

ALBERTIANA



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The primary aim of ALBERTIANA is to promote the interdisciplinary collaboration and understanding among members of the I.U.G.S. Subcommittee on Triassic stratigraphy. Within this scope ALBERTIANA serves as the newsletter for the announcement of general information and as a platform for discussion of developments in the field of Triassic stratigraphy. An electronic version of ALBERTIANA is also available in PDF format at the [ALBERTIANA website](#)

Editor

Dr. Wolfram M. Kürschner, Palaeoecology, Laboratory of Palaeobotany and Palynology, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands, w.m.kuerschner@bio.uu.nl;

Editorial Committee

Dr. Aymon Baud, Musée de Géologie, BFSH2-UNIL, 1015 Lausanne, Switzerland, aymon.baud@sst.unil.ch;

Prof. Dr. Hans Kerp, WWU, Abt. Palaeobotanik, Hindenburgplatz 57, 48143 Münster, Germany, kerp@uni-muenster.de;

Dr. Spencer G. Lucas, New Mexico Museum of Natural History, 1801 Mountain Road N. W., Albuquerque, NM 87104, USA, slucas@nmmnh.state.nm.us;

Dr. Mike Orchard, Geological Survey of Canada, 101-605 Robson Street, Vancouver, British Columbia, V6B 5J3, Canada, morchard@nrcan.gc.ca;

Dr. E. T. Tozer, Geological Survey of Canada, 101-605 Robson Street, Vancouver, British Columbia, V6B 5J3, Canada, etozer@nrcan.gc.ca;

Prof. Dr. Henk Visscher, Palaeoecology, Laboratory of Palaeobotany and Palynology, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands, h.visscher@bio.uu.nl.

Cover: The participants of the GLOBAL TRIASSIC meeting in Albuquerque.

Executive Notes

From the Chair

Welcome to a landmark issue of *Albertiana*! Those of you who have followed our steady march toward GSSP resolution will recognize the present large volume as a major achievement for STS task groups in particular and for the Subcommittee as a whole, not least Wolfram Kuerschner for producing it. As discussed (some might say dictated!) during our successful meeting in Albuquerque in May, this volume contains an account, in whole or updated, of all candidate sections for the five outstanding Triassic GSSPs. The process of bringing all candidates to the table is now over. What remains to be done is to complete the voting now in progress on the base Olenekian GSSP (in China or India), and the base Carnian in Italy; to agree on the best datum for base Anisian in Romania, and the base Rhaetian in Austria; and to complete dossiers for base Norian and choose between Canada and Italy. Where choices still need to be made, the contents of this volume will permit those interested to assess the merits of candidates and still have their voices heard. None of the voting has yet reached the STS voting stage (and nor therefore the ICS), but this should begin around the New Year, if not sooner, once the task groups have declared their preferences. This means we could still be at least three months away from having dossiers presented for ratification, but I hope we can accomplish this for most if not all GSSPs by the IGC next August, that is the original target date for completion of the ICS Time Scale. Therefore the next few months will be critical and I urge task group members and STS voters to take their responsibilities seriously to expedite this process.

I'd like to take this opportunity to recap the events of the last few months and summarise the GSSP situation. Our meeting in Albuquerque was the last international meeting planned under my chairmanship, following meetings in Hungary (2002), Canada and Italy (2003), Spiti and the Florence IGC (2004), China (2005), and New Zealand, England, and Svalbard (2006). This ambitious program, fortunately supported by IGCP 467 (<http://paleo.cortland.edu/IGCP467/index.html>), allowed us to view and discuss many of the GSSP candidates against a backdrop of Tethyan, Panthalassan, Boreal and Notal Triassic rocks. Rounding out the story with both marine and non-marine strata of the western US brought us to Albuquerque and, thanks to the considerable efforts of Spencer Lucas, a two volume set of key boundary papers published ahead of the meeting. Thanks to the equally sterling efforts of Chris McRoberts, all these papers are now available for free download as pdfs at <http://paleo.cortland.edu/globaltriassic/>. It is upon that foundation that the current issue of *Albertiana* was built.

There are two candidates for the base Olenekian GSSP: Chaohu, China proposed by a team led by Jinnan Tong, and Mud, Spiti, led by Leo Krystyn. Yuri Zacharov, as task group Chair, took this to a vote immediately after the Albuquerque meeting but neither candidate gained the

necessary 60% majority. Subsequently, intense focus on the proposed boundary resulted in significant improvements to both dossiers (Tong et al., Sun et al., Krystyn et al.) and therefore eventually to an enhanced final proposal that will go forward from here. This is a positive outcome that to my mind trumps the considerable liveliness of the discussions that have swirled around this boundary in recent months. Whatever the final outcome, advocates should realize that the science has advanced and provided us with more than a single improved reference section for future work.

The Lower-Middle Triassic boundary will be defined at Desli Caira in Romania. This has been a long time in the making, it being over seven years since the section was examined during the 2000 Bucharest meeting. Eugen Gradinaru and his task group have finally brought this to fruition and provided us with a GSSP section that has multiple proxies. A magnetostratigraphy-based option for GSSP definition at Desli Caira has also been tabled by Mark Hounslow and others, who have in that work expanded our knowledge of global correlations around this boundary. I look forward to the base Anisian GSSP deliberations and voting being completed soon.

The Ladinian-Carnian boundary proposal for Stuares, Italy has been 'on the books' for some time. Over recent years valuable and necessary comparative data was gathered from both Spiti and Nevada, chiefly by Marco Balini. It was the completion of this work – presented in Albuquerque – that set the stage for broad acceptance of the Italian candidate, which Paolo Mietto and his co-authors fully describe herein. Hence, a ballot is now underway to accept the appearance of *Daxatina* as the key defining event and we should have a decision early in January from Maurizio Gaetani, the task group chair.

The base Norian GSSP has candidates in British Columbia, Canada and in Sicily. In this volume, summaries are provided for each section. These build on previous publications and add considerable new data, much of it acquired during the summer. The broad dataset available from Pizzo Mondello, summarized by Alda Nicora and her colleagues, can be compared with the Black Bear Ridge dataset that includes precise alignment of conodont (Orchard), bivalve (McRoberts), and C-isotope (Williford) data at the newly proposed boundary level. A decision on this boundary should move forward in the New Year.

Finally, the Norian-Rhaetian boundary situation at Steinbergkogel, Austria is updated by Leo Krystyn et al., following their initial proposal in the Albuquerque volume. There appears to be broad support for a GSSP at this site, although 'trans-Panthalassan' correlation is a problem due to provincialism. For this GSSP, we need an agreement about the best datum, as discussed also by Beth Carter and myself in this volume.

Hence, with this process nearing completion, we can all look forward to soon arriving at an agreed Triassic time scale, which, as it ends, becomes the starting point for elucidating Earth History through use of a common language. This will take place under the guidance of a new

STS executive announced elsewhere in this volume. Please give them your full support as they shape the future direction of STS activities.

Mike Orchard
November, 2007

From the Secretary

Minutes of joint business meeting of the STS and IGCP Project 467 The Global Triassic (Albuquerque) May 22-25, 2007

May 24, 2007

PRESENT

A. Baud, G. Bachmann, M. Balini, N. Bonis, H. Bucher, T. Breuhwiler, Chen Zhong, E. Gradinaru, J. Jenks., T. Kolar-Jurkovsek, H. Kozur, L. Krystyn, W. Kürschner, C. Lopez, S. Lucas, L. Mander, C. McRoberts, M. Menning, R. Nicoll, A. Nicora, M. Orchard, G. Piero, S. Richoz, M. Ruhl, Tong Jinnan, R. Weems, K. Williford, Yin Hongfu, Y. D. Zacharov, J.-P. Zonneveld.

AGENDA

1. Welcome and general STS remarks (by M. Orchard)
2. Presentation of Norian/Rhaetian boundary

(by L. Krystyn)

3. Presentation of Carnian/Norian boundary
(by M. Orchard)
4. Presentation of Ladinian/Carnian boundary
(by M. Balini)
5. Presentation of Olenekian/Anisian boundary
(by E. Gradinaru)
6. Presentation of Induan/Olenekian boundary
(by Y. Zakharov)
7. Closing remarks
(by M. Orchard)

ITEM 1.

Chairman opened the meeting at 17:40 and welcomed participants to the joint STS and IGCP 467 business meeting. Chairman thanks all those who participated in the Global Triassic Meeting. Chairman noted this is the final meeting of IGCP Project 467 and thanked all who participated. The chair also noted potential changes in the STS executive which will take effect at the next IGC in Oslo 2008. The proposed executive subject to voting are Macro Balini as new Chair (replacing M. Orchard), M. Hounslow and Jinnan Tong as incoming Vice Chairs (replacing M. Balini and Yin Hongfu), and Christopher McRoberts continuing to

serve as Secretary. The chair stressed the need to complete selection of Triassic GSSPs before the stated ICS goal of having all GSSPs ratified by 2008.

ITEM 2.

L. Krystyn made a report on the status of the Norian/Rhaetian GSSP. Only one candidate section (Steinbergkogel, near Hallstatt, Austria) has been proposed with a preferred defining datum as the FO of *Misikella posternsteini*, although other datums are possible (FO of *M. hernsteini* and the FO of *Paracochloceras suessi*). Krystyn noted that the section has produced paleomagnetic and geochemical results and supports several closely separated bioevents that can be utilized as proxies. A choice for *M. posternsteini* would place the base of the Rhaetian to equate to the base of Sevatian 2. W. Kuerschner noted that the pollen record at Steinbergkogel did not agree so with the conodonts with some Norian forms occurring above the FO of *M. posternsteini*. There was general agreement on the choice of *Misikella posternsteini* (e.g., H. Kozur, A. Nicora,) and S. Lucas suggested the task group was essentially ready to proceed with voting.

ITEM 3.

M. Orchard made a report on the status of the Carnian/Norian boundary. At present, two candidate GSSP sections have been proposed: Black Bear Ridge (Williston Lake, B.C. Canada) and Pizzo Mondello (Sicily, Italy). Orchard presented results on conodont lineages across the Carnian/Norian sequence at Black Bear Ridge and introduced a new zonation. Several possible conodont-defined datums were noted, including *Metapolygnathus echinatus* and a higher datum based on *M. quadrata*. Correlation of these conodonts was possible throughout the Cordilleran Terranes. Primary correlation to the Pizzo Mondello section was, at this point in time, difficult. Orchard commented that the Black Bear Ridge section (and others in the Peace River area) have experienced some thermal alteration precluding the potential for magnetostratigraphy. Orchard and others (A. Nicora and M. Balini) commented on the Pizzo Mondello section and its published magneto and chemostratigraphy and the preliminary results on conodonts. It was noted that work on the microfauna (conodonts) and macrofauna (mostly halobiid bivalves) continues at a fast pace by the Milan group. Spencer Lucas commented that once a primary datum for the C/N boundary is agreed upon, the section with the most proxies would be preferable.

ITEM 4.

M. Balini made a report on the status of the Ladinian/Carnian boundary. At present, only one candidate GSSP section (Stuores, Dolomites, Italy) has been proposed using the FO of the ammonoid *Daxatina canadensis* as the defining marker. The proposed datum has closely associated proxies (e.g., *M. polygnathiformis*) and a refined magneto and chemostratigraphy. There seemed to be a general consensus as to the proposed GSSP and defining criterion. Balini also discussed similarities of the Stuores section with the ammonoid, conodonts, and halobiid bivalve succession South Canyon section (New Pass Range,

Nevada, USA). It was agreed this proposal can be brought to the Task Group for a rapid vote.

ITEM 5.

E. Gradinaru reported on the status of the Olenekian/Anisian GSSP. Only one candidate section (Desli Caira, Romania) is active, yet a final proposal is not yet available. At present, the preferred defining datum is the FO of the conodont *Chiosella timorensis* which is well correlated to other sections. Gradinaru remarked that the relatively deep-water section has a well-understood macro- and microfossil succession and chemo- and magneto-stratigraphic record, and despite some new ammonoid finds which require further study, a proposal would be forthcoming by the Fall. Other sections in China (Guandao) and Russia (Primorye) contribute to our understanding of the Olenekian/Anisian succession and provide good correlations based on conodonts, and geochemistry, yet have a relatively poor ammonoid record. M. Orchard stated that, after undue delay, a complete proposal should be forthcoming and that Gradinaru should work his Task Group to complete a final proposal shortly.

ITEM 6.

Y. Zacharov made reported on progress on selecting the Induan/Olenekian GSSP. Two candidate GSSPs have been proposed: Chaohu (Anhui, South China) and Mud (Pin Valley, Spiti India). At the Chaohu section, the proposed

defining datum (base of bed 24.1) to be the FAD of the conodont *Neospathodus waageni*, with *Euflemingites* appearing slightly later. At the Mud section, potential datums also included the FO of the conodont *Neospathodus waageni s.l* and a broadly contemporaneous FO of *Rohillites rohilla*. Zacharov continued with a presentation on correlations of the *Flemingites-Euflemingites* beds in both proposed candidate sections with the succession in South Primorye (Russia) and, in particular the possible presence of *Rohillites* in Chaohu. However, direct correlation of the ammonoid species is somewhat problematical. Discussion continued with contributions by Yin Hingfu, Zhong Chen, L. Krystyn and S. Richoiz on the completeness of each of the sections, depositional rates, and the differences in the carbon isotope records between the Chaohu and Mud sections.

ITEM 7.

Chairman asked if there was any other business to be discussed and no further points were raised. Chairman thanked those present for their participation and declared the meeting closed at 20:30

Duly submitted,

Christopher McRoberts
STS Secretary

**Voting results for new STS Executive
October 30, 2007**

Following IUGS and ICS statutes, a new slate for the 2008-2012 STS Executive is required by the close of 2007. At the Global Triassic Meeting in May 2007 (see above) the candidates below were nominated. Ballots were sent by e-mail and/or FAX to all 25 voting members of the STS. Twenty-three completed ballots were returned by the specified time and the results are tabulated below

	Yes	No	Abstain	% (affirmative)
Marco Balini (Chair)	22	0	1	96%
Mark Hounslow (Vice Chair)	21	1	2	91%
Jinnan Tong (Vice Chair)	14	2	7	61%
Christopher McRoberts (Secretary)	23	0	0	100%

The newly elected executive will begin their terms at the 33rd International Geologic Congress (Oslo, August, 2008) at which time Mike Orchard will assume the position of Past Chair.

Duly submitted,

Christopher McRoberts
STS Secretary

Past Meetings

**THE GLOBAL TRIASSIC—
CONFERENCE REPORT**

**Spencer G. Lucas and Michael J.
Orchard**

During May 2007, the New Mexico Museum of Natural History and Science in Albuquerque, New Mexico, USA, hosted “The Global Triassic,” an international symposium on the Triassic timescale and related topics that was also sponsored by the Subcommittee on Triassic Stratigraphy (STS) and IGCP 467. The meeting began with a three-day fieldtrip to west-central Nevada to examine classic marine Triassic sections. Key localities examined included those at Fossil Hill and Favret Canyon, essential to Anisian ammonoid biostratigraphy, South Canyon in the New Pass Range, a potential GSSP for the base of the Carnian and New York Canyon in the Gabbs Valley Range, a potential GSSP for the base of the Hettangian (Triassic-Jurassic boundary).

The symposium in Albuquerque followed, and was attended by 63 scientists from the following countries: Australia, Austria, Canada, England, France, Germany, Italy, Japan, The Netherlands, Peoples Republic of China, Romania, Russia, Slovenia, Switzerland, and the USA. Three days of talks and posters (see program below) focused on definition of the Triassic GSSPs (first day), Triassic numerical ages, cyclostratigraphy, magnetostratigraphy and isotope stratigraphy (second day) and Triassic bio-events and nonmarine biostratigraphy (third day).

The post-meeting fieldtrip examined classic nonmarine Triassic sections (Moenkopi and Chinle groups) in New Mexico and Arizona. These included the Petrified Forest National Park in Arizona as well as a visit to the Meteor Crater (not a Triassic feature, though) and the nearby classic Moenkopi footprint and fossil bone quarries.

Some of the key scientific results of the meeting include:

1. Data presentation and discussion of the Triassic GSSPs that remain to be formally defined—bases of the Olenekian, Anisian, Carnian, Norian and Rhaetian.
2. The great potential for a carbon-isotope stratigraphy of the Triassic is clear, with particularly significant excursions during the Early Triassic indicating physical events and corresponding biotic shifts that affected the pace and nature of recovery after the end-Permian extinctions.
3. Both the radioisotopic age and magnetostratigraphic databases for the Triassic timescale are expanding and being refined.

4. New conodont and ammonoid data that continue to refine Triassic correlations.

5. New studies of key nonmarine groups, especially paly-nomorphs and vertebrates, are improving the understanding of biotic events on land during the Triassic and their application to nonmarine Triassic chronology.

The STS met in conjunction with the conference (see accompanying report here by C. McRoberts).

The proceedings of the conference and its fieldtrips have been published as Bulletins 40 and 41 of the New Mexico Museum of Natural History and Science, both edited by Spencer G. Lucas and Justin A. Spielmann. Bull

DAY 1—MAY 23, 2007

Triassic timescale

time	title	speaker
8:00 AM	Introduction/ Triassic timescale	S. Lucas/ M. Orchard
8:30 AM	The Permo-Triassic crisis is prolonged, and the PTB mass extinction is multi-phase.	Yin Hongfu
9:00 AM	Permian-Triassic climatic oscillations in the east Asian continental margin (Sikhote-Alin area), as indicated by fossils and carbon-isotope data	Yuri Zacharov
9:30 AM	Smithian (Early Triassic) ammonoid successions of the Tethys: new preliminary results from Tibet, India, Pakistan and Oman	T. Brühwiler
10:00 AM	The South Canyon section (New Pass Range, Nevada) and its bearing on the definition of the Ladinian/Carnian boundary	Marco Balini
10:30 AM	Coffee break	
11:00 AM	New constraints for the Ladinian-Carnian boundary in the southern Alps: Suggestions for global correlations	Paolo Mietto
11:30 PM	Sedimentary framework of the lower Black Bear Ridge section, British Columbia: A potential Carnian-Norian boundary GSSP	John-Paul Zonneveld
12:00 PM	Conodont lineages across the Carnian-Norian boundary	Michael Orchard
12:30 PM	The Rhaetian candidate GSSP Steinbergkogel (Salzkammergut, Austria) and global correlation of the Norian-Rhaetian boundary	Leopold Krystyn
1.00 PM	Definition and potential GSSPs for the base of the Jurassic System	Spencer Lucas
1:30-4:00 PM	Lunch break	
4:00-7:00 PM	Posters: Mark Hounslow --Magneto-biostratigraphy of the Middle Triassic and the Lower-Middle Triassic transition, central Spitsbergen: Interrelationship of Tethyan and Boreal stratigraphies Tatiana Klets and Alyona Kopylova --The problem of Triassic gondolellid conodont systematics (Conodontophorida, Conodonta) Toshifumi Komatsu --Bivalve assemblage in North Vietnam and South China following the end-Permian crisis Claude Monnet and Hugo Bucher --Ammonite-based correlation of the middle/late Anisian boundary between Nevada and the Southern Alps. Alda Nicora --New biostratigraphic data from the Pizzo Mondello section (Sicani Mounts, Sicily) James G. Ogg and Robert S. Nicoll --Triassic chronostratigraphic database and a display interface Joachim Szulc --Tectonic controls of the high-frequency sedimentary cycles in the Upper Triassic Dachstein platform carbonates, northern calcareous Alps Seyed Hamid Vaziri --Middle to Upper Triassic deep-water trace fossils from the Ashin Formation, Hakhlak area, Central Iran	

DAY 2—MAY 24, 2007

Triassic numerical ages, cyclostratigraphy, magnetostratigraphy and isotope stratigraphy

Time	Title	speaker
8:00 AM	Critical view of the calibration of the Triassic time scale	Roland Mundil
8:30 AM	Early Triassic timescale and new U-Pb ages from south China: First calibration of the Early Triassic carbon cycle perturbations.	Hugo Bucher
9:00 AM	⁴⁰ Ar- ³⁹ Ar constraints on the Norian-Rhaetian boundary, northern Vancouver, Island, Canada	Graham Nixon
9:30 AM	Calibration of Early and Middle Triassic time scales using orbital-climate cycles	M. Menning
10:00 AM	Coffee break	
10:30 AM	The Late Triassic astronomically-calibrated time scale: Advances and challenges	Paul Olsen
11:00 AM	Lower Triassic cyclostratigraphy in Chaohu, China	Jinnan Tong
11:30-1:00PM	Lunch	
1:00-1:30PM	Triassic magnetostratigraphy: Overview	Maureen Steiner
1:30 PM	What do we know about the magnetostratigraphy across the Triassic-Jurassic boundary?	L. Donohoo-Hurley
2:00 PM	The Early Triassic carbon, sulfur and nitrogen isotope record	V. Atudorei
2:30	$\delta^{13}\text{C}$ isotope curve in the Lower Triassic from shallow water carbonates in Japan, Panthalassa realm	M. Horacek
3:00	Coffee break	
3:15 PM	Interpreting the Upper Triassic carbon isotope record	Lawrence Tanner
3:45 PM	Towards a carbon isotope reference curve of the Upper Triassic	S. Richoz
4:15 PM	Multistratigraphic constraints on the NW Tethyan "Carnian crisis"	Thomas Hornung
4:45 PM	Detailed carbon isotope analysis of Triassic-Jurassic key sections in the western Tethys realm	Micha Ruhl
5:15 PM	Organic biogeochemistry of the Triassic-Jurassic boundary	K. Williford
7-9 PM	Meeting of STS	

DAY 3—MAY 25, 2007

Triassic bio-events, tectonics and nonmarine biostratigraphy

Time	Title	Speaker
8:00 AM	Ecologic collapse of benthic communities from restricted platform to ramp during the Permian-Triassic mass extinction	Chen Zhong
8:30	Lower Triassic microbialites versus skeletal carbonates, a competition on the Gondwana margin	Aymon Baud
9:00 AM	Sponge-microbial stromatolites and coral-sponge reefs recovery in the Triassic of the Western Tethys domain	M. Szulc
9:30	Diversity dynamics and evolutionary ecology of Middle and Late Triassic halobiid and monotid bivalves	Christopher McRoberts
10:00 AM	Coffee break	
10:30 AM	Paleoecology of the Late Triassic extinction in southwest Britain	Luke Mander
11:00 AM	Triassic paleogeographic and tectonic evolution of southwestern Laurentia through Jurassic tectonic overprint	John Marzolf
11:30 AM	Conodont biostratigraphy and paleogeography of the Triassic	Robert Nicoll
12-1:30PM	Lunch	
1:30 PM	Upper Triassic Radiolaria and conodonts from San Hipolito Formation, Baja California Sur, Mexico	Patricia Whalen
2:00 PM	Late Triassic palynostratigraphy	W. Kuerschner
2:30 PM	Floral and palaeoenvironmental changes during the end-Triassic: New data from European key sections	N. Bonis
3:00 PM	Tetrapod footprints--potential and limits for biochronology of Triassic continental sequences	H. Klein
3.30	Coffee	
4:00 PM	Triassic nonmarine ichnofacies	A. Hunt
4:30 PM	Upper Triassic conchostracan biostratigraphy of the continental rift basins of eastern North America	H. Kozur
5:00 PM	Triassic tetrapod biostratigraphy and biochronology	J. Spielmann
5:30 PM	Late Triassic aetosaur biochronology revisited	A. Heckert
7-9 PM	Banquet	

Scientific Reports

Final report of the GSSP candidate for the I/O boundary at West Pingdingshan Section in Chaohu, Southeastern China

Chinese Triassic Working Group

Four sections have been successively proposed as the Global Stratotype Section and Point (GSSP) candidates for the Induan-Olenekian (I/O) boundary: (1) Tree Kamnya Cape section in South Primorye (Zakharov, 1994, 1996); (2) Abrek Bay section (Zakharov et al., 2000, 2002); (3) West Pingdingshan (WP) section in Chaohu (Tong et al., 2003, 2004a); and (4) M03 section near Mud in Spiti (Krystyn et al., 2007).

The First Appearance Datum (FAD) of the conodont *Neospathodus waageni* Sweet (*sensu lato*) has been basically accepted as the primary marker to define the I/O boundary (Tong et al., 2003; Krystyn et al., 2007; Zhao et al., 2007; also refer to discussions at recent workshops and voting).

The GSSP guided by the ICS is a permanent reference for geological time. The selection of a GSSP is very strict in order to meet the requirements as a global standard. The GSSP is a specific point in a single stratotype, not a line in a composite section (Salvador, 1994; Murphy and Salvador, 1999; Remane, 2003; Walsch et al., 2004).

Taking account of the requirements for the GSSP, two sections from South Primorye have been withdrawn from the GSSP candidates for the I/O boundary (Zakharov, 2004; also see the recent open letter from Dr. Zakharov). Therefore, the available candidates for the I/O boundary are only the WP Section in Chaohu and the M04 section in Spiti. The choice between the two candidates must of course be based upon a comparison according to the ICS guidelines for the GSSP.

Most data on the Lower Triassic and I/O boundary in Chaohu, especially the WP Section, have been successively published, mainly in recent years (a full list of the publications is on request from jntong@cug.edu.cn). Thus, here we only provide a summary according to the requirements of the GSSP as well as some requested update information, e.g. conodonts at the I/O boundary of the WP Section, magnetostratigraphy of the WP Section.

Global Boundary Stratotype Section and Point (GSSP) Guidelines for GSSP proposals (From Albertiana 26: 63)

‘The Global Boundary Stratotype Section and Point is a permanent reference for geological time. The GSSP is a specific point in a stratotype, clearly marked and documented.’

1. Stratigraphic rank of boundary

Boundary between the Induan and Olenekian Stages in the Triassic System.

2. Geographic and Physical Geology

A. Geographic location (refer to Tong et al., 2003 and web site: <http://www.chaohu.gov.cn>)

A1. Accessibility

The West Pingdingshan (WP) Section (31.6°N, 117.8°E) is about 3 km from downtown Chaohu City, about 1 hour’s drive from the Hefei airport, 2 hours’ drive from Nanjing airport, 5-6 hours from the Shanghai airports, and 3 hours from the GSSPs of the P/T boundary and Wuchiapingian/Changhsingian boundary in Meishan, Changxing mostly through expressways.

A2. Working condition

Chaohu is a medium-sized city in the rapidly developing zone of eastern China with a good economic environment and living conditions. The sections can be visited all the year around though it is sometimes a little hot and humid during summer and occasionally snowy in winter.

B. Geological location (refer to Tong et al., 2003, 2005; Tong and Yin, 2002)

During the early Triassic, Chaohu was paleogeographically situated in a deeper part of the Lower Yangtze carbonate ramp in the low-latitude eastern Tethys.

The Lower Triassic is composed of rhythmic interbeds of mudstone (or shale) and limestone, among which the lower part is dominated by alternations of mudstones

and limestones and the upper part is dominated by limestone, especially nodular limestones.

Conodonts, ammonoids and bivalves are abundant throughout the sections while vertebrates (fishes and ichthyosaurs) and ichnofossils are common only at some horizons.

C. Location of Level and Specific Point (refer to Tong et al., 2003 and Sun et al. in this Albertiana volume)

The proposed I/O boundary in the WP Section, defined by the FAD of *Neospathodus waageni* Sweet (*sensu lato*), is at the base of Subbed 24-16 within a 20 cm bed of limestone that is subdivided into three subbeds, i.e. 24-15, 24-16 and 24-17. It is 23 cm below the FAD of *Neospathodus posterolongatus* Zhao and Orchard, 26 cm below the base of the ammonoid *Flemingites-Euflemingites* Zone, 2.05 m below a positive peak of $\delta^{13}\text{C}_{\text{carb}}$, and 0.6 to 1 m below the base of a normal magnetozone in the WP Section.

In order to precisely define the I/O boundary in the WP Section, the boundary strata have been investigated and sampled repeatedly in detail to confirm the FADs of the key fossils. All the limestone beds thicker than 10 cm around the boundary are subdivided into subbeds. Thus the FAD of *N. waageni* is confirmed in the second subbed (Subbed 24-16) of a 20 cm limestone bed.

D. Stratigraphic completeness (refer to Tong et al., 2003; Zhao et al., 2007)

The Lower Triassic of Chaohu, as one of the classic successions in South China, has been extensively studied, including (conodont, ammonoid and bivalve) biostratigraphy, chemical (carbon isotope) stratigraphy, sequence stratigraphy, magnetostratigraphy, ecostratigraphy, sedimentology, and cycle stratigraphy. All the evidence indicates that there are no evident breaks near to the I/O boundary in Chaohu. Sedimentary facies evolved successively from the late Permian deep-water chert-argillite facies to the Early Triassic deep-ramp carbonate-argillite facies, then to the Middle Triassic lagoon carbonate-evaporite facies. The proposed GSSP for the I/O boundary falls within a natural bed of limestone, which formed in a deep carbonate ramp setting.

The 10 m strata around the I/O boundary in the WP Section have been repeatedly studied and a large number of conodont specimens have been recovered, which show excellent successions in both intraspecies and interspecies variations (or lineages). Both conodont lineages proposed by Orchard (2007) and Zhao (2007, also see previous report of Chaohu) are easily defined in the strata across the I/O boundary in the WP Section. *Neospathodus dieneri* Sweet yields three morphotypes and they show a good succession below the I/O boundary, i.e. *N. dieneri* M1 Subzone – *N. dieneri* M2 Subzone – *N. dieneri* M3 Subzone. The *N. waageni* group has more types identified, including morphotypes, subspe-

cies, and even species such as *N. posterolongatus* Zhao and Orchard that was previously considered to be a subspecies or morphotype of *N. waageni*. Some forms also show a succession in the I/O boundary strata of the WP Section, i.e. *N. waageni eowaageni* Subzone – *N. posterolongatus* Subzone – *N. waageni waageni* Subzone (Tong et al., 2003; Zhao et al., 2007). In addition, the specimens in the key conodont elements such as *N. waageni eowaageni* and *N. posterolongatus* also seem to show a successive variation with the stratigraphic sequence (see below—3.A). Therefore, the conodonts also proved the continuity of the I/O boundary sequence in the WP Section.

The carbon isotope excursion shows a gentle and smooth change across the I/O boundary strata in the WP Section (Tong et al., 2003; Zuo et al., 2006; Horacek et al., 2007a), indicating continuous rock records and stable depositional setting. This case also has been confirmed by the study of cyclostratigraphy, in which the cumulative curve of the thickness of cycles has proved the completeness of strata and the stability of sedimentation rate (Guo et al., in press — a PDF file on request from jntong@cug.edu.cn).

E. Adequate thickness and stratigraphic extent (refer to Tong et al., 2003, 2005; Guo et al., in press)

The Lower Triassic in Chaohu is totally about 250 m in thickness, constituting the core of the Majiashan–Pingdingshan syncline in the northwestern Chaohu and the core of the Sanbing–Yinping syncline in the southwestern Chaohu. The whole sequence formed in a shallowing-upward sedimentary facies and the sedimentation rate gradually shifted from medium to high with the increase of carbonate component in the late Olenekian.

The WP Section continuously exposes the Lower Triassic from the P/T boundary to the upper Olenekian (lower Spathian), covering the Early Triassic strata of about 110 m thickness. The Induan Stage is about 40 m thick and the depositional rate was roughly around ~3.7 cm/ka through the stage (after compaction), according to cyclostratigraphic estimation in the WP Section (Guo et al., in press).

The Lower Triassic is widely distributed in South China and the sequence is easily correlated through the various attributes of the strata such as biostratigraphy (e.g. Yang et al., 1987; Tong and Yin, 2002), ecostratigraphy (Yin et al., 1995), sequence stratigraphy (Tong and Yin, 1998; Wang et al., 2000), carbon isotope excursion (Tong et al., 2007), and magnetostratigraphy (see below—3.B2).

