Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 83 (1990)

Heft: 1

Artikel: Permo-Carboniferous stratigraphy in SE Zanskar and NW Lahul (NW Himalaya, India)

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DOI: https://doi.org/10.5169/seals-166581

Eclogae geol. Helv. 83/1: 143–161 (1990)

0012-9402/90/010143-19 $ 1.50 + 0.20/0
Birkhäuser Verlag, Basel

Permo-Carboniferous stratigraphy in SE Zanskar and NW Lahul (NW Himalaya, India)

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Key-words: Carboniferous, Permian, Stratigraphy, Himalaya, Brachiopoda, Bivalvia, Sandstone petrography.

ABSTRACT

The sedimentary and volcanic succession cropping out in SE Zanskar and NW Lahul, lying between the Lower Carboniferous Lipak Fm. and the Lower-Middle Triassic Tamba Kurkur Fm., is described. Four units are distinguished. In ascending order they are: Po Fm., Chumik Fm., Panjal Traps, and Kuling Fm.

The Po Fm. consists of alternating whitish quartzarenites and black splintery shales. These are interpreted as formed in a near-shore environment, with clastic input from a cratonic source. The age is Middle-Late Carboniferous. In the next higher Chumik Fm. (new name proposed here) two members are distinguished. Member A consists of dark green to brown glauconitic sandstones, with occasional arenitic limestones and siltstones containing *Megadesmus, Neochonetes* and *Neospirifer,* a fauna of Sakmarian age. Rare volcanic detritus suggests that rift volcanism began during the Early Permian. Member B contains quartzose microconglomerates in metric cycles of alluvial origin. The effusion of the Panjal Traps took place in rifted valleys, whilst on rift-shoulders, as at Spiti, there was erosion or non deposition. Marine sedimentation returned during the Late Permian with the Kuling Fm. Two members, arenaceous and shaly, may be distinguished. The brownish sublitharenites of the Gechang Member contain a *Spiriferella/Lamnimargus* fauna of Early Djulfian age. The basal part of the shaly Gungri Member contains phosphatic nodules with rare *Aulosteges* of Late Djulfian age. The Kuling Fm. records a passive margin subsiding into progressively deeper and cooler water, with low sedimentation, low oxygen concentrations and upwelling. Sandstone petrography and diagenesis of sedimentary units are also discussed.

RÉSUMÉ

Une analyse détaillée des terrains sédimentaires et volcaniques du SE du Zanskar et du N du Lahul nous a amené à distinguer, entre la Formation de Lipak du Carbonifère inférieur et la Formation de Tamba Kurkur du Trias inférieur à moyen, quatre Formations, respectivement, de bas en haut, Po, Chumik, Panjal Trap et Kuling.

La Formation de Po (Carbonifère moyen à supérieur) consiste en une alternance de quartzarénites claires et de «shales» noires. L'environnement du dépôt est considéré comme côtier. La Formation de Chumik, introduite ici, est composée de deux membres, A et B. Le premier est formé d'une succession de grès glauconieux accompagnée de rare niveaux de calcaires gréseux et de silitites contenant une faune assez riche *(Megadesmus, Neochonetes* et *Neospirifer)* qui indique un âge Sakmarien (Permien inférieur). L'apparition de rares éléments volcaniques nous permet de situer là le début de la phase de rifting. Le second membre contient des cycles métriques de microconglomérats quartzeux d'origine alluviale. Les épanchements des Panjal Trap sont localisés dans l'axe du rift, alors que les épaulements du rift sont le siège d'une érosion ou d'une absence de dépôts, comme dans la région de Spiti. La reprise de la sédimentation marine se produit pendant le Permien supérieur avec la Formation de Kuling. On peut distinguer un membre gréseux et un membre argileux. Les sublitharénites brunâtres du Membre de Gechang ont livrés une faune à *Spiriferella* et *Lamnimargus,* d'âge Djulfien inférieur. Des nodules phosphatés de la partie basalé du Membre de

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Gungri contiennent de rares *Aulacosteges* d'âge Djulfien supérieur. La Formation de Kuling témoigne de l'effondrement de la marge passive dans un environnement d'eaux de plus en plus froids et profonds, dans des conditions de faible sédimentation, de faible oxygénation et d'«upwelling». La pétrographie des grès, ainsi que l'évolution diagénétique des unités sédimentaires sont également discutées.

Introduction

Carboniferous and Permian rocks crop out widely in Zanskar and Lahul, mostly forming the sole of the Zangla Nappe (Baud et al. 1984). However, complete and less metamorphosed or tectonized sequences may be found only in the area between Phugtal and the Upper Lingti Valley (Fig. 1). The upper part of the Permian succession, i.e. the Panjal Traps and Kuling Fm., are usually better exposed.

The aim of the present paper is to describe the main stratigraphic and sedimentologic characters of the sequence lying between the Lipak Limestone, of Early Carboniferous age, and the Tamba Kurkur Formation, of Early to Middle Triassic age. Palaeontological descriptions will be given elsewhere.

Previous knowledge

Following the reconnaissance papers of Stoliczka (1866) and Lydekker (1883), studies on Permian rocks in Zanskar and Lahul came to a halt, major interest being

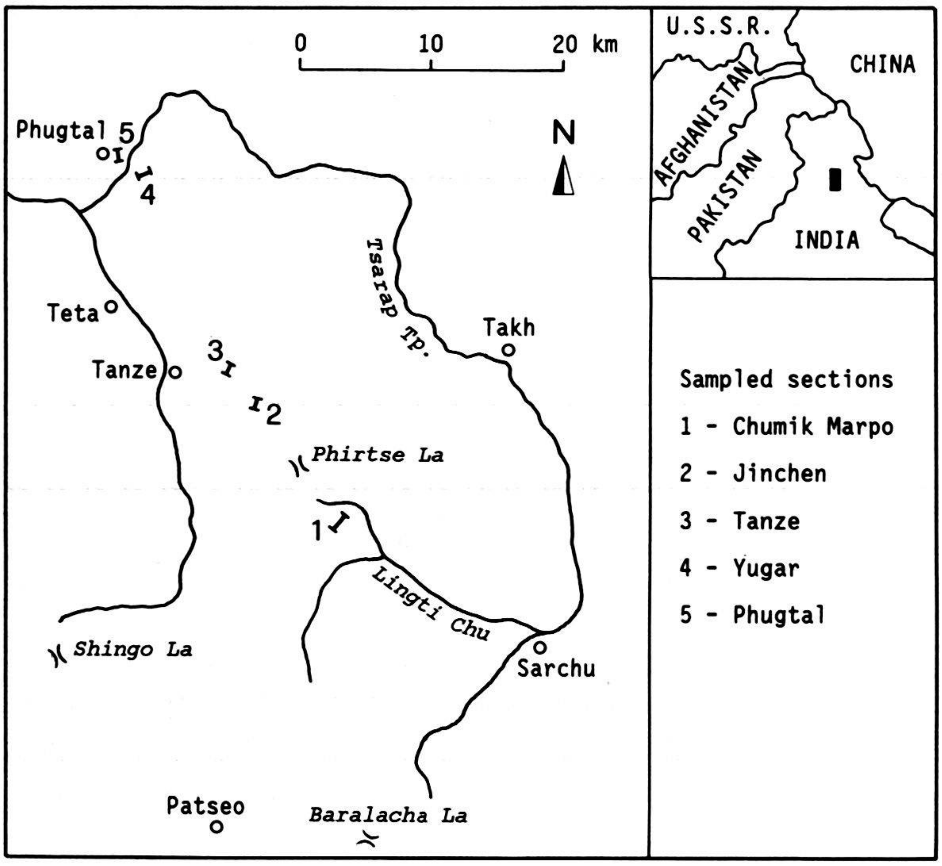


Fig. 1. Index map of the area under consideration in SE Zanskar and NW Lahul.

