# Revised Litho- and Sequence Stratigraphy of the Spiti Triassic

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## Introduction

The marine Triassic in the Indian Subcontinent, except Burma, is confined to the Himalaya (Salt Range included). The biostratigraphy of the Salt Range, Spiti, Kumaon (see Pascoe, 1968 for earlier references; Sweet, 1970; Guex; 1978; Garzanti et al., 1995) and partly of Nepal (Krystyn, 1982; Gradstein et al., 1992; Garzanti et al., 1994; Waterhouse, 2002b) sequences have been extensively worked out. The Permian-Triassic boundary has been investigated in detail in Salt Range (Pakistani-Japanese Research Group, 1985; Baud et al., 1998) and Kashmir (Nakazawa and Kapoor, 1981) and to some extent in Spiti (Bhatt et al, 1999).

The Triassic sequence in the Spiti is supposed to be the best developed in terms of biostratigraphic contents and continuity. Stolickza (1865) used the name Lilang for the Upper Triassic sequence. Later this term was adopted by Hayden (1904) for the Triassic rocks above the Kuling 'System' and below the Kioto 'System', later he incorporated Kioto too under the Lilang System (Hayden, 1908). In 1973 Srikantia (published in1981) mapped the Spiti Valley on 1:50000 scale along the main routes, he redesignated the Lilang System as the Lilang Group and divided it into five formations (Fig 1). His oldest Tamba Kurkur Formation measuring 500m seems to include sequence from the *Otoceras* Beds to the Grey Beds, yet the youngest fossil reported in this formation was *Hedenstroemia*. As per thickness the Hanse Formation (350m) is likely to include *Tropites* Limestone and possibly a part of *Juvavites* Bed, however the youngest fossils recorded from this formation were those of the *Halobia* Limestone. The Nimoloksa Formation (300m) thickness wise should include the *Juvavites* Beds, the Coral Limestone and part of the *Monotis* Shale, yet the youngest fossils reported from this formation were of the *Juvavites* Beds. The Alaror Formation though measured only 100m included fossils of the *Juvavites* Beds, Coral Limestone, *Monotis* Shale and Quartzite 'Series.' The term Simokhomda proposed by Srikantia (1981) for the well-known Kioto was *ab initio* redundant. The lithologic discrimination of all the formations, save Simokombda, was vague as each formation was described mainly to comprise carbonate with more or less identical lithologic assemblage and there was no mention of predominant argillaceous (e.g. *Daonella* Shale, Grey Beds, *Juvavites* Beds, *Monotis* Shale) and arenaceous contents (e.g. Quartzite Series). Besides the type localities of these formations affording poor and structurally complicated sections, the Nimoloksa Formation largely was found to be a strike extension of the Hanse Formation. These anomalies cropped as none of the formation was mapped. This classification not tested by mapping, therefore, should have remained at best informal. Fuchs (1982) followed Hayden's classification for the Triassic rocks. The aforementioned shortcomings in the classification proposed by Srikantia made identification of those units in field difficult and adoption of these names ticklish. Bhargava (1987), therefore, divided the Lilang Group into eight mappable formations (Fig. 1) and proposed a new classification. Only the members A, B, and C of his Sanglung Formation, though have appreciable thickness, were not accorded formational status (Bhargava and Bassi, 1998, p. 55) because they could not be delineated on the map due to constraints of the rugged terrains. The Para and Tagling subdivisions of the Kioto Formation, of earlier classification, were redefined as members and mapped on 1:50,000 scale (Bhargava and Bassi, 1998). Garzanti et al (1995) integrated classifications of Hayden (1904), Srikantia (1981) and Bhargava (1987). Though they adopted the term Tamba Kurkur (Srikantia, 1981; thickness 500m) it was used in the sense of Mikin (maximum thickness about 50m), similarly, the terms Hanse, Nimoloksa and Alaror were used without proper analysis as to their original contents and exact exposure at the type localities. These authors further rejected an independent formation status for the Coral Limestone, Monotis Shales and Quartzite Series. In the present paper the Lilang is being raised to a supergroup, the Sanglung and Kioto formations as groups and the members A, B and C of the Sanglung and Para of the Kioto are being reclassified as formations (Fig. 1) with geographic location (Fig. 2) and historical reference (Fig. 3) of the studied sequences.

## Lithostratigraphy

The Lilang Group, intervened by a ferruginous layer, lies above the Gungri Formation, which on the bases of *Cyclolobus oldhami, Marginifera himalayaensis, Xenaspis carbonaria* and *Xenodiscus carbonaius* has been assigned an age range from Dzulfian to a part of Dorashmian, the late Doarshmian being absent. Bhandari et al. (1992) reported europium anomaly from the ferruginous layer lying below the Lilang Supergroup. However, a close resampling revealed that the europium

| SPITI Hayden 1904 | | SPITI Srikantia 1981 | SPITI Fuchs 1982 | | SPITI Bhargava 1987 | | SPITI Garzanti & al. 1995 | | SPITI This paper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Kioto limestone 700m | SIMOKHAMBDA Formation 750m | | Kioto limestone | | KIOTO Formation 700m | | KIOTO Group >600m | KIOTO GROUP | | PARA limestone 150m | |
| | Quarzite series 100m | ALAROR Formation 100m | | Quarzite series 50-100m | | NUNULUKA Formation 100m | ALAROR GROUP | Quarzite series 15-35m | LILANG SUPER GROUP | NIMOLOKSA GROUP | NUNULUKA Formation 90m | |
| | Monotis shales 90m | | | Monotis shales<br>Coral limestone<br>Juvavites Shales<br>250-300m | | ALAROR Formation 90m | | Monotis shale 120-160m | | | ALAROR Formation -140m | |
| | Coral limestone 30m | NIMALOKSA Formation 300m | | | | HANGRANG Formation 20m | | Coral limestone 15-20m | | | HANGRANG Formation 30m | |
| | Juvavites beds 150m | HANSE Formation 350m | | | SANGLUNG Formation | Member C 180m | | Juvavites beds 110-195m | | | RANGRIK Formation 180m | U. M. 110m<br>L. M. 60m |
| TROPITES BEDS | Dolomitic limestone 90m | | TROPITES LST. | Limestones & dolostones ~ 120m | | Member B 265m | NIMALOKSA Fm. | Upper Member 105-160m | | SANGLUNG GROUP | RONGTONG Formation | Upper M. 120m |
| | Limestone & shale 65m<br>brachiopod limestone 120m | | | limestones, marls, sandstones & shales ~80m | | | | Middle Member 170-205m | | | | Middle M. 170m |
| | | | | limestone with shales ~80m | | | | Lower Member 160m | | | | Lower M. 90m |
| | Grey beds 165m | | | Grey beds 175-225m | | Member A 195m | HANSE GROUP | Grey beds 205m | | | RAMA Formation -220m | |
| | Halobia limestone 40m | | | Halobia / Daonella limestone 80-90m | CHOMULE Fm. | Halobia beds 35m | | CHOMULE Formation 85-100m | | TAMBA KURKUR GROUP | CHOMULE Formation 85-100m | |
| | Daonella limestone 45m | | | | | Daonella limestone ~50m | | | | | | |
| | Daonella shales 50m | TAMBA KURKUR Formation 500m | | Daonella shales 45-55m | KAGA Fm. | Daonella shale ~50m | | KAGA Formation 42-60m | | | KAGA Formation 60-90m | |
| | Upper & Lower Muschelkalk 8m | | | SCYTHO – ANISIAN 30m | MIKIN Formation | Upper & Lower Muschelkalk 8m | TAMBA KURKUR Formation | Muschelkalk 5-7m | | | MIKIN Formation | H. Muschelkalk Member 6-8m |
| LOWER TRIAS | Nodular limestone 18m | | | | | Nodular limestone 18m | | Nodular limestone 14-21m | | | | Niti Limestone Member 16m |
| | Horizons of *R. griesbachi* & *P. himaica* 2m | | | | | Basal Muschelkalk ~1m | | Hedenstroemia beds 13-25m | | | | Limestone & Shale M. 15m |
| | Hedenstroemia beds 10m | | | | | Hedenstroemia beds 7m | | | | | | |
| | Meekoceras zone Ophiceras zone Otoceras zone 2m | | | | | Meekoceras zone Ophiceras zone Otoceras zone ~4m | | First limestone band 0-1m | | | | Lower Limestone Member 1m |

Figure 1: Summary of alternative lithostratigraphic nomenclature for the Triassic of Spiti.

