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PALEOZOIC TO EARLY MESOZOIC STRATIGRAPHY AND SEDIMENTARY EVOLUTION OF CENTRAL DOLPO (NEPAL HIMALAYA)

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Riassunto. La successione stratigrafica del Dolpo centrale inizia con una potente unità metacarbonatica di età Cambro?-Ordoviciana, attraversata da filoni pegmatitici formati per fusione parziale della crosta durante l'acme termico dell'orogenesi terziaria. La successione Paleozoica comprende poi marne fossilifere, quarzareniti dolomitiche e dolomie, seguite in discordanza da calcareniti bioclastiche di età Frasniana. Un orizzonte ricco di ooidi e noduli ferruginosi sottolinea poi una fase di rapido approfondimento, legata a un evento tettono-eustatico di importanza forse globale, seguito nel Devoniano sommitale da potenti peliti nere di piattaforma con livelli quarzarenitici e bioclastici.

Il Carbonifero è poco rappresentato nell'area studiata. Un livello di biocalcareniti di età Carbonifero inferiore? ritrovato solo a Tarap, profondamente eroso e ricoperto da un suolo tipo "terra rossa", è seguito in discordanza da una alternanza di quarzareniti bianche e peliti scure. Segue un livello marker a grandi Brachiopodi di età medio-Permiana (areniti a *Costiferina*), che passa verso l'alto a peliti di piattaforma e quindi a quarzareniti deposte in ambienti di estuario (Formazione di Thini Chu). Nel Permiano superiore, un'altra discordanza ricoperta da areniti conglomeratiche e glauconitiche è seguita ancora da peliti di piattaforma (Formazione di Kuling). La successione del Paleozoico superiore documenta un periodo di grande instabilità tettonica, con sollevamento ed erosione del margine continentale indiano.

Nel Triassico inferiore, subarkose dolomitiche sono seguite da due orizzonti condensati di carbonati pelagici di età Dieneriana e Smithiana, separati da argilliti nere (Formazione di Tamba Kurkur). La fauna ad Ammoniti e Conodonti e le strutture sedimentarie indicano un ambiente di piattaforma esterna, con profondità tra i 100 e i 200 m raggiunte durante le fasi trasgressive. La parte inferiore della Formazione di Mukut contiene calcari marnosi di età Scitico superiore e Anisico inferiore, alternati a peliti calcaree che diventano via via più abbondanti.

Le potenti Argilliti di Tarap, la cui base è sottolineata da uno strato pelagico condensato a pseudostromatoliti, contengono nella parte inferiore Ammoniti di età Norico inferiore, mentre la parte centrale termina con una alternanza ritmica di peliti e siltiti calcaree bioturbate. Esse sono seguite da arenarie quarzoso-feldspatiche molto fini, peliti calcaree e calcari nodulari con intercalati livelli ferriferi ("upper assemblage"). La sequenza regressiva triassica si chiude con quarzareniti dolomitiche e oolitiche deposte in ambienti costieri influenzati dalla azione di correnti di marea (Quartzite Series).

I Calcari di Kioto, deposti in ambienti subtidali poco profondi, contengono frequenti intercalazioni di quarzareniti ibride nella parte basale, e sono seguiti nel Giurassico medio dalle "lumachelle" della Formazione di Laptal.

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Abstract. The stratigraphic succession of central Dolpo (Tarap-Atali area) begins with thick calcsilicate marbles of inferred Cambro?-Ordovician age, injected by pegmatitic dykes. The strongly deformed mid-Paleozoic sequence comprises fossiliferous marls, dolomitic quartzarenites and dolomites. The latter are unconformably followed by earliest Late Devonian biocalcarenites, capped by a major ironstone layer. The overlying offshore black pelites contain quartzose sandstones and bioclastic limestones at several intervals, indicating deposition in shelfal environments at latest Devonian times.

The Carboniferous is poorly represented in the surveyed area. A major disconformity, cutting deep into Early? Carboniferous fenestellid-rich biocalcarenites at Tarap, is overlain by white quartzarenites interbedded with dark pelites, sharply followed by a fossiliferous marker horizon yielding a large brachiopod fauna of mid-Permian age (*Costiferina* arenites); the overlying fossiliferous shelfal pelites are unconformably followed by coarsening-upward quartzarenite sequences deposited in estuarine environments (Thini Chu Formation). In the Late Permian, another disconformity is overlain by conglomeratic to glauconitic arenites and shelfal pelites (Kuling Formation).

The Triassic Tamba Kurkur Formation, with dolomitic subarkoses at the base, consists of two condensed pelagic carbonate horizons of Dienerian and Smithian age, separated by dark pelites. Marly limestones and marls were deposited from the Spathian through the Carnian (Mukut Formation), and are overlain by the thick Tarap Shale. A thin basal condensed bed is followed by dark pelites yielding Early Norian ammonoids, by thick siltstones with phosphatic nodules and next by dark shales and calcareous siltstones with large *Zoophycos*-type burrows. The upper part of the unit contains up to fine-grained quartzo-feldspathic sandstones, nodular marly limestones and ironstone horizons ("upper assemblage"). The Late Triassic shallowing-upward succession is capped by dolomitic and oolitic quartzarenites with spectacular herringbone structures (Quartzite Series).

The largely Lower Jurassic shallow-water Kioto Limestone, still containing metric intervals of up to medium-grained hybrid quartzarenites in the lower part, is followed by Middle Jurassic lumachelles (Laptal Formation). Younger terms of the succession are not exposed in Dolpo.

Introduction.

Sedimentary rocks belonging to the Tethys Himalaya sedimentary succession are exposed in the Dolpo-Manang Synclinorium (central Nepal), a nearly 200 km long structure formed as a consequence of the collision between India and Asia in the Tertiary. Highly metamorphosed Paleozoic and less deformed Triassic and Jurassic units crop out to the north of the High Himalaya Crystalline belt ("Dalle du Tibet" of French Authors) and south of the Indus-Tsangpo suture. Cretaceous formations are preserved only in the Thakkhola graben, which is a late orogenic feature running northeast-southwest between the Annapurna and Dhaulagiri massifs, and separating the Manang region to the east from the Dolpo region to the west (Bordet at al., 1971).

During our september 1990 Ev-K2-CNR expedition, after crossing the crystalline axis along the Thulo Bheri River north of Dunai and up above Khanigaon, and then the Tethys Himalaya Early Paleozoic metasediments along the Tarap Khola, we reached the less deformed Late Paleozoic and Early Mesozoic sedimentary rocks of Dolpo (Fig. 1). Our attention was focused on the Permian and Triassic succession of the Tarap-Atali area, where we measured several detailed stratigraphic sections and collected about 300 samples for paleontological and petrographic study.

Aim of the present paper is to describe the stratigraphy of central Dolpo, adding new stratigraphic information to the great pioneering work carried out by Gerhard Fuchs during his 1963 and 1973 expeditions (Fuchs, 1967, 1977; see also Waterhouse,

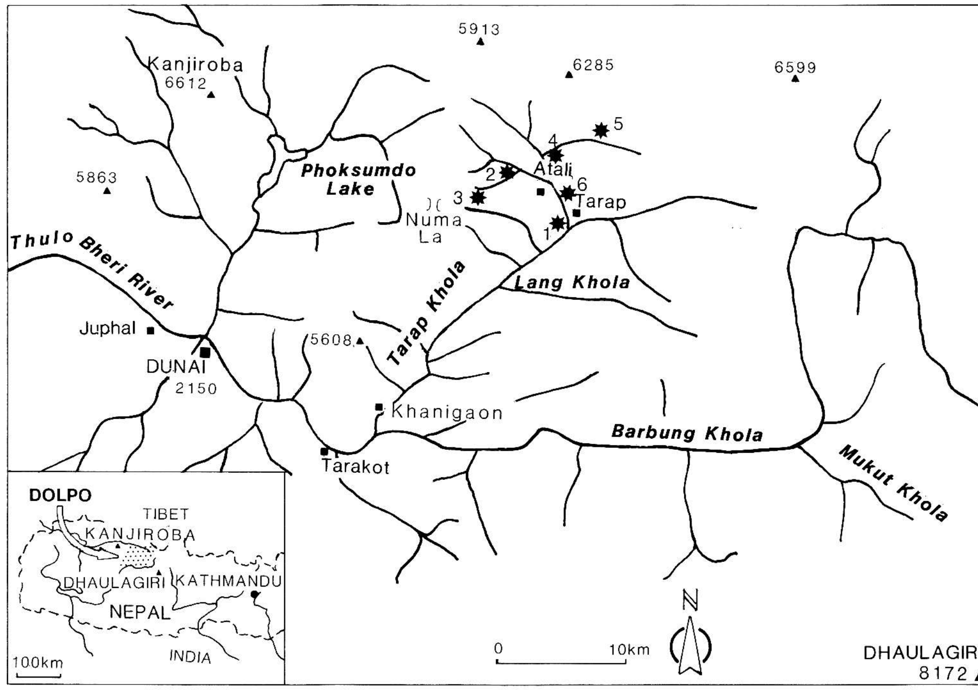


Fig. 1 - Geographic map of the studied area. Black stars indicate location of measured stratigraphic sections. 1) Tarap section (Carboniferous to Permian); 2) Atali South section (Permian to Norian); 3) Atali-Numa La section (Devonian to Anisian); 4) Atali section (Norian to Lias); 5) Atali North section (Norian to Lias); 6) Tarap section (Norian to Lias).

