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55

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Structure and metamorphism of the Karakorum gneisses in the Braldu-Baltoro Valley (North Pakistan)

Structure et métamorphisme des gneiss du Karakorum dans la vallée de la rivière Braldu et du glacier du Baltoro (Nord Pakistan)

by Jean-Michel BERTRAND*, Jean-Robert KIENAST** and Jean-Luc PINARDON**

ABSTRACT. — The Karakorum gneisses outcrop north of the complex suture separating the Indian-Pakistan plate from the Europe-Asia block; they grade to deformed earlier members of the Karakorum batholith ranging in age from Cretaceous to Miocene and are cross-cut by its later members. The main interest of the region lies in the fact that very young high-grade gneisses (Miocene), outline the southern edge of the Europe-Asia Plate. The tectonic and metamorpic evolution of the Braldu-Baltoro region is interpreted here as resulting from a polyphased history. The following structural sequence has been defined : - (1) A D1 isoclinal folding was accompanied by subparallel healed shear zones and by intense boudinage, and cross-cut by a dense net of post-D1 heterogeneous leucogranitic veins and stocks; - (2) a major phase of EW trending recumbent folds (D2), is followed by (3) large open D3 folds generating EW trending domal structures (Dassu and Panmah domes); and (4) a late set of brittle to locally more ductile structures such as the southern thrust contact of the Karakorum gneisses with the Shyok suture zone. The sequence proposed here differs from other interpretations (Rex et al. 1988). We consider that the D1 event only may be attributed to the main India-Asia collision and that the D2-D3 events, interpreted as having occurred in a continuum, correspond to a late reactivation of the major thrusts and sutures related to continuing continental subduction.

A D1-related intermediate pressure assemblage is preserved (Grt-St-Ky) in the upper levels of the tectonic pile; the estimated PT conditions determined are 10-4 Kb and 700°-525°C. In the core of the large D3 domes, late granoblastic recrystallization is widespread together with almost complete S1-S2 transposition, incipient melting and development of a low-pressure sillimanite-bearing assemblage where relicts of higher pressure minerals are locally preserved. Corresponding PT conditions are 650°-550°C and a lower pressure (5.5 to 2.5 Kb). As most of the observed structures at the lower levels (mineral lineations, boudinage) are clearly associated with (or reworked by) D2 and accentuated by D3 which was accompagnied by partial melting, D2 and D3 are interpreted as representing a continuum developed in the same PT field. It can be assumed also that the Baltoro granite was emplaced by the end of this combined D2-D3 event. From the Miocene ages published for the Baltoro granite (20 Ma to 8 Ma), the low-pressure evolution of the Karakorum gneisses may represent a very young high-grade assemblage. The age of D1 is less defined but at least older than 36 Ma old leucogranites.

The sharp contact along the Shyok Suture zone, interpreted as a large thrust (Main Karakorum Thrust = MKT) of this young high-grade metamorphic terrane against the older (older than 30-45 Ma from late undeformed intrusives) Kohistan-Ladakh island-arc domain, is interpreted, following Mattauer (1985), as resulting from the interaction between the still-ongoing northward movement of the Indo-Pakistan plate and an opposite southward continental subduction, seismically active, operating in Pamir.

Key-Words : Himalayan belt. Miocene metamorphism. Polyphase metamorphism. Collision tectonics.

RÉSUMÉ. — Le Karakorum forme l'extrême sud de la plaque Eurasiatique au niveau de la grande virgation de l'Himalaya occidental. Il est constitué de matériel d'origine Gondwanienne accrété à l'Eurasie au cours du Mésozoique. Lors de la collision avec la plaque Indo-Pakistanaise, le Karakorum occupe une situation du même type que celle du sud du Tibet à ceci prés qu'ici, entre les deux plaques, un grand domaine d'arc insulaire (Kohistan et Ladakh), a été impliqué dans une évolution géodynamique et tectonique complexe. Du fait de l'existence de cet arc, la collision s'est produite en deux temps, entrainant la formation de deux sutures distinctes, celle du nord- suture de Shyok -fermée entre 90 et 75 Ma et celle du sud- Main Mantle Thrust -fermée entre 54 et 45 Ma.

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La particularité et l'intérêt du Karakorum, particulièrement dans les vallées de Hunza et de la Braldu-Baltoro, est de présenter, outre un batholite composite mis en place par intrusions successives entre le Crétacé et le Miocène, une zone étroite formée de gneiss de haut degré, les gneiss du Karakorum. Ce domaine gneissique est limité au sud par la Suture de Shyok et au nord par le batholite; il passe rapidement vers l'ouest et vers l'est à des formations paléozoiques et mésozoiques de bas degré.

Les âges très jeunes (Miocène), déterminés dans cette région (Debon *et al.*, 1986) et les taux de surrection très rapides (Zeitler, 1985), impliquent une histoire tectonique et métamorphique très différente de celle décrite classiquement en Himalaya. En particulier, les structures les plus récentes correspondent à des dômes, allongés subparallèlement à la zone de Shyok, exposant des assemblages à sillimanite + orthose dont les âges de refroidissement sont de l'ordre, voire inférieurs à 8 Ma.

L'évolution tectonique et métamorphique de la région du Baltoro est polyphasée. La séquence structurale suivante a été définie : (1) une phase de plissement isoclinal D1 est accompagnée de cisaillements subparallèles recristallisés et par un boudinage intense; ces plis sont recoupés par un réseau dense de veines et de stocks leucogranitiques hétérogènes; - (2) une phase majeure de plis déversés à couchés d'axes EW (D2) est suivie par - (3) de grands plis ouverts D3 formant des structures en dôme d'axe EW (dômes de Dassu et de Panmah); - (4) un ensemble tardif de structures cassantes, localement plus ductiles, comme le contact anormal sud des gneiss du Karakorum sur la zone de suture de Shyok. La différence avec l'interprétation proposée par le groupe de Leicester réside dans le fait que nous considérons que seul l'événement D1 peut être attribué à la collision principale; par contre D2 et D3 représentent un continuum et leur origine doit être recherchée dans une réactivation récente (Miocène) des grands contacts anormaux et des sutures, à la faveur de la subduction continentale ayant fonctionné après la collision (encore active ?).

Cette note décrit un type de zonation tectonique et métamorphique particulier, bien exposé en 3D sur des coupes verticales exceptionnelles; cette zonation constitue l'argument principal à l'appui du caractère polyphasé de l'évolution tectono-métamorphique. En effet, les associations métamorphiques de pression intermédiaire (Grt-Disth-St), attribuées à l'événement D1, sont uniquement conservés au sommet de la pile tectonique où les conditions PT sont estimées à 10-4 Kb et 700-525°C. Par contre, au cœur des grands dômes D3, une recristallisation tardive granoblastique accompagne un début de fusion et le développement d'associations métamorphiques de basse pression à sillimanite où, toutefois, des reliques de minéraux de plus haute pression sont préservées localement. Les conditions PT correspondantes ont été estimées à 5,5-2,5 Kb et 650-550°C. Puisque la plupart des structures observées dans les niveaux les plus profonds (linéations minérales, boudinage) sont associées à (ou réactivées par) D2 ou accentuées par D3 et accompagnées de fusion partielle, D2 et D3 sont interprétés comme représentant une évolution continue dans le même champ PT. De même, le granite du Baltoro s'est mis en place vers la fin de cet événement D2-D3. L'événement tardif de basse pression observé dans les gneiss du Karakorum représente une association de haut degré de métamorphisme très jeune, d'aprés les âges Miocène publiés pour le granite du Baltoro (20 à 8 Ma). L'âge de l'événement D1 est moins bien défini mais antérieur à la mise en place de leucogranites datés à 36 Ma.

Le contact brutal, le long de la zone de suture de Shyok, entre le domaine Karakorum à métamorphisme très jeune et le domaine Kohistan-Ladhak où le métamorphisme est au moins âgé de 30-45 Ma, est interprété comme résultant d'un charriage très récent reprenant approximativement la zone de suture (Main Karakorum Thrust). Ce charriage est interprété, à la suite de Mattauer (1985) comme une conséquence de l'interaction entre le déplacement vers le nord de la plaque Indo-Pakistanaise, toujours actif après la collision, et d'une subduction continentale de sens inverse, sismiquement active, fonctionnant au Pamir.

Mots-clés : Chaîne Himalayenne. Métamorphisme Miocène. Métamorphisme polyphasé. Colllison.

I. — INTRODUCTION

In Northern Pakistan, the Karakorum mountain range is situated to the north of the complex suture zone separating the Indian Plate from the Asian plate (Figure 1, insert). Two distinct sutures have been defined in this region : (1) the southernmost suture, « Main Mantle Thrust = MMT » (Tahirkheli, 1979), which separates the India-Pakistan plate, represented in the studied area by the Nanga Parbat - Haramosh gneisses, from a Mesozoic to Eocene island arc (Kohistan - Ladakh); (2) a northern suture, the « Shyok Suture Zone = SSZ » which corresponds along most of its length to a major thrust zone, the « Main Karakorum Thrust = MKT » (Tahirkheli, 1979, 1982; Pudsey, 1986; Mattauer, 1985), and which separates the Kohistan - Ladakh island arc domain to the south from the Karakorum terrane to the north. The Karakorum terrane shows Gondwanian affinities (Marcoux *et al.*, 1982) and was accreted to Asia before Cretaceous times; it comprises both low-grade and high-grade formations, and is intruded by a large composite batholith (Karakorum Batholith) emplaced in successive pulses since Cretaceous times (Petterson & Windley, 1985; Debon *et al.*, 1987). Interpretations differ about the relative chronology of the closure of the two sutures. Most authors consider the northern « Shyok Suture Zone » as the older suture, closed between Cenomanian and Eocene (Coward *et al.*, 1986, Petterson & Windley, 1985, Tahirkheli, 1982, Debon *et al.*, 1987) while others (Tahirkheli, 1979; Bard, 1983; Brookfield & Reynolds, 1981; Andrews-Speed & Brookfield, 1982) contend that the island arc was obducted earlier onto the Indian crust or have discussed the possibility for a more recent closure of the Shyok Suture Zone (Malinconico, 1986).

