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Preliminary Geological Map And Description of the Himalaya-Karakorum Junction in Chogo Lungma to Turmik Area (Baltistan, Northern Pakistan)

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ABSTRACT

Some 800 km^2 of the area lying between the Haramosh Spur of the Himalaya and the Southern Karakorum Complex, centered on the Chogo Lungma glacier system, is presented on a preliminary geological map, after three expeditions. It includes three major units from SW to NE: the High Himalayan Nanga Parbat - Haramosh Crystallines (HHC), the Ladakh Paleo Island Arc, and the Karakorum Metamorphic Complex intruded by granitoids. The three units are thrust to the south. The High-Himalayan ortho- and para-gneisses are metamorphosed to granulite facies and migmatised. The Ladakh Arc is made up of two groups of formation, the Askore Amphibolite to the SW and the Greenstone Complex to the NE, separated by a screen of serpentinized ultramafics. It is intruded by numerous granitoids including a leuco-trondhjemite body cutting the Himalaya-Ladakh contact. The metasedimentary and metavolcanic sequences of the Greenstone Complex include limestone horizons that have yielded post-Valanginian fossils. The Karakorum Metamorphic Complex includes orthogneiss domes of granitoids intruded into the surrounding metasedimentary formations. A syenitic dome of granitoid at Hemasil is apparently syntectonic. Two phases of deformation are observed in Karakorum and Ladakh and seem to correspond, but with different grades of metamorphism. The late doming structures are characteristic of the Karakorum. The Himalaya-Karakorum contact varies from south to north, from a normal fault to a strike-slip shear zone, and finally a thrust fault. The original Ladakh-Karakorum contact (Shyok Suture) is folded and reactivated by late brittle thrusting, possibly the latest large-scale deformation of the region. The closure of the Ladakh-Kohistan back-arc basin followed by the collision of India is mostly overprinted by the recent structures.

INTRODUCTION

The paper deals with the preliminary field and petrological data collected in the area between the Nanga Parbat - Haramosh Spur (Himalaya) and the southern part of the Karakorum Metamorphic Complex. A preliminary geological map is also prepared.

The area studied covers around 800 km^2. It comprises the upper Chogo Lungma glacier system flowing into the Basha River, the Turmik Valley, and the upper part of the Stak Valley, all three located on the right (northern) bank of the Indus River (Fig. 1 and 2). Previously it was mapped schematically by Zanettin (1964), in the Stak and Turmik Valleys, Desio et al. (1985), in the lower Chogo Lungma, Verplanck (1986) in the southern part of the Stak Valley and adjoining areas of Indus Valley, and Hanson (1986 & 1989), along the lowermost Basha Valley. Before the present study, the area was almost geologically unknown in its key part, that is, on both sides of the Chogo Lungma glacier. We have surveyed it during three expeditions (around 240 days of field work):

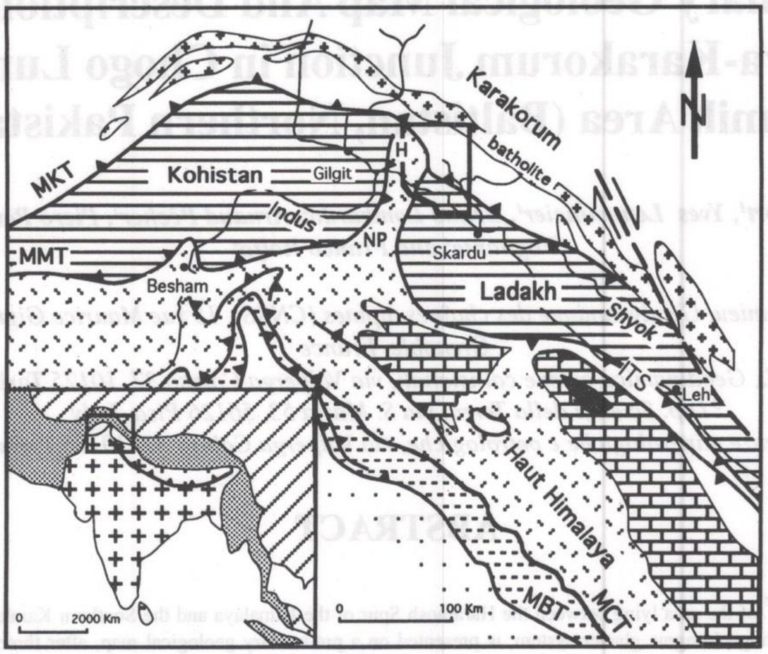

Fig. 1 General location map of the studied Chogo Lungma area ITS = Indus-Tsangpo Suture; MBT = Main Boundary Thrust; MCT = Main Central Thrust; MKT = Main Karakorum Thrust; MMT = Main Mantle Thrust; NP = Nanga Parbat Spur

- Turmik and Stak Valleys during the Autumn of 1991, mapping on the 1:100,000 Italian map (Lombardi, 1991);

- Basha, Kero Lungma, Berelter Valleys and the left bank of the lower Chogo Lungma during the Spring of 1992, with mapping on an enlarged version of the 1:250,000 map of the Swiss Foundation for Alpine Research (1990);

- Upper Chogo Lungma and tributaries, Basha Valley , and lower Turmik during the Summer of1993, with mapping of the Chogo Lungma Valley on an enlarged version of Kick's (1964) 1:100,000 map.

The area consists of three major units: the High Himalayan Nanga Parbat - Haramosh Crystallines (HHC), to the SW, part of the Indian Plate; the Ladakh terrain to the SE corresponding to the eastern part of the fossil Kohistan-Ladakh Island Arc; and the Karakorum Metamorphic Complex representing the northern margin of Neotethys, largely intruded by the Karakorum Batholith. These units are thrust on each other along two major fault systems:

- the Indus Tsangpo Suture Zone (ITS) between Ladakh and HHC,

- the Shyok Suture Zone (SSZ, Sharma & Gupta, 1978; Gansser, 1979; Brookfield, 1980) or Northern Suture (Pudsey, 1986; Pudsey et al., 1985), between Ladakh and Karakorum.

The area was covered in sufficient detail in order to map the different formations throughout, gather the structural information, and collect petrographic and geochemical samples for characterising and dating the different formations. A simplified version of the map is presented in Fig. 2. It is the base for the following description of the area.

