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# The Geology of the Pin valley in Spiti, H. P., India

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With 21 Figures and 3 Plates (= Beilagen 4, 5, 6)

*Schlüsselwörter*
*Himalaya*
*Spiti*
*Stratigraphie*
*Paläozoikum*
*Mesozoikum*
*Tektonik*

CONTENTS

Abstract ... 326
Zusammenfassung ... 326
1. Preface ... 326
2. Stratigraphy ... 327
2.1 The Haimanta Formation and Parahio Series ... 327
2.2 The Ordovician-Silurian ... 332
2.3 The Muth Quartzite ... 337
2.4 The Lipak Formation ... 338
2.5 The Kuling Formation ... 341
2.6 The Triassic-Jurassic ... 345
2.6.1 The Scytho-Anisian ... 346
2.6.2 The Daonella Shale ... 346
2.6.3 The Daonella- and Halobia Limestone ... 346
2.6.4 The Grey Beds ... 346
2.6.5 The Tropites Limestone ... 347
2.6.6 The Juvavites- and Monotis Shales ... 347
2.6.7 The Quartzite Series and Kioto Limestone ... 349
2.6.8 The Dogger ... 350
2.6.9 The Spiti Shale ... 351
2.7 The Giumal Sandstone ... 351
3. Tectonics ... 351
3.1 The Baldar Syncline ... 351
3.2 The Muth Syncline ... 352
3.3 The Pakchung Anticline ... 352
3.4 The Mikin Syncline ... 352
3.5 The Gungri Anticline ... 352
3.6 The Ghungma Syncline ... 354
3.7 The Chhidang Anticline ... 354
3.8 The Tanjangkari Syncline ... 354
3.9 The Lingti Anticline ... 355
4. Conclusions ... 355
Acknowledgements ... 357
References ... 357

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**Zusammenfassung**

Die während unserer „Indisch-Österreichischen Spiti Expedition 1978" erforschte Geologie des Pin-Gebietes in Spiti wird in der Arbeit dargestellt. Die stratigraphischen Detailstudien in der Trias werden später veröffentlicht werden.

Stratigraphie: Die Schichtfolge von Spiti beginnt mit der Haimanta-Formation, einer mächtigen präkambrisch-kambrischen Geosynklinalserie. Die ordovizisch-silurischen Seichtwasserablagerungen liegen mit einer Winkeldiskordanz auf den Haimantas. Der devonische Muth-Quarzit markiert eine weitere Regression als Folge der kaledonischen Orogenese. Der Muth-Quarzit und die unterkarbone Lipak-Formation fehlen in Teilen des kartierten Gebietes, da sie in vor-permischer Zeit abgetragen wurden. Die oberkarbone Po-Formation fehlt im gesamten Pin-Tal. Variszische Bewegungen sind gesichert. Die unterschiedliche Entwicklung der permischen Schichten deutet darauf hin, daß die permische Transgression von NE gegen SW erfolgte. An der Basis der Otoceras-Bank ist eine geringe Schichtlücke festzustellen. Die folgenden Trias-Ablagerungen zeigen kalkig-tonige Seichtwasserfazies. Ab dem Oberkarn ist zunehmender Silt- und Sandgehalt festzustellen. Die Quarzit-Serie zeigt eine deutliche Regression im Rhät an. Der Kioto-Kalk (Rhät-M. Dogger) und die Ober-Doggerschichten sind in sehr seichtem Milieu abgelagert worden. Die Spiti-Schiefer (Malm-Neokom) zeigen tieferen Ablagerungsraum an, sie sind die jüngsten Schichten im Pin-Tal.

Überblickt man die Schichtfolge Spitis so wurde sie, abgesehen von der präkambrisch-kambrischen Geosynklinalfolge, unter Bedingungen eines Schelfs oder einer Miogeosynklinale abgelagert.

Tektonik: NW-SE-streichende Faltenstrukturen beherrschen den Bau. Die Vergenz der Faltung ist teils SW-, teils NE-gerichtet. Im Zuge der Faltung kam es in einigen seltenen Fällen zu Schuppungen. Eine Reihe junger Brüche schneidet die Faltenstrukturen, die Versetzungsbeträge bleiben jedoch im Bereich von Meterzehnern.

**Abstract**

The geology of the Pin area in Spiti (H. P.) is described in this paper. The results of the detailed stratigraphical work of our "Indo-Austrian Spiti Expedition 1978" on the Triassic formations shall be published later.

Stratigraphy: The sedimentary succession of Spiti commences with the Haimanta Formation, thick geosynclinal series of Precambrian – Cambrian age. With an angular unconformity they are succeeded by Ordovician – Silurian shallow-water deposits. The Devonian Muth Quartzite signals another regression caused by the Caledonian disturbance. The Muth Quartzite and the Lower Carboniferous Lipak Formation are missing in parts of the mapped area due to pre-Permian erosion. The Upper Carboniferous Po Formation is missing in the whole Pin Valley. Hercynian movements are proved. The differing development of the Permian indicates transgression from NE towards SW. At the base of the Otoceras Bed there is a slight gap. The succeeding Triassic formations show calcareous-argillaceous shallow-water facies. With the Upper Carnian increasing silt- und sand content comes in. The Quartzite Series marks a regression in the Rhaetic. The Kioto Limestone (Rhaet.-Mid Dogger) and the Upper Dogger beds were deposited in very shallow sea. The Malmian-Neocomian Spiti Shales, the youngest series in the Pin Valley, indicate deeper water.

Thus the Spiti succession was deposited on a shelf or in a miogeosyncline, except the basal Precambrian – Cambrian geosynclinal sequence.

Tectonics: Fold structures striking NW-SE are predominating. These folds are partly directed SW or NE. In some occurrences wedge structures formed during the folding. A series of young faults cut the fold structures, the displacement generally is some tens of meters only.

# 1. Preface

Spiti, a sub-division of the Lahaul and Spiti district of Himachal Pradesh, India, is a rather remote area in the northern Himalaya. The fossiliferous Palaeo- and Mesozoic formations of Spiti have attracted geologists as early as in the middle of the 19th Century, inspite of its remoteness. The pioneering work by STOLICZKA, GRIESBACH, VON KRAFFT, DIENER, and HAYDEN has made Spiti famous as a classical geological area of the Himalaya, particularly of the Tethys or Tibetan Zone. Since the publication of HAYDEN's monograph in 1904, however, the region was visited by geologists only occasionally and reports became sporadic.

The present studies are the result of a joint Indo-Austrian expedition carried out under the framework of the I. G. C. P. Project No. 4 – The Triassic of the Tethys realm. The Indian team consisted of D. K. BHATT (leader), K. C. PRASHRA and R. K. ARORA, all officers of the Geological Survey of India, which was the organiser of the Indian side. The Austrian members of the expedition were G. FUCHS (leader, Geological Survey, Vienna), L. KRYSTYN and R. GOLEBIOWSKI (both of the Palaeontological Institute, University of Vienna, Austria). Prof. H. ZAPFE (Palaeontological Institute, University of Vienna), who headed the I. G. C. P. Project No. 4, initiated the programme of work on the Austrian side. Towards the end of field work he also visited the expedition group together with Director A. P. TEWARI and Senior Geologist H. M. KAPOOR (both of the Geological Survey of India) for a workshop.

The target of the Project was the detailed stratigraphic investigation of the Triassic formations of Spiti to establish a world-wide standard. From Indian side it was recommended to study the sections along the Pin river.

The field work was carried out from end of July to the beginning of September, 1978.

While detailed measurements were taken by the stratigraphers in the Triassic formations, G. FUCHS mapped the Pin and Parahio valley region in association with D. K. BHATT. The results of the survey, the geological map of the Pin valley (scale 1 : 50,000), and the various important sections are presented in this paper. In describing the geology I have restricted myself to the lithological characteristics of the formations given in part 2, as the time at disposal now does not permit for scrupulous stratigraphic-palaeontological studies, pending fuller palaeontological work. The Permo-Triassic stratigraphy will be presented in a separate paper as soon as the rich fossil collection is examined and the material is elaborated.

## 2. Stratigraphy

The Pin river flows from the Great Himalaya, the crystalline axial zone, to the north to join the Spiti river. Along its course, almost 50 km long, all the formations from the crystallines to Spiti Shale (Upper Jurassic) are exposed. The Cretaceous formations richly developed in the wide syncline N of the Spiti river are not exposed in the Pin section.

### 2.1 The Haimanta Formation and the Parahio Series

The base of Palaeozoic-Mesozoic sequence of Spiti is formed by a thick argillaceous-arenaceous series, which is built up over a wide area adjacent to the Central Crystallines. The Cambrian sequence is divided into following two broad divisions:

Parahio Series
Haimanta Series

In the Pin valley I did not cross the Haimantas down to their boundary adjacent to the crystallines. GRIESBACH (1891, p. 209) and HAYDEN (1904, p. 9 – 10) describe a passage between the crystallines and the succeeding sedimentaries, an observation made also in various other parts of the Himalaya. On our approach to Spiti via Kunzam La I was able to make some cursory observations along the upper Chandra valley. It appears that the transition zone referred to above is crossed between the bend of the river east of Shigri and the Batal bridge just before the ascent to Kunzam La begins. But the lithology there is complicated by a boss of granite-gneiss and severe folding. The passage beds comprise grey-green, also black phyllites interlaminated with medium to light-grey metasiltstone, fine-grained metasandstone or quartzite.

The Haimantas met in the Pin valley between south of Mud (Muth) and Baldar camping ground are made up of grey, green slates, silty slates, siltstones, fine- to medium-grained micaceous sandstones, quartzitic sandstones with fine brecciaceous layers and micaceous quartzites. These rocks are finely interbedded or alternate in beds several meters thick. The s-planes are even or wavy. Convolute bedding, load cast, flute cast, rill mark, slump structure, burrow and hieroglyphs are common in the lower and middle portions of the series (Figs. 1 – 3). There are also found graded bedding (Fig. 4), lenticular or flasery stratification, which stress the flysch character of this rock sequence. In the upper portions, load casts, and occasionally current beddings, desiccation cracks, and clay gall breccias are found. Some of the sandstones contain carbonate matter and show ochre, ferruginous weathering. They yielded fossil detritus of small brachiopods and hyolithes. These beds probably correspond with Upper Haimanta (Middle to Upper Cambrian vide HAYDEN). The middle subdivision, which is described as bright red and black slate series with some quartzites, is well-developed in the Pin valley according to HAYDEN (1904, p. 13 and 19), but

Fig. 1: Ball and pillow structures and load casts in sandstone bed, particularly at the contact to underlying shale (left side); Haimanta Formation SSW of Mud (Muth) in the Pin valley, Spiti.

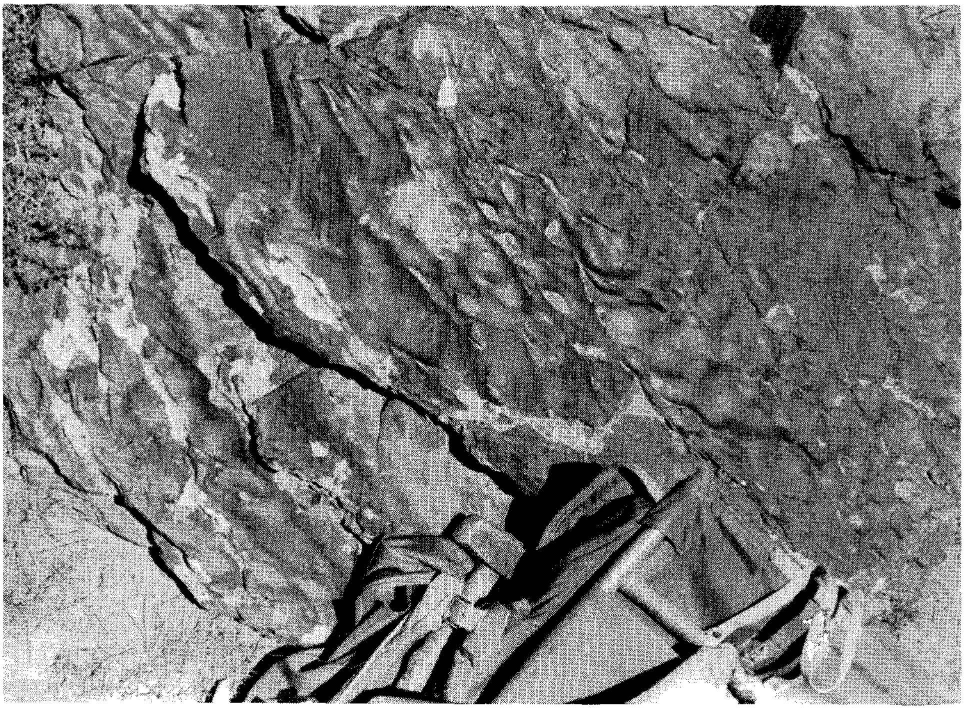

Fig. 2: Flute casts on s-plane of sandstone, Haimanta Formation, upper Pin valley, Spiti.

