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.
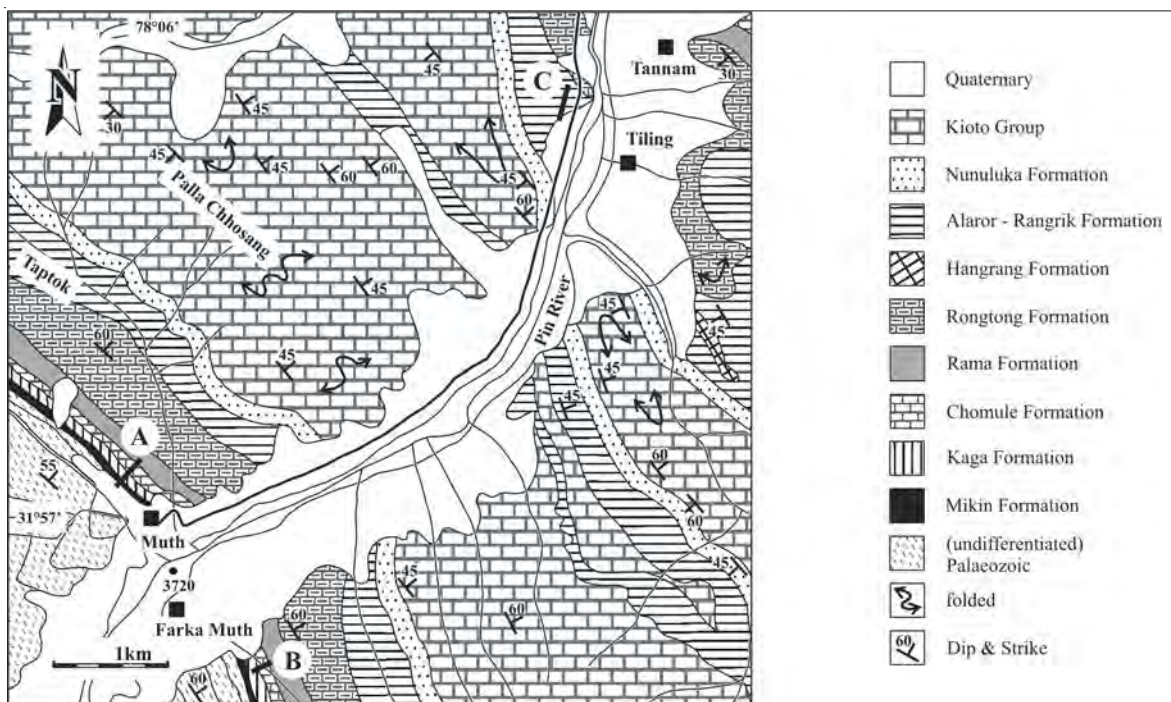

Figure 1: Geology of Muth (after Fuchs, 1982) with position of sections E/M 03 **(A)**, Muth 3 near Farka Muth **(B)** and opposite Tilling **(C)**.