The Karakorum gneisses and associated orthogneisses derived from the deformation of early members of the Karakorum batholith, outcrop just north of the Main Karakorum Thrust. They are limited to the north by the Karakorum composite batholith. To the west, they are believed to grade into the low-grade Darkot group of Upper Paleozoic age (Ivanac *et al.*, 1986). To the east (Masherbrum area and Hushe Valley), metamorphic grade decreases gradually (Rex *et al.*, 1988). It is not clear whether they correspond, on the other side of the Karakorum Fault, to the south Tibet domain or not (discussion in Srimal, 1986).

The Braldu Valley shows a good section of the Karakorum gneisses; preliminary results have been previously presented (Bertrand & Debon, 1986). As recent geochronological data indicate young ages up to Upper Miocene for the emplacement and cooling of the Baltoro pluton (Debon *et al.*, 1986; Rex *et al.*, 1988), improved

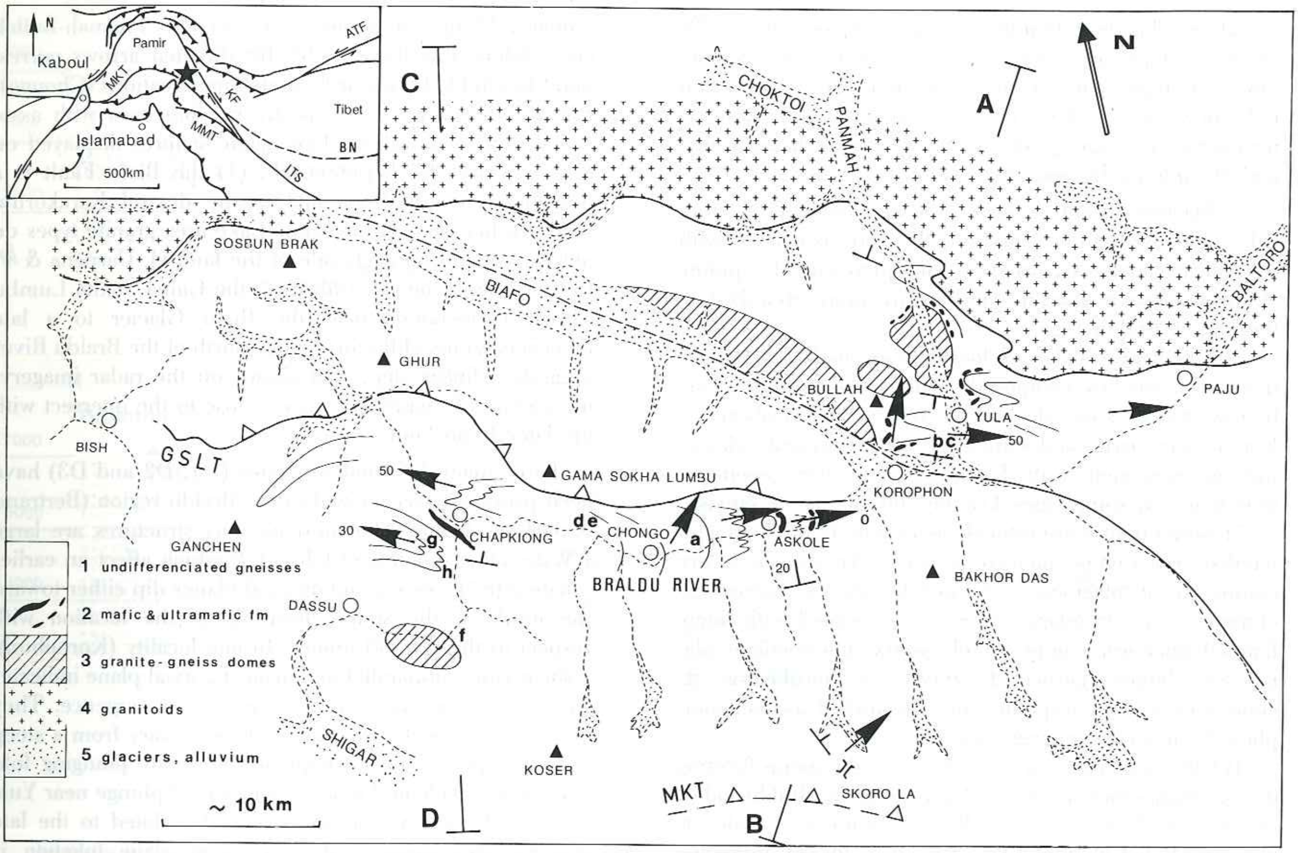

FIG. 1. — **Sketch structural map of the Braldu valley.**
The insert shows the location of the area studied (star) to the West of the Himalayas and Tibet. MKT : Main Karakorum thrust; MMT : Main Mantle thrust; ITS : Indus Tsangpo suture; BN : Bangong-Niujang suture; ATF : Altyn Tagh fault; KF : Karakorum fault. The map is drawn from radar imagery SIR-A (32-33). The Biafo fault, the MKT (approximate location) and the Gama Sokha Lumbu thrust (GSLT) are indicated in bold. Major summits are shown with triangles. The average foliation, which corresponds either to Sl or S2 or S2-S3 in different places, dips toward NE- Large F2 folds are symbolized by structural lines. Arrows correspond to fold axe plunges an/or to mineral lineations (rare streching lineations). Cross-sections of Fig.2 are indicated AB and CD; analyzed samples are shown in bold letters : a= BK79; b =BK155; c= Bb24; d= BK70; e =BK71; f =BK3; g= BK35; h =BK50.

FIG. 1. — ***Carte structurale schématique de la vallée de la Braldu.***
Le cartouche indique la localisation de la région étudiée (étoile) à l'ouest de l'ensemble Himalaya-Tibet; MKT : grand chevauchement du Karakorum; MMT : grand chevauchement « du manteau »; ITS : suture de l'Indus-Tsangpo; BN : suture de Bangong-Niujang; ATF : faille de l'Altyn Tagh; KF : faille du Karakorum. Sur la carte, dessinée d'après la photo radar (SIR-A, 32-33), la faille du Biafo est indiquée en traits gras et les chevauchements du MKT (localisation approximative) et de Gama Sokha Lumbu (GLST) sont agrémentés de triangles vides. Les principaux sommets sont indiquées par des triangles pleins. La foliation moyenne, qui correspond selon les endroits à S1, S2 ou S2-S3 est à pendage Nord-Est; les lignes structurales indiquées symbolisent les grands plis F2. Les flèches correspondent aux axes de plis et/ou à des linéations minérales (localement d'étirement). Les coupes de la figure 2 sont indiquées AB et CD. les échantillons analysés sont localisés en caractères gras : a = BK79; b = BK155; c = Bb24; d = BK70; e = BK71; f = BK3; g = BK35; h = BK50.

understanding of the structural evolution and thermal behavior of the Karakorum gneisses was an exciting target. New results presented here deal with the tectonic and metamorphic evolution of the gneisses south of the Baltoro Granite, as determined from structural observations and sampling in the lower Braldu Valley and in two north-south tributaries (Hoh Lunghma and Panmah Valleys).

II. — ROCK TYPES

Within the Karakorum gneisses, three formations have been previously distinguished by Desio (1964) and Desio & Zanettin (1970) : the Dassu Gneisses, the Ganchen Formation and the Dumordo Formation. From our observations, this three-fold distinction is very doubtful as the same rock types are known in all three units. For example, key rock types such as the mafic-ultramafic association have been observed in both the Ganchen and Dumordo formations. Five groups of rock types may be distinguished and are intimately associated in the field :

1) Marbles usually contain subordinated quartz, diopside, phlogopite and corundum; they are associated with calc-silicate gneisses (garnet + clinopyroxene + epidote + plagioclase +quartz). Marbles are more abundant in the Upper Braldu region.

2) Metapelitic rocks are locally associated with impure quartzites; they are composed of quartz, sodic plagioclase, biotite, garnet and Al-silicates. When the Al-silicate is kyanite, muscovite and staurolite may be present; sillimanite is associated with K-feldspar and late secondary muscovite. In some cases kyanite and sillimanite cœxist.

3) Amphibolites are intimely associated in the field with banded calcareous metagreywackes. Amphibolites are composed of plagioclase + hornblende + garnet ± clinopyroxene ± quartz. They are associated with finely banded gneisses, composed of quartz, intermediate plagioclase, biotite, garnet ± zoisite ± hornblende ± clinopyroxene ± scapolite and interpreted as metamorphosed calcareous metagreywackes.

4) Ultramafic rocks occur as lenses and boudins forming discontinuous trails in many places along the Braldu Valley (Figure 1). They are generally serpentinites ± talc ± chlorite. Relict textures are rare but altered pyroxene cumulate textures (2 to 5 cm) occur near Chapkiong. These ultramafic rocks have already been described from the Panmah Valley by Searle *et al.* (1986).

5) Orthogneisses, leucocratic gneisses and leucogranites form locally large units. Their relative chronology and setting will be discussed later. Granodioritic and quartz-dioritic orthogneisses are always strongly deformed and recrystallized. Leucogranitic and aplo-pegmatitic bodies and dykes are either foliated or unfoliated; large units of leucocratic gneisses (for example above Chapkiong), with sillimanite nodules, may represent either deformed granitic or migmatitic bodies or metasedimentary rocks.

