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Contents

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PREFACE

The Himalaya is one of the rare areas in the world where rich Lower and Middle Triassic pelargic faunas are developed. Since the first reconnaissance tours in the early nineteenth century a large amount of faunistic and stratigraphic data have been accumulated and have underlined the importance of the region for the international biochronological division of this interval of time. Many of the fossiliferous areas either in Nepal, Tibet or India, are still remote and/or due to close boarder position restricted to the public. Spiti is the only open and due to forced road construction relatively easy accessible region and has therefore attracted geoscientists for renewed studies within the last decade. Project 467 of the International Geological Correlation Programme – designed to refine the Triassic timescale, establish GSSPs for Triassic stages and improve trans-Panthalassan as well as Tethyan, Panthalassan and Boreal correlation – takes the opportunity to present these newly achieved results in the 2004 Field meeting and workshop on *Triassic Stratigraphy of the Himalayas (Spiti, India)* held in Manali and Spiti (Himajal Pradesh) from June, 25 to July 6, 2004.

PROGRAM

25.6. Travel New Delhi—Manali

Meeting: 26.—27. 6. 2004 in Manali, Himachal Pradesh

Field Workshop: 28. 6.—3. 7. 2004 in Spiti (including business meetings of IGCP-467 and STS)

4. 7./5. 7. Travel/ Stay in Manali

6. 7. Travel Manali—New Delhi

DETAILED ROUTE AND PROGRAM

June, 23-24: Arrival at N. D. (latest 24. 6) – from Europe mostly around midnight! Transfer to hotel.

June, 25: Morning (7 am) departure by bus to Manali, travel time at least 12 hours.

June, 26: Meeting at Manali

June, 27: Morning trip to Rohtang pass (4000m) for altitude test , return by early afternoon or stay in Manali

June, 28: Departure (5 am) and travel to Kaza (capital of Spiti) by jeep (4 people by car); arrival late afternoon, accommodation in double rooms in good local hotel

June, 29: social program (acclimatisation day) with visit of famous Tibetan monasteries in Spiti Valley (Dankhar Gompa, Tabo Monastery)

June, 30: All-day field-excursion to Guling (middle Pin Valley) by jeep, evening return to Kaza

• P-T boundary with brachiopod-bearing Kuling Shales (Gungri Formation, Wuchiapingian) overlain by ammonoid-conodont rich *Otoceras* Beds (Griesbachian)

• Griesbachian-Dienerian boundary in ammonoid-conodont bearing *Otoceras* Beds

• Olenekian, Anisian to Ladinian sequence overview

• Upper Ladinian *Daonella* rich Kaga Formation

• Ladinian-Carnian boundary beds with detailed ammonoid-daonellid-conodont record Beds

July, 1: All day field excursion to Muth (upper Pin Valley) by jeep, evening return to Kaza

• Induan-Olenekian boundary beds within ammonoid-conodont controlled *Flemengites* Beds

• Olenekian-Anisian boundary in conodont –bearing top of Niti Limestone

• Anisian to basal Upper Ladinian Ammonoid succession of “Himalayan Muschelkalk”

• Lower Carnian detritics (Rama Fm.) with presence of Reingraben (anoxic) event

July, 2: All day field excursion to Muth (upper Pin Valley) by jeep, evening return to Kaza - alternatively social program (visit of tourist sites)

• Ladinian-Carnian boundary succession at Muth

• Fossil collecting opportunity (ammonoids, daonellids, brachiopods) in the Middle Triassic rocks at Muth

• Upper Triassic (Norian) detritics (Rangrik Fm.) along road, opposite of Tiling

July, 3: Alternative field excursions to A) Ratang and lower Pin Valley

• Upper Carnian shallow water carbonates Rongtong Fm. of Ratang Valley

• Middle Norian Reef Limestone Hangrang Fm., Upper Norian detritics (Alaror Fm.),

• Upper Norian sandstones (“Nunuluka Fm.”) and Rhaetian platform carbonates (Para Fm.) up to the T - J boundary along Pin Valley road and B) Lalung (Lingti Valley) with Anisian fossil collecting opportunity

July, 4: Travel Kaza-Manali with sightseeing stops in Kibber (highest village in Spiti surrounded by Jurassic and Cretaceous rocks) and Ki Gompa (large monastery)

July, 5: Recreation day in Manali

July, 6: Travel Manali-New Delhi

Abstracts

The Continental Permian-Triassic Boundary Interval, Central Germany: Evidence for long-term cosmic influx?

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The Permian-Triassic Boundary (PTB) interval in the Central European Basin (CEB) developed in continental redbed facies. Lithostratigraphically, it belongs to the uppermost Zechstein (Bröckelschiefer = Fulda Fm.) and the lowermost Buntsandstein (lower Calvörde Fm.). This study presents an integrated correlation of the continental and marine PTB. It concentrates on outcrops situated in an intermediate marginal facies in the southeastern part of the CEB.

Facies

The Fulda Fm. is approx. 30 m thick and consists of predominantly reddish, non-fissile shales, siltstones and thin layers of sandstones, so-called "Bröckelschiefer" (= crumbly shales). In the lower part there are nodular gypsum residues and mudcracks. First lacustrine shales and siltstones with conchostracans occur in the upper Fulda Fm. The approx. 150–200 m thick Calvörde Fm. consists of reddish, partly grey and greenish, mostly fissile shales, siltstones, and thin greyish sandstone beds without any evaporites basinwide in its lowermost part. At the basin margin, the depositional environment of the Fulda Fm. represents a sabkha system, which grades into a playa system in the Calvörde Fm. Both interfinger with distal fluvial systems, whereby the fluvial influx substantially increases in the Calvörde Fm.

Cyclic stratigraphy

The Fulda Fm. consists of 2 fining-upward cycles, each with sandstone beds at the base and siltstones and shales in the upper part. The Calvörde Fm. consists of ous fining-upward cycles, which are 10-20 m thick and similar to those of the Fulda Fm., but containing more sandstones. Basinwards, the basal sandstones become less abundant and gradually give way to oolite beds, so-called "Rogensteine" (roestones). The fining-upward clearly shows up in gamma-ray logs (GRL) cycles of outcrops and wells and can be correlated readily in large parts of the CEB. The cycles seem to be quasi-isochronous and provide a robust high-resolution lithostratigraphic framework. Alternatively, they can be interpreted as more or less asymmetrical baselevel cycles.

The cycles are considered to represent ~100 kyr Milankovitch eccentricity cycles. The base of the first distinct ~100 kyr cycle of the Calvörde Fm. is, by definition, the Zechstein-Buntsandstein boundary. The Milankovitch cyclicity suggests high sedimentation rates of approx. 15 m/100 kyr, i. e. 100 times more than in the Meishan section (compaction not considered) and 10 times more than in the Iranian sections (Jolfa, Zal, Shareza, Abadeh).

Biostratigraphy

The continental sections can be correlated with the marine scale by conchostracans and sporomorphs. The Upper Fulda Fm. belongs to the *Falsisca eotriassica* conchostracan Zone, which corresponds to the Late Permian (late Dorashamian) *Clarkina iranica* and *C. hauschkei* conodont Zones. The ~100 kyr cycle 1 and the first ~20 kyr cycle of ~100 kyr cycle 2 (below the so-called Oolite Alpha 2) of the Calvörde Fm. correspond to the *Falsisca postera* conchostracan Zone and the *Lundbladispora obsolete - L. noviaulensis* sporomorph Zone, which can be correlated with the *Clarkina meishanensis-Hindeodus praeparvus* conodont Zone of latest Dorashamian age. The upper part of ~100 kyr cycle 2 (so-called Oolite Alpha 2 and above) belongs to the *Lundbladispora willmotti-L. hexagona* sporomorph Zone and corresponds to the earliest Triassic (lower Gangetian Substage of the Indusian/Brahmanian Stage) and is, at least to its main part, an equivalent of the *Hindeodus parvus* Zone. The conchostracan fauna of this level consists predominantly of *Euestheria gutta*, which straddles the PTB. The lowermost Triassic index species *Falsisca verchojanica* is extremely rare in the CEB, except in SE Poland (Ptaszynsky & Kozur, in prep.). The biostratigraphically defined continental PTB is within the so-called "Graubankbereich" (= grey bed interval) of Calvörde Fm. cycle 2 (lower part), or, more precisely, at so-called Oolite Alpha 2.

Magnetostratigraphy

The cycles were used as a high-resolution lithostratigraphic framework for detailed magnetostratigraphic investigations. The uppermost numerZechstein (upper Leine Fm. to Fulda Fm.) comprises 2 normal and 2 reversed magnetozones. The upper normal polarity zone (sn1) begins in the lower third of the Upper Fulda Fm. and extends into the Lower Buntsandstein, comprising Calvörde Fm. cycles 1 – 7 (lower part). The biostratigraphically defined PTB at Oolite Alpha 2 is in the lower third of normal polarity zone sn1. Reliable palaeomagnetic data of marine sections indicate that the PTB is in the lower third of an normal polarity zone, too. The only, not yet understood, exception is Meishan, where Bed 27, comprising the upper *meishanensis-praeparvus* Zone and the entire *parvus* Zone, seems to be within a thin reversed polarity zone (Zhu Yanming & Liu Yuyan 1999, Yin Hongfu et al. 2001). This could not be confirmed in well-dated Iranian sections or elsewhere (Kozur 2004, Szurlies & Kozur, in press).

The magnetic susceptibility curve of the PTB interval in the CEB shows, after Hansen et al. (pers. comm.), a characteristic pattern recorded also in other both marine and continental sections, which would support the PTB in Calvörde Fm. cycle 2 (Oolite alpha 2).

δ^{13}C-isotopes

The curve of $\delta^{13}C_{org}$-isotopes shows a distinct negative excursion in the lower part of Calvörde cycle 2 (Oolite Alpha 2), predated by a another, weaker negative excursion at the cycle 1/2 boundary. Both minima are characteristic for the PTB interval of other marine and continental sections (Hansen et al., pers. comm.). Plots of $\delta^{13}C_{carb}$ isotopes show a distinct drop from Calvörde Oolite Alpha 1 to Oolite Alpha 2 as well, with the minimum in the lower Oolite Alpha 2 (Korte, pers. comm.). In Meishan, the $\delta^{13}C_{carb}$ minimum is in the lower part of Bed 27, in the upper *meishanensis-praeparvus* Zone, approx. 6 cm below the PTB (Bowring et al. 1998). In Abadeh (Iran), the minimum is in the same position, with a second, somewhat stronger minimum in the *isarcica* Zone (Korte et al., in press). In Jolfa (Iran), the first minimum is also below the PTB, with a second, stronger minimum at the PTB. In Shareza and Zal the $\delta^{13}C_{carb}$ minimum is at the PTB (Korte et al., in press). Thus, the δ^{13}C isotopes indicate that the PTB is either at the base of Oolite Alpha 2 or somewhat higher up.

Microsphaerules

Microsphaerules (MS), known from several marine PTB intervals, have been found in the Fulda Fm. to the lowermost Calvörde Fm. A distinct maximum occurs in Oolite Alpha 1 and overlying grey shales of Calvörde cycle 1. A second, less distinct maximum is in Calvörde cycle 2 just above Oolite Alpha 2. The magnetic MS are 5-50 ˜m in diameter. Most of them are spherical, some are drop-shaped. They consist of matter rich in Fe, many entirely of Fe-oxide, others of Fe-rich silicates, few of spinel. There is often a typical wrinkle structure, characteristic of molten material that rapidly cooled. Some MS contain relatively much Ni and Cr. We assume that these MS are of cosmic origin. Silicatic MS with relatively high Ti content, which are especially abundant in the Fulda Fm., are considered to be of volcanic origin. Others seem to be mineralized Prasinophyte algae, typical disaster biota, which occur also in the Boundary Beds of South China and the Southern Alps. Under consideration of the supposed Milankovitch cyclicity, the time interval of increased MS occurrence at the PTB would be some 300 kyr, suggesting long-term cosmic (and volcanic) influx that may be punctuated by one or several large impacts and/or explosive volcanic eruptions.

Late Scythian to Carnian conodonts from Spiti

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The Keyserlingites dieneri bed (Diener, 1912), overlying the Nodular limestone, in the Spiti section yields abundant Late Scythian-Anisian conodonts, represented by the elements of Neospathodus homeri, N. spathi, N. timorensis, Neogondolella jubata and N. regale, which occur in the same sample in the Lalung (=Lilang) section. In the material from the Mud (=Muth) section, however, N. regale was not detected in the horizon defined by the Keyserlingites dieneri bed (Bhatt, 1999).

The overlying horizon of ?Daonella shales? Reveals Anisian-Ladinian elements like Neogondolella regale, N. navicula, N. excelsa, N. pseudolonga, N. bulgarica and Nicoraella kockeli. The succeeding ?Daonella limestone? towards its base yields the supposedly Late Ladinian conodont ?Epigondolella? mungoensis and some 20 m higher up in the sequence of ?Daonella limestone? Carnian elements Neogondolella polygnathiformis, N. noah, Mosherella newpassensis, etc., start appearing. However, further up in the succession conodont yield is almost absent.

The biochronology of the Spiti sequence based on conodonts complements well with the one assigned on the basis of ammonites by Diener (1912) more than nine decades back, except for some marginal refinement in the delineation of the stage boundaries.

A suggestion for an early Tuvalian time segment for the Tiki Formation, South Rewa Gondwana Basin, India and other correlatable continental sequences

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Red bed paleosol sequences of the Late Triassic Tiki Formation of the South Rewa Gondwana Basin, Madhya Pradesh, India have been found to be enriched with both mega, and micro-tetrapod assemblages. In mega-tetrapod assemblage the important index fossils are a phytosaurid reptile *Parasuchus* (Chatterjee, 1978), a rhynchosaurid reptile *Hyperodapedon* (Benton, 1983), a rauischuid reptile *Tikisuchus* (Chatterjee and Majumdar, 1987) and a metoposaurid amphibian *Buettneria* (Sengupta, 2002). In micro-tetrapod assemblage the important inmates are an advanced cynodont dromatheriid *Rewaconodon* (Datta, et al., 2004, in press), a morganucodontid mammal *Gondwanadon* (Datta and Das, 1996), an unnamed rank mammal *Tikitherium* (Datta, 2004, in press) and several isolated dental remains of orinithischian dinosaurs and sphenodontians. This faunal assemblage of the Tiki Formation shows a striking resemblance to the lower fauna of the Late Triassic Maleri Formation, India and to the oldest “North America Land Vertebrate Faunachron A” of the Camp Springs Member of the Dockum Formation, Texas, North America and these three lithounits exhibit strong correlation (Chatterjee, 1986; Kutty and Sengupta, 1989; Hunt and Lucas, 1991; Hunt, 1993; Datta, et al., 2004, in press).

The most significant is the marker taxon of *Parasuchus* (synonymous to *Paleorhinus*), as this taxon is known from late Carnian (early Tuvalian) ammonoid sequences of Austria (Hunt and Lucas, 1991). Therefore, an early Tuvalian age is assigned to all other terrestrial units containing *Paleorhinus* or its related genera namely, the Popo Agie Formation of Wyoming, the lower part of the Petrified Forest Member of Arizona, the Camp Springs Member of the Dockum Formation of Texas, the Blasensandstein of Bavaria, the Argana Formation of Morocco and the lower Maleri Formation of India. All these terrestrial lithounits are collectively defined as *Paleorhinus* Biochron (Hunt and Lucas, 1991) and logically, therefore, the Tiki Formation of the South Rewa Gondwana Basin should also belong to the *Paleorhinus* Biochron.

The dental morphology of *Rewaconodon*, identified by several postcanine teeth from the Tiki Formation, is most similar (about 70-80% similarity) to dromatheriid *Microconodon* recovered from the late Carnian (Tuvalian) Cumnock Formation of North Carolina and the late Carnian sediments of the Dockum Group of North America. *Rewaconodon* is also similar (about 50%) to the therioherpetid cynodont *Therioherpeton* recovered from the late Carnian (Tuvalian) sediments of the Santa Maria Formation of South America. The Tiki morganucodontid *Gondwanadon*, represented by a well preserved right lower molariform tooth is one of the earliest mammal. The unnamed rank mammal *Adelobasileus* (Lucas and Luo, 1993) recovered from the Tecovas Member, which immediately overlies the Camp Springs Member, is also considered to be one of the oldest mammals in the world. The Tecovas Member is dated as 225 Ma (Lucas and Luo, 1993). Thus, the record of the earliest mammals appears to be from the lower part of the Tuvalian.

Therefore, with regard to intercontinental correlation the fauna of the Tiki Formation can be correlated with the vertebrate fauna of the Camp Springs Member of the Dockum Formation, also termed the “North American Land Vertebrate Faunachron A” (Lucas and Hunt, 1993) and can also be compared with the Carnian (early Tuvalian) tetrapod assemblages ($CRNL_1$) (Benton, 1994) of other nonmarine strata of the *Paleorhinus* Biochron.

It now appears that there is a strong case for formally denoting an early Tuvalian segment on a global basis with the help of both megavertebrate and microvertebrate assemblages within the Carnian continental sequences.

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Towards an integrated Upper Triassic magneto-biostratigraphic time scale

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Krystyn et al. (2002) recently proposed a new geological calibration of the Upper Triassic sedimentary sequence recovered in the Newark continental basin of eastern North America. This calibration was established by correlating biostratigraphically-dated Upper Carnian to Norian magnetostratigraphic sections from the Tethyan realm and the astronomically tuned geomagnetic polarity time scale from the Newark basin. This correlation, however, introduced the need for a significant revision of the previosuly considered geologic age of the Newark deposits, lowering in particular the location of the Carnian-Norian boundary by some 500 meters, placing it at the base of magnetic interval E7n. If correct, the Newark sequence would lie between the Uppermost Carnian (Tuvalian 2) and the Norian-Rhaetian. We will show that the new calibration of the Newark sequence allows one to reconcile the magnetostratigraphic data obtained both from marine and continental environments, the Upper Triassic biostratigraphy (including data on Tethyan marine faunas and on vertebrates from North America), the cyclostratigraphy from the Newark sequence and the most recent geochronologic data for the Triassic.

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Conodont fauna from the Raibl Beds of Karavanke Mts., Slovenia and its stratigraphic significance

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Several geological studies dealing with “Raibl beds” have been conducted in western part of the southern Karavanke Mts. in the last few decades. Carnian “Raibl beds” of the Košuta nappe north of Mojstrana attain thickness of some hundred meters. A sequence situated between the Belca valley and Mt. Jepca (1610 m) was studied micropaleontologically. The upper part of an 85 m thick “Raibl beds” succession below Mt. Jepca was measured and sampled. It is mainly made up of dark grey limestone and marly limestone with intercalations of marls. Limestone is platy to thin-bedded, and according to its texture, biomicrite prevails. An internal lamination can be observed in some limestone beds, but rarely calcarenitic or brecciated beds also occur. Micropaleontological study revealed presence of diverse fossil content of the investigated section. Examined samples produced the conodont apparatus *Nicoraella ? budaensis* Kozur & Mock, sponge spicules, ostracods and holothurians, as well as frequent dasyclad algae and abundant posidonias. Ammonoids occur rather rare. Plant fossils of the genus *Voltzia*, and well preserved fishes with the prevailing genus *Peltopleurus* are frequent in more marly beds.

Presence of the conodont apparatus *Nicoraella ? budaensis* Kozur & Mock together with other fossils confirm a Carnian age. This conodont species was first described from the Middle Carnian (Julian) of Buda Mts. in Hungary, and it has been reported from few other locations of Pilis Mts., Hungary and Sicily, Italy, yet the entire range of the species is presently unknown. Dasyclad alga *Clypeina besici* Pantiæ is an index species of the taxon-range zone with verified Carnian range. Diverse fossil content of the study section in Karavanke Mts. makes possible wide biostratigraphic correlation, and contributes to the intercalibration of Upper Triassic conodont and dasyclad zonations.

Recovered conodont fauna from the »Raibl beds« of Slovenia yields segminate elements of a single genus, *Nicoraella*, and thus an apparatus reconstruction is feasible. *Nicoraella* apparatus beside the spathognathiform and ozarkodiniform elements includes also enantiognathiform, hindeodelliform, prioniodiniform and hibbardelliform elements. A comparison with two other gondolellid apparatuses, *Neogondolella* and *Cratognathodus*, demonstrates a great similarity in composition of the three Triassic apparatuses.

