deformed in two rougthly cylindrical folds, of similar orientation but opposite senses of plunge (viz. 42-216 and 13-25). **Diagram 13:** MMT zone, south east boarder of the Haramosh dome (Stak area). Late or post metamorphic folding scattering the foliation (fold axis direction: 35-46).

*Orientation des marqueurs structuraux pour le sud du Karakoram (canevas et zones indexées 1 à 5), le nord du Kohistan-Ladakh (stéréos 6 à 9) et le nord du promontoire himalayen (stéréos 10 à 13) (d'après Pêcher et Le Fort, 1999, modifié). Géologie: en gris sombre, les plutons du Karakoram et du Kohistan-Ladakh, en gris clair les gneiss feldspathiques du Karakoram et les gneiss himalayens, en gris moyen les orthogneiss du Karakoram. Canevas de Wulff, hémisphère inférieur. Symboles communs à tous les canevas. Croix: foliation; cercles vides: axes de pli ou intersections foliation-stratification (linéations "B"); disques noirs: linéation d'étirement; circles avec un point au centre: plis post-métamorphiques; croix épaisse: meilleur pôle calculé pour la foliation; disque gris: pôle calculé pour le meilleur grand cercle (distribution en guirlande, pli concentrique) ou le meilleur petit cercle (pli cônique); en trait continu, meilleur grand cercle (ou petit cercle) calculé en utilisant les pôles de foliations (mise en évidence de plis post foliaux); en trait tireté, meilleur grand cercle (ou petit cercle) calculé en utilisant les pôles des plis ou des linéations d'intersection (mise en évidence du plan de dispersion des plis). Orientations données par le plongement (ou pendage) de 0 à 90° et la direction du plongement (ou pendage) de 0 à 360°.* ***Canevas 1 à 3:*** *sud Karakoram, hors de la zone d'influence des dômes. Foliation régulièrement orientée, linéation, souvent fortement plongeante, dispersée dans un plan (grand cercle) proche de la meilleure valeur calculée pour la foliation. Pôles des meilleurs grands cercles et meilleur pôles de la foliation respectivement à 56-26 et 72-24 (canevas 1), 64-46 et 79-38 (canevas 2), 68-29 et 78-35 (canevas 3).* ***Canevas 4 et 5:*** *terminaison nord-ouest du dôme orthogneissique d'Arendu et Dassu. Foliation deformée et dispersée par la formation du dôme. La dispersion se fait soit selon un petit cercle (pli cônique, canevas 4) soit selon un grand cercle (pli cylindrique, canevas 5). Dans les deux cas, axes plongeant au nord-ouest (viz. 63-161 et 27-137). La linéation ancienne est tournée vers le coeur du dôme. Dans le dôme d'Arendu, la forte linéation d'étirement, soulignée par les minéraux de métamorphisme M2, est proche de l'axe du dôme.* ***Canevas 6 to 8:*** *complexe de roches vertes du Kohistan-Ladakh. Disposition très semblable à celle observée dans le sud Karakoram (canevas 1 à 3). Linéations B dispersées dans le plan de foliation, et généralement à fort plongement (canevas 6, meilleur grand cercle à 84-196, et meilleur plan de foliation à 84-185). Dans la zone 7 et 8 (formations du Ladakh dans les zones non affectées par les dômes), lineations de nouveau à fort plongement (grand cercle fin: trace cyclographique des meilleurs plans de foliation, respectivement 67-33 et 70-36 pour les canevas 7 et 8). Canevas 9: structure en dôme observée dans les formations du Ladakh, dans la vallée de l'Indus, au sud de la valléée de Turmik. Foliation très irrégulièrement dispersée, dans une structure ni cylindrique ni cônique.* ***Canevas 10 à 12:*** *structures en dôme dans l'Himalaya. La forme globale de la terminaison du promontoire du NPHM correspond à un vaste dôme, fait de la juxtaposition de plusieurs dômes/plis de plus petite dimention (deux d'entre eux sont recoupés par la route de l'Indus à l'ouest et à l'est du village de Shengus: canvas 12 et 13). Dans la région du col du Rakhan (canevas 10), la foliation à l'extréémité nord-ouest du dôme principal dessine un pli à peu près cônique, d'axe76-346, et les linéations anciennes sont dispersées sur un petit cercle centré à 26-91. Dans la vallée de l'Indus (canevas 11 et 12), foliation deformée en deux plis à peu près cylindriques, d'orientations proches mais de sens de plongement opposés (respectivement 42-216 et 13-25).* ***Canevas 13:*** *zone du MMT, bordure sud-est du dôme de l'Haramosh (région de Stak). Plis tardi- ou post-métamorphique dispersant la foliation (direction de l'axe du pli: 35-46).*



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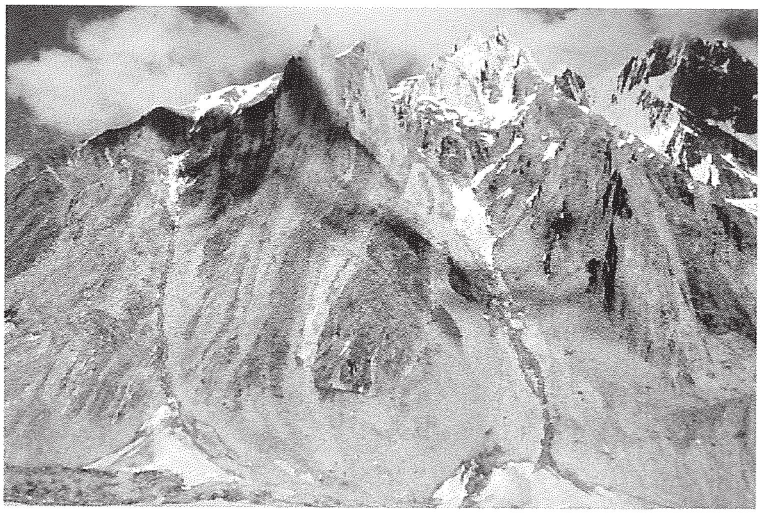

