Scientific Reports

A candidate GSSP for the base of the Olenekian Stage: Mud at Pin Valley; district Lahul & Spiti, Himachal Pradesh (Western Himalaya), India.

L. Krystyn[1], O. N. Bhargava[2] and S. Richoz[1]

[1] Department of Palaeontology – Geozentrum, A-1090 Wien, Althanstrasse 14,

leopold.krystyn@univie.ac.at

[2] 103, Sector 7, Panchkula 134109, Haryana, India.

Abstract The M04 section near Mud (Spiti, India: N 31°57’55.5 / E 78°01’28.5) is proposed as candidate GSSP for the base of the Olenekian stage. The boundary interval is within the second or Limestone and Shale Member of the Mikin Formation, slightly above the base of the *Flemingites* Beds, which constitute the middle part of this member. Following the recommendation of the Subcommission on the Triassic Stratigraphy, the boundary is drawn 60cm above the base of *Flemingites* Beds corresponding to the FAD of the conodont *Ns. waageni* s.l. in sub-bed 13A. The worldwide found *Ns. waageni* group allows an intercontinental Tethyan-Panthalassan and a trans-provincial correlation of the boundary between low and high palaeolatitudes. Additional boundary events are (i) the FAD of the ammonoid *Rohillites rohilla* appearing also in 13A closely associated with other typical Olenekian genera (*Kashmirites, Beoflemingites, Pseudaspidites, Pseudohedenstroemia*), and (ii) a characteristic inflexion point respectively positive peak in the δ^{13}C-curve of sub-beds 13A/B described earlier from many Induan-Olenekian boundary (IOB) sequences. The event is also characterized by an explosive radiation in conodonts with nearly concurrent appearance of several genera (*Eurygnathodus, Discretella*) and species. A second conodont event, 90 cm above the proposed boundary point in bed 15, correlates to the FAD of *N. spitiensis* and to that of the ammonoid *Euflemingites* whose pandemic occurrence provides another worldwide recognizable datum.

The section is excellently exposed and since it is located in a National Park, its long-time preservation is assured. Fossils are abundant and well preserved at the boundary. Despite half the rate of sedimentation as compared to that of the other candidate GSSP in Westpingdingshan, Chaohu (China) – the Mud sequence shows no signs of breaks or condensation and maintains a uniform lithofacies across the boundary level. Apart a regional remagnetisation, preventing a meaningful magnetostratigraphy, the Mud section full-fills all other requirements necessary for a global stratigraphic section and point selection.

Introduction

The marine Palaeozoic and the Mesozoic sequences in the Indian Plate are mainly preserved in the inner part of the Higher Himalaya and in literature have been referred to as the Tethyan sequences which often rest with a tectonically decoupled contact over the crystalline rock. These successions are well exposed in the Western (Kashmir, Zanskar- Spiti and Uttrakhand) and the Central (Nepal) Himalaya (Fig. 1). Due to rich fossil contents the Tethyan sequences of Kashmir, Spiti and Kumaon (Uttrakhand) have been investigated since 19th century (e.g. Stoliczka, 1864). Amongst all the Palaeozoic and Mesozoic sequences, the Triassic is most complete and extensively developed. It rests over the Permian Gungri Formation with minor break where a part of Dorashmian is missing. During the Triassic time, this Himalayan zone had formed a part of the tropical Gondwana margin, hence often described as Peri-Gondwana Tethyan succession (Matsuda, 1985). The original mid-low latitude provided a large and mixed pelagic faunal diversity and a high carbonate precipitation rate favoured an exceptional fossil preservation potential. Of all the areas mentioned above, the Triassic succession (Lilang Supergroup, redesigned by Bhargava et al., 2004), particularly the Lower Triassic (Mikin Formation) of the Spiti Valley is one of the best in the world with a well-known, classically monographed ammonoid fauna by Diener (1897) and Krafft & Diener (1909).

The Spiti Valley forms part of the district of Lahul & Spiti (Fig. 2) located in the northern part of the Himachal Pradesh, which occupies a central position in the Western Himalaya. Mud Village is situated in the Pin Valley, which is an important tributary of the Spiti River. This area is open to persons of all nationality and is becoming an important tourist place due to the Pin Valley being developed as a National Park for high altitude wild life. Spiti can be approached from (i) Shimla via National Highway 22, following the Sutlej River up to Khab and then the road is along the Spiti River up to Attargoo and (ii) from Manali (on NH 21) via Rohtang and Kunzam Passes, first following the Chandra river and then the Spiti river up to Attargoo, beyond which the road is along the Pin River (Fig. 2). The total journey from Delhi to Mud with prior arrangements can be accomplished in

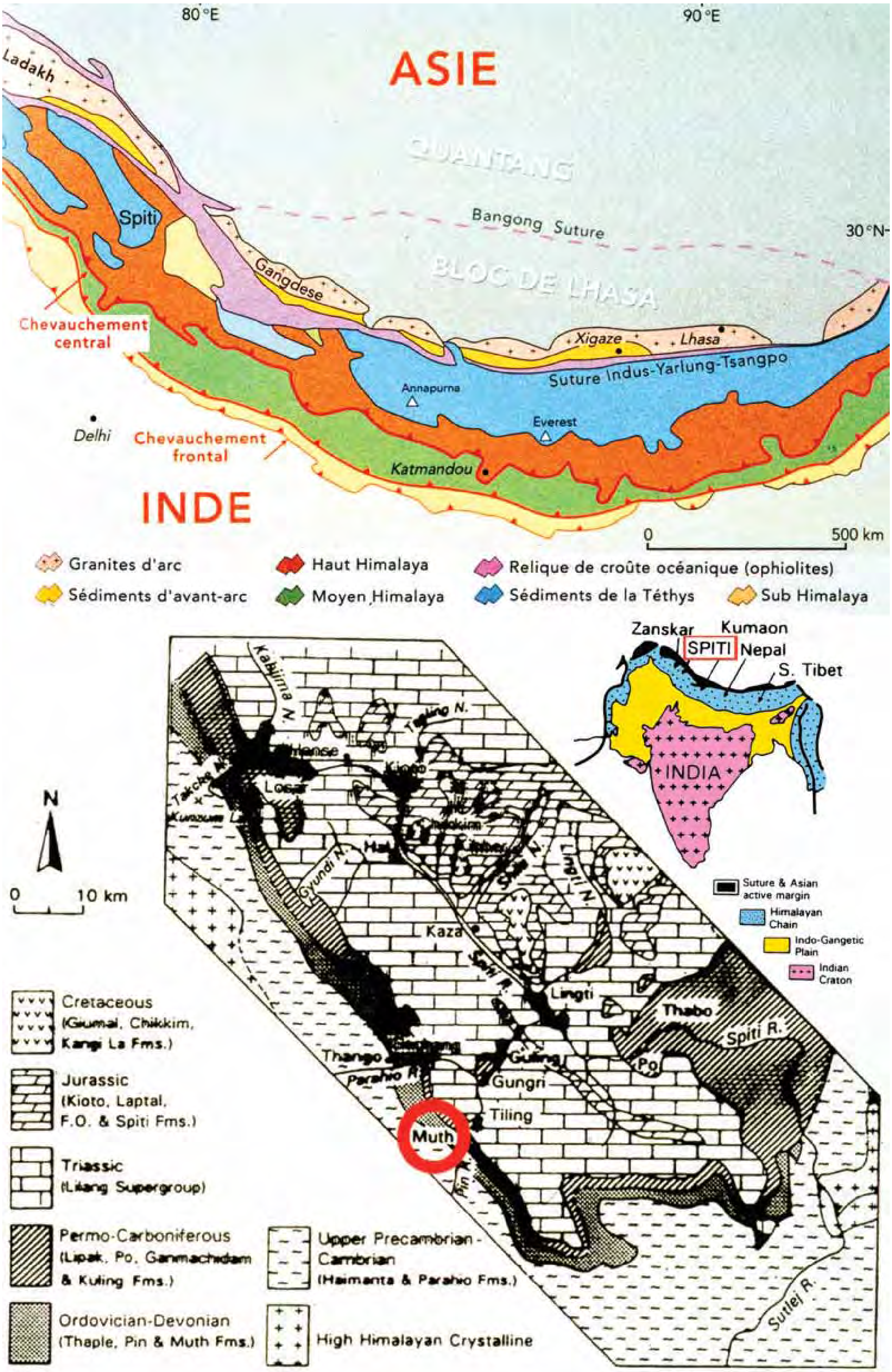

Fig. 1. Tectonic outline of the Himalayas and geological map of Spiti (after Garzanti et al., 1995) with location of Mud (Muth).

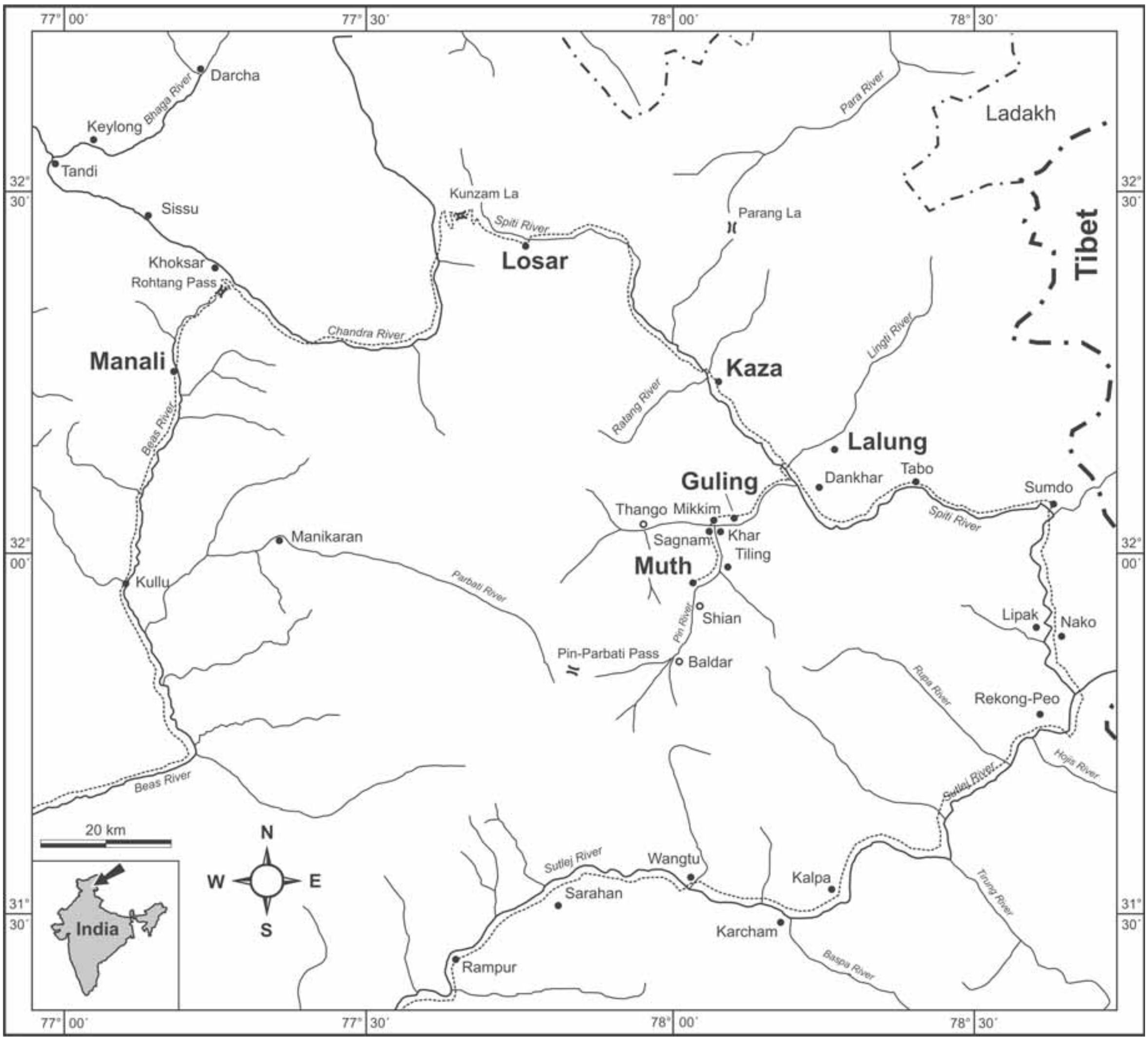

Fig. 2. Topographic map of Spiti and Lahul with location of Mud and other main Lower Triassic sites (after Draganits et al., 2004).

