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TRIASSIC STRATIGRAPHY AND SEDIMENTARY EVOLUTION OF THE ANNAPURNA TETHYS HIMALAYA (MANANG AREA, CENTRAL NEPAL)

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Key-words: Tethys Himalaya, Triassic, Ammonoids, Conodonts, Brachiopods, Corals, Stratigraphy, Arenite petrography.

Riassunto. Dopo l'apertura iniziale della Neotetide nel Permiano, la subsidenza termica continua nel Triassico inferiore, caratterizzato da tre orizzonti condensati di carbonati pelagici, di età Griesbachiana inferiore-Dieneriana inferiore, Smithiana inferiore-media e Smithiana sommitale-Egeica basale, separati da argilliti nere (Formazione di Tamba Kurkur). Le strutture sedimentarie indicano un ambiente di piattaforma non molto profonda per le argille, mentre per i carbonati nodulari la ricca fauna ad Ammoniti e Conodonti suggerisce profondità massime attorno ai 150 ÷ 200 m, raggiunte sulla piattaforma esterna durante fasi trasgressive.

La Formazione di Mukut contiene marne e calcari marnosi deposti in ambienti di piattaforma dall' Anisico inferiore al Norico basale. Peliti calcaree e siltose sono più abbondanti nella parte carnica della formazione, dove i tassi di accumulo in rapido aumento suggeriscono una nuova fase tettonica estensiva.

La potente Formazione di Tarap, attribuibile in gran parte alla parte centrale del Norico, è costituita da una fitta alternanza di peliti scure e di subarkose a grana fine ("membro inferiore"), seguite localmente da patch-reefs a Coralli ("membro centrale") e quindi da peliti intercalate ad areniti ibride spesso contenenti chamosite e deposte durante eventi trasgressivi ("membro superiore").

La successione Triassica termina con quarzareniti ibride e subarkose alternate con peliti e calcari ("Quartzite Series"), seguite da carbonati di piattaforma (Calcari di Kioto).

Abstract. After initial opening of Neotethys in the Permian, thermal subsidence and deepening continued in the Triassic. In the Scythian, three pelagic nodular carbonate intervals of Early Griesbachian to Early Dienerian, Early to mid-Smithian and latest Smithian to earliest Aegean age are interbedded with shelfal shales (Tamba Kurkur Formation). Ammonoid- and conodont-rich condensed carbonates were deposited on the outer shelf, with maximum depths around 150 ÷200 m reached during transgressive stages.

The Anisian to lowermost Norian shelfal succession mostly consists of marly limestones and marls (Mukut Formation). Thick calcareous siltstones rapidly accumulated in the Carnian, testifying to a new stage of tectonic extension affecting the Tethys Himalayan passive margin. The thick Tarap Formation of largely mid-Norian age points to strong continuing subsidence. Interbedded siltstones and subarkosic sandstones ("lower member") are locally overlain by coral-bearing patch reefs ("middle member"). Chamosite-bearing hybrid arenites deposited at transgressive stages characterize the "upper member".

The Triassic succession is capped by subarkoses and quartzarenites, interbedded with dolomitic to bioclastic hybrid sandstones and silty limestones ("Quartzite Series"), in turn overlain by the Kioto Limestone.

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Introduction.

Sedimentary rocks belonging to the Tethys Himalayan sedimentary succession are exposed in the Dolpo-Manang Synclinorium (central Nepal), a nearly 200 km-long structure formed during the Tertiary Himalayan Orogeny as a consequence of the collision between India and Asia (Fig. 1).

During our october 1991 Ev-K2-CNR expedition, we studied the Triassic succession cropping out in the Manang area of central Nepal (Fig. 2). One almost complete composite stratigraphic section and several logs were measured between Thakkhola and Braga, and about 250 samples were collected for detailed paleontological and petrographical analysis.

Aim of the present paper is to provide stratigraphic and biostratigraphic data, adding new information to previous works (Bodenhausen et al., 1964; Bordet et al., 1971, 1975; Fuchs et al., 1988), and to compare the sedimentary evolution of the region with the adjacent Thakkhola and Dolpo areas of central Nepal (Garzanti & Pagni Frette, 1991; Garzanti et al., 1992). For information on the underlying Upper Paleozoic succession the reader is referred to the companion paper by Garzanti et al. (1994).

Stratigraphic nomenclature adopted in this paper is after Fuchs et al. (1988; see also Fuchs, 1967, 1977). Conodont zones are according to Matsuda (1985), Sweet (1988 a,b) and Kozur (1989). Sandstone classification is after Folk (1980).

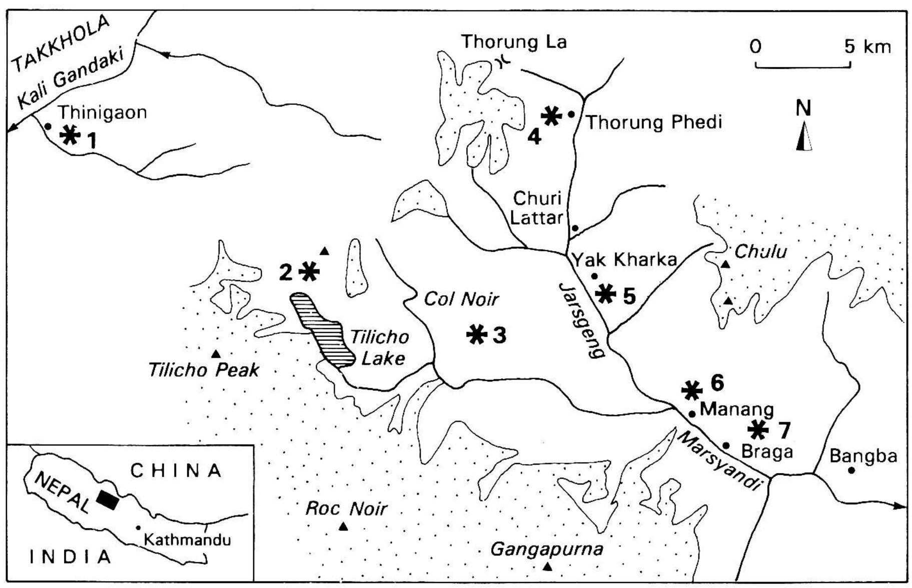

Fig. 1 - Geographic map of the studied Manang area. Asterisks indicate location of measured Triassic stratigraphic sections. 1) Thinigaon (Smithian to Aegean); 2) Tilicho (Dorashamian to Carnian); 3) Col Noir (Dorashamian to Anisian); 4) Thorung Phedi (Norian-Rhaetian); 5) Yak Kharka (Norian); 6) Manang (Dorashamian to Aegean); 7) Braga (Bolorian to Dienerian). Glaciated areas are stippled.

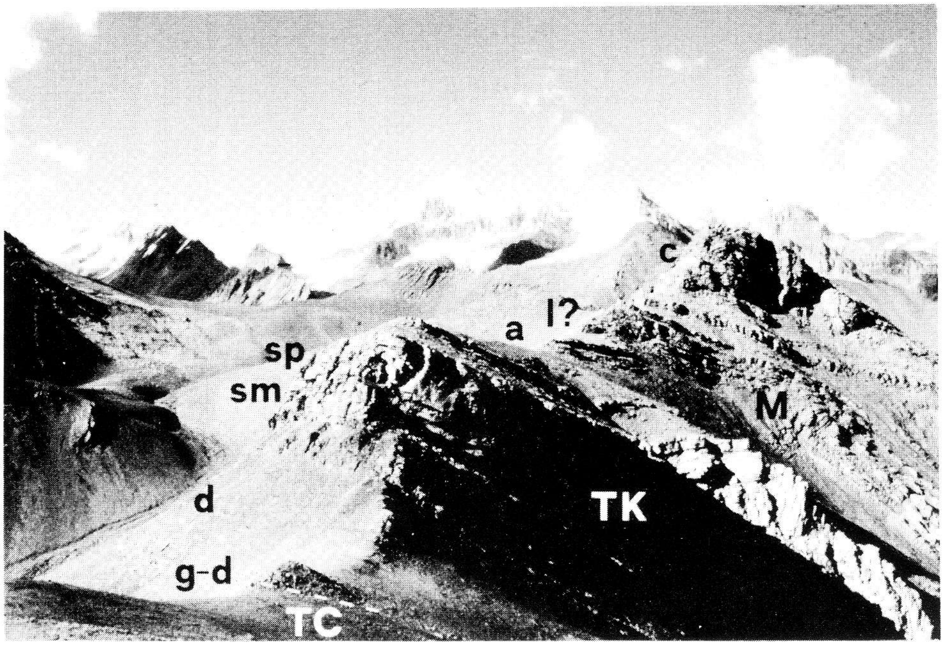

Fig. 2 - In the Col Noir section, above the Permian upper part of the Thini Chu Group (TC), the Griesbachian/Dienerian (g-d), Smithian (sm) and Spathian (sp) carbonate bands of the Lower Triassic Tamba Kurkur Formation (TK) pass upward to Anisian (a), Ladinian (l ?) and Carnian (c) folded marly limestones of the Middle Triassic Mukut Formation (M).

Stratigraphy

Tamba Kurkur Formation.

The unit, between 37 and 50 m thick in the Thakkhola-Manang area (Fig. 3), is characterized by metric horizons of grey to reddish, planar to nodular pelagic wackestones, separated by metric to decametric intervals of dark grey pelites (Fig. 4).

The basal contact, corresponding to the Permo-Triassic boundary, occurs within an orange-weathering condensed carbonate interval. It is marked by abrupt transition from dolomitized floatstones with still mainly calcitic bryozoans, brachiopods and corals, capping the Thini Chu Group ("topmost biocalcarenites"; see companion paper by Garzanti et al., 1994 for further information), to dolomitic wackestones with sparse and still calcitic pelagic bivalves, crinoids and ostracods.

The first carbonate band (increasing eastward in thickness from 1.8 m at Tilicho, to 1.9 m at Col Noir, 2.0 m at Manang Gompa and 2.4 m at Braga), is overlain by dark pelites (20 to 30 m thick), containing burrowed and pyritic clayey mudstone beds in the lower 5 to 7 m, and marly siltstones with hummocky cross-lamination and current ripple marks pointing to northeastward paleocurrents in the upper part.