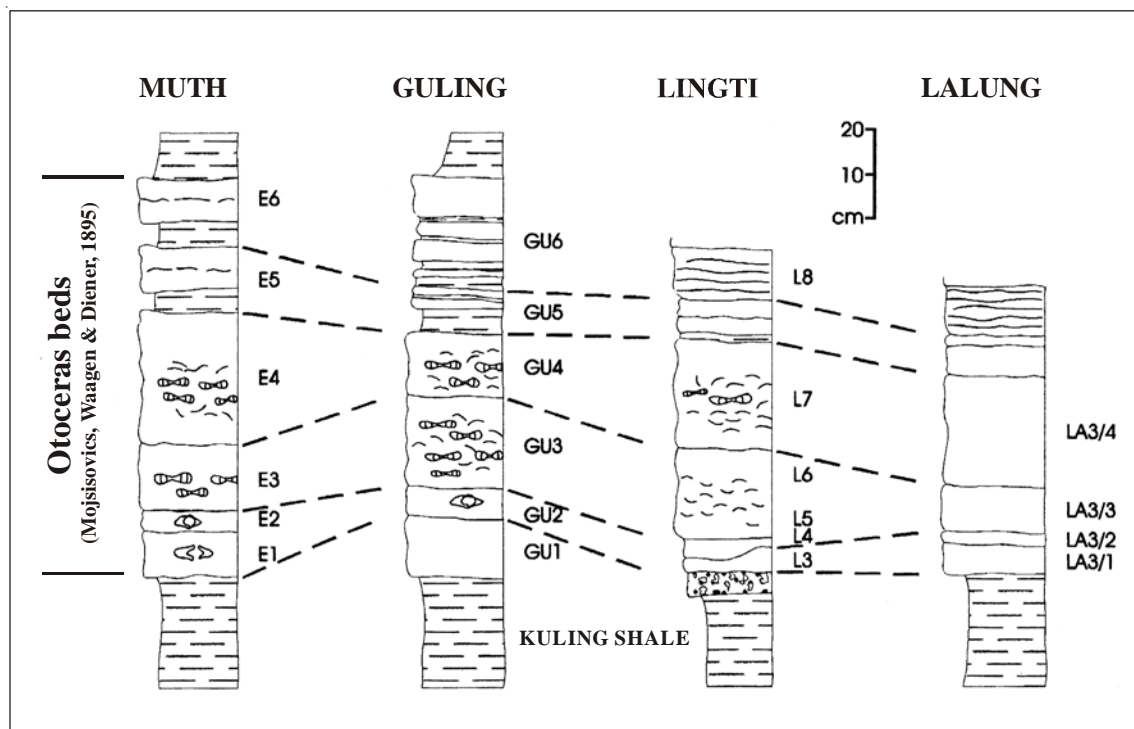
Figure 2: Lithology and conodont-based correlation of the *Otoceras* beds along a 30 km wide basin transect from Muth to Lalung (modified from Orchard and Krystyn, 1998).

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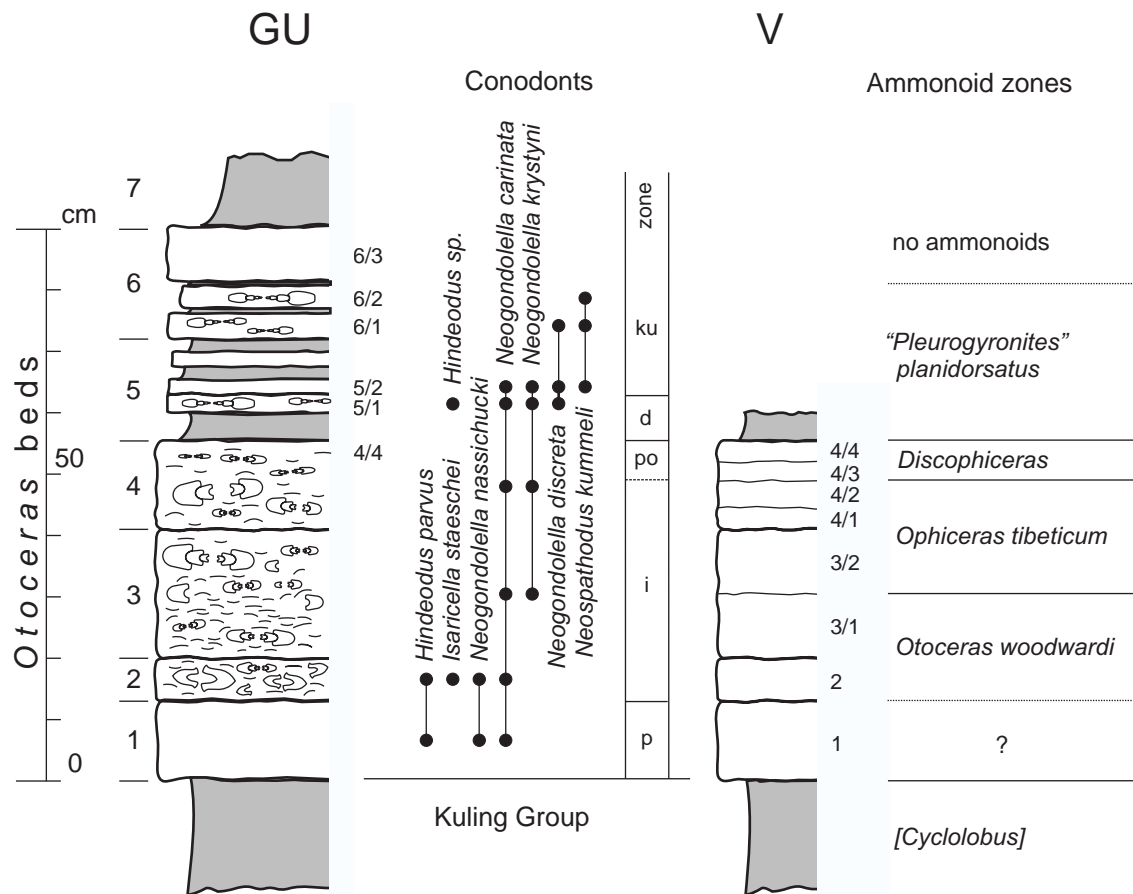
Figure 3: Ammonoid and conodont biochronology of the *Otoceras* beds in sections GU and V on the hill above Guling.