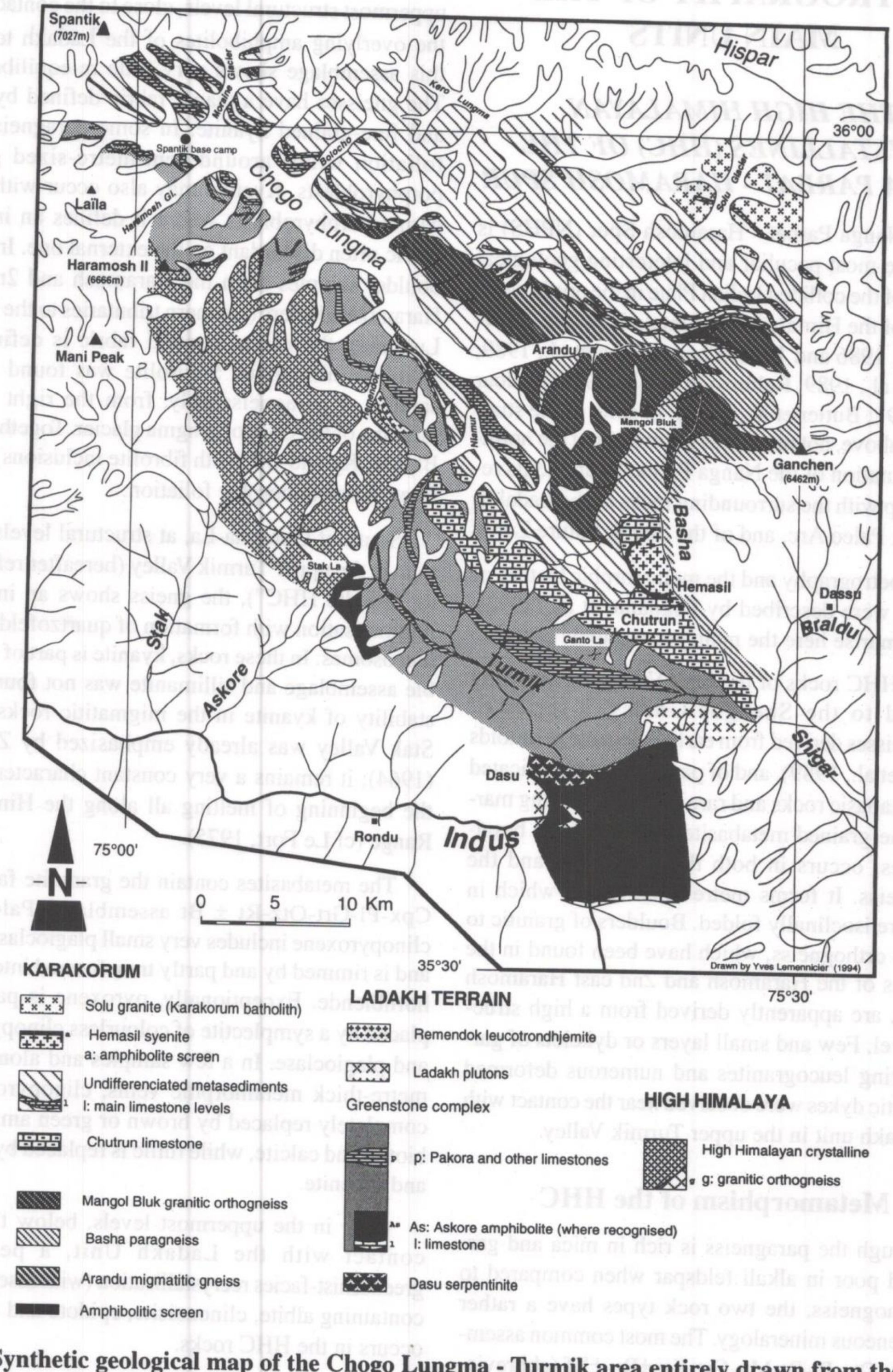

Fig. 2 Synthetic geological map of the Chogo Lungma - Turmik area entirely drawn from the 1991-1993 franco-italian expeditions

PETROGRAPHY OF THE MAIN UNITS

THE HIGH HIMALAYAN CRYSTALLINES (HHC) OF THE NANGA PARBAT - HARAMOSH SPUR

The Nanga Parbat - Haramosh Spur (NPHS) is one of the most peculiar and interesting geological features of the collided Indian Plate in the north-western part of the Himalayan Mountain Belt (e.g. Coward et al., 1986 and 1988; Chamberlain et al., 1989; Madin et al., 1989; Rehman & Majid, 1989; Treloar et al., 1991; Butler et al., 1992). In spite of the studies cited above, not much was known about the northern termination of the Nanga Parbat Spur and its relationship with the surrounding rocks of the Ladakh-Kohistan Paleo Arc, and of the Shyok Suture Zone.

The petrography and the metamorphic history of this unit were described by Pognante et al. (1993). We summarise here the main petrographic aspects.

The HHC rocks of the Stak Valley are currently ascribed to the Shengus Gneiss, a series of orthogneisses derived from early Paleozoic granitoids (Zeitler et al., 1989), and of paragneisses imbricated with metabasic rocks and rare diopside-bearing marbles. Fine-grained metabasite, deriving from basaltic dykes, occurs in both the paragneiss and the orthogneiss. It forms metre-thick layers which in places are isoclinally folded. Boulders of granitic to tonalitic orthogneiss, which have been found in the moraines of the Haramosh and 2nd east Haramosh glaciers, are apparently derived from a high structural level. Few and small layers or dykelets of garnet-bearing leucogranites and numerous deformed pegmatitic dykes were observed near the contact with the Ladakh unit in the upper Turmik Valley.

Metamorphism of the HHC

Though the paragneiss is rich in mica and garnet, and poor in alkali feldspar when compared to the orthogneiss, the two rock types have a rather homogeneous mineralogy. The most common assemblage is: Qtz-Pl-Bt-Mu-Grt-Ky ±Ru ±Kf (abbreviations are after Kretz, 1983). Except for the eastern uppermost structural levels, close to the contact with the overlying amphibolites of the Ladakh terrane, this assemblage shows very little re-equilibration. The gneisses have a planar fabric defined by mica and fine-grained kyanite. In some paragneiss, the foliation wraps around centimetre-sized garnet porphyroblasts. Kyanite may also occur within the garnet porphyroblasts where it defines an internal fabric often discordant on the external one. In a few boulder samples from the Haramosh and 2nd east Haramosh glaciers (southern tributaries to the Chogo Lungma), the garnet internal fabric is defined by fibrolitic sillimanite. Staurolite was found in one sample of paragneiss only, from the right lateral moraine of the Chogo Lungma glacier. Together with Bt, Mc, Ky and Grt (with fibrolite inclusions), it defines the metamorphic foliation.

South of Goropha-La, at structural levels lower than in the upper Turmik Valley (hereafter refered to as "middle HHC"), the gneiss shows an incipient migmatisation with formation of quartzofeldspathic leucosomes. In these rocks, kyanite is part of the stable assemblage and sillimanite was not found. The stability of kyanite in the migmatitic rocks of the Stak Valley was already emphasized by Zanettin (1964); it remains a very constant characteristic of the beginning of melting all along the Himalayan Range (cf Le Fort, 1975).

The metabasites contain the granulite facies of Cpx-Pl-Grt-Qtz-Rt ± Bt assemblage. Pale green clinopyroxene includes very small plagioclase grains and is rimmed by and partly transformed into brown hornblende. Exceptionally, pyroxene is partly replaced by a symplectite of colourless clinopyroxene and plagioclase. In a few samples and along centimetre-thick metamorphic veins, clinopyroxene is completely replaced by brown or green amphibole, biotite and calcite, while rutile is replaced by sphene and ilmenite.

Only in the uppermost levels, below the main contact with the Ladakh Unit, a pervasive greenschist-facies recrystallisation (with assemblages containing albite, clinozoisite, epidote and chlorite) occurs in the HHC rocks.

Geothermobarometry of the HHC

Metamorphic temperatures and pressures of the gneissic rocks were determined using Grt-Bt thermometers, and Grt-Pl-Ky, Grt-Pl-Bt-Ms and Grt-Pl-Ms geobarometers. In the metabasites, they were calculated using Grt-Cpx, Grt-Bt, and Grt-Hbl geothermometers, and Grt-Pl-Cpx-Qtz barometer.

The thermobarometric data obtained (Fig. 3) suggest that the rocks of the Stak Valley suffered a metamorphic peak at T = 650-700°C and P = 8-13 Kbar. Comparable P-T estimates have been obtained for garnet granulites from the HHC of Zanskar (northern India, Pognante & Lombardo, 1989). However in Zanskar, the mineral assemblages produced during the pressure peak occur as rare relics in rocks *showing a pervasive high-temperature recrystallisation* during exhumation

Metamorphic Zonation and P-T Evolution of the HHC

Metamorphic assemblages are the same throughout the HHC of the Stak Valley, but in the upper structural levels, thermobarometry indicates temperatures 50 to 70°C lower and pressures 1 to 2 Kbar lower than elsewhere. Within the Upper Shear Zone, the syn-tectonic greenschist facies retrogression is linked to southward shearing of the Ladakh unit. Away from the Upper Shear Zone, the post-peak transformations

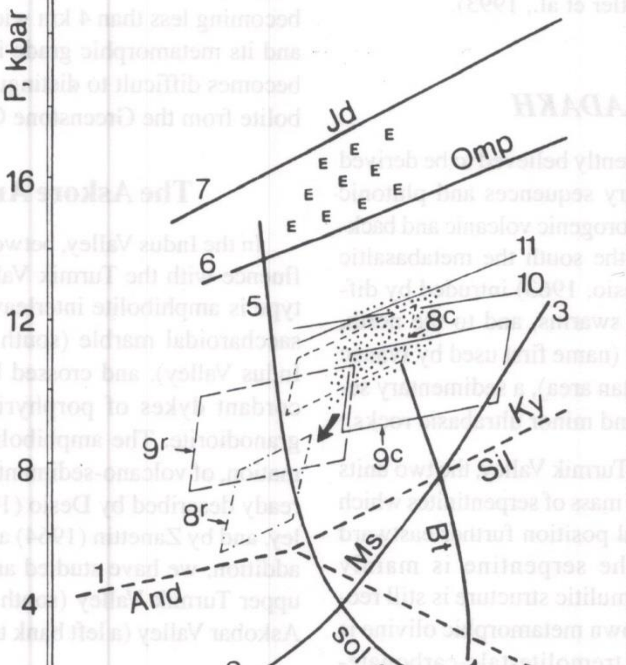

Fig. 3 Pressure-temperature grid showing the conditions of the metamorphic peak of the middle HHC from the Stak valley (dotted area). The arrow defines the possible retrograde path suggested by the study of garnet zoning profiles. The different reaction curves are numbered and explained in Pognante et al (1993, fig. 7)

are rare and restricted to discrete zones. In the metabasites, these transformations chiefly occur along millimetre- to decimetre-thick veins and their formation is controlled by fluid infiltration along fractures. Clinopyroxenes are zoned with decreasing jadeite content in the rim, while green amphibole grows in veins and reaction rims bordering clinopyroxene and brown hornblende. This is consistent with a retrograde decompressional evolution.