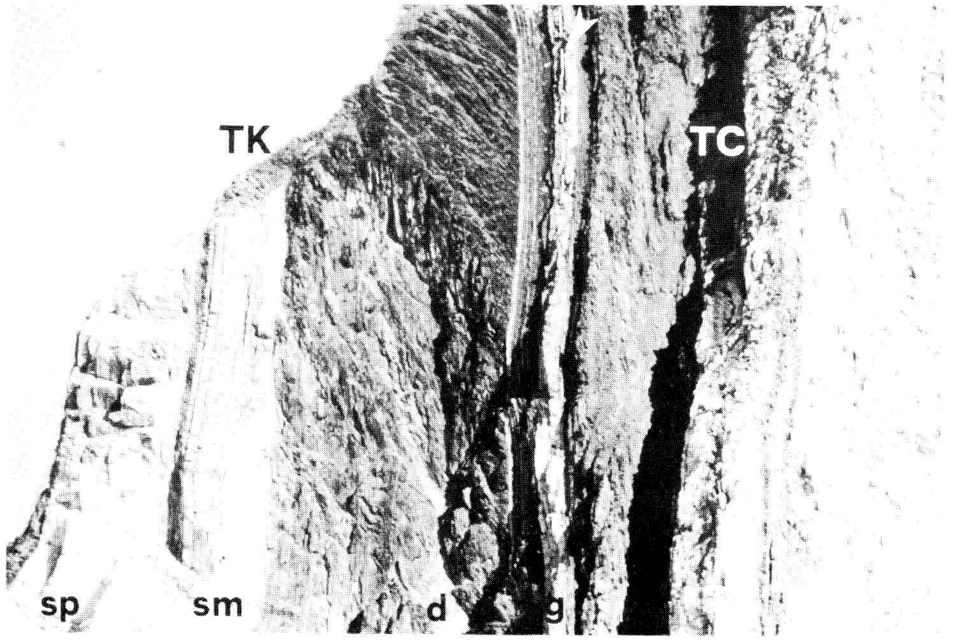

Fig. 3 - The Lower Triassic Tamba Kurkur Formation (TK) above Tilicho Lake ("Dent permienne" of French Authors). The Permian/Triassic boundary lies within the thin resistant carbonate band at the center of the photo (arrow), overlying the Thini Chu Group (TC). The Griesbachian/Dienerian (g), Smithian (sm) and Spathian (sp) carbonate bands are separated by thick Upper Dienerian (d) and thin Upper Smithian black pelites.

The second carbonate band (4.2 to 10.5 m), with thin basal beds of rippled silty marls pointing to northeastward paleocurrents, is followed by a thin dark pelitic interval (1.1 to 3.4 m thick) and by a third carbonate band (7.2 to 9.3 m). In the Thakkhola Graben above Thinigaon, only this third carbonate band is well exposed.

Fossils, age and regional correlations.

The *first carbonate band* contains in the lower 80 ÷ 120 cm the conodonts *Hindeodus* cf. *typicalis* Sweet, 1970, *Gondolella carinata* Clark, 1959 and representatives of the *G. subcarinata* group (Tab. 1 to 5; Pl. 1 to 3), indicating the Early to Late Griesbachian (Subcarinata and Isarcica Zones). The upper 50 ÷ 120 cm yielded *Neospathodus kummeli* Sweet, 1970, *N. dieneri* Sweet, 1970 and *N. cristagalli* Sweet, 1970, indicating the Early Dienerian (Kummeli/Cristagalli Zone).

The *first thick pelitic interval*, still containing Early Dienerian conodonts in the lower 1 ÷ 2 m, yielded *Gondolella nepalensis* Kozur & Mostler, 1976 and *Neospathodus pakistanensis* Sweet, 1970 in the middle-upper part, indicating the Late Dienerian (Pakistanensis Zone of Sweet 1998 a,b) or the earliest Smithian (Matsuda, 1985; Kozur, 1989; see Tab. 6).

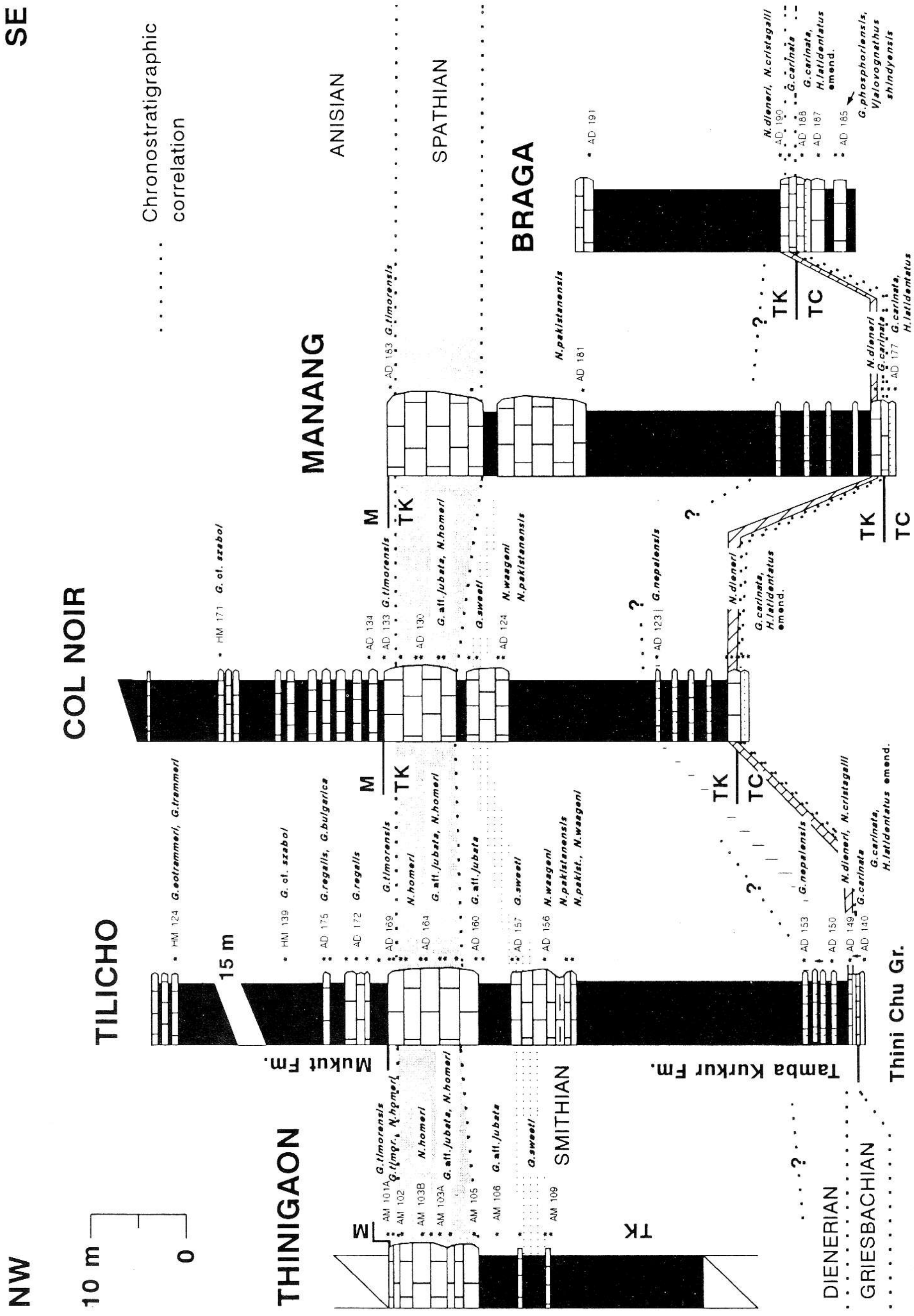

Fig. 4 - Measured stratigraphic sections in the largely Scythian Tamba Kurkur Fm. (TK) and Anisian lower part of the Mukut Fm. (M) (lithozones 1 to 3). The uppermost part of the Thini Chu Group (TC) ("topmost biocalcarenites" of Garzanti et al., 1994) ranges in age from late Early Permian (Bolorian) to latest Permian (Late Dorashamian).

THINIGAON SECTION	Sample-distance from section base (m)	Samples	Neospathodus cristagalli	Gondolella sweeti	Gondolella aff. jubata	Neospathodus waageni	Neospathodus homeri	Neospathodus spathi	Gondolella timorensis	Ramiforms	Foraminifers	Ostracods	Zone	Age		
Tamba Kurkur Fm.	15.50	AM 101 A	barren										?	?	ANISIAN	TRIASSIC
	15.00	AM 101					2		33	3	X		Timorensis	E. AEGEAN		
	13.00	AM 102					1			3	X	X	Jubata ? Collinsoni	SPATHIAN	SCYTHIAN	
	11.50	AM 103 B					6	1		29						
	11.00	AM 103					37			124						
	10.00	AM 103 A					25	10		130						
	9.55	AM 104					7	1		11		X				
	6.30	AM 105			94	1?	15			13			upper Triangularis	L. SMITHIAN		
	4.80	AM 106			4					1			lower Triangularis	L. SMITHIAN		
	2.00	AM 107		1									Milleri	M. SMITHIAN		
	0.50	AM 108		62						13						
	0.00	AM 109	2	2												

Tab. 1 - Conodont distribution in the Scythian to lowermost Anisian section measured above Thinigaon.

TILICHO SECTION	Sample-distance from TK base (m)	Samples	Gondolella orientalis gr.	Gondolella subcarinata gr.	Hindeodus cf. typicalis	Gondolella carinata	Hindeodus latidentatus emend	Neospathodus dieneri	Neospathodus cristagalli	Gondolella nepalensis	Neospathodus pakistanensis	Neospathodus waageni	N. waageni morphotype 3	Neospathodus conservativus	Gondolella sweeti	Gondolella aff. jubata	Neospathodus homeri	Gladigondolella carinata	Neospathodus spathi	Gondolella timorensis	Gondolella regalis	Ramiforms	Foraminifers	Ostracods	Zone	Age		
Mukut Fm.	54.50	AD 175																			17	4	X	X	Regalis	L. AEGEAN	ANISIAN	TRIASSIC
	53.70	AD 174																			32	15	X	X				
	51.40	AD 173	barren																									
	50.85	AD 172																			10	13		X				
	49.45	AD 171																		157		37			Timorensis	E. AEGEAN		
	49.05	AD 170	barren																									
Tamba Kurkur Fm.	47.05	AD 169															1			84		10	X					
	46.35	AD 168															24		10	95		89						
	43.85	AD 167															6					9			Jubata ? Collinsoni ? Triangularis	SPATHIAN	SCYTHIAN	
	43.75	AD 166																	1?			23		X				
	42.85	AD 165															69		24			137						
	42.00	AD 164															22		8			81						
	41.45	AD 163														9	3					5						
	40.60	AD 162														183	75					93		X				
	39.60	AD 161														148	37					85						
	38.60	AD 160														84	12	23				26		X				
	38.20	AD 159														1						2		X	lower Triangularis	L. SMITHIAN		
	35.80	AD 158	barren																						?	?		
	35.59	AD 157													57							8			Milleri	M. SMITHIAN		
	33.80	AD 156									1	3	2									13		X	Waageni	E. SMITHIAN		
	32.05	AD 155							1		18	21	19	4								10						
	30.55	AD 154							8		8	2										3						
	6.85	AD 153								16	8											5	X	X				
	4.60	AD 152								3															Pakistanensis	L. DIENERIAN		
	4.45	AD 151							2																Kummeli / Cristagalli	E. DIENERIAN		
	3.00	AD 150						3	21													5						
	1.65	AD 149						6	6																			
	1.45	AD 148							4													2						
	1.15	AD 147						33	11													1						
	1.00	AD 146	barren																						?	?		
	0.80	AD 145		15		82																						
	0.50	AD 144		17		23																1	X		Isarcica	L. GRIESBACHIAN		
	0.40	AD 143		8	1	30																5			Subcarinata	E. GRIESBACHIAN		
Thini Chu Gr.	-0.10	AD 142	12	37	2	117	68															18			Orientalis ?	DORASHAMIAN ?		P.
	-0.17	AD 141	13	7	7	25																4						
	-0.67	AD 140	barren																									

Tab. 2 - Conodont distribution in the uppermost Permian to Anisian section measured above Tilicho Lake.