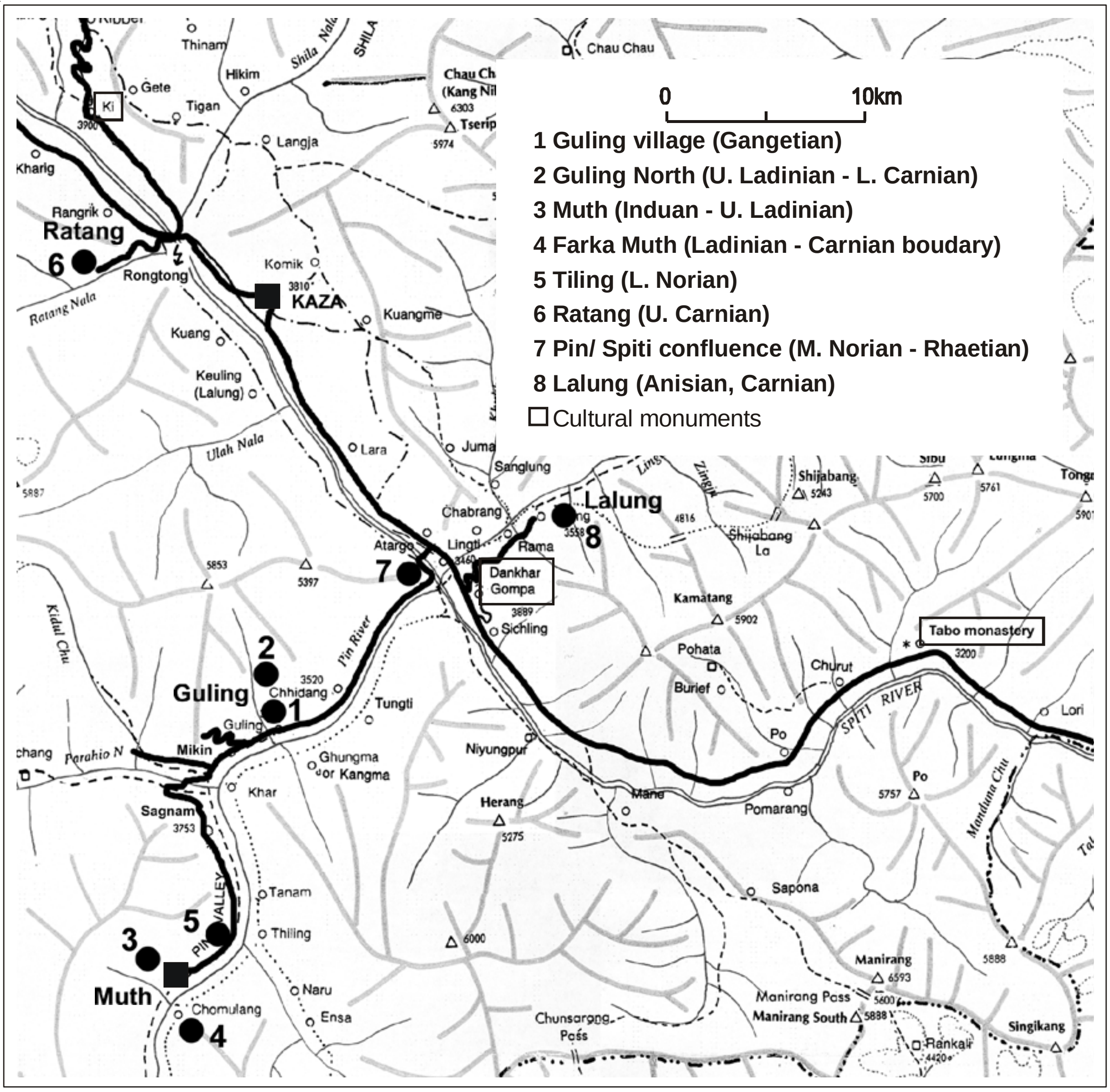

Figure 2: Road map of central Spiti with location of important Triassic outcrops.

anomaly is confined to the top one-centimeter layer of the black shale of the Gungri Formation immediately below the ferruginous layer (Bhargava and Bassi, 1998). A brief description of various groups and formations of the Lilang Supergroup is given below.

### 1 *Tamba Kurkur Group.*

The Tamba Kurkur Formation of Srikantia (1981) measuring 500m is being accorded a group status. The Mikin, Kaga and Chomule Formations are placed under this group. The Mikin Formation forms low but abrupt steep cliffs above the gentle topography of the Kuling Formation. The Kaga Formation forms gentler slopes capped by cliff of the Chomule Formation.

### 1.1. *Mikin Formation* (Induan – early Upper Ladinian)

It rests disconformably over the Gungri Formation and comprises gray to dark gray limestone in basal part, sporadic argillaceous (marl) limestone and subordinate thin shale bands in middle and predominantly limestone in upper parts (Fig. 4). The limestone often weathers to brown color. Nodular bedding, concretionary and wavy beddings are common in this formation. Limestone-shale unit forms several sedimentary cycles. It is divisible in the following four members:

(A) Lower Limestone Member. It is made up of hard ferruginous limestone, brown slightly dolomitic limestone, gray and concretionary limestone, often rich in shelly fauna made of ammonoids and occasionally pteriid bivalves.

(B) Limestone and Shale Member. It is constituted of thin wavy bedded limestones with thin shale partings and rare compact limestones weathering to brown color.

(C) Niti (Nodular) Limestone. As name indicates it comprises thin nodular, locally marly limestone.

(D) Himalayan Muschelkalk. It consists of thin bands of limestone, somewhat argillaceous limestone and minor shale thickest at the base of sequence (Fig. 5). Limestones are sometimes concretionary, rich in fossils (domi-

| Superg./Group | | Formation | Mb. | Classical name | Type (T)/ Reference (R) section |
|---|---|---|---|---|---|
| KIOTO GROUP | | PARA | | Para Limestone | R: Pin Valley entrance (road cut)<br>(32°06´00´´, 78°10´30´´) |
| LILANG SUPERGROUP | NIMOLOKSA GROUP | NUNULUKA | | Quarzite Beds | T: Pin/ Spiti Confluence (road cut)<br>(32°06´05´´, 78°10´27´´) |
| | | ALAROR | | Monotis Beds | T: Pin/ Spiti Confluence (road cut)<br>(32°06´10´´, 78°10´25´´) |
| | | HANGRANG | | Coral Limestone | R: Pin/ Spiti Confluence (road cut)<br>(32°06´10´´, 78°10´25´´) |
| | | RANGRIK | U | Juvavites Beds | T: Geichang (32°03´15´´, 77°59´37´´)<br>T: Ratang Valley<br>(32°14´22´´, 78°01´30´´) |
| | | | L | Zoophycus L. | |
| | SANGLUNG GROUP | RONGTONG | U | U. Tropites L. | T: Ratang Valley<br>(32°14´22´´, 78°01´30´´) |
| | | | M | M. Tropites L. | |
| | | | L | L. Tropites L. | |
| | | RAMA | | Grey Beds | T: E of Lalung<br>(32°08´50´´, 78°15´25´´) |
| | TAMBA KURKUR GROUP | CHOMULE | | Daonella +<br>Halobia L. | R: N of Guling<br>(32°03´00´´, 78°05´16´´)<br>E of Muth<br>(31°56’76”, 78°02’59”) |
| | | KAGA | | Daonella Shale | R: N of Guling<br>(32°02´97´´, 78°05´14´´)<br>N of Lalung<br>(32°09’37”, 78°14’03”) |
| | | MIKIN | D | Muschelkalk | R: Muth<br>(31°57´30´´, 78°02´00´´) |
| | | | C | Niti Limestone | |
| | | | B | Hedenstroemia B. | |
| | | | A | Otoceras B. | |

Figure 3: Adopted lithostratigraphic nomenclature, classical counterparts and type or reference sections of the Triassic formations of Spiti.

nantly ammonoids, but also brachiopods, gastropods and bivalves) and often with erosional tops. Thick iron oxide coatings top some Upper Anisian beds and, point together with occasional phosphatic fossil preservation in the Lower Anisian to partly starved or condensed sedimentary conditions.

The main carbonate microfacies in the Mikin Formation are: (i) bioturbated thin to thick-shelled packstone (in basal member), (ii) whole fossil wackestone, (iii) thin- shelled cephalopod wackestone and (iv) thin-shelled filamentous packstone with local calcispheres and radiolarian.

The basal part of the Mikin Formation with thick shelly beds shows somewhat shallower marine environment above mean wave base It is succeeded by mudstone with thin-shelled “flaser-bedded” filamentous packstone interpreted as distal tempestite, signifying deepening of the basin to below wave base with mild bottom currents.

Best sections of the Mikin Formation (Fig. 4 and 5), are exposed in the vicinity of Muth, in the slopes north, as well as between Guling (old spelling Kuling) and Mikin villages along the old mule track, and north of Lalung (old spelling Lilang). Excellent, continuous and least folded section of this formation is exposed at both the localities and so also its contact with the Guling Formation. The strike of the beds varies N30°E-S30°W to N40°E-S40W° with northwesterly dips between 35° and 40°.

## 1.2. *Kaga Formation* (Upper Ladinian)

This formation conformably overlies the Mikin Formation and is made of earthy to gray shale, marls and silty marls, with some thin bedded gray limestones and marly-limestones intercalations in the lower and middle part.

This unit weathers to earthy color. The carbonate microfacies are: (i) bioclastic mudstones. (ii) bioclastic wackestones/packstones, (iii) layered thin-shelled packstones, interpreted as storm layers.

The thickness of the Kaga Formation is decreasing from South towards North. In the Muth area the unit is 110-120 m thick, while the thickness is 60 m at Guling. A similar thickness is also estimated at Lalung. Lower and upper boundaries are sharp.

Due to the abundance of marls and shales the unit is soft and often it is disturbed by tectonics (folding and cleavage), or covered by debris.

Fossils are very common in the Kaga Formation, in particular daonellids, can be found in both marls and limestones. Ammonoids are less frequent than daonellids, and occur more often in the limestones than in the marls. From

