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INTRODUCTION TO THE GEOLOGICAL MAP OF THE NORTH KARAKORUM TERRAIN FROM THE CHAPURSAN VALLEY TO THE SHIMSHAL PASS 1:150,000 SCALE

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Riassunto. Questa nota introduce una nuova carta geologica a scala 1:150.000, allegata al presente articolo. L'area cartografata include un vasto settore dell'alta valle di Hunza (Karakorum, Pakistan), situato a N del Batolite Assiale del Karakorum e comprendente la copertura sedimentaria del Karakorum, l'età della quale è compresa tra il Permiano e il Cretacico superiore. Sono state riconosciute 4 grandi unità strutturali, che risultano dislocate in modo complesso durante eventi orogenetici polifasici, attivi dal Cretaceo sino a tutto il Cenozoico, in conseguenza delle successive collisioni contro il margine asiatico dell'Arco del Kohistan prima e della Placca Indiana poi. La cartografia presentata, pur avendo un marcato carattere stratigrafico-strutturale, tiene conto, a grandi linee, anche della distribuzione dei depositi quaternari.

Abstract. These notes introduce a new geological map at 1:150,000 scale of a large part of the Upper Hunza valley (Karakorum, Pakistan). The mapped area includes the Permian to Cretaceous sedimentary cover of the Karakorum, which is located north of the Karakorum Axial Batholith. The mapped sedimentary and intrusive complexes form four major tectonic units, stacked in a very complex system, due to polyphase events, spanning from Cretaceous to Cenozoic. These events are linked to repeated collisions against the Asian margin of the Kohistan Arc during the Cretaceous and of the Indian Plate during the Cenozoic. Beyond the stratigraphic and structural characteristics of the deformed units, our map also considers the general setting of quaternary deposits.

Introduction.

The area depicted by the present map is located in the Upper Hunza valley, northern Pakistan (Fig. 1). The mapped area extends around the Hunza valley and along the Chapursan and Shimshal side valleys. Field work was mainly carried out by

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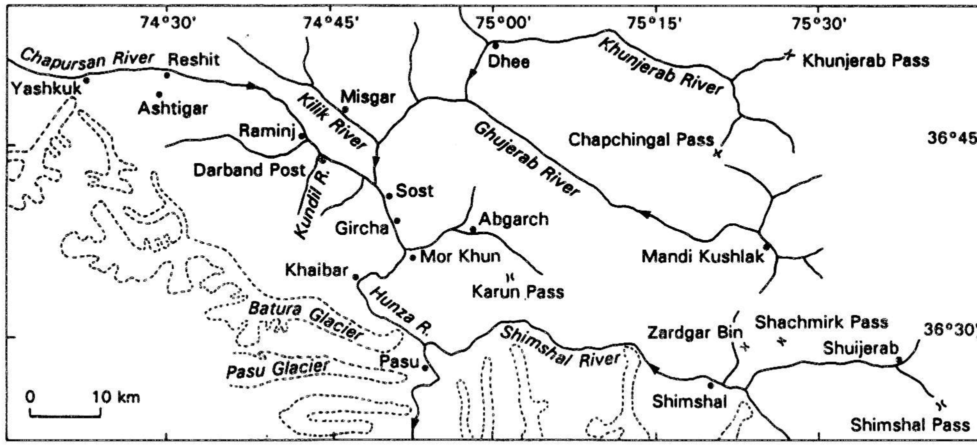


Fig. 1 - Simplified geographic scheme of the mapped area.