COL NOIR SECTION	Thini Chu Gr.				Tamba Kurkur Fm.															Mukut Fm.	
Sample-distance from TK base (m)	-2.27	-1.97	-1.29	-1.00	0.00	0.73	1.78	1.93	10.13	25.43	28.03	30.23	30.53	31.23	31.73	33.63	35.13	37.13	39.13	42.33	42.68
Samples	AD 115	AD 116	AD 117	AD 118	AD 119	AD 120	AD 121	AD 122	AD 123	AD 124	AD 125	AD 126	AD 127	AD 128	AD 129	AD 130	AD 131	AD 132	AD 133	AD 134	AD 135
Gondolella orientalis gr.				45																	
Gondolella orientalis transcaucasica	barren	barren	barren	1									barren	barren							barren
Hindeodus typicalis				17																	
Hindeodus typicalis trans. form to H.julfensis				1																	
Gondolella subcarinata gr.				64																	
Hindeodus latidentatus emend				28																	
Gondolella carinata					29	3															
Neospathodus kummeli						74															
Neospathodus dieneri							37	5													
Neospathodus cristagalli							49	2		1											
Gondolella nepalensis									2												
Neospathodus pakistanensis									7		1										
Neospathodus waageni										1	9	3									
N.waageni morphotype 3											4										
Gondolella sweeti												26									
Gondolella aff. jubata															7	177		1			
Neospathodus homeri															3	107	28	10	2		
Neospathodus spathi																	3	1			
Gondolella timorensis																			125	20	
Gladigondolella tethydis																			6		
Ramiforms				10	1	6	1			1	5	4			14	125	21	25	16	3	
Foraminifers									X										X		
Ostracods								X													
Zone	?			Orientalis	Isarcica	lower Kummeli/Cristagalli	Kummeli / Cristagalli		Pakistanensis	Waageni		Milleri	?		Jubata ? Collinsoni				Timorensis		?
Age	?			DORASHAMIAN	L. GRIESBACHIAN	E. DIENERIAN			L. DIENERIAN	E. SMITHIAN		M. SMITHIAN	?		SPATHIAN				E. AEGEAN		?
					SCYTHIAN														ANISIAN		
	PER.				TRIASSIC																

Tab. 3 - Conodont distribution in the uppermost Permian to Anisian section measured at Col Noir

MANANG SECTION	Thini Chu Gr.		Tamba Kurkur Fm.				
Sample-distance from TK base (m)	-1.65	-0.20	1.00	2.00	22.00	33.58	42.34
Samples	AD 177	AD 178	AD 179	AD 180	AD 181	AD 182	AD 183
Gondolella orientalis gr.	barren	13					
Gondolella subcarinata gr.		37	5				
Hindeodus latidentatus emend		14					
Hindeodus typicalis		9					
Gondolella carinata		95	32				
Neospathodus kummeli				10?			
Neospathodus dieneri				68			
Neospathodus cristagalli				104			
Neospathodus pakistanensis				21	3		
Gondolella aff. jubata						1	
Neospathodus homeri							1
Gondolella timorensis							20
Gladigondolella tethydis							1
Ramiforms		6	1		1	3	3
Zone	?	Orientalis	Subcarinata ?	Kummeli / Cristagalli	Waageni	Triangularis	Timorensis
Age	?	DORASHAMIAN	GRIESBACHIAN	E. DIENERIAN	E. SMITHIAN	L. SMITHIAN	E. AEGEAN
			SCYTHIAN				ANISIAN
	P.		TR.				

Tab. 4 - Conodont distribution in the uppermost Permian to lowermost Anisian section measured above Manang.

BRAGA SECTION	Thini Chu Gr.					Tamba Kurkur Fm.		
Sample-distance from TK base (m)	-35.47	-4.27	-3.09	-1.16	-0.17	1.20	2.40	27.75
Samples	AD 184	AD 185	AD 186	AD 187	AD 188	AD 189	AD 190	AD 191
Vjalovognathus shindyensis	barren	17	barren	barren				barren
Gondolella phosphoriensis		9						
Gondolella orientalis gr.					45			
Gondolella subcarinata gr.					15	17		
Hindeodus typicalis					4			
Gondolella carinata					37	83		
Neospathodus kummeli							1?	
Neospathodus dieneri							21	
Neospathodus cristagalli							77	
Ramiforms					10		15	
Foraminifers			X					
Ostracods							X	
Bellerophon	X							
Zone	?		?		Orientalis	Subcarinata	Kummeli / Cristagalli	?
Age	?	BOLORIAN-KUBERG./MURGAB.	?		DORASHAMIAN	? E. GRIESBACHIAN	E. DIENERIAN	?
						SCYTHIAN		
	PERM.					TR.		

Tab. 5 - Conodont distribution in the upper Lower Permian to Scythian section measured above Braga.

MATSUDA, 1985		SWEET, 1988 b		KOZUR, 1989 Pelagic facies		
AE.	?	AEGEAN	REGALE	AEGEAN		NEOGONDOLELLA REGALIS A.Z.
SPATHIAN	TIMORENSIS		TIMORENSIS			CHIOSELLA TIMORENSIS A.Z.
	TRIANGULARIS - HOMERI	SPATH.	JUBATA	OLENEKIAN s.l.	U.	GLADIGONDOLELLA CARINATA NEOSPATHODUS HOMERI A.Z.
			COLLINSONI			PARAGONDOLELLA ? JUBATA / ICRIOSPATHODUS COLLINSONI A.Z.
SMITHIAN	ELONGATA	SMITHIAN	TRIANGULARIS			NEOSPATHODUS TRIANGULARIS NEOSPATHODUS HOMERI A.Z.
	MILLERI		MILLERI		L.	SCYTOGONDOLELLA MILLERI - PARAGONDOLELLA SWEETI A.Z.
	WAAGENI		WAAGENI			SCYTOGONDOLELLA ? MOSHERI A.Z.
						PSEUDOGONDOLELLA NEPALENSIS
DIENERIAN	PAKISTANENSIS	DIENERIAN	PAKISTANENSIS	BRAHMANIAN (= INDUAN)	G.	NEOSPATHODUS DIENERI A.Z.
	CRISTAGALLI DIENERI KUMMELI		KUMMELI - CRISTAGALLI			CLARKINA CARINATA - NEOSPATHODUS KUMMELI A.Z.
GRIESBACHIAN	CARINATA ISARCICA	GRIESBACHIAN	ISARCICA		E.	CLARKINA CARINATA I.Z.
	PARVUS		SUBCARINATA			HINDEODUS POSTPARVUS A.Z.
	MINUTUS					ISARCICELLA ISARCICA Z.

Tab. 6 - Scythian to earliest Anisian conodont biochronozones according to Matsuda (1985), Sweet (1988 a,b) and Kozur (1989).

The *second carbonate band* yielded conodonts (*N. pakistanensis*, *N. waageni* Sweet, 1970) of Early Smithian age (Waageni Zone). *Gondolella sweeti* Kozur & Mostler, 1976 appears in the topmost 0.5 m, indicating the mid-Smithian (Milleri Zone).

The *second thin pelitic interval* yielded the brachiopod "*Rhynchonella*" *dieneri* Bittner, 1901, pointing to the Smithian, and at the top the conodont *Gondolella* aff. *jubata* Sweet, 1970, suggesting the Late Smithian (base of Triangularis Zone).

The *third carbonate band* contains conodont assemblages [*G.* aff. *jubata*, *Neospathodus homeri* (Bender, 1970), *Gladigondolella carinata* Bender, 1970 and *Neospathodus spathi* Sweet, 1970] of latest Smithian to latest Spathian age (topmost Triangularis, Collinsoni and Jubata Zones). *Gondolella timorensis* Nogami, 1968 occurs in the topmost 0.6 m, indicating the earliest Aegean (Timorensis Zone). Vertebrae of the ichtyosaur *Cymbospondylus* sp. (Fig. 5) were found in loose carbonate blocks containing Spathian conodonts.

Ammonoids are common, but difficult to extract from the rock. Other fossils include thin-shelled bivalves, ostracods, gastropods, brachiopods, crinoids, radiolaria, benthic and sessile foraminifers.

The first and second carbonate bands, with the intervening pelitic interval,

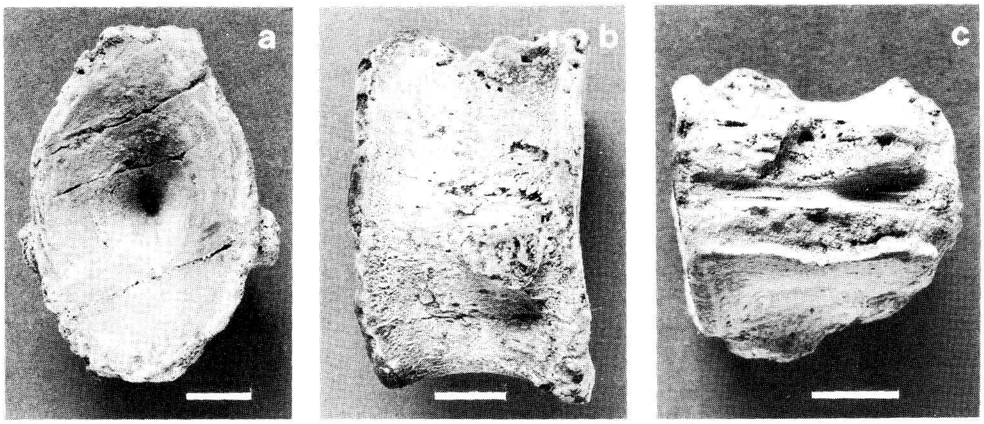

Fig. 5 - Anterior caudal vertebra of the ichtyosaur *Cymbospondylus* sp., found in the Spathian third carbonate band of the Tamba Kurkur Fm. at Col Noir. Scale bar = 10 mm. a) Posterior view; b) left lateral view; c) dorsal view, anterior to the right.

correlate precisely (at conodont zone level) with analogous horizons recognized in central Dolpo, where however no evidence of Griesbachian sediments was found (Nicora, 1991). In the Atali-Tarap area of central Dolpo (Nicora, 1991), the second pelitic interval and the third carbonate band of the Tamba Kurkur Formation are replaced by 12 m of alternating marly limestones and marls (basal part of the Mukut Formation), deposited in presumably shallower-water shelfal settings during the latest Smithian to earliest Aegean. In other parts of Dolpo, however, the Tamba Kurkur Fm. is reported to extend up to the Lower Anisian and, although considerably thinner, it displays the same three carbonate bands as in Manang (Fuchs & Mostler, 1969, fig. 1; G. Fuchs, writ. comm. 1994). In the Zanskar-Spiti Synclinorium, the Tamba Kurkur Formation ranges up to the Anisian/Ladinian boundary (Nicora et al., 1984; Garzanti et al., 1993).

Sedimentary evolution.

Conodont distribution indicates strongly condensed sedimentation around the Permian/Triassic boundary. Constant thickness of all stratigraphic horizons, observed across the Dolpo-Manang Synclinorium for over 110 km along strike, is consistent with homogeneous sinking of the newly-formed continental margin after break-up. Deepening resulted from thermal subsidence and reduced average accumulation rates (4 to 5 m/Ma according to the Haq et al., 1988 time scale; down to 1 m/Ma for carbonate bands and up to well over 10 m/Ma for pelitic intervals). Drowning was more pronounced in the more distal Thakkhola-Manang area, where condensed reddish limestone sedimentation persisted up to the top of the Lower Triassic, with respect to central Dolpo, where the Tamba Kurkur Formation reaches only up to the Smithian, and the Spathian is represented by the lowermost part of the shelfal Mukut Formation (Nicora, 1991).