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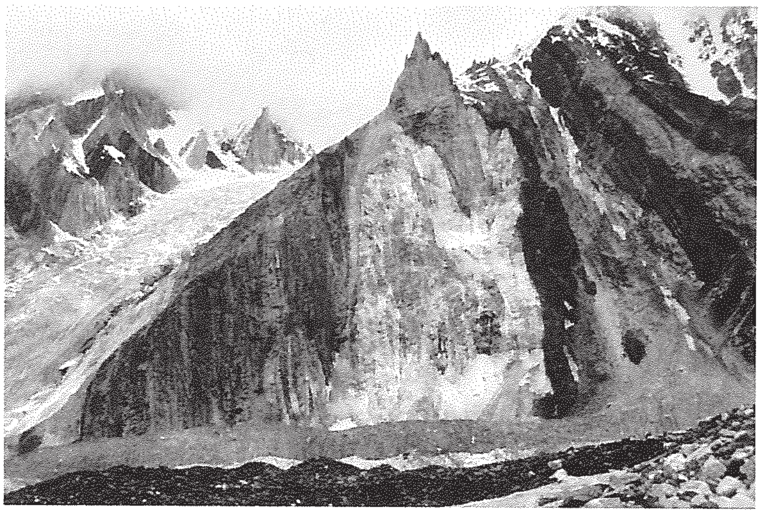

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FIG. 40. Synmetamorphic hectometer-scale folds in Karakoram Metamorphic Complex: **A:** Isoclinal antiform of marbles with a core of Bolocho orthogneiss (Hunza type granitoid), left bank of the Moraine valley. Samples TK642 and 643 come from the granitic core at the center of the photo. On the left side of the photo, another slice of orthogneiss is visible (AP slide **93.8.13**, 6/8/93, 4245 m, looking N 105° E). **B:** Folds with steeply plunging axes, folding marbles (white colored), metapelites and quartzites (brownish) and amphibolites (black). Spur between Serac glacier and Moraine glacier (AP slide **93.6.33**, 4/8/93, 4070 m, from left bank of Moraine glacier, looking west).

*Plis syn-métamorphique d'échelle hectométrique dans le Complexe Métamorphique du Karakoram: **A:** Antiforme isoclinal de marbre, avec un coeur d'orthogneiss de Bolocho (granitoïde de type Hunza), rive gauche du glacier Moraine. Les échantillons TK642 et TK643 proviennent du coeur granitique du pli, au centre de la photo. A gauche, on voit une autre lame d'orthogneiss (photo AP **93.8.13**, 6/8/93, 4245 m, vers N 105° E). **B**: Plis à axes très raides, affectant la série de marbres (au centre, très blanc), de métapélites et quartzites (brunâtres) et d'amphibolites (très sombres) du Chogo Lungma. Eperon entre le glacier Serac et le glacier Moraine (photo AP **93.6.33**, 4/8/93, 4070 m, depuis la rive gauche du glacier Moraine, en regardant vers l'ouest).*

and the correlative piling in a reverse order of slices of different metamorphic grade. This interpretation is again adopted by Crawford and Searle (1993). But, taking into account the remarkable lithological continuity that we have observed and mapped from one metamorphic zone to the other, for example most conspicuous when following limestone levels, we feel that this interpretation should be further supported. During our field work, we have not been able to evidence such thrusts, using either sudden metamorphic gaps or microtectonic criteria. Only in a few places we observed shearing criteria, with small structures indicating top to the south movements, and we hardly could follow laterally such zones for more than a few hundred meters. Nor does the map underline any nappe structure, whereas it clearly indicates tight isoclinal folding at kilometre scale (Toltar-Karimabad zone, for example). Thus, although we cannot exclude the existence of tectonic contacts, we have preferred to consider as normal the limits between the different metamorphic domains or lithological units (such as the limit between terrigenous formations of Shittinbar and the other metasedimentary formations located more to the north). In a similar way, we feel it possible to interpret the Bola Das and Arendu migmatitic gneisses to be part of a structurally in place Karakoram basement, rather than to attribute them to a particular tectonic unit.

The grade of metamorphism of the KMC formations varies largely from one area to another. Several studies deal with the subject (Broughton et al., 1985; Hanson, 1986 & 1989; Bertrand et al., 1988; Rex et al., 1988; Searle et al., 1989; Allen & Chamberlain, 1991; Searle, 1991; Lemennicier, 1996; Lemennicier et al., 1996; Searle et al., 1999; Rolland, 2000, Rolland et al., 2001b).

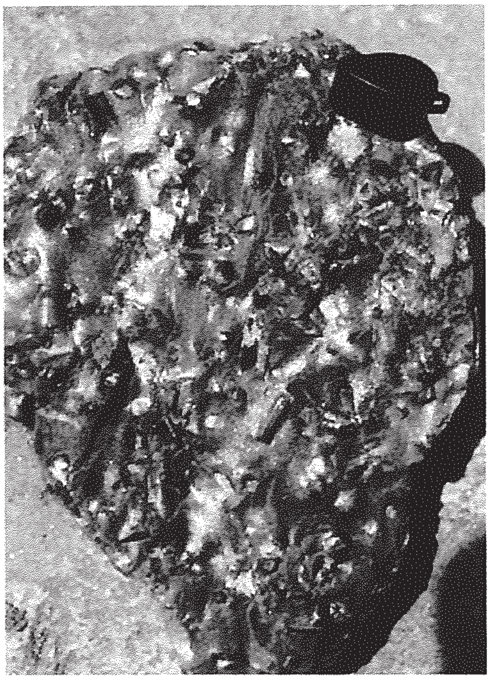
Along the Hunza section, metamorphic isograds have been mapped (Broughton et al., 1985) from chloritoid to garnet + K-feldspar, through staurolite, kyanite, and sillimanite. These isograds can be regularly traced south-eastward up to the Hoh Lungma valley (Lemennicier, 1996; Rolland, 2000). Several comparable PT estimates have been obtained on the highest grade rocks of the Hunza section using different assemblages, among which:

- 580-640 °C for 5.0 ± 0.5 kbar (Debon et al., 1987), on the highest grade samples at the base of the sheared Hunza meta-granodiorite,
- 620°C for 6-7 kbar (Okrusch et al., 1976), on corundum-bearing marbles from a ruby mine located just south of the sheared contact with the Hunza granodiorite,
- 670°C for 5.5 kbar (Prior & Broughton, 1986), on siliceous dolomites sampled a few kilometres down stream from the same contact,
- 630°C for 5.5 kbar (Prior & Broughton, 1986), on pelitic assemblages from the same locality.

In the aluminous St-Gr schists cut by the KKH, opposite to Tashot, the garnets may reach several cm in diameter and present beautiful snow-ball textures, with inclusion spirals of quartz and graphite; they have been used as a model for the study of the syntectonic growth of garnets by Powell and Vernon (1979).