F. Provisions for conservation and protection (refer to the previous report of Chaohu)

The Pingdingshan Hill and its neighboring areas have been strictly reserved by the government since the Chaohu Symposium in 2005. All quarries in the reserved

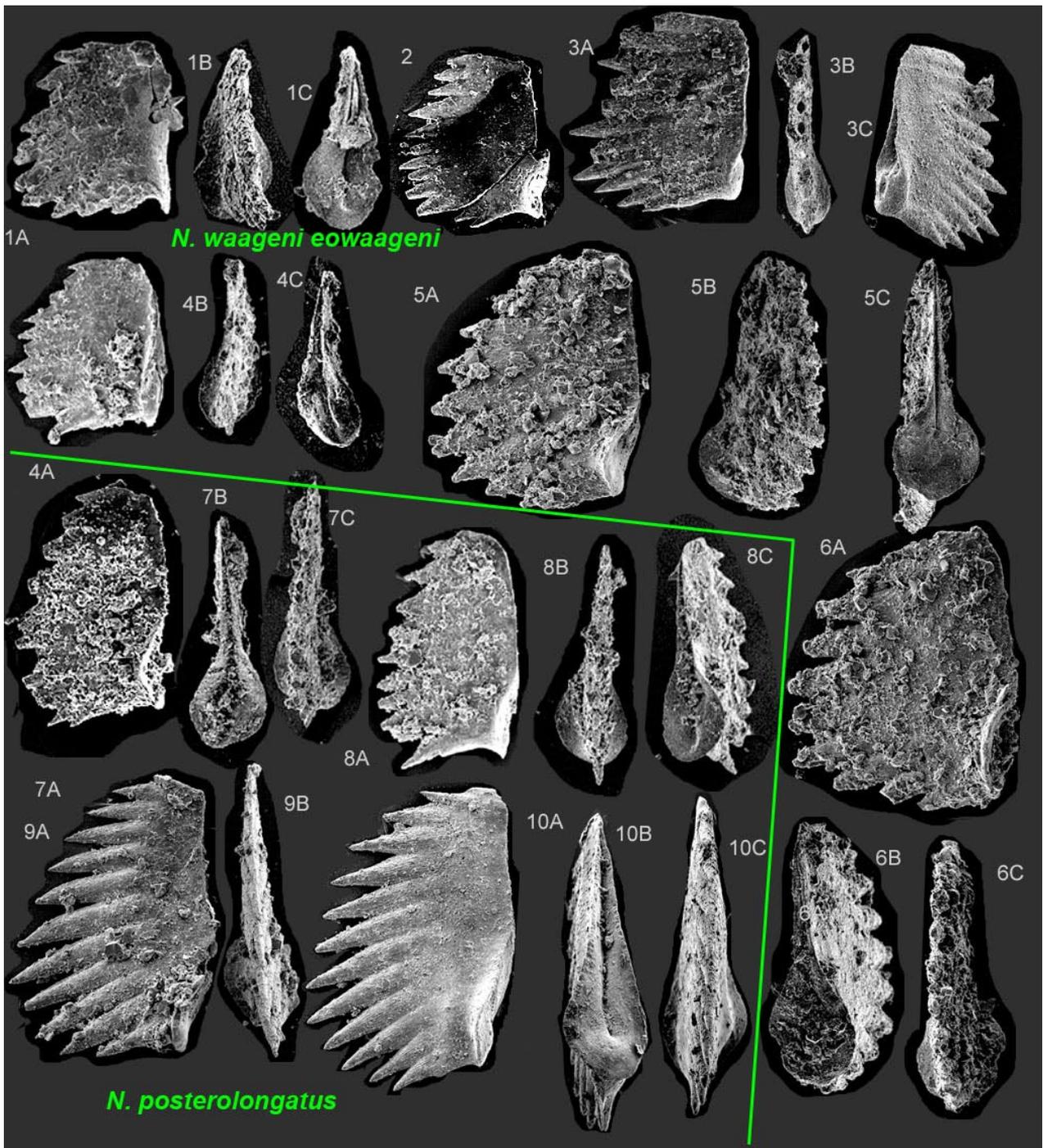


Figure 1: Some conodonts from the basal part of Olenekian in the WP Section, Chaohu. Magnification x160 except fig. 10 x80

1-6. *Neospathodus waageni eowaageni* Zhao & Orchard. **1**, CUG030006, Sample (Bed): CP24-6-2 (Bed No. **24-16**); **2**, CUG030005, Sample (Bed): CP24-7 (Bed No. **24-20**); **3**, CUG03024-21, Sample C24-8 (Bed No. **24-21**); **4**, CUG030008, Sample (Bed): CP24-9 (Bed No. **24-22**); **5**, CUG03026-4, Sample (Bed): CP26-4 (Bed No. **26**); **6**, Holotype: CUG030007, Sample (Bed): CP27-1 (Bed No. **27**). **Variation:** size: small→large; denticles: slender→robust, fused→semi-fused→relatively isolated; flank ornaments: weak→marked.

7-10. *Neospathodus posterolongatus* Zhao & Orchard. **7**, CUG030005, Sample (Bed): CP24-7 (Bed No. **24-20**); **8**, CUG030008, Sample (Bed): CP24-9 (Bed No. **24-22**); **9**, CUG030004, Sample (Bed): CP25-7 (Bed No. **25-25**); **10**, Holotype: CUG030002, Sample (Bed): CP25-7 (Bed No. **25-25**). **Variation:** size: small→large; denticles: slender→robust, fused→semi-fused→isolated; flank ornaments: weak→marked; oral view: flat→thickened; basal cavity: subrounded→elliptical.

areas have been permanently closed, though the sections were initially uncovered by the quarries. The WP Section has been especially prepared with all the bed numbers fixed permanently in the section. In addition, a stele is set up at the section by the government to claim the permanent protection of the area.

3. Primary and Secondary Markers

A. Principal correlation event (marker) at GSSP level (refer to Tong et al., 2003; Zhao et al., 2007)

The conodont *Neospathodus waageni* Sweet was first proposed as the primary marker to define the I/O boundary (Tong et al., 2003) according to the data in Chaohu and it was then adopted by Krystyn et al. (2007) who suggested the Mud Section as an alternative candidate.

In order to ensure the first occurrence (FO) of *N. waageni* in the WP Section, numerous samples from the boundary strata in the section have been prepared through acidization, even a house at the section was rented for the acidization of samples in field during 2002-2004. So each bed (subbed) across the I/O boundary has been successively sampled and studied, including the shale beds.

Conodonts are very rich in the I/O boundary strata in Chaohu. With the accumulation of conodont specimens, an intraspecies variation of the species becomes apparent, thus different morphotypes are generally used to distinguish these intraspecies variations by conodont paleontologists. The stratigraphic importance of these morphotypes has been first taken into account, thus the *Neospathodus dieneri* Zone is subdivided into three subzones according to the successive occurrence of the different morphotypes in the WP Section (Zhao et al., 2003, 2007). The *N. waageni* Zone is also subdivided into three subzones according to the successive FOs of three different types (subspecies) among the *N. waageni* group, i.e. *N. waageni* n.subsp. A (= *N. waageni eowaageni* Zhao and Orchard, 2007 = *N. waageni* Morphotype 3 Orchard, 2007) – *N. waageni* n.subsp. B (= *N. posterolongatus* Zhao and Orchard, 2007) – *N. waageni waageni* (= *N. waageni* Morphotype 2 Orchard, 2007) (Tong et al., 2003; Zhao et al., 2003). Orchard and Krystyn (2007) distinguished six morphotypes among *N. waageni*, excluding the new species *N. posterolongatus*, but they did not indicate the significance and succession of these morphotypes.

The FO of *Neospathodus waageni* (*sensu lato*) in the WP Section is in Subbed 24-16 and it slightly preceded the *N. posterolongatus*, 23 cm below the FO of *N. posterolongatus* in the WP Section, and also 26 cm below the base of the *Flemingites-Euflemingites* Zone (Tong et al., 2003; Zhao et al., 2007). The same succession also occurs in the North Pingdingshan (NP) Section (Zhao et al., 2007).

N. waageni eowaageni Zhao and Orchard (= *N. waageni* Morphotype 3 Orchard, 2007) occurred first in the *N. waageni* group in Chaohu. The specimens of this form also show variation through the section in the WP Section (Fig. 1). The specimens occurring earlier look more primi-

tive: smaller size, more slender and more fused denticles, and weaker flank ornaments. The similar tendency can also be seen in the variation of the *N. posterolongatus* specimens from the WP Section (Fig. 1). These primitive—typical variations are direct evidence of the FADs of these forms.

The conodont *Neospathodus waageni* is so far known as the most widespread form with a certain age range during the early Olenekian time. Not only was it common in the low-latitude Tethys and peri-Gondwana regions, but it also occurs in western America and the Boreal realm such as Spitsbergen and South Primorye (Zhao et al., 2007).

B. Other stratigraphy

B1. Biostratigraphy (refer to Tong et al., 2003, 2005; Zhao et al., 2007)

The Lower Triassic of Chaohu has received detailed investigation and the whole biostratigraphic succession has been established, including an 8-zone conodont succession, a 6-zone ammonoid succession and a 4-zone bivalve succession (Tong et al., 2005; also see the early report of Chaohu).

The conodont study in Chaohu has resulted in many discoveries of new forms, detailed understanding of basic successions and its global correlation are constructed (Zhao et al., 2007). As the primary marker defining the I/O boundary, conodonts in the WP Section and at the I/O boundary have been especially clarified.

Ammonoids are very common in Chaohu but the specimens from shale and mudstone in the lower part of the Lower Triassic are preserved only as molds. The better preserved ammonoid specimens are mainly from upper Olenekian limestones (Guo, 1982; Tong and Zakharov, 2004). The same situation exists throughout South China. Therefore, the Lower Triassic ammonoid zonation is based at a genus level in Chaohu and it is applied at least through South China (Tong and Yin, 2002). However, the ammonoid zones are hardly bounded so precisely as the conodonts because they are preserved poorly in many rocks and hardly identified bed by bed.

In comparison with the conodont *Neospathodus waageni*, the primary marker for the I/O boundary, the ammonoids show more of a facies-related distribution around the I/O boundary. So far no single ammonoid species has been known occurring in both low-latitude and medium to high latitude regions. Many important ammonoid genera, such as *Hedenstroemia* and *Rohillites* existed in only certain regions (though it was orally mentioned that *Rohillites* was seen in Guangxi, China, there has never been a specimen formally reported up to now). *Flemingites*, *Euflemingites* and some other genera had a wider distribution at generic level, but their species were strongly facies-related and their occurrences might be diachronous in different latitudes. In addition, to meet the ICS guidelines to define the GSSP at a specific point, the microfossil conodonts can be more precise than the macrofossil ammonoids.

However, ammonoids are more practical and effective

for most general studies because they are easily observed and identified in field, so it is one of the most important secondary markers to define and correlate the GSSPs. The *Flemingites-Euflemingites* Zone is a good marker for the I/O boundary in Chaohu, as well as in South China, and the specific ornaments of some index fossils such as *Euflemingites* sometimes makes them identifiable, even though preserved only in molds. In Chaohu a definite *Euflemingites* (cf. *E. tsotengensis* Chao) was collected in Beds 50~52 of the NP Section, correlated with Beds 25~26 of the WP Section (Tong et al., 2004b). A *Flemingites*-like specimen was observed in Subbed 24-21 of the WP Section, which is the lowest horizon probably recognized from fossil records of the ammonoid zone in Chaohu. Among the ammonoids around the I/O boundary the ***Flemingites-Euflemingites* Zone** occurring a little higher than the I/O boundary is well correlated in most regions, e.g. in Primyore, South China and Spiti, so it is one of the important secondary markers for correlation.

Bivalves are very common in the Lower Triassic of Chaohu. A zonation of four assemblage zones is roughly correlative through South China though the two upper zones are dominated by endemic elements (Tong and Yin, 2002; Tong et al., 2006).

Only a few microspores were retrieved from the WP Section (See Albertiana 34:58-59).

Bony fishes are rich at three horizons in Chaohu. Nine species of 6 genera are identified, showing a transitional actinopterygian fauna from the Paleozoic to Mesozoic (Tong et al., 2006).

Some marine reptile fossils were collected in the upper Olenekian of Chaohu, and they are one of the oldest ichthyosaurs known (Motani and You, 1998).

B2. Magnetostratigraphy (refer to Sun et al. in this Albertiana volume)

In the early years Dr. Hans Hansen performed extensive sampling throughout the Lower Triassic in Chaohu and obtained preliminary results based upon this analysis, which has caused a great deal of attention and discussion. Unfortunately, the work has not been finished and finalized by now, because of his retirement and health problems.

In 2005 after the Chaohu Symposium Dr. Sun Zhiming and his colleagues at the Laboratory of Paleomagnetism of the Chinese Academy of Geological Science re-sampled the WP Section from the topmost part of the Permian to the base of the Olenekian. The measurement was finished a few weeks ago. Drs. Mark Hounslow and James Ogg, have carefully assisted in this work examining all the raw data and providing many valuable and critical comments. The following is a brief summary of this new study (Fig. 2).

Samples were taken for paleomagnetic study in the 44 m strata from the uppermost Permian (Dalong Formation) to the base of the Olenekian (top of Bed 25) in the WP Section. The samples were mainly taken from limestone

and argillaceous limestone beds at 10-15 cm intervals. 295 plugs underwent stepwise (15-20 steps) thermal demagnetization to measure the remanent magnetization (refer to Sun et al. in this Albertiana volume).

Of these specimens 66% contained evidence of a Triassic magnetisation, from which the original magnetic polarity can be determined (Fig.2). The remaining 34% were dominated by a strong Jurassic-Cretaceous age magnetisation, which has fully overprinted the Triassic magnetisation in these specimens. This overprint magnetisation, also in part masks the magnetisation in 55% of the specimens. The clearly documented Triassic magnetisation shows evidence of some 97° anticlockwise tectonic rotation of the WP section, a situation which is not unusual for this part of South China. The magnetostratigraphy for the study section part is dominated by reversed polarity, but is intercalated by six normal polarity intervals that are confirmed by two or more adjacent specimens. Two normal polarity intervals are more substantive, occurring in Beds 16 to 17 and Bed 25 (Fig.2). The basal Griesbachian normal polarity observed in many sections over the world is not evident in the base of the section, probably suggesting it may be condensed, or masked by the dominant overprint in this part of the section. However, the normal magnetozone (WP4n) just above the I/O boundary can be easily correlated to other conodont and ammonoid bearing sections in South China, Iran, Italy, Spitsbergen and Arctic Canada (Fig.3). With the constraint provided by these marine intersection correlations it is also possible to map the base of this normal magnetozone (and by inference the I/O boundary) into non-marine facies such as the Buntsandstein, where there is a well constrained magnetostratigraphy (Szurlies, 2007) (Fig.4). This correlation to the Buntsandstein (see Sun et al., this Albertiana volume), along with the ~100 ky cyclicity present in the Buntsandstein suggests a duration for the Induan stage of ~ 1.2 Ma, which is close to the ~1.1 Ma estimate of Guo et al. (in press) based on the shorter-scale cycles in the Chaohu sections (see below—3.B5).

Whilst determination of the magnetostratigraphy is difficult, in the Lower Triassic of Chaohu, this work demonstrates that with further more detailed palaeomagnetic work on the Chaohu sections, it should be possible to determine a well constrained magnetostratigraphy for the entire Lower Triassic, using the other nearby sections, and the upper-part of the WP section. It should also be possible, using more detailed sampling across the normal magnetozone near to the I/O boundary, to better define the position of the base of magnetozone W4n, for precise correlation (see Sun et al. in this Albertiana volume).

B3. Chemical stratigraphy (refer to Zuo et al., 2006; Tong et al., 2007)

Carbon isotope is supposed to be of great potentiality in stratigraphic correlation as well as reconstruction of ecological environments. About 600 samples were successively studied in 3 sections of Chaohu to compose a complete Lower Triassic carbon isotope succession (see Fig.5A, B, C). The carbonate carbon isotopes ($\delta^{13}\text{C}_{\text{carb}}$) through the Lower Triassic show a characteristic pattern with all the

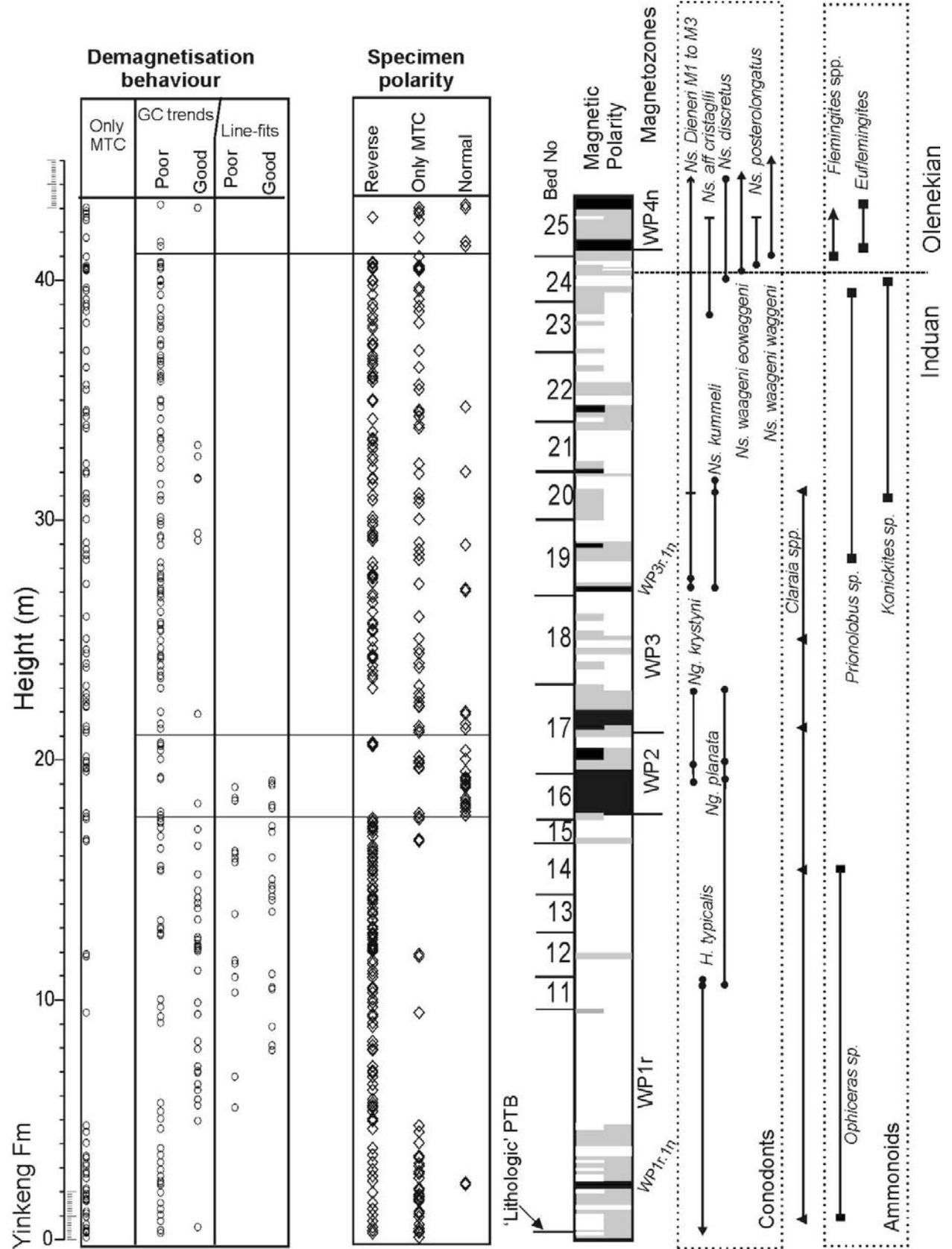


Figure 2: Induan paleomagnetic polarity in the WP Section, Chaohu. Black=normal polarity, white=reverse, grey=uncertain. Full-bars= greater than 1 adjacent specimens, ½ bar=single specimen with no adjacent supporting specimens (from Sun et al., this Albertiana volume).

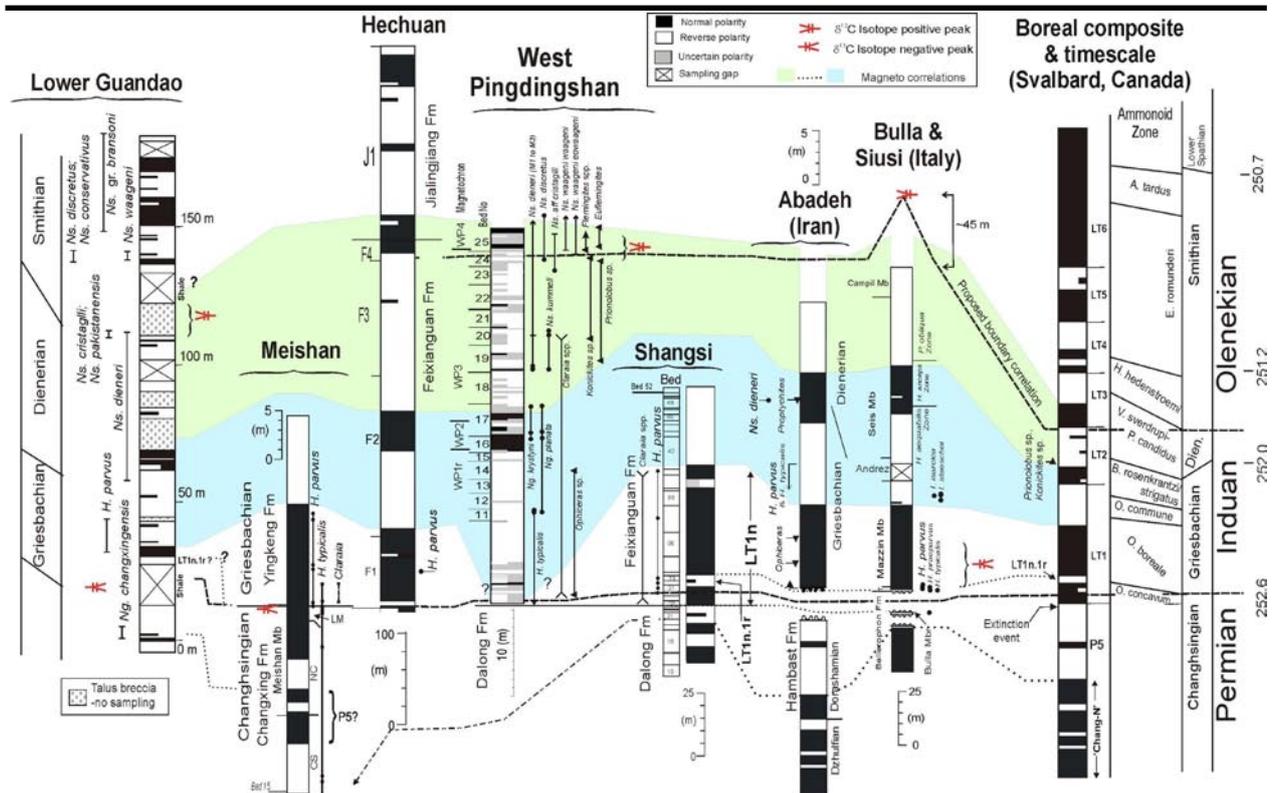


Figure 3: Comparison of the Lower Triassic paleomagnetic polarity in various marine sections over the world (from Sun et al., this Albertiana volume).

curves expressing smooth excursions except for a sharp shift at the Smithian/Spathian boundary. This sharp-shift is explained as corresponding with a marked environmental and ecologic event (Galfetti et al., 2007). The excursion must be smooth in a continuous depositional section such as at the I/O boundary where no marked (environmental and ecological) events happened during the time. A sharp shifting of $\delta^{13}\text{C}$ means either an unusual environmental and ecological event or an unusual depositional record such as non-deposition (break), highly condensed or diagenetically altered rocks.

Frankly speaking, the diagenesis (and weathering) should have more or less affected the composition of carbon isotopes in rocks (not only Chaohu). Some data from Chaohu, especially those from the marlstones in the lower Griesbachian and middle Smithian, probably have been affected by diagenesis and weathering because some of the $\delta^{13}\text{C}$ values look unusually low below -5‰. Similarly, the unusually high values of carbon isotope composition, say over 5‰, are also probably altered by some factors. However, when we studied 8 Lower Triassic sections from various facies in different areas of South China, we found that the pattern of the carbon isotope excursion is of great significance in stratigraphic correlation across facies and regions (see Tong et al., 2007), and this pattern might be globally correlated (Fig.5), even into the lacustrine carbonate facies (Korte et al., 2007). Horacek and others in Albertiana (No.35, pp.41-45), reported a study of the carbon isotopes in the WP Section, getting similar results with ours (see Fig.5D) indicating that perhaps diagenesis did not significantly altered these rocks.

Because of the general diagenetic effect on all rocks and

the differences in the fractionation of carbon isotopes in various environmental settings it is impossible to correlate the absolute values of $\delta^{13}\text{C}$ in different sections, but the fluctuating curves of the carbon isotope excursions are obviously correlative (Tong et al., 2007; Korte et al., 2007). Therefore, the carbon isotope excursion can also be taken as one of the key markers for general stratigraphic correlation.

In addition, Dr. Thomas Algeo spent a few days in Chaohu and has collected a large number of samples for chemical analysis through the whole Lower Triassic sections last summer. The samples are under analysis and study.

B4. Sequence stratigraphy (refer to Tong, 1997)

The sequence stratigraphy has not been studied directly in the WP Section, but the Majiashan Section had been studied in earlier years (Tong, 1997) and a sequence stratigraphic framework and sea level change had been also constructed through the Lower Yangtze region (Yin et al., 1994; Tong and Yin, 1998) and South China (Wang et al., 2000). The sequences are easily correlated and recognized in the WP Section. Since Chaohu was in a deep part of the carbonate ramp during the Early Triassic, the third-order (ortho-) sequences are all the type II sequence, which are mainly composed of TST and HST.

Because the I/O boundary was defined at the top of the *Flemingites* Zone in China in the early years (Tong and Yin, 2002; Yin and Tong, 2002), it was in the basal part of the third sequence. Now the I/O boundary, based on the conodont *Neospathodus waageni*, is much lower than the previous boundary, below the *Flemingites- Euflemingites* Zone, situated in the TST of the second sequence.

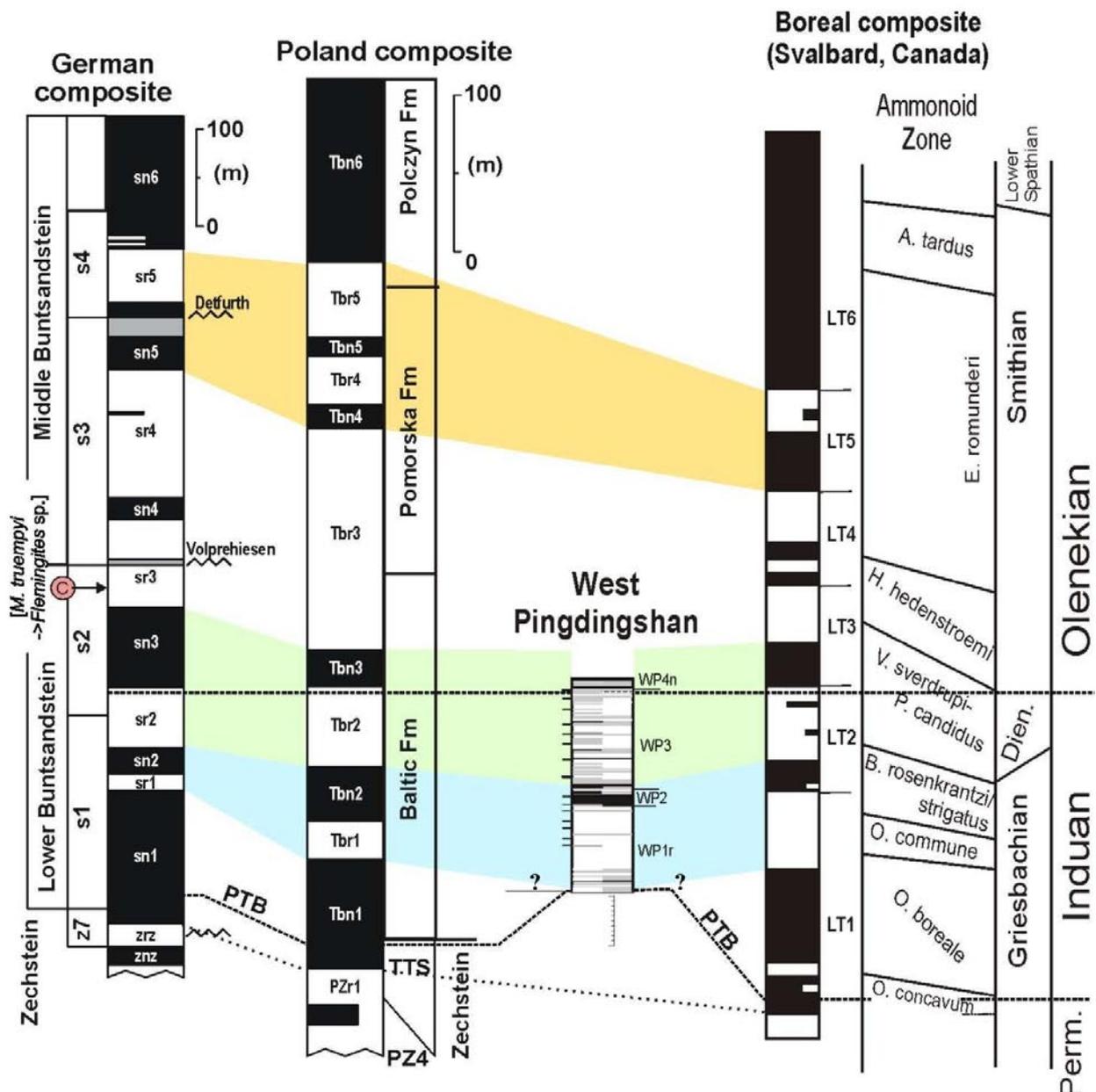


Figure 4: Comparison of the magnetostratigraphy at West Pingdingshan to that from the Buntsandstein (non-marine facies) (from Sun et al., this Albertiana volume).

B5. Cycle stratigraphy (refer to Guo et al., in press; Li et al., 2007)

Cycle stratigraphy (cyclostratigraphy) has been considerably emphasized in recent stratigraphic studies as it becomes a powerful method to calibrate the geologic time scale (Gradstein and Ogg, 2004). It is even suggested to be included in the ICS guidelines as one of the desirable criteria used in GSSP selection (Walsh et al., 2004).

The Lower Triassic in WP Section shows a persistent rhythmic repetition of couplets composed of ~50 cm mudstone and ~20 cm limestone beds. It is impossible not to notice the rhythmic bedding, and the consistency of bed thicknesses is characteristic of orbital forcing climate changes. Li et al. (2007) presented a general study on the depositional cycles of the whole Lower Triassic in Chaohu, while Guo et al. (in press, a PDF file available on request from jntong@cug.edu.cn) has greatly increased the details

of the cycles in the Induan Stage of the WP Section. The orbital-forcing Milankovitch cycles have been clearly recognized based upon the lithologic repetition and magnetic susceptibility data. This estimates the duration of the Induan Stage at ~1.1 Ma. Supposing the Permian-Triassic boundary aged at 252.6 Ma, the I/O boundary is around 251.5 Ma according to the records in the WP Section.

The cumulative curve of thickness of cycles shows that the depositional rate was roughly constant at ~3.7 cm/ka (after compaction) in the WP Section through the Induan, indicating an excellent sedimentary succession for various stratigraphic studies.