three days. Alternatively, during fair weather, one could take a flight from Delhi to Kullu and reach Mud the same day or at best the next day. Guling is also situated in the Pin Valley and is about 18km from the Attargoo bridge. Lalung in the Lingti Valley is about 15 km from Attargoo along a branch road to the North.

June to September is ideal period for a visit, which can also be carried out during the month of October, provided there is no early snowfall. The snowfall normally commences in the month of November and the area remains snow bound till April. Board and lodging facilities are available at Mud and Guling, the more adventurous can pitch tents, which either can be carried or hired from several travel agencies located at Manali and Shimla. At Lalung board and lodging facilities can be availed of at the local gompha (monastery).

Geographic and geologic setting

The Mud (old spelling Muth) section in the Spiti Valley provides excellent exposures of nearly the complete Triassic within the northern, flat to moderately steep towards northeast dipping limb of an anticline (Fig. 3). Lower Triassic rocks are represented by the Mikin Formation, which is divisible in three members from bottom to top i) the Lower Limestone Mb., ii) the Limestone and Shale Mb. and the iii) the Niti Limestone Mb. (Fig. 4; 6). Of relevance to the IOB is the second member with its three subdivisions: *Gyronites* Beds (3,5m) of Dienerian, *Flemingites* Beds (2m) of topmost Dienerian to basal Smithian and *Parahedenstroemia* Beds (app. 10m) of Smithian age (Fig. 4).

The most remarkable faunal change, both in ammonoids and conodonts, is found in the basal *Flemingites* Beds, which are rich in extractable ammonoids and enclose abundant conodont fauna, and their integrated biostratigraphy provides an excellent control on IOB. The beds form continuous exposures on the northern valley slope at Mud and afford ample scope of measurement and sampling of the entire sequence at several places, viz. M03 (close to Mud Village) and between M04 and M06 at 3900m and 4100m (Fig. 5). All the sections are reachable through normal walking (without climbing), the most distant place is M05 (Fig. 6) at an altitude of 4100m and a one and half hour walk from Mud (3750m). Section M04 (Fig. 7) is located below at an altitude of about

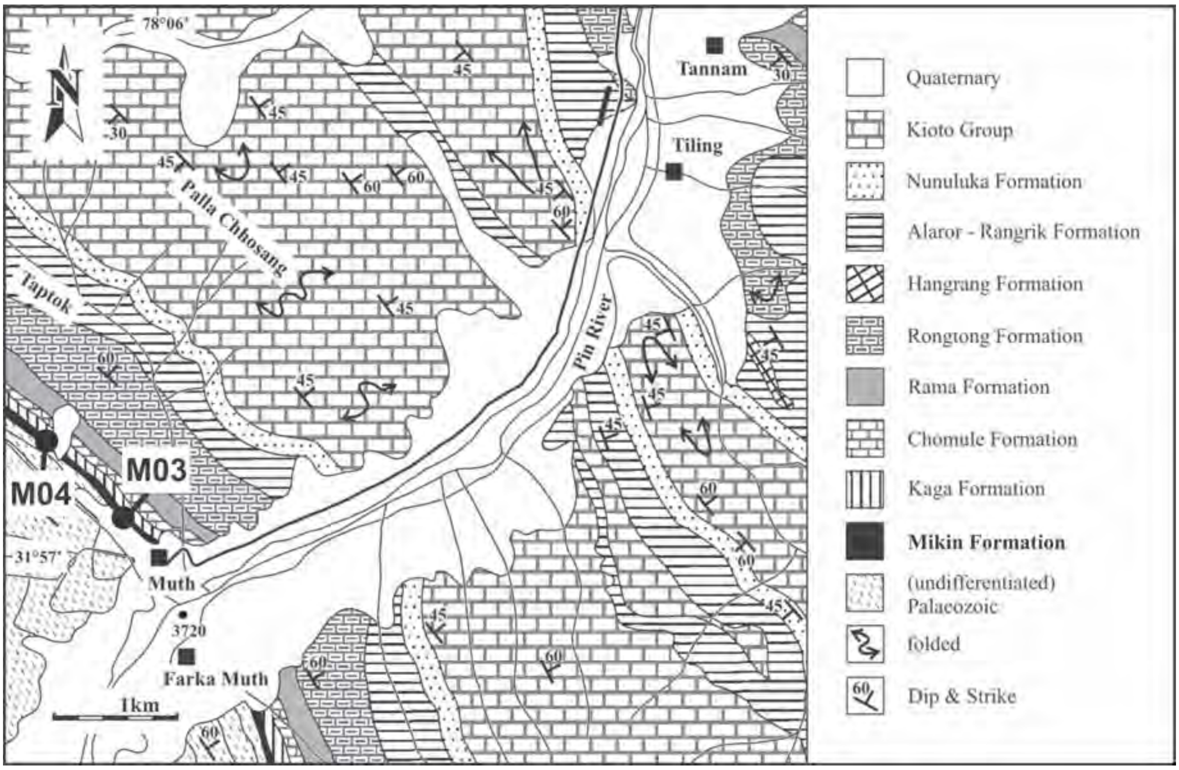

Fig. 3. Geology of Mud with position of sections M03 and M04 (proposed candidate GSSP) in the Mikin Formation.

4000m, to the west of an old rock fall (Fig. 3) and is reachable from Mud within an hour. East of the rock fall follows the locality M06 and, just 100m above Mud village lies the section M03 (Fig. 3; 7). Though the last locality is within a walking distance of less than 30 minutes, and thus the easiest to access, it is poor in ammonoid record within the critical boundary interval (Table 1). As the section M04 (coordinates N 31°57'55.5 / E 78°01'28.5) contains the richest macrofauna and a complete succession of all zonal markers resp. boundary-relevant ammonoid species, it is explicitly selected as the candidate GSSP (Fig. 8). Of the 400 specifically determinable ammonoids, 60% have been collected in M04, 25% in M06, 10% in M05 and only 5% in M03.

The outcrops between M04 and M05 are extensively weathered and offer ideal setup for collection of macrofossils from each bed. The added advantage in this section is that each bed can be traced for several kilometers with high level of confidence due to comparable lithology (Fig. 9) and excellent fossil control. This allows a range chart presentation within one composite section (Fig. 10) complemented, of course, by individual ammonoid (Table 1) and conodont faunal details (Orchard and Krystyn, this volume). A comprehensive geological description of the Mud site is to be found in Krystyn et al., (2004) and additional outcrop photos can be made available on request.

The other good Lower Triassic sections are at Guling in the Pin Valley itself and another at Lalung in the Lingti Valley, a northern tributary of the Spiti River (Fig. 2). At the later locality the Mikin Formation is exposed on a dip slope that affords excellent condition for sampling. Garzanti et al., (1995) restudied Triassic rocks of Spiti, and Bhargava and Bassi (1998) have published a more recent geological monograph on Spiti.

Faunal content

According to the basinal depositional setting ammonoids and conodonts are dominating and only associated with some rare or indeterminate pteriod bivalves. Ammonoids are very common in bed 10, almost missing in bed 11 and not so rare in the boundary-near bed 12. The latter bed is, however, too compact and difficult to break thereby reducing the fossil extractability. A rich and very well preserved fauna occurs in beds 13 and 14 with large-sized and undeformed specimens. The fauna of these two beds forms a major part of the monographs of Diener (1907) and Krafft and Diener (1909). The preservation of the fauna is not so good in beds 15 and 16 but it is smaller-sized or fragmented and sometimes distorted, and the ammonoids are less well extractable. The newly collected material is listed in Table 1 and figured in plates 1-4.

Conodonts are prolific, well preserved and diverse from bed 13 upwards. Specimens from below (bed 13) though still common, are more fragmented and often diagenetically overgrown. The faunal composition is of basinal type as demonstrated by the *Neospathodus* dominance and comparably underrepresented ramiforms. Age relevant taxa are described and documented in Orchard and Krystyn (this volume).