III. — TECTONOMETAMORPHIC EVOLUTION

A. Tectonic setting

The sketch map of the Figure 1 is based upon detailed sections and landscape observations; corresponding interpretative cross-sections are given on Figure 2. The map shows the main E-W trend of major folds with varying axial plunges. Elongated domes in Dassu and Panmah-Bullah areas follow this trend. N20°-40° directed arrows correspond to refolded folds or to stretching lineations (Chongo); EW trending arrows are mostly F2 fold axes with associated mineral lineation. Two major features displayed on this map are still hypothetical : (1) the Biafo Fault is a dextral wrench fault parallel to the dextral Karakorum Fault further east; in the Snow Lake area granite types do not correspond on each side of the fault (J. Carpena & P. Le Fort, pers. comm., 1986); (2) the Gama Sokha Lumbu Thrust corresponds near the Biafo Glacier to a late brecciated zone; cliff morphology north of the Braldu River suggests a linear step, well shown on the radar imagery; the section of Figure 2 is drawn close to the intersect with the later Biafo fault.

Three main deformation events (D1, D2 and D3) have been previously recognized in the Braldu region (Bertrand & Debon, 1986). The most obvious structures are large EW trending recumbent folds (F2) which affect an earlier foliation (S1); corresponding axial planes dip either toward the north or the south according to the location with respect to the late D3 domes. In one locality (Korophon), a shear zone subparallel to a major F2 axial plane indicates from mesostructural criteria a southward vergence. They are not cylindrical structures. Fold axes vary from a steep westward plunge near Chapkiong to gently plunging fold axes near Askole and to a steep eastward plunge near Yula (Figure 3); such variation is probably related to the late doming. Development of a S2 axial plane foliation is restricted to some lithologies and to the lowest levels of the section; the fold shape may vary from large open folds (near Chongo, with a near vertical plunging axe) to tight isoclinal folding with horizontal axes between Askole and the Biafo Glacier.

The non-cylindrical D2 structures are wrapped around large-scale east-west elongated D3 dome structures, the known culminations of which correspond to the Dassu granite-gneisses and migmatites and to the granite-gneiss occurring in the middle part of the Panmah Valley. Deeper levels of the same D3 dome outcrop on the northern edge of the Biafo glacier (D. Prior. pers. comm.).

The major D1 event which occurred prior to the large-scale D2 recumbent folds is characterized by a well-defined S1 foliation but, except in the uppermost tectonic level, most of the metamorphic assemblages appear as late-kinematic granoblastic textures related to D2 or D3. S1 is a compositional layering, obviously tectonic in origin as evidenced by relict isoclinal folds, deformed migmatitic mobilisates, healed pre-D2 shear zones, boudinage and superimposition patterns (Figure 4, BCE). Isoclinal folds and associated boudins parallel to the fold axes (Figure 4E) formed during the D1 event have an average N20°-40° trend; L1 mineral (quartz, biotite) or stretching lineations and fold axes are rarely preserved.

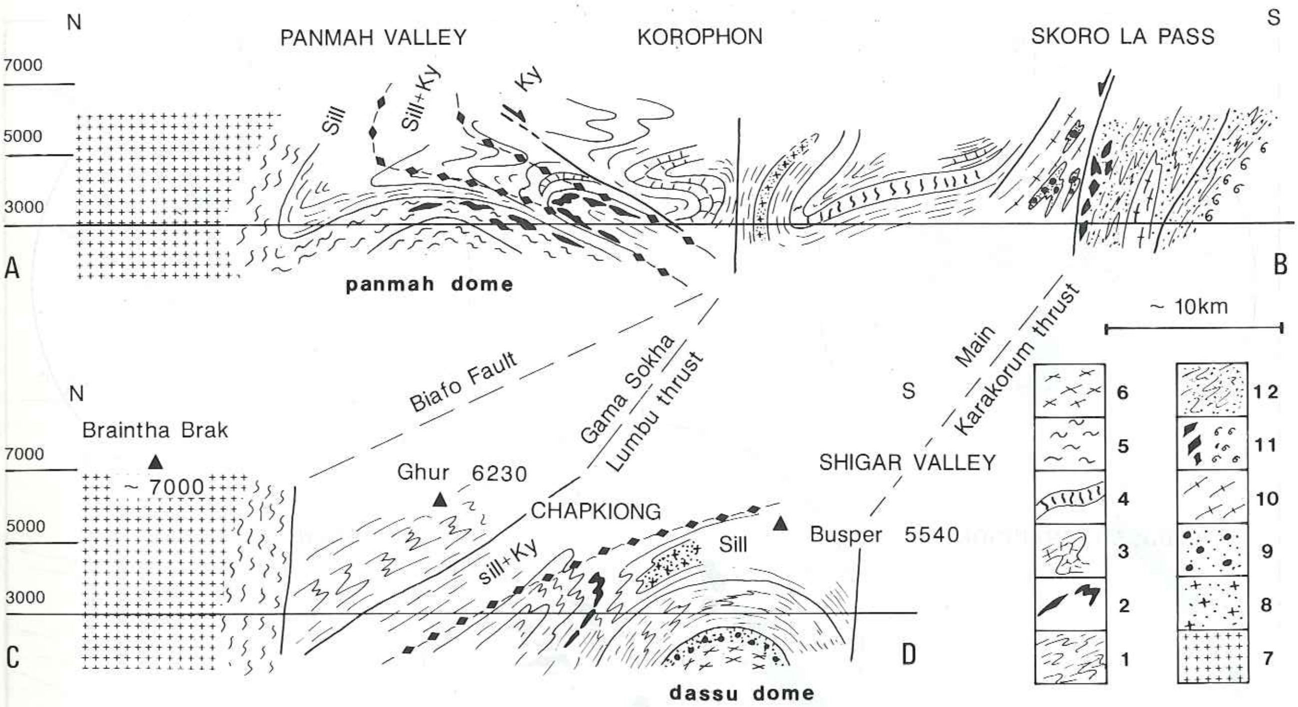

FIG. 2. — **Interpretative cross-sections**

Vertical scale is x 2 (see Fig. 1 for location of the sections). Assumed location of the limits of metamorphic zones are indicated. 1) undifferenciated gneisses; 2) ultramafic rocks; 3) marbles; 4) gneisses invaded by aplites and pegmatites; 5) migmatites and « High ductility zone »; 6) Dassu granite; 7) Baltoro granite; 8) leucogranites and leucocratic gneisses; 9) stocks of aplites and pegmatites; 10) granodioritic orthogneisses; 11) tectonic melange and serpentinites of the Shyok zone; 12) low-grade metasediments of the Shyok zone.

A-B Section : Panmah-Skoro La. The Main Karakorum Thrust (MKT) is outlined here by a thin leucocratic, garnet-bearing, mylonite separating the orthogneisses from a tectonic « melange » containing mafic and ultramafic blocks; the sense of shear is deduced from the rotation of clasts.

C-D Section : Biafo-Shigar Valley. The core of the Dassu dome is formed by a foliated leucocratic augen granite with an aplo-pegmatitic rim; the outer part, where S1-S2 transposition is complete, is formed by banded gneisses and augen migmatites (Dassu).

FIG. 2. — ***Coupes interprétatives.***

Les coupes AB et CD sont localisées sur la figure 1. L'échelle verticale est double de l'échelle horizontale. La localisation approximative des zones métamorphiques est indiquée par des losanges pleins. 1) gneiss indifférenciés; 2) roches ultrabasiques; 3) marbres; 4) gneiss envahis de filons aplo-pegmatitiques (« persillé ») de la vallée de Skoro La; 5) migmatites et zone ultraductile; 6) granite de Dassu; 7) granite du Baltoro; 8) leucogranites et gneiss leucocrates; 9) aplites et pegmatites en amas; celles de Skoro La sont déformées; 10) orthogneiss granodioritiques; 11) mélange tectonique et serpentinites de la zone de Shyok; 12) métasédiments peu métamorphiques (zone de Shyok).

Coupe A-B. Le dome de Panmah est surmonté par les migmatites de la « zone ultraductile » avec ses boudins ultrabasiques réorientés et recristallisés. La zone de cisaillement du grand pli couché de Korophon est tardi-D2- Le mouvement apparent est vers le Sud; ce n'est pas une structure d'extension mais plutôt un chevauchement basculé lors de la formation du dôme de Panmah - ce chevauchement corespond peut-être au chevauchement du Gama Sokha Lumbu. Il existe une discontinuité structurale majeure au niveau de la faille du Biafo. Au Sud de cette faille, la lame granitique de Bakhor Das (granite daté à 36 Ma) est interprétée comme anté-D2- Les failles du secteur du col de Skoro La sont tardives et rétromorphiques; la direction de mouvement correspondante est déterminée d'aprés la rotation des clastes dans les mylonites associées au contact principal du MKT.

Coupe C-D. Deux grands plis couchés d'axe E-W, attribués à l'événement D2, sont accompagnés d'une transposition S1-S2 très avancée. Le cœur du dôme est occupé par un granite orienté, coiffé par un complexe aplo-pegmatitique à structure en « peigne ».

Except perhaps for the existence of rare pre-D2 healed small-scale shear-zones, there is no clear evidence of a simple shear regime during D1 : the parallelism of the boudins with the fold axes suggest that F1 folds are « b » folds. Different types of leucocratic intrusions, cross-cut the S1 foliation and are deformed during the D2 event; they confirm the individuality of this D1 event.