1966 and 1978 for paleontologic information). A detailed study of the collected Early Triassic conodont faunas has already been published (Nicora, 1992).

Toponyms in the present paper are those introduced by the Survey of India and used in the geological maps of Fuchs (1967, 1977). The local Tibetan names of Tarap and Atali are *Do* and *Tok-Khyu* respectively.

Stratigraphic nomenclature is mostly after Fuchs (1977). Sandstone classification is after Folk (1980).

Stratigraphy

The High Himalaya Crystalline and the base of the sedimentary cover.

The High Himalaya Crystalline represents the backbone of the mountain chain, and comprises several units strongly affected by Tertiary metamorphism. Along the Thulo Bheri in the Juphal - Dunai area (Fig. 1), greenschist facies paragneisses and quartzites, locally with intercalations of sparsely fossiliferous marbles, pass upward to richly garnetiferous medium-grade rocks. Lower grade phyllites are found at Tarakot, along the contact between the Lower and the Upper Kathmandu Nappes recognized by Fuchs (1977). Next, garnet-kyanite paragneisses, augengneisses, micaschists and coarsely crystalline impure marbles are widely exposed up to above Khanigaon in the lower Tarap Khola. Dykes and small bodies of leucocratic migmatitic rocks become important at the top of the crystallines, where upper amphibolite facies was reached and crustal melting occurred during the climax of Himalayan metamorphism.

The base of the Tethys Himalaya metasediments is marked by a sharp tectonic surface gently dipping to the north, found in the Tarap Khola at 3300 m a.s.l. Similar anomalous contacts between the High Himalaya and the Tethys Himalaya, recently recognized all along the chain from Zanskar (Baud et al., 1984; Herren, 1987) to Nepal and Tibet (Burg et al., 1984; Inger, 1991), are ascribed to normal faulting at a late stage of the Tertiary Himalayan orogeny (= 20 MA; Hodges et al., 1992).

The lower part of the Tethys Himalayan succession.

Thick banded calcsilicate marbles of inferred Cambro?-Ordovician age (Dhaulagiri Limestone of Fuchs, 1977) are injected by closely spaced pegmatitic dykes up to 1 m in width for over 2 km above the top of the High Himalaya Crystalline. The dykes cross-cut the main schistosity but are in turn deformed and boudinaged (Fig. 2).

Fig. 2 - Deformed tourmaline-bearing leucocratic dykes injected in the impure Dhaulagiri marbles of the Tarap Khola, about 1 km above the tectonic base of the Tethyan sedimentary succession. Hammer for scale.

Higher up in the Tarap Khola deformation becomes milder, and the mid-Paleozoic sequence comprises richly fossiliferous marls yielding echinoderms, nautiloids and low-spired gastropods ("Silurian" of Fuchs, 1977), dolomitic quartzarenites and siltstones, and finally dolomites at the top ("Muth Formation" of Fuchs, 1977).

The fossiliferous Late Devonian limestones and ironstones.

In the Numa La area, locally breccioid and quartzose hypidiotopic dolomites (at least 30 m thick) are followed disconformably by fossiliferous calcarenites with marly interbeds (20 m; Fig. 3), yielding abundant bryozoans, brachiopods, Rugosa and Tabulata corals (*Kuangxiastrea, Scruttonia, Sinodisphyllum, Thamnopora, Cladopora, Alveolites, Alveolitella*) of Early? Frasnian age (Flügel & Tintori, in press). The biocalcarenites are capped by a major oolitic ironstone horizon (1 to 2.8 m thick), displaying spectacular mammillary crusts and ferriferous nodules reaching up to 10 cm in size. Abundant bioclastic debris includes crinoids, nautiloids, ostracods and bryozoans. Dolomite or phosphatic matrix occur.

At Numa La, the bedded dolomites are overlain by a reddish conglomerate, yielding black pebbles, echinoderms, ferruginous ooids and arenaceous lithoclasts (up to 1.5 m thick), followed by greenish wackestones with echinoderms, ostracods and

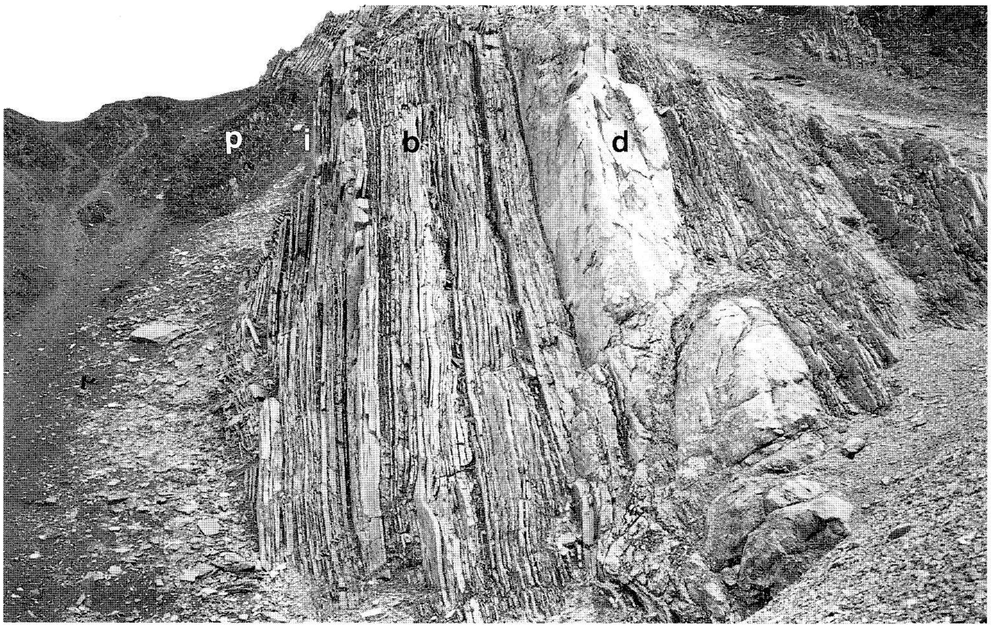


Fig. 3 - Early Late Devonian succession in the Atali-Numa La section. Thick-bedded white *dolomites* (d) are overlain disconformably by thin-bedded *biocalcarenites* of Early? Frasnian age (b). After a condensed ironstone surface (i), *dark pelites* follow (p).

ferruginous ooids (up to 4 m), and by another lenticular conglomeratic ironstone with ferruginous ooids and black hybrid arenite lithoclasts up to 15 cm in size (up to 0.3 m thick).

The dark pelites.

This unit, in sharp paraconformable stratigraphic contact with the underlying ironstone horizon and about 300 m thick between south of Tarap and Numa La (Fig. 4), is markedly reduced (tectonically?) at Numa La, where only about 10 m of poorly-sorted dark arenites and siltstones with chert, phyllosilicate clasts and rare echinoderms are preserved.

At Atali-Numa La, dark pelites predominate in the lower 75 m; coarse calcareous and micaceous siltstones in 5 to 10 cm thick beds showing parallel lamination at the base and ripple marks at the top are intercalated with very fine-grained quartzarenites and subordinate biocalcarenites yielding crinoids and undeterminable brachiopods.

Next, 8 m thick, lower fine-grained cross-laminated and quartz-cemented quartzarenites with rare metamorphic rock fragments are followed by 18 m of yellow-

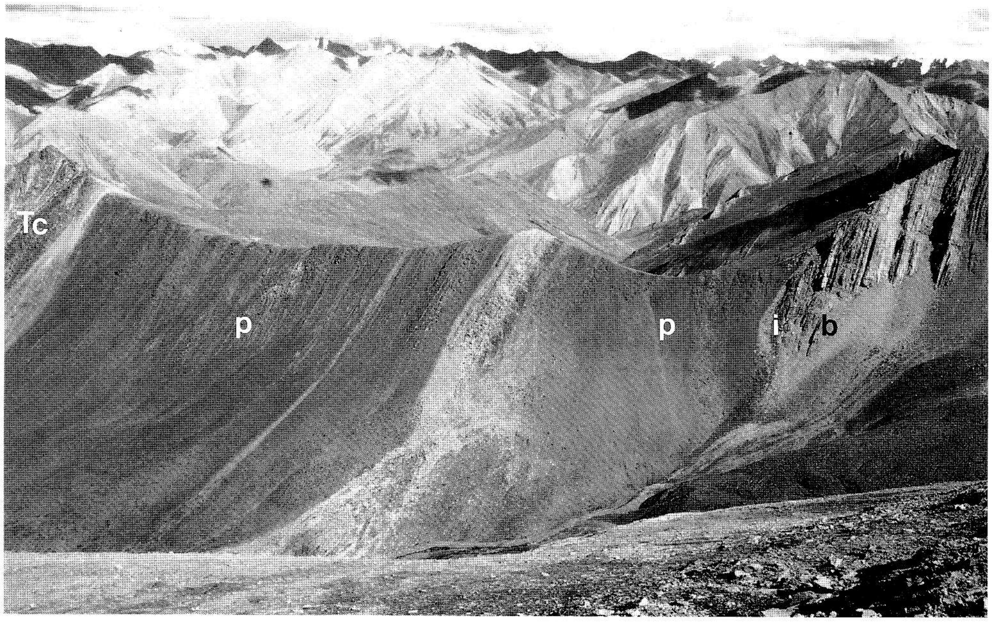


Fig. 4 - *"Dark pelites"* of inferred Late Devonian age in the Atali-Numa La section (p). The dark pelites (note the metric quartzarenite interval, followed by pelites capped by a thin marker layer of biocalcarenites in the middle part of the unit) are comprised between the Early? Frasnian *biocalcarenites* (b) and *ironstone horizon* (i), and the *"white quartzarenites"* at the base of the *Thini Chu Formation* (Tc).

weathering, thin to medium-bedded biocalcarenites with intercalated pelites, yielding abundant fragments of bryozoans, crinoids, brachiopods, gastropods and bivalves. Dip of cross-laminae in the quartzarenites points to northeastward sediment transport.