It suggests a relatively high rate of exhumation which allowed rapid cooling and prevented pervasive low-pressure reequilibrations. This is in good accordance with the rapid cooling rates of 15-20°C/Ma obtained for the early exhumation of Eocene age of the Kaghan eclogites (Tonarini et al., 1993) and with the very rapid uplift rates (5 to 7 mm/yr) obtained for the NPHM during the last million years (Treloar et al., 1991; Zeitler et al., 1993).

THE LADAKH

The Ladakh unit, currently believed to be derived from volcano-sedimentary sequences and plutonic bodies generated in a pre-orogenic volcanic and back-arc basin, comprises to the south the metabasaltic Askore Amphibolite (Desio, 1963) intruded by different plutons and dyke swarms, and to the north, the Greenstone Complex (name first used by Ivanac et al., 1956, in the Kohistan area), a sedimentary sequence with metabasic and minor ultrabasic rocks.

At Dasu, in the lower Turmik Valley, the two units are separated by a lensoid mass of serpentinites which keeps the same structural position further eastward in Khomara valley. The serpentine is mainly antigorite, but a relict cumulitic structure is still recognizable, and newly grown metamorphic olivine is abundant. A screen of tremolite-talc-carbonate-epidote rodingite appears at the contact with the overlying Cretaceous volcano-sedimentary series. A block of possible crushed pillow-lavas has been described near the "power station" of Dasu (Zanettin, 1964). Ultrabasic rocks and calc-silicate fels also outcrop in lower Remendok Valley, in a similar structural position. 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).

One of the main differences between the Askore Formation and the Greenstone Complex is the grade of metamorphism. The Greenstone Complex displays a greenschist facies while the Askore Amphibolite is in amphibolite facies with metamorphism increasing toward the south-east (Skardu area), where the Cretaceous metasediments of the Katzarah Formation are affected by HT and low to moderate P metamorphism as first described by Hanson (1986 & 1989). It is to be noted that although it has been searched for, no trace of the blue schist-type metamorphism observed 150 km more to the east (Honegger et al., 1989), has been found.

Westward, around the syntaxis, the Ladakh unit is laminated between the HHC and the Karakorum, becoming less than 4 km wide in Remendok Valley, and its metamorphic grade increases. In this part it becomes difficult to distinguish the Askore Amphibolite from the Greenstone Complex.

The Askore Amphibolite

In the Indus Valley, between Tungas and the confluence with the Turmik Valley, the dominant rock type is amphibolite interleaved with layers of pure saccharoidal marble (south of Tungas, across the Indus Valley), and crossed by concordant and discordant dykes of porphyritic quartz diorite and granodiorite. The amphibolites of the Askore Formation, of volcano-sedimentary origin have been already described by Desio (1963) in the Askore Valley, and by Zanettin (1964) along the Indus River. In addition, we have studied and sampled them in the upper Turmik Valley (south of Stak-La) and in the Askobar Valley (a left bank tributary of the Turmik).

They include garnet amphibolites (well exposed in Askore Valley and in Askobar), and repeated fine grained layers of amphibolite gneisses, amphibolite-biotite gneisses, biotite-amphibole gneisses, and epidote amphibolite gneisses. The main paragenesis contains plagioclase (andesine-oligoclase) - hornblende ± biotite, ± epidote and rare quartz (Zanettin, 1964; Rolfo, 1994). Southward, the amphibolites become more quartzo-feldspathic with some quartzopelitic horizons and conglomeratic layers with amphibolitised pyroxenitic blocks or quartzo-feldspathic and amphibolitic blocks. In the Askobar Valley, the amphibolite is overlain by pink quartzite and white marble, possibly a metasedimentary cover of the original basaltic sequence.

The Greenstone Complex

Strictly speaking, the Turmik and Ganto-La Formations (Desio, 1963 & 1964; Zanettin, 1964; Desio et al., 1985) exposed in the Turmik Valley, and the amphibolites of the Askore Formation (Zanettin, 1964; Desio, 1964; Desio et al., 1985) exposed in the adjoining Askore Valley, constitute the Greenstone Complex of Stauffer (1975), slightly more restricive than the original Greenstone Complex of Ivanac et al. (1956). After the presentation of the Askore Formation, we now describe the Turmik part of the Greenstone Complex.

In the Turmik Valley, the Greenstone Complex consists of a metasedimentary sequence tightly interbedded with basic metavolcanics and minor ultrabasic rocks, the Turmik Formation of Desio et al. (1985).

A little north of Dasu, on both sides of the valley, blastomylonitic arenaceous slates mark the beginning of the Greenstone Complex volcano-sedimentary series. The stratigraphic sequence of the slates is not known because they are strongly folded.

On the northern side of the Turmik Valley, the clastic nature of the metasedimentaries becomes more conspicuous as they include quartz-albite-epidote-chlorite-carbonate arenaceous slates, conglomeratic schists with variably abundant micaceous matrix, and conglomerates. The clasts of the conglomeratic material, up to 15 cm in length, are of acid to intermediate volcanic rocks, marble, quartzite, amphibolites, and minor serpentinite. There is a general opposition between the dominant nature of the clasts and that of the matrix: when the clasts are metavolcanic, the matrix tends to be limy; and reciprocately, when the clasts are made up of marble, the matrix contains much volcanic material.

Also occurs a sheet, more than one hundred metres thick, made up of light green quartz-plagioclase-muscovite-chlorite-epidote phyllite with large rhombohedral carbonate pseudomorphs and, sporadically, of low-iron epidote, partly to completely replacing plagioclase porphyroclasts (Rolfo, 1994).

The Greenstone Complex contains numerous limestone horizons. The major one, the Pakora Limestone, separates a southern band of tuffaceous schists from a northern band richer in mafic material and including lenses of serpentinite.

The Pakora Limestone

The Pakora Limestone reaches a maximum thickness of about 2 km along the Pakora section, SW of the Ganto-La, but has the shape of a very elongated lense. 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 post-Valanginian rudists in black limestone boulder from the left bank of the Pakora stream (Le Fort et al., 1992), *belemnite* remains and *echinoderm* fragments from the Tisar side (new finding of the 1993 expedition).

The Pakora Limestone is a succession of different horizons of white massive marble, dark limestone, and banded limestones (green and white). The rocks are resistant and the *belemnites* show rotation structures. The Pakora Limestone displays a good continuity along the northern (left) bank of the Turmik Valley but exhibits very rapid change of thickness. In the eastern part (Tisar Valley, near the Shigar Valley) it disappears completely in spite of the 2 km vertical thickness in the Pakora gorges ten kilometres westward. In the same manner, its thickness decreases dramaticaly to the west where it swirls around the syntaxis. A similar variation of thickness is shown by the limestone band of the southern side of the valley.

The Pakora Limestone is strongly deformed and metamorphosed. Metamorphic minerals include white mica and chloritoid in limestone, and kyanite in graphitic schist intercalations (Rolfo, 1994).

The Northern Band

The Northern Band is composed of tectonic lenses of limestone, quartzite, micaschist, mylonitizised biotitic gneiss, black shale, amphibolites, serpentinite, gabbro (described below), meta-conglomerate with basic elements, chloritoschist, and metabasite.

The Southern Band

South of the Pakora Limestone the Turmik Valley cuts a thick volcano-sedimentary formation mainly composed of alternances of greenschists with pluri-millimetric rhombic calcite and minor horizons of fine pyritic amphibolitic and conglomeratic layer, more quartzofeldspathic with centimetric elements of amphibolites and greenschists. A few boulders of stretched pillow-lavas are also observed.

The Ladakh Plutons

Numerous plutons and dykes are intruded into the different formations of the Ladakh unit.

Along the Indus, at the confluence with the Turmik River, a network of dykes intrude the Askore Amphibolites. It is related to a plutonic body exposed near Skoyo, previously named Skoyo Gneiss (Desio, 1963; Zanettin, 1964), that has a composition of a magnesian tonalite (Table 1A). The main petrographic type of the Skoyo pluton is a mesocratic gneiss consisting of oligoclase megacrysts in a ground mass of quartz-oligoclase-biotite-epidote-hornblende. 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 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).

South of the Skoyo pluton, between Baycha and the ridge south of Turmik, a small laccolith of Bt-Mc leuco-granodiorite, concordant with the foliation, can be observed on both banks of the Indus. The hypersthene diorite, described by Zanettin (1964), near Tungas, is not outcropping along the valley bottom. Only big boulders were found on the right bank of the Indus, coming with a rockslide from higher up on the right bank of the valley. It has a composition of quartz-diorite (Table 1B).

