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The Devonian of Western Karakorum (Pakistan)

MAURIZIO GAETANI[1], RUTH MAWSON[2], DARIO SCIUNNACH[3] & JOHN A. TALENT[2]

[1]*Dipartimento di Scienze della Terra, Università di Milano, Via Mangiagalli 34, 20133 Milano, Italy.*
E- mail: maurizio.gaetani@unimi.it
[2]*Department of Earth and Planetary Sciences, Macquarie University, NSW 2109, Australia*
[3]*Regione Lombardia, Infrastruttura per l' Informazione Territoriale, Via Sassetti 32, 20124 Milano, Italy*

ABSTRACT:

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Devonian rocks crop out in several thrust sheets in the sedimentary belt of North-Western Karakorum, both to the south and to the north of the Reshun Fault. Gently metamorphosed Devonian dolostones and volcanics are also present in the Tash Kupruk Zone north of the thrust sheet system. The most complete succession is found in the Karambar Thrust sheet where dolostones and recrystallized limestones (Vandanil Formation) lie above the black shales and siltstones of the Baroghil Group. The age of the Vandanil Formation is poorly defined, approximating latest Silurian or earliest Devonian at its base and proven to be Pragian in the 4th of its 5 lithozones. The overlying Chilmarabad Formation is divided into two members. The lower member is a mixed siliciclastic–carbonate package, present in most southern and western thrust sheets. The upper member is ubiquitous; it consists of dolostones, often stromatolitic. The calcareous part of the Tash Kupruk Zone consists of similar facies. The carbonate flats of the Chilmarabad Formation display a trend towards emersion towards the top, and are overlain, with regional unconformity, by the basal unit of the Shogrām Formation. The base of the latter consists of arenite and fine conglomerate (deposited in an alluvial setting) overlain by alternating marine bioclastic limestones and litharenites with one or two coral bafflestones in the middle to upper part. The age of the lowermost part of the Shogrām Formation is Givetian, extending through the Frasnian and seemingly into the Famennian, but the last is poorly documented (contrasting with the classic Shogrām and Kurāgh sections of Chitral); it reflects a return to fine terrigenous input.

The inferred palaeogeography accords with the Northern Karakorum having been part of the Gondwana margin during the Devonian. A wide, mostly calcareous platform, characterised extensive areas of the Karakorum, Central Pamir, Badakhshan and, in a minor way, Central Afghanistan (Helmand Block). The sandstone petrography suggests that clastics polluting the carbonates originated from erosion of a pre-existing sedimentary cover. During the Givetian a first rifting episode, possibly echoing the opening of an ocean to the east, affected the whole area, with volcanic outpourings in the rifts, while eroding shoulders fed the basins, though never extending as deep as the crystalline basement. A minor volcanic input is also recorded. The tectonic pulse almost ceased during the Frasnian, gradually resuming towards the end of the Devonian.

Key words: Stratigraphy, Sandstone petrography, Palaeo-Tethys, Devonian, Conodonts, Brachiopods.

INTRODUCTION

The Karakorum Range, in its geological extension (GAETANI 1997), contains a lithosphaeric fragment that during the Palaeozoic was part of the Gondwana margin (Text-fig. 1). From south to north, the Karakorum Block consists of two major structural elements: i) the Southern Metamorphic Belt and the Karakorum

Batholiths, separated in the west by the Intermediate Sedimentary Belt, and ii) the crystalline and Palaeozoic-Mesozoic sedimentary rocks of the Northern Karakorum Terrain (Text-fig. 2). Recognition of Devonian sedimentary successions has been possible only in the Northern Karakorum Terrain where a major metamorphic imprint is absent.

The first collection of Devonian rocks from the Karakorum was made by I.H. GRANT in 1898 from the vicinity of the Baroghil Pass; the fauna was described by REED (1911) as Early Devonian. HAYDEN (1915) insisted this fauna must have come from the vicinity of Showar Shur and gave precise coordinates for the supposed locality. We were unable to duplicate the GRANT–REED fauna in that region nor in the Ribat Valley. Incidentally, the locality and surroundings of Showar Shur about 20 km to the east are Permian (Text-fig. 3). The first geological reconnaissance in the area may thus have been made by HAYDEN (1915); it involved sampling the ridge immediately west of Gharil in front of our Yarkhun River section but he seems not to have visited Showar Shur. A poorly preserved spiriferid "from the Baroghil Pass" was identified as *Spirifer* cf. *mediotextus* D'ARCHIAC & DE VERNEUIL (REED 1922), though HAYDEN (1915) reported "badly preserved specimens of *Spirifer*… [that] may be *Sp. Verneuili*" [= *Cyrtospirifer*] "on the southern shore of a small lakelet at the southern end of the Dasht-i-Baroghil".

J.A.TALENT and R.A.K. TAHIRKHELI, who visited the Baroghil area in 1973, found a Devonian sequence with conodont-coral-brachiopod faunas (TALENT & MAWSON 1979; TALENT & *al*. 1982), apparently including HAYDEN's above locality.

M. GAETANI investigated the Devonian of the region in 1992, 1996, 1999, and 2004, with field assistance from his wife LIA and from L. ANGIOLINI, A. ZANCHI and A. NICORA in the Chillinji area. Some Devonian samples were collected by P. LE FORT during the 1992 expedition. A. ZANCHI made the geological map (ZANCHI & *al*. 2007) from which the geological sketches reproduced here are derived. In 1999 and 2004 respectively, Devonian outcrops around Baroghil were visited by participants of the IGCP 421 project and the PR01 Field Excursion of the 32nd International Geological Congress (GAETANI & *al*. 2004b). Results concerning the Devonian from the above expeditions have been published (GAETANI 1997; GAETANI & *al.* 1996, 2004a; TALENT & *al*. 1999; SCHRÖDER 2004; HUBMANN & GAETANI 2007).

Soviet and Afghan geologists working in the 1970s on the Afghan side of the Baroghil Pass (KAFARSKIY & *al*. 1974; KAFARSKIY & ABDULLAH 1976) reported a Devonian sequence more than 1000 m thick in their Tash Kupruk Zone near the village of Sarhad; their data are summarized by ABDULLAH & CHMYRIOV (1980).

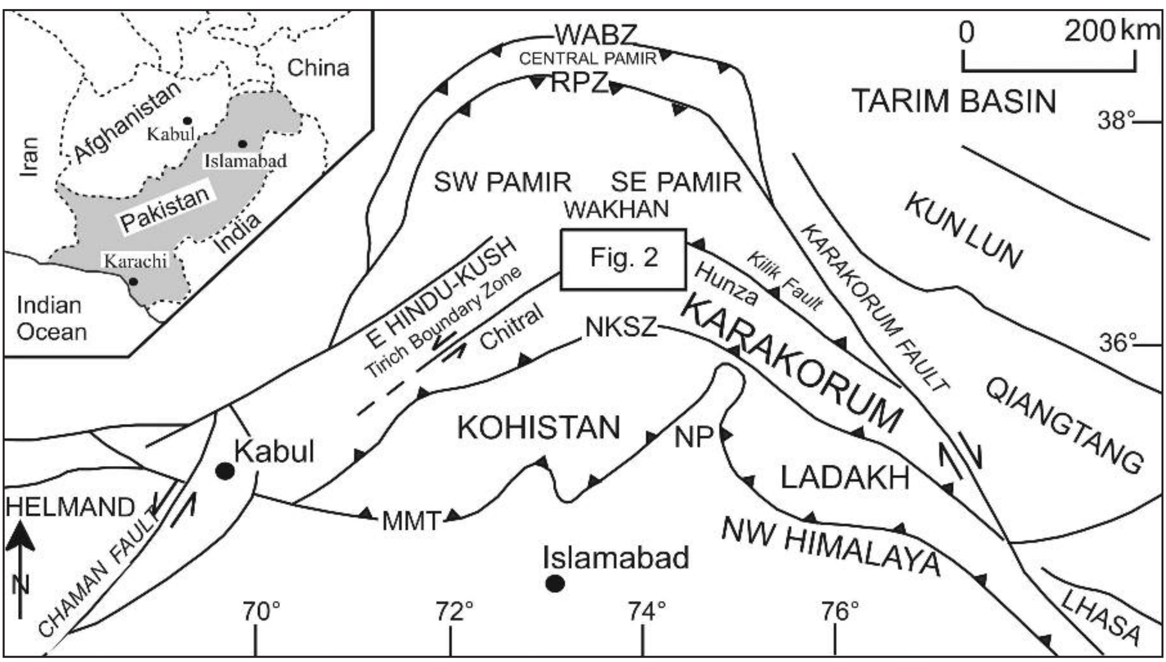

Fig. 1. Index map of the Karakorum and surroundings regions. Acronyms: MMT – Main Mantle Thrusts, the boundary between Indian Plate and the Kohistan Arc; NKSZ – North Kohistan Suture Zone; RSZ – Rushan – Pshart Zone, the boundary between Central and South Pamir; WABZ – Wanch-Ak Baital Zone, the boundary between Central and North Pamir

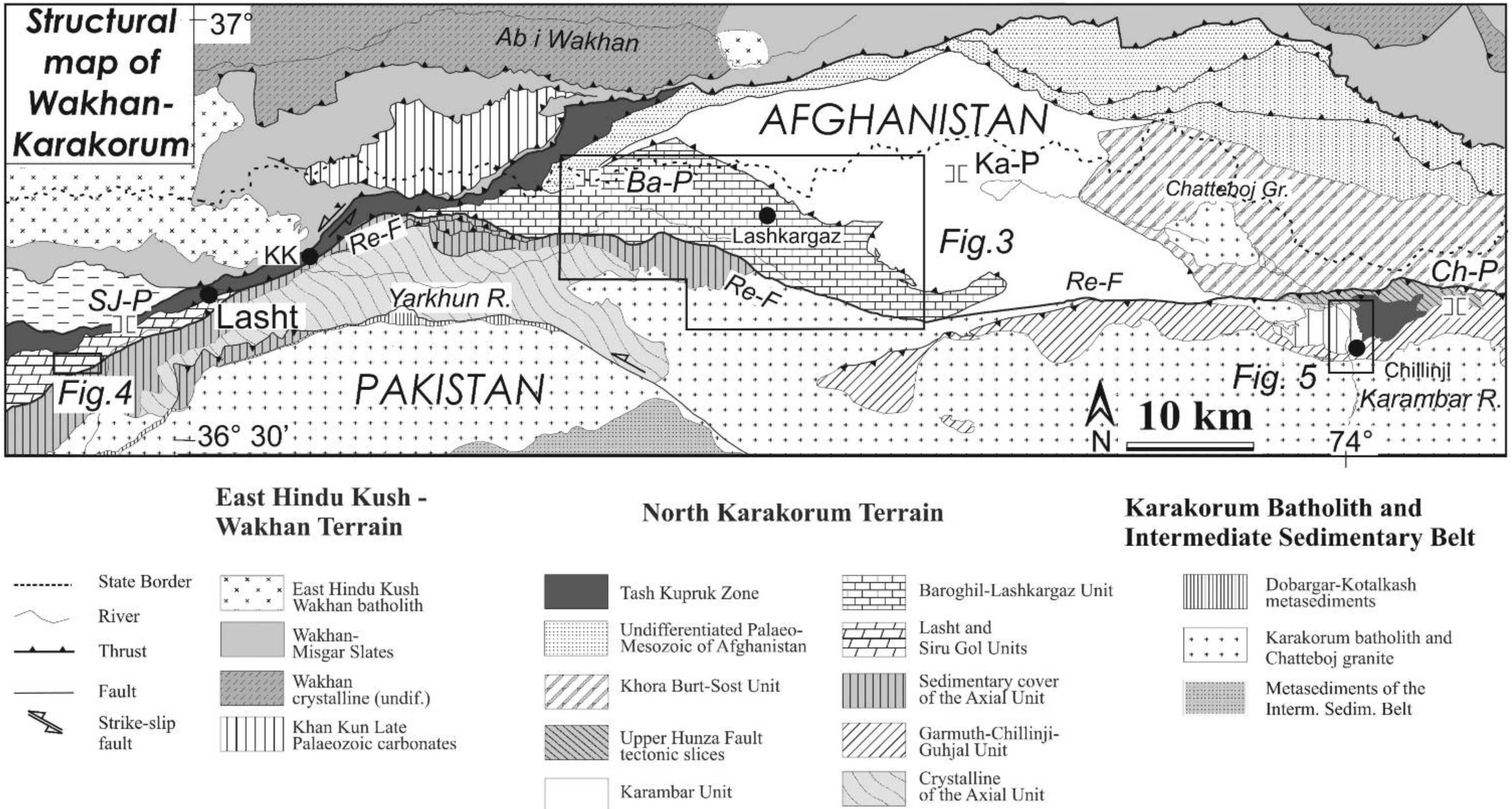

Fig. 2. Simplified geological map of the Western Karakorum and Eastern Hindu Kush. Devonian rocks have been recognized in the Siru Gol/Lasht; Baroghil/Laskkargaz, and Karambar Thrust sheets to the north of the Reshun Fault and in the Chillinji/Axial Thrust sheets to the south of the Reshun Fault. Acronyms: Ba-P = Baroghil Pass, Ch-P = Chillinji Pass, KK = Khan Kun village; Ka-P = Karambar Pass;. Re-F = Reshun Fault, SJ-P = Shah Jinali Pass

