Rivista Italiana di Paleontologia e Stratigrafia	volume 102	numero 2	tavola 1	pagine 175-200	Agosto 1996

THE PERMIAN KULING GROUP (SPITI, LAHAUL AND ZANSKAR; NW HIMALAYA) : SEDIMENTARY EVOLUTION DURING RIFT/DRIFT TRANSITION AND INITIAL OPENING OF NEO-TETHYS

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Key-words: Tethys Himalaya, Permian, Brachiopods, Stratigraphy, Sandstone petrography, Transgressive arenites, Continental break-up.

Riassunto. La fine della glaciazione gondwaniana fu segnata in tutto il Tethys Himalaya dalla deposizione, in ambienti da paralici a marini poco profondi a partire dal Sakmariano superiore, di arenarie conglomeratiche intercalate ad areniti ibride trasgressive a brachiopodi e briozoi. Nella regione di Spiti, questi sedimenti costituiscono la base del Gruppo di Kuling, che riposano in discordanza erosiva su formazioni più antiche, da Siluriane e Devoniane nella Valle del Parahio, a Carbonifere inferiori nella Valle del Pin, fino a ricoprire le diamictiti di età Permiana basale nella Valle dello Spiti. Tale discordanza, presente anche in Zanskar e Lahaul dove la serie Paleozoica viene progressivamente a mancare sia verso ovest (Zanskar occidentale) che verso sud (Sinclinale di Tandi), chiude la fase di rifting e segna l'inizio dell'apertura della Neotetide tra il Gondwana e i blocchi Peri-Gondwaniani.

Il Gruppo di Kuling a Spiti è costituito da arenarie glauconiose, conglomeratiche o contenenti brachiopodi di età Sakmariana superiore alla base e Midiana/Djulfiana inferiore al tetto (Formazione di Gechang), seguite da argilliti nere fosfatiche e ricche di brachiopodi di età Djulfiana (Formazione di Gungri). In Zanskar la successione è assai più potente: areniti glauconiose con brachiopodi di età Sakmariana superiore, peliti e microconglomerati (Formazione di Chumik) sono seguiti dai basalti dei Panjal Traps e quindi da areniti glauconiose con brachiopodi di età Midiana/Djulfiana inferiore, corrispondenti alla sommità della Formazione di Gechang in Spiti. Le sovrastanti argilliti nere della Formazione di Gungri, deposte su una piattaforma aperta in condizioni climatiche calde verso la fine del Permiano, suturano ovunque la successione Paleozoica, testimoniando la definitiva sommersione delle spalle del rift in seguito all'avvenuta oceanizzazione della Neotetide.

Abstract. All along the Tethys Himalaya, sandstones and conglomerates interbedded with transgressive arenites rich in bryozoans and brachiopods were deposited in estuarine to shallow-marine environments since the Late Sakmarian, at the end of the Gondwana glaciation. These clastics, representing the base of the Kuling Group in Spiti, disconformably overlie arenaceous to carbonate sedimentary units of various age, from Silurian and Devonian in the Parahio Valley to Lower Carboniferous in the Pin Valley, whereas they paraconformably follow lowermost Permian diamictites in the Spiti Valley. This major unconformity, which can be traced to the adjacent Zanskar and Lahaul regions where the Paleozoic succession is eroded more and more towards the west (western Zanskar) and south (Tandi Syncline), marks the end of rifting, followed by initial opening of Neo-Tethys and thermal subsidence of the newly-formed Indian passive margin.

The Kuling Group in Spiti consists of glaucony-rich pebbly arenites yielding brachiopods of Late Sakmarian age at the base and Midian/Early Djulfian age at the top (Gechang Formation), overlain by black phosphatic shales rich in brachiopods of Djulfian age (Gungri Formation). The much thicker Zanskar succession consists of glaucony-rich arenites containing brachiopods of Late Sakmarian age, mudrocks and microconglomerates (Chumik Formation), overlain by the Panjal Trap basaltic lavas and in turn by glaucony-rich arenites yielding brachiopods of Midian/Early Djulfian age, equivalent to the top of the Gechang Formation in Spiti. The overlying black shales of the Gungri Formation, deposited on an open shelf in warm climates, seal the Paleozoic succession in all studied areas, and thus document the final submergence of rift shoulders following the opening of Neo-Tethys.

Introduction.

Spectacular Paleozoic and Mesozoic successions crop out in the classic Spiti region of the Tethys Himalaya (Fig. 1). During our summer 1992 expedition, we studied in detail the well-exposed Permian sediments capping the thick Carboniferous-lowermost Permian succession exposed along the Spiti Valley from Losar to Lingti (described in the companion paper by Garzanti et al., 1996) or resting unconformably on Lower Carboniferous, Devonian or even Silurian units in the upper Pin and Parahio Valleys. In the whole Zanskar-Spiti Synclinorium, the Permian is followed with sharp paraconformity by the pelagic carbonates of the Tamba Kurkur Fm. (for a complete description of the Triassic succession see the other companion paper by Garzanti et al., 1995a).

Five complete stratigraphic sections and several logs were measured; 40 samples were collected for petrographic analysis.

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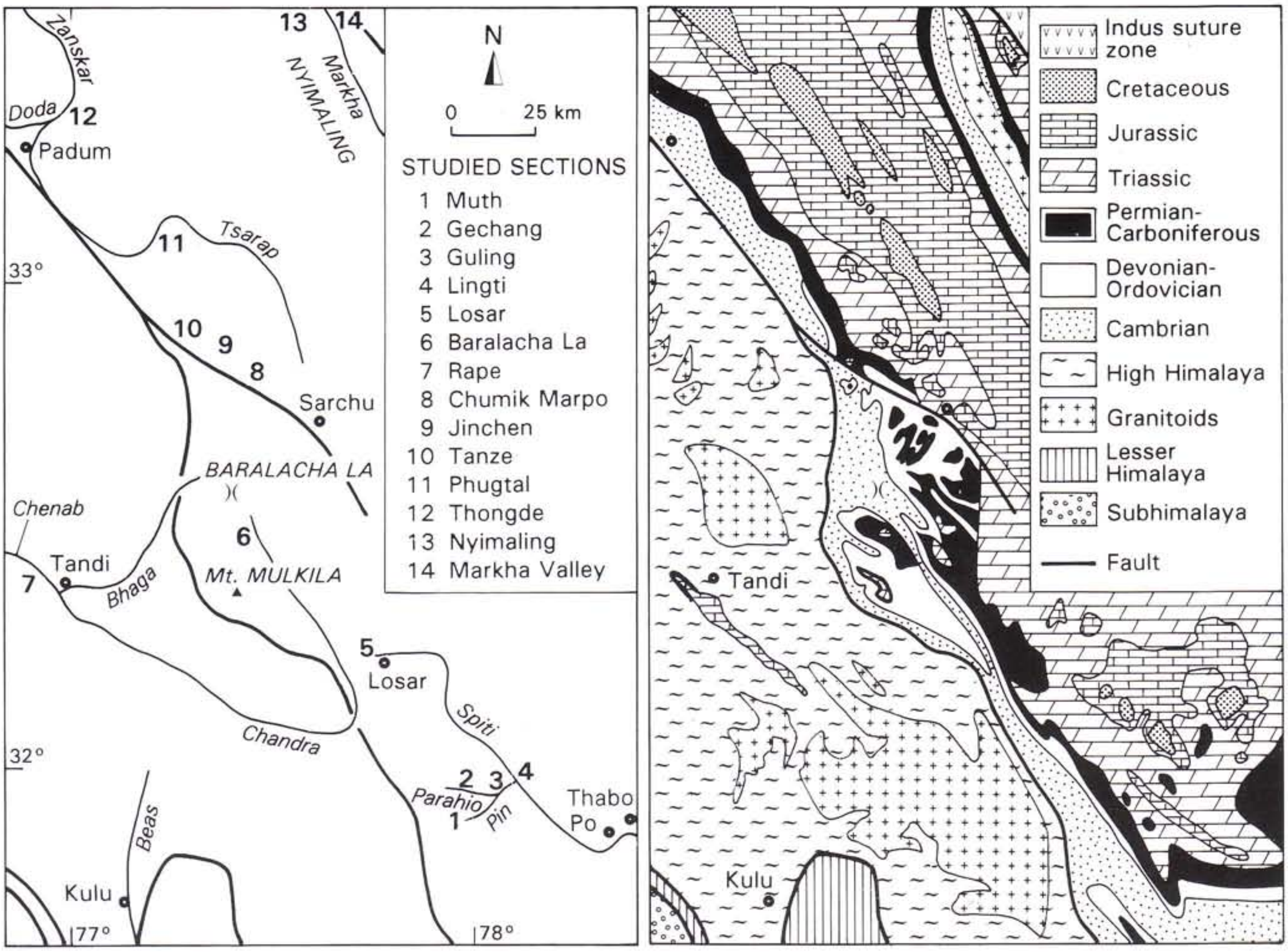

Fig. 1 - Location map (left) and geological sketch map of the study area (right; compiled after Fuchs, 1987; Stutz, 1988; Bagati, 1990; Spring, 1993; Vannay, 1993).

The purposes of the present paper are: a) to provide stratigraphic, paleontologic and petrographic data from the Permian succession of the Spiti region, adding new information to previous works (Srikantia, 1981; Fuchs, 1982; Rao et al., 1982; Bagati, 1990); b) to compare the Spiti succession with that of the adjacent Zanskar (Gaetani et al., 1990a; Lucchini, 1991; Zelioli, 1992) and Lahaul (Baralacha La and Tandi; Vannay, 1993) regions, in order to establish a firm stratigraphic framework for the whole Zanskar-Spiti Synclinorium; c) to shed new light on sedimentary and paleogeographic evolution of the northwestern Himalaya during initial opening of Neo-Tethys between Northern Gondwana and the Peri-Gondwanian blocks (Baud et al., 1993).

Methods.

Sandstones were quantitatively analyzed (300 points on each of the 33 analyzed sections) according to the Gazzi-Dickinson point-counting method (Ingersoll et al., 1984), modified to take into full account the coarse-grained rock fragment population. Mineralogical and textural classification of sandstones is after Folk (1980). Petrographic parameters (Q = quartz; F = feldspars; L = aphanitic lithic fragments) are after Dickinson (1970, 1985); the L pole includes carbonate extrabasinal grains (CE of Zuffa, 1985) and chert. Study of intrabasinal grains (CI = carbonate; NCI = non-carbonate) followed criteria outlined by Zuffa (1980, 1985) and Garzanti (1991). Grain size was determined according to semiquantitative method described in Garzanti (1986a).

The Kuling Group in Spiti

The term "Kuling shales" was first introduced by Stoliczka (1866) for the fossiliferous black shales exposed at Guling (Pin Valley), where they overlie an interval of locally bioclastic sandstones with a basal conglomerate. The name was revived by Hayden (1908) and more recently by Srikantia (1981), who subdivided the "Kuling Formation" into a lower arenaceous Gechang Member and an upper shaly Gungri Member, with type-localities in the Parahio and Pin Valleys of Spiti respectively. The type-section of the Kuling Formation has been described also by Fuchs (1982).

The Gechang Member (mid-Permian "calcareous sandstone" of Hayden, 1904) and Gungri Member (Upper Permian "Productus shales" of Hayden, 1904) are

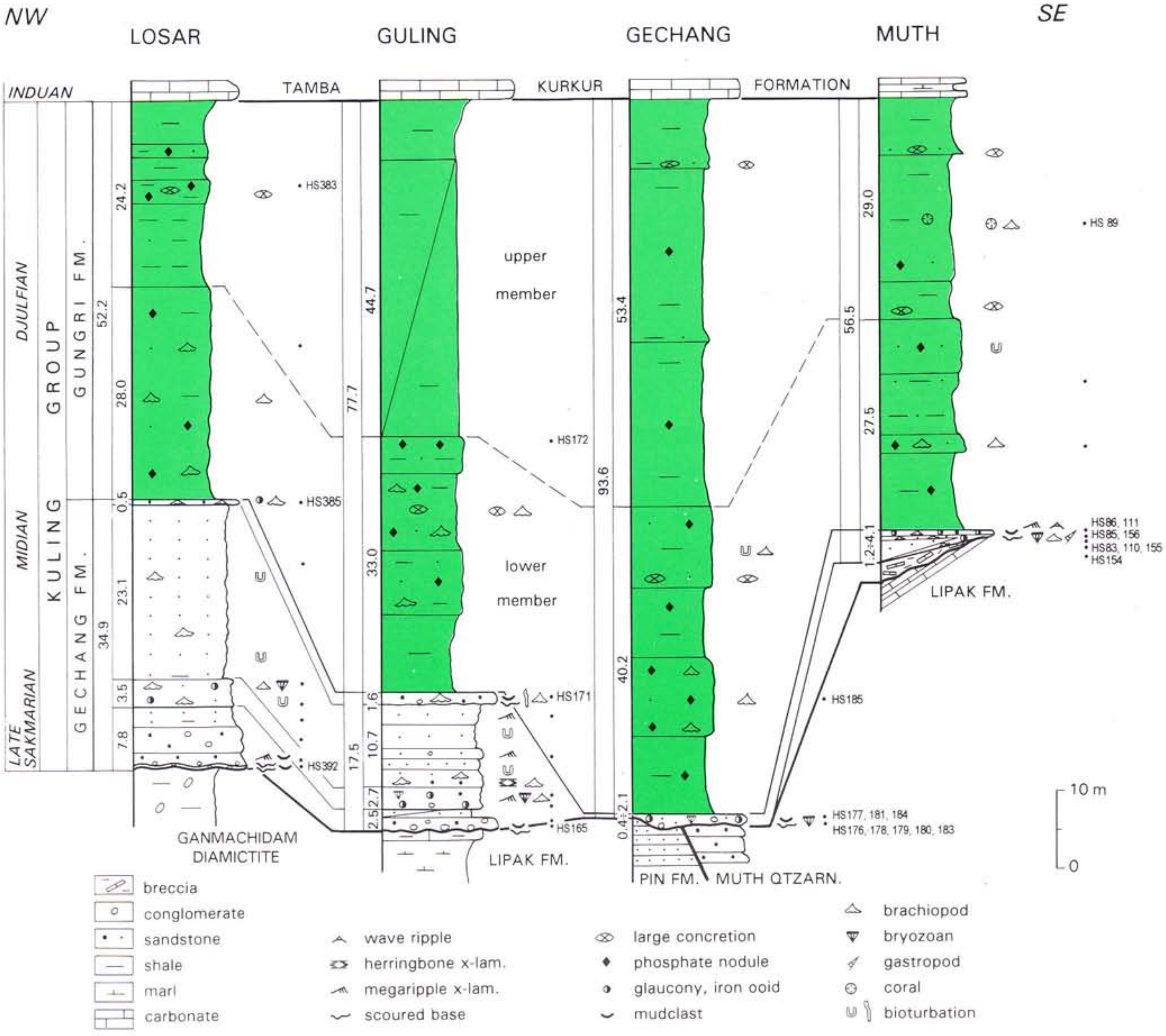

Fig. 2 - Stratigraphic columns and sedimentary features of the Kuling Group in Spiti.

here formally elevated to formation rank, according to the "strong recommendation" by Waterhouse (1985, p. 71) and recent views expressed in Singh et al. (in preparation). In fact, the black shales of the Gungri Formation (50 to 100 m-thick in Spiti) are easily mappable throughout the Spiti-Zanskar Synclinorium. The much coarser-grained hybrid clastics of the Gechang Formation (reaching a thickness of 35 m at Losar) are mappable all along the Spiti Valley and in the lower Pin Valley, whereas its thickness is reduced to a feather-edge (few metres or even decimetres) in the upper Pin and Parahio Valleys. As a consequence, the Kuling is elevated to group rank (Fig. 2).

Complete reference stratigraphic sections of the Kuling Group were measured both in the Pin and Parahio Valleys (60.6 m-thick at Muth, 94.0 m at Gechang, 95.2 m at Guling) and in the Spiti Valley (about 93 m at Lingti, 87.1 m at Losar; Fig. 3).

