Towards a Tethyan Carnian–Norian boundary GSSP

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Abstract

Long distance correlation of the Carnian-Norian (C-N) boundary is possible by ammonoids, conodonts and likely by pelagic bivalves of the genus *Halobia*. Depending on the chosen fossil group and bioevent, this boundary may be located at the base of the *Guembelites jandianus* Zone of the current Tethyan ammonoid scale and/or at the co-eval FO of *Metapolygnathus communisti* B within the Tethyan conodont zonal framework as applied in this paper. A second and slightly earlier conodont event, the FO *of M. communisti*, may have the potential for worldwide recognition but it is presently not well individualized in the ammonoid and halobiid Tethyan successions. Other conodont events are less favourable: the incoming of *Norigondolella navicula* is unsatisfactory because its stratigraphic level appears to differ from one area to another and the potential of *Epigondolella abneptis* A as boundary guide needs additional clarification. The first two mentioned conodont FOs are well constrained by magnetostratigraphic data: the *communisti* event and the *communisti* B event occurring respectively at the base and at the top of a reversed polarity interval during the topmost part of the Carnian. If *M. communisti* B turns out to be missing in North America, the communisti event may remain as the only reliable time indicator for intercontinental correlation of the C–N boundary in low paleolatitudes between the Panthalassa and Tethys oceans. In this study, pelagic sequences from three Western Tethys regions (Slovakia, Turkey and Sicily) are documented, correlated with each other and compared for their sedimentary and magnetobiochronological potential to serve as GSSP candidates for the Carnian–Norian boundary. Sections from Turkey and Slovakia are suitable for magnetostratigraphy, are rich in conodonts and also display megafossil data (halobiids, ammonoids), but they are developed as sedimentary condensed Hallstatt limestones and thus reduced in thickness. A thick and stratigraphically expanded section in Sicily (Pizzo Mondello) shows the most complete magnetostratigraphic sequence but a qualitatively unsatisfying conodont record and it presently misses any megafossil support. If the fossil record from this section could be improved, Pizzo Mondello would become the best available Tethyan locality for the implementation of a GSSP.

Introduction

Compared with many disputed Triassic stage boundaries, the Carnian-Norian boundary is a rare exception because of its well defined and undisputed status. This is surprising since no reliable historical reference section has been mentioned so far and that the presumable Norian stratotype in Sommeraukogel near Hallstatt (Salzkammergut) lacks an age-diagnostic megafauna at the base (Krystyn et al., 1971). The earliest Norian ammonoid Sommeraukogel record belongs to the “Zone des *Discophyllites patens*” (Mojsisovics, 1873-1902) and represents an interval now known as corresponding to the top-Lower Norian *Juvavites magnus* Zone. A more appropiate age for the base of the Norian stage may be obtained from the analysis of those faunas which were included by Mojsisovics (1893) in the Upper Carnian or Tuvalian substage (in Mojsisovics et al., 1895). According to our present knowledge, the youngest Mojsisovics s Carnian fauna is from the “Linse mit *Thisbites agricolae*” and correlates to a very short-ranging level (*Euisculites* Biohorizon) of less than one ammonoid subzone within the topmost Carnian *Spinosus* Zone of the Tethys (level b in fig. 1). The North American equivalent is found in the *Klamathites macrolobatus* Zone of Canada (Tozer, 1994) and Nevada (Silberling, 1959). Norian faunas above this level were included in the *Guembelites* Zone by Silberling (1959) and later referred to the Zone of *Mojsisovicsites* (now *Stikinoceras*) *kerri* by Tozer (1967). *Dimorphites*, *Griesbachites* and *Guembelites* are characteristic genera of the zone which was first identified in the Tethys at Feuerkogel (Krystyn, 1974) and later named as *Guembelites jandianus* Zone (Krystyn, 1980).

Beside the Alps, Tethyan places with a reliable Upper Carnian to lower Norian ammonoid record across the C-N boundary are known from Sicily (Gemmellaro, 1904) and from the Himalayas (Diener, 1906; Jeannet, 1959; Krystyn, 1982). However, a detailed faunal sequence information is still restricted to Feuerkogel and this locality is thus the only one which provides direct intercalibration between ammonoid, halobiid and conodont zonal schemes. Magnetostratigraphic results unfortunately could not be obtained from Feuerkogel (J. Besse, pers. comm.) but several conodont-dated pelagic limestone sections from Turkey have provided numerous magnetostratigraphic data allowing the construction of a geomagnetic polarity time scale for this time interval (Gallet et al., 1992; 2000; Krystyn et al., in press). These data are in good agreement with the most complete Tethyan C-N magnetostratigraphic record recently obtained by Muttoni et al. (2001) at Pizzo Mondello (Sicily), although the lack of time diagnostic fossils prevented Muttoni et al. 2001 to locate the boundary to better than a 40 m-thick interval. Based on a combined analysis of all available data, we discuss here the significance of the various bioevents with respect to faunistic, magnetostratigraphic and interregional cross-correlations,