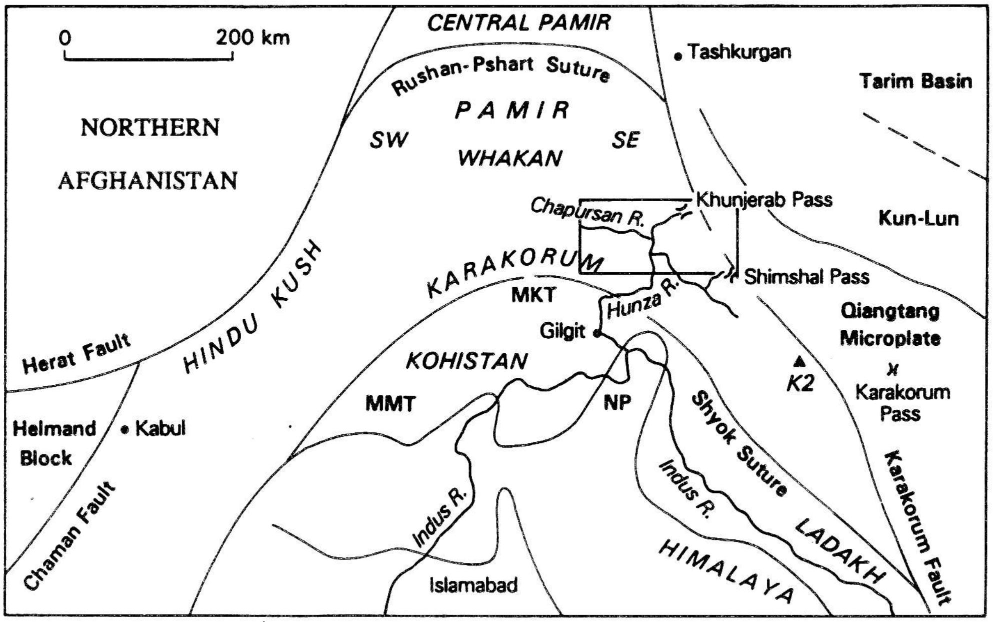
A. Zanchi during 1991 and 1992 and partly by M. Gaetani, F. Jadoul and L. Angiolini; F. Debon mapped the Karakorum Axial Batholith (KAB) along the Batura and Kuk-Ki Jerab glaciers during 1991. Paleontological data on conodonts by A. Nicora, Milano and on fusulinids by E. Leven, Moscow, substantially helped in establishing the stratigraphic succession. L. Angiolini studied the Permian brachiopods. The drawing process was coordinated by A. Zanchi.

A substantial contribution to the geological knowledge of the area came from the first expedition lead during 1986 in the Chapursan valley by the Italian team (Gaetani et al., 1990), whereas only general geological data were before available on the region (Schneider, 1957; Desio & Martina, 1972; Desio, 1979; Casnedi & Nicora, 1985). Moreover, the area covered by our new map is largely unrepresented in the recent map of Karakorum published by Searle (1991), as well as in the previous map edited by Desio (1964).

Field work was realized with the aid of the SPOT satellite imagery (scene 197-276 and 198-277) magnified at 1:50,000 scale. In order to have the contour lines we eventually decided to redraw a simplified topographic basis using the 1:250,000 scale topographic map edited by the American Army Map Series (Series U502 NJ 43-14 and 43-15), notwithstanding the evident biases, especially in the area north of Shimshal, where distances are severely distorted and reliability of the map is very poor.

Geological setting.

The Karakorum Terrane belongs to the peri-Gondwanian blocks rifted away from Gondwana during Late Paleozoic and accreted along the southern Eurasian margin before final collision with the Indian plate (Gaetani et al., 1990; Searle, 1991; Crawford & Searle, 1992). The Karakorum Block (Fig. 2) is located between two major suture zones: the Shyok Suture Zone to the south (Coward et al., 1986; Pudsey



MMT = Main Mantle Thrust MKT = Main Karakorum Thrust NP = Nanga Parbat

Fig. 2 - Tectonic sketch map of Northern Pakistan and surrounding regions. Squared area refers to the mapped area. NP) Nanga Parbat, MKT) Main Karakorum Thrust, MMT) Main Mantle Thrust. Modified from Gaetani et al. (1990) and Zanchi (1993).

et al., 1985; Searle, 1991 and ref. therein) and the Rushan-Pshart Suture to the north (Pashkov & Shvol'man, 1979; Shvol'man, 1981).

The Karakorum Block includes a thick sedimentary cover, which is mainly Paleozoic in the western termination and Permian to Cretaceous in the central and eastern area. In the Hunza valley, the cover consists of a thick pile of Permian-Cretaceous sediments cropping out north of the Karakorum Axial Batholith (KAB). The KAB separates the sedimentary cover to the north, named North Karakorum Terrain by Searle (1991), from high to low grade metamorphics present south of the KAB just north of the Shyok Suture Zone (see Searle, 1991 for a review).

The area here considered mostly includes part of the Northern Karakorum Terrain, which comprises intensively folded and thrusted sedimentary rocks with a very low metamorphic imprint, locally reaching low grade conditions (Zanchi, 1993). The Lower Permian to Upper Cretaceous succession of the North Karakorum represents one of the few terrains which escaped strong metamorphism during the India-Eurasia collision, thus permitting a detailed reconstruction of its stratigraphic framework (Gaetani et al., 1990; Gaetani et al., 1993). Plutonic bodies mainly of mid-Cretaceous age intrude the sedimentary cover forming a discontinuous granitic belt developed about 100 km north of the KAB.