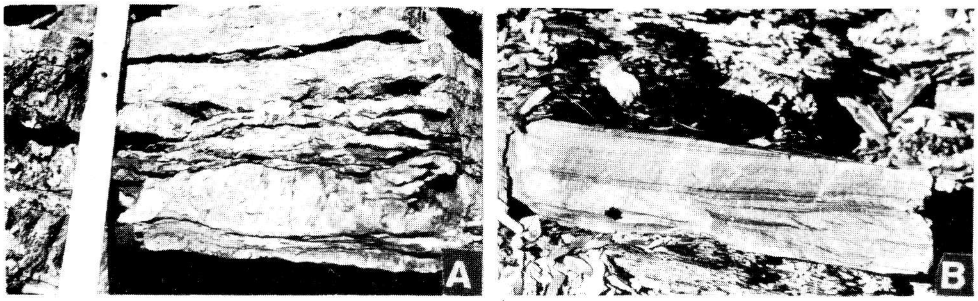

Fig. 6 - Typical lithofacies of the Tamba Kurkur Fm. A) Ferruginous condensed pelagic mudstones with bacterial mats (lower part of the first carbonate band; Subcarinata Zone; AD 143; rule for scale). B) Parallel lamination to current ripple marks (first pelitic interval; Pakistanensis Zone; lens cap for scale).

Cyclic alternation of carbonatic and pelitic lithofacies is interpreted as chiefly controlled by eustatic sea-level changes (Fig. 6). Carbonate bands all along the Dolpo-Manang Synclinorium in fact correlate well with transgressive tracts of the global eustatic curve, their tops coinciding with the mid-Dienerian, late Smithian and earliest Anisian major global downlap surfaces (third-order cycles UAA-1.2 to UAA-1.4; Haq et al., 1988).

Condensed, ammonoid-rich and commonly dolomitic limestones (Fig. 6A) were deposited onto the outermost shelf to upper slope (water depths up to 150 ÷ 200 m), during transgressive stages characterized by upwelling and expansion of the oxygen-minimum layer. "Pseudo-stromatolitic" lamination, commonly displayed in the middle part of carbonate bands, is ascribed to bacterial mats similar to those forming close to modern shelfbreaks in zones of coastal upwelling (Williams & Reimers, 1983; Williams, 1984). Packing of bioclasts with local lack of micrite suggests winnowing by intruding oceanic currents.

Black pelitic intervals, which show little burrowing, were instead deposited during highstand stages on offshore middle shelf bottoms deepening towards the northeast (water depths of some to several tens of metres). In the sporadically interbedded silty layers, parallel to hummocky lamination and current ripple marks (Fig. 6B) point to deposition above major storm wave base, at water depths of some tens of metres. Veneers of locally rippled micaceous and dolomitic siltstones, which commonly mark the base of carbonate bands, indicate storm reworking at relatively shallow water-depths, probably reached on the outer continental shelf in the subsequent lowstand stages.

Mukut Formation.

The unit consists of alternating marly limestones and marls, with silty layers becoming more important upwards (thickness over 206 m, probably around 300 or even 400 m, since the transitional upper boundary with the Tarap Formation could not be established; Fig. 7).

In the well-exposed Tilicho section, twelve lithozones can be recognized.
(Top to bottom):

12) subarkosic silty wackestones/packstones with crinoids, thin-shelled bivalves and brachiopods, rhythmically alternating with calcareous marls continuing upward for 100 or even 200 metres;
11) marls alternating with burrowed and bioclastic subarkosic siltstones rich in thin-shelled bivalves (6.1 m thick);
10) silty marls with subordinate silty wackestones/packstones containing abundant crinoids, thin-shelled bivalves, echinoids and locally phosphatized ammonoids (22.7 m thick);
9) marls with a thin basal bed of winnowed crinoidal grainstone containing black grains (14.1 m thick);
8) interbedded marls and silty marlstones, with subordinate marly limestones and a thin basal bed of subarkosic silty and bioclastic wackestone yielding bivalves and echinoderms (16.65 m thick);
7) marls with subordinate dark marly limestones, with a thick basal bed of crinoid-bearing burrowed silty mudstone with quartz, muscovite, biotite and authigenic albite with Roc-Tourné "fourling" twinning (21.1 m thick);
6) dark marly limestones, locally crinoid-bearing and displaying wave-ripple marks, with subordinate marls (17.7 m);
5) predominating marls with burrowed marly limestones (34.65 m thick);
4) marly limestones in 5 to 30 cm thick beds with subordinate marls (21 m thick);
3) alternating marls and marly limestones, locally yielding ammonoids and crinoids, with a basal interval of orange-weathering burrowed and microlaminated mudstones locally with phosphates (15.35 m thick; HM 124);
2) dark marls, locally with loose ammonoids (30.5 m thick; HM 139);
1) knobby, burrowed bioclastic limestones, locally very rich in brachiopods and also yielding bivalves and ammonoids, interbedded with grey marls with calcareous or phosphatic nodules (6.5 m thick).

At Col Noir, lithozone 1 is thicker (9.2 m); lithozone 2, well developed and rich in ammonoids, contains marly limestones in the lower 7.6 m (HM 171). Folds affect the upper part of the section. Above a carbonate band (lithozone 4), marls (lithozone 5) are followed by several tens of m thick silty marls, marly limestones and rare arenite beds (lithozones 6 to 10).

Fossils, age and regional correlations.

A rich brachiopod assemblage, found between 1.5 and 2 m above the base of lithozone 1 at Tilicho [*Punctospirella stracheyi* (Salter, 1865), "*Dielasma*" *himalayanum* Bittner, 1898, "*Rhynchonella*" *mutabilis* Stoliczka, 1865 and "*Rhynchonella*" *griesbachi* Bittner, 1895], points to the Early Anisian. The Aegean is indicated up to at least 2.4 m above the base of the unit, where *Gondolella timorensis* is exclusive (Tab. 2 and 3; AD 171). Conodonts found at Tilicho from 2.8 m above the base of the Mukut Fm. [*Gondolella regalis* (Mosher, 1970); AD 172] to the top of lithozone 1 [*G. regalis*, *Gondolella bulgarica* (Budurov & Stefanov, 1975); 6.5 m above the base; AD 175] indicate the Early Bithynian (Fig. 4).

The lower part of the Mukut Formation is also rich in ammonoids of Anisian age: *Hollandites* sp. and a possibly new genus were found in lithozone 1; *Gymnites (Buddhaites) rama* Diener, 1895 was collected in the scree (AD 136); *Salterites*? *truncus* (Diener, 1895) occurs 4.5 m above the base of lithozone 2 (HM 139), where conodonts found in the matrix (*Gondolella* cf. *szaboi* Kovacs, 1983) already indicate the Illyrian. The conodont *G.* cf. *szaboi* Kovacs, 1983 also occurs 7.6 m above the base of lithozone 2 at Col Noir (HM 171). The mid-Anisian (Late Bithynian to Pelsonian) is thus poorly represented (a few meters of sediment at most). Early Ladinian conodonts (*Gondolella eotrammeri* Krystyn, 1983 and *Gondolella trammeri* Kozur, 1971; HM 124) were found at the top of the 0.75 m thick basal interval of lithozone 3 at Tilicho.

Lithozone 1 thus correlates with the middle (to upper?) part of the 35 m thick basal marly limestone/marl interval of the Mukut Formation in central Dolpo (containing Early Aegean and Early Bithynian conodonts respectively 14 and 20 m above its base; Garzanti et al., 1992).

Lithozone 2, largely Late Anisian (Illyrian) in age, may be broadly correlated with the about 45 m thick pelitic interval in the lower part of the Mukut Formation of central Dolpo (Garzanti et al., 1992). In the Spiti-Zanskar Synclinorium, the whole Anisian is still represented by the condensed upper part of the Tamba Kurkur Formation (Gaetani et al., 1986; Garzanti et al., 1993).

Lithozone 3, of Ladinian age, corresponds with the Daonella Shale of the Spiti region; the Ladinian/Carnian boundary possibly lies within the carbonate band of lithozone 4 ("Mukutkalk s.str." of Krystyn, 1982, seemingly correlatable with the Daonella/Halobia Limestone of Spiti). The Ladinian succession in the Zanskar Range is instead represented by the much thicker lower and middle members of the Hanse Formation (250 to 300 m thick; Gaetani et al., 1986, fig.10).

Occurrence of *Tropites subbullatus* (v. Hauer, 1849) in lithozone 10 indicates the Upper Carnian (mid-Tuvalian). Lithozones 5 to 10 are thus all ascribed to the Carnian. Lithozones 5 to 9 (thickness 104.2 m at Tilicho) roughly correlate with the "untere Thinigaon Fm." of Krystyn (1982) and with the Grey Beds of Spiti. Lithozones 10, 11 and 12 can be instead equated with the "obere Thinigaon Fm." of Krystyn (1982) and with the Tropites Beds of Spiti. Lithozones 4 to 12 would correspond with the 250 to 300 m thick Carnian upper member of the Hanse Formation and uppermost Carnian/lowermost Norian Zozar Formation in the Zanskar Range (Gaetani et al., 1986, fig. 8; Jadoul et al., 1990).

Sedimentary evolution.

The Mukut Formation marks an increase in clay and silt supply to the Tethys Himalayan passive margin during the Middle to early Late Triassic. Deposition occurred in shelfal settings, at water depths ranging from a few tens to several tens of metres, as indicated by sporadic ripple marks and thin to thick storm beds. Winnowed thin bioclastic layers occurring at a few intervals may reveal action of oceanic currents intruding onto the outer part of the shelf at transgressive stages.

Accumulation rates rapidly increased from less than 10 m/Ma in the Anisian and Ladinian (according to the Haq et al., 1988 time scale; Fig. 7A) to even more than 50 m/Ma in the mid- to Late Carnian (Fig. 7B). This strong increase in tectonic subsidence, coupled with increased supply of both K-spar and plagioclase-bearing silt recorded from the Thakkhola area to Spiti (Krystyn, 1982; Garzanti et al., 1993), is ascribed to a Late Triassic extensional? event affecting the whole Tethys Himalayan margin, possibly triggered by a global reorganization of plate motion (Veevers, 1989; Garzanti, 1993).