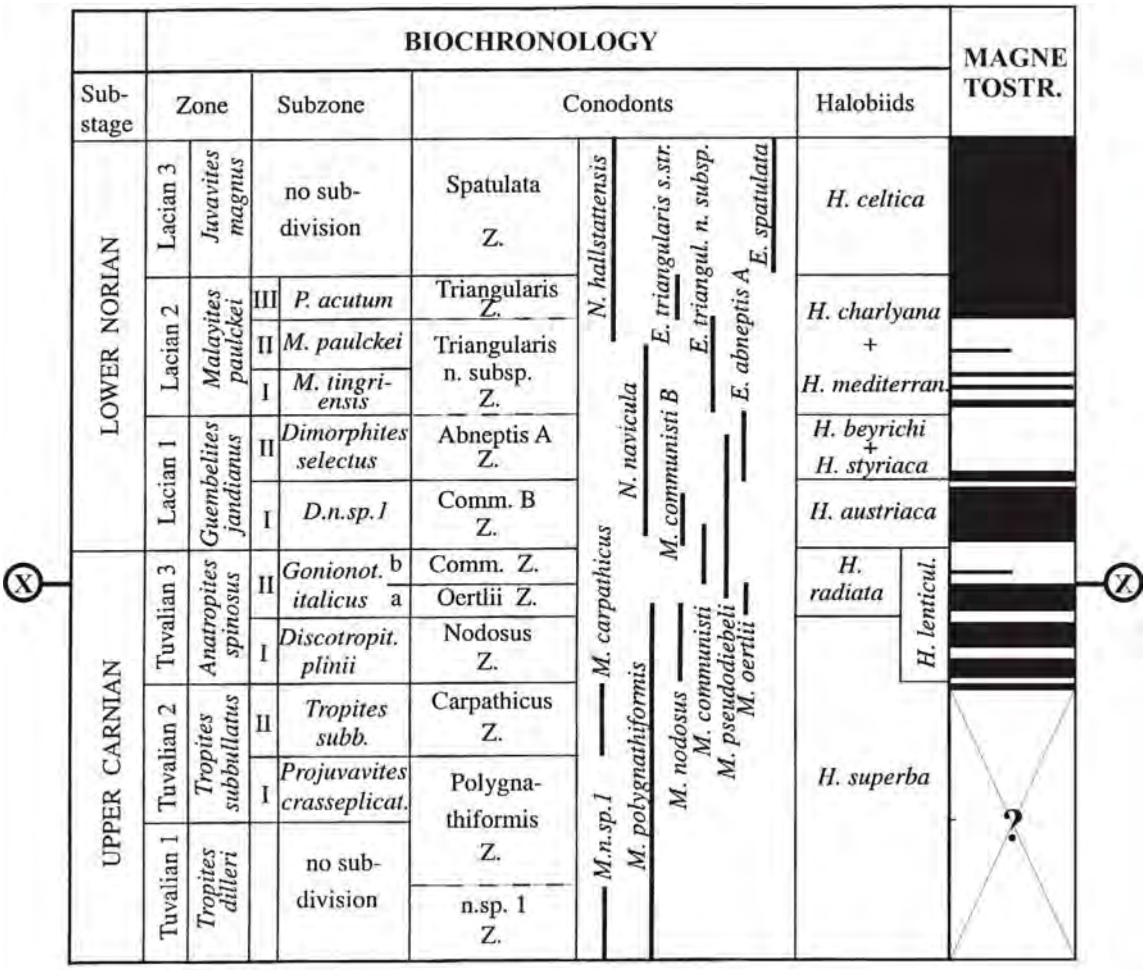

Fig. 1: Upper Carnian to Lower Norian Tethyan magnetobiochronology . The encircled X marks the Carnian-Norian boundary proposed by Orchard et al. (2000) for the *communisti* event.

and we evaluate the sequential and fossiliferous potential of the studied sections as C-N boundary GSSP candidates.

Magnetobiochronology

We recently carried out a study on the Carnian-Norian magnetobiochronology (Krystyn et al., in press). We summarize below our general conclusions.