Biostratigraphy

The Lower Triassic fossils of Mud have been studied for

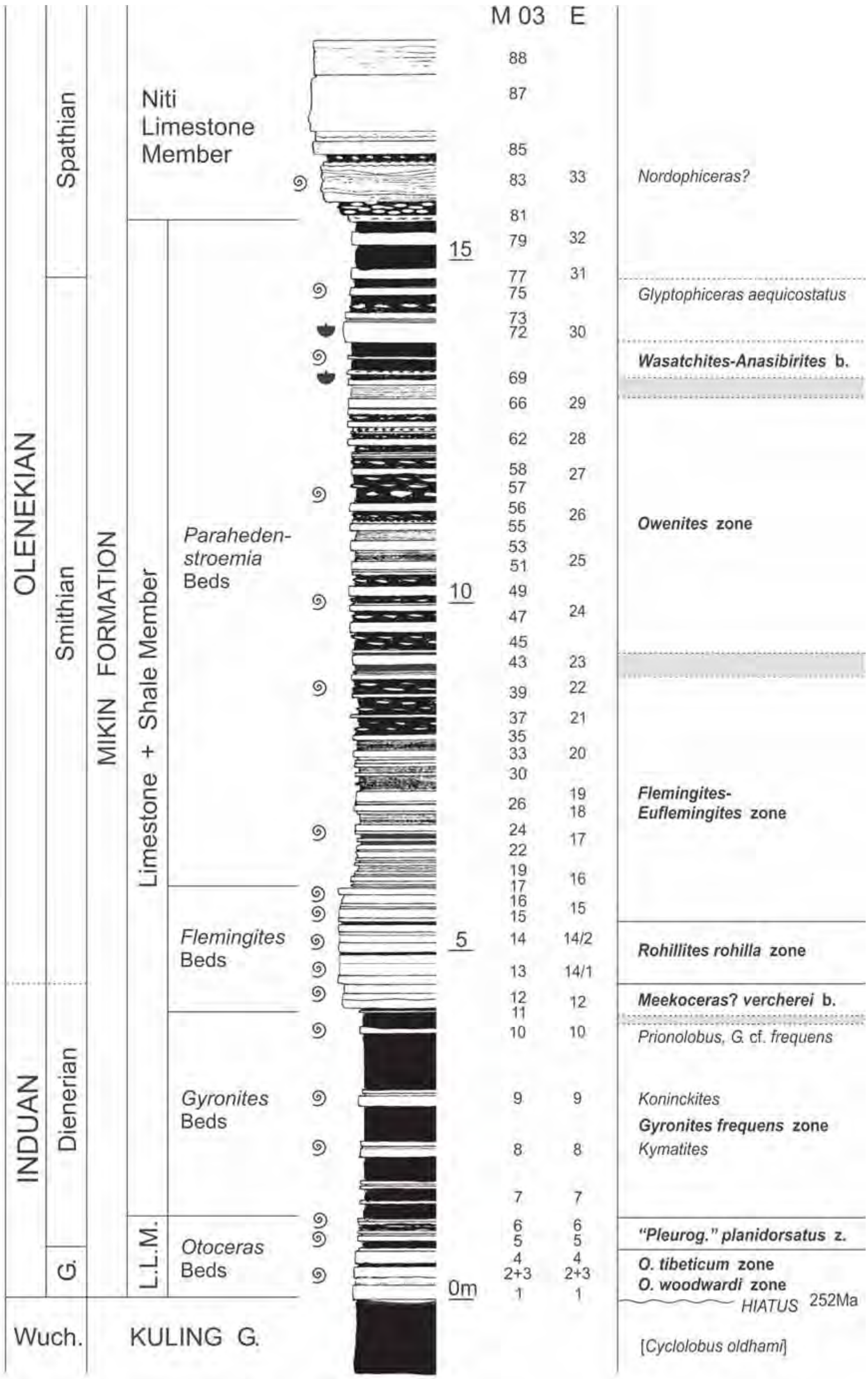

Fig. 4. Lower Triassic (Induan, Olenekian) stratigraphic column and ammonoid zones for Mud.

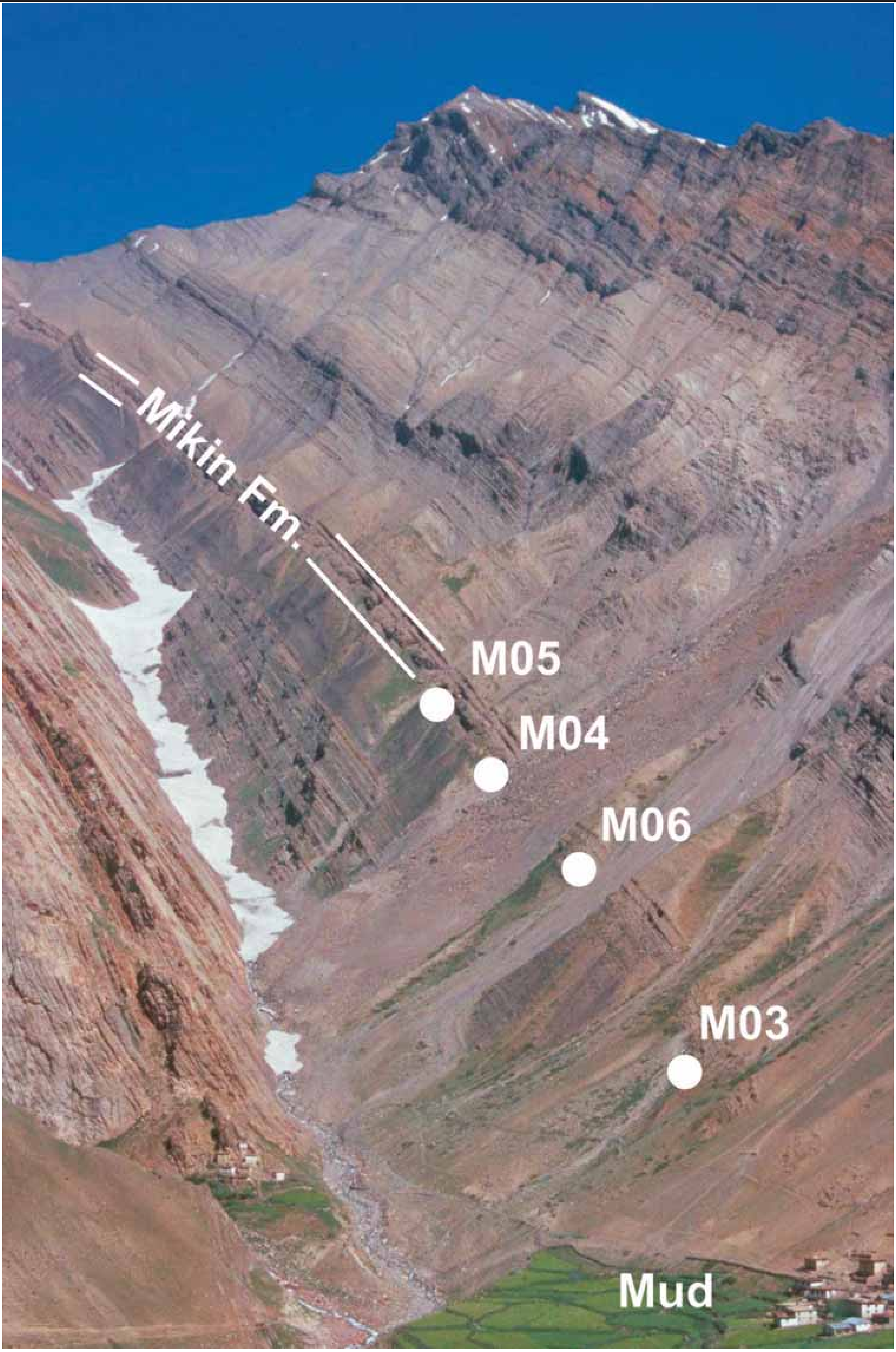

Fig. 5. Views of Mud and the western Pin valley flank with location of IOB sections M03 till M06.

Fig. 6. Overview of section M05 with subdivisions of the Mikin Formation.

more than a century, but key investigations are rare and centered on the ammonoid monographs of Diener (1897) and Krafft & Diener (1909), the shelly fauna study of Bittner (1899) and a recent conodont investigation by Bhatt et al. (2004). Krystyn and Orchard (1996) and Krystyn et al. (2005, 2006) presented detailed summaries including new biostratigraphic data.

Ammonoids

The *Flemingites* Beds (Fig. 10) constitute a monofacial succession (of) in the lower part, approximately 1dm-, and in the upper third c. 5 cm-bedded, dark grey limestones. Fifteen layers, numbered as 12A to 12C, 13A to C, 14A to C, 15A to C and 16A to C record a sequence of three ammonoid zones. From the base to the top these are (thicknesses according to M04):

1) *Meekophiceras*? *vercherei* beds (0,6 m – beds 11 to 12C);
2) *Rohillites rohilla* Zone (0,9 m – beds 13A to 14C);
3) *Flemingites* – *Euflemingites* Zone (0,4m – bed 15A to 16C + 3,6m of *Parahedenstroemia* Beds).

Meekophiceras? *vercherei* Beds

They contain a relatively poor fauna and have not been sampled extensively. Besides the index, *Proptychites* and *Koninckites* also, both of typical Induan affinity, are present. *Meekophiceras*? *vercherei* (Waagen) was originally assigned to *Koninckites* with which it differs by tabulate cross-section and strong terminal umbilical egression. *Meekophiceras* Tozer, 1994 is more similar but shows a less eggressive and externally rounded adult whorl.

Rohillites rohilla Zone

Named for the first time by Krafft around 1900 and later discussed in more detail by Krafft and Diener (1909), this zone includes beds 13 and 14. It is defined at the base (13A) by the FA of the genus *Rohillites* and the presence of Induan holdovers (*Prionolobus*, *Proptychites*). *Rohillites* has a general gyronitid morphology with faint strigate ornamentation and a tendency to increasing costulation through time. The oldest representative *Rohillites* n. sp. 1 is seen with evolute, very week strigate and narrowly tabulate whorls found in 13A, whereas *Rohillites rohilla* occurring from 13A to 13C is less evolute, variably smoothly to coarsely ribbed, externally again it has narrow tabulate whorls. It is replaced in 14A by *Rohillites* n. sp. 2 with closer spaced but still broad ribs, a fat tabulate venter and a distinct umbilical shoulder that is missing in the stratigraphically older species. The new species seems to have a close and most probably time-correlative counterpart in *Rohillites* sp.