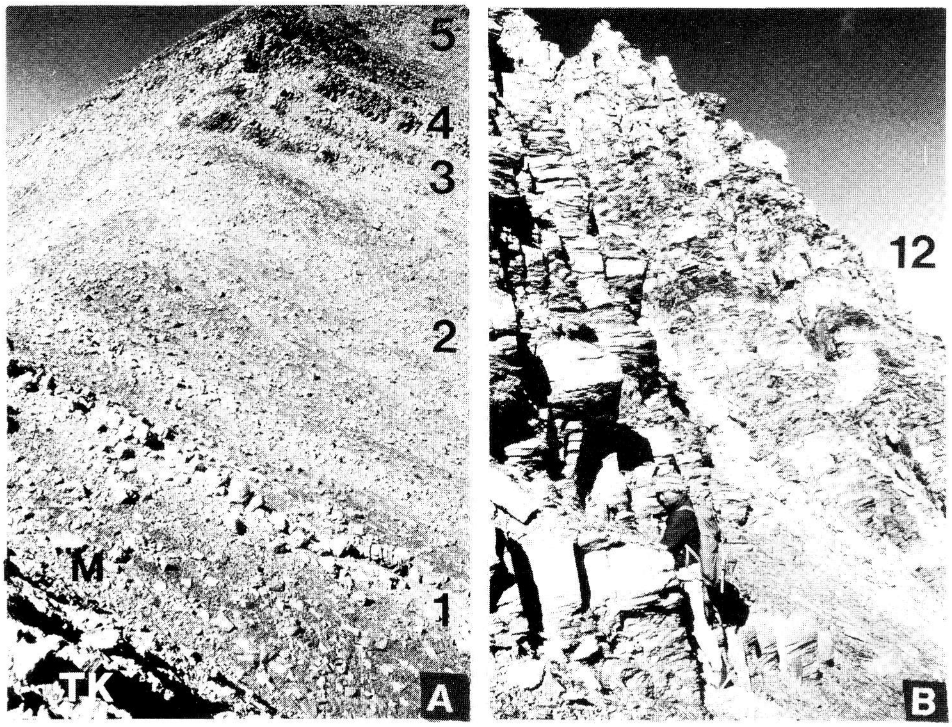

Fig. 7 - The Mukut Formation (M) above Tilicho Lake. A) The sharp basal boundary with the Tamba Kurkur Fm. (TK) is overlain by about 60 m of Middle Triassic marls and limestones (lithozones 1 to 4), deposited at accumulation rates of less than 10 m/Ma. B) Thick alternating calcareous siltstones and marls, deposited in the Upper Carnian at accumulation rates up to over 50 m/Ma (lithozone 12; sherpa Tenzi for scale).

Tarap Formation.

The Tarap Formation (thickness over 335 m, but possibly even 500 m, since the basal part of the unit could not be measured) largely consists of grey siltstones, with intercalated hybrid arenites and thin-bedded grey to greenish subarkoses in the upper 130 metres ("upper assemblage" of Garzanti et al., 1992).

Occurrence of a major coral limestone interval in the middle Jarsgeng Valley (Yak Kharka; Fig. 8A) allowed recognition of three members within the formation.

Lower member. Alternating pelites and grey to greenish, thin to medium-bedded, micaceous and calcareous, plagioclase-rich subarkosic siltstones, burrowed or showing parallel to hummocky cross-lamination. Siltstones occasionally contain few echinoderms or bivalves, and are locally rich in pyrite or Fe-rich dolomite. The member is over 200 m thick above Thorung Phedi. At Yak Kharka the upper 20 m display a distinct coarsening-upward trend, from alternating pelites and very fine-grained, moderately-sorted subarkoses with parallel or hummocky lamination, to up to upper

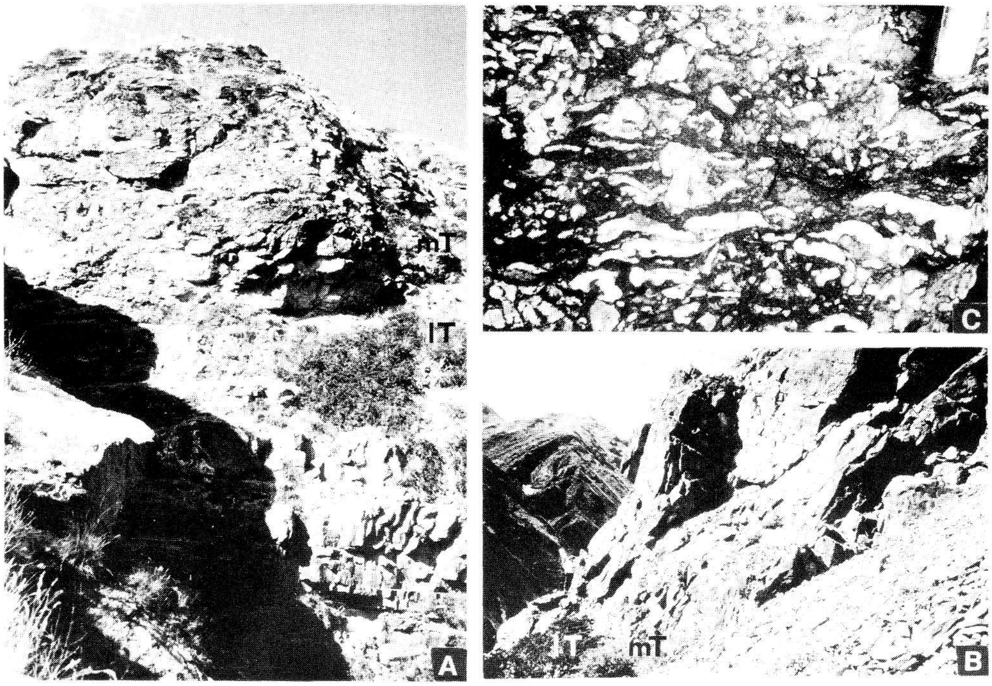

Fig. 8 - The Coral Limestone (middle member of the Tarap Fm.; mT) on both western (A) and eastern (B; A.Nicora for scale) banks of the Jarsgeng Khola at Yak Kharka. The unit, sharply overlying coarsening-upward sandstones of the lower member (lT), was deposited in shallow transgressing seas during the mid-Norian. C) Patch-reef boundstones (hammer head for scale).

medium-grained quartz-rich subarkoses with cross-lamination indicating northeastward sediment transport.

Middle member. A basal layer of medium-grained, moderately-sorted, hybrid quartz-rich subarkoses with echinoderms, pyrite and dolomite passes upward to bioclastic quartz-rich subarkoses, bioclastic wackestones/floatstones and grainstones/rudstones with cross-lamination pointing to northwestward paleocurrents (22.4 m thick at Yak Kharka, Fig. 8B; not present above Thorung Phedi). Crinoid plates and other echinoderm remains, bivalves, corals and bryozoans are abundant; gastropods, benthic foraminifers, brachiopods and algae were also recorded. Bafflestones and coral-bearing framestones occur (Fig. 8C), as well as bioclastic grainstones characterized by abundant black grains, reworked peds, arenaceous lithoclasts and very reduced quartzarenitic extrabasinal fraction. Chamosite, Fe-rich dolomite and pyrite are common interstitial minerals.

Upper member. Alternating grey to greenish burrowed micaceous siltstones, up to lower medium-grained subarkoses with parallel to hummocky lamination, graded-bedding or current ripple marks (pointing to eastward to northeastward paleocurrents), and up to coarse-grained medium-grained hybrid packstones/grainstones with ferruginous ooids, bivalves, brachiopods, gastropods, echinoderms, benthic foraminifers and bryozoans (106 m thick at Yak Kharka). Many arenite samples throughout the member contain greenish to yellowish chamositic groundmass and peloids, blackened bioclasts, embayed quartz grains, arenaceous and shale lithoclasts; some layers yielded also phosphatic nodules or plant material. Authigenic minerals include Fe-rich dolomite, pyrite and rare quartz. Arenites bearing non-carbonate intrabasinal grains (NCI; Garzanti, 1991) were sampled at 15 and 25 metres below the top of the unit above Thorung Phedi, and 50 m below the top at Yak Kharkha.

Fossils, age and regional correlations.

The Tarap Formation is poorly fossiliferous. A phosphatized ammonoid was found 270 m below the top of the unit at Thorung Phedi; blocks in the scree at Tilicho yielded large vertebrae of ichtyosaurs. Age control is consequently poor for this Norian unit.

The *lower member* may be largely assigned a middle to late Early Norian age, since in the Thakkhola area it overlies strata of the middle Lacian Paulckei Zone (Krystyn, 1982) but in central Dolpo *Griesbachites himalayanus* Wang & He, 1976 (indicative of the same Paulckei Zone) was found in the lower part of the Tarap Shale (Garzanti et al., 1992, fig. 8). The member, hundreds of m thick in central Nepal, roughly correlates with the "Juvavites Beds" of Spiti (Hayden, 1904; Garzanti et al., 1993), with the lower part of the "Quartzite Series s.l." in the Zanskar Range (up to 97 m thick member"a" and basal 10 to 20 m of member"b"; Jadoul et al., 1990), and of the Khar Series in the Nyimaling area (interval 2 of Stutz, 1988, p. 48).

The *middle member*, containing the Norian corals *Retiophyllia clathrata* (Emmrich, 1853), *Pamiroseris rectilamellosa rectilamellosa* (Winkler, 1861) and "*Thecosmilia*" sp. (N. Fantini Sestini, pers. comm. 1993), was correlated with the "Coral Limestone" of Spiti and ascribed to the mid-Norian by Fuchs et al. (1988). In central Dolpo, it may correspond with the NCI-bearing bioclastic arenites at the base of the "upper assemblage" of the Tarap Shale (Garzanti et al., 1992). In the Zanskar Range and Nyimaling area, coral-bearing limestones were recognized respectively in the middle part of the "Quartzite Series s.l." (lower-middle part of member"b"; Jadoul et al., 1990), and in interval 3 of the Khar Series, dated as not younger than the late Early Norian (Stutz, 1988).

The *upper member* is correlatable with the over 100 m thick upper part of the Tarap Formation in the Thakkhola region, which also contains transgressive NCI-bearing arenites (Garzanti & Pagni Frette, 1991), with most of the 92 to 128 m thick "upper assemblage" of the Tarap Shale in central Dolpo (Garzanti et al., 1992), and broadly with the "Monotis Shale" of Spiti and with the up to 71 m thick central part of the "Quartzite Series s.l." of Zanskar (middle and upper parts of member "b"; Jadoul et al., 1990). The upper member can be largely ascribed to the mid-Norian. Correlation with intervals 4 and 5 of the Khar Series in the Nyimaling area in fact suggests that its lower part is still late Early Norian in age, since ammonoids of the late Lacian Magnus Zone were reported from the base of interval 5 (Stutz, 1988). Moreover, its upper part would not reach into the latest Middle Norian, since ammonoids diagnostic of the upper part of the late Alaunian Columbianus Zone were found in the overlying interval 6, about 40 m below the base of the Kioto Limestone (Baud et al., 1982).

Sedimentary evolution.

Abundance of storm-deposited silty and sandy layers documents shelfal depositional environments, at water depths around average storm wave base (a few tens of metres), not far from deltaic entry points of terrigenous detritus. The coarsening-upward trend displayed at the top of the *lower member* at Yak Kharka points to progressive shallowing, and deposition in coastal environments during a lowstand stage, followed by ravinement and transgression. This sedimentary event might be correlated with the base of the "upper assemblage" of the Tarap Shale in central Dolpo, which is marked in proximal areas (Tarap) by a major downward shift in coastal onlap, and in distal areas (Atali North) by the subsequent? transgressive NCI-bearing arenites (Garzanti et al., 1992).

The coral-bearing biocalcarenites with black grains and arenaceous lithoclasts of the *middle member* indicate local growth of patch reefs at times of markedly reduced terrigenous influx and coastal retreat caused by rapid transgression. The *upper member*, commonly containing NCI-bearing and NCI-rich layers, testifies to strong subsidence punctuated by several transgressive events (Garzanti, 1991).

The thick Norian succession of central Nepal documents a further increase of both accumulation rates (even approaching 100 m/Ma according to the Haq et al., 1988 time scale) and grain size of quartzo-feldspathic detritus, hinting to rejuvenation of the Indian continental block located to the south. This feature, recorded in the whole Tethys Himalayan succession as well as strong continuing subsidence, is ascribed to a major regional tectonic event, possibly with global significance (Gaetani & Garzanti, 1991; Garzanti, 1993).