Four main tectonic units were recognized in the mapped region (Gaetani et al., 1990).

1) The Misgar Unit.

The Misgar Unit largely extends along the northern part of the studied area and includes the monotonous succession of the Misgar Slates (Desio, 1963) in which only very few metacarbonatic and quartzitic intercalations were found. The thickness of the slates is high, exceeding thousand metres, although tight folding still prevents any precise measurement. No fossil findings are so far known in the studied area. The unit is strongly folded with intensive development of slaty cleavage. Fold axes generally trend E-W up to the Khunjerab Pass, where they turn to NNW-SSE. The Misgar Slates show local occurrence of low grade metamorphic conditions indicated by the presence of biotite, chlorite and muscovite (Gaetani et al., 1990). Granodioritic plutons with mid-late Cretaceous cooling ages (Crawford & Searle, 1992; Le Fort, 1993 pers. comm.; Ogasawara et al., 1992) are intruded in the northern part of the unit close to the Chinese and Afghan borders (Debon et al., 1987; Searle, 1991), as well as eastward in the Ghujerab and upper Shimshal valleys (Zanchi, 1993) and southward not far from Sost. Most of the plutonic bodies cross schistosity and folds; andalusite, biotite, muscovite and chlorite bearing contact metapelites are present around the main intrusives.

The southern boundary of the Misgar Unit is always tectonic, generally consisting in a south vergent thrust plane, the Northern Fault of Gaetani et al. (1990), stacking the Misgar Slates over Jurassic limestones and sandstones of the Sost belt. Large recumbent folds present along the northern flank of the Chapursan valley suggest southward motion of the Misgar Unit. South vergent thrusting clearly postdates folding and metamorphism of the unit.

A complex pattern related to dextral shear with a low grade metamorphic imprint and superposed brittle strike-slip faulting is present along the Misgar shear zone, which displaces and is in part coincident with the Northern Fault and the Misgar Fault of Gaetani et al. (1990) along the Karakorum Highway.

2) The Sost Unit.

This unit was defined by Gaetani et al. (1990) and includes the area mapped with major detail. The Sost Unit comprises a thick pile of folded and thrusted sheets forming in the whole an antiformal stack, later disrupted by strike-slip faults. The unit is bounded by two major faults, the Upper Hunza Fault (Desio, 1979) to the south-east and the Northern Fault to the north. Complexity of the tectonic pattern often prevented the reconstruction of continuous stratigraphic successions, as in the Middle to Late Jurassic sediments.

Very low metamorphic conditions are generally present with development of slaty cleavage and calc-mylonites along thrust planes. A low grade metamorphic imprint was observed in the lowermost units of the stack along the lower part of the

Shimshal valley. Only deep diagenetic conditions are also present in many units; here the Conodont Alteration Index is mostly around 4-5.

Fold axes and fault striations along the main thrust surfaces generally indicate a N-S compression. Northward and southward directed tectonic transport is respectively present along the southern and northern sides of the stack. In the lower part of the Shimshal valley the slates display well developed axial plane foliations, transposition, boudinage of quartzitic layers and mylonitic shear zones. Most of the structures here trend NW-SE as in the Guhjal Unit which is described further on. Schistosity is defined by sericite, muscovite and fine grained biotite, with occasional occurrence of epidote and chloritoid. This suggests low grade conditions of metamorphism with an important increase of temperature with respect to the other thrust sheets of the Sost Unit. The meaning of these shear zones is still poorly understood and may possibly be related to the eastward prosecution of the Hunza Fault juxtaposing the Gircha slates of the Guhjal Unit to analogous metasediments of the Sost Unit.

Important E-W trending sinistral strike-slip faults are present all along the Sost Unit and are possibly associated to NW-SE dextral strike-slip faults in the eastern side of the studied region and along the Kilik valley, where a NNW-SSE trending dextral strike-slip fault, the Misgar Fault, displacing previous contacts for some kilometres was noted by Gaetani et al. (1990). Wrench motions have been interpreted as related to complex deformation mechanisms active along the eastern side of the Indian Plate indenter (Zanchi, 1993 and 1994).