Conodont fauna at the Ladinian/Carnian boundary interval in the Southern Alps

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The conodont distribution about the Ladinian/Carnian boundary in selected sections of the Southern Alps is here reviewed. The examined sections are: (1) Stuores Wiesen, proposed as GSSP of the base Carnian (Broglio Loriga *et al.*, 1999), located on the crest between Badia and Cordevole valleys; (2) Bec de Roces, on the Eastern flank of the Sella massif, nearby Campolongo Pass; (3) Antersass, on the North-eastern flank of the Gardenaccia massif in the Badia Valley. The three sections encompass the stratigraphic interval Regoledanus-Aon ammonoid subzones (*sensu* Mietto and Manfrin, 1995). The Daxatina cf. canadensis Subzone has been particularly investigated.

The FO of *Paragondolella polygnathiformis* is discussed and compared with published data in order to define the FAD of this critical taxon.

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Selected ammonoid fauna at the Ladinian/Carnian boundary interval in the Southern Alps

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The ammonoid distribution about the Ladinian/Carnian boundary interval, checked in selected sections of the Southern Alps, is here reviewed. The examined sections are: (1) Stuores Wiesen, proposed as GSSP of the base of the Carnian (Broglio Loriga et al., 1999), located on the crest between Badia and Cordevole valleys; (2) Bec de Roces, on the Eastern flank of the Sella massif, nearby Campolongo Pass; (3) Antersass, on the North-eastern flank of the Gardenaccia massif in the Badia Valley. The three sections encompass the stratigraphic Regoledanus-Aon ammonoid subzones interval (*sensu* Mietto and Manfrin, 1995). The Daxatina cf. canadensis Subzone has been particularly investigated.

The taxonomical position of *D.* cf. *canadensis* of the Southern Alps is defined. The co-occurence of *Trachyceras* is also documented on the basis of the suture line. Other critical taxa, both occurring in Canada and Southern Alps, as *Frankites* and *Zestoceras*, are clearly documented.

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Upper Triassic conodont biostratigraphy in the Lagonegro Basin (Southern Apennines): work in progress

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Several Upper Triassic sections of the Lagonegro Basin have been examined for what the conodont biostratigraphy is concerned. Three selected sections, namely Petina Chiana (near Moliterno), Pignola-Abriola (near Potenza), and Sasso di Castalda (near Brienza), encompass the uppermost Ladinian - uppermost Rhaetian interval. This interval is represented by the uppermost Monte Facito, *"calcari con selce"*, and lowermost *"scisti silicei"* formations.

Some of the recognized conodont taxa are known to occur also in Canada. Their occurence in the Tethys Realm, and their biochronostratigraphic meaning, is discussed.

Papers related to the Spiti meeting

Brief outline of the tectonic history of the NW Himalayas with emphasis on Spiti

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Introduction

Spiti and in particular the Pin Valley represent an "El Dorado" for geologists and palaeontologists, renown for the excellent outcrop situation, rich fossil content, lithological variation and the almost continuous stratigraphic range from Neoproterozoic to Cretaceous. However, Spiti is part of the impressive Himalayan mountain range including most of Earth´s highest peaks with eye-catching structures of the dominant Tertiary deformation everywhere. It is clear that any stratigraphic or sedimentologic investigation in this area has to take the Tertiary, but also the pre-Himalayan deformation structures into account. This text aims to provide a brief outline of the tectonic zones of the NW Himalaya and the tectonic history of Spiti.

History of geological investigations in Spiti

Bhargava and Bassi (1998 and references therein) have summarized the history of geological investigation. See also Sinha (1989), Bhargava (1997), Srikantia and Bhargava (1998), Bhargava and Bassi (1998) and Steck (2003) for summaries of the geology of Himachal Pradesh and especially of Spiti.

Early in the 19th century Gerard (1827) made first reports about fossil occurrences in the sedimentary successions of Spiti. Ferdinand Stoliczka from the Austrian Geological Survey published his pioneering results in 1866. After his early death, these investigations have been continued by Griesbach (1891). Hayden (1904; 1908) carried out valuable geological investigations in Spiti. He mapped large areas and established a lithostratigraphy, which is still widely accepted.

Reed (1910; 1912) described Lower Palaeozoic fossils of the Pin and Parahio Valleys in detail. The numerous publications of Carl Diener (see Gansser, 1964 for references) with emphasis about Triassic successions in the Himalaya are still valuable sources for this period. Auden (1935) introduced the term "Tethys Himalaya" (TH) for the fossiliferous sequences north of the Higher Himalaya Crystalline (HHC). Fuchs (1982) mapped the Pin Valley in detail in the scale of 1:50.000. Srikantia (1981) and Bagati (1990) straightened up the lithostratigraphy of Spiti. A multitude of detailed mapping and geological research has been carried out by Om Bhargava, summarized in Bhargava and Bassi (1998 and references cited therein). In the 80´s and first half of the 90´s a lot of valuable sedimentological and stratigraphical research has been carried out by earth scientist from Milano (e.g. Gaetani and Garzanti, 1991; Garzanti et al., 1993; Garzanti et al., 1996a; 1996b and references cited therein). In the last two decades the Triassic successions of Spiti have been studied in detail by Marco Balini and Leo Krystyn (see this volume). Recently, the Devonian to Lower Carboniferous successions have been investigated by Draganits et al. (2001; 2002; 2004). Wiesmayr and Grasemann (2002) and Neumayer et al. (2004) reconstructed the structural history of the Pin and Lingti Valleys and calculated balanced cross-sections.

It should be stressed out, that the spurious paleontological reports by V.J. Gupta in the 1970s and 1980s should be ignored (Talent et al., 1988; Shanker et al., 1993).

Tectonic zones of the Himalayan orogen

Palaeomagnetic data indicate that India, after the separation from other parts of Gondwana super-continent some 130 million years ago moved north-eastwards at a velocity of 18-19 cm per year and additionally rotated more than 30° counter clockwise (Molnar & Tapponier, 1975). During this movement oceanic crust of the Tethys Ocean was subducted beneath the Asian southern continental margin, melted at depth and the ascending melts formed the granites of the Transhimalaya plutonic belt. The actual collision of India and Asia is considered to start between 65-55 Ma ago (Klootwijk et al., 1992; Klootwijk et al., 1994). Based on isotope dating and sedimentological constraints Guillot et al. (2003) estimate the beginning of the collision at 55 ±2 Ma. After the collision Indian continental crust started to subduct below Asia and the northward movement of India slowed down to some 5 cm per year, a velocity that continues up to present.

The still ongoing collision causes deformation, crustal thickening and surface uplift. The upper continental crust

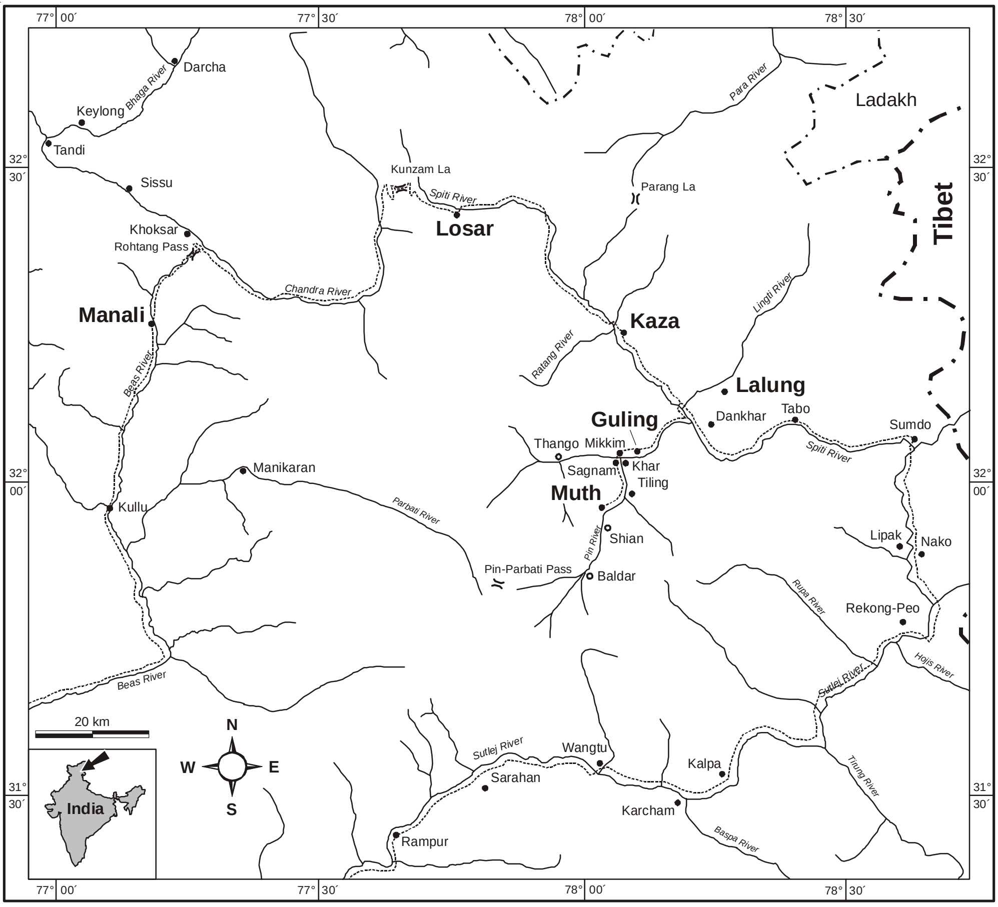

Figure 1: Topographic overview map of the north-eastern part of Himachal Pradesh (India). Dashed line indicate important roads.

of India is sheared off and thrust in south-westward direction along major, several hundreds of meters thick thrust zones propagating in-sequence from north to south, thus becoming increasingly younger towards the south. Based on the classic book by Gansser (1964) these tectonic zones divide the orogen into five tectonic units (see also Medlicott and Blanford, 1879/1887), which on the whole correspond with the geomorphological divisions (Srikantia and Bhargava, 1998). For recent reviews see Hodges (2000) and Yin and Harrison (2000). The tectonic units from south to north are (i) Sub-Himalaya, (ii) Lesser Himalaya (LH), (iii) Higher Himalaya (HH), (iv) Indus Yarlung Suture Zone (IYSZ), (v) Transhimalaya (Fig. 2). Below, the tectonic units are described briefly; the three southernmost zones that are transversed on the travel from Delhi to Spiti (Fig. 1) are explained in more detail with emphasis on the geological situation in this area:

Sub-Himalaya

This unit represents the outermost zone of the mountain belt that rises up just north of the recent Indus-Ganges plains constituting of densely vegetated low-altitude foothills with an average altitude of 900-1500 m. Its southernmost part is known as Siwalik Range. The Sub-Himalaya tectonic unit comprises Tertiary molasse-type sediments, which are overthrusted by the Lesser Himalaya (LH) along the Main Boundary Thrust (MBT) and subsequently the unit itself is thrust southwards at the Main Frontal Thrust (MFT) above Holocene sediments of the Indus-Ganges plains (Fig. 2). The sedimentary successions are folded and imbricated (Srikantia and Bhargava, 1998). In Himachal Pradesh the lower Eocene to lower Miocene Sirmur Group (Subathu, Dagshai and Kasauli Formations) consisting of foraminiferal limestone, sandstone and mudstone is succeeded by mainly terrigenous clastic sediments of the middle Miocene to Pleistocene Siwalik Group (Medlicott and Blanford, 1879/1887).

Lesser Himalaya

The Lesser Himalaya shows alpine-type mountain ranges with altitudes ranging between some 1500 to 5000 m. Due to the position directly south of the main range, this densely vegetated zone benefits from much rain during monsoon. At the northern boundary the Lesser Himalaya tectonic unit is overthrusted by the Higher Himalaya (HH) at the Main Central Thrust (MCT; Heim and Gansser, 1939) and at the southern boundary the LH is thrust above the Sub-Himalaya at the MBT (Fig. 2). Additionally, Lesser Himalaya lithologies can be found in large tectonic windows below the Higher Himalaya, the Kishtwar Window (Fuchs, 1975; Guntli, 1993) and the Larji-Kullu-Rampur Window (Auden, 1934; Frank et al., 1973) indicating a minimum thrusting distance of 100 km on the km-thick MCT-Zone (Fig. 2).

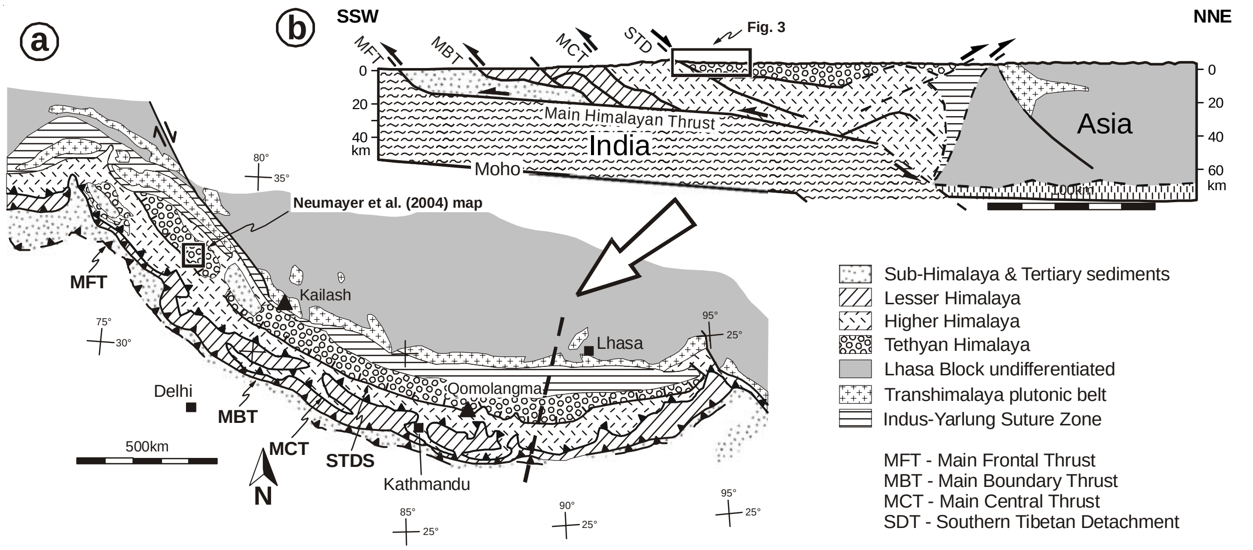

Figure 2: a) Tectonic map of the Himalaya (modified after Hodges 2000). b) Section of the Himalayan orogen (modified after Hauck et al. 1998).

The ages of the lithologies range from Precambrian to Eocene with a major depositional break between middle Cambrian and Eocene. The metamorphic grade is generally low, but can reach lower greenschist conditions in the uppermost nappes (Srikantia and Bhargava, 1998). Within the LH several tectonic units can be distinguished; several nappes are thrust above nearly unmetamorphosed, imbricated, para-autochthonous sedimentary series (Frank et al., 1995; Srikantia and Bhargava, 1998; Vannay and Grasemann, 1998).

Four successive para-autochthonous Proterozoic sedimentary megacycles, bounded by unconformities, have been distinguished (Virdi, 1995; Srikantia and Bhargava, 1998): (i) Rampur-Berinag cycle (~ 1800 Ma; Miller et al., 2000) consist of striking ortho-quartzites and slates associated with basic volcanics; (ii) Shali (= Larji, = Deoban) cycle (c. 1400-900 Ma) comprises dolomitic and calcareous stromatolites with very rare siliciclastics; (iii) Simla cycle (c. 900-700) is made of shales and greywackes with minor carbonates and rare volcanics; the cycle ends with redbeds (Nagthat Formation); (iv) Blaini-Krol-Tal cycle (c. 700 Ma to early Cambrian) shows two diamictite horizons (Blaini Group) followed by black shales and carbonates (Infra Krol Formation) and finally succeeded by dolomites with some siliciclastics.

The Proterozoic sedimentary series of the LH represent thick and uniform successions that can be traced for long distances in the Himalaya. For example the Simla Slates can probably be correlated with the Attock - and Hazara Slates west of the syntaxis in Pakistan (Wadia, 1934; Pascoe, 1959; Gansser, 1964). Some lithological, geochemical and geochronological similarities between the Lesser Himalayan Simla and Krol cycles and the Haimanta Group of the HH suggest a correlation and a deposition in the same basin (Virdi, 1995; Frank et al., 1995). An alternative model has been presented by Myrow et al. (2003).

Isolated remnants of the Palaeocene to lower Eocene Kakara Formation (Srikantia and Bhargava, 1967), which were deposited during a transgression on the Precambrian to middle Cambrian series, can be found in the southern part of the Lesser Himalaya (Srikantia and Bhargava, 1998).

Higher Himalaya

In the general accepted opinion the HH forms the northernmost tectonic unit of Indian continental crust in the Himalayan orogen. The Main Central Thrust marks the southern limit, where the HH is thrust above the LH tectonic unit. The ophiolithic melange of the Indus-Yarlung Suture Zone, which represents remnants of the subducted Neo-Tethys Ocean, forms the northern limit (Fig. 2).

In principal the Higher Himalaya is divided into 2 subunits: (i) Higher Himalaya Crystalline (HHC), i.e. “Central Gneiss” of Stoliczka (1866) and “Vaikrita Group” of Griesbach (1891), and the (ii) Tethyan Himalaya, i.e. “Tethys Himalaya” of Auden (1935) and “Tibetan Himalaya” of Gansser (1964).

The Higher Himalaya Crystalline is located north of the MCT, where it is thrust above the LH tectonic unit. The unit comprises amphibolite grade metasediments of the Vaikrita Group in lower levels with gradually decreasing metamorphic grade towards higher levels into hardly metamorphosed sediments towards the north, the Haimanta Group (Griesbach, 1891; Frank et al., 1995). The boundary between the HHC and the TH is formed by the large normal fault systems of the South Tibetan Detachment Zone (STDZ) and similar faults (Burg et al., 1984; Burchfield et al., 1992).

Abundant Early Ordovician high-level intrusions consisting of peraluminous granites with minor associated basic intrusions are restricted to the HHC; they are not found in the LH (Frank et al., 1995). According to Miller et al.

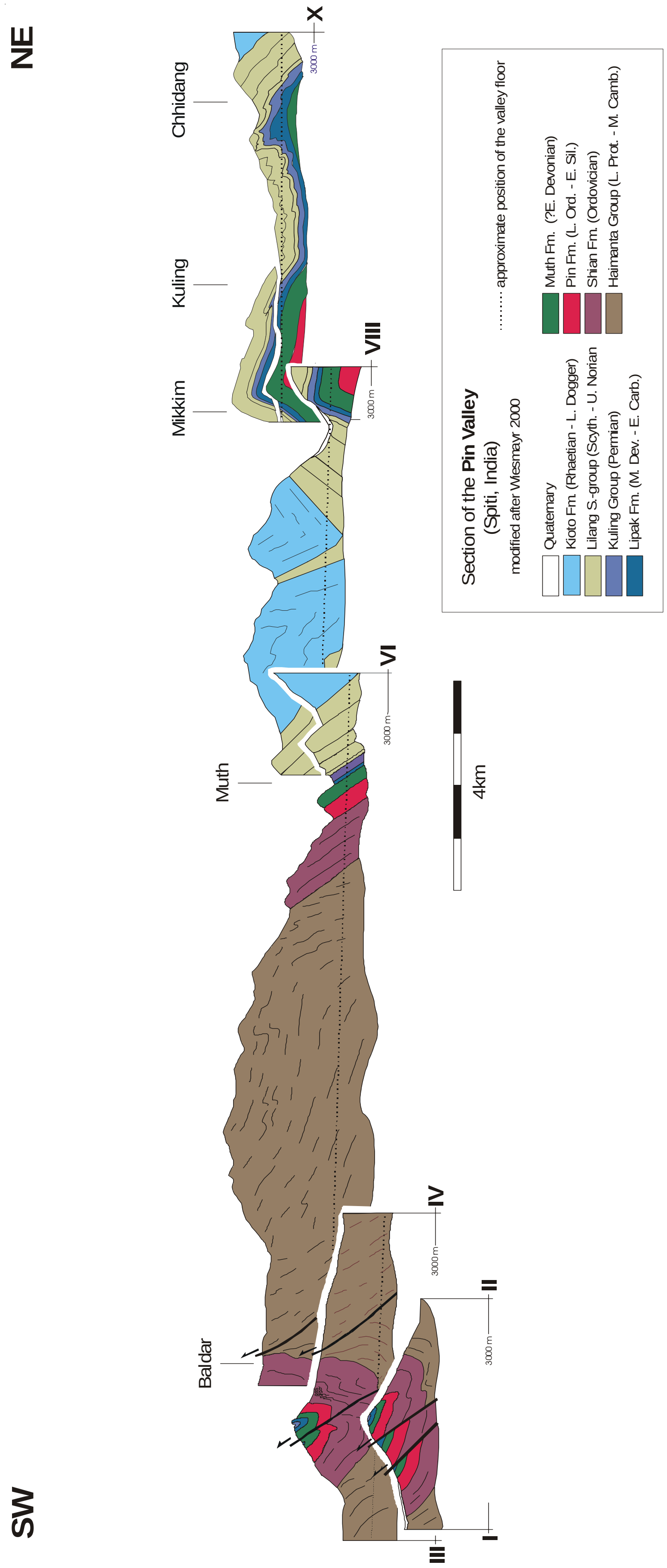

Figure 3: Tectonic section of the Pin Valley (modified after Wiesmayr and Grasemann, 2002).