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 sharpedged 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	*I. isarcica*	*Ng. krystyni*		
			Ophiceras tibeticum				
			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-
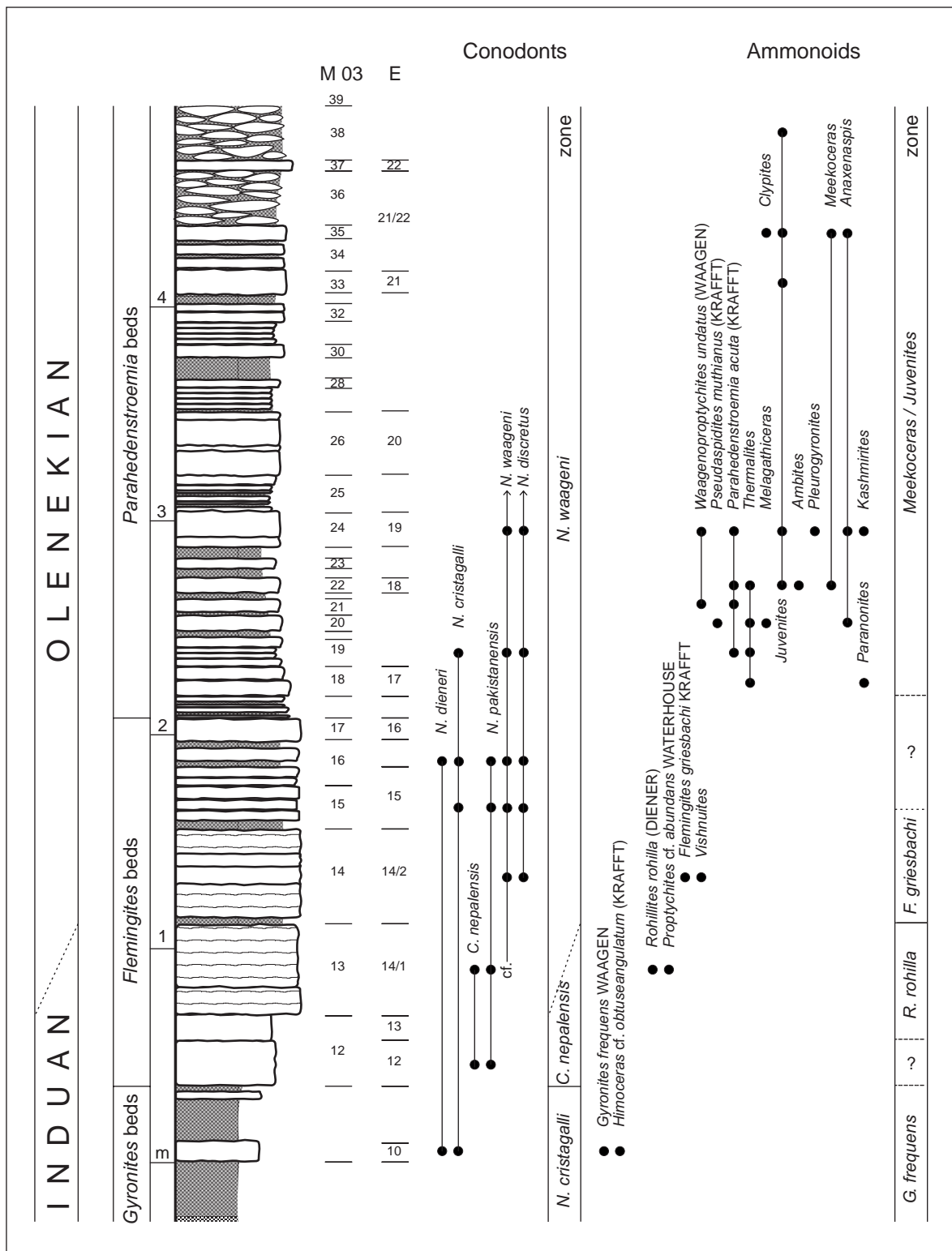
Figure 6: Ammonoid and conodont faunal sequence around the Induan-Olenekian boundary at Muth.