Gechang Formation.

Parahio Valley (Gechang).

In the Parahio Valley type-area above Gechang, thickness is minimum (increasing laterally within about 150 m from 0.4 m to 2.1 m and then decreasing again to 1.4 m; Fig. 4). The Gechang Fm. disconformably overlies the Silurian Pin Fm. or fills pockets up to 20 cm deep into the Devonian Muth Quartzarenite; it also seals a system of paleofaults oriented roughly NE-SW and offsetting the underlying mid-Paleozoic units.

Two lithozones can be distinguished.

Basal ferruginous conglomerate. These microconglomerates to pebbly sandstones (0.2 to 1.3 m; HS 176,178,179,180,183) contain both intraformational particles (glaucony, iron ooids, dark to limonitic soil fragments; NCI grains of Garzanti, 1991) and extraclasts derived from the underlying substratum (quartzarenite to hybrid arenite and limestone fragments up to 20 cm in size).

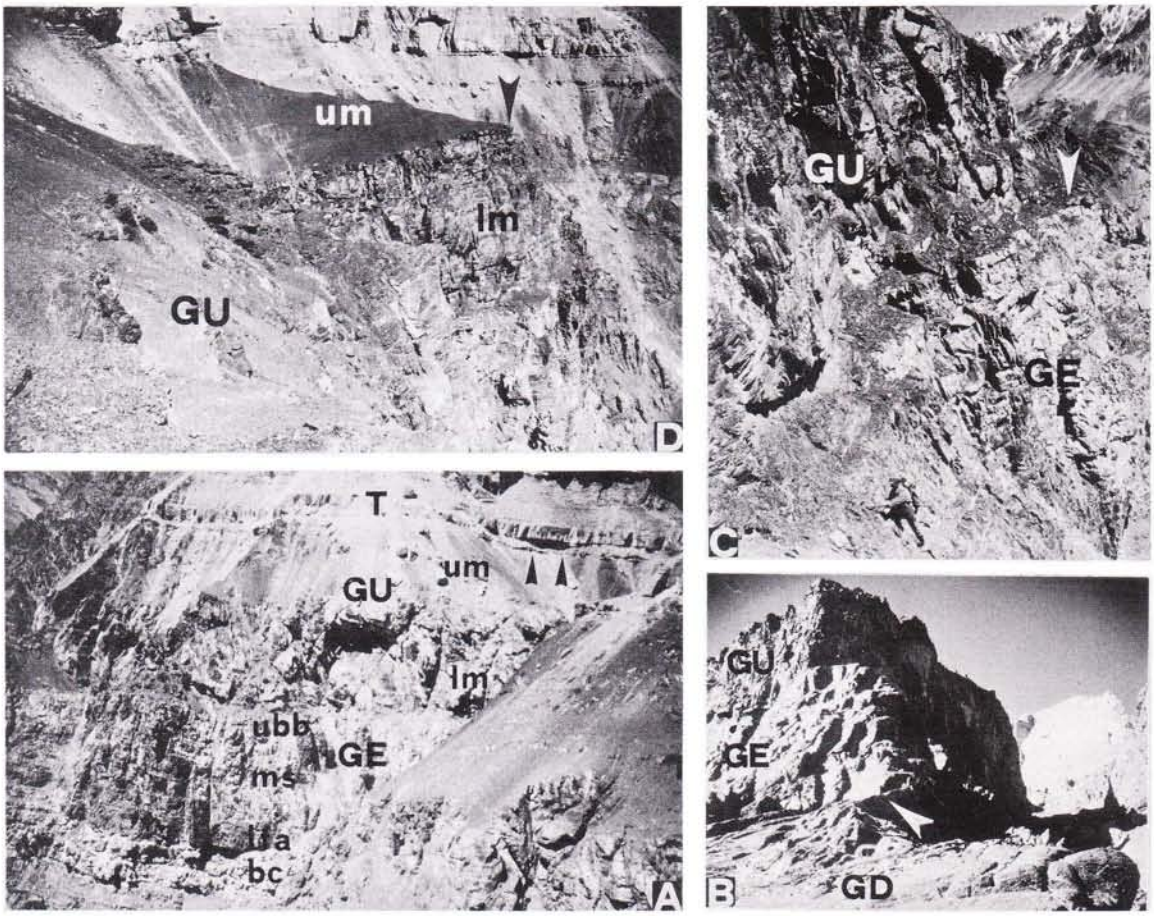

Fig. 3 - Kuling Group at Losar (A): GE=Gechang Fm. (bc=basal conglomerate; lfa=lower ferruginous arenite; ms=middle sandstone; ubb=upper brachiopod-rich beds); GU=Gungri Fm. (lm=silty lower member; um=clayey upper member); black arrows show paraconformable boundary with Triassic Tamba Kurkur Fm. (T). B) Unconformable basal boundary (white arrow) with the Ganmachidam Diamictite (GD). C) Sharp boundary (white arrow) between Gechang Fm. and Gungri Fm. (F. Berra for scale). D) Gungri Fm., with abrupt boundary (black arrow) between lower and upper member.

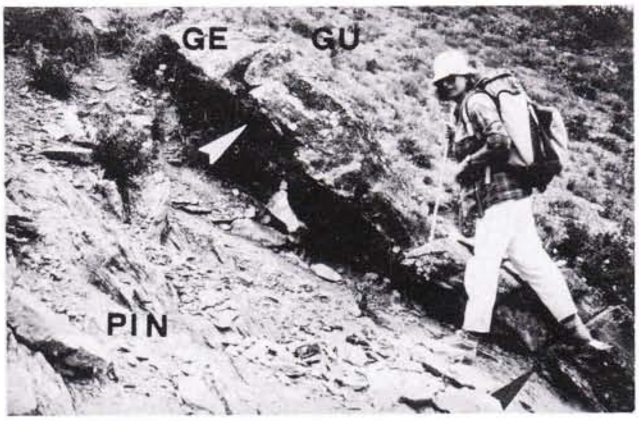

Fig. 4 - The Gechang Fm. (GE) at Gechang is reduced to a thickness of only 0.4 m; the unit rests disconformably (arrows) on the Silurian Pin Fm. and is sharply overlain by the Gungri Fm. (GU; A. Nicora for scale).

From the distance of just ten metres, crossed a pre-Sakmarian paleofault, to the opposite side of the Parahio Valley (Fig. 13B), the Kuling Group rests disconformably on the Devonian Muth Quartzarenite.

Topmost ferruginous arenite. These fine-grained and strongly burrowed green sandstones (0.2 to 0.8 m; HS 177,181,184) contain glaucony and dark mudclasts; subangular quartzarenite to chert pebbles up to 7 cm in size still occur.

Upper Pin Valley (Muth).

Above Muth, a major disconformity is marked by a sharp-based lenticular *breccia* (up to 2.4 m; HS 154), cutting at low-angle into the Lower Carboniferous Lipak Fm. (about 1 m in 100 m; less than 1°). The breccia, supported by a dark shale matrix and containing clasts and broken beds up to 1.6 m in length from the underlying Lipak carbonates, pinches out within 300 m along strike.

The overlying arenites can be subdivided into four lithozones; since the first three, making a distinct resistant horizon up to 3.2 m-thick, are replaced laterally by 0.5 m-thick hybrid ferruginous arenites (HS110), overall thickness of the formation (excluding the breccia) varies within 300 m along strike from 1.2 m to 4.1 m.

Basal ferruginous conglomerate. This lithozone (up to 0.1 m; HS 83,155) contains brachiopods, subordinate gastropods, black mudclasts and angular carbonate extraclasts up to 10 cm in size, eroded from the Lipak carbonates.

Middle sandstone. These medium-grained quartzose sandstones (up to 2.9 m) display truncated wave-ripples and lenticular lags enriched in brachiopod shells (HS 84). Large-scale, high-angle cross-lamination in the upper part indicates NE-ward paleocurrents (50° to 70°N).

Upper brachiopod-rich beds. These coarse-grained arenites rich in spiriferids (0.2 to 0.4 m; HS 85,156) contain extraclasts up to 2 cm in size.

Topmost ferruginous arenite. This brachiopod-bearing ironstone (0.7 to 0.9 m; HS 86,111) displays sharp base and top.

Lower Pin Valley (Guling) and Spiti Valley (Lingti, Losar).

To the north of the confluence between the Pin and Parahio rivers, the Gechang Fm. increases in thickness. At Guling (17.5 m; Fig. 5), the unit disconformably overlies the Lower Carboniferous carbonates of the Lipak Fm., whereas at Lingti (19 m at least) and Losar (34.9 m) it unconformably follows the lowermost Permian Ganmachidam Diamictite.

In these sections, the Gechang Fm. can be subdivided into four lithozones. At Lingti, the first two are replaced by a 40 cm-thick conglomerate bed containing quartzarenite to carbonate extraclasts up to 30 cm in size and abundant bryozoans, echinoderms and brachiopods (HS 190).

Basal conglomerate. This lithozone (2.5 m at Guling, HS 165, 166; 7.8 m at Losar, HS 392, 391, 390) displays strongly erosional base and contains common quartzarenite extraclasts, as well as mudclasts and reddened to yellowish soil fragments. Maximum extraclast size decreases from Guling (15 cm) to Losar (3 cm), where channelized conglomeratic lenses interbedded with pebbly sandstones to shales display NW-ward dipping cross-lamination. The upper 1.2 m (Guling) to 2.7 m (Losar; HS 389) consist of finer-grained sandstones interbedded with siltstones.

Lower ferruginous arenite. These grey-greenish hybrid arenites (2.7 m at Guling, HS 167,168; 3.5 m at Losar, HS 388, 387) contain shell lags (bryozoans, brachiopods, echinoderms) and abundant glaucony and other NCI grains, including silicate ooids and peloids; bioclasts are commonly glauconized or silicified. The lithozone displays sharp burrowed base at Losar and comprises microconglomerates in the lower part at Guling (extraclasts up to 3 cm).

Middle sandstone. These amalgamated NCI-bearing ferruginous arenites with sparse brachiopods and reddish to greenish or black alteration surfaces (10.7 m at Guling, HS 169,170; 23.1 at Losar, HS 386) are up to fine-grained and burrowed at Losar, where siltstones occur only at the very base and beds are 5 to 10 cm-thick. Sandstones in 10 to 50 cm-thick beds are locally microconglomeratic (clasts up to 3 cm) at Guling, where low-angle stratification to locally E-W bipolar cross-lamination occurs. Dip of cross-laminae indicates NE-ward (70°N) paleocurrents at the top.

Upper brachiopod-rich beds. These quartzose arenites (1.6 m at Guling, HS 171; 0.5 m at Losar, HS 385) contain abundant moulds of spiriferid brachiopods up to 15 cm in width. The base is sharp and mantled by shell lags (Losar) or microconglomeratic arenites with black flat mudclasts up to 3 cm in size (Guling). The topmost surface is also very sharp and displays extensive *Skolithos*-type vertical burrows both at Guling and Lingti.

Arenite petrography.

The base of the Gechang Fm. consists of mainly medium to very coarse-grained pebbly sublitharenites (*basal ferruginous conglomerate*: Q 89±5 F3±5 L8±5, n=7, HS 83, 110, 176, 178, 179, 180, 183; *basal conglomerate*: Q93±6 F1±2 L6±6, n=5, HS 165, 166, 392, 391, 390, 389; *lower ferruginous arenite*: Q93±9 F1±1 L7±9, n=5, HS 167, 168, 190, 388, 387; Tab. 1), containing a variety of terrigenous (shale to quartzarenite; 1.5% of framework), chert (1.3%) and a few carbonate grains (CE 0.5±1%, vanishing upsection) (Fig. 6A). Volcanic rock fragments include some felsitic to vitric grains, locally showing embayed quartz phenocrysts or pumiceous textures, and abundant pseudomatrix (V/L about 30%; Dickinson, 1970). Igneous and metamorphic rock fragments are subordinate. Pseudomorphs and altered grains occur (7±7%). Cr-rich chromian spinel [Cr/(Cr+Al) 0.79±0.09] was found at Losar (HS 387). Mudclasts, illite to glaucony peloids, phosphate clasts, ferricrete grains and iron (chamositic?) ooids are widespread; soil clasts, angular and up to 10 cm in size, occur at the base at

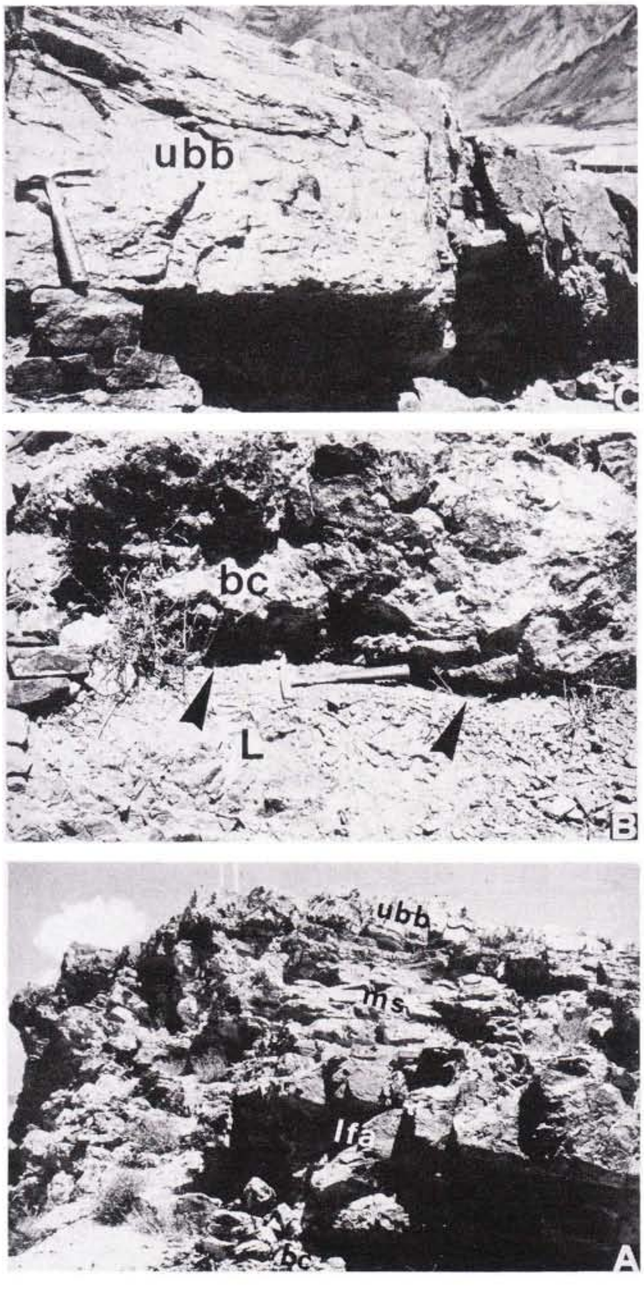

Fig. 5 - Gechang Fm. at Guling (A; acronyms as in Fig. 3). B) Disconformable basal boundary (arrows) with the Lipak Fm. (L). C) Sharp base and top of the *upper brachiopod-rich beds.*