In the central and eastern part of the map, the highest grade metamorphism is centred on the orthogneiss domes and decreases towards the south as well as towards the centre of the map. For example, the sillimanite paragenesis of Bisil, becomes a Grt-St paragenesis in the Niamur region (Fig. 41), whereas in Moraine and Bolocho glaciers we have only noticed the development of Bio-Grt association in the metapelites, and phlogopite in some limestone horizons. South of the Dassu dome of orthogneiss, the metamorphism regularly decreases down to the smectite + chlorite zone, in the fossiliferous formations of the Bauma Harel - Thalle region. Several P-T estimates have been obtained outside the zone of influence of the domes, among which:

- 700°C and 8 to 12 kbar (Lemennicier, 1996), conditions close to granulitic facies, for the Q-Pl-Gr-Bi-Mu-Sil migmatitic gneiss of Arendu, on samples taken in the lower Kero Lungma valley,
- 680 ± 50°C and 7 ± 2 kbar (Rolland, 2000), on a Gr-Bi-Ky (subsequently retrograded into Sill) - Pl gneiss taken just downstream of the Hoh Lungma confluence,
- 550°C and 8 kbar (Lemennicier, 1996), on a Q-Pl-Gr-Bi-Mu-St micaschist taken on Chogo Lungma left bank, south of Khurumal (Fig. 41),



**A** OW35 **B** 92.2.22

FIG. 41. Metamorphic minerals in the Karakoram Metamorphic Complex: micaschists with euhedral cristals of dark garnet and black staurolite. **A:** Boulder right bank of the Chogo Lungma (PLF slide **OW35**, 26/7/93, 2985 m). **B:** Outcrop upstream of Domok, left bank of the Kero Lungma valley (AP slide **92.4.18**, 22/5/92, 3560 m).

*Minéraux de métamorphisme dans le Complexe Métamorphique du Karakoram: micashistes riches en cristaux euhédraux de grenat sombre et de staurotide noir. **A:** Bloc en rive droite du Chogo Lungma (photo PLF slide **OW35**, 26/7/93, 2985 m). **B:** Affleurement en amont de Domok,rive gauche de la vallée du Kero Lungma (photo AP **92.4.18**, 22/5/92, 3560 m).*

- south of the zone of domes, the metamorphism (Fig. 42) associated to the pre-dome structures (south verging folds turning into southward thrusting) is less intense: 535°C ± 55°C and 5 ± 2 kbar for a Mu-Gr-Bi-Ky Khusomik schist taken in the Skoro Lungma (Rolland, 2000), whilst more to the south-east, just outside of the map, the smectite-Fe-Chlorite-Mu±Ctd parageneses correspond to temperatures lower than 400°C and pressures lower than 5 Kbar (ibid).

As for the Zil aluminous paragneiss, between the Dassu and Mangol Bluk domes, they present a first HT-MP assemblage with Gr-St-Ky, followed by a second HT one characterised by the transformation of kyanite into sillimanite. Allen and Chamberlain (1991) give pressure and temperature estimates at 4-10 kbar and 550-625°C respectively.

The metamorphism is polyphased and its age has been much debated. In the Hunza region, Searle et al. (1999) distinguish an old metamorphism recorded in two sillimanite phases M1 and M2 that occurred before the first granitic dykes (35 Ma), from a late 3 phase dated between 14 and 16 Ma by U/Pb on syn-metamorphic monazite (schist of staurolite grade in the Hunza valley, at Nasirabad, Fraser et al., 1998), that would correspond to the St-Gr or Bi-Gr metamorphism of the Shittinbar formations.

In the eastern part of our map, for Searle et al. (1987 & 1989) as for Allen & Chamberlain (1991), the metamorphic fabric would be sealed by the 37.0 Ma Mango Gusar intrusion. For Bertrand et al. (1988), the main D2 Sil-Gr-St tectonometamorphic event post-dates the leucogranite intrusions and predates the pegmatitic intrusions and the orthogneiss doming; it would be bracketed between ca 37 and ca 20 Ma. For Lemennicier (1996), using the P-T-t paths and cooling rates constrained by $^{40}Ar$-$^{39}Ar$ ages on micas and amphibole (Villa et al., 1996a), most of the metamorphic imprint would be Mio-Pliocene in age, and would largely obliterate the old M1 event.

3. Kohistan-Ladakh

When crossing the SKF zone, there is no change in the style and orientation of the deformational fabric (Figs. 38 and 39). On both sides of the Nanga-Parbat spur the Arc formations present the same syn-metamorphic isoclinal folds. As in the case of southern Karakoram, the fold axes, scattered in the foliation plane, usually plunge steeply (Fig. 39). Again, such a pattern probably indicates shearing parallel to the SKF in an overall dominant flattening regime.

In the strip of Greenstone Complex, north of the Nanga-Parbat spur, shear criteria are rare, but generally consistent with an upward movement of the northeastern compartment. No unambiguous criteria of normal type ductile shearing or brittle faulting (descent of the northern compartment) have been found: exhumation of the NPHM has been obtained by a simple tilting of the old syn-MMT fabric, that displayed (after substracting the tilting effect) a top to the south movement. Two samples from the northern strip of Greenstone Complex have yielded $^{40}Ar$-$^{39}Ar$ amphibole ages of 14.3±1.9 Ma and 8.8±2.6 Ma, and biotite plateau ages of 7.9±0.1 and 6.25±0.07 Ma (Villa et al., 1996b).

The screen of Dobani-Dasu ultramafics that divides Kohistan and Ladakh in two sub-units, is a good marker of the global deformation of the Arc. Away from the MMT, it is parallel to the NW-SE general structural trend of the range, it is bent on both sides when getting closer to the contact with the NPHM gneisses. To the east, the bending of the lower Turmik screen marks and supports the right-lateral movement also evidenced in the Greenstone Complex. To the west, the curvature of the Bilchar-Dobani screen also indicates a right-lateral movement, which seems to contradict the movement deduced from the observation of the mylonitic Himalayan gneiss of the upper Darchan valley that marks the thrusting of the Arc over the Himalaya.

More to the south, we have not observed large field structures in the Askor amphibolites, with the exception of their southwest portion, in the vicinity of Stak, where syn- and post-metamorphic folds of all sizes are visible, with an average NE-SW axial orientation. In thin section, late green hornblende and epidote often recrystallise across the hinges of accompanying folds (Rolfo et al., 1997). Locally, one recognises Himalayan type gneisses in the heart of several ten of metres large folds, thus indicating that the Himalaya-Ladakh contact (MMT) has been refolded, before the end of metamorphism. Fracturation that affects the complex in the Indus valley (Verplanck, 1987) is a late phenomenon with retrogression of the previous metamorphic assemblages.