The stratigraphic succession present in the Sost Unit spans from Permian to Late Cretaceous. The main activity of the Italian team was devoted to unravel this Permo-Mesozoic succession. Beyond published papers on the subject and numerous communications presented to International Workshops and Congresses, several works are now in progress.

The presence of reworked carbonates older than Permian is suspected along the west side of the Yashkuk glacier, but at present they are still included in the Lower Permian succession. The succession starts with a terrigenous alluvional plain interfingering with a marine terrigenous shelf *(Gircha Fm.)*. In the middle part of this formation Late Asselian-Early Sakmarian brachiopods were found, nevertheless the base of the formation is not exposed, being always tectonic or in the core of an anticline. During Sakmarian a mixed terrigenous-carbonate shelf and successively a carbonate ramp develop *(Lupghar Fm.)* on this terrigenous shelf. Another mixed terrigenous-carbonate unit *(Panjshah Fm.)*, Bolorian to Murgabian-Midian in age, follows with a gap at the base; shelf sands and shales mark this unconformity.

During Late Permian the terrigenous-carbonate shelf drowned, giving way to well bedded cherty limestones with episodes of resedimentation *(Kundil Fm.)*. Black shales with occasional cherty limestones intercalations *(Wirokhun Fm.)* follow, testifying to a sharp decrease of the calcareous input; this unit contains the P/T boundary.

From Early Triassic to Ladinian the carbonate sedimentation recovers with the deposition of black cherty limestones *(Borom Fm.)*. During Late Triassic, possibly up to the beginning of Jurassic, a widespread carbonate platforms developed with two main facies, bedded dark-grey limestones and light-grey peritidal dolomites *(Aghil Fm.)*. Breccia bodies, possibly representing slope deposits of the carbonate complex, were observed in the Lupghar valley.

Apparently, the central and southern part of the Sost Unit drowned once again at the beginning of the Jurassic. The through was filled by the sandstones of orogenic provenance of the *Ashtigar Fm.* Shallow water limestones persisted up to the Late Pliensbachian in the northern part, when the continental red sandstones of the *Yashkuk Fm.* spread over the whole area. By the end of the Aalenian or at the base of the Bajocian a generalized transgression occurred with the deposition of shallow water oncolitic limestones *(Reshit Fm.)*. Later on, due to the intensity of the successive tectonics, a detailed reconstruction of the succession was impossible; the succession ends with micritic limestones with breccia intercalations. Few indications of earliest Cretaceous sediments were found in this succession.

A very strong uplift, accompanied by deformation, anchimetamorphism and erosion of the whole sedimentary succession, occurred during Early Cretaceous. The conglomerates of the *Tupop Fm.* seal in the Tupop and Kundil valleys the stacked thrust sheets originated during this important tectonic event, probably related to the collision of the Kohistan Arc with the southern margin of Eurasia, here represented by the Karakorum Block.

A new marine ingression is occasionally documented by the sandstones, conglomerates and Campanian pelagic marls of the *Darband Fm.*, which cover the Tupop Fm. with a slight unconformity. Also these Upper Cretaceous sediments are included in the thrust fans indicating a post-Cretaceous motion of the main thrust sheets.

3) The Guhjal Unit.

This tectonostratigraphic unit was defined by Gaetani et al. (1990) and includes the sediments lying between the KAB and the Upper Hunza Fault. A sharp closure of the unit is noted eastward along the lowermost part of the Shimshal valley, where the dolomitic marbles terminate along a subvertical N-S trending fault, possibly related to the original paleogeographic setting. Southward, the unit is intruded by the KAB, here represented by generally undeformed or poorly deformed intrusives. Contact metapelites generally bear biotite, muscovite and andalusite. Folds within the unit trend from NW-SE to NNW-SSE and are generally NE-facing. Thrust planes show the same trends and are NE-vergent, as in the case of the Upper Hunza Fault.

The Guhjal Unit is composed by two unit, a terrigenous unit below (*Pasu Slates* of Desio, 1963) and a calcareous-dolomitic unit above *(Guhjal Fm.)*, generally with an anchimetamorphic imprint. Intricacy of the structure, poor accessibility of the outcrops, rare fossils and metamorphism hamper stratigraphic reconstructions and precise mapping. The major points are the finding of fusulinids of mid Permian age near the top of the terrigenous succession near Pasu and the attribution of the Pasu Slates to the lowermost terrigenous succession defined as *Gircha Fm.* in the Sost Unit and hence to the Upper Paleozoic.