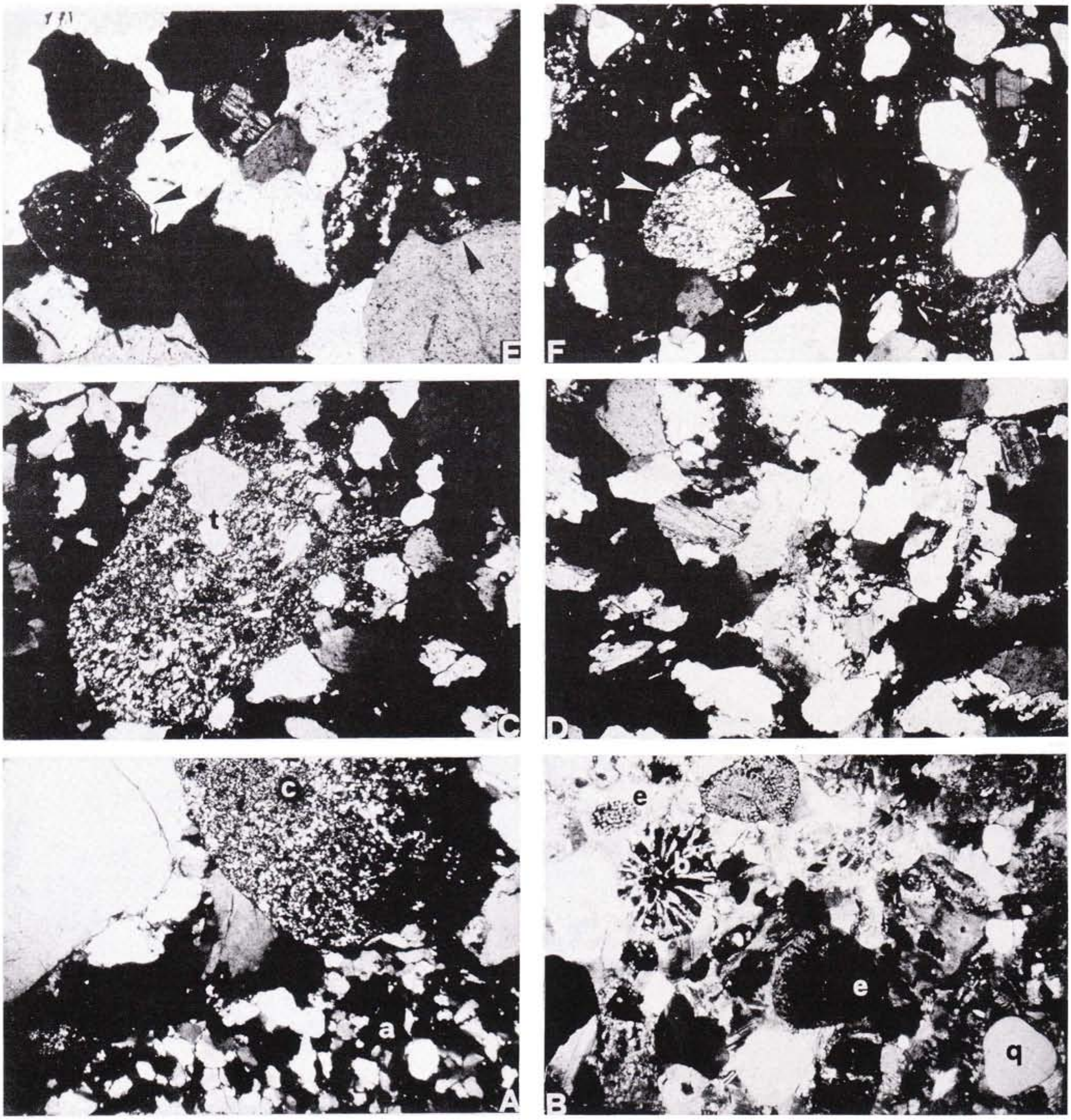

Fig. 6 - Petrography of the Gechang Fm. in Spiti. A) Arenaceous (a) and chert (c) rock fragments (*basal conglomerate*; Losar, HS 391; 20x, 2N). B) Bryozoans (b), echinoderms (e) and rounded quartz (q; *basal ferruginous conglomerate*; Lingti, HS 190; 18x, 2N). C) Tilloidal arenaceous grain (t; *middle sandstone*; Guling, HS 169; 31x, 2N). D) Subarkose (*middle sandstone*; Muth, HS 84, 45x, 2N). E) Iron ooids (black arrows; *upper brachiopod-rich beds*; Guling, HS 171; 31x, 2N). F) Silicate peloid (white arrows; *topmost ferruginous arenite*; Muth, HS 111; 40x, 2N).

Guling (NCI 9±8%). Common bioclasts (CI 7±16%; absent at Gechang) include bryozoans (zoecia commonly filled by phosphate or glaucony), brachiopod valves and spines, echinoderm plates (Fig. 6B).

The *middle sandstone* of the Pin and Spiti Valleys consists of fine to coarse-grained hybrid sublitharenites to subarkoses (Q90±10 F5±9 L5±9, n=4, HS 84, 169, 170, 386; Fig. 6D); slightly greater feldspar/rock fragment ratio may be accounted for by finer grain size of analyzed samples with respect to the underlying lithozones. Altered volcanic grains were locally recorded; sedimentary rock fragments are rare (chert, tilloid clasts; Fig. 6C). Pseudomatrix is 8±10% of framework; phosphate, glaucony and silicate peloids may be abundant (NCI 12±10%). Commonly silicified brachiopods occur (CI 2÷3%).

The *upper brachiopod-rich beds* and *topmost ferruginous arenite* also consist of fine to coarse-grained hybrid sublitharenites (Q91±5 F3±3 L6±4, n=8, HS 177, 181, 184, 85, 86, 111, 171, 385). Terrigenous grains (1.6%) prevail over chert (0.3%) and rare carbonate rock fragments (HS 85). V/L ratio averages 40%; pseudomatrix is 15±12%. Glaucony to silicate peloids, phosphate clasts, mudclasts, iron (chamositic?) ooids and a few graphite particles are widespread (NCI 22±12%; Fig. 6E,F); brachiopods and bryozoans occur (CI < 1%).

SAMPL	UNIT	Qs	Qsb	Qp	Pl	AF	PRF	MRF	Felsite	Chert	TRF	CE	HM	Pseud	CI	NCI	Mat	Cem	Aut	Tot	GSZ	SRT	Q	F	L	C/Q	P/F	V/L
MUTH																												
HS 111	*TFA*	42.0	5.3	6.7	2.3	1.0	-	-	-	-	2.3	-	-	-	-	37.7	-	0.3	2.3	100.0	350	M	90	6	4	.12	.70	0
HS 86	*TFA*	30.0	1.7	6.3	1.3	1.7	-	-	0.7	0.7	2.3	-	0.3	-	tr.	25.0	27.0	0.7	2.3	100.0	325	M/P	85	7	8	.17	.44	.18
HS 85	*UBB*	44.3	2.7	9.3	1.3	tr.	-	-	-	-	2.0	tr.	-	-	5.0	18.3	2.7	1.3	13.0	100.0	695	M/P	94	2	4	.17	-	0
HS 84	*MS*	43.3	-	3.7	5.0	5.0	1.3	-	-	-	-	-	tr.	3.3	0.3	0.7	2.3	15.7	19.3	100.0	190	W	81	18	1	.08	.48	-
HS 83	*BFC*	40.3	0.3	1.3	3.3	1.3	0.7	-	-	-	0.7	1.0	-	6.7	5.7	1.3	0.7	2.7	34.0	100.0	400	P	87	10	3	.03	.73	0
HS 110	*BFC*	34.7	2.3	5.3	2.3	1.7	0.3	-	-	0.7	1.7	-	0.3	0.3	10.7	6.0	12.3	2.3	19.0	100.0	415	M/P	87	8	5	.12	.58	0
GECHANG																												
HS 184	*TFA*	44.3	3.7	8.7	0.3	-	-	-	5.0	-	1.0	-	-	18.7	-	4.3	5.7	4.7	3.7	100.0	440	M/P	81	1	18	.15	-	.80
HS 181	*TFA*	56.3	3.7	8.0	0.3	0.3	-	-	1.3	0.3	0.7	-	-	14.0	-	3.0	5.7	5.7	0.7	100.0	405	M/P	92	1	7	.12	-	.60
HS 177	*TFA*	45.7	1.7	4.7	2.7	0.7	1.0	-	2.0	-	-	-	0.3	17.7	-	-	11.3	10.3	2.0	100.0	170	M/P	90	7	3	.09	.67	1
HS 183	*BFC*	38.7	1.7	5.7	-	-	tr.	0.7	7.0	0.3	1.7	-	-	5.0	-	9.7	5.3	8.0	16.3	100.0	940	M/P	80	0	20	.12	-	.74
HS 180	*BFC*	35.7	-	11.3	-	-	-	0.7	1.0	tr!	2.0	0.3	-	7.0	-	1.0	1.0	6.0	34.0	100.0	1065	P	85	2	13	.24	-	.25
HS 179	*BFC*	51.7	-	9.7	-	-	-	-	1.0	-	0.7	tr.	-	-	-	2.7	1.3	15.0	18.0	100.0	780	M	97	0	3	.16	-	.60
HS 178	*BFC*	43.7	0.3	12.3	-	-	1.0	-	4.0	0.3	0.3	-	-	1.0	-	5.3	1.7	22.7	7.3	100.0	1150	M/P	90	0	10	.22	-	.69
HS 176	*BFC*	48.0	1.0	5.7	-	-	tr.	-	1.0	1.3	1.7	-	tr.	12.0	-	8.0	10.3	7.7	3.3	100.0	1500	P	92	0	8	.11	-	.20
GULING																												
HS 171	*UBB*	53.7	-	12.0	-	-	-	tr.	2.3	1.0	2.0	-	tr.	0.7	-	1.3	-	22.7	4.3	100.0	885	P	92	0	8	.18	-	.44
HS 170	*MS*	44.3	0.3	5.0	-	-	-	-	-	-	-	-	-	1.3	3.7	11.0	3.0	27.3	4.0	100.0	325	M/W	99	1	0	.10	-	-
HS 169	*MS*	54.0	4.0	7.0	-	-	-	-	15.3	-	tr.	-	0.3	1.3	-	-	3.7	9.0	5.3	100.0	500	P	82	1	17	.10	-	1
HS 168	*LFA*	49.0	0.7	5.3	-	-	-	-	2.3	-	-	-	-	4.3	1.3	6.0	0.3	24.7	6.0	100.0	635	M	90	0	10	.10	-	1
HS 166	*BC*	61.0	-	4.7	tr.	-	-	tr.	0.7	0.3	-	-	0.3	5.3	-	0.3	4.3	22.3	0.7	100.0	250	M/W	91	7	2	.07	-	-
LINGTI																												
HS 190	*BFC*	15.7	-	2.0	-	-	-	-	-	1.0	1.7	2.0	-	0.3	37.0	tr.	1.7	0.7	38.0	100.0	1250	M/P	82	0	18	.11	-	0
LOSAR																												
HS 385	*UBB*	45.0	-	5.7	-	-	-	-	-	-	-	-	0.3	17.0	-	-	3.0	10.3	18.7	100.0	165	M/W	100	0	0	.11	-	-
HS 386	*MS*	42.7	-	8.0	0.7	0.3	-	-	-	0.3	-	-	tr.	15.3	-	0.3	8.0	14.0	10.3	100.0	180	W	97	2	1	.16	-	0
HS 387	*LFA*	44.7	tr.	3.3	0.7	-	-	-	-	-	-	-	tr.	18.0	5.7	2.7	15.0	2.3	7.7	100.0	335	P	98	2	0	.07	-	-
HS 388	*LFA*	52.0	0.3	4.7	-	-	-	-	-	-	-	tr.	-	1.7	5.7	5.0	-	3.3	27.3	100.0	335	M/P	100	0	0	.08	-	-
HS 389	*BC*	60.3	-	6.0	-	-	-	0.3	0.3	0.3	-	-	-	0.3	-	tr.	6.3	25.7	0.3	100.0	540	M	98	0	2	.09	-	-
HS 390	*BC*	49.3	-	10.3	-	-	-	-	2.3	3.0	3.0	-	-	1.7	-	2.7	7.0	20.7	-	100.0	1110	P	88	1	11	.17	-	.32
HS 391	*BC*	53.7	-	12.0	-	-	-	tr.	tr.	6.7	3.0	0.7	-	2.7	-	-	1.0	16.3	4.0	100.0	1600	P	85	0	15	.18	-	.08
HS 392	*BC*	55.0	-	4.7	-	tr.	-	-	-	0.3	0.3	-	0.7	7.7	-	0.3	15.7	14.3	1.0	100.0	170	M/W	99	0	1	.08	-	-
Baralacha La																												
V 172	GU	28.7	0.7	2.3	7.7	tr.	tr.	-	-	-	-	-	3.0	0.7	-	tr.	51.7	0.7	4.7	100.0	130	M	79	19	2	.07	1	-
B 44	GU	31.0	-	2.0	4.0	-	-	-	-	-	-	-	0.3	2.0	-	-	49.0	2.0	9.7	100.0	105	M	85	10	5	.06	1	-
V 171	*MS*	59.3	-	5.0	tr.	-	tr.	-	2.0	-	tr.	tr.	-	0.3	-	-	3.0	12.7	17.7	100.0	315	M/W	96	0	4	.08	-	.86
L 78	*C*	22.3	0.3	6.0	14.3	4.3	1.0	-	-	-	-	-	1.0	0.7	-	10.3	21.0	9.3	9.3	100.0	125	P	60	39	1	.20	.77	-
V 338	*C*	32.0	4.3	3.3	tr.	tr.	tr.	-	0.3	tr.?	-	-	tr.	23.3	-	-	32.7	2.0	2.0	100.0	225	M/P	84?	0?	6?	.08	-	-

Tab. 1 - Detrital modes for the Kuling Group in Spiti and Lahaul. C=Chumik Fm.; other acronyms as in Fig. 3. Q=quartz (Qs=single; Qsb=embayed; Qp, C=polycrystalline); F=feldspars (Pl, P=plagioclase; AF=alkali feldspars including chessboard-albite); L=fine-grained "aphanitic" lithics. RF=fine- to coarse-grained rock fragments (P=plutonic to hypabissal; V=volcanic; M=metamorphic; T=terrigenous). E and I=extra- and intra-basinal grains (C=carbonate; NC=non-carbonate). HM=heavy minerals and micas. Pseud=pseudomatrix; Mat=matrix and epimatrix; Cem="compatible" syntaxial cements; Aut=authigenic minerals and carbonate replacements. Tot=total. GSZ=grain size (in µm); SRT=sorting (W=good; M=moderate; P=poor).

Fossils and age.

Basal conglomerate and *lower ferruginous arenite.* The spiriferid *Trigonotreta* cf. *orientensis* Singh & Archbold, 1993 and one Ingelarellidae were collected at Muth (Pl. 1), suggesting a Late Sakmarian (Sterlitamakian) age and cool climatic conditions (Singh & Archbold, 1993).

Trepostomata bryozoans (similar to *Pamirella*; S.Sakagami, writ. comm., 1996) are widespread, from Muth and Guling to Lingti and Losar, where also *Pseudoabatostomella* sp. occurs (det. by S. Sakagami, 1995; Fig. 7A,B). Correlation with the mid-Lower Permian "Ritung Bioturbated Mudstone" of the Nepal Lesser Himalaya is thus indicated (Sakagami & Sakai, 1991).

Upper brachiopod-rich beds. The spiriferid *Cleiothyridina gerardi* (Diener, 1899) constitutes a monospecific assemblage found at the base of the lithozone at Muth, reflecting unfavourable sandy substrates; a Late Permian (Midian/Early Djulfian) age is indicated (Thomas, 1969; Archbold et al., 1993). The top of the lithozone at Guling contains abundant large spiriferids of Late Permian age (*Neospirifer* sp.; *Fusispirifer* sp.; A. Tintori, pers. comm. 1994) and yielded the bryozoan *Rhombopora* sp. at Muth (det. by S. Sakagami, 1995).

The Gechang Fm. was thus deposited from the Late Sakmarian to the Midian or even Early Djulfian, at very low average accumulation rates. In the Pin Valley type-area, about 25 Ma (according to the Harland et al., 1989 time scale) are documented by as little as 0.4 m. The mid-Permian seems to be largely represented by the less fossiliferous *middle sandstone*, but significant gaps are at least locally present.

Depositional environments.

In the upper Pin and Parahio Valleys, the unit was largely deposited in high-energy shoreface settings. Sedimentation of condensed hybrid arenites took place during successive transgressive stages, of Late Sakmarian (*basal ferruginous conglomerate*) to Midian/Early Djulfian (*topmost ferruginous arenite*) age.