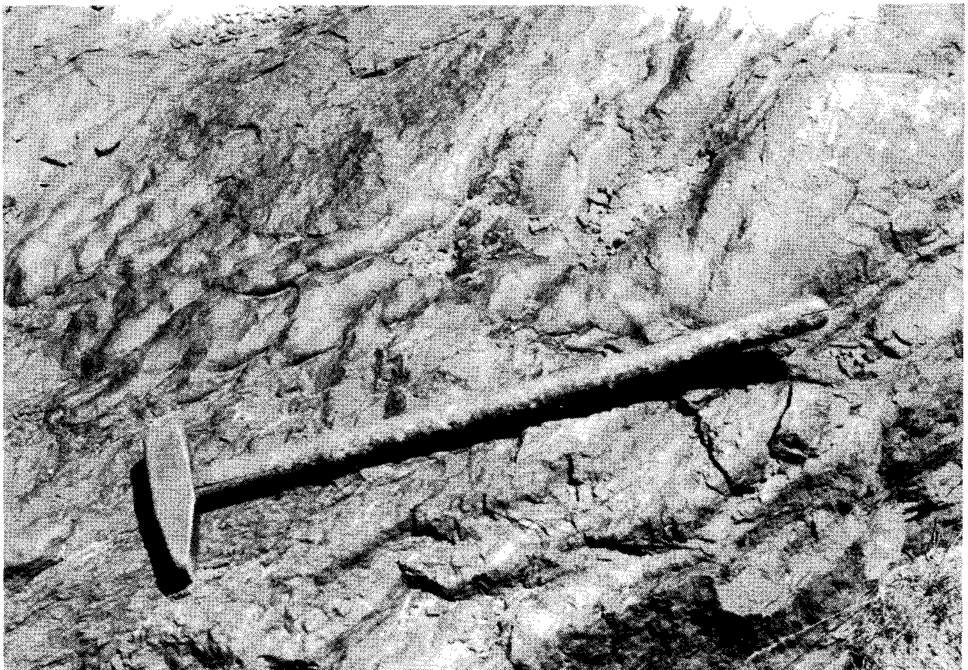

Fig. 3: Flute moulds in siltstone, Haimanta Formation, upper Pin valley, Spiti.

was not observed by us. Red colour is rare and appears only in the uppermost 20 m of the Haimantas of the Pin valley and is evidently caused by infiltration from the erosional and weathering surface below the Ordovician unconformity.

HAYDEN showed that the highest portions of the Haimanta complex were preserved from the pre-Ordovician erosion only in the Parahio valley. The sequence, termed Parahio series by PASCOE (1975), consists of a cyclic alternation of slate, quartzite and limestone or dolomite. HAYDEN (1904, p. 14 – 17) reported a series of fossil horizons, which yielded brachiopods and trilobites, giving an Upper Cambrian, possibly also a Middle Cambrian age. REED (1910) later gave a description of fossils. Recently BHATT & KUMAR (1980) have discovered conodont elements in the dolomite layers of the Parahio Series.

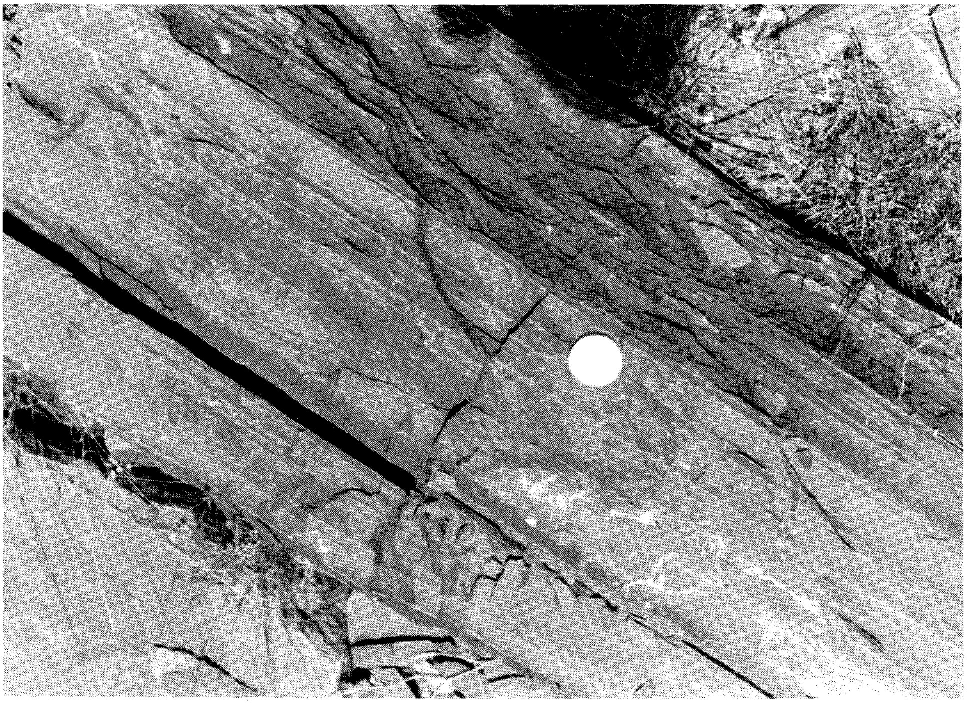

Fig. 4: Laminated siltstone showing graded bedding (fining upwards in the photo); Haimanta Formation, upper Pin valley, Spiti.

I examined the Parahio Series at the place Thango in the Parahio valley, south of the river, and found the following rock sequence (from top to bottom):
Ordovician conglomerate (*ca* 8 m)

light-coloured dolomite, massive, feruginous weathering (*ca* 5 m)

medium-grained, light-coloured sandstone, thick bedded, characteristic friable surface (*ca* 15 m) passage into light to green-grey sandstone interbedded with grey splintery slates (*ca* 10 m)

ferruginous dolomite (*ca* 0.5 m)

thin-bedded sandstone and shales, current bedding (*ca* 1 m)

thick-bedded, pale calcareous sandstone (*ca* 12 m)

green sandstones and shales alternating, convolute bedding (*ca* 10 m)

grey, splintery slates with thin layers of sandstone (*ca* 8 m)

grey dolomite with ferruginous weathering, upper portion with shaly laminae, lower portion thick-bedded to massive (*ca* 8 m)

green-grey, fine-grained micaceous sandstone, flute casts, convolute bedding (*ca* 15 m)

ferruginous dolomite (*ca* 0.3 m)

light-grey, pale sandstone showing friable surface (*ca* 6 m)

thin-bedded alternation of green-grey slate and sandstone, load casts (*ca* 30 m)

well-bedded, medium grey dolomite, iron-stained surface (*ca* 3 m)

light carbonate sandstone, the base consists of arenaceous dolomite (*ca* 12 m)

grey arenaceous shale (*ca* 4 m)

fine- to medium-grained, grey sandstone with burrows and ripple marks passing down into a thin-bedded alternation of slate and sandstone, flute casts (*ca* 11 m)

thick-bedded sandstone (*ca* 10 m) passing down into thin-bedded alternation of slate and sandstone

The described succession clearly shows cycles, which start with an argillaceous-arenaceous flysch series passing into light-coloured sandstone and carbonate sandstone, and beds of dolomite on the top. The thickness of these cycles varies between 25 and 35 m. From these cycles it is also obvious that the Parahio Series is the continuation of the Haimanta sedimentation; the latter event took place in a geosynclinal trough and produced a rather monotonous argillaceous-arenaceous sequence. Strong internal folding and shearing has made it difficult to estimate the primary thickness, but it should be at least 2000 m. The sedimentary structures, which indicate rapid deposition, and the frequently observed cyclicity suggest a flysch environment. The dolomites, which come in towards the end of this trough sedimentation, signal shallowing due to regression. I agree with HAYDEN, who opines that the Haimanta sedimentation started in the Precambrian itself and came to an end in the Upper Cambrian as shown by the age of the fossiliferous beds of the Parahio Series, local conglomerates in it and the Ordovician unconformity. In my view the Haimantas correspond with the Attock-, Hazara-, Dogra-, and Simla Slates and Cambrian of Kashmir, Martoli- and Garbyang Formations and the Dhaulagiri Limestone of Nepal. The Caledonian movements, which put an end to the late Precambrian-Early Palaeozoic geosynclinal sedimentation, did not occur synchronously. In Spiti it began in the Upper Cambrian itself, whereas in other parts of Himalaya started later in Ordovician or Upper Silurian times. KANWAR & BHANDARI (1979) found acid and basic intrusions in the Ordo-Silurian series of the Sarchu area, which may be related to the Caledonian activity.

## 2.2 The Ordovician-Silurian

This rock group can clearly be subdivided into several formations, but as we did not work on it in detail and did not make new fossil collection, this sequence is dealt with together.

A Caledonian disturbance in the Himalaya can be deduced from marked changes in facies in the regional development of the Lower Palaeozoic formations (FUCHS, 1967, PANDE & SAXENA, 1968, etc.), but opponents argue that an unconformity is missing.

GRIESBACH (1891) whereas spoke of a conformable Lower Palaeozoic sequence, HAYDEN (1904) recognised the unconformity from the presence or absence of certain Cambrian beds below the Ordovician conglomerate in different parts of Spiti. In the course of my survey an angular unconformity was found to occur in outcrops 2.3 km southwest of Mud (Muth) (Figs. 5, 6). There the Ordovician conglomerate, dipping NE approximately 50°, lies discordantly over the Haimantas which dip NE with steep to near-vertical angles. The plane of discordance is irregular and the conglomerates fill deep pockets in the older formation, which in its uppermost 20 m is impregnated along joints and fractures with haematitic pigment, obviously derived from the plane of discordance (Fig. 7). The conglomerate consists of pebbles and boulders of quartz and quartzitic matter (up to 30 cm in diameter) in a purple, arenaceous, partly schistose matrix. The size of the components varies and sorting is poor. The thickness of the conglomerate changes between 5 and 40 m. Upwards in the sequence, the pebbles become rare and there is a passage into the thick red to purple quartzite series.

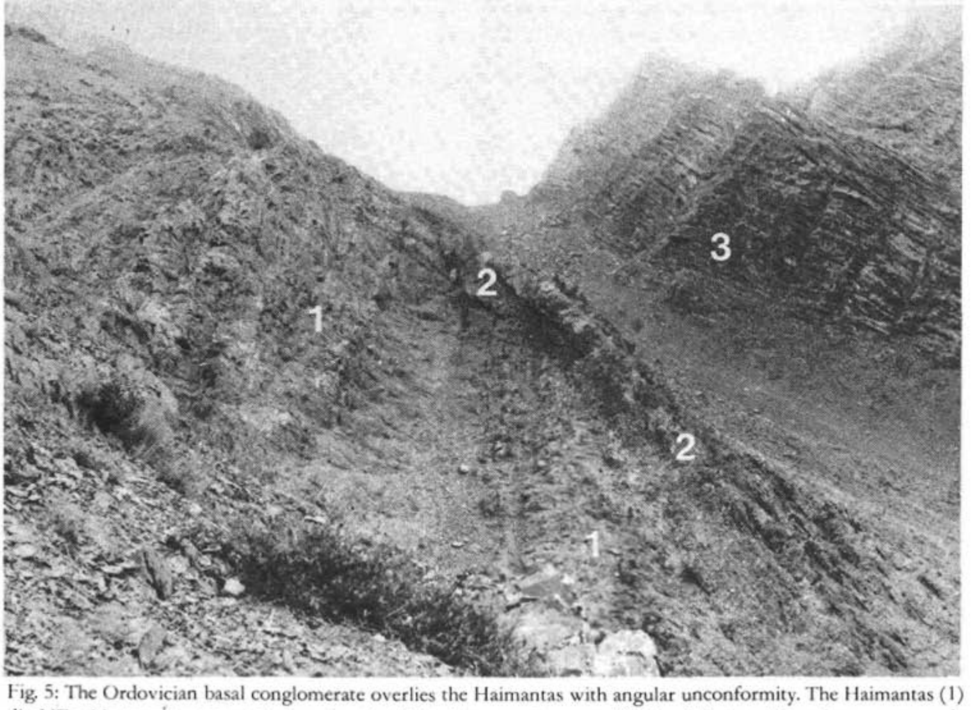


Fig. 5: The Ordovician basal conglomerate overlies the Haimantas with angular unconformity. The Haimantas (1) dip NE with steep to near-vertical angles; the Ordovician conglomerate (2) dips NE at ca 50° and passes upwards into thick quartzite series (3). Ridge 2.3 km SW of Mud (Muth), Pin valley.