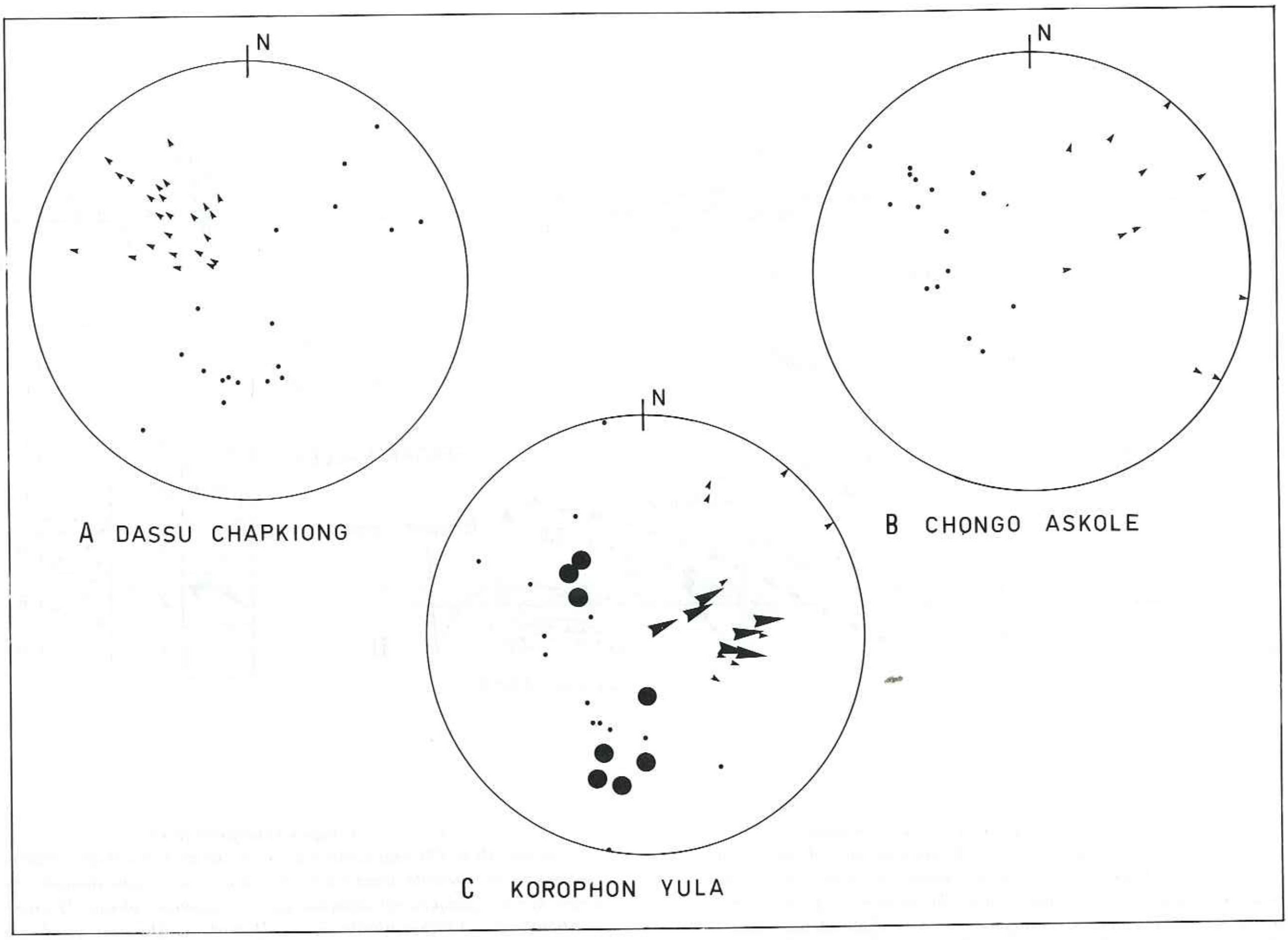

Fig. 3. — **Stereograms of structural measurements (Schmidt, lower hemisphere).**

A) Dassu-Chapkiong : Zones (B) and (C), Sillimanite; all mineral lineations and fold axis are grouped and plunge toward the NW, often steeply.- B) Chongo-Askole: Zone (B), Sillimanite-Kyanite; NE trending lineation corresponds to D1, EW are F2 foldaxis; average foliation (S1) is toward East. - C) Korophon-Yula : Zone (A) : some relict F1 isoclinal folds trend to the NE (Figure 5E) but most of the folds and mineral lineations show an eastward plunge. Larger points and arrows correspond to data along the Yula bridge section : they show that the foliation is S1 refolded by F2.

Fig. 3. — ***Stéréogrammes de mesures structurales (diagramme de Schmidt, hémisphère inférieur).***

Les points représentent les pôles de foliation; les flèches représentent les linéations indifférenciées. - A) Secteur de Dassu-Chapkiong (zones tectoniques B et C, sillimanite); toutes les linéations minérales et les axes de plis sont groupés et plongent au NW souvent fortement. - B) Secteur Chongo-Askolé (zone B, disthène-sillimanite); la linéation NE correspond à une linéation d'étirement, portée par les plans S1 qui pendent en moyenne dans cette zone vers l'Est, à la faveur d'un grand pli d'axe ESE-WNW à fort plongement vers l'ESE. - C) Secteur Korophon-Yula (zone A, disthène); quelques plis isoclinaux F1 ont un axe orienté au NNE mais la plupart des axes de pli et des linéations minérales plongent à l'Est; les pôles de foliation et les linéations indiquées en plus gros correspondent aux mesures effectuées aux environs du « pont » de Yula, dans les deux flancs du pli de Korophon: leur étalement sur un grand cercle montre que la foliation a valeur de S1.

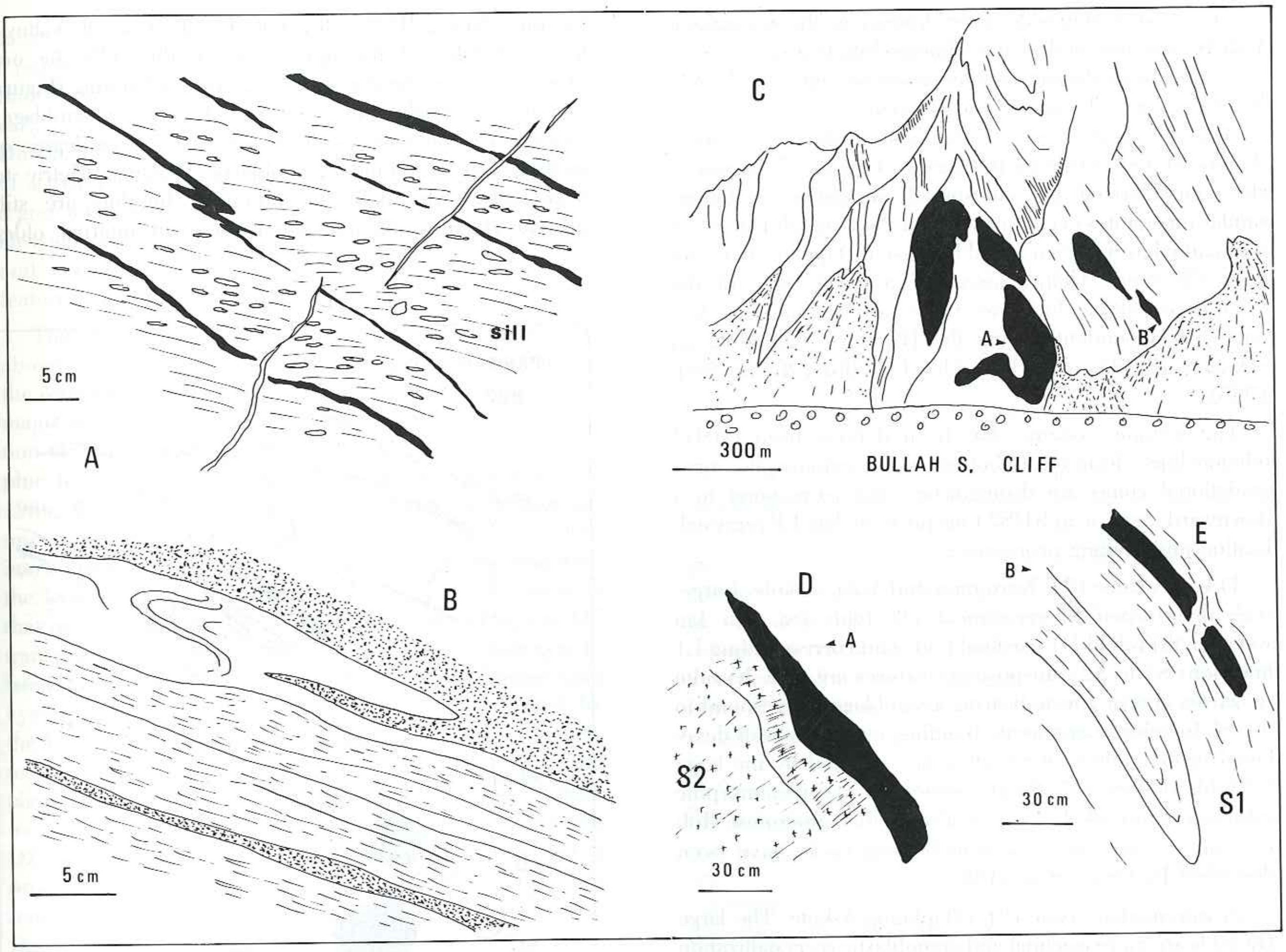

FIG. 4. — **Field relationships near Chapkiong (A and B) and near Korophon (C and D).**

A) S1/S2 relationships between Dassu and Chapkiong; Sillimanite nodules are aligned along L2; B) Early intrafolial fold near Chapkiong; C) Bullah southern cliff showing the large pre-D2 ultramafic boudins; D) detail of the contact of a boudin : leucogranite in close contact is foliated by S2; E) F1 isoclinal fold (N40 °E) and small-scale boudinage parallel to the S1 foliation and refolded by the Korophon fold.

FIG. 4. — ***Relations de terrain observées aux environs de Chapkiong (A et B) et de Korophon (C et D).***

A) Relations S1/S2 : les nodules de sillimanite sont allongés selon L2 et S2 est oblique par rapport au rubanement S1. Le rubanement est souligné par des niveaux fins plus riches en biotite. B) Micropli isoclinal précoce (F1?) affectant le rubanement. C) Paroi Sud du Bullah, au-dessus de Korophon montrant les grands boudins de roches ultrabasiques plissées par un pli F2. D) Détail du contact d'un boudin : la foliation S2 est à angle droit de l'allongement du boudin et un filonnet de leucogranite, qui souligne le contact avec les gneiss encaissants, est folié par S2. E) Pli isoclinal de direction N40°E attribué à D1 : le boudinage est ici parallèle à l'axe du pli F1.