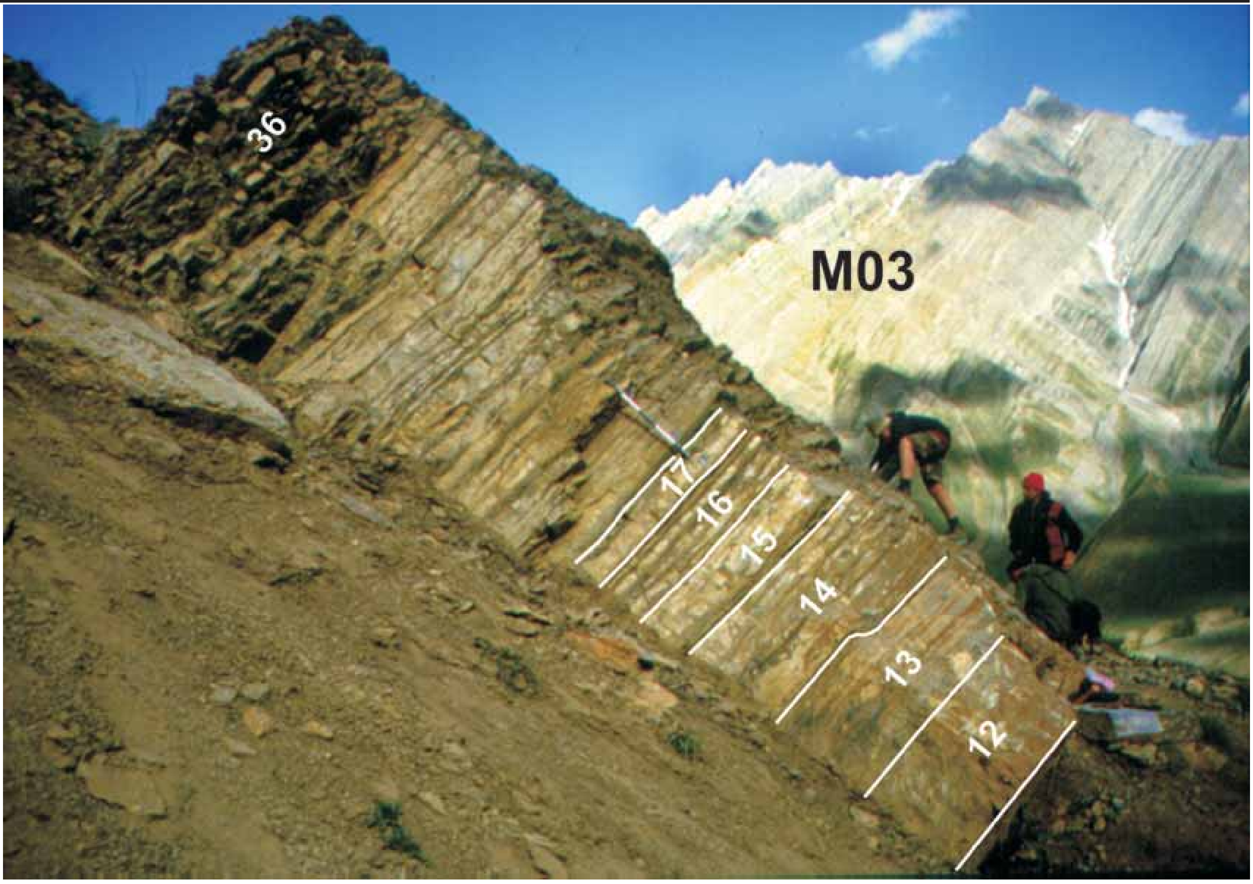

Fig. 7. Photo of section M03 showing bed sequence 12 to 40 (*M.*? *vercherei* beds to *Flemingites-Euflemingites* zone).

indet. in the upper "*Kashmirites kapila* beds" of north-western Guangxi, China (Brayard & Bucher, in press).

Successive appearances of other flemingitids allow a discrete subdivision of the *rohilla* Zone by the FA of *Beoflemingites griesbachi* (Krafft) in 13B and *Beoflemingites mandhata* (Diener) in 14B. The genus *Beoflemingites* has been established by Waterhouse (1996) for *Flemingites trilobatus* Waagen, 1895 and is distinguished from *Flemingites* s. str. by a stronger incised suture line and, in the Himalayan species by slender balloon-like saddles. Other common *rohilla* Zone species are *Kashmirites kapila* (Diener) and *K. nivalis* (Diener) first reported in 13B, and ranging slightly above the top of the zone (15C). Of further importance could be the FA of the hedenstroemiid *Pseudohedenstroemia himalayica* (Spath) in 13B and that of *Pseudaspidites muthianus* (Krafft) in 13A.

The *rohilla* Zone contains a rather rich fauna dominated by flemingitids (40-60%) and *Kashmirites* (30-40%). Compared to the underlying *Meekophiceras*? *vercherei* beds the fauna is highly diverse and marked by an explosive radiation in the ammonoids. Of the represented 10 genera at least five are definitely new, only two are true holdovers and three are indefinite (*Parakymatites*, "*Koninckites*", "*Meekoceras*" *pulchrum*). Ammonoids of bed 13 show by far the best preservation within the *Flemingites* beds by protecting the shell and the original body form.

Flemingites – Euflemingites Zone

Including only beds 15 and 16, the *Flemingites* Beds contain a very minor part (10%) of this zone; its major part is confined to the lower *Parahedenstroemia* beds (Fig. 4; 11). The FAD of the genera *Flemingites* and *Euflemingites*, a first order bioevent of obvious world-wide correlatability, marks bed 15. *Flemingites* disappears soon above bed 16 for unknown reasons; of 11 specimens from beds 15 and 16 some are close to *F. compressus* Waagen, 1895 with respect to style of ribbing and the whorl proportions (i.e. height and degree of involution). Specimens of *Euflemingites* are still more rare (two each in bed 15 resp. 16), fragmentary and distorted but the preserved strigate rib-less ornamentation allows at least a generic identification. Of importance is a specimen of *Euflemingites guyerdeti* documented in Diener (1897, pl. 1, Fig. 7) from Mud, housed in the collections of the Geological Survey of India (GSI 5293) in Kolkata (old spelling Calcutta). Waterhouse (1996) has created a new genus (*Colchenoceras*) for this species, which seems untenable. *Euflemingites guyerdeti* has been recorded by Diener (1897, p. 99) as belonging to a "dark semicristalline limestone containing *Nannites herberti* and *N. hindustanus* from the *Otoceras* beds". The two "*Nannites*" are now referable to the genus *Juvenites*, which has a massive occurrence in a thin dark gray tempestitic packstone layer numbered as bed 23 of the Mud sequence, thus *E. guyerdeti* is relocated to this level about one meter above the base of this zone (Fig. 11).

Additional genera appearing in bed 15 are *Anaxenaspis*,

Fig. 8. Photo of the candidate GSSP (section M04) with beds numbers.

Waagenoproptychites and *Parahedenstroemia* with the species *P. acuta* (Krafft). Holdovers in bed 15 from the underlying zone are *Beoflemingites mandhata*, *Pseudohedenstroemia himalayica* (Spath) and *Pseudaspidites muthianus* (Krafft). *Kashmirites* ranges up from the *rohilla* Zone and is common in beds 15 and 16 with newly appearing zones forms (Kashmirites sp. 1 and Kashmirites cd. borealis Tozer). Bed 16 shows the FA of *Juvenites* and *Dieneroceras*? followed by the entry of additional genera (*Prejuvenites*, *Paranannites*, *Paranorites*, *Nilgiria*) slightly higher, within one meter of thickness (Fig. 11).

The base of the *Flemingites – Euflemingites* Zone recalls a second strong turnover in the ammonoid fauna with six newly appearing and four holdover genera, followed closely by another four new genera., many of them worldwide known in lower to middle palaeolatitude southeastern Tethys, China, US, Canada). Most of the collected material (75%) comes from the section M04 and is dominated by the genus *Kashmirites* (>50%) with orthoceratids being further common. Stratigraphically relevant taxa are rare comparably rare but collections could be easily enlarged with additional sampling.

Conodonts

Details on the conodont succession of Mud can be found in Orchard and Krystyn (this volume). Results of the study are here summarized as follows:

1) Three intervals have been discriminated corresponding to the above-described ammonoid zones (Fig. 10):

Zone 1 (Beds 11–12 = *M.*? *vercherei* B.) shows a typical Induan fauna dominated by *Ns. dieneri*, *Ns. cristagalli*, *Ns. pakistanensis*, and *Bo. nepalensis*, with uncommon *Ns. chii* and *Ns. concavus* restricted to the interval.

Zone 2 (Beds 13–14 = *Rohillites rohilla* Zone) contains *Ns. posterolongatus*, *Ns*. ex gr. *waageni* (FAD in 13A) and *D. dicreta*, and by this a traditional Olenekian fauna initially associated with species of the underlying bed.

Zone 3 (Beds 15–16 = basal *Flemingites–Euflemingites* Zone) is marked by the entry of *Ns. spitiensis*, which occurs in association with *Ns. waageni* and *D. dicreta*.

2) The conodont sequence is directly correlatable with West Pingdingshan (Chaohu, South China), the other proposed candidate GSSP for the IOB. Compared with Chaohu, Zone 1 of Mud can be broadly correlated with the upper part of the *dieneri* Zone. Zone 2, based on the FAD of *Ns. waageni* s.l. can be recognized in both areas: in West Pingdingshan, it falls in the top-part of Bed 24 compared with a position close to the base of the *Rohillites* Zone in Mud. A further difference about these levels is the order of appearance of *Ns. waageni* morphotypes 2 and 3. In West Pingdingshan, the appearance of *Ns. w. eowaageni* (~morphotype 3) is slightly earlier (in bed 24 top) than *Ns. w. waageni* (~morphotype 2, bed 25 base), whereas the two forms appear either concurrently or in reverse order at Mud. The base of Zone 3, identified by the FAD of *Ns. spitiensis*, begins in bed 15 in Mud and

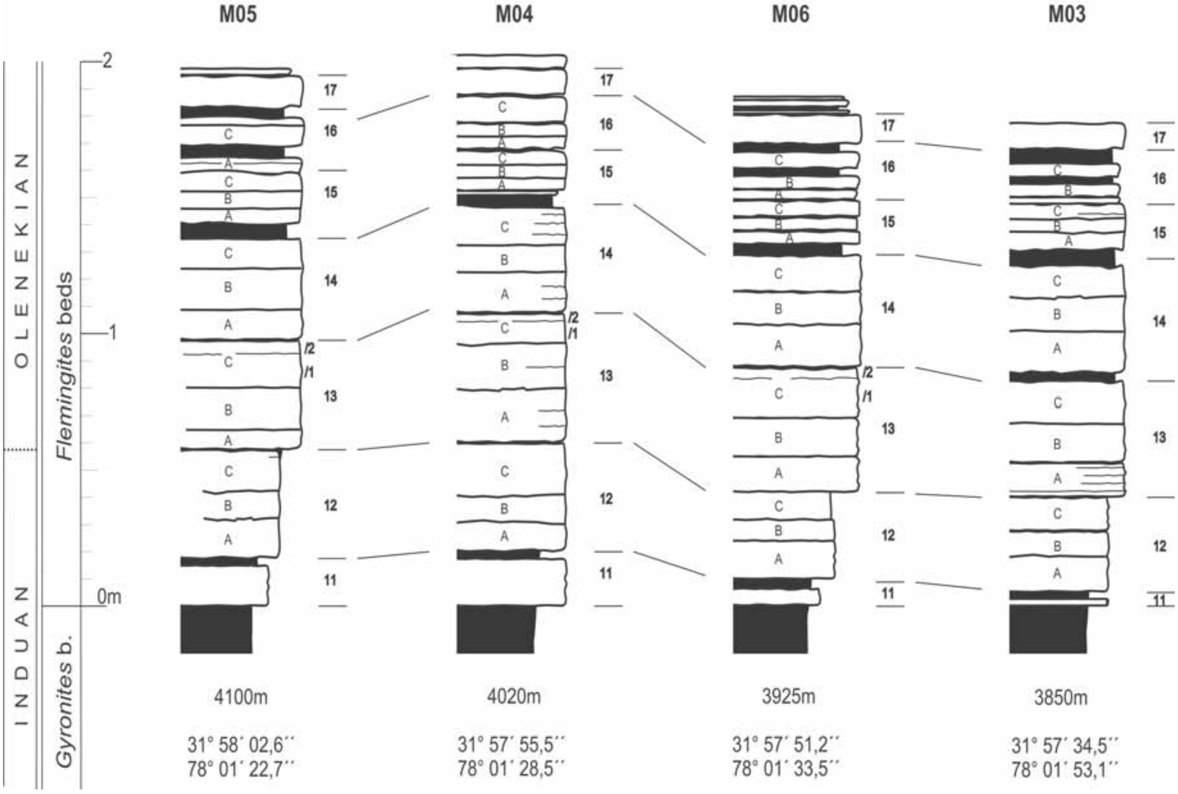

Fig. 9. Lithostratigraphic correlation and location of the sections M03 to M06 (M04 = candidate GSSP).

in bed 26 in the West Pingdingshan section. In both cases it corresponds to the *Flemingites – Euflemingites* Zone.