B6. Other event stratigraphy (refer to the previous report of Chaohu)

In ecostratigraphy, the Lower Triassic of Chaohu (Majashan Section) is subdivided into 5 community sequences and 12 community zones (Yin et al., 1995). The other stud-

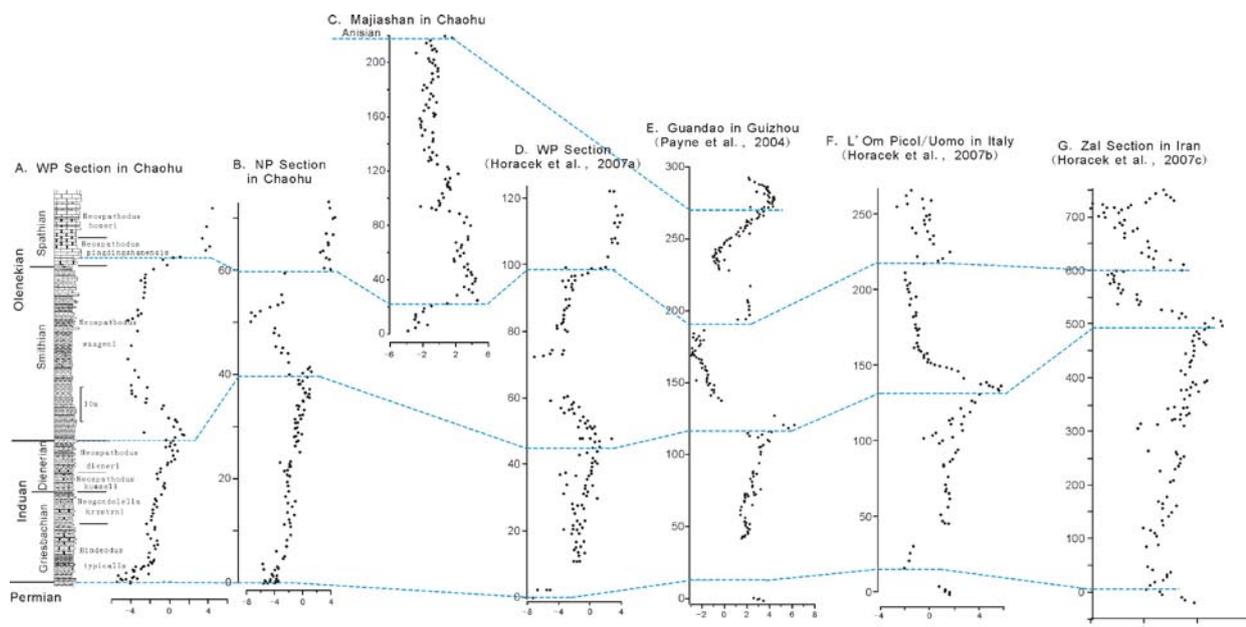


Figure 5: Comparison of Lower Triassic carbon isotope excursions. In the I/O boundary strata of the WP Section the excursion continually increases through the boundary and reaches the highest point in Subbed 25-24, 2.05 m above the I/O boundary, then declines through the early Smithian. This excursion pattern can be easily correlated through all the sections (Refer to Tong et al., 2007 in Geol. Jour. 42: 371-389 for a correlation through South China. A PDF file is available on request from jntong@cug.edu.cn)

ies in Chaohu deal with lithology and lithofacies, storm and earthquake deposits and structures, volcanic events and sediments (see the previous report of Chaohu).

B7. Marine-Land correlation potential

No study has focused on the Triassic marine to non-marine correlation at Chaohu yet. Spores are very rare and poorly preserved. The magnetostratigraphy is likely to be useful to aid this respect now that the WP section can be related to other marine and non-marine sections with a polarity stratigraphy (Figs.3 and 4). The carbon isotopes have proved to be of potentiality for a good correlation in lacustrine carbonate facies, too (Korte et al., 2007).

In addition, the Lower Triassic covers a series of sections from marine to terrestrial via paralic facies in the western part of the Yangtze Block. The marine sections are easily correlated with the WP Section. Thus a further study in the Yangtze Block might bridge the marine-land correlation.

B8. Amenability to geochronometry

Three volcanic ash beds exist within the 2 m strata above the I/O boundary in the WP Section, but only very few small-sized well-crystallized zircons have been retrieved and no isotope dating performed yet.

The cyclostratigraphic study calculates the age of the I/O boundary at ca. 251.5 Ma, taking account of the P/T boundary at 252.6 Ma.

C. Demonstration of regional and global correlation

The proposed GSSP for the I/O boundary is the base of Subbed 24-16 in the WP Section, Chaohu with the FAD of

the conodont *Neospathodus waageni* Sweet (*sensu lato*) as the primary marker. The secondary markers include:

- (1) the FAD of the conodont *Neospathodus posterolongatus* Zhao and Orchard, 23 cm above the GSSP in the WP Section;
- (2) the base of the *Flemingites-Euflemingites* Zone (*sensu lato*, here including the *Hedenstroemia* horizon and the *Rohillites* horizon), 26 cm above the GSSP in the WP Section;
- (3) the base of magnetozone WP4n, which is the 2nd major Lower Triassic normal magnetozone, following the basal Griesbachian normal magnetozone, 0.6 to 1 m above the GSSP in the WP Section;
- (4) the positive peak of $\delta^{13}C$, which is the first Triassic main positive peak of carbon isotopes, 2.05 m above the GSSP in the WP Section;
- (5) about 1.1 Ma after the P/T boundary according to the cyclostratigraphic data in the WP Section.

Accordingly, the GSSP can be globally correlated:

- (1) Tethys: conodonts, ammonoids, paleomagnetism, carbon isotopes, cyclostratigraphy(?);
- (2) peri-Gondwana: conodonts, ammonoids(?);
- (3) Boreal realm: paleomagnetism, ammonoids, conodonts;
- (4) Western America: conodonts, ammonoids(?), carbon isotopes(?);
- (5) land: paleomagnetism, cyclostratigraphy, carbon isotopes.

4. Selection process

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5. Other useful sections

Among the four GSSP candidates for the I/O boundary, only the Chaohu (WP) section is from the Tethys region, while the Spiti (Mud) section is from the peri-Gondwana region and two South Primorye sections are regarded as the intermediate between the Boreal and Tethyan realms. The **South Primorye sections** are preponderant in ammonoid records, bridging a correlation into the Boreal realm where the Olenekian originated. The paleomagnetic correlation also confirms the relation between the I/O boundary in the WP Section and the ammonoid *Hedenstroemia hedenstroemi* Zone in the Boreal realm (Fig.3; and Sun et al. in this Albertiana volume).

The **Spiti (Mud) section** is one of excellent intermediaries to correlate the I/O boundary into the middle to high latitude regions. Despite the hard working condition in a high altitude region, ca. 4 000 m, the I/O boundary section has received a proper investigation in biostratigraphy, sedimentology, sequence stratigraphy and carbon isotopes though the paleomagnetism and cycle stratigraphy are impossible. The I/O boundary is placed at the base of Sub-bed 13A-3 (updated Mud report in this Albertiana volume). However, in most I/O boundary sections, the positive peak of carbon isotopes is at or a little above I/O boundary (Payne et al, 2004; Zuo et al, 2006; Tong et al., 2007; Horacek et al., 2007b, c; Korte et al., 2007). As indicated by Korte et al. (2007), “Mud would be the only locality in the world where the maximum in $\delta^{13}\text{C}$ lies before the base of the Olenekian. This indicates that the first occurrence of *N. waageni* (*sensu lato*) in Sub-bed 13A-3 is obviously a first occurrence datum (FOD), not a first appearance datum (FAD) which should be earlier. According to Orchard, in Sub-bed 13A-1 ‘incomplete specimens of *Neospathodus* are difficult or impossible to determine although they may appear superficially like *N. waageni*’.” (Korte et al., 2007, p.4). We thus believe that the I/O boundary should be placed below Sub-bed 13A-1 in the Mud Section, which is shortly below the positive peak of carbon isotopes and the *Rohillites rohilla* Zone, thus coinciding with the $\delta^{13}\text{C}$ maximum horizon and ammonoid boundary in other regions. But it is to be explained why the curves of carbon isotopes are different in the strata below sequence boundary but coincident above the boundary among the M04, M04A and M05 sections (see Fig.4 of the updated Mud report), and why the carbon isotopes from Bed 13 in the M03 section are entirely different from those in the M04 section (see Fig.12 of Krystyn et al., 2007).

Moreover, the updated Mud report induced a great possibility that there is a break at the base of Bed 13A-1, which was suggested as a sequence boundary of SB₁ (or SB₂?) in the recent updated Mud report. Since “current- indicative layers occur in bed 12C within two 1-2 cm thin and discontinuous shelly packstones” (Krystyn et al., 2007, p.14) and “sub-bed 13A-1 and 13A-2 consists of well-sorted shallow water bioclasts of crinoids and brachiopods” (the updated Mud report), both of the underlying (Sub-bed 12C) and

overlying (Sub-bed 13A-1) strata of this sequence boundary formed in shallow facies above the wave base. Thus there should be a depositional break or exposure surely between 12C and 13A. This also is clearly demonstrated by the sharp shifting of $\delta^{13}\text{C}$ across the boundary (see Fig.4 of the updated Mud report).

Consequently, the Mud Section is a useful section for the I/O boundary correlation but not suitable for a GSSP definition of the I/O boundary because ‘continuity of sedimentation through the boundary interval’ is a basic requirement for a GSSP (see Boundary Stratotypes B.III.5; ref. Cowie, J. W., Ziegler, W., Boucot, A. J., Bassett, M. G. and Remane, J. 1986. Guidelines and Statutes of the International Commission on Stratigraphy, Courier Forschungsinstitut Senckenberg, 83:1-14). In addition, to evaluate the M04 section as a GSSP candidate properly, the fossils from other section should be deleted from Fig.3 of the updated Mud report.

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Magnetostratigraphy of the West Pingdingshan section, Chaohu, Anhui Province: relevance for base Olenekian GSSP selection

Sun Zhiming^{1,2}, Mark W. Hounslow³, Pei Junling², Zhao Laishi¹, Tong Jinnan¹, James G. Ogg⁴

¹Laboratory of Paleomagnetism, Institute of Geomechanics, CAGS, Beijing, China; ²Faculty of Earth Sciences, China University of Geosciences, Wuhan 430074, China; ³Centre for Environmental Magnetism and Palaeomagnetism, Geography Dept, Farrer Avenue, Lancaster University, Lancaster, UK., LA1 4YQ; ⁴Dept. Earth &

Introduction

The Lower Triassic sections at Chaohu have been extensively investigated using a variety of detailed lithostratigraphic, biostratigraphic and chemostratigraphic tools (Tong et al., 2003, 2005, 2007; Zhao et al., 2007). In addition a set of samples measured by Hans Hansen through the entire Lower Triassic has been previously evaluated for magnetostratigraphy (Tong et al., 2003; Hansen & Tong, 2005). However, doubts remain about the validity of this dataset, since a fuller explanation of the Hansen dataset has not been presented (Hounslow, 2006). We here evaluate, new and existing magnetostratigraphic data for the Chaohu sections, and consider its relevance to the proposed GSSP at Chaohu.

In this work we present detailed information on a second set of palaeomagnetic samples collected from the lower 44 m of the West Pingdingshan section (31.6°N, 117.8°E), from the latest Permian into the Olenekian. Permian ammonoids occur in the highest beds of the Dalong Formation just below the “boundary clay bed” and strata containing *Claraia*

and *Ophiceras* occur about 50 cm above the “boundary clay bed”, which is located at 0.33 m in the section. More extensive biostratigraphic data on the overlying Induan is summarized in Zhao et al. (2007). The conodont specimens from the WP Section are not clearly darkened and have a conodont alteration index for the section of about 2.0, which is consistent with alteration index’s of 1.5 to 2.0 in the general study area (Wang, 1993). The bedding in the West Pingdingshan section dips at some 75-85° towards the E, forming part of the core of the Majiashan-Pingdingshan synclinorium.

Methods

A total of 347 drill-plugs were collected for palaeomagnetic investigations from the Yinkeng Formation. These were collected, using a gasoline-powered drill, and were oriented using a magnetic compass. Samples were collected at 10-15 cm intervals. The sampling interval covers the stratigraphic interval from just below the lithologic PTB, to just above the proposed base of the Olenekian (at FAD of *Neospathodus waageni eowaaageni*, morphotype of

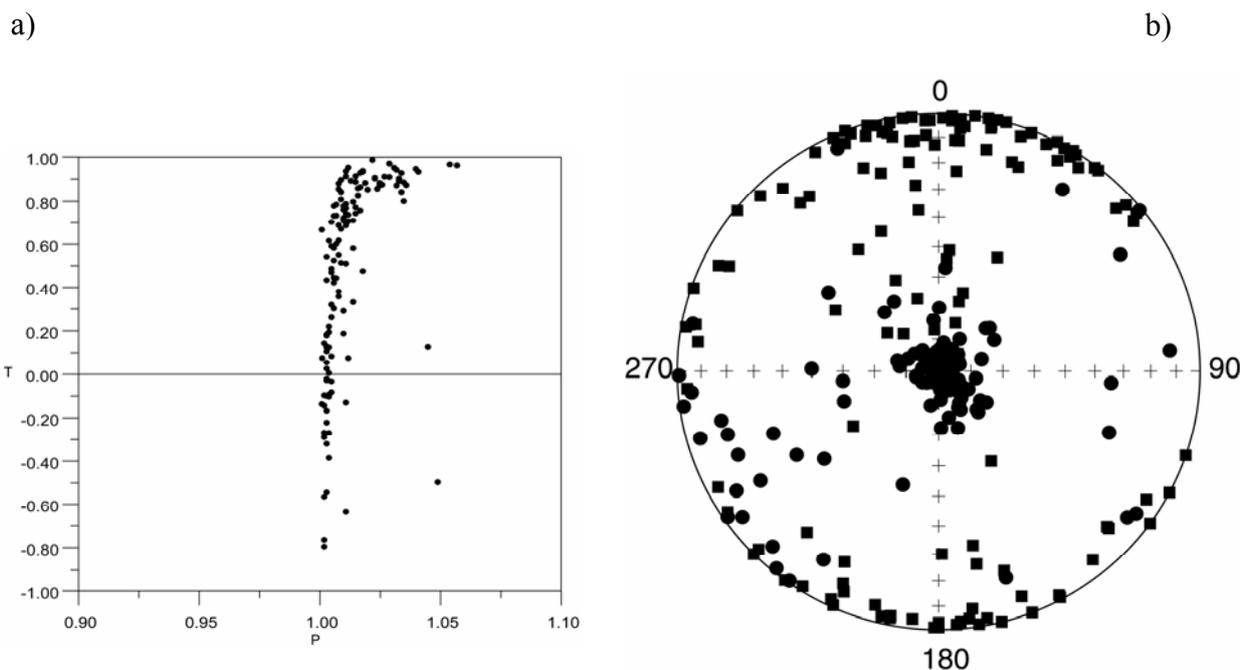


Figure 1: a) AMS. Plots of shape parameter (T) versus anisotropy degree (P'), b) Stereographic projection of AMS principle axes in stratigraphic coordinates for specimens from the Yinkeng Fm. K1 (square): maximum, K3 (circle): minimum.

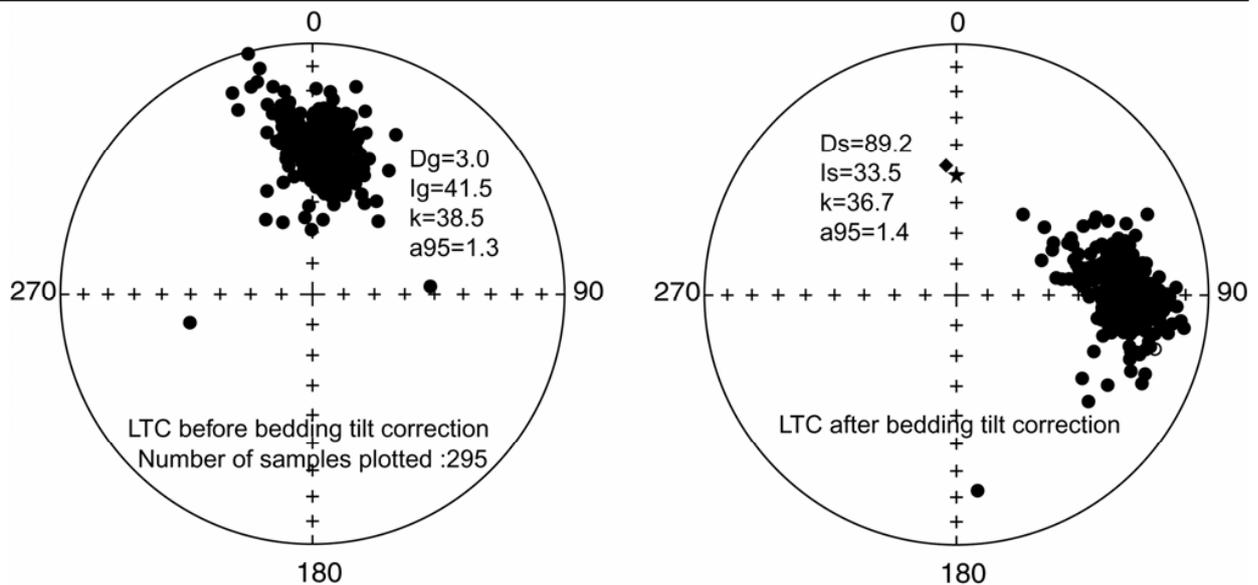


Figure 2: Equal-area projections of the LTC component. Star is the geocentric axial dipole field, and square the present-day field directions

Ns. waageni).

Fifty-two drill-plugs did not produce suitable paleomagnetic specimens for the magnetometer. The suitable remaining 295 specimens underwent stepwise thermal demagnetization using 15-20 steps in an ASC TD-48 oven with an internal residual field less than 10nT. Remanent magnetization was measured with a 2G cryogenic magnetometer at the palaeomagnetic laboratory of the Institute of Geomechanics, CAGS in Beijing. The magnetometer is located inside a Helmholtz coils that reduces the ambient geomagnetic field to around 300nT. Remanent components directions were determined by principal component analysis, as implemented in the Enkin suite of software. Software of Cogné (2003) was also used in the analysis of the resulting demagnetisation data. A KLY-4 Kappabridge susceptibility system was used to measure the anisotropy of magnetic susceptibility (AMS) of 137 specimens, prior to thermal demagnetisation, to assess if these rocks have suffered substantive tectonic strain.

Anisotropy of magnetic susceptibility results

The anisotropy degree (P') of the samples ranges from 1.001 to 1.057 (Fig. 1a). The mean anisotropy degree is 1.013. The anisotropy shape factor (T) varies widely, mostly independent of P' and is distributed mostly in the oblate field ($T > 0$; Fig. 1a). The principal anisotropy directions ($K1$) are dispersed but show some evidence of a preferred N-S orientation (Fig. 1b). The $K3$ directions are on average perpendicular to the bedding plane. The low degree of anisotropy and the reasonably large scatter in the maximum susceptibility axis directions within the bedding plane, indicates these rocks have not experienced large amounts of tectonic strain, although the orientation of the $K1$ axes approximately parallel to the Majiashan-Pingdingshan synclinorium axis is evidence of weak strain, not out of the ordinary for such folded rocks.

Palaeomagnetic Results

The specimens have natural remanent magnetisation (NRM) intensities between 10^{-4} and 10^{-3} A/m. Thermal demagnetization isolated three magnetisation components:

(a) Firstly a low-temperature component (component A: LTC) is isolated in all samples below about 300°C. The mean direction of this component is $D=3.0^\circ$, $I=41.5^\circ$ ($N=295$ and $\alpha_{95}=1.3^\circ$ before tilt correction), and is indistinguishable from the present-day field direction ($D=355.4^\circ$ and $I=47.3^\circ$; Figs. 2a, 4).

(b) A second component (component B: MTC) is determined mostly between the 300-480°C demagnetisation steps, by a well-defined linear segment on the orthogonal vector diagrams in nearly all specimens. This magnetisation component largely dominates the NRM. This component is NNW and down-directed in geographic coordinates and easterly and down-directed in stratigraphic coordinates (Figs. 3, 4). The Fisher precision parameter changes from 42.2 before bedding correction to 40.3 after bedding correction, indicating a slightly tighter directional dispersion in insitu coordinates. The mean magnetisation direction at 350° , $+32^\circ$ ($k=42.2$, $\alpha_{95}=1.4$) in geographic coordinates is not distinct from that expected for the Jurassic-Cretaceous of the South China block (SCB). Hence, we interpret this component B as probably a remagnetization acquired during the Jurassic-Cretaceous period, acquired after tilting of the beds.

(c) Thirdly a high-temperature component (component C: HTC). This component is mostly present between 480-580°C. Its direction is of dual polarity, and is interpreted as a Triassic magnetisation (Figs. 4, 6). Only some 66% of samples showed evidence of this magnetisation component, the remaining specimens were dominated by component B up until complete demagnetisation. Component C has a strong overlap of unblocking temperature with component B in a large majority of specimens at and above 480°C. Only some 11% of specimens show clear linear segments separating component C from component

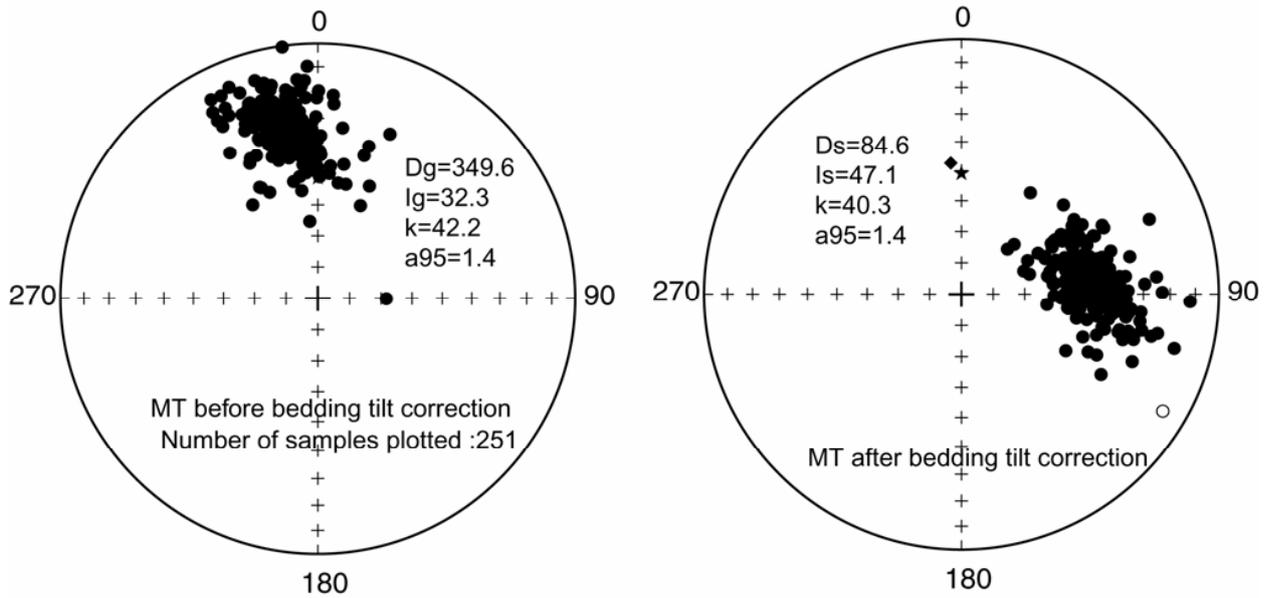


Figure 3: Equal-area projections of Middle temperature component, here termed component B.

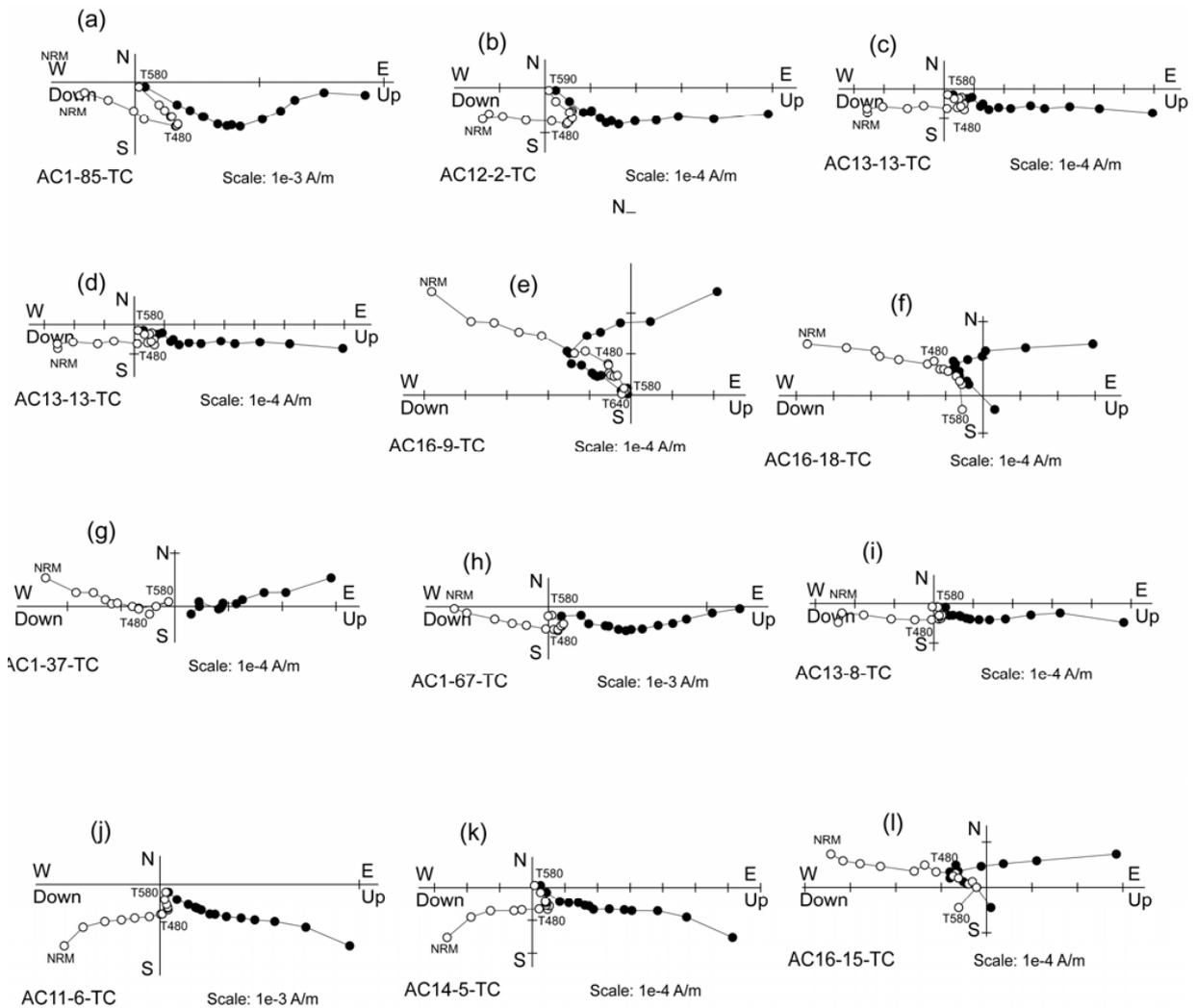


Figure 4: Representative orthogonal demagnetization diagrams (in stratigraphic coordinates). The ChRM directions in the type of specimens displayed were here determined easily by principle component line-fits. a-f: good quality line-fit; g-l: poor quality line-fit; Demagnetization steps in °C in all plots.

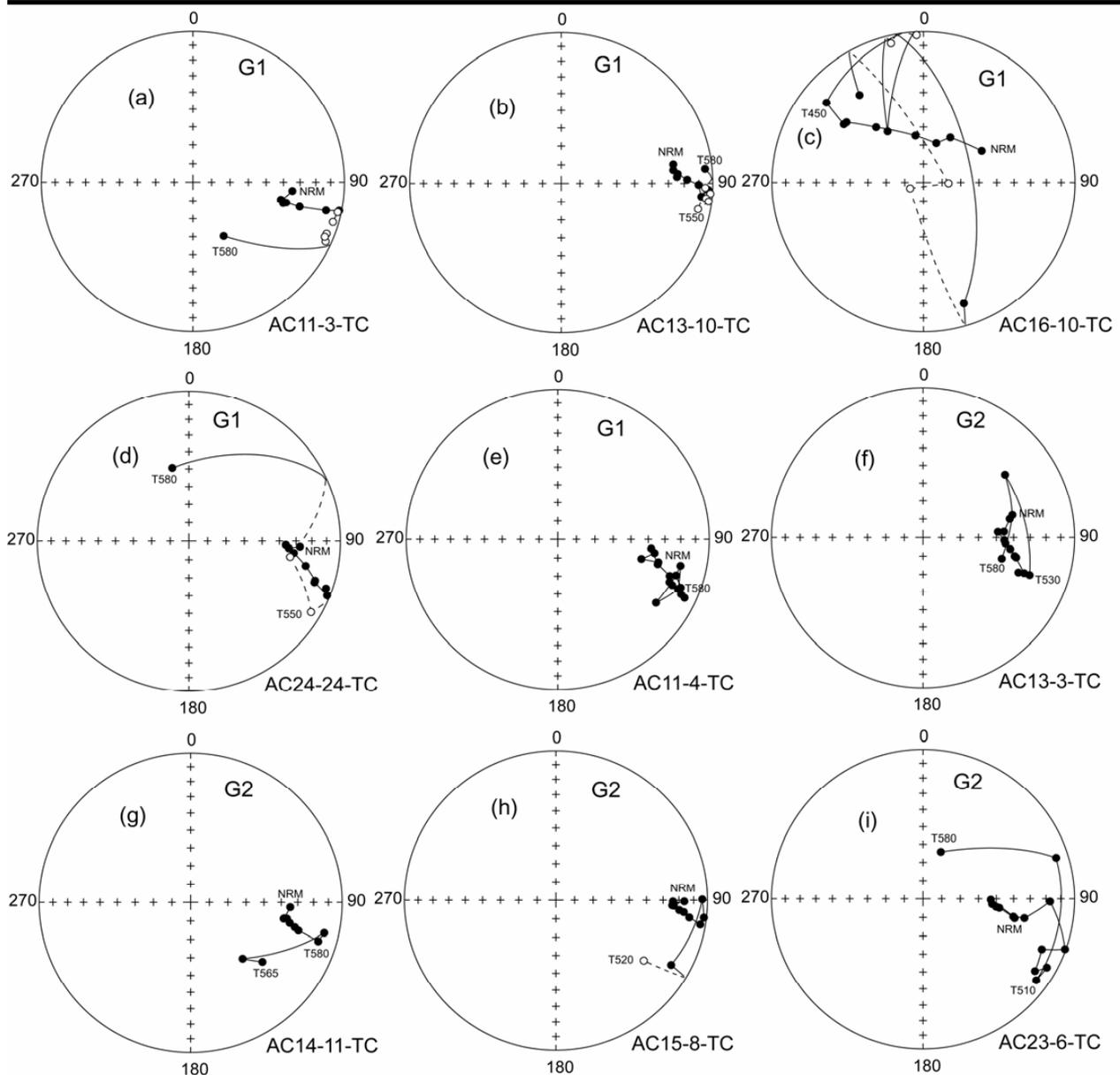


Figure 5: Equal-area projections of the magnetisation directional tracks during thermal demagnetization of representative samples with a variable content of component C (all in stratigraphic coordinates). G1: good quality great circle data; G2: poor quality great circle (with only short paths towards directions that are consistent with component C being present). Plot c) is for a normal polarity sample, all others for interpreted reverse polarity specimens.

B on Zijdeveld plots (Figs. 4, 5).

Categories of demagnetisation behavior were visually assigned to the types of demagnetisation data shown by the specimens.