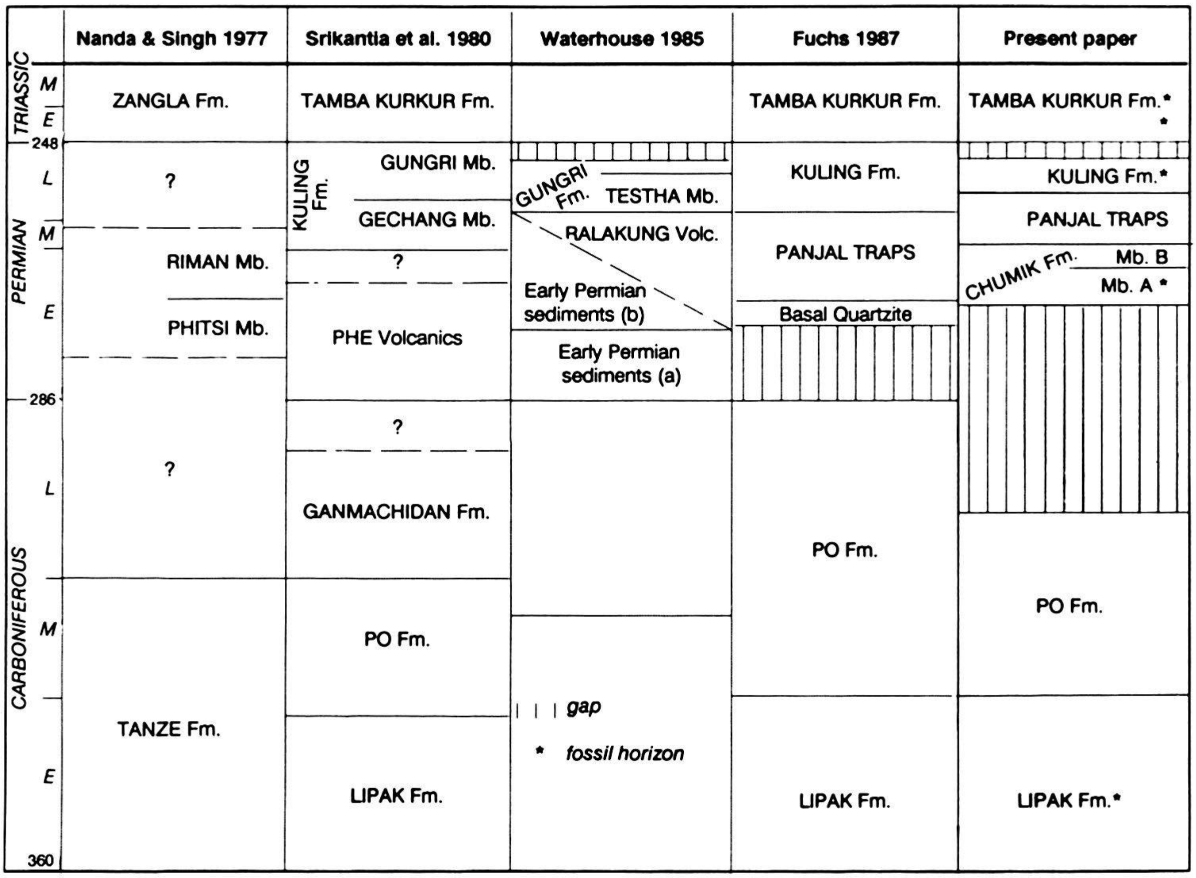


Table 1: Comparisons of the stratigraphic nomenclatures proposed for the Carboniferous and Permian of Zanskar and NW Lahul. (We prefer to disregard papers by V.J. Gupta, because of the inconsistency of his data; Talent 1989; Lewin 1989; Ahluwalia 1989; Gaetani et al. 1986; Whittington 1986).

transferred to the neighbouring region of Spiti (Hayden 1904). Studies resumed in the nineteenseventies were described in a number of papers (Nanda & Singh 1977, Singh et al. 1978, Gupta & Waterhouse 1983, Takhur & Gupta 1983, Waterhouse 1985). They proposed several new lithostratigraphic schemes, but without accurate and measured stratigraphic sections. A different approach was followed by Srikantia et al. (1980), Nicora et al. (1984), Gaetani et al. (1986) and Fuchs (1987), who tried to use the same stratigraphic nomenclature as that of Spiti. Table 1 compares the terminology adopted by previous authors with that used in the present paper.

We recognize four main units in the interval between the Early Carboniferous limestones (Lipak Fm.) and the base of the Triassic carbonates (Tamba Kurkur Fm.) in SE Zanskar and NW Lahul. In ascending order, they are:

1. **Po Formation:** alternating whitish quartzarenites and black splintery shales.
2. **Chumik Formation:** Dark green to brown glauconitic arenites, with few arenitic limestones and siltstones near the base, containing *Megadesmus, Neochonetes* and *Neospirifer* (Member A). Quartzose microconglomerates in metric cycles above (Member B).

3. **Panjal Traps:** Lava flows of basaltic composition with tholeitic-subalkaline affinity.
4. **Kuling Formation:** Dark splintery shales, overlying brownish sublitharenites, with a sparse *Lamnimargus/Spiriferella* fauna.

Po Formation

Name. The unit was introduced in Spiti by HAYDEN (1904), for a mainly terrigenous sequence in which he distinguished, from top to bottom:
— carbonaceous shales intercalated with quartzarenites, locally extremely rich in *Fenestella;*
— quartzarenites interbedded with black shales, in a coarsening upward megasequence, several hundred metres thick.

Lithology. In Zanskar and NW Lahul, this unit is often affected by faulting and thrusting. So we could not assess whether *Fenestella* Shales are present or not. The general picture fits well with the Spiti sequence except for the thickness, which is much reduced.

Two lithozones may be recognized, from bottom to top:

a) Well bedded, dark grey sandstones with subordinate silty marls. Lenticular beds frequently display parallel or low-angle cross-lamination. Bioclastic layers and burrows are present at the base. The thickness is about 20 m. This lithozone was observed mostly above Tanze, whilst it is missing or tectonically reduced to thin slices in the Chumik Marpo area. Brachiopod, echinoderm and bryozoan fragments were observed in bioclastic lenses. Rare bioclastic hybrid arenites with quartz extraclasts may also be found at the top of the lithozone.

This lithozone may represent the basal transition from the shallow-water carbonates of the Lipak Formation.

b) Fine to coarse-grained, whitish quartzarenites in small to thick beds with festoon cross-lamination. In the lower part, they are arranged in thickening-upward sequences up to 15 m thick. Towards the top the lithozone smoothes out into lenticular, thinner bodies a few meters thick. These are interbedded with planar, thin and finer quartzarenitic beds and black splintery shales. The latter are subordinate in the lower part, but increase upwards in thickness until the sandstone/shale ratio approaches unity. The Chumik Marpo section (Fig. 2) is about 125 m thick, whilst in the Tanze area the unit is tectonically reduced. No identifiable fossils were detected in this unit.

Sandstone petrography. 300 to 400 grains were counted on 11 samples, according to both traditional and GAZZI-DICKINSON point-counting methods (INGERSOLL et al. 1984). Main petrographical parameters are after DICKINSON (1970) and textural nomenclature after FOLK (1980).