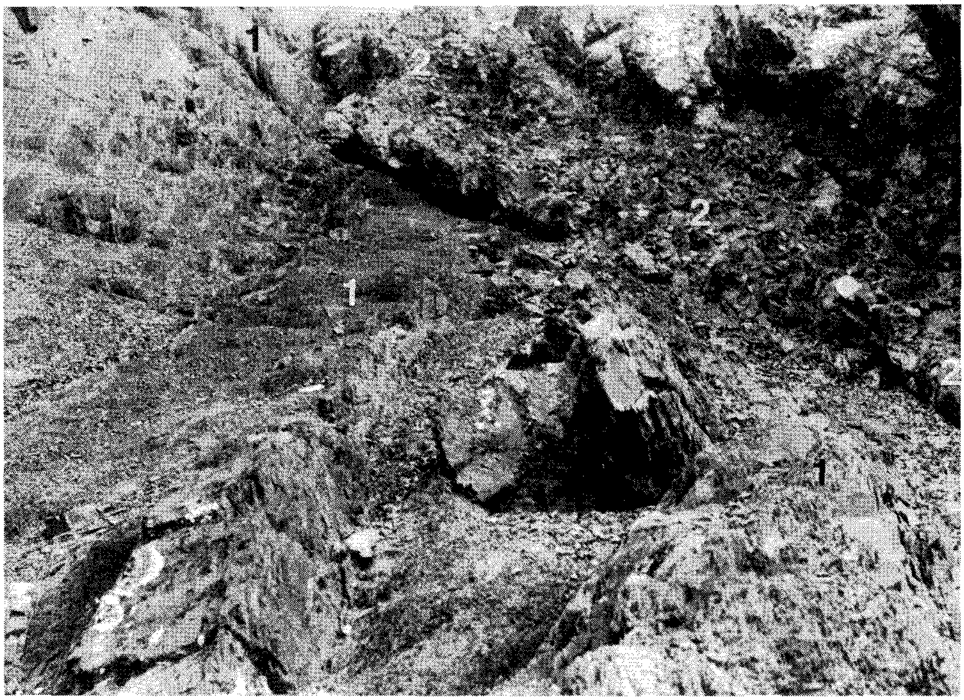

Fig. 6: Detail of fig. 5 showing the angular unconformity between the Cambrian beds (1) and the transgressing Ordovician conglomerate (2).

Fig. 7: Detail of fig. 5; the Ordovician conglomerate (2) fills pockets in the Cambrian beds (1).

Fig. 8: The Ordovician conglomerate contains huge boulders derived from the underlying beds (compare to size of rucksack). Faint stratification is developed in finer layers only (near rucksack). Thango, Parahio valley, Spiti.

In the Parahio valley the conglomerate becomes very coarse and contains, beside quartzite, boulders of carbonates derived from the underlying Parahio Series (Fig. 8).

The conglomerates are followed by a thick (*ca* 600 m) sequence of well-bedded purple, pink, and brownish quartzites. GOEL & NAIR (1976) term these quartzites the Shian Quartzite. The quartzites are generally fine-grained, but in the Parahio valley some conglomeratic layers similar to those of the basal portion have been found also in this younger quartzite series. Argillaceous layers between the quartzitic beds are rather subordinate. Sedimentary structures such as current beddings, ripple marks, desiccation cracks, and clay gall breccias indicate deposition in very shallow water to terrestrial environment (Fig. 9, 10). Traces, imprints made in two parallel lines, probably made by trilobites, occur in the quartzite series; otherwise it is completely devoid of fossils. Approximately 10 m below the top, carbonate quartzites also come in and the uppermost 20 m consists of an alternation of red and white quartzites, carbonate quartzites, and red arenaceous shales. Coating of blue and green secondary copper minerals are occasionally observed along joints of the quartzites.

The above was observed near Mud (Muth), but in the upper Pin valley, in the Baldar Syncline, the quartzite series is more thick-bedded, fine- to coarse-grained, and the colour is red, pink, and white. The latter probably is, as already stated by HAYDEN (1904, p. 23), due to loss of colour caused by metamorphism.

Fig. 9: Transverse ripple marks in red Ordovician quartzite, SSW of Mud (Muth), Pin valley.

Fig. 10: Desiccation cracks in red Ordovician quartzite, SSW of Mud (Muth), Pin valley.

In the section south-west of Mud (Muth) the purple quartzite series is succeeded by the following sequence (from top to bottom):

Muth Quartzite (Devonian)

red and brown weathering, thick-bedded alternation of cross-bedded sandstone and grey marly, siliceous limestone with crinoids (HAYDEN's bed no. 8) passing down into ochre-weathering grey shaly marls and limestones (HAYDEN's bed no. 7); *ca* 50 m

grey limestone, partly marly or silty, containing numerous brachiopods, corals, and crinoids. The corals (*Halysites, Chaetetes* and others) occur in situ and form bioherms (HAYDEN's bed no. 6); *ca* 15 m

alternation of dark shale, marl, and limestone; *ca* 3 m

thick-bedded, grey, siliceous limestone (ferruginous weathering) passing down into a thin-bedded alternation of silty shales and marls; *ca* 30 m

alternation of grey silty shale, siltstone, sandstone, grey, impure, limestone and dolomite, rich in brachiopods and detritus of other fossils; *ca* 100 m

grey limestone, carbonate quartzite and light-coloured quartzite; *ca* 8 m

thin-bedded alternation of grey shales, silty shales, fine-grained grey sandstones, and carbonate sandstones (ochre-weathering), brachiopoda are frequent; *ca* 20 m

carbonate quartzite and medium-grey, arenaceous limestone weathering brown; *ca* 6 m

thick-bedded, light-coloured quartzite; *ca* 7 m

grey shales, silty shales with calcareous layers; *ca* 1.5 m

red and grey carbonate quartzites and ochre-weathering sandy limestones; *ca* 6 m

thick-bedded, light grey, pink, slightly brownish, fine- to medium-grained quartzite and carbonate quartzite, current bedding (lower part of HAYDEN's bed no. 1); *ca* 15 m

red quartzite series already described

The work of HAYDEN (1904) and palaeontological deductions on his collection by REED (1912) has shown that the above sequence comprises the Ordovician (Caradoc) to Silurian (Wenlock). GUPTA (1973) summarises the palaeontological record from the Ordovician and Silurian formations. Based on the fossils he draws the Ordovician/Silurian boundary against HAYDEN's zone 4, whereas HAYDEN has drawn it against zone 5 and REED against zone 6. However, the lithological sequence is more or less continuous.

The facies of Ordovician and Silurian shows a transgression of probably terrestrial beds after an orogenic event. After the coarse material of the basal conglomerate, finer sands were deposited giving rise to the regularly bedded quartzites. Colour of the sediments and sedimentary structures suggest warm to hot arid climate. Gradually the sea got access and arenaceous-argillaceous-calcareous fossiliferous beds were deposited. Rather slowly the water-depths increased (central portion rich in silty shale), but did not become very deep, and then became shallow again (coral limestone and carbonate sandstones at the top of the succession). The climax of regression was reached with the deposition of the Muth Quartzite.

## 2.3 The Muth Quartzite

The Muth Quartzite forms a marker horizon in Spiti and other parts of the Tibetan Zone, easily recognisable by its white colour and its resistivity to weathering. The formation consists of thick-bedded to massive, white or slightly greenish, fine- to medium-grained rather pure quartzites. The rocks exhibit current bedding, ripple marks, and burrows.

In the uppermost 20 m of the formation, which has a total thickness of nearabout 120 m near Mud (Muth), beds of grey carbonate quartzite, sandy dolomite, or dolomite are intercalated in the quartzites. They weather in ochre colours, and are 3 – 4 m thick. Intraformational breccias are not rare in these shallow-water dolomites, which resemble closely to those of western Dolpo in Nepal (FUCHS, 1977 a; p. 196).

Near the top of the Muth Quartzite, which is exposed in the dip slope of the ravine WNW of Mud (Muth), boulders of quartzite up to 0.8 m in diameter, weather out from the wavy s-planes of the quartzite (Fig. 11).

Fig. 11: Wavy s-plane of Muth Quartzite; note the big boulder weathering out in lower right side of the picture; ravine WNW of Mud (Muth) village.

We did not find any fossils in the formation as did HAYDEN, who, however, asserted that its age was Upper Silurian or Devonian. His conclusion was drawn from the fact that the beds immediately underlying have yielded *Pentamerus oblongus*, and that the Muth Quartzite passed upwards into siliceous limestones of probable Devonian age (1904, p. 34). GUPTA (1969 and 1973) suggests a Lower or Middle Devonian age for the Muth Quartzite of the Spiti region, his main argument being his record of the fossil *Psilophyton princeps* in beds just below the Muth Quartzite, west of Losar (upper Spiti valley). This fossil is very common there and was observed there by the author also. Further GUPTA & JAIN (1967) have found a Middle Devonian brachiopod fauna in the Muth Quartzite west of Losar. GOEL & NAIR (1976), on the other hand, argue for a pre-Devonian age of the Muth Quartzite. According to them *Pentamerus oblongus* suggests rather an early Silurian age and the beds containing these fossils pass into the overlying Muth Quartzite. Certainly there is an increase of sand towards the top of the Silurian succession indicating a regression; but a major gap below the white Muth Quartzite is very likely, I would say rather probable. Hence the argument for a pre-Devonian age is not very strong.

The upper boundary of the Muth Quartzite is marked by an increase of carbonate content. The poorly preserved fossils, however, make it difficult to give a precise age of the overlying beds. We shall deal with this problem in the following chapter.

## 2.4 The Lipak Formation

HAYDEN (1904) found the carbonate series overlying the Muth Quartzite in several places (like Losar, Pin valley, etc.); in other places, however, it is wanting because of its removal by erosion prior to the deposition of the Permian beds.

We examined this carbonate series west of Losar, in the Chhidang- and Gungri Anticlines (Pin valley) and WNW of Mud (Muth). The last two localities show most complete development of these beds.

In the ravine WNW of Mud (Muth) the Muth Quartzite forms the dip-slopes on the orographically right side. On the left side we find the following succession (from bottom to top):

thick-bedded, grey quartzite with ferruginous weathering, brachiopod shell layers. The impure quartzite layers contain carbonate and silt. There is also indication of re-working; *ca* 15 m

Prof. Dr. R. SIEBER kindly examined the ill-preserved brachiopoda; they are referable to *Atrypa* sp. and *Cyrtina* sp., productidae are missing. A rhynchonellid is referable to "*Camerotoechia*". The character of the faunula is more indicative of Upper Devonian than of Lower Carboniferous age.

thick-bedded sequence of blue-grey, laminated limestones, sandy-silty limestones, and light-coloured dolomite layers. The series is rich in spiriferids (viz. *Syringothyris cuspidata*) and productids, which start 15 m above the basal carbonate quartzites. In the upper portion of the series black argillites are intercalated in the carbonates; *ca* 80 m

breccia composed of re-worked fragments of the above rocks, belongs to the transgressing Permian series.

From the lithology and sedimentary structures (e. g. intraformational breccia etc.) it is evident that the series was deposited in shallow sea, which gradually replaced the arenaceous, probably mainly terrestrial sedimentation of the Muth Quartzite. As is shown by the brachiopod fauna, the main mass of the carbonates is Lower Carboniferous and represents Lipak Formation. The carbonate quartzites at the base, however, may also belong to the upper part of Devonian (cf. HAYDEN, 1904).