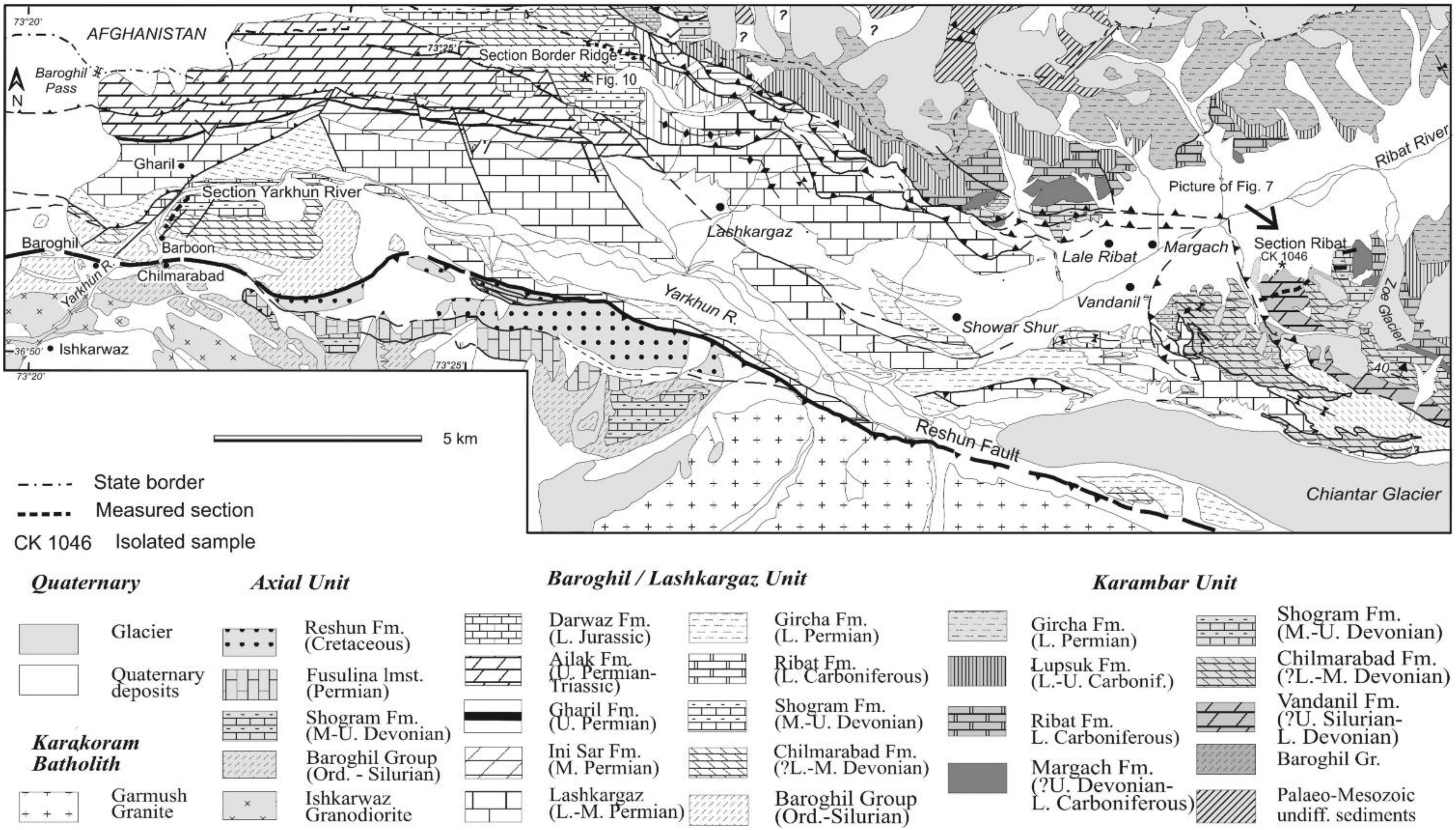

Fig. 3. Baroghil–Ribat area (after ZANCHI & *al.* 2007 and in progress, simplified), with location of measured sections, isolated sample locality, and pictures (Text-figs 7, 10)

McMahon & Hudleston (1902) were the first to draw attention to the Devonian around Kurāgh and Shogrām in Chitral, studied subsequently by Hayden (1915), Desio (1963, 1966), Stauffer (1975) and especially by Talent & *al.* (1982, 1999). This succession provides the framework for correlation through the present region. The faunas collected were illustrated by Reed (1922), Sartenaer (1965), Vandercammen (1965), Schouppé (1965), Talent & *al.* (1999) and Feist & *al.* (2001).

The aim of the present paper is to illustrate and summarize the general stratigraphical and geological setting of the Devonian successions measured and sampled during our field investigations. R. Mawson worked on the conodonts, and D. Sciunnach on sandstone petrography. Brachiopod identifications are by Chen & Talent (work in progress).

REGIONAL GEOLOGY

The North Karakorum Terrain, as defined recently (Zanchi & Gaetani 1994; Gaetani & *al.* 1996; Zanchi & *al.* 2000), consists of a thick, polyphase stack of thrust sheets lying north of the Karakorum Batholiths (Le Fort & Gaetani 1998) (Text-figs 1, 2). In the Chitral region, this terrain is separated from the East Hindu Kush–Wakhan by the Tirich Boundary Zone, a left-lateral shear zone including deformed ultramafic rocks (Zanchi & *al.* 1997, 2000). These rocks record pre-mid-Cretaceous accretion of the Karakorum Block to the Pamir Blocks. The Tirich Boundary Zone is intercepted tectonically east of the Shah Jinali Pass by northeast–southwest left-lateral strike-slip faults and the Palaeozoic Wakhan and Misgar slates of the Wakhan; these are stacked directly against the Karakorum units.

The North Karakorum Terrain includes several thrust sheets showing complex geometrical relationships (Text-figs 2, 3). To the northwest, the Tash Kupruk Zone contains alkali basalts, tuffs and dolostones bounded by shear faults. The dolostones are mildly metamorphosed and contain Devonian Tabulata (Hubmann & Gaetani 2007). Devonian rocks are present in at least three thrust sheets south of the Tash Kupruk Zone: the Siru Gol, Lashkargaz/Baroghil, and Karambar thrust sheets (Text-figs 2-5). Southwards, a major disjuncture is marked by the Reshun Fault (Pudsey & *al.* 1985; Zanchi & *al.* 1997, 2000) joining with the Upper Hunza Fault in the east, and extending for more than 200 km (Text-figs 1-3). The tectonic units south of this fault include locally pre-Ordovician crystalline basement and Palaeozoic–Mesozoic sediments of reduced thickness. Devonian rocks are mostly absent, but in the Chillinji Unit an almost complete Palaeozoic succession, unconformably overlying pre-Ordovician intrusives, is exposed (Text-fig. 5).

The southern margin of the sedimentary units of the Northern Karakorum Terrain is intruded by Cretaceous to Paleogene plutons, the Karakorum Batholiths

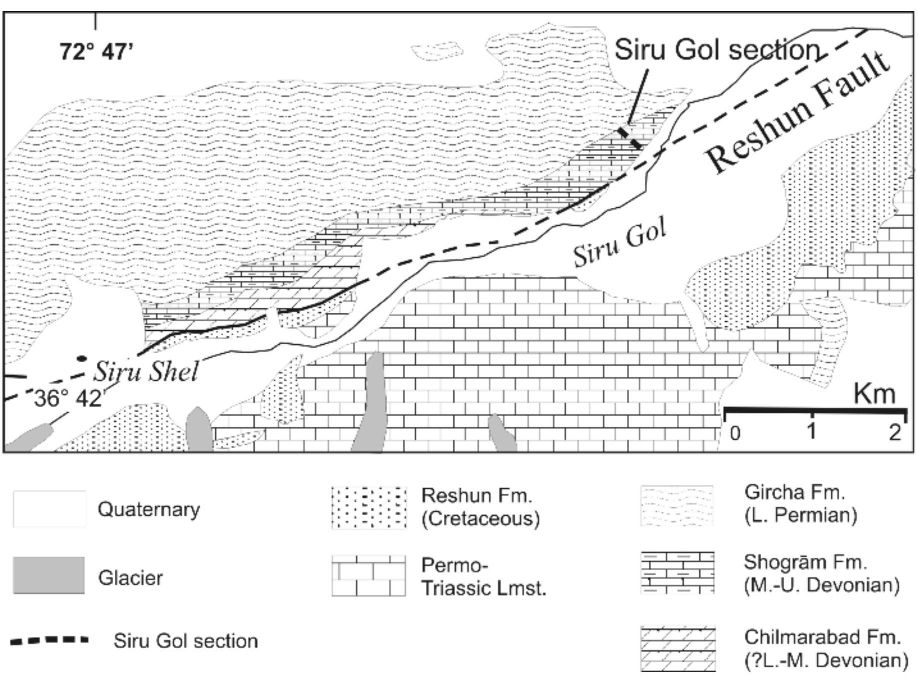

Fig. 4. Location of the Siru Gol section and geology of the surrounding area

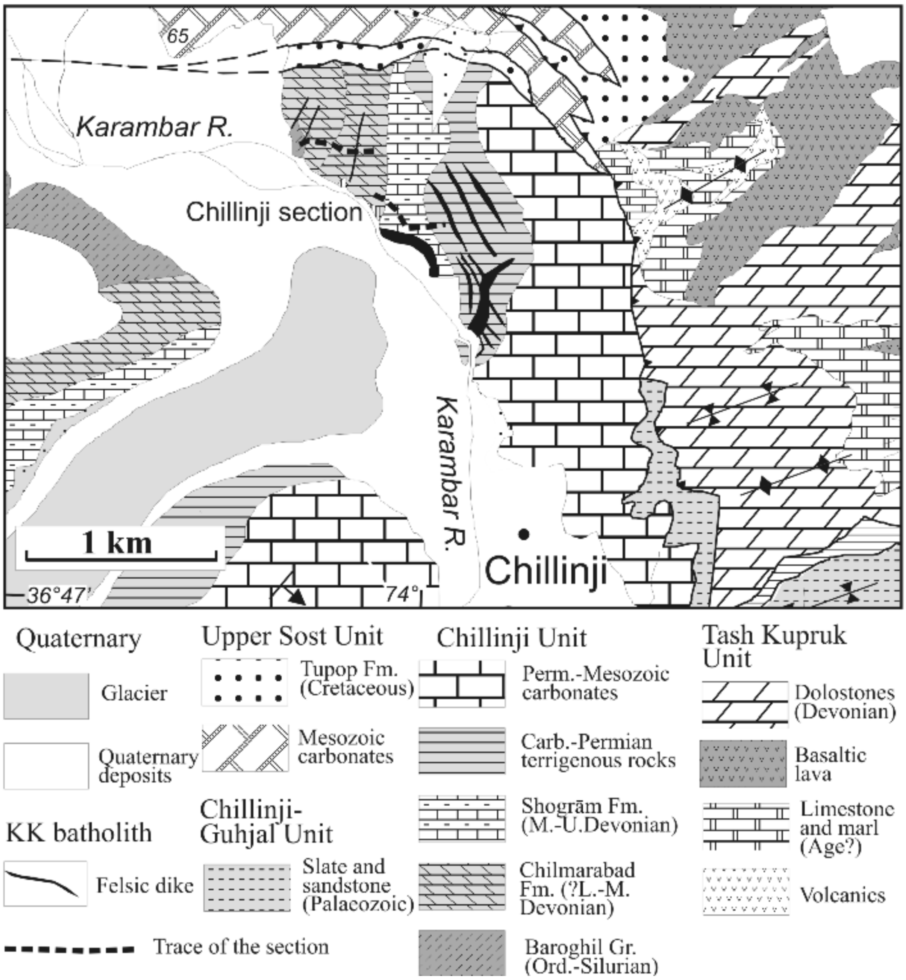

Fig. 5. Geological map of the Chillinji area (after ZANCHI & *al*. 2007 and in progress, simplified), with location of the measured section

(DEBON & *al*. 1987, 1996; DEBON 1995; DEBON & KHAN 1996; LE FORT & GAETANI 1998).

The thrust sheets between eastern Chitral and the upper reaches of the Karambar River consist mostly of Palaeozoic sequences, and at minor extent Mesozoic, the youngest being Early Jurassic in age, unconformably overlain by the Cretaceous Reshun Conglomerate. This contrasts with the central and eastern side of the range from the Chapursan Valley to the Hunza Valley and Shimshal Pass, where the thrust sheets include rocks not older than the Permian (GAETANI & *al*. 1990; ZANCHI & GAETANI 1994). From within a conglomerate of the Permian Gircha Formation along the western side of the Yashkuk Glacier (see map in ZANCHI & GAETANI 1994), we have found the colonial coral *Aphyllum* testifying to the probable former presence of Devonian rocks in that area (FLÜGEL 1995). Devonian tabulate corals were also found in debris on the north side of the uppermost Chapursan Valley towards Irshad Owin An (HUBMANN & GAETANI 2007).

THE SEDIMENTARY SUCCESSION

From bottom upward, we recognized the following units (Text-fig. 6):

Vandanil Formation (here defined)

This unit, identified only in the Karambar Thrust Sheet (Text-fig. 3) and measured along the southeast side of Ribat Valley above the summer meadows of Vandanil [from which the name originates (Text-figs 7, 8)] is about 625 m thick. Its base is covered by scree, though the underlying Baroghil Group slates crop out higher in the valley in the core of the anticline. Five litho-intervals were identified, from bottom to top:

1. Grey, medium to thick-bedded limestone with parallel lamination or gentle ripple marks. When thinly bedded, it has shaly interbeds; these may alternate with thicker amalgamated beds. Bedding surfaces are

Fig. 6. Stratigraphic subdivisions of Devonian rocks in the most complete thrust sheets: Karambar, Baroghil-Lashkargaz and Chillinji/Axial

planar or gently wavy. They became slightly dolomitized upwards. Fossils (crinoid ossicles and brachiopod fragments) are rather abundant. Recrystallization is substantial with fossil cavities filled by large calcite crystals. In its uppermost part there are intervals of well-rounded quartz grains up to 2-3 mm in diameter. Conodont samples proved to be barren. Thickness (base covered): at least 135 m.

2. Light grey dolostone with beds 20-40 cm thick, totalling about 50 m.

3. Grey to dark grey calcareous siltstone, brownish when altered, with intercalations of up to 20 m of well-bedded, grey nodular limestone, slightly arenaceous, and with a few dolostone banks. This litho-interval is capped by about 30 m of calcareous brownish slates with crinoids and deformed brachiopod fragments. Thickness is uncertain due to the broken slope, but about 150 m.

4. Grey nodular limestone with shaly interbeds, rich in brachiopods, corals, crinoids and nautiloids, all much recrystallized and sheared. They are overlain by light grey dolostone, or partly dolomitized packstone in 30-40 cm beds, overlain by thinner flattish-bedded dolomitic limestone still rich in crinoids. This unit is capped by metre-thick nodular amalgamated beds with ghosts of bioclasts and some shaly intercalations. Thickness about 120 m.