The Upper Carnian (Tuvalian) Tethyan ammonoid biochronology was previously proposed by Krystyn (1980) and it was summarized in Gallet et. al. (1994). We also consider the Lower Norian (Lacian) ammonoid zones and subzones defined by Krystyn (1980) and Krystyn (1982), respectively. Originally established in rather thin and sediment-reduced red cephalopod limestones of the so-called Hallstatt facies in Austria, this zonation has meanwhile been found applicable to many Tethys regions (e.g., Timor, Oman, Himalayas). The Carnian-Norian boundary has been defined at the base of the North American Kerri Zone (Tozer, 1967) which correlates with the Tethyan Jandianus Zone as both zones share the FO of the distinct juvavitid genus Dimorphites (Figure 1; Krystyn, 1980). This boundary reflects the strong faunistic changes observed between the *Euisculites* Biohorizon and the *Dimorphites* n. sp. 1 Subzone which are well demonstrated in the faunal record of sections 4 and 5 in Feuerkogel (Austria). The Tuvalian and Lacian substages are each divided into 3 standard zones with twofold subzonal divisions in most cases.

Halobiids form easily recognizable species with little chance of taxonomic confusion and are extremely useful for independent calibration when tied into the ammonoid time scale. This is the case for the Carnian-Norian boundary interval where *H. radiata*, *H. austriaca* and *H. styriaca* constitute a sequence of short successive ranges in many areas of the Tethys, from Sicily to the Himalayas (Krystyn et al., in press). Data from the Alps show that the FAD of *H. austriaca* corresponds with the base of the Jandianus Zone (and thus with the C-N boundary; Krystyn, 1980), and suggest an age range of one ammonoid subzone for each of the forementioned halobiid species. In addition, the widespread geographic distribution of halobiids provides a firm basis for long distance correlation of the Carnian-Norian boundary in ammonoid free *Halobia*-bearing Tethyan rocks.

Previous Tethyan Upper Triassic conodont zonations have

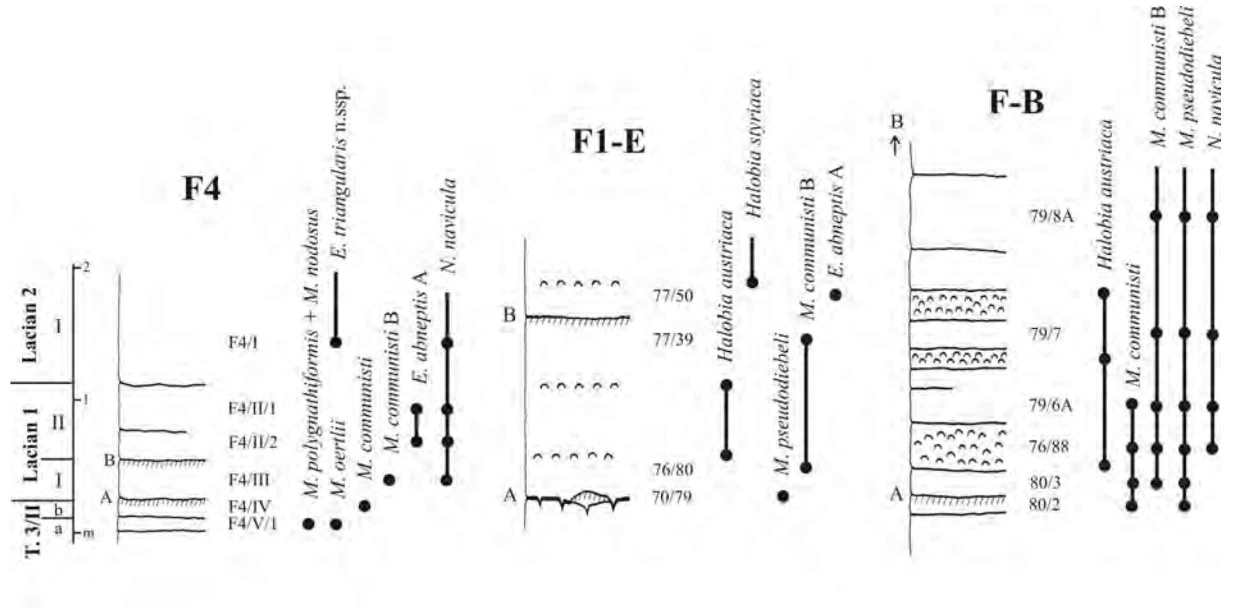

Fig. 2: Halobiid and conodont biochronology of three sections in Feuerkogel. Note the lithostratigraphic marker levels A and B ("A" corresponding to the Carnian-Norian boundary).