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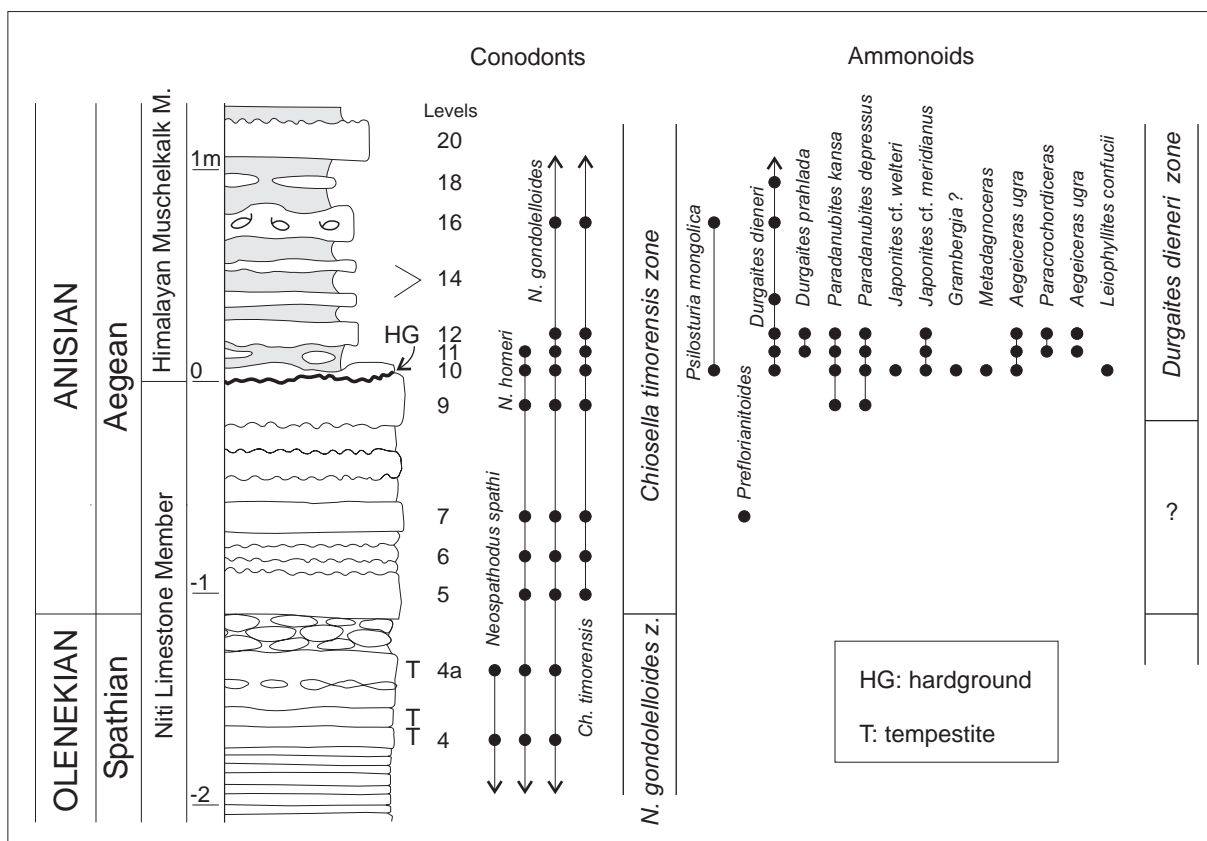
Figure 7: Ammonoid and conodont record across the Olenekian–Anisian boundary at Muth. The boundary is drawn with the FO of *Chiosella timorensis*. Note the sequence boundary (HG) on top of the Niti Limestone Mb.