Dark pelites predominate again in the following 188 m; sporadically biocalcarenites and up to lower fine-grained, rippled micaceous quartzarenites with a few metamorphic rock fragments in beds up to 0.6 m thick are intercalated.

In the upper part, a 6.5 m thick interval of up to medium-grained, thin-bedded quartzarenites showing parallel lamination and containing common muscovite, is followed by at least 30 m of pelites. Unfortunately the boundary with the overlying Thini Chu Formation is largely covered and somewhat tectonized at Atali-Numa La.

The dark pelites, which are still ascribed to the Late Devonian, can be correlated with the Tilicho Pass Formation of the Thakkhola area (Fuchs, 1977).

The fenestellid-rich limestones.

Only at Tarap, a 7 m thick interval of medium-bedded biocalcarenites rich in fenestellid bryozoans and containing rare silicified productids, crinoids and solitary Rugosa corals of Early? Carboniferous age (H.W. Flügel, pers. comm. 1992) was observed at the top of the dark pelites. These layers, which are seemingly missing to the east (Atali-Numa La), are correlated with the Tilicho Lake Formation of the Thakkhola - Manang area (Fuchs, 1977; Fuchs et al., 1988).

Thini Chu Formation.

The name Thini Chu Formation was introduced by Bodenhausen et al. (1964) to describe a several hundred metres thick alternation of dark shales and white quartzarenites of mid-Carboniferous to Late Permian age, cropping out in the Thakkhola and Manang regions (Bordet et al., 1971, 1975). The Late Paleozoic succession of Dolpo (Fig. 5) has similar sedimentary features and, even if the older Carboniferous part seems to be largely missing whereas the younger mid- to Late Permian part is particularly well-represented, the term Thini Chu was adopted also in this area (Fuchs, 1967, 1977). Other authors (Waterhouse, 1976, 1978; Waterhouse & Shi, 1990) preferred instead to introduce an abundance of ill-defined new terms (see discussion in Fuchs, 1977, p. 202), which are not adopted here since they do not even conform with the basic requirements of lateral continuity and mappability prescribed by international stratigraphic standards (North American Commission on Stratigraphic Nomenclature, 1983). The Thini Chu Formation is here subdivided into four members.

The white quartzarenites.

The base of the member at Tarap is strongly erosive and cuts about 1 metre down into the underlying limestones within only 5 metres of outcrop width. The disconformity is marked by a yellow limonitic crust up to 0.5 m thick and containing ghosts of fenestellids, followed by 2.2 m of dark pelites yielding productid spines, sparse crinoids and bivalves (*Parallelodon* sp.), and by another 5.1 m of interbedded pelites and quartzarenites. Next, up to upper medium-grained, up to very well-sorted and supermature, cross-laminated, and quartz-cemented white quartzarenites in up to 7 m thick amalgamated bars, commonly with scoured base and sharp top, are interbedded with dark unfossiliferous pelitic intervals up to 3 m thick and containing finer-grained, commonly burrowed grey quartzarenites. Feldspars are absent throughout the member. Dip of cross-laminae in megaripples points to northeastward (30° to 60°N) sediment transport. At the top of the member, pelites with limonitic nodules are followed by a 0.6 m quartzarenite bed, full of wave ripples sometimes truncated due to wind action, locally reddened and with bored and knobby top.

Total thickness of the member ranges between a minimum of 65 m at Tarap, where it may be somewhat reduced by tectonic deformation in the lower part, to a maximum of 98 m at Atali-Numa La, where the lower boundary is poorly exposed.

The Costiferina arenites.

This fossiliferous marker horizon (26.6 m at Tarap, 24.1 m at Atali South, and 18.4 m at Atali-Numa La) has a very sharp base, locally marked by up to 0.2 m thick pockets of ferruginous, burrowed and sparsely bioclastic arenites. Even if rapid lateral lithological variability from very coarse-grained quartzarenites to ferruginous bioclastic

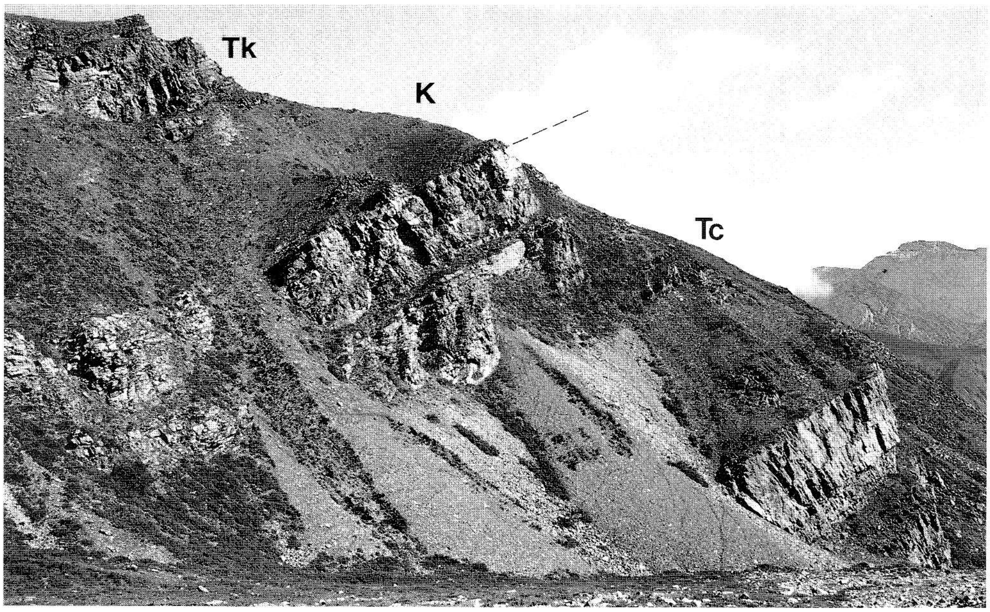


Fig. 5 - The *Thini Chu* (Tc), *Kuling* (K) and *Tamba Kurkur* (Tk) *Formations* at Atali South. Note occurrence of the resistant "*white quartzarenites*" and "*Costiferina* arenites", overlain by the "*ochre pelites*" and by the "*estuarine quartzarenite*" walls. Next, conglomeratic sandstones at the base of the *Kuling Fm.* are followed by pelites, in turn overlain by resistant carbonate bands of Scythian age.

arenites and pelites takes place in the study area, three stratigraphic intervals can be recognized within this member.

The lower 4 to 5 m consist of up to coarse-grained, medium-bedded, moderately to moderately well-sorted, ferruginous, dark bioclastic quartzarenites rich in large brachiopods, bivalves and bryozoans.

The following more pelitic interval, 6 to 16 m thick, still contains ferruginous fossiliferous arenites or quartzarenites locally showing sharp knobby top and displaying bioturbation or large-scale cross-lamination indicating northeastward paleocurrents (mode towards 30°N).

The upper part is 7.5 to 8.7 m thick in the Atali-Numa La and Atali South sections respectively, where it consists of up to coarse-grained, mainly moderately sorted, medium-bedded or amalgamated white quartzarenites. At Tarap, ferruginous quatzarenites (5 m) still contain abundant large brachiopods up to the very top of the member.

Sporadic detrital feldspars, as well as polycrystalline quartz and quartzarenite or felsic volcanic rock fragments were recorded. Non-carbonate intrabasinal grains (silicate peloids, phosphates, chert), associated with arenaceous lithoclasts and chemically etched quartz grains probably derived from erosion of tropical soils (Garzanti, 1991), are significant components of the arenite framework.

Preliminary paleontological study of the rich bivalve (*Pteriacea*) and brachiopod fauna (productids, spiriferids, rhynchonellids), characterized by *Costiferina alata* Waterhouse, 1966 (Fig. 6) and *Fusispirifer nitiensis* (Diener, 1897), indicates an early Late Permian (Murgabian-Midian?) age. The *Costiferina* arenites are therefore younger than the Late Sakmarian-Artinskian? Chumik Formation of Zanskar (Gaetani et al., 1990).

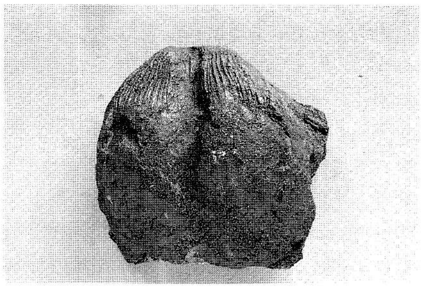


Fig. 6 - *Costiferina alata* Waterhouse, 1966 (internal mould from the "*Costiferina* arenites", Atali-Numa La section; sample AD60; x 0.37.

The ochre pelites.