Along the right bank of the Shigar Valley a great plutonic complex is exposed (Desio, 1964). It has been previously described as Tisar Tonalite, Chundupon Gabbro-diorite and Skoyo Gneiss by Desio (1963), tonalite, gabbro-diorite and amphibole-gabbro by Zanettin (1964), and Twar diorite and Skoyo gneiss (Desio et al., 1985). Our observations confirm that this plutonic complex is composed of several bodies of gabbroic, granodioritic, tonalitic, dioritic and granitic composition (Table 1C-1F). The diorites are the dominant type with few gabbros and granites. They are intruded into the Askore Formation and Greenstone Complex and seem to cut the contact between the two, although we have not been able to reach this far off point. These plutonic rocks are either deformed, with a penetrative metamorphic cleavage, or undeformed, underlining the polyphased nature of the plutonism occuring before and after the collision of the Ladakh island arc with the northern margin, the Shyok Suture, between 80 and 70 Ma (Honegger et al., 1982; Petterson & Windley, 1985; Pudsey, 1986; Treloar et al., 1989a; Reuber et al., 1990).

In the Greenstone Complex, along the valley of Gontsar, also called Matumber Lungma, a left bank tributary of the Turmik River, a kilometre thick body of gabbro is intruded into the meta-sedimentary and meta-volcanic formations. Chemically, the rock has a sub-alkaline tendancy (monzogabbro). It is deformed on its border, but quite massive and isotropic in its central part. The contact with the surrounding formations is partly faulted.

Finally, in the valley of Remendok, a southern tributary to the Chogo Lungma, at the limit between the Ladakh and the Himalaya units, we have discovered an elongated body of intrusive leuco-trondhjemite (Table 2). The importance of this body rests in the fact that, little deformed, it is intruded in both units, and thus, should enable us to date the contact.

Table 1 Chemical analyses of major and some trace elements for some plutonic bodies of the Ladakh unit. The four Debon and Le Fort (1988) parameters are also given. n = number of analyses
Analyses by ICP and ICPMS, by K. Govindaraju (C.R.P.G., Nancy, France)

	A	B	C	D	E	F
	Skoyo	Tungas		other Ladakh plutons		
	To	DQ	To	MZDQ	D	Go
n	2	1	1	2	1	1
SiO2	67.62	53.57	69.29	59.76	54.71	47.71
Al2O3	16.15	17.56	16.28	16.90	16.68	15.74
Fe2O3t	2.58	9.53	2.66	5.90	9.37	11.20
MnO	0.03	0.20	0.08	0.10	0.15	0.18
MgO	1.72	4.25	0.77	2.40	3.73	7.43
CaO	4.34	8.21	3.77	5.46	6.46	10.87
Na2O	4.90	2.61	4.00	3.97	3.81	2.40
K2O	1.19	1.70	1.77	2.80	2.03	1.31
TiO2	0.30	0.90	0.27	0.50	1.27	0.65
P2O5	0.11	0.22	0.13	0.24	0.35	0.20
I.L.	0.84	1.10	0.64	1.64	1.21	2.08
Total	99.78	99.85	99.66	99.67	99.77	99.77
P	**-210**	**-194**	**-158**	**-166**	**-195**	**-243**
Q	**140**	**80**	**173**	**80**	**61**	**30**
A	**-21**	**-67**	**55**	**-74**	**-69**	**-184**
B	**79**	**235**	**18**	**140**	**226**	**332**
Ba	255	176	276	730	275	222
Be	0.65	0.96	0.9	1.83	1.5	0.2
Cr	44	29	13	22	4	184
Cu	11	59	<5	25	42	98
Ga	18	20	43	18	18	16
Nb	1.8	4.9	8	7	9.9	1.9
Ni	23	19	16	11	7	44
Rb	30	75	60	94	50	20
Sc	5.9	20	4.5	10	15	30
Sr	555	357	419	613	433	597
Th	1.7	6	10	15	4	1
U	0.78	1.2	nd	3	1.1	0.5
V	60	256	25	115	185	337
Y	4.8	24	9.7	18	22	13
Zn	32	90	51	65	75	75
Zr	68	110	134	139	125	32

THE KARAKORUM METAMORPHIC COMPLEX (KMC)

It is the most complex unit, that can be schematically subdivided into three sub-units: the gneissic domes representing the backbone of the structure, the metasedimentary formations lying north and south of them, and the undeformed granitoid intruded into the metasedimentary formations. The relationship between the orthogneiss and the metasedimentary formations is not always clear. 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;

(ii) the Aralter elongated body, forms an individualized dome intruded into an amphibolitic layer north of the Ganchen peak. This body as the previous meta-granitoid is gneissified by the main tectono-metamorphic events.

Table 2 Average chemical composition and standard deviation of four samples from the Remendok leucotrondhjemite, with Debon and Le Fort (1988) parameters
Analyses by ICP and ICPMS, by K. Govindaraju (C.R.P.G.), Nancy, France

SiO_2	***73.77 ± 1.05***	*Ba*	***425 ± 218***
Al_2O_3	15.11 ± 0.37	Be	2 ± 0.7
Fe_2O_3	0.66 ± 0.28	Cr	0.8 ± 0.7
MnO	0.02 ± 0.02	Cu	2.7 ± 0.5
MgO	0.15 ± 0.12	Ga	14 ± 2
CaO	2.23 ± 0.33	Nb	2.3 ± 1.6
Na_2O	5.22 ± 0.36	Ni	1.7 ± 0.6
K_2O	1.83 ± 0.55	Rb	53 ± 18
TiO_2	0.03 ± 0.03	Sr	415 ± 86
P_2O_5	0.04 ± 0.02	Th	0.3 ± 0.3
I.L.	0.53 ± 0.20	U	0.5 ± 0.4
Total	99.57 ± 0.41	V	2.7 ± 1.5
		Y	3 ± 2.8
P	-170	Zn	25 ± 14
Q	176	Zr	34 ± 10
A	10		
B	12		

The domes themselves are composed of alternances of ortho- and para-gneisses whose metamorphic grade is stronger than that of the metasedimentary formations, with a sharp transition. Moreover, ortho-gneisses can be found as fold cores (Bolocho), or as screens inside the metasedimentary formations (Moraine, Bolocho) (Fig. 4).

In addition, the Solu granitoid (Karakorum batholith), non deformed, is intruded into the metasedimentary formations and includes some screens of limestone. Its contact with the country rocks has not been observed, although it sends a swarm of dykes into it.

The Gneissic Domes

In the mapped area, two main gneissic domes are individualizised: the Mangol Bluk dome and the Bukpun dome west of Arandu, that shows a migmatitic core well exposed at the entrance of Kero Lungma. A third smaller one, the Aralter dome, is mantled by amphibolitic levels. In addition, to the SE, lies the first recognised dome of the area, the Dassu gneiss dome (Bertrand et al., 1988; Allen and Chamberlain, 1991) extending across the entire Braldu Valley.

The domes are composed of orthogneiss (with compositions ranging from granite to tonalite) and paragneiss strongly structured by a phase of isoclinal folds preceeding the doming phase. The paragneiss, of pelitic origin, 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) give pressure and temperature of 4-10 kbar and 550-625°C.

On both sides of the Basha Valley the gneisses are cut by late plurimetric pegmatitic dykes with a gentle dip and a mild deformation.

The Metasedimentary Formations

These formations are composed of alternances of limestone, dolomite, quartzite, micaschist with some conglomeratic layers, and rare amphibolitic horizons of basaltic composition (Fig. 4). They are well exposed on the northern side of the Chogo Lungma and in the Niamur Valley south of the Chogo Lungma. They have been strongly structured by at least two phases of deformation including a south vergent isoclinal folding well preserved in Moraine Glacier (Fig. 5) and in Kero Lungma, and include some slabs or fold cores of orthogneiss. The deformation and lack of good marker beds preclude retrieving the stratigraphy and original thickness of these formations.

Some marble horizons show a good continuity and can be followed all along the left (north) bank of the Chogo Lungma, underlining the main structures. The limestones are marbles, usually saccharoid, more or less impure, and sometimes banded. The Chutrun limestone (Matuntore limestone of Desio, 1963) outcrops west of the Basha River in the Baltoro and Naltoro Valleys, where it underlines the contact of the Karakorum Metamorphic Complex with the Greenstone Complex, and occasionally contains tremolite

The quartzite layers are more or less compact, sometimes alternating with micaschist. Ripple-marks have been observed in the Niamur and Naltoro Valleys.