To the north and west (Guling, Lingti, Losar), the *basal conglomerate* was sedimented in estuarine channels. A major transgression is testified by the *lower ferruginous arenite.* The *middle sandstone* and *upper brachiopod-rich beds* were deposited in estuary mouth to shoreface environments during renewed transgression. Final drowning of the Neo-Tethyan shelf is documented by the *topmost ferruginous arenite.*

Coarser grain size throughout the unit at Guling documents more proximal environments with respect to Losar. Northward dispersal of detritus is also suggested by paleocurrent indicators, directed both towards the NE and NW.

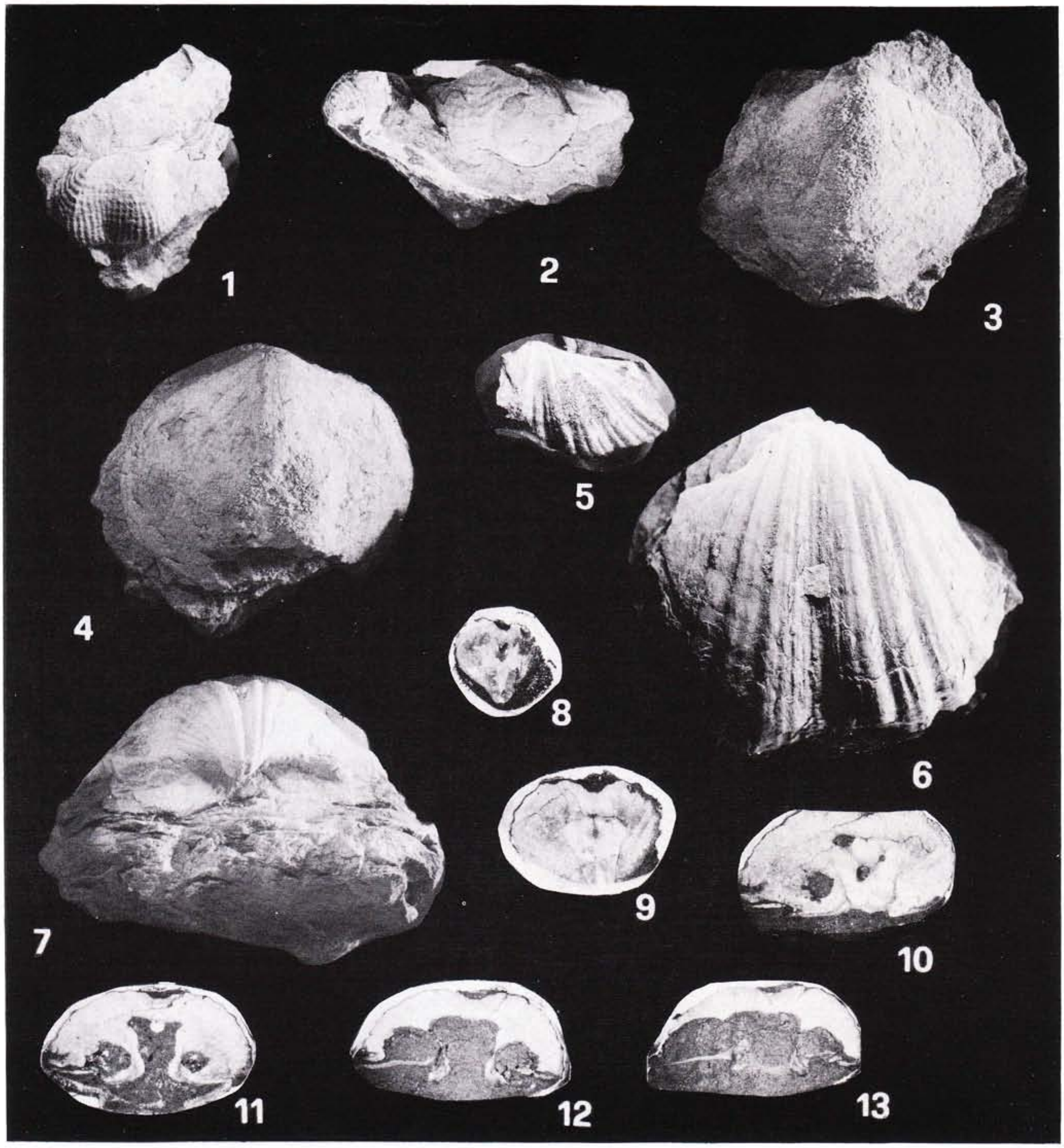

PLATE 1

Permian brachiopods from the Kuling Group in Spiti (Gechang Fm.: *basal ferruginous conglomerate* at Muth, HS 155; *upper brachiopod-rich beds* at Muth, HS 156. Gungri Formation: lower member at Muth, HS 87). All photos 1x.

Fig. 1, 2 - *"Lamnimargus" himalayensis* (Diener), ventral valves: 1) specimen MPUM 7902; 2) specimen MPUM 7903.

Fig. 3, 4 - *Cleiothyridina gerardi* (Diener): 3) dorsal valve, specimen MPUM 7907; 4) ventral valve, specimen MPUM 7908.

Fig. 5 - *Trigonotreta* cf. *orientensis* Singh & Archbold, ventral valve, specimen MPUM 7911.

Fig. 6, 7 - *Tintoriella rajah* (Salter), ventral valve in: 6) ventral view, specimen MPUM 7912; 7) posterior view, specimen MPUM 7912.

Fig. 8-13 - *Tintoriella rajah* (Salter), serial sections of ventral valve (specimen MPUM 7913; all 1.3x) at: 8) 2.5 mm; 9) 3.1 mm; 10) 5.5 mm; 11) 6.1 mm; 12) 6.7 mm; 13) 7.7 mm from the umbo.

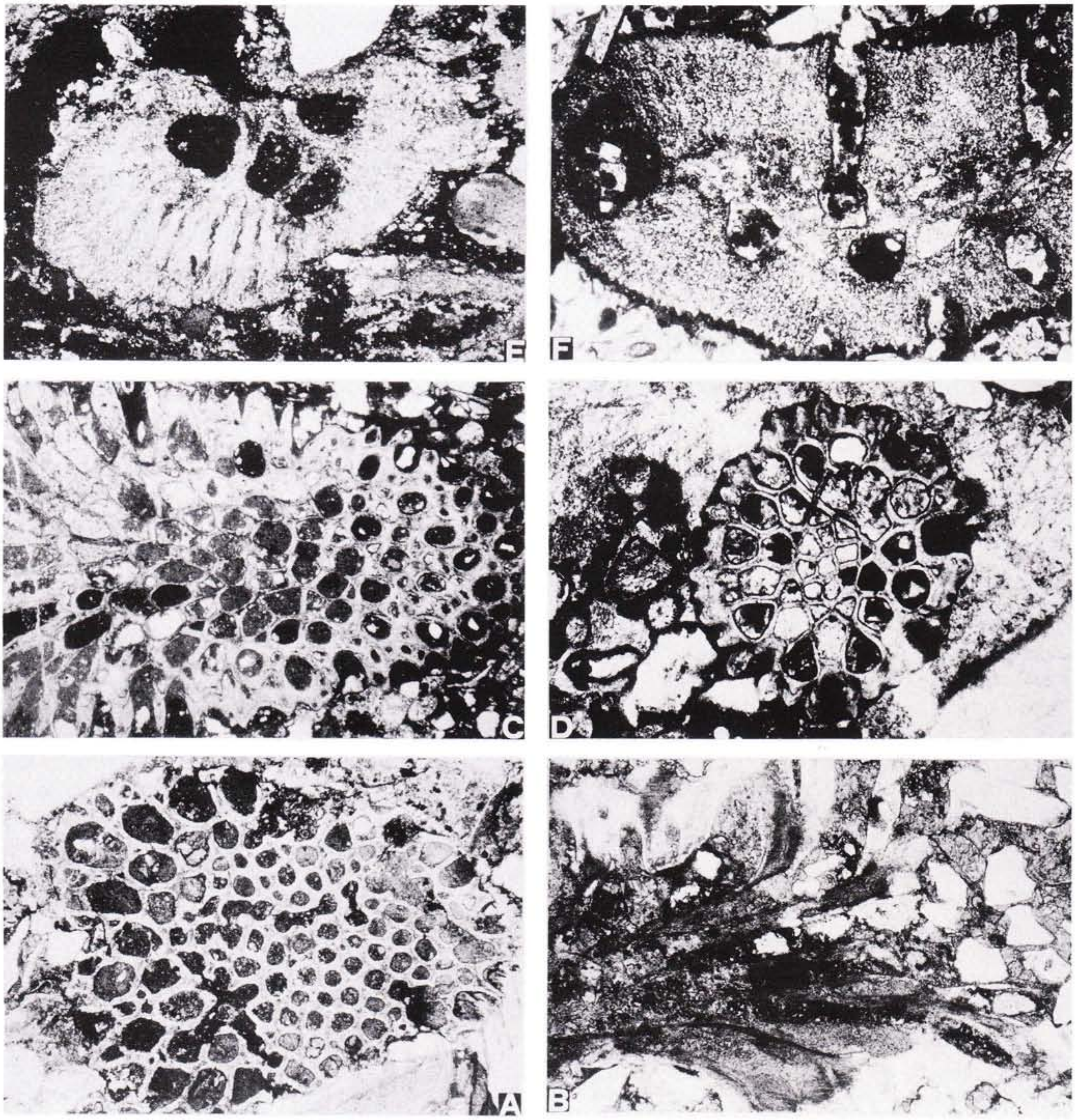

Fig. 7 - Permian bryozoans from the Kuling Group in Spiti and Zanskar (all determinations by S. Sakagami, 1995). Gechang Fm. in Spiti (*basal ferruginous conglomerate* at Lingti, HS 190; *lower ferruginous arenite* at Losar, HS 387): A) *Trepostomata* gen. et sp. indet. (HS 190; 50x, 1N); B) *Pseudoabatostomella* sp. (HS 387; 50x, 1N). Gechang Fm. in Zanskar (upper lithozone at Jinchen): C) *Discrytella* sp. (HZ 47; 25x, 1N); D) *Rhombopora* sp. (HZ 47; 50x, 1N); E) *Polypora*? sp. (ZZ 6; 62x, 2N); F) *Sulcoretepora* sp. (HZ 47; 40x, 1N).

Provenance.

The Gechang Fm. mostly consists of quartzose sublitharenites derived from sedimentary successions uplifted during rifting. Subordinate contribution from igneous and metamorphic sources indicates that uplift and erosion of rift shoulders only locally were intense enough to exhume basement rocks beneath the thick pre-rift sedimentary cover.

Although the unit unconformably overlies various carbonate to terrigenous Paleozoic formations, relative abundance of rock fragment types is not significantly controlled by lithology of substratum, suggesting homogeneous detritus dispersal during widespread transgression onto the newly-formed passive continental margin. Feldspars however are more common at Muth, possibly reflecting local sources.

Terrigenous and chert rock fragments, along with Cr-rich chromian spinels, characterize the *basal conglomerate* and *lower ferruginous arenite* (average detrital modes: Q91 F2 L7), as other Upper Sakmarian to Artinskian sandstones of the Tethys Himalaya from

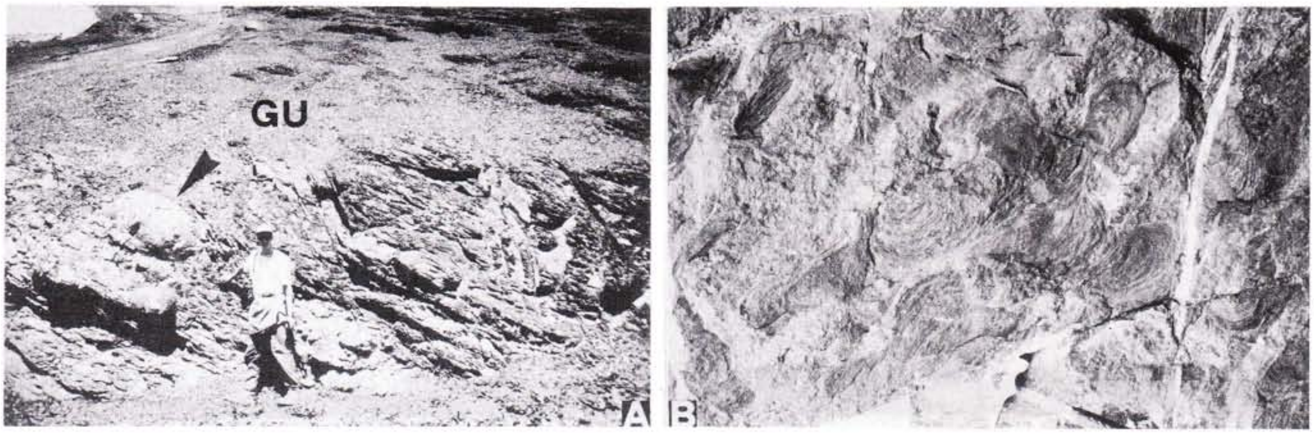

Fig. 8 - Upper member of the Gungri Fm. (GU) at Lingti. A) Black shales with large concretions (arrow; F. Berra for scale). B) *Zoophycos*-type burrows.

Zanskar (Chumik Fm., Member A: Q90 Ftr. L10; base of Member B: Q97 Ftr. L3; Gaetani et al., 1990a) to Manang (Puchenpra Fm., Member A: Q92 F1 L7; Garzanti et al., 1994).

Detrital modes from the *middle sandstone* (Q90 F5 L5) to the *upper brachiopod-rich beds* and *upper ferruginous arenite* (Q91 F3 L6) also compare with those of coeval lithozones from Zanskar (Gechang Fm.: Q88 F2 L10) to Dolpo (Puchenpra Fm., *Costiferina arenites* to base of *glauco-phosphorites* and *black shales*: Q97 F1 L2 to Q93 F2 L5; Sciunnach & Garzanti, 1996) and Manang (Puchenpra Fm., Member B to lower-middle Member C: Q95 F2 L3 to Q96 F1 L3).

Gungri Formation.

This pelitic unit (56.5 m at Muth; 93.6 m at Gechang; 77.7 m at Guling; about 74 m at Lingti; 52.2 m at Losar) can be subdivided into a *lower member*, characterized by two relatively resistant bands of brachiopod-rich phosphatic siltstones, and an *upper member*, made by black fissile shales with sparse large concretions (Fig. 8A).

The *lower member* (27.5 m at Muth, HS 87,88; 40.2 m at Gechang, HS 185; 33 m at Guling, HS 172; about 34 m at Lingti; 28 m at Losar, HS 384) begins with black shales (10 m), followed by micaceous phosphatic siltstones rich in productid and subordinately spiriferid brachiopods (2.3 to 10.6 m). Next, black shales with brachiopods (5.2 to 10 m) are capped by a second resistant band containing brachiopods and burrowed phosphatic siltstones in up to 20 cm-thick beds at Muth (4.5 to 12 m); phosphate nodules reach 30 cm in size.

The *upper member* (29 m at Muth; 53.4 m at Gechang; 44.7 m at Guling; about 40 m at Lingti; 24.2 m at Losar, HS 383) consists of black shales with rare intercalations of thin micaceous siltstones. Phosphate nodules and large concretions (up to 120 cm in size at Lingti) occur. Brachiopods and corals are locally found (Muth, HS 89); spectacular *Zoophycos*-type burrows (Fig. 8B; Bhargava et al., 1985) characterize the lower part at Lingti.

Fossils and age.

Spiriferid [*Tintoriella rajah* (Salter, 1865)] and productid [*"Lamnimargus" himalayensis* (Diener, 1899)] brachiopods, collected in the first phosphatic band of the *lower member* (11 m above the base of the unit at Muth), indicate warm water conditions during the Early Djulfian.

Ammonoids of Djulfian age (*Cyclolobus walkeri* Diener) are reported to occur up to 1.3 m below the top of the unit at Lingti, where the Dorashamian seems to be largely missing (Bhatt et al., 1980)

The Gungri Fm. is therefore Djulfian in age.

Depositional environments.