5. Grey dolostone in 30-50 cm beds alternating with massive dolostone forming mounds (up to 15 m thick in the lower part) built by dendroid to phaceloid colonies of rugosans, tabulates, and small stromatolitic mounds. Up-sequence the mounds, very rich in corals, are as much as 3-5 m in thickness and are interbedded with thinner bioclastic dolomitic limestones. Because of heavy recrystallization, no sampling was undertaken. The mound complex interfingers with thin-bedded grey crinoidal limestone, forming along section intercalated packages 2-4 m thick. Thickness estimated to be about 170 m.

Top: Chilmarabad Formation upper dolostone member.

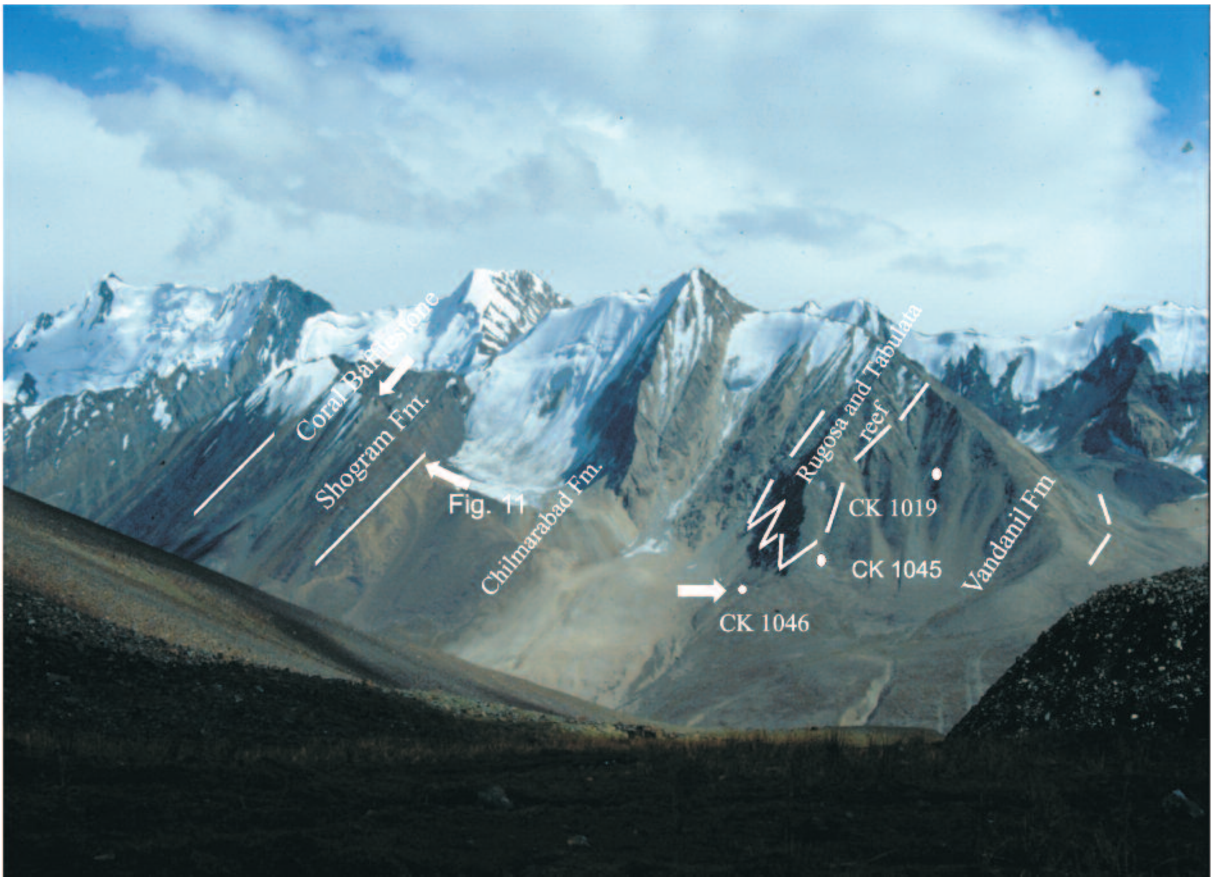

Fig. 7. The Ribat section in the Karambar thrust sheet, with location of significant samples. For location see Text-fig. 3 (photo courtesy of A. ZANCHI)

Fossils and age

Due to incipient metamorphism, the fossil content, even when fairly abundant, is too poorly preserved for identification. Conodonts, though not in great abundance, have been obtained from litho-intervals 3 and 4 (samples CK 1019 and CK 1045). CK 1019 produced a single specimen of *Pandorinellina steinhornensis miae* BULTYNCK (Pl. 1, Fig. 10); it is indicative of an age-range of late in the *sulcatus* Zone to *dehiscens* Zone (Pragian-early Emsian). Conodonts from CK 1045 include *Ozarkodina excavata excavata* (BRANSON & MEHL) (Pl. 1, Fig. 4), *Oz. remscheidensis remscheidensis* (ZIEGLER) (Pl. 1, Fig. 1), an Sc element of *Oulodus* sp. (Pl. 1, Fig. 5), reminiscent of one published by PICKETT (1980, fig. 12H) from a fauna now considered to be no older than *sulcatus* Zone, *Pandorinellina steinhornensis miae* (Pl. 1, Fig. 2), an M element of *Amydrotaxis druceana* (PICKETT) (Pl. 1, Fig. 3), and *Amydrotaxis* n. sp. (Pl. 1, Figs 6, 7), a form identified from the Darling Basin, western New South Wales (MATHIESON & *al*., in prep.). The age-range indicated for this fauna is Early Devonian; the last three conodont taxa refining the age to Pragian, *sulcatus* Zone, probably late *sulcatus* Zone (see: Taxonomic comments).

The c. 200 m of sequence between (uppermost litho-interval 4 and litho-interval 5) failed to produce evidence of late Pragian through Emsian and Eifelian.

Out of the section laterally, we found an isolated outcrop very rich in corals and brachiopods (CK 1046, Text-fig. 7), thought to be a lateral equivalent of the thin bedded interfingerings observed in litho-horizon 5. SCHRÖDER (2004) described from this sample the coral *Spongophyllum* cf. *sedgwicki* (MILNE-EDWARDS & HAIME), assuming a Givetian age for the top of the Vandanil Formation. But caution is here called for; the genus *Spongophyllum* is long-ranging (Silurian to Middle Devonian) and the type species, *S. sedgwicki*, was based on material from a “pebble in a river bed”. Though a positive indentification at species-level is not possible, the associated brachiopod faunule (CHEN XIUQIN, pers. comm.) of “*Spinatrypa*” *spinosa chitralensis* (REED) and species of *Gypidula* (*Devonogypa*), *Uncinulus*, *Nalivkinaria*, and *Waiotrypa* accords with an age close to the Givetian-Frasnian boundary. Because this brachiopod faunule is characteristic for low in the Shogrām Formation, we are

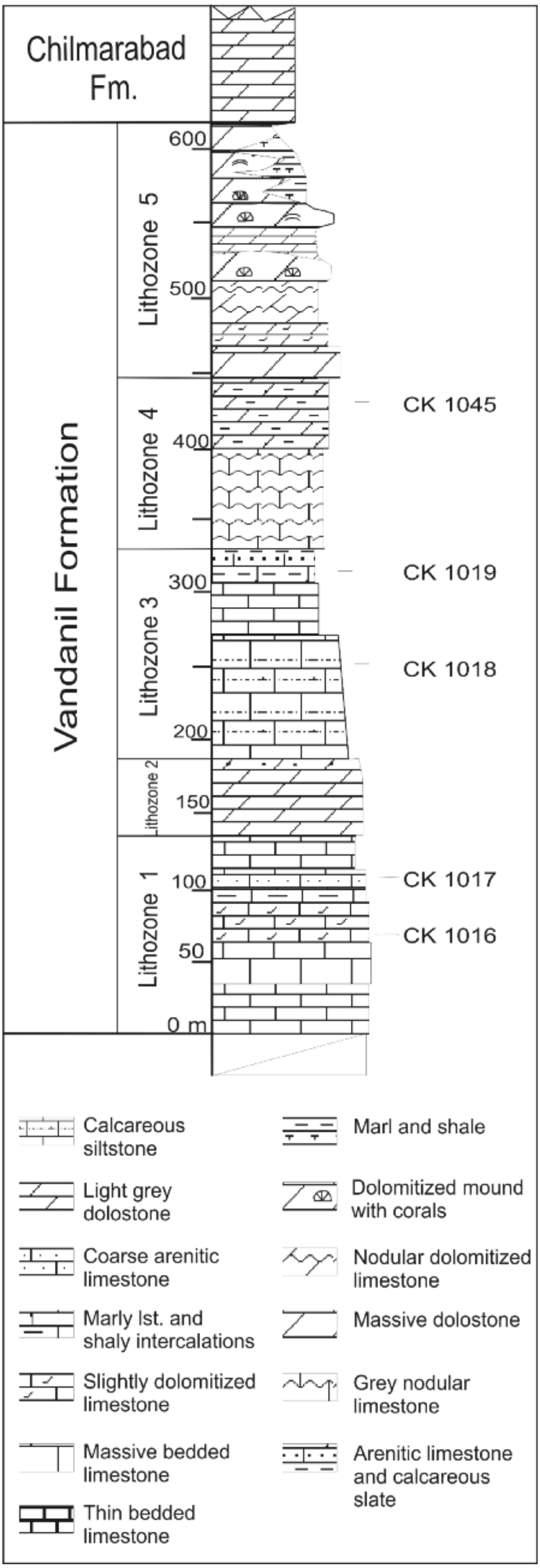

Fig. 8. Stratigraphic log of the type-section of the Vandanil Formation

thus suggesting this isolated outcrop may be a slab of Shogrām Formation displaced by the glacier.

Chilmarabad Formation (Gaetani & *al.* 1996)

The unit is ubiquitous in all thrust sheets in which Devonian rocks are present. The type section, here described, was measured upwards on the slopes on the left side of the Yarkhun River from the locality known as Barboon (Text-fig. 9).

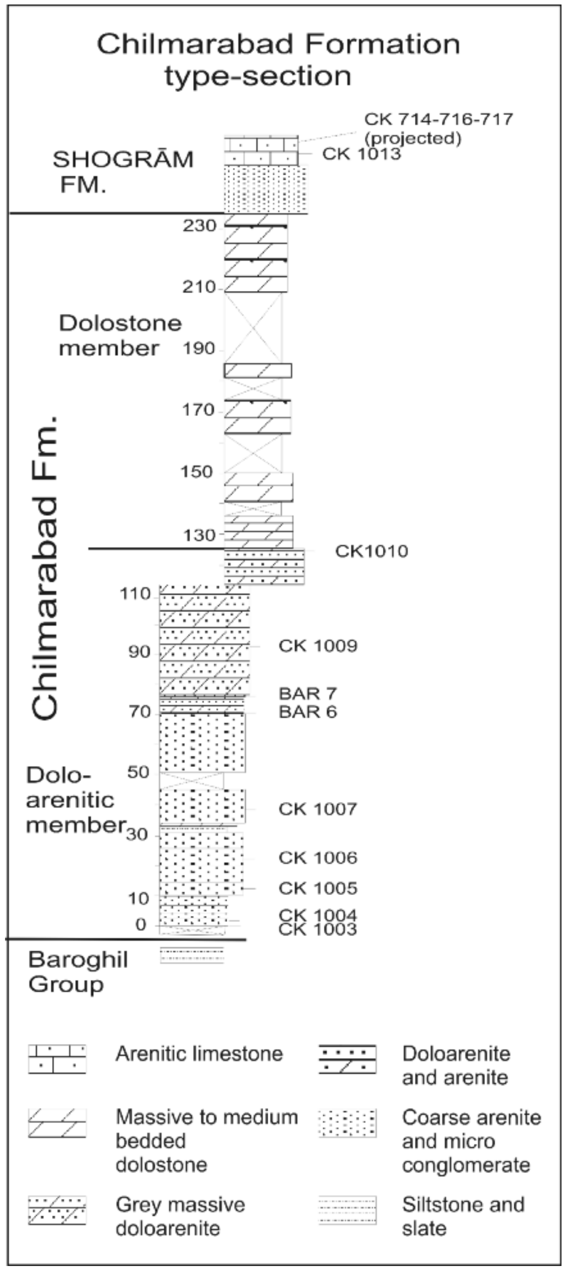

Fig. 9. Stratigraphic log of the type-section of the Chilmarabad Formation

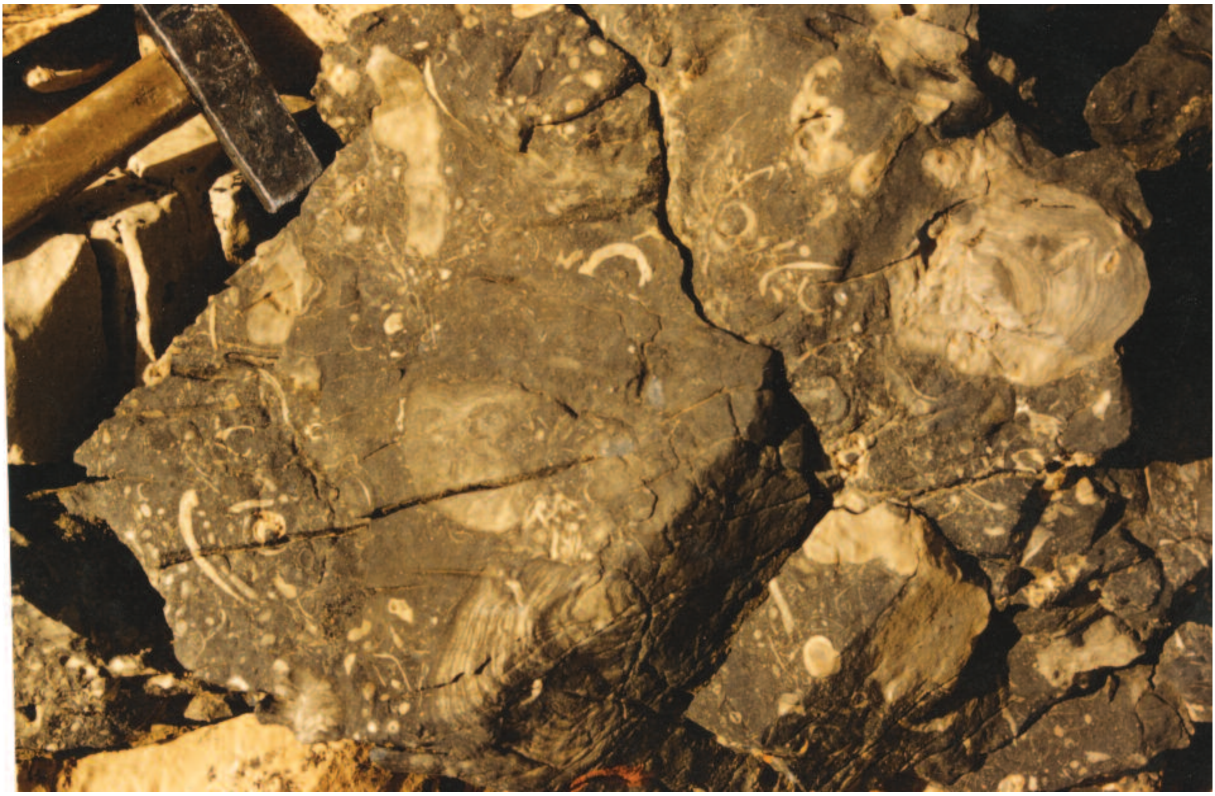

Fig. 10. Package of tabulates, gastropods and bivalves in the dolostone member of the Chilmarabad Formation on the plateau east of Darwaz An at about 4400 m altitude (hammer for scale). (Photo courtesy P. Le Fort 1992)