The Po sandstones are fine to medium grained, laminated or locally bioturbated, moderately to well sorted, submature to supermature, white quartzarenites (average composition Q=99, F=tr., L=tr.). Quartz grains are mostly monocrystalline (Composite to total Quartz ratio, $C/Q \leq 0.10$) and occasionally show embayments due to magmatic resorption or leaching in tropical soils (CROOK 1968). Among the other framework grains, volcanic (mainly felsitic) and possibly metamorphic and arenaceous rock fragments occur, while feldspars are very rare. White micas are frequent, and up to

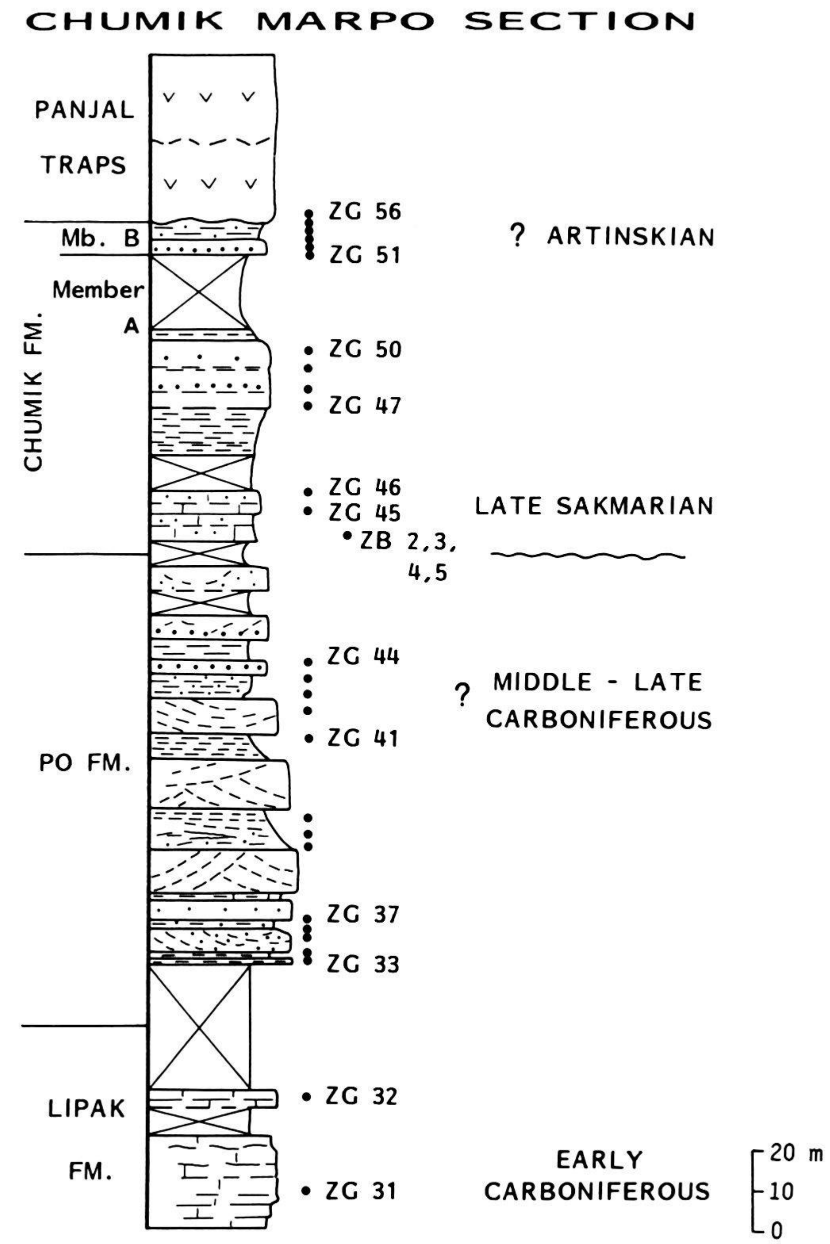


Fig. 2. The Chumik Marpo section is the most completely surveyed so far in Zanskar and NW Lahul through the interval between the Lipak Fm. and the Panjal Traps. An unconformity is inferred, but not observed, at the base of the Chumik Formation.

rounded tourmaline, zircon and rutile prevail among the heavy minerals. Squashed sericitic intraclasts and sericitic pseudomatrix, probably of intrabasinal origin, occur in many samples.

Primary porosity was occluded during relatively early diagenesis by syntaxial quartz cementation (often 20% to 30% of the rock), but authigenic interstitial phyllosilicates (illite or sericite) or clay introduced by organic activity (up to 20% and 15% respectively) were also recognized in most samples. Late diagenetic replacements are very subordinate.

Strong deformation and incipient quartz recrystallization during the Tertiary Himalayan Orogeny is indicated by extensive migration of crystal boundaries.

The increase in quartzose terrigenous detritus in the Po Fm., which contains only a few resistant felsitic rock fragments (Cameron & Blatt 1971), points to provenance from "continental block" crystalline sources (Dickinson & Suczek 1979). Significant amounts of detritus may have been provided by recycling of older quartzose sands, as suggested by low C/Q ratio and occurrence of arenaceous rock fragments and rounded heavy minerals.

Sedimentary environment. At the top of the Lipak Fm., shallow-water carbonates and sabkha evaporites were increasingly polluted by clayey and, rarely, sandy siliciclastic influx. Clean and pure quartz sands were deposited by the action of tractive currents in nearshore high-energy environments, as indicated by the abundance of megaripple cross-lamination. The upward increase in clay and the thinning of sand layers point to the transition to a more sheltered part of the coastal environment. Conglomerates or tilloids were never observed in the area under investigation.

Age. No direct age assignment can be made. By correlation with Spiti, a Middle-Late Carboniferous age may be inferred.

Chumik Formation

Name. An alternative could be the term Ganmachidan Fm., introduced by Srikantia (1974 unp. rep., et al. 1980, 1982) to designate the conglomerate-bearing beds disconformably overlying the Carboniferous Po Fm. in Spiti. The same unit was called Losar Diamictite by Ranga Rao et al. (1984). Srikantia extended this unit to Lahul and Zanskar to include the terrigenous sequence between the Po Fm. and the Panjal Traps. Other authors failed to recognize the unit in the Zanskar Range, or included it in the Po Fm. Srikantia, however, ascribed a Late Carboniferous age to this unit, and described in Zanskar an abundance of sediment-derived conglomerates, with 50% quartzite and 20% carbonate pebbles, that we never found. The Agglomeratic Slates of Kashmir could also be equivalent in part, but the most typical facies, the pebbles embedded in abundant matrix, are missing here. Thus, to avoid miscorrelations, we feel obliged to introduce a new term, for the mostly terrigenous sequence lying between the Po Fm. and the Panjal Traps.

Lithology. Two members may be distinguished: a calcareous, shaly and arenaceous sequence below (Member A), and a microconglomerate unit above (Member B) (Figs. 3, 4).

Member A

Lithology. Three lithozones have been detected, from bottom to top:

a) Grey-brown siltstones, hybrid fine sandstones, splintery black shales, passing upwards into thin-bedded, bioturbated, arenaceous limestones. Brachiopods, bivalves and gastropods may be locally abundant. Thickness 15–20 m.

b) Coarsening-upward grey and green siltstones in metre-thick parallel-laminated or locally bioturbated beds of glauconitic arenites and thin veneers of microconglomerates. Thickness 30–35 m.