(2001) these granites indicate an extensional setting in their geochemistry that fits to the observation of pre-Himalayan deformation in the Pin Valley (Wiesmayr and Grasemann, 2002). Leucogranitic intrusives generated by anatexis during the Tertiary metamorphism are rare and occur near the top of the HHC (Le Fort, 1975; Dèzes, 1999), but may even intrude basal horizons of the Ordovician Ralam Conglomerate in Kumaon (Griesbach, 1891).

The term Higher Himalaya Crystalline is somehow misleading, because this unit experienced its main metamorphism together with the TH during Tertiary times, thus per definition it can not represent the crystalline basement of the TH sediments. In analogue, according to Parrish and Hodges (1996) there is no real basement found for the late Proterozoic sediments in the HH of Nepal. The HH rather constitutes Neoproterozoic to Cambrian metasediments (Vaikrita and Haimanta Groups) below the TH with continuous sedimentation into the Palaeozoic, apart from a depositional break in upper Cambrian to lower Ordovician time. In places where the contact between Vaikritas and Haimantas is not complicated by faults, the gradual relationship is clearly evident. "Between it [Vaikritas] and the next following clearly sedimentary rocks, which I have termed the haimanta system, a clearly defined boundary scarcely exists. In nearly all sections which I have hitherto examined between the Kali river and Spiti, the schists seem to pass gradually into the overlying slates, phyllites and quartzites of the haimantas" (Griesbach, 1891).

Wadia (1934) and Gansser (1964) describe the same situation in Kashmir, where the Salkhala Schists and Dogra Slates represent correlatives of the Vaikrita and Haimanta Groups. "Dogras and Salkhalas may after all represent deeper geosynclinal sediments of the Precambrian which change gradually into shallower deposits with the beginning of the Palaeozoic" (Gansser, 1964).

Recently, Dèzes (1999) pointed out, that "It is now an established fact that the relation between the HHCS [HHC Sequence] and the TH is not one of basement-cover type, but that the metasedimentary series of the HHCS represent the metamorphic equivalent of the lowermost sedimentary series of the TH".

This argumentation rises the question of the location of the real basement *senso stricto* for the Higher Himalaya sedimentary sequences, i.e. distinctly older metamorphous lithologies below the Neoproterozoic Vaikrita/Haimanta Groups. The most probable candidates for this basement are peculiar lithologies (augengneisses, calcite-marbles and carbonaceous slates) at the base of the HH tectonic unit, which have first been described by Fuchs (1967) from western Nepal, who called this unit the Lower Kathmandu Nappe. Fuchs and Frank (1970) and Frank and Fuchs (1970) introduced the term Lower Crystalline Nappe for this some 10 to several 100 m thick unit. Apart from the characteristic lithology this unit is typically situated at the base of the HH above the brittle contact of the MCT to the LH, with a more or less gradational increase in metamorphic grades into higher structural levels (Thöni, 1977; Honegger, 1983). Whole rock Rb/Sr isochron ages on these augengneisses gave 1960±29 Ma for a sample from the Bharagaon gneiss in the Sutlej Valley and around 1860 Ma for a sample near Bajaura in the Kullu Valley (Frank et al., 1995; Miller et al., 2000). Comparable lithologies in the same tectonic position at the base of the Higher Crystalline have been found from the Kishtwar to the Anapurna region (Frank et al., 1995 and references cited therein).

The Tethyan Himalaya laying north of the HHC comprises nearly continuous sedimentary sequences from Cambrian to Eocene (Hayden, 1904; Heim and Gansser, 1939; Baud et al., 1984). The pronounced depositional gap below the trangressive conglomerates of the Shian Formation from middle Cambrian to lower Ordovician is associated with an angular unconformity, weak folding and granitic intrusions (Stoliczka, 1866; Fuchs, 1982; Wiesmayr and Grasemann 2002; Miller et al., 2001; Thompson et al., 2001). Marine sedimentation in Zanskar terminated with Eocene nummulitic limestones (Gaetani et al., 1986).

In the NW Himalaya the southern boundary of the TH is formed by normal fault systems of the Zanskar Shear Zone (Herren, 1987; Dézes et al., 1999), Sangla Detachment (Vannay and Grasemann, 1998) and the South Tibetan Detachment Zone (STDZ) far to the East (Burg et al., 1984; Burchfield et al., 1992) (Fig. 2). At least in the NW Himalayas there are indications that these Miocene normal faults represent reactivated thrusts, which had been active during Eocene crustal thickening prior to the Miocene onset of the MCT (Jain and Manickavasagam, 1993; Vannay and Grasemann, 1998; Wiesmayr and Grasemann, 2002). The throw of these normal faults is variable, the values may be very small but may also reach c. 25 km (Herren, 1987) or 35 ± 9 km (Dèzes, 1999) at the Zanskar Shear Zone. In some places the primary relationship of the sedimentary series in the hanging wall and footwall are still recognizable.

Transhimalaya

The Transhimalaya tectonic unit is dominated by bright, coarse-grained granitic rocks, cropping out directly to the north of the Indus-Yarlung Suture Zone along the complete orogen (Fig. 2). Geochemical and age data indicate that these igneous rocks originate from melts related to Andean-type subduction of oceanic Tethyan crust beneath Asia, before the actual collision of India and Asia. The granitic intrusions terminated with the complete closure of the oceanic crust between India and Asia.

Indus-Yarlung Suture Zone

The Indus-Yarlung Suture Zone defines the zone of collision between Indian and Asian crust (Fig. 2) and consist of suites of various rocks, very characteristic of such sutures. Deep-sea sediments like turbitites and radiolarites, rocks from volcanic arcs, oceanic basalts and even mantel rocks, all together in chaotic, highly deformed way delineate a colourful "ophiolithic mélange".

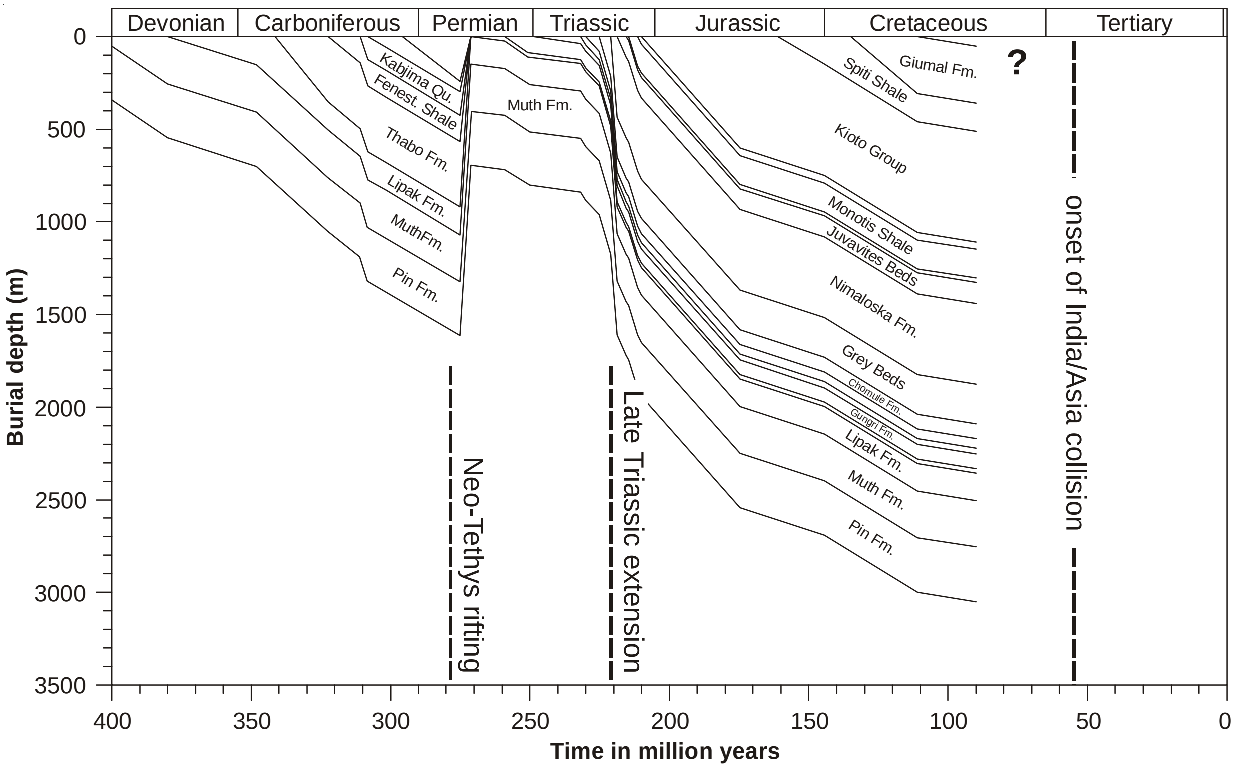

Figure 4: Burial curve for the Middle Palaeozoic to Late Cretaceous succession in the Pin Valley. Compaction has not been taken into account. Note the dramatic uplift and erosion in the Early to Middle Permian resulting from rifting and break up of the Neo-Tethys Ocean (Stampfli et al., 1991) and the sharp increase in deposition rate in the Late Carnian/Early Norian (Garzanti et al., 1995). The curve has been constructed based on lithostratigraphic and age data from Garzanti et al. (1993), Garzanti et al. (1995), Garzanti, Angiolini and Sciunnach (1996a), Garzanti, Angiolini and Sciunnach (1996b), Bhargava and Bassi (1998) and Draganits et al. (2002).

Tectonic history of the Pin Valley

Despite of the strong deformation during the Tertiary Himalayan orogeny (see Hodges, 2000 for a general review), several older deformation events are recognizable (see also Wyss et al, 1999). Based on deformation structures and the sedimentary record in the Pin Valley (see also Bhargava and Bassi, 1998; Wiesmayr and Grasemann, 2002) the existence of three pre-Himalayan and three Himalayan deformation events are evident:

(1) A weak pre-Ordovician deformation event, indicated by slight buckling and tilting of strata, and by the prominent angular unconformity between the Upper Proterozoic Haimanta Group and the Ordovician Shian Formation (Griesbach, 1891; Fuchs, 1982; Garzanti et al., 1986; Wiesmayr and Grasemann, 2002). This deformation resulted in a depositional gap of latest Cambrian to earliest Ordovician time and broadly coincides with widespread granitic intrusions in the HH (Miller et al., 2001).

(2) Late Carboniferous to Middle Permian rifting and break up of the Neo-Tethys Ocean (Stampfli et al., 1991; Garzanti et al., 1996b). This event resulted in the effusion of Early Permian Panjal Traps flood basalts and the formation of the Neo-Tethys Ocean (e.g. Lydekker, 1883; Stampfli et al., 1991; Pogue et al. 1992; Garzanti et al., 1996b; Garzanti et al., 1999). The rifting event had pronounced effects on the sedimentation of this region (Fig. 4) and fragmented the late Proterozoic to early Palaeozoic depositional area of the former northern Indian passive margin. Surface uplift of the rift shoulders resulted in widespread non-deposition, erosion and the formation of angular unconformities and depositional gaps in the stratigraphic record (Stampfli et al., 1991; Gaetani et al., 1990; Garzanti et al., 1996b).

(3) During the Late Carnian/Early Norian large areas of the northern Indian continental margin have been affected by a pronounced increase in tectonic subsidence (Fig. 4), indicated by very high sedimentation rates (Garzanti et al., 1995); knowledge about the origin and kinematics of this event is still very poor. Garzanti et al. (1995) interpret a disconformity and sandstone dykes on top of the Early Norian Nimaloska Formation as a result of an extensional tectonic event.

Conjugate deformation band faults (Aydin, 1978; Antonellini et al., 1994), cutting sedimentary bedding at high angles have been found in the Muth Formation near Mikkim (Draganits et al., submitted). Deformation band faults are characteristic deformation structures in unconsolidated sand and porous sandstone, therefore their formation predates complete cementation of the Muth Formation. The bands are folded by Eo-Himlayan folds, therefore they are interpreted as pre-Himalayan structures. Among the known pre-Himalayan (pre-Tertiary) deformation events the early Carboniferous rifting event and the Late Carnian/Early Norian extensional tectonic event are plausible candidates for their formation. However, the possibility can not be excluded that the deformation band faults in the Muth Formation represent a hitherto unknown pre-Himalayan deformation event (Draganits et al., submitted).

(4) The area is clearly dominated by large-scale inclined horizontal folds, with fold axes trending NW-SE and wavelengths of approximately 5 km, caused by Eocene "Eohimalayan" crustal thickening (Fuchs, 1982; Wiesmayr and Grasemann, 2002). These dominant structures are large scale, SW-vergent folds with wavelengths of approximately 5 km, associated with shallowly NE-dipping, SW-directed thrusts and subvertical, NE-SW trending tear faults (Fig. 3) (Wiesmayr and Grasemann, 2002). A couple of internal detachment horizons (e.g. at the base of the Lipak Formation, at the base of the Nimaloksa Formation and at the base of the Kioto Group) facilitated the development of local detachment folds.

There is a long standing discussion whether the TH in respect to the underlying HHC is an autochtonous unit (Fuchs, 1987) or the TH represents a succession of nappe stacks (Baud et al., 1984). This conflicting interpretation results from the observation that the STDZ normal fault, separating the TH from the HHC, is a reactivated thrust, which accommodated subduction of the HHC (Jain and Manickavasagam, 1993; Vannay et al., 2004) and therefore records a highly variable bulk displacement (Grasemann et al. 1999). However, internal shortening of the TH (Searle et al., 1988; Steck et al., 1993; Wiesmayr and Grasemann, 2002) as well as the fact that amphibolite or even migmatite facies rocks of the HHC are juxtaposed against lower greenschist facies rocks of the TH, requires major detachment horizons within and between these units. Although the HHC represents a metamorphic equivalent of the lowermost parts of the TH (see above), the TH is clearly an allochtonous fold and thrust belt.

(5) The Early Miocene ("Neohimalayan") deformation in the Pin Valley is related to thrusting at the Main Central Thrust forming a shallowly NE-dipping crenulation cleavage in the SE part of the Pin Valley (Wiesmayr and Grasemann, 2002). This deformation has been dated by Ar/Ar stepwise heating method on 2-11 mm small illite crystals from cleavage domains in the Pin Valley (Wiesmayr and Grasemann, 2002).

(6) Late Miocene, broadly E-W directed extension affected the Pin Valley only in its NW-most parts, but is well visible in the Lingti Valley (Neumayer et al., 2004).

Acknowledgements

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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		250-300m	Monotis shales		ALAROR Formation 90m		Monotis shale 120-160m				ALAROR Formation -140m
	Coral limestone 30m	NIMALOKSA Formation 300m		Coral limestone		HANGRANG Formation 20m		Coral limestone 15-20m				HANGRANG Formation 30m
	Juvavites beds 150m	HANSE Formation 350m		Juvavites Shales	SANGLUNG Formation	Member C 180m		Juvavites beds 110-195m			RANGRIK Formation 180m	U. M. 110m 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 brachiopod limestone 120m			limestones, marls, sandstones & shales ~80m limestone with shales ~80m				Middle Member 170-205m				Middle M. 170m
								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.

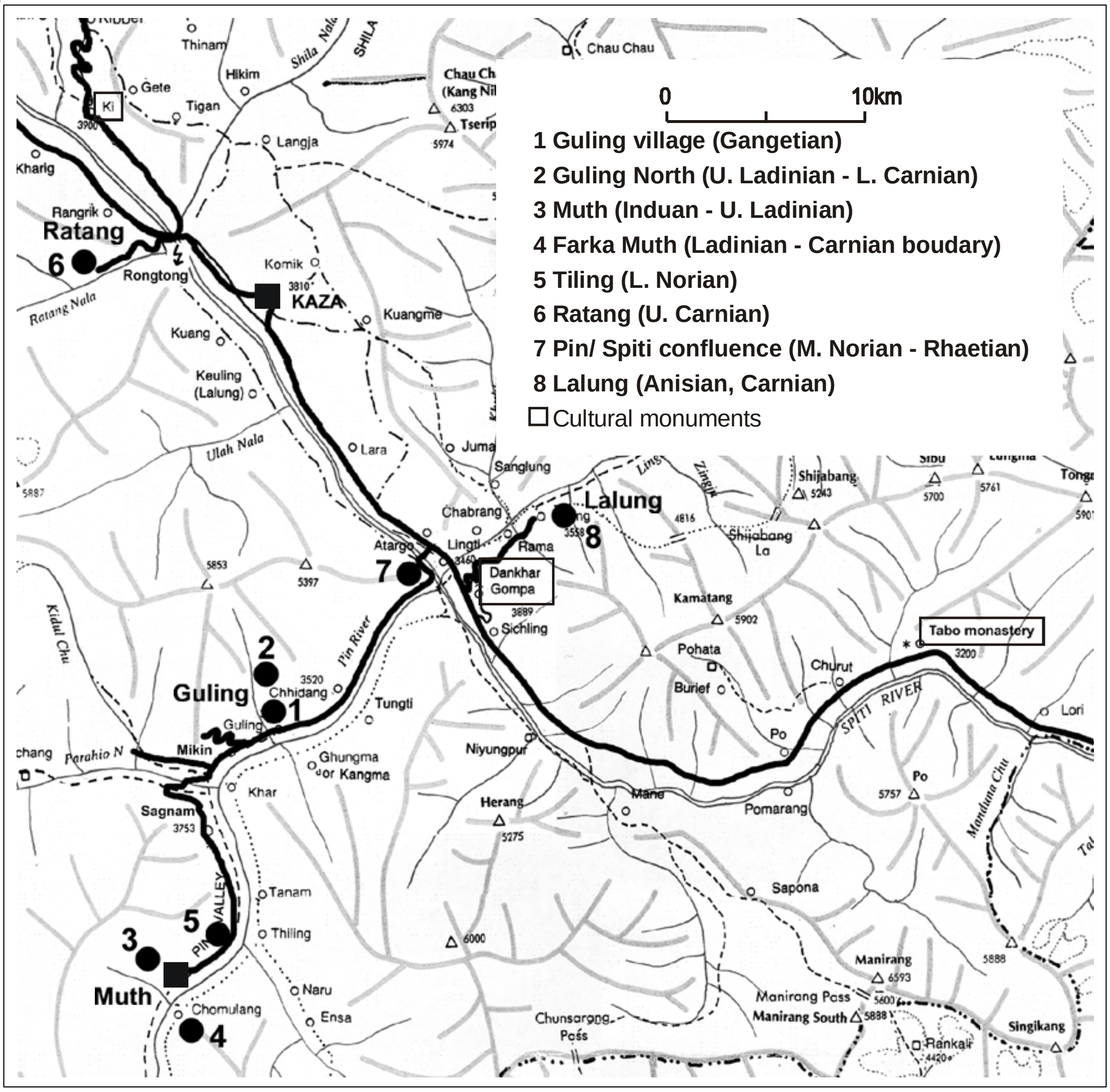

Figure 2: Road map of central Spiti with location of important Triassic outcrops.