been proposed by several authors since the early seventies (Kozur and Mostler, 1973; Kozur, 1980; Krystyn, 1980; Vrielynck, 1987; Budurov and Sudar, 1990). All of them are rough, with long ranging zonal intervals exceeding the duration of the ammonoid zones by two or three times. None of the cited studies, but Krystyn (1980), has provided accurate sequential information on the ranges of stratigraphically relevant taxa against the ammonoid zonal frame. In a more detailed subdivision, Kozur (1990) increased the number of Upper Carnian and Lower Norian zones to six but missed again a direct integration into the ammonoid scale. Based on conodont collections obtained from ammonite-controlled sections in Austria and Timor (Indonesia), completed by material from newly measured sequences in Turkey, Krystyn et al. (in press) improved and refined this zonation to a sequence of 11 zones for the same time interval (Figure 1). The zonal guides of the Upper Carnian to basalmost Norian are thereby based on the genus *Metapolygnathus*, and those of the Norian on *Epigondolella* species. Each zone is defined by the FAD of its index species and is ended by the FAD of the succeeding zonal guide. This allows to define zonal boundaries independently from the total range of the zonal marker which may extend into the next younger zone or beyond. This procedure avoids problems in taxonomy used differently by the various authors, what ultimately leads to strongly differing ranges of many zonal index species in the literature. Reference sections for the new resp. redefined conodont zones have been named in Turkey (see below).

In order to avoid any misleading interpretations, the following remarks on some conodont boundary interval species are necessary. *Metapolygnathus primitius* is typical for North America and obviously missing in the Tethys as many other Pacific metapolygnathids and epigondolellids (Orchard, 1991). It is replaced in Tethyan sections by the time-equivalent *M. pseudodiebeli* long used as zonal index for the Carnian-Norian boundary interval (Kozur, 1973). *Metapolygnathus communisti* A of Krystyn, 1980 corresponds to *Metapolygnathus communisti* Hayashi, 1968 (see Krystyn, 1980, pl. 12, fig.8-14). The usefulness of *Metapolygnathus communisti* B for determining the base of the Norian by conodonts has been questioned by Muttoni et al. (2001) who considered the species as doubtful and held it in synonymy with *M. nodosus* although there is a distinct time break between the two species (Figure 1). There is now convincing morphological evidence that *M. communisti* B is closely related to *M. oertlii* (Kozur) and this latter species bridges the stratigraphic gap between *M. nodosus* and *M. communisti* linking perhaps the three taxa in a phylomorphogenetic cline. *M. nodosus* sensu Orchard is morphologically close to *M. carpathicus* (Mock) and may have been misinterpreted in North America. *Epigondolella abneptis* A is identical to *E. abneptis* sensu Kozur and very similar to *E .quadrata* Orchard. *E. triangularis* n. ssp. is distinguished from *E. abneptis* A by the asymmetrically expanding semi-triangular posterior platform end. The newly discriminated subspecies of *Epigondolella triangularis* (Budurov & Stefanov) has smaller platform nodes and a less widening posterior platform than *E. triangularis* sensu stricto. Note that all epigondolellid species can be safely distinguished only in adult stages.

Carnian- Norian boundary sections

Feuerkogel

Located in the classical Hallstatt region of the Northern Calcareous Alps, the Feuerkogel has gained wide attention as historical reference both for the Tuvalian substage and for the base of the Norian (Krystyn and Schlager, 1971). Pelagic megafossils from this place are therefore

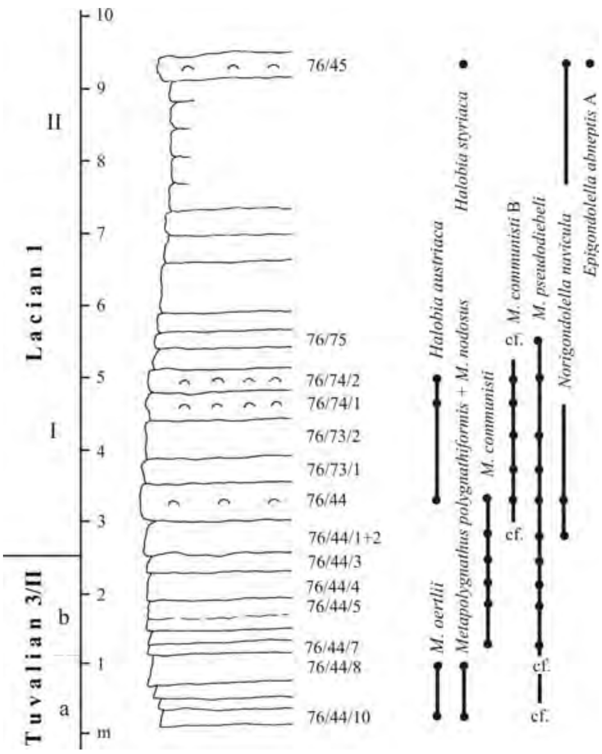

Fig. 3: Biochronology of the Silicka Brezova section.