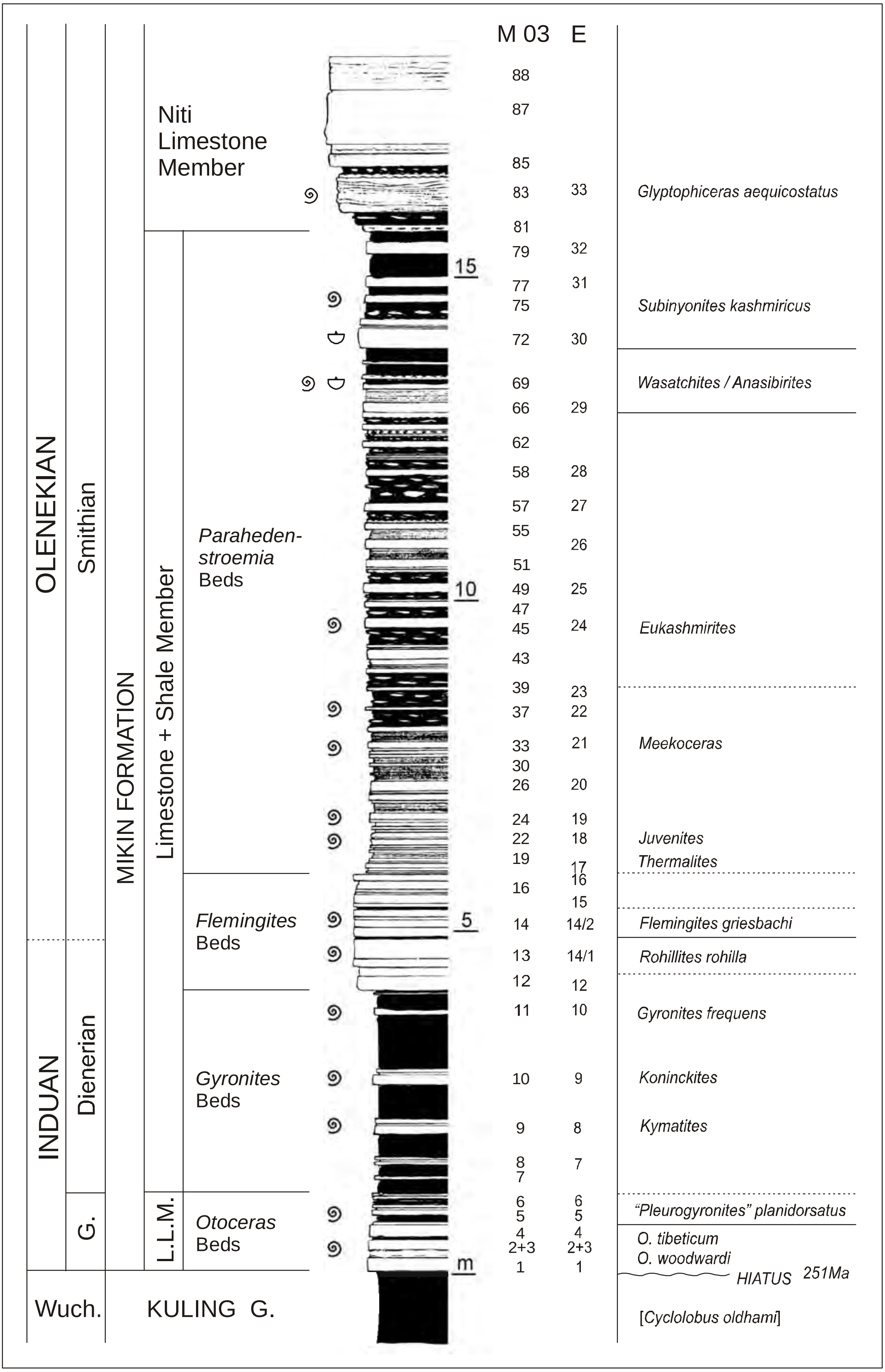

Figure 4: Stratigraphic log of the Mikin Formation, Lower Limestone to Niti L. Mb. in Muth, upper Pin Valley.

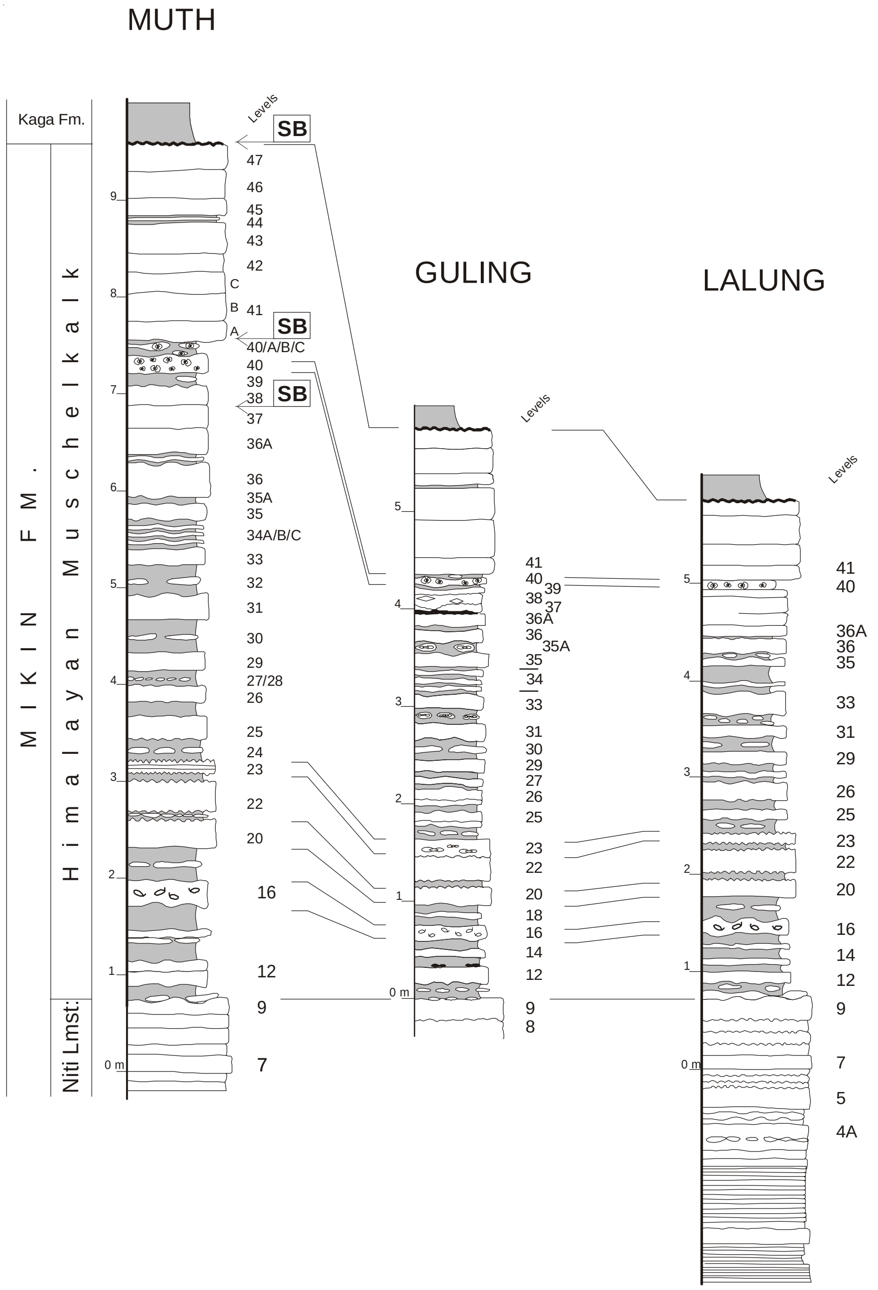

Figure 5: Stratigraphic log of the Mikin Formation, Himalayan Muschelkalk Mb. in Muth, upper Pin Valley, and its correlation with Guling and Lalung. Thikness of member is decreasing towards north.

the practical point of view the collection of fossils, especially of daonellids, is strongly influenced by the deformation (cleavage) of the unit.

The depositional environment of the Kaga Formation is a neritic shelf below to sometimes above the storm wave base.

The best exposure of the Kaga Formation in the study area is North to the village of Guling, on the left hand side of the tributary river of the Pin river. There the whole Kaga Formation is very well exposed, so that a complete section has been measured (section Guling 1: Fig. 6). A second important outcrop (Lalung 3: Fig. 6) is located in Lingti Valley, close to the village of Lalung, on the right hand side of the valley.

### 1.3. *Chomule Formation* (uppermost Upper Ladinian-Lower Carnian)

The Chomule Formation conformably overlies the Kaga Formation and forms a distinct cliff between the Kaga Formation and Rama Formation (“Grey beds” of Hayden, 1904). The lithology of the unit is rather monotonous, and consist of thin to medium bedded dark grey to black limestones and marly limestones, with some marly/shaly intercalations. Bedding is planar to nodular.

The limestones are mostly (i) mudstones to bioclastic mudstones, with rare (ii) bioclastic wackestones containing pelagic bivalves, crinoids, ammonoids and nautiloids, (iii) radiolarian wackestones (Lingti section), (iv) thin shelled gastropod wackestones/packstones.

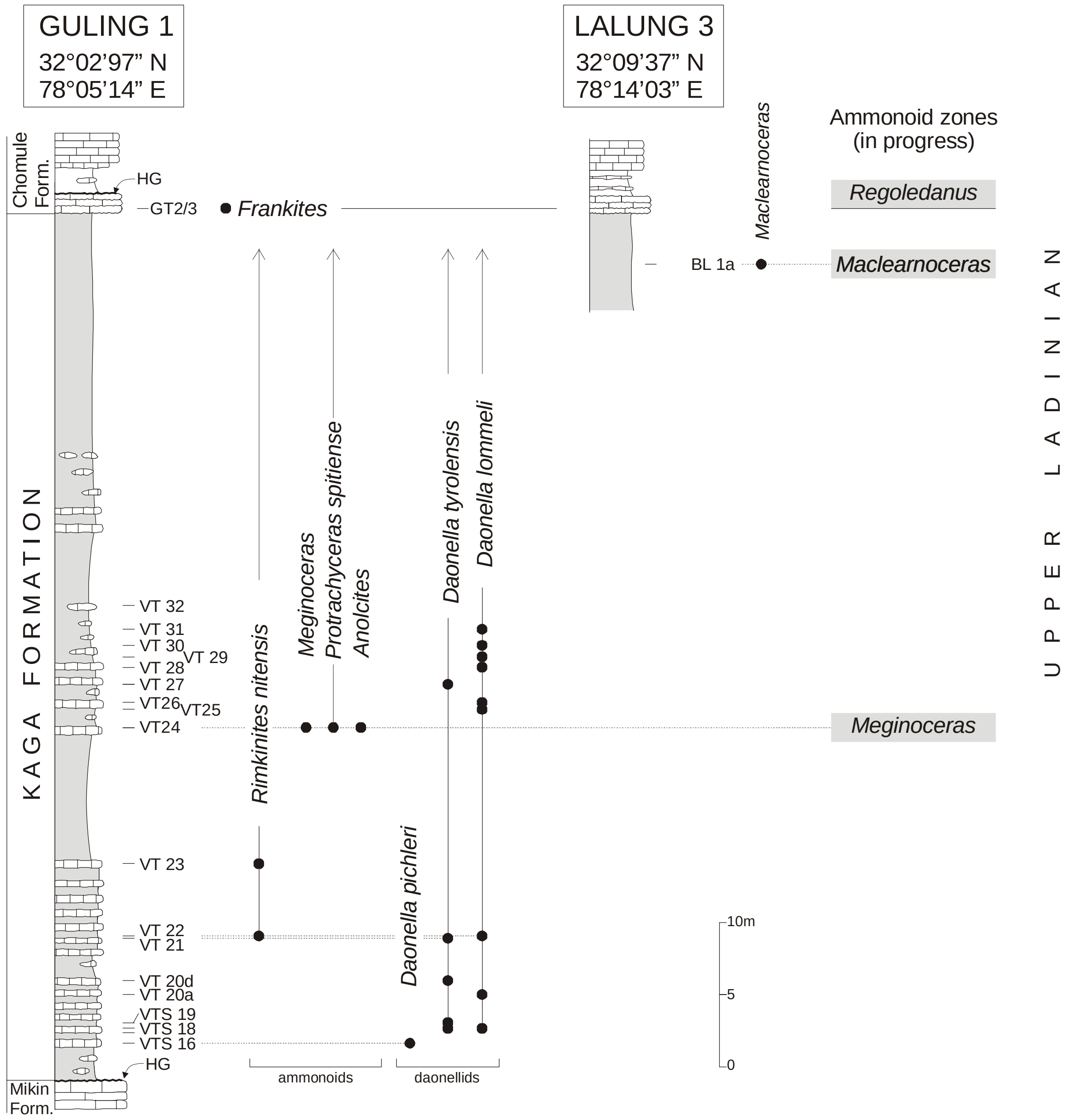

Figure 6: Stratigraphic log of the Kaga Formation at Guling 1 (N of Guling) and correlation with Lalung 3 (Lingti Valley).

