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

EDUARDO GARZANTI, LUCIA ANGIOLINI & DARIO SCIUNNACH

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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 trasgressivi e brachiopodi. Nella regione di Spiti, questi sedimenti costituiscono la base del Gruppo di Kuling, che risposano in discordanza erosiva su formazioni più antiche, da Siluriane e Devoniane nella Valle del Parhio, a Carboniferi inferiore nella Valle del Pin, fino a ricoprire le diametrie 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 (Sincinalle di Tandi), chiude la fase di rifring e segna l’inizio dell’apertura della Neotetide tra il Gondwana e i blocchi Perigondwaniani.

Il Gruppo di Kuling a Spiti è costituito da arenarie glauconifere, conglomeratiche o contenenti brachiopodi di età Sakmariana superiore alla base e Midiana/Djulfiana inferiore al tetto (Formazione di Gechang), seguite da argilite osnofiche 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 del 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 argilite nere della Formazione di Gungri, deposite su una piattaforma aperta in condizioni climaliche calde verso la fine del Permiano, separano 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 brachiopods 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, unconformably overlie arenaceous to carbonate sedimentary units of various ages, from Silurian and Devonian in the Parhio Valley to Lower Carboniferous in the Pin Valley, whereas they conformably follow lowermost Permian diamictites in the Spiti Valley. This major unconformity, which can be traced at 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 Sakmaranian 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 Parhio 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.

- Dipartimento di Scienze della Terra dell’ Università degli Studi di Milano, via Mangiagalli 34, 20133 Milano, Italy.
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=feldspar; L=aphanitic lithic frag-

ments) 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).

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
Kuling Group, Spiti, India

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 paleo faults 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; lfs=lower ferruginous arenite; ms=middle sandstone; ubb=upper brachiopod-rich bed); GU=Gungri Fm. (lm=silty lower member; um=clayey upper member); black arrows show paraconformable boundary with Triassic Tambi Kurkur Fm. (T). B) Unconformable basal boundary (white arrow) with the Gannacha dam 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.

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 mud-
clasts 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 layers eroded 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 crinoids (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 Split Valley (Lingti, Losar).**

To the north of the confluence between the Pin and Para River, the Guling 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 Guling Fm. can be subdivided into four lithostratigraphic units. 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 bryozaoids, 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 at Guling to 2.7 m at Losar (HS 389) consist of fine-grained sandstones interbedded with siltstones.

**Lower ferruginous arenite.** These grey-green hybrid arenites (2.7 m at Guling, HS 167,168; 3.5 m at Losar, HS 388, 387) contain shell lags (bryozaoids, brachiopods, echinoderms) and abundant glaucony and other NCI grains, including silicate ooids and peloids; bioclasts are commonly glauconitized 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 12 cm-thick. Sandstones in 10 to 50 cm-thick beds are locally microconglomeratic (clasts up to 3 cm) at Guling, where low-angle stratification at locally E-W bipolar cross-lamination occurs. Dip of cross-lamine indicates NE-ward (70°N) palaeocurrents 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 mounds of spiniferid 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 Losar.

**Arenite petrography.**

The base of the Guling Fm. consists of mainly medium to very coarse-grained pebbly sublitharenites (basal ferruginous conglomerate of the Lipak Fm.). Its top is marked by a thin bed of black, fine-grained paragneiss in the Losar area.

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

Note: Q-8985 Fl±L 385, n=7, HS 83, 110, 176, 178, 179, 180, 181; basal conglomerate: Q93±6 Fl±L 856, n=5, HS 165, 166, 392, 391, 390, 389; lower ferruginous arenite: Q93±9 Fl±L 7±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 carbonatic 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, 1972). Igneous and metamorphic rock fragments are abundant. Pseudomorphs and altered grains occur (7±10%). Cr-rich chromian spinel [Cr/(Cr+Al) 0.79±0.09] was found at Losar (HS 387). Mudclasts, ilite 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
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±15% 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%).
Late Sakmarian
Pseudoabatostomella comm. *ridina* S.Sakagami, Archbold, Archbold, Fossils

The Trepostomata (P1. Himaiaya and Guling and Psui:pseudomatrix; Qsb-embayed; "Ritung 4-3 - €.0 1.0 5.7 €.0 1.3 3.7 11.0 3.0 GSZ:grain size (in µm); SRT=sorting (W = good; M = moderate; P = poor).