The unit accumulated in offshore shelf environments only episodically disturbed by major (*lower member*) to exceptional (*upper member*) storm events. During the Late Permian, water depth thus increased from a few to many tens of metres, due to thermal subsidence of the newly-formed passive continental margin (Gaetani & Garzanti, 1991; Vannay, 1993). Abundance of phosphates is ascribed to strong upwelling of nutrient-rich waters in the E-W trending narrow Neo-Tethyan oceanic seaway (Cook & McElhinny, 1979).

The Kuling Group in Zanskar, Ladakh and Lahaul

The stratigraphic framework suggested in previous papers by European teams (e.g., Baud et al., 1984; Nicora et al., 1984; Gaetani et al., 1986, 1990a; Spring, 1993; Vannay, 1993) was based on extensive field work carried out in Zanskar and Lahaul but not in Spiti: the area where the Kuling Formation was originally defined (Stoliczka, 1866; Hayden, 1908; Srikantia, 1981) was then closed to foreigners for political reasons. Only in the 1992 expedition we have been able to study the Kuling Group in Spiti, and to realize that its base contains Late Sakmarian fossils and is thus significantly older than previously thought (major paleogeographic and paleogeodynamic implications of this discovery will be discussed below).

Therefore, stratigraphic sketches tentatively proposed a few years ago (e.g., Gaetani et al., 1990a, fig. 6; Vannay, 1993, fig. 23) need substantial revision. In particular:

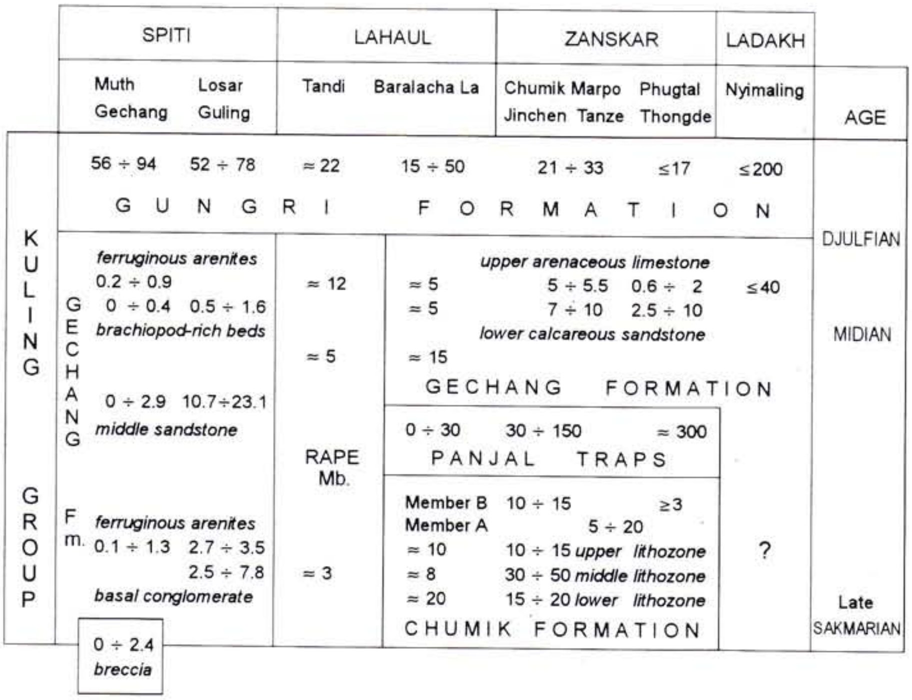

Fig. 9 - Stratigraphic framework for the Kuling Group in the Zanskar-Spiti Synclinorium. Thickness for each unit is indicated in metres. Due to intense tectonic deformation, the Lower Permian succession in the Nyimaling region is still poorly understood (Stutz, 1988; Fuchs & Linner, 1995). See text for full explanation.

1) the Kuling Formation as originally defined in Spiti is equivalent not only to the sediments overlying the Panjal Traps, but also with the lithologically similar Chumik Formation underlying the traps;

2) the Chumik Formation does not occupy the same stratigraphic position as - and is by no means equivalent to - the Ganmachidam Diamictite, which is distinctly older and separated from it by a first-order unconformity (as seen locally also in eastern Zanskar; Garzanti et al., 1996, p. 88).

As a consequence:

1) the usage of "Kuling Formation" to desribe only the Upper Permian sediments overlying the Panjal Traps in Zanskar must be abandoned;

2) the terms "Ganmachidam" and "Chumik" designate two distinct formations which differ notably in lithology, sedimentary features and fossil content. Moreover, their contrast in paleogeographic and paleotectonic significance is apparent: the Ganmachidam Diamictite, originally defined in the Losar area of Spiti by Srikantia (1981) and comprising uppermost Carboniferous to lowermost Permian pebbly glaciomarine sediments, was accumulated during the climax of rifting (Garzanti et al., 1996); the Chumik Formation, originally defined in eastern Zanskar by Gaetani et al. (1990a) and mostly consisting of marine arenites and mudrocks similar to those contained in the lower part of the Gechang Fm. in Spiti, was instead deposited during transgression at the end of the rifting stage (see discussion below).

Zanskar.

In Zanskar, the mid-Lower Permian to Upper Permian sedimentary succession is much thicker than in Spiti, and comprises the Chumik Formation, the Panjal Trap basalts (up to 300 m-thick) and the overlying sediments ("Kuling Fm." of Srikantia et al., 1980; Baud et al., 1984; Gaetani et al., 1990a), including hybrid arenites at the base (Gechang Fm.) and black shales in the upper part (Gungri Fm.; Fig. 9).

Chumik Formation.

The Chumik Fm. unconformably overlies mid-Carboniferous quartzarenites of the Po Group; the lowermost Permian diamictites are only locally represented (Garzanti et al., 1996).

The unit, 65 to 85 m in the east (Chumik Marpo area; Chumik Unit) and reduced to about 20 m or less westward (Tanze; Zangla Unit), is subdivided into two members (Gaetani et al., 1990a; Lucchini, 1991).

Member A begins with burrowed phosphatic subarkosic siltstones yielding brachiopods, pelecypods, echinoderms, gastropods, bryozoans and conulariids, followed by quartzose hybrid arenites containing glaucony peloids and iron ooids (*lower lithozone*, 15 to 20 m; ZB 2, ZG 45, 46, LZ 85, 54, 37). The overlying dark-green glaucony-rich sublitharenites (*middle lithozone*, 30 to 50 m; ZG 47, 48, 49, 50, LZ 86a, 87, 74, 75, 52, 41, 42, 31, 32, 38, 9) are up to coarse-grained and contain a variety of NCI peloids (Garzanti, 1991) (Fig. 10A). Interbedded placers are strongly enriched in higher-density heavy minerals such as rutile and chromian spinels [yellow-brown Al-rich to dark-red Cr-rich picotites, with Cr/(Cr+Al) ratio from 0.62 to 0.94]; zircon, tourmaline, monazite also occur (Fig. 10B). The *upper lithozone* (up to 15 m) is pelitic and poorly exposed.

Member B consists of cross-bedded quartzose microconglomerates with sharp erosive base, containing chert, felsite and arenaceous rock fragments (10 to 15 m; ZG 51, 52, 53, 54, LZ 10), passing upward to greenish tuffaceous rocks (ZG 55, 56) directly overlain by the Panjal Trap lavas.

Member A, yielding a varied cold-water fauna of Late Sakmarian age (Archbold & Gaetani, 1993), is

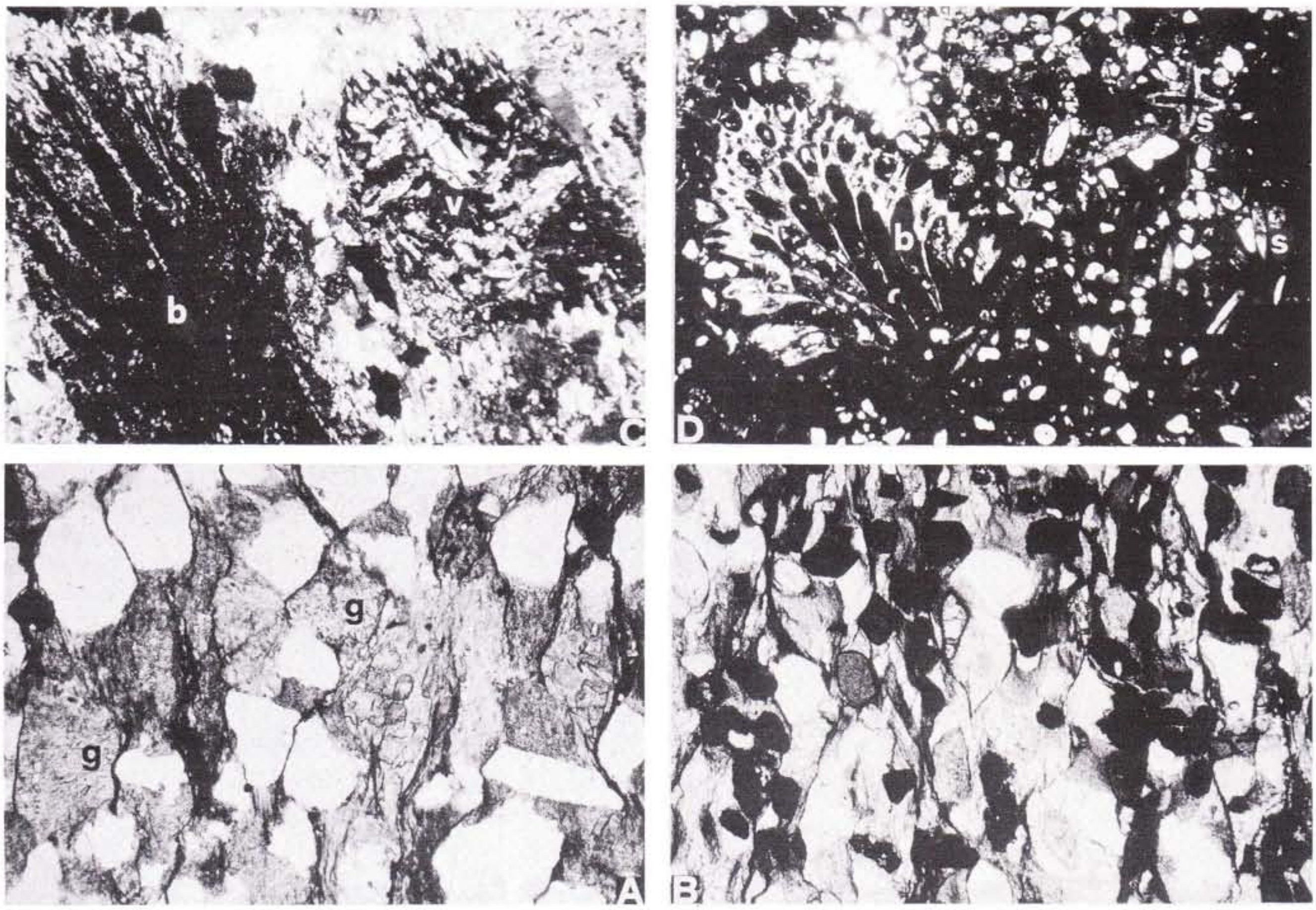

Fig. 10 - Petrography of the Kuling Group in Zanskar. A, B) Glaucony-rich (g) greensands (Chumik Fm., Member A; Chumik Marpo) (A: ZG 50; 63x, 1N), locally strongly enriched in heavy minerals with density between 4.5 and 5 g/cm^3 (rutile, monazite, chromian spinel, opaques) (B: LZ 86; 45x, 1N). C) Glauconized bryozoan (b) and lathwork volcanic grain (v; Gechang Fm., lower lithozone; Thongde, H 134; 40x, 2N). D) Glauco-phosphorite with bryozoans (b) and siliceous spicules (s; Gechang Fm., upper lithozone; Jinchen, HZ 47; 16x, 2N).

time-equivalent with the base of the Gechang Fm. in Spiti (e.g., *basal ferruginous conglomerate*). Abundance of glaucony suggests deposition in shoreface to shelfal environments during major transgression at the end of the Gondwana glaciation (Gaetani et al., 1990a; Garzanti, 1991). Such condensed arenites can be traced in fact along the Tethys Himalaya to as far as Nepal (Garzanti et al., 1994, fig. 5).

Member B documents a major regression shortly before the emplacement of continental flood basalts (Fig. 11A). Coarse siliciclastics with similar composition are found at the base of the Gechang Fm. in Spiti and in Nepal (Member A of the Puchenpra Fm.; Garzanti et al., 1994).

Gechang Formation.

The Gechang Member of Srikantia et al. (1980) and Gaetani et al. (1990a), designating the arenaceous unit overlying the Panjal Traps (Fig. 11B) and yielding spiriferid brachiopods of Late Permian age, is here elevated to formation rank.

The name "Testha Member" used by Waterhouse (1985) for the same unit is a younger synonym. Moreover, the term should be abandoned for poor original description and synonymy with the mid-Cambrian Teta (another spelling of the same village, located about 8 km NW of Tanze) Member of the Karsha Fm. (Gaetani et al., 1986; Garzanti et al., 1986; Stutz, 1988; Spring, 1993; Vannay, 1993).

The Gechang Fm., 12 to 15 m in the east (Jinchen-Tanze area) and reduced to only 3 m westward (Thongde), consists of two lithozones ("lower calcareous sandstone" and "upper arenaceous limestone" of Joshi & Arora, 1976; lithozones a and b of Gaetani et al., 1990a; Zelioli, 1992).

In the Jinchen-Tanze area, the *lower lithozone* (7 to 10 m) consists of a basal horizon of fine-grained sublitharenites with a few green peloids or ferruginous ooids (3 to 5.8 m; ZZ 1, 2, 3, 8, HZ 534); brachiopods, echinoderms or bryozoans occur locally at the base (HZ 533) and commonly in the upper part (ZZ 4, HZ 46). The overlying very fine-grained burrowed sublitharenites are sparsely bioclastic and contain phosphatic matrix and glaucony peloids (3.5 to 4.7 m; ZZ 5, 9, 10, 14). The *upper lithozone* (5 to 5.5 m) consists of burrowed and phosphatic, very fine-grained hybrid arenites (ZZ 11,12,15,47b, HZ

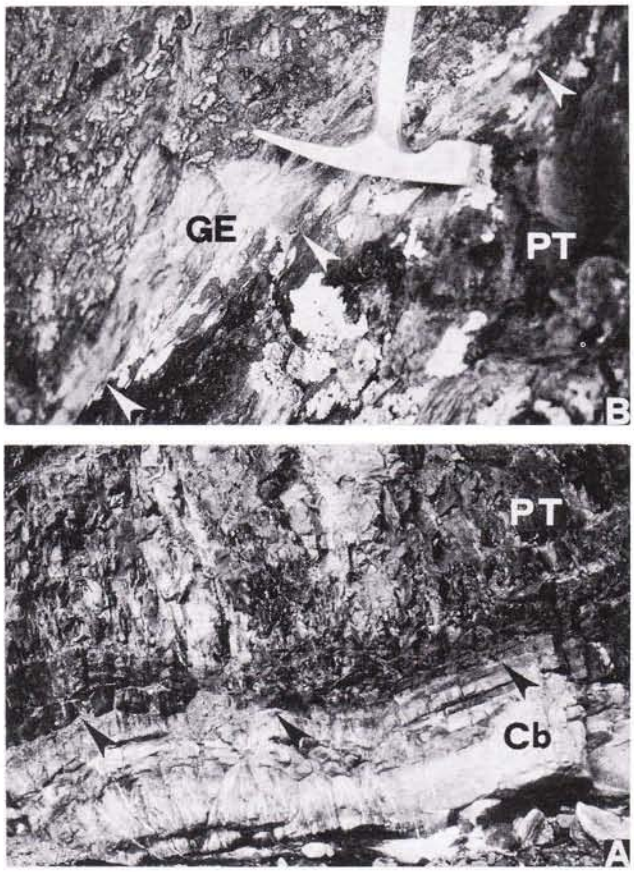

Fig. 11 - Base and top of the Panjal Trap basalts (PT) in Zanskar. A) Abrupt basal boundary (black arrows) with arenaceous Member B of the Chumik Fm. (Cb) east of Phugtal (photo by courtesy of M. Gaetani). B) Disconformable upper boundary (white arrows) with channelized breccias with angular basaltic clasts (base of Gechang Fm. at Thongde; GE).