The grade of metamorphism in the Kohistan-Ladakh formations greatly varies from one locality to another. Concerning the area covered by the map, it has mainly been studied on the Ladakh side, in particular by Rolfo et al. (1997), from which we pull out most of the following data (Fig. 43).

The Turmik group has been only slightly metamorphosed, usually in the green schist facies with a typical Q-Pl-Mu-Chl-Bi-Ep±Cc assemblage (ibid). In the more metamorphic zones, a Ky-Bi-Ctd assemblage indicates pressures above 4 Kbar and temperatures around 450-550°C. But next to the MKT (Ganto La region), values of 650 ± 40°C for 9.5 to 10 ± 0,5 Kbar have been obtained on Hb-Bi-Pl-Cc schists (ibid); such values are very similar to those found in the same zone, north of the MKT. However, the same samples have yielded amphibole and biotite $^{40}Ar$-$^{39}Ar$ ages ranging from 6 to 14 Ma (Villa et al., 1996b). The increase of temperature towards the MKT should thus be connected to the M2 metamorphism, linked to doming (cf. infra), itself reworked by the brittle MKT faulting.

Metamorphism is higher in the Askor amphibolites (amphibolite facies); it is

FIG. 42. Metamorphic pattern in Karakoram domes area (from Rolland, 2000, and Rolland & al., 2001, modified). Upper map refer to pre-doming metamorphism, lower one to syn-doming metamorphism. The typical mineral associations are defined in the metapelitic rocks. For M1, they are: (1) Fe-chlorite - smectite, (2) mus - bio - chl, (3) grt - bio - mus - ctd, (4) sta - grt, (5) ky -sta -grt; in zone (6), M1 metamorphism is nearly completely hidden by the high temperature M2 metamorphism. For M2, the associations are (7) ky - bio - grt ± sill ±sta, (8) sil - Kfs - bio - grt ± mus (+ melting).

*Métamorphisme dans la zone des dômes du Karakoram (d'aprés Rolland, 2000, et Rolland & al., 2001, modifié). La carte du haut correspond au metamorphisme pré-dômes, celle du bas au métamorphisme syn-dôme. Les paragnèses caractéristiques sont définies dans les métapélites. Pour M1, ce sont: (1) Fe-chlorite - smectite, (2) mus - bio - chl, (3) grt - bio - mus - ctd, (4) sta - grt, (5) ky -sta -grt; dans la zone (6), le métamorphisme M1 est presque totalement oblitéré par le métamorphisme M2. Pour M2, les associations sont (7) ky - bio - grt ± sill ±sta, (8) sil - Kfs - bio - grt ± mus (+ fusion).*

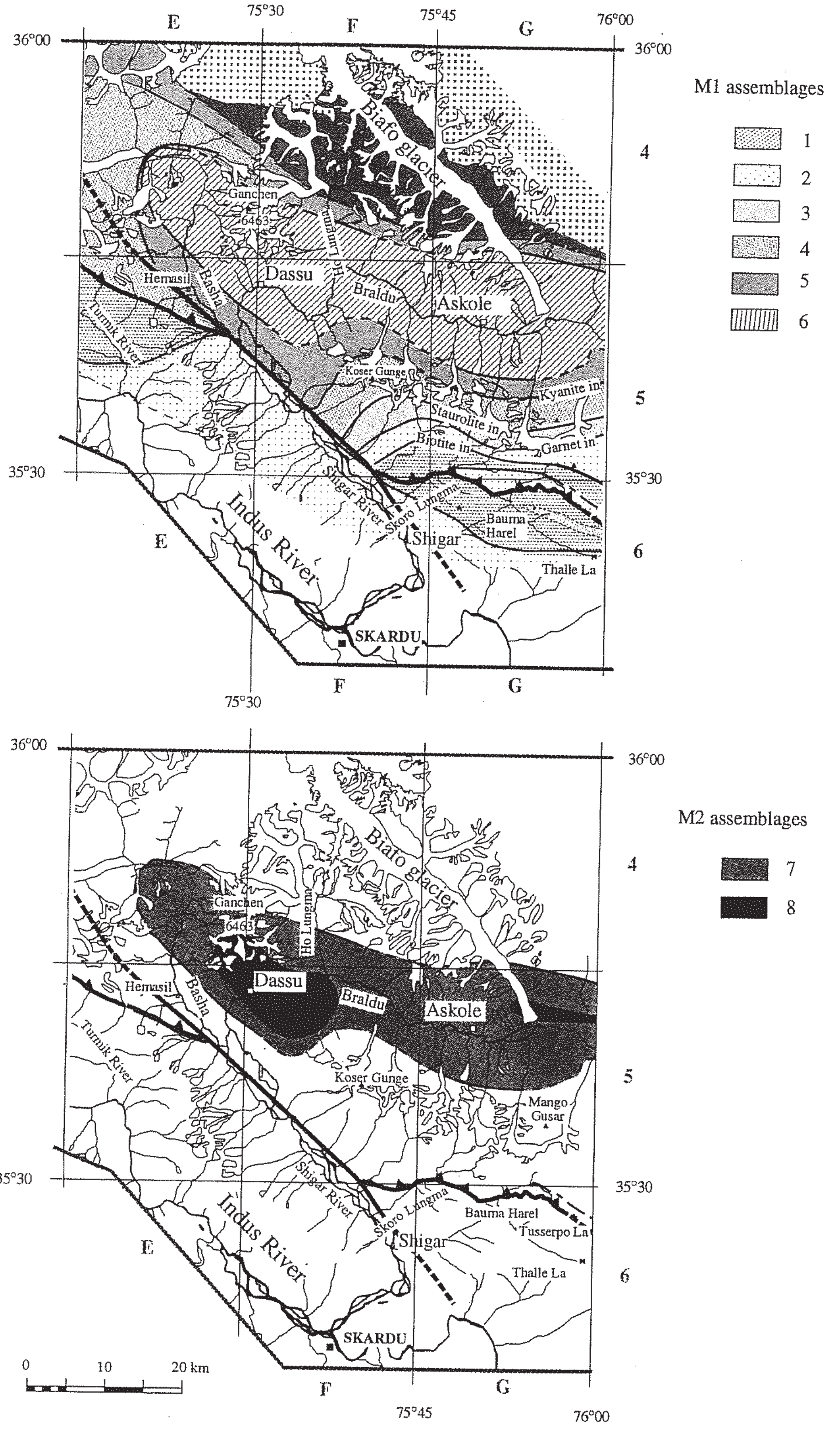
represented by the Hb-Olg-Bi-Ep-Q ± Rt ± Chl ± Czo assemblage in the garnet amphibolites. Baro-thermometric estimates on two samples from Askober (garnet amphibolite) and the lower Turmik valley (epidote amphibolite) yield very different values (Rolfo et al., 1997): 6.2 ± 0.5 kbar and 660 ± 75 °C for a Hb-Pl-Ep-Q-Rt fine grained amphibolite (Turmik), and 10.3 ± 0.4 kbar and 670 °C for a Hb-Pl-Q-Gr-Ep-Bi porphyroblastic amphibolite (Indus).