The bioclastic wackestones mostly occur at the base of the Chomule Formation where they form a thin but distinct marker interval that can be followed in all the study area.

This interval, informally called "Traumatocrinus Limestone" (Balini et al., 1997) by reference with Painkhanda (Shalshal Cliff), is 2.8 m thick at Muth 3 and 1.4-1.5 m thick at Guling (Fig. 7). This interval is rather rich in fossils, however their extraction is very difficult because of the hardness of the rock. The upper part of the "Traumatocrinus Limestone" is also characterised by hardgrounds. At Muth 3 section hardgrounds are also present above the "Traumatocrinus Limestone".

Marly intercalations are 10 cm to 4 m thick and are more frequent at Muth than at Guling and Lalung. The limestone beds and the marly intercalations are often organized in limestone-marl cycles. This cyclicity, visible at Guling 1 but best developed at Muth 3, does not fit with the shallowing upward marl-limestone cyclicity described by Garzanti et al (1995) at different scale in the Lower and Middle Triassic succession of Spiti.

In general the Chomule Formation is less fossiliferous than the Kaga Formation. The most common macrofossils are the pelagic bivalves, which occur more frequently in the marly intercalations than in the limestones. The ammonoids are more rare, and can be found within the limestone beds, where they are very difficult to extract, or on the bedding surfaces, where collection depends only on the outcrop.

The total thickness of the formation is about 100-120 m. Due to the interest for the definition of the Ladinian/

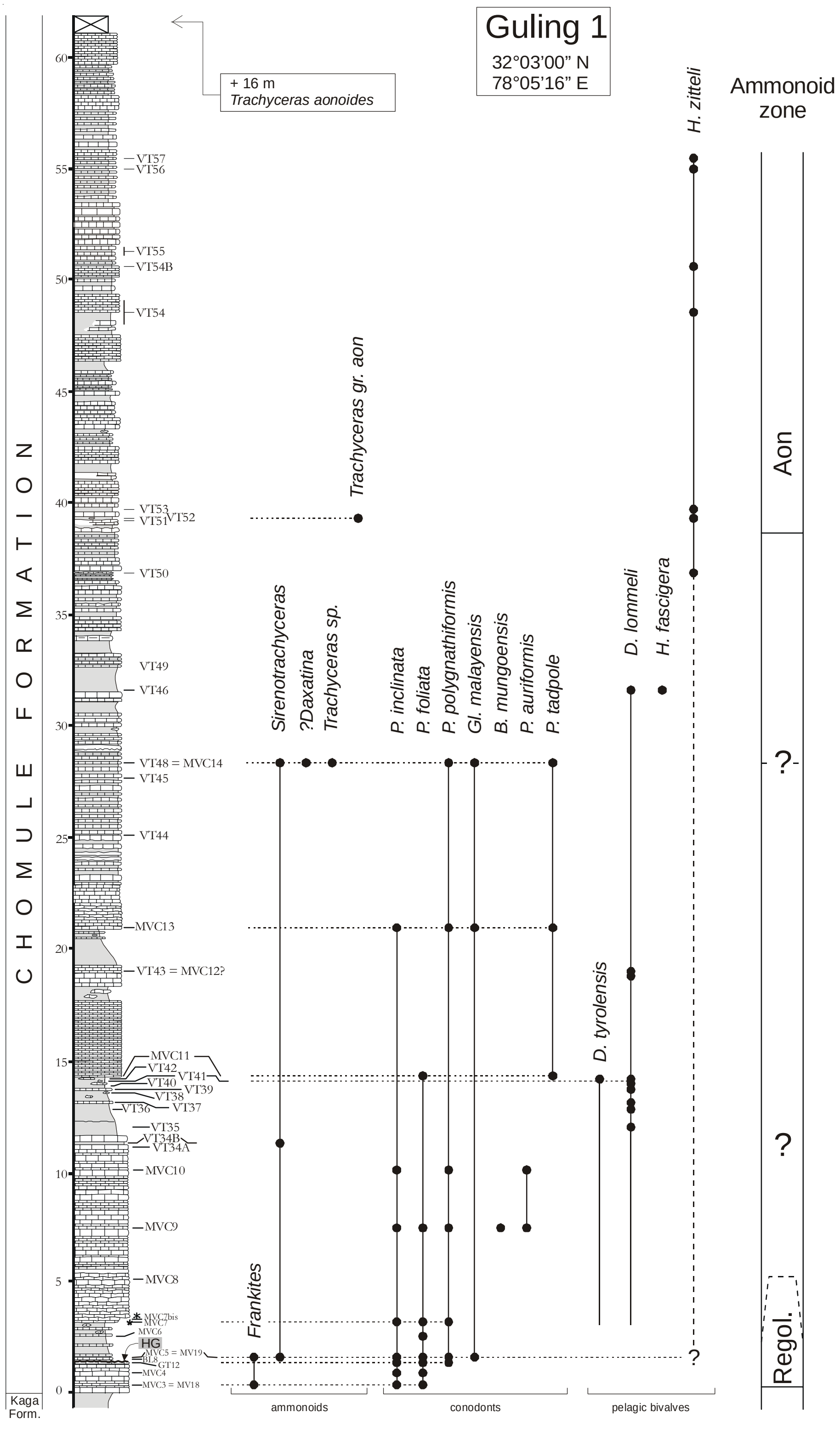

Figure 7: Stratigraphic log of the Chomule Formation, at Guling 1 section, N of Guling.

Carnian boundary only the lower half of the Chomule Formation has been investigated in detail.

The Chomule Formation was deposited on a neritc shelf with calcareous sedimentation and locally strong terrigenous supply.

The best sections are North of the Guling village, and in the Muth area, in particular at Farka Muth on the right hand side of the Pin river in front of Muth Village.

## 2. Sanglung Group.

It is a successor of the Sanglung Formation, members A and B, and is divisible in the new Rama and Rongtong Formations which are successors of the members A and B, (Bhargava, 1987) respectively. The Rama and Rangrik Formations form gentle to rather steep slopes.

### 2.1. *Rama Formation* (latest Lower Carnian – early

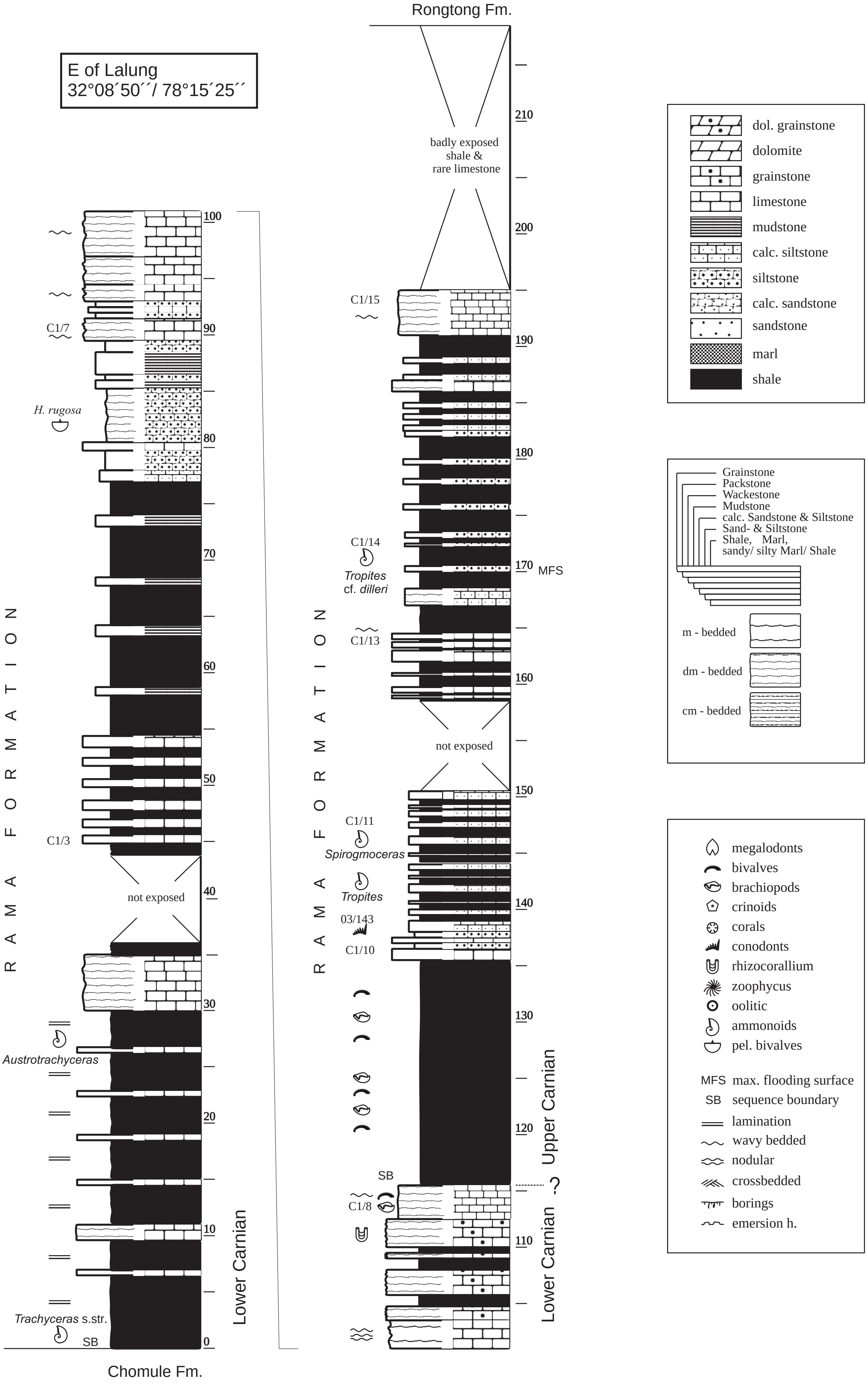

Figure 8: Stratigraphic log of the Rama Formation (type section), E of Lalung.