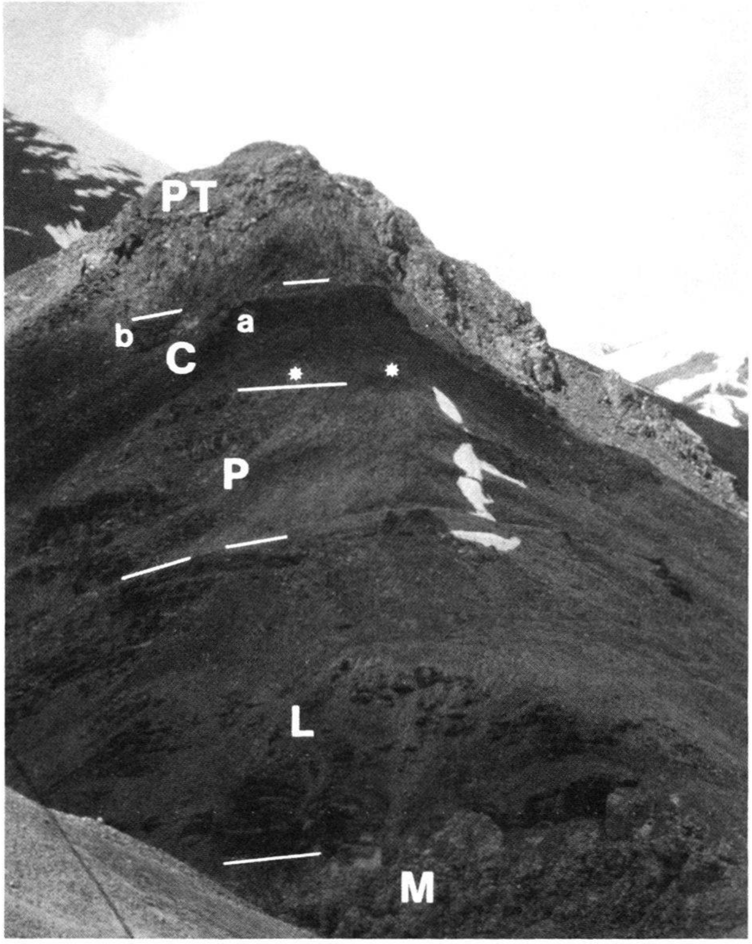


Fig. 3. The ridge along which the Chumik Marpo section was measured as seen from the ENE. The Lingti river is to the right of the picture. Bottom to top: M=Muth Quartzite; L=Lipak Formation; P=Po Formation; C=Chumik Formation, a=Member A, b=Member B; PT=Panjal Traps. The asterisks indicate the fossiliferous localities ZB at right and ZG at left.

c) Black and green shales and siltstones, occasionally with fossil fragments, usually poorly exposed. Maximum inferred thickness 10–15 m.

Sandstone petrography. The Chumik Member A sandstones are very fine to fine-grained, poorly to moderately sorted, immature to submature greensands (average composition Q=90%, F=tr., L=10%).

Half of the rock is made of mainly monocrystalline, locally embayed quartz grains (C/Q≤0.15), largely predominating among the extrabasinal grain population, whereas the other half largely consists of glaucony grains or of a green to brown "matrix" and pseudomatrix. Feldspars occur only in traces, whereas among the lithic population, some volcanic (mainly felsitic) and a few metamorphic (slate, paragneisses) rock fragments occur. Frequent white and chloritized mica flakes and up to rounded, ultrastable heavy minerals were also recorded. Mud intraclasts occur in several samples and chamosite-goethite iron ooids are found in abundance in the lower part of the unit. Quartzose bioturbated bioclastic siltstones with crinoids, gastropods and bivalves, yielding muscovite and biotite flakes, occur near the base. Volcanic clasts replaced by a

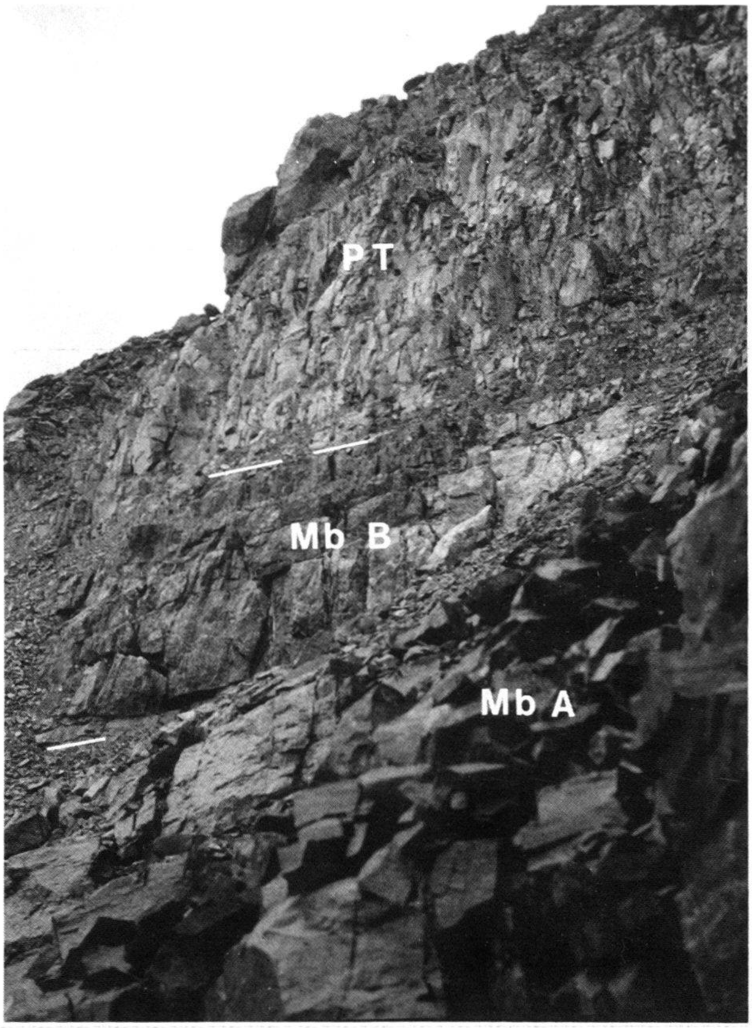


Fig. 4. The two members of the Chumik Formation and the sharp contact with the Panjal Traps.

greenish phyllosilicate paste are estimated to represent 5% to 10% of the framework. Diagenetic phyllosilicate replacements partly affected even quartz grains. Quartz cement and authigenic calcite or opaques make up a few percent and about 10% of the rock, respectively.

Incipient quartz recrystallization and the occurrence of mica beards testify intense anchimetamorphic deformation during the Tertiary Himalayan Orogeny ("Zone of quartzitic structures" or early metagenesis; Kossovskaya & Shutov 1970). The abundance of sericite, with alteration of detrital micas and incipient growth of muscovite lamellae, and the occurrence of stilpnomelane and epidote, testify the attainment of upper anchizonal conditions at temperatures of about 300 °C (Garzanti & Brignoli 1989).

Although quartzose detritus still predominates, the occurrence of glauconized volcanic grains points to the onset of volcanic activity at this stage.

Paleontological content. A highly significant fauna was found in the lowest part of the unit. The fossil locality lies on the spur immediately east of the Chumik Marpo yak alpage, on the right side of the Lingti Chu, at 4,900 m altitude (Fig. 3). The fauna identified is the following (See also Fig. 5).

1. Isolated blocks on the northern ridge (samples ZB 1–5):

Scyphozoa: *Paraconularia* sp. ind. (1 specimen).