4. Himalaya

The NPHM has the general shape of a large dome, but, inside the massif, mapping of the foliation pattern outlines several typical second order domal structures; they form the western part of the line of domes that can be traced from the Askole region up to the Karakorum. Two of them, already described by Gansser (1980), and later by Madin et al. (1989), are cut by the Indus valley. The domes deform former isoclinal folds whose relationship with and the metamorphism is not always clear. For example, in the Stak area, biotite and kyanite clearly develop on the axial plane of folds that deform the metamorphic foliation and affect as much the Himalayan gneisses as the Ladakh formations. In a similar way, the Himalayan gneiss is often overprinted by a strong mylonitic fabric with ribbon-quartz, and C/S structures (Fig. 44B), easily recognisable in orthogneiss. At landscape-scale, the mylonitic structure of the gneiss gives a banded appearance to the outcrops (cf. the "Layered Unit" of Butler et al., 1992, in the higher Darchan valley). Towards the border zone, the ductile mylonitic fabric is linked to the ductile shearing, at the time of Kohistan-Ladakh thrusting over the Himalaya, and post-dates magmatic activity in the Arc. The mylonitic fabric is deformed by the syn- to late-metamorphic folds, and the whole is affected by the curving of the domes.

The metamorphism of the Himalayan gneiss is of high grade type, everywhere marked by a relatively strong migmatisation. In the Stak (Shengus) paragneiss, the main metamorphic assemblage, with Q-Pl-FK-Grt-Bi-Ky and/or Sil-Rt, corresponds to a medium to high pressure granulite grade (Wheeler et al., 1995). The presence of kyanite and garnet in equilibrium with K-feldspar suggests a water-free melting (without muscovite), under estimated conditions of T = 850°C and P > 10 kbar (ibid; and Treloar et al., 2000a). In the higher Stak valley, Pognante et al. (1993) give P-T estimates largely spreading between 510 to 750°C and 5 to 13 kbar for Q-Olg-Bi-Mu-Gt-Ky-Rt paragneiss.

The chronology of deformation and metamorphism in the NPHM gneiss is still largely debated. Zircons of the NPH gneisses have yielded ~ 1850 Ma igneous crystallisation ages for the Iskere orthogneisses, and early Palaeozoic metamorphic ages with inherited components around 2500, 1500 and 1000 Ma for the Shengus paragneisses (Zeitler et al., 1989). The metamorphic fabric is considered to be either essentially pre-collision for the core of the massif (Butler et al., 1992; Treloar et al., 1992; Wheeler et al., 1995), or syn-collisional (Chamberlain & Zeitler, 1996). For the latter authors, the post-metamorphic cooling (with retrogradation of the granulite into amphibolite facies, as described by Pognante et al., 1993) would have occurred initially, between 45 and




25 Ma, at a lower rate, later increased from 25 to 16 Ma. They interpret the strong cooling rate as resulting from a tectonic denudation, Kohistan dropping down to the north along normal faults. However, we have not observed a systematic normal fault strike slip downward movement in the late-metamorphic MMT mylonites. On the contrary, the latter have retained evidences of top to the south movement. In addition, $^{40}Ar$-$^{39}Ar$ cooling ages

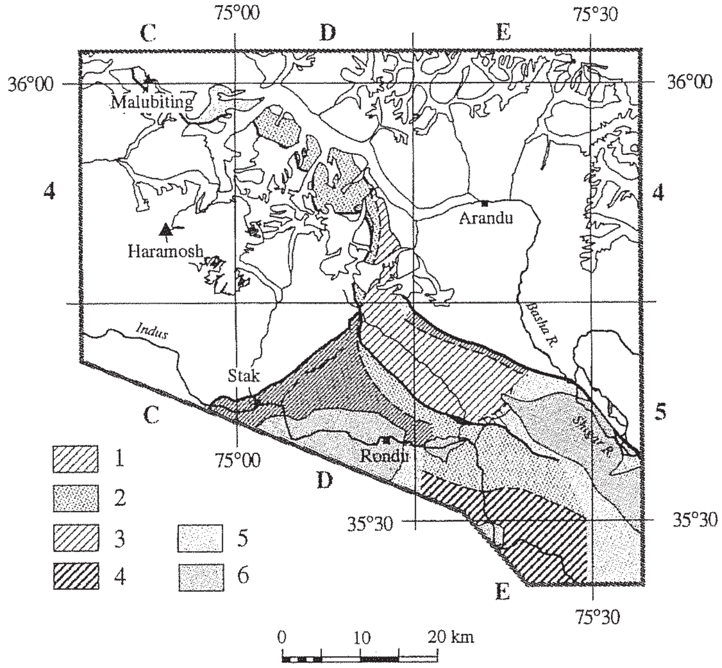



FIG. 43. Metamorphism in the Ladakh formations, South of MKT. Redrawn from Rolfo, 1998. Metamorphic zones defined by the following paragenesis: (1) chlorie - albite - epidote, (2) epidote - hornblende - biotite, (3) garnet - hornblende, (4) garnet – sillimanite, (5) and (6): undifferentiated greenstone rocks and Ladak plutons.

*Métamorphisme dans les formations du Ladakh, au sud du MKT. D'après Rolfo, 1998. Les zones métamorphiques sont définies par les paragénèses à (1) chlorie - albite - épidote, (2) epidote - hornblende - biotite, (3) grenat - hornblende, (4) grenat – sillimanite, (5) et (6): roches vertes et plutons du Ladakh indifférenciés.*

on two muscovites of a mylonitic banded gneiss from the upper Darchan valley (14.6 ± 0.2 et 13.3 ± 0.3 Ma, George and Bartlett, 1996), and the refolding of mylonites by late-metamorphic folds testify of a continued compressive deformation stage.