The metamorphism of the metasedimentary formations decreases progressively from east to west. In Niamur, the micaschists display a Grt-St paragenesis while in Moraine and Bolocho glaciers we have only noticed the development of phlogopite in some limestone horizons.

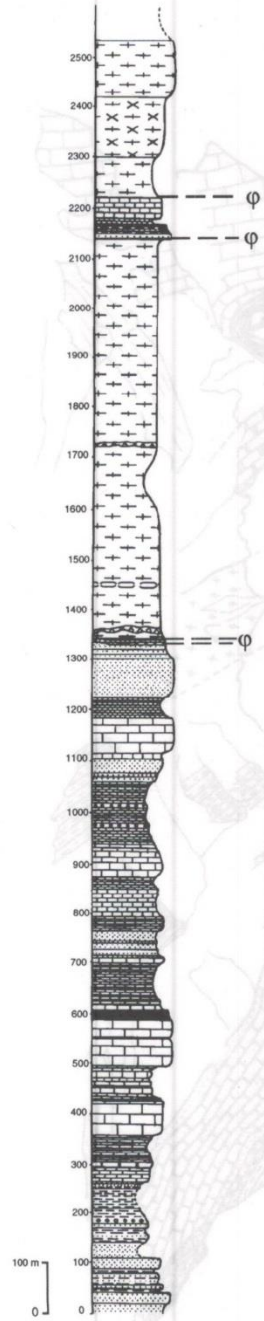

Fig. 4 Stratigraphic column of the left bank of the Moraine glacier
It is made up of alternances of marble, quartzite, micaschist, with some amphibolitic layers, and screens of orthogneiss with mafic dykes.
The contact between the orthogneiss and the meta-sediment is concordant and follows the axial plane schistosity. Neither contact metamorphism, nor mylonites has been noticed. Notwithstanding the isoclinal folding, the massive marble layers have a remarkable continuity along the Chogo Lungma watershed (see map, Fig 2).

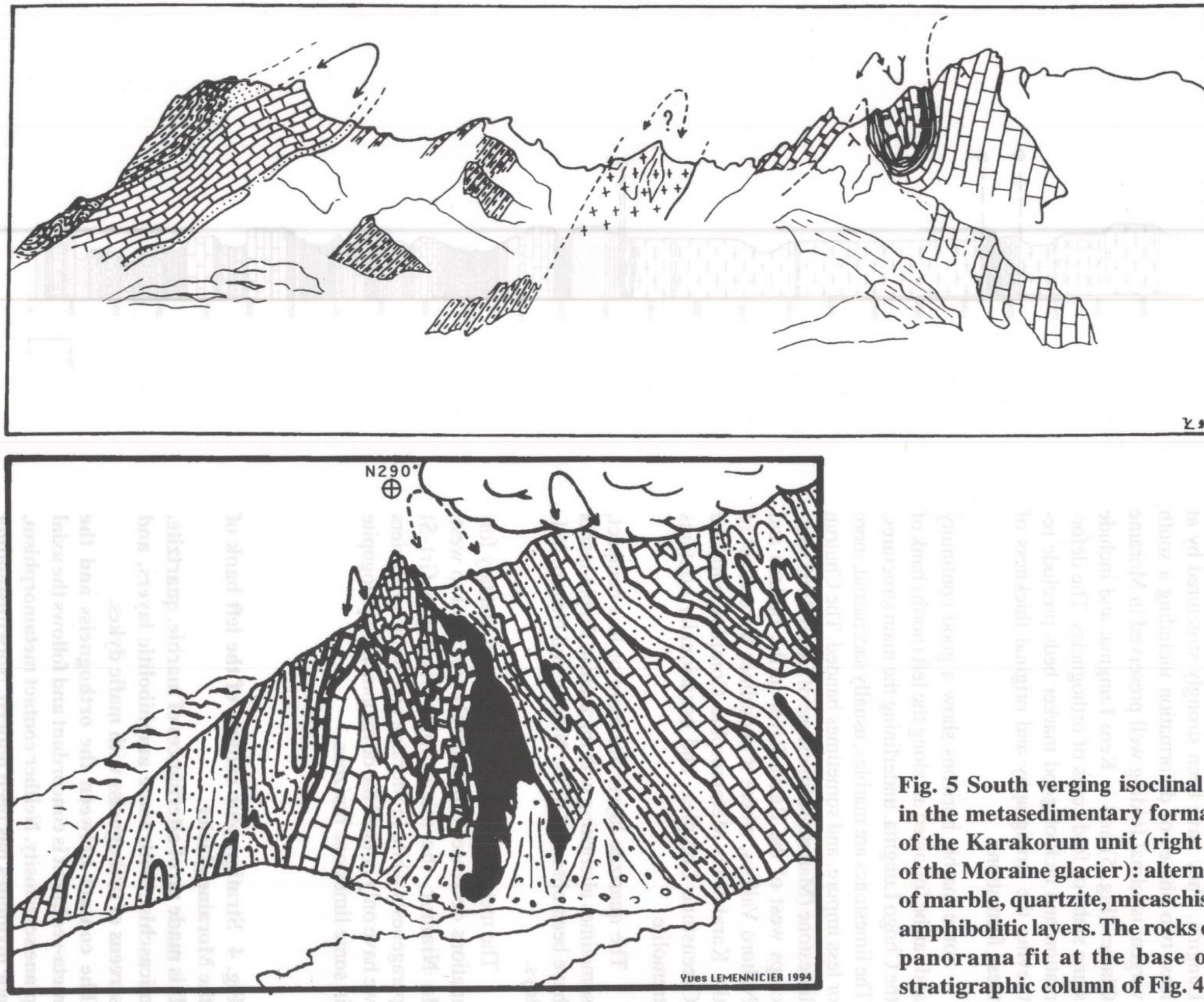

Fig. 5 South verging isoclinal folds in the metasedimentary formations of the Karakorum unit (right bank of the Moraine glacier): alternances of marble, quartzite, micaschist and amphibolitic layers. The rocks of this panorama fit at the base of the stratigraphic column of Fig. 4.

The Syn-Doming Magmatism: the Hemasil Syenite

On the left bank of the Basha River, just north of Hemasil, a small body of syenite is exposed and forms the hart of a small domal structure. It has a gneissic aspect at the outcrop scale. Microscopically, it shows a magmatic texture with oligoclase-microcline-green biotite- sphene ± hornblende and some relict pyroxenes. 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.

The syntectonic character of the syenite is mainly supported by the following observations:

- a magmatic foliation, even in the central part of the pluton, the foliation being concordant with the regional tectono-metamorphic cleavage,

- the development of ductile shear planes at the border of the pluton, and

- its domal structure elongated in a N140° direction.

Dating of the syenite may thus provide a lower age limit for the doming.

REGIONAL TECTONICS AND STRUCTURAL OBSERVATIONS

We will consider some structural aspects of the three units and of their two contacts.

THE KARAKORUM METAMORPHIC COMPLEX

The structural and metamorphic aspects of the KMC have been already considered by Bertrand et al. (1988), in the Braldu Valley, just east of the mapped area, and by Allen and Chamberlain (1991) in the Braldu and Basha Valleys.

The geometry of this unit is well shown by the metamorphic cleavage trajectories map that we have established using our detailed structural measurements (Fig. 6). Two main phases of deformation have been identified: a first phase of isoclinal folds, corresponding to the D2 phase of Bertrand et al. (1988), and a second phase of open folds corresponding to the dome structuration. The first phase of Bertrand et al. (1988) (D1), a N20-N40° isoclinal folding, has not been clearly observed.

The isoclinal phase is well preserved in the northern part of the metasedimentary formations, in the valleys of Moraine glacier and Kero Lungma (Fig. 5). The south-verging isoclinal folds are observed at all scales with the development of an axial plane schistosity (Fig. 7A), transposition of the bedding, and formation of boudins and subparallel shears giving a south-verging direction of movement. The structuring of the orthogneiss sheets observed in moraine glacier, showing a concordant foliation with the rest of the formation can be linked to this phase.The main axial direction of the folds is N120° in Moraine glacier and N107° in Kero Lungma. Folds axes are dispersed in the main metamorphic cleavage plane, implying a strong flattening deformation (Fig. 7B). The presence, in the Aralter orthogneiss, of flattened Bt-rich autoliths with a circular section confirm this kind of regime. The flattening ratio observed on these enclaves give a qualitative estimation of 1/10.

A second E-W phase of open folds with a north-verging direction, well exposed in the upper part of Bolocho, redeforms the isoclinal fold phase. It can be linked to the doming phase.