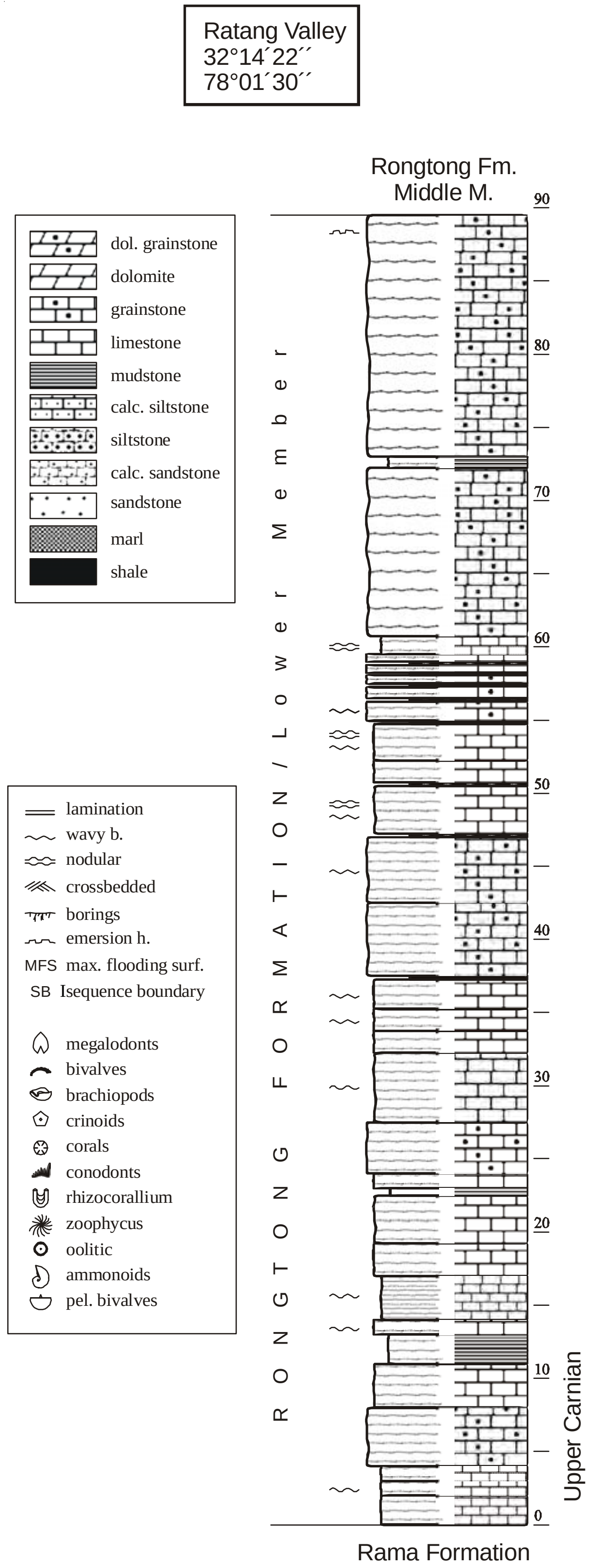

Figure 9: Stratigraphic log of the Rongtong Formation, Lower Mb. (type section), Ratang Valley.

Upper Carnian)

It corresponds to the 'Grey Beds' of Hayden (1904). The Rama Formation conformably follows the Chomule Formation and is made up of gray, locally carbonaceous fine-grained siltstone, shale and limestone repeated in cyclic order (Fig. 8). These lithounits weather to ash gray color. Lamination is common in the basal shale, silt- and mudstone, cross-bedding and parallel bedding are present in the siltstone and very rare fine-grained sandstone higher up. The pelitic fraction of the siliciclastic sediments of the Rama Formation is exclusively composed of illite and chlorite.

Carbonate microfacies recorded in the Rama Formation are: (i) bioclastic/lithoclastic wackestone containing dark rimmed bryozoans, echinoid spine, mollusks and rare oolites and algae, (ii) massive bedded mudstone partly with sponge spicule, (iii) rare thin-shelled filament wackestone, (iv) common packstone with clasts of bivalves, gastropod, iron-coated echinoid spine, crinoid ossicles, serpulids, foraminifers and fish teeth, (v) coral wackestone and (vi) sandy floatstone with bivalves, corals and hydrozoa.

The mixed facies of thin-shelled packstone and coral, oolite, algae indicate a depositional environment of the Rama Formation to vary from shallow subtidal shelf to deeper neritic basin below wave base during short termed transgressive pulses.

Type section of the Rama Formation is well exposed in the Lingti Valley between Rama and Lalung villages, especially along the slopes of the right bank of the valley and below the Sechen peak (opposite Lalung). The strike of the beds varies from N15°W-S15°W to N20°W-S20°W with southwesterly dips between 20°and 30°.

## 2.2. *Rongtong Formation* (middle to late Upper Carnian)

It is equivalent of the Tropites Limestone of Hayden (1904) and rests conformably over the Rama Formation forming craggy topography. Appearance of a thick limestone bed marks the contact between these two formations. The new formation is divisible in following three members.

(A) Lower Member (Fig. 9): it comprises nodular limestone with basal shale interlayer providing continuity with the Rama Formation.

(B) Middle Member (Fig. 10): it is made up of a distinct sand- and siltstone interval at the base overlain by a mixed sequence of dark fossiliferous splintery limestone (with basal *Tropites* bed), calcareous shale and limestone with some marl (in upper part).

(C) Upper Member (Fig. 10): it is constituted of cliff-forming thick to medium bedded limestone and dolomite with bivalve-bearing limestone (megalodonts ?), and common emersion horizons (in upper part).

Cross-bedding, wavy and nodular bedding, thin parallel/

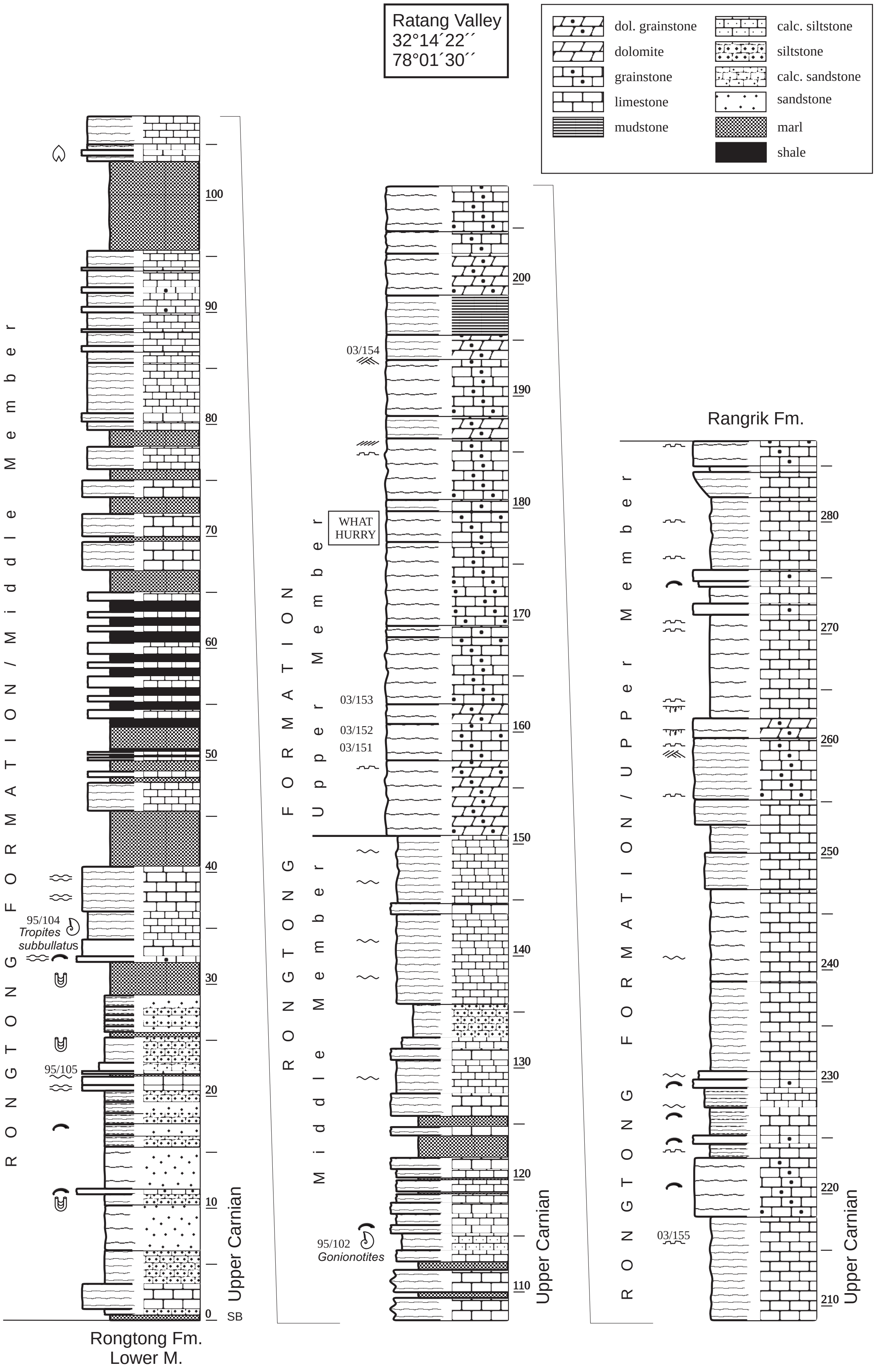

Figure 10: Stratigraphic log of the Rongtong Formation, Middle and Upper Mb. (type section), Ratang Valley.

subparallel bedding, local mud cracks (in Lalung section of the Upper Member) and small-scale channel-fills are the main bedding features in the Rongtong Formation.