This debate has been completed by the numerous age dating recently performed on the entire NPHM (Zeitler et al., 1993; Winslow et al., 1996; Treloar et al., 2000a & b; Schneider et al., 1999a & 2001). For Treloar et al. (2000a), essentially using Sm-Nd ages obtained on the mafic dykes that crosscut the granulitic fabric, the main metamorphic imprint of the NPHM would be Meso-Proterozoic, and the Tertiary leucogranites would derive from the in situ anatexis of the granulites. For Schneider et al. (2001), based on numerous U-Pb and Th-Pb measurements obtained on accessory minerals from granites and gneisses, as well as on 125 biotite cooling ages, most of the metamorphism presently visible, the anatexis in particular, would be Tertiary, totally reworking the Proterozoic gneisses, and following three major steps:

- syncollisional metamorphism and anatexis, "typically Himalayan", with production of granite and prograde metamorphism up to garnet at least, between 44 and 36 Ma; "post-Himalayan" cooling down to around 300°C during Oligocene (30-20 Ma) (Zeitler, 1985),
- syn-doming metamorphism, late-Miocene (12-10 Ma), generally in northern NPHM (see infra),
- lower than 5 Ma metamorphism, Pliocene and younger, including granulite, migmatite, and granite formation, with, for the latter, crystallisation ages between 3 and 1 Ma (Tato and Mazeno Pass granites, Zeitler et al., 1993; Schneider et al., 1999a); this Pliocene does not seem to affect the portion of NPHM located north of the Indus (portion corresponding to our

map), but is associated to the "pop-up" extrusion of the southern part of the massif (Nanga Parbat region).

*Structures and metamorphism associated to the Late-Miocene domes*

South-east of Arendu, up to the eastern side of the lower part Biafo glacier, mapping of the foliation trajectories reveals several typical dome shaped structures (Fig. 38), more or less ellipsoidal, in most occurrences with an orthogneiss core (such as the gneissic dome of Dassu, Bertrand et al., 1988). Their length reaches 20 km. They are elongated in an NW-SE (Dassu dome) or E-W direction (Askole dome), or can be circular (Mangol Bluk and Hemasil domes); their sides are steep, their geometry conical, with steeply plunging axes (cf. Lemennicier et al., 1996). In the dome area, one often observes a down plunging stretching lineation (Fig. 39), along which the minerals from the high-temperature peak metamorphism have recrystallised. For instance, in the Arendu region, the almost vertical very strong stretching lineation that gives to the rock the conspicuous "pipe fabric" visible in the landscape, is underlined by sillimanite and biotite overgrowing a kyanite assemblage (cf. Lemennicier et al., 1996). In the Basha valley, the Hemasil dome (Fig. 38) is an important chrono-tectonic marker. In this small body of syenitic rocks, the domal pattern can be seen in the metamorphic fabric of the surrounding metasediments, in the sub-solidus fabric of the external zones of the syenite massif, as well as in the preserved magmatic fabric of the core of the syenite. It implies that dome formation is contemporaneous with syenitic plutonism, which has probably occurred around 9 Ma ($^{40}Ar$-$^{39}Ar$ hornblende age of 7.0 to 7.7 Ma and biotite age around 4 Ma, Villa et al., 1996a).

The same domal structures are found again on the other side of the MKT, where they are partly responsible for the particular pattern of the MMT in the upper valleys of Turmik and Niamur. We have mapped a large domal structure around the Turmik-Indus confluence (Fig. 38); however, none of the four samples of Askor formation from the Indus valley, dated by $^{40}Ar$-$^{39}Ar$ on amphibole (Villa et al., 1996b), have shown any evidence of Miocene metamorphic episode or overprint. Finally, north of the Indus, the NPHM gneisses are also reshaped by several domes that, to the west, about against the Raikot-Sassi fault. In this latter zone, in particular along the Indus section, numerous $^{40}Ar$-$^{39}Ar$ biotite cooling ages have been obtained by Treloar et al. (2000a) and Schneider et al. (2001). Here again, their span, from around 13 Ma to less than 5 Ma, clearly indicates the youthful ending of the tectono-metamorphic evolution.

Altogether, the zone of domal structures forms a remarkable alignment, nearly eastwest, more than 100 km long, very young (10 Ma and less), cutting across the two major contacts (Shyok suture and MMT), deforming the metamorphic structures related to syn- and post-collisional thickening, little or not at all affected by the MKT. The domes have been interpreted to have form by amplification of folds at crustal scale (Pêcher & Le Fort, 1999), in an oblique convergence regime, with a partition of the deformation between two directions of shortening, respectively perpendicular and parallel to the global direction of convergence (Seeber & Pêcher, 1998).

The domes are associated with a high temperature metamorphic resumption, well studied in Karakoram (Lemennicier et al., 1996; Rolland, 2000), and presently well dated from the 17-7 Ma period by many age measurements (see Rolland, 2000, for Karakoram and Ladakh, and Schneider et al., 1999b, for NPHM). In the Askole and Dassu zones, the recent metamorphic isogrades are regularly east-west oriented; they clearly cut across the old NW-SE zonality of the south- Karakoram metamorphic complex, but they closely copy the dome pattern (Fig. 42) underlining the relationship between the formation of the domes and the thermal structure. In the core of the domes, metamorphism reaches a high to very high temperature granulite grade, be it made up of orthogneiss (Dassu), or of sedimentary or volcano-sedimentary formations (Askole). The P-T estimates obtained for the highest grade zones yield 776 ± 10°C and 4.6 ± 1 kbar in the Askole dome, and 735 ± 15°C and 9.2 ± 2 kbar

FIG. 44. The contact between the Himalaya and the Kohistan-Ladakh (the Indus-Tsangpo suture zone, or MMT): **A:** The Sassi-Raikot fault, few kilometers south of its northern tip, on the rough Sassi-Khaltaro road. Left, the Kohistan amphibolites; right, the heterogeneous Himalayan gneiss, which make the western cover of the Iskere orthogneiss; between, a approximatively 20 m thick gouge zone (AP slide **95.7.13**, 8/9/94, 1915 m of elevation, looking N 320° E). **B:** Mylonitized orthogneiss, approximatively 20 m below the Himalaya-Kohistan contact, east side of the Rakhan Gali pass. Himalayan orthogneiss are strongly re-deformed, and acquire at landscape scale a regular "banded" aspect. Top to the south criteria are frequent in those mylonite; sometimes, late top to the north shears (normal fault type movments) can also be observed, as here (AP **96.5.27** slide, 10/7/96, 3855 m, looking West). **C:** Contact of the Ladakh island arc formations (dark-coloured Askor amphibolites to the left) over the Himalayan gneisses (clear-colouredStak-La gneisses to the right), seen from the left bank of the upper Turmik valley. The Stak pass lies just ot the right of the photograph (PLF slide **NR85**, 5/9/91, 3960 m of elevation, 50 mm lens, oriented around N 200° E). **D:** Folds and boudins in the injected Himalayan gneisses just beneath the contact with the Ladakh unit (folds and boudins axes at N80° E, dipping 30° E). Left bank of the upper Turmik valley (PLF slide **NR82**, 4/9/91, 4135 m of elevation, 35 mm lens, oriented N 12° E).