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,
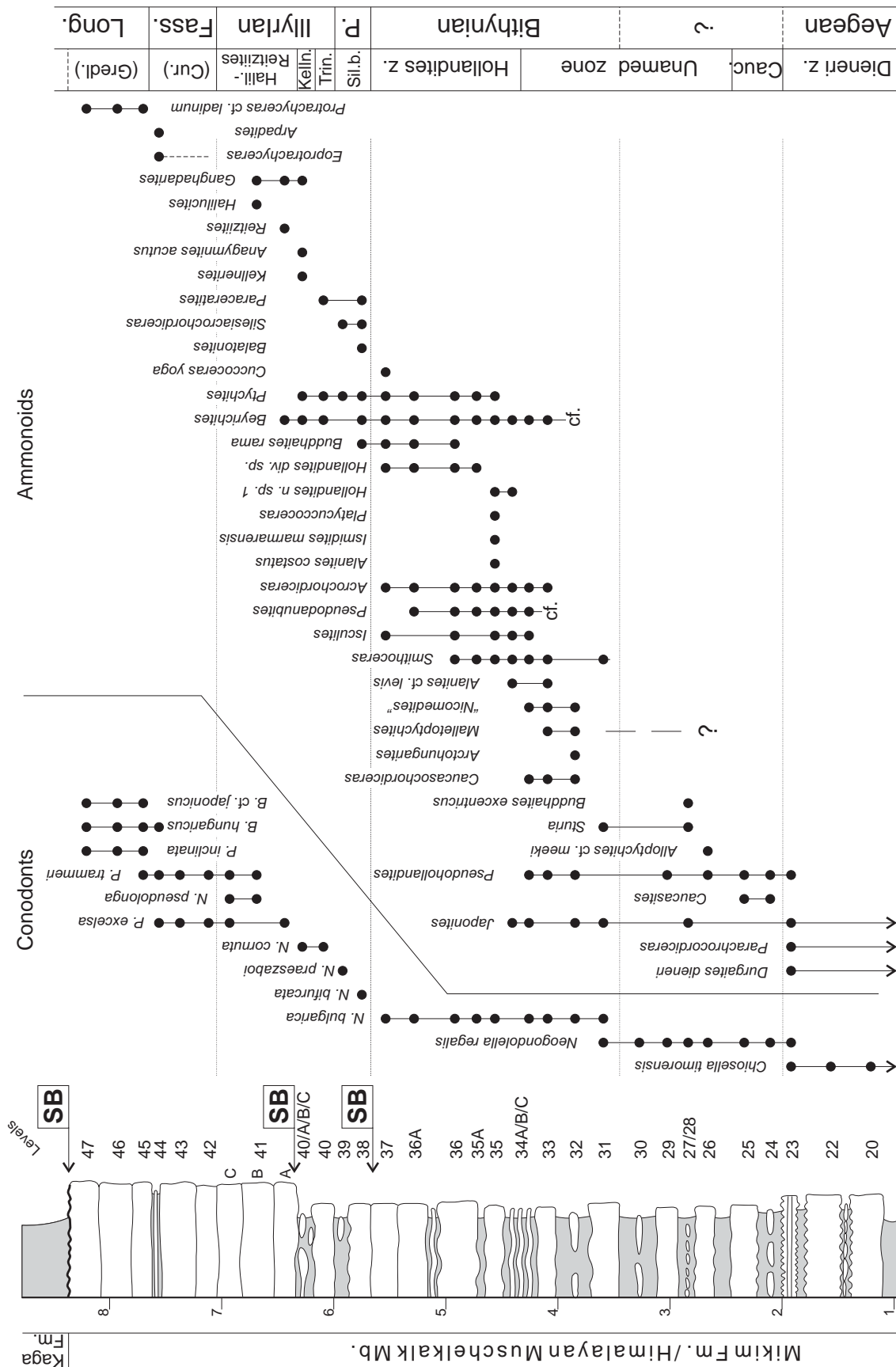
Figure 8: Ammonoid and conodont faunal sequence of the Himalayan Muschelkalk Mb. Note the strongly reduced thickness in the Upper Anisian and 3 sequence boundaries (SB) in upper part of the section.