The dome structures are well exposed along the Basha Valley and in the lower part of the Chogo Lungma. The main domes are: (i) the Bukpun Dome, an elongated dome of N115° direction with a migmatitic core; (ii) the Mangol Bluk Dome with an elongation axis around N140° (Fig. 8A); (iii) the elongated and pinched Aralter Dome, oriented around N115°, with a boudinaged western termination; and (iv) the small N140° syenitic dome of Hemasil. The structure of the domes is underlined by the main schistosity inherited from the isoclinal folding phase

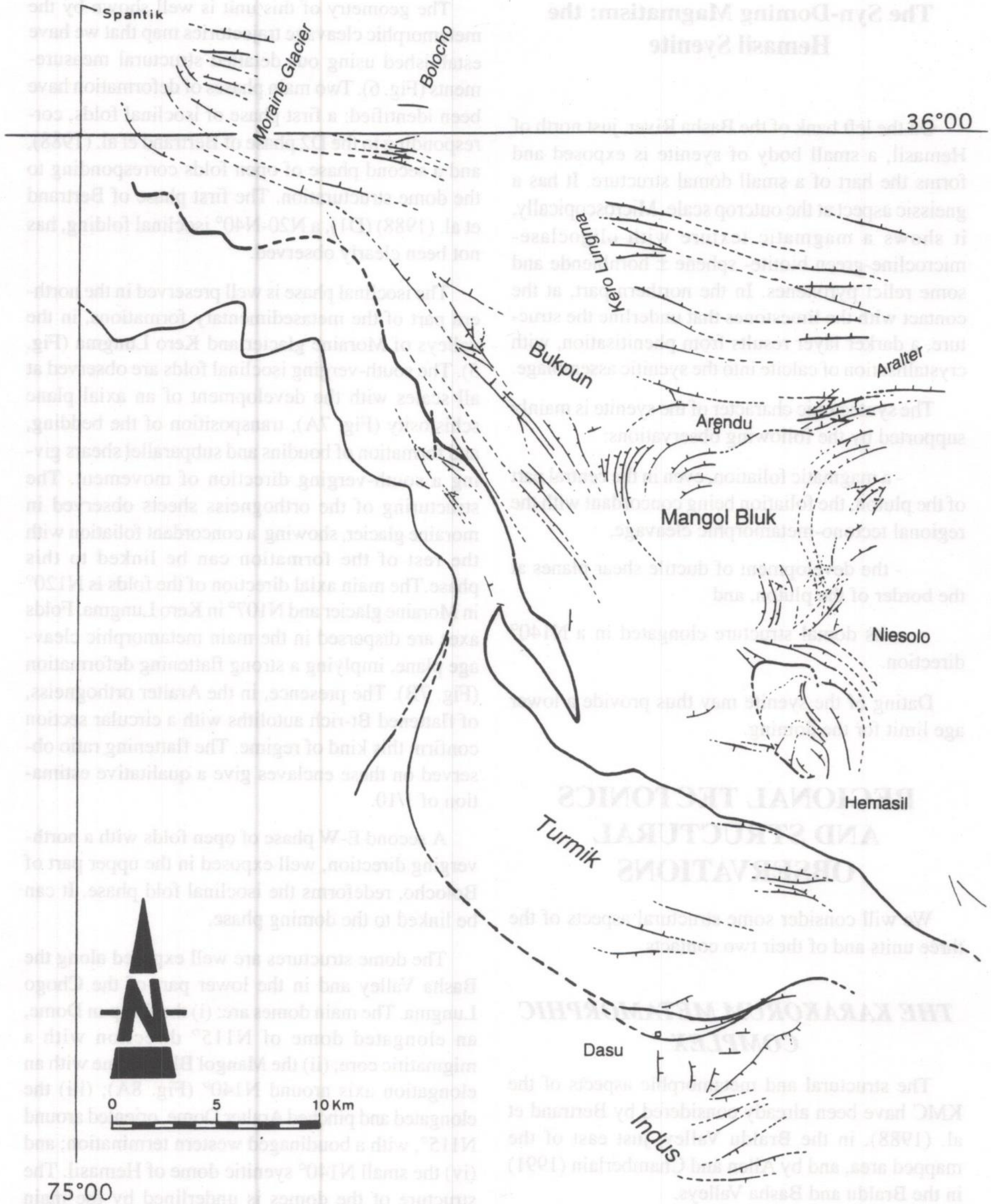

Fig. 6 Metamorphic cleavage trajectory map

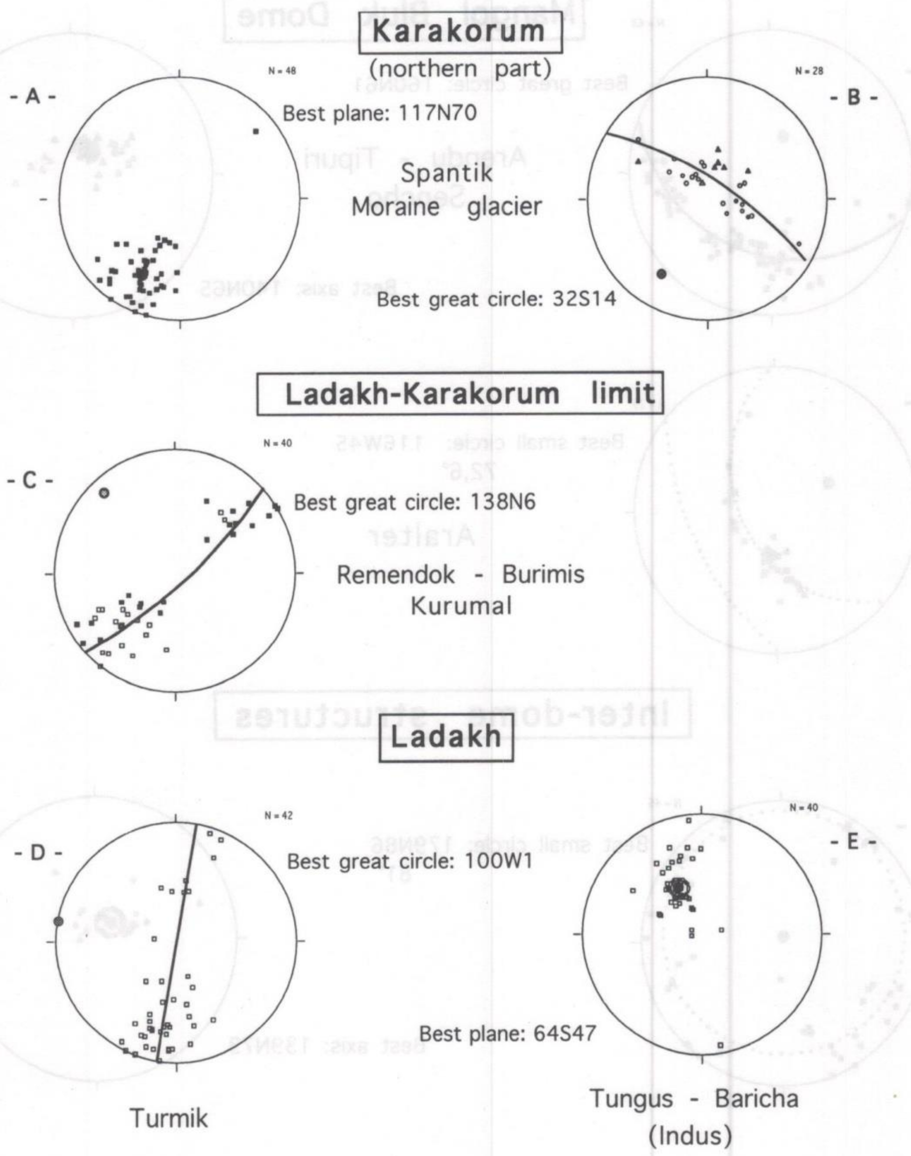

Fig. 7 Stereographic representation of the main structural aspects of the Karakorum and Ladakh metasedimentary formations (Wulff, lower hemispher)
Filled squares: metamorphic cleavage in Karakorum; open squares: metamorphic cleavage in Ladakh; open circles: intersection lineation; filled circles: fold axis; open triangles: stretching lineation; filled triangles: mineralogical lineation
A: isoclinal folds in Moraine glacier B: dispersion of the intersection lineation in the axial plane of the isoclinal folds corresponding to a flattening regime of deformation C: folding of the Karakorum-Ladakh limit by the N140° direction folds D: late folding of the Ladakh formation E: monoclinal structure of the amphibolites along the Indus river