B. Relationships between metamorphism and tectonics

The most impressive feature of the Karakorum Gneisses is their large-scale tectonic and metamorphic zonation, controlled by the D3 domes. Such zonation concerns both tectonic styles at all scales and metamorphic associations. Metamorphic and tectonic zones correspond broadly but along the Braldu Valley, metamorphic zones appears oblique to the D2 large-scale folds and are controlled by the Dassu and Panmah Domes and by the southern edge of the Baltoro Granite (Figure 2). From mineral assemblages observed in metapelitic rocks, three metamorphic zones have been defined in the area studied; they are, from top to bottom of the tectonic pile :

1) a kyanite-staurolite zone, known in the Korophon-Yula Bridge area and in the Chongo-Askole area.

2) a kyanite-sillimanite zone observed along the Braldu River between Chapkiong and Chongo.

3) a sillimanite zone centered around the Dassu Dome (Figure 1) and bordering the Baltoro Granite. This zone is also characterized by widespread migmatitic evolution; similar migmatites occur also around the Panmah Dome but sillimanite has not been found because metapelites have not been observed. Melting occurred at each stage of the tectonic evolution but was more widespread and less rock-type dependent during the D3 stage leading to an enhanced ductility in the lowest level (Hollister & Crawford, 1986).

The tectonic zonation has been defined from D1/D2 relationships : from top to bottom of the tectonic pile, three gradational zones are distinguished and correspond to a downward increase in S1/S2 transposition, late LP recrystallization and melting processes :

1) Upper zone (A), Korophon and Yula, Askole. Large-scale overturned to recumbent D2 folds (ca. 0,5 km wavelength) refold D1 isoclinal folds and corresponding L1 lineation; S1 to S2 transposition features are rare. Kyanite + garnet and/or zoisite-bearing assemblages correspond to the S1 foliation. Large-scale boudins, especially well developed in meta-ultramafic bodies, are refolded by the large D2 folds (Figure 4C). Similar structures and metamorphic associations are likely to exist also in the uppermost Hoh Lunghma Valley where kyanite-bearing rocks have been described by Desio *et al.* (1985).

2) Intermediate zone (B), Chapkiong-Askole. The large D2 folds are more isoclinal and granoblastic recrystallization becomes widespread. Numerous polyphase metamorphic reactions have been observed in this zone, showing for example relict kyanite in sillimanite gneisses. The L2 lineation, parallel to small-scale fold axes is dominant (rare F1 folds and/or L1 lineations have been observed) and a well-defined S2 foliation is developed; it locally cross-cuts the S1 foliation and banding (Figure 4A). Sillimanite is always associated with the S2/L2 structures. In the leucogranitic sillimanite flecky gneisses, the sillimanite nodules are parallel to L2 and show a progressive crystallization outlined by crack-seal microtextures. Boudins are still present but it is often difficult to determine whether they predate or they are associated with D2. From associated healed shear zones cross-cut by the D2 foliation observed in Chapkiong, boudins are more likely to be related to D1 but are reworked and exaggerated during D2.

3) Lower zone (C), edge of the Dassu Dome and upper Panmah. The most conspicuous feature of this zone is a regular, migmatite-like banding, with very rare isoclinal small-scale folds and no or very little mineral lineation (L2 lineation is best preserved around the Dassu Dome than in Panmah). The gradation into the (B) zone appears as a High Ductility Zone (HDZ) well exposed in the Panmah Valley : large F2 folds of the upper part of the cliffs die out progressively in the dome-forming regular banding (Figure 2 and 5A). High-grade, muscovite-free LP assemblages characterize this zone, with evidence of a large degree of melting and ubiquitous granoblastic textures. Metric to hectometric-scale mafic to ultramafic boudins are still present (Figure 5B) and often show an internal older

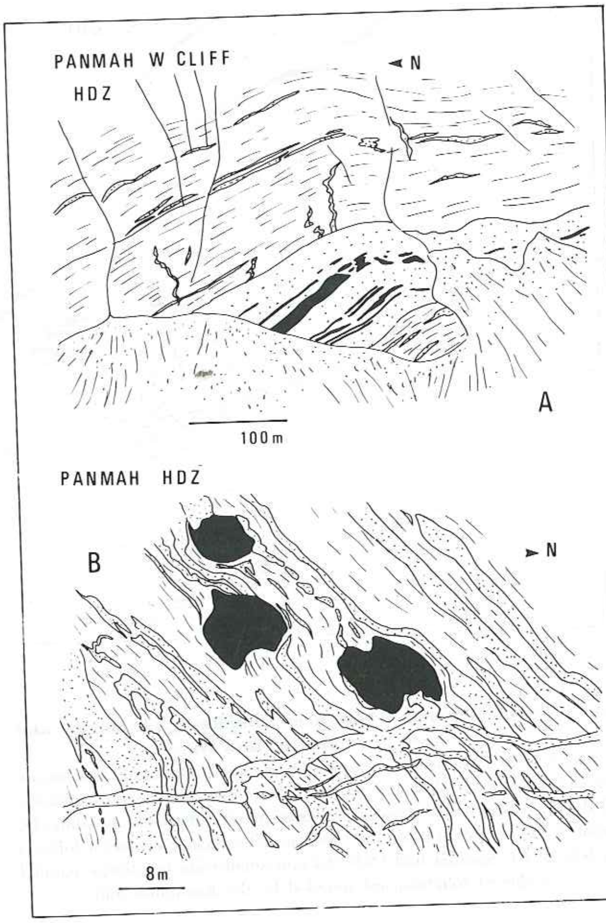

FIG. 5. — **The « High ductility zone » in the Panmah valley.**
A) Left bank of the river showing leucocratic sills (dotted) with restitic layers (black) and foliated migmatitic gneisses. B) Detail on the right side of the valley; black ultramafic boudins show sometimes a relict pre S2-S3 foliation. Leucocratic mobilisates (dotted) belong to several generations.

FIG. 5. — ***La « zone ultraductile » de la vallée de Panmah.***
A) Rive gauche de la rivière montrant les sills leucocrates mobilisés (points) avec les niveaux restitiques discontinus correspondants (en noir); les gneiss migmatitiques situés au-dessus montrent une foliation unique parallèle à l'enveloppe du dôme et sont recoupés par plusieurs générations d'aplites et de pegmatites. B) Détail de la « zone ultraductile » sur la rive droite de la vallée; les boudins ultrabasiques en noir comportent parfois une foliation relique antérieure à S2-S3; les mobilisats leucocrates (points) appartiennent à plusieurs générations.

foliation; ultramafic rocks are completely recrystallized into a phlogopite +olivine +green spinel assemblage (checked under microprobe). Tourmaline-bearing leucogranites locally cross-cut the regularly banded gneisses of the « High Ductility Zone ». The exposed core of the domes consists of a two mica foliated porphyritic granite in Dassu and in a grey adamellitic granite-gneiss in Panmah. An S3 vertical cleavage may occur in the central part of the Dassu Dome and corresponds to cross-cutting migmatitic veins; this feature is unknown in the Panmah Dome.

The metamorphic and structural zonation described above is clearly linked to the latest D3 event which controls the recrystallization in the lower and intermediate zones. A major consequence of the metamorphic and tectonic zonation described above is that there is no regional metamorphic foliation as defined by other authors (Searle *at al.*, 1986, Rex *et al.*, 1988) but an early S1, preserved in the uppermost tectonic zone, transposed into a S2 and lately into a dome-controlled S3. The best evidence for associating the kyanite-staurolite MP assemblages to the D1 event is that in the geometrically upper levels (zone A), where D2 transposition is absent, these minerals are obviously syn- to late-kinematic with respect to the S1 foliation together with kyanite-bearing syntectonic leucosomes. As suggested by the D2 controlled growth of sillimanite in the intermediate tectonic zone (B) and by the parallelism between S2 axial plane foliation and S3 forming the margins of the domes, we favor a metamorphic and tectonic continuum between D2 and D3. Metabasic and ultramafic boudins show a progressive reworking from D1 — related boudins to reorientated and recrystallized boudins in the « High Ductility Zone » (Figure 5B).

C. Relative chronology and significance of intrusive rocks

Intrusive rocks are widespread in the Braldu Valley, most of them being foliated. They are used to establish a relative chronology. Five successive groups may be defined :

1) Pre-D1 meta-igneous rocks are metagranodiorites and metaquartz-diorites (widespread in Hushe area - Searle *et al.*, 1986); as Desio & Zannetin's (1970) « peribatholitic gneisses » occurring north of the Baltoro Granite, they represent cordilleran-type intrusives similar to those of the Hunza Valley, where the oldest have been dated at 95 Ma (Le Fort *et al.*, 1983; Debon *et al.*, 1987). Metadiorites and metagabbros associated with meta-ultramafic layers and boudins are well exposed in Chapkiong, near Askole, in Korophon and in the Panmah Valley.

2) Post-D1/pre-D2 leucocratic veins and bodies (garnet ± muscovite ± sillimanite) cross-cut the S1 foliation and are in turn deformed by D2. The large sillimanite + garnet + muscovite-bearing heterogeneous leucocratic gneiss units (above Chapkiong and in the Bullah area) are igneous or migmatitic in origin as evidenced by xenoliths and restite developed along their margins. The Mango Gusor garnet-bearing granite described by Searle *et al.* (1986) probably belongs to this stage.