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) (32°06´00´´, 78°10´30´´)
LILANG SUPERGROUP	NIMOLOKSA GROUP	NUNULUKA		Quarzite Beds	T: Pin/ Spiti Confluence (road cut) (32°06´05´´, 78°10´27´´)
		ALAROR		Monotis Beds	T: Pin/ Spiti Confluence (road cut) (32°06´10´´, 78°10´25´´)
		HANGRANG		Coral Limestone	R: Pin/ Spiti Confluence (road cut) (32°06´10´´, 78°10´25´´)
		RANGRIK	U	Juvavites Beds	T: Geichang (32°03´15´´, 77°59´37´´) T: Ratang Valley (32°14´22´´, 78°01´30´´)
			L	Zoophycus L.	
	SANGLUNG GROUP	RONGTONG	U	U. Tropites L.	T: Ratang Valley (32°14´22´´, 78°01´30´´)
			M	M. Tropites L.	
			L	L. Tropites L.	
		RAMA		Grey Beds	T: E of Lalung (32°08´50´´, 78°15´25´´)
	TAMBA KURKUR GROUP	CHOMULE		Daonella + Halobia L.	R: N of Guling (32°03´00´´, 78°05´16´´) E of Muth (31°56’76”, 78°02’59”)
		KAGA		Daonella Shale	R: N of Guling (32°02´97´´, 78°05´14´´) N of Lalung (32°09’37”, 78°14’03”)
		MIKIN	D	Muschelkalk	R: Muth (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

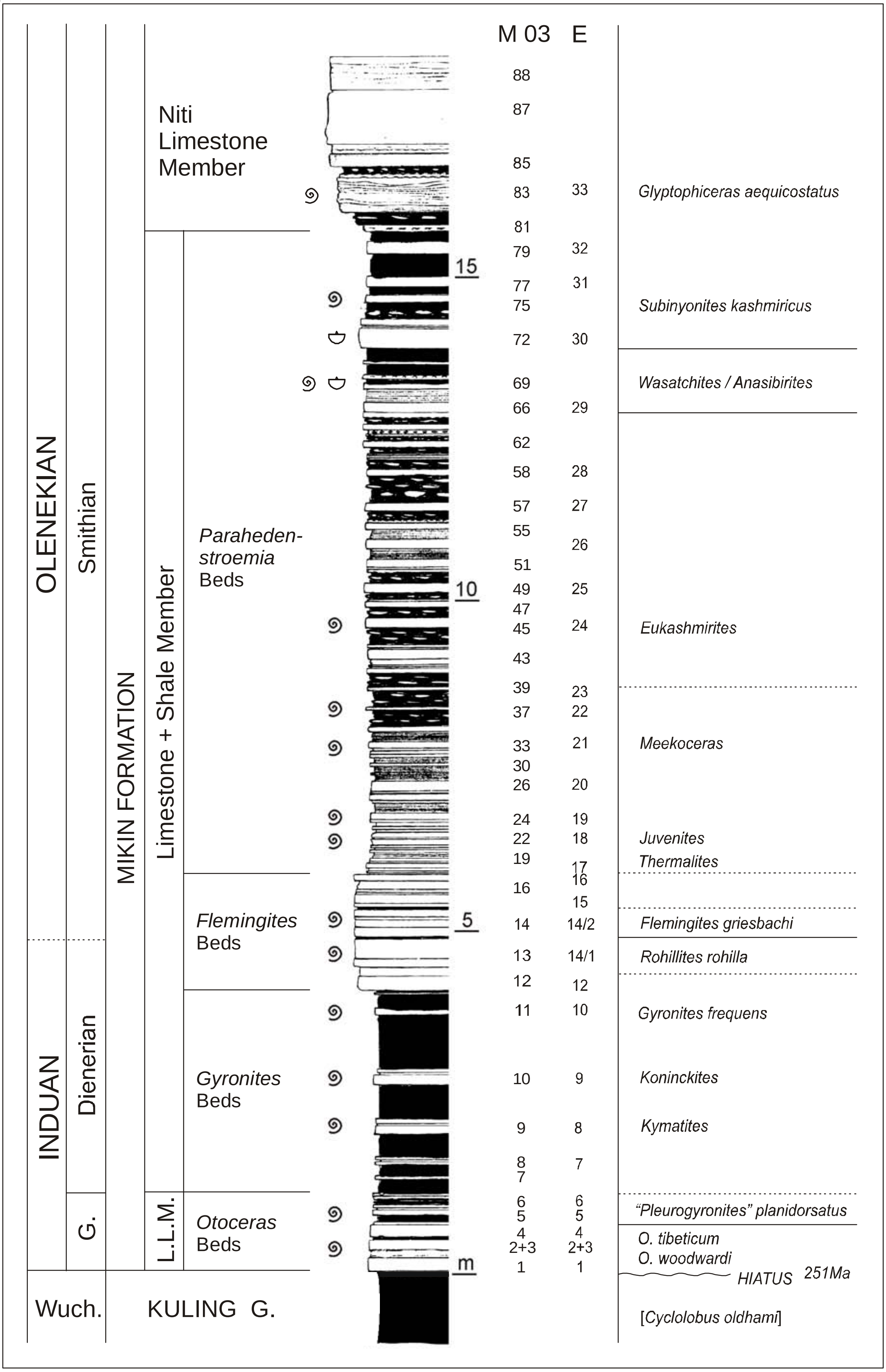

Figure 4: Stratigraphic log of the Mikin Formation, Lower Limestone to Niti L. Mb. in Muth, upper Pin Valley.

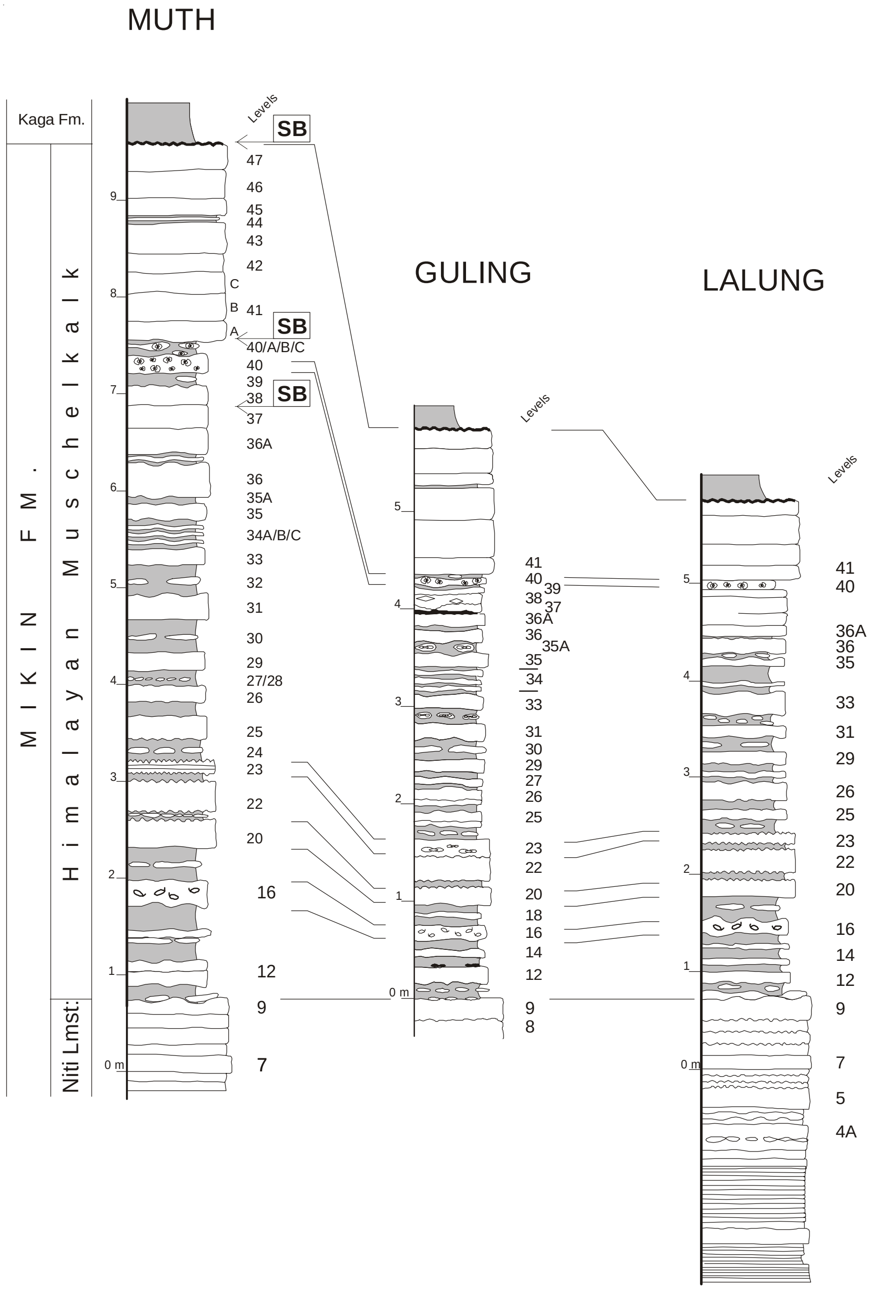

Figure 5: Stratigraphic log of the Mikin Formation, Himalayan Muschelkalk Mb. in Muth, upper Pin Valley, and its correlation with Guling and Lalung. Thikness of member is decreasing towards north.

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.

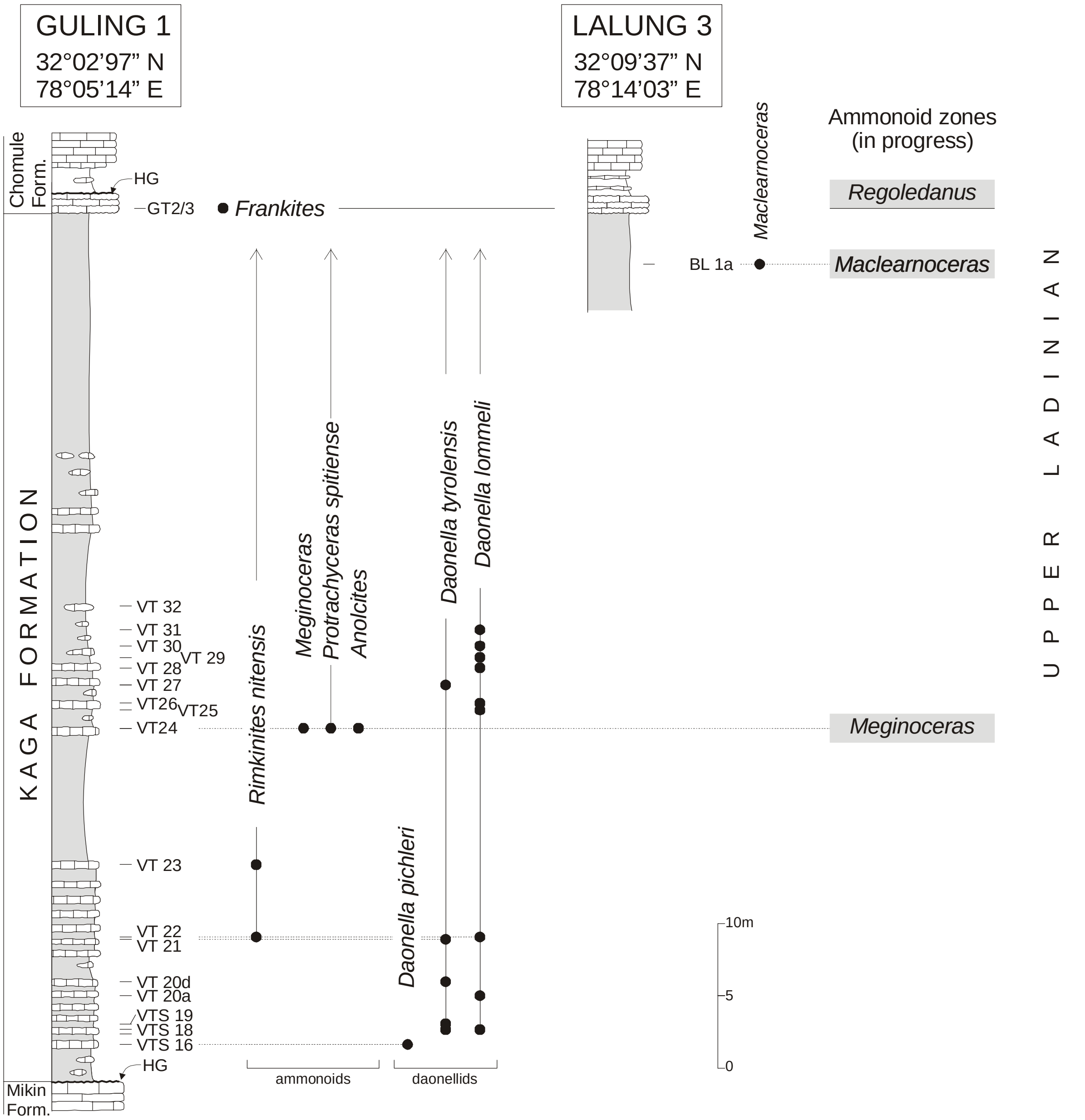

Figure 6: Stratigraphic log of the Kaga Formation at Guling 1 (N of Guling) and correlation with Lalung 3 (Lingti Valley).

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/

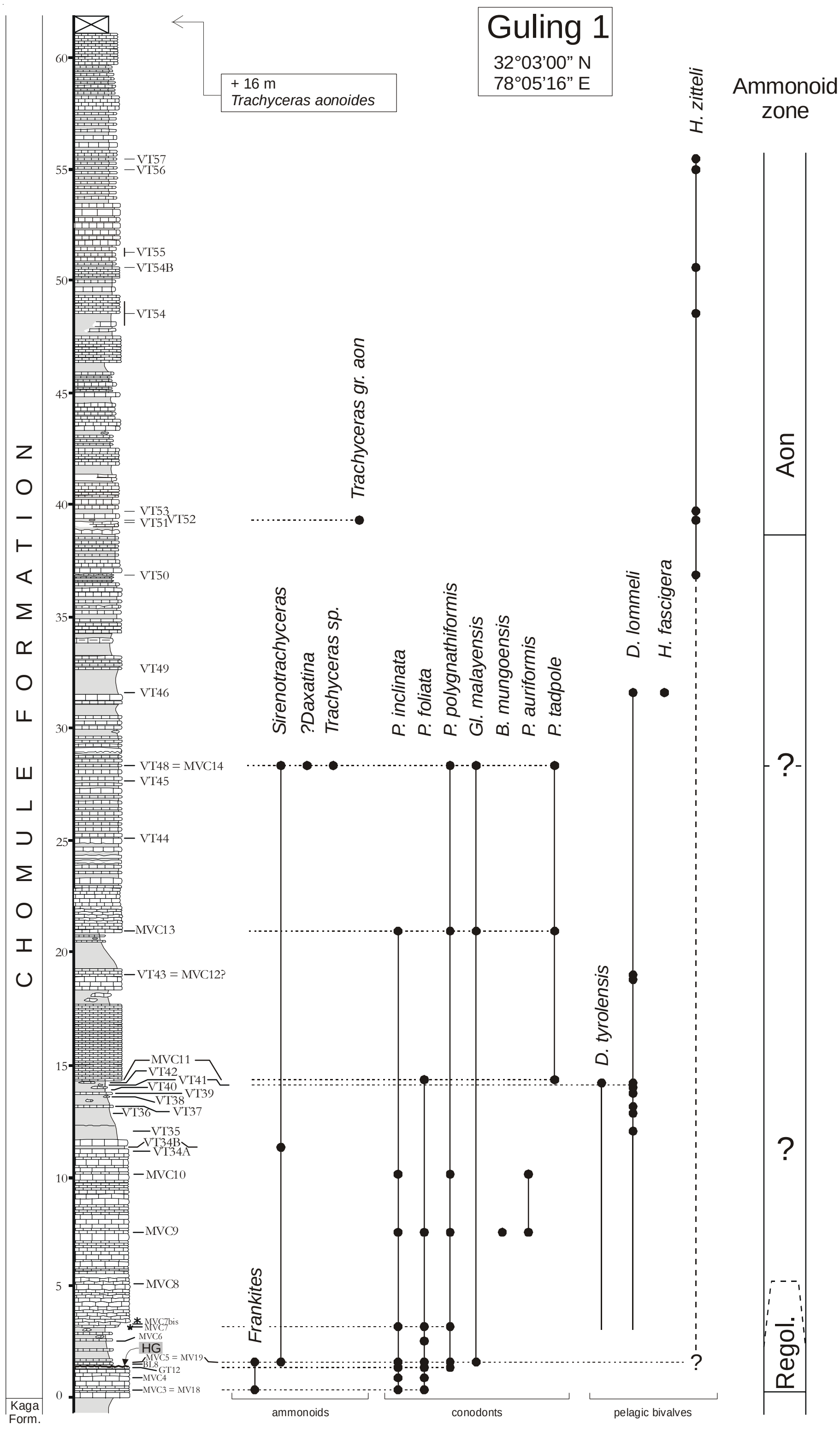

Figure 7: Stratigraphic log of the Chomule Formation, at Guling 1 section, N of Guling.

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

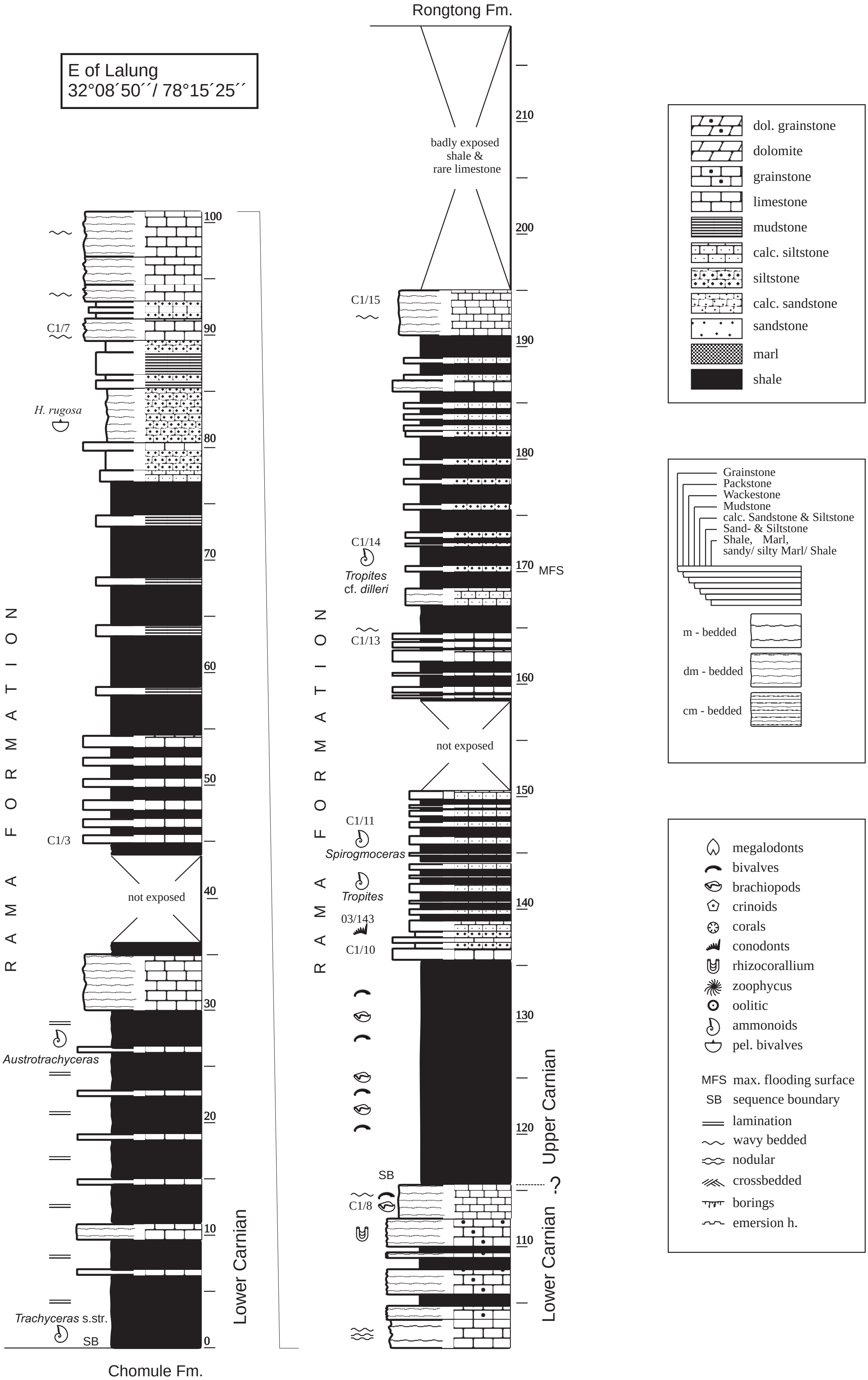

Figure 8: Stratigraphic log of the Rama Formation (type section), E of Lalung.