Brachiopoda: *Neochonetes* sp. *A* (37 specimens); *Neochonetes* sp. *B* (5 specimens); *Neospirifer kimsari* (BION 1928) (1 specimen); *Cyrtella nagmargensis* (BION 1928) (1 specimen), *Trigonotetra* sp. ind. (1 specimen).

Bivalvia: *Parallelodon brenensis* REED 1932 (6 specimens); *Megadesmus* sp. (3 specimens).

Rostroconchia: *Conocardium* (1 specimen).

2. Sample ZG 45 (collected in the measured section, probably lying above the previous samples):

Brachiopoda: *Neospirifer kimsari* (2 specimens).

Bivalvia: *Parallelodon brenensis* (3 specimens); *Aviculopecten cunctatus* REED 1932 (1 specimen).

3. In the scree below the ZG 45 bed were also collected:

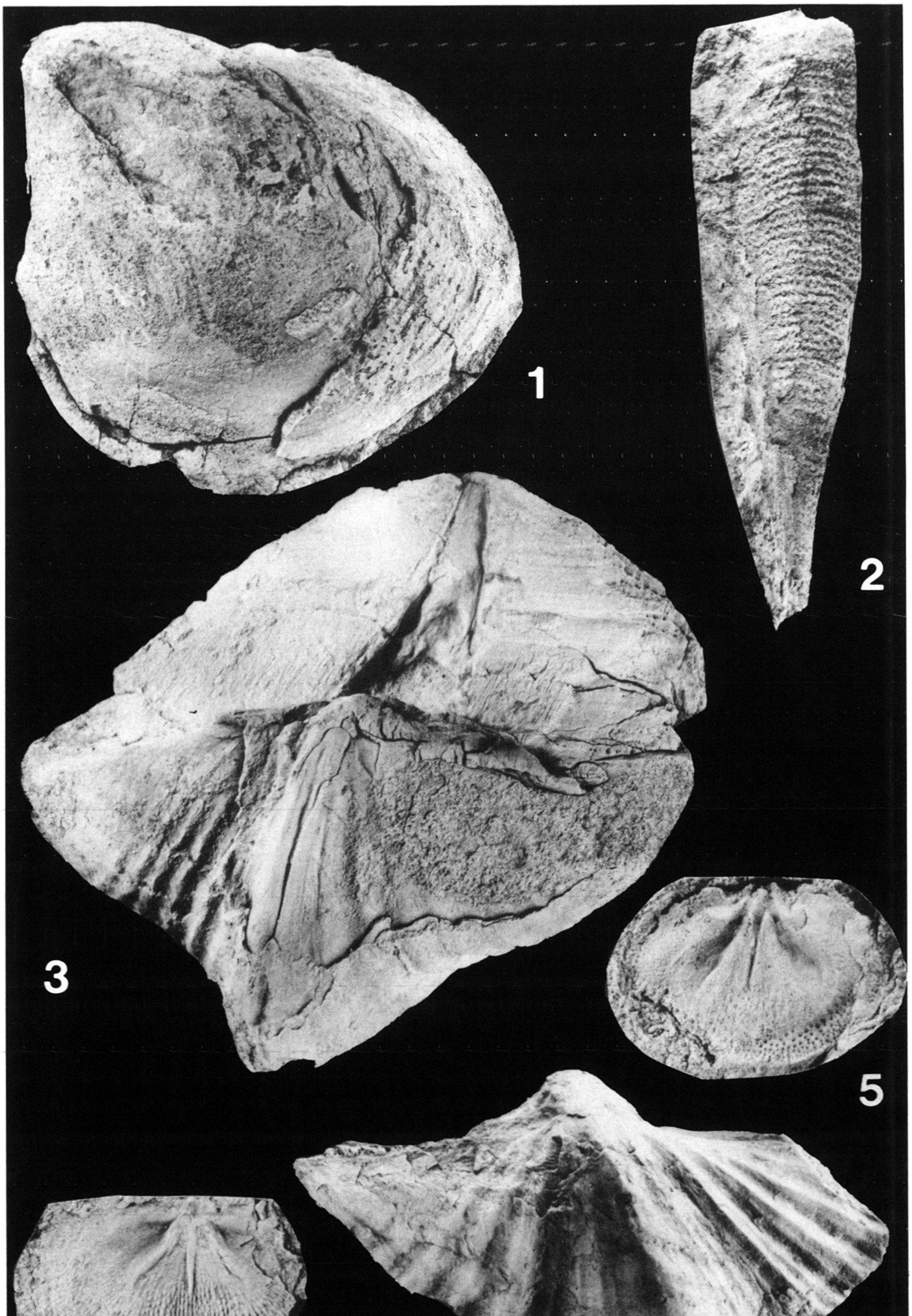
Brachiopoda: *Neochonetes* sp. *A* (9 specimens); *Neochonetes* sp. *B* (5 specimens); *Neospirifer kimsari* (3 specimens); *Cyrtella nagmargensis* (3 specimens); *Dielasma* cf. *lidarense* (DIENER 1915).

Bivalvia: *Myonia (Pachymyonia)* sp. ind. (1 specimen).

Faunal differences between the blocks on the northern ridge and the arenaceous limestones may be due to difference in age, or to environmental control. The muddier bottom contains more endobiontic bivalvia and a few Spiriferids. It also contains dominantly the genus *Neochonetes,* which would indicate a very marginal and shallow water environment (ARCHBOLD 1981). The total lack of Productids in these outcrops, should also be pointed out a fact which could be related to a very shallow and muddy sea-bottom. The fauna examined contains, but is not dominated by, *Megadesmus* and *Conularia* which are usually considered as cold climate indicators (DICKINS & SHAH 1979). Brachiopods would indicate a warmer environment. Consequently, as reported from other Himalayan localities, the Chumik Marpo fauna may be considered a mixed fauna of temperate climate (ARCHBOLD 1988, pers. comm.).

Age. This fauna is Permian. In a broad sense it correlates with the Nagmarg and the Bren Spur faunas in Kashmir (BION & MIDDLEMISS 1928; REED 1932). All the species found, but for *Neochonetes,* are present in Kashmir, some in Nagmarg, some others in Bren Spur. Concerning this latter locality, correlations from Zanskar may be made especially with the lower-middle part of the levels surveyed by THOMPSON, whose fauna was studied by REED (1932). The Kashmir faunas need revision, however, they have been considered mostly as Sakmarian, except for the lowest *Megadesmus* fauna which could be regarded as Asselian (DICKINS & SHAH 1979; ARCHBOLD & GUPTA 1986). Consequently, the fauna from Chumik Marpo is ascribed to the Sakmarian, possibly Late Sakmarian (Sterlitamakian).

Environment. The Member A of the Chumik Fm. consists of marine sands and muds deposited in a shallow embayment and coastal flats, in which transgressive carbonate layers interfinger with reworked continental detritus. The glauconitic arenites may be considered as "transgressive system tract" sands (HAQ et al. 1987; GARZANTI et al. 1989), indicating slow deposition during rapid eustatic rise. If the age assignement is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correct, their deposition could coincide with the major worldwide transgression at the end of the Gondwana glaciation (Frakes et al. 1975; Martin 1981; Veevers & Powell 1987).

Member B

Lithology. Microconglomerates with quartzitic pebbles up to a few cm in size, arranged in festooned high-angle cross-bedded cycles. Fining-upward cycles are up to 3 m thick and display flat paraconformable bases and sandy to silty top layers. Green and black tuffaceous angular chips are frequently included within the rounded conglomerates. The thickness of the Member B is about 10–15 m. Fuchs (1987) was the first to recognize the presence of the conglomerates immediately below the Panjal Traps, but he did not separate them nomenclaturally.