3) Post-D2 leucocratic dykes occur as subvertical undeformed, but sometimes curved, aplo-pegmatitic dykes cross-cutting the D2 folds. They constitute a complex network with several successive intrusions which may reflect the changing extension direction during the late D2 to D3 events; the network observed in the valley between Askole and Skoro La is a good example. As for curved dykes they may be explained by sliding along the foliation planes during the D3 dome formation and/or by the progressive change in the relative attitude of the foliation planes and the extension direction during the uplift of the domes. Such pattern is in agreement with a D2-D3 continuum. It must be also noticed that similar dykes occur along the roof zone of the Baltoro granite; they correspond to subvertical NS veins perpendicular to an EW extension direction outlined by a magmatic linear fabric in the outer zone of the granite and by the orientation of deformed metasedimentary xenoliths (Bertrand & Debon, 1986).

4) « Core » D3 granites are exposed in the Dassu and Panmah Domes. The Dassu Granite is a two mica porphyritic foliated granite with granoblastic textures (recrystallization of a syn to late D2 body ?). However its margins show a gradational evolution to a non orientated aplogranite with pegmatitic muscovite-bearing patches; irregular veining (quartz) subparallel to the contact and a veined pegmatite outlining the contact itself confirm the syn-dome emplacement of, at least, part of the body. Tourmaline is abundant in and around the Dassu Dome and in all the cross-cutting pegmatites of the Dassu area. The Panmah Granite-gneiss is a foliated adamellitic grey granite showing gradational contacts with the surrounding highly melted « High Ductility Zone »; in contrast to the Dassu area, tourmaline is rare and was observed only in small granite veins cross-cutting the S2-S3 foliation.

5) The Baltoro Granite has been described in several papers (Desio & Zannetin, 1970; Debon *et al.*, 1986; Bertrand & Debon, 1986; Searle *et al.* 1986, Rex *et al.*, 1988). It is a large pluton of two-mica monzogranite cross-cutting locally earlier granodioritic orthogneisses. Its two margins are highly contrasted : low-grade Permian to Mesozoic sediments on the north side are overprinted by a narrow contact aureole while high-grade Karakorum gneisses of unknown age form the south side with no clear contact aureole. Ages are very young (21 Ma., U/Pb zircon, Rex et al., 1988; 9 Ma., Rb/Sr internal isochron, Debon *et al.*, 1986). In the Panmah Valley, the « High Ductility

Zone » grades northward to more and more homogeneous migmatites when approaching the contact of the granite; these migmatites are bent along an axis similar to that of the D2 folds and the granite may locally overlie the metamorphic rocks. This structure suggests a genetic relationships between anatexis occurring in the dome, increasing toward the granite, and the granite itself. The Baltoro Granite could then represent an intruded equivalent, probably with a different and deeper source zone suggested by the moderate Sr initial ratio (Debon *et al.*, 1986), to the D3 dome *in situ* evolution.

D. Evidence for a polyphase metamorphic evolution

Ubiquitous granoblastic textures and frequent relicts of medium-pressure minerals (kyanite, zoisite) in low-pressure assemblages suggest a polyphase metamorphic evolution. Medium-pressure kyanite-bearing assemblages are located in the upper levels of the tectonic pile and define the S1 foliation while sillimanite + orthose assemblages are known around the D3 domes (Dassu and Panmah), the appearance of sillimanite being controlled by the development of the S2 foliation in the intermediate zone (B); such a geometry implies that a late D2+D3-controlled LP metamorphic event has been superimposed onto earlier higher pressure assemblages.

In the kyanite-staurolite zone, no coronitic evolution has been found but staurolite appears sometimes as prograde relict in a kyanite-garnet assemblage.

Polyphase metamorphic textures are well-displayed in the kyanite - sillimanite zone with the presence of two Al-silicate polymorphs : kyanite appears always as a relict

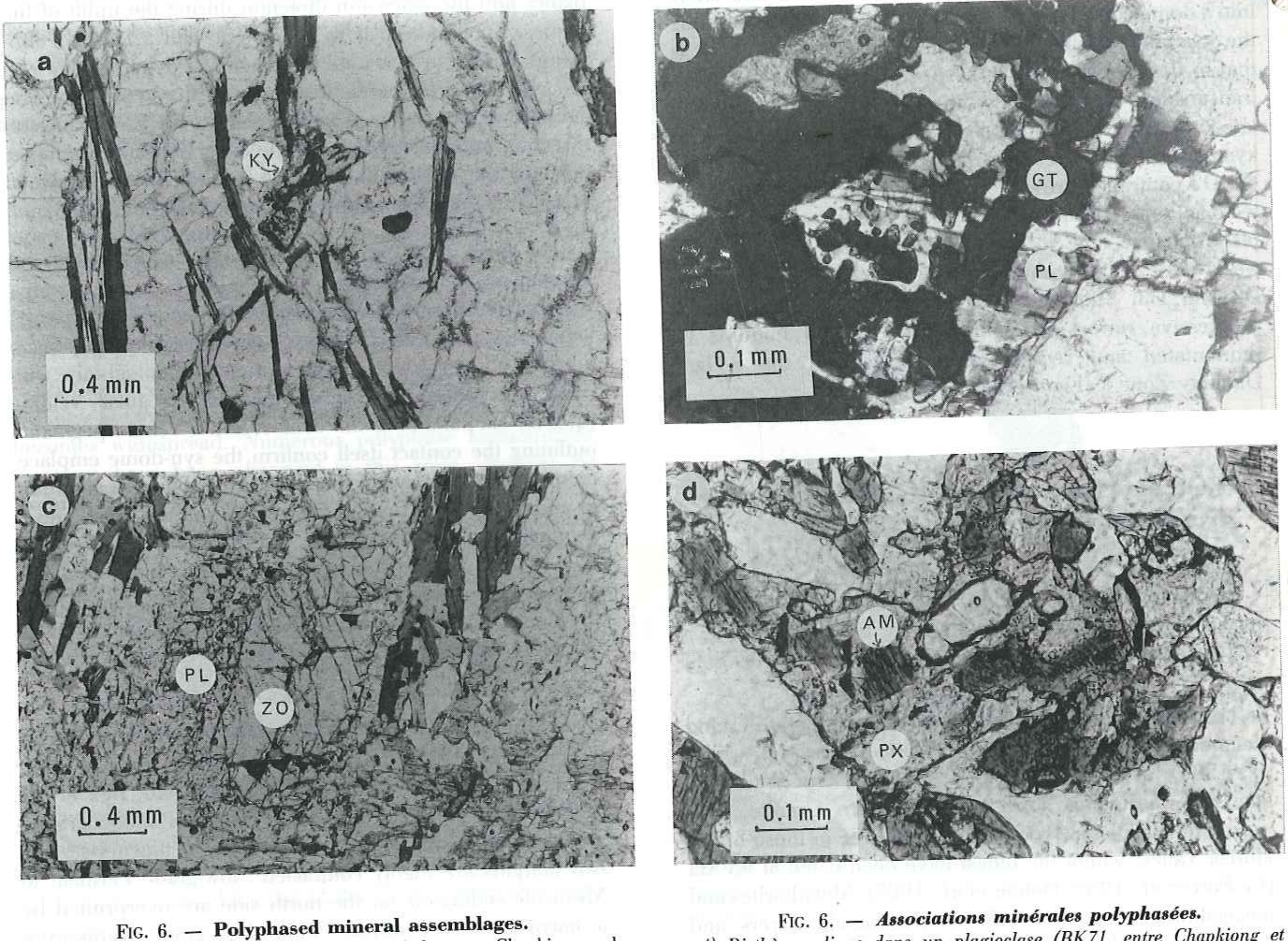

FIG. 6. — **Polyphased mineral assemblages.**
A) Relict Kyanite within plagioclase (Bk 71, between Chapkiong and Chongo). B) Destabilization of Garnet to Plagioclase (between Dassu and Chapkiong). C) Destabilization of Zoisite to Plagioclase (Askole). D) Transformation of Hornblende to Clinopyroxene (between Dassu and Chapkiong).

FIG. 6. — ***Associations minérales polyphasées.***
A) Disthène relique dans un plagioclase (BK71, entre Chapkiong et Askolé). B) Destabilisation de grenat en plagioclase (entre Dassu et Chapkiong). C) Destabilisation de zoïsite en plagioclase (Askolé). D) Transformation de hornblende en clinopyroxène (entre Dassu et Chapkiong).

mineral within plagioclase (Figure 6A) while sillimanite is in equilibrium with biotite and garnet. As quoted before, this zone is also characterized by S2/S1 obliquity and/or transposition.

In the sillimanite zone, particularly around the Dassu Dome, widespread evidence for mineral reactions and for coronitic assemblages have been found. Such reactions imply (1) a pressure decrease, as for exemple the transformation of garnet into plagioclase + biotite + hornblende (Figure 6B) — cordierite has not been observed — and the generality of sillimanite nodules, or (2) a temperature increase (or fH20 decrease) from the appearance of plagioclase around biotite and muscovite. In other rock types, like amphibolites and metagreywackes, similar (2)-type reactions have been observed like the transformation of hornblende into clinopyroxene (Figure 6D) or the destabilization of zoisite into plagioclase (Figure 6C). Such a polyphase evolution, characterized by relict kyanite in the sillimanite zone has been already recorded by Searle *et al.* (1986).

Such inversion in pressure conditions across the metamorphic zones, the medium-pressure assemblages being restricted to the highest levels, accompanied by evidence of relict medium-pressure minerals in the sillimanite zone would imply a superimposition of two distinct events rather than a simple plurifacial evolution.

E. Evaluation of PT conditions

Samples of metapelites were selected from each of the zones defined above to determine the P, T and fH20 conditions. All selected samples contain biotite and garnet for determining T values (Ferry & Spear, 1978) and quartz, plagioclase, Al-silicate and garnet for estimating P (Newton & Haselton, 1981). The results are given in Table I (mineral analyses are available upon request). Each point of figure 7 represents a particular typomorphic assemblage defined in thin section (*i.e.* the last observed equilibrium assemblage on one point); no attempt has been made to study the internal zonation of garnets.