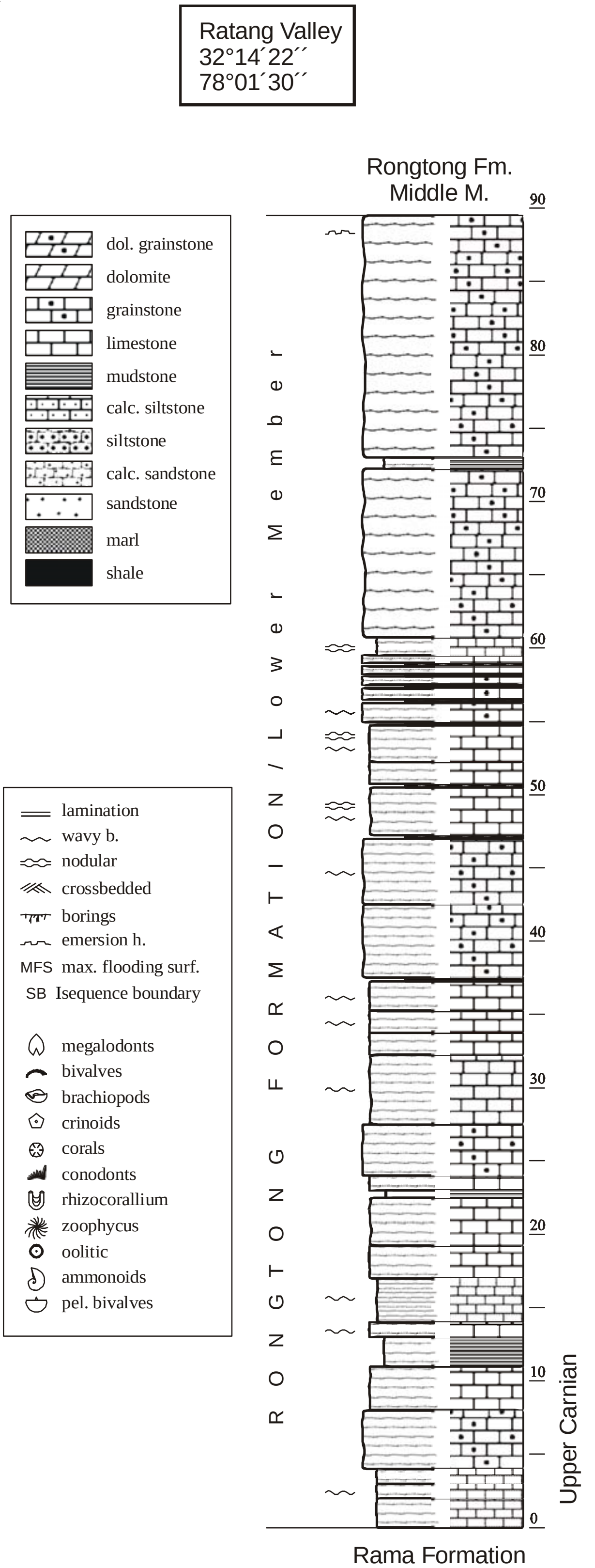

Figure 9: Stratigraphic log of the Rongtong Formation, Lower Mb. (type section), Ratang Valley.

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/

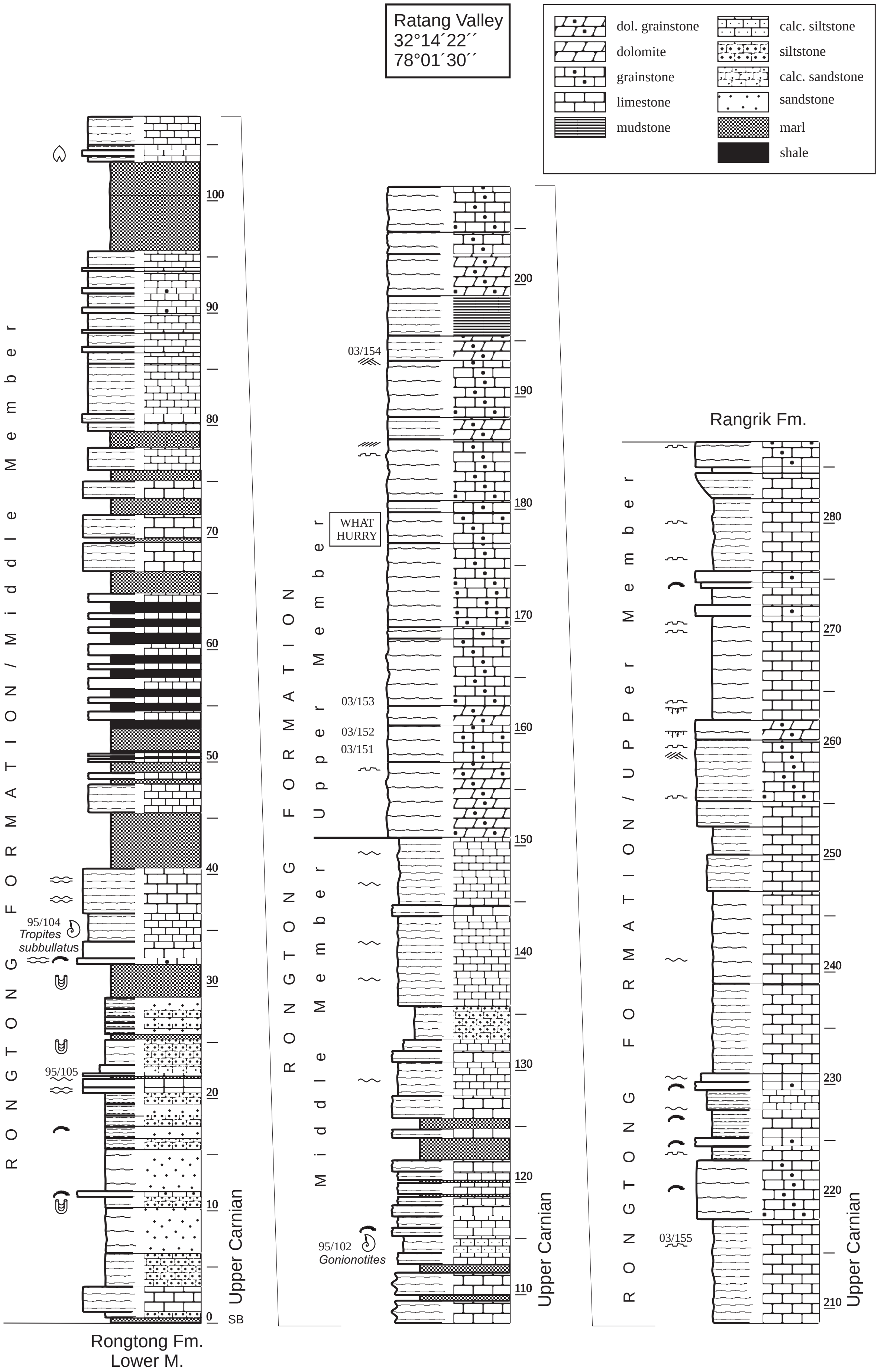

Figure 10: Stratigraphic log of the Rongtong Formation, Middle and Upper Mb. (type section), Ratang Valley.

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.

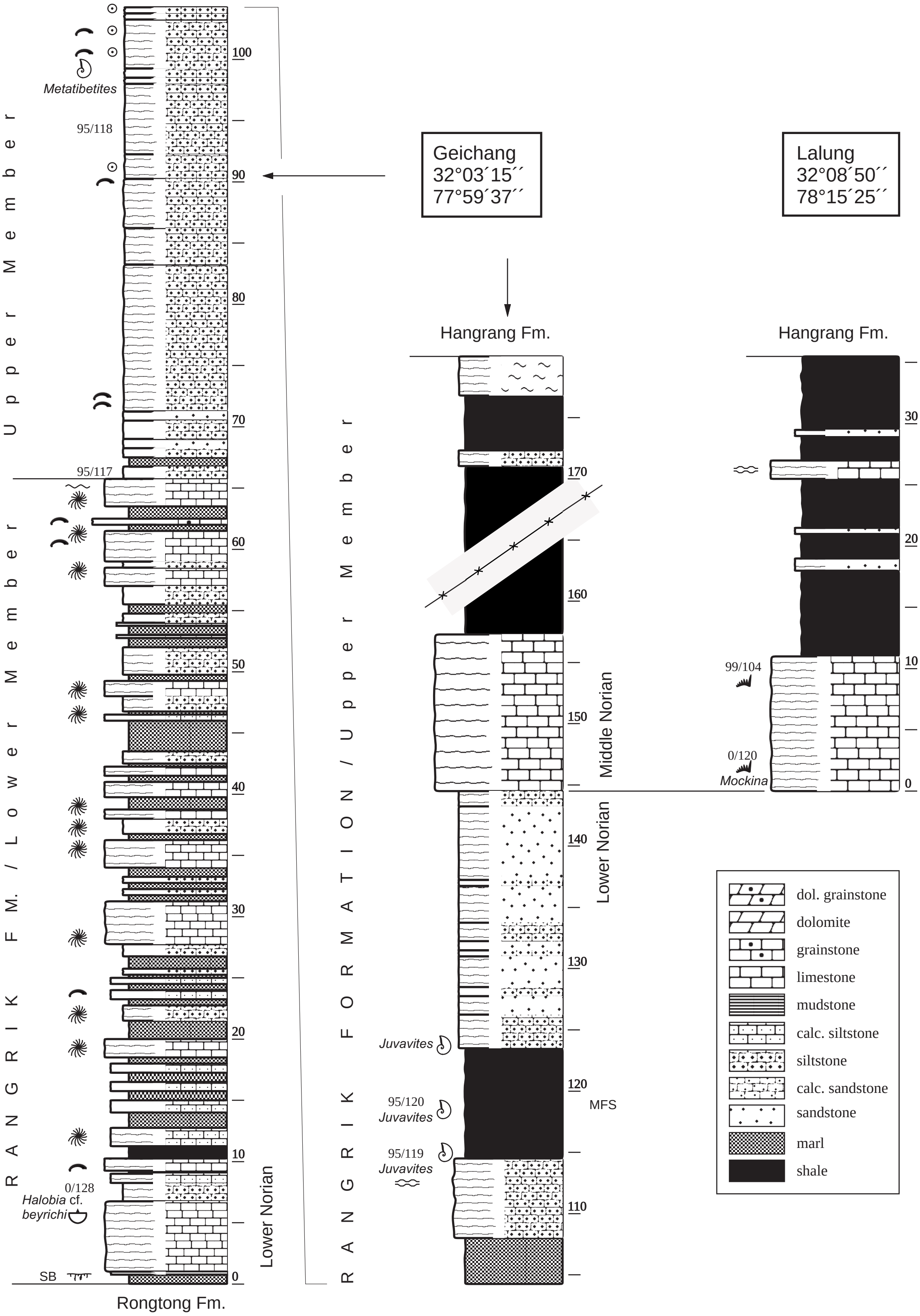

Figure 11: Stratigraphic log of the Rangrik Formation (type section), N of Geichang and E of Lalung.

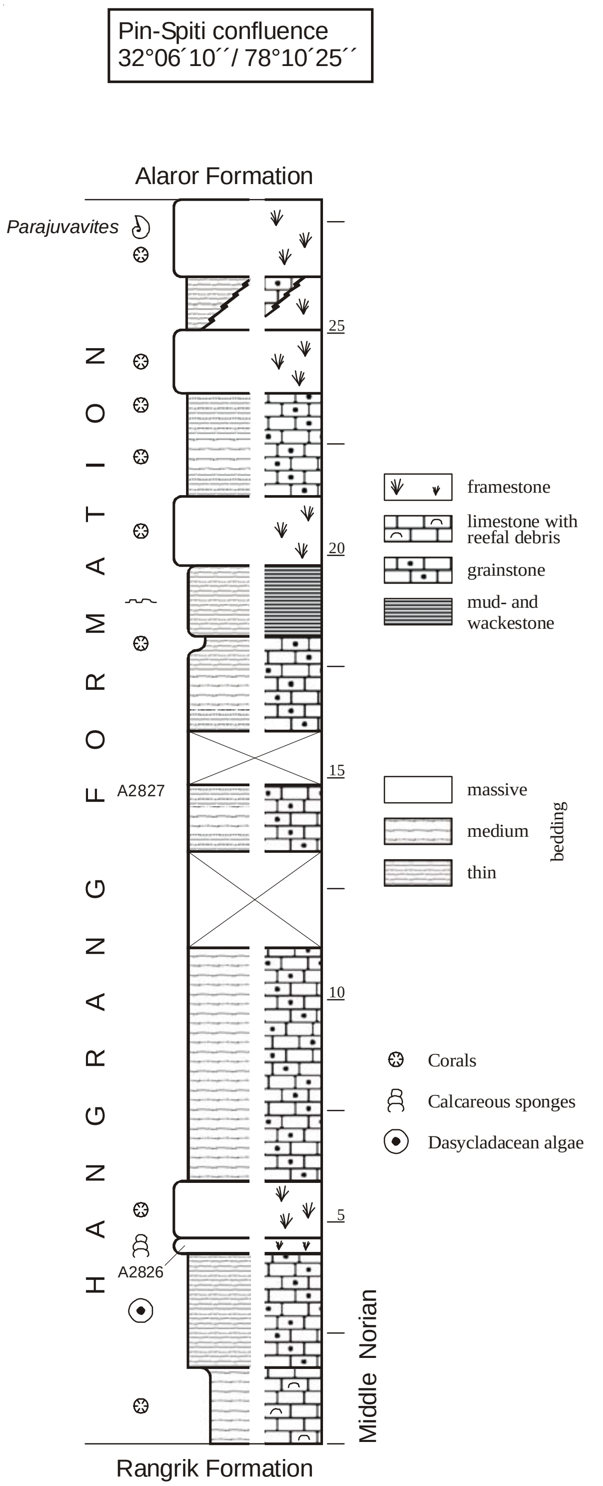

Figure 12: Stratigraphic log of the Hangrang Formation , Pin-Spiti confluence.

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.

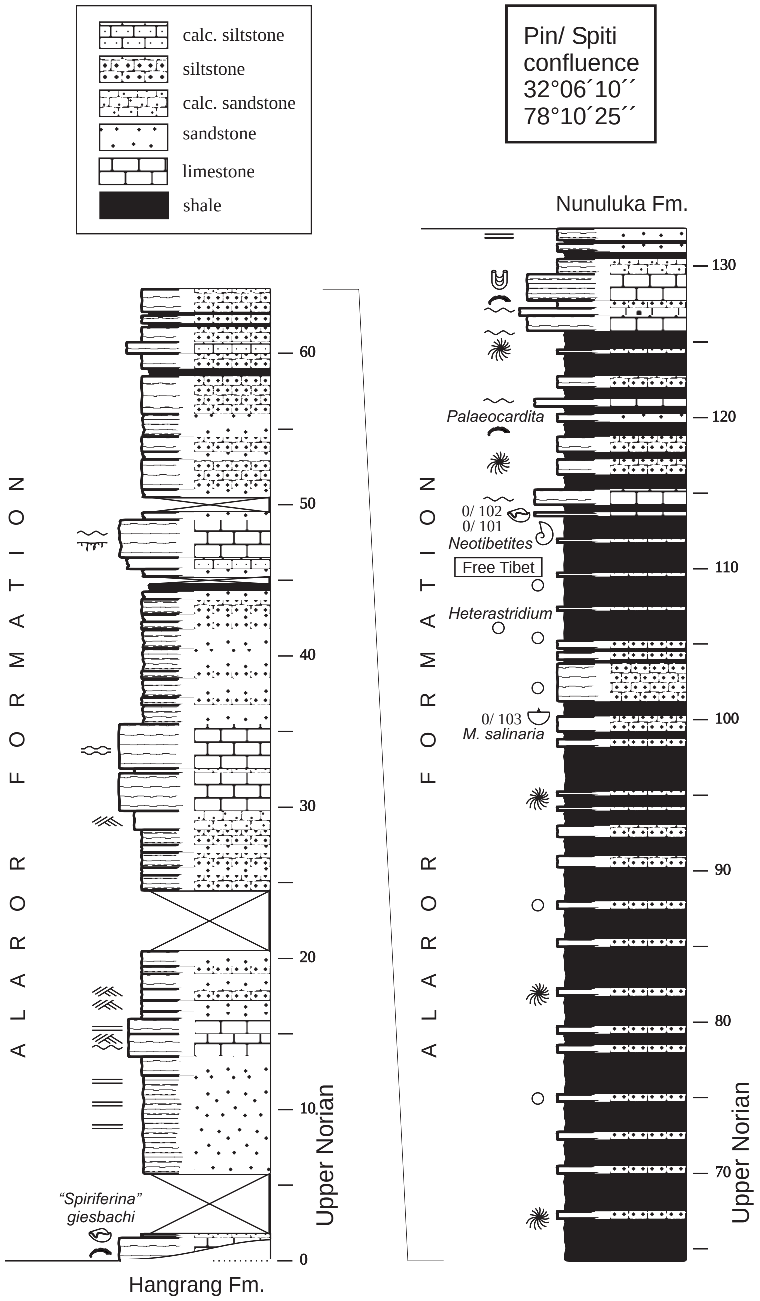

Figure 13: Stratigraphic log of the Alaror Formation (type section), Pin-Spiti confluence.

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

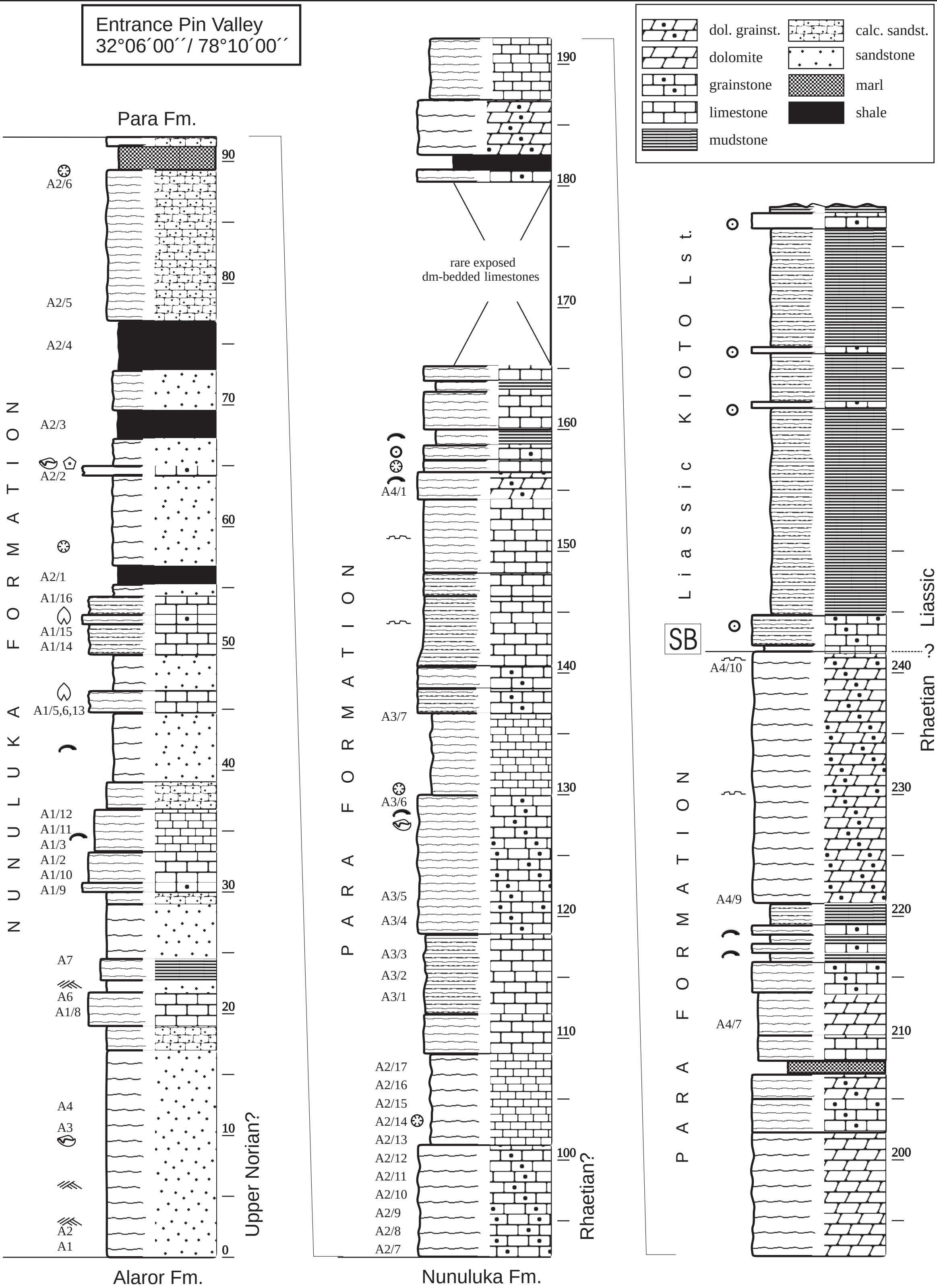

Figure 14: Stratigraphic log of the Nunuluka Formation (type section) and Para Formation, Pin Valley entrance.