- Firstly, a category indicating no component C could reliably be interpreted from the specimen data ('MTC only' in Fig. 7). This type of behaviour is dominant in the lower 5 m of the section (which is more weathered than the overlying parts), and above 20 m in the section (Fig. 7). Some 34% of samples possess this type of behavior.
- Secondly two classes (good and poor) of ChRM line-fit data (Figs. 4, 7), which are exclusively present in the levels between 5 and 20 m (Fig. 7). Some 11% of samples possess this type of behavior.
- Thirdly, specimen data, which showed evidence of incomplete separation of components B and C, but which showed evidence of great circle trends towards either the reverse or normal polarity directions of component C ('GC trends' in Fig. 7). Two sub-categories of good and poor behavior were evaluated, based on the amount of approach towards the component C dual polarity directions (Figs. 6, 7). Some 55% of specimens possess this type of behavior.

At the time of writing, we have not fully completed the analysis of the mean directions and great circle data, however a preliminary analysis using the combined line-fit and fitted great circle data, was determined using the method

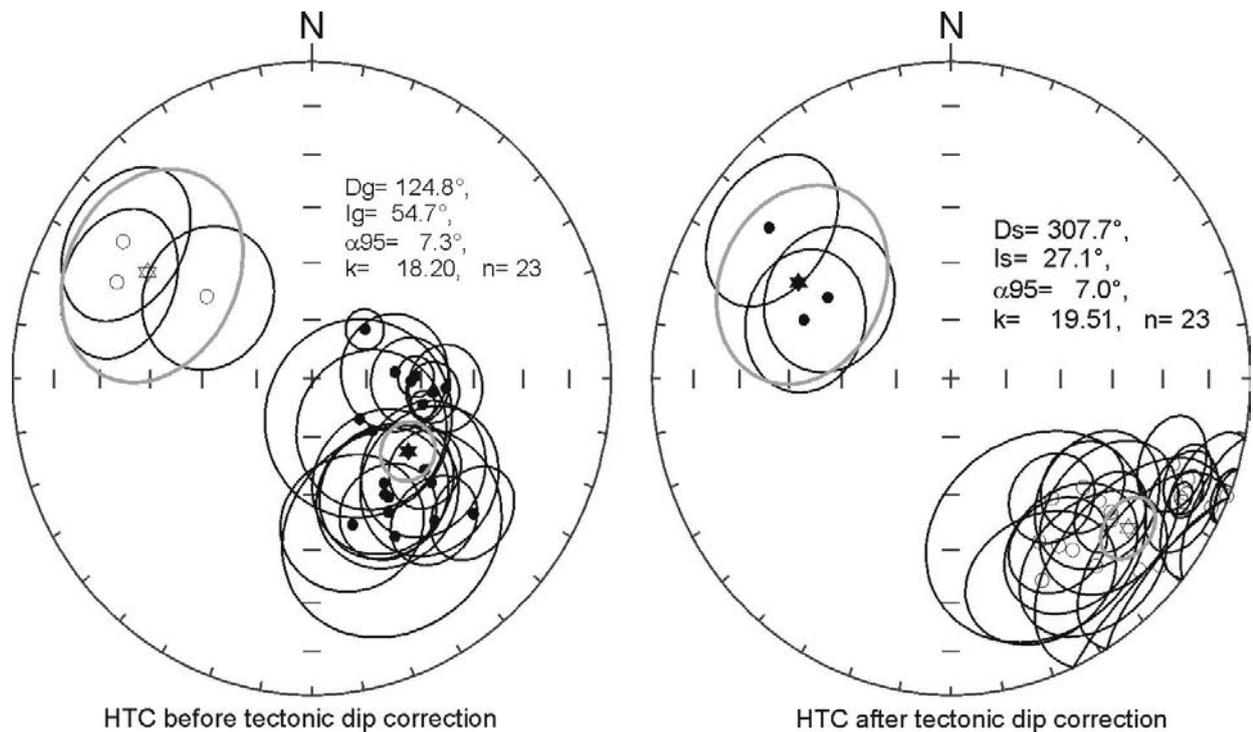


Figure 6: Equal-area stereographic projection of mean directions of high temperature component C for stratigraphic groups of specimen data. Lower (upper) hemisphere directions are marked with closed (open) symbols. Ellipses are 95% confidence cones of group means. Stars=mean directions of these dual polarity magnetisations.

of McFadden and McElhinny (1988), as implemented in the Cogné (2003) software (Fig. 6). The reversal test (McFadden & McElhinny, 1990) on the component C mean direction passes the reversal test although the reverse and normal directions are 16.6° apart ($\gamma_{Obs}=16.6$; $\gamma_{Critical}=29$, simulation test). It may be possible to apply a fold test to the data, when the directional analysis is complete, although the relatively similar bedding dips in the sections may make this poorly conditioned. The averaged normal polarity site-mean direction is $D_g=125^\circ$, $I_g=55^\circ$, $\kappa_g=18.2$, $\alpha_{95}=7.3^\circ$ before tilt correction, and $D_s=308^\circ$, $I_s=27^\circ$, $\kappa_s=19.5$, $\alpha_{95}=7.0^\circ$, $N=23$ after tilt correction (Fig. 6). The mean directions for component C are substantially different in declination from the Lower Triassic means for the South China block, a result of 97° ($\pm 4.6^\circ$) anti-clockwise vertical axis rotation with respect to the stable South China block. Similar anticlockwise rotations occur further south adjacent to the Tanlu fault (Tan et al., 2007). These are probably associated with local rotation of the Chaohu area, during docking with the nearby North China block, along the Tanlu fault.

The determined paleopole lies at 39.4°N, 14.4°E with $A_{95}=5.6^\circ$. The paleolatitude of 14.4° for the section is not significant different (at 95% confidence level) with that predicted for the stable South China Block (Heller et al., 1995, 1998; Steiner et al., 1989; Lehrmann et al., 2006). Hence, we infer component C is a Lower Triassic magnetisation, acquired prior to folding.

Although, we have been unable to examine the raw palaeomagnetic data from the work of Hansen & Tong (2005),

the directions presented by these authors, that were used to interpret the polarity have been made available. The distribution of directions presented by Hansen & Tong (2005) are similar to our directions, only if no distinction is made between component B and C. In addition, the magnetisation components isolated by Hansen were between the 360 and 400°C thermal demagnetisation steps (Tong et al., 2003), which is within the isolation range of our component B (MTC of inferred Jurassic - Cretaceous age). Hence, the magnetostratigraphic interpretation using Hansens data is fundamentally flawed, for two reasons. Firstly, they appear to have failed to separate component B from component C, with their presented ChRM apparently being a mix of these two components. Secondly, they appear to have failed to recognize the ~97° tectonic, vertical-axis, anticlockwise rotation of the Triassic magnetisation. As such, the magnetostratigraphy presented by Hansen & Tong (2005) is erroneous, and should not be considered further.

Magnetostratigraphy

At the time of writing, we have not fully completed the analysis of the mean directions and great circle data, and can not present the specimen VGP latitudes based on the line fit and great circle data. Nevertheless, the qualitative evaluation of the magnetic polarity of each specimen is displayed in Fig. 7, along with the interpreted magnetostratigraphy. The magnetic polarity of the section is dominated by reverse polarity, with three substantive normal polarity magnetozones (WP2n, WP3n and WP4n), and two much thinner (<0.5 m thick) normal magnetozones (WP1r.1n, WP3r.1n), represented by sampling at adjacent horizons.

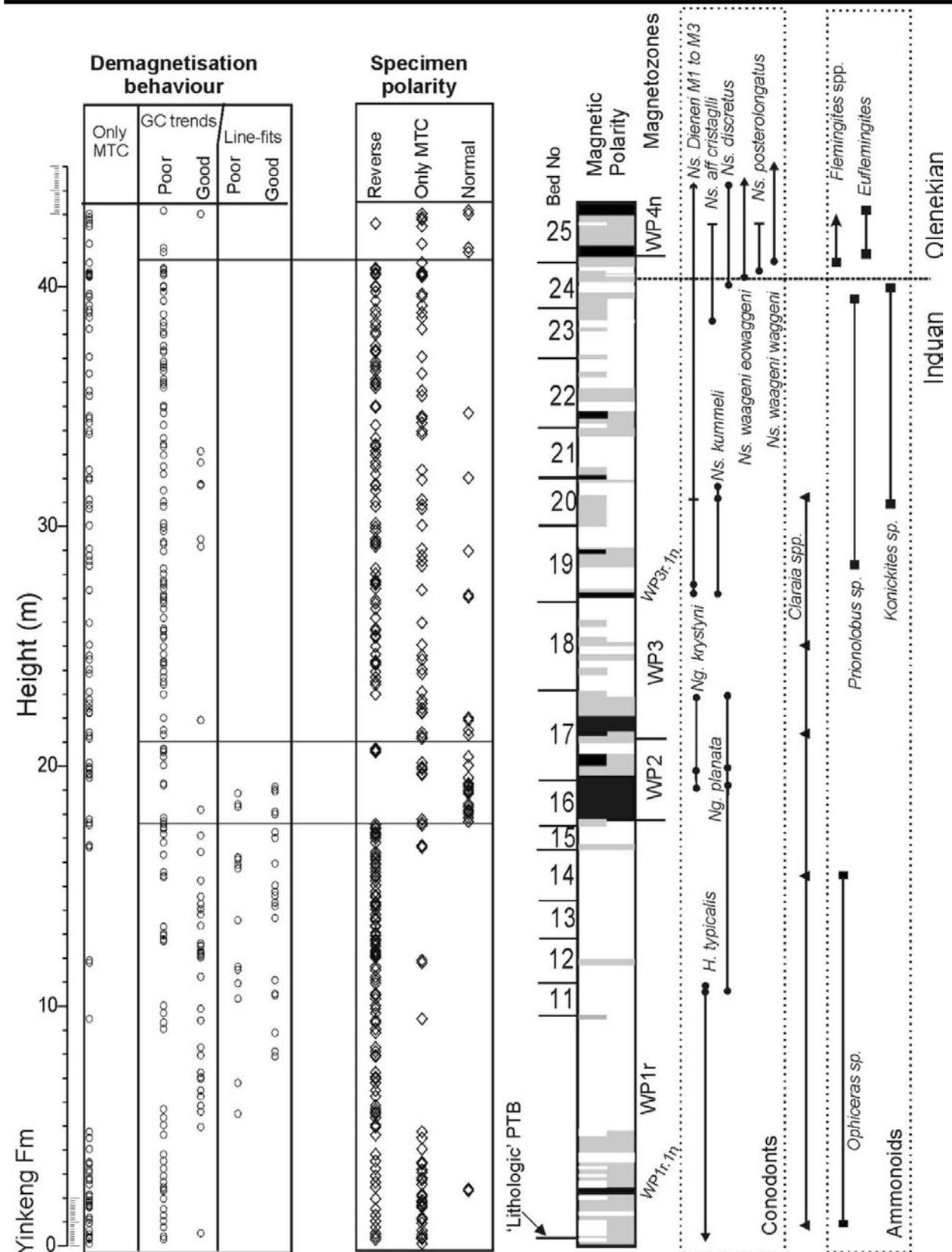


Figure 7: Demagnetisation behaviour (see text), specimen polarity, and the magnetostratigraphy measured in the West Pingdingshan section, along with relevant biostratigraphic data (Zhao et al., 2007). Magnetozones defined by no adjacent specimens of the same polarity, are indicated by half bars, with full bars indicating two or more adjacent specimens of the same polarity. Full grey bars indicate adjacent specimens with only component C present. The major magnetozones have been labeled WP (for West Pingdingshan), for ease of description.

A number of tentative normal polarity sub-magnetozone, represented by a single specimen are present within WP3r. If use is made of recent radiometric and cyclostratigraphic dating of the Lower Triassic (Galfetti et al. 2007; Szurlies, 2007), and the correlations suggested later are accepted, all of these short duration sub-magnetozone (i.e. WP1r.1n, WP3r.1n plus half-bar sub-magnetozone) individually represent a duration less than 15 kyrs.

The magnetic polarity at the proposed base of the Olenekian (at the first occurrence of morphotype *Ns. waageni eowaggeni* in subbed 24-16) is probably reversed, since underlying sub-bed 24-15 and overlying sub-bed 24-17 are reversed, with both sampled intervening beds not containing any evidence of Triassic component C. The FAD of *Ns. waageni eowaggeni* is between 0.6 to 1.0 m below the base of WP4n, with the overlying subbed 25-13 (sample AC25-6) preserving normal polarity (intervening sampled subbed 25-5, sample AC25-2 is indeterminate). Hence, the base of magnetozone WP4n provides a good secondary marker for the proposed base of the Olenekian in the Chaohu sections.

Discussion and global magnetostratigraphic correlation

There exist many magnetostratigraphic studies of Lower Triassic marine sections, many of these within South China; some of the relevant sections are summarized in Fig. 8. It is clear that the magnetostratigraphy of the upper part of the sampled West Pingdingshan section, bears a fairly close correspondence to other studies over this age interval, particularly that at Hechuan (Fig. 8).

The dominance of reverse polarity in the lower part of the section (i.e. that below bed 15, Fig. 8) would suggest, according to the magnetostratigraphy, that this interval is entirely late Griesbachian, since no substantive evidence of the equivalent of normal polarity magnetozone LT1n occurs in the base of the section. It is perhaps possible the normal magnetozone WP1r.1n, some 2.0 m above the "PTB set" (Peng et al. 2001) may represent the equivalent (or part of) of LT1n. Alternatively; the basal Griesbachian normal magnetozone may be hidden by the absence of better quality data in this interval (Fig. 8). The basal part of the West Pingdingshan section was only uncovered in recent years, and not much biostratigraphic work has been done on it, but neighboring sections such as North Pingdingshan and West Majiashan sections have been studied in detail at the boundary, with no evident breaks in sedimentation.

Predominantly normal polarity interval WP2n to WP3n (in beds 16-17) appears to be the LT2n magnetozone in the Boreal composite, which falls close to the Griesbachian-Dienerian boundary, both in the Boreal sections and sections such as Abadeh and Lower Guandao (Fig. 8). The reverse magnetozone (WP2r, represented by 3 sampling levels, in mid parts of bed 17) that divides this magnetozone (i.e. WP2n to WP3n) is between 0.14 and 0.9 m thick, and has no clear equivalent in others sections. Tentative reverse sub-magnetozone are identified at this level in the Gaundao and Bulla sections (Fig. 8) and the Creek of

Embry section in Arctic Canada (Ogg & Steiner, 1991). Clearly further palaeomagnetic sampling at this level could consolidate the precise position of the magnetozone boundaries. At the Bulla/Siusi section, the correlation of the upper-most normal magnetozone shown in Fig. 8 is consistent with the $\delta^{13}\text{C}$ positive isotope spike (which characterizes the Induan-Olenekian boundary interval Tong et al. 2007; Richoz et al. 2007), which there occurs some 45 m above the top of the section sampled for magnetostratigraphy (Horacek et al. 2007).

The magnetozone in the top of the sampled section at Chaohu, WP4n (in bed 25) appears to be the equivalent of LT3n in the Boreal composite, and the normal magnetozone straddling the Feixianguan-Jialingjiang formation at Hechuan (Fig. 8). The exact position of the boundaries of the WP4n magnetozone at Chaohu needs consolidating, with additional sampling in the section. The equivalent magnetozone (i.e. to LT3n) at Greisbach Creek in arctic Canada is preceded by *V. sverdrupi*, some 15 m below (in top part of LT2r), followed by *H. hedenstroemi* (in lower part of LT3r) some 12 m above the top of the magnetozone (Ogg & Steiner, 1991; Hounslow et al. in press). Hence, we can clearly demonstrate the close equivalence of the proposed base Olenekian at Chaohu, with the traditional ammonoid base of the Olenekian in Boreal successions. This strengthens the case for Chaohu as a GSSP in terms of possible ammonoid correlations, even though it has an ammonoid record which has been much debated. To some extent this magnetostratigraphic correlation, seem to echo the comments of Krystyn et al. (2007), who suggest that true *Euflemingites*, are perhaps not as low in the section as might soundly be interpreted. In the Boreal sections, *Euflemingites* do not appear until within LT4n, the overlying normal magnetozone.

There is a close correspondence between the magnetostratigraphy of Lower Triassic marine successions, and that emerging from non-marine successions (Steiner, 2006; Szurlies, 2007; Fig. 9). The magnetostratigraphic correlation suggests that WP4n corresponds to the normal magnetozone (sn3, Tbn3) in the upper part of the Lower Buntsandstein in Germany and Poland (Fig. 9).

Figure 8 (next page): Comparison of the magnetostratigraphy at Chaohu with other studies of marine sections through the latest Permian and Lower Triassic. Data for columns: Guandao (Lehrmann et al. 2006), Meishan (Li & Wang, 1989; Zhu & Lui, 1999; Yin et al. 2001, 2005); Hechuan (Steiner et al., 1989), Shangsi (Heller et al., 1988; Lai et al., 1996; Nicoll et al., 2002; Glen et al. 2002), Abadeh (Gallet et al., 2000), Bulla/Siusi (Perri & Spalletta, 1998; Scholger et al., 2000; Perri & Farabegoli, 2003; Horacek et al. 2007). Meishan Conodont zones:- CS= *Neogodolella* (Clarkina) subcarinata; NC= *Ng. changxingensis yini* – *Ng. changxingensis*; LM= *Hindeodus latidentatus* - *Ng. meishanensis*. Conodont genus abbreviations Ns= **Neospathodus**, Ng= **Neogodolella**. The composite ammonoid-based boreal bio-magnetostratigraphy is from Hounslow et al (in press) with Permian part from Steiner (2006), and the radiometric ages from Galfetti et al. (2007), Lehrmann et al. (2006) and Mundil et al. (2004).

Evidence consolidating this is firstly the co-occurrence of conchostracans (which have a well defined zonation in the Buntsandstein) and ammonoids. Specifically *Magniestheria truempyi* closely occurs with *Flemingites* in Madagascar. *M. truempyi* occurs high in the Lower Buntsandstein within magnetozone sr3 (Kozur and Bachmann, 2005) indicating that these Buntsandstein strata are above the proposed base Olenekian at Chaohu (Fig. 9). Secondly, the ~100 kya cyclicality in the Buntsandstein shows 12 cycles (~1.2 Ma) between the presumed base of the Triassic in the "Graubankbereich" and the base of magnetozone sn3, the level approximately correlated to the West Pingdingshan section (Szurlies et al. 2003; Figs. 8, 9). This estimated ~1.2 Ma of time is close to the ~1.1 Ma duration of the Induan estimated at Chaohu using shorter-term cycles (Guo et al., in press), confirming the likely-hood of the proposed marine to non-marine magnetostratigraphic correlations.

These indicate that the West Pingdingshan magnetostratigraphy has the ability to export the proposed GSSP datum into non-marine and Boreal successions, with a high degree of confidence. In the longer-term this ability may allow greater-detail in the cross-calibration of the cyclostratigraphy from Lower Triassic marine and non-marine successions.

Conclusion

A dual polarity Triassic magnetisation can be extracted from the West Pingdingshan section, in spite of the associated tectonic deformation. The Triassic magnetisation is masked by a strong Jurassic-Cretaceous overprint magnetisation, acquired post-tilting, which variably masks the Triassic magnetisation. Nevertheless some 66% of specimens display evidence in the demagnetisation diagrams of characteristic polarity, either through conventional magnetisation component isolation, or great circle trends. The previous magnetostratigraphic summary of Hansen and Tong (2005) is erroneous, and should be discounted, since it appears to have neither separated the overprint magnetisation from the Triassic magnetisation, or recognized the ~97° anticlockwise rotation of the Triassic magnetisation, due to tectonic rotation of the Majiashan-Pingdingshan synclinorium. The magnetic polarity pattern in the West Pingdingshan section can be closely correlated with other Lower Triassic successions at both low and high palaeolatitudes, although problems remain near the Permian-Triassic boundary due to the inadequate number of suitable quality data. The proposed conodont marker for the GSSP in the Chaohu sections is closely coincident with the base of a normal magnetozone some 0.6 to 1.0 m above. This provides an excellent secondary marker in the Chaohu sections, for mapping of the base Olenekian into successions without conodonts. It also demonstrates that the proposed conodont marker is fairly close to the traditional base of the Olenekian in Boreal successions, near the base of the *H. hedenstroemi* Zone. The magnetostratigraphy also allows export of the proposed Induan-Olenekian boundary into non-marine successions, a feature which seems to be confirmed by the cyclostratigraphic cross calibration of age duration for the Induan.

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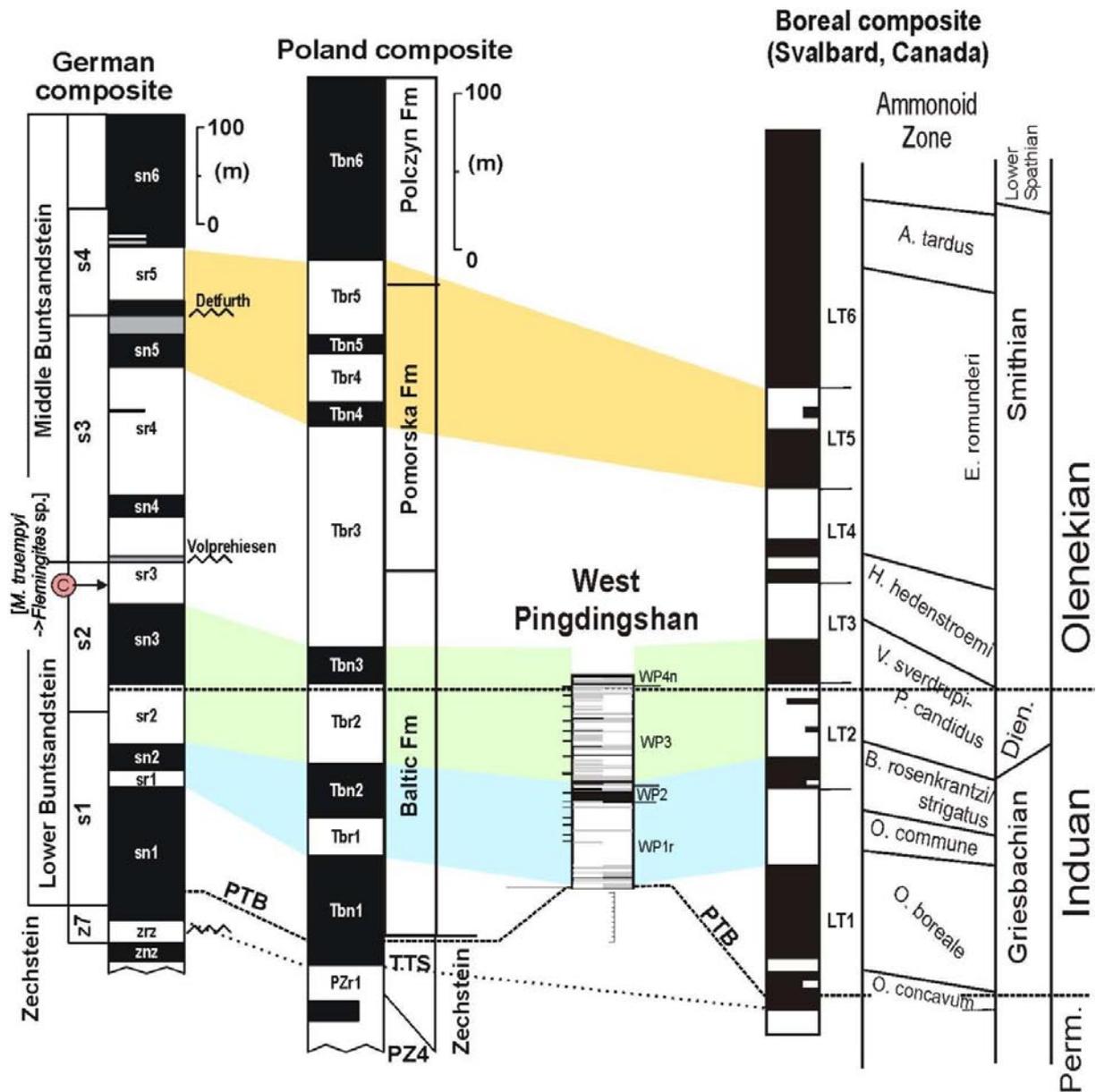


Figure 9.: Comparison of the magnetostratigraphy at West Pingdingshan to that from the Buntsandstein, along with correlations proposed (see text). C=conchostracan-ammonoid tie-point near the base of the Olenekian (Buntsandstein magnetostratigraphic columns from Szurlies, 2007).

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The Induan-Olenekian Boundary (IOB) in Mud – an update of the candidate GSSP section M04

L. Krystyn¹, S. Richoz¹ and O. N. Bhargava²

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

leopold.krystyn@univie.ac.at

²103, Sector 7, Panchkula 134109, Haryana, India.

Abstract A refined study of the Induan–Olenekian boundary beds in Mud has evidenced differences in the boundary relevant fauna of the formerly faunistically undifferentiated bed 13A. The latter bed could be subdivided along internal partings into three sub-beds of which the lower (13A1) demonstrates a pronounced shallowing and the beginning of a prominent $\delta^{13}\text{C}$ excursion. Fragmented brachiopod shells and crinoid ossicles characterize its fossil contents, ammonoids are almost absent; conodonts occur abundantly represented by *Bo.* (=Chengyuania) *nepalensis*, *N. cristagalli* and by the appearance of *N. novaehollandiae*. Sub-bed 13A2 contains the first Olenekian-typical ammonoids including *Rohillites rohilla*, *Parahedenstroemia* and *Kashmirites*, whereas the conodont fauna is similar to 13A1 with additional entry of *N. posterolongatus* and *E. hamadei*. The 10–12 cm thick sub-bed 13A3 shows a well-preserved ammonoid fauna of the rohilla Zone and a rich conodont association of the above cited species plus first representatives of *N. waageni* s.l. According to the recommendation of the Subcommittee on Triassic Stratigraphy, the FA of *N. waageni* s.l. is used to define the IOB at the base of sub-bed 13A3 in section M04 of Mud. The boundary is located close to but distinctly above a probably wider recognizable sequence boundary between beds 12C and 13A and around a prominent positive

1. Introduction

Following a demand of some members of the IOB Task group, we present the results of a most recent (August 2007) and more detailed resampling of the proposed GSSP candidate section in Mud (Spiti Himalaya, Fig. 1). Some of the data are quite surprising and shed new light on the suitability of the proposed boundary event (FA of the conodont *Neospathodus waageni* s.l.) for an interregional and/or intercontinental correlatability of the boundary. In the following paragraphs, we will only deal with the I-O boundary relevant interval of candidate section M04 (including M04A), for a more general background the reader may refer to the earlier documentation in Krystyn et al., 2007 and Orchard et al., 2007.

Based on the presence of the above mentioned boundary-diagnostic conodonts in M04 the sequence documentation is restricted to an interval of 1 m including 2 bed bundles (12, 13) with 6 individual beds (12 A, 12 B, 12C; 13A, 13B, 13C) and 3 sub-beds in 13A and 2 in 13C (Fig. 2). New sedimentary data are presented for the mentioned interval whereas the faunistic update is concentrated on the three sub-beds of 13A and the lower half of 13B (=conodont sample 13B1). Earlier intense collection of macrofossils has produced a rather hard and fresh rock surface in M04, which hampered the extraction of new macrofauna. Fortunately, additional material from well-weathered rock could be collected along strike 70m to the west of M04 where an identical litho-sequence of slightly different thickness (called as M04A, see Fig. 4) allowed an exact bed-by-bed

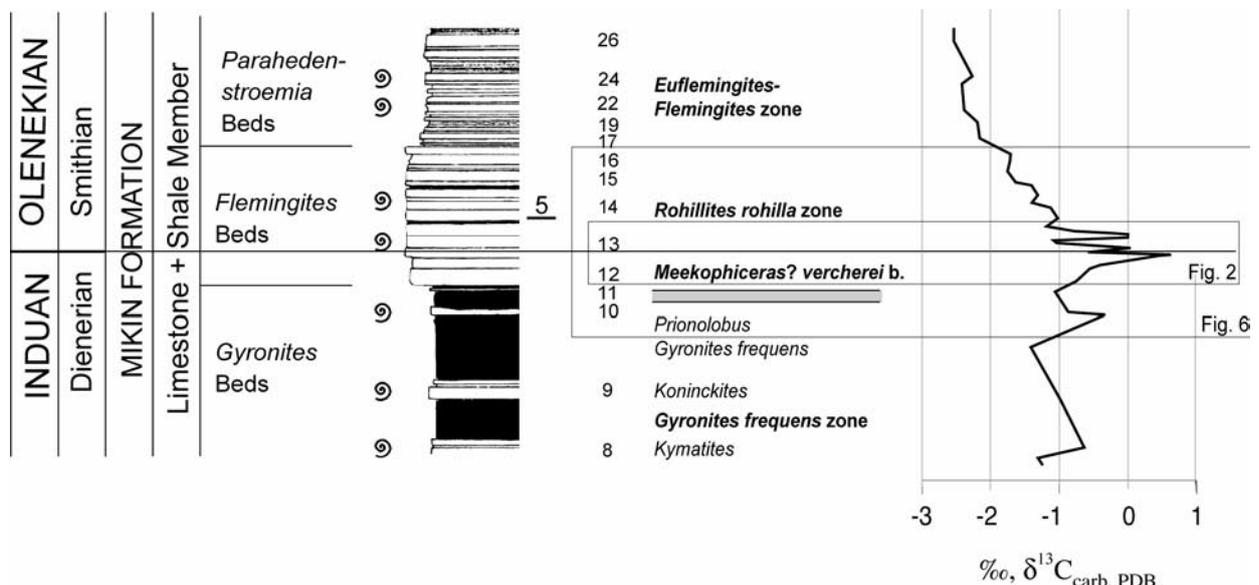


Figure 1: Lower Triassic (Induan, lower Olenekian) litho-, bio- and chemostratigraphy in Mud.

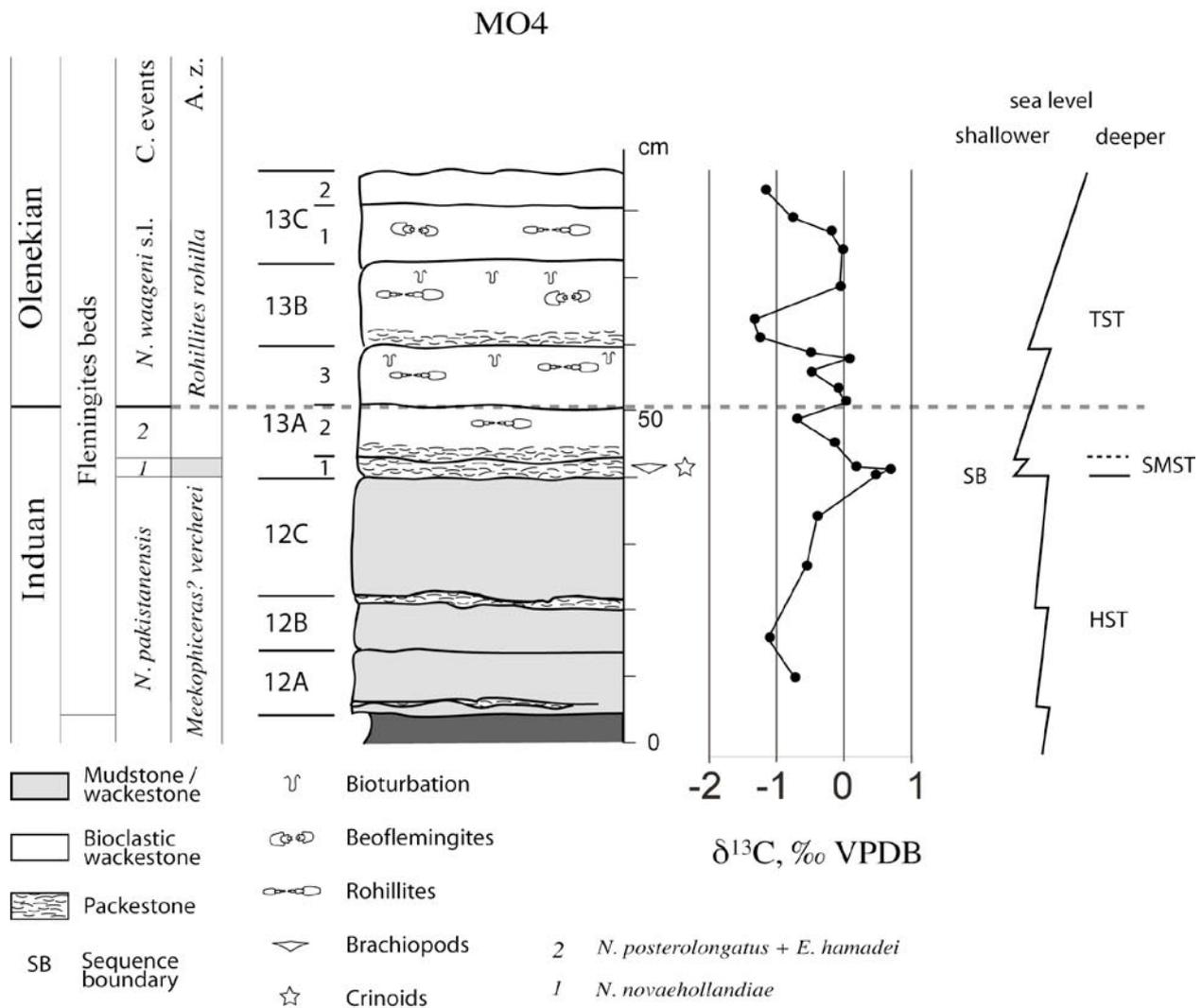


Figure 2: Detailed bedding sequence, microfacies, sequence stratigraphy, conodont and ammonoid events, sea level interpretation and carbon isotope curve in the GSSP candidate section M04.

correlation of the two sites. New cm-scaled carbon isotope data of these two sections and of a third one (M05) show mirroring high-resolution profiles and demonstrate the reliability of the earlier presented curve of section M04 (Richoz et al., 2007).