Tab. 1 - Detrital modes for the Kuling Group in Spiti and Lahaul. C = Chumik Fm.; other acronyms as in Fig. 3. Q=quartz (Qt=single; Qb=embayed; Qt,p=polycrystalline); Pf=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-extrusive and intra-basinal grains (C=carbonate; NC=non-carbonate); HM=heavy minerals and micas; Pseudopseudomatrix; Lithozime at Muth; other abbreviations are given in the text. See also Figs. 1-3 for lower Permian and Upper Triassic sequences of the study area.

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 (Sterlitamaikian) age and cool climatic conditions (Singh & Archbold, 1993).

TrepSimonata 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 braconnioid-rich beds. The spiriferid Cleiothyridina genardi (Diener, 1899) constitutes a monospecific assemblage found at the base of the lithozone at Muth, reflecting unfavourable sandy substrates; a Late Permian (Midian/Early Dujflian) 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 Sakmorian to the Midian or even Early Dujflian, 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 Sakmorian (basal ferruginous conglomerate) to Midian/Early Dujflian (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 braconnioid-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.
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 genardi (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 - Tintorie rajah (Salter), ventral valve in: 6) ventral view, specimen MPUM 7912; 7) posterior view, specimen MPUM 7912.
Fig. 8-13 - Tintorie 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.
Kuling Group, Spiti, India

Permian bryozoans from the Kuling Group in Spiti and Zanskar (determinations by S. Sakagami, 1995).

Gechang Fm. in Spiti (basal ferruginous conglomerate at Lingti, HS 190; lower ferruginous arenite at Losar, HS 387): A) Tropostomata 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 a7; 25x, 1N); D) Rhombopora sp. (HZ 47; 50x, 1N); E) Polypond sp. (ZZ 6; 62x, 2N); F) Sulcoretepora sp. (HZ 47; 40x, 1N).

Provenance.

The Gechang Fm. mostly consists of quartzose sub-litharenites 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...
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).

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

**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 Productus and subordinately spiriferid brachiopods (2.5 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 [*"Lamminargus" himalaysis* (Diener, 1899)] brachiopods, collected in the first phosphatic bed of the lower member (11 m above the base of the unit at Muth), indicate warm water conditions during the Early Djulflan.

Ammonoids of Djulflan age (*Cyclolobus walker* 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 Djulflan in age.

**Depositional environments.**

The unit accumulated in offshore shelf environments only episodically disturbed by major (upper member) to exceptional (lower 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 paleoecologic 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:
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 describe 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 paleontologic significance is apparent: the Ganmachidam Diamictite, originally defined in the Losar area of Spiti by Srikantha (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 Srikantha 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 oxides (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 86, 87, 74, 75, 53, 41, 43, 31, 32, 38, 9) are up to coarse-grained and contain a variety of NCI peloids (Garzanti, 1991) (Fig. 10A). Interebbed placers are strongly enriched in higher-density heavy minerals such as rutile and chromian spinels [yellow-brown Al-rich to dark red Cr-rich picrites, 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 ruffaceous rocks (ZG 55, 56) directly overlain by the Panjal Trap lavas.

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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. (1982) 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 (Jinch-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 Jinch-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
538), commonly capped by up to coarse-grained condensed glauco-
phosphorites (ZZ 6, 18, HZ 47); these layers contain commonly glau-
conized bryozoa, brachiopod shells and spines, echinoderm remains,
siliceous sponge spicules, benthic foraminifers, greenish phyllosilicate
to cherty peloids, silt to arenaceous lithoclasts and pyrite (Fig. 10D).