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).

Acknowledgments

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Lower and Middle Triassic stage and substage boundaries in Spiti

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Introduction

Spiti is known for long as host of large and diverse ammonoid faunas of Lower and Middle Triassic age (Diener, 1895, 1897, 1907, 1908; Krafft and Diener, 1909). All these classical monographs, however, lack precise sequential information on the vertical distribution of the ammonoids in the rocks/field. They are thus useless from viewpoint of modern biochronological standards without a thorough reinvestigation of the sections from where the fauna was derived. This is our goal, and at the same time a chance to contribute substantially to the presently intense discussion focussing on new boundary definitions of Triassic stages (and substages), with special attention to the Lower and Middle Triassic. The presented data are in part a culmination of the preliminary work commenced in 1978 by an Indian-Austrian Expedition team comprising D.K.Bhatt, K.C.Prashra, R.K.Arora (Indian members), H.Zapfe, G.Fuchs, L.Krystyn, R.Golebiowski (Austrian members). Later after a gap of two decades L. Krystyn, M. Balini and A. Nicora recommenced the biostratigraphic work in Spiti the results of which form the basis of this paper.

Gangetian

The Lowermost Triassic ammonoids are extensively found in Spiti. The most easily accessible and also most fossiliferous localities are close to Guling and Muth in the Pin valley (Fig.1). The first detailed account of this rich fauna has been provided by Krystyn and Orchard (1996), followed by documentation of the accompanying conodonts by Orchard and Krystyn (1998). This fauna comes from a distinct grey, brownish weathering limestone band of about 1m thickness, called as *Otoceras* beds since Griesbach's (1880) pioneering study more than a century back, here designated as the Lower Limestone Member of the Mikin Formation. The *Otoceras* beds are well demarcated and unequivocally recognizable, being "sandwiched" between the black or dark grey, in part laminated shales below and above – known traditionally as Kuling Shale (now Gungri Formation of the Kuling Group) and *Meekoceras* beds (here *Gyronites* beds) respectively.

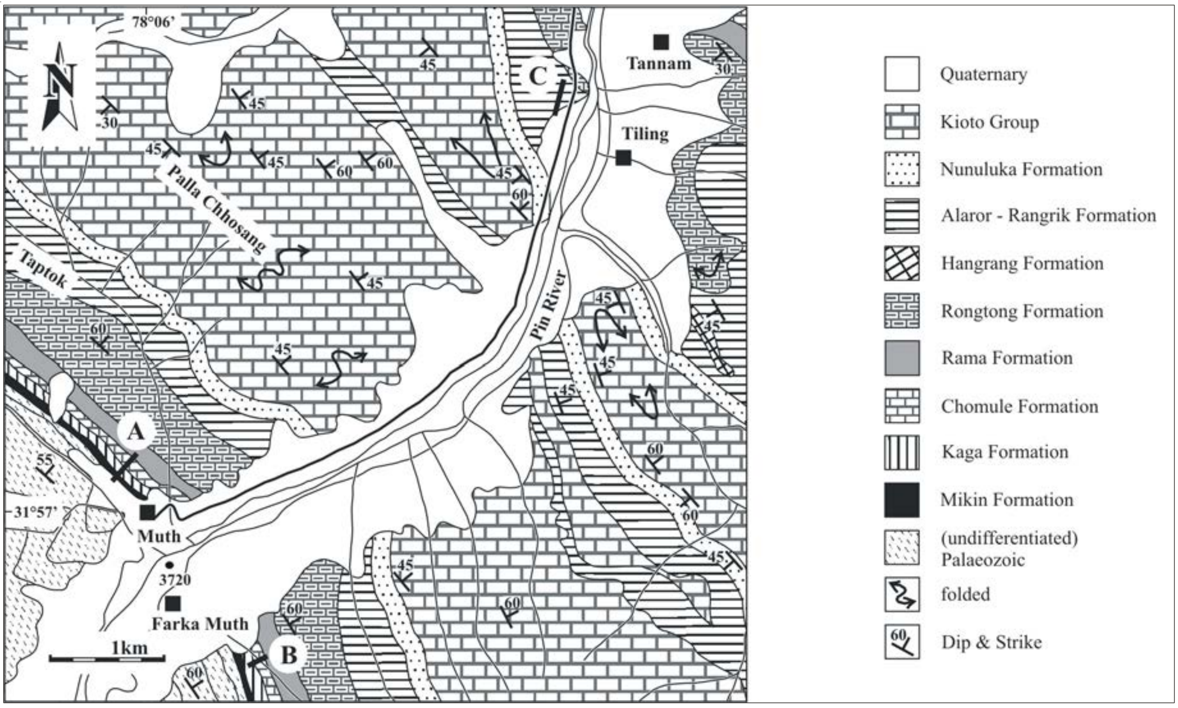

Figure 1: Geology of Muth (after Fuchs, 1982) with position of sections E/M 03 **(A)**, Muth 3 near Farka Muth **(B)** and opposite Tilling **(C)**.

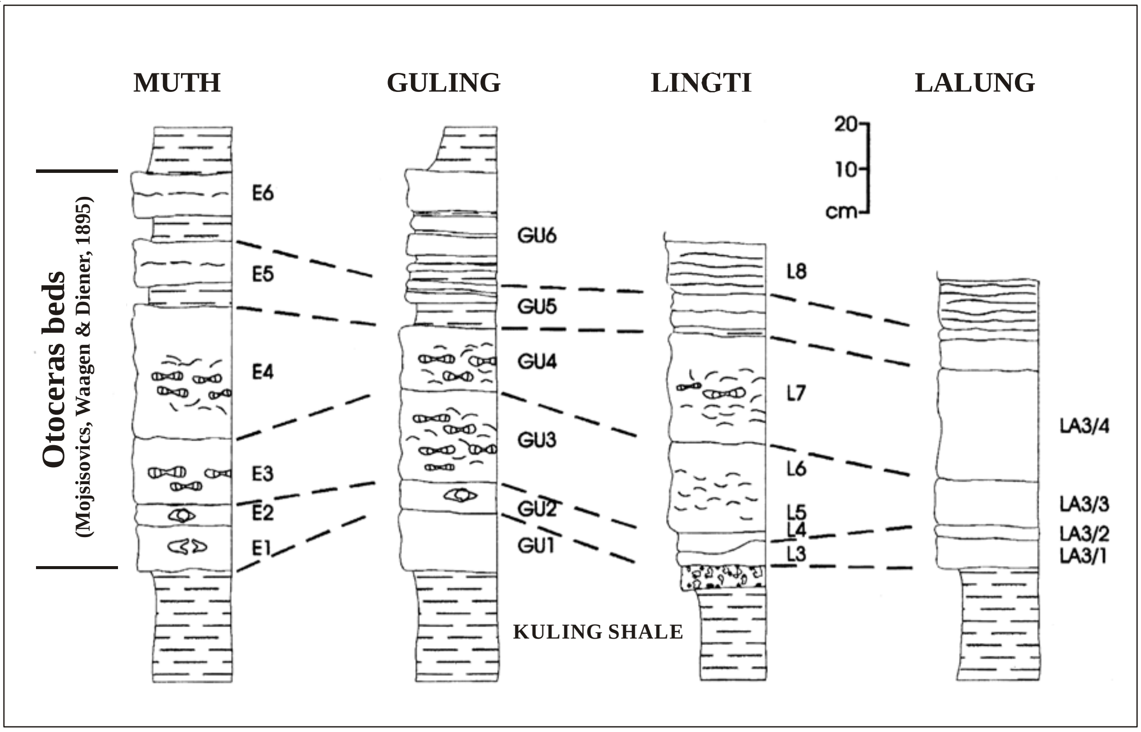

Figure 2: Lithology and conodont-based correlation of the *Otoceras* beds along a 30 km wide basin transect from Muth to Lalung (modified from Orchard and Krystyn, 1998).

The term *Meekoceras* beds was introduced by von Krafft based on a section "1 mile north of Lilang" (now spelt Lalung), located in the lower Lingti valley about 20 km away from Guling Von Krafft (in Krafft and Diener, 1909) unfortunately identified several species named as typical for the *Otoceras* beds by Diener (1897) from the *Meekoceras* beds. This has led to serious stratigraphic misinterpretations and confusion with far reaching consequences for the lowest Triassic substage terminology (discussed in sequel). The name "*Meekoceras* beds" is a misfit and also misleading because the fauna has no *Meekoceras* affinity. Instead it is dominated by gyronitids, and is a time-stratigraphic equivalent of the *Gyronites* bearing beds found elsewhere on the northern margin of the Indian plate (Salt Range, Tibet, Nepal). Compared with the true mid-Smithian *Meekoceras* level (Fig. 6) these beds are much older and represent an undoubted pre-Olenekian age. Following von Krafft, Krystyn (in Krystyn and Orchard, 1996) restricted the *Otoceras* beds to the basal two third of the Lower Limestone member - indicated in the Guling section as beds GU 1 to GU 4. The two overlying thinner bedded limestone intervals, numbered GU 5 and GU 6 were merged with the *Meekoceras* beds despite their lithological similarity with the limestones below. This erroneous placement was realised only subsequently after a restudy of Krafft's type section where the two intervals can be distinguished by distinct carbonate lithologies. Limestones of the *Meekoceras* beds are impure mudstone, blackish to dark grey, starting in Guling section above the level 6 and they distinctly differ from the litho- to lithoclastic ammonoid lumachelles bearing wacke- and packstones of the Lower Limestone Member (levels 1-6) formed in a better oxygenated and shallower, in part current-induced depositional environment.

Retained in the original scope (Diener, 1897), the *Otoceras* beds (Fig. 2) in Spiti represent a package of more than 10 well-defined limestone beds up to 90 cm thick. In Guling, Krystyn and Orchard (1996) have discriminated 6 levels, which correspond either to individual beds (GU 1 – GU 4) or form bundles of several thin beds (levels GU 5 and GU 6). Levels 1-3 have been lumped together as *Otoceras woodwardi-Ophiceras bandoi* zone, level 4 was called *Ophiceras tibeticum-Discophiceras* cf. *wordiei* zone and levels 5 to 6 were combined to a newly introduced *Pleurogyronites planidorsatus* zone. Subsequent conodont research (Orchard in Orchard and Krystyn, 1998) could demonstrate that the ammonoid-free level GU 1 corresponds to the *parvu*s zone and is older than the overlying *O. woodwardi* bearing beds which are all of *isarcica* zone and thus of post- *parvus* zone age (Fig. 3). *O. latilobatum* recorded by Orchard et al.(1994) from the parvus zone in Selong (Tibet), may also be anticipated in GU 1. This is important in the light of the supposed synonymy of the species with *O. fissisellatum* Diener and of a possible time link between the basal most Himalayan *Otoceras* layer and the Arctic *boreale* zone (Krystyn and Orchard, 1996).

To enlarge the ammonoid database and to prove the doubtful co-occurrence of *Otoceras woodwardi* and *Ophiceras tibeticum* in GU, a detailed resampling of the Guling section has been carried out in a new parallel section (V). It led to the discovery of a two-fold internal parting of the GU 3 (vide V 3/1 and V 3/2) and a four-fold subdivision of the GU 4 (Fig.3) as well as to a considerably richer fauna- both in number of specimens and also species. A careful taxonomic revision of the GU collections further

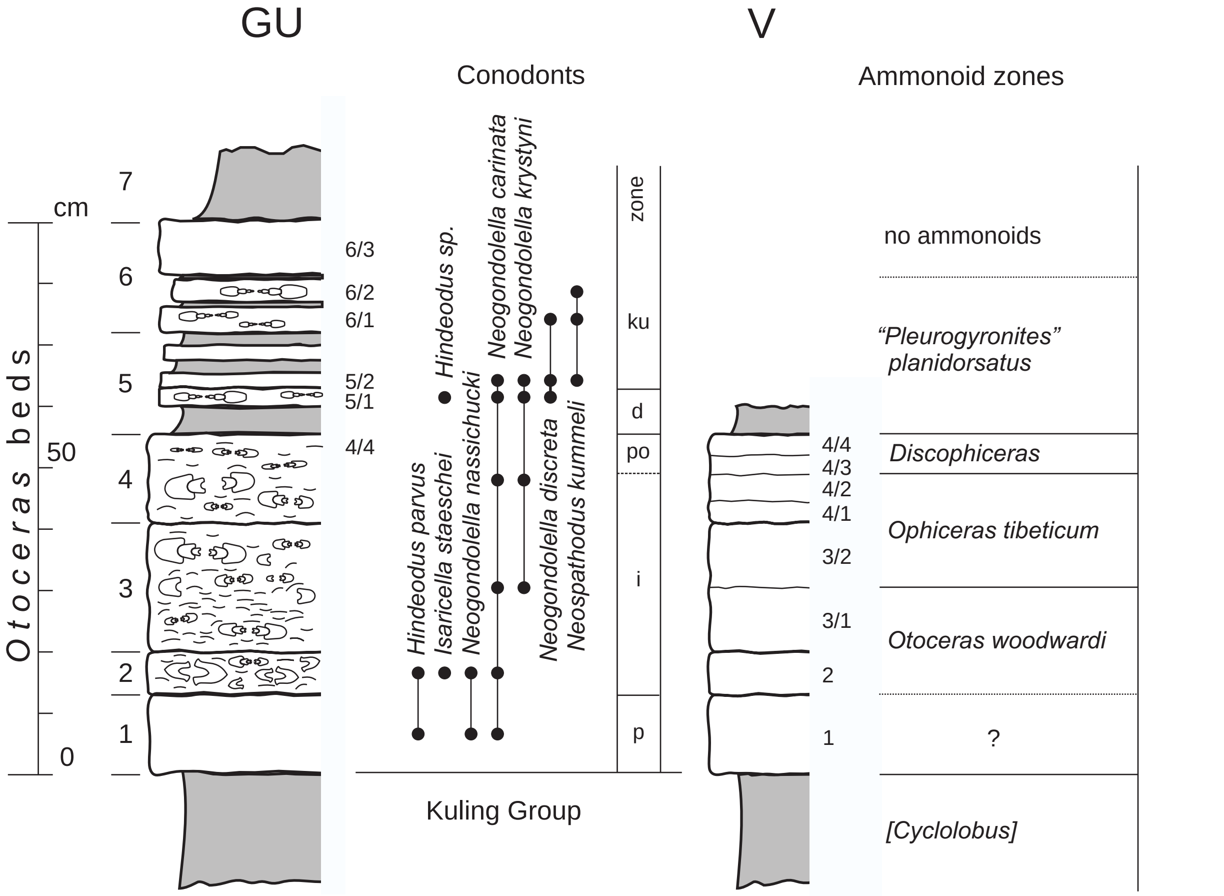

Figure 3: Ammonoid and conodont biochronology of the *Otoceras* beds in sections GU and V on the hill above Guling.

increased the faunal diversity and provided some important taxonomic changes. The new faunas are listed in Fig. 4 and allow a somewhat different subdivisions of the Spiti *Otoceras* beds into 4 zones (ignoring an unproven *O. latilobatum* interval at the base):

1) *Otoceras woodwardi* zone (beds 2 + 3/1)

The zonal guide is accompanied by *Lytophiceras connectens* formerly identified as *Ophiceras bandoi*. The later species has too wide an umbilicus for *Ophiceras* and looks closer to the genus *Metophiceras*, however, the absence of suture documentation of the type material does not permit verification of this suggestion. Bed 3/1 shows additional appearance of *O. paraserpentinum* Waterhouse. At Losar, a time equivalent of the bed 2 contains also *Shalshalia* , a distinct member of the basal *woodwardi* zone in Nepal (Waterhouse, 1994).

2) *Ophiceras tibeticum* zone (beds 3/2 + 4/1)

Beside the name bearer only *L. medium* and *O. paraserpentinum* are known from 3/2. A more diverse fauna appears in 4/1 containing the aforementioned species together with more involute ophiceratids (*L.* cf. *ptychodes*, *L.* cf. *sakuntala* and the first representatives of gyronitid like forms with a flattened from the flanks well-separated venter ("*Pleurogyronites*"). The early appearance of gyronitid shaped genera has also been mentioned from Nepal (Waterhouse, 1994) and is a widespread phenomenon, even known from the arctic Greenland (Spath, 1935).

3) *Discophiceras* zone (beds V 4/3 + V 4/4, GU 4/4)

Restricted to less than 20 cm thickness in Spiti and probably also thin in other regions of the Himalayas, the interval has not attracted much attention till now. The fauna is shared between the last *Ophiceras* representatives (*Ophiceras tibeticum, L. connectens, L.* cf. *ptychodes, L.* cf. *sakuntala*) and considerably evolved, involute forms ascribed to *Discophiceras* with at least two different species (Fig. 4). Gyronitid-like forms get more diverse but are still rare, resembling "*Pleurogyronites*" and *Mesokantoa* Waterhouse, 1994. Of value for fine tuned correlation may be *Fuchsites markhami* found as one well-preserved specimen in GU 4/4 and cited formerly as *Bukkenites* sp.

4) "*Pleurogyronites" planidorsatus* zone (intervals 5 + 6)

There is some uncertainty in the generic position of the zonal index as a considerable younger *P. kraffti* Tozer, 1994 – type species of *Pleurogyronites* – shows no well preserved inner whorls. Morphologic comparisons are thus restricted to a minor part of the shell, i.e. the ultimate whorl that looks close in the Spiti material. Sutural differences regarding size and shape of the third lateral saddle may otherwise indicate generic independence. Together with "*Pleurogyronites*" n. sp. 1, a slender and

GU 2	*Otoceras woodwardi* Griesbach, *Lytophiceras connectens* Schindewolf; equivalent bed in Lossar: *Shalshalia* sp.
GU 3	*O. woodwardi* Griesbach, *Ophiceras tibeticum* Griesbach, *L. connectens* Schindewolf, *L.* cf. *ptychodes* Diener, *L.* cf. medium Griesbach
V 3/1	*O. woodwardi* Griesbach, *Ophiceras paraserpentinum* Waterhouse
V 3/2	*O. tibeticum* Griesbach, *O. paraserpentinum* Waterhouse
GU 4	*O. tibeticum* Griesbach, *O. paraserpentinum* Waterhouse, *L. serpentinum* Diener, *L. medium* Griesbach, *L.* cf. *sakuntula* Diener, *Lytophiceras* n. sp., *Wordieioceras* sp., *Discophiceras* cf. *wordiei* Spath, *D.* cf. *subkyoktikum*, Spath, *Mesokantoa* sp., n. gen. n. sp.(like *Mesokantoa* but with rounded inner whorl)
GU 4/4	*L.* cf. *medium* Griesbach, *Fuchsites markhami* (Diener)
V 4/1	*O. tibeticum* Griesbach, *O. paraserpentinum* Waterhouse, *L.* cf. *ptychodes* Diener, *L. medium* Griesbach, *L. sakuntula* Diener
V 4/3	*L. connectens* Schindewolf, *L.* cf. *medium* Griesbach, *L.* cf. *sakuntula* Diener, *Discophiceras* cf. *wordiei* Spath, *D.* cf. s*ubkyoktikum* Spath, *Mesokantoa*? sp. ("*Kymatites*"), "*Pleurogyronites*"
V 4/4	*Lytophiceras* cf. *chamunda* Diener, "*Pleurogyronites*"
GU 5/1	"*Pleurogyronites*" n. sp. 1, "*Koninckites*" sp. 1 + 2, *Pseudoproptychites scheibleri* (Diener)
GU 6	"*Pleurogyronites*" *planidorsatus* Diener, "*Kymatites*", "*Koninckites*" sp. 1 + 2, *Pseudoproptychites scheibleri* (Diener)

Figure 4: Gangetian ammonoid fauna of sections GU and V at Guling.

more weakly ribbed form, "*Kymatites*" sp. 1 and 2 and "*Koninckites*", dominate gyronitid like morphologies the fauna. A direct link with the *Ophiceras* bearing beds is provided by *Pseudoproptychites scheibleri*), known presently from the *tibeticum* zone of the Himalayas and of Oman (Krystyn et al., 2003).