538), commonly capped by up to coarse-grained condensed glauco-phosphorites (ZZ 6, 18, HZ 47); these layers contain commonly glauconized bryozoans, brachiopod shells and spines, echinoderm remains, siliceous sponge spicules, benthic foraminifers, greenish phyllosilicate to cherty peloids, silty to arenaceous lithoclasts and pyrite (Fig. 10D).

At Phugtal the formation is largely represented by poorly fossiliferous and cross-laminated coarse-grained calcareous siltstones (about 10 m; H 171, 172), capped by a bioclastic horizon. Thickness is greater east of Phugtal (Baud et al., 1984; Nicora et al., 1984).

At Thongde, the *lower lithozone* (2.5 m) includes up to 0.3 m-thick basal lenses of channelized bioclastic breccia with angular volcanic pebbles and glauconized bryozoans (Fig. 10C; H 134, 135), overlain by fine-grained, cross-laminated greenish sublitharenites with green peloids, enriched in echinoderms and partially silicified brachiopods in the upper part (H 136, 137, 138, 139, 140, 141, HZ 287, 288). The *upper lithozone* (0.6 to 2 m; H 139, HZ 288b, 289) consists of sandy biocalcarenites with echinoderms and silicified brachiopods (Garzanti, 1986b).

Abundant *Neospirifer* and subordinate productids occur in the lower-middle part of the Gechang Fm.; Waterhouse (1985) reported *Cleiothyridina gerardi* (Diener, 1899) 4 to 6 m above the base.

The upper lithozone contains rich foraminiferal [*Nodosaria* (?) *lagenocamerata* Sosnina, 1978, *Nodosaria* sp., *Protonodosaria* sp., *Lingulonodosaria* sp., *Frondicularia* aff. *ornata* Mikhluko-Maclay, 1954, *F.* aff. *dilemma* Gerke, 1962, *Dentalina* aff. *orienta* Sosnina, 1965, n.gen. aff. *Austrocolomia*, n. gen. aff. *Calvezina*, *Gerkeina* (?) sp., *Geinitzina* (?) sp.; det. by D. Vachard, 1995] and bryozoan (*Dyscritella* sp., *Rhombopora* sp., *Sulcoretepora* sp.; *Polypora* sp.; det. by S. Sakagami, 1995; Fig. 7C, D, E, F) assemblages of Late Permian age.

The very top of the Gechang Fm. is dominated by *"Lamnimargus" himalayensis* (Diener, 1899), *Tintoriella rajah* (Salter, 1865) and *Cleiothyridina subexpansa* (Waagen, 1883), indicating the Early Djulfian (Gaetani et al., 1990a).

The unit, Midian to Early Djulfian in age, was deposited in shoreface to rapidly deepening shelfal environments after the end of rift-related magmatic activity. Up to coarse-grained fossiliferous glauco-phosphorites are roughly coeval with similar NCI-rich arenites in Nepal (Garzanti et al., 1994, fig.9), documenting a major regional transgression.

The Gechang Fm. in Zanskar is time-equivalent only with the topmost part of the Gechang Fm. in Spiti (i.e., *upper brachiopod-rich beds, topmost ferruginous arenite*). The Panjal Traps in Zanskar are thus roughly time-equivalent with the main part of the Gechang Fm. in Spiti (*middle sandstone*) and can be constrained paleontologically as post-Sakmarian and pre-Midian. This is consistent with the late Early Permian age ascribed to the Panjal Traps in Kashmir (Nakazawa et al., 1975; Srikantia & Bhargava, 1983), but is at odds with the latest Permian (Tatarian) age recently given by Veevers & Tewari (1995).

Gungri Formation.

The unit (Waterhouse, 1985; Gaetani et al., 1990a) consists of black shales rich in brachiopods and phosphatic nodules; burrowed phosphatic and chloritic siltstones or silty micrites with sponge spicules and crinoids are intercalated. Thickness is 21 to 33 m in the Jinchen-Tanze area and 17 m east of Phugtal (Baud et al., 1984); to the northwest (Phugtal, Thongde) it is tectonically reduced to only a few m.

Megasteges nepalensis and *Aulosteges dalhousii* indicate the Late Djulfian (Gaetani et al., 1990a). The Dorashamian has never been documented and is possibly missing.

Ladakh (Nyimaling).

In the Nyimaling region, the Kuling Group unconformably overlies a reduced Carboniferous section, consisting of recrystallized carbonates (Lipak Fm.) locally followed by quartzites (Po Group; Stutz, 1988, p. 41) or even diamictites (Fuchs & Linner, 1995, p. 670).

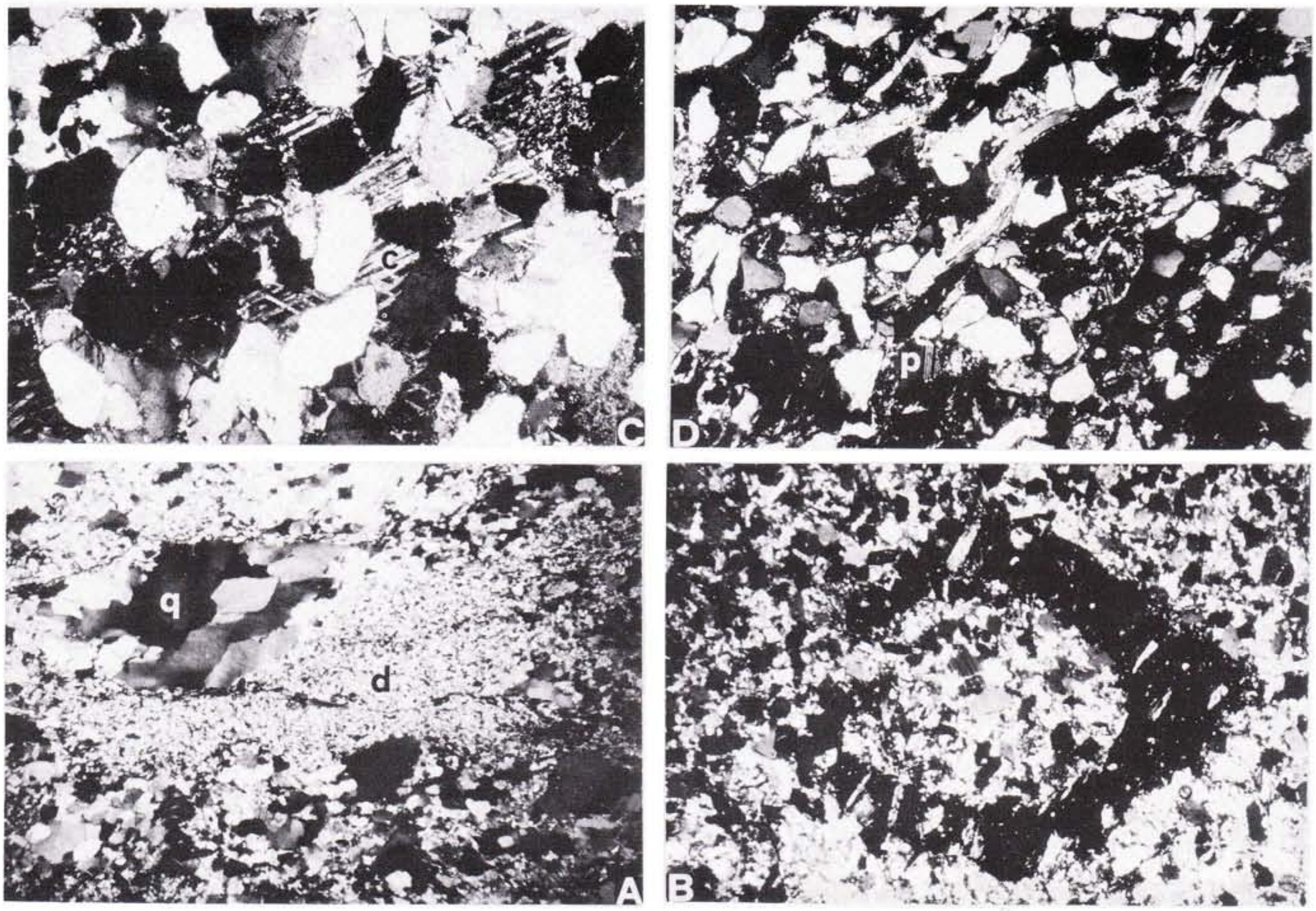

Fig. 12 - Petrography of the Kuling Group in Lahaul. A) Quartzose (q) and dolomitic (d) rock fragments (Rape conglomerate; Rape, V 256A; 16x, 2N). B) Chitinous periderm of conulariid (Chumik Fm., Member A; Chandra Valley, L 78; 25x, 2N). These cold-water schyphozoans typically occur in the Chumik Fm. C) Well-sorted calcitic (c) quartzarenite (Gechang Fm.; Baralacha La, V 171; 40x, 2N). D) Very fine-grained micaceous subarkose with plagioclase (p; Gungri Fm.; Baralacha La, V 172; 45x, 2N).

The basal crinoidal marbles, up to 40 m-thick, contain at the top phosphate nodules, corals and brachiopods of Djulfian age (*Tintoriella* cf. *rajah*; Stutz, 1988); these layers thus correlate with the Gechang Formation.

The upper part, up to 200 m-thick and still strongly deformed, mainly consists of pyritic to calcareous black shales; it thus corresponds to the Gungri Formation. Late Permian brachiopods (*Fusispirifer* cf. *nitiensis*), benthic foraminifers (*Hemigordius* ssp.) and bryozoans (*Frondina* sp.) are locally found; an up to 10 m-thick interval of cross-laminated dolomitic quartzose sandstones capped by crinoidal carbonates is intercalated (Stutz, 1988).

In the Markha Valley further to the northeast, thin-bedded grey quartzose schists (Lutchungse Fm.), over 100 m-thick and intercalated with greenschists or locally associated with serpentinite lenses, have been tentatively interpreted as Permian turbidites deposited at the oceanward edge of the newly-formed Indian margin (Stutz, 1988, fig. 15). Their Permian age, however, is disputed (Fuchs & Linner, 1995, p. 660).

The occurrence of a bryozoan assemblage of Artinskian age, found in a block of phosphatic ferruginous packstone further to the north close to the Tethyan suture (Stutz, 1988, p. 69), is consistent with opening of a rifted seaway in the late Early Permian.

Lahaul.

Baralacha La.

In the Baralacha La area (uppermost Chandra Valley), the Kuling Group (80 to 90 m) paraconformably overlies the Ganmachidam Diamictite (Vannay, 1993). Stratigraphic information and samples kindly provided by J.-C.Vannay document several similarities with the Permian succession of eastern Zanskar and allowed us to recognize the occurrence of the Chumik Fm., sharply overlying the Ganmachidam Diamictite and followed by the Gechang Formation. We could thus extend to northern Lahaul the stratigraphic scheme proposed by Gaetani et al. (1990a) and make direct correlations with the nearby Losar section of western Spiti.

The Chumik Formation (40 m overall) consists of grey-brown siltstones and phosphatic hybrid arenites with chonetid brachiopods (*lower lithozone* of Member A; about 20 m), followed by grey-green sandstones (*middle lithozone*; 8 m) and next by burrowed siltstones (*upper lithozone*; 10 m). Dark green, glaucony- and phosphate-bearing arkoses rich in the cold-water scyphozoan *Paraconularia* sp. also occur (Fig. 12B).

The cold Gondwanian fauna reported from the base of the Kuling Group by Srikantia et al. (1978) probably comes instead from the underlying diamictites (see Rao et al., 1982).

The Chumik Fm. includes fine-grained burrowed quartzose sandstones containing abundant cherty to phyllosilicate peloids and pseudomatrix (up to 37% of framework; V 338) and hybrid arkoses (Q 60 F 39 L 1; L 78) yielding microlitic volcanic rock fragments, conularids and echinoderm remains (NCI 18%).

The Panjal Trap basalts are absent in the Baralacha La area, but are 20 to 30 m-thick in the Chandra Valley to the east (above Likhim Yongma: Vannay, 1993, fig. 44; Vannay & Spring, 1993).

The Gechang Formation (25 m overall) consists of cross-laminated quartzose sandstones (15 m), followed by hybrid arenites (about 10 m) rich in brachiopods of Early Djulfian age (*Tintoriella rajah*, *"Lamnimargus" himalayensis*), becoming more calcareous, intensely burrowed and rich in phosphate nodules in the upper half ("upper arenaceous limestone" of Joshi & Arora, 1976; lithozone b of Gaetani et al., 1990a). The unit is time-equivalent with the middle-upper part of the Gechang Fm. in Spiti (i.e., *middle sandstone*, *upper brachiopod-rich beds*, *topmost ferruginous arenite*).

The base of the Gechang Fm. includes medium-grained and well-sorted calcitic quartzarenites (Q 96 F 0 L 4, V 171; Fig. 12C).

The Gungri Formation consists of burrowed carbonaceous siltstones (*lower member*) gradually passing upward to burrowed calcareous siltstones and black shales with phosphatic nodules deposited on an offshore shelf (*upper member*; Kanwar & Ahluwalia, 1979; Vannay, 1993); overall thickness decreases towards the northwest from 40 ÷ 50 m to only 15 m.

Intercalated at the base of the Gungri Fm. are very fine- to fine-grained subarkoses (Q 82±4 F 15±6 L 3±2; B 44, V 172; Fig. 12D); NCI particles are lacking, but for common graphite grains. Detrital modes compare with the feldspar-enriched top of the Puchenpra Fm. in Dolpo (lower-central part of *glauco-phosporites and black shales*: Q81 F17 L2; Sciunnach & Garzanti, 1996).

Tandi and Mulkila Synclines.

In the Tandi Syncline (lowermost Chandra Valley), about 40 m-thick and strongly deformed transgressive marine sediments of Permian? age (Rape Member of the Kukti Fm.; Srikantia & Bhargava, 1979; Prashra & Raj, 1990; Fuchs & Linner, 1995) unconformably onlap the Upper Precambrian-Cambrian Phe Fm. (Vannay, 1993, p. 55). We have no personal experience with this area; the following considerations stem from study of samples and stratigraphic information kindly provided by J.-C. Vannay.

The Rape Member begins with lenticular (up to a few m-thick) and subangular pebble conglomerates containing abundant quartzarenitic and dolomitic rock fragments (maximum clast size 15 cm; Fig. 12A); rare tourmaline-bearing NCI grains occur. Next, some metres of interbedded quartzose sandstones and impure dolostones pass rapidly upward to an about 10 m-thick interval of strongly recrystallized hybrid dolomitic limestones yielding brachiopod valves and echinoderm plates. The upper half of the unit (about 22 m), consisting of calcareous siltstones and black shales with spiriferid remains, is directly followed by Triassic cephalopod-bearing carbonates; it can be thus correlated with the Gungri Formation.

A similar section is described from the Mt. Mulkila Syncline (about half-way between Tandi and Baralacha La), where Late Permian? sediments unconformably overlie the Ordovician Thaple Fm. (Vannay, 1993).

Sedimentary evolution during opening of Neo-Tethys

The break-up unconformity.

The base of the Kuling Group is invariably marked by a major unconformity (Hayden, 1904; Fuchs, 1982), which is overlain by Upper Sakmarian strata from Spiti (base of the Gechang Fm.) to Zanskar (Member A of the Chumik Fm.) and can be traced all along the Himalayan Range.