The sedimentary environment of the Middle Member of the Rongtong Formation is a storm-dominated ramp. The sequence starts in quiet water with sediments, which were accumulated probably below the wave base: bioclastic grainstones, pellet- dominated soft-bottom sediments and intercalations of distal tempestite layers. Coarse-grained (proximal) limestone tempestites, oolithic and oncolithic grainstones in the Middle and Upper member of the Rongtong Fm. indicate a stepwise upward shallowing sequence

The carbonate microfacies include: (i) mudstone, (ii) bioclastic wackestone/packstone with mollusk shells, crinoids and coral, (iii) very rare whole coral wackestone, (iv) peloidal wackestone with bioclasts (v) bioclastic grainstone, mainly in upper part of the Lower Member and lower part of the Upper Member.

The Rongtong Formation was – except for the ammonoid bearing short deeper marine incursion in the Middle Member (Fig. 10) - deposited in subtidal to intertidal environment of moderate to high energy, with increasing emergence phases towards the top.

Easily accessible, its best section is exposed one km upstream of the Rongtong dam along the road of the Rongtong Project in the Ratang Valley. The beds show gentle warping to minor folding. The strike of the rocks varies from N25°W-S25°E to N55°W-S55°E with southwesterly dips between 35° and 65°, due to local folding northeasterly dips between 40° and 70°are also observed.

## 3. *Nimoloksa Group*.

The Nimoloksa Formation of Srikantia (1981) is being redefined and raised to a group level. Under this group are classified the new Rangrik, the Hangrang, Alaror and Nunuluka Formations. The Hangrang Formation made up of massive to bedded limestone forms prominent slopes. The Rangrik, Alaror and Nunuluka Formations are mostly exposed in the cliffs.

### 3.1 *Rangrik Formation* (Lower to Middle Norian)

It is a successor of the *Juvavites* Beds of Hayden (1904) and has a conformable contact with the Rongtong Formation. This formation is composed of two lithologically different members (Fig. 11), a lower limestone dominated one, with minor marl and siltstone, and an upper siliciclastic one with siltstone, in part iron oolitic sandstone (Garzanti et al., 1995), gray to greenish gray partly phosphatic nodules bearing shale, and rare limestone. These lithounits form prograding cycles constituted of limestone-shale-siltstone-sandstone, some of the cycles are truncated. Ripple bedding, low angle cross-bedding are common sedimentary structures in the formation.

The carbonatic microfacies in the Rangrik Formation are: (i) bioclastic grainstone/packstone with numerous bivalves and crinoids, (ii) lithoclastic grainstone, (iii) rare ooidal packstone/grainstone and (iv) mudstone with Fe-rich layers.

The trace and body fossils (common *Zoophycus* in the lower member), sedimentary structures and carbonate microfacies indicate low to moderate energy with occasional high energy, and especially in the basal upper part of the formation possibly even to circa-littoral environment (Bhargava and Bassi, 1998).

The type section of this formation is located in the Parahio Valley north of Geichang (Fig. 1). Other useful outcrops are in Ratang Valley, close to Rangrik (in Indian toposheet also named Rangarik), in the Gyundi Valley close to Hal and in the Pin Valley opposite of Tiling.

In the Ratang Valley, the formation is exposed above the Rongtong Formation along the road of the Rongtong Project. There are a few short stretches of “No Exposures” along the road, however, outcrops can be studied in the hill section above the road. The sequence here shows minor warps and local folds. The variation in strike and dip of this formation is similar to those of the Rongtong Formation.

### 3.2 . *Hangrang Formation* (late Middle Norian)

It is constituted of light to dark gray limestone, massive or well bedded. Coral knoll reefs form part of this formation. Bharghava and Bassi (1985) reported from the majority of their sections three cycles of reef formation. In other sections, like at the Pin-/Spiti river confluence, this trend could not be confirmed. In fact every correlation in detail is hampered by the complicated local topography between the small sized reefs, causing rapid lateral facies change.

In the most cases the sequence starts with bioclastic grain- and wackestones containing fragments of reef-building organisms. (Fig. 12). In the Pin/Spiti confluence section an intercalation of dasycladacean grainstones reflects a short temporary episode of shallowing. The framestones above contain only a thickness of few meters. Calcareous sponges (“*Stylothalamia*” sp., *Cinnabaruria* sp., *Platythalamiella* sp., *Parauvanella* sp., *Colospongia* sp.) represent the predominant element of the reef dwelling fauna, whereas the corals are less important. The composition of the coral-fauna reflects a clear deepening trend of the environment towards the top. Branching corals, frequent at the base, are replaced by platy corals at the top. The termination of the reef-growth is marked by layers of coarse grained bioclastic grainstones, often rich in rhynchonellids, succeeded by mudstones included here in the Alaror Fm.

The reef-building association of the Hangrang Formation differs strongly from that of the Upper Triassic reefs of the Alps, whereas similarities to the Upper Triassic reefs of Iran and the Pamir are evident. The paleobathymetric range of the Hangrang Formation extends from shallow water environment /shallow ramp facies with *Griphoporella* sp.) to deeper water environments (within the photic zone) with hexactinellids.

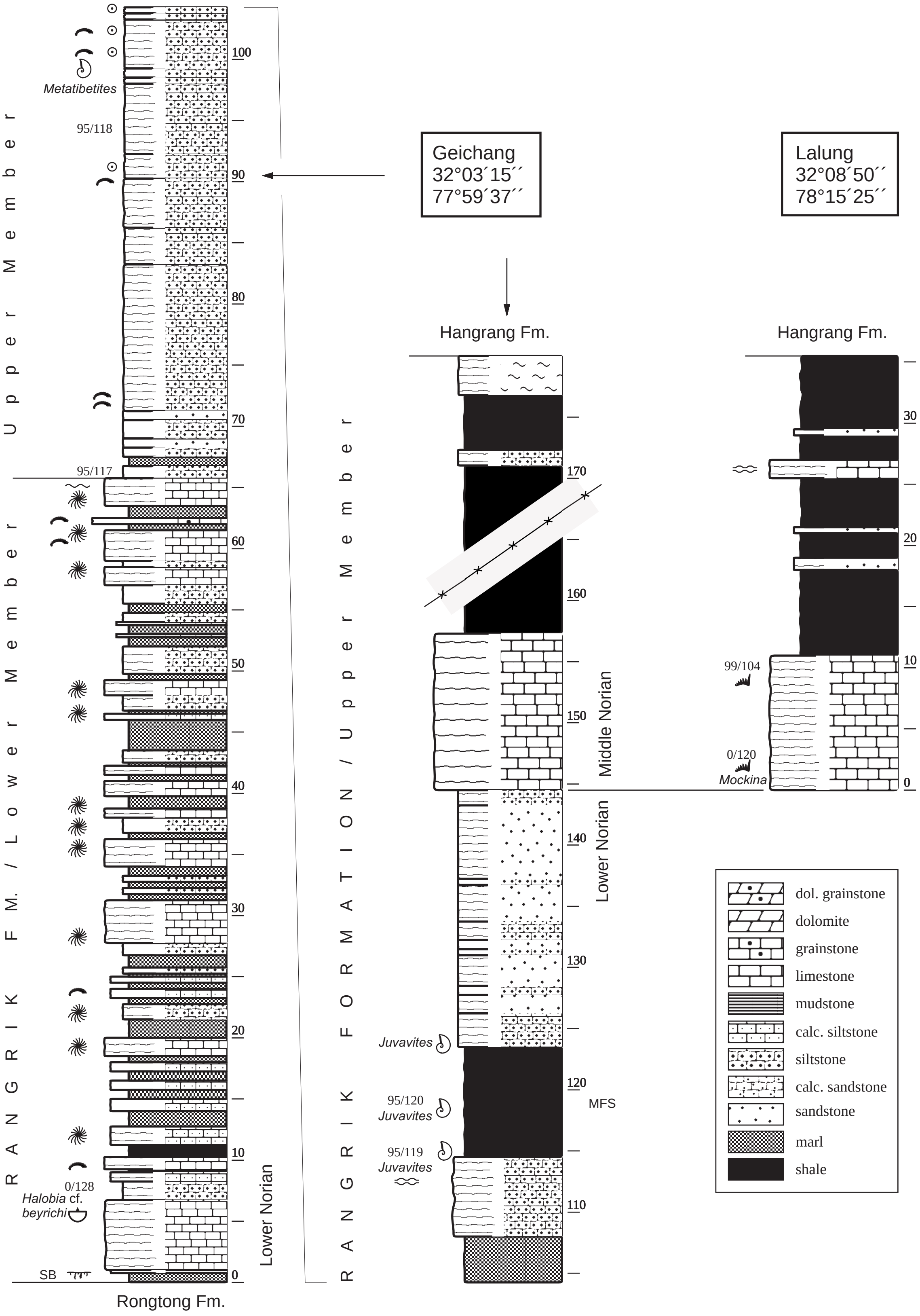

Figure 11: Stratigraphic log of the Rangrik Formation (type section), N of Geichang and E of Lalung.

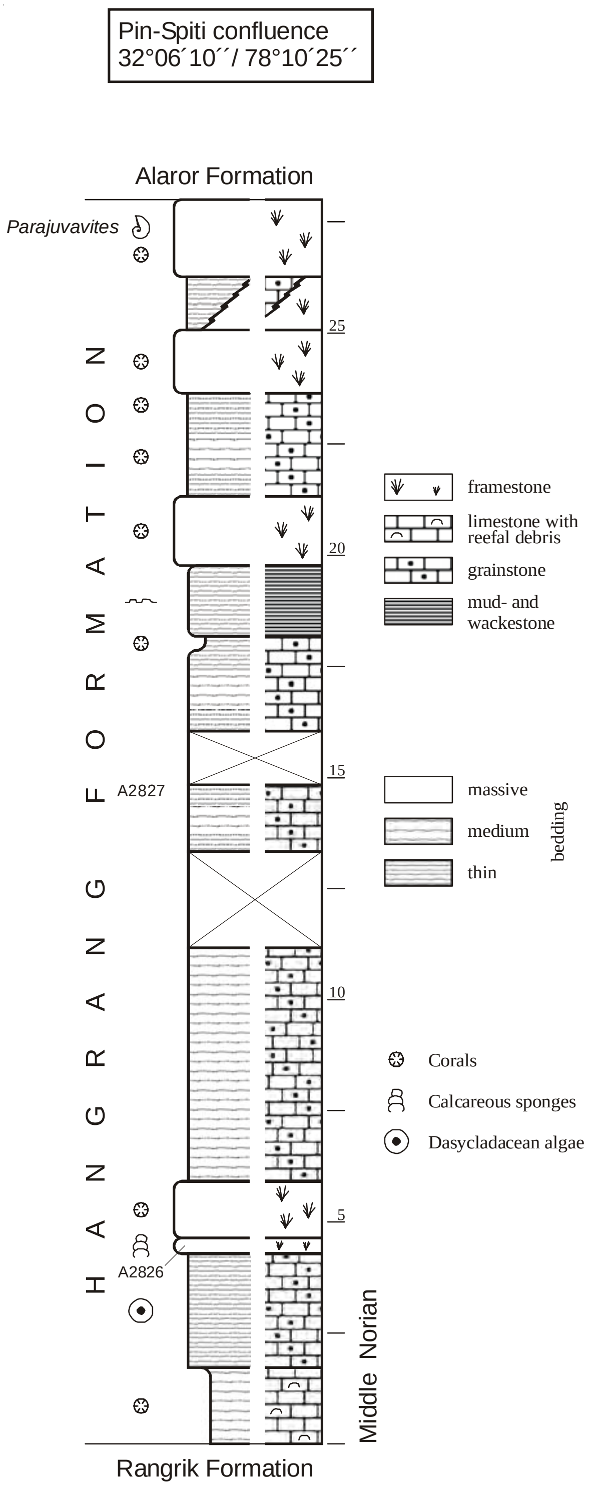

Figure 12: Stratigraphic log of the Hangrang Formation , Pin-Spiti confluence.