Immediately west of the village Mud (Muth), the following succession was observed above the Muth Quartzite (from base to top):

black shales passing into siltstone and impure quartzite; 1.5 m

thin-bedded dolomite with a layer of quartzite, which fills pockets in dolomite; *ca* 4 m

gap in observation (talus)

thick-bedded, blue-grey dolomitic limestone and dolomites, ferruginous weathering, nodular structures, crinoids; *ca* 5 m

grey, marly limestones, blue limestones, and dolomitic limestones with sandy layers, crinoids, solitary corals, bryozoa and abundant brachiopoda; *ca* 8 m

light quartzite, thick-bedded; 3 m

black argillites; *ca* 6 m

dark-grey, laminated limestone with sandy layers containing fragments of limestone; *ca* 5 m

blue, thin- to thick-bedded limestones, laminated, rich in brachiopoda, bryozoa, and corals (?); *ca* 8 m

light limestones with marly, sandy or silty layers; rich in spiriferidae and productidae, spongae and crinoids; *ca* 4 m

Prof. Dr. R. SIEBER (Geol. B.-A., Vienna) kindly examined a sample from this bed and identified: *Syringothyris* sp., *Sprifer (striatus), Choristites* (? larger productid, *Buxtonia* sp.); a small productid is rare but significant for Lower Carboniferous, the larger *Spiriferida* are more frequent.

talus

dark, blue limestone, partly laminated and current-bedded, sandy-oolitic layers, intraformational breccias and detritus of crinoids and brachiopods; *ca* 30 m

According to Prof. Dr. R. SIEBER the brachiopods are spiriferids, productids and *Atrypa* sp.

The total thickness of the carbonate formation overlying the Muth Quartzite exceeds 100 m. Most of it is definitely Lower Carboniferous, but the basal unfossiliferous beds may be partly Upper Devonian.

South-west of Gungri and east of Khar the lower boundary of the Lipak Formation is well-exposed. The basal limestone is arenaceous and fills the pockets in the underlying Muth Quartzite. Then follow a few meters of alternating light, cross-bedded quartzites, carbonate quartzites, sandy limestones and blue, layered limestones. Brecciaceous layers and lenses are also found sporadically in these basal beds, which are succeeded by blue limestones, dark argillites, and light dolomites alternating.

Immediately west of Guling (Kuling) the top of the Lipak Formation is exposed, where the sequence down from the top is:

Permian conglomerate

grey shaly marls and blue limestones, ferruginous weathering, intraformational breccias; *ca* 18 m

grey splintery shales with thin layers of calcareous sandstone and blue limestone, reworking; *ca* 4 m

thick-bedded blue limestone

If we compare the described succession and the sections reported by HAYDEN (1904) we find a rather similar and characteristic association of rocks: A carbonate sequence with argillaceous and arenaceous intercalations. The series was deposited in shallow water, which explains the difficulty to correlate individual beds. The thickness as well shows great variation. In the Pin valley the thickness of the formation is between 80 and 150 m, whereas HAYDEN (1904, p. 36 – 37) recorded a thickness of 600 m from Kinnaur (south-east of Spiti). In other locations, like in the Parahio valley, the carbonate formation is missing altogether. HAYDEN reported thickening and dwindling down of the formation when followed along the strike, and he appears to be correct that this was caused by the pre-Permian or Lower Permian denudation. Additionally, the carbonate sedimentation, after the deposition of the Muth Quartzite, may have started at different times in different places. This may explain the presence of almost 300 m of carbonate series between the top of the Muth Quartzite and the first Carboniferous fossil horizon in Kinnaur, whereas in the Pin valley this horizon is separated from the Muth Quartzite by a few tens of meters only (HAYDEN, 1904; p. 36 – 43). This also suggests that the presumably Devonian limestones of Kinnaur are missing in the Pin valley or are represented there by the basal beds of the Lipak Formation, a few meters thick only. The predominating part of the Lipak Formation of the Pin valley is definitely Lower Carboniferous.

The thick argillaceous-arenaceous series, which makes up the upper part of Lower to Upper Carboniferous in eastern and western Spiti, the Po Series, is missing in the Pin valley. On our approach to the Pin valley we examined these beds cursorily on the Ganmachidum hill near Losar. For a complete and detailed description of Po Series I may refer to HAYDEN (1904; p. 45 – 51). The Po Series consists of a shale-quartzite alternation and may attain a thickness of *ca* 600 m. The dark and earthy shales prevail in the lower portion, whereas the upper one is predominated by quartzites. The plant fossils found in the lower part of this succession, the Thabo Stage, indicate still a Lower Carboniferous age; higher up brachiopods and bryozoa (fenestellids) occur giving a Middle to Upper Carboniferous age. Towards the top of the series conglomerates and pebbly mudstones come in, which resemble the tillites and tilloids of the Agglomeratic Slate of Kashmir-Chamba. As these conglomerates are unfossiliferous the Carboniferous/Permian boundary is uncertain.

In this regard some observations made in the Chichong section, south-west of Losar (upper Spiti valley) may be of interest. There white, grey, brownish weathering, very hard quartzites build up 5 – 8 m thick beds and show cross bedding. They alternate with black splintery shales, silty shales, pebbly mudstones and rare calcareous layers. Hieroglyphs are frequent. This series that represents the upper part of the Po sequence is overlain by conglomerate beds along an angular unconformity. Above the contact follows a 0.5 – 1 m bed of calcareous sandstone with layers of conglomerate and dark shale. Then follow massive conglomeratic sandstones and pebbly shales; rounded and angular pebbles of quartzite, slate, siltstone, carbonate, etc. are sporadically embedded in a green-grey matrix of sandstone or silty shale. An alternation of conglomerate and quartzite follows higher up.

The lithology of the above succession resembles the Agglomeratic Slate, particularly the characteristic tilloids are identical. They occur below and above the angular unconformity. It is a problem now, whether this unconformity indicates a local disturbance within the upper part of the Po Series or signals the herald of the Permian sequence. The latter is likely to be the case as the Permian beds transgress upon different older formations in Spiti and other parts of the Tibetan Zone and thus the basal Permian unconformity is wide-spread.

Another problem of the Carboniferous of Spiti is the existence of basic volcanics comparable to the Panjal Trap of Kashmir-Chamba. HAYDEN (1904; p. 45) studied the occurrence of trap in south-eastern Spiti, reported earlier by STOLICZKA (1866) to be contemporaneous, and came to the conclusion that these rocks were really dikes. Diabase or doleritic dikes were observed by us in the Ordovician or Muth Quartzite of the Pin valley. But in the upper course of that valley, in the fan of the Larang stream, a tributary from the west, I found a boulder of a basic trap rock exactly resembling the Panjal Trap. The light-green, slightly schistose, fine-grained rock beautifully shows the amygdales and phenocrysts on the iron-stained surface. I climbed the Larang valley up to the cirque with the intention to find the trap in situ, but in vain. Later I found a boulder of basic agglomerate in the river bed of the Pin near Chhidang. I suspect that these basic volcanics correspond with the Panjal Trap and are derived from the southern parts of Spiti, where the facies of the Tibetan Zone may pass into that of Kashmir-Chamba.

An updated list of the fossil content of all Carboniferous formations is given by GUPTA (1973).

## 2.5 The Kuling Formation

According to HAYDEN (1904) the Permian commences with conglomerates, which pass into calcareous sandstone rich in fossils. Then a series of dark shales follow – the 'Kuling Shale' (STOLICZKA, 1866). As the whole Permian succession is very well exposed in the village Guling (Kuling), I suggest the name of this village as the term for all the Permian beds (Fig. 12).

At Guling (Kuling) we find the following sequence from top to bottom:

Otoceras Bed

'Kuling Shale' (55 m): In the upper 18 m black needle shales predominate, the lower portions are composed of green-grey to black silty shales with siltstone layers. In the upper half of the 'Kuling Shale' there are a few lenses of black calcareous siltstone containing concretions. Fossils are found almost throughout the 'Kuling Shale', most common are *Marginifera (Lamnimargus) himalayensis* and *Spiriferella rajah.*

thick-bedded, light-coloured, coarse-grained, quartzitic and calcareous sandstone, showing current bedding and some gritty layers, the weathered surfaces are generally brown; 14 m; the uppermost bed is very rich in large brachiopods (spirifers, productids, etc.). 6 – 7 m above the base a calcareous sandstone bed contains plenty of brachiopods, small pockets and lenses of weathered brachiopods are sporadically distributed almost throughout

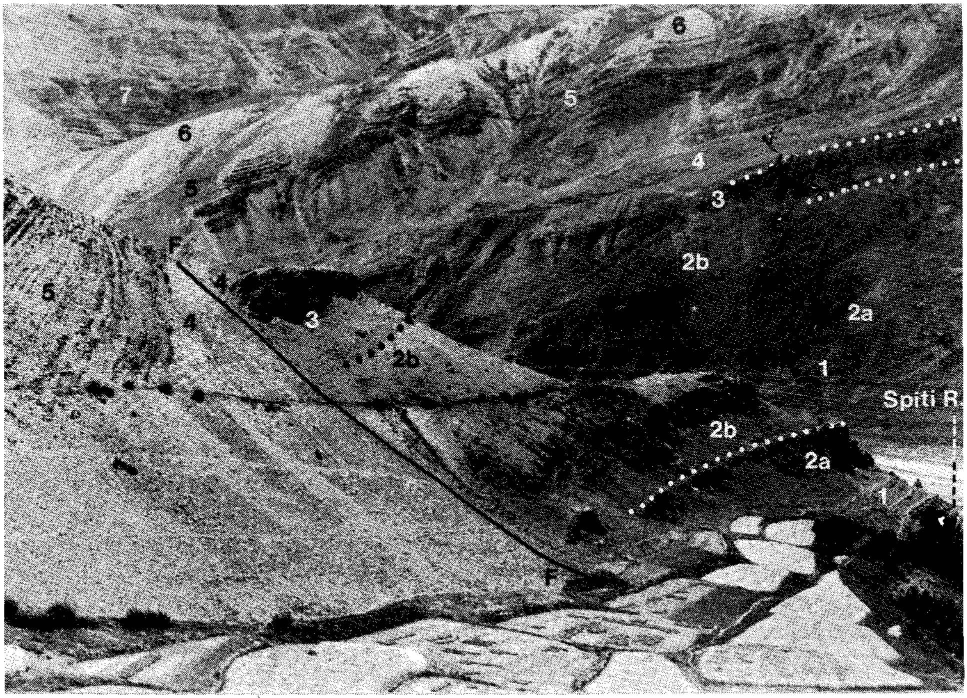


Fig. 12: The ridge NW of Guling (Kuling) seen from the NW, from a side valley.

1. Lipak Formation (Lower Carboniferous)
2. Kuling Formation (Permian)
   a) Conglomerate and quartzite
   b) Kuling Shales, lower part richer in siltstone, upper part more argillaceous
3. Scythian to Lower Ladinic
4. Daonella Shales (Ladinic)
5. Daonella Limestone
6. Grey Beds (Carnic)
7. Tropites Limestone (Carnic)

F fault

light-coloured, ochre-weathering, coarse-grained to conglomeratic sandstone and carbonate sandstone. The components of the conglomeratic portions reach 10 cm size; 1.5 – 2 m

Lipak Formation

East of the Khar village (WSW of Guling or Kuling) the Permian consists of light quartzites and carbonate sandstones overlain by green-grey silty shales and siltstones and black needle shales forming the top. The whole succession is 50 – 60 m thick.

Good sections through the Permian beds (*ca* 60 m) are found in the ravine WNW of Mud (Muth) (Fig. 13):

Otoceras bed

'Kuling Shale': green-grey and black silty shales (52 m), 10 m and 11 m above the base there are beds of dark impure calcareous sandstone (0.5 m) rich in brachiopoda

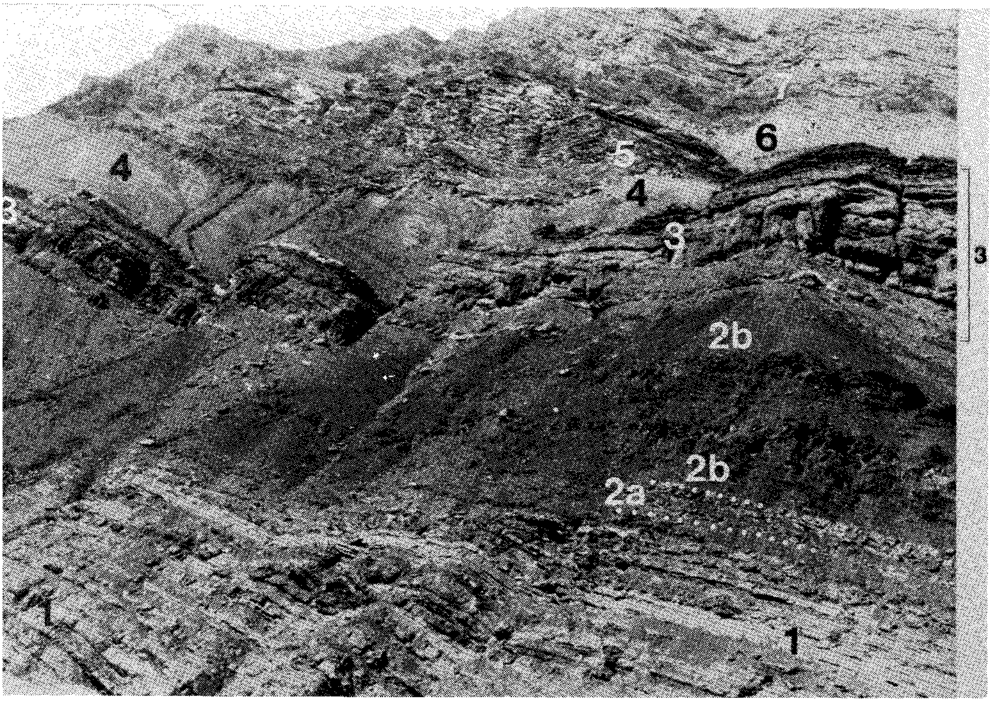


Fig. 13: The orographically left slope of the ravine WNW of Mud (Muth).