*Le contact entre Himalaya et Kohistan- Ladakh (la zone de suture Indus-Tsangpo, ou MMT):* ***A:*** *La faille de Sassi-Raikot, à quelques km de son extrémité nord, au niveau de la mauvaise piste menant de Sassi à Khaltaro. A gauche, les amphibolites du Kohistan; à droite, les gneiss hétérogènes qui forment la couverture ouest des orthogneiss d'Iskere; entre les deux, une zone de gouge de faille d'environ 20m de puissance (photo AP* ***95.7.13****, 8/9/94, 1915 m d'altitude, vers N 320° E).* ***B:*** *Orthogneiss mylonitisés, environ 20m sous le contact du Kohistan, versant est du col du Rakhan (Rakhan Gali). Les orthogneiss sont ici fortement redéformés, et prennent à l'échelle du paysage un aspect homogène et lité. On observe souvent des cisaillements haut vers le sud, ou plus rarement, comme ici, des petits cisaillements tardifs en faille normale (photo AP* ***96.5.27****, 10/7/96, 3855 m, vers l'Ouest).* ***C:*** *Contact des formations d'arc du Ladakh (à gauche, amphibolites d'Askor de couleur sombre) sur les gneiss de l'Himalaya (à droite, gneiss de couleur claire du Sak La), vu depuis la rive gauche de la haute vallée de Turmik. Le col de Stak est situé juste à droite de la photo (photo PLF* ***NR85****, 5/9/91, 3960 m d'altitude, orientée environ N 200° E).* ***D:*** *Plis et boudins dans les gneiss himalayens injectés de granite, juste en dessous du contact avec les unités du Ladakh (plis et axes de boudins à N 80° E, plongeant 30° E). Rive gauche de la haute vallée de Turmik (photo PLF* ***NR82****, 4/9/91, 4135 m of d'altitude, vers N 12° E).*

at the core of the Dassu dome. The peak of syn-domal metamorphism is dated at Dassu by a 6.7 ± 0.5 Ma monazite U-Pb age in the surrounding sillimanite-bearing schists (Smith & al., 1992, Smith, 1993). Rolland (2000), drawing on the mantle isotopic signature obtained for the Hemasil syenite (Lemennicier, 1996) and the Baltoro granite (Searle et al., 1992), on the younging of ages from north to south, as well as on the gravimetric anomaly maps (Caporali, 1995, 2000), suggests that the thermal anomaly is of mantle origin, and likely to be linked to the breaking and southward backward movement of the Indian lithosphere.

It can also be noticed that outside the domes zones, the dome formation period corresponds to some leucogranite crystallization, for instance the Sumayar pluton (Fraser et al., 1998).

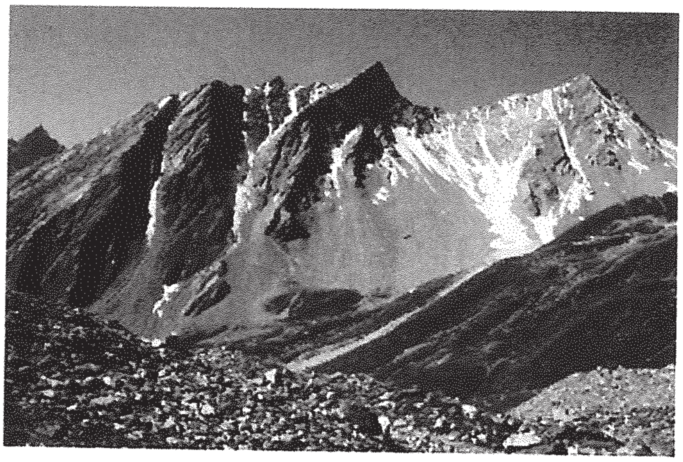
## The Two Major Contacts

### *The Arc-Karakoram contact*

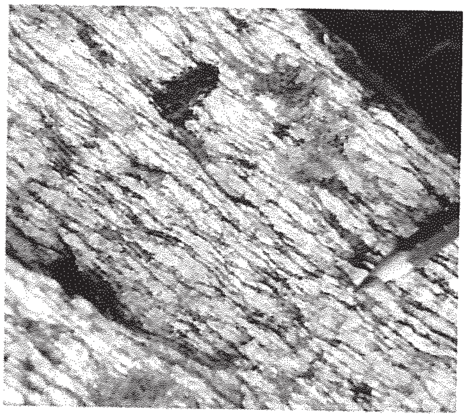
This contact, sometimes named the Northern Megashear (Tahirkheli & Jan, 1979) or the Main Karakoram Thrust (MKT), corresponds to the reactivation of the Shyok suture by the MKT (Bard et al., 1980). It is marked by sporadic pods of serpentinite.

We have mapped the MKT from Chalt to the Shigar valley (the two zones where it had already been recognised), and then up to Bauma Harel. Between Chalt (Hunza valley) and Tisar (Shigar valley), its rectilinear pattern, slightly bent in the Niamur region, strongly contrasts with the NPHM contact. Actually, map and field data show that the contact is not a thrust but a steep to vertical brittle fault cross cutting at low-angle the earlier syn-metamorphic deformation pattern, as well as, to a certain extent, the latest metamorphic fabric. We would rather refer to it as the South Karakoram Fault (SKF). East of the Shigar valley, from Hushupa up to the Thalle valley, east of the map, the MKT effectively presents several overthrusting contacts, again underlined by lenses of serpentinite; there, it slices the old Shyok suture, making sigmoid scales out of it.