3) The highly diverse conodont fauna contains elements (*Ns. pakistanensis*, *Bo. nepalensis*) of specific importance for long-distance correlations within the Tethys as well as with the Panthalassa and Boreal realm, which are either rare or missing in Chaohu.

Depositional Setting

The Induan-Olenekian boundary beds of Mud (and Spiti respectively) show a gradual change in the sedimentary environment from black laminated pyrite-rich an- or disoxic shales (below bed 10) to dark gray, brownish weathering lime mudstones (beds 10 – 12) with rare thin ammonoid shell concentrations followed up-section by gray well oxygenated and bioturbated bioclastic wackestones rich in fragments or complete specimens of large ammonoids (beds 13-16). The consistent pure mud-dominated sediment indicates deposition in calm water below active wave base. Current-indicative layers occur only in bed 12C within two 1-2 cm thin and discontinuous shelly packstones, and as a single ripple-bedded packstone layer in 14B. Shelly-rich, thin pack- to grainstone intercalations get common and thicker within the overlying *Parahedenstroemia* beds (bed 22 and above). Sharp erosive base, dense grain-supported accumulation of predominantly fragmented small ammonoid shells (mean diameter below 5 cm) or lumachelles of parallel-aligned thin-shelled bivalves are interpreted as tempestitic layers. Their higher frequency can be explained either by a sea level drop or an increase of storm activity and of bottom water currents. A distinction between the two alternatives would be important but seems presently not possible. At least a primary basin depth close to storm weather base (i.e. 50-70 m) is most logical. The pelagic fossils such as ammonoids, specific bivalves and conodonts are found both in fine-grained carbonates (mudstone, wackestone,) as well in tempestites (filamentous pack- to grainstone).

The Himalayan Lower Triassic thus formed part of a large deeper-neritic basin and the Spiti sediments were deposited on wide stable shelf to provide extensive continuity to the beds. This not only affords ideal setup for delineation and improvement of the IOB but also for a long-distance correlation of the discriminated ammonoid zones along the southeastern Gondwana margin.

Carbon isotope stratigraphy and magnetostratigraphy

Richoz et al.(this volume) have published a detailed account of δ^{13}C-curve of Mud. Because of a relatively high thermal overprint (CAI~5) during the Himalayan orogeny, rocks in Spiti might have suffered a certain degree of diagenetic alteration that could have influenced the isotopic signature. Thin section, carbonate content and C- versus O-isotopes cross-plot studies have, however, shown that the limestones have not been affected enough by diagenesis for any significant alteration of the C-isotope signature (Richoz et al., this volume). To get a reliable isotope profile more than 60 samples have been measured within a 3m interval around the IOB with repeated runs for the 20 sampled beds.

The δ^{13}C-curve (Fig. 13) fluctuates in the top-*Gyronites*

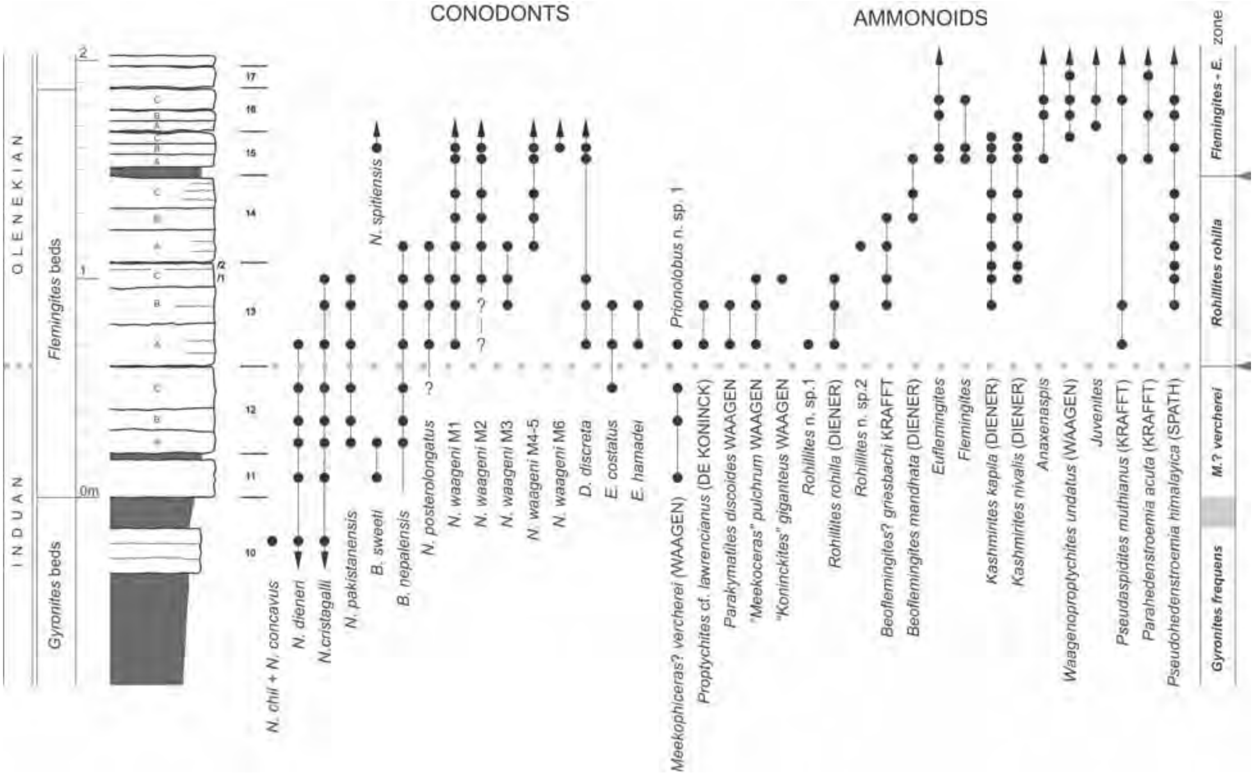

Fig. 10. Vertical range and zonation of conodonts and ammonoids in the IOB beds in Muth. Arrows mark the two boundary options of which the lower (bed 13A) is preferred.

Beds (11-12) around -1‰, followed by a sharp positive excursion of 1‰ leading to a prominent peak close to 0‰ in 13A and 13B. Bed 13C records a quick return to more negative values of below -1‰. Within bed 14 occur only minor variations till a second negative shift in 15A leads to a minimum around –2.5‰. The signal recovers slightly to –1.7‰ during bed 16 to return again to - 2‰ in bed 17.

To summarize, the Mud curve is characterized by a well-marked singular inflexion point in connection with a relatively small positive excursion (of 1‰) in the basal *rohilla* Zone (from 13A to 13B). This positive excursion seems to reflect a distinct, widespread and short-termed event known from many Tethyan sections around the Induan-Olenekian boundary with usually much larger amplitude of 4-6‰. Correlation of this excellent marker event to West Pingdingshan is problematic since a strongly deviating curve with an unusual flat and long-lasting C-isotope plateau between the *dieneri* and the *spitiensis* conodont Zones replaces the short peak developed elsewhere (Richoz et al., this volume).

Due to common thermal overprint during the Himalayan orogeny it can be assumed that the original palaeomagnetic signature in the Mikin Formation has been erased and has received a Tertiary remagnetisation.

Correlation

Induan-Olenekian boundary options

The Mud data are crucial to delineate two potential boundary levels indicated by arrows in Fig. 10:

1) *Base of Bed 13*: the FAD of R*ohillites rohilla* in bed 13A marks the entry of flemingitids or typical Olenekian (Smithian) ammonoids. The nearly contemporaneous appearance of kashmiritids and of *P. himalayica* strengthens the event as the latter may indicate close synchronicity (?) with the appearance of *Hedenstroemia* in the Boreal. According to Orchard and Krystyn (this volume) the same event corresponds to the strongest change in the conodonts with the FAD of *Ns. waageni* and other typical Smithian fauna, allowing long distance correlations to both basinal (by *Ns. waageni*, *Discretella*) and platform environments (by *Eurygnathodus*). The presence of *Bo.* (=*Ch.*) *nepalensis* further facilitates cross-correlation with the Boreal. Following the data of Richoz et al. (this volume) a characteristic turning point in the C-isotopes in bed 13 is another advantage of and point for this boundary. The strongest argument for option 1 stems from the decision of the STS to prefer the FAD of *Ns. waageni* s.l. as defining bio-event and this recommendation is followed here too.

2) *Base of Beds 15*: the FOs of *Flemingites* and *Euflemingites* in bed 15A correspond to a second ammonoid radiation phase with intercontinental correlation potential from the Tethys to Panthalassa (North America) and to the Boreal. Conodonts and C-isotopes are, however, less indicative for boundary option 2.

Regional correlation

The co-occurrence of well preserved diverse and biostratigraphically diagnostic ammonoid and conodont