"Quartzite Series".

A complete section throughout the "Quartzite Series", a laterally extensive quartzose sandy interval recognized throughout the Tethys Himalaya, was measured above Thorung Phedi (128.5 m thick; Fig. 9).

The unit may be tentatively subdivided into six lithozones, showing mostly transitional boundaries. (Top to bottom):

UPPER PART

6) alternating bioclastic sandstones and arenaceous oolitic grainstones (4.6 m thick; minor faults affect the lithozone). Bioclastic lenses and thin pelitic interbeds occur; bioturbation is minor.
Medium to coarse-grained hybrid oolitic grainstones contain a fine-grained subarkosic extrabasinal fraction, bioclasts (echinoderms, bivalves), aggregate grains, superficial ooids, dolomitic lithoclasts or cha-

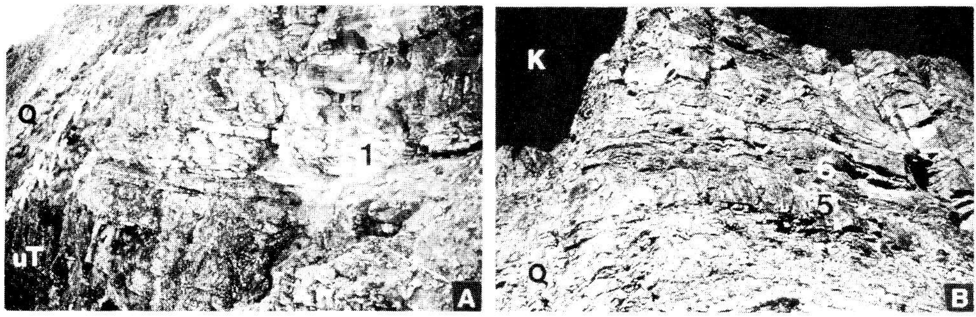

Fig. 9 - The "Quartzite Series" (Q) above Thorung Phedi. A) The sharp-based sandy lithozone 1 overlies the silty uppermost Tarap Fm. (uT; rule at lower right corner for scale). B) Regressive dolomitic quartzarenites (lithozone 5) passing upward to transgressive hybrid arenites (lithozone 6), are followed by oosparites of the Kioto Limestone (K).

mosite peloids. They show ESE-ward-dipping cross-lamination and WSW-ward-dipping rippled caps.
Thin to medium-bedded, up to upper very fine-grained, grey to greenish quartz-rich hybrid subarkoses contain bioclasts (echinoderms, bivalves), intraclasts, rare calcareous or chamosite ooids, and display storm-generated hummocky or parallel to wave-ripple lamination. Polycrystalline quartz is very subordinate, microcline is locally common, muscovite occurs, and zircon prevails within the ultrastable heavy mineral fraction. Lithoclasts of iron-rich dolomite and chamosite peloids occur also at the core of calcareous ooids, which may show micritization and incipient silicification;

5) alternating sandstones and dolomitic sandstones, with intercalated micaceous silty horizons (24 m thick). Embayed quartz and a few possible felsitic volcanic rock fragments were frequently recorded. Rare black grains and chamositic peloids occur in the upper part; calcareous intraclasts and bioclasts (bivalves, gastropods), largely replaced by authigenic dolomite, were observed only in the basal and topmost 5 m of the lithozone.
Very thin to medium-bedded, light to dark grey, lower fine to lower medium-grained, moderately well-sorted, commonly quartz-cemented subarkoses to feldspar-bearing quartzarenites locally display cross-lamination and wave ripples; pelitic interbeds and micaceous laminae at the top of the beds occur. Strongly burrowed samples are rich in yellowish matrix, authigenic iron-rich carbonates and opaques.
Quartzarenites rich in dolomitic intraclasts and authigenic patches are medium-grained, lack feldspars and are characterized by poor sorting and also poor roundness and sphericity sorting. They grade to burrowed quartzarenitic wackes with very fine to medium sand-sized mostly monocrystalline quartz irregularly dispersed in abundant micrite.

LOWER PART

4) alternating burrowed grey micaceous siltstones, dolomitic quartzarenites, reddish dolomitic mudstones and bivalve wackestones/packstones with a few up to lower fine-grained quartz grains (20 m thick). Thin to medium-bedded, upper fine to lower medium-grained, moderately to moderately well-sorted white quartzarenites display wave ripples or cross-lamination (SE-ward to W-ward paleocurrents), lack feldspars and contain abundant authigenic carbonates. Sandstones with micritic laminae or discontinuous sandstone lenses embedded in dolomicrite occur;

3) thin to thick-bedded, up to medium-grained, moderately well-sorted, light grey to white, quartz-cemented quartzarenites, alternating with subordinate grey pelites, burrowed calcareous sandstones and grey, thin to medium-bedded, silty to bioclastic limestones (36.6 m thick). Quartzarenites are rarely burrowed or show S-ward-dipping small to medium-scale cross-lamination and wave ripples with E/W-directed crests. Rare feldspars are altered and confined to the very fine sand fraction. Oxidized pyritic cubes occur;

2) light grey to white, thin-bedded to amalgamated, fine to medium-grained, moderately-sorted quartzarenites, burrowed or showing cross-lamination and locally with pelitic interbeds (35 m thick). Altered feldspars are concentrated in the very fine sand fraction;

1) thin-bedded, locally burrowed, greenish to white and pinkish, very fine-grained, moderately well-sorted, quartz-cemented subarkoses containing common plagioclase and K-feldspar, with thin siltstone interbeds (8.3 m thick). At Yak Kharkha, the possibly tectonically disturbed sharp base of the unit is directly overlain by cross-laminated, fine-grained, dolomitic quartz-rich subarkoses with echinoderm remains and dolomitic intraclasts.

Fossils, age and correlations.

The "Quartzite Series" commonly contain bivalves, gastropods or echinoderms, but age-diagnostic fossils are lacking. According to stratigraphic position, the unit is ascribed to the Late Norian-Rhaetian?, as in adjacent regions.

The *lower part* of the unit (100 m thick) displays an overall coarsening-upward trend (sand-rich lithozones 1 and 2), followed by increasing abundance of intercalated limestones (lithozones 3 and 4). It roughly correlates with the "lower interval" of the "Quartzite Series", at least 88 m thick in the Thakkhola area (where four alternatively sand-rich and limestone-rich intervals were recognized), and 56 to 69 m thick in central Dolpo (where dolomitic quartzarenites predominate but bioclastic or oolitic layers occur at several intervals; Garzanti et al., 1992). Similar lithologies, with alternating quartzose arenites and bioclastic to oolitic, sandy dolomitic limestones, characterize the 43 to 70 m thick member "c" of the unit in the Zanskar Range (Jadoul et al., 1990).

The *upper part* of the unit (lithozones 5 and 6; 28.6 m thick), although deposited in more distal, lower shoreface to subtidal environments and bearing ooids at the top, may be correlated with the "upper interval" of the "Quartzite Series", 26.8 m thick in the Thakkhola area (Garzanti & Pagni Frette, 1991; "white quartzite marker bed" p.p. of Gradstein et al., 1989) and 19 to 27 m thick in central Dolpo (Garzanti et al., 1992). Occurrence of chamosite above Megalodon-bearing strata at the top of the unit in Spiti (Garzanti et al., 1993), and abundance of dolomite intraclasts in correlative layers of the Zanskar Range (17 to 35 m thick sublithozone a1, marking the transition to the Kioto Limestone; Jadoul et al., 1990), may help to trace this distinct transgressive interval up to the NW Himalaya.

Sedimentary evolution.

Sedimentological features indicate shallow-marine (below to above fair-weather wave-base) subtidal environments, located close to estuarine entry points of terrigenous detritus and influenced by waves and both storm-generated and tidal currents.

The sharp base of the unit (*lower part;* Fig. 9A) attests to a downward shift of coastal onlap ("forced regression" of Posamentier et al., 1992), followed by an overall coarsening-upward trend from lower (lithozone 1) to mostly upper shoreface (lithozone 2) environments, possibly documenting a shelf-margin wedge. Transgression in the central part of the unit led to upward transition from shoreface sandstones with intercalated subtidal limestones and pelites (lithozone 3) to largely subtidal sediments with locally intercalated open shelf bioclastic layers (lithozone 4).

The *upper part* of the unit was deposited in shallow-water to marginal marine environments (lithozone 5), passing upward during renewed transgression to storm-influenced subtidal environments, characterized by normal to high salinity (lithozone 6).

The "Quartzite Series", which recorded overall shallowing associated with continuing supply of quartzose detritus at the close of the Triassic, point to both reduced uplift of the Indian continental block and decreasing rates of differential subsidence all along the Tethyan passive margin. Other causes may have also contributed to the increased stability of extrabasinal detritus, including climatic changes towards more humid conditions. Sandstone mineralogy is strongly dependent on grain size, feldspars being notably concentrated in the very fine sand fraction (Odom et al., 1976).

The overlying Jurassic units.

The base of the largely Lower Jurassic Kioto Limestone (Jomosom Limestone of French Authors) above Thorung Phedi (Fig. 9B) consists of light grey oolitic grainstones with rare gastropods, peloids, and authigenic iron-rich dolomite (11.5 m), followed by prevailing dark grey mudstones. The unit, deposited in shallow shelfal environments, is some hundreds of m thick, and it is followed by the quartzose calcarenites and calcareous pelites of the Middle Jurassic Laptal (Lumachelle) Formation, deposited on a mixed carbonate-siliciclastic storm-influenced shelf. The overlying Upper Jurassic Spiti Shale, cropping out at the core of the Thorung La syncline, was deposited on a largely undisturbed middle to outer shelf.

Conclusions

Condensed outer shelf carbonate sedimentation on the newly-formed passive margin of Neotethys began as early as the late Early Permian in the Braga area, and became widespread throughout Manang in the Dorashamian ("topmost biocalcarenites" capping the Thini Chu Group; see companion paper by Garzanti et al., 1994). The boundary between the Permian and the Triassic is marked only by a faunal break occurring within rather homogeneous outer shelf condensed dolomitic limestones.

In the Early Triassic, continuing thermal subsidence led to deepening of the newly-established Tethys Himalayan passive margin of Neotethys, as indicated in the Manang area by deposition of three pelagic nodular carbonate intervals of Griesbachian-Early Dienerian, Smithian and Spathian-earliest Anisian age, interbedded with shelfal shales (*Tamba Kurkur Fm.*). Ammonoid- and conodont-rich condensed carbonates were deposited on the outer shelf during global stages of sea-level rise, with maximum depths of 150 ÷ 200 m. Intervening shales were deposited at much higher accumulation rates during highstand stages (Fig. 10).