Two members may be identified:

The lower *dolo-arenitic member* is characterized by significant terrigenous content, mostly arenitic but also microconglomeratic, interfingering with light grey dolostone. This member may be present in all thrust sheets, including the Chillinji Thrust Sheet, but has not been encountered in the Karambar Thrust Sheet. The terrigenous content occurs as grey to light brown, fine to coarse sandstone with dolomitic matrix in 10-100 cm beds, mostly with parallel laminations or gentle, low-angle cross-laminations. Siltstone intercalations are thin. The lower part of this unit is about 80 m thick on Vidiakot Ridge where it consists of metre-scale packages of coarser conglomerate with angular to poorly rounded clasts of black chert up to 5-6 cm, and quartzose sandstone layers interbedded with grey (yellow when weathered) dolostone. These mostly lack obvious structures, occur in 20-40 cm beds, and are usually subordinate to the arenites and hybrid arenites. Total thickness of the member: 90-130 m.

The upper *dolostone member* is monotonously dominated by light grey dolostone, usually in 20-50 cm beds with parallel lamination, stromatolitic laminae, and local enrichments of tabulates, bivalves, and gastropods (Text-fig. 10). Subordinate are coarse light grey dolostone in thick, poorly-defined beds. At the top, the stromatolitic laminae are locally deformed by tepee structures (Text-fig. 11). This member is present in all thrust sheets; the dolostones of the Tash Kupruk Zone are similar to it. The thickness is 100 to 300 m. This last figure was estimated, not measured.

Fig. 11. The stromatolitic layers deformed by tepee structures, at the top of the Chilmarabad Formation, are unconformably overlain by the coarse arenites and microcoglomerates of the Shogrām Formation. Ribat section. Ski stick for scale

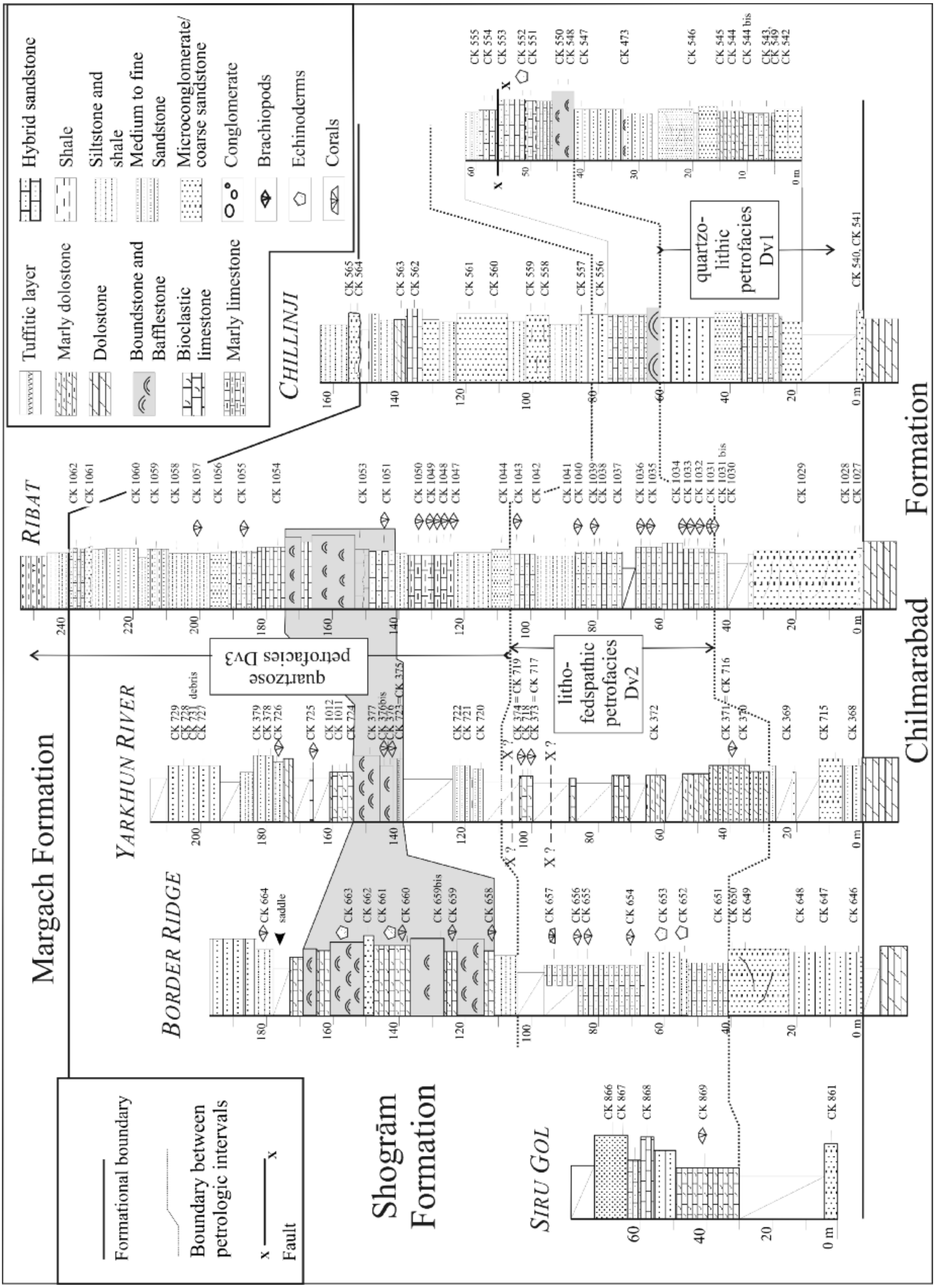

Fig. 12. Correlations and petrofacies through the measured sections of the Shogrām Formation. Extension of the coral bafflestone lithohorizon in indicated in grey

Sandstone petrography

A single sandstone sample from the lower member (Chillinji section: CK 534) is a coarse-grained, moderately to poorly-sorted sublitharenite with little plagioclase; volcanic, subvolcanic and cherty lithics represent over 7% of the sandstone framework. Phyllosilicate pseudomatrix (DICKINSON 1970) may represent the remnant of further, deeply-diagenized sedimentary rock fragments (shale to slate).

Fossil and age

Fossils are rare in the peritidal dolostones and very poorly preserved; only algae and tabulates have been recognized in this unit (HUBMANN & GAETANI 2007). They are *Pseudopalaeoporella*? sp., *Thamnopora* cf. *longdongshuiensis* DENG, *Pachycanalicula*? sp., *"Caunopora"* sp. They are consistent with a Middle Devonian age.

It should be noted that on the Wakhan side in the Darya-i-Baroghil catchment area, KAFARSKIY & *al.* (1974) and KAFARSKIY & ABDULLAH (1976) quote several species of Rugosa and Tabulata of Early Devonian age. Further research should focus particularly on the area around the Baroghil Pass on both sides of the watershed, because that area seems to have better preservation of fossils than the Devonian carbonate rocks on the southern side of the watershed.

Shogrām Formation (DESIO 1963, 1966)

The formation is present in all sequences in which Devonian rocks are preserved. It corresponds broadly to intervals 10-19 of the Mount Shogrām section originally described by DESIO (1966). A standard succession for the Yarkhun and Karambar river basins appears to be as follows, from bottom to top (Text-figs 12, 13):

1. The unit invariably starts with a terrigenous package of 15-35 m of conglomerates and coarse grained arenites. Some sections exhibit only rather homogeneous coarse arenites; others, such as the Ribat section, have 1-2 m conglomerates channelling previous conglomeratic or arenitic layers. High-angle cross-laminations arranged in festoons are common. In no case, however, is the base of the formation deeply cut into the dolostone of the Chilmarabad Formation. Pebbles, up to 8 cm in size, consist of white quartzite and angular black chert clasts similar to those in the lower member of the Chilmarabad Formation.

2. The second litho-interval consists of fine arenites in thin to medium layers with faint parallel laminations, burrowed and containing rare bioclasts, cyclically overlain by bioclastic calcarenites (mostly packstone) with parallel and high angle cross-lamination. The cycles are several metres thick. The bioclastic layers may be very rich in fossils, especially brachiopods and crinoids, but also coelenterates may occur locally. Conodonts are extremely rare. Thickness: 90 to 120 or 130 m.

3. Coral bafflestones usually form a single ridge in the landscape, rarely two as in the Border Ridge section. They are commonly crowded with colonial rugosans, tabulates, bryozoans and, in a minor way in the lower part, also brachiopods. Coral colonies, up to 50 cm high, may be preserved in life position. Unfortunately, especially in the Ribat section, the pronounced recrystallization prevents useful collections. Local interruption of sedimentation with lithified surfaces may be present. Thickness: from less than 10 up to 34 m.

4. Nodular grey limestone in medium to thin beds, with increasing shaly intercalations and siltstone. Arenaceous limestone and bioclastic calcarenite with brachiopods also occur. Thickness: from 5 to 20 m.

5. The uppermost litho-interval consists mostly of very fine terrigenous sediments (fine arenites, siltstones and shales) with gentle parallel lamination and diffuse burrowing of *Rhizocorallium* type or with limonitized nodules, probably originally pyrite. Cross laminations are rarer. Rare occurrence of calcareous siltstone crowded with brachiopods (CK 1057). The thickness varies from less than 20 m up to 45 m. Transition upwards to the Margach Formation is gradual with almost complete disappearance of limestone intercalations following a basal package of 45 m of siltstones and fine arenites.

Sandstone petrography

Twenty-three sandstone samples of this sand-rich unit were quantitatively analysed. They range from sublitharenites and subarkose/arkose to almost pure quartzarenites; grain size of the analysed samples ranges from very coarse- to very fine-grained sandstone. Monocrystalline quartz is by far the dominant grain type. Only exceptionally, it displays resorption embayments, indicating a volcanic origin. Polycrystalline quartz (Qp) also occurs, with a highly variable abundance that is positively correlated to sandstone grain size, although with low coefficients (PEARSON's $r = 0.66$, sign. lev. $< 0.1\%$). Especially in fine-grained sandstones, however, anomalously high Qp content might represent an overestimate due to subgranulation of monocrystalline quartz (CARTER & *al.* 1964) at grain boundaries under deep diagenetic conditions.

Feldspars consist of plagioclase, commonly untwinned (probably as an effect of diagenetic albitisation) and alkali feldspar. A single occurrence of chessboard-albite was noted, pointing to diagenetic destabilisation of high-temperature alkali feldspar. Volcanic rock fragments (VRF) display felsitic and vitric structures; subvolcanic and plutonic rock fragments are comparatively rare. Sedimentary rock fragments are represented mainly by chert, occurring in low numbers throughout the unit, and by less common shale and siltstone fragments (TRF). Not a single carbonate lithic (CE of ZUFFA 1980) was detected. Low-grade metamorphic grains are minor.

Heavy minerals are restricted to an ultrastable zircon-tourmaline (ZTR) suite, with minor rutile and very little detrital mica. Pseudomatrix (DICKINSON 1970) and phyllosilicate to tectosilicate pseudomorphs are common; they were partitioned between lithic grains (VRF or TRF) and feldspars depending on mineral association, apparent hardness (deduced from the degree of deformation at grain boundaries) and relict crystal shape. Intrabasinal grains are restricted to rip-up clasts and "ghosts" of allochems, locally recognised as bioclasts (mostly represented by echinoderms, brachiopods and less commonly bivalves). Despite pervasive diagenetic dolomitization, such carbonate intrabasinal grains (CI *sensu* ZUFFA 1980) retain their original calcite composition in samples where their abundance is maximal (CK 546, CK 547, CK 554, CK 653).

Primary pores were filled by epimatrix and syntaxial cements, mostly quartzose, whereas secondary pores were filled by authigenic carbonates, ferroan carbonates and opaques. The sum of interstitial components in samples CK 556, 662, and 1041 exceeds the theoretically expected maximum for grain-supported sands (48.8%); in the same samples, interstitial carbonates represent at least 9% of rock volume. This indicates partial diagenetic dissolution of framework grains and growth of authigenic carbonates in secondary pores (SCHMIDT & MCDONALD 1979). In those samples, quartz content in the QFL mode is probably overestimated, as sandstone composition tends towards "diagenetic quartzarenite" (HARRIS 1989) due to higher mineralogical stability of quartz compared to feldspar and most lithic grains.