of great importance for our understanding of the stratigraphic subdivision of the Carnian-Norian boundary interval. Rich ammonoid faunas were found in quarry F4 (and F5), where the accumulation rate was stongly reduced during the interval. The present top-Carnian *Euisculites* Biohorizon consists of a 15 cm thin bed (F4/IV) containing the genera *Euisculites*, *Thisbites*, *Hadrothisbites*, *Microtropites* and *Margarijuvavites*. From the overlying 30 cm thick bed F4/III (fig. 2), a different fauna is observed, marked by the appearance of the juvavitid genera *Dimorphites* and *Griesbachites*, and, except *Thisbites*, all forementioned genera have disappeared. Bed F4/III further yields the FO of *Halobia austriaca* replacing *H. lenticularis* found in F4/IV. The tops of the two beds in quarries F4 and F5 are developed as thin white limestone layers with characteristic mm-thick ichnoburrows, numbered A and B in fig.2. These levels are distinct lithostratigaphic marker horizons which are followed laterally over relatively large distances. Level A allows the exact recognition of the C-N boundary in other ammonoid free areas of the Feuerkogel where a more expanded sedimentary record is present (F 1-E and F-B on fig.2). They have been described by Krystyn (1980) and provide a more detailed insight on the ranges of stratigraphically significant *Halobia* and conodont species. The two sections indicate: 1) the FAD of *Halobia austriaca* and the FO of *Norigondolella navicula* are close to the base of the Norian, 2) the range of *Halobia styriaca* is directly above the one of *H. austriaca,* 3) each species are restricted to just one ammonite subzone, 4) the FO *of Metapolygnathus communisti* postdates both *M. polygnathiformis* and *M. nodosus*, and 5) the FO of *M. communisti* B is at the very base of the Norian. All these data provide the basis for an exact correlation of the current C-N boundary in ammonoid free pelagic sections throughout the Tethys realm with pelagic bivalves of *Halobia* type and/or conodonts. With the exception of section F-B, Feuerkogel is clearly unsatisfying as GSSP candidate due to the reduced sedimentation rate. The lack of any primary palaeomagnetic record, likely due to lightning effect, is also a negative point for this locality (J. Besse, pers. comm.).

Slovakia

The section (fig. 3), called Silicka Brezova from the name of a nearby village located in the eastern part of the West Carpathians, was documented by various authors (Mock, 1980; Korte, 1999). It contains reddish fine-grained pelagic limestones of Hallstatt type and has some importance as type locality of Upper Carnian conodont zones (Kozur, 1980). Materials mentioned below have been collected together with the late J. Bistricky more than 20 years ago when only rare natural outcrops partly covered by grass were accessible. A trench was recently digged providing now a much better exposed bed-by-bed sequence which is currently under study for detailed magnetobiochronology (H. Kozur and others, pers. comm.).

The section is included to this paper for discussing its potential as boundary GSSP in comparison with the other described localities. It is very similar to Feuerkogel F-B by the joint appearance of *H. austriaca*, *M. communisti* B and *N. navicula* at or closely above the C-N boundary (fig. 3). The top Tuvalian is less than 2 m thick with a rather late occurrence of *M. polygnathiformis* and *M .nodosus* just below *M. communisti*. This may be explained by a short stratigraphic gap or by faulting not visible at that time due to the restricted outcrop situation. Based on our data elsewhere, the magnetostratigraphy is predicted as follow: Reversed polarity between 1 m and 3 m, Normal polarity from 3 m to approximately 6 m.

Turkey

Three sections (KA, BT and EM2) are presented which all belong to the Bakirli Dag unit of the Upper Antalya Nappes (Marcoux, 1987). They are located relatively close to each other. Two sections have been described earlier, the Bölücektasi Tepe (BT) section by Gallet et al. (1992) and the Kavaalani (KA) section by Gallet et al. (2000). Erenkolu Mezarlik 2 (EM2), located 4 km SSW of BT, is a new and hitherto undescribed section with the most expanded and complete Carnian sedimentary record known to date from any Upper Antalya Nappe outlier. The magnetobiochronology (fig. 4, 5) of the C-N boundary interval is figured for the first time in detail and allows a better insight on the faunal sequences and on the magnetostratigraphic correlation between the Turkish data.