These sparsely fossiliferous and ochre-weathering shales, siltstones and marls have a homogeneous thickness of 47 m in the Tarap-Atali area. Thin coquina layers with disarticulated brachiopod valves or fetid calcarenites yielding fenestellid bryozoans, crinoids, brachiopods, bivalves and benthic foraminifers, as well as phosphatic nodules up to 15 cm in size, occur in the lower 35 m at Atali South, whereas the upper 8 to 12 m are characterized by grey, burrowed, fine-grained quartz-rich subarkoses and lower medium-grained quartzarenites, locally containing rip-up clasts.

The member contains *Spiriferella rajah* (Salter, 1865) in the lower part and *Neospirifer moosakhailensis* (Davidson, 1862) in the upper part, and may be thus assigned a middle Late Permian age (Djulfian?).

The estuarine quartzarenites.

The member (40.6 m at Tarap, 37.5 m at Atali South and 31.2 m at Atali-Numa La) may be subdivided into thickening and coarsening-upward cycles of variable thickness (7 to 21 m) and locally with burrowed top. The unconformable base of the interval is locally overlain by a lenticular layer full of intraclasts derived from the underlying substratum. Next, within each cycle, thin-bedded and burrowed grey siltstones and very fine-grained sandstones are gradually replaced upward by up to medium-grained, well to very well-sorted and quartz-cemented quartzarenites with spectacular sigmoidal cross-bedding, testifying to mainly northeastward sediment transport (20° to 50°N at Tarap; 320° to 60°N at Atali South). Sigmoidal bundled bed-sets are up to 40 cm thick, and mud couplets, rippled caps or clay chips up to 10 cm in size are commonly observed. At the top of the member, up to coarse-grained, moderately well-sorted and ferruginous quartzarenites contain a few brachiopods and echinoderms as well as quartz with rounded outlines, silicate peloids and carbonate or cherty fragments. Detrital feldspars (alkali feldspars - orthoclase, chessboard albite, perthite - and plagioclase in subequal amounts) are concentrated in the finer sand fractions (below 2Φ), and even lower medium-grained sandstones are occasionally subarkoses. Micas and felsitic rock fragments were sporadically recorded; polycrystalline quartz may be common.

Kuling Formation.

The uppermost part of the Permian succession displays sedimentary features very similar to the Kuling Formation of the northwestern Himalaya (Fuchs et al., 1988; Gaetani et al., 1990). The unit (55.3 m at Tarap, 37.1 m at Atali South and 48 m at Atali-Numa La) can be subdivided into three intervals.

The lower boundary is a major disconformity overlain by mainly moderately to poorly sorted, cross-laminated conglomeratic quartzarenites yielding large brachiopods and rounded quartzose pebbles up 10 cm in diameter. The basal interval (2 to 5.8 m thick) is characterized by glaucony, reworked phosphates, silicate or ferruginous peloids, bioclasts (including partly silicified brachiopod shells, benthic foraminifers and siliceous sponge spicules), arenaceous, cherty or dolomitic lithoclasts, and pelitic intraclasts. Quartz is commonly well-rounded and sometimes shows embayments and straight extinction; polycrystalline grains were also recorded. Feldspars occur in the finer sand fractions (below 2Φ), and upper fine-grained sandstones are occasionally subarkoses. Rare lithic grains include mostly felsitic volcanic rock fragments, sometimes with quartz phenocrysts showing bypiramidal outlines, and a few quartzose arenaceous clasts.

The overlying ochre-weathering bioclastic marls and burrowed micaceous siltstones (15.7 to 31.2 m thick) sparsely contain large spiriferids. In the lower part, up to medium-grained bioclastic quartzarenites still occur, as well as glauconitic or phosphatic arenites full of calcitized, originally siliceous sponge spicules cemented by poikilotopic calcite, and containing echinoderms, brachiopods and ostracods.

The upper interval, with a homogeneous thickness of 18 m, largely consists of black pelites. Starved ripples or thin parallel-laminated layers of up to lower fine-grained micaceous subarkoses occur at the top.

The unit is ascribed to the Late Permian, as indicated by ill-preserved conodonts found at its top (Fuchs & Mostler, 1969; Kozur & Mostler, 1973).

Tamba Kurkur Formation.

The Triassic Tamba Kurkur Fm. (23.4 m at Atali South and 32.8 m at Atali-Numa La) starts with orange-weathering, thin-bedded, very fine-grained, micaceous dolomitic subarkoses (0.9 m at Atali South). Its lower boundary with the Kuling Formation is rapid but transitional at Atali South, where subarkoses become progressively enriched in ferriferous dolomite and dolomitic clasts. Veins filled by late diagenetic dolomite occur.

The overlying dark grey, condensed planar wackestones, in beds 3 to 10 cm thick (1 to 1.2 m), are still dolomitic at the base and yielded abundant thin-shelled bivalves [*Claraia aurita* (Hauer, 1850)], ostracods, crinoids, ammonoids (Pl. 22) [*Gyronites frequens* Waagen, 1895, *Clypeoceras alterammonoides* (v. Krafft, 1909), *Koninckites kraffti* Spath, 1930, "*Meekoceras*" *joharense* v. Krafft, 1909, *Prionolobus lilangensis* (v. Krafft, 1909), *Proptychites markhami* (Diener, 1897)] and conodonts [*Gondolella carinata* Clark, 1959, *Neospathodus kummeli* Sweet, 1970, *N. dieneri* Sweet, 1970, *N. pakistanensis* Sweet, 1970, *N. cristagalli* (Huckriede, 1958)]. These rich faunal assemblages indicate an Early to Late? Dienerian age.

Next, dark pelites (2.4 to 3.1 m) are followed by one thin bioclastic mudstone bed (0.1 to 0.3 m), yielding still Late Dienerian conodonts along with silicified thin-shelled bivalves, ostracods and ammonite nuclei. Another thicker interval of grey pelites (13.5 to 22 m) follows.

The upper part of the unit consists of dark grey, burrowed, planar to nodular condensed wackestones in 5 to 15 cm thick beds, with discontinuous ferruginous seams, greenish colour and marly intercalations in the upper part (5.5 to 6.2 m). This interval contains thin-shelled bivalves, crinoids, radiolaria, benthic foraminifera, ammonoids (*Anasibirites kingianus* Waagen, 1895, *Flemingites* sp.) and conodonts [*Neospathodus waageni* Sweet, 1970, associated with *N. pakistanensis*, *N. dieneri*, *N. cristagalli* at the base and with *G. milleri* Muller, 1956, *G. mosheri* Kozur & Mostler, 1976 and *G.* aff. *elongata* (Sweet, 1970) at the top]. These assemblages indicate an Early to Late Smithian age. As indicated by the same conodont assemblages characterized by *N. waageni* (Nicora, 1992), only this Smithian, quartz-free, condensed carbonate interval is represented at Tarap (2.6 m), where the Dienerian carbonate band is missing, probably due to faulting. The upper boundary with the Mukut Formation is gradual and marked by increasing abundance of marly intercalations.

The Tamba Kurkur Formation in central Dolpo is thus dated precisely as Early Dienerian to Late Smithian.

Mukut Formation.

The Mukut Formation, comprising about 200 to 250 m of marls and subordinate marly limestones, is folded and never exposed continuously in the surveyed area. Only the lower part was studied in detail.

At Atali South, planar, locally silty, grey marly mudstones in 10 to 40 cm thick beds, yielding bivalves, echinoderm remains, brachiopods and rare spicules, are intercalated with bioclastic siltstones and marls in the lower 35 m. Ochre-weathering silty marls, locally with phosphatic nodules or containing ammonoids, characterize the overlying 45 m. At Tarap, marly mudstone beds with ferruginous seams are only up to 10 cm thick and contain abundant thin-shelled bivalves; tiny calcite prisms derived from bivalve shells may even make up the bulk of the rock.

At Tarap, Late Spathian to Early Aegean conodonts [*Neospathodus homeri* (Bender, 1970), *Gondolella timorensis* Nogami, 1968] were found 12 m above the base of the unit, and 14 m above the base *G. timorensis* becomes exclusive, indicating an

Fig. 7 - The sharp paraconformable stratigraphic contact at Tarap between the topmost *Mukut Fm.* (M) (made of interbedded marls and limestones followed by light grey marls) and the darker *Tarap Shale* (T).

Early Aegean age. At Atali South, Early Bithynian conodonts [*G. regale* (Mosher, 1970), *G. bulgarica* (Budurov & Stefanov, 1975)] occur 20 m above the base of the unit.

The upper part of the Mukut Formation is represented by interbedded pelites and burrowed clayey mudstones. Ammonoid assemblages indicate that from Dolpo to Manang the top of the unit may reach into the earliest Norian (Fuchs, 1977; Krystyn, 1982; Fuchs et al., 1988).

Tarap Shale.

This very thick (around 600 m) incompetent unit is invariably folded in the studied area, and stratigraphic sections continuous from base to top could not be measured.

The sharp basal contact at Tarap (Fig. 7) is marked by a thin and microlaminated condensed biosparite bed, made of winnowed and packed thin-shelled bivalves. The overlying dark pelites, more than a hundred metres thick and yielding ammonoids of Early Norian age (*Palicites*; *Griesbachites himalayanus* Wang & He, 1976; Fig. 8), are interbedded with laminated calcareous quartzose siltstones containing feldspars, white and brown micas, bivalves, echinoderms and gastropods. Small black phosphatic nodules are common. Next, dark calcareous pelites alternate with lower very fine-grained layers of micaceous and locally phosphatic subarkoses in beds up to 12 cm thick, showing hummocky cross-lamination, parallel lamination followed by ripple marks, or thin cross-laminated sets suggesting eastward sediment transport. Echinoderms and ostracods may be present. Black pelites with pyritiferous phosphatic nodules reaching 20 cm in diameter become again exclusive upward.