1. Lipak Formation (Lower Carboniferous)
2 a. Permian conglomerate and quartzites } Kuling Formation
2 b. Kuling Shales } Kuling Formation
3. Scytho-Anisian } Kuling Formation
4. Daonella Shales (Ladinic)
5. Daonella-Halobia Limestone (Ladinic-Carnic)
6. Grey Beds } (Carnic)
7. Tropites Limestone } (Carnic)

carbonate sandstone and quartzite, medium- to coarse-grained, containing abundant brachiopods; the basal 0.2 m of this bed still contain pieces of Lipak limestone up to 20 cm size; thickness varies between 1.5 and 3 m

breccia composed of fragments derived from the Lipak Formation; 0.6 m

bed of blue limestone; 0.2 m

breccia composed of angular limestone and shale fragments of the re-worked Lipak Formation, embedded in a ferruginous weathering, calcareous-silty matrix; 1.1 m

Lipak Formation

The re-working of the Lipak Formation and the small thickness of the basal arenaceous beds of the Permian in the section are significant.

The Permian described above continues from Muth to the north-west into the Parahio valley. There it directly overlies the Muth Quartzite or the Silurian beds. Near the village

Gechang the Ordovician-Silurian and the Muth Quartzite are highly disturbed by a series of faults with displacement of few tens of meters or only few meters. We observed that the thickness of the Muth Quartzite, which is much less than near Mud (Muth) or Sagnam, changes abruptly along these faults. Followed NNW from Gechang the Muth Quartzite is missing altogether and the Kuling Formation transgresses directly on the Silurians. This occurs along one of the faults (see Pl. 1). Thus there is evidence that the pre-Permian rocks were faulted, eroded, and then transgressed by the Permian beds. Locally the old faults are rejuvenated, where Permian and Mesozoic beds are disturbed.

The base of the Kuling Formation consists of conglomeratic sandstone, green-grey gritty sandstone and grey quartzite, showing rusty weathering. The components, all well-rounded or angular fragments of the Muth Quartzite or Silurians, are poorly sorted. Their sizes are generally 2 – 6 cm, only rarely they reach 30 cm. The basal conglomerates and arenites fill pockets and holes in the Silurian limestone, which apparently had attained its rough surface in a pre-Permian or Lower Permian period of weathering and erosion. The coarse, arenaceous basal beds are approximately 2 m thick and are followed immediately by 'Kuling Shale', which is about 55 m thick. Thus the development of the 'Kuling Shale' is rather constant; the underlying Permian beds, however, show a considerable change in thickness.

The northern-most outcrops of the Kuling Formation in the Pin valley are those of the Chhidang Anticline. There the quartzites, green-grey sandstones, and carbonate sandstones, rich in brachiopods, crinoids, and hieroglyphs are roughly 15 m thick; the 'Kuling Shale' shows its usual thickness of about 55 m. The Kuling Formation, however, is much disturbed by folding there.

Near Lingti in the Spiti valley, opposite the Pin river confluence with the Spiti river, there is a thicker and different development of the Permian: The base is not exposed, but the thickness of the lower clastic division is not less than 250 m. It consists of an alternation of thick quartzite beds, conglomerates, tilloids, sandstones, siltstones and slates. The quartzites are fine- to coarse-grained or gritty, light-grey, green and brown, partly massive and pass into arkose-quartzite or sandstone. The grey, green sandstones are frequently silty or micaceous. The conglomerates are either thickly packed or of tilloid type. The matrix of the latter is sandstone or silty shale; the well-rounded or angular components are quartz quartzite, slate, limestone, dolomite, granite-gneiss and various rocks from the same formation. The siltstones and silty shales are green-grey, the slates and shales dark-grey to black. The Calcareous beds in the upper portion are full of brachiopods (*Neospirifer* and productids). Plant detritus is not rare in the sandstones. *Zoophycus* is observed in the higher part of the sequence. There is much similarity with the Thini Chu Formation of Dolpo (north-western Nepal; see FUCHS, 1967 and 1977 a).

The 'Kuling Shale' consists of shaly siltstones and silty shales in the lower 30 m, the upper 25 m are formed by black needle shale and dark-grey silty shales with black concretions. *Marginifera (Lamnimargus) himalayensis* and *Spiriferella rajah* and *Zoophycus* are very common in the lower portion. From 8 to 1.3 m below the *Otoceras* limestone several specimens of *Xenaspis carbonaria* and *Cyclolobus* were found (see BHATT et al., 1980).

In the classical Lilang section, further north, still greater thickness of pre-'Kuling Shale' Permian beds is present (BHATT & JOSHI, 1980 a).

In respect of the palaeogeography the Upper Palaeozoic development of Spiti is of great interest. According to HAYDEN (1904) the Calcareous Sandstone and the Productus Shale or the 'Kuling Shale' are regularly developed all over Spiti, but the underlying formations are very variable. The fact that the Permian sequence transgresses on different older formations down to the basal Ordovician quartzite (HAYDEN, 1904; p. 52) suggests that much of the pre-Permian succession has been removed by erosion. The same observation has been made by KANWAR & BHANDARI (1979) in the region adjacent to Spiti in the north-west.

Obviously this denudation, which was related to the Hercynian disturbance, was most effective in southern Spiti, from the Thanam valley in the south-east to the Parahio valley in the north-west. If we go towards the north-east the Palaeozoic sequence becomes thicker. I suspect that the gap is smaller towards the north-east, along the axis Losar-lower Spiti valley. At Losar the facies of the Po Series below the unconformity, described in part 2.4, is the same as that of the succeeding Permian beds thus it may be assumed that the tectonic event did not interrupt the sedimentation seriously. The facies reflects changing conditions in a basin disturbed by contemporaneous orogenic activity and is the same as that of the Agglomeratic Slate of Kashmir-Chamba. In the axial zone of the basin the sedimentation was almost continuous giving rise to thick Permian beds, while in the southern portions of the Spiti basin during a part of this period removal of the older formation was going on. Thus I think that deposition started in southern Spiti with the sedimentation of the Calcareous Sandstone or even only a few meters before the 'Kuling Shale'. Consequently the basal conglomerates of southern Spiti appear to be younger than those of the basin-axis. If we follow HAYDEN, who placed the Calcareous Sandstone in the Middle Permian, the Lower Permian should be missing in the south. According to BHATT & JOSHI (1980 a) the fauna of the Calcareous Sandstone is of Lower Permian (Artinskian), which would mean that the lower portions of the "Permian" of the basin-axis would actually be of Upper Carboniferous age.

After the deposition of the 'Kuling Shale' (uniform all over Spiti), the sedimentation was again interrupted at the top of the shale sequence (see chapter 2.6.1).

## 2.6 The Triassic-Jurassic

The Mesozoic formations have a wide distribution in the Spiti Synclinorium, and are very important in the lower and middle course of the Pin river. In the local landscape they are easily recognised (Fig. 12, 13 and 16 – 21 on Pl. 3): The thin, dark band of the 'Kuling Shale' marks the top of the Palaeozoics and above this horizon the Scytho-Anisian stands out as a thin, resistant band. Then follows the thick, well-bedded Triassic-Jurassic carbonate sequence with its characteristic light-grey weathering colours. Generally the terrain is rather rugged. Differences in the content of argillites make certain bands less resistant and others to form cliffs. Accordingly, the whole succession can be subdivided into formations, which may be traced from afar.

Due to this natural demarcation, we discerned the same litho-units as VON KRAFFT (in HAYDEN, 1904); in the geological map of HAYDEN, however, these subdivisions are not shown.

As our fossil material and the detailed sections measured by the stratigraphers are not worded out, I provisionally use the old stratigraphic terminology in many cases. Regarding the fossil occurrence and their stratigraphic distribution we refer to HAYDEN (1904), DIENER (1912), PASCOE (1975) and GUPTA (1975).

### 2.6.1 The Scytho-Anisian

The boundary between the 'Kuling Shale' is sharp and marked by ochre-weathering, grey, massive limestone. A thin lateritic layer and re-working of the underlying Permian rocks in the lowest 10 cm of the limestone indicate a break in sedimentation (BHATT et al., 1980, and BHATT & JOSHI, 1980 b). Further the contact is not strictly conformable, as the lowest bed, the Otoceras limestone, fills small moulds and thus its thickness is variable.

The Scytho-Anisian shows thickness of approximately 30 m and is composed of well-bedded, chiefly platy dense limestones of light-grey and blue colour. These limestones form a resistant band in the landscape and weather in characteristic khaki and brownish colours. In certain horizons grey shales are interbedded with the limestones. A characteristic of this carbonate sequence is the abundance of fossils, chiefly ammonites, in certain beds (e. g. Meekoceras Bed, Hedenstroemia Bed, Anisian). Brachiopods, gastropods, and bivalves are locally abundant in certain horizons. The distribution of the fossils in the formation and their stratigraphic significance are dealt by HAYDEN (1904), DIENER (1912), GUPTA (1975), etc., to whom we refer. According to DIENER (1912, p. 71) and L. KRYSTYN (personal communication) the formation comprises not only the Scythian and Anisian, but its uppermost beds are Ladinic. On the other hand, according to BHATT et al. (in press) and BANDO et al. (in press) the basal Otoceras bed represents the highest stage of Permian, i. e. Dorashamian, on conodont evidences.

### 2.6.2 The Daonella Shales

Above the resistant band of the Lower Triassic and Anisian – Lower Ladinic a thin-bedded succession of mainly earthy-coloured shales and mudstones follows. This rock formation exhibits softer geomorphological form, mostly covered by talus. This band is 45 – 55 m thick. The fauna, consisting of lamellibranch, brachiopods, and ammonites, is distinctly Ladinic (HAYDEN, 1904; DIENER, 1912, and GUPTA, 1975). Due to bad exposures, however, the fossils are not easy to collect.

### 2.6.3 The Daonella- and Halobia Limestone

The Daonella Shales are succeeded by 80 – 90 m of thin- to thick-bedded, black and blue limestone with subordinate argillaceous partings. Like the underlying formation they also bleach on weathered surfaces, certain beds exhibit ochre tinge. Between the softer Daonella Shales below and Grey Beds above, this predominantly carbonate succession forms a regularly bedded cliff recognisable from afar. Within this complex rock unit VON KRAFFT distinguished a lower Daonella Limestone from the upper Halobia Limestone (HAYDEN, 1904). The Ladinic/Carnic boundary is assumed between these two subdivisions. The leading fossil *Daonella lommeli* occurs only in the lower portion of the Daonella Limestone. As good fossils are generally rare we did not separate the Ladinic from the Carnic part and mapped the lithologically uniform limestone as one unit.

### 2.6.4 The Grey Beds

This name is derived from the light-grey weathering colours shown by the alternation of dark shales, marls, and limestones that constitute the Grey Beds. From the Scythian up to the Grey Beds practically the same rock types are found, only the ratio of argillaceous to calcareous rocks changes. In the Grey Beds marls and shales predominate. This soft rock complex is much folded and it is not easy to estimate the original thickness, which appears to be 175 – 225 m. The fossil content listed by HAYDEN (1904) and DIENER (1912) supports a Carnic age.

### 2.6.5 The Tropites Limestone

Upwards the Grey Beds pass into a 250 – 300 m thick limestone complex, which forms a marked cliff. The lower portion of the complex (*ca* 80 m) consists of well-bedded grey, blue, and black limestones with subordinate argillaceous layers. The middle parts (*ca* 80 m) comprise dark-grey and black silty or sandy shales, calcareous and cross-bedded sandstones, impure limestones and marls, and blue limestones. This soft, brownish weathering band is succeeded by thick-bedded grey and blue limestones, partly cherty, and dolomites (*ca* 120 m).