At Phugtal the formation is largely represented by poorly fossi-
iferous and cross-laminated coarse-grained calcareous siltstones (about
10 m; H 171, 172), capped by a bioclastic horizon. Thickness is grea-
ter east of Phugtal (Baud et al., 1984; Nicola 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 volca-
nic pebbles and glauconized bryozoa (Fig. 10C; H 134, 135), overlap-
ping by fine-grained, cross-laminated greenish sublithoclastites with
green peloids, enriched in echinoderms and partially silicified brachi-
opods in the upper part (H 136, 137, 138, 139, 140, 141, HZ 287, 288).
The upper lithozone (2.6 to 2 m; H 139, HZ 288b, 289) consists of
sandy biooclastites with echinoderms and silicified brachiopods
(Garzanti, 1986a).

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

The upper lithozone contains rich foraminaliferous
(Nodosaria (?) lagenocamerata) Sosnina, 1978, Nodosaria
sp., Protonodosaria sp., Lingulonodosaria sp., Prondicula-
ria aff. ornata Mikhluko-Maclay, 1954, E aff. dilemma
aff. Astrostocolia, n. gen. aff. Calvezia, Gerkeina (?)
sp., Geinitzina (?) sp.; det. by D. Vachard, 1995) and
bryozoan (Dyctiella 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 “Laminargyas” himalayensis (Diener, 1899), Ti
ntoriella 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 inshoreface to rapidly deepening shelf envir-
nonments after the end of rift-related magmatic activity.
Up to coarse-grained fossiliferous glauco-phosphorites
are roughly coeval with similar NC1-rich arenites in Nep-
Gazzanti 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 pa-
leontologically as post-Sakmarian and pre-Median. This
is consistent with the late Early Permian age ascribed to
the Panjal Traps in Kashmir (Nakazawa et al., 1975; Srik-
anta & Bhargava, 1983), but is at odds with the latest
Permian (Tatarian) age recently given by Veever & Te-

Gungri Formation.

The unit (Waterhouse, 1985; Gaetani et al., 1990a)
consists of black shales rich in brachiopods and phos-
phatic nodules; burrowed phosphatic and chloritic silt-
stones or silty micrites with sponge spicules and crin-
oids are intercalated. Thickness is 21 to 33 m in the
Jinch-Tanzee area and 17 m east of Phugtal (Baud et al.,
1984); to the northwest (Phugtal, Thongde) it is tec-
tonically reduced to only a few m.

Megasteges nepalensis and Aulosteges dalhouisi indi-
cate 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 uncon-
formably overlies a reduced Carboniferous section,
consisting of recrystallized carbonates (Lipak Fm.) locally
followed by quartzites (Po Group; Stutz, 1988, p. 41)
or even diamicites (Fuchs & Linner, 1995, p. 670).
The basal crinoidal marbles, up to 40 m-thick, contain at the top phosphate nodules, corals and brachiopods of Djulfiian 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. *nitensiti*), 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 sandstones (upper lithozone; 10 m). Dark green, glaucony- and phosphate-bearing arkoses rich in the cold-water scyphozoan Panacraulis a sp. also occur (Fig. 12B).

The cold Gondwanian fauna reported from the base of the Kuling Group by Srikanthia 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 cherry 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 Gecham Formation (25 m overall) consists of cross-laminated quartzose sandstones (15 m), followed by hybrid arenites (about 10 m) rich in brachiopods of Early Djulian age (Tintoriella rajab, "Lamnirnargus" 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 Gecham Fm. in Spiti (i.e., middle sandstone, upper brachiopod-rich beds, topmost ferruginous arenite).

The base of the Gecham Fm. includes medium-grained and well-sorted calcite-carbonates (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 & Ahiwuialia, 1979; Vannay, 1993); overall thickness decreases towards the northwest from 40 to 50 m to only 15 m.