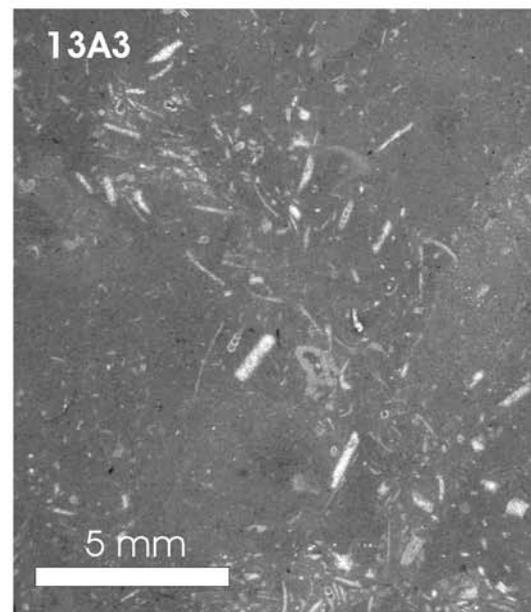
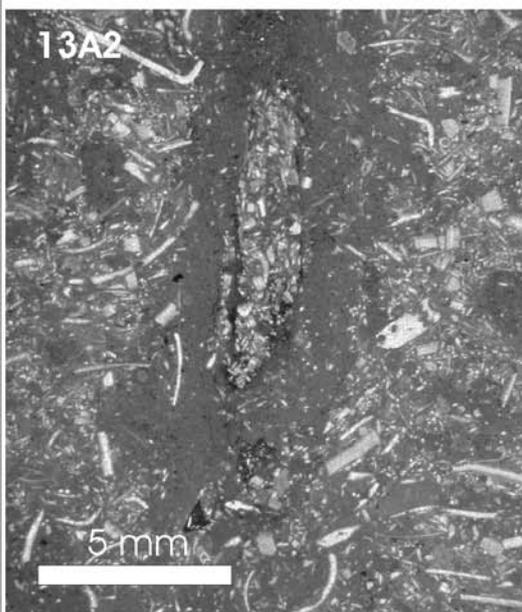
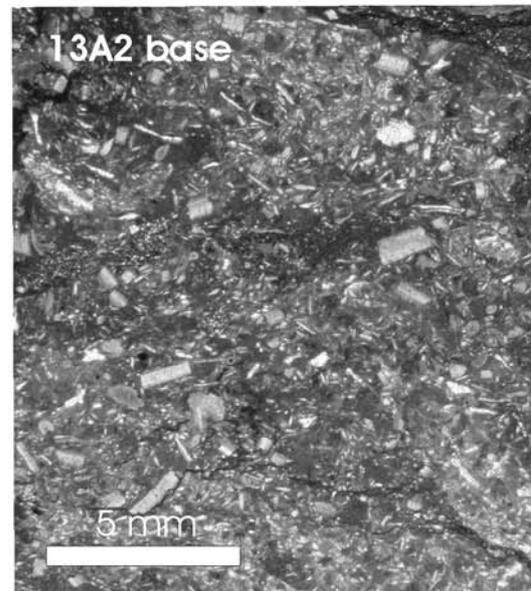
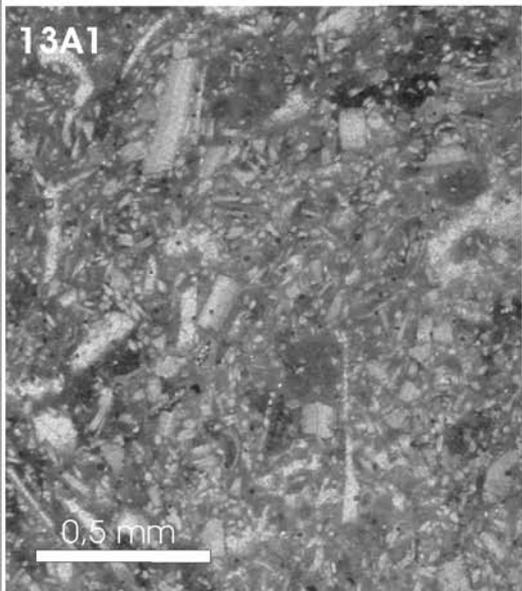
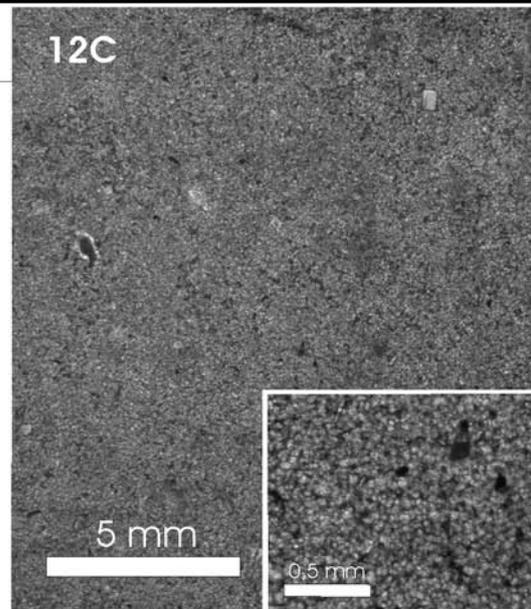
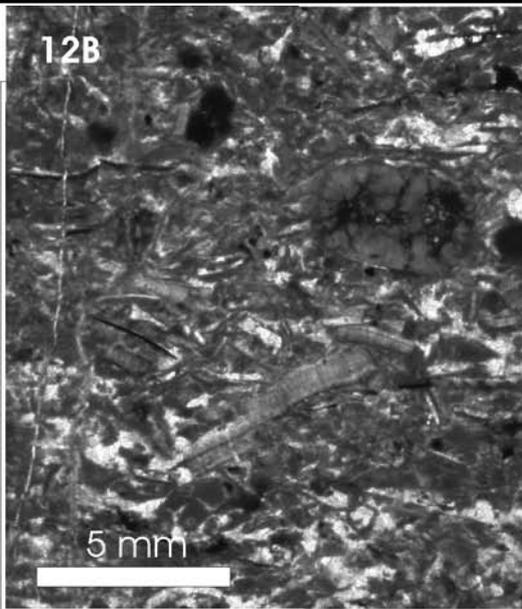
2. Sequence and depositional setting

Many beds of the Mikin Formation with some variation in thickness have been found to be continuous over an aerial distance of more than 40 km in a folded terrain. If un-folded, the distance between Losar and Mud and between Mud and Lalung will be at least 55 km and 65 km respectively. Lateral continuation of beds of even small thickness points to regular slow deposition on a wide/broad shelf of extremely gentle inclination in a period of tectonic quiescence. Presently we are concerned particularly with beds 12 and 13.

Pure grainstone layers (e.g. 12B top, Fig. 3) are restricted to interval 12, where they form sharp-based thin and discontinuous layers under- and overlain by homogeneous secondarily recrystallized mudstone (e.g. 12C, Fig. 3). The 12B shows unsorted mm-sized intraclasts and bioclasts of thin-shelled bivalves, and thicker-shelled brachiopod

fragments of probably shallower origin. It is interpreted as a storm-generated event bed made of current-induced laterally widely transported material. Coarse layers in 13A-1 (Fig. 3) and basal 13A-2 (Fig. 3) are built dominantly by bioclastic packstone with subordinate grainstone nests. They consist of densely packed small bioclasts (< 1 mm) of brachiopods, crinoids and predominantly thin-shelled molluscs. Bioturbation - recorded in common, up to 5 mm thick, burrows enriched in bioclasts - may have destroyed the primary texture (eventually graded?). The upper part of 13A-2 (Fig. 3) changes gradually to a bioclastic wackestone with loosely spaced shell fragments of pelagic bivalves, cephalopods, and rarely brachiopods. Sub-bed 13A3 is a biogen-poor wackestone (Fig. 3) with rare and small fragments of pelagic bivalves and cephalopods representing the typical Lower Triassic autochthonous deep water microfacies of Mud.

Broadly, the bedding features and the carbonate microfacies show a shoaling cycle from bed bundle 12 to sub-beds 13A-1 and 13A-2, culminating in above or close to the lower wave base that was affected by storms resulting in deposition of bioclastic pack- and grainstone layers. The litho-changes between 12C and 13A reflect a rapid change in the depositional environment from below wave



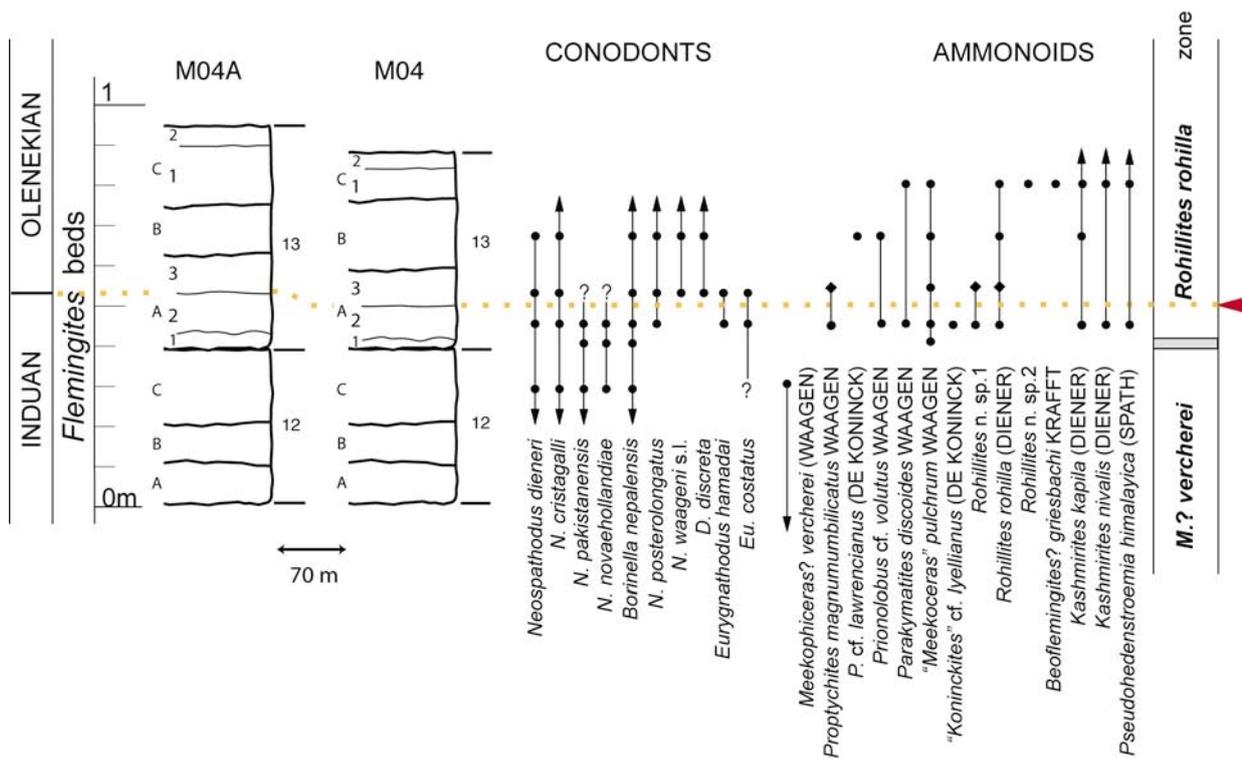


Figure 4: Vertical ranges of conodonts and ammonoids in the candidate GSSP section M04 (with additional ammonoid data from M04A, see text). Arrow marks the conodont based Induan-Olenekian boundary at the base of sub-bed 13A3.

Figure 3 (previous page): Photomicrographs of the Induan-Olenekian boundary beds of Mud M04.
 12B: Grain-/packstone with unsorted mm-sized intraclasts and bioclasts of thin-shelled bivalves and thicker-shelled brachiopod fragments.
 12C: Microsparite, secondarily recrystallized homogeneous mudstone.
 13A1, 13A2 base: Bioclastic packstone with densely packed small bioclasts (< 1 mm) of brachiopods, crinoids and predominantly thin-shelled mollusks.
 13A2: Burrowed bioclastic wackestone with loosely spaced shell fragments of pelagic bivalves, cephalopods, and rarely brachiopods.
 13A3: Biogen-poor wackestone with rare and small shell fragments of pelagic bivalves and cephalopods.

base to episodic bottom-current movement and sediment winnowing due to a sea level fall. Restricted occurrence of benthonic fauna of small rhynchonellid brachiopods and crinoids also indicates shallowing and a better oxygenated bottom facies for sub-beds 13A-1 and 13A-2. The sharp C-isotope changes in MO4A and MO5 from 12C to 13A-1 could be interpreted towards a (short) break in sedimentation between bed 12 and 13 (Fig. 1). In MO4 otherwise, an initial increase of the $\delta^{13}C$ values in 12C towards the 13A-1 peak (Fig. 6) points more to stratigraphic continuity or to, if any, a non-relevant gap. This alternative is in support of a sudden change in the oceanic current system concurrent to the sea level fall and of a subsequent rapid environmental recovery with a most probably global background (Payne et al., 2004).

The following provisional sequential interpretation, subject to detailed microfacies studies, can be made: late highstand system tract (HST) in 12, lowstand system tract (LST) in 13A-1 (to eventually base of 13A-2), transgressive system

tract (TST) in 13A-2 and above [this is the text version of the initial report to the Boundary Working Group where the sea level lowstand phase at the base of 13A was called as LST. However, in exact sequence stratigraphic terminology the lowstand phase above a SB 2 has correctly to be called as SMST (shelf margin sequence tract). All previously recorded faunistic, sedimentary and facial data are in accordance with a deep marine ramp setting interpretation for the IOB in Mud (as well as the Himalayan Lower Triassic in general). The calculated water depth of at least 50-70m (i.e. below mean wave base) should therefore exclude a priori a SB 1 for which also no physical evidence (emersion, erosion, karstification, phreatic cementation) exists. The changes to bottom-winning wave activity at the base of bed 13A1 can be best interpreted as a sea level drop that, taking into account the principal flat ramp geometry of the Himalayan margin, should have affected regionally a wide area. The flat geometry should have also created wide lateral facies shifts even by minor sea level changes. The discussed results therefore point to a submarine SB 2 with continuous water depth of below 50 m in Mud].

The sequence boundary between 12 and 13, therefore, implies not necessarily a break, and if present, it should have been too short to be geologically or stratigraphically relevant. A time-corresponding sequence boundary called as “natural mid-Lower Triassic boundary” (Henderson, 2005) of large lateral extent in Western Canada could be seen as supporting the idea of a coeval worldwide sea level change useful as an additional correlation tool. Though, according to the available sequential and stratigraphic data, the sea level drop seems to have lasted only for short, it had a tremendous oceanographic and faunistic impact as manifested in the marine geochemistry and the explosive faunal radiation at the IOB.

Biostratigraphy

Conodont fauna

Mud has a much richer and more diverse conodont fauna than Chaohu. Details on the emended conodont succession of Mud are contained in the “Report on 2007 conodont collections from Mud, Spiti” by M. Orchard in this Albertiana volume. Two sets of samples (each sample weighting app. 4 kg) have been collected from M04 and M04A (Fig. 4). M. Orchard, whose results are summarized below, has studied the conodonts from M04 in Vancouver:

1) Within bed 13A three successive FO events are discriminated:

- Appearance of *Neospathodus novaehollandiae* in sub-bed 13A-1
- Appearance of *Neospathodus posterolongatus* and *Eurygnathodus hamadei* in 13A-2
- Appearance of *Neospathodus waageni* s. l. in 13A-3

2) Base of 13A3 records a frequency change from *Borinella nepalensis* to *Neospathodus posterolongatus* dominance, an abundance peak of *Eurygnathodus* and ?disappearance of *Neospathodus cristagalli*.

3) Changes in conodont fauna are gradual and specimens show no signs of corrosion or reworking; samples are very rich in individuals of all sizes.

4) Both the successive appearances of different species as well as the highly differing faunal spectra in the sub-beds of 13A are a strong argument against an interpretation of 13A as a single storm-induced event bed.

The Vienna sample set from M04A has yet to be studied in more detail but it shows a coeval appearance date of *Neospathodus waageni* s. l. in 13A3. This date seems therefore qualified to define the Induan-Olenekian boundary in section M04 at the base of sub-bed 13A3.

Absence of *N. waageni eowaageni* in Mud, in our opinion, points to a general rare and limited occurrence of this form. Looking to its record in West Pindingshan substantiates this conclusion because the FAD is based on 1 specimen in sub-bed 24-16 while the next higher and more common report is fairly above, in the *N. posterolongatus* appearance level (sub-bed 24-20) according to CTWG, 2007 (internal task force report). This underlines the accuracy of the STS decision to use the *N. waageni* s.l. date for defining the IOB.

Ammonoid fauna

The ammonoid fauna of the Olenekian base in Mud is currently worldwide unique and there is nothing in Chaohu that may be of help for a detailed correlation. The slow replacement rate of Induan taxa by Olenekian ones in the boundary beds of Mud again points to a continuous sedimentary record and against a break. The low paleolatitude and wide geographical distribution of the *Rohillites* fauna has been demonstrated by Bruewhiler et al., 2007 (Fig. 5).

Ammonoids are almost missing in sub-bed 13A1 (Fig. 4) except for a single specimen of “*Meekoceras pulchrum* Waagen (Pl. 2, fig. 4) found in M04A. *Paranorites aequalis* Spath, 1934 from the upper(?) Ceratite Marls of the Salt Range is morphologically very close and could be a younger synonym. Zhakarov (pers. comm., 2007) compares “*Meekoceras pulchrum* with *Lepiskites kolymensis* (Popov, 1961) The two forms are, however, different in body shape by the narrow, strongly tabulate venter and the smooth shell of the former (see Waagen, 1895, pl. 29, fig. 1c) and the externally rounded, well ribbed phragmocone of the latter (Dagys and Ermakova, 1990, pls. 15-17). “*Meekoceras pulchrum* (Waagen) may cross the IOB as it has originally been described from a low position in the Ceratite Marls of the Salt Range. The sub-bed 13A1 is, thus, of indistinctive zonal age.

No ammonoids could be detected and collected in 13A2 of M04 and it is, therefore, highly probable that all earlier findings from 13A do belong to 13A3. New 13A2 material comes from subsection M04A where fossils are common and the weathered rock surface allowed their extraction. Though the fauna is less well preserved than in 13A3 (no shell preservation) yet is easily determinable to species level. The new M04A collection contains several

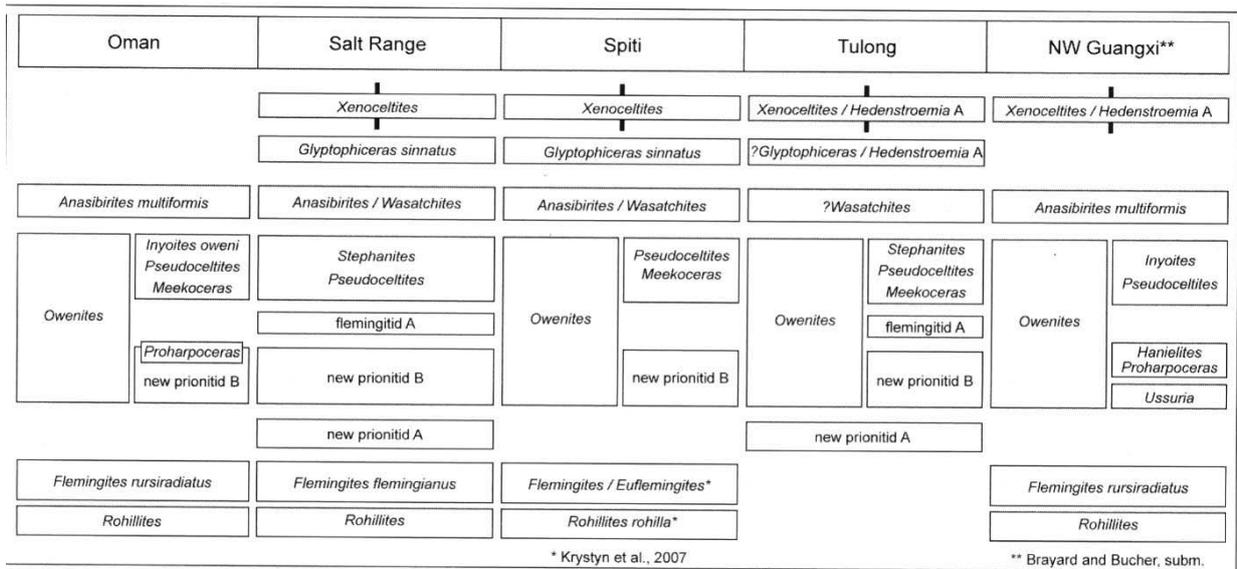


Figure 5: Correlation of Smithian Tethyan ammonoid successions (Brüwhiler et al., 2007). Note wide geographic extent of the *Rohillites* interval below the *Flemingites* zone.

specimens of “*Meekoceras pulchrum* (Pl. 2, fig. 4) and *Kashmirites kapila* (Diener), and a single set of *Rohillites* n. sp. 1 (Pl. 2, fig. 2), *Rohillites rohilla* Diener, *Proptychites magnumumbilicatus* Waagen, *Prionolobus* cf. *volutus* Waagen, *Parakymatites discoides* Waagen, “*Koninckites lyellianus* (De Koninck), *Parahedenstroemia himalayica* (Spath), and *Kashmirites nivalis* (Diener). Almost all these forms occur also in the undifferentiated sub-beds 13A2/3 of sections M03 to M06 (plates 1 and 2).

The ammonoid fauna of sub-beds 13A2 and 13A3 constitutes an interesting and, obviously, a natural melange of Induan and Olenekian taxa. Induan holdovers are *Proptychites*, *Prionolobus* and *Koninckites*, Olenekian innovations include *Rohillites*, *Parahedenstroemia* and *Pseudaspidites*. The FO of *Rohillites* in 13A2 defines currently the base of the *rohilla* Zone in Mud. Several of the above-mentioned species recur in Waagen’s upper(?) Ceratite Marls of the Salt Range and may indicate partial contemporaneity of Frech’s *Prionolobus volutus* Zone with the Himalayan *rohilla* Zone. Below the *volutus* Zone, Frech (1905) discriminated another zone based on *Celtites* (now *Bernhardites*) *radiosus*, a species, which may well belong to *Kashmirites* and if so, it would also point to an Induan onset of this genus.

Carbon isotope stratigraphy

A first detailed documentation of the $\delta^{13}C$ -curve of Mud was published by Richoz et al., (2007). This study was criticized for its synthetic curve combined from different sections, and because of some contradictory results between the sections M03 and M04. To resolve these problems, the IOB interval (Beds 12 to 14) has been resampled in detail (at least one sample each 8cm) in four different sections: M03, M04 (the proposed GSSP), M04A, 70m along the strike and M05 situated still higher up (see cover figure of Albertiana v. 35). Renewed investigation of section M03 has produced again depleted values and confirms the earlier result that these section underwent an alteration of the

primary carbon isotopic signal, eventually due to a local, bedding plane-parallel fault at the base of the *Flemingites* Beds seen only in M03. Data from M04, M04A and M05 sections show a perfect fit and correlation capacity (Fig. 6) and confirm - in more detail - the results published by Richoz et al. (2007). We see the excellent correlation between these three sections as well with Losar 60km away (Atudorei, 1999), as a confirmation of the primary origin of the isotopic signal in the proposed GSSP of Mud. The IOB peak may be worldwide identifiable and clusters in Mud around the FA of *N. waageni* s.l. in beds 13A+B.

The $\delta^{13}C$ -curve (Figs. 1, 6) fluctuates in the top-Gyronites Beds (beds 11-12) around -1‰, followed by a sharp positive excursion of 1 to 2‰ of amplitude leading to a prominent peak close to 1‰ in the base of Bed 13A (13A-1). The $\delta^{13}C$ -curve shows then a decrease of around 1.5‰ from 13A2 to the base of 13B. In the middle of bed 13B is recorded a sharp and short peak of around 1‰ amplitude. From top of 13B to 13C there is a rapid return to more negative values of around -1‰. Within bed 14 occur only minor variations till a small negative shift in 15B leads to values around -1.5‰ and then to - 2‰ in bed 17. In summary, the Mud curve is characterized by a distinct inflexion point between values increasing from the *Otoceras* beds to decreasing values till the *Parahedenstroemia* beds in connection with a well-marked positive excursion (of 2‰) in the basal *rohilla* Zone (from 13A to 13B; Fig. 1).

To avoid the problem of an over-interpretation of single data points we do not interpret not reproducible changes <1‰ value as such low differences in bulk rock samples may rely on subordinate changes in rock composition and chemistry. We have to consider that the IOB falls in a time of important oceanographic change and thus a sampling in different heights (even on cm scale) of bed 12 C can easily produce deviant signals explaining the small noticed discrepancies. The “sharp” shift between 12C and 13A with the best spatial resolution in M04 has an amplitude of 0,9‰, with 8cm between the two samples making it

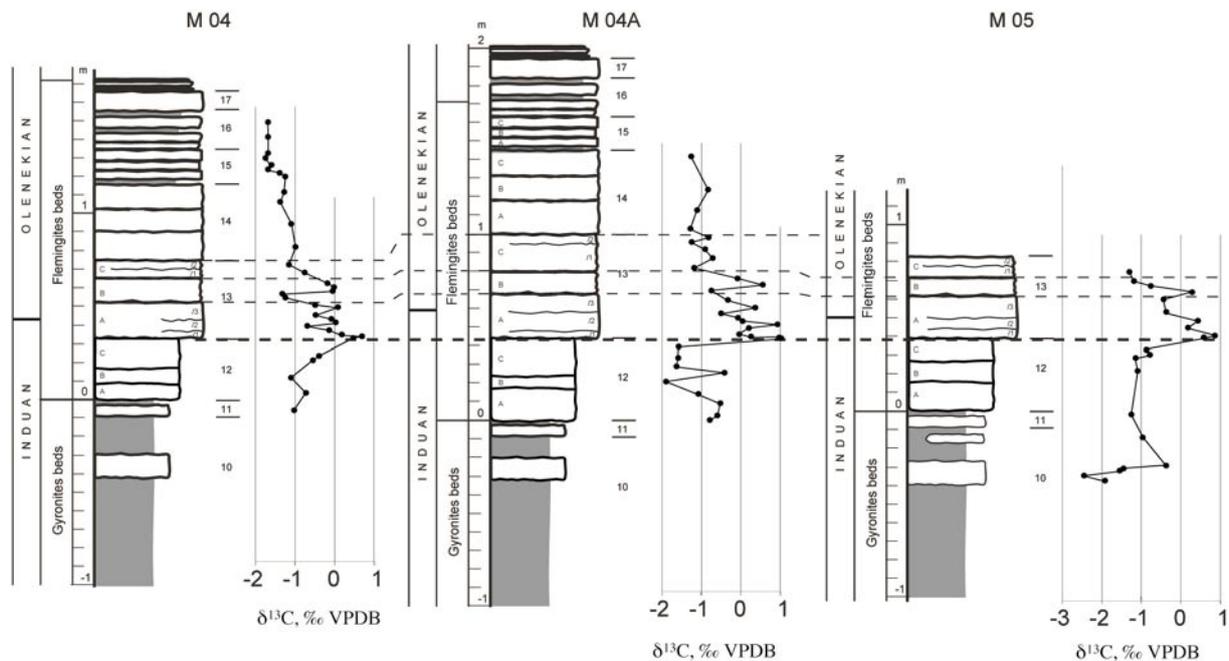


Figure 6: $\delta^{13}\text{C}$ isotope curve of the I-O boundary beds in Mud. The positive peak and inflexion point in beds 13A and 13B is a good chemostratigraphic marker for the proposed boundary. Note the distinct and widely recorded early Smithian negative trend from 13C onwards, starting above the appearance of *N. waageni*, and the high level of concordance between sections M04, M04A and M05.

insufficient to conclude a gap. West Pindingshan shows many sudden jumps of 1-2‰ between successive samples (Fig. 7, cf. CTWG, 2007, fig. 13 and 15), often stronger than in Mud. Until now nobody has concluded that each of these changes may record a gap. Certain strongly deviant values are especially developed within bed 25 in WP and, if isolated considered, may lead to serious misinterpretations (Korte et al., 2007 – Horacek, pers. comm.).

There is now common agreement that this IOB sharp and strong positive carbon isotope excursion (CIE) reflects a primary and drastic change in ocean circulation (Payne et al., 2004, 2007; Corsetti et al., 2005, Richoz 2006, Zuo et al., 2006; Richoz et al., 2007, Horacek et al., 2007 (a,b,c), Galfetti et al., 2007, Tong et al., 2007). We have marked in figure 7 with a red (in black & white grey) bar the full width of the positive excursion with an amplitude greater than 1‰ around the IOB. This excursion is in Mud and West Pindingshan too small to be one by one compared with the 3-7‰ excursion amplitudes of many other (mostly shallow water) sections. The CIE is equally short-lived in all three measured sections of Mud. In terms of bio-events it starts slightly below the FA of *N. waageni* s.l. and ends soon above this date (Fig. 7) representing a short time space of less than half of one *short* ammonoid zone (*rohilla* Z.). The two figured West Pindingshan CIEs (Fig. 7) otherwise are both much wider and show different ranges based on an additional marked negative excursion in the CWTG 2007, fig. 15 curve beginning below the FA of *N. waageni* s.l. and ending after the FO of *N. waageni waageni*. This leads to the image that the Horacek et al., (2007c) CIE is starting early in the Induan whereas the CWTG, 2007 CIE follows later slightly above *N. waageni* s.l. Noteworthy is that both CIE end well above the FA of *N. spitiensis* and thereby distinctly (one ammonoid zone,

Flemingites-Euflemingites Z.) later than in Mud and in North Pingdingshan (CTWG, 2007). The in shape and time deviating WP curve(s) demonstrate in this comparison the current problem in Chaohu to use the isotopic signal as a *high-resolution* event marker.