Sandstone petrography. The Member B fining-upward sequence is made up of coarse-grained and submature white quartzarenites at the base, followed by very fine grained, moderately sorted and submature quartzose sandstones (average composition Q=97, F=tr., L=3) and finally by bioturbated wackes (composition up to Q=80, F=tr., L=20).

Monocrystalline quartz invariably predominates ($C/Q \leq 0.15$), but volcanic (mainly felsitic) and a few metamorphic and possibly arenaceous rock fragments also occur. Unfortunately, the very fine grain size and intense recrystallization do not allow precise assessment of detrital modes at the top of the unit, where abundant pseudomatrix of possible volcanic origin would record the rapid increase of volcanic detritus. Feldspars are virtually absent, while ultrastable or opaque heavy minerals and white micas were frequently recorded. Interstitial phyllosilicates (sericite and chlorite "epimatrix" or biologically introduced clay) are invariably abundant (15% of the rock or more). Quartz cement (decreasing upward from 10% to 0%) and late diagenetic carbonates or opaques (up to 25%) also occur.

Environment. The Chumik Conglomerate (Member B) may be interpreted as a fining-upward fluvial sequence made of basal coarse sandstones overlain by muddy interchannel deposits. Magmatic activity immediately before the effusion of the Panjal Trap basalts would be indicated by the abundant pseudomatrix at the top of the member, if this is indeed of volcanic origin.

Age. No fossils were detected in this unit.

Panjal Traps

Very few data may be added to what has been reported in Baud et al. (1984) and Gaetani et al. (1986).

The basal lava flow lies directly on the sandstones of the Chumik Fm., Member B, which show a 10 cm thick whitish band possibly due to contact metamorphism or

Fig. 5. Significant species of the Sakmarian fauna of Chumik Marpo. Fig. 1. *Megadesmus* sp. X 1.5. Fig. 2. *Paraconularia* sp. ind. X 1.5. Fig. 3. *Cyrtella nagmargensis* (Bion 1928). X 1. Fig. 4. *Neochonetes* sp. A. X 1.5. Fig. 5. *Neochonetes* sp. A. X 1.5. Fig. 6. *Neospirifer kimsari* (Bion 1928). X 1.5.

pedogenic alteration. We never observed the marine carbonatic sedimentary intercalations quoted by Nanda & Singh (1977), Singh et al. (1978). Gupta & Waterhouse (1983) described a brachiopod fauna, which subsequently was not found by Waterhouse in his 1985 traverse of the E Zanskar area. The severe faulting existing between Tanze and Chumik Marpo, partly prevents a detailed stratigraphy. However, two students from Milan University, G. Lucchini and A. Zelioli, failed to find such a sedimentary intercalation in that area, during the 1989 summer season. On the other hand, we prefer to ignore the extravagant "findings" by V.J. Gupta, like the fusulinid-bearing Sarchu Limestone (Gupta & Khaler 1973; Ahluwalia 1989).

We maintain a tectonic interpretation for the disconformity between the Panjal Traps, with or without slices of Lipak to Chumik Fms. at their sole, and the Paleozoic or Late Precambrian units. The tectonic interpretation is imposed also by Fuchs's map (1987), as may be seen in the Phugtal area, and between Tanze and Kuru. Fuchs (1987, p. 475) considers the presence of Panjal Trap dyke-swarms traversing the Lower Palaeozoic units as indicative of authoctonism. In fact this criterion is not valid if the area occupied by the Panjal Traps is much larger (Papritz & Rey 1989) than the amount of thrust shortening. Moreover, dyke-swarms, with a NW-SE trend, are present in the area between Tanze and the Baralacha La, where the Permo-Mesozoic sequence is not separated from the underlying Palaeozoic by a low angle fault. Northwest of the Tanze area, where the thrusting is more significant, dyke-swarms were not observed.

Age. The effusion of the Panjal Traps occurred between the Late Sakmarian and the base of the Late Permian, as bracketed by the collected faunas. The topmost Chumik Fm. is possibly Artinskian, restricting the age for the Panjal Traps mostly to the Middle Permian. The lavas may therefore have been erupted in a period of time of a few MA, as in the case of Deccan Traps or other flood basalts (Jaeger et al. 1989). The Zanskar succession thus may contain gaps, either at the base or at the top of the Traps, as also suggested by comparison to the Kashmir sequence (Nakazawa et al. 1975; Bossart et al. 1988).

Kuling Formation

Name. The term was introduced by Stoliczka (1866) to identify the black shales which cap the Permian sequence in Spiti (Kuling Shales). Subsequently Hayden (1904) and Srikantia et al. (1980) used the same term in Spiti and in Zanskar-Lahul. Srikantia et al. (1980) recognized two members: the Gungri Mb. for the shales above, and the Gechang Mb. for the sandstones below. Unfortunately they introduced some confusion about the age, which they supposed to be Early Permian. Fuchs (1982) proposed to extend the term Kuling Fm. in the type-area to include also the basal sandstones, labelling the whole as Kuling Formation. Nicora et al. (1984) followed Fuchs' nomenclature and produced preliminary data from several sections. Waterhouse (1985), apparently ignoring Fuchs' (1982) and Srikantia's (1982) papers, promoted the Gungri Member to formational rank, and introduced the new name Testha Member for the lower sandstones. In the present paper we retain the name Kuling Formation, with the two members introduced by Srikantia et al. (1980).

Lithology. Three lithozones may be recognized in the Kuling Fm., from bottom to top:

a) Microconglomerates in lenses of up to 0.3 m (maximum clast size 5–10 cm, modal size 2–3 cm), and greenish sublitharenites with megaripple cross-bedding showing northward paleocurrents, in a fining-upward cycle with a scoured base. Brachiopod, echinoderm, gastropod and bryozoan fragments occur. Thickness 5–25 m.

b) Hybrid arenites interbedded with arenaceous bioclastic limestones in poorly defined beds, rich in brachiopods and bryozoans. This horizon is discontinuous and black shaly interbeds increase upwards. Maximum thickness 5 m.

c) Black splintery shales with carbonate-fluorapatite cm-sized nodules randomly dispersed in the matrix. In the lower part, brachiopods occasionally occur. Maximum thickness 21 m, but often tectonically reduced.

Sandstone petrography. The angular bioclastic conglomerates at the base of the Kuling Fm. contain echinoid plates, bivalves, bryozoans, brachiopods and gastropods. All of the pebbles are oversized chlorite clasts derived from the underlying Panjal Traps, whereas most of the quartzose detritus is fine-grained. Only two quartz grains over 0.5 mm were observed, and one of them shows abraded syntaxial overgrowths, indicating polycyclic origin.

The overlying and locally bioclastic sandstones are fine to very fine-grained, well to moderately sorted and subangular sublitharenites. Counts of 250 points on 8 samples yielded an average composition of Q=88, F=2, L=10, with little variability (Q=84–91, F=1–3, L=8–13). The bulk of the framework is thus made of fine-grained quartz, locally showing vermicular chlorite inclusions indicative of hydrotermal origin (Blatt et al. 1980; Figs. 8–4). Composite to total quartz (C/Q) and plagioclase to total feldspars (P/F) ratios are less than 10%. Among the rock fragments, which are all of volcanic origin (V/L=100%), felsitic and lathwork types can be recognized. Soft oversized clasts derived from local scours into the underlying Panjal Trap tuffs are deformed and recrystallized to chlorite "pseudomatrix" (5–15% of the rock). Chlorite flakes, tourmaline, rutile and zircon were also observed, as well as various oversized bioclasts (echinoderms, silicified brachiopods, pelecypods, bryozoans).