Lists of fossils are given by HAYDEN (1904) and DIENER (1912), however, well-preserved fossils are rather rare. We found algae, ill-preserved corals, bryozoa, brachiopods, bivalves (including *Megalodon,* in the Gyundi rive section), gastropods, nautiloids, ammonoids, crinoids and spines of *Cidaris.* Layers of oolite, re-worked carbonates, fossil debris as well as current bedding in the arenaceous beds of the middle portion indicate deposition in shallow water. Up to the Tropites Limestone the calcareous sedimentation of the Trias was mixed with argillaceous matter, but higher up arenaceous and silty beds make their appearance.

The age of the Tropites Limestone is generally accepted as Upper Carnic.

### 2.6.6 The Juvavites- and Monotis Shales

At the top of the Tropites Limestone I observed a marked horizon of re-working in the Gyundi river section (near Hal village) and other places. Fragments of the underlying carbonates, up to dm-sizes are embedded in the lowest arenaceous limestone bed of the transgressing series. Up to 1 m above the base several breccia layers are found, which are fining upwards. Ill-preserved corals, brachiopods, gastropods, ammonites, and crinoids occur in this basal bed.

Then a 250 – 300 m thick alternation of argillaceous, calcareous and arenaceous beds follows: Grey and dark silty shales (with frequent *Zoophycus*), blue, schistose marls, predominantly thin-bedded, blue, nodular limestones, grey, silty or sandy limestones, weathering in ochre colour and mainly thin-bedded, grey, partly calcareous sandstones. A zone of hard, thick-bedded sandstone resembles very much the quartzitic sandstone in the Tarap Shales of Dolpo (Nepal; FUCHS, 1977 a, p. 207). Cross-bedding and convolute bedding are frequent in the sandstones.

In several cases a cyclic sedimentation is indicated by the sequence: Silty shale – silty or arenaceous limestone – blue nodular limestone. In the topmost 40 m of the formation beds of sandstone and quartzite are intercalated in the silty series signalling increasing arenaceous influx.

Fossils are not rare, but mostly poorly preserved: sponges, corals, brachiopods, nautiloids, ammonoids and lamellibranchs of *Halobia* type.

The above succession is definitely Noric in age. HAYDEN (1904) subdivided it into the lower 'Juvavites Beds' and the upper 'Monotis Shales', which are separated by a band of massive limestone, the 'Coral Limestone'. This limestone horizon, however, is missing in several areas of Spiti (Gyundi river – Kaja, upper Pin valley around Mud or Muth), and there the lithologically identical lower and upper portions are inseparable. Good fossil mark ers are too scarce to be used for palaeontological distinction. As such I mapped the 'Juvavites-' and 'Monotis Shales' as one unit.

The Coral Limestone is light-grey, massive limestone full of coral colonies and crinoids (Fig. 14). But it also contains fragments of brachiopoda and bryozoa (see HAYDEN, 1904; p. 82 and GUPTA, 1975; p. 54). In the midst of the soft shaly series, the Coral Limestone weathers out as a hard, resistant band (Fig. 19 – 21 on Pl. 3). The thickness varies from a few meters to approximately 30 m. As mentioned above it is missing around Mud (Muth), but is well-developed in the middle and lower course of the Pin valley. The fact that the Coral Limestone is missing in certain parts of Spiti is easily explained, for it occurs in the nature of a reef deposit with restricted lateral extent. Even where this reef deposit is well-developed, sometimes it has pinched out of the section due to folding, shearing or faulting.

The facies of the Juvavites- and Monotis Shales documents a strong, rhythmic influx of silty and arenaceous matter in a basin with carbonate sedimentation. Probably the water was not very deep, but the subsidence, as may be adduced from the thickness and the lithology of the formation, was considerable. The Coral Limestone apparently marks a swell area, which was almost free of the clastic matter that contaminates the adjoining part of the basin. This swell appears to have existed for a relatively short period in the Middle Noric.

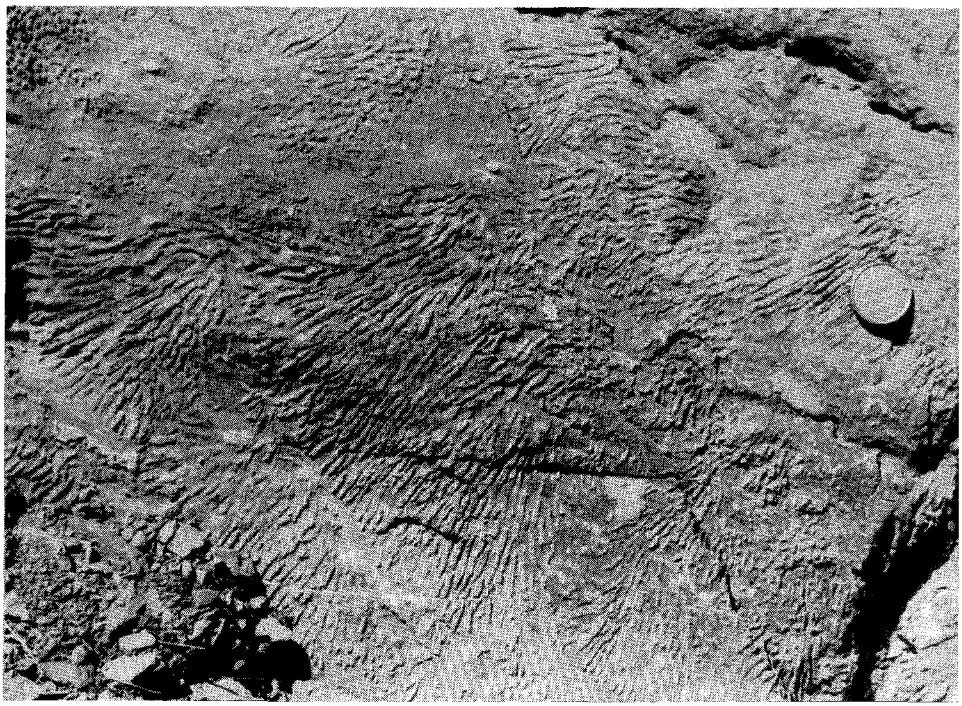

Fig. 14: Coral colonies in block of Coral Limestone, E of Chhidang on the orographically right side of the Pin valley.

### 2.6.7 The Quartzite Series and Kioto Limestone

The soft Monotis Shales are overlain by a thick-bedded carbonate complex, the Kioto Limestone, which contains arenaceous beds in its basal part, the Quartzite Series. The carbonate succession is several hundred meters thick and forms lofty cliffs.

The Quartzite Series consists of a 50 – 100 m thick alternation of white, grey, and brown quartzite, carbonate quartzite, sandy limestone, exhibiting cross-bedding and brown to orange weathering colours, blue to black limestone and subordinate shaly layers. Shell beds full of brachiopods and bivalves and cross-sections of large specimens of *Megalodon* are not rare.

Upwards the arenaceous beds become insignificant and without a sharp boundary there is a passage into the overlying Kioto Limestone. The formation is composed of light-grey, cream, blue, and black partly cherty limestones, dolomites, and subordinate marls. Arenaceous limestone beds often show current bedding. Intraformational breccias, oncoidal layers and beds containing fossil debris stress the shallow-water origin of the carbonate complex.

Near the base, large thick-shelled bivalves *Megalodon* and *Dicerocardium* are frequent (Fig. 15, 16); the higher portions yielded *Lithiotis*. Algae, corals, bryozoa, brachiopods, gastropods, bivalves and crinoids are found at various levels in the formation. Since the beginning of this century it is known that the Quartzite Series starts in the Noric or Rhaetic and the Kioto Limestone is Triassic in its lower part and comprises the Liassic and the lower Dogger in its upper part. This was proved by later studies also in other parts of the Tibetan Zone and is generally accepted (FUCHS, 1967).

Fig. 15: Cross-sections of large specimens of *Megalodon* in basal beds of Kioto Limestone, SE of Tiling.

Fig. 16: Cross-sections of large individuals of *Dicerocardium* and *Megalodon* in basal beds of Kioto Limestone, SE of Tiling.

### 2.6.8 The Dogger

In the Pin area, formations younger than Kioto Limestone are eroded away with the exception of the Kirgarang valley, N of Chhidang. In the orographically left slope of the valley I found the following descending succession:

Spiti Shales

blue-grey lumachelle limestone (1.5 m)

black shales (4 m)

grey shales containing layers of ferruginous oolitic, ochre-weathering arenaceous limestone and brachiopod limestone (*ca* 6 m)

calcareous sandstone to sandy limestone and blue, platy limestone yielding *Trigonia* and other bivalves; current bedding in the arenaceous beds (*ca* 15 m)

Kioto Limestone

Followed upstream belemnites were found not only in the overlying Spiti Shales but also in the Dogger beds. The thickness of the latter is approximately 30 m.

Based upon field evidence HAYDEN (1904, p. 85) regarded these beds as upper Middle to Upper Jurassic. Beds of rather similar lithology, but larger thickness, were described by DIENER (1912, p. 101 – 102) from the Shalshal Cliff (Painkhanda, Kumaun) and by HEIM

& GANSSER (1939) as Laptal Series. Corresponding beds are also found in northern Nepal (FUCHS, 1967; p. 186 – 190; and BORDET et al., 1971; p. 146 – 153). Towards the north-west of Spiti KANWAR & BHANDARI (1979) report about corresponding beds under the name Belemnites Beds. FUCHS (1977 b) found a rather thin development of the Dogger in south-western Ladakh.

#### 2.6.9 The Spiti Shales

In the syncline in which the Dogger was preserved from erosion (the Tanjangkari Syncline), Spiti Shales are also exposed. Their thickness is 40 – 60 m. The Spiti Shales consist of soft, dark grey to black, silty shales containing sporadic and thin beds of dark impure limestone. Abundant belemnites are found in the lowest portion of the Spiti Shales, the rest of which has yielded only some bivalves in the Kirgarang valley. The famous ammonoid faunas (DIENER, 1895 and UHLIG, 1903 – 1910) were not observed in the highly squeezed occurrences of the Kirgarang valley. The age of the Spiti Shales generally is accepted as Upper Oxfordian-Lower Neocomian, except in Nepal where they end with the Upper Jurassic according to BORDET et al. (1971).

### 2.7 The Giumal Sandstone

This Upper Neocomian clastic formation, which succeeds the Spiti Shales, is missing in the Pin valley. It is well-developed in the wide syncline north-east of the Spiti river and was not observed by us in situ. Blocks of the white and grey quartzites and green sandstones are found along the road from Lingti to Kaja, particularly near the village Lidang, where they are brought down from the north along a series of nalas (small valleys).

## 3. Tectonics

In Spiti the Tibetan Zone forms a wide synclinorium. If we approach this synclinorium from the south-west, from the Central Crystalline axis, the grade of metamorphism decreases and we get into the Precambrian-Palaeozoic formations. As we go from the Great Himalayan Range to the north towards the axis of the Synclinorium, we cross the whole Palaeozoic-Mesozoic sequence of Spiti and the younger formations become more and more important. This general picture of a succession younging northwards is complicated by the folding. In the following chapters I describe the fold elements from the south-west to the north-east.

### 3.1 The Baldar Syncline

GRIESBACH (1891), who gave the first geological section along the Pin valley, recognised the syncline that crosses the Pin valley at Baldar camping ground. In the midst of the north-east dipping Haimantas intricately folded Ordovician quartzites cross the valley reaching its bottom (Pl. 1 und 2). Younger formations filling the core of the syncline are exposed in the mountain south of the Larang cirque and SSE of Baldar above the trail to Bhabeh Pass. From binocular observation and fallen blocks I come to the inference that Triassic beds are also found in that syncline. The whole sequence, however, is metamorphosed to the grade of the greenschist facies. East-west and north-west striking faults cross the syncline and complicate it. The north-eastern limb is generally overturned towards the south-west.

From the Baldar Syncline down the Pin valley towards Mud (Muth) all the country is built of Haimantas. There is much folding in this series; the dips, however, remain north-east.