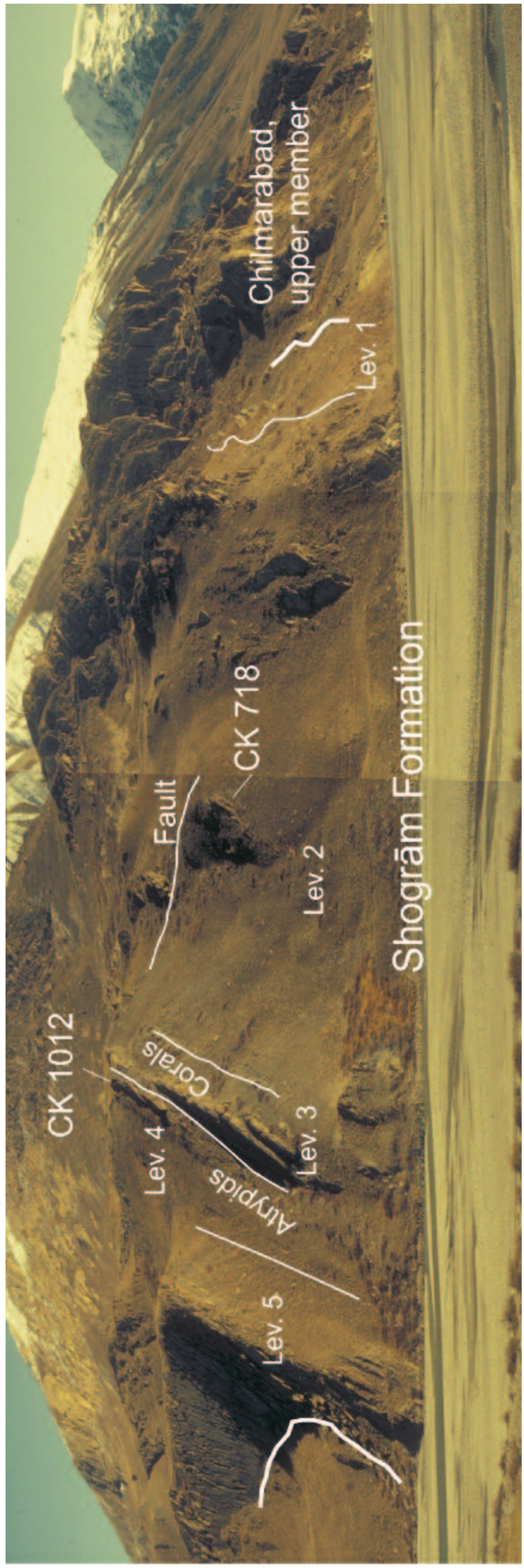

Fig. 13. View of the Yarkhun River section measured in the Shogrām Formation. The position of the problematic CK 718 sample is indicated

Fossils and age

The Shogrām Formation is the most fossiliferous unit of the Karakorum Devonian.

The tabulate, rugosan, and brachiopod horizon at the base of the second litho-interval, contains *Cyathophyllum afghanense* (BRICE), identified by SCHRÖDER (2004), and the tabulates *Alveolites hudlestoni* REED and *Heliolites*? sp. identified by HUBMANN in HUBMANN & GAETANI (2007); these are consistent with a Givetian age. Amongst brachiopods (CK 1013, CK 1031, CK 1032, CK 1034) were identified: *Schuchertella* sp., *Schizophoria striatula* (SCHLOTHEIM), *Cupularostrum koraghensis transiens*(REED), *Nymphorhynchia* sp. nov., *Athyris asiatica* REED, *Athyris triplesioides* OEHLERT, *Douvillina dutertrei* (MURCHISON), *Ambocoelia asiatica* REED, *Rugosatrypa* sp.

In the second litho-interval, several layers are rich in brachiopods and also contain rugosans such as *Siphonophrentis* sp. A, *Siphonophrentis* sp. B, *Enallophrentis*? sp., *Endophyllum* sp., *Spinophyllum* sp. cf. *varioseptatum* (SPASSKY), *Spinophyllum*? *shogramense* SCHRÖDER, *Spinophyllum* sp., *Keriophyllum* sp., *Stringophyllum acanthicum* FRECH, *Macgeea* cf. *gallica gigantea* BRICE & ROHART, *Phillipsastrea* cf. *orientalis* SMITH, *Pseudozaphrentis sirius* SCHRÖDER, *Macgeea* cf. *multizonata* (REED), *Macgeea*? sp., *Disphyllum caespitosum lazutkini* (IVANIJA), *Hexagonaria* cf. *sanctacrucensis* MOENKE, *Hexagonaria* sp. B, *Hexagonaria* sp. C. or tabulates such as *Pachyfavosites polymorphus* (GOLDFUSS). Amongst brachiopods (CK 1040, CK 1041, CK 1044, CK 1046, CK 1048, CK 1049, Text-fig. 14) are *Schizophoria striatula*, *Costatrypa* sp., *Rugosatrypa* sp., *"Spinatrypa" spinosa chitralensis*, *Waiotrypa* sp., *Gypidula (Devonogypa)* sp., *Sinotectirostrum*? sp., *Uncinulus* sp. nov., *Nalivkinaria* sp. nov., *Athyris triplesioides*, *Ambocoelia asiatica*, *Cyrtospirifer verneuili* (GOSSELET), *Tenticospirifer triplisinosus* (GRABAU).

In the Yarkhun River section (Text-fig. 13), TALENT & *al*. (1999) identified *Icriodus* conodont faunas of early Famennian age from samples CK 374 and CK 718. Sample CK 718, collected 104 m above the base of the Shogrām Formation, was dated as being early Famennian (from mid *triangularis* Zone to mid *crepida* Zone) on the basis of co-occurrence of *I. a. alternatus* BRANSON & MEHL morph 1, *Icriodus alternatus alternatus* BRANSON & MEHL, morph 2, *I. a. mawsonae* YAZDI, *I. homeomorphus* MAWSON, *I. iowaensis iowaensis* YOUNGQUIST & PETERSON, and *I. i. ancylus* SANDBERG & DREESEN. These identifications and the inferred age were confirmed by colleagues Gilbert KLAPPER and Charles SANDBERG; we have no doubt about the published identifications or the age inference (TALENT & *al*. 1999, p. 212 and fig. 4). Sample CK 374 from 1 m below CK 718 contains fragments of the icriodid forms also identified from CK 718; accordingly it too is considered to be early Famennian in age. The icriodid faunas from the Yarkhun River can be correlated with the Kurāgh section samples KUR 21 to KUR 24 (TALENT & *al.* 1999). In these horizons, two Famennian species make their first appearance: *Icriodus iowaensis iowaensis* and *I. alternatus mawsonae.* Associated with them are other species that cross the Frasnian–Famennian boundary, principally *I. alternatus alternatus* morph 1, *I. homeomorphus*, *Polygnathus brevilaminus* OVNATANOVA, *P. politus* OVNATANOVA (= *P. pacificus*) and *P. webbi* STAUFFER. This interval, isolated by debris from other parts of the Yarkhun River section (Text-fig. 13), is biostratigraphically anomalous, raising the question of a possible fault-slice.

Coral bafflestones of the third litho-interval have produced rugose and tabulate faunas of broadly Frasnian aspect: *Pseudopexiphyllum occultum* SCHRÖDER, *Hexagonaria* sp., *Argutastrea* sp., *Tryplasma*? sp., *Disphyllum* cf. *caespitosum caespitosum* (GOLDFUSS), and *Disphyllum* sp. described by SCHRÖDER (2004). HUBMANN in HUBMANN & GAETANI (2007) described *Thamnopora grandis* DUBATOLOV, *Thamnopora* cf. *reticulata* (BLAINVILLE) and *Alveolites hudlestoni* REED. Amongst brachiopods are identified (CK 377, CK 1051, CK 1052) *Schizophoria striatula*, *Schuchertella* sp., *"Spinatrypa" spinosa chitralensis*, *Spinatrypa* sp., *Waioatrypa* sp., *Nymphorhynchia* sp. nov., *Tabarhynchus*? *pamirica* (REED), *Tenticospirifer triplisinosus*, and *Ambocoelia asiatica.*

The fourth litho-interval is still Frasnian in the lower part with conodonts *Icriodus alternatus alternatus*, morph 2 and *Polygnathus decorosus* STAUFFER (Yarkhun River section, sample CK 1012). According to ZIEGLER & SANDBERG (1990), *I. a. alternatus* first occurs at or just above the start of the Late *rhenana* Zone. The range for *P. decorosus* given by JI & ZIEGLER (1993) is from within the *disparilis* Zone through to the *linguiformis* Zone; BARSKOV & *al.* (1991) suggest the range, in recent zonal terminology, to be from the *triangularis* to *rhenana* zones. Co-occurrence of the two forms in question indicates probable Late *rhenana* Zone. The presence of atrypid brachiopods above this sample (Text-fig. 13) is consistent with this allocation. The following brachiopods were identified (CK 1022, CK 1023, CK 1026, CK 1057, CK 1062): *Douvillina dutertrei, Rhipidomella*? sp., *Exatrypa* sp., *Planatrypa* sp. nov., "*Spinatrypa*" *spinosa chitralensis, Spinatrypa* sp., *Radiatrypa* sp., *Gypidula* (*Gypidula*) sp. nov., and *Athyris asiatica*.

Margach Formation (Gaetani & *al.* 2004a)

This recently described unit is briefly summarized. Three litho-intervals were discriminated in the type-section in the Ribat valley, from bottom to top:

1. Dark grey to dark green splintery siltstones intercalated with thin-bedded arenites, rarely with parallel laminations; intercalations of bioclastic limestones bearing brachiopods and crinoid fragments are rare; the sequence includes a single 0.5 m bed with *Receptaculites* cf. *chardini*. Thickness: 92 m.

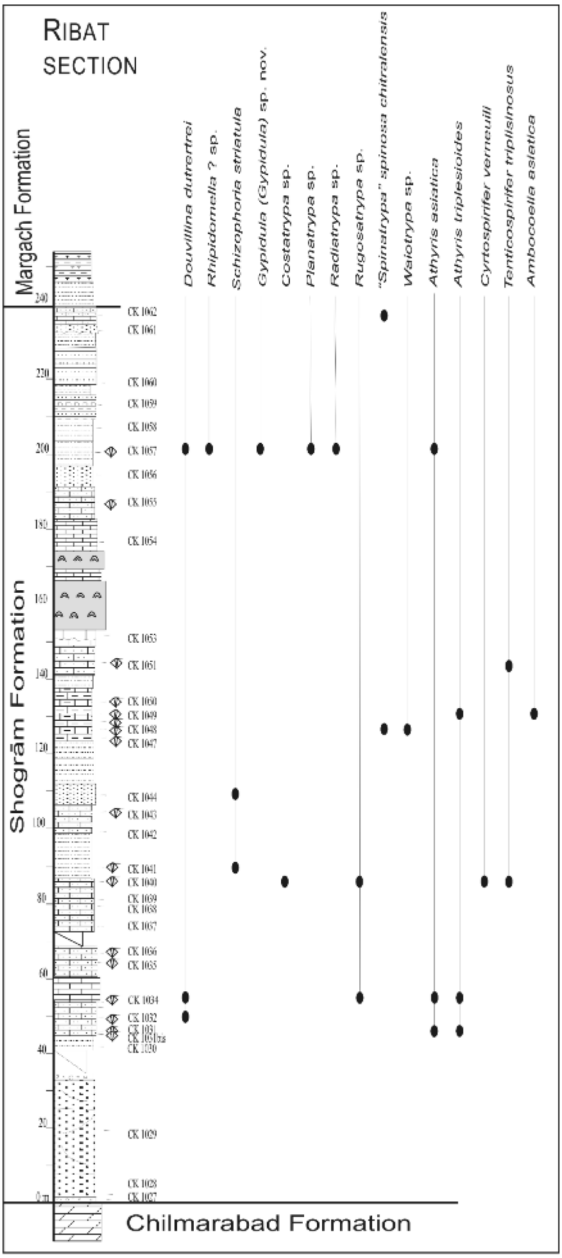

Fig. 14. Range of brachiopods in the Ribat section

2. Dark grey to black splintery siltstones and slates with bioturbated horizons and rare arenitic intercalations with dish-and-pillar structures. Thickness: 118 m.

3. Fine- to very fine-grained arenites in 20-40 cm beds, locally displaying parallel lamination, dominate in the lower part. Coarser arenites, also displaying microconglomerate lags and erosional channels, tend to predominate upwards. Asymmetric ripple marks indicate progradation from S to N. Bioturbation is more common in the thinner bedded arenites; hybrid biocalcarenites and biocalcirudites are also present. Thickness: 84 m.

Sandstone petrography

Two samples from the Chillinji section (CK 564-565) are coarse to very coarse-grained, moderately to poorly-sorted quartzarenites with very few feldspars (both plagioclase and K-feldspar) and felsitic volcanic, cherty and silty lithics. Heavy minerals are restricted to an ultrastable ZTR suite, while interstitial constituents are epimatrix, syntaxial quartz cement and authigenic dolomite in variable proportions.

Fossils and age

Receptaculites cf. *chardini* Nitecki & Lapparent, a form of a group of green algae which appeared in the Early Ordovician and disappeared in the Permian was collected in the Ribat section (CK 1066) (Hubmann & Gaetani 2007). No fossils were discovered in the second litho-interval, but in the third litho-interval a small brachiopod assemblage with *Parallelora* aff. *subsuavis* (Plodowski), *Rhipidomella* sp., and *Rhynchopora* sp. accords with an early middle Tournaisian age (Gaetani & *al*. 2004a).

Tash Kupruk Zone (Kafarskiy & *al.* 1974)

The only comprehensive geological study of the Wakhan corridor is an internal report by Kafarskiy & *al*. (1974) undertaken during the Soviet–Afghan cooperation programme. Their data were summarized by Kafarskiy & Abdullah (1976) and by Abdullah & Chmyriov (1980) in their comprehensive books and maps on the geology of Afghanistan. Kafarskiy considered all sedimentary rocks cropping out south of the Wakhan slates and crystalline rocks to belong to his Tash Kupruk Zone which, in fact, includes the entire Northern Karakorum Terrain. Gaetani & *al*. (1996) adopted this term, restricting its meaning to the belt with dolostones and volcanics outcropping extensively a few km north of the Baroghil Pass. We did not have access to this area but from the Pakistan–Afghan border we could identify the succession illustrated in Text-fig. 7 of KAFARSKIY's report (1974). Our Tash Kupruk Zone is thus only part of the complex of thrust sheets that forms the Northern Karakorum Terrain. This tectonostratigraphic unit contains the following principal rock units on the Pakistan side of the border:

1. Grey yellow dolostone in thick to massive beds, usually heavily dolomitized (with boudinage "fishes"), aggregating about 100 m in thickness. Locally and especially in the area north of Inkip on the eastern flank of the Kushrao valley, and to a lesser degree along Khan Kun Gol at an altitude about 4000-4100 m, ooidal dolostones, with stromatolitic laminae, sparse tabulates and bryozoans were collected. B. HUBMANN in HUBMANN & GAETANI (2007) identified *Celechopora devonica* (SCHLÜTER) suggesting a Givetian age. The dolostones on the Pakistan side are intimately associated with dark green tuffs and lavas, but contacts are sheared in the area we studied.