To use a CIE as a globally instantaneous event means first to test its supposed isochrony against an accurate high-resolution biozonal scheme. This fine-tuned scale is presently from no other sections than Chaohu and Mud available. It is therefore unjustified and scientifically unsound from our current regional chronostratigraphic database to declare single points of the IOB-CIE as reference for specific biotic events. Proposing exactly this, Korte et al. (2007, p.4) declare: "Mud would be the only locality in the world where the maximum in $\delta^{13}\text{C}$ lie before the base of the Olenekian", which is unsubstantiated and objectively wrong. A careful biostratigraphic evaluation of their cited sections leads to a contrasting result: in Iran, Italy (Horacek et al., 2007a,b) and Turkey (Richoz, 2006) the IOB is placed primarily on the CIE, without any *waageni* control. In Pufels, (N Italy), the only place with own marine bio-data, Korte et al., (2005) define the base of the Smithian on the FAD of *Pachycladina obliqua*, a shallow-water conodont of reduced biostratigraphic correlation potential whose FO dates to the Dienerian. In Wadi Maqam, Oman, Richoz (2006) shows the first appearance of *N. waageni* contemporary to the isotope peak but without additional bio-data from below, and with sparse isotopic data. Several biostratigraphically better constrained isotope curves are known from China, where in Guizhou Payne et al., (2004) place the CIE clearly below the FO of *N. waageni* and of *Platyvillosus* (= *Eurygnathodus*); in Meishan, Guandao and Zuodeng, the positive peak is also below the IOB, in Hushan, Daxiakou und Lekang, it is slightly above (Tong

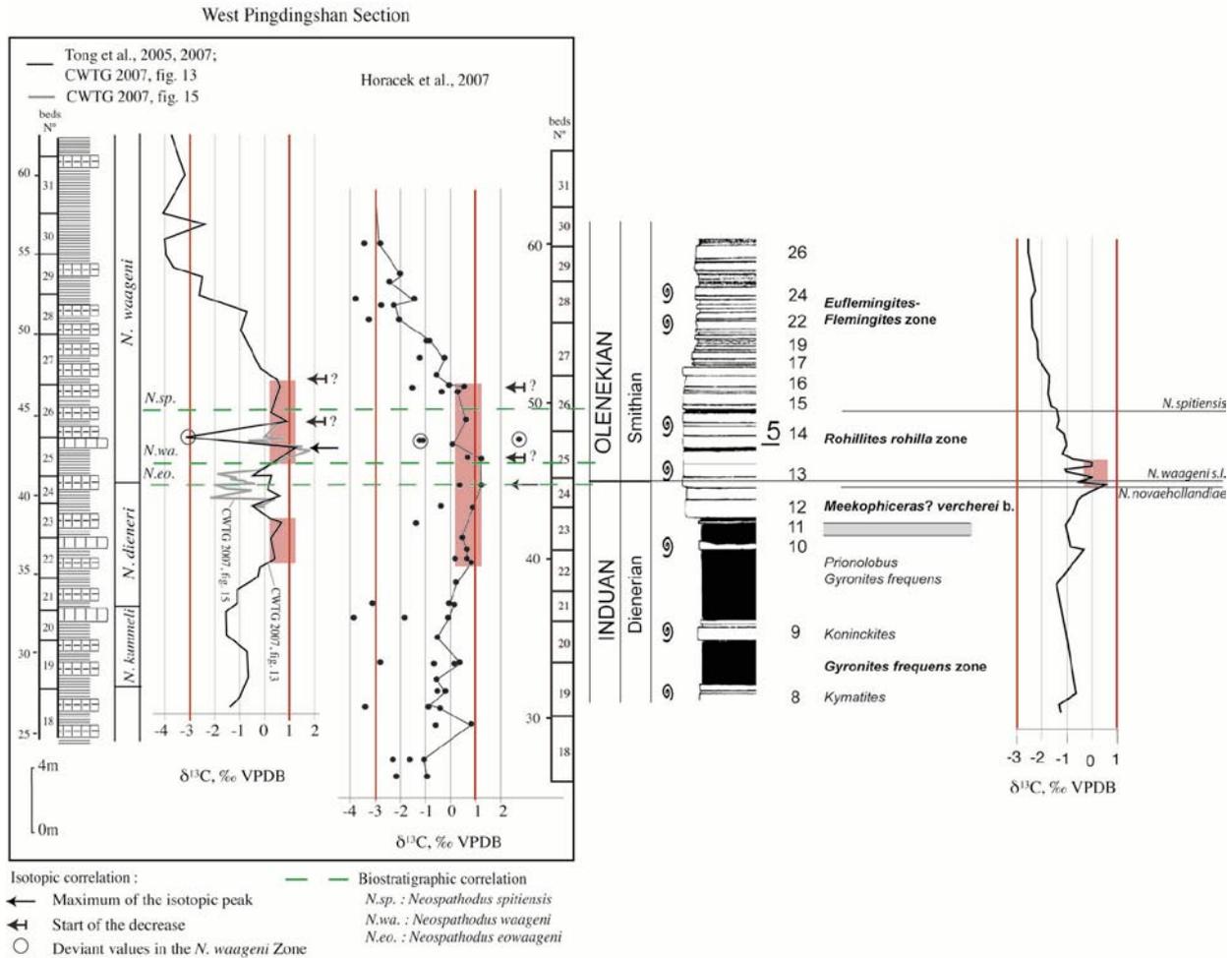


Figure 7: Comparison of the $\delta^{13}\text{C}$ isotope curve of the I-O boundary interval in Mud and West Pingdingshan (CTWG, 2007 and Horacek et al. 2007c). The red (in black & white grey) bar marks the full width of the positive excursion around the IOB with an amplitude greater than 1‰.

et al., 2007); in NW Guangxi, Galfetti et al., 2007 show the CIE within the *Kashmirites* beds (counterpart of the *rohilla* Z.) what could correspond to a position below, together with or above the *waageni* date; and only in West and North Pingdingshan (version in CTWG, 2007), the peak is clearly above – but for West Pingdingshan, the position of the peak above FO of *N. waageni* is not so clear in the dataset of Horacek et al. (2007c), as discussed above. In summary, the evaluation of all these data results in the same conclusion drawn further up from the Mud curve: a prominent positive CIE occurs in the vicinity of the FA of *N. waageni* s.l. and, with adequate representation, can serve in fossil-poor sections as close proxy for the IOB.

Meanwhile nitrogen and organic carbon isotope as well as major, minor and trace elements analyses have also been carried out in Mud with good results (data in process of publication - Algeo, oral comm.). The Mud section is thus suitable for further chemostratigraphic studies.

Chronologic calibration of the IO boundary beds in Mud

New high-precision U-Pb ages from the biochronologically well dated Lower Triassic on NW Guangxi, China

(Galfetti et al., 2007) allow a rather exact time calculation of the Smithian ammonoid (resp. conodont) zones in Mud and West Pingdingshan. Galfetti et al., (2007) report a U-Pb age of 251,22±0,20 Ma (Chin 40) for the basal Smithian *Kashmirites densistriatus* beds of NW Guangxi, which are time-correlative to the *Rohillites rohilla* Zone in Mud (Brühwiler et al., 2007; Fig. 5). Another U-Pb date (Chin 10) of 250,55±0,40 Ma is recorded by Ovtcharova et al. (2006) for the lower Spathian *Tirolites/Columbites* beds of NW Guangxi, a time interval occurring already above the first Spathian ammonoid zone. From these data it can be safely concluded that the Smithian stage is bracketed between 0,7 and max. 1,3 Ma (Galfetti et al., 2007). Calculated durations of Smithian biochrons by cross-plotting the new U-Pb ages against sediment accumulation rates demonstrate a high level of timely coincidence between Mud and Chaohu but also extremely disproportionate zonal durations (Fig. 8). This new age constrain confirms the extremely short duration of the basal Olenekian ammonoid (*rohilla* Z.) and conodont (FA *N. waageni* s.l. – FA *N. spitiensis*) intervals and the high rate of the pelagic faunal diversification during the earliest Smithian. It further provides a more precise timing of the carbon cycle perturbations around the CIE, which according to data in

time interval	Mud MO4			Chaohu, WP		
	thickness m	time duration		thickness m	time duration	
		min	max		min	max
Smithian	10,0	0,7 Ma	1,3 Ma	52,0	0,7 Ma	1,3 Ma
	5,2	0,36 Ma	0,68 Ma	27,2	0,36 Ma	0,68 Ma
<i>Flemingites- Fuflemingites Zone</i>	4,0	0,28 Ma	0,52 Ma	21,2	0,28 Ma	0,52 Ma
FAD <i>waageni</i> s.l.- FAD <i>spitiensis</i> I.Z.	0,7	49 Ka	91 Ka	3,6	48,5 Ka	91 Ka
<i>rohilla</i> Z.	0,8	56 Ka	104 Ka			
CIE : Mud WP	0,4	28 Ka	52 Ka	3,0	40 Ka	75 Ka

Figure 8: Calculated durations of biochrons in Mud M04 and Chaohu (West Pindingshan) based on sediment accumulation rates versus Smithian U-Pb ages of Galfetti et al. (2007).

Fig. 8 last considerable longer in W.P. than in Mud.

Acknowledgements

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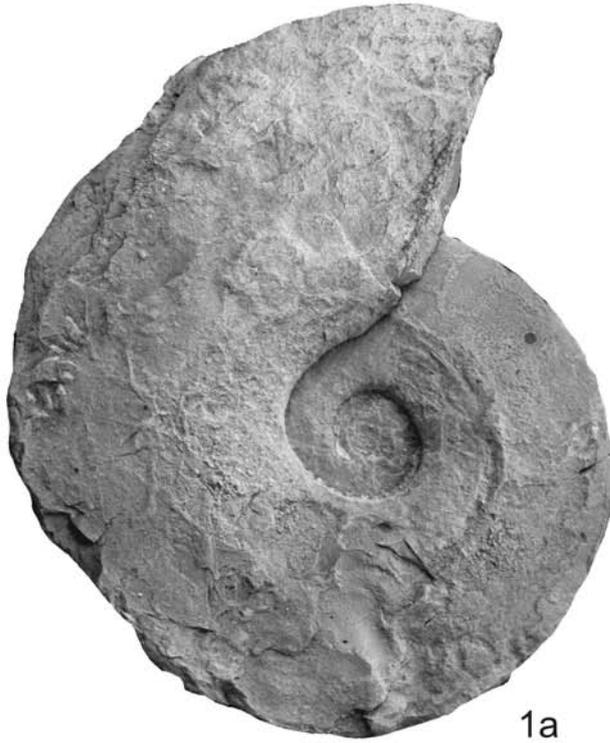
Specimens are figured in natural size and housed in the collection of the Department of Palaeontology, Vienna University.

Plate 1

Fig. 1: *Meekophiceras? vercherei* (Waagen); M03-12B

Fig. 2: *Rohillites rohilla* (Diener); M04-13A-2/3

Plate 1



1a



1b



2

Plate 2

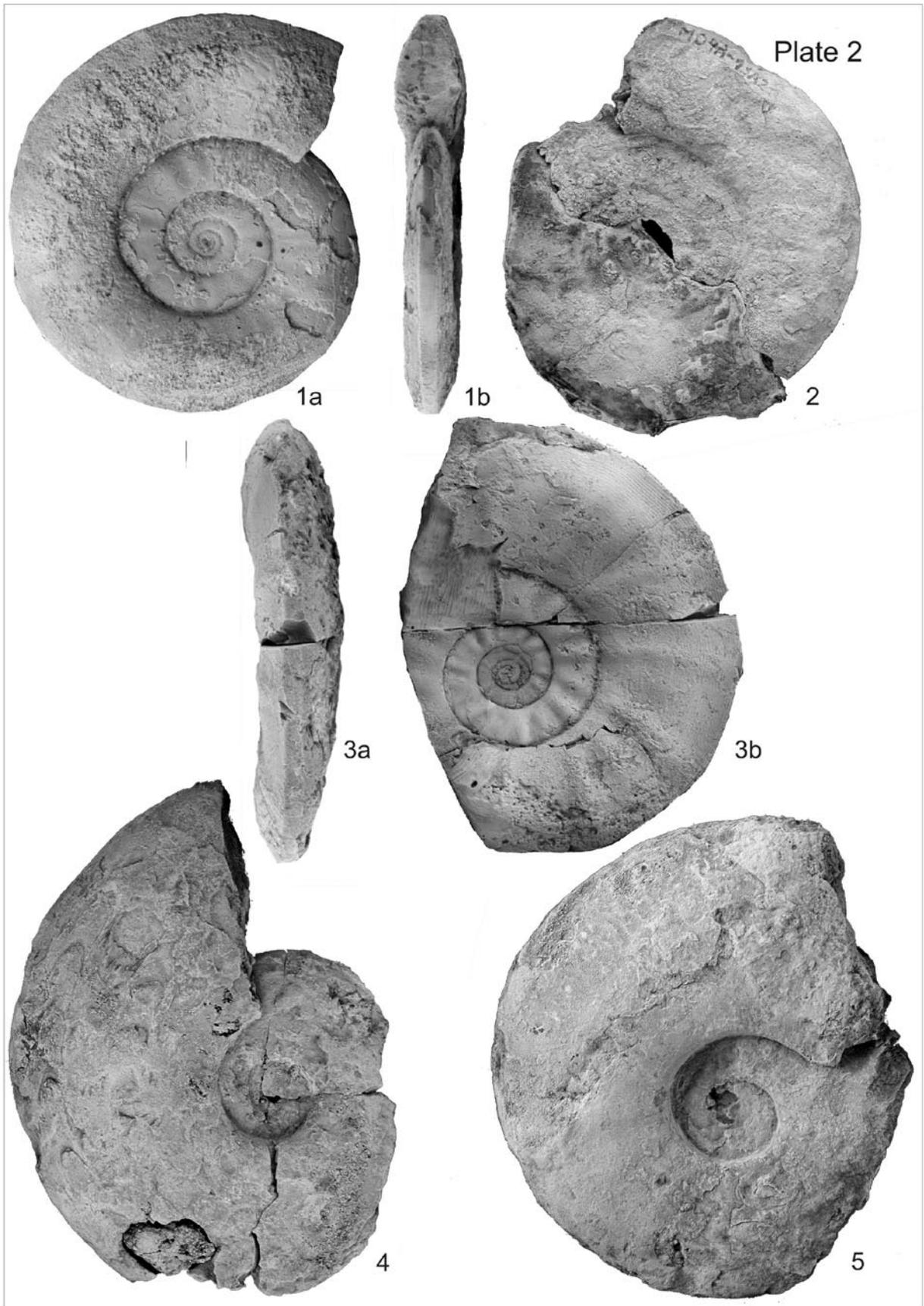
Fig. 1: *Rohillites* n. sp. 1; M06-13A2/3

Fig. 2: *Rohillites* n. sp. 1; M04A-13A2

Fig. 3: *Rohillites rohilla* (Diener); M04-13C

Fig. 4: “*Meekoceras*” *pulchrum* Waagen; M04-13A1

Fig. 5: “*Meekoceras*” *pulchrum* Waagen; M04-13B



Report on 2007 conodont collections from Mud, Spiti.

M.J. Orchard

Four conodont concentrates representing subsets of beds 13A and 13B at Mud section MO4 were received from Leo Krystyn in September 2007. These were picked in Vancouver and my interpretation of the content of the resultant collections are presented below in Table 1. Some key elements are illustrated on Plate 1. The following is a summary of the fauna in general and some observations on the composition of each collection.

General observations

The faunas are very rich in individuals showing a range in size. Many elements are broken but none show corrosion or any indication of reworking. The CAI is ~5.

Sample 13A-1

This collection is dominated by *Neospathodus pakistanensis* and *Borinella nepalensis*. Complete specimens of the former species of small to moderate size show characteristic downturning of the posterior lower margin, and a relatively long blade compared with its height. The outline of the basal cavity is round. Larger specimens develop thickening of the basal cup and lateral ‘flanges’ that narrow to the anterior. In these, the lower basal profile is more commonly straight. These large specimens correspond to *N. novaehollandiea*, the appearance of which may be useful in identifying IOB strata. It needs to be determined as to whether populations of *N. pakistanensis* always include such forms, as is the case both in Spiti and in the Australian type collections of *N. novaehollandiea*. Incomplete specimens of *Neospathodus* are difficult or impossible to determine although they may appear superficially like *N. waageni*.

Sample 13A-2

This collection is very similar to 13A-1. It differs in having also uncommon examples of the older, Induan species *N. cristagalli* and *N. dieneri*, plus the first *N. posterolongatus*. Just as *N. pakistanensis* and *N. waageni* can be hard to separate in broken material, so too can *N. cristagalli* and *N. posterolongatus*, which both have an elongate basal cavity. Also appearing in this collection are *Eurygnathodus* spp., which is also known from bed 12 (Orchard & Krystyn, 2007).

Sample 13A-3

This collection represents a change compared with those sub-beds below. The following are notable features:

1. Decline in abundance of *B. nepalensis*. This is still common but is no longer dominant.
2. Dominance of *N. posterolongatus*.
3. Abundance of *Eurygnathodus* spp.
4. Appearance of *N. waageni*

5. ?Disappearance of *N. pakistanensis*
6. ?Appearance of *Discretella* sp.

Uncommon elements of both *N. cristagalli* and *N. dieneri* remain in this collection but the dominant neospathodids fall into two groups. The first is represented by relatively short and high (compared with *N. pakistanensis*) *N. waageni*, and the second are elongate *N. posterolongatus*. As in beds 13A-1 and -2, large specimens of these species may develop short posterior and narrow lateral platforms, but these features occur in specimens that are either relatively shortened with round basal cavities (*N. waageni* Morphotype 1 of Orchard & Krystyn, 2007), or which are elongated with posteriorly extended basal cavities (as in *N. posterolongatus*). Typical *N. waageni* are most conspicuous as smaller specimens, which are shorter and higher compared with the older species.

Sample 13B-1

This collection is similar to 13A-3 but differs in containing more common *N. waageni*. This includes Morphotype 1 (with thickened basal cup), Morphotype 2 (*N. waageni* sensu stricto, with inclined denticles), and the diminutive Morphotype 3 (= *N. w. eowaageni*, with upright denticles). There are no typical *N. pakistanensis* in this collection but *N. posterolongatus* remains abundant. A few *Neospathodus* elements resemble Induan holdovers, and *B. nepalensis* occurs in much reduced numbers. *Eurygnathodus* does not occur. *Discretella* is rare.

Summary

Compared with the previously determined distribution of conodonts at Mud (Orchard & Krystyn, 2007, table 1), this suite of samples introduce some refinement. Most notable is the confirmed appearance of *N. waageni waageni* in the upper part of bed 13A, and of certain *N. w. eowaageni* in bed 13B. Morphotype 1 of *N. waageni* was recorded previously from undifferentiated bed 13A, and so it too may have originated from the upper part of that bed (see Orchard & Krystyn, 2007, *Albertiana* 35: 30-34, pl. figs 8-10). The choice of *N. waageni* sensu lato as an index to the IOB has been suggested and is again supported here. Morphotype 1, like *N. novaehollandiea*, may be a useful guide to the IOB strata since many younger Olenekian faunas do not include it. In the present material, smaller, more typical elements of *N. waageni* appear concurrently and distinctive *N. w. eowaageni* soon after. The latter is not common but it is very distinctive.

The faunal succession in MO4 appears gradational. Most of the elements known from beds 11 and 12 range into strata carrying *N. waageni*. Within bed 13A, there appears to be evolutionary innovation that leads from *N. pakistanensis* to both *N. waageni* and *N. posterolongatus*. This narrow interval may be characterized by large specimens of these

Four conodont concentrates representing subsets of beds 13A and 13B at Mud section MO4 were received from Leo Krystyn in September 2007. These were picked in Vancouver and my interpretation of the content of the resultant collections are presented below in Table 1. Some key elements are illustrated on Plate 1. The following is a summary of the fauna in general and some observations

Table 1 Occurrence of conodonts in new collections from Mud. Relative abundance indicated by font. Large, bold font = abundant; small, bold font – common; small, regular font -= present.

		13A-1	13A-2	13A-3	13B-1
N. cristagalli			x	x	x
N. dieneri			x	x	x
N. pakistanensis + novae	x	x	?		
N. posterolongus			x	x	x
Bo. nepalensis	x	x	x	x	x
D. discreta				?	x
N waageni, M1				x	x
N. w. waageni				x	x
N. w. eowaageni					x
Eurygnathodus hamadai			x	x	
Eu. costatus			x	x	

Plate description

1-6. *Neospathodus posterolongatus* Zhao & Orchard, 2007.

1, 2, 5, 6. from bed 13A-3; 3, 4, from bed 13B-1.

7, 8. *N. w. eowaageni* Zhao & orchard, 2007. Bed 13B-1.

9-14, 21, 22. *N. w. waageni* Sweet, 1970.

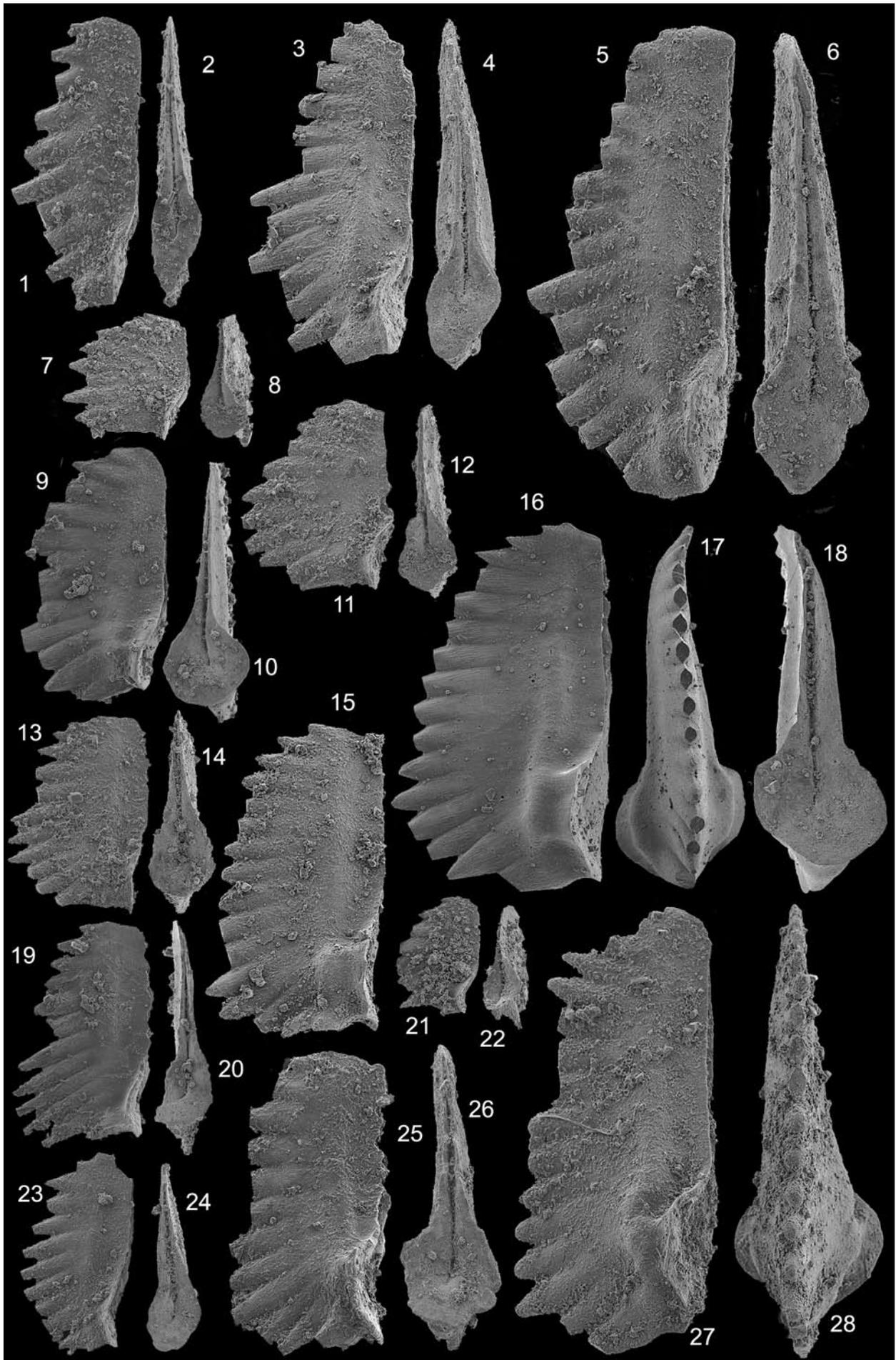
9, 10, 13, 14, 21, 22, from bed 13A-3; 11, 12, from bed 13B-1.

15-18. '*Neospathodus novaehollandiea*' McTavish, 1973 transitional to *N. waageni* Morphotype 1 Orchard & Krystyn, 2007. Bed 13A-3.

19, 20, 23-26. *Neospathodus pakistanensis* Sweet, 1970.

19, 20, from bed 13A-2; 23-26, from 13A-1.

27, 28. '*Neospathodus novaehollandiea*' McTavish, 1973. Bed 13A-1.



Induan-Olenekian Boundary correlations, new proposal, or how to calibrate a Carbon isotope curve.

Aymon Baud*

*c/o Baud Geological Consultant

Parc de la Rouvraie 28, CH-1018 Lausanne, Switzerland

Introduction: in 2004, the wind was blowing with the magnetostratigraphy

In the Germanic basin, the Olenekian lower boundary IOB) published by Bachman & Kozur (2004) was firmly based on magnetostratigraphy correlated with Chaohu magnetostratigraphy and conchostracan. It was placed between the *E. nodosocostata* Zone s. s. and the *C. germari-M. subcircularis* A. Z, correlated with the upper part of the only normal magnetozone Sn3 of the Bernburg Formation, which ends around the base of cycle 8 (Szurlies et al. 2003). In these continental beds, the biostratigraphically and magnetostratigraphically correlated base of the Olenekian (IOB) was also confirmed with carbon isotopes by comparison with the Pufels (Bulla) section, where occurs a distinct positive $\delta^{13}C$ excursion somewhat more than 3 of a so called short eccentricity cycles above the Olenekian base, as published by Bachman & Kozur (2004) followed by Korte & Kozur, (2005b). In the Germanic Basin lacustrine

sediments, a distinct positive $\delta^{13}C$ excursion is present in the lower M. truempyi Zone, likewise of somewhat more than 3 of their so called short eccentricity cycles above the base of the Olenekian.

In the shallow marine section Pufels (Bulla) of the Southern Alps, the Olenekian lower boundary published by Korte & Kozur. 2005a, was based on the FAD of *Pachycladina oblique*, a facies controlled conodont. In Bachmann and Kozur, 2004, this base was checked on Scholger et al. (2000) very precise palaeomagnetic data, a little below the top of N3 palaeomagnetic zone, a very good palaeomagnetic marker for correlation with continental beds in the Germanic Basin.

But from the dawn of 2007, the wind changes and the correlations have to be done on carbon isotopes stratigraphy.

As explained in p. 147 of Kozur and Weems, 2007, Kozur

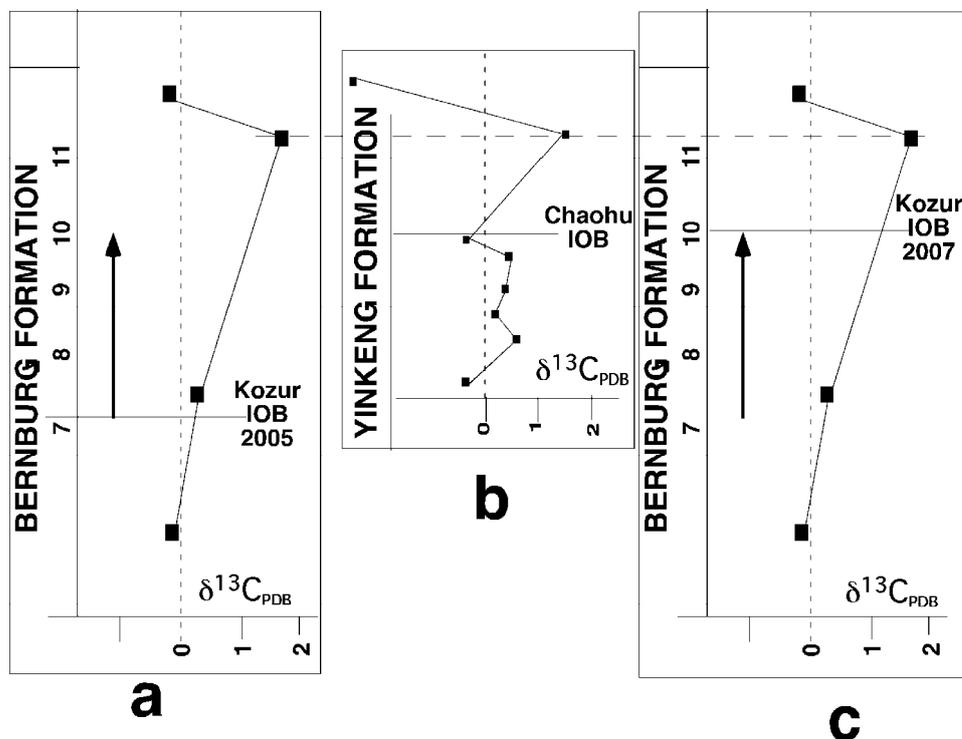


Figure 1: Carbon isotope peak correlation close to IOB, Bunsandstein (Germany) - Chaohu (China). No vertical scale
a: Carbon isotope trends at the IOB from the Germanic Lower Buntsandstein from Korte & Kozur, 2005b, with the position of the IOB based on magnetostratigraphy and conchostracan zonation. Cycles number 7 to 11,
b: $\delta^{13}C$ -curve for the West Pingdingshan section (Chaohu, China, according to Tong et al. 2007, with the position of the IOB defined by the FAD of *Neospathodus waageni* s.l.
c: Carbon isotope trends at the IOB from the Germanic Lower Buntsandstein from Korte et al. 2007 with the new position of the IOB shift up of 3 cycles (arrow), based on carbon isotope peak correlation and conchostracan zonation.

discovered a distinct positive carbon isotope peak at the IOB, described from Losar, Spiti in the Atudorei, (1999) thesis. More precisely Richoz et al., 2007, in the Mud section, confirmed this peak about 60 km S of Losar. But for Korte, Kozur and Bachmann, their distinct positive $\delta^{13}\text{C}$ excursion was entirely within their Olenekian. It is why, as written in Korte et al 2007, they remember suddenly that the conchostracan loose spines at the IOB in the Buntsandstein and accordingly, they have to shift the former published boundary, from cycle 7 to cycle 10 (Korte et al. 2007, p. 4), exactly the 3 needed cycles. They blow up the IOB boundary both in Buntsandstein (fig. 1c) and in Pufels (fig. 2c), make it corresponding not to Mud but to Chaohu distinct C isotope peak published by Tong et al. 2007. Then they were able to write, p. 5, that the distinct positive shift at Chaohu resemble in the marine Pufels and in the continental Buntsandstein data, and the distinct peak at the IOB in Spiti does not fit with any other IOB transition section.

New proposals

Following this new and promising method for stratigraphy, I just remember that the *Magniestheria truempyi* species occurs in Madagascar immediately below the *Flemingites* beds (Korte et al. 2007, p. 4). It means that in the Buntsandstein, the IOB must be just above the *Magniestheria truempyi* zone. It is my new proposal in Figure 3a. With this, the Sn3 palaeomagnetic zone of Szurlies et al., 2003 is late Induan (Dienerian) as it was published.