The type section of this formation is present at Hangrang Pass; a comparably well developed locality lies along a hillock just below the Atargoo-Guling road about one kilometer upstream of the confluence of the Pin and Spiti rivers. The continuous and also laterally well exposed section shows a minor fault just below the road and extends in the hill above the road. The strike of the beds varies between NW-SE to N50°W-S50°E with 50-60°northeasterly dips. In the Ratang Valley also this formation having northwesterly strike and steep southwesterly dips is exposed. However, in this section much of the reef has been mined for making a canal just above a good outcrop, also the muck generated by digging the canal has covered quite a bit of the outcrop.

### 3.3. *Alaror Formation* (lower Upper Norian)

Disconformably resting on the underlying formation the Alaror Formation consists at the base of a short brachiopod rich limestone package ("*Spiriferina griesbachi* beds") showing onlap geometry over the Hangrang Fm. (Fig. 13). Above follow dark gray to brownish shale, siltstone to fine grained sandstone and rare limestone. The carbonate-shale-siltstone units form several prograding cycles in this part. The upper half of the formation is dominated by silty shale with minor siltstone rich in pelagic fossils (*Heterastridium, Monotis salinaria*) and some carbonate bands at the top. Sedimentary features in the silt- and sandstone dominated part are cross-bedding, ripple cross-bedding, lenticular bedding, interference ripple marks and local mud cracks.

The carbonate microfacies are represented by: (i) sandy ooidal grainstone/packstone, (ii) layered mudstone with tempestite layers of bioclasts and (iii) bivalve-ooidal grainstone/packstone.

The depositional environment as revealed by the sedimentary sandstone features and the carbonate microfacies was shallow marine well above wave base. The presence of pelagic *Monotis* and widespread *Heterastridium* towards upper part apparently shows deeper neritic environment section up.

A good more or less continous section is exposed along the Atargoo-Guling road near the Pin-Spiti confluence and has been designated as type section by Bhargava (1987). Outcrops are concealed along the road in small stretches; nevertheless, they can be examined in the slopes above the road. The rocks show gentle warping. The general strike of the rocks is in NW-SE direction with southeasterly dips between 50-65°.

### 3.4. *Nunuluka Formation* (Upper Norian ?)

It corresponds to the Quartzite Series which according to Hayden (1904) constituted the most conspicuous horizon in the Lilang Supergroup, visible from a distance. The Nunuluka Formation (Fig. 14) conformably succeeding the Alaror Formation comprises moderately sorted sandstone, shale and thick, medium to finely bedded limestone/dolostone in decreasing order of abundance. Limestone-shale-sandstone/ sandstone-shale units form several cycles of varying thickness. In upper part of this formation along the Atargoo-Guling road occur *Megalodon* in abundance in a limestone bed that is overlain by sandstone. Earlier this level was classified with the Para subdivision of the Kioto 'Formation'. Wave/interference ripple marks, large scale cross-bedding, herringbone cross-bedding and wavy cross- bedding are present in this formation.

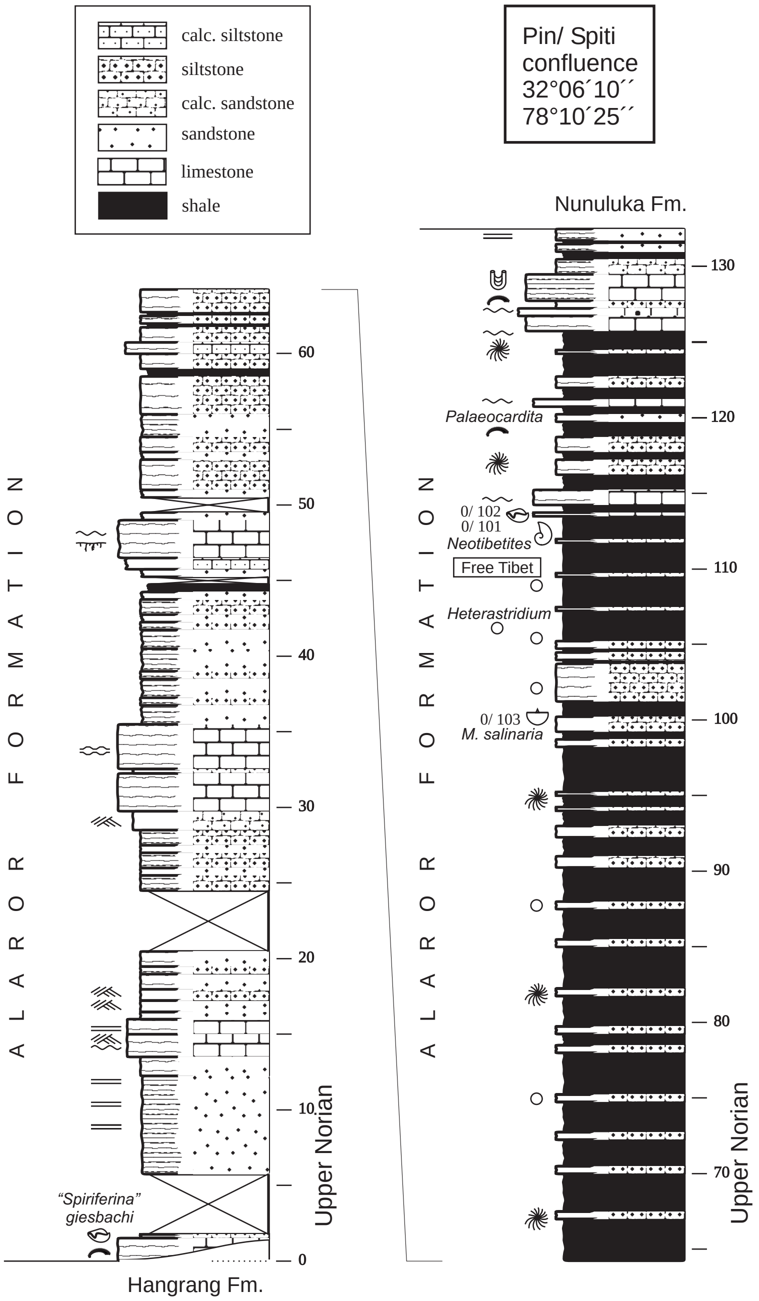

Figure 13: Stratigraphic log of the Alaror Formation (type section), Pin-Spiti confluence.

The arenaceous succession is composed of silt- and fine-sand sized arkoses and subarkoses with low roundness and sphericity. The abundance of feldspar and the bad roundness of the arenitic grains may be interpreted as indications for a short transport in a semiarid climate.

The rare limestone intercalations within this sequence point again to a storm dominated shallow water regime with strong resedimentation indicated frequent presence of blackened extraclasts ("black pebbles"). The bioclastic wacke- and grainstones predominantly contain crinoidal ossicles, pelecypod valves, but also occasionally fragments of reef organisms (calcareous sponges, corals) and calcareous algae (Cyanophycea and Codiacea).

The depositional environment of the Nunuluka Formation varied from coastal to intertidal with local shoal and winnowed shelf conditions in upper most part of the sequence.

This formation is best exposed near Hanse (old spelling Hansi) and along the Atargoo-Guling road below the Nunuluka Hill at the Pin Valley entrance. Concealed portions along the road can be examined in its strike continuity in the steep slopes above the road. The strike of the rocks varies from NW-S to N50°W-S50°E with 60-70° dips towards southwest.

## 4. *Kioto Group.*

The Kioto 'Limestone' was earlier divided in the Para Limestone/Stage and Tagling Limestone/Stage mainly as biostratigrahic subdivisions. These units were lithosrtatigraphically redefined and mapped as Para and Tagling members (Bhargava and Bassi, 1998), now being raised to formational level. The Para Formation as defined here is restricted in age to the Rhaetian while the