Syntaxial quartz cements are present (up to 10%). Authigenic calcite (up to 40%) replaced both framework grains and interstitial components. Extensive post-depositional quartz recrystallization and development of Boehm lamellae, with selective alteration of strained zones, indicate high-temperature deformation during orogeny (supermature diagenetic stage; Schmidt & McDonald 1979).

The upper part of the lithozone B contains very fine-grained, well-sorted or burrowed, subangular and immature quartzose hybrid arenites (bioclastic quartzarenites or phosphatic quartzose biomicrites), with only a few felsitic volcanic rock fragments (composition Q=98, F=1, L=1). Among the bioclasts, brachiopod spines and shells (sometimes with incipient silicification), whole bryozoans, echinoderms, gastropods, thin-shelled bivalves, siliceous (mainly calcitized) sponge spicules, calcispheres and possible ostracods were recorded.

The petrography of the Kuling arenites reveals reworking in high-energy shallow-marine environments of partly polycyclic quartzose grains supplied from crystalline rocks, while the composition of volcanic detritus seems to reflect the bimodal (basaltic-rhyolitic) magmatism typical of rift settings.

Fossil content. The Gechang Mb. is usually rich in brachiopods, at least in its middle-upper part, but their preservation is mostly poor. Dyscritellid bryozoans were collected from the lithozone A in the Tanze section (Gaetani et al. 1986). Above and west of the Jinchen Camping ground, at about 4,900 m, a good exposure allowed collection of well preserved specimens.

The identified fauna is the following:
1. In the scree below the lower part of the lithozone B:
Neospirifer sp. (4 specimens).
2. In the upper part of the lithozone B:
Lamnimargus himalayensis (20 specimens), *Spiriferella rajah* (7 specimens), *Cleiothyridina* cf. *subexpansa* (1 specimen).
3. A few other specimens have been collected in the upper tectonic slice on the ridge between the Tongde-La and the Sultanlango summit, at about 5,200 m. They are *Megasteges nepalensis* (1 specimen), *Aulosteges dalhousii* (1 specimen). Owing to tectonic deformation no measurements were possible. These specimens are from the Gungri Mb. dark-grey shales, lying above Gechang sandstones yielding poorly preserved *Neospirifer* and productids.

In the Gechang Mb. two main fossiliferous horizons may be distinguished, the lower dominated by *Neospirifer* and the upper rich in *Lamnimargus* and *Spiriferella.* Preservation is also different in the two members because only in the latter level nice phosphatic internal moulds are present. The Gungri Mb. is usually barren, but for phosphatic nodules; only at the Tongde La fossils are present, again as phosphatized internal moulds.

Age. The *Lamnimargus himalayensis* assemblage is the most typical in the Upper Permian in the Himalayan region (Spiti, Dolpo, etc.), being also found in Member B2 of the Zewan Fm. at Barus (Kashmir; Nakazawa et al. 1975). Correlation with the Salt Range Kalabagh Mb. (Waterhouse 1978) suggests that age of the *L. himalayensis* fauna can be considered as Lower Djulfian (Nakamura et al. 1985; Pakistani-Japanese Research Group 1985). Regarding the *Megasteges nepalensis* assemblage, it has been found in Dolpo (W Nepal), in the *Marginalosia kalikotei* zone (Waterhouse 1977), and in the Salt Range (Assemblage C3 of the Chhidru Fm., Pak.-Jap. Res. Gr. 1985). According to the latter authors the age of the *M. nepalensis* fauna is most probably late Djulfian. Nicora et al. (1984) instead hypothesized a Dorashamian age for the shales.

Environment. Two very distinct environments are observed in the Kuling Fm. The first two lithozones may be interpreted as shallow-water transgressive deposits overlying the mainly flat surface of the Panjal Trap. The small amount of reworked volcanic clasts suggests very limited erosion of the lavas. Moreover, volcanic detritus is confined to the lower part of the unit mostly as lag in channels scoured in the underlying tuffs, while the bulk of the unit contains quartzose detritus at least partly polycyclic and ultimately derived from granitoid rocks. Large brachiopod/bryozoan communities could flourish, with some carbonate production.

Gradually, energy decreased by deepening and clastic deposits became mostly shaly. Near the base a limited brachiopod community was able to survive; higher up only pelagic forms like nautiloids and ammonoids are found. Near Phugtal, the phosphatic nodules contain also sponge spiculae. Carbonate production was near zero, and diagenesis dissolved carbonate shells, leaving only internal moulds.

Neospirifer and *Spiriferella* point to a cool water environment (NAKAMURA et al. 1985). This may be related to upwelling episodes, which is also supported by the richness in phosphorites of the middle and upper Kuling Fm. The phosphorite accretion occurred very early during diagenesis as proved by the presence of bioturbation in the nodules and brachiopod internal moulds. Burrowing organisms looked for the organic matter inside the phosphorite patches as yet not completely lithified still uncovered by other sediments. This is in agreement with observations made on modern phosphorites (PRICE 1976). They form in shelf areas (max. depth 400 m), with high primary production and sedimentary rate, usually at latitudes less than 40°, in presence of well established upwelling and prevalent oxygen-poor bottom conditions (PRICE 1976; CALVERT 1976; BATURIN 1982). This interpretation would explain why benthic brachiopods are missing from most of the Gungri Member, and the scanty opportunity for fossilization of other fauna.

Discussion

The NW Lahul-SE Zanskar area contains a stratigraphic sequence comparable in many respects to the classical sequence of Spiti.

The Carboniferous Po Formation may be interpreted as indicative of relative low sea-level, which occurred during the Late Carboniferous, connected with the Gondwanian glaciation. Any link with the Hercynian orogeny seems to us inappropriate (KANWAR & BHANDARI 1979; FUCHS 1982). The easier explanation is to consider the marine-deltaic interfingering as reflecting the sea-level fluctuations. We consider the reduced thickness of the Po Fm. and the absence of the *Fenestella* Shale in the investigated area to be due either to tectonic deformation, or to erosion or non deposition during the earliest Permian.

We cannot check if an angular unconformity is present at the base of the Permian clastics in Zanskar, as it is the case in Spiti (FUCHS 1982). The most important new point is that a marine fauna has now been found at the base of the Permian sequence in the Lahul-Zanskar Synclinorium. It is thus possible to make somewhat firmer correlations with the Kashmir area, namely with the Agglomeratic Slates. In terms of the stratigraphic schemes of MIDDLEMISS (1910) and BION & MIDDLEMISS (1928), recently revised by KAPOOR in NAKAZAWA et al. (1975) and by KAPOOR & NAKAZAWA (1981), the fauna of Chumik Marpo and consequently the base of the Chumik Fm. should be correlated with the central portion of the Agglomeratic Slates in the Bren Spur section. The occurrence of volcanic debris allows us to date the beginning of the volcanic activity as latest Sakmarian or earliest Artinskian. RANGA RAO et al. (1984) quote an assemblage dominated by *Deltopecten* and *Eurydesma* at the base of the Permian sequence in Spiti.

The Member B of the Chumik Fm. gives evidence of subaerial sedimentation. Sandstone petrography suggests cratonic provenance for the alluvial plain sandstones and possibly volcanic explosive activity, shortly followed by the thick lava flows of the Panjal Traps.