The dominance of ammonoids with gyronitid affinity coupled with the disappearance of *Ophiceras* related genera and the supposed contemporaneity of this interval with von Krafft's *Meekoceras* beds were the reasons for Krystyn and Orchard (1996) to merge this zone with the Dienerian substage. This is no longer tenable and for reasons of historical priority and also nomenclature stability the *planidorsatus* zone is now fitted in the original sense and faunistic contents of the Himalayan *Otoceras* beds - a matter of prime importance for the classification and naming of the basal most Triassic substage. Moreover, after the international agreement to define the base of the Lower Triassic by the FAD of *Hindeodus parvus*, the Gangetian of Mojsisovics, Waagen and Diener, 1895 now corresponds exactly to the time interval between the Changxingian and the Dienerian. It should, therefore, be reinstalled and preferred over the later proposed term Griesbachian which obviously needs a precise redefinition. A preference for the Gangetian substage was also expressed since earlier by Kozur, and also by Shevyrev and Waterhouse (2002b). The Gangetian-Dienerian (or Gandarian) boundary may be based with ammonoids at the entry of true gyronitids with tabulate, flat and sharp-edged venter (*Gyronites frequens* group) and with conodonts at or close to the appearance of *Neospathodus dieneri* Sweet- a well-defined and worldwide-distributed species. This definition is seen in favour of the alternative *kummeli* date that falls within the *planidorsatus* zone and is not recognizable by ammonoids (Fig. 5).

Induan–Olenekian boundary

Sediments representing this time interval in Spiti are found in the lower third of the Limestone & Shale (or second) Member of the Mikin Formation. Varying lithologies within the member allow a discrimination of three intervals named for their diagnostic ammonoids as basal 2-3 m thick *Gyronites* beds (the former *Meekoceras* beds of Krafft) followed by 2 meter thin *Flemingites* beds and topped by up to 10 m thick *Parahedenstroemia* beds (Fig. 6). As for the underlying *Otoceras* beds, the intervals can be traced along the Pin and Lingti rivers over tens of kilometres across strike and like the former seems to constitute identical time-equivalent rock units. Faunistic studies of the boundary interval so far have been concentrated in Muth, though Guling and Lalung may provide important data in the future. Both Muth and Guling sections are easily accessible with better exposures at Muth. At Guling the fossil bearing limestone beds of the second member are being intensively quarried for house construction since the early eighties of the last century. Consequently, their outcrops have become scarce and are often covered by rock debris and, therefore, can be missed in hurried studies (see Garzanti et al., 1995).

Faunas from Muth resulted from two sampling campaigns - an old from 1978 (suffix E.) and a recent more detailed one from the last year called as M 03. Muth (3800 m)

St.	Subst.		Ammonoids	Conodonts		Bivalves
OLENEKIAN	Spathian		undifferentiated	*N. gondolelloides*		
				Undifferentiated		
	Smithian		*Wasatchites/ Anasibirites*	*N. waageni*		*"P." himaica*
			Meekoceras gracilitatis			
			Flemingites flemingianus			
INDUAN (=BRAHMANIAN)	Dienerian	Gandar.	*Rohillites rohilla*	*C. nepalensis*		
			Gyronites frequens	*N. cristagalli*		
				N. dieneri		
	Griesbachian	Gangetian	*"Pleurogyronites" planidorsatus*	*N. kummeli*		*Claraia griesbachi*
				Ng. discreta		
			Discophiceras		*Ng. krystyni*	
			Ophiceras tibeticum	*I. isarcica*		
			Otoceras woodwardi		*Ng. meishanensis*	
				H. parvus		

Figure 5: Ammonoid and conodont zones as recognized in the Lower Triassic of Muth. Nomenclature of Induan substages needs international agreement but Gangetian is here preferred against Griesbachian. Induan-Olenekian boundary depends on future accord. The Spathian is poor in ammonoids and has not been studied for conodonts. Ammonoid zones of the Upper Induan are not well constrained.

itself rests on the Mikin Formation that extends from Muth towards northwest along a side valley for several kilometres to the crest between the Pin and Parahio valleys (Fig. 1). Extensive continuous exposures on the northern valley slope provide excellent conditions for measuring and sampling of the section. For logistic reasons work was concentrated at a place (A in Fig. 1) situated about 100 m in altitude above the village, which has easiest accessibility and is closest to Muth village. Here, within a 4 m thick rock package four faunal intervals are discriminated by ammonoids and three by conodonts, close to the boundary (Fig. 6). Not many of the differentiated 20 levels provide a substantial faunal record but altogether they provide a sustained feeling of the rapid turnover from Induan to Olenekian fauna. Whether this impression is amplified by the reduced sedimentation rate or perhaps by a paraconformity at the boundary needs further investigation.

Though preliminary, the Spiti data are of prime importance for the intercalibration of conodonts and ammonoids as the latter are common and usually well determinable due to minimal distortion. Depending on the fossil group chosen, there are different possibilities to define the boundary. A currently preferred option by the Triassic Subcommission of Stratigraphy favours the FAD of *Neospathodus waageni waageni*, which is located within the upper half of the *Flemingites* beds (Fig. 6). The underlying *Gyronites* (former *Meekoceras*) beds are characterized in Muth, Guling and Lalung (Krafft and Diener, 1909) sections by a variety of gyronitid ammonoids and Bed 10 still contains *Gyronites frequens* and *Himoceras.* The basal 60 cm (12-13) of the overlying *Flemingites* beds are unfortunately barren but constitute a distinct lithological marker horizon by the intensive yellowish weathering. In bed E 14/1 marks *Rohillites rohilla* the entry of *Flemingites* s.l. and a first possible Induan – Olenekian ammonoid boundary. Another boundary option may be indicated by the appearance of *Flemingites* s. str. in the overlying bed 14/2. After three fossil poor and currently unstudied beds (15 to 17) of a total thickness of 80 cm follows a 2 m thick rich faunal interval, informally named for its two more prominent members as *Meekoceras / Juvenites* zone. Conodont faunas are present throughout the sequence but have not been studied in great details as several beds still await sampling. Yield is also poor from critical beds 14/1 and 14/2 which obviously need further collection. Three zones (with beds in brackets) are currently distinguished: *cristagalli - pakistanensis* ? (10 downward), *nepalensis* (12-14/1) and *waageni* (14/2 upward). Neospathodid conodonts of the *waageni* group are unfortunately not well preserved in bed 14/1. Those from 14/2 may be close to *N. waageni* n. subsp. A as differentiated recently by Zhao Laishi et al. (2004). First true *N. waageni waageni* in the sense of the afore mentioned authors is represented in M 03-15.

Olenekian–Anisian boundary

Following the recommendations of the Triassic Subcommission of Stratigraphy this boundary is placed at the appearance (FAD) of the conodont *Chiosella timorensis* known in Spiti from upper part of the Niti Limestone Member (Garzanti et al.,1995). The exact position has been found in the Lalung 2 section (about 2 km air dis-

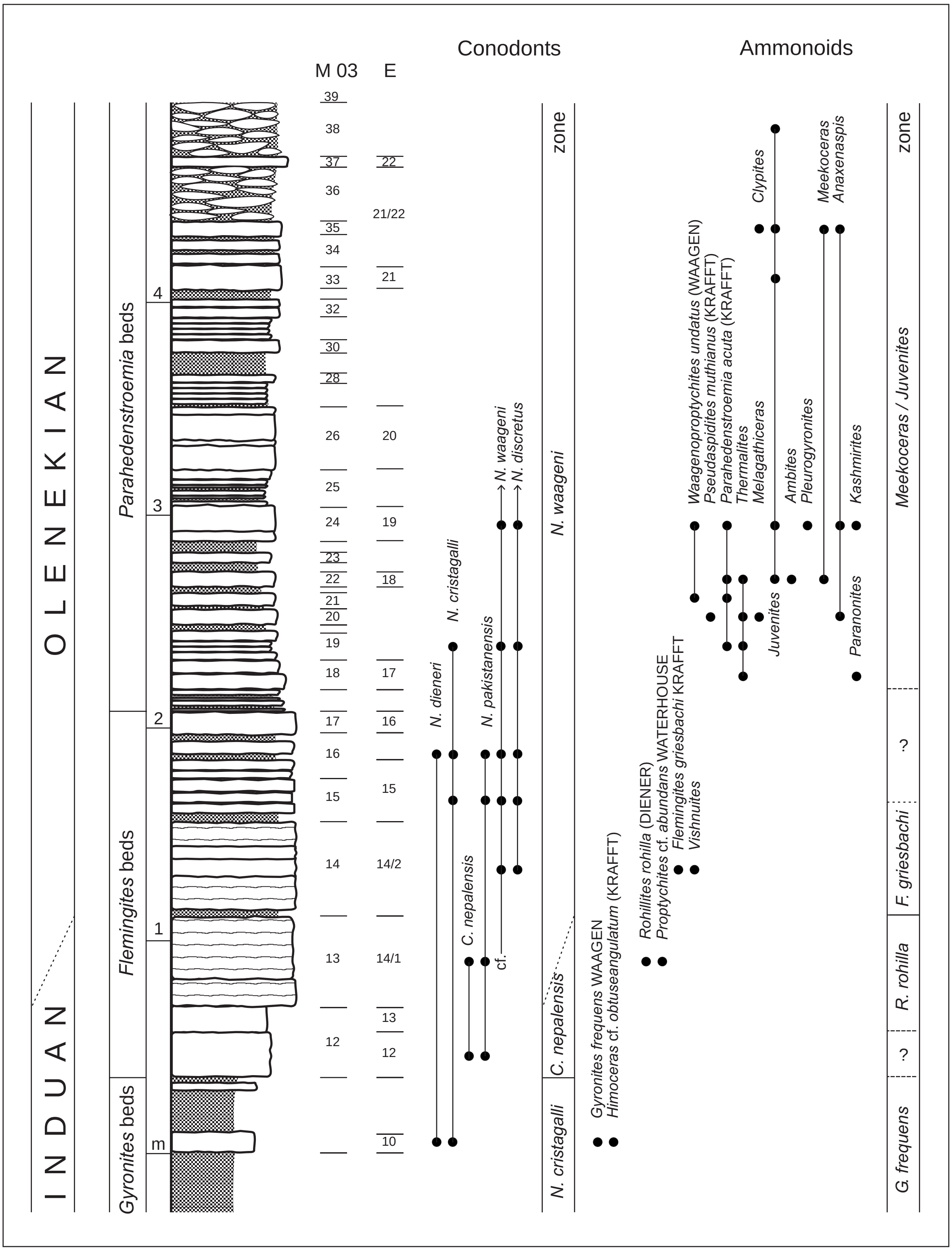

Figure 6: Ammonoid and conodont faunal sequence around the Induan-Olenekian boundary at Muth.

tance from Lalung to the northeast) in bed 5, one meter below the top of the member (Fig. 7). Except for the basal most parts, the Niti Limestone in Spiti is poor in ammonoids, precluding a calibration with the conodont sequence. *Preflorianitoides* from the bed 7 is the first and only cephalopod found within the lowermost Aegean. Richer faunal documentation starts in the topmost Niti Limestone (bed 9) and continues upward into the lower beds of the Himalayan Muschelkalk member (10 – 12).

Durgaites dieneri, the zonal guide of the Himalayan Aegean occurs from bed 10 to 23 with giant-size specimens of up to half a meter in diameter in the shales between 12 and 18. Independent from the conodont evidence *Paracrochordiceras, Paradanubites, Japonites* and *Aegeiceras* underline the Anisian character of the fauna of the *dieneri* zone. More important would be a faunal record of the unfossiliferous part below because faunas of that peculiar age are presently rare worldwide or dep-

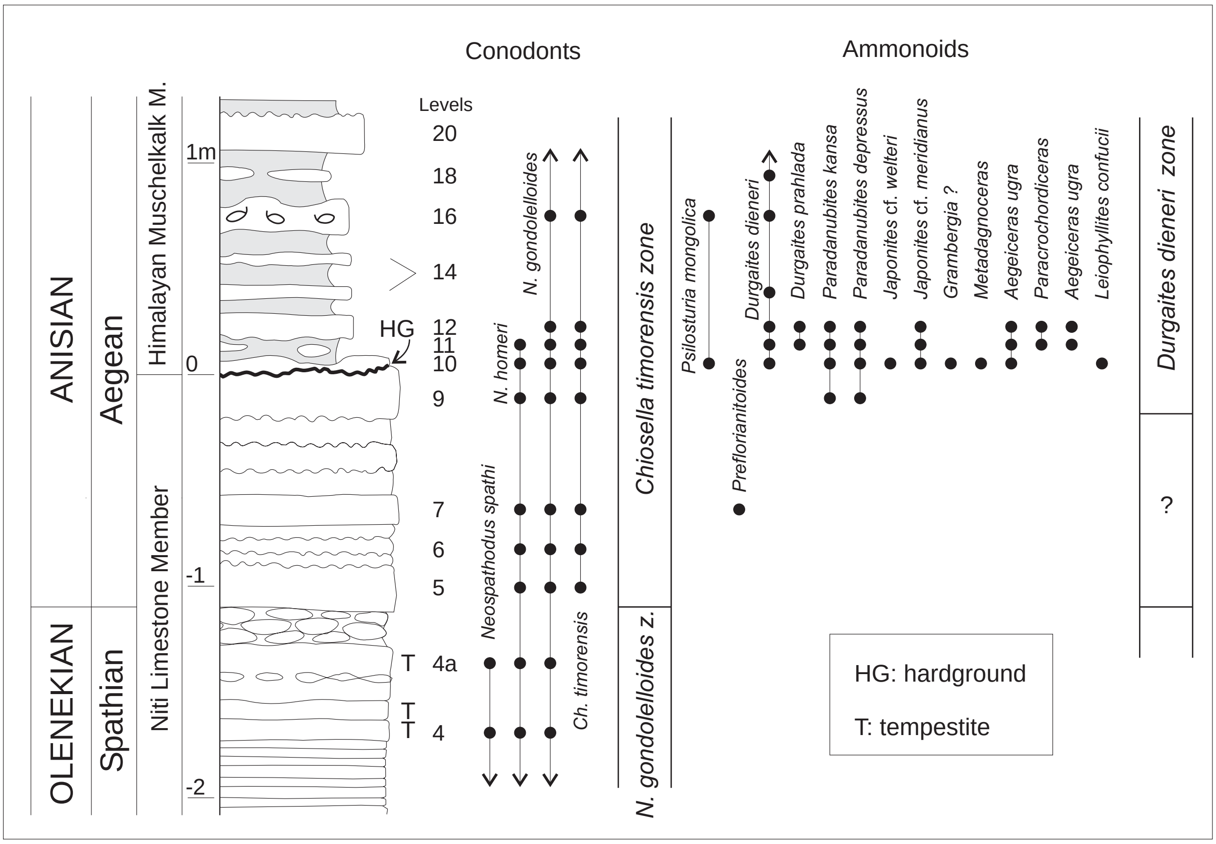

Figure 7: Ammonoid and conodont record across the Olenekian–Anisian boundary at Muth. The boundary is drawn with the FO of *Chiosella timorensis*. Note the sequence boundary (HG) on top of the Niti Limestone Mb.

auperate (barren interval in Nevada – Bucher 1989, Hallstatt limestone of Chios – Gaetani et. al., 1992). Lack of sequential data from interval 5-8 impedes integration of new early Anisian faunas classed as *Grambergia latiumbilicata* and *Stenopopanoceras kukrii* zone in Nepal (Waterhouse, 1999). Part of them could be missing in Spiti in the hardground (bed 9) on top of the Niti Limestone Member, which is thought to represent a major sequence boundary. Though the latter is lithologically very pronounced there is, however, no palaeontological evidence of a time-diagnostic hiatus as neither conodonts nor ammonoids show changes across the boundary (Fig. 7).

Anisian to Ladinian subdivisions of the Himalayan Muschelkalk member

The first detailed overview of the Anisian ammonoid fauna of Spiti was presented by Balini and Krystyn (1997). Since then additional collections have considerably enlarged the faunal data for the upper part of the sequence whereas the lower part (beds 26-31) still remains faunistically poor. Eight zones are now distinguished in biochronologic scheme (Fig. 8) which is still partly preliminary. Minor nomenclatural modification in the scheme of Balini and Krystyn (1997) become necessary due to availability of additional material and also some taxonomic revisions. The number of Anisian fossil layers has increased to 40 by a more detailed subdivision of certain beds (e.g. 34, 40) and that of the zones to 8, named in ascending order as *dieneri* zone (9-23), unnamed zone (24-34B), *Hollandites* zone (34C – 37), *Silesiacrohcordiceras* zone (38-39), *trinodosus* zone (40), *Kellnerites* zone (40B/C) and *Reitzi-Halilucites* zone (41A-C). Severely reduced sedimentary thickness, many gaps characteristic of the Pelsonian and Illyrian and stratigraphic condensation at least at subzonal level may be common. A much thicker but presently faunistically less documented lower Anisian sequence (up to bed 37) looks comparably uncondensed and may provide interesting fine-scale subdivision possibility, once better collections are available.