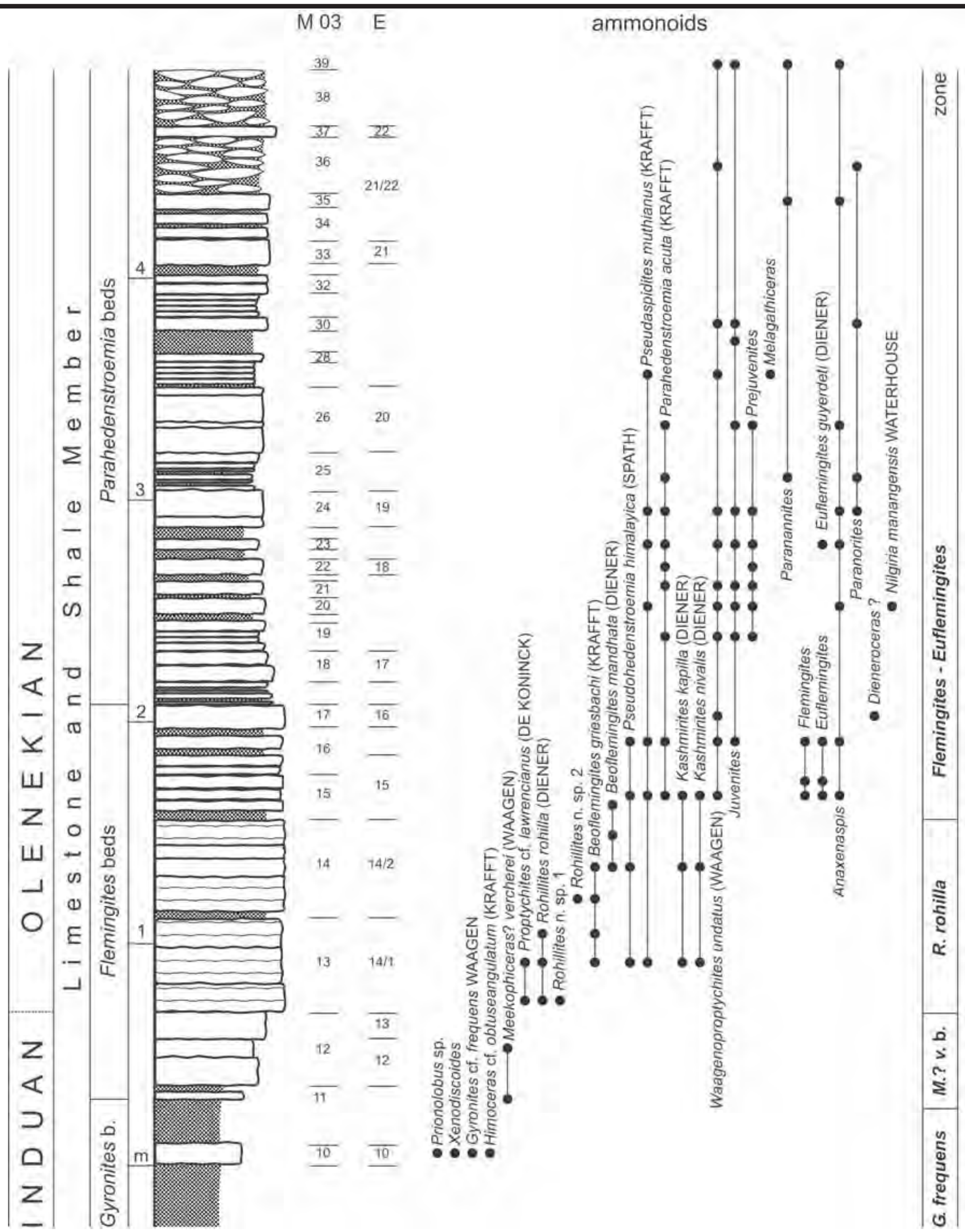

Fig. 11. Composite ammonoid fauna of the *Flemingites* beds in Mud.

faunas is rare in strata corresponding to beds 12-14 of Mud anywhere in the world. Evident ammonoid counterparts of the Spiti *rohilla* Zone are indicated only along the southeastern Tethys margin between Kumaon, Nepal (Waterhouse, 1996), Tibet (Wang and He, 1976) and Timor (Welter, 1922), usually without detailed sequential information. Most of the other low palaeolatitude areas contain either no (Salt Range, USA) or so badly preserved fauna (China: Chaohu) that precise ammonoid correlation within the critical interval becomes highly speculative (Fig. 13).

Comparison with Chaohu and northwestern Guangxi (South China)

A correlation with Chaohu (sections North Pingdingshan/N.P. respectively West Pindingshan/W.P., the other proposed candidate GSSP) is of special importance and can be confidently attempted on the basis of recently documented ammonoid (Tong et al., 2004; 2006) and conodont faunas (Zhao et al., 2007). Both the sections show an identical conodont record with appearance of *Ns. waageni* s.l. in top of bed 24 (W.P). versus mid-bed 49 (N.P.), a level tied together in terms of the ammonoid

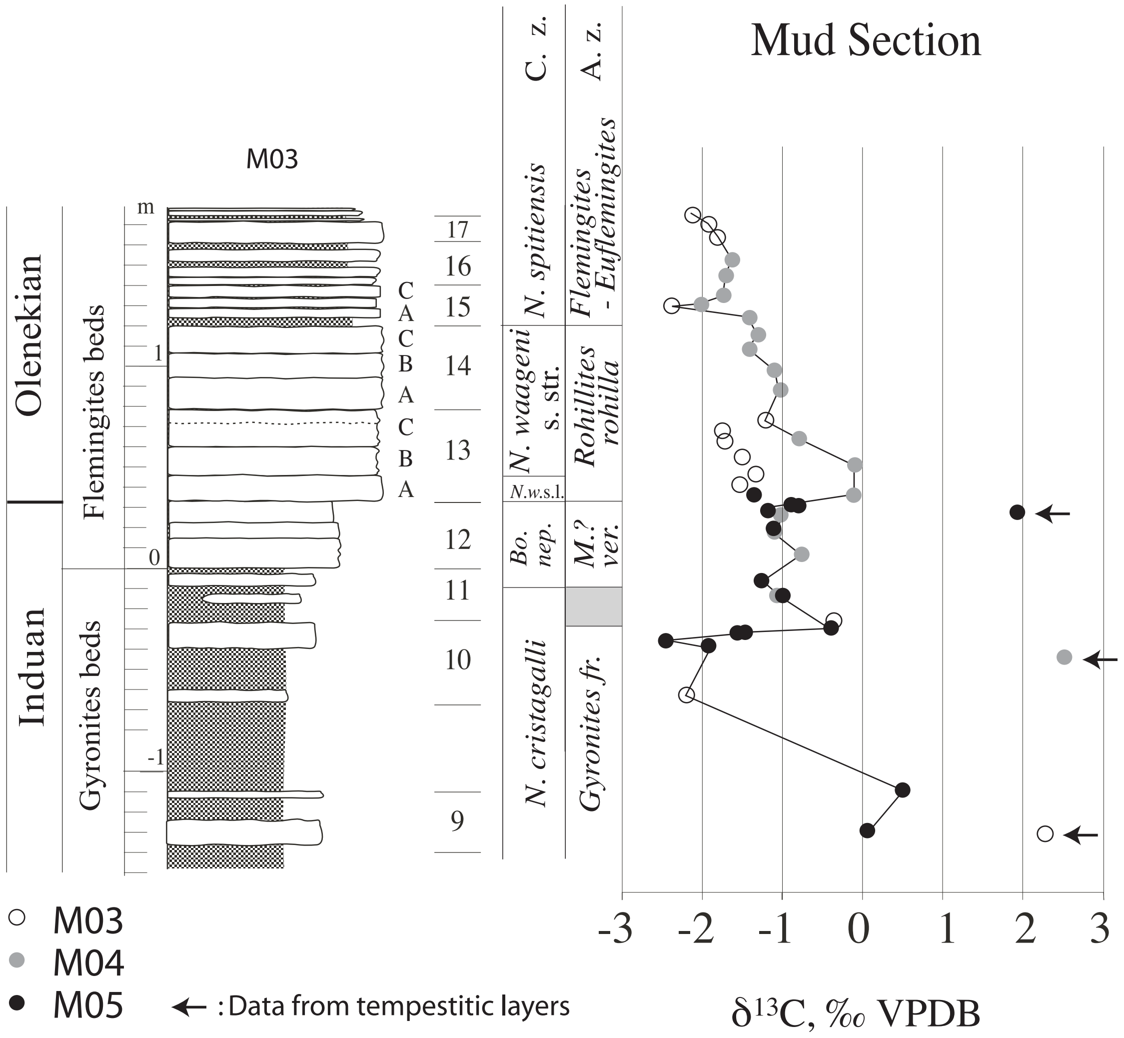

Fig. 12. δ^{13}C isotope curve of the I-O boundary beds in Mud. Note the positive peak and inflexion point in beds 13A and 13B close to the proposed boundary (from Richoz et al., this volume).

record with the *Flemingites-Euflemingites* Zone (Tong et al., 2003). The latter zone starts in a three times thinner Mud section one meter (1m) above *Ns. waageni* s.l. (Fig. 10) and contains *Ns. spitiensis*, a species otherwise found earliest in W.P. in bed 26 or four meters above the base of the *Flemingites-Euflemingites* Zone – a serious biostratigraphic paradox.

The above-mentioned inconsistencies impede the correlation of the integrated ammonoid-conodont zonal schemes of Chaohu and Spiti. These inconsistencies have to be resolved before a decision on the boundary biomarker(s) and the definite GSSP site are decided. As conodonts are common and taxonomically well documented in Chaohu, attention has been concentrated on the ammonoids, which in some levels are quite common (W.P. 24 and 25), while in others missing or, if present, not mentioned (W.P. 26). Exactly constrained ammonoids are figured in Tong et al. (2004) and in greater quantity in Tong et al. (2006). Of those deserving special attention – including taxonomic annotations – is in top of bed 24 (base of Olenekian):

- *Euflemingites* sp. (Tong et al., 2006, pl. 2, fig. 13) – due to inadequate preservation generically indeterminate.

- *Euflemingites* cf. *tsotengensis* Chao (Tong et al., 2006, pl. 2, fig. 14) – without any sign of the genus-typical spiral ornamentation, a to narrow umbilicus (just 15%) and through the unusually deep and slender lateral lobe, gyronitid-looking suture certainly no *Euflemingites*.

in bed 25 (basal Olenekian):

- *Preflorianites*? sp. (Tong et al., 2006, pl. 2, fig. 15) – could likewise be a *Rohillites*? sp.

- *Euflemingites*? sp. (Tong et al., 2006, pl. 3, figs. 4, 8, 13, 20) – all without spiral strigation and indeterminate.

- *Flemingites*? sp. (Tong et al., 2006, pl. 3, fig. 7) – could be a *Rohillites*? sp.

Mud bed	Mud		Salt Range	NW Guangxi	Chaohu bed	Chaohu	Primoriye
16 15	*Flemingites-Euflemingites*		*Flemingites flemingianus*	*Flemingites rursiradiatus* b.	52 26?	*Flemingites-Euflemingites*	*Hedenstroemia bosphorensis*
							?
14C 14B	*Rohillites rohilla*	*Beoflem. mandhata*	?	*Kashmirites kapila* beds	25	? (*"Flemingites-Euflemingites"*)	?
14A 13C 13B		*Beoflem. griesbachi*					
13A		*R.* n.sp.1					
							?
12 11	*Meekophiceras*? *vercherei* beds		*Prionolobus volutus*	*Clypeoceras* n. sp. A beds	24	*Prionolobus - Gyronites*	*Gyronites subdharmus*

Fig. 13. Regional ammonoid zonal correlation of the boundary interval and of the proposed boundary for the base of the Olenekian stage. Data from Chaohu reinterpreted, Guangxi sequence according to Brayard and Bucher, in press.

• *Flemingites*? sp. (Tong et al., 2006, pl. 3, fig. 17) – eventually a *Kashmirites*? sp.

in the coeval bed 50 of North Pingdingshan:

• *Flemingites* sp. (Tong et al., 2004, text-fig. 8, pl. 2, fig. 11) – a juvenile fragment of indeterminate generic position. The suture line shows a high second and third lateral saddle resembling more *Kashmirites* than flemingitids.

in bed 52 of North Pingdingshan (3m above bed 50):

• *Euflemingites* cf. *tsotengensis* Chao (Tong et al., 2004, pl. 2, figs. 13, 14) – by the well visible spiral strigation true *Euflemingites*.