A 95.7.13



C NR85



B 96.5.27

D NR82

The MKT reworks the original northern suture zone (Shyok zone), the trace of which is poorly distinguishable, as it has been deformed with the south Karakoram margin during the main pre-domal tectono-metamorphic episodes. For instance, in the upper Niamur valley, one can observe kilometre-scale folds of the contact between the greenschists from Ladakh and limestones from the Karakoram. Similarly, a narrow band of polygenic conglomerate and greenschist stretches across most of the map to the north of the SKF, locally oblique to the structural trend (Le Fort & Pêcher, 1995). These rocks probably represent synclinal inliers of arc material folded within the Karakoram metamorphic complex.

Finally, at map scale as on satellite imagery, the MKT in turn seems to be shifted by a right lateral strike slip fault at the level of the Shigar valley, that could correspond to a small very young basin, partly Quaternary. This Shigar fault, named as "Shigar line" by Casnedi (1976), could extend northward to the west of the Hemasil dome and would be responsible of the Chogo Lungma orientation in its Niamur-Khurumal stretch. Two similar faults probably exist more to the east, one along the Hoh Lungma (?), the other one along the Biafo glacier. Although these faults would correspond to very conspicuous lineaments on the images, we have not been able to evidence them doubtlessly in the field; this is why we have not reported them on the map, but the Shigar fault is indicated on Figure 42.

*The contact of the Himalaya with the Kohistan-Ladakh Arc*

This contact, sometimes, named Main Mantle Thrust (MMT, Tahirkheli et al., 1979) corresponds to the Indus-Tsangpo suture zone. It is generally marked by a strong contrast of lithology, between the dioritic arc formations and the aluminous Himalayan gneiss, although here it is not identified by glaucophane and serpentinite bearing lenticular bodies, as it is further southwest and south-east of the NPHM. Its characteristics vary considerably from one side to the other of the NPHM.

On the western side, the Himalaya - Kohistan contact is a reverse fault, almost vertical in its northern part, overthrusting to the east more to the south: the Raikot fault, also known as the Liachar thrust in the south-west (Lawrence & Ghauri, 1983; Butler & Prior, 1988; Madin et al., 1989). However, this brittle deformation is superimposed on older ductile structures: mylonitic fabric, as in the lower Astor and Raikot valleys and in the Darchan valley, or previous syn-metamorphic isoclinal folds, as along the Indus, south of Sassi. Actually, the trace of the fault is not always simple, and slices of Kohistan terrain appear within the Himalayan gneiss (Indus road, south of Sassi). North of the Indus, the contact is relatively simple, and corresponds to a major fault, dipping around 70°E, with a 2 to 3 m thick gouge zone (Fig. 44A). More to the north, this fault dies out in the upper Darchan valley and does not cut across the narrow strip of Greenstone complex that joins Kohistan with Ladakh. The activity of the Raikot fault, cutting through Quaternary deposits at Raikot itself (south of the map), is also recorded by $^{40}Ar$-$^{39}Ar$ and fission-track cooling ages which show that the Nanga-Parbat gneisses have undergone a rapid denudation history during the past 10 Ma (Zeitler, 1985; Zeitler et al., 1989; Treloar et al., 1991, 2000a; Schneider et al., 1999a & 1999c).

North of Darchan, the old Arc-Himalaya contact is still well preserved. There is no such tectonic slicing as shown by Butler et al. (1992, figure 2), but instead, above the contact, hectometre- to decametre-scale isoclinal folds, folding the Kohistan dolomitic limestone (south of the trail to the Rakhan Gali pass or in the higher reaches of the crest edging the left bank of the eastern Dobani glacier), or, beneath the contact, blastomylonites with C-S almonds (Fig. 44B) indicating le left-lateral shearing (that is top to the south, once the verticalisation linked to the doming is tilted back).

To the east, the Himalaya – Ladakh contact is well exposed in the Turmik valley (Figs. 44C and D). It is marked by a ductile shear zone with right-lateral strike-slip movement, indicated by rotation at map scale of the syn-metamorphic structures (Pognante et al., 1993). This shear-zone is superimposed by pervasive crenulation folds that indicate a similar right-lateral movement (Arc formations to-the-south), accompanied by retrogressive metamorphism (Pêcher & Le Fort, 1999). The shear-zone vanishes in the NW-SE Greenstone complex strip. More to the south, where it crosses the Indus, the Himalaya - Ladakh contact is difficult to locate accurately. There, Treloar et al. (1992) have already described interleaving units derived from the Kohistan and Indian formations. On a section of more than 6 km west of the Askor valley, numerous folds (cf Fig. 39, diagram 13) at various scale lead to the intrication of amphibolitic Arc-looking and granitic Himalaya-looking formations, sometimes blastomylonitic. Lenticular bodies of serpentinised peridotites and garnet-bearing pyroxenites, retrogressed from eclogitic facies, have also been found in the Arc-type material; the pressure-temperature evaluation (13 ± 1 kbar, 610 ± 30 °C) is typical of low- to intermediate-temperature eclogites (Le Fort et al., 1997). In addition, the entire zone has been reworked by numerous brittle faults having limited displacements, mapped by Verplank (1986).

On the northern side, the relief opposition between the elevated Haramosh spur, with its high-grade metamorphic rocks, and the lower and less metamorphosed domain north of it, suggests a normal fault boundary between the two. However, along the south bank of the Chogo Lungma glacier, most of the local syn-metamorphic rotational deformation criteria indicate north-to-the-top (or top-to-the-south) sense of motion. In some places, normal and reverse senses of shearing are both present, indicating a predominance of flattening (pure shear) on shearing. But nowhere has clear field evidence of relative descent of the northern compartment been found.

Locally, in the Remendok valley, the northern contact of the NPHM is cut across by a slightly deformed leucotrondhjemitic body. The muscovite-bearing leucotrondhjemite, about one kilometre wide, intrudes both the Arc and the Himalayan units, with cross-cutting aplo-pematitic dykes reaching several hundred of metres out of the pluton. Dating of one muscovite by $^{40}Ar$-$^{39}Ar$ (Villa et al., 1996a) has yielded an age of $8.37 \pm 0.07$ that represents a lower limit to the thrusting movement along the northern side of the Himalaya.

Altogether, the continuity and similarity of the fabric from the South Karakoram metamorphic complex to the northern part of the Himalayan gneisses, suggest that the major structural and metamorphic imprint observable in Himalaya, results from the same tectonic evolution visible in Karakoram, rather than from an older tectonic evolution, whose existence yet appears here and there. In the MMT zone, the interleaving of rocks of different origin would be due to south vergent syn-metamorphic refolding of the former mylonitic contact, rather than to syn-suture tectonic scales. This hypothesis, however, remains to be confirmed by a more detailed mapping of the zone.

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