4) The Karakorum Axial Batholith (KAB).

The KAB crops out along the southern part of the studied area, where two major plutonic complexes were recognized, the *Hunza* and *Batura Units* (Debon et al., 1987).

The Hunza Unit is mid-Cretaceous in age and is described in detail by Debon et al. (1987) and by Crawford & Searle (1992, 1993). It consists in a huge plutonic unit extending for more than 250 km, made up of foliated and more or less deformed medium-grained rocks, dominantly granodioritic in composition, which is locally (Hunza valley) strongly recrystallized (metagranodiorite). Highest P-T conditions for this recrystallization are estimated at 580-640°C and 5±0.5 kbar (Debon et al., 1987). Granodiorites contain biotite and, usually, amphibole with occurrence of residual clinopyroxene, whereas epidote, allanite and sphene are frequent in recrystallized samples. They represent a calc-alkaline association. Mafic enclaves of various size are abundant and a conspicuous network of Cenozoic leucocratic dykes is locally present (e.g. Hunza valley). The only reliable crystallization age for the *Hunza Unit* is a U-Pb zircon age of 95 Ma (Le Fort et al., 1983).

The areal distribution of the Batura Unit intrusives, spanning in age from Paleocene to Eocene, is mostly new, as well as the findings of plutonic bodies belonging to this unit along the Yashkuk and Kuk-Ki-Jerab glaciers in the upper Chapursan valley. The *Batura Unit* includes two main intrusives: the Kuk (K-Kd) and the Sarbzea (B) plutons (1). The Kuk pluton consists in pinkish, undeformed and unfoliated granitoids of various grain size (usually medium to fine), locally with porphyritic, microgranular and rapakivi textures. The Kuk pluton is associated with stocks of pyroxene and amphibole gabbroes, in particular along the western branch of the upper Kuk-Ki-Jerab glacier; dark quartz-diorites with biotite and amphibole are present along the Yashkuk glacier. The Sarbzea pluton mainly differs from the Kuk pluton by its very coarse- to medium-grained rocks, sometimes deformed.

Both plutons are dominantly granites and adamellites with biotite, rare amphibole, accessory sphene, allanite, apatite, zircon and opaque minerals. These rocks belong to ferriferous and light-coloured subalkaline (monzonitic) associations. Rb-Sr whole rock isochrons yield a Paleocene age of 63±2 Ma ($^{87}Sr/^{86}Sr_i$ = 0.7050; updated in proof; Debon, in progress) to the Kuk pluton and a poorly-constrained Eocene age of 43±3 Ma ($^{87}Sr/^{86}Sr_i$ = 0.7056; Debon et al., 1987) to the Sarbzea pluton. Their contact with the Hunza Unit and the sedimentary succession are mostly intrusive as observed along the Batura and Kuk-Ki-Jerab glaciers, whereas local south vergent thrusting was observed along the Yashkuk glacier (Zanchi, 1993), suggesting post-40 Ma stacking of the unit. Intrusive relationships with the Cretaceous Hunza plutonic unit are remarkably exposed in the Pup-i-Shikorga area, north (left) bank of the middle Batura glacier.

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(1) Added in proof. Outcrops north of the Batura glacier which are attributed on the map to the Batura Unit (Sarzbea pluton) should be attributed to the Kuk pluton.

Structural evolution of the North Karakorum Terrain.

Several deformational events have been recognized on the basis of structural and geological analyses. A "mid-Cretaceous event" is testified by the folded succession cropping out below the Cretaceous Tupop and Darband Formations in the Sost Unit. The slates of the Guhjal and Misgar units are respectively crossed by the Late Cretaceous Hunza Unit of the KAB (Debon et al., 1987) and by the Khunjerab and Sost intrusives, which bear similar radiometric cooling ages (Crawford & Searle, 1992). Moreover, also the Shuijerab granodiorites and possibly the Warbin granodiorite of the Ghujerab valley, bear mid-Cretaceous radiometric ages (Le Fort, 1993 pers. comm.). These field relationships possibly suggest that the "mid-Cretaceous" deformational event may be much more widespread in the sedimentary cover of the Karakorum than previously recognized, even if further radiometric dating and structural work is necessary to confirm this hypothesis. As discussed in Gaetani et al. (1990) and by Zanchi (1993), this phase may be related to the early collision of the Kohistan island arc with the Karakorum microplate occurring in mid-Cretaceous (Coward et al., 1986; Searle, 1991), leading to the closure of the Shyok Suture Zone and definitive accretion of the Kohistan arc along the Eurasian margin (Pudsey et al., 1985; Pudsey, 1986).