Also, in the correlative Bulla (Pufels) section, the IOB must be shift up of more than 4 cycles (figure 3c). With this, the N3 palaeomagnetic zone of Scholger et al. (2000) will be entirely Induan, as it was published and the conodont *Pachycladina obliqua* is appearing in the late Induan (Dienerian) as written by Orchard (2007). Now the correlation with the Mud proposed stratotype fit perfectly as shown by the figure 3. Concerning the Chaohu proposed stratotype, he lost, in Horacek et al, 2007 as shown in fig. 3c, his

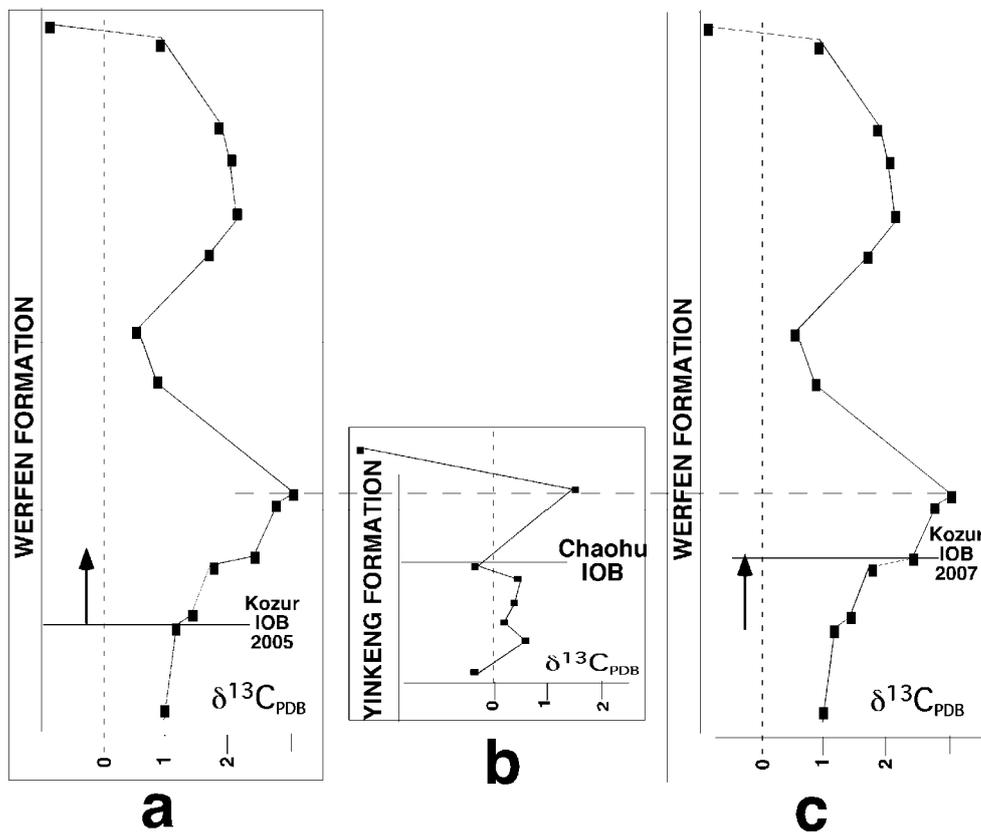


Figure 2: Carbon isotope peak correlation close to IOB, Pufels (Bulla, Italy) - Chaohu (China). No vertical scale.
 a: Carbon isotope trends at the IOB from the shallow marine section Pufels (Bulla) of the Southern Alps according to Korte & Kozur. (2005a). The position of the IOB is based on the FAD of *Pachycladina obliqua* and checked on Scholger et al. (2000) very precise palaeomagnetic data, a little below the top of N3 palaeomagnetic zone.
 b: $\delta^{13}\text{C}$ -curve for the West Pingdingshan section (Chaohu, China, according to Tong et al., 2007, with the position of the IOB defined by the FAD of *Neospathodus waageni* s.l.
 c: Carbon isotope trends at the IOB from the shallow marine section Pufels (Bulla) of the Southern Alps according to Korte et al. (2007). The position of the IOB is no more based on very precise palaeomagnetic data, nor on biostratigraphy, but has been shifted up of 3 "cycles" (arrow), to correspond to the new shifted IOB in the Buntsandstein (fig. 1 in Korte et al. 2007).

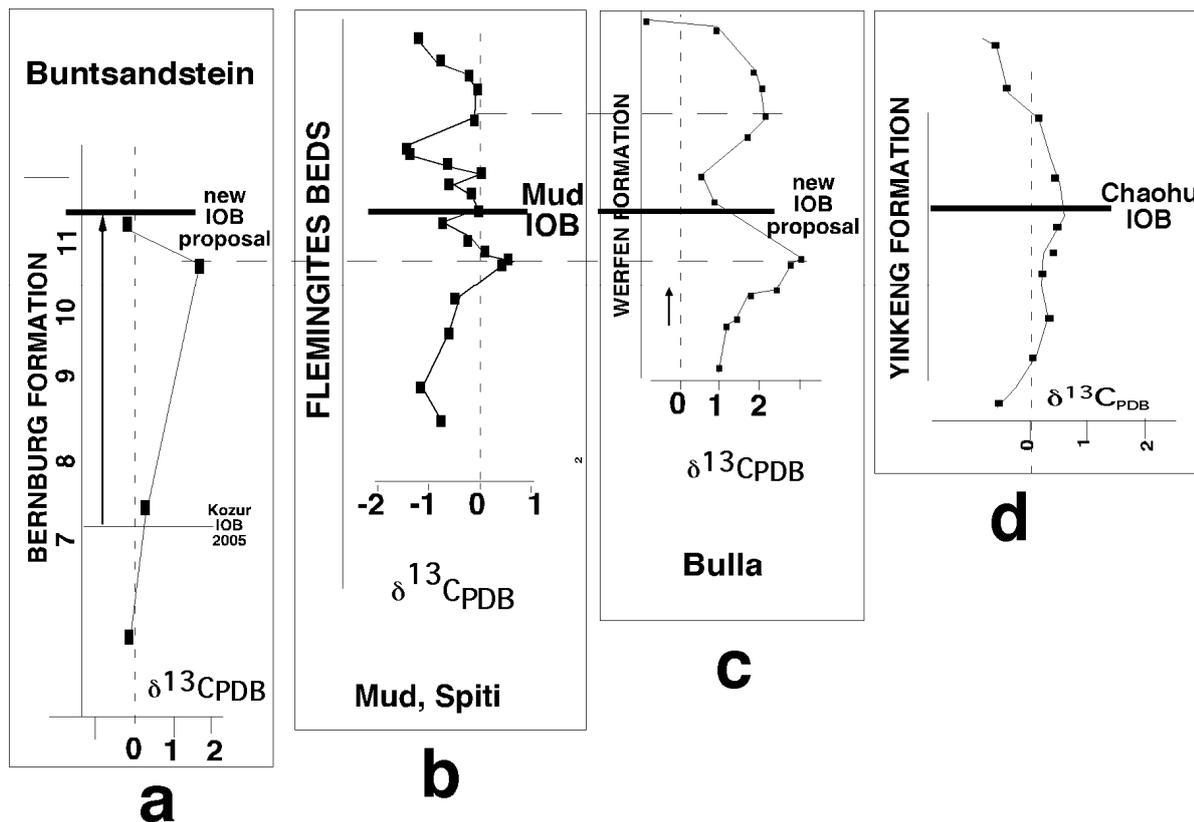


Figure 3: Carbon isotope peak correlation close to IOB, Buntsandstein (Germany) -Mud (Spiti, India) - Pufels (Bulla, Italy) -Chaohu (China). No vertical scale
 a: Carbon isotope trends at the IOB from the Germanic Lower Buntsandstein from Korte et al. 2007 with the new position of the IOB adapted from conchostracan zonation.
 b: $\delta^{13}\text{C}$ -curve for the Mud section, Spiti, from Richoz et al., 2007, and Indo-Austrian Working Group, in press, with the position of the IOB defined by the FAD of *Neospathodus waageni* s.l
 c: Carbon isotope trends at the IOB from the shallow marine section Pufels (Bulla) of the Southern Alps according to Korte et al. (2007). The position of the IOB is shifted up of 4 cycles (according to Korte et al. 2007) and now well correlated with the 2 separated C isotope peaks of Mud
 d: Carbon isotope trends (plateau) at the Chaohu IOB according Horacek et al., 2007.

distinct C isotope peak published by Tong et al. 2007 and the large C isotope plateau is indistinctly correlated with all IOB sections.

Conclusion

Thanks to Korte, Kozur and Bachmann for the promising method for stratigraphy. Before, the Buntsandstein age calibration appeared as a sandcastle. With my new proposal, it is becoming “eine feste Burg”.

Now I can write that the distinct positive shift at Mud, Spiti, resemble in the marine Pufels and in the continental Buntsandstein data and fit with most of the other IOB transition sections as do also the large C isotope plateau from Chaohu.

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The Global Boundary Stratotype Section and Point (GSSP) for the base of the Anisian Stage:

Deşli Caira Hill, North Dobrogea, Romania

Eugen Grădinaru¹, Michael J. Orchard², Alda Nicora³,
Yves Gallet⁴, Jean Besse⁴, Leopold Krystyn⁵,
Evgeny S. Sobolev⁶, Nicu-Viorel Atudorei⁷, Daria Ivanova⁸

¹ University of Bucharest, Faculty of Geology and Geophysics, Department of Geology and Palaeontology, Blvd. Bălcescu Nicoale 1, RO-010041 Bucharest, Romania, E-mail: egradin@geo.edu.ro; ² Geological Survey of Canada, 625 Robson Street, Vancouver, B.C., V6R 5T3 Canada, E-mail: MOrchard@nrcan.gc.ca; ³ Università degli Studi di Milano, Dipartimento di Scienze della Terra, Via Mangiagalli 34, 20133 Milano, Italy, E-mail: alda.nicora@unimi.it; ⁴ Institut de Physique du Globe de Paris 4, place Jussieu - Case 89 - 75252, Paris Cedex 05, France; E-mails: gallet@ipgp.jussieu.fr; ⁵ University of Vienna, Department of Palaeontology, Geozentrum, Althanstrasse, A-1090, Vienna, Austria, E-mail: leopold.krystyn@univie.ac.at; ⁶ Siberian Branch of Russian Academy of Sciences, Trofimuk Institute of Petroleum Geology and Geophysics, Akademgorodok, Koptyug Ave. 3, 630090 Novosibirsk, Russia, E-mail: SobolevES@ipgg.nsc.ru; ⁷ University of New Mexico, Department of Earth and Planetary Sciences, Stable Isotope Laboratory, Northrop Hall Rm. 225C, Albuquerque, NM, United States, E-mail: atudorei@unm.edu; ⁸ Bulgarian Academy of Sciences, Geological Institute "Strashimir Dimitrov", Acad.G.Bonchev Str., bl. 24, 1113 Sofia, Bulgaria, E-mail: dariaiv@hotmail.com

Introduction

The Deşli Caira Hill is herein proposed as the Global Boundary Stratotype Section and Point (GSSP) for the base of the Anisian Stage, and for the base of the Middle Triassic Series in the Triassic Time Scale. Multidisciplinary research by a multinational Task Group has provided a considerable amount of biostratigraphic, magnetostratigraphic, and chemostratigraphic data that allow us to have a multi-proxied definition of the Olenekian-Anisian (Lower-Middle Triassic) Stage and Series boundary in the section. This report summarises the attributes of the Deşli Caira Hill, which fulfil almost all of the ICS requirements for a GSSP.

The Global Boundary Stratotype Section and Point for the base of the Anisian Stage

(E. Grădinaru)

Geographic location and access

The Deşli Caira Hill lies in the northern part of Dobrogea, a province of Romania situated between the lower course of the Danube and the Black Sea coast, south of the Danube Delta (Fig. 1A). Having an altitude of 175 m, the Deşli Caira Hill is an impressive, isolated hill, located in the middle of hilly agricultural land, approximately 6 km east of Mihail Kogălniceanu village, or approximately 8 km west of Agighiol village (Fig. 1B), both of which are situated approximately 17 km south of Tulcea city, the capital of the Tulcea County. The hill can be easily reached by car, on asphalted roads from Tulcea to the above-mentioned villages, and then on unpaved roads. The coordinates are 28° 48' 08" E and 45° 04' 27" N. The name of the hill,

Deşli Caira (in Simionescu, 1910a) or Berge Taşli (in Kittl, 1908), is Turkish in origin, and the feature is actually known in the Romanian toponymy as Stânca Mare (Big Stone) or Muchea Ascuţită (Sharp Summit).

Geological context

Deşli Caira Hill is located in the Agighiol Zone of the Tulcea Unit, a part of the Eo-Alpine North Dobrogea fold and thrust belt. The Tulcea Unit (Fig. 1A), which is famous in the classic literature for the spectacular development of the Triassic ammonoid faunas (Kittl, 1908; Simionescu, 1913), includes both basinal facies with thick marly sequences located in the western part, and carbonate platform facies located in the central-eastern part (Grădinaru 1995, 2000). The Agighiol Zone had an external position in the framework of the Triassic carbonate platform of the Tulcea Unit, westwards in actual geographic position. It is characterized by thick sequences of Hallstatt-type massive limestones, grouped in the Agighiol Limestone, and extending in age from the upper Spathian up to the lower Carnian. The Hallstatt-type limestones are interbedded with, or grade laterally and/or vertically into Ammonitico Rosso-type nodular siliceous limestones. The areal and stratigraphic distribution of these two sedimentary facies suggests complex sedimentary environments, controlled by active syn-sedimentary block faulting whereby raised blocks of seamount-type were separated by intra-platform depressions. The Hallstatt-type limestone facies were deposited on the top of the seamounts whilst the Ammonitico Rosso-type were deposited in the intra-platform depressions. As a consequence of the prevailing tectonics, the stratigraphic distribution of the two lithofacies show pronounced diachronic relationships which are elucidated

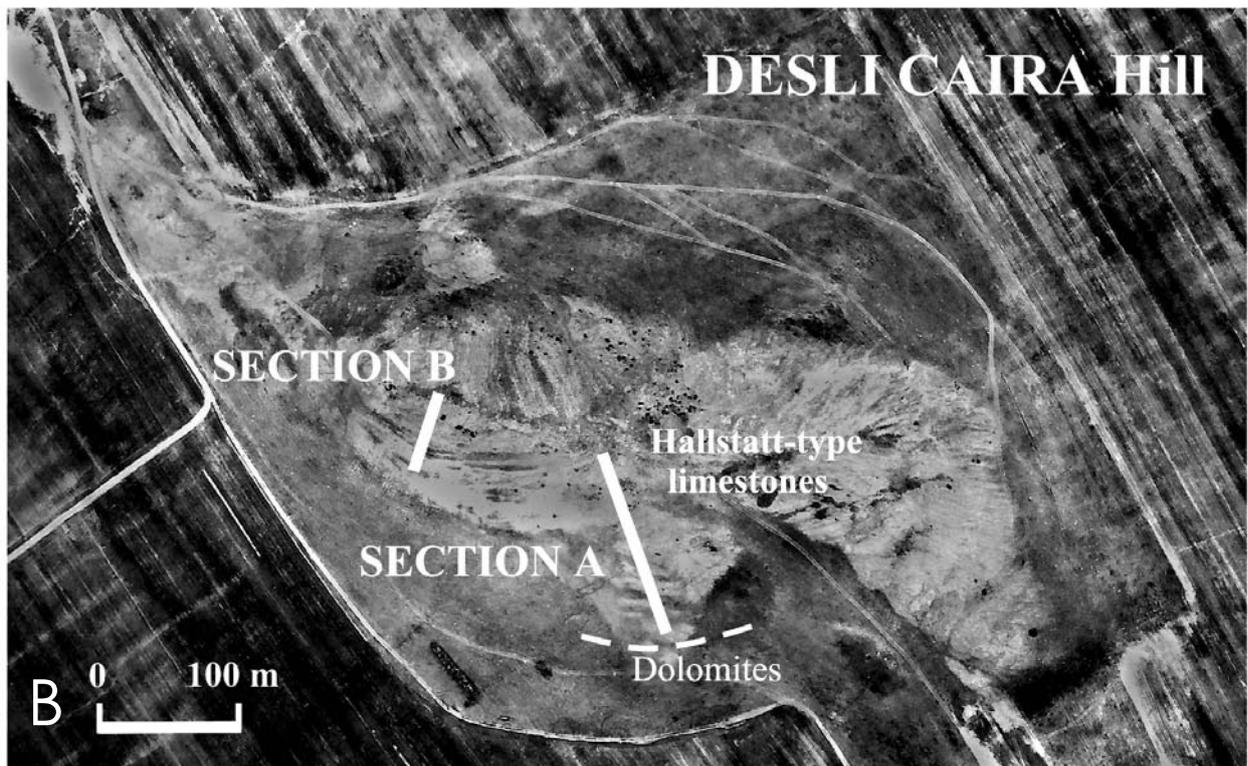
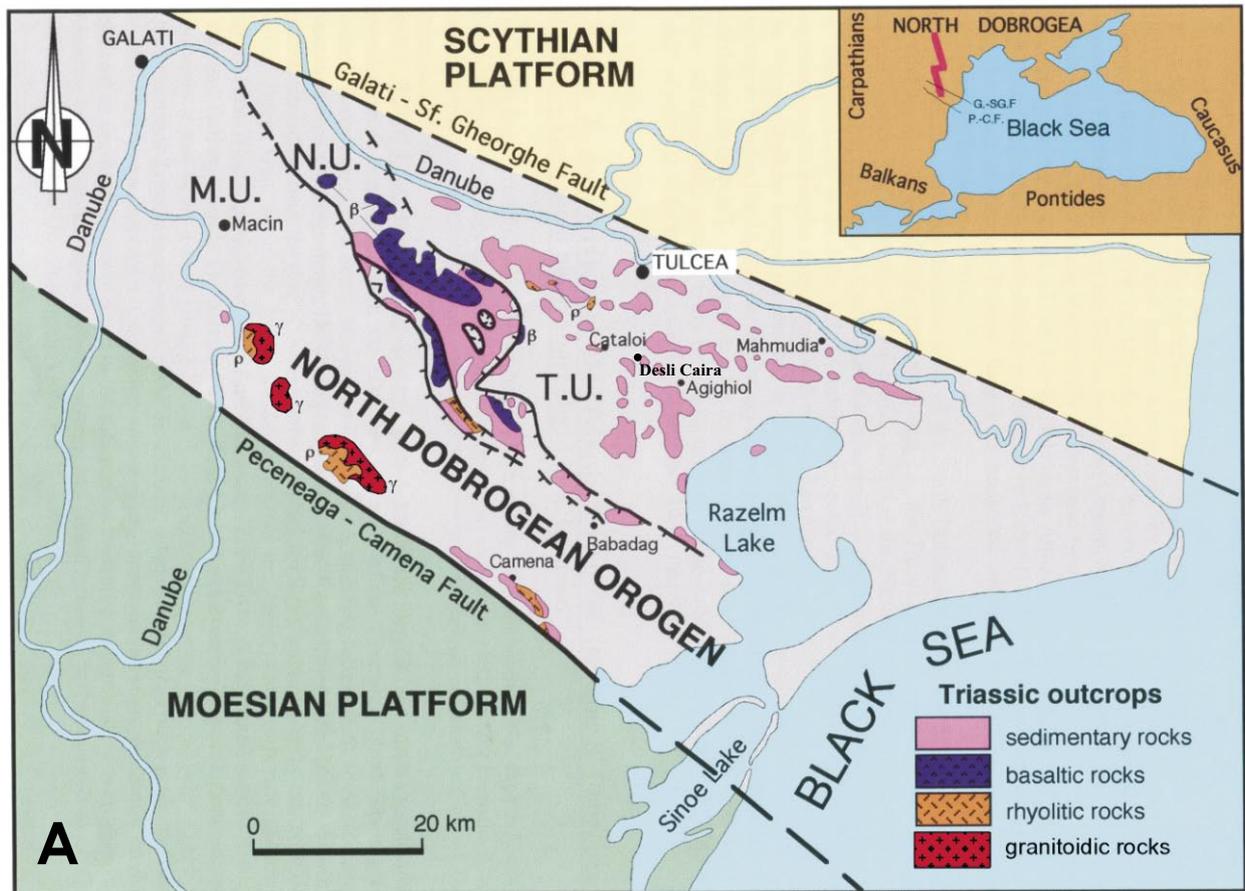


Figure 1: A. Locality map of the Dobrogea region in Romania showing the location of Deșli Caira Hill. B. Aerial photograph of the Deșli Caira Hill showing the locations of sections A and B.

Geological context

Deşli Caira Hill is located in the Agighiol Zone of the Tulcea Unit, a part of the Eo-Alpine North Dobrogea fold and thrust belt. The Tulcea Unit (Fig. 1A), which is famous in the classic literature for the spectacular development of the Triassic ammonoid faunas (Kittl, 1908; Simionescu, 1913), includes both basinal facies with thick marly sequences located in the western part, and carbonate platform facies located in the central-eastern part (Grădinaru 1995, 2000). The Agighiol Zone had an external position in the framework of the Triassic carbonate platform of the Tulcea Unit, westwards in actual geographic position. It is characterized by thick sequences of Hallstatt-type massive limestones, grouped in the Agighiol Limestone, and extending in age from the upper Spathian up to the lower Carnian. The Hallstatt-type limestones are interbedded with, or grade laterally and/or vertically into Ammonitico Rosso-type nodular siliceous limestones. The areal and stratigraphic distribution of these two sedimentary facies suggests complex sedimentary environments, controlled by active syn-sedimentary block faulting whereby raised blocks of seamount-type were separated by intra-platform depressions. The Hallstatt-type limestone facies were deposited on the top of the seamounts whilst the Ammonitico Rosso-type were deposited in the intra-platform depressions. As a consequence of the prevailing tectonics, the stratigraphic distribution of the two lithofacies show pronounced diachronic relationships which are elucidated by biostratigraphic data.

The Tulcea Unit is the lowermost tectonic unit of the Eo-Alpine North Dobrogea fold and thrust belt, which in its turn represents the westernmost prolongation of the Cimmeride Orogenic System. The Niculiţel Unit, situated in the internal part and having thick pillowed basaltic rocks of Middle Triassic age, represents the Cimmerian suture zone of the Eo-Alpine North Dobrogea fold and thrust belt. In the actual regional tectonic framework of the Alpine-deformed regions around the Black Sea, the Tethyan-type Triassic terrains of North Dobrogea have a remote position as compared to the major Alpine-deformed regions. During the Triassic, the North Dobrogea region was included in the main Tethys area but post-Triassic large-scale horizontal movements displaced the North Dobrogea terrane to its present position. It is interpreted as an exotic terrane docked to Eurasia during the Alpine deformations of the Tethys area (Grădinaru, 1995, 2000).

Description of the GSSP section

The Stratotype Section and Point for the base of the Anisian Stage in the Deşli Caira Hill is located on the southern slope of the hill, in its western quarried side (Fig. 2A, B). There, Section B exposes a 60+ m thick sequence made up of Hallstatt-type massive to well-bedded bio-micritic limestones, mostly of wackestone type. In the area of the Deşli Caira Hill, the Hallstatt-type limestones are underlain by lower Spathian pinkish-white dolomites that represent dolomitic cuppolas developed on the higher paleoreliefs of the Variscan granitic basement. Eastwards and southwards, in the area of the nearby hills of Cara

Constantin and Orta Bair, the Hallstatt-type massive limestones are overlain by the Ammonitico-Rosso siliceous nodular limestones starting within the basal part of the middle Anisian. On the contrary, in the area of the Uzum Bair Hill, 1 km westwards, the Ammonitico Rosso-type facies starts already in the lower Anisian, demonstrating its diachronic relationships with the Hallstatt-type facies.

Section A, located in the eastern side of the southern slope of the Deşli Caira Hill, includes the lower part of the Hallstatt-type limestone section. Having only scarce fossiliferous beds with poorly preserved ammonoid faunas, the Hallstatt-type limestones of the Section A are placed in the middle part of the Spathian. The dolomites underlying Section A are interbedded with or grade laterally into bio-micritic and oncoid-bearing limestones that are coeval with the basinal bituminous marly-limestone sequence containing the Early Spathian *Tirolites cassianus* Beds in the Tulcea city area.

Stratotype Section B starts below the small abandoned quarry noted above, the bottom of which exposes cream-coloured limestones whereas the front of the quarry exposes a total of 5 m of mixed reddish to light gray coloured limestones that grade upwards into red-brick coloured limestones at the top of the quarry face. Subordinate “*Posidonia*”-bearing, whitish coquinoïd limestones are interbedded with the Hallstatt-type limestones. The quarried sequence has abundant ammonoids and fewer nautiloids of late Spathian age. Other macrofaunas are poorly represented, with rare occurrences of small-sized brachiopods, gastropods and crinoids, and thin shelled bivalves at a few levels.

The Olenekian-Anisian Boundary (OAB) is located just above the top of the quarry (Fig. 2B). Above the OAB, the basal part of the lower Anisian is made up almost exclusively of thick-bedded, red-brick coloured Hallstatt-type limestones, with only rare intercalations of “*Posidonia*”-bearing reddish coquinoïd limestones. The Hallstatt-type limestones are extensively bioturbated at some levels, with mottled aspects, and at few levels they show condensed sedimentation features; small open-space features are present in the upper part of the section. Neptunian dykes filled with gray sparry calcite, exposed in the quarried part of the Section B, cut the Hallstatt-type limestone sequence. The tops of the Neptunian dykes, filled with sediment, are located at the level of the *Aegeiceras ugra* Beds, thus suggesting a corresponding time for the dyke opening.

Below the OAB, sampling for macrofaunas is favoured by the now-abandoned quarrying works, whereas above the quarry and below the well-exposed strata of the *Aegeiceras ugra* Beds there is a relatively poorly exposed sequence in the basal part of the Anisian. If not covered by soil, the beds are heavily masked by lichen crusts which make the sampling for fossils difficult. To improve this, extensive trenching was done in the basal part of the Anisian section, just above the quarry. Compared with the upper Spathian sequence, which is very fossiliferous and shows a remarkable continuity in macrofossil occurrence, the basal part of the lower Anisian shows a marked impoverishment in the

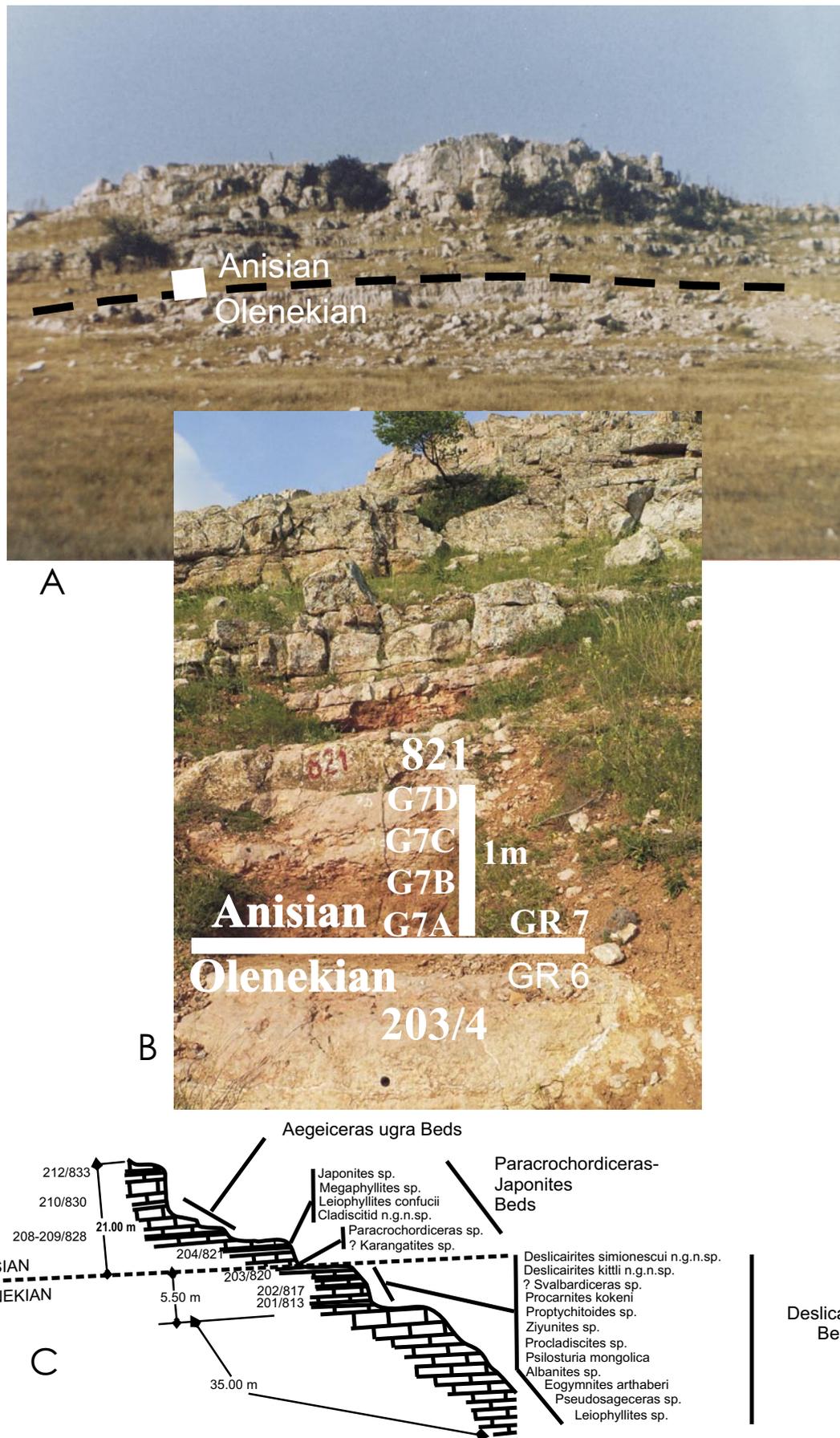


Figure 2: A. Panoramic view of southern slope of Deşli Caira Hill showing the quarry front and the position of the trench exposing the proposed OAB GSSP. B. Photograph of beds straddling the OAB. C. Sketch of the proposed GSSP showing bed numbers, the location of the OAB, and the position and composition of the ammonoid faunas.

macrofossil content. Nevertheless, both macro- and micro-fossil fauna constrain the position of the OAB.

Biostratigraphy (E. Grădinaru, E. S. Sobolev, M. J. Orchard, A. Nicora, D. Ivanova)

Several fossil groups provide biostratigraphic markers for the boundary interval: ammonoid and non-ammonoid cephalopods studied by E. Grădinaru and E. S. Sobolev, conodonts studied by M. J. Orchard and A. Nicora, and foraminifera studied by D. Ivanova.

Ammonoid and non-ammonoid cephalopods

The Hallstatt-type limestones from the Deşli Caira Hill Section B share a continuous record of ammonoid and non-ammonoid cephalopod faunas around the Olenekian-Anisian boundary. Figure 2B summarizes the occurrence data for ammonoids, and Figure 3 shows the data for non-ammonoid cephalopods. The present data demonstrates that the Deşli Caira Hill Section B has the most complete ammonoid and non-ammonoid cephalopod sequence in the Tethyan realm for the time interval around the OAB (Grădinaru & Sobolev, 2006).

The ammonoid and non-ammonoid cephalopod faunas of the Deşli Caira Hill section were first investigated by Kittl (1908) and Simionescu (1910a, b), who described several new taxa. Both authors emphasized the importance of the locality for the ammonoid biostratigraphy of the Anisian in the Tethyan Realm. During the last decades cephalopod faunas have been intensively collected from several stratigraphic levels by the first author (EG). At least eleven levels of distinct, stratigraphically successive cephalopod faunas were identified in the Deşli Caira Hill Section B (Grădinaru, 2000), and there remains a high potential to improve this record.

The latest Olenekian is documented by the *Deslicairites* Beds (Fig. 2B, levels 203/820 and 203/204) characterized by the occurrence of a very abundant and diversified ammonoid fauna including species of well-known latest Spathian genera such as *Procarinites*, *Albanites*, *Proptychitoides*, *Preflorianitoides*, *Ziyunites*, *Leiophyllites*, *Eogymnites*, *Pseudosageceras*, and several new ammonoid taxa. Of outstanding value is the occurrence in the latest Spathian of an olenekitid-like ammonoid species group informally assigned to the new genus *Deslicairites* (Grădinaru, 2003). Some genera traditionally considered as diagnostic for the early Anisian, such as *Procladiscites* and *Psilosturia*, appear first in the latest Spathian. On the other side, there are also some genera considered as diagnostic for the Spathian, such as *Ziyunites* (Wang, 1978, 1985; Wang & He, 1979) that straddle the boundary level, as Fantini Sestini (1981) already mentioned for Chios.