In the Spiti Valley (Losar, Lingti) to northern Lahaul (Baralacha La area), the unconformity is underlain by lowermost Permian diamictites, and the associated time-gap is minimum (Fig. 3). In other localities, the gap includes large parts the Carboniferous, as in eastern Zanskar and Pin Valley of Spiti (Fig. 5B, 13A). Permian units directly overlie the Devonian Muth Quartzarenite or the Silurian Pin Fm. in the Parahio Valley (Fig. 4, 13B), the Ordovician Thaple Fm. in the Mt. Mulkila area and the Upper Precambrian-Cambrian Phe Fm. in the Tandi syncline (Vannay, 1993). The complete Ordovician to lowermost Permian succession was eroded also in Zanskar west of Phugtal (Srikantia et al., 1980; Gaetani et al., 1986).

To the east, the Kuling Group is reported to unconformably overlie the Devonian Muth Quartzarenite both in Kinnaur (Bassi et al., 1983; Bassi, 1989) and Kumaon (Heim & Gansser, 1939; Sinha, 1989). Further to

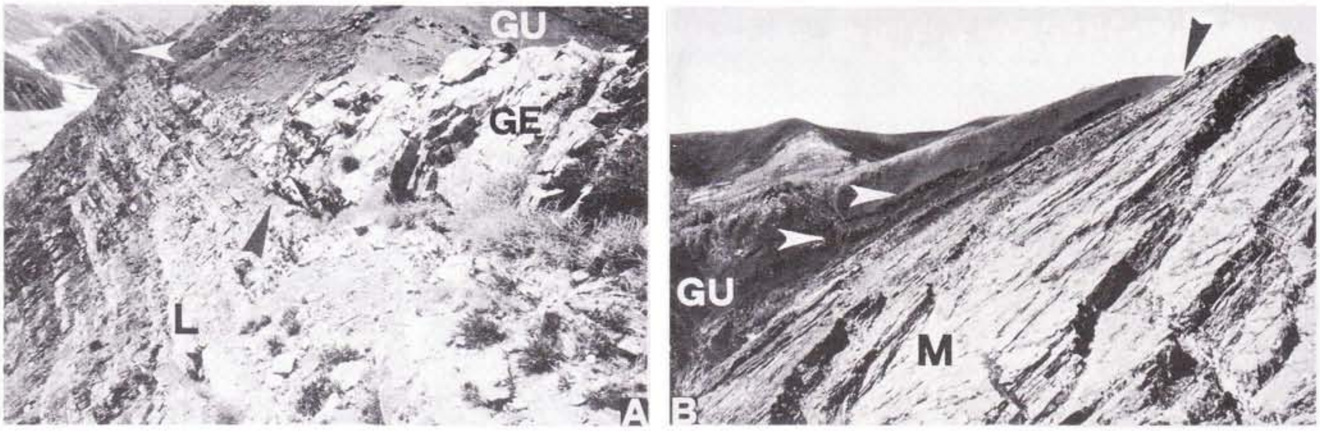

Fig. 13 - Basal unconformity (black arrow) in the Pin Valley (Muth; A) and Parahio Valley (Gechang; B), where the Gechang Fm. (GE) is reduced to a few m and unconformably onlaps the earliest Carboniferous Lipak Fm. (L) or the Devonian Muth Quartzarenites (M) respectively. White arrows indicate the two phosphatic siltstone bands in the lower member of the Gungri Fm. (GU).

the east, the time-equivalent Puchenpra Fm. of Nepal unconformably overlies Devonian dolomites in western Dolpo (Fuchs, 1977, fig. 22), mid-Carboniferous quartzarenites in central Dolpo (Garzanti et al., 1992) and lowermost Permian diamictites in Manang (Colchen et al., 1986; Garzanti et al., 1994). In west Southern Tibet, diamictites are unconformably followed by Lower Permian tholeiites, locally with intervening transgressive black mudrocks and debris flow deposits (Garzanti et al., in preparation).

In the central Nepal Lesser Himalaya, the lowermost Permian Sisne diamictites are transgressed by the "Ritung Bioturbated Mudstone" (Sakai, 1991), which is correlatable with the Kuling Group. Even within several basins in Peninsular India, lowermost Permian continental diamictites (i.e., Talchir Boulder Beds) are separated from the overlying coal-bearing paralic to marine sediments by the Umaria Unconformity (Frakes et al., 1975).

The Visean to Lower Sakmarian succession below the unconformity is absent in several regions (western Zanskar; Nyimaling; Mulkila and Tandi synclines; Pin and Parahio Valleys; Kinnaur; Kumaon; western Dolpo), while in others it varies rapidly in thickness from less than 100 m (central Dolpo) or only a few hundred metres (eastern Zanskar to Baralacha La), to as much as 750÷1000 m (Losar, Manang) or even 1000÷1500 m (Southern Tibet).

The Permian succession above the mid-Sakmarian unconformity (Kuling Group) is instead present everywhere; thickness varies little and gradually, from a minimum of 40 m (Tandi) to 60÷95 m (Baralacha La to Spiti). Similar thickness (about 50 m, locally up to 100 m) is reported from Kinnaur, Kumaon and western Dolpo (Heim & Gansser, 1939; Fuchs, 1977; Bassi et al., 1983); further to the east, the time-equivalent Puchenpra Fm. varies from 145÷170 m in central Dolpo to 60÷125 m in Manang. Thickness becomes much greater only in Southern Tibet (up to 570 m) and in the northwestern Himalaya, where the Panjal Traps are present (reaching about 300 m in Zanskar - where the basaltic unit itself is tabular and its thickness increases gradually towards the northwest - but much more in Kashmir).

Moreover, the major mid-Sakmarian unconformity seals paleofaults in the Parahio Valley (Fig. 4; Fuchs, 1982, p. 344), and is mantled by veneers of transgressive arenites enriched in Cr-rich chromian spinels from Zanskar to Spiti and Dolpo (Sciunnach & Garzanti, 1996). Since it marks a major change both in tectonic style and magmatic character (Spring et al., 1993; Vannay & Spring, 1993; Caironi et al., 1996), it is interpreted here as the break-up unconformity.

Dating of Upper Sakmarian fossiliferous strata transgressing the rift shoulder in Spiti (Fig. 2) thus allows us to revise previous interpretations, made when the Spiti region was still closed to foreigners (Baud et al., 1984; Gaetani et al., 1990a, fig. 6; Gaetani & Garzanti, 1991, fig. 7; Stampfli et al., 1991, fig. 5). Recent studies have shown in fact that Neo-Tethys opened north of India in the Early Permian (Garzanti et al., 1994), notably earlier than previously expected.

The break-up unconformity caps the rift sequence, which in many areas (e.g., eastern Zanskar, Dolpo) is reduced to bits of Carboniferous units bounded by unconformities; even where it is most complete (e.g., Losar, Manang, Southern Tibet; Garzanti et al., 1994, 1995b, 1996), the Upper Carboniferous is very poorly represented, suggesting widespread thermal uplift during the climax of rifting (Vannay, 1993, p. 72).

In large parts of the Himalaya, the rift sequence is entirely missing, and the break-up unconformity coincides with the post-Tournaisian rift unconformity (Garzanti & Sciunnach, 1996; Sciunnach & Garzanti, 1996). At several places (i.e., western Zanskar, Tandi, Parahio

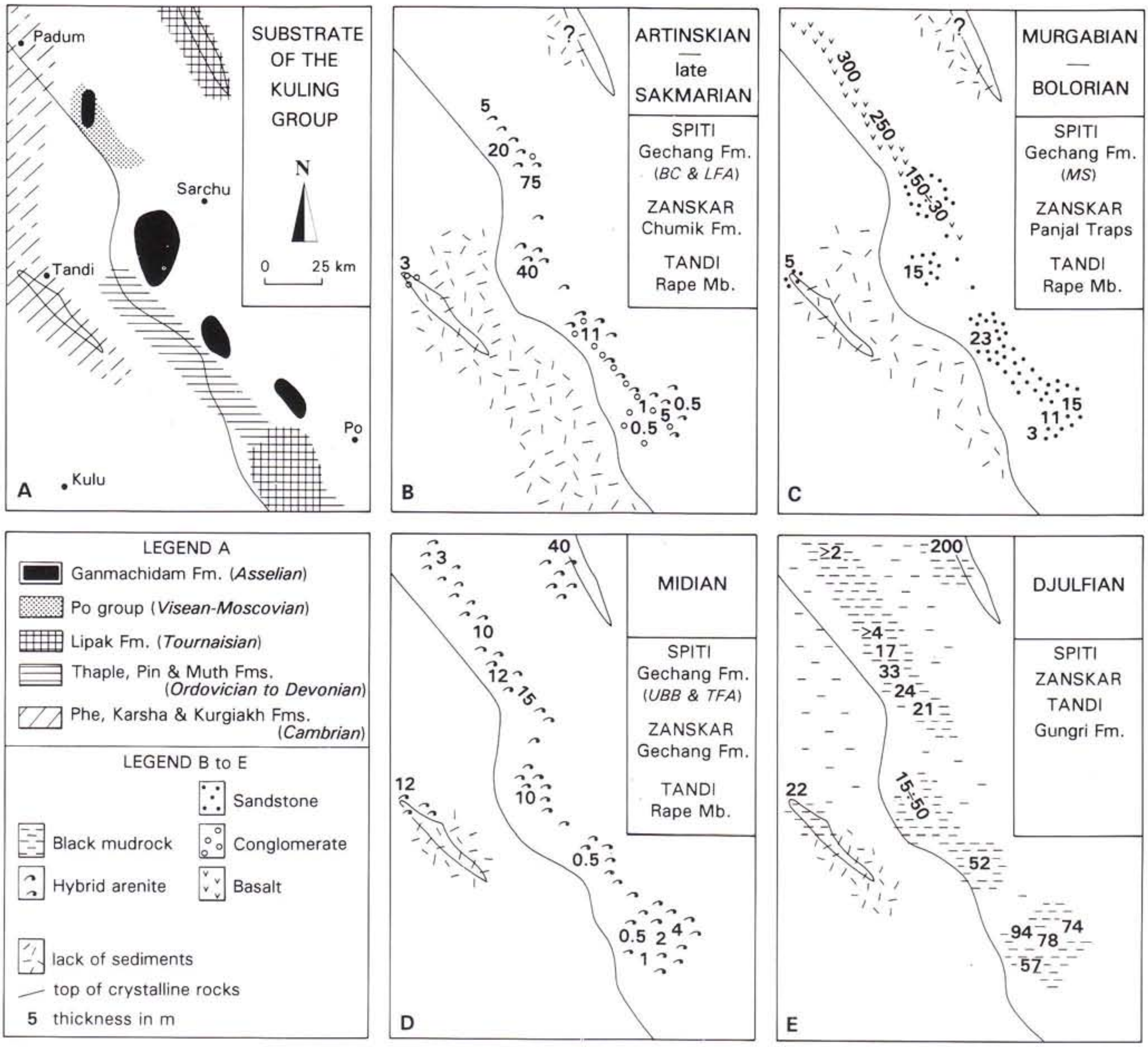

Fig. 14 - Facies and thickness maps for the Kuling Group in the studied Spiti-Lahaul-Zanskar area. Acronyms as in Fig. 3.

Valley), even pre-rift units of Precambrian to earliest Carboniferous age were uplifted, exhumed and deeply eroded during rifting (Fig. 14A).

Paleogeographic scenario.

The Gondwanian glaciation came to an end in the mid-Sakmarian, when melting of continental ice induced rapid sea-level rise and widespread marine transgression onto the newly-formed Himalayan and Karakorum margins of Neo-Tethys (Gaetani et al., 1990a, 1995; Fig. 14B).

As indicated by cool-water faunas contained in condensed sediments at the base of the drift sequence, cold-temperate climates persisted until the end of the Early Permian at least (Garzanti et al., 1994), when northern India lay at middle-high southern latitudes (Scotese & Mc Kerrow, 1990).

At this stage, the Panjal Trap basaltic lavas and similar subalkalic tholeiites fed by MORB-type magmas were emplaced all along the Tethys Himalaya (Fig. 14C; Garzanti et al., in preparation), suggesting increasing amounts of partial melting of the rising astenosphere during initial opening of Neo-Tethys (Coffin & Eldholm, 1992; White, 1992).

In mid-Permian times, when the crust remained hot and subsidence was negligible (pelagic sediments were deposited only in eastern Manang; Garzanti et al., 1994), sedimentation occurred in high-energy nearshore environments, with veneers of NCI-rich hybrid arenites documenting starvation during peak transgressive stages (Fig. 14D). From the Zanskar-Spiti Synclinorium to central Nepal, deepening took place mostly at Djulfian times, when the widespread black shales of the Gungri Fm. eventually sealed the topography created by rift tectonism and associated magmatism (Fig. 14E).

Brachiopod faunas indicate rapid warming at the close of the Paleozoic, when climates turned to semiarid (Dutta & Suttner, 1986; Sciunnach & Garzanti, 1996) as the Tethys Himalaya was being rapidly displaced northward towards the Southern Tropic (Scotese & McKerrow, 1990; Baud et al., 1993).

Stratigraphic model.

Passive margin sedimentary successions consist of nested sets of aggrading, backstepping and forestepping sequences at various scales, controlled by the interplay of eustasy and tectonism (Hubbard et al., 1985; Boote & Kirk, 1989; Bosellini, 1989; Gaetani & Garzanti, 1991; Mitchum & Van Wagoner, 1991; Premoli Silva et al., 1992; Garzanti, 1993).

The Kuling Group, as the correlative Puchenpra Fm. of Nepal, is made by a stack of third-order depositional sequences, which are easier to distinguish in the thicker successions of central Dolpo and Southern Tibet (Garzanti et al., 1995b; Sciunnach & Garzanti, 1996). In Spiti, due to much lower subsidence rates, they are reduced to a series of transgressive horizons, which only seldom can be resolved with paleontologic or petrographic tools. The Zanskar succession is thicker, but complicated by processes related to the emplacement of the Panjal Trap basalts. Therefore, recognition of third-order "Vail-type" depositional sequences and systems tracts in the Permian of the northwestern Himalaya is by no means straightforward, and will not be attempted here.

If the stratigraphic model of Van Wagoner et al. (1988) can be applied at the scale of second-order sequences, the lower part of the Upper Sakmarian/lowermost Norian supersequence (Gaetani & Garzanti, 1991; Garzanti et al., 1995a) may be subdivided into second-order systems tracts punctuated by major flooding surfaces.

The break-up unconformity, separating the rift sequence from the drift sequence, is overlain by transgressive hybrid arenites gradually thickening oceanward and deposited during long-term relative sea-level rise (Gechang Fm. in Spiti; Chumik and Gechang Fms., with the intervening Panjal Trap basalts, in Zanskar). These aggrading ("keep-up") Upper Sakmarian to lowermost Djulfian units (lowstand tract) are followed by the backstepping ("give-up") black shales of the Djulfian Gungri Fm. (transgressive tract) (Fig. 3, 4, 5).

In this framework and at this scale, final drowning of the Indian shelf occurred at the end of the Permian, followed from Zanskar to Southern Tibet by the pelagic limestones of the Triassic Tamba-Kurkur Fm. (early highstand tract). All along the Tethys Himalaya maximum water depth was reached in the Olenekian (Garzanti et al., 1995a; 1995c).

Interpreting the gap at the Permian/Triassic boundary as associated with long-term maximum flooding is clearly at odds with the commonly held views that it marks instead a major eustatic fall all over the world (e.g., Duval et al., 1992) and in the Himalayas as well (e.g. Bhatt et al., 1980; Atudorei et al., 1995). However, not only in Spiti (Fig. 2, 3, 4, 5) but also in Nepal and Tibet (Garzanti et al., 1992, 1994, 1995b), the Sakmarian to Induan succession unquestionably documents a second-order transgressive trend, interrupted only by third-order downward shifts of coastal onlap (Garzanti & Sciunnach, 1996).

This shows once more that regional subsidence patterns have to be carefully investigated before almighty sea-level is invoked: eustasy may well be just a higher-frequency modulation of the long-term tectonic signal!

Geodynamic model.