The antiformal stack recognized in the Sost Unit includes deformed Late Cretaceous sedimentary rocks, suggesting that thrust stacking largely occurred also after Cretaceous. Furthermore, pinkish granites and diorites, belonging to the Paleocene-Eocene Batura-type granitoids, seem to have been locally thrusted along the southern part of the stack. The formation of the thrust fan was probably polyphasic as suggested by different trends of folds, cleavages and slip-vectors, as described in Zanchi (1993). Northeastwards tectonic transport is mostly evident in the Guhjal Unit and in the lower Shimshal valley, where deformation is coeval with low grade metamorphism. North vergent tectonic transport is dominant within the Sost Unit and seems to be followed in time by south vergent thrust motion causing the overthrusting of the Misgar Slates above the northern margin of the Sost Unit. Cataclastic shear zones related to this event cross the previously folded metapelites of the Misgar Unit. The southern termination of the stack is locally thrusted over the KAB in the Yashkuk area by reverse faults with the same attitude. This may suggest that this phase might be a distinct successive event of south vergent tectonic transport due to the prosecution of crustal thickening after India-Eurasia continental collision.

The last important tectonic phase consists in the activation of strike-slip fault systems, generally post-dating thrust emplacement. E-W trending sinistral strike-slip faults were observed along the central part of the Sost Unit, and are probably related with major NW-SE trending dextral strike-slip faults. This complex pattern of deformation may be connected to the latest phase of tectonic indentation between India and Eurasia following continental collision (Tapponnier et al., 1986), as suggested in Zanchi (1993, 1994).

Quaternary evolution.

Detailed study of the superficial deposits was done only in a few selected areas in the Chapursan valley (Yashkuk glacier snout, Raminji) and in the Hunza valley (Sost and Pasu). Moreover, the map scale allows little room for details. The Quaternary geology team (A. Bini, I. Rigamonti and A. Uggeri) will publish elsewhere the full account of their results.

The main geomorphic agents in Hunza are ice, water and gravity.

The ice forms wide glaciers especially in the southwestern area, where peaks high as 7,000 m are present in the Batura and Yashkuk drainage basins. The Batura glacier reaches 55 km in length and the Yashkuk glacier 20 km. Smaller glaciers (at the Karakorum scale) are spread in all tributary valleys, above 4,500-5,000 m. Glacial deposits are widespread. However, they are not continuous along the bottom of the Chapursan, Shimshal, and Hunza valleys. A surprising result was that no continuous glacier flows occupied the main valley bottoms during the latest Pleistocene, but smaller glaciers coming down from tributary valley dammed the main valley, forming lakelets. When possible, morphological features are distinguished in the map. A peculiar feature of the middle Chapursan valley is the hummocky morphology spread on the valley floor between the Yashkuk glacier snout and the villages of Shuinj and Reshit. Large boulders standing on the top of clay hillocks, spread near the houses and cultivated fields, testify to a glacier surge from the Yashkuk glacier, that came down along the valley for some 12 km no more than 200 years ago (Schomberg, 1935).

The local dams formed by the tributary glaciers caused small lakes of usually short life. The organic matter preserved in the lacustrine sediments allowed to obtain about 15 C^{14} ages, which span from 1,640 to 9,900 Ka B.P. (Bini A., pers comm.). Due to the close interfingering between lacustrine and alluvial deposits, on the map they are grouped as alluvium. A number of terraces formed in the superimposed systems of glacial/lacustrine/alluvial deposits.

The even smallest temporary creeks from side valleys form a significant alluvial fan when entering into the main valley. This is due to the strong activity of erosional processes, due to the lack of vegetation cover and protection. This large amount of loose material contributes to form huge debris fans on the slopes, that may coalesce in a more or less continuous debris fan along the valley side.

Since the Chapursan river is embanked from Kiin to the confluence with the Khunjerab river and the Shimshal river is deeply embanked from Ziarat to its end, most of the superficial deposits are terraced. The very deep gorges (up to thousands of metres) recently formed by most of the main rivers (Khunjerab, Hunza and Shimshal rivers) suggest a prosecution of very intensive uplifting phenomena up to very recent times.

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