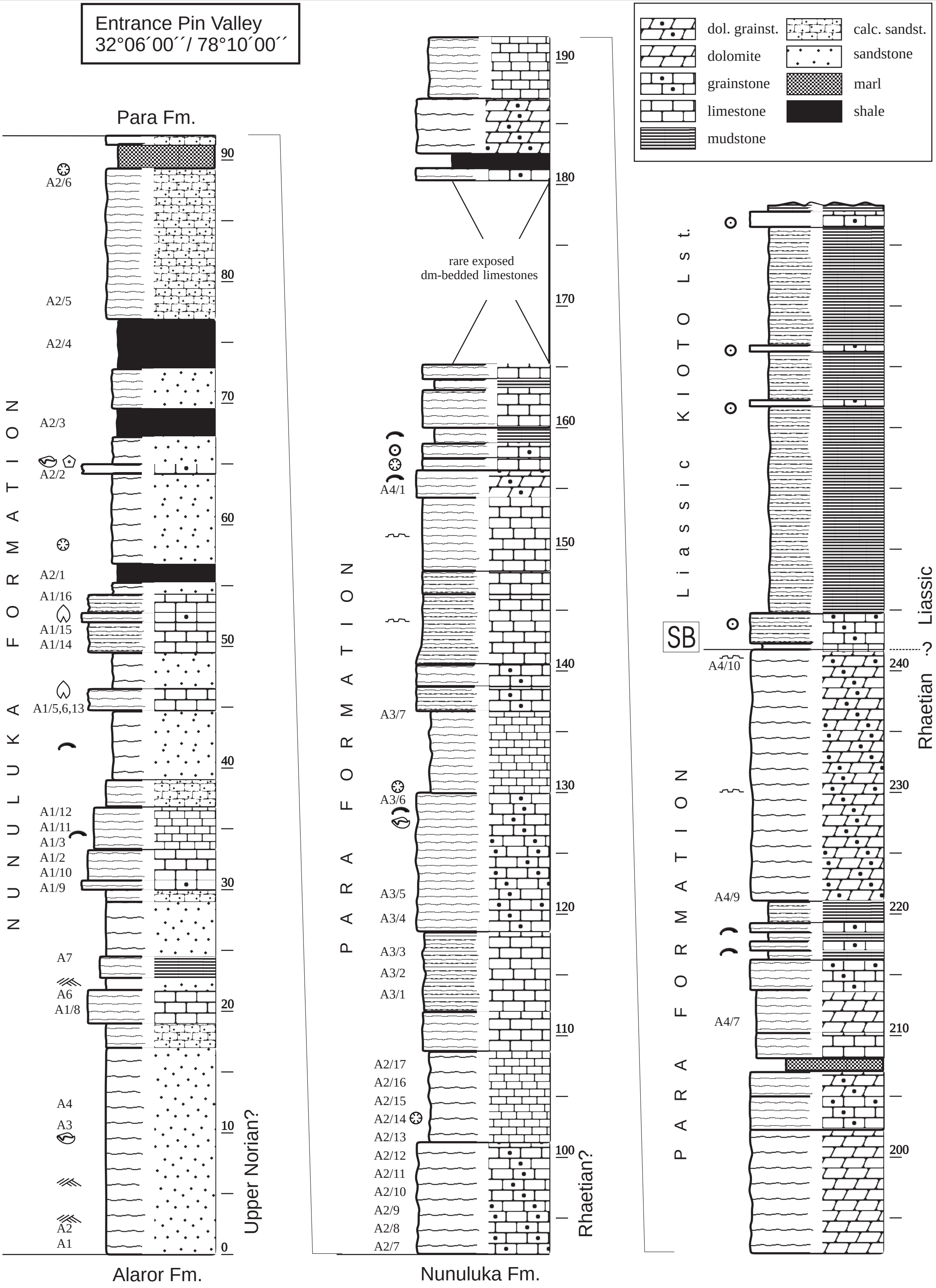

Figure 14: Stratigraphic log of the Nunuluka Formation (type section) and Para Formation, Pin Valley entrance.

Kioto *s. str.* is exclusively of Liassic to lowest Dogger (?) age. The Para Formation together with the Kioto *s. str.* mostly forms steep slopes whereas the Tagling Formation forms gentler and soft topography.

## 4.1. *Para Formation* (Rhaetian ?)

This formation conformably resting over the Nunuluka Formation consists of gray thin to medium bedded limestone and towards the top increasingly of dolomite (Fig. 14) with a disconformal contact to the Jurassic rock sequence.

The carbonate microfacies in this formation are: (i) lithoclastic wackestone/packstone containing clasts of bivalve filled with peloidal mud, ooids, faecal pellets, (ii) foraminiferal (quinquilinoids)-ooidal/oolitic grainstone/

packstone and (iii) peloidal aggregate bioclstic/lithoclastic floatstone/packstone. Crinoid fragments, which are much more frequent than in the underlying part, are the most characteristic element among the bioclastic grains. The distribution of all bioclasts, the pelecypods, gastropods, foraminifera (with *Aulotortus* sp. and *Triasina* sp.) and calcareous algae indicate a transport, which was controlled by hydrodynamic processes on a storm dominated shallow shelf. Neomorphism and the presence of granular cements indicate a diagenetic overprint in a freshwater phreatic zone and testify the vicinity to emerged areas.

Of facies diagnostic importance is the common occurence of black pebbles, which are more frequent in the Para Fm. than in the limestone intercalations of the Nunuluka Fm. below. The subrounded mm- to cm-sized early lithified extraclasts are accumulated in storm layers. Major blackening agent is organic matter, coming from the decay of seagrass and algae, which infiltrates porous limestone (Strasser 1984). The degree of blackening, which may vary from light brown to black, is therefore dependent on the permeability of the clasts. Additional adsorption and fixation through microcrystalline cementation makes the black organic matter resistant. Iron sulfides may also contribute to the blackening process. In most cases this blackening process happens in tidal pools under anoxic conditions. The reworking process affecting this habitat indicates a slow eustatic sea level rise. The prevailing presence of black pebbles proof a shelf environment with emerged shoals nearby as source area of the blackened extraclasts. The increasing amount of black pebbles in the in the top part of the Triassic sequence of the Spiti area has therefore to be interpreted as a decrease of proximity of storm generated deposits. In spite of the probable vicinity of the coastline boundstone-rubble is almost missing, indicating a primary defiency of reef organisms.

The Para Formation was deposited at winnowed shelf edge sand area with tidal channels and partly in shoal area; overall its basin was deeper than that of the Nunuluka Formation.

In many sections the Para Formation rests over older formations, in the upper Lingti Valley it rests over the Lipak Formation (?) and also over the Precambrian Batal Formation (Bhargava and Bassi, 1998). Fuchs (1981) explained this anomalous stratigraphic relationship in the Spiti Valley by a thrust at the base of the Para Formation. Bhargava (1987) attributed it to sedimentologic overlap due to relative deepening of the basin combined with tectonic movement along this plain of weakness.

The Para Formation together with the Kioto forms steep and high cliff all over the central Spiti Valley slopes between Hanse and Lingti. Its type locality near Kioto is inaccessible and tectonically overprinted. Along the Atargoo-Guling road and also above the road along the steep slopes this formation is well exposed. In this stretch it is folded in a syncline. The strike of the beds in the eastern limb in general is NW-SE with steep westerly dips, In the hanging wall of the Para Formation a sequence follows, composed of alternating limestone /marl-cycles (“Liassic Kioto Formation”), which is characterized by a very thin and platy bedding. Also in microfacies a distinct change can be noticed: distal oolitic and gastropod tempestite layers and the nearly complete absence of black pebbles point to a deeper water environment without emerged zones in the neighbourhood.

## Sequence stratigraphy

About twenty depositional sequences, 4 in the Lower Triassic, only 1 in the Middle and the remaining majority in the Upper Triassic, have been distinguished in Spiti by Garzanti et al.(1995). Many of them, however, are poorly constrained and based more on theoretical approach than on sound geological background. Changes from carbonate rich to more terrigenous sediment packages used by Garzanti et al.(1995) for the placement of sequence boundaries are per se not distinctive, and may equally be interpreted as expression of a palaeoclimatic turnover in the hinterland. Pronounced erosional surfaces are well known in the Lower and Middle Triassic deeper neritic carbonate rocks of Spiti and recognizable by erosive and partly ironstoned hardgrounds with commonly corroded or relictic bioclasts. They have already been identified as sequence boundaries (SB) by Garzanti et al.(1995) and are equally treated here. All sedimentologically well constraint sequence boundaries – either by unconformities (a), onlap geometries (b) or abrupt vertical lithological changes from more distal carbonates to relatively proximal clastic deposits (c) – are listed below and, compared with Garzanti et al. (1995) are more numerous in the Middle but less common in the Lower as well Upper Triassic:

1) base of Triassic (a)

2) top of Niti Limestone Mb. (a)

3) – 4) within the upper Himalayan Muschelkalk Mb. (a)

5) base of Kaga Fm. (a)

6) close to the base of the Chomule Fm. (a)

7) base of Rama Fm. (c)

8) top of Rongtong Fm./Lower Mb. (type 1 SB, a)

9) top of Rongtong Fm./Upper Mb. (type 1 SB, a)

10) base of Alaror Fm. (b)

11) top of Para Fm. (a)

Distinction of system tracts is difficult in the Lower and Middle Triassic because of the uniform deeper water character of the sediments built below wave base, and a more detailed sedimentological and palaeoenvironmental analysis seems inevitable to reach the above goal. Shallow Upper Triassic sequences may show lithologically similar lowstand and highstand deposits again not easy to be distinguished without additional survey. Short pelagic incursions (carrying ammonoids and/or conodonts) can help to define with some confidence the maximum flooding surface and thus the boundary between transgressive and highstand system tract but this has to be substantiated by a physical separation of the respective tracts. Lowstand system tracts may often be missing or may not be distinctive with exception of sequence boundary 7 (see above). There a laminated, poorly oxygenated to anoxic shale interval (fig. 8) is interpreted as the result of a lowstand related sea level drop in late Lower Carnian time coeval to a similar event known widespread in the northwestern Tethys as Reingraben-Wende (Schlager & Schöllnberger, 1973).

Principally the Triassic of Spiti has been studied for sequence stratigraphy in a very preliminary way. The results, however, indicate that it has good potential to provide the temporal and spatial/sequential frame work for a sequence stratigraphy reference of the wide eastern Gondwana Tethys margin.

Uniformity of the Lilang supergroup sequence in Spiti and surrounding Himalayan regions points to a rather homogeneous epicontinental type of shelf with little lateral variations in subsidence and a nearly flat or extremely gently inclined basin floor. Relatively shallow depth of at maximum some tens of meters below wave base in the Lower and Middle Triassic, and very shallow depositional conditions in the Upper Triassic, from the Upper Carnian onwards produce wide lateral facies shifts during sea level changes. Another type of sequence boundary suggested by the earlier mentioned authors was the onset of terrigenous sediments above calcareous intervals. Its sequence stratigraphic related background is not so clear and the change in lithofacies may. Boundaries of this type are not well defined and reflect more theoretical approach than sound scientific background. Those here identified are located  lowstand above followed by a distinct unoxic event (Reingrabener Wende). Type 1 sequence boundaries with shelf emersion are to be recorded from 8) the top of the Rongtong F. / lower member (middle Upper Carnian) and from that of 9) the upper member (around carnian-norian boundary) of the Rongtong F. and from top of the Para Limestone (presumed Triassic-Jurassic boundary).

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