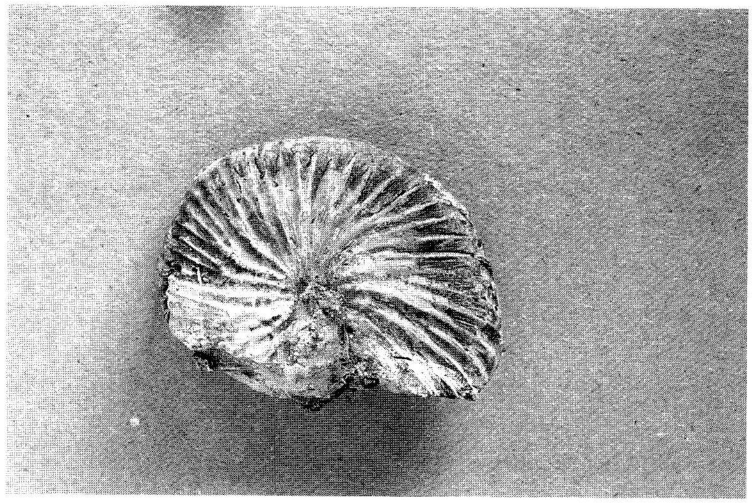


Fig. 8 - *Griesbachites himalayanus* Wang & He, 1976. Specimen from the scree below the basal part of the *Tarap Shale* at Tarap (x 0.75).

In the upper middle part of the unit, measured at Atali North (Fig. 9), 80 m of black shales with rippled or burrowed calcareous quartzose siltstones containing feldspars, micas, bivalves and echinoderms in the upper metres, are followed by 150 m of dark pelites alternating with orange-weathering micaceous siltstones with abundant poikilotopic authigenic calcite, in beds up to 1 m thick and containing large *Zoophycos*-type burrows. Rippled, very fine-grained and plagioclase-rich arkoses and subarkoses in up to 30 cm thick beds, containing both muscovite and biotite, are intercalated. Phosphatic nodules reach up to 10 cm in size; abundant plant material was found at the top of this interval at Tarap.

These lower to middle parts of the Tarap Shale are all ascribed to the Early Norian, even though age-diagnostic fossils occur only in the basal hundred metres.

The upper assemblage.

In the upper 92 to 128 m of the Tarap Shale, siltstones are interbedded with impure nodular limestones, very fine to fine-grained subarkoses and hybrid arenites yielding ferruginous ooids.

At Tarap, the unconformable base of the member is marked by a 0.2 m thick layer rich in black clayey to sandy intraclasts up to 10 cm in size, containing both brown and white micas, and yielding bivalves and echinoderms, followed by lower

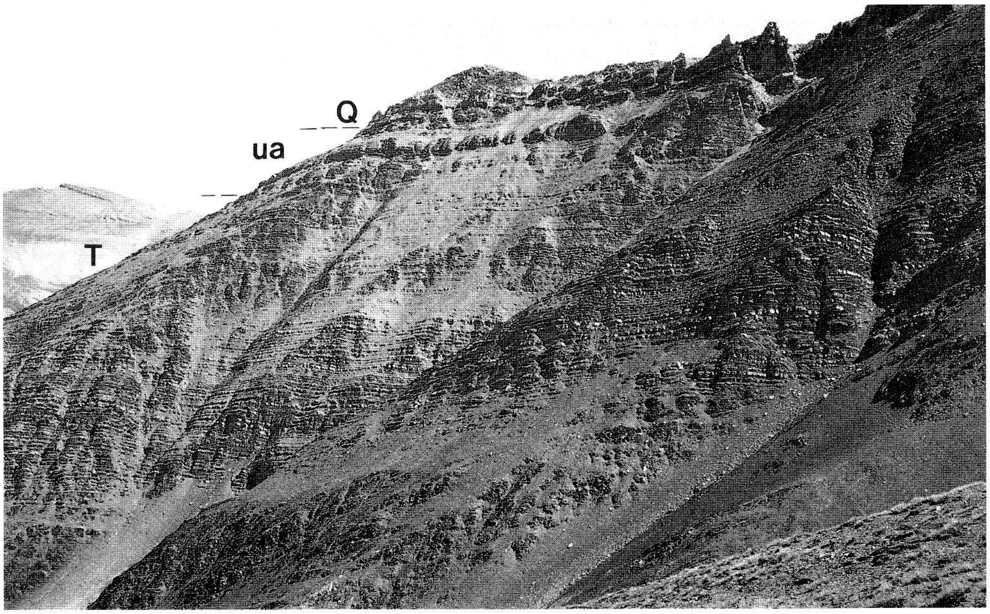


Fig. 9 - The Norian-Rhaetian succession at Atali North. The upper middle *Tarap Shale* (T), made of rhythmically interbedded shales and calcareous siltstones, passes upward to the "*upper assemblage*" (ua) and finally to the oolitic quartzarenite walls of the Quartzite Series (Q).

fine-grained subarkoses with truncated wave ripples and low-angle cross-lamination (4.2 m). Veins filled by late diagenetic dolomite occur. At Atali North the member begins with a 4 m thick horizon of amalgamated, very fine-grained ferruginous hybrid arenites containing chamosite peloids and intraclasts. Iron-rich green phyllosilicates fill and partially replace bioclastic debris, including echinoderms, gastropods, bivalves and ostracods. Quartz and subordinate feldspars, as well as non-carbonate intrabasinal grains, increase upward at the expense of micrite and calcareous allochems.

Two intervals are recognized in the "upper assemblage".

In the lower interval (45 to 51 m thick), burrowed carbonaceous pelites, interbedded with orange-weathering calcareous siltstones in beds up to 1 m thick, still prevail over medium-bedded, up to very fine-grained calcareous and micaceous grey subarkoses locally containing bivalves, echinoderms, ostracods, peloids or clay chips. Phosphatic nodules are small and sporadic. Thin-bedded grey mudstones/wackestones with a few feldspars displaying authigenic syntaxial rims occur in the Atali North section. In the Atali section this interval is covered.

The upper interval (31 to 83 m thick) largely consists of grey nodular limestones and micaceous silty biocalcarenites. The basal horizon, 7 to 8.5 m thick, is made of arenaceous limestones and very fine-grained bioclastic subarkoses containing intraclasts, crinoids, echinoids, ammonoids, large bivalves, brachiopods, gastropods, and characterized by locally abundant ferruginous ooids and peloids. In all of the sections, the central part of the interval is characterized by up to 18 m thick poorly exposed calcareous pelite intervals, containing up to very fine-grained hybrid subarkoses with bivalves, ostracods and crinoids. In the upper part, nodular limestones become amalgamated and up to thick-bedded. The upper 14 m at Tarap and 32 m at Atali North already contain up to lower medium-grained, dolomitic quartz-rich arenites with intraclasts or ooids and oolitized quartz.

The "upper assemblage" correlates broadly with the Coral Limestone horizon recognized in the Jarsgeng Khola, NW of Manang (Fuchs et al., 1988; own unpublished data, 1991). This significant transgressive stage can be traced up to the northwestern Tethys Himalaya, where the ironstone and coral-bearing horizons contained in the middle part of the Norian-Rhaetian arenaceous succession are ascribed to the mid-Norian (Jadoul et al., 1990).

Quartzite Series.

The unit persistently occurs throughout the Tethys Himalaya from Zanskar to Nepal. In central Dolpo it is 73 to 90 m thick, and can be subdivided into two intervals.

The lower interval (56 to 69 m thick) is characterized by orange-weathering, thin to thick-bedded and amalgamated, up to medium-grained, grey, dolomitic hybrid quartzarenites with intraclasts and bioclasts (mainly echinoderms), displaying spectacular cross-lamination indicating mainly northward paleocurrent directions (300° to 60°N). Hypidiotopic dolomite beds and lower medium-grained, very well-sorted hybrid arenites containing ooids and oolitized quartz grains also occur, as well as truncated wave ripples, rippled caps and grey clay chips up to 15 cm in size. Within ooids, changes from radial to tangential structures and micritization are frequently observed. Relative abundance of siliciclasts and allochems vary vertically very rapidly and microcline is locally abundant. The upper part of this interval is partly covered at Tarap and Atali North.

The upper interval (19 to 27 m thick) is represented by a wall of upper fine to medium-grained hybrid quartzarenites, displaying spectacular herringbone structures and characterized by oolitized quartz, ooids, intraclasts and bioclasts. Paleocurrents were multidirectional, with predominating north-south sediment transport. The interval is capped by 2 m thick, upper fine to lower medium-grained, very-well sorted and quartz-cemented quartzarenites.

The Quartzite Series is assigned a Late Norian to Rhaetian age, but biostratigraphic evidence is poor and inconclusive. The lithologic succession, with two ironstone layers in the "upper assemblage" of the Tarap Shale, upward increasing mineralogical stability and dolomite abundance in the Quartzite Series, is remarkably comparable to that occurring in the Zanskar Range (Jadoul et al., 1990).

Kioto Limestone.