Leading genera of the *dieneri* zone are *Durgaites* and *Paracrochordiceras*, further common is *Japonites* with species known from Nevada (*J.* cf. *welteri*) or Timor (*J.* cf. *meridianus*). The *Caucasites* zone is restricted to two beds corresponding to the total range of the index genus in Spiti, which is found together with first representatives of the genus *Pseudohollandites*. The fauna is also meagre in the overlying "unnamed zone" with *Pseudohollandites*, *Malletoptychites* and *Isculites* ranging throughout this interval. A more diverse fauna found in the upper part with *Beyrichites* (above 32), "*Nicomedites*" (32-34B), *Acrochordiceras* (from 33 upwards), *Arctohungarites* (32) and *Alanites* (33). *Alloptychites* ("= *Isculites*") cf. *meeki* from bed 26 permits a partial correlation with the *caurus* zone of Nevada, smooth alanitids and *Acrochordiceras* of the *hyatti* group from bed 33 with the basal *hyatti* zone of Nevada (Bucher, 1992). An ammonoid based correlation with the Bithynian substage of northern Turkey (stratotype region) seems more difficult. *Nicomedites* itself is not very helpful and,

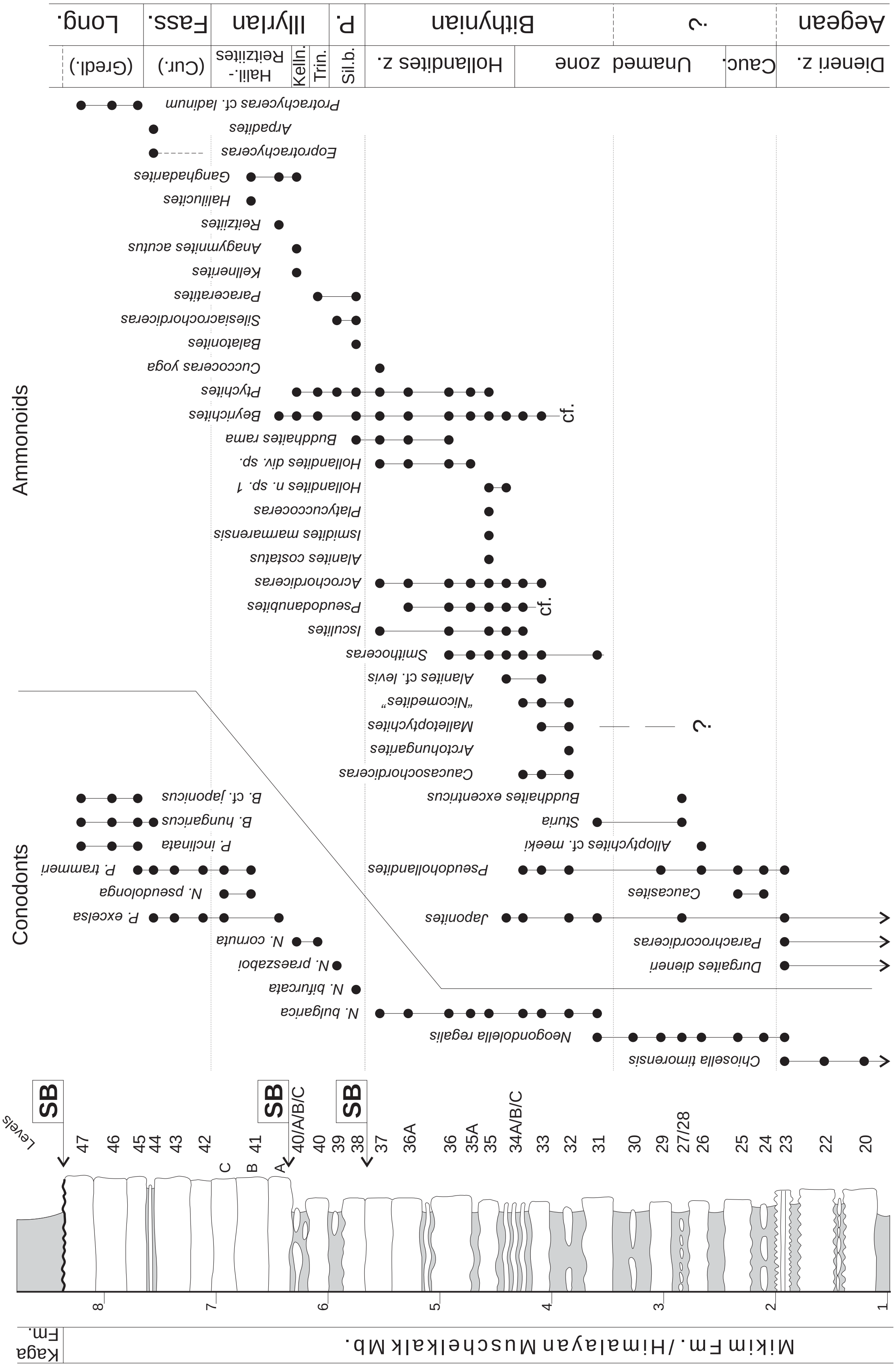

Figure 8: Ammonoid and conodont faunal sequence of the Himalayan Muschelkalk Mb. Note the strongly reduced thickness in the Upper Anisian and 3 sequence boundaries (SB) in upper part of the section.

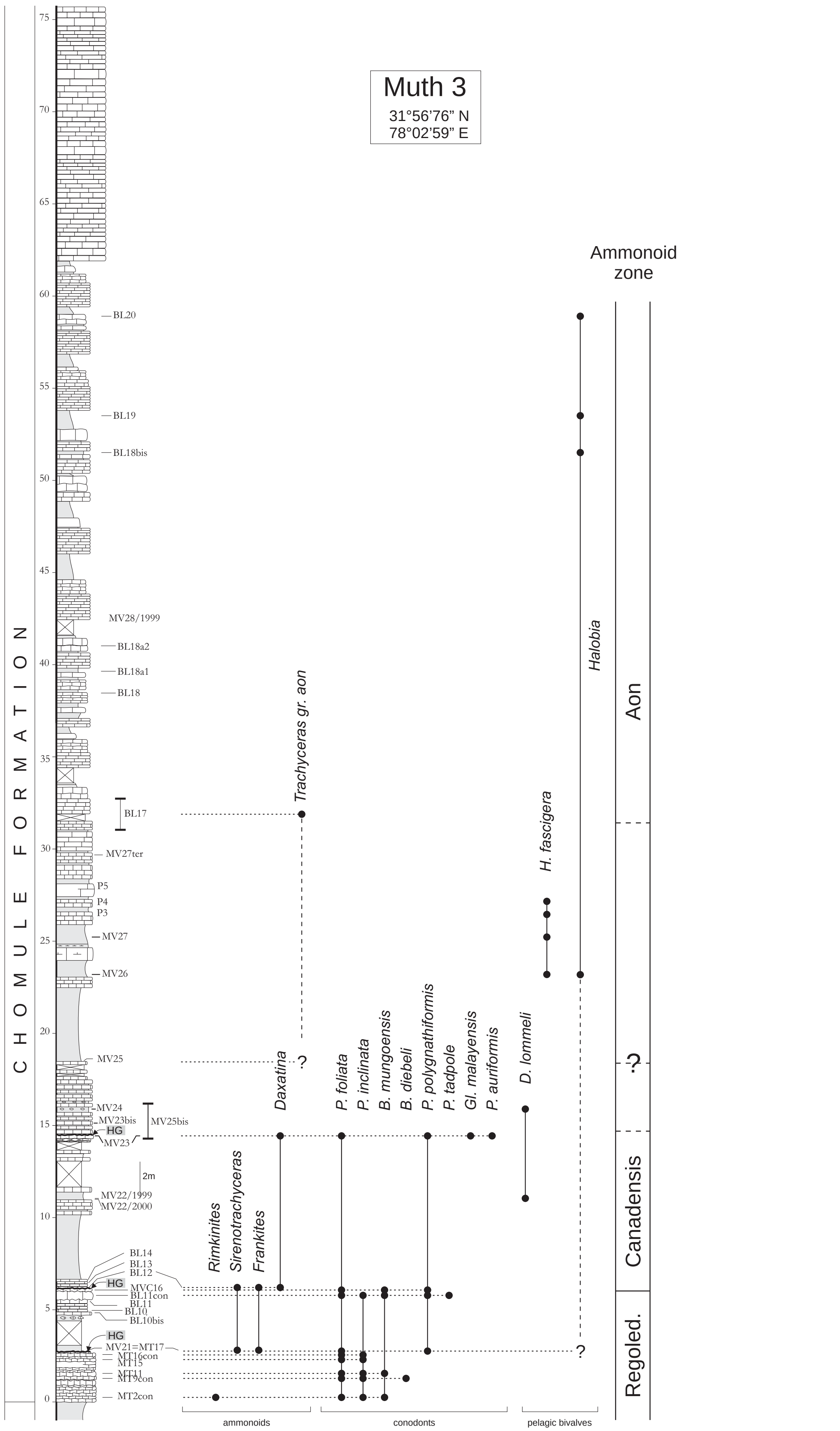

Figure 9: Distribution of ammonoids, conodonts and pelagic bivalves in the lower part of the Chomule Formation at Muth 3

by revision may turn out to be biogeographically restricted to the Palaeotethys domain. Spiti "*Nicomedites*", close to conch shape, differs by a less intended suture line with entire rounded saddles and should represent an independent genus. The North American "*Nicomedites*" specimens from British Columbia (Tozer, 1994) lack the genus-typical adult umbilical egression and show a suture with stronger intended saddles much closer to *Beyrichtites* or *Semibeyrichites*. A correlation thus seems to be easier with conodonts as *Neogondolella bulgarica* appears at the base of the Bithynian substage in Turkey (Nicora, 1977) and has its first occurrence in Spiti in bed 31 allowing a tentative placement of the Bithynian base somewhere in the middle of the unnamed zone. This opens the question of the chronostratigraphic position of the interval from bed 30 down to the top of the *dieneri* zone which is unrepresented in both the type-Aegean and -Bithynian. Another question concerns the varied placement of the substage within the Anisian stage by different workers. Introduced by Assereto (1974) as Lower Anisian, the substage should be used in that sense and not differently until an international agreement may decide otherwise.

High diversity characterizes the *Hollandites* zone and successive appearance of *Hollandites* species makes it open for future subdivision not attempted here. Other distinct members of the zone are *Acrochordiceras* of *hyatti* group, *Alanites Ismidites, Isculites* plus *Smithoceras, Pseudodanubites, Buddhaites* and *Ptychites* of the group of *impletus*. *Alanites costatus* from the base of the zone is a strong tie with the top of the *Hyatti* zone in Nevada (Bucher 1992). High general similarity in faunal composition may indicate a correlation of the upper *Hollandites* zone with the Nevada *taylori* zone of Bucher, 1988.

The beds 38 and 39, overlying the *Hollandites* zone are referred to the Pelsonian Substage on the basis of the occurrence of *Silesiacrochordiceras* and *Balatonites*. The two genera are accompanied by possible ancestors of *Paraceratites*, as well as by *Ptychites* of the group of *P. impletus*, *Beyrichites* and *Buddhaites*. Correlation of this interval is not fully solved in details, so that the levels 38 and 39 at the moment are informally separated as *Silesiacrochordiceras* beds.

The base of the Illyrian substage is well documented in level 40, one of the most rich in ammonoids of the Himalayan Muschelkalk Member. This level can be easy recognised in all the studied sections as it is almost full of ammonoids. The fauna is dominated by leiostraca ammonoids as *Ptychites*, *Discoptychites*, *Sturia*, gymnitids, and arcestids, but it includes also ceratitids as *Beyrichites* (very common) and *Paraceratites* and the noritids *Bosnites*. The attribution to the *Trinodosus* zone is proved by the occurrence of *Paraceratites* of the group of *P. trinodosus*.

Final decision on the Anisian-Ladinian boundary at the FA of *Protrachyceras* (according to a recent report by A. Baud) leads to a considerably enlarged upper Illyrian represented in Muth at least by beds 40C and 41A-C. They are dominated by leiostracean ammonoids (40C: ptychitids, 41: gymnitids) and beyrichitids with very a few ceratitids. Of the latter, *Kellnerites* is time-relevant for 40C, whereas *Reitziites* (41A or B) and *Halilucites* cf. *arietiformis* (41C) may indicate presence of *avisianum* and/or *secedensis* zone in 41 C.

Ladinian sediments correspond to beds 42 – 47 with a thickness of 1,2 m in Muth with increasing condensation of sequence towards the north (e.g. Lalung). The fauna is meagre, not well preserved and difficult to extract. Shells are often fragmentary except for the more common joannitids (*Istreites, Joannites*), *Proacestes,* and *Arpadites* in bed 44. Based on protrachyceratids with ceratitic (42 – 44) respectively ammonitic suture (45-47) a lower – Fassanian - is distinguished from an upper - Longobardian - interval. They are conventionally treated as *curionii* and *gredleri* zones though no index species have been found. A single well preserved *Protrachyceras* from bed 47 is close to *P. gredleri* (lectotype designated here for pl. 17 in Mojsisovics, 1882) except for the presence of a faint additional lateral row of nodes. The representation of the *gredleri* zone is underlined by the co-occurring conodonts *Budurovignathus japonicus* and *Paragondolella inclinata* in beds 45-47. Ammonoids of the *archelaus* zone have not been found in the Himalayan Muschelkalk Mb. and are expected to occur in the overlying Kaga Formation.

Upper Ladinian and Ladinian-Carnian boundary

The general chronostratigraphic classification of the Kaga and Chomule Formations was relatively well outlined by Diener (1908), who attributed the Daonella Shales (=Kaga Formation) and the Daonella Limestone (=lower part of Chomule Formation) to the Ladinian, while the overlying Halobia Limestone was referred to the Carnian. A similar subdivision was also suggested by Garzanti et al. (1995) on the basis of conodonts.

At the present after four expeditions specifically dedicated to this time interval, the detail of the bio- and chronostratigraphic subdivision is greatly improved.

In the Kaga Formation (Guling 1), fossils are extremely common in the lower half of the section, and consist of daonellinds and ammonoids (see fig. 6 in Bhargava et al, this volume). The upper part of the section, more shaly, is disturbed by cleavage, so that only fragments of daonellids can be found. This part is not tectonically disturbed at Lalung 3 (Lingti Valley).

In the studied sections the most common fossils are daonellids. *Daonella pichleri* is restricted to one thin interval in the lowermost part of the formation, while *Daonella lommeli* and *D. tyrolensis* show a much wider distribution. Some key ammonoids allow a chronostratigraphic calibration of the range of daonellids as well as correlations with other sections in the Tethys and North America.

The finding of *Meginoceras* (level VT24 at Guling 1), *Maclearnoceras* (level BL1 at Lalung 3), and *Frankites* (basal Chomule Fm.) document three ammonoid zones correlative with the Meginae, Maclearni and Sutherlandi

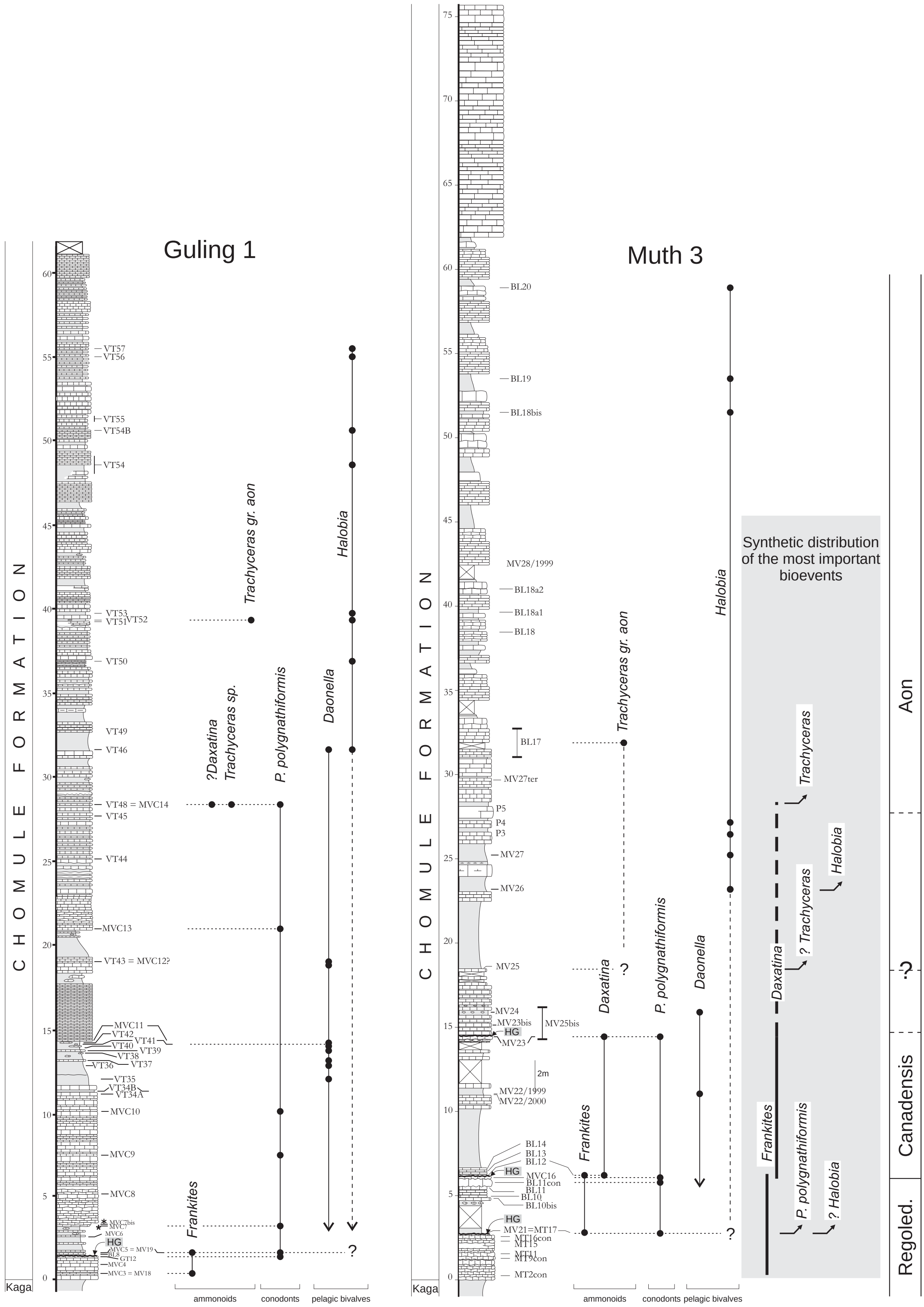

Figure 10: Distribution of the most important key taxa in the Ladinian-Carnian boundary interval at Guling 1 and Muth 3. In the grey area the synthetic distribution of the most important bioevents.

Zones of the Upper Ladinian of British Columbia.

The Ladinian-Carnian boundary interval falls in the lower half of the Chomule Formation (Fig. 9 and 10; see also fig. 7 in Bhargava et al., this volume).

At Guling 1 section (Fig. 10; see also fig. 7 in Bhargava et al., this volume), the lower part of the Chomule Formation is characterised by *Daonella lommeli*, with isolated occurrence of *D. tyrolensis*. *Daonella* is for sure replaced by *Halobia* from level VT46 upward (*H. fascigera*, *H. zitteli*), but there is a doubtful occurrence of *Halobia* already at the top of the "Traumatocrinus Limestone". A very similar picture comes out also from Muth 3 section (Fig. 9).

The ammonoid record is more complete at Muth 3 than at Guling 1 (Fig. 9 and 10). As already pointed out, the "Traumatocrinus Limestone" is fossiliferous, but ammonoids are difficult to extract. At Guling 1 *Frankites* has been collected in level GT2-3. In both Guling 1 and Muth 3 a rich ammonoid fauna is documented in the hardground at the top of the "Traumatocrinus Limestone". This fauna is dominated by *Sirenotrachyceras* over *Frankites*, *Protrachyceras* and leiostraca ammonoids. The last occurrence of *Frankites* is recorded in the hardground on top of level BL12, together with *Daxatina*, *Sirenotrachyceras* and *Rimkinites*. The stratigraphic position of the last occurrence of *Daxatina* with respect to the first occurrence of *Trachyceras* is not easy to solve, because a) there are relatively few fossil bearing levels, and b) ammonoids are often crushed and/or preserved with test. At Muth 3 *Daxatina* is common in level MV23, while the first sure *Trachyceras* occurs higher up in sample BL17 (Fig. 9). In between crushed specimens with doubtful attribution have been found in level MV25.

At Guling 1 a small and incomplete specimen with a ceratitic suture (?*Daxatina*) has been found in level VT48, together with *Trachyceras* (Fig. 10).

The conodont fauna of the lower portion of the Chomule Formation is very similar at Guling 1 and Muth 3. It is mostly represented by the genus *Paragondolella* (*P. foliata*, *P. inclinata*, *P. polygnathiformis*, *P. auriformis* and *P. tadpole*), few specimens of *Budurovignathus mungoensis* are still present after the first appearance of *P. polygnathiformis* (Fig. 10).

At the present, the Carnian Stage has not yet been formally defined by a GSSP. One specific Working Group of the Subcommission on Triassic Stratigraphy is dealing with the problem and one proposal has been already presented by Broglio Loriga et al., (1999). The discussion is in progress and several possible criteria are under consideration.

Taking into account the ammonoids, the possible marker events are the a) the first appearance of *Trachyceras aon* (traditional boundary in the Tethys: see Krystyn, 1978); b) the first appearance of the genus *Trachyceras* (traditional boundary in North America: see Silberling and Tozer, 1968); c) the first appeareance of *Daxatina* cf. *canadensis* (Broglio Loriga et al., 1999). Considering conodonts, the first appeareance of the species *Paragondolella polygnathiformis* seems to be the only marker for the base of the Carnian Stage.

The contribution of the Spiti succession to the discussion on the Ladinain/Carnian boundary is represented by the co-occurrence of ammonoids, conodonts and pelagic bivalves in the same sections. The distribution of conodonts and pelagic bivalves seems to be very constant in the studied sections. The first occurrence of *P. polygnathiformis* is recorded at the top of the "Traumatocrinus Limestone" (level GT12 at Guling 1 and MV21 at Muth 3) in the middle of the range of the genus *Frankites*. There is an overlap of *Daonella* and *Halobia*. The last occurrence of *Daonella* is above the first occurrence of *Trachyceras*. *Halobia* is for sure recorded in the possible overlapping of *Daxatina* and *Trachyceras*, but the first occurrence of *Halobia* could be much more older and coeval with the first occurrence of *P. polygnathiformis*.

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From: Salvador, A. (ed.), 1994. International Stratigraphic Guide. Second Edition. International Commission on Stratigraphic Classification of IUGS International Commission on Stratigraphy. IUGS/GSA, Boulder, Co, p. 66.

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