The Permian sedimentary evolution of the Himalayan margin of Neo-Tethys facing Karakorum (Gaetani et al., 1990b; Gaetani & Garzanti, 1991) can be interpreted according to models of asymmetric rifting dominated by simple shear (e.g., Wernicke, 1985). In this framework, the northwestern Himalaya represents an "upper plate margin", characterized by intense volcanism and slow gradual subsidence with absence of block faulting (Stampfli et al., 1991).

Time elapsed from the beginning of rifting to oceanisation was however as long as 80 Ma (i.e., one order of magnitude more than observed in the North Atlantic; e.g., Eldholm et al., 1987). This may be ascribed to a complex tectonic evolution, occurring at slow strain rates and possibly fostered by a Late Paleozoic "superplume" event (Larson, 1991; Garzanti, 1993).

Rift stage (from transtension to shoulder uplift).

The first stages of intense extensional activity, associated with sporadic mafic magmatism, date from the close of the Tournaisian (Garzanti, 1986b, pp. 69-70; Vannay, 1993; Garzanti & Sciunnach, 1996), even though transtensional (?) movements might have begun as early as the Late Devonian (Garzanti et al., 1992, 1996).

The major thermal uplift event, associated with limited but widespread production of alkalic magmas with bimodal basaltic/granitic composition (Spring et al., 1993; Vannay & Spring, 1993; Caironi et al., 1996), took place in the Late Carboniferous to earliest Permian.

The shoulder of the rift was located in the southernmost part of the study area, as documented by the deeply-eroded Paleozoic successions of Parahio Valley and Lahaul (Vannay, 1993, fig. 23, 24) but also of western Zanskar, Kinnaur, Kumaon and Dolpo. These glaciated reliefs extended roughly parallel to the future Tethyan margin, and separated the rift basins of the Tethys Himalaya to the north, from the rim basins of the Lesser Himalaya (e.g., Chamba and Kashmir basins; Jain et al., 1980; Bhat, 1982; Guntli, 1993) and northern Pakistan (e.g., Salt Range, Potwar and Peshawar basins; Stampfli et al., 1991; Pogue et al., 1992; Wardlaw & Pogue, 1994) to the south.

This model explains why Paleozoic strata are largely missing in the Lesser Himalaya (Gansser, 1964; Brookfield, 1993), and rectifies the old idea of a ridge rising in the course of the Paleozoic to separate Lesser Himalayan basins to the south from Tethyan basins in the north (e.g., Fuchs, 1976; Srikantia & Bhargava, 1979; Jain et al., 1980). It also accounts, in a radically different geodynamic framework, for extensive Late Paleozoic uplift in the Himalayas, ascribed instead by several authors to an "Hercynian" orogenic event (e.g., Kanwar & Bhandari, 1976; Srikantia, 1981; Fuchs, 1982).

Drift stage (from oceanisation to thermal subsidence).

The rift stage ended in the mid-Sakmarian, when major transgression also marked the end of the Gondwanian glaciation. Sea-level rise is thus seemingly largely glacio-eustatic in nature, even though we cannot exclude that opening of a rifted seaway could have been at least in part responsible for the climatic amelioration which brought about the end of glaciation.

Nearby tholeiitic magmatism heated the Indian crust, and subsidence in Spiti remained negligible for some 25 Ma (Late Sakmarian to Midian; "juvenile ocean stage" of Von Rad & Bralower, 1992). Shortly after break-up, subsidence was faster only in areas burdened by thick piles of lava or close to magmatic centres (e.g., eastern Manang, west Southern Tibet).

Rapid thermal subsidence began everywhere in the Himalayas at Midian/Early Djulfian times (Gaetani & Garzanti, 1991, fig. 14; Vannay, 1993, fig. 25, 26) and after less than 10 Ma the newly-formed passive margin was buried beneath pelagic sediments ("mature ocean stage").

Conclusions

The Kuling Group in Spiti consists of transgressive basal conglomerates and NCI-rich arenites of Late Sakmarian to Midian/Early Djulfian age (Gechang Fm.), overlain by shelfal black shales of Djulfian age (Gungri Fm.).

The Kuling Group is capped by the Gungri shales also in Zanskar, where the underlying succession is thicker and includes subalkalic MORB-type tholeiites (Panjal Traps), sandwiched between condensed transgressive arenites of Late Sakmarian (Chumik Fm.) and Midian/Early Djulfian age (Gechang Fm.).

The Kuling Group was deposited at the end of the Gondwanian glaciation, and recorded progressively warming climates from cold periglacial to temperate-cool in the Early Permian, and finally to tropical-arid at the end of the Late Permian.

All along the Spiti-Zanskar Synclinorium, the Gechang Fm. onlapped and the Gungri Fm. eventually buried rift-related reliefs during a long-term relative sea-level rise, documenting onset of thermal subsidence of the newly-formed Neo-Tethyan margin.

The major pre-Upper Sakmarian unconformity, which seals paleofaults and marks the end of continental rifting and associated alkalic magmatism, is thus interpreted as the break-up unconformity, followed by initial opening of the Neo-Tethys Ocean.

Acknowledgments.

Maurizio Gaetani, Jean-Claude Vannay, Gianmarco Lucchini, Laurent Spring and Andrea Zelioli kindly provided many samples, various personal material and precious unpublished stratigraphical information on Zanskar and Lahaul. Alda Nicora and Fabrizio Berra gave fundamental help measuring sections and collecting samples in the field. We heartily thank Sumio Sakagami (Tokyo) and Daniel Vachard (Lille) for determination of Permian bryozoa and foraminifera respectively. Views on the Pin Valley outcrops were exchanged with Trilochan Singh (Dehra Dun), who also kindly provided copy of papers in preparation.

Thanks also to Giovanni Chiodi, Curzio Malinverno, Magda Minoli and Agostino Rizzi for carefully-made photographs, thin sections, drawings and SEM-EDS analyses of chromian spinels. The manuscript has benefitted from the valuable advice of Maurizio Gaetani and careful reviews by Dr. T.N. Bagati, Aymon Baud and Jean-Claude Vannay.

EG is responsible for field work, stratigraphic framework and paleogeographic interpretation; LA studied brachiopod associations; DS quantitatively analysed sandstone mineralogy. The expedition, partly supported by Ev-K^2-CNR, was carried to full success by our guide Rahoul, driver Balwinder Singh and Dawa sherpa. Printing expenses partly covered by Progetto Coordinato CNR "Ritmi ed Eventi in Biostratigrafia" (Coord. Prof. A. Farinacci) - Sottoprogetto "Microfossili ed Eventi Paleozoici" (Resp. Sc. Prof. M. Tongiorgi).

APPENDIX

Systematic descriptions

L. Angiolini

Order Productida Sarycheva & Sokolskaya, 1959

Suborder Productidina Waagen, 1883

Superfamily *Productacea* Gray, 1840

Family *Marginiferidae* Stehli, 1954

Genus *Lamnimargus* Waterhouse, 1975

Type-species: *Retimarginifera perforata* Waterhouse, 1970

"Lamnimargus" himalayensis (Diener, 1899)

Pl. 1, fig. 1, 2

1899 *Marginifera himalayensis* Diener, p. 39, pl. 2, fig. 1-7; pl. 6, fig. 1, 2.
1903 *Marginifera himalayensis* - Diener, p. 104, pl. 5, fig. 5, 6, 27.
1915 *Marginifera himalayensis* - Diener, p. 79, pl. 8, fig. 9.
1941 *Marginifera himalayensis* - Muir-Wood & Oakley, p. 19, pl. 1, fig. 1-3.
1975 *Lamnimargus himalayensis* - Waterhouse, p. 10.
1978 *Lamnimargus himalayensis* - Waterhouse, p. 31, pl. 2, fig. 11-15.
1979 *Lamnimargus himalayensis* - Gupta & Waterhouse, pp. 8, 15, pl. 1, fig. 3-8; pl. 3, fig. 6.
1985 *Lamnimargus himalayensis* - Waterhouse, pp. 70-72.
1990 a *Lamnimargus himalayensis* - Gaetani et al., p. 156.

Material and locality. 1 complete specimen (MPUM 7906), 3 ventral valves (MPUM 7902, 7903, 7904) and 1 dorsal valve (MPUM 7905) from the Gungri Fm. (lower member) at Muth (sample HS 87).

Comments. We did not observe the two or three trails arising from the marginal ridges in both valves, which seem to characterize the genus *Lamnimargus* described by Waterhouse (1975, p. 10) with type-species *Marginifera himalayensis* Diener. Furthermore, the description and illustrations of Diener do not show the multiple trails described - but never illustrated - by Waterhouse (1975, 1978). However, we retain Diener species in the genus *Lamnimargus*, due to the exiguity of the material at hand.

L. himalayensis characterizes the Late Permian of Himalaya, occurring in Nepal (Waterhouse, 1978), Spiti (Gupta & Waterhouse, 1979), Zanskar (Gaetani et al., 1990a) and of Kashmir, where it has been found in the Zewan Fm. Mb. B2 (Nakazawa et al., 1975). Waterhouse (1978, 1985) correlates the *L. himalayensis* zone with the Kalabagh member and the lower to middle Chhidru Fm. of Salt Range (Gupta & Waterhouse, 1979; Waterhouse, 1985), suggesting an Early Djulfian age (Pakistani-Japanese Research Group, 1985).

Order Athyridida Dagys, 1974

Suborder Athyrididina Boucot, Johnson & Staton, 1964

Superfamily *Athyridacea* Mc Coy, 1844

Family *Athyrididae* McCoy, 1844

Genus *Cleiothyridina* Buckman, 1906

Type-species: *Atrypa pectinifera* Sowerby, 1840

Cleiothyridina gerardi (Diener, 1899)

Pl. 1, fig. 3, 4

1899 *Athyris gerardi* Diener, p. 56, pl. 6, fig. 12-14.
1903 *Athyris gerardi* - Diener, p. 110, pl. 5, fig. 10, 11.
1985 *Himathyris gerardi* - Waterhouse, pp. 70-72.

Material and locality. 13 ventral valves (MPUM 7908, 7909) and 3 dorsal valves (MPUM 7907, 7910) from the Gechang Fm. (upper brachiopod-rich beds) at Muth (sample HS 156).

Comments. The available specimens clearly belong to *Cleiothyridina gerardi* (Diener) by the large dimensions and the flat ventral valve with a poorly defined sulcus. The species *gerardi* has been recorded as *Himathyris gerardi* by Waterhouse (1985) from the Testha Sandstone Member of the Gungri Fm. (= Kuling Fm.) in South Zanskar. According to Branson (1948) and to Grunt (1986) the species *gerardi* is here included in the genus *Cleiothyridina*.

A large species of *Cleiothyridina*, very similar to *C. gerardi*, has been described as *Cleiothyridina* sp. n. cf. *C. gerardi* by Thomas (1969) from the Hardman Fm. of Canning Basin. The age of this formation is Midian-Early Djulfian, according to Thomas (1969) and Archbold et al. (1993).

Superfamily *Spiriferacea* King, 1846

Family *Spiriferidae* King, 1846

Subfamily *Trigonotretinae* Schuchert, 1893

Genus *Trigonotreta* Koenig, 1825

Type-species: *Trigonotreta stokesi* Koenig, 1825

Trigonotreta cf. **orientensis** Singh & Archbold, 1993

Pl. 1, fig. 5

Material and locality. One ventral valve (MPUM 7911) from the Gechang Fm. (basal ferruginous conglomerate) at Muth (sample HS 155).

Comments. The transverse ventral valve of the available specimen of *Trigonotreta* is characterized by small and pointed umbo, "V" shaped ventral sulcus, 4 plications on the lateral flanks and fascicles anteriorly consisting of 3-4 costae.

The species from Spiti seems to belong to the species *Trigonotreta orientensis* Singh & Archbold, 1993 (p. 70, fig. 10 A-J), described as early Sterlitamakian (Late Sakmarian) from the Garu Fm. of the Eastern Himalaya (Singh & Archbold, 1993).

Subfamily *Spiriferellinae* Waterhouse, 1968

Tintoriella gen. n.

Type-species: *Spirifera rajah* Salter, 1865

Derivatio nominis. *Tintoriella* from the name of Dr. Andrea Tintori.

Diagnosis. Large, strongly plicate, biconvex Spiriferellinae. Hinge line rather wide, but less than maximum width. Ventral umbo recurved; ventral interarea high, with open delthyrium. Ornamentation of strong fascicles of 3-6 costae each. Interior of ventral valve with very long dental plates and adminicula and a tubercular myogliphe.

Discussion. The new genus is characterized by its open delthyrium, strongly fasciculate ornamentation and very long and high dental plates and adminicula.

Tintoriella gen. n. differs from *Spiriferella* Tschernyschew, 1902 by means of the open delthyrium, longer dental plates and adminicula which are not embedded in the apical callus; from *Elivina* Fredericks, 1924 by means of the strongly fasciculate ornamentation and the parallel dental plates; from *Hunzina* Angiolini, 1995 by means of the ornamentation and of the very long dental plates and adminicula.

Tintoriella rajah (Salter, 1865)

Pl. 1, fig. 6 - 13

1865 *Spirifera rajah* Salter & Blanford, pp. 59, 111.
1866 *Spirifer rajah* - Davidson, p. 40, pl. 2, fig. 3.
1899 *Spirifer rajah* - Diener, p. 68, pl. 4, fig. 1-7; pl. 5, fig. 1.
1903 *Spirifer rajah* - Diener, pp. 105, 131, 186, pl. 4, fig. 3-5.
1915 *Spirifer rajah* - Diener, p. 86, pl. 9, fig. 5, 6.
1941 *Spiriferella rajah* - Muir-Wood & Oakley, p. 36, pl. 2, fig. 2, 3, 9-11.
1966 *Spiriferella rajah* - Waterhouse, p. 48, pl. 1, fig. 5; pl. 3, fig. 2; pl. 7, fig. 1, 2, 4; pl. 11, fig. 2; pl. 12, fig. 2.
1978 *Spiriferella rajah* - Waterhouse, pp. 38, 88, 123, pl. 4, fig. 1-7; pl. 14, fig. 1-13; pl. 24, fig. 2.
1979 *Spiriferella rajah* - Gupta & Waterhouse, p. 11, pl. 1, fig. 10-14; pl. 2, fig. 1-10; pl. 3, fig. 1.
1985 *Spiriferella rajah* - Waterhouse, pp. 70-72.
1990 *Spiriferella rajah* - Gaetani et al., p. 156.
1994 *Spiriferella rajah* - Garzanti et al., p. 171, pl. 1, fig. 5.

Material and locality. 1 complete specimen (MPUM 7914) and 2 ventral valves (MPUM 7912, 7913) from the Gungri Fm. (lower member) at Muth (sample HS 87).

Description. Large, biconvex shell with elongated oval outline. Hinge line rather wide, less than maximum width which is anteriorly. Cardinal extremities obtuse. Anterior commissure uniplicate, with rather high fold.

Ventral valve strongly convex, with high recurved umbo. Interarea high and concave, orizontally striated with large open delthyrium. Median sulcus moderately deep, "V" shaped, widening anteriorly and producing in a tongue towards the dorsal valve.

Dorsal valve less convex than the ventral one. Fastigium low, with acute section and with a narrow median groove.

Ornamentation of ventral valve of six strong plications forming fascicles of 4-5 rounded costae on each flank. The plications bounding the sulcus are larger than the lateral ones. The ventral sulcus is ornamented by simple ribs, as is the dorsal fastigium. Concentric growth lamellae are developed anteriorly.

Interior of ventral valve (Pl. 1, fig. 8 to 13) with long, subparallel dental plates and adminicula prolonging anteriorly up to 7 mm from the umbo. They are apically embedded in the umbonal filling. A tubercular myogliphe is present at about 5-6 mm from the umbo. Muscle field deeply impressed and diamond shaped.

Comments. *T. rajah* (Salter) is common in the *"Lamnimargus" himalayensis* zone, but it may occur also higher (Waterhouse, 1978). According to this author *T. rajah* (Salter) ranges from Djulfian to Dorashamian.

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Received February 29, 1996; accepted May 29, 1996