This unit (Jomosom Limestone of Bodenhausen et al., 1964) is about 350 m thick, but only its lower 50 m were studied in detail. The base of the formation is sharp, and overlain by hybrid arenites containing common quartz, bivalves, echinoderms, gastropods, peloids and intraclasts up to 10 cm in size; these cross-laminated layers display herringbone structures indicating bimodal (NW/SE) sediment transport. In the lower 24 m, calcite-cemented quartzarenites alternate with idiotopic dolomite beds, coarse-grained intrasparites, cross- or parallel-laminated fine-grained dolomitic quartzarenites with a few feldspars, rippled hybrid arenites containing bivalves, gastropods, peloids and dolomite, grey mudstones/wackestones with bivalves, ostracods, gastropods and rare quartz, and finally oosparites and quartzose oosparites.

Higher up in the sequence, mudstones/wackestones, biocalcarenites with pectinid bivalves and oolitic grainstones occur. Metric intervals of up to upper medium-grained, cross-laminated hybrid quartzarenites, locally dolomitic and yielding commonly oolitized quartz, ooids, peloids, intraclasts, subordinate bioclasts (bivalves, echinoderms), and lacking feldspars, are found up to 50 m from the base of the unit. Neither the *Megalodon* nor the *Lithiotis* layers, which characterize the Kioto Limestone Group in the northwestern Himalayas (Fuchs, 1982; Jadoul et al., 1990), were observed in the surveyed Tarap-Atali area.

Inferred age is Early to early Middle Jurassic (Fuchs, 1977).

Laptal (Lumachelle Formation).

In central Dolpo, the Laptal Formation (upper "Lumachelle" of Bodenhausen et al., 1964; Lumachelle Formation of Bassoullet & Mouterde, 1977; Fuchs, 1977), consists of hybrid arenites and pelites ascribed to the Middle Jurassic. The unit is exposed only in the deformed core of a few synclines located at high altitudes, and younger units do not crop out in the investigated area.

Sedimentary evolution

Sedimentary history of the Tethys Himalaya seemingly began sometime in the Late Proterozoic, with formation of a passive continental margin facing an ocean of unknown width. This Late Pan-African cycle was completed during the Early Paleozoic, when the Gondwana supercontinent was eventually assembled (Garzanti et al., 1986; Gaetani & Garzanti, 1991).

Cambrian? to Devonian.

Early Paleozoic sediments are strongly metamorphosed and deformed tectonically in central Nepal, and sedimentary evolution at this stage has yet to be fully understood. The considerable thickness of the Cambro?-Ordovician to Devonian succession with respect to the northwestern Himalaya and the occurrence of graptolite and nautiloid-bearing offshore pelites in the Silurian (Bodenhausen et al., 1964; Fuchs, 1977) testify to still very significant tectonic subsidence through the Early and early Late Paleozoic.

Dolomites capping the Silurian to mid-Devonian transgressive-regressive supersequence are unconformably overlain by earliest Late Devonian fossiliferous limestones capped by a major ironstone layer (Fig. 10). This abrupt facies change indicates rapid transgression and drowning (Garzanti, 1991), seemingly related to the Frasnian global tectono-eustatic event (Kominz & Bond, 1991).

The thick dark pelitic unit of inferred latest Devonian age contains at several intervals storm-deposited sandstones and bioclastic arenites yielding a rich open marine shallow-water fauna. Shelfal environments at water depths ranging from very few to many tens of metres are thus indicated. The strong reduction in thickness at Numa La is ascribed to Tertiary tectonic deformation, but a sharp original change in paleogeography cannot be ruled out.

Carboniferous and Permian.

The Early? Carboniferous in central Dolpo is testified by thin fossiliferous limestones, found only in the eastern part of the surveyed area, which are capped by a

Fig. 10 - The 2.4 m thick Late Devonian ironstone interval in the Atali-Numa La section (i, see Fig. 3 and 4), separating shallow-water *biocalcarenites* (b) from *dark pelites* (p) both of Frasnian age, was deposited during a global? tectono-eustatic transgression. Hammer for scale.

strongly erosive surface mantled by a typical "terra rossa" (Fig. 11). This major disconformity of regional importance (Fuchs, 1977, p. 200) testifies to a significant time gap, with prolonged subaerial exposure, karstification, and deep erosion of the underlying section.

The overlying Thini Chu Formation, which contains marine fossils at the base and was deposited in coastal environments invaded by terrigenous detritus, might be ascribed to the Late Carboniferous or more probably to the Permian. A second transgressive event was recorded in the mid-Permian by the nearshore "*Costiferina* arenites". The overlying ochre pelites were deposited in deeper, middle shelf settings episodically influenced by storms, passing upward to lower shoreface environments. The regressive trend continued with composite prograding sequences of quartzarenites characterized by sigmoidal bundled bedsets, formed by vertically-stacked amalgamated tidal bars deposited in the high-energy, shallow subtidal part of a tide-dominated delta (Clifton, 1982; Mutti et al., 1985). Most of the sandstone units were deposited under predominant flood conditions, with local development of ebb caps. A third major transgression was recorded in the Late Permian, marked by pebbly bioclastic arenites yielding glaucony and phosphates, passing upward to pelites containing sparse open marine fauna and deposited in middle shelf settings.

The sudden influx of sand-sized siliciclastics in the Thini Chu Formation points to uplift of the Indian cratonic block during continental rifting. The unconformities recognized at the base, within, and at the top of the unit, locally marked by pebbles and cobbles derived from quartzose sedimentary or basement rocks, indicate continuous tectonic activity at this stage. Detrital feldspars are absent in the "*white quartzarenites*", rare in the "*Costiferina* arenites", and more common in the finer-grained samples contained at the top of the "*ochre pelites*", "*estuarine quartzarenites*" and in the Kuling Formation. Their abundance thus slightly increases upward, possibly indicating stronger tectonic uplift and rapid erosion (or, alternatively, more arid climate?) in the Late Permian. Sedimentary structures indicate that sand transport was mainly towards

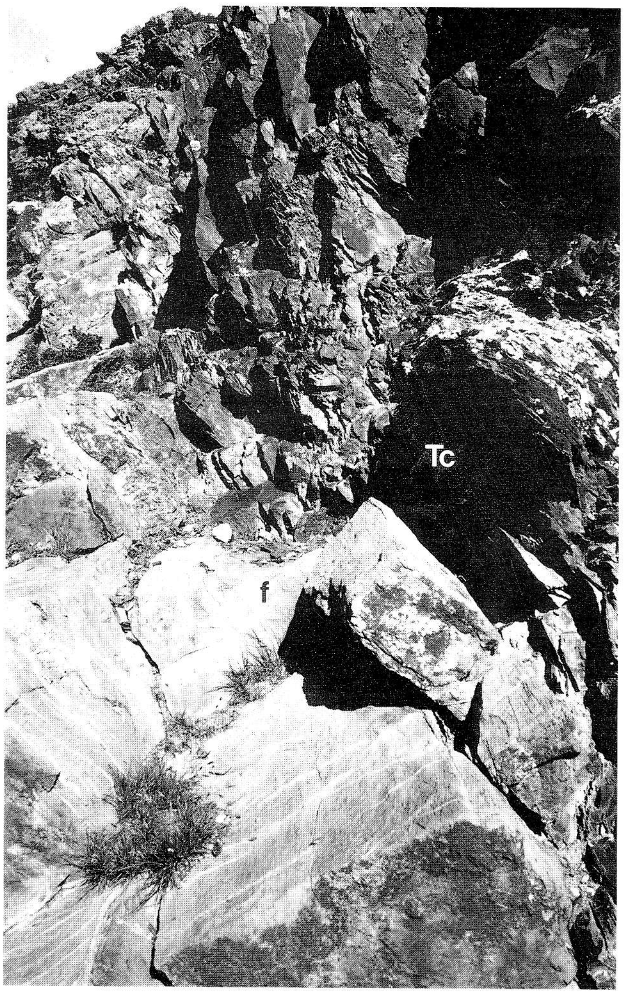


Fig. 11 - The sharp erosional unconformity, observed at the base of the *Thini Chu Formation* (Tc) at Tarap, developed during prolonged subaerial exposure of the underlying "*fenestellid-rich limestones*" (f), and documents uplift during the first stages of Neotethyan rifting, followed by influx of siliciclastic supply.

the northeast throughout the Late Paleozoic. Stratigraphic intervals in the surveyed area are of rather constant thickness, but generally tend to thicken eastward and to thin northward. Lack of mafic detritus and volcanic rocks suggests that basaltic magmatic activity was not associated with rifting in the vicinity of central Dolpo. Instead, a few rhyolitic rock fragments may have been derived either from penecontemporaneous ignimbrites or from the Precambrian rhyolites of the Indian Craton (Gansser, 1964, p. 16). We failed to identify tilloid units deposited under the direct influence of continental ice.

Triassic and Jurassic.