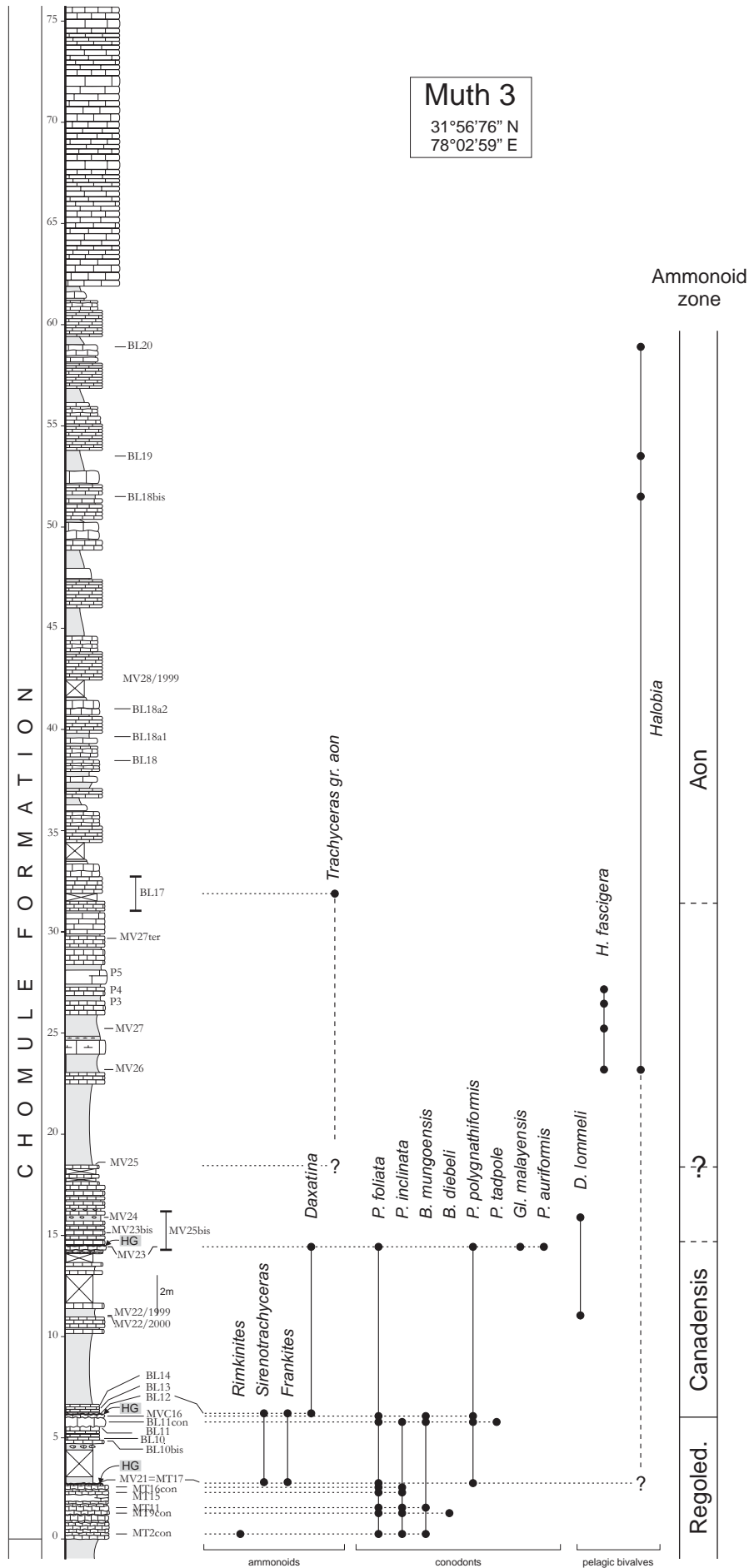
Figure 9: Distribution of ammonoids, conodonts and pelagic bivalves in the lower part of the Chomule Formation at Muth

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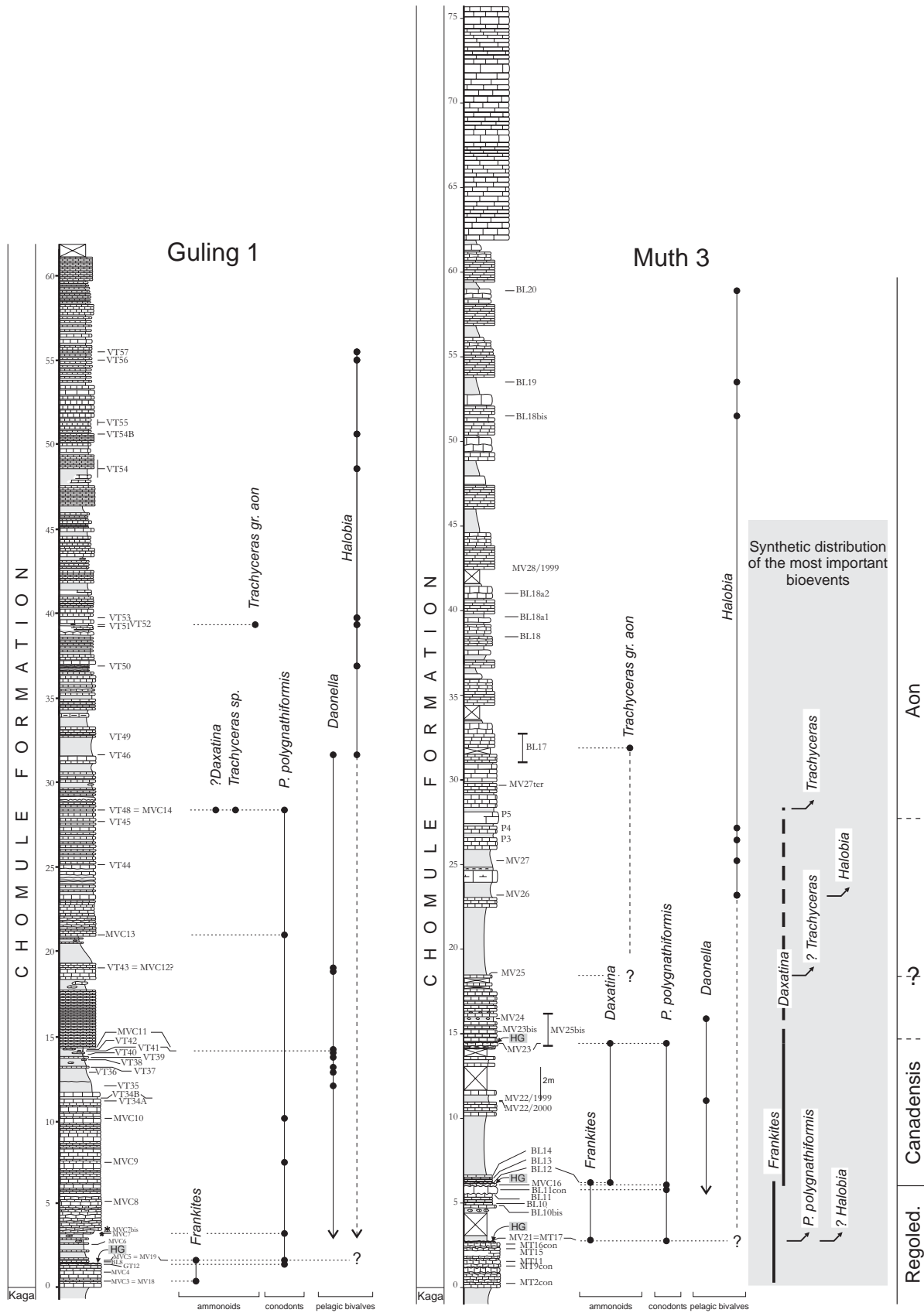
Figure 10: Distribution of the most important key taxa in the Ladinian-Carnian boundary interval at Guling 1 and Muth 3. In the grey area the synthetic distribution of the most important bioevents.

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*.

Acknowledgements

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