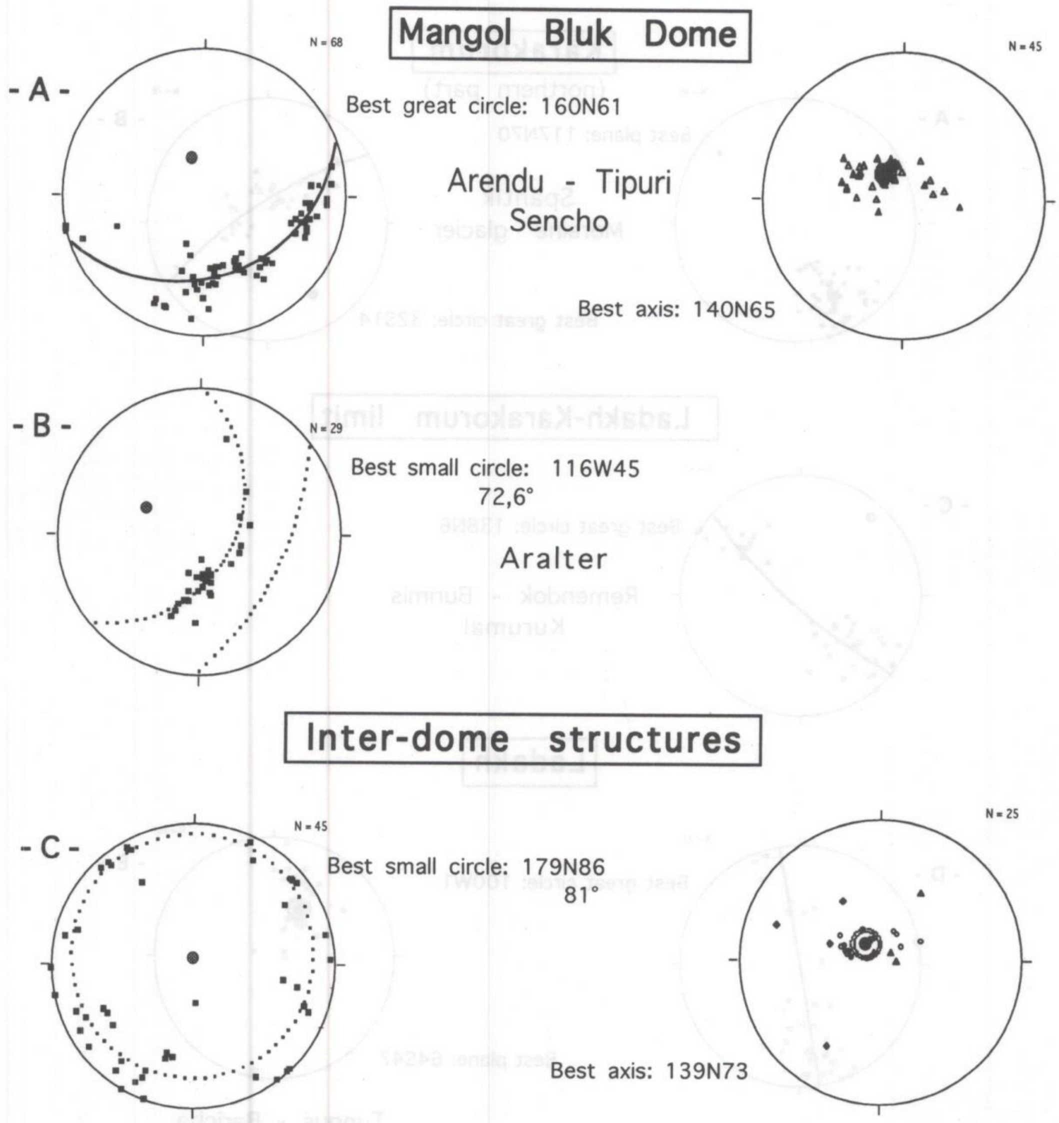

Fig. 8 Stereographic representation of the main structural aspects of the Karakorum domes (Wulff, lower hemisphere)

Filled squares: metamorphic cleavage; open circles: intersection lineation; filled circles: fold axis; open triangles: stretching lineation; filled triangles: mineralogical lineation; filled diamond: magmatic lineation.

A: main axial direction of the Mangol Bluk dome in the northern limb of the structure B: conical fold pattern in Aralter valley C: conical fold pattern of the interdome structure in the area of Niesolo. This area corresponds to a "triple point of schistosity" between the Mangol Bluk dome and the Hemasil dome

as shown by the internal structures of the Mangol Bluk dome in the upper valley of Doko. In this valley, the isoclinal folds, marked out by an alternance of light coloured orthogneiss and dark paragneiss layers are refolded in a great antiformal structure of N140° direction. Conical shapes, following the metamorphic cleavage distribution, are observed near Niesolo and Aralter (Fig. 8B, 8C). These conical folds have a steep NW plunge (nearly at 45°) except for the Niesolo one that corresponds to an interdome structure with a quasi-vertical axis. The conical folds are characteristic of interference patterns (Ramsay, 1967; Nicol, 1993) and can be formed in a one- or two-phases fold system. The two-phase interference domes have a very high degree of geometric organisation. They show systematic differences in style, amplitude, wavelength of the folds and in the nature of the accompanying linear and planar fabric (Ramsay and Huber, 1987). These features are not present in the KMC domes as shown by the difficulty to interpret the linear fabrics and the impossibility to define a chronology for the two fold sets. This is why we consider the KMC dome structures as a one-phase fold system.

THE LADAKH UNIT

The Ladakh unit has undergone a minimum of two phases of deformation, as shown by the two schistosities observed under the microscope, before a late N100° direction fold event (Fig. 7D), that deforms the Askore-Turmik contact.

Along the Indus River and in the Turmik Valley, the structure appears to be relatively monoclinal with a south (Turmik) or south-east plunge (Indus) (Fig. 7E). In the Askore amphibolites, along the Indus, we have noticed the following points: (i) strongly deformed dykes, either transposed in the schistosity, or folded in a ptygmatitic manner; (ii) strong boudinage; (iii) small pluricentimetric isoclinal folds; (iv) asymmetric boudins at the entrance of the Baycha Valley; (v) shear movements in the granitoid dykes.

In the Turmik Formation, the northern part is mainly structured by the brittle structures forming the tectonic lenses, concordant with the main schistosity. Mineral lineations observed are concordant with those seen in the Karakorum Metamorphic Complex. Small isoclinal folds have been noticed in several places but are not easy to recognize. In the northern band, the schistosity is subvertical or with a strong northern dip, stronger than the bedding.

THE HIGH-HIMALAYA

The structure of the HHC seems to be independent from the general shape of the Nanga Parbat - Haramosh spur. Only at the top, close to the contact with the Ladakh unit does the gneissic foliation tend to be parallel with the tectonic contact and show a periclinal trend. This observation has been made both in upper Turmik Valley on the Indus side, and in Niamur and Remendok Valleys on the Chogo Lungma side.

The internal structure of the antiform along the Indus gorge section is complicated by second order antiforms, such as the north-plunging Bulache Antiform (Verplanck, 1986). Like in the major antiform, folding along the Bulache Antiform is relatively late and post-dates an early imbrication between the Iskere and the Shengus Gneisses (Madin et al., 1989). Imbrication is defined by sillimanite-bearing mylonites (Treloar et al., 1991).

THE MAIN TECTONIC CONTACTS

The Himalaya - Ladakh Contact (or ITS)

In the studied area, the HHC are tectonically bounded by amphibolites of the Ladakh unit. Near the confluence of Stak Valley with the Indus River, the contact between the HHC and the amphibolites and gabbros of the Ladakh unit is a normal fault zone with mylonitisation and brecciation according to Verplank (1986).

In the upper Turmik Valley, just east of Stak-La, the boundary is defined by a shear zone dipping 25° to 40° towards the ESE. There, the ductile mylonitic zone is a few tens of metres thick (Fig. 9) and the shear-sense indicators (i.e. asymmetrical folds and minor S-C fabrics) give a prevalent dextral strike-slip regime with lateral shear of the Ladakh unit to the south (Pognante et al., 1993). This movement is contemporaneous with retrograde metamorphism at the top of the HHC.

In the area between the Turmik and Chogo Lungma Valleys, the strike of banding, foliation and of the HHC-Ladakh contact rotate from N-S to SE-NW and then to E-W. The contact itself is difficult to reach in this area because of the thick glacial deposits, rugged terrain, and, in Remendok Valley, is masked by a leuco-trondhjemitic intrusion on the contact zone. A few observations tend to prove, however, that thrusting has been the main mechanism operating in this portion of the contact.

The Ladakh - Karakorum Limit (Shyok Suture or Northern Suture)

The contact between the Ladakh unit and the Karakorum Metamorphic Complex was surveyed at several places including the western side of the Burimis Valley (between Remendok and Niamur), the Niamur Valley, and the area between Hemasil and the Ganto-La.