The overlying *Mukut Fm.*, consisting of shelfal marls and marly limestones of Early Anisian to earliest Norian age, marks a widespread increase of fine-grained ter-

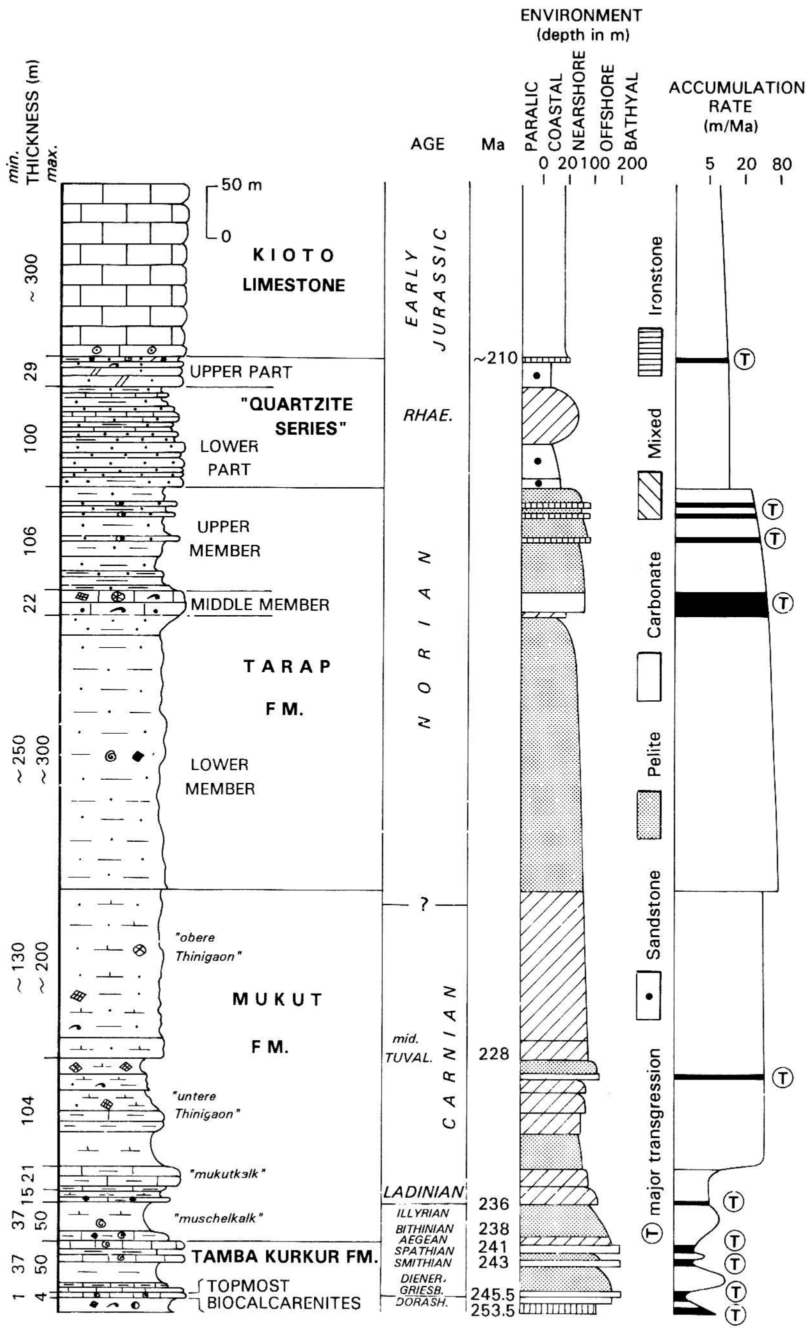

Fig. 10 - The Triassic stratigraphic succession of Manang, with inferred depositional environments and accumulation rates. Absolute ages are according to the chronostratigraphic scale of Haq et al. (1988). Informal lithostratigraphic divisions by Krystyn (1982) are also reported.

rigenous detritus. The lower 60 ÷ 70 m contain Anisian to Ladinian ammonoids, conodonts and brachiopods. The upper 250 to 300 m are instead ascribed to the Carnian, when calcareous feldspathic siltstones deposited at greatly increased accumulation rates suggest a new regional stage of tectonic extension.

The base of the *Tarap Fm.*, a thick unit mainly consisting of interbedded shelfal siltstones and storm-deposited subarkoses, is probably mid-Early Norian. Further increase of both accumulation rates and size of terrigenous detritus suggests that at this stage tectonic activity reached its climax. In the middle Jarsgeng Valley, progressive shallowing at the top of the *lower member* is followed by ferruginous bioclastic arenites and coral patch-reefs (*middle member*); the latter were deposited during a transgressive stage, characterized by coastal retreat and reduced terrigenous influx. Several flooding events are documented also in the *upper member*, containing successive chamosite-bearing hybrid arenite layers.

The Late Norian-Rhaetian? "*Quartzite Series*" include up to medium-grained quartzarenites interbedded with finer-grained subarkoses, hybrid arenites and silty to bioclastic limestones. The *lower part* of the unit consists of a sharp-based coarsening-upward shoreface sequence (Plint, 1988), progressively transgressed by more pelitic and calcareous shelfal deposits. In the *upper part*, transition from marginal marine dolomitic quartzarenites to oolitic subtidal deposits documents renewed transgression. Reduced uplift and decreasing rates of differential subsidence are suggested by supply of more quartzose detritus at the top of the Triassic succession, which is overlain by the Kioto platform carbonates all along the Tethyan passive margin.

Systematic paleontology (A. Nicora)

Complete synonymies, descriptions and occurrences for all the species of this study are readily available in Sweet (1970 a, b), Sweet et al. (1971), Sweet (in Ziegler 1973), Kozur & Mostler (1973, 1976), Goel (1977), Solien (1979), Matsuda (1982, 1983), Nicora (1991). As all the species are very well known, only remarks concerning *Gondolella* aff. *jubata* (Sweet) are here presented. SEM photomicrographs of most of the species recovered are included in Pl. 1-3. Material figured and described is retained at the Department of Earth Sciences, Geology and Paleontology Section, University of Milano, Via Mangiagalli 34, Milano, Italy.

Genus *Gondolella* Stauffer & Plummer, 1932

Type-species: *Gondolella elegantula* Stauffer & Plummer, 1932

Gondolella aff. **jubata** (Sweet, 1970)

Pl. 2, fig. 2, 4-9; Pl. 3, fig. 5-7, 9

Remarks. Some specimens representing the population of *Gondolella* aff. *jubata* (Sweet) are reported on Pl. 2 and Pl. 3. In both plates the population of a single sample is represented. In Pl. 2 from sample AD 160, in Pl. 3 from sample AD 162. The elements in question show a wide spectrum of transitional characters. Considering Pl. 2, fig. 2, 4 and 5, specimens in fig. 2 and 5 are very similar to *G. jubata* (Sweet) (1970b, pl. 2). Specimens from Manang area have a carina more arched and slightly higher as in fig. 9, 11, pl. 2 of Sweet (1970b). Specimen of fig. 4 shows a shorter platform that anteriorly grades abruptly into a midlateral rib on the free blade. This development has been described by Sweet (1970b) for *Gondolella elongata* (Sweet). The specimens at hand differ from *G. elongata* because of the carina type, having *G. elongata* a carina characterized by few, discrete, massive denticles, while in *G.* aff. *jubata* the carina is high, evencrested, with numerous 9 to 23 slightly inclined, laterally compressed fused except apically denticles. A transition from longer platform to shorter platform can be followed in fig. 5, 2, 4 (Pl. 2).

Moreover on the lateral platform margins some corrugations or crenulations are developed. Also this feature shows a transitional trend. Corrugations can be very weak either on form with long or shorter platform (Pl. 2, fig. 7, 9) or well developed (Pl. 2, fig. 6, 8). The same trend was observed in the population of stratigraphically higher samples (Pl. 3). Possibly in stratigraphically higher specimens the carina is narrower. Elements with corrugations or crenulations represent about one third of one sample population of *G.* aff. *jubata.*

Range. According to Sweet (1970b), Sweet et al. (1971), and Sweet (in Ziegler 1973), *G. jubata* ranges from Platyvillosus Zone to Jubata Zone, Early-Middle Spathian. Sweet (1988b) enlarges its range from the Triangularis Zone to the Timorensis Zone included, Latest Smithian to Early Aegean.

Matsuda (1985) refers *G. jubata* from the upper part of the *G. elongata* Zone to the top of the *N. timorensis* Zone, latest Smithian to latest Spathian.

Occurrence. Samples AD 159 - AD 163, Tilicho section; AD 129 - 132, Col Noir section; AD 182, Manang-Gompa section; AM 106 - AM 105, Thinigaon section.

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PLATE 1

Fig. 1 a, b - *Neospathodus kummeli* Sweet. Intermediate growth stage with narrow platformlike brim. Sample AD 120; a, b) x 100.

Fig. 2 - *Neospathodus dieneri* Sweet. Sample AD 147; x 90.

Fig. 3 - *Neospathodus kummeli* Sweet. Sample AD 120; x 100.

Fig. 4 a, b, c - *Neospathodus kummeli* Sweet. Late growth stage with well-developed platformlike brim. Sample AD 120; x 100.

Fig. 5 a, b, c - *Gondolella nepalensis* Kozur & Mostler. Sample AD 153; x 100.

Fig. 6 b, c - *Gondolella nepalensis* Kozur & Mostler. Sample AD 153; x 90.

Samples AD 120 from Col Noir section; AD 147, AD 153 from Tilicho section. All sections from Manang area, central Nepal.
a) Upper view; b) lateral view; c) lower view.

PLATE 2

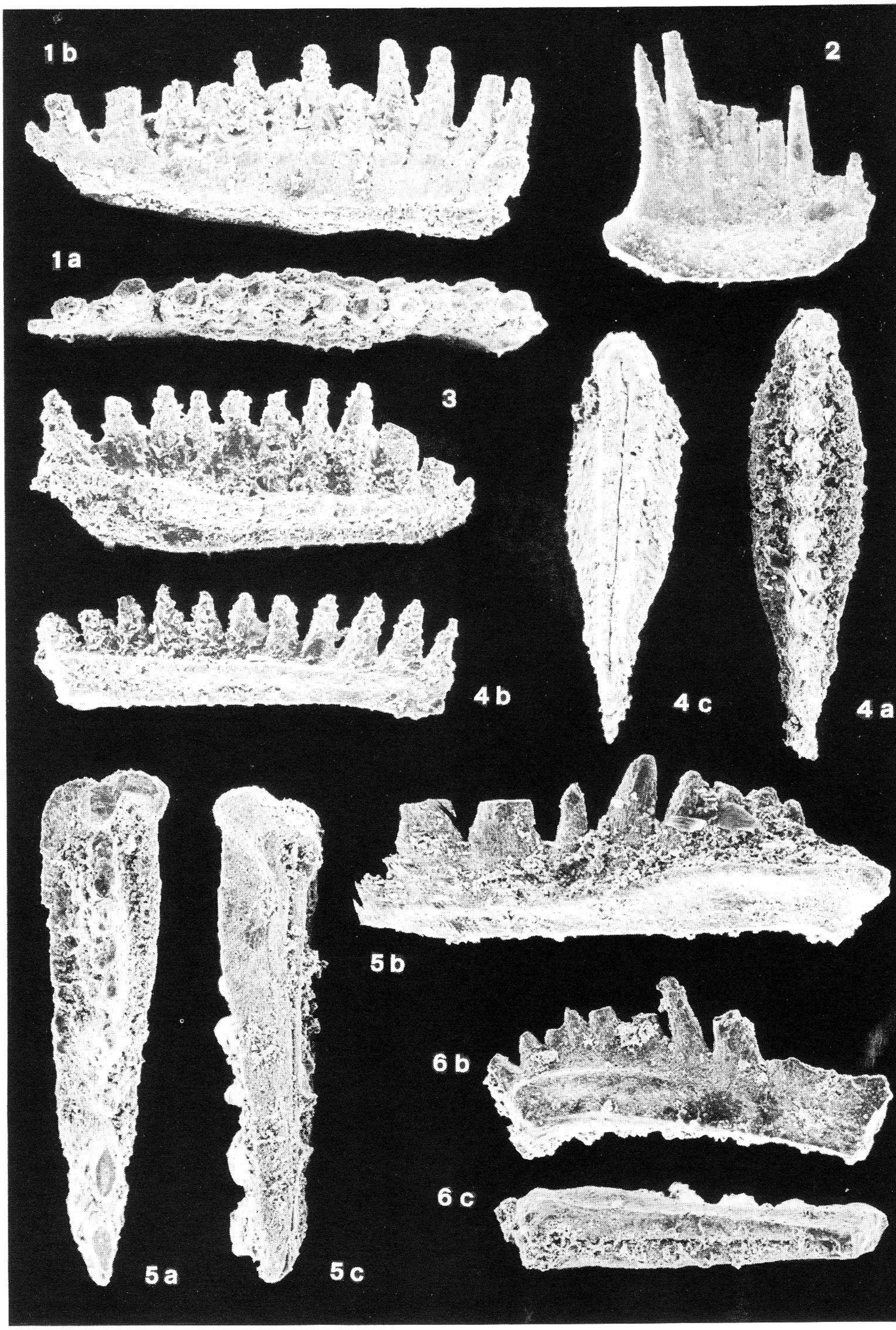
Fig. 1 a, b, c - *Gondolella sweeti* Kozur & Mostler. Sample AD 157; a) x 60; b, c) x 65.
Fig. 2 a, b - *Gondolella* aff. *jubata* (Sweet). Sample AD 160; x 75.
Fig. 3 b, c - *Neospathodus homeri* (Bender). Sample AD 160; x 65.
Fig. 4 a, b, c - *Gondolella* aff. *jubata* (Sweet). Sample AD 160; a, c) x 70; b) x 65.
Fig. 5 b, c - *Gondolella* aff. *jubata* (Sweet). Sample AD 160; x 75.
Fig. 6 a, b - *Gondolella* aff. *jubata* (Sweet). Sample AD 160; x 55.
Fig. 7 a, b - *Gondolella* aff. *jubata* (Sweet). Sample AD 160; x 50.
Fig. 8 a, b, c - *Gondolella* aff. *jubata* (Sweet). Sample AD 160; x 50.
Fig. 9 b, c - *Gondolella* aff. *jubata* (Sweet). Sample AD 160; x 50.