### 3.2. The Mud Syncline

Near the village of Mud (Muth) the Haimantas are followed by the Palaeo-Mesozoic sequence up to the Kioto Limestone. The formations which form the south-western limb of the Mud Syncline dip regularly towards the north-east at 50° – 60° (Fig. 17). Only small-scale folding is found in the Kioto Limestone in the core of the syncline. These chevron folds are observed in the Palla Chhosang mountain north of Mud (Muth) (Pl. 2 [3]). Here the Juvavites- and Monotis Shales are upthrown along a steep-faulted anticline that separates the Kioto Limestone of the Palla Chhosang from a secondary syncline to the north-east. This V-shaped fold, assymmetrical to the north-east, is rather conspicuous in the landscape and is also indicated in BERTHELSEN's section along the Pin valley (1953). Towards the south-east this syncline can be traced along the Ensa valley and is separated from the main Mud Syncline by a band of disturbed Juvavites-Monotis Shales. Followed towards the north-west the double syncline crosses the Parahio valley between Khaga and Gechang. The Kioto Limestone does not reach the bottom of the valley, as it closes in the cores of the synclines in the cliff-faces south of the river. There the folds are disturbed by strike faults. Further, the south-western limb of the Mud Syncline of the Parahio valley is cut by a series of faults striking approximately west-east.

### 3.3 The Pakchung Anticline

Along the Parahio river below the village Pakchung the Scytho-Anisian limestones crop out as the oldest beds. Much folded Daonella Limestone is exposed in the rock faces above the village. Towards the north-west the anticline continues along the Kidul Chu (river), just north-east of this river. The south-eastern continuation of the Pakchung Anticline is the fold exposed south-east of the village Tiling. There Tropites Limestone forms the core of the anticline. Around the village Ensa, Juvavites and Monotis Shales form the core and plunge south-eastward beneath Kioto Limestone.

### 3.4 The Mikin Syncline

North of Mikin, the village that is situated at the confluence of the Pin and Parahio rivers, a marked symmetrical syncline is exposed (Fig. 18 on Pl. 3). Kioto Limestone forms the core of the syncline, capping the mountain NNW of Mikin. Towards the south-east the syncline is less pronounced. It is indicated by the Juvavites Shales syncline east of Tiling and the Kioto Limestone in the slopes north-east of the village Ensa.

### 3.5 The Gungri Anticline

Immediately east of the junction of the Pin and Parahio rivers Muth Quartzite forms the core of an anticline (Fig. 18 on Pl. 3). Near the orographically right bank of the Pin river

Fig. 17

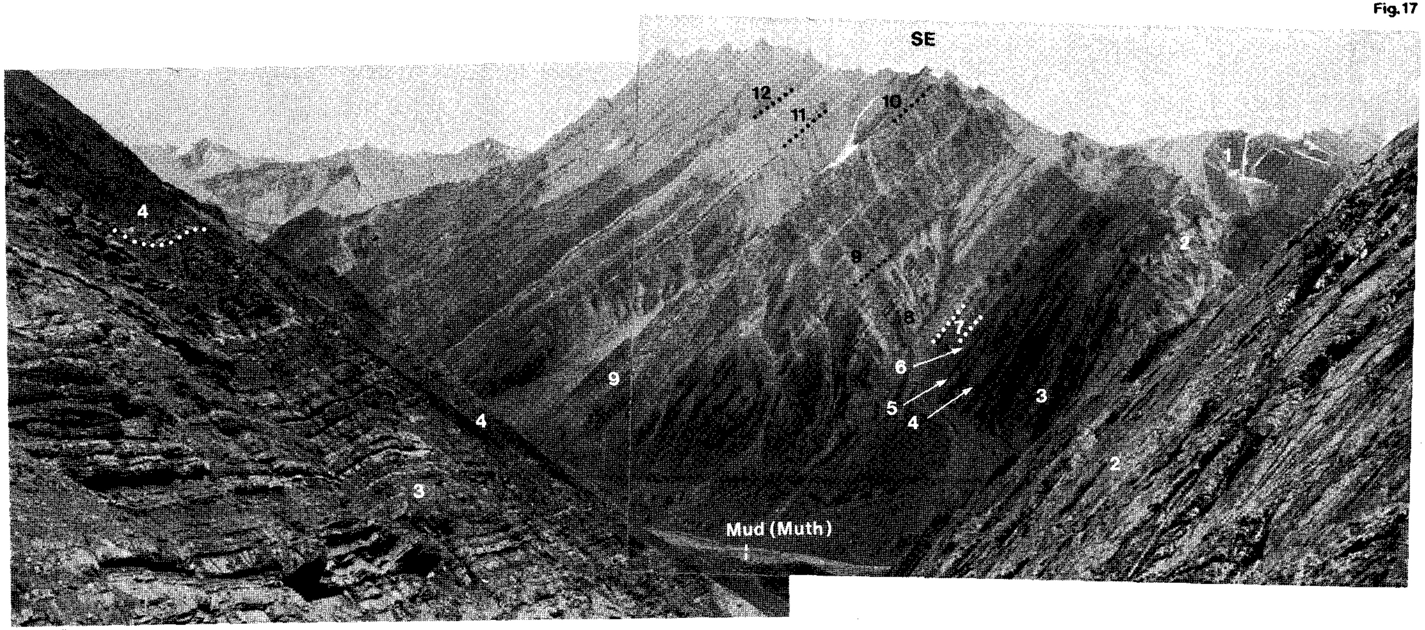


Fig. 17: The Pin valley around Mud (Muth).

1. Siluro-Ordovician
2. Muth Quartzite
3. Lipak Formation
4. Kuling Formation (Permian)
5. Scytho-Anisian
6. Daonella Shales
7. Daonella-Halobia Limestone
8. Grey Beds
9. Tropites Limestone
10. Juvavites-Monotis Shales
11. Quartzite Series
12. Kioto Limestone

even the topmost Silurian beds seem to be exposed, in a small outcrop in the core. The Palaeozoics of this anticline dip towards the south-west at medium angles and towards ENE at gentle angles. East of Tannam the Middle Triassic formations are intricately folded in the crest of this anticline (Fig. 19 on Pl. 3). South-east of the Mangling mountain the Gungri Anticline is exposed in the north-eastern tributary of the Kuokli Gad river. There the oldest rocks forming the core of the anticline belong to the Daonella-Halobia Limestone.

### 3.6 The Ghungma Syncline

Near the villages Guling (Kuling) and Ghungma a syncline is marked by the folded band of Daonella-Halobia Limestone. Higher up the slopes on both sides of the Pin river the south-western limb shows gentle to medium dip, whereas the north-eastern limb is steeply folded and partly overturned, particularly the Tropites Limestone. The youngest beds of the syncline are Kioto Limestones building up the Solokyo and Mangling mountains (Fig. 20, 21 on Pl. 3). In the north-eastern tributary of Kuokli Gad river, east of Ensa, the Ghungma Syncline is weakly indicated.

### 3.7 The Chhidang Anticline

South-west of the village Chhidang the succession Lipak Formation-Daonella Limestone is steeply folded in an anticline. In the mountain, N of Guling (Kuling), the Grey Beds and Tropites Limestone are intimately folded along this anticline. East of Solokyo mountain, the limb between the Ghungma Syncline and the Chhidang Anticline is sheared. Along a steeply inclined tectonic plane, Tropites Limestone of the Chhidang Anticline comes in contact with Juvavites Beds and Coral Limestone. In the corresponding situation south of the Pin river (north of Mangling mountain) the Kioto Limestone of the Ghungma Syncline is overriden by Tropites Limestone of the adjoining anticline. The vergency is clearly south-west. It appears that the plastic deformation of the Upper Palaeozoic to Grey Beds succession of the Chhidang Anticline changed to non-plastic deformation in the Tropites Limestone and higher up. The south-western limb of this anticline became sheared and it was thrust over the Ghungma Syncline (Fig. 20, 21 on Pl. 3). The displacement is of the order of tens or a few hundred of meters only.

ESE of Gyanak Shekher mountain the Chhidang Anticline is found again at the bend of the tributary of the Kuokli Gad river. There the oldest rocks exposed are the Grey Beds. Thus as observed in the already described fold elements, there appears to be a general axial plunge towards the south-east. The opposite plunge, which should be expected in the Kinnaur region where the Spiti Synclinorium ends, is not indicated in the range of the Pin river system.

### 3.8 The Tanjangkari Syncline

Widely extended Kioto Limestone marks this syncline, which is exposed all along the mountains south-west of the Spiti valley and strikes parallel to this valley. Within this syncline there are developed a series of secondary folds (Fig. 21 on Pl. 3). The youngest beds, the Spiti Shales, are exposed in such a secondary syncline along the Kirgarang valley, bordered on both sides by secondary anticlines. In the Pin valley, the secondary anticline north-east of the mentioned Jurassic series brings up the Coral Limestone as oldest beds. N of the Tanjangkari mountain another secondary syncline follows marked by Spiti Shales.

These beds, however, are exposed only in the crest of the range, east of the Pin. Then the next secondary anticline is indicated by Monotis Shale, brought up along a fault in the Pin valley. One more secondary syncline of Kioto Limestone and older beds follows, representing the north-eastern limb of the Tanjangkari Syncline.

### 3.9 The Lingti Anticline

The Spiti river has eroded its course along an anticlinal zone. Between Kaja and Lingti, this anticline is overturned towards the south-west. At Kaja the core of the anticline consists of Tropites Limestone, whereas Permian beds crop out around Lingti. Strike faults complicate this anticline. Particularly the thick Kioto Limestone N of the Spiti river has moved south-westward along a rather flat plane of displacement. Thus the Juvavites- and Monotis Shales have been locally cut out.

North-east of the Lingti Anticline a syncline follows in which, according to HAYDEN, the youngest formations (Cretaceous) build up a wide terrain. This last mentioned syncline marks the axis of the Spiti Synclinorium. This area was not investigated by the members of our expedition.

## 4. Conclusions

Finally I should like to discuss the geology of the Pin area with a broad overview.

First a review of the stratigraphic-facial development in Spiti is given: It fits very well with the rest of the Tethyan Zone and also with the Lesser Himalaya – the thick monotonous trough series forms the Precambrian-Early Palaeozoic basal succession (FUCHS, 1967, 1975 and 1977 a). Part of the Haimantas is typical flysch indicative of a geosynclinal deposit. The dolomites of the Parahio Series show the beginning of a regression towards the end of the geosynclinal period. In Spiti an orogenic event occurred in the Upper Cambrian as documented by the Ordovician angular unconformity. The Caledonian granites of Chamba-Lahoul (JAEGER et al., 1971 and FRANK et al., 1976) seem to be related with this disturbance. In other parts of the Tethys the geosynclinal conditions ended in the Silurian. There the Muth Quartzite indicates a principal change of facies. This change from trough sedimentation to epicontinental or even terrestrial facies occurred earlier in Spiti. The Ordovician conglomerates and quartzites are of distinct shallow-water or terrestrial origin. In the Upper Ordovician-Silurian marine conditions were restored, but towards the end of this period the sea regressed again. The acid and basic intrusives reported by KANWAR & BHANDARI (1979) may be related with this late Caledonian phase.

The Muth Quartzite marks a post-Caledonian period of land or littoral conditions. In the Upper Devonian or with the Lower Carboniferous, carbonates were deposited on a shelf. In the upper part of the Lower Carboniferous the epicontinental facies was replaced by trough sedimentation. The Po Series indicates rapid deposition in a subsiding basin strongly influenced from land. Like the synchronous formations of Chamba and Kashmir (FUCHS & GUPTA, 1971 and FUCHS, 1975) a glacial influence from the Gondwana continent seems to be shown by the tilloids of the Po Series. Also in Nepal and Sikkim glacial deposits reached the Tibetan (Tethyan) Zone (BORDET et al., 1975 and WAGER, 1939). The frequent change from argillaceous to coarse clastic beds in the Po Series is evidence of unstable conditions, probably related to the Hercynian orogenesis. This event is proved in Spiti as in other regions (GRIESBACH, 1891 and HEIM & GANSSER, 1939) by a marked unconformity. The gap is particularly large in south-western Spiti, where Lower Permian beds transgress on even the Ordovician quartzites (HAYDEN, 1904). From place to place the pre-Permian formations have been removed at different rates. The gap is smallest along the axial zone of the Spiti Synclinorium. The transgressing series clearly shows deepening in course of Permian. After the deposition of the 'Kuling Shales', however, there is a slight gap in deposition (BHATT et al., 1980 and BHATT & JOSHI, 1980) beneath the Otoceras Bed, which was found also in Nepal (COLCHEN, 1975 and FUCHS, 1977 a).

The Triassic is characterised by calcareous-argillaceous, epicontinental sedimentation up to the Tropites Limestone (Upper Carnic). In the middle part of this limestone silty and arenaceous matter influences the sedimentation of the Triassic for the first time. The clastic influence is especially strong during the deposition of the Juvavites-Monotis Shales. The Coral Limestone (Middle Noric), which was deposited between the named series, is, however, rather free of clastic matter. This reef sediment is restricted to certain areas of Spiti. In the whole Tibetan Zone from Spiti to Nepal the Noric is predominantly clastic (Kuti Shales) and towards the east the calcareous content further decreases (Tarap Shales).