The re-interpretation of the above discussed taxa leads to a conclusion that i) as in Spiti first true *Euflemingites* appears well above the *Ns. waageni* group and ii) for the most of the Chaohu specimens even a generic determination remains doubtful. Strong compression and extensive diagenetic de-carbonatisation have produced flattened, sometimes paper-thin imprints, where diagnostic features (shell sculpture, original cross-section and sutural details) have been lost. To distinguish between the genera *Gyronites, Rohillites, Beoflemingites, Flemingites* or *Euflemingites* under such conditions is practically impossible.

A diverse, well-preserved and stratigraphically detailed documented ammonoid fauna has recently been studied in the Luolou Fm. in northwestern Guangxi (Brayard and Bucher, in press) with a three-fold zonal division ("*Clypeoceras* n. sp. A beds", "*Kashmirites kapila* beds", "*Flemingites rursiradiatus* beds") that can be recognized in Mud too (Fig. 13). Taking aside the poorly constrained "*Clypeoceras* n. sp. A beds" and a short barren interval above, the"*Kashmirites kapila* beds" are linked by *K. kapila* with the *rohilla* Zone of Mud where this species is common. A second link between the upper parts of the "*Kashmirites kapila* beds" and of the *rohilla* Zone is established by *Rohillites* sp. indet., a morphological twin of *Rohillites* n. sp. 2 in Mud. Diverse and generically similar *Flemingites* faunas occur in both cases only above this bed. The Guangxi ammonoid record thus mirrors the Spiti succession and is a reasonable confirmation that the *Flemingites-Euflemingites* bearing interval is separated from Induan faunas by another ammonoid association, which can claim an independent status at the very base of the Olenekian stage and is currently not known or distinguished in Chaohu (Fig. 13).

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Table 1. Ammonoid distribution through the I-O boundary beds in Mud, sections M03 to M06.

	04/11	03/12B	04/12C	03/13A	04/13A	06/13A	03/13B	04/13B	05/13B	06/13B	04/13C	05/13C	06/13C	04/14A	04/14B	04/14C	04/15A	05/15A	06/15A	04/15B	05/15B	06/15B	04/15C	06/16A	03/16B	04/16B	05/16B	04/16C	06/16C	03/17
M.? vercherei	X	X	X																											
Prionolobus n. sp. 1					X																									
Proptychites cf. lawrencianus				X			X	X																						
Parakymatites discoides						X		X		X	X																			
"Meekoceras" pulchrum					X	X		X		X	X																			
Rohillites n. sp. 1						X																								
Rohillites rohilla					X	X	X		X	X	X	X	X																	
Rohillites n. sp. 2														X																
Beoflemingites griesbachi									X		X	X		X	X															
Beoflemingites mandhata															X	X	X			X										
Flemingites																	X	X		X			X				X	X	X	
Euflemingites																	X			X			X	X		X		X		
Kashmirites sp.										X							X							X				X		
Kashmirites kapila								X	X		X			X			cf.			X										
Kashmirites nivalis											X			X	X	X	X		X	X		X	X			cf.		cf.		
Anaxenaspis																	X		X					X		X				
Waagenoproptychites undatus																	cf.						X		X	X				X
Juvenites																								X	X				X	
Pseudaspidites muthianus										X							X											X		
Parahedenstroemia acuta																	X									X				X
Pseudohedenstroemia himalayica									X	X	X			X	X	X			X	X				X		X		X		

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Plate 1
Fig. 1: *Prionolobus* n. sp. 1; M04-13A
Fig. 2: *Meekophiceras*? *vercherei* (Waagen); M03-12B
Fig. 3-4: *Rohillites rohilla* (Diener); M04-13C

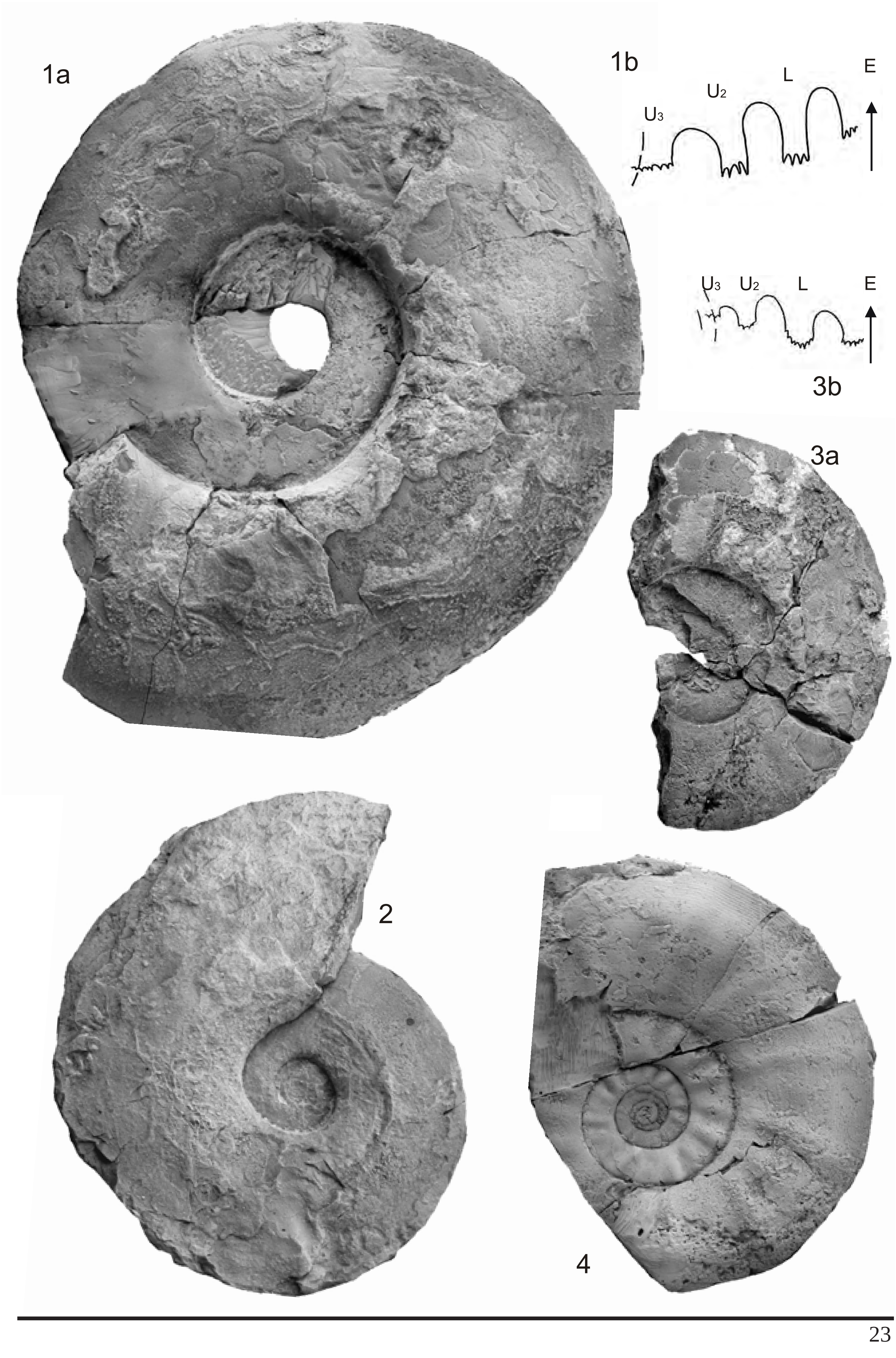
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Plate 2
Fig. 1: *Rohillites* n. sp. 1; M06-13A
Fig. 2: *Rohillites* n. sp. 2; M04-14A
Fig. 3: *Beoflemingites mandhata* (Diener); M04-14B
Fig. 4: *Beoflemingites griesbachi* (Krafft); M04-14A
Fig. 5: *Flemingites* cf. *compressus* Waagen; M05-15B

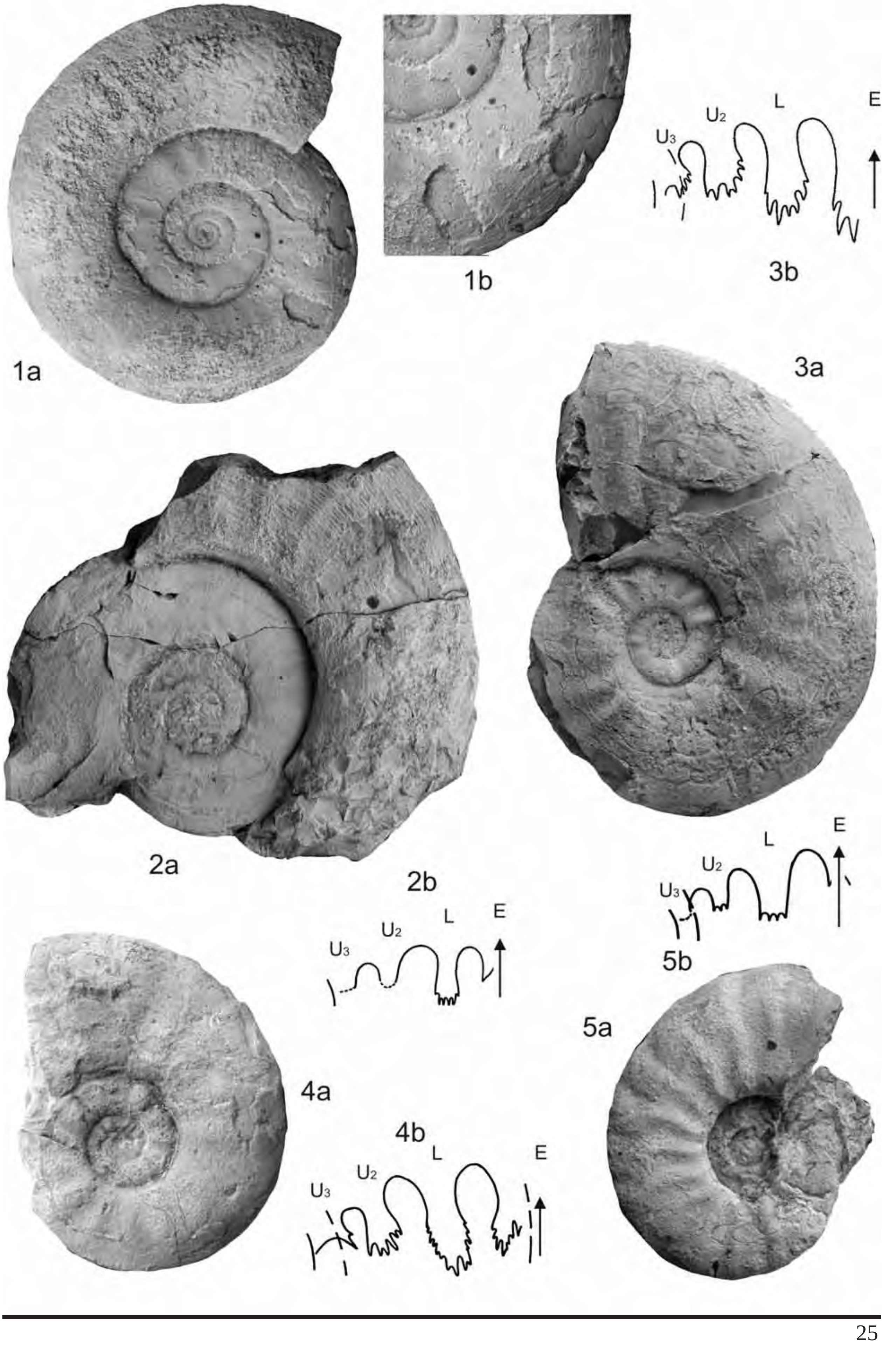
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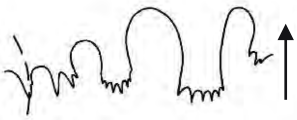
Plate 3
Fig. 1: *"Meekoceras" pulchrum* Waagen; M04-13B
Fig. 2: *Proptychites* cf. *lawrencianus* (De Koninck); M03-13B