The three Turkish sections give us the opportunity to refine the ages of C-N boundary conodont datums in the Tethys and, in particular, to establish true first appear-

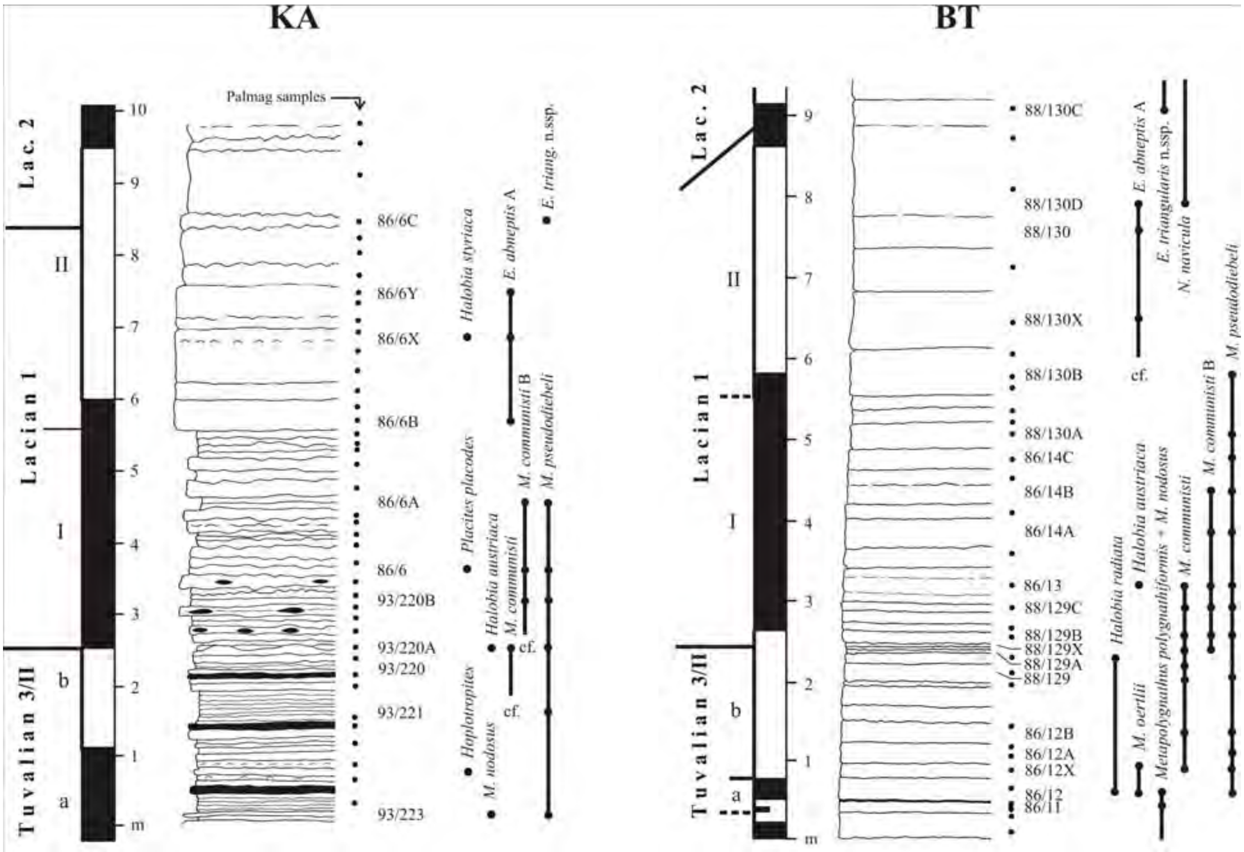

Fig. 4: Magnetobiochronology of Kavaalani (left) and Bölücektasi Tepe (right) sections. Note the short sedimentary break at the Carnian-Norian boundary in KA and the strongly reduced early Tuvalian 3 in BT, further indicated by the magnetostratigraphic record.

ance datums (FADs) for the species concerned. These sections display similar lithologies of Hallstatt-type consisting in fine-grained pelagic limestones with mostly reddish to light grey thin beds for the Carnian and whitish, thicker beds for the lowermost Norian. The basal beds of KA contain additional rare chert layers resp. nodules (fig.3). The thickness of BT and KA is nearly identical which makes very easy the comparison between the two sections. EM2 is much thinner and may represent short-termed hiati close to the C-N boundary but stratigraphic condensation can be clearly excluded by the normal, i.e. non-mixed conodont record. A discontinuity surface also marks the C-N boundary in KA and the occurrence of the Norian exactly at the onset of a magnetic polarity interval further suggests a short sedimentary break at this level. Distinct ammonoid genera (*Tropiceltites*, *Griesbachites*) allow the control of the conodont-based determination of the C-N boundary in EM2 (fig.5). The Kavaaalani and BT sections yield a Tuvalian 3 to Lacian 1 halobiid succession identical to the one obtained from Feuerkogel whose time stratigraphic validity can be proven by a cross-correlation with the conodont zonation. Both BT and EM 2 show an excellent conodont record with a complete zonal succession from the Upper Carnian to the lowermost Norian (fig. 4, 5). For this reason, we consider the two sections as references for the following conodont zones: *M. oertlii* (EM2), *M. communisti* (BT), *M. communisti* B (EM2) and *E. abneptis* A (EM2).