The Quartzite Series marks a regression in the Upper Noric-Rhaetic, which occurred in the whole Tibetan Zone and in Kashmir. In the same way the Kioto Limestone (Rhaetic-Lower Dogger) shows a uniform development. It was deposited in a rather shallow sea under shelf conditions. The Upper Dogger principally shows the same facies and is also uniform in its characters from Ladakh to Nepal. FUCHS (1967, p. 186) gave reasons that the Laptal Series in Kumaun is not Liassic as HEIM & GANSSER (1939) assumed, but corresponds to the Upper Dogger formations of Nepal (EGELER et al., 1964; FUCHS, 1967 and BORDET et al., 1971), Painkhanda and Spiti (DIENER, 1895 and 1912; and HAYDEN, 1904).

The Spiti Shales, representing an euxinic facies, succeed the shallow water beds of the Dogger, probably after a gap like in other parts of the Tibetan Zone (HEIM & GANSSER, 1939 and COLCHEN, 1975). Ferruginous oolitic horizons at the base of Spiti Shales are indicative of this in Spiti.

The Giumal Sandstone signals a regression, the first sign of the approaching Alpine Orogenesis.

Reviewing the stratigraphic development of Spiti there are typical geosynclinal conditions only up to the Upper Cambrian. The Caledonian disturbance, after a break in deposition, brought about conditions of shallow sea with strong terrigenous influence. Also the Hercynian movements are indicated by syn-orogenic sediments (Po Series) and the Permian unconformity.

The Triassic-Jurassic sedimentation occurred in a shallow sea. It is still a matter of dispute whether the Spiti basin was part of a miogeosyncline attached to the Indian continent or its sediments were deposited in an epicontinental environment.

The tectonics of the Spiti region are not too much complicated and do not offer open problems. The discovery of a pre-Permian fault pattern is quite interesting. It is documented by different rates of denudation in various faulted blocks (see Chapter 2.5), and proves the existence of Hercynian structures.

The fold structures are Alpine in age and strike NW-SE, the vergency, however, is rather variable. This is a common phenomenon in the Tibetan Zone. In Kumaun and south-western Ladakh, however, the movements are generally directed towards south-west. But in both these cases the uniform vergency appears to be caused by higher nappes (flysch, ophiolites), which have overridden the Tibetan Zone (FUCHS, 1977 b and 1979). From the open folding observed in southern and central Spiti, it may be concluded that the area was never reached by higher thrust sheets from the north.

Locally reversed faults have developed with the folding (e. g. north and south-east of Guling or Kuling). Younger than these strike faults are the faults that cut across the strike of the beds (e. g. Baldar Syncline, Gechang area in Parahio valley).

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G. FUCHS – Plate 1

# Geological Map of the Pin Valley, Spiti (H.P.)

(Mapped by G. FUCHS, 1978)

# Geological Sections across the Pin Valley area, Spiti (H.P.)

G. Fuchs, 1979

Scale: 1: 50.000 (heights not exaggerated)

0 4000 m

For index see Pl. 1


Graphische Gestaltung und Reprotechnik
GEOLOGISCHE BUNDESANSTALT WIEN

**Fig. 18**


Fig. 18: Panorama of the middle course of the Pin valley seen from ridge E of Khar.
1. Muth Quartzite (Devonian)
2. Kuling Formation (Permian)
3. Scytho-Anisian
4. Daonella Shales (Ladinic)
5. Daonella-Halobia Limestone (Ladinic-Carnic)
6. Grey Beds (Carnic)
7. Tropites Limestone (Up. Carnic)
8. Juvavites – Monotis Shales (Noric)
8 a. Coral Limestone
9. Quartzite Series (Noric – Rhaetic)
10. Kioto Limestone (Rhaetic – Lower Dogger)

**Fig. 19**

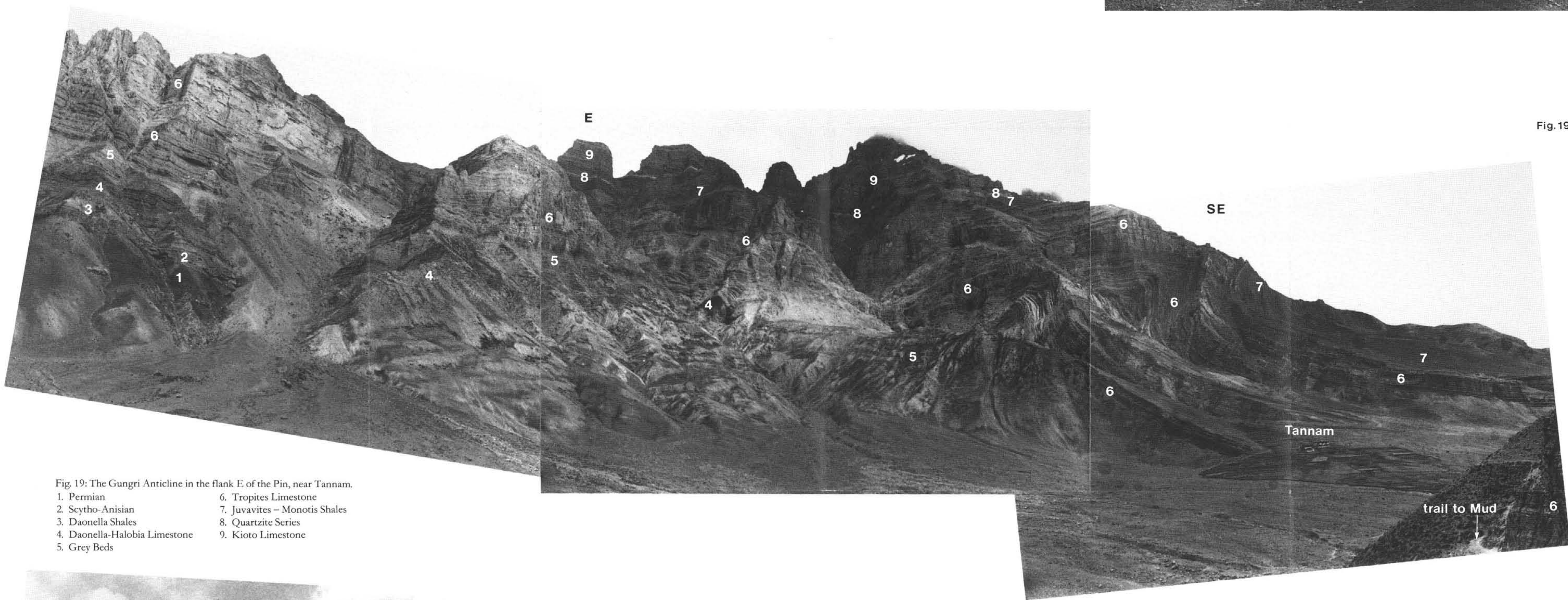


Fig. 19: The Gungri Anticline in the flank E of the Pin, near Tannam.
1. Permian
2. Scytho-Anisian
3. Daonella Shales
4. Daonella-Halobia Limestone
5. Grey Beds
6. Tropites Limestone
7. Juvavites – Monotis Shales
8. Quartzite Series
9. Kioto Limestone

**Fig. 20**

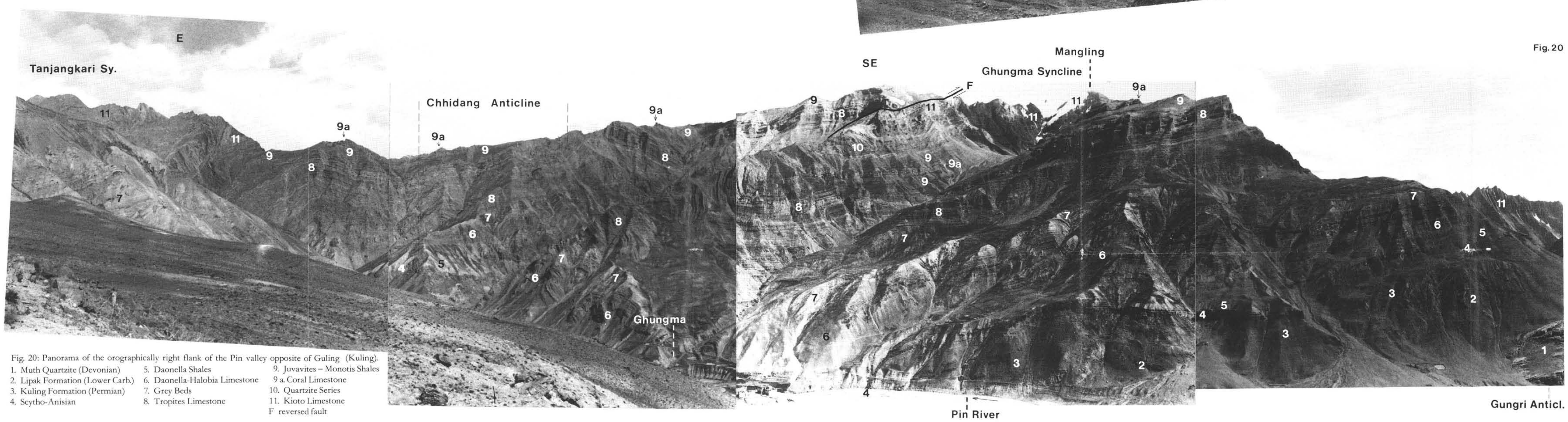


Fig. 20: Panorama of the orographically right flank of the Pin valley opposite of Guling (Kuling).
1. Muth Quartzite (Devonian)
2. Lipak Formation (Lower Carb.)
3. Kuling Formation (Permian)
4. Scytho-Anisian
5. Daonella Shales
6. Daonella-Halobia Limestone
7. Grey Beds
8. Tropites Limestone
9. Juvavites – Monotis Shales
9 a. Coral Limestone
10. Quartzite Series
11. Kioto Limestone
F reversed fault

**Fig. 21**

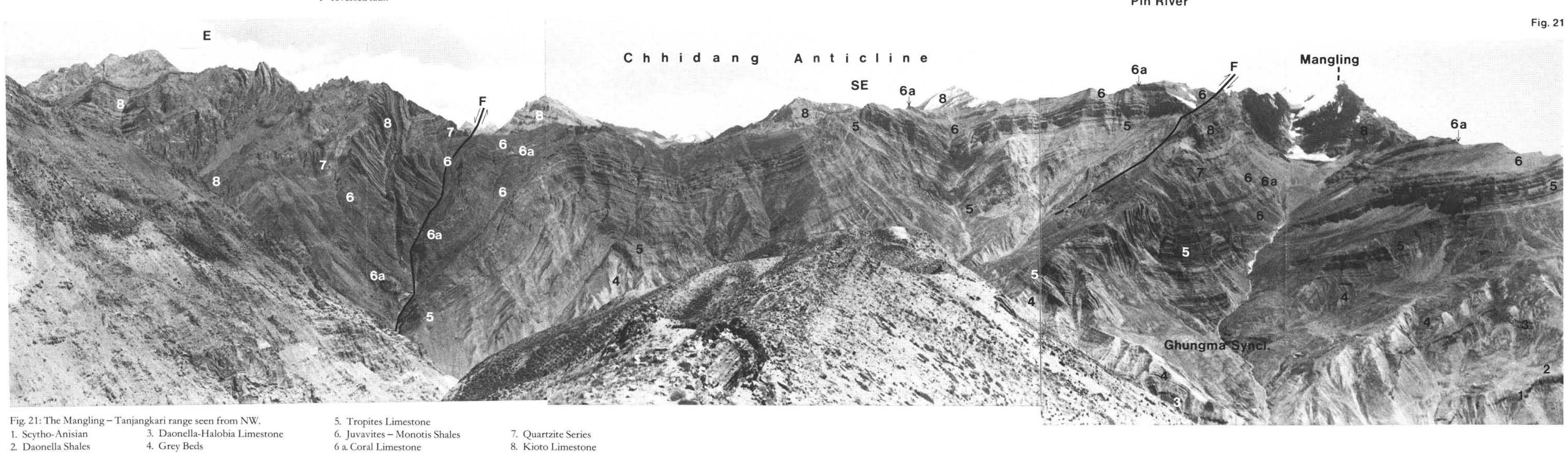


Fig. 21: The Mangling – Tanjangkari range seen from NW.
1. Scytho-Anisian
2. Daonella Shales
3. Daonella-Halobia Limestone
4. Grey Beds
5. Tropites Limestone
6. Juvavites – Monotis Shales
6 a. Coral Limestone
7. Quartzite Series
8. Kioto Limestone