Intercalated at the base of the Gungri Fm. are very fine-to-fine-grained subarkoses (Q 82 F 15 L 52, L 312, 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 Puchanpa Fm. in Dolpo (lower-central part of glauco-phosphorites and black shales: Q 81 F 17 L 2; Scinnach & Garzanti, 1990).

Tandi and Mulkila Synclines.

In the Tandi Syncline (lowest Chandra Valley), about 40 m-thick and strongly deformed transgressive marine sediments of Permian age (Rape Member of the Kukti Fm.; Srikanthia & Bhargava, 1979; Prashra & Raj, 1990; Fuchs & Linner, 1995) unconformably overlap the Upper Precambrian-Cambrian Ph. 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 Gecham 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 lowest 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 Ph. Fm. in the Tandi syncline (Vannay, 1993). The complete Ordovician to lowest Permian succession was eroded also in Zanskar west of Phugtal (Srikanthia 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 (Hein & Gansser, 1939; Sinha, 1989). Further to
the unconformity from the black Permian bet, et al., quartzarenites unconformably and locally varied. (Kuling Group) and the Devonian Muth Quartzarenites (M) respectively. White arrows indicate the two phosphatic siltstone bands in the lower member of the Gungri Fm. (GU).

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.

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; Kinnear; 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 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 Kinnear, 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).

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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-Jura/Tournaisian rift unconformity (Garzanti & Sciunnach, 1996; Sciunnach & Garzanti, 1996). At several places (i.e., western Zanskar, Tandi, Parahio...
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., 1999a, 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 & McGrew, 1992).

At this stage, the Panjal Trap basaltic lavas and similar subalkaline 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 asthenosphere 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. 12E).

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 & McRerow, 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 "Val-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 backstepping ("give-up") black shales of the Djulfian Gungr 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 Indian 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 (Stampfl 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 alkaline 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 Parabio 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; Gunthi, 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 Paleozone 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 drift 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 NCl-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 paleoautlants 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.

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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.
1905 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.
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.
1983 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 in 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 Djulian age (Pakistan-Japanese Research Group, 1985).

Order Athyridida Dagys, 1974
Suborder Athryiditina Boucot, Johnson & Staton, 1964
Superfamily Athyridacea McCoy, 1844
Family Athyrididae McCoy, 1844
Genus Cleiothyridina Buckman, 1906
Type-species: Atlryris perotti Sowerby, 1840

Cleiothyridina gerardi (Diener, 1899)
Pl. 1, fig. 3, 4

1899 Atlryris gerardi Diener, p. 56, pl. 6, fig. 12-14.
1903 Atlryris gerardi - Diener, p. 110, pl. 5, fig. 10, 11.
1985 Hima lottery gerardi - Waterhouse, pp. 70-72.

Material and locality. 13 ventral valves (MPUM 7908, 7909) and 3 dorsal valves (MPUM 7907, 7910) from the Gecchag Fm. (upper brachiopod-rich bed) 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 Hima lottery gerardi by Waterhouse (1985) from the Testa Sandstone Member of the Gungri Fm. (Kulung 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 Djulian, 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 Gecchag 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
Applications 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 adnicipula and a tubercular myoglyphe.

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

Tintoriella gen. n. differs from Spirifera Tschernyschew, 1902 by means of the open delthyrium, longer dental plates and adnicipula which are not embeded in the apical callus; from Elwina 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 adnicipula.

Tintoriella rajah (Salter, 1865)
Pl. 1, fig. 6-13

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 Gungru 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. Fas- tigium low, with acute section and with a narrow median groove.

Ornamentation of ventral valve of six strong pli- cations 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 adnicipula prolonging anteriorly up to 7 mm from the umbo. They are apically embedded in the umbonal filling. A tubercular myoglyphe 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 "Lamnimmargus" himalayensis zone, but it may occur also higher (Waterhouse, 1978). According to this author T. rajah (Salter) ranges from Djulfian to Doraschamian.

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