All samples from Tilicho section, Manang area, central Nepal.
a) Upper view; b) lateral view; c) lower view.

PLATE 3

Fig. 1 b, c - *Neospathodus homeri* (Bender). Sample AD 162; x 75.
Fig. 2 - *Neospathodus homeri* (Bender). Sample AD 168; x 50.
Fig. 3 - *Neospathodus homeri* (Bender). Sample AD 162; x 50.
Fig. 4 - *Neospathodus homeri* (Bender) transition to *Gondolella timorensis* Nogami. Sample AD 168; x 75.
Fig. 5 b, c - *Gondolella* aff. *jubata* (Sweet). Sample AD 162; x 50.
Fig. 6 a, b, c - *Gondolella* aff. *jubata* (Sweet). Sample AD 162; x 50.
Fig. 7 a, b, d - *Gondolella* aff. *jubata* (Sweet). Sample AD 162; a, b) x 50; d) enlargement of fig. 7b; x 250.
Fig. 8 - *Gondolella timorensis* Nogami. Sample AD 168; x 70.
Fig. 9 a, b, c - *Gondolella* aff. *jubata* (Sweet). Sample AD 162; x 50.
Fig. 10 b, c - *Gondolella timorensis* Nogami. Sample AD 169; x 75.

All samples from Tilicho section, Manang area, central Nepal.
a) Upper view; b) lateral view; c) lower view; d) enlargement.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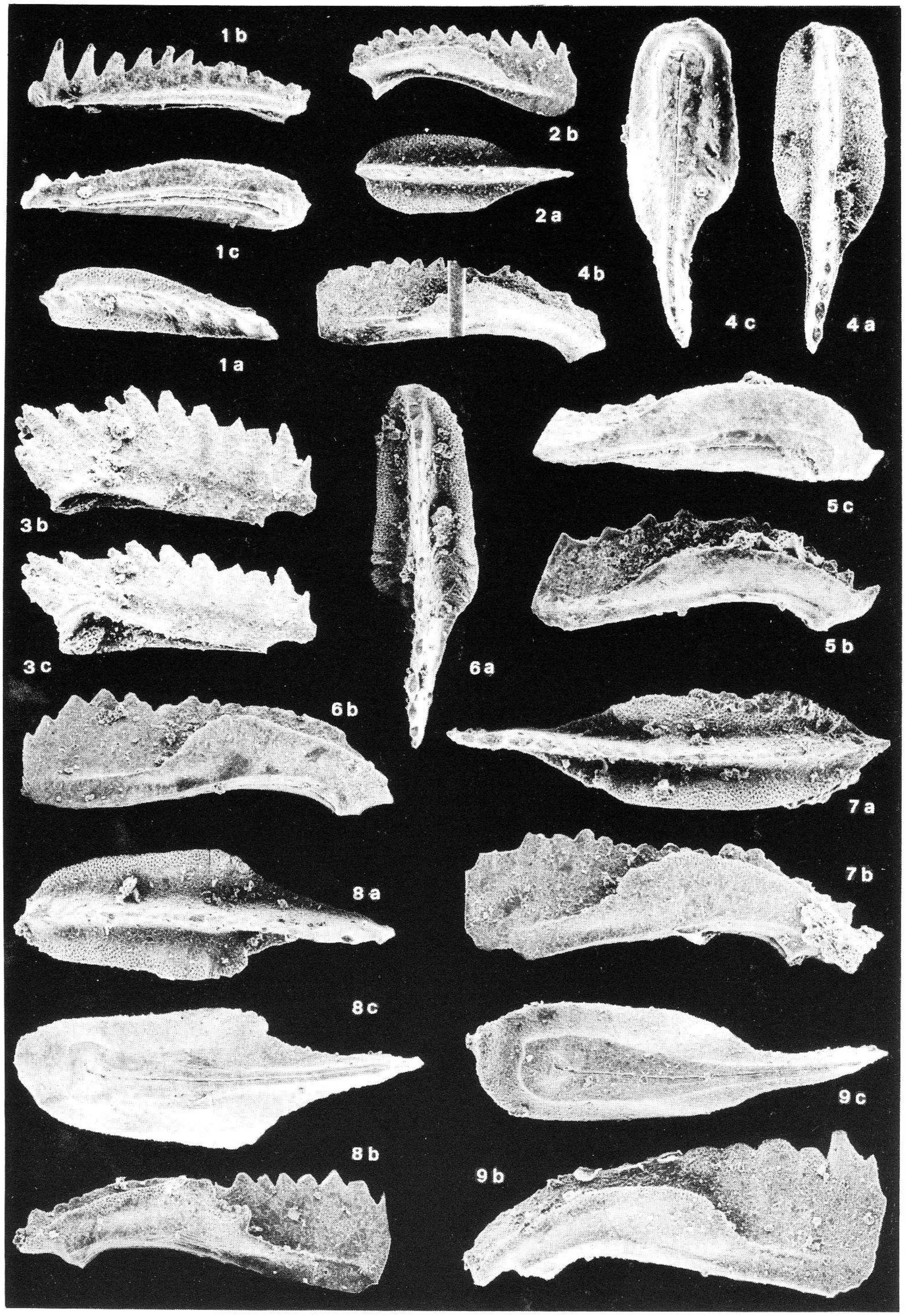
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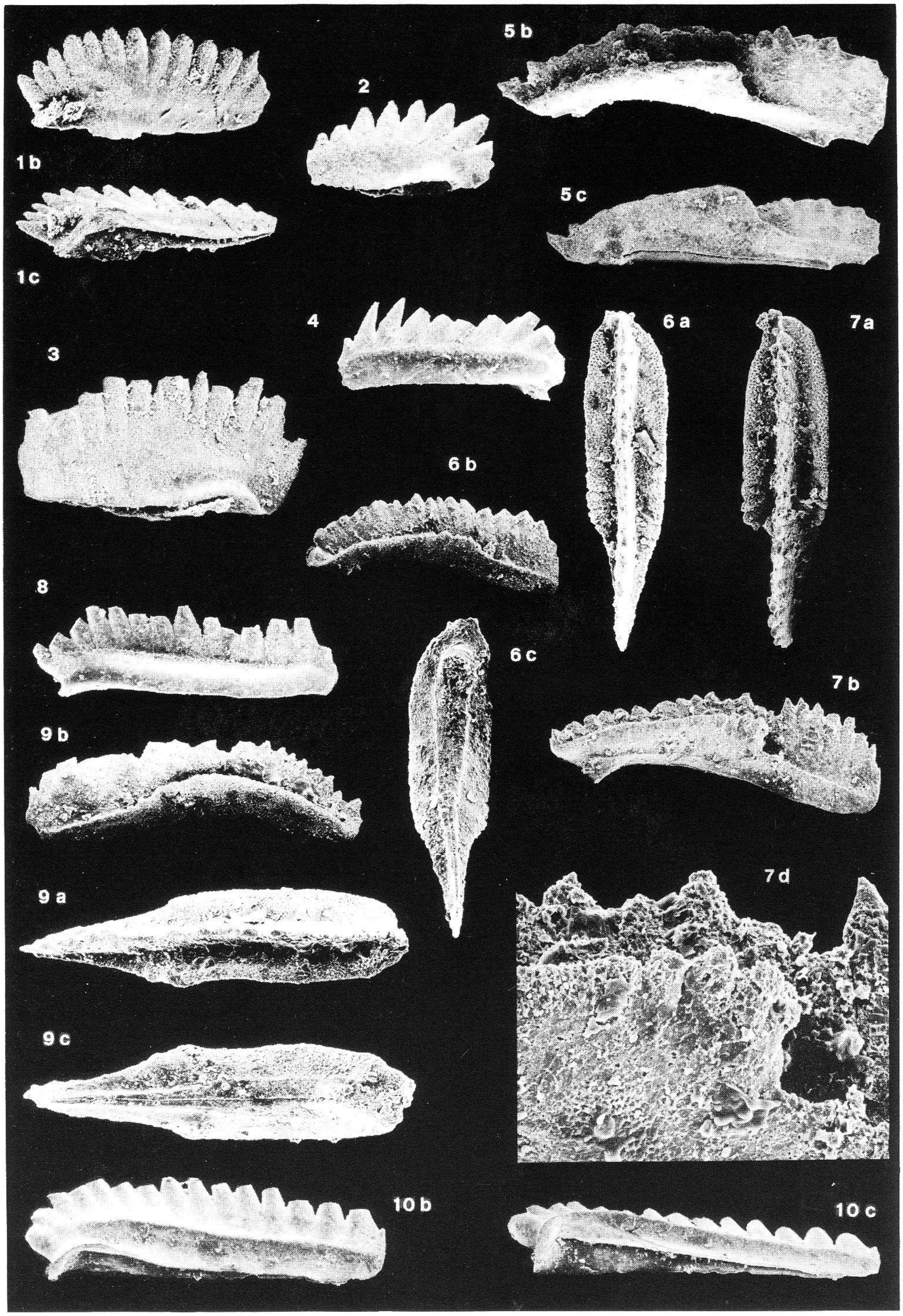
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