After the unconformable Permian/Triassic boundary, sedimentation resumed only in the Early Dienerian, with dolomitic subarkoses reported to locally contain rolled phosphorite concretions (Fuchs, 1977). These arenites were probably accumulated on the outer part of the continental shelf during a lowstand stage, and redeposited as discontinuous sand sheets during the subsequent transgression. Nonplanar dolomite with strong undulatory extinction points to growth largely from basinal fluids during burial diagenesis, at relatively high temperatures (above the critical roughening temperature, which is estimated to lie between 50° and 100°C; Sibley & Gregg, 1987; S. Frisia, pers. comm., 1991). These sediments pass rapidly upward to carbonates characterized by pelagic mollusk fauna and "pseudo-stromatolitic" lamination interpreted as due to bacterial mats similar to those forming today in zones of coastal upwelling at water depths of many tens to a few hundred metres (Williams & Reimers, 1983). Deposition of ammonoid-rich nodular carbonates suggests reworking by the action of oceanic currents intruding onto the outermost shelf during peak global transgressions, probably corresponding to stages of expanded oxygen-minimum zone in the ocean. These well-dated condensed intervals in fact correspond with transgressive tracts on the global eustatic curve, and their top correlates with the mid-Dienerian (245.5 MA) and top Smithian (243 MA) global downlap surfaces (Haq et al., 1988). The thick black pelite intercalations occurring in the middle part of the Tamba Kurkur Fm. and in the lower part of the Mukut Fm. may be interpreted as deposited in offshore, middle shelf settings below the action even of major storms, during global highstand stages. If this is correct, Early Triassic sedimentation in central Dolpo occurred mostly on the continental shelf, maximum water depth probably approached 200 m, but truly bathyal conditions were never reached. Thermo-tectonic drowning was thus less pronounced than in the Thakkhola-Manang area (Garzanti & Pagni Frette, 1991; own unpublished data, 1991), western Dolpo (multicoloured nodular pelagic carbonates reported by Fuchs, 1977) or in the northwestern Himalaya (Nicora et al., 1984; Gaetani & Garzanti, 1991).

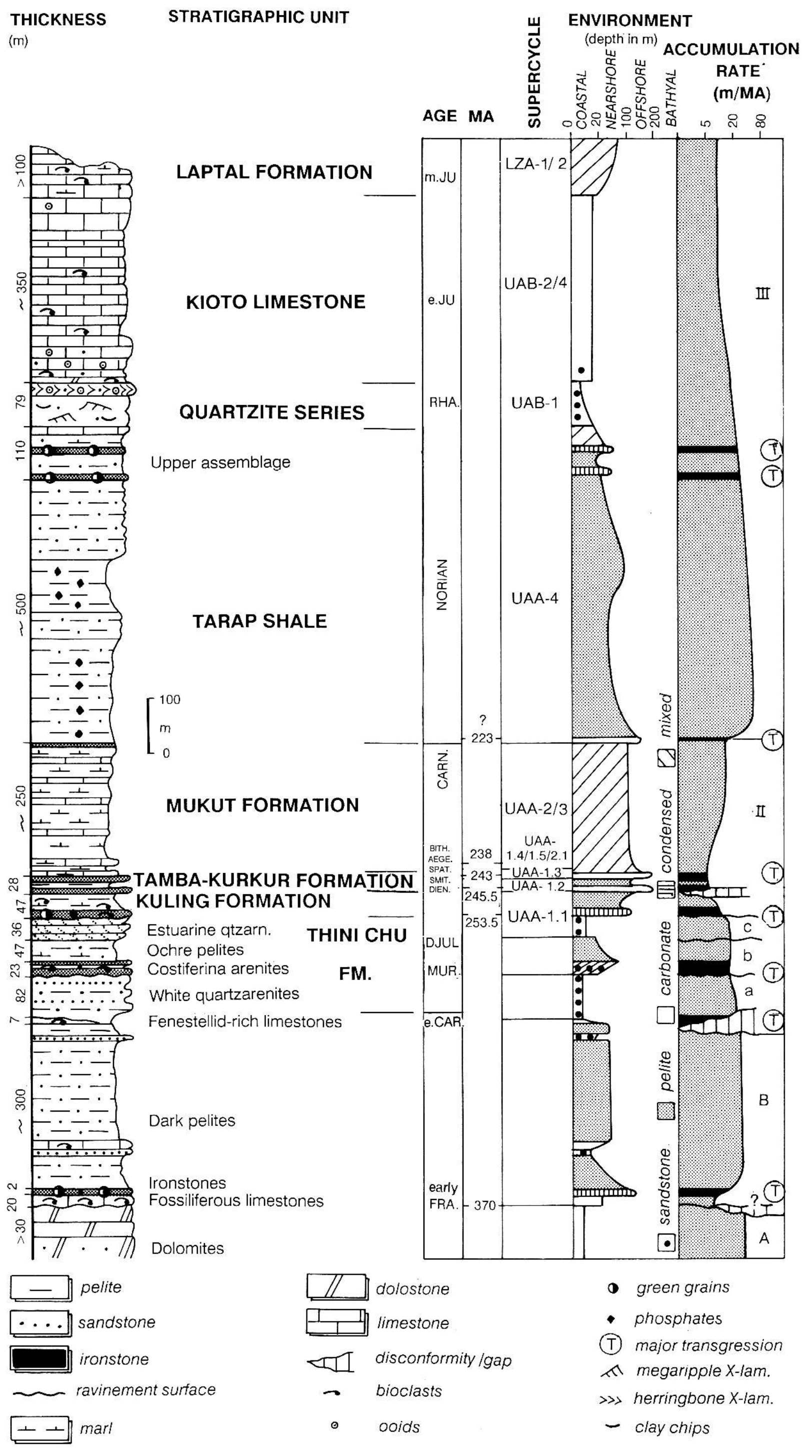
The Mukut Formation was characterized by the increasing influx of quartzose silt. The occurrence of sparse ammonoids throughout the unit points to deposition in many tens of metres deep, middle to outer shelf waters below the action even of major storms. The boundary with the Tarap Shale is marked by a thin condensed layer deposited in relatively high-energy deep-water environments, where oceanic? currents intruding onto the outer shelf during a short-term transgressive event were strong enough to prevent the deposition of micrite. Transgressive conditions characterized by very low sedimentation rates and poor oxygenation in zones of coastal upwelling are also suggested by microlaminated fabric, ascribed to the action of filamentous bacteria (Williams, 1984; Delamette, 1990; Jenkyns, 1991). This event might be possibly correlatable with the global condensed section at 223 MA (Haq et al., 1988).

Calcareous siltstones frequently contain ammonoids only in the basal part of the Tarap Shale; their scarcity in the subsequent intervals is chiefly ascribed to high accumulation rates. Widespread phosphate nodules suggest offshore sedimentation under the mild influence of an oxygen-minimum zone impinging on the shelf, at water depths of several tens of metres. Current-laminated sandy layers, mainly occurring in the lower middle part of the unit, indicate storm action and thus deposition around average storm wave base, at a depth of only a few tens of metres (Nelson, 1982). In the upper middle part, thick rithmic alternations of pelites and calcareous siltstones were deposited in circalittoral environments episodically affected by storm action, as also indicated by trace fossils of the *Zoophycos* ichnofacies (Seilacher, 1967; Bromley, 1990). Abundance of feldspar grains points to rapid erosion of crystalline basement rocks at this stage (Garzanti & Pagni Frette, 1991).

The transition to the "*upper assemblage*" in the more proximal Tarap section is rather abrupt and marked by deposition of coastal sands probably at a stage of eustatic lowstand. In this member, chamositic and bioclastic ironstone layers are interbedded with calcareous siltstones very similar to the underlying ones, and with nodular limestones containing open marine fauna at times of transgression.

Sedimentary structures generated by both waves and tidal currents, along with ooids and shallow-marine bioclasts, become widespread in the Quartzite Series. Even if some dolomite may be primary in origin, the abundance of non-planar dolomite is largely ascribed to relatively high temperature growth from basinal fluids enriched in magnesium during burial diagenesis of the thick underlying shales (M. Mutti, pers. comm., 1991). The oolitic quartzarenites in the upper part of the unit were deposited in high-energy, shallow subtidal environments dominated by strong bidirectional tidal currents and characterized by warm tropical, normal to high but probably episodically fluctuating salinity, relatively far from estuarine "entry points" of terrigenous detritus ("winnowed platform edge" facies belt of Wilson, 1975). The Quartzite Series is capped by a metric horizon of pure quartzose beach sands.

Overall regression in the Late Triassic, in spite of strong tectonic subsidence, resulted from huge sediment supply and long-term eustatic fall (Haq et al., 1988). Higher quartz/feldspar ratio in the Quartzite Series is largely ascribed to more subdued relief and less rapid erosion of granitoid basement rocks, associated with longer residence time of terrigenous detritus in temporary deposits or subtropical soils. Increased mineralogical stability might be partly due also to coarser average grain-size


THICKNESS (m)
STRATIGRAPHIC UNIT
AGE
MA
SUPERCYCLE
ENVIRONMENT (depth in m)
COASTAL
NEARSHORE
OFFSHORE
BATHYAL
ACCUMULATION RATE (m/MA)
LAPTAL FORMATION
KIOTO LIMESTONE
QUARTZITE SERIES
Upper assemblage
TARAP SHALE
MUKUT FORMATION
TAMBA-KURKUR FORMATION
KULING FORMATION
Estuarine qtzarn.
Ochre pelites
Costiferina arenites
White quartzarenites
Fenestellid-rich limestones
THINI CHU FM.
Dark pelites
Ironstones
Fossiliferous limestones
Dolomites
m.JU
e.JU
RHA.
NORIAN
CARN.
DJUL.
MUR.
e.CAR.
early FRA.
223
238
243
245.5
253.5
370
LZA-1/2
UAB-2/4
UAB-1
UAA-4
UAA-2/3
UAA-1.4/1.5/2.1
UAA-1.3
UAA-1.2
UAA-1.1
mixed
condensed
carbonate
pelite
sandstone
pelite
sandstone
ironstone
ravinement surface
marl
dolostone
limestone
disconformity /gap
bioclasts
ooids
green grains
phosphates
major transgression
megaripple X-lam.
herringbone X-lam.
clay chips

(Odom et al., 1976), more intense shallow-marine reworking (Mack, 1978), latitudinal drift towards more humid climates (Dutta & Suttner, 1986), greater contribution from multicyclic coastal plain sources (Nicora et al., 1987, p. 457), or preferential dissolution of detrital feldspars (Helmold, 1985; McBride, 1985). Evidence of extensive feldspar solution or of a climate change pronounced enough to produce first-cycle quartzarenites, however, is lacking, and marine reworking is generally thought not strong enough to completely destroy the feldspar fraction (Suttner et al., 1981; Winn et al., 1984, tab. 1; Garzanti, 1986).