P values vary from 10 Kb to 4 Kb in the kyanite -staurolite and in the transition zones and vary from 5.5 Kb to 2.5 Kb in the sillimanite zone (Figure 7). Temperature estimates are in the 700-525°C range for the kyanite-staurolite and the transition zones and 650-550°C for the sillimanite zone; the latter figures are very similar to those previously published for the Braldu Valley (Searle *et al.*, 1986), but Hunza Valley's data, also similar, point out to an inversion of metamorphic zones (Broughton *et al.*, 1985).

Each sample from the kyanite - staurolite and from the transition zones shows several values which indicate a decrease of both P and T, the lowest values of this trend falling in the vicinity of the PT conditions determined for the sillimanite zone. This feature is interpreted as the result of a more or less complete reequilibration during a polyphase history. Such a reequilibration could have happened during the isostatic uplift following a major nappe-forming event. In the sillimanite zone, some values are still lower in P and T. They may also correspond to a late decrease of P and T associated with the still-going uplift (see Zeitler, 1985, for fission tracks data in the neighbouring Nanga Parbat area); the appearance of secondary muscovite is probably associated with this event. These data are in good agreement with the presence of post-D1/pre-D2 leucogranitic melts which postdate the kyanite-bearing foliation.

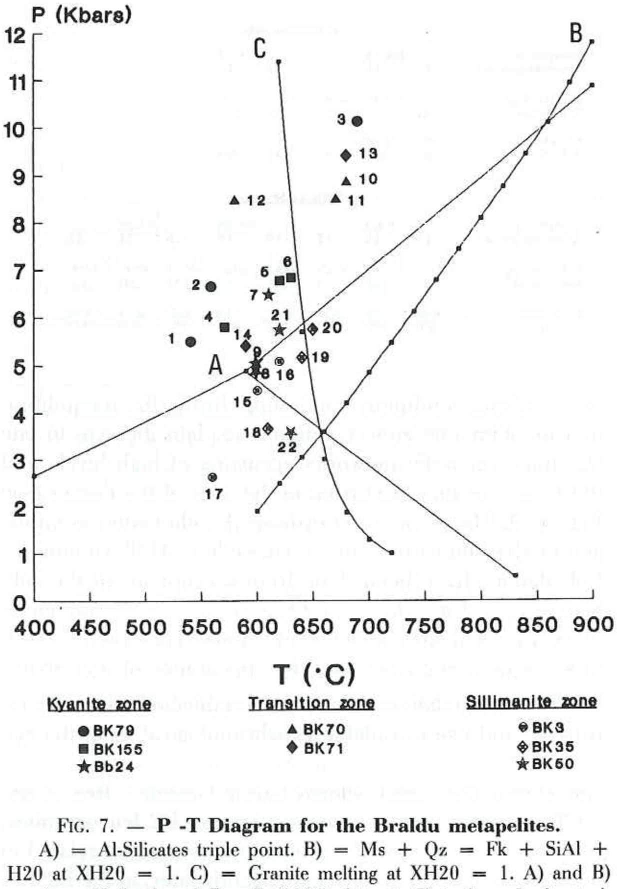

FIG. 7. — **P -T Diagram for the Braldu metapelites.**
A) = Al-Silicates triple point. B) = Ms + Qz = Fk + SiAl + H20 at XH20 = 1. C) = Granite melting at XH20 = 1. A) and B) are from Holland and Powell (1985) dataset. C) is from Luth et al. (1964). Numbers 1 to 22 correspond to the assemblages quoted on Table I.

FIG. 7. — ***Diagramme Pression-Température.***
A) = Point triple des alumino-silicates. B) = Réaction Ms + Qz = FK + SiAl + H20 pour XH20 = 1. C) = Courbe de fusion du granite pour XH20 = 1. A) et B) sont tirés de la base de données de Holland et Powell (1985). C) est dessiné d'après Luth et al. (1984). Les numéros de 1 à 22 correspondent aux assemblages du Tableau I.

TABLE. I. — **Geothermobarometry.**
All pressures are calculated from the Garnet - Plagioclase - Al-silicate Quartz assemblage, with the calibration of Newton & Haselton (1981). All temperatures are calculated from the Biotite - Garnet - Al-silicate - Quartz assemblage, with the calibration of Ferry & Spear (1978).

TABLEAU. I. — ***Géothermométrie.***
Les pressions ont été calculées d'après l'assemblage Grenat — Plagioclase — Silicate d'Alumine — Quartz, en utilisant la calibration de Newton et Haselton (1981). Les températures ont été calculées d'après l'assemblage Biotite — Grenat — Silicate d'Alumine — Quartz, en utilisant la calibration de Ferry et Spear (1978).

Kyanite zone

Samples n°		BK79			BK155		Bb24		
Assemblages n°	1	2	3	4	5	6	7	8	9
Kd Grt-Plg	.00586	.01093	.02850	.00750	.00874	.00788	.00725	.00202	.00220
Kd Bi-Grt	.166	.176	.244	.177	.204	.210	.201	.196	.196
P (Kbars)	5.51	6.64	10.14	5.76	6.77	6.81	6.46	4.90	4.99
T (°C)	544	564	689	566	616	628	610	602	601

Transition zone

Samples n°		BK70			BK71
Assemblages n°	10	11	12	13	14
Kd Grt-Plg	.02297	.02115	.08052	.03612	.00410
Kd Bi-Grt	.241	.233	.185	.186	.241
P (Kbars)	8.86	8.49	8.46	9.41	5.37
T (°C)	683	670	581	684.	589

Sillimanite zone

Samples n°		BK3			BK35		BK50	
Assemblages n°	15	16	17	18	19	20	21	22
Kd Grt-Plg	.00127	.00161	.00043	.00061	.00147	.00202	.00283	.00050
Kd Bi-Grt	.195	.208	.173	.202	.217	.225	.205	.210
P (Kbars)	4.48	5.08	2.61	3.67	5.16	5.77	5.74	3.57
T (°C)	600	623	558	612	641	654	618	627

Near-melting conditions continuing during the reequilibration to sillimanite zone conditions explain the syn- to late D2 aplo-pegmatitic networks occurring at high levels and the *in situ* melting occurring in the core of the domes (see Figure 5). The presence of orthose + sillimanite assemblages in the sillimanite zone suggest low fH20 conditions. Calculations have been done from metapelites of the sillimanite zone from the assemblage Kfeldspar + sillimanite + biotite + quartz, which confirm low fH20 values; fH20 increase occurred later with the appearance of muscovite.

From the relative chronology established from the intrusives and from available geochronological data, the age of the kyanite association may be estimated at ca. 40 Ma (by considering the dated Mango Gusor Granite - Rex *et al.*, 1988 - as equivalent to our post-D1/pre-D2 leucogranites, see discussion below); the sillimanite association, related to the formation of the domes and, slightly later, to the Baltoro Granite emplacement, has been formed 21 Ma ago (ibid.). Younger ages of 14 to 5 Ma obtained by the K/Ar and Rb/Sr methods (Rex *et al.*, 1988; Debon *et al.*, 1986) for the Baltoro Granite and associated migmatites, and of 5 Ma on the Dassu Dome by the 39 Ar/40 Ar method (Maluski, pers. comm.), may represent the cooling evolution toward secondary muscovite and the last recorded stages of the regional uplift (Zeitler, 1985).

IV. — DISCUSSION AND CONCLUSIONS

From the field observations and data presented here, the following structural sequence has been defined and is summarized in Table II:

1) D1 isoclinal folding was accompanied by subparallel healed shear zones and by intense boudinage occurring under medium-pressure metamorphic conditions, followed by the emplacement of a dense net of post-D1 heterogeneous leucogranitic material;

2) a major phase of recumbent folding (D2), roughly trending EW;

3) large open D3 folds generating EW trending domal structures (Dassu and Panmah Domes); both D2 and D3 occurred under high-grade LP conditions and were shortly followed by the emplacement of the Baltoro Granite;

4) a late set of brittle to locally more ductile structures such as the southern thrust contact of the gneisses with the Shyok suture zone.

D1 is interpreted as a separate event from its tectonic style, medium-pressure metamorphic conditions and from the occurrence of leucogranites. It probably corresponds to a large-scale nappe-forming event. The complete change in the shortening directions between D1 and D2 (respectively ca.NW-SE for D1 - if favoring the NE trending folds and

TABLE. II. — **Chronology of events**
The vertical arrow outlines the simultaneous increase in the S1-S2 transposition and of the low-pressure granoblastic recrystallization down the tectonic pile, toward the dome's cores.

TABLEAU. II. — ***Interprétation de la chronologie des événements.***
La flèche verticale symbolise l'augmentation simultanée de l'intensité de la transposition S1-S2 et de la recristallisation granoblastique de basse pression, lorsque l'on descend dans la pile tectonique vers le cœur des dômes (augmentation des effets de D3).

Tectonic evolution	Metamorphic evolution	Intrusions	Geochronology
		Ultramafics Orthogneisses	
D1 EVENT Isoclinal folding F1; mineral and stretching lineations L1; boudinage and shear zones N20°E-N40°E	Ky + Grt + St	late to post D1: sill±Grt-bearing leucogranites	ca. 40 Ma (U/Pb Zr) Rex et al., 1987
Discontinuous transition			
D2 EVENT E-W trending isoclinal to open recumbent folds F2; L2 lineation; shear zones (south vergence)	Sill + Grt + St LP granoblastic recrystallization	post D2 aplite and pegmatite dykes	ca. 20 Ma (U/Pb Zr) Rex et al., 1987
D3 EVENT E-W trending domes and large upright open folds		Dassu and Panmah granite-gneisses Baltoro granite	ca. 20 Ma (U/Pb Zr) Rex et al., 1987 9 Ma (Rb/Sr and K/Ar) Debon et al, 1986
MKT EVENT (Searle et al., 1986)	musc. local retrogression		5 Ma ($^{39}Ar/^{40}Ar$) Maluski, pers. comm.

boudins against the rare NE stretching lineations - and NNE-SSW for D2) and the contrasting metamorphic conditions together with the occurrence of migmatitic and plutonic events by the end of the D1 event, support a polyphase evolutionary model. On the contrary, all observations concerning the D2-D3 transition such as the metamorphic similarities and the smooth tectonic grading indicate a continuous evolution between these two events.