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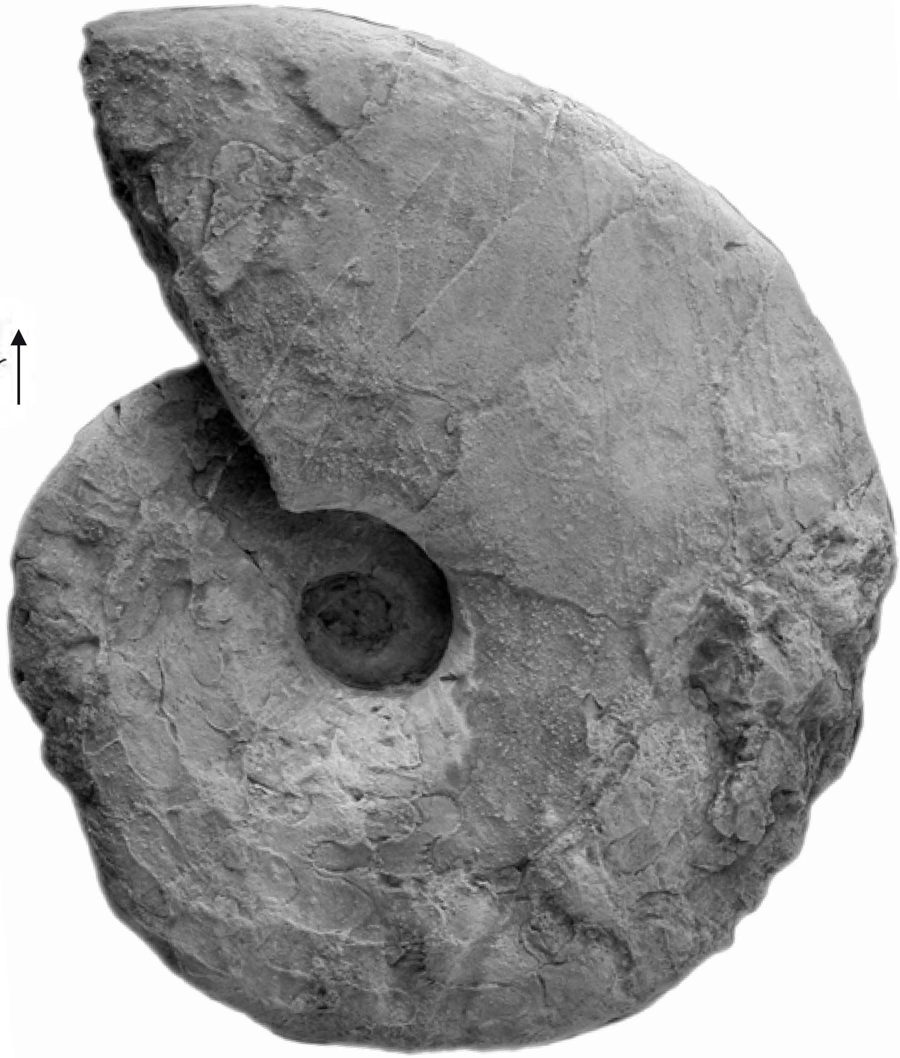

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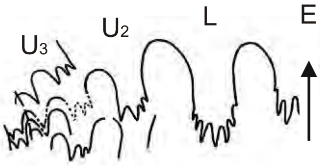

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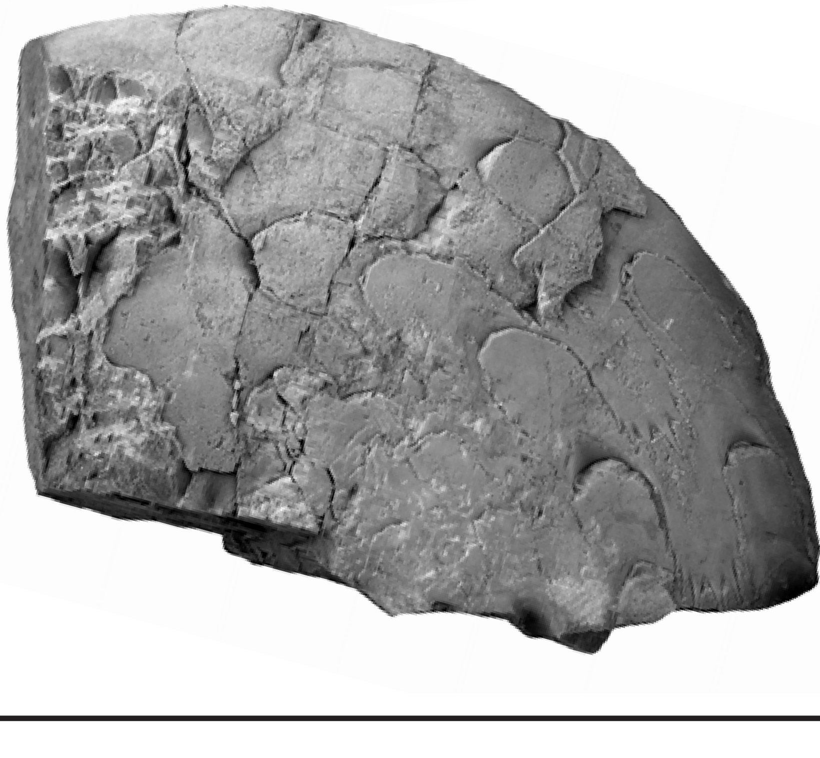

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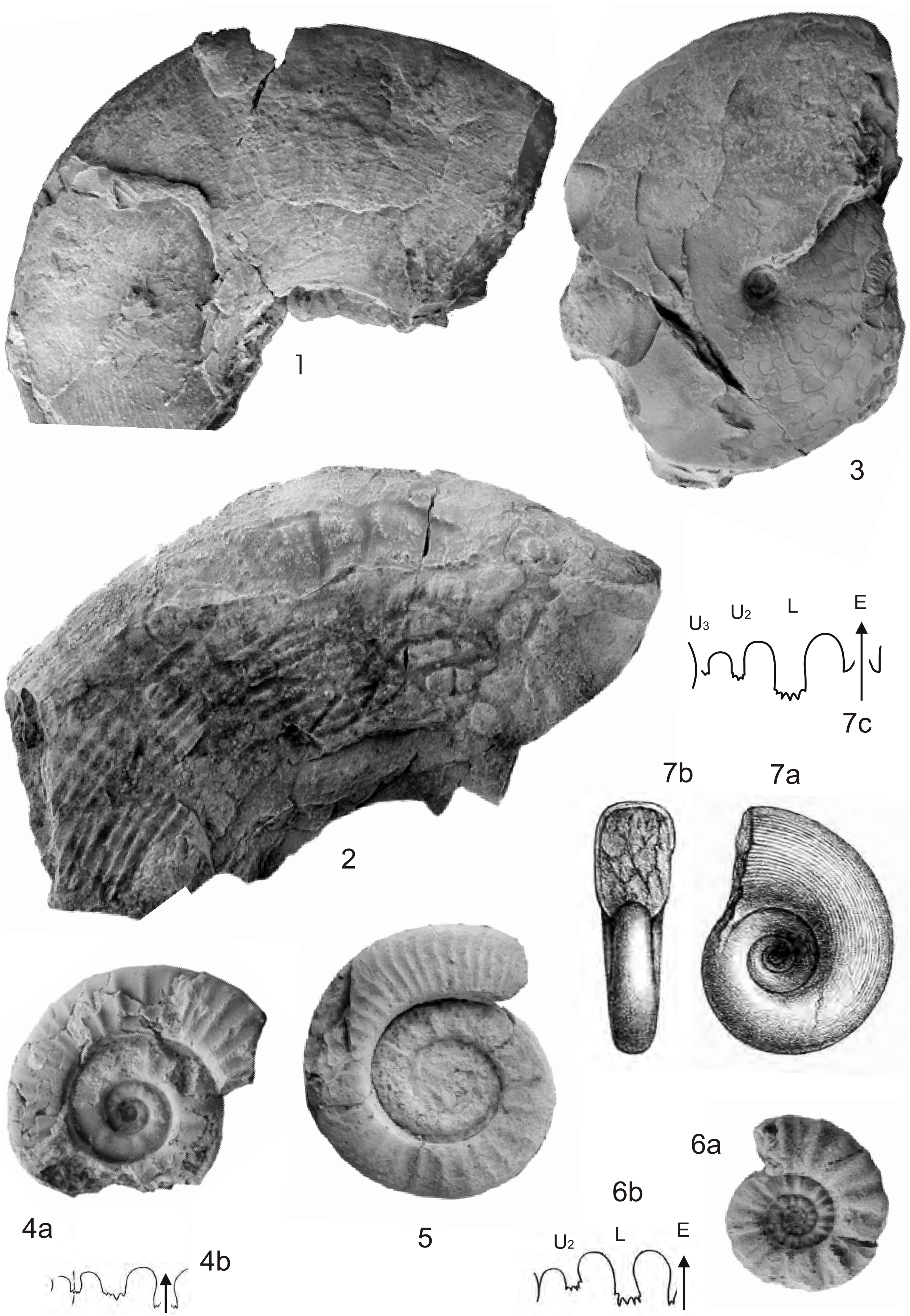
Plate 4
Fig. 1-2: *Euflemingites* sp.; 1: M04-16B, 2: M04-15B
Fig. 3: *Pseudohedenstroemia himalayica* (Spath); M04-15C
Fig. 4: *Kasmirites nivalis* (Diener); M04-13C
Fig. 5: *Kashmirites kapila* (Diener); M04-13C
Fig. 6: *Kashmirites* sp.; M04-16C
Fig. 7: *Euflemingites guyerdeti* (Diener); Mud, app. bed 23 - copy from Diener, 1897.

All specimens are figured in natural size and housed in the Department of Palaeontology, Vienna University.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