Quartzose sand-sized detritus persisted in the lower part of the Kioto Limestone, a largely Early Jurassic shallow-water carbonate unit found all along the Tethys Himalaya Zone.

Conclusions

The Tethys Himalaya sedimentary succession of central Dolpo tectonically overlies medium to high grade metamorphic rocks; its base is injected by leucocratic dykes formed by partial melting of the Indian crust at a late (Early Miocene?) stage of Himalayan deformation.

Still strong metamorphism hampers stratigraphic analysis in the Early Paleozoic succession. A deepening event in the Early? Silurian is followed by a very thick shallowing-upward dolomite-quartzarenite succession in the Devonian.

Earliest Late Devonian *fossiliferous limestones* follow with sharp, disconformable base. Next, a major *ironstone* interval, indicating rapidly deepening environments and reduced sediment supply, is overlain by thick "*dark pelites*" mainly deposited in offshore shelfal settings probably during the latest Devonian (Fig. 10).

Onset of continental rifting, which will lead to opening of Neotethys, occurred between the Early? Carboniferous, represented by only a few metres of shallow-marine "*fenestellid-rich limestones*", and the mid-Permian. Tectonic uplift of rift shoulders is indicated by prolonged exposure and deep erosion of the carbonate shelf ("rift unconformity"; Fig. 11), followed by the sudden influx of quartzose siliciclastic detritus (Thini Chu Formation). Mafic volcanic detritus or tilloid deposits were not

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Fig. 12 - The stratigraphic succession of central Dolpo, with inferred depositional environments and accumulation rates. Absolute ages are according to the chronostratigraphic scale of Haq et al. (1988) for the latest Permian and Mesozoic, and to that of Harland et al. (1989) for the Paleozoic.
In the column to the right: upper-case letters (A, B) refer to the two megasequences recognized in the mid-Paleozoic succession and separated by the pre-Late Devonian unconformity (note that these long-term tectono-eustatic sequences broadly correlate in age with the Tippecanoe and Kaskaskia continental encroachment cycles of Sloss, 1972); lower-case letters (a, b, c) correspond to syn-rift sequences recognized in the Thini Chu Fm. (partly correlatable with supersequence I of Gaetani & Garzanti, 1991); roman numerals (II, III) correspond to the Neotethyan tectono-eustatic supersequences of Gaetani & Garzanti (1991).

recognized in the Permian section of Dolpo; instead a few rhyolitic grains were recorded.

The largely shelfal Middle to Late Permian terrigenous succession can be subdivided into four well-distinguishable members, mostly separated by unconformities (Fig. 12). Three major transgressive events are recorded by the marine pelites at the base of the "*white quartzarenites*" (undetermined age), by the "*Costiferina* arenites" overlain by "*ochre pelites*" and regressive "*estuarine quartzarenites*" (Murgabian-Djulfian), and finally at the base of the Kuling Formation in the Late Permian. Throughout the Tethys Himalaya, the base of the Kuling Formation is thought to mark the onset of Neo tethyan spreading ("break-up unconformity" of Gaetani & Garzanti, 1991).

Rapid subsidence and deepening after breakup is indicated by two condensed carbonate horizons with pelagic fauna of Early to Late? Dienerian and Early to Late Smithian age (Tamba Kurkur Formation). Truly bathyal conditions were never reached, as indicated by the interbedded middle-outer shelf pelites. Silty marls become common in the Spathian to Bithynian lower part of the Mukut Formation and predominant in the overlying section.

A short-term transgressive event was recorded at the very base of the Tarap Shale, followed by accumulation of thick and monotonous shelfal pelites, indicating very significant tectonic subsidence in the Early Norian (Fig. 12). In the upper part of the unit ("*upper assemblage*"), middle-outer shelf pelites and impure nodular limestones with ironstone horizons record another important transgressive episode, interrupting an overall regressive trend. The Late Triassic succession is capped by dolomitic or oolitic quartzarenites deposited in tidally-dominated shallow-water environments (Quartzite Series). Sedimentation in shallow-marine, carbonate to mixed carbonate-siliciclastic subtidal environments continued in the Jurassic with the Kioto Limestone and the overlying Laptal Formation.

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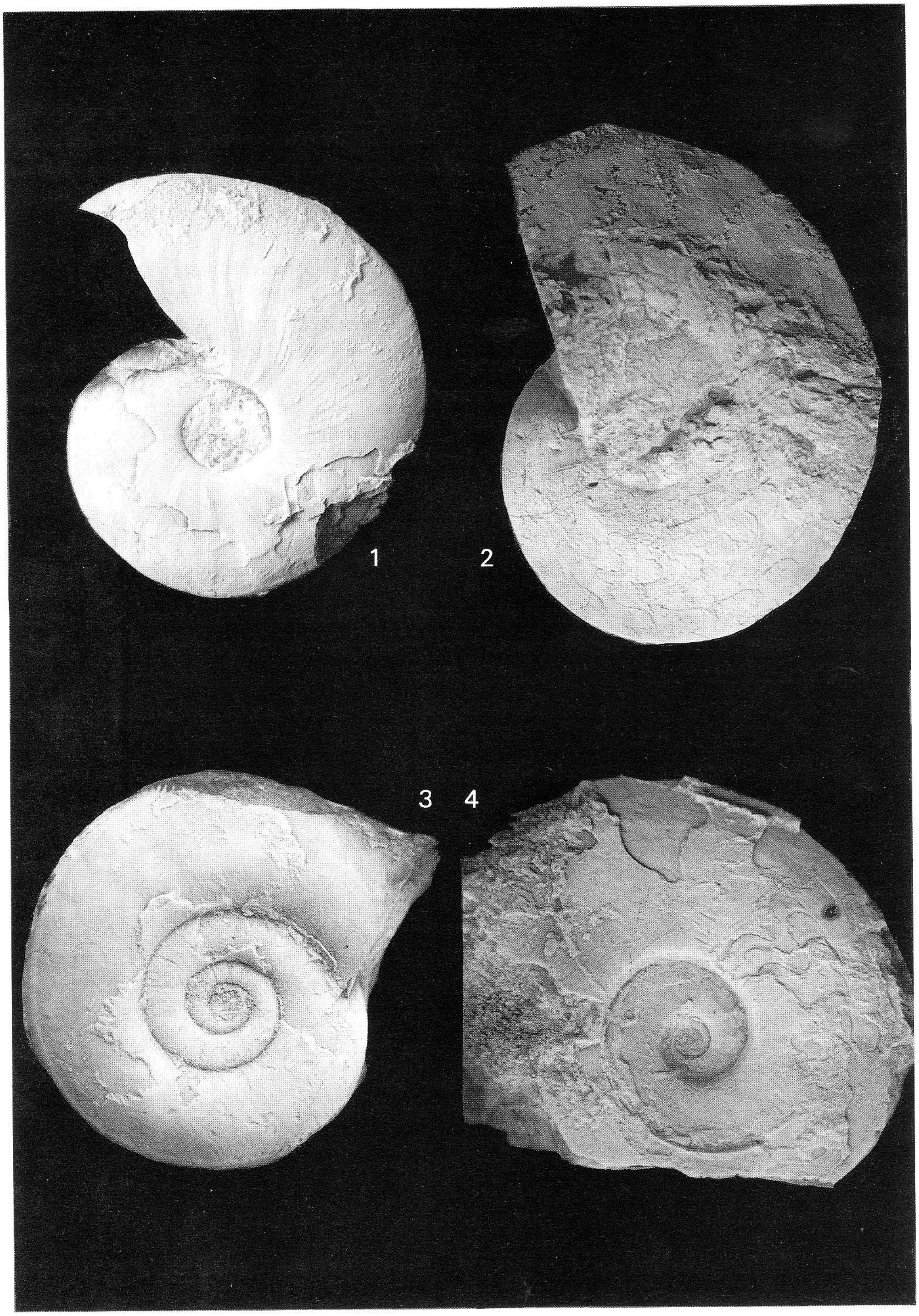
PLATE 22

Fig. 1 - *Proptychites markhami* (Diener, 1897); x 1.1.
Fig. 2 - *Prionolobus lilangensis* (v. Krafft, 1909); x 2.1.
Fig. 3 - *Gyronites frequens* Waagen, 1895; x 2.
Fig. 4 - "*Meekoceras*" *joharense* v. Krafft, 1909; x 1.4.

All specimens were found in the basal (Dienerian) limestone band of the Tamba Kurkur Formation in the Atali-Numa La section.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