On a regional scale, at the upper level of the tectonic pile, an intermediate pressure assemblage corresponding to D1 is preserved (Grt-St-Ky). Estimated PT conditions are ca. 9 Kb and 700°C (Figure 7) In the core of the large D3 domes late granoblastic recrystallization is widespread together with almost complete S1/S2 transposition, incipient melting and development of a low-pressure sillimanite-bearing assemblage where relicts of higher pressure minerals are locally preserved. PT conditions are close to 600° with a lower pressure (4 to 5 Kb). Except for the late development of muscovite, the observed structures at the lower levels (mineral lineations, boudinage, melting etc..) are clearly associated with (or reworked by) D2 and further exaggerated by D3. The two later phases are interpreted as representing a continuum developed in the same PT field. For the same reasons, it can be assumed that the Baltoro granite was emplaced by the end of this combined D2-D3 event as an intruded, probably deeper, equivalent of the parautochtonous D3 « core » granites. The metamorphic evolution described above fits with a now classical crustal thickening model related to nappe tectonics. This event was followed, after a delay, by a decrease in P with T increasing or being stable during a subsequent deformation, according to the rates of erosion and isostatic reequilibration. A similar polyphase evolution has been recently described as an alternative and/or complement to the Himalayan model of inverted metamorphism (Le Fort, 1975), by Brunel & Kienast (1986).

This interpretation of the tectonometamorphic evolution of the Karakorum gneisses is different from that proposed by the Leicester group (Searle *et al.*, 1986, Rex *et al.*, 1988). These authors have recognized further east in the Hushe Valley an early low-pressure metamorphic event which seems to have left no recognisable trace in the Braldu region (M1 event). They group our D1 and D2 in a single M2 event characterized by a regional metamorphic foliation, and describe a continuous evolution from kyanite to sillimanite during the same event. They suggest, however, that most of the sillimanite is due to a later thermal effect (M3) associated with the emplacement of the Baltoro Granite. The critical question is thus : dœs it exist a D1-D2 continuum or, alternatively, a D2-D3 continuum ? Our main evidence against a D1-D2 continuum is that the garnet-sillimanite bearing leucogranitic intrusives have been emplaced before D2. On the contrary, there exist obvious links between the emplacement of the aplo-pegmatitic net and D2 deformation such as syntectonic veins and dykes. The ca. 20 Ma age difference between these two groups of intrusives, the younger being synchronous with the Baltoro granite emplacement support the discontinuity between D1 and D2.

From available ages, the D1 event is post-dated by the intrusion of the Mango Gusor granite, 37 ± 0.8 Ma ago (Parrish & Tirrul, submitted, quoted in Rex *et al.*, 1988). The Baltoro granite and associated pegmatites, which post-date the D2-D3 events yield ages from 21 ± 0.5 Ma (U/Pb on zircon) to 5 Ma (Rb/Sr, K/Ar on minerals), (Debon *et al.*, 1986; Searle *et al.*, 1987; Rex *et al.*, 1988); corresponding initial Sr ratio is close to 0.708. Thus the age range for the late high-grade metamorphic event and granite emplacement in Karakorum (20 to 5 Ma) is very close to the age of 18 Ma determined for leucogranites in Nepal (Le Fort *et al.*, 1987), and in the Hazara region (23 Ma, Maluski & Matte, 1984) and to the age of the major thermal event occurring in the North Himalaya domain (Maluski *et al.*, 1988).

Concerning more precisely the age of the D1 event, several possibilities exist :

1) D1 may represent the deformation event associated with the main India-Eurasia collision (54 Ma ago according to Patriat & Achache, 1984); if the ca. 40 Ma old leucogranites represent the delayed consequence of the collision and related thickening, this is the best hypothesis.

2) D1 may be correlated with the formation of the Shyok Suture Zone. In the Hunza region, Coward et al. (1986) have shown that sheared basic volcanics, sediments and ophiolitic melange occurring South of the Shyok Suture Zone are folded by northward verging folds with locally a N30° stretching lineation and reorientation of fold axis. These folds are sealed by the latest terms of the Kohistan batholith. North of the suture, these early folds are refolded by ESE trending southward verging overturned folds and associated shear zones, which are interpreted as related to a lateral ramp with a dextral sense of displacement and an SE verging overthrust component (Coward *et al.*, 1986). The latter structures are easily comparable with our D2 but earlier folds are more difficult to equate with D1 because N30° direction represents in Hunza a transport direction; this is not the case in the Braldu valley where D1 folds, identical in direction, correspond to « b » folds.

3) Another possibility for the relative age of D1 should be a still older event as described further East in the Lhasa block (Burg, 1983; Girardeau *et al.*, 1984) predating the Banjang-Niugang suture zone Middle Jurassic in age. Such interpretation is unlikely because the numerous dioritic and granodioritic orthogneisses occurring within Karakorum gneisses, correspond probably, although undated, to the oldest terms of the Karakorum batholith, emplaced ca. 100 Ma ago (Le Fort *et al.*, 1983; Debon *et al.*, 1987). However older deformation events may be suspected in the poorly

known region North of the Karakorum batholith as post tectonic intrusives have given minimum ages ca. 115 Ma. in the Kunjerab area (Debon & Zimermann, pers comm., 1987).

From our interpretation, a major low-pressure high-grade metamorphic event have occurred around 20 Ma ago, in Miocene times (Rex *et al.*, 1988), very close in time to the emplacement of many leucogranites in the High Himalayas (Le Fort *et al.*, 1987) and to the major tectonometamorphic event dated in the North Himalaya belt (Maluski *et al.*, 1988). As deformation and metamorphism of the Ladakh and Kohistan domains are postdated by 40-45 Ma old granitoids (Petterson and Windley, 1985; Honnegger *et al.*, 1982), the so-called « Shyok Suture » is not actually a suture but appears from most authors (Coward *et al.*, 1986; Pudsey, 1986; Hanson, 1986; Mattauer, 1985...) as a major tectonic contact (Main Karakorum Thrust) separating sharply two metamorphic terranes of different ages. A review of the litterature indicates that the width of the deformed Main Karakorum Thrust zone varies, that ophiolitic melanges are discontinuous, that there is not any trace of HP metamorphism and that wrench-faulting (especially where the fault is NW trending) grades to thrust (Coward *et al.*, 1986; Pudsey, 1986; Hanson, 1986; Srimal, 1986; Andrews-Speed & Brookfield, 1982). Extrapolating from Hanson's thesis (1986), a Post Miocene age is suggested for the main offset of the MKT as the LP isograds, which we consider as related to the Baltoro granite, are cross-cut by the Main Karakorum Thrust in the Shigar valley - from all available data metamorphic isograds in the Kohistan region are older than 40 Ma. Taking the age data into account it appears now that the Main Karakorum Thrust is a major thrust separating high-grade metamorphic rocks of Miocene age (at least for the last event) and metavolcanic units metamorphosed at varying degrees before 40-45 Ma ago. Gravimetric modelling suggest an average gentle northward dip for the MKT (Malinconico, 1986). The existence of a local retrogression along the contact has been quoted by Searle *et al.* (1987). The displacement of such a nappe may be very large and may explain the meeting of the two « sutures » in the Haramosh region.

The ultramafic rocks occurring within the Karakorum gneisses may be considered, on a first attempt, as corresponding to an unique discontinuous unit, tectonically disrupted, which may be followed from the Masherbrum area (Searle *et al.*, 1987) to Chapkiong. Despite the lack of petrological study, they are good candidates to represent oceanic remnants or, at least products of a pre-D1 extensional event (Searle *et al.*, 1987). This unit may represent :

- Complexly folded remnants of the « true » Shyok Suture Zone; such interpretation is suggested by Hanson's map implications (1986); the Braldu ultramafics could represent, if the continuity is confirmed, more metamorphic equivalents to serpentinite bodies occurring in the Shigar and Hushe areas. This would also support the relative age of the Shyok suture zone. older than the Main Mantle Thrust closure and than the main collision.

- An equivalent of some older suture as the Bangong-Nujiang suture in Tibet (Girardeau *et al.*, 1984; Srimal, 1986), considered as Jurassic in age as it is sealed by the Cretaceous Takena formation. This would imply the presence of a basement in the Karakorum, which is not recognized so far.

In any case, the Karakorum gneisses may represent a tectonic layered cake of two distinct terranes including a highly deformed suture, and sealed by a later high-grade metamorphic event.

The dominantly Miocene metamorphic evolution shown in the Karakorum range differs from the high-grade Miocene evolution of the High Himalaya region which was directly controlled by the collisional stacking of the Indian crust (Le Fort *et al.*, 1987). In Karakorum, late tectonothermal domes and associated granitic intrusions outline a sharp tectonic and metamorphic contrast across the Main Karakorum Thrust. Such a setting is symetric to the reworking of internal nappes quoted in the Kangmar region (Maluski *et al.*, 1988) on the other side of the Indus-Zangbo suture. Following Tapponnier *et al.* (1981), a control of the Miocene Karakorum evolution by the still seismically active continental subduction operating in Pamir may be proposed as a working hypothesis. Indeed, the Chaman and Karakorum megawrench-faults of opposite sense may have focussed the intraplate deformation related to the continental subduction in the Karakorum and Nanga Parbat regions and may explain the location of young high-grade metamorphism and crustal melting, perhaps still operating at mid-crustal depth in south Tibet (Pham *et al.*, 1986), enhanced uplift (Zeitler 1985), and still-ongoing thrusting (Butler & Prior, 1988).

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