2. Other rock units are represented by volcanics (spilites) which, petrographically, are extremely altered with a dirty assemblage of quartz-albite-chlorite-amphibole-epidote-sphene and opaques, due to thorough greenschist-facies recrystallisation. Samples analysed plot in an alkaline to peralkaline field of basalts to latibasalts (DEBON & LE FORT 1988). Trace elements and REE support these alkaline features. The high Zr, Nb and La (LE FORT in GAETANI & *al.* 1996) compare well with oceanic island basalts (OIB, e.g. PEARCE & NORRY 1979) and other alkali basalts from continental rifting situations (e.g. BARBIERI & *al.* 1975). Very high Cr and Ni contents testify to a mantle source.

SANDSTONE PETROFACIES AND PROVENANCE: PALAEOTECTONIC IMPLICATIONS

Although the studied sandstones from the Chilmarabad, Shogrām and Margach formations are invariably quartz-rich, vertical trends of sand mineralogy allowed us to recognise three distinct petrofacies in the studied population of 26 samples, based on standard QFL modes (DICKINSON 1970; Text-fig. 15). The three petrofacies characterise regularly superposed petrologic intervals as originally defined by DICKINSON & RICH (1972).

The Quartzo-lithic Petrofacies Dv1 (n = 12) is defined by detrital modes Q = 93.5±5.5, F = 2.5±2.4, L

Symbol	Petrofacies	*Petrologic interval*
●	Quartzose Petrofacies Dv3 (n = 9)	*Upper Shogrām & lower Margach Fms.*
■	Litho-feldspathic Petrofacies Dv2 (n = 5)	*Middle Shogrām Fm.*
▲	Quartzo-lithic Petrofacies Dv1 (n = 12)	*Chilmarabad & lower Shogrām Fms.*

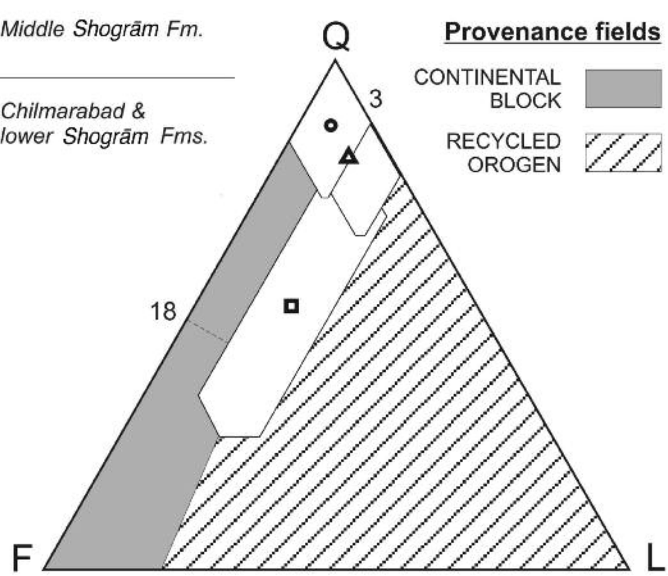

Fig. 15. Provenance fields and petrofacies distribution in the Devonian sandstones of the Western Karakorum. Due to consistently quartz-rich composition of sandstones, only the upper part of the QFL triangle (DICKINSON 1985) is displayed (baseline at Q = 65)

= 4.0±3.7; sublitharenites are the dominant sandstone type. Quartz is mostly monocrystalline (C/Q = 10 ± 10%), whereas feldspar is mostly represented by plagioclase (P/F = 90 ± 20%); volcanic rock fragments are widespread, but subordinate relative to other sedimentary lithic types (V/L = 30 ± 30%). Carbonate intrabasinal grains (CI; in the present case study, bioclasts from benthic communities) are abundant only at definite stratigraphic intervals. Petrofacies Dv1 characterizes a petrologic interval including the Chilmarabad Formation and the first (basal) litho-interval of the Shogrām Formation as described above.

The Litho-feldspathic Petrofacies Dv2 (n = 5) is defined by detrital modes Q = 83.0±9.0, F = 11.2±8.9, L = 5.8±2.5; subarkoses are the dominant sandstone type. Quartz is mostly monocrystalline (C/Q = 10±0%), while feldspar is represented by both plagioclase and K-feldspar (P/F = 60±30%); volcanic rock fragments are more abundant than other sedimentary lithic types (V/L = 60±50%). CI's are abundant only at definite stratigraphic intervals. Petrofacies Dv2 characterizes a petrologic interval roughly corresponding to the second litho-interval of the Shogrām Formation as described above.

The Quartzose Petrofacies Dv3 (n = 9) is defined by detrital modes Q = 95.6±5.0, F = 2.5±3.2, L = 1.9±2.2; quartzarenites are the dominant sandstone type. Quartz is mostly monocrystalline (C/Q = 10±0%); feldspar is mostly represented by plagioclase (P/F = 90±30%); volcanic rock fragments are widespread, but subordinate relative to other sedimentary lithic types (V/L = 30±40%). Both carbonate and non-carbonate intrabasinal grains are rare. Petrofacies Dv3 characterizes a petrologic interval including the upper two litho-intervals of the Shogrām Formation as described above, plus the lower member of the overlying Margach Formation

Since Petrofacies Dv1 and Dv3 are defined by similar detrital modes, the corresponding petrologic intervals can be distinguished with confidence mostly due to the interposition of sandstones characterised by Petrofacies Dv2.

In terms of provenance, the studied sandstones consistently point to a scenario of limited tectonic inversion and shallow dissection of older sedimentary basins filled up by terrigenous and cherty sediments, as well as of volcanic successions that might be penecontemporaneous with the sedimentation. From the stratigraphic reconstruction here proposed, such volcanic successions might be found in the Tash Kupruk Zone. Relative abundance of feldspar, characterising the Litho-feldspathic Petrofacies Dv2, might be interpreted as the result of more pronounced block-faulting in the drainage basin ("tectonic arkose" *sensu* Folk 1974). Alternative explanations are less viable: control by grain size on feldspar abundance, although expected theoretically (Odom & *al*. 1976), is not significant (r = – 0.46); rather, feldspar concentration might be due to hydraulic selection of feldspar in shelf settings (Ibbeken & Schleyer 1991). However, the abundance of lithic grains is not correlated with grain size (r = – 0.13), so the concurrent increase of feldspars and lithics in Petrofacies Dv2 can be regarded as a true provenance signal.

The story that sandstones tell us is intriguing. After the initial stage of block-faulting that caused recycling of Early Palaeozoic to Precambrian sedimentary rocks (seemingly associated with some volcanic activity) a second stage of block-faulting during the Givetian involved the newly-emplaced volcanic successions. Topographic trends towards more subdued relief characterised sand accumulation during the Frasnian-Famennian, resulted in mineralogically stable and texturally submature sediments. Such a trend was interrupted by a major rift unconformity within the Tournaisian part of the Margach Formation (when micaceous subarkoses were deposited), pointing to first-cycle contributions from uplifted crystalline rocks and thus to a deeper level of rift-related crustal dissection (Gaetani & *al*. 2004a). A locally deep diagenetic overprint partially obscured the already described petrographic signals.

PALEOENVIRONMENTAL EVOLUTION

The palaeogeographic scenario for the Devonian of the NW Karakorum is that of a marine coastal shelf on which carbonate sedimentation gradually became dominant over the poorly oxygenated muddy flats of the Vidiakot Formation (Baroghil Group). There was not complete cessation of terrigenous input. This, episodically, became coarser, reaching microconglomerate-scale. The occurrence of terrigenous compared with carbonate sedimentation also varies between the different thrust sheets, being generally more abundant and coarser in the most southern and western sheets, but rarer and finer in the Karambar Sheet, one of the higher structural elements. Accurate age identifications are scanty and therefore correlations between sheets are tentative. Also it should be kept in mind that, south of the Reshun Fault, Devonian rocks are exposed expecially in the Chillinji Anticline. Along the Axial Unit, usually the Permian Gircha Formation unconformably overlies the Baroghil Group and only few sparse outcrops of Shogrām Formation are preserved.

The Early Devonian saw the onset of very shallow-water carbonate factory environments over most of the area. Occasional intervals of submature terrigenous clastics (quartz and black cherts) interfinger with the carbonates; the latter were often later transformed into dolostones. Noteworthy is the well-sorted nature of the clastic bars and the absence of mud. Apparently the coastal flats were not favourable for benthic invertebrates; stromatolitic laminae occur occasionally. Only in the Karambar Sheet is more diversified life present: solitary and colonial corals, brachiopods, and crinoids. In this structural unit, clastics are much reduced with a few metres richer in quartz grains and some shaly intercalations in litho-intervals 3 and 4 of the Vandanil Formation. It is difficult to discriminate if the clastic input was linked to erosional pulses connected with eustatic cycles or to incipient tectonic activity along the passive margin of the Northern Karakorum.

The terrigenous inputs gradually diminished or even disappeared during the Middle Devonian; a wide peritidal carbonate platform spread over the area, with local ponds and shoals. Small and patchy tabulate mounds (Text-fig. 12 – Chilmarabad Formation in the Lashkargaz Sheet) and a larger rugose/tabulate mound (litho-interval 5 of the Vandanil Formation) developed. Age-control at this level is difficult; the correlations are very tentative.

During the Givetian a very important rifting event occurred over a wide area. The carbonate platform [homogeneous under peritidal conditions (bedded stromatolitic dolostones)] rifted and emerged. On the shoulder of the rift, quartzitic rocks (like the pre-Ordovician Chikar Quartzite) and again dark cherts from an unknown, possibly Pre-Cambrian sedimentary unit, were vigorously eroded. This early stage of block-faulting did not, however, exhume micaceous crystalline basement units; these were unroofed during deposition of the upper member of the Margach Formation, already well into the Carboniferous (GAETANI & *al.* 2004a). A blanket of terrigenous sediments, 10 to 30 m thick, spread over the entire area, deposited at least in part under alluvial conditions, with channels and cross-laminated festoons. The Tash Kupruk volcanics might be linked to this early rifting episode.

The sea gradually transgressed once more, initially with marginal mixed carbonate–clastic facies, then with prevailing packstone; grainstone sediments rich in bioclasts were rare. The benthic invertebrate community was dominated by brachiopods, sometimes in gregarious patches or accumulated by bottom currents in lenses along the shelf. On well-washed, clean bottoms during the Frasnian, corals and bryozoans flourished, building thick bindstones and bafflestones. Fine terrigenous input gradually recovered during the Frasnian. During the Famennian, the area received coarser inputs of arenites, mostly litharenites, with carbonate sedimentation becoming subordinate. Age-control for the Famennian is poor. Around the Devonian–Carboniferous boundary, the Margach Formation records sedimentation on a muddy shallow-marine flat, with significant terrigenous input under low-energy conditions, mainly sheltered from waves. No significant emersion was detected. No ironstones were noted, though these are present in the Kurāgh Spur and Mt. Shogrām sections in Chitral (TALENT & *al.* 1982, 1999; KLOOTWIJK & CONAGHAN 1979). A general increase in energy was observed at the beginning of the Carboniferous (GAETANI & *al.* 2004a) with traction currents, erosional channels and coarser-grained detritus documenting a general forestepping of more proximal facies.

PALAEOGEOGRAPHY AND REGIONAL CORRELATION

Wakhan

The Devonian succession on the northern side of the Baroghil Pass was described by KAFARSKIY & *al.* (1974) and KAFARSKIY & ABDULLAH (1976); their data are summarized in ABDULLAH & CHMYRIOV (1980). At least part of that area is to be included in our Lashkargaz-Baroghil

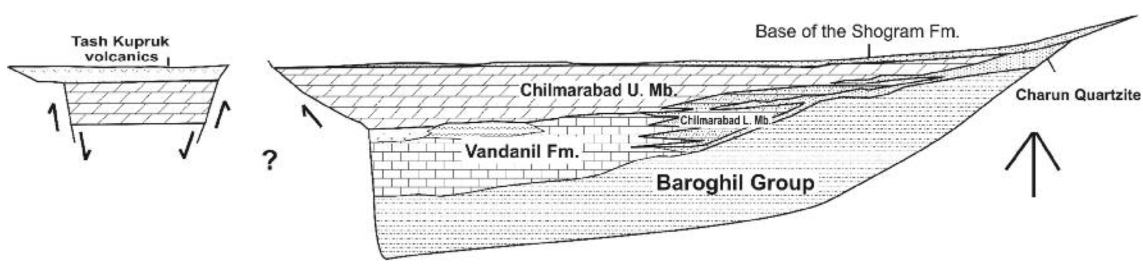

Fig. 16. Palaeogeographic cartoon for the Early–Middle Devonian in Western Karakorum. Outpouring of the Tash Kupruk volcanics is interpreted as linked to Givetian rifting. The Charun Quartzite was not discriminated in the Upper Yarkhun area, but the doloarenitic member of the Chilmarabad Formation and especially the basal beds of the Shogrām Formation could be its distal equivalents

Thrust Sheet. The lower part of the section, up to 800 m thick, consists of massive limestone with rugosan and tabulate corals of Early Devonian age, overlain by alternating fine terrigenous sediments and limestones, tentatively regarded as Middle Devonian. The Frasnian part of the section consists mostly of limestones, c. 360 m thick with two coral horizons. The Devonian rocks are overlain by Lower Carboniferous rocks with an erosional contact. It should be noted that the faults we trace on the Pakistan side are not recognized on their map and sections, and what is mapped by them as a granitoid of Late Triassic age, on the Pakistan border corresponds to a light massive limestone of Permian–Triassic age (LEVEN & *al*. 2007). Looking from the border, part of the Devonian-Carboniferous section belongs to our Tash Kupruk Zone. Reinvestigation of this section is very important.