The fairly homogeneous thickness of the volcanic traps testifies a tabular morphology for the Zanskar area. The volcanic flows are apparently absent east of the Lingti, as well as in Spiti (FUCHS 1982). We are inclined to refuse the presence of sedimentary rocks interbedded with the Traps, as claimed by Nanda & Singh (1977) and Singh et al. (1978). At least at Thongde La, we were able to prove that they belong to the Permian Kuling Fm., as shown by the typical brachiopod fauna.

The Panjal Trap eruptions may have occurred between the Artinskian and the Midian. The volcanic activity could have been very short (2–3 MA) with respect to a 10–15 MA interval between the two faunal markers at our disposal. At present we cannot better constrain the Panjal Trap effusion. There are no other significant volcanics in Zanskar, below thin tuffitic layers in the Middle Triassic. Permian pillow-lavas described by Reuber et al. (1987) in the Spongtang Klippe belong to a different tectonic and paleogeographic unit, formed further seaward; most probably they are slightly younger. The Traps expanded into rift valleys, since the overlying Kuling sandstones are very poor in volcanic detritus and only locally do they cut slightly into the underlying Traps. Regional unconformities and gaps, like in Spiti, with most of the Permian and Carboniferous terrigenous units or even the underlying Lipak missing (Srikantia 1982; Fuchs 1982) suggest that the latter acted as rift-shoulder areas (Baud et al. 1989; Gaetani & Garzanti 1989) (Fig. 6).

The Kuling Fm. testifies the transgression and deepening occurring during Djulfian, which spread over the whole Himalayan passive margin. Cratonic detritus transported by streams to coastal plains, together with shallow-water reworking and a certain amount of carbonate production occurred during the deposition of the Gechang Mb. Very widespread brachiopod paleocommunities, with *Lamnimargus* and *Spiriferella,* locally associated with bryozoans, characterize this typical Late Permian horizon. Deepening, associated with a drop in carbonate production, and upwelling charac-

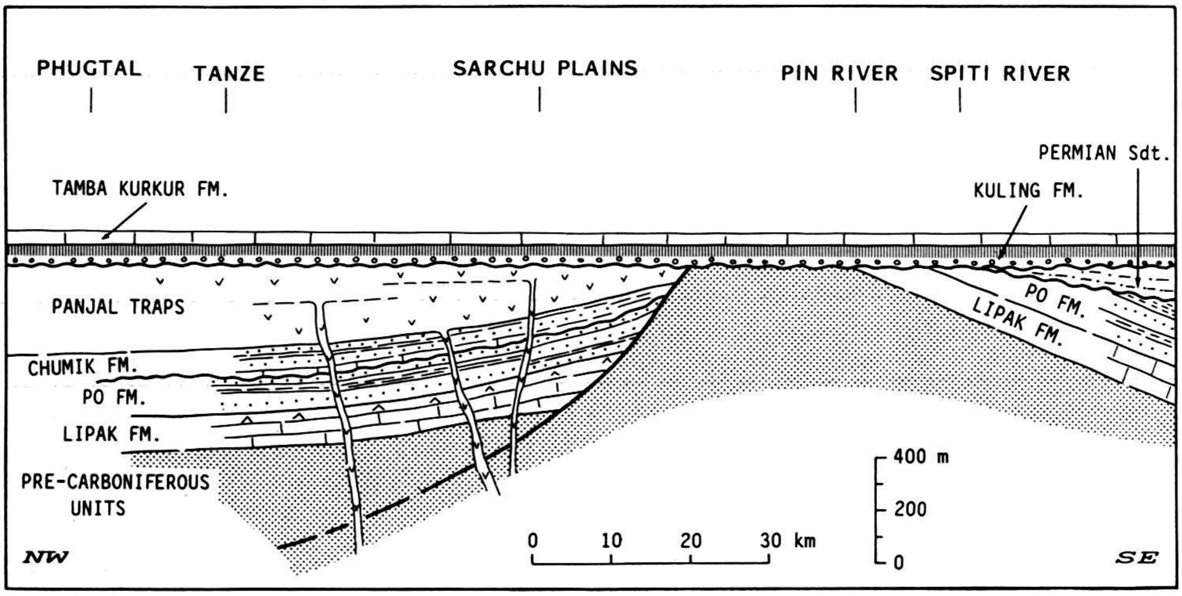

Fig. 6. Stratigraphic and paleotectonic sketch for the Permian sequence. The Zanskar area acted as a valley during the Early Permian rifting, whilst the Spiti area stood as a rift shoulder, tilted because of crustal extension. The very uniform Late Permian Kuling Fm. terminated the early rifting phase of the north Indian passive margin and thermotectonic subsidence may have brought the area into the deeper conditions of the top Kuling and Tamba Kurkur Formations. The area from west of Sarchu Plains to the NW of Pin River has no reliable survey. Consequently, the low angle fault is only inferred, but not actually observed.

terize the following Gungri Mb. The phosphatic nodules contain at their base rare brachiopods of the *Aulosteges* community, associated with sponge spicules. Upwards, carbonate shells are missing, suggesting primary or early diagenetic solution.

In this respect, there are differences compared with Spiti, where sparse ammonoids were collected within the phosphatic nodules in the black shales (Hayden 1904; Bhatt et al. 1981). We disregard the *Comelicania* occurrence, suggesting the Dorashamian, claimed by Gupta & Waterhouse (1986) in Spiti. The P/T gap is supposed to exist in Zanskar, because of the abrupt change in sedimentation, but it is not proved by fossil findings just below the boundary. In Spiti 10 cm haematitic nodules and crusts mark the sedimentation gap (Bhatt et al. 1980). The renewed carbonate production in the Early Griensbachian is testified in Zanskar by deep-water flaser nodular limestones, with a rich conodont fauna of the *Gondolella carinata/Hindeodus minutus* zone (Nicora et al. 1984). This assemblage, which is immediately followed by *G. carinata* alone, suggests in fact the Early Griensbachian, rather than the Permo-Triassic boundary.

Conclusions

The NW Lahul-SE Zanskar area provides evidence in support of the Neotethyan early rifting within the Indian passive margin.

After the Late Carboniferous regression, linked to the Gondwanian glaciation, rifting started in the Early Permian. Sandstone supply is interpreted mainly as the result of incipient extensional tectonics, which led to the uplift, to the South, of the Indian Craton and its fringe constituted by the Pan-African Orogen (Jain 1981; Jain et al. 1980; Garzanti et al. 1986). Biostratigraphy and volcanic debris enable us to correlate this phase with the middle part of the Agglomeratic Slates in Kashmir and to suggest as Late Sakmarian or Artinskian the starting of the volcanic activity. Major Panjal Trap effusions took place during Middle Permian times. In the Late Permian (? Midian-Djulfian) marine transgression sealed the horst and graben morphology in the Spiti-Zanskar Synclinorium. The area entered in a deeper-water environment during the late Djulfian. The Triassic carbonate recovering, brought the whole area into a deep-water, low deposition rate regime (Nicora et al. 1984).

Acknowledgments

We are deeply indebted to our colleagues A. Nicora and M. Balini, who helped us in the field. N. Archbold (Melbourne) and J.M. Dickins (Canberra) discussed with us problems of correlation and provided literature. M. Antoniotti and F. Perrone helped in the petrographic analysis of the Lower Permian units. M. Lucchini and A. Zelioli provided us with new field data on the area.

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Manuscript received 3 July 1989
Revision accepted 3 November 1989