Sicily

The Pizzo Mondello sequence has been studied in detail by Muttoni et al. (2001) to establish the Carnian–Norian boundary interval magnetostratigraphy. The section is well exposed and rather thick in the basal Tuvalian 3 (80 m) and from the Lacian 2 upward. Across the C-N boundary, the sedimentation rate is reduced, to 7 m within the topmost Tuvalian equivalent of the *Euisculites* Biohorizon and to 18 m in the basalmost Norian (Lacian 1 zone). However, these thicknesses are still three to four times higher than in the coeval parts of the Slovakian and Turkish sections. Pizzo Mondello was therefore an ideal place for magnetostratigraphic investigations and it has indeeed provided the most complete magnetostratigraphic record (fig.5).

According to Muttoni et al. (2001), the greyish to light grey fine-grained calcilutites are almost barren of megafossils and contain a diversity reduced conodont fauna in which boundary diagnostic species such as *N. navicula* and *M. communisti* B are missing. As a result, Muttoni et al. (2001) failed to locate precisely the C-N boundary and introduced instead a 40 m-thick boundary interval. To improve its potential for correlation with other sections, one of us (LK) collected there megafossils and

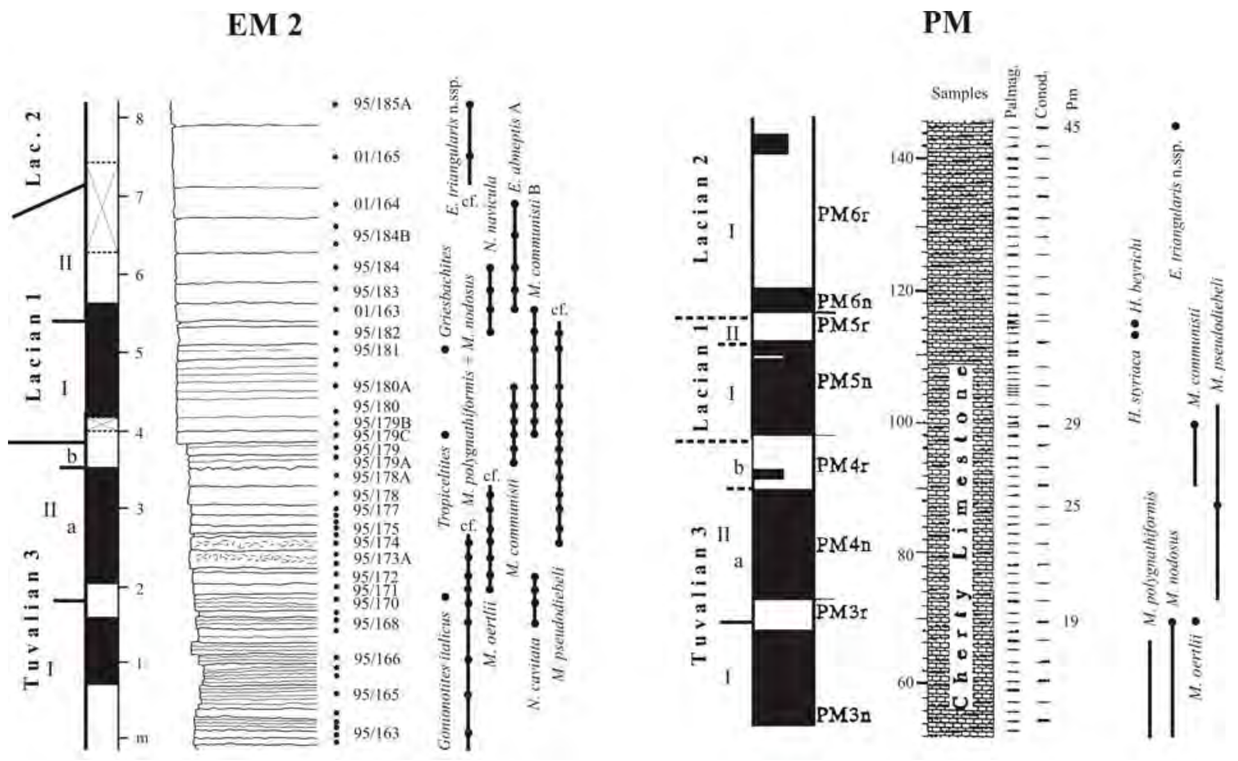

Fig. 5: Magnetobiochronology of Erenkolu Mezarlik 2 (left) and Pizzo Mondello (right). We underline the almost perfect agreement between the two magnetostratigraphic records for the Tuvalian 3 and the Lacian 1 despite strongly differing thicknesses.