Chitral

Though Devonian rocks are not particularly well preserved around the Karakorum, correlation of sequences in the Upper Yarkhun area with the classic succession in Chitral is obvious (HAYDEN 1915; DESIO 1966; STAUFFER 1967, 1975; TALENT & *al*. 1982, 1999). Two sections are most interesting: Mt. Shogrām and the especially fossiliferous Kurāgh Spur. The first was briefly described by DESIO (1966), the last by HAYDEN (1915) and described in detail by TALENT & *al.* (1999). The base of both sections has not been described in detail, but the lower part consists of alternating dolostones and quartzarenites named the Charun Quartzite by STAUFFER (1967, 1975).

The Charun Quartzite may be compared with the lower doloarenitic member of the Chilmarabad Formation with which it shares similar sandstone composition of the interbedded arenites, but the environments of deposition appear to be different. P. CONAGHAN (pers. comm. 2005) believes that at least the lower part of the Charun Quartzite was deposited by turbidity currents and therefore represents a deeper environment. We have not found evidence of deposition of the Chilmarabad Formation under deep conditions in the Upper Yarkhun area. In the Mt. Shogrām section, DESIO (1966) described up to 160 m of limestone below the quartzarenitic and microconglomeratic beds (Charun Quartzite) that could be tentatively aligned with the Vandanil limestones. This warrants closer investigation.

The base of the Shogrām Formation is Givetian (*varcus* conodont zone) on the Kurāgh Spur section (TALENT & *al*. 1999) as well as in our study area. However, the arenitic and microconglomeratic basal litho-interval is absent in the Kurāgh section and the coral assemblage is somewhat different (SCHRÖDER 2004). It was from this section that KLOOTWIJK & CONAGHAN (1979) and KLOOTWIJK & *al*. (1994) endeavoured to obtain palaeomagnetic data.

Peshawar area

In the Khyber region, MOLLOY & *al*. (1997) documented a section with a quartzarenitic unit at the base overlain by a siliciclastic-carbonate sequence. The base of the latter is thought to be Givetian (with abundant colonies of the rugose coral *Phillipsastraea*) passing upwards through Frasnian and Famennian horizons into the early Tournaisian. An even better sequence occurs at Ghundai Sar on the eastern margin of the Khyber ranges overlooking the Peshawar Basin; only one horizon has been acid-leached, producing *expansa* Zone Famennian conodonts. The Devonian sequence (Nowshera Limestone) at Nowshera within the Peshawar Basin has been shown to span the Silurian–Devonian boundary and extend up to within the Emsian (MAWSON & *al*. 2003) before giving way to quartzites that bring to mind the Charun Quartzite of Chitral. Sampling a scatter of localities from carbonates in siliciclastic-carbonate sequences in the Panjpir–Swabi–Jafar Kandao–Rustam area on the NE margin of the basin has indicated a broad spectrum of ages extending through the Devonian into younger horizons (POGUE & *al*. 1992; AHMAD & *al*. 2001).

Afghanistan

Devonian rocks are present in several tectonic zones of Afghanistan; two of them are relevant for the present paper:

Central Badakshan (ABDULLAH & CHMYRIOV 1980)

The Early and Middle Devonian are characterized by about 600-700 m consisting of massive limestones and dolostones; some arenitic and shaly intercalations occur in its lower part. This succession is unconformably overlain by a Frasnian complex up to 400 m thick of dolostones, platy limestones, shales and siltstones. A distinctive horizon of quartzarenites occurs at their base. The overlying Famennian is represented by up to 350 m of a mixed succession of sandy–shaly sediments and limestones with abundant brachiopods. The succession is similar to that of the Central Pamir.

Helmand

The Helmand Block (Montagnes Centrales of French authors; South Afghan Middle Massif of Soviet authors) was studied extensively by French and German missions to Afghanistan (BLAISE & *al.* 1977; DÜRKOOP 1970; PLODOWSKI 1970, and references therein) and under the Soviet–Afghan Cooperation Programme (ABDULLAH & CHMYRIOV 1980). The Devonian crops out extensively and was subsequently described by MISTIAEN (1985), who grouped it in the "Zone de Tezak-Nawar". ABDULLAH & CHMYRIOV (1980) instead discriminated three zones: Tirin, Logar and Argandab zones respectively.

In the Tirin Zone (equivalent to the "bordure nord et nord-ouest du bassin" of BLAISE & *al.* 1977) only the Upper Devonian is present, with the Frasnian transgressive onto various Silurian, Ordovician or even Precambrian sequences. The rocks are mostly calcareous with quartzarenitic intercalations.

The Logar Zone corresponds to the area of Toyka-Dewal of MISTIAEN (1985), and contains the most complete successions. The entire Lower and part of the Middle Devonian are mostly terrigenous, with the "*Formation quartzo-dolomitique de Ghujurak*" recalling the doloarenitic member of the Chilmarabad Formation of Karakorum. These Afghan successions are overlain by a widespread calcareous succession, several hundred metres thick, the "*Formation des calcaires massifs de Bokan*" which recalls the ubiquitous dolostone member of the Chilmarabad Formation of Karakorum. Mixed carbonate–terrigenous successions overlie the Bokan Formation, recalling the Shogrām Formation of Karakorum–Chitral, but several different erosional surfaces are present in the Givetian and Frasnian of Helmand, and not a single more pronounced Givetian unconformity, as in Karakorum. The reappraisal of the prevailing terrigenous sedimentation occurs in the middle Frasnian and extends to the Famennian with the "*Formation des encrinites ferrougineuses de Ko-e-Giru*", rich in *Receptaculites*. A correlation to the Margach Formation of Karakorum is suggested (MISTIAEN 2008, pers. comm.). However, the onset of the Margach Formation is gradual and not abrupt as in the Dasht-e-Nawar area.

The Argandab Zone is characterized by a thinner thickness of mostly terrigenous sediments with frequent calcareous intercalations in the Middle Devonian. A significant unconformity lies between the lower and upper Frasnian, with an overlying succession of up to 800 m of conglomerates and arenites with sporadic calcareous intercalations.

Central Pamir

Devonian rocks are not known from the eastern Hindu Kush, southeast Pamir and its extension to the SE in Shaksgam Valley. Instead Devonian rocks are scattered in the Central Pamir (KARAPETOV 1963, 1971; BARDASHEV & BARDASHEVA 1999; SCHRÖDER & LELESHUS 2002). Succeeding the Upper Silurian, represented by dark limestones, the Devonian is mostly calcareous with spectacular Middle Devonian reefoidal facies up to 1300 m thick. From the late Givetian upwards, terrigenous input recurs sporadically, becoming significant in the late Famennian. In the thrust sheets along the Ak Baital zone, KARAPETOV (1963, 1971) described more than 200 m of dolostones of Frasnian age overlain by limestones passing into marly limestones and marls in the Famennian, separated by an unconformity from the overlying red platy limestone of Tournaisian age. There are significant analogies with the Northern Karakorum Terrain, especially with the Karambar unit, with dark limestones in the Early Devonian, thick reefoidal dolomitized Middle Devonian and an unconformity in the Givetian.

NW Himalaya

The classical Devonian succession of the NW Himalaya, i.e. Muth Quartzite overlain by the Lipak Formation, has been recently recalibrated in age by DRAGANITS & *al.* (2002). It is interpreted as a coastal shelf with barrier island quartzarenites (Muth Quartzite), gradually ingressed by a shallow sea with mixed calcareous/fine terrigenous sedimentation (Lipak Formation). The Lipak transgression occurred during the Givetian at approximately the same time as the similar transgression in the Karakorum/Chitral. DRAGANITS & *al.* (2002) documented a gap in the Frasnian of the Himalaya, an interval that has instead a sedimentary record in the Karakorum.

PALAEOGEOGRAPHIC INTERPRETATION

The North Karakorum Terrain during the Devonian was apparently linked to neighbouring, though now-dispersed, blocks forming a wide, gently subsiding platform. During a time span (roughly Early Devonian to Givetian) a wide shallow carbonate platform dominated in Central Badakshan, Central Pamir, Karakorum and Chitral. Add to these the NW Himalaya, interpreting the Karakorum and NW Himalaya as parts of the same passive margin, with a more external, salient and subsiding section in the Karakorum and a more inner-shelf section in the NW Himalaya, more prone to intermittent emersion and sedimentary gaps. The platform periodically received inputs of ultrastable clastics, increasing towards Chitral. Central Afghanistan (the Helmand/Dasht-e-

Nawar region) had a more diversified pattern with more intense erosion and subsidence, but also there the massive carbonates spread during the late Early and Middle Devonian.

During the Givetian the structural platform underwent emersions and gentle tectonics interpreted as the initial episode of rifting, disrupting the wide platform. The volcanic episode of the Tash Kupruk Zone should be linked to this extensional activity, even though its precise timing is not yet determined. The age of the unconformity is apparently slightly younger in the Central Pamir. The arenitic composition also shows a shift from stable sublitharenites to ultrastable quartzarenites within Petrofacies Dv1, deriving lithics from a shallow-crustal section (older sedimentary successions to low-grade metamorphic basement) including some volcanics.

Erosion of the rift shoulders during the Frasnian generated an influx of litho-feldspathic material to the passive margin where it mixed with the important carbonate production, with coral boundstones and shelly accumulations with brachiopods. A crisis in the carbonate factory during the Famennian reduced the importance of the carbonate accumulations. Gaps, ironstone horizons and/or more shaly input due to the demise of the initial rift shoulders, characterized the final stage of the Devonian.

The subsequent rifting and spreading during the Carboniferous–earliest Permian, leading to the opening of Neo-Tethys separated these previously closely-juxtaposed areas, driving the Peri-Gondwanan Fringe towards the Asian margin, away from the remnant Devonian sequences on the Gondwana side of the NW Himalaya.

The meaning of the Givetian unconformity and onset of erosion on the rift shoulder during the Frasnian should be interpreted as echoing opening of a sea-way (Palaeo-Tethys in Metcalfe's 1996 and 1999 terminology) far to the east. It should be noted that this extensional activity took place on blocks that drifted away subsequently, during the Permian, such as the Karakorum and Central Pamir, both lying to the north of the future passive margin of the Indian Plate in the NW Himalaya. This indicates that the opening of Neo-Tethys occurred to the south of Karakorum (in present coordinates). According to the Stampfli *& al.* (1991) model, Karakorum was therefore situated on the lower plate or at the extreme boundary of the upper plate, later drifting away on the lower plate.

CONCLUSIONS

The Devonian succession of the Western Karakorum represents a fragment of the former passive margin of the Gondwana Supercontinent. It represents the gradual onset of carbonate sedimentation over a wide structural platform in shallow to very shallow conditions. Peritidal carbonates, early transformed into dolostone, were locally interrupted by mounds and reefs built by stromatolites, rugose and tabulate corals. The more complete and thicker successions accord with an increase in area and subsidence (approximately northwards according to present coordinates) extending to higher structural elements. During the Givetian mild tectonic activity led to emersion and erosion of the carbonate platform, with fluviatile sedimentation and clastic input from the rift shoulders. The lava flows and tuffaceous intervals of the Tash Kupruk Zone are interpreted as reflecting accumulation in a graben of the rift system. Gradual spreading of marine conditions connected with an increased rate of subsidence occurred during the Givetian, though with intermittent terrigenous inputs continuing during the Frasnian with development of coral bafflestones. The reduced carbonate productivity in the Famennian, coupled with more intense erosion, produced fine to very fine terrigenous sedimentation on the marine shelf. About the Devonian–Carboniferous boundary, poorly oxygenated muddier conditions prevailed.

TAXONOMIC COMMENTS ON CHRONOLOGICALLY SIGNIFICANT CONODONTS FROM THE WESTERN KARAKORUM (by Ruth Mawson)

Order Ozarkodina Dzik, 1976
Family *Icriodontidae* Müller & Müller, 1957
Genus *Icriodus* Branson & Mehl, 1938

TYPE SPECIES: *Icriodus expansus* Branson & Mehl, 1938.

Icriodus alternatus alternatus Branson & Mehl, 1934
(Pl. 1 Fig. 9)

REMARKS: In their study of Late Devonian icriodontid biofacies, Sandberg & Dreesen (1984, p. 158) designated two morphs of this subspecies, Morphotype 1 with laterally compressed medial-row denticles, and Morphotype 2 with rounded medial row denticles. The specimen from CK 718 illustrated herein has rounded medial-row denticles that, in line with Sandberg & Dreesen's (1984) argument is an example of Morphotype 2. According to Ziegler & Sandberg (1990), *I. a. alternatus* first occurs at or just above the beginning of the Late *rhenana* Zone.

Genus *Oulodus* BRANSON & MEHL, 1933

TYPE SPECIES: *Cordylodus serratus* STAUFFER, 1930.

Oulodus sp.
(Pl. 1, Fig. 5)

REMARKS: From faunas, now recognised as referrable to the *sulcatus* Zone (MATHIESON & *al.*, in prep.), PICKETT (1980, text-fig. 12H) illustrated an Sc element of *Oulodus* with a close resemblance to the element illustrated herein as Pl. 1, Fig. 5. As with the specimen illustrated by PICKETT, the main cusp is situated above a deeply-excavated basal cavity – it is of comparable size – and the lateral peg-like denticles appear to be grooved along their leading edge.

Family Spathognathodontidae HASS, 1959

Genus *Amydrotaxis* KLAPPER & MURPHY, 1980

TYPE SPECIES: *Spathognathodus johnsoni* (KLAPPER, 1969).

Amydrotaxis druceana (PICKETT, 1980)
(Pl. 1, Fig. 3)

1980. *Ozarkodina druceana nom. nov.* PICKETT, p. 73-77, figs 5A-W, 6A-U, 7A-C. [q.v. for earlier synonymy].
1990. *Amydrotaxis druceana* (PICKETT); BISCHOFF & ARGENT, p. 453-454, pl. 1, figs 1-29.
1994. *Amydrotaxis druceana* (PICKETT); MAWSON & TALENT, p. 49, fig. 10 A-P.
1995. *Amydrotaxis druceana* (PICKETT); WALL & *al.*, 378, pl. 1, figs 1-17.
1999. *Amydrotaxis druceana* (PICKETT); TALENT & MAWSON, pl. 4, figs 10-21; pl. 5, text-fig. 10; pl. 8, figs 3, 5, 7, 15; pl. 11, text-fig. 8.
2003. *Amydrotaxis druceana* (PICKETT); FARRELL, p. 129-131, pl. 4, figs 13-21; pl. 5, figs 1-9.