In the two first areas, Karakorum marbles overlie Ladakh basic schists. The marbles are strongly cataclastic, and the schists show S-C structures giving a top to the S-SW shear sense. The S-C structures are younger than the regional foliation in both series. Similar structures are documented in the Ladakh rocks, together with asymmetrical metric folds and slickenslides, which give the same sense of movement as the Karakorum rocks.

In the third area, the contact between the Chutrun Limestones and the Greenstone Complex that marks the limit is clearly folded by the N140° fold phase that deforms the Metasedimentary Formations in this area (Fig. 6). This fold direction corresponds to the doming phase, post-isoclinal folding. The structural similarity of the last major phase between Ladakh and Karakorum in this area, implies a common stress field during this deformation.

The folded Ladakh - Karakorum limit was reactivated by the late brittle thrusting of the Main Karakorum Thrust (MKT; Tahirkheli et al., 1979; Tahirkheli, 1982; Coward et al., 1986; Hanson, 1986 & 1989; Bertrand et al., 1988; Allen & Chamberlain, 1991; Searle & Tirrul, 1991) which has already been described further east in the Bauma Harel and Skoro-La areas. It now follows a quite planar trajectory accross the entire territory, and is one of the latest tectonic event of the region.

SOME CONCLUDING REMARKS

In the Ladakh unit, the volcano-sedimentary formation of the Askore amphibolites represents the volcanic part of the Ladakh island arc. From its compositional and deformational characteristics, it is equivalent to the Dras1 Formation (Reuber ,1989), described some 100 km south-eastward in Ladakh.

The Turmik Formation, with its varied and typical lithology, its low-grade metamorphism and internal structures is a tectonic mélange formation. Its petrographical and structural features can be compared to those of the Shyok Suture Formations (Brookfield, 1980; Coward et al., 1982; Pudsey, 1986). However, the thickness of the latter does not exceed 4000 m, while the thickness of the Turmik Formation reaches 10 km at its maximum. As already mentioned for Ladakh by Hanson (1986) and for Kohistan by Pudsey (1986) and Sullivan et al. (1993), this formation very well corresponds to a back-arc basin of post-Valanginian age, wedged between the island arc sensu stricto. and the Karakorum margin of the neo-Tethys.

For the tectonometamorphic evolution of the KMC, two models have been put forward:

- Allen and Chamberlain (1991), suggest an inverted metamorphic sequence due to nappe emplacement.with a simple prograde metamorphism of medium to high-pressure producing Ky and Ky-Sill grade rocks. This metamorphic evolution is considered older than the 37.0 ± 0.8 Ma Mango-Gusor pluton and predates the main tectonic evolution;

- Bertrand et al. (1988), on the other hand consider a two-phase metamorphic evolution with a Grt-Ky-St paragenesis associated to the D1 ante-Mango Gusor intrusion isoclinal folding, and a Sill + higher pressure minerals corresponding to the doming phase between 20 and 8 Ma.

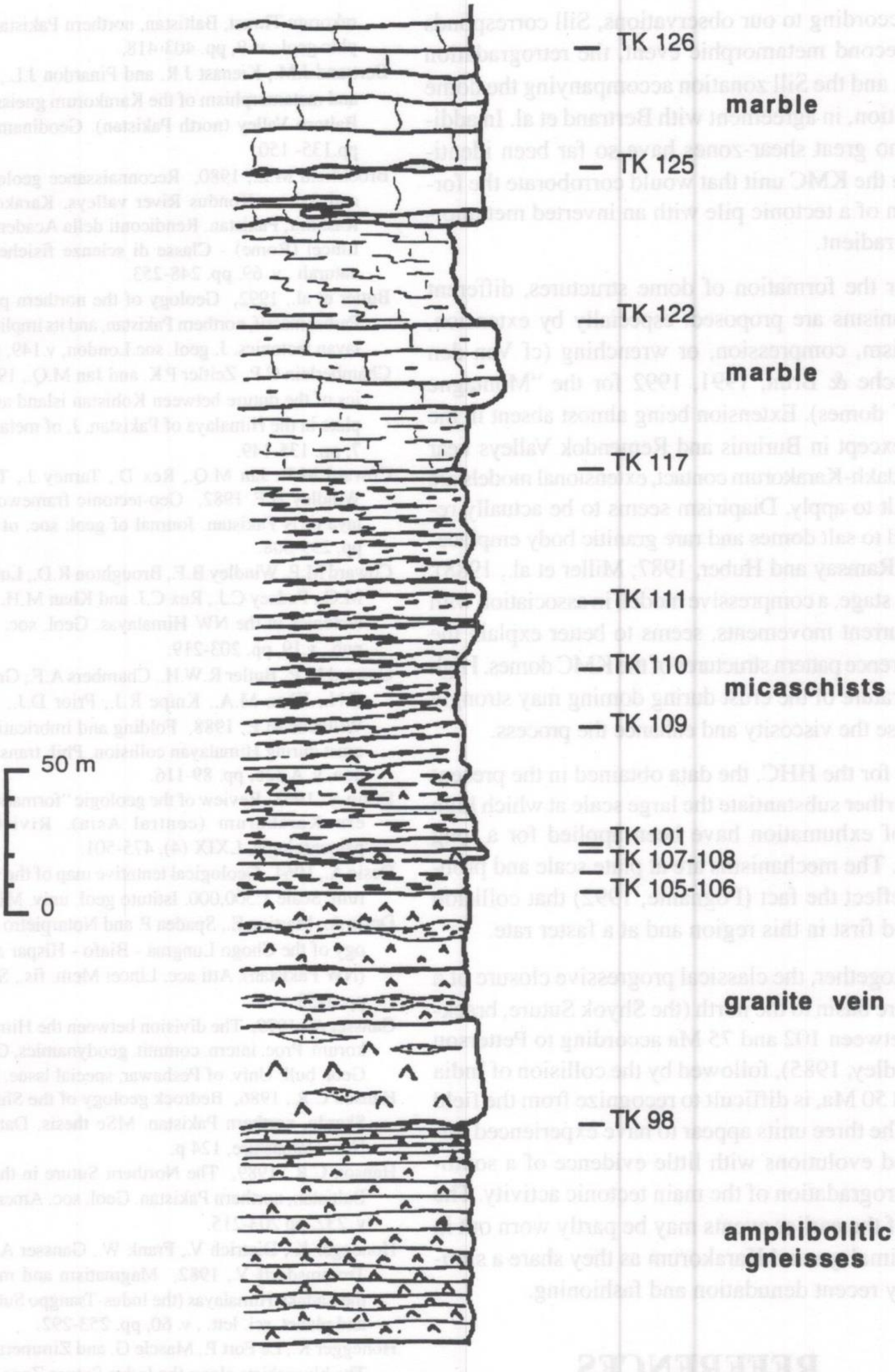

Fig. 9 Synthetic log of the western contact of the HHC with the Ladakh unit, left bank of the upper Turmik valley. The amphibolitic gneisses at the base, intruded by granitic dykes having boudin structures, probably belong already to the Askore amphibolite. Higher up, come the schists and marbles of the Greenstone Complex (Turmik formation). The position of the major samples is indicated.

According to our observations, Sill corresponds to a second metamorphic event, the retrogradation of Ky, and the Sill zonation accompanying the dome formation, in agreement with Bertrand et al. In addition, no great shear-zones have so far been identified in the KMC unit that would corroborate the formation of a tectonic pile with an inverted metamorphic gradient.

For the formation of dome structures, different mechanisms are proposed: especially by extension, diapirism, compression, or wrenching (cf Van den Driessche & Brun, 1991, 1992 for the "Montagne Noire" domes). Extension being almost absent in the area, except in Burimis and Remendok Valleys near the Ladakh-Karakorum contact, extensional models are difficult to apply. Diapirism seems to be actually restricted to salt domes and rare granitic body emplacement (Ramsay and Huber, 1987; Miller et al., 1988). At this stage, a compressive model, in association with transcurrent movements, seems to better explain the interference pattern structures of the KMC domes. High temperature of the crust during doming may strongly decrease the viscosity and enhance the process.

As for the HHC, the data obtained in the present area further substantiate the large scale at which high rates of exhumation have been applied for a long period. The mechanisms are at plate scale and probably reflect the fact (Pognante, 1992) that collision occured first in this region and at a faster rate.

Altogether, the classical progressive closure of a back-arc basin to the north (the Shyok Suture, bracketed between 102 and 75 Ma according to Petterson & Windley, 1985), followed by the collision of India around 50 Ma, is difficult to recognize from the field data. The three units appear to have experienced imbricated evolutions with little evidence of a southward progradation of the main tectonic activity. The trace of the earlier events may be partly worn out in NW Himalaya and Karakorum as they share a similar very recent denudation and fashioning.

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