some new conodont samples (Krystyn et al., in press). The new sampling clearly indicate different ranges for stratigraphical conodont guides as those cited in Muttoni et al. (2001). These differences may be explained in different ways but we interprete them as resulting from an inadequate taxonomy. The biochronology shown in fig. 5 is a combination of our (black dots) and reinterpreted range data (black bars). The reinterpretations are based on the presence of *M. nodosus* together with *M. oertli* at 70 m (sample PM 19), the exclusive occurrence of *M. pseudodiebeli* without *M. communisti* at 88 m (PM 25) and the last (?) appearance of *M. communisti* at 100 m (PM29). An independent confirmation of the different chronostratigraphic correlations is given by the presence of *H. styriaca* within the first longer reversed polarity interval (PM 5r) above the Carnian-Norian boundary. Following our reference frame (fig.1), the current C-N boundary occurs below the last occurrence of *M. communisti*. The alternative boundary proposed by Orchard et al. (2000) at the FO of the forementioned species is located 7-8 m below and the base of the Lacian 2 zone approximately corresponds to 116 m, slightly above the disappearance of *H. beyrichi*. Here we point out the excellent agreement between the magnetostratigraphic data from Pizzo Mondello and those previously obtained from Turkey (Krystyn et al., in press).

The Pizzo Mondello section constitutes a part of the Upper Triassic deep marine Sicani basin (Catalano and D'Argenio, 1978), which has a minimal size of more than 200 square kilometers on mainland Sicily, where many sections contain the Carnian- Norian time interval. Within a distance of less than 10 km from Pizzo Mondello, there are at least 4 outcrop regions (Monte Triona, Contrada Votana, Monte Cammerata and Contrada Modanesi) which, according to the large faunas described in Gemmelaro's (1888 and 1904) monographs, may provide the missing megafaunal evidence. This will be the task of future work to recollect those data and integrate them into a new stratigraphic network. If this happens, Pizzo Mondello will become the best Tethyan GSSP candidate for the C-N boundary.

Conclusions

Any selection of the Carnian-Norian GSSP will depend on the event chosen to define the boundary. A combination of different events would be preferable to strengthen the adopted boundary as a single event could not be safe enough to insure the validity of long distance correlations. Concerning bioevents, a decision has to be taken about the favourite fossil group. If priority is given to conodonts, their events should preferably correlate to one or more megafossil datums to represent a biochronologically more significant level. This is the case with the FO of M. communisti B which equals the traditional ammonoid-defined base of the Norian and which is close to the FO of *Halobia austriaca* (F-B, SB, BT). The communisti B date is also close to a magnetic polarity reversal (top of PM 4r sensu Muttoni et al., 2001) and may therefore be independently approximated by magnetostratigraphy. *M. communisti* B, however seems to have a facies-restricted and palaeogeographically limited distribution. It is presently not known from Pizzo Mondello and may not be found outside the Tethys what would exclude its use as a worldwide correlation tool. The slightly older FO of *M. communisti* is currently not reproducable by any other bioevent. It may correspond to the onset of one or more diagnostic ammonoids of the *Euisculites* Biohorizon but this needs future verification. An advantage of the *communisti* event is its magnetostratigraphic correlation with the base of the top-Carnian reversed polarity interval PM 4r (fig. 5). However, this almost perfect fit may be incidental because of the slow sedimentation rate in the Turkish sections and it needs a confirmation from a detailed resampling of the uncondensed Pizzo Mondello section. The lowering of the C-N boundary towards the *communisti* event as proposed by Orchard et al. (2000) seems therefore premature but this may remain the single alternative for an intercontinental recognition of the boundary by conodonts. The *abneptis* A event is the youngest possible C-N boundary level. Favoured by H. Kozur (pers. comm.), it may be recognized worldwide but it is not unequivocal constrained in the Turkish sections (Fig. 4,5). Another sometimes favoured alternative, the FO of *Norigondella navicula* is clearly undermined by the presented data.

Finally, we summarize below the results presented in our paper:

- The *abneptis* A event is presently not well constrained and the often mentioned *navicula* date is completely inadequat.
- The *communisti* B event can be determined in the Slovakian and Turkish sections which are all thin but not condensed. The biochronological records are similar and no section can be clearly favoured.
- The *communisti* event is found in all discussed sequences but Pizzo Mondello should be clearly preferred because of its expanded sedimentary thickness and of the most detailed magnetostratigraphic record obtained there. However, additional studies are necessary to improve the fossil record from this section before any formal steps may be initiated.
- Classical sections in Feuerkogel (Salzkammergut, Austria) though preparing the base for the ammonoid defined C-N boundary, are useless because they are highly condensed and they do not provide a primary magnetostratigraphic record.
- Chemostratigraphy may provide other constraints, but which are still not available from any of the described section. Stable isotope studies are in progress both from Bölücektasi Tepe and Pizzo Mondello.

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