REMARKS: PICKETT (1980) identified the various elements of the apparatus of *Amydrotaxis druceana* from collections from the Rookery Limestone Member at "The Rookery", c. 35 km SE of Cobar, NSW, Australia. The M element illustrated here as Pl. 1, Fig. 3 is very similar to that illustrated by PICKETT (1980, p. 72, text-fig. 5D) and to the M element illustrated by WALL & *al.* (1995, pl. 1, text-fig. 13) from the Lilydale Limestone, Victoria, Australia.

Amydrotaxis sp. nov.
(Pl. 1, Figs 6, 7)

REMARKS: A single Pa element of a new species of *Amydrotaxis* occurs in the fauna from CK 1045. It is distinguished by having a single row of low, stubby denticles with those posterior to the basal cavity being lower than those above and anterior to the restricted basal cavity lobes that expand at mid-length and tend to be swept forwards towards the anterior of the unit. The nature and step-like arrangement of the stubby denticles and the deep, clearly defined basal cavity separate this from other spathognathodontiform elements described elsewhere. The new species is presently being documented (MATHIESON & *al.*, in prep.) from faunas from the Cobar Supergroup, of western New South Wales dated as late in the *sulcatus* Zone.

Genus *Ozarkodina* BRANSON & MEHL, 1933

TYPE SPECIES: *Ozarkodina typica* BRANSON & MEHL, 1933.

Ozarkodina excavata excavata (BRANSON & MEHL, 1933)
(Pl. 1 Fig. 4)

1933. *Prioniodus excavatus* n. sp.; BRANSON & MEHL, p. 45, pl. 3, figs 7-8.
1933. *Trichognathus excavata* n. sp.; BRANSON & MEHL, p. 51, pl. 3, fig. 35.
1933. *Ozarkodina simplex* n. sp.; BRANSON & MEHL, p. 52, pl. 3, figs 46-47.
1994. *Ozarkodina excavata* (BRANSON & MEHL); VALEMZUELA-RÍOS, p. 69-70, pl. 4, fig. 4.
1995. *Ozarkodina excavata excavata* (BRANSON & MEHL); SIMPSON & TALENT, p. 147-152, pl. 8, figs 16-25; pl. 9, figs 1-24 [q.v. for extensive synonymy prior to 1995].
1995. *Ozarkodina excavata excavata* (BRANSON & MEHL); COLQUHOUN, pl. 1, fig. 16.
1995. *Ozarkodina excavata excavata* (BRANSON & MEHL); DONGOL, fig. 4G-J.
1995. *Ozarkodina excavata* (BRANSON & MEHL); MILLER, pl. 1, fig. 8.
1999. *Ozarkodina excavata excavata* (BRANSON & MEHL); TALENT & MAWSON, pl. 4, figs 1, 3-4; pl. 5, figs 1-4; pl. 6, figs 19-22; pl. 7, text-fig. 14; pl. 9, figs 8-9; pl. 11, figs 12-14; pl. 12, figs 1-4.
2001. *Ozarkodina excavata excavata* (BRANSON & MEHL); SLAVÍK, pl. 2, figs 11, 15, 19.

2003. *Ozarkodina excavata excavata* (Branson & Mehl); Mawson & *al.*, pl. 3, figs 1-19; pl. 4, figs 1-15.
2003. *Ozarkodina excavata excavata* (Branson & Mehl); Farrell, p. 135-136, pl. 6, figs 10-21.
2004. *Ozarkodina excavata excavata* (Branson & Mehl); Slavík & Hladil, pl. 1, figs 14, 15, 17-19.
2004. *Ozarkodina excavata excavata* (Branson & Mehl); Slavík, pl. 1, figs 10, 11.

REMARKS: O*zarkodina excavata excavata* is recognised as a long-ranging species with its Pa element exhibiting a high degree of variation (e.g. Klapper & Murphy 1975; Jeppsson 1975). Other elements, including the M element illustrated on Pl. 1, fig. 4 from CK 1045, are easily distinguished by their unique 'excavated' basal cavities.

Ozarkodina remscheidensis remscheidensis (Ziegler, 1960)
(Pl. 1, Fig. 1)

1960. *Spathognathodus remscheidensis* n. sp.; Ziegler, p. 194-196, pl. 13, figs 1-2, 4-5, 7-8, 10, 14.
2001. *Ozarkodina remscheidensis remscheidensis* Ziegler; Slavík, pl. 2, fig. 9.
2003. *Ozarkodina remscheidensis remscheidensis* Ziegler; Mawson & *al.*, p. 90-92, pl. 2, figs 1-19; pl. 4, figs 1-6, 17 [q.v. for extensive synonymy prior to 2000].
2003. *Ozarkodina remscheidensis remscheidensis* Ziegler; Farrell, p. 90-92, pl. 2, figs 1-19; pl. 4, figs 16, 17.

REMARKS: *Oz. r. remscheidensis sensu stricto* can be identified by its irregular denticulation with a large cusp and a group of large denticles along the anterior of the blade with an enlarged denticle about mid-way above a heart-shaped (rather than ear-shaped) basal cavity.

Genus *Pandorinellina* Müller & Müller, 1933

TYPE SPECIES: *Pandorina insita* Stauffer, 1940.

Pandorinellina steinhornensis miae Bultynck, 1971
(Pl. 1, Figs 2, 10)

1971. *Pandorinellina steinhornensis miae* n. sp.; Bultynck, p. 25-31, pl. 4, figs 13-20; pl. 5, figs 1-14.
1980. *Pandorinellina steinhornensis miae* Bultynck; Klapper & Johnson, p. 451 [q.v. for additional synonymy prior to 1980].
1991. *Pandorinellina steinhornensis praeoptima* (Mashkova) *sensu* Lane & Ormiston 1979; Uyeno, pl. 21, text-fig. 19.
1992. *Pandorinellina miae* Bultynck; Bardashev & Ziegler, pl. 1, figs 41, 47.
1994. *Pandorinellina steinhornensis miae* Bultynck; Mawson & Talent, p. 55-57, text-fig. 11A–G.
2003. *Pandorinellina* cf. *miae* Bultynck; Farrell, p. 150, pl. 12, figs 5, 6.

REMARKS: This form was originally described from Spanish collections dated as *dehiscens* Zone (Bultynck 1971). Mawson & Talent (1994) obtained 694 specimens from sampled sections of *sulcatus–kindlei* age at Tyers and Boola in east-central Victoria, Australia. The specimens from CK 1045 (Pl. 1, Fig.2) and CK 1019 (Pl. 1, Fig. 10) fit within the range of variation of the above as well as within the range of material illustrated by Bultynck (1971, figs 19, 20 a-c; pl. 4, figs 13, 14; pl. 5, figs 1-14). Specimens from faunas from the *sulcatus* to early *kindlei* zones from the Hill End Trough of east-central New South Wales (Talent & Mawson 1999, pl. 5, figs 11, 20-24) show, in lateral view, the posterior upward curving of the ventral margin from the anterior end of the basal cavity as shown here (Pl. 1, Fig. 2) and, in the same publication (Talent & Mawson 1999, p. 5, figs 12, 19; text-fig. 12, figs 11-13), show the asymmetric basal lobes above the basal cavity that are seen with specimens from the Western Karakorum (Pl. 1, Fig. 10).

Genus *Polygnathus* Hinde, 1879

TYPE SPECIES: *Polygnathus dubius* Hinde, 1879.

Polygnathus decorosus Stauffer, 1938
(Pl. 1, Fig. 8)

1938. *Polygnathus decorosus* n. sp.; Stauffer, p. 438, pl. 53, figs 5, 6, 10, 15-16 (non figs 1, 11, 20, 30).
1973. *Polygnathus decorosus* Stauffer; Klapper in Ziegler (*Ed.*), p. 351-352, *Polygnathus* pl. 1, text-fig. 5 [q. v. for additional synonymy].
1980. *Polygnathus decorosus* Stauffer; Perri & Spalletta, p. 305, pl. 6, figs 7a-9c.
1993. *Polygnathus decorosus* Stauffer; Ji & Ziegler, p. 77, pl. 40, figs 16-18; text-figs 18, 16-17. [q.v. for additional synonymy].
1993. *Polygnathus decorosus* Stauffer; Matyja, pl. 19, fig. 1; pl. 20, fig. 1.

REMARKS: The Pa element is distinguished by having a narrow, symmetrical, saggitate platform. The free blade is normally half the length of the unit; this is not apparent from the damaged specimen from CK 1012 illustrated in Pl. 1, Fig. 8. Distinct nodes occur along the margins of the platform. Geniculation points are opposite and the anterior trough margins are short and curve upwards. The specimen from CK 1012 closely resembles those dated as Early *rhenana* Zone from western Pomerania (Matyja 1993, pl. 19, fig. 1; pl. 20, fig. 1).

The range for *P. decorosus* given by Ji & Ziegler (1993) is from within the *disparilis* Zone up to and into the *linguiformis* Zone; Barskov & *al.* (1991) suggest the range to be from *triangularis* Zone [Late *hassi* Zone to *gigas* Zone = *rhenana* Zone]; Ziegler & Sandberg (1990) mention *P. decorosus* as an important associated conodont in the Late Devonian from Early *falsiovalis* to Late *rhenana* zones.

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PLATE 1

Chronologically significant conodonts from Devonian carbonates of the Western Karakorum. (All specimens housed in the Department of Earth and Planetary Sciences, Macquarie University, with numbers prefixed by MU; scale bar = 0.1 mm)

1 – *Ozarkodina remscheidensis remscheidensis* (Ziegler, 1960), lateral view of Pa element, CK 1045, MU61781;

2, 10 – *Pandorinellina steinhornensis miae* Bultynck, 1971, lateral view of Pa element, CK 1045, MU61782; and upper view of Pa element, CK1019, MU61783, respectively;

3 – *Amydrotaxis druceana* (Pickett, 1980), anterior-lateral view of M element, CK 1045, MU61784;

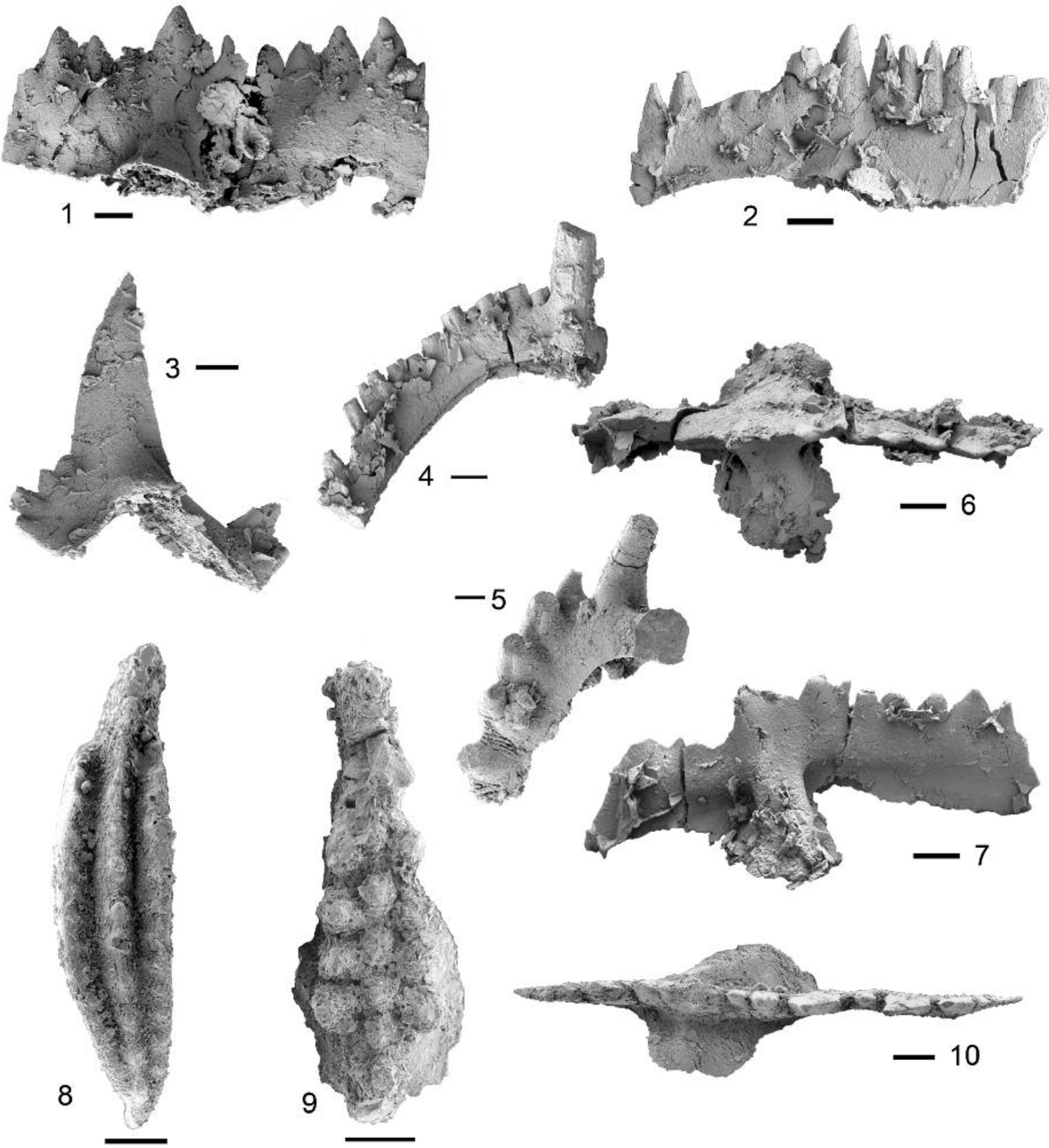
4 – *Ozarkodina excavata excavata* (Branson & Mehl, 1933), lateral view of M element, CK 1045, MU61785;

5 – *Oulodus* sp., lateral view of M element, CK 1045, MU61786;

6, 7 – *Amydrotaxis* n. sp., upper and lateral views respectively of Pa element, CK 1045, MU61787;

8 – *Polygnathus decorosus* Stauffer, 1938, upper view of Pa element, CK 1012, MU61788;

9 – *Icriodus alternatus alternatus* Branson & Mehl, 1934, Monotype 2 upper view of I element, CK 1012, MU61789.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