The basal Anisian is documented by the *Paracrochordicerias-Japonites* Beds (Fig. 2B, level 204/821), in which the presence of a *Karangatites*-akin ammonoid and also '*Romanites*' cf. *simionescui* Welter are recorded. The succeeding interval (Fig. 2B, levels 826 to 830) contains ammonoid assemblages grouped in the *Aegeiceras ugra* Beds.

Until recently, non-ammonoid cephalopods from the OAB interval in the Tethyan areas remained almost completely unknown. It is now established by the data in the Deşli Caira Hill Section B that three orders of non-ammonoid cephalopods are represented in the OAB interval: Orthocerida, Nautilida, and Aulacocerida (Fig. 3). Besides new species of known genera there are also representatives of several new genera. The orthocerids, which are the most numerous amongst those recovered, are represented by the genera *Trematoceras*, *Romanorthoceras* gen. nov. (Pseudorthoceratidae), and *Paratrematoceras* (Orthoceratidae). The nautilids include the genera *Syringoceras*, *Deslinautilus* gen. nov., *Ascutitonautilus* gen. nov. (Syringonautilidae), and *Phaedrysmocheilus* (Tainoceratidae). The aulacocerids have rare representatives of the genera *Atractites*, as rests of phragmocones (Xiphoteuthidae), and *Dictyoconites* (Dictyoconitidae).

The analysis of the stratigraphic distribution of the non-ammonoid cephalopods has resulted in the recognition within the OAB interval at Deşli Caira Section B of five assemblages characterized by specific orthocerids and nautilids (Fig. 3). For the aulacocerids it is not possible to distinguish assemblages due to their rarity.

In the topmost Olenekian, the orthocerid-based "beds with *Paratrematoceras abundans*" are characterized by a rather varied assemblage including five new species assigned to the genera *Paratrematoceras*, *Trematoceras*, and *Romanorthoceras*. The nautilids are grouped in two distinct, successive assemblages: the "beds with *Deslinautilus limatulus*" and "beds with *Syringoceras mediocre*", respectively. The lower assemblage includes three new species assigned to the genera *Deslinautilus* and *Phaedrysmocheilus*. The upper assemblage is represented only by the index species.

In the basal Anisian, the orthocerid-based "beds with *Paratrematoceras conspicuum*" include, besides the index-species, a new species of the genus *Trematoceras* and the species *P. productum*, known also in the underlying beds of the topmost Olenekian. Besides the index species, the nautilid-based "beds with *Syringoceras exiguum*" include representatives of the new genus *Ascutitonautilus*, which is the direct descendant of the Olenekian genus *Deslinautilus*. The *Dictyoconites* species with poorly advanced and thin sculpture are common for the topmost Olenekian, whilst in the basal Anisian there are more roughly sculptured forms (*D. kongazensis* Kittl).

Thus, in the Tethyan Triassic of North Dobrogea there are essential changes across the OAB in the orthocerids and nautilids. Three genera (*Romanorthoceras*, *Deslinautilus*, and *Phaedrysmocheilus*) that are known in the late Olenekian do not pass into the early Anisian, where the new genus *Ascutitonautilus* appears in a more impoverished nautilid assemblage. Among the aulacocerids changes occur only at a specific level.

Conodonts

Conodonts from Deşli Caira were collected over many

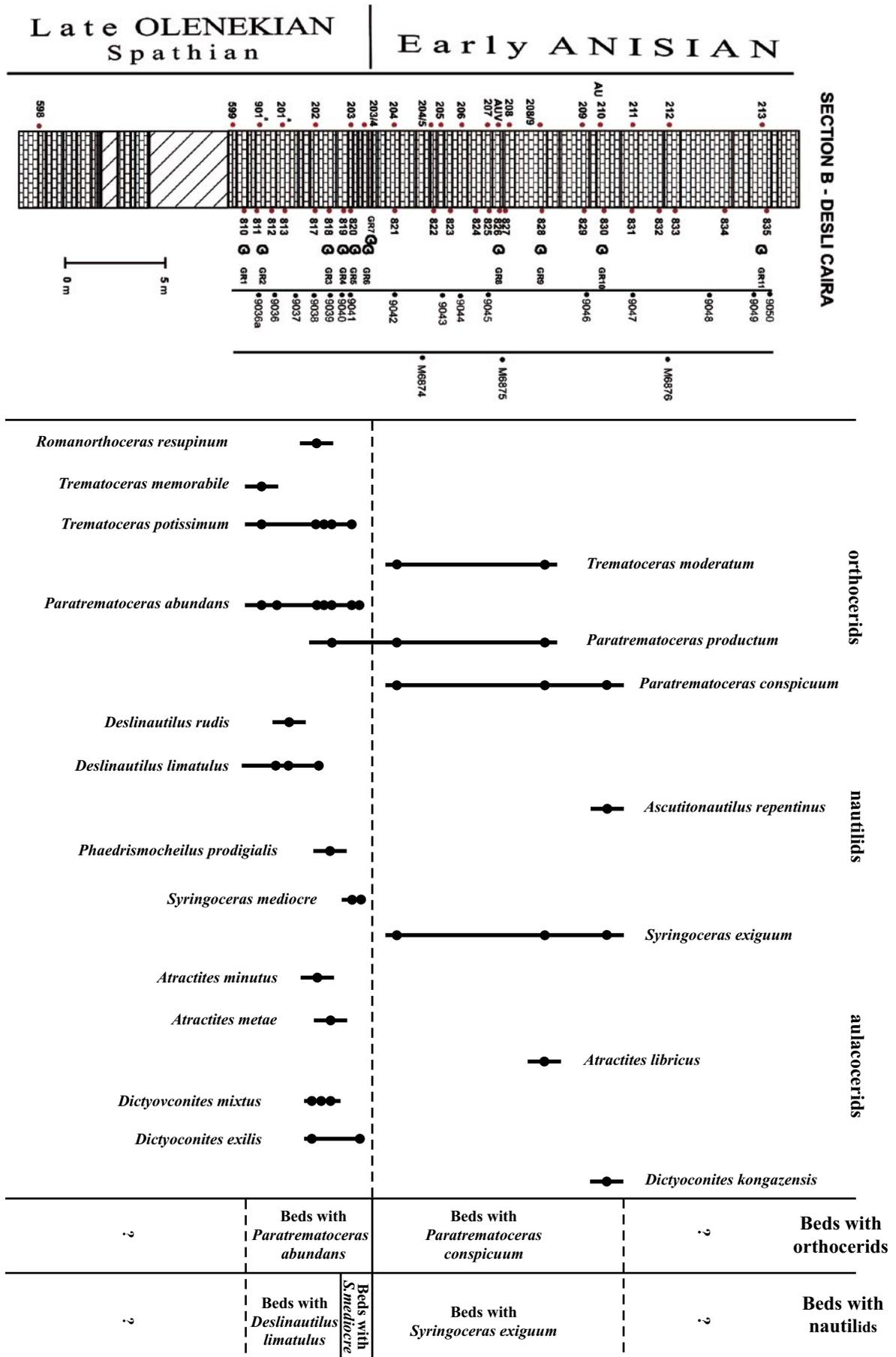


Figure 3: Stratigraphic distribution of non-ammonoid cephalopods across the proposed OAB in the Deșli Caira section (North Dobrogea).

years and by several workers. Some of these data have been presented in preliminary papers by Mirăuță (1974, 2000) and Grădinaru et al. (2002, 2006). The data have most recently been summarized by Orchard et al. (2007a; Figs. 4, 5), and many of the taxa and their distribution were discussed by Orchard et al. (2007b).

Conodont samples were recovered from about 25 m of section straddling the OAB. Several species present in the samples from the upper Olenekian – *Triassospathodus*, *Cratognathus* spp., *Spathiscuspis*, '*Gladigondolella*' *carinata*, and new genus A – probably have a longer history prior to the latest Olenekian, so their appearances in this section are not regarded as significant. In contrast, nine conodont appearances (i.e., FAD) and disappearances (i.e., LAD) are identified as guides to identify the OAB in the Deșli Caira section. Several of these are coincident, and all occur within about 4.25 m of strata. For the remaining 20 m of section, the fauna maintains a relatively constant composition (Fig. 4). These conodont events are (with positions relative to the OAB):

- 1) FAD of *Chiosella gondolelloides* (-3 m)
- 2) LAD of *Spathiscuspis* (-1 m)
- 3) LAD of *Neospathodus triangularis* (0 m)
- 4) FAD of *Chiosella timorensis* (0 m)
- 5) LAD of '*Gladigondolella*' *carinata* (0 m)
- 6) FAD of *Chiosella* n. sp. A (0 m)
- 7) FAD of *Gladigondolella tethydis* (+0.5 m)
- 8) LAD of *Triassospathodus* (+1.25 m)
- 9) FAD of *Neogondolella* (+1.25 m)

These conodont events are grouped so as to define five datums at Deșli Caira:

Datum 1

The first significant datum is the FAD of *Chiosella gondolelloides* at about 3 m below the OAB. The appearance of *C. gondolelloides* is an easily recognized datum since the separation of the species from its apparent forebear and common associate, *Triassospathodus* ex gr. *homeri*, is straightforward.

Datum 2

The LAD of *Spathiscuspis spathi* at 1 m below the OAB is an earlier LAD than is seen elsewhere (e.g. at Guandao, China; Orchard et al., 2007b), where the species ranges into basal Anisian strata. The species is far less common in the Romanian faunas and this datum is not a useful one for correlation.

Datum 3

This is the major faunal change of the succession and is marked by the appearance of *Chiosella timorensis* and *Chiosella* n. sp. A, and the disappearance of both *Gladigondolella carinata* and '*Neospathodus*' *triangularis*.

These four conodont events are not entirely synchronous elsewhere (e.g. Orchard et al., 2007b), but they all cluster around the OAB.

Datum 4

The FAD of *Gladigondolella tethydis* occurs 0.5 m above the OAB. This appearance in the early Anisian is consistent with records elsewhere (e.g. Orchard et al., 2007b).

Datum 5

At 1.25 m above the OAB, the LAD of *Triassospathodus* ex gr. *homeri* coincides with the FAD of *Neogondolella* sp. These two taxa are known to overlap elsewhere in Tethys and also in North America. In Tethyan successions, the overlap is within the basal Anisian, as it is in the Deșli Caira, but in North America it occurs first in the late Spathian. Although the overlap of taxa is not a reliable datum worldwide, the LAD of *T. ex gr. homeri* is nevertheless a reliable early Anisian event.

Foraminifera

The studied foraminifera contains very rich, diverse, and well-preserved taxa, including more than 25 species, belonging to eight agglutinated and ten non-agglutinated genera. These were investigated both as isolated forms obtained by dissolution and in thin sections. The stratigraphic distribution of the foraminifera in Deșli Caira Hill Section B is shown in Figures 4, 5.

The lower part of the Deșli Caira Hill Section B contains a rich foraminiferal association, including species which share a high potential for biostratigraphic correlation. These are: *Rectocornuspira kalhori* Broennimann, Zaninetti & Bozorgnia, *Cornuspira mahajeri* (Broennimann, Zaninetti & Bozorgnia), *Glomospira tenuifistula* Ho, *Glomospirella vulgaris* Ho, *Hoyenella* gr. *sinensis* (Ho), *Meandrospira cheni* (Ho), *Meandrospira pusilla* (Ho), *Ammobaculites radstadtensis* Kristan-Tollmann, *Ammobaculites duncani* Schröder, *Ammodiscus parapriscus* Ho, *Trochammina almtalensis* Koehn-Zaninetti, *Textularia racemata* Terquem & Berthelin, *Textularia rectangularis* Deprat, *Earlandia tintinniformis* (Misik), *Bigenenerina vallis* (Trifonova), *Nodogordiospira conversa* Trifonova, *N. praeconversa* Trifonova and *Neotolypammmina discoidea* (Trifonova). The above-mentioned foraminiferal association, referred to the *Rectocornuspira kalhori* - *Cornuspira mahajeri* assemblage (Assemblage 1 in Fig. 4), is diagnostic for the upper part of the Olenekian Stage (Spathian Substage) and shows many affinities with globally-distributed taxa.

For the upper part of the Deșli Caira Hill Section B, the foraminiferal assemblage (Assemblage 2 in Fig. 4) includes the following taxa: *Meandrospira dinarica* Kochansky-Devide & Pantic, *Endotriadella wirzi* (Koehn-Zaninetti), *Krikoumbilica peleiformis* He, *Glomospirella grandis* (Salaj, Biely & Bystricky), *Hoyenella* gr. *sinensis* (Ho), *Trochammina almtalensis* Koehn-Zaninetti, *Neotolypammmina discoidea* (Trifonova), *Textularia racemata* Terquem & Berthelin, *Textularia rectangularis* Deprat, *Turriplomina conica* (He), *Earlandia tintinniformis* (Misik), *Earlandia amplimuralis* (Pantic) and *Nodosaria* sp. These foraminif-

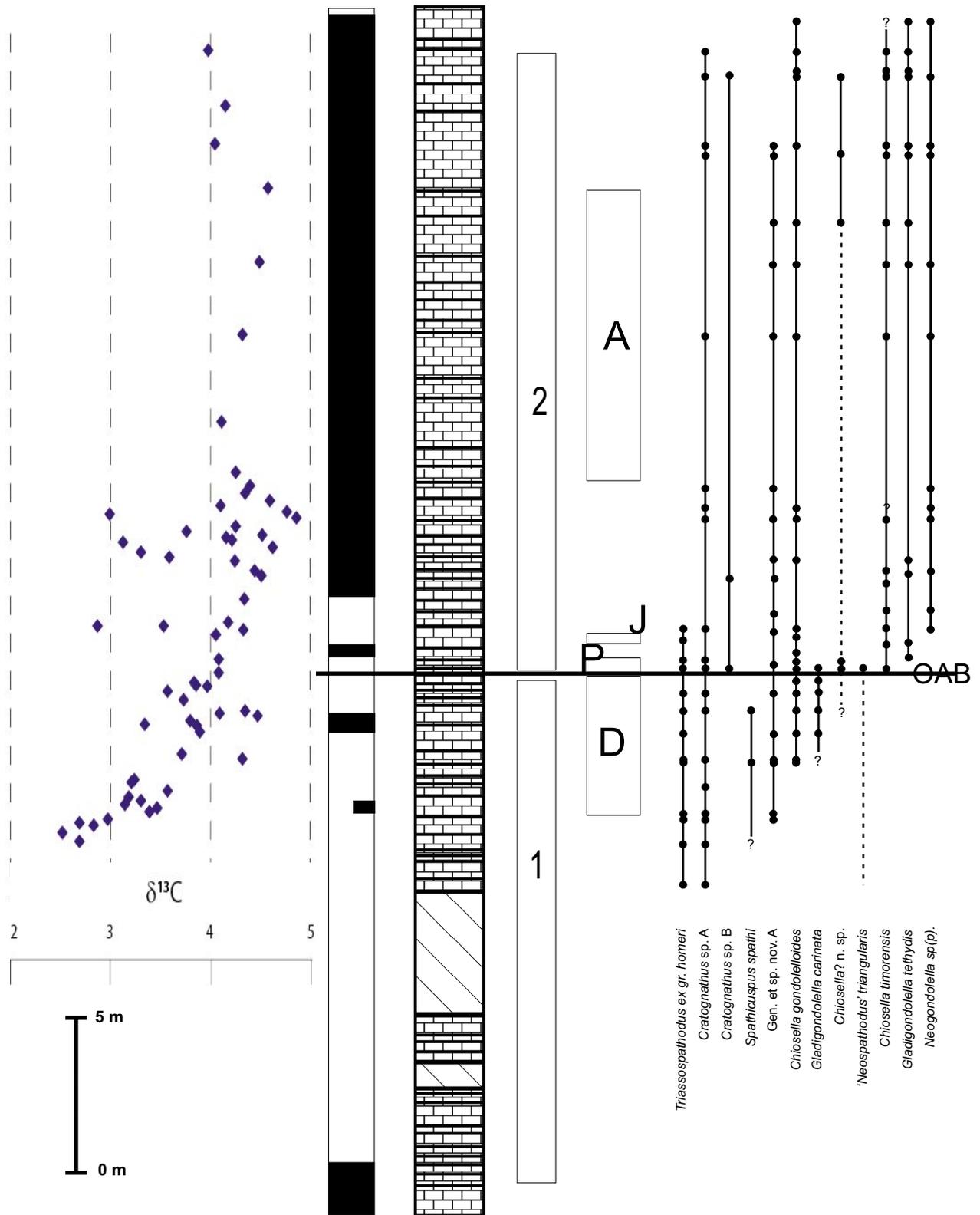


Figure 4: Schematic presentation of (from right) conodont, ammonoid, foraminifers, stratigraphic section, magnetic polarity, and carbon isotope data from Deşli Caira Hill with proposed position of OAB GSSP. For ammonoids, D = Deslicairites Beds; P, J = Paracrochordiceras - Japonites Beds; A = Aegeiceras ugra Beds. See text for details of foraminiferal assemblages 1 and 2.

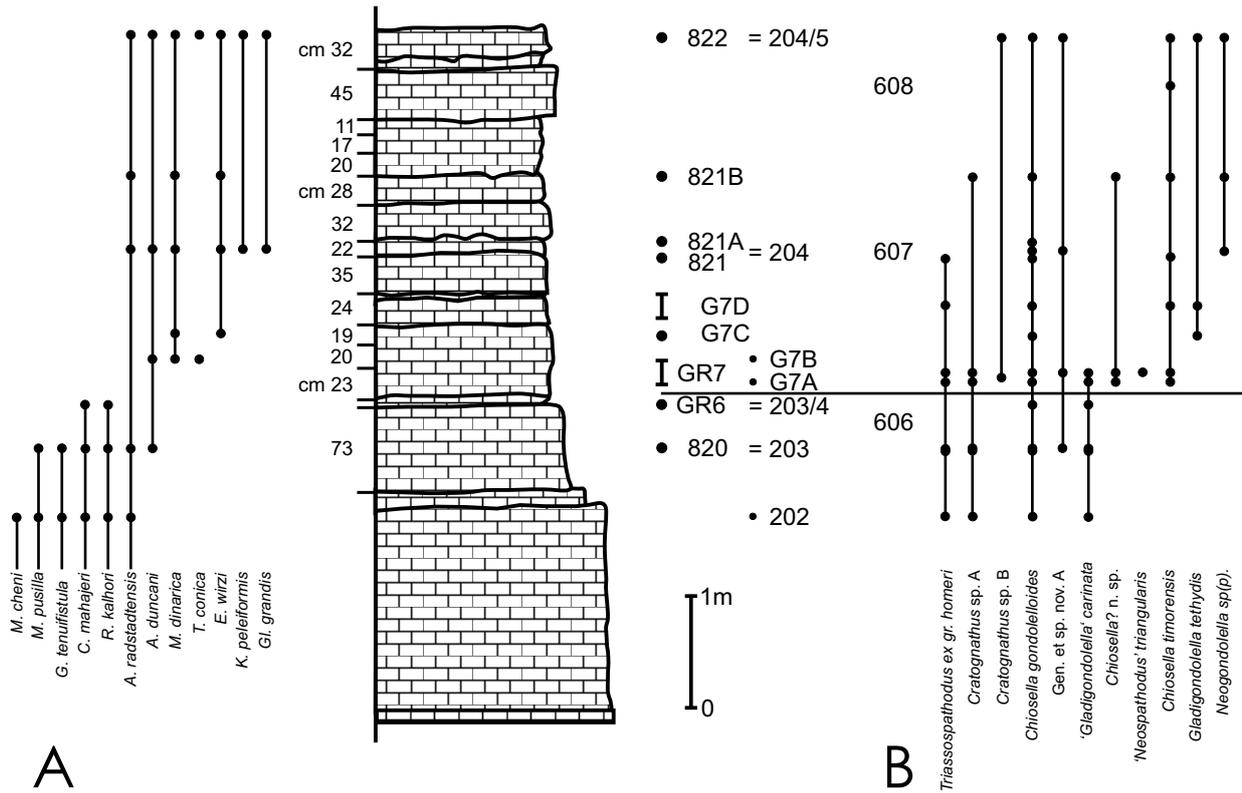


Figure 5: Details of the occurrence of A, foraminifers and B, conodonts, across the OAB at Deşli Caira Hill.

ers is diagnostic for the lowermost Anisian Stage (Aegean Substage) and shows many affinities with globally-distributed taxa.

Some results concerning taxonomic status and stratigraphic distribution of studied foraminifera have to be underlined, as follows:

1) The *Rectocornuspira kalhori* – *Cornuspira mahajeri* assemblage is known to be widespread in the Lower Triassic of the Tethyan Realm. In several Tethyan sections, it is the first Triassic foraminifera association appearing above the Permian-Triassic boundary, and has been used as an indicator marker for the lower part of Lower Triassic. The predominance of this assemblage in the Deşli Caira Hill Section B confirms the conclusions of Trifonova (1993) and Hips (1996) that the vertical range of the assemblage is not limited to the lower Induan but occurs throughout the Lower Triassic.

2) The age of the species *Bigenerina vallis*, originally reported as a new species from the Spathian of northeast Bulgaria (Trifonova, 1967), is here confirmed in the Deşli Caira Hill section on the evidence of associated conodonts and ammonoids.

3) Based on detailed foraminiferal investigation we are not able to establish the distribution of the genus *Meandrospira* of the lineage *M. cheni* – *M. dinarica*, which evolves from *M. pusilla*. Although the thin sections and isolated samples were very poor in species of this genus, we are neverthe-

less able to confirm the results of Rettori et al. (1994) that *M. dinarica* appears during the early Anisian. In terms of systematics, the problem with the species assignment to the genus *Meandrospira* is still open for discussion.

4) *Krikoumbilica peleiformis* has been known in the Middle Triassic of China (Ho, 1984). Rettori et al. (1994) recorded the species for the first time from the Scythian in Hydra Island, Greece “on the basis of the presence of the conodont *Neospathodus homeri* in the same sample”. Taking into account that the species *N. homeri* in Deşli Caira Hill Section B range up to the lowest meter of the section above the boundary level (Grădinaru et al., 2002; Orchard et al., 2007a), it seems that the species is earliest Anisian in age.

Only a limited number of papers describe isolated Triassic foraminifera, and these are from only a few isolated levels. The identification of species and genera from Triassic rocks has been essentially done in thin sections. The main problem that arises is how to correlate the taxonomy of foraminifera in thin sections to those ones identified as isolated forms. In the present study we could not resolve these taxonomic problems, but nevertheless we propose realistic assemblages, identified both in thin sections and washed isolated material. Of particular stratigraphic importance are the following conclusions:

- in the Lower Triassic part of the Deşli Caira Hill Section B representatives of the *Glomospira* – *Glomospirella* microfacies are predominant;

- typical Lower Triassic *Rectocornuspira kalhori* – *Cornuspira mahajeri* assemblage disappears 0.50 m below the boundary level;

- in the Deşli Caira Hill Section B typical Lower Triassic species are identified as *Bigenerina vallis*, *Nodogordiospira conversa*, and *N. praeconversa*;

- *Meandrospira dinarica* occurs in the lowest meter of the Deşli Caira Hill Section B above the boundary level; in the same thin section we found a single specimen of species *Turriplomina conica*, another characteristic Middle Triassic taxa;

- the typical Middle Triassic species *Endotriadella wirzi* appears first about 0.50 m above the boundary level;

- some characteristic Anisian taxa such as *Krikoumbilica peleiformis* and *Glomospirella grandis* appear first at about 1.20 m above the boundary level. This occurrence is chronologically important because there are no isolated foraminifers from this first meter, and the association is indicative for the Middle Triassic age.

- The agglutinated genera belonging to the foraminiferal Suborders Textulariina, Miliolina, Fusulinina, and Lagenerina are predominant in the Hallstatt-type limestones of the Deşli Caira Hill Section B and they have a high taxonomic diversity.

Magnetostratigraphy (Y. Gallet, J. Besse, L. Krystyn)

About 150 samples were collected from the two subsections of the Deşli Caira Hill sections, Section A and Section B. Only the results obtained from Section B are relevant for the OAB. The samples were analyzed in the paleomagnetic laboratory at the Institut de Physique du Globe de Paris.

Thermal demagnetization reveals two magnetic components. A first largely predominant component (LTC) is isolated over a wide temperature range, from the first demagnetization step up to 400°C, and sometimes higher (Fig. 6A). The mean direction obtained for this component is roughly parallel to the present day field at the site (Fig. 6Ba). A high temperature component (HTC) is then isolated up to 580°C or to 640°C-680°C, which indicates that this component is carried by magnetite and/or by hematite (Fig. 6A). In some cases, a large overlap exists between the LTC and HTC components, which precludes the determination of a precise (« end-points») direction for the HTC component; for these samples, however, great circle analyses help to constrain the magnetic polarity of the HTC component (grey circles in Fig. 7). The HTC component has dual magnetic polarities and is interpreted as being acquired during, or very soon after sediment deposition (Fig. 6Bb). The HTC directions (and great circles) define a magnetic polarity sequence which allows us to place the Olenekian (Spathian)-Anisian (Aegean) boundary with respect to the chronology of the geomagnetic field reversals (Fig. 7).

The results of this study show that the OAB is located between two short normal magnetic polarity intervals.

These results align well with the magnetic polarity profile at the Kçira section in Albania (Muttoni et al., 1996), and furthermore confirm the incomplete nature of the Chios section (Muttoni et al., 1995) at the Lower-Middle Triassic transition (as recognized by Muttoni et al. (1998).

Carbon isotope stratigraphy (V. Atudorei)

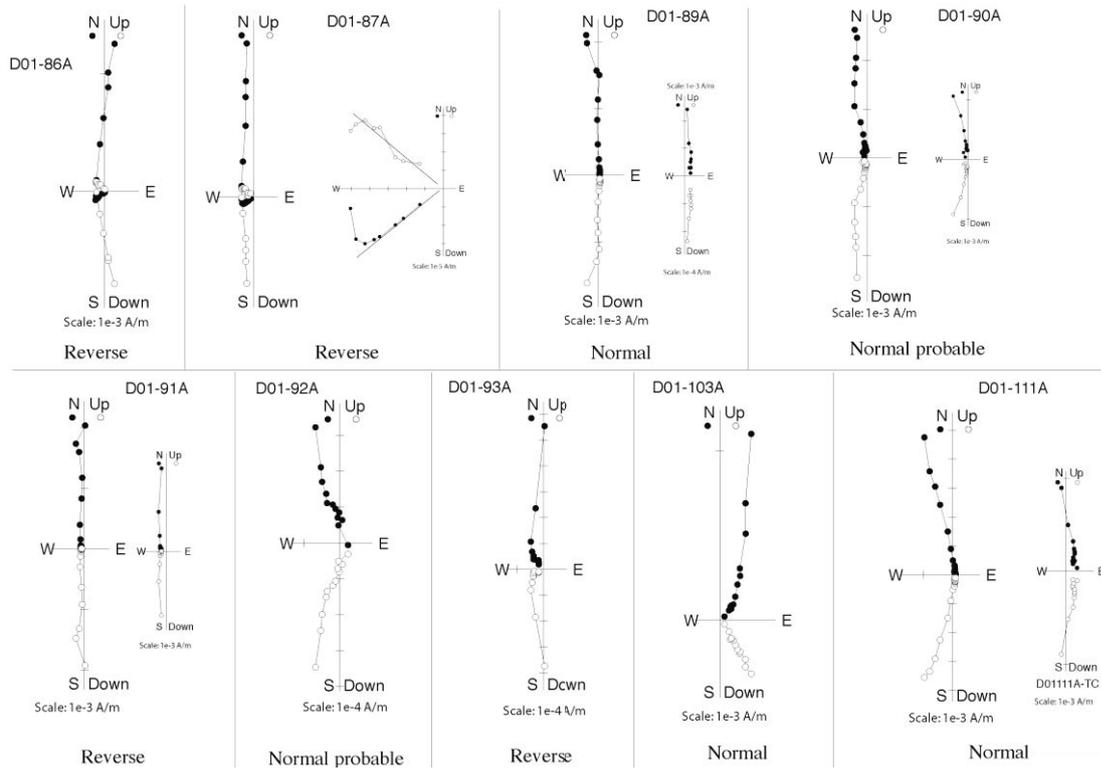
Sixty-five samples were collected for carbon and oxygen isotope analysis, starting with the base of the small quarry in Section B. Most of the results were reported in Atudorei (1999), however here we also include results from a subset of samples from the basal part of the Anisian subsequent to trenching of the rock sequence

At Deşli Caira, the isotope results show a gradual increase in $\delta^{13}\text{C}$ values from +2.5‰ recorded at the base of the quarry, to values as high as 5‰ in the middle and the upper part of the section, where they remain relatively constant (Fig. 4). A number of samples just above the proposed boundary yielded $\delta^{13}\text{C}$ values outside the general trend, 1-2‰ lower. We believe them to represent heterogeneities of the original sediment rather than primary changes of the seawater. Also, a diagenetic overprint of the the primary $\delta^{13}\text{C}$ values does not appear to be a concern at Deşli Caira because the $\delta^{18}\text{O}$ values are relatively high (between -2‰ to -3‰) and they do not show any correlation with the $\delta^{13}\text{C}$ values. Further considerations on this subject can be found in Atudorei (1999).

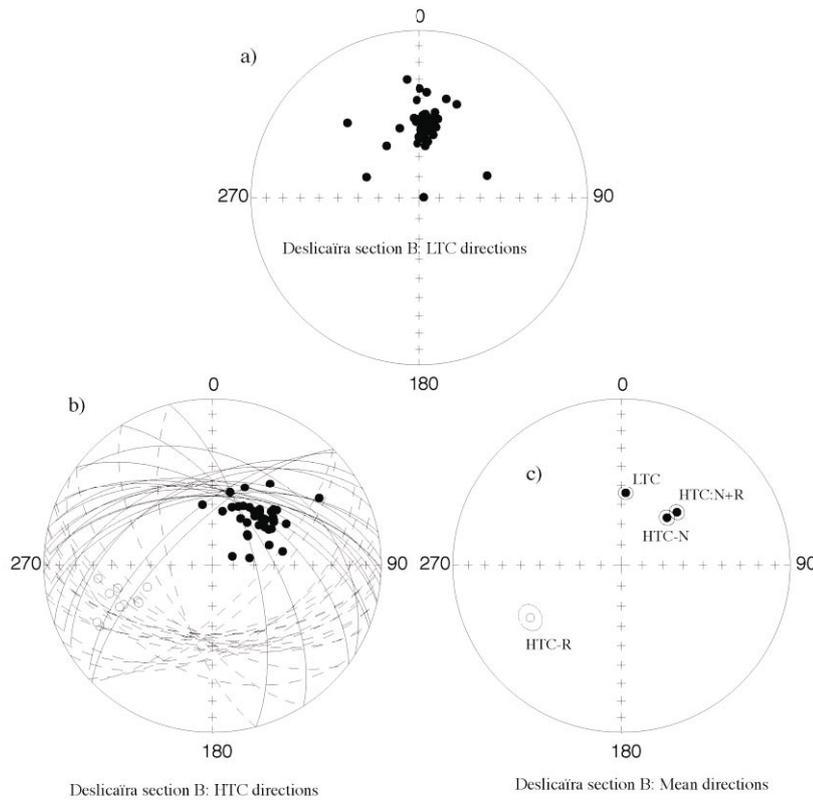
While the upward trend is well marked at Deşli Caira, the peak shape is difficult to visualize when looking at the Deşli Caira data alone, because the background values, below and above the peak, are missing. However, in a composite section including Deşli Caira and several sections located at Dealul Pietros, 6 km southeast of Deşli Caira, the carbon isotope excursion is clearly marked. At the other sections, within the same lithology as at Deşli Caira (Hallstatt-type limestones), the $\delta^{13}\text{C}$ values are close to 2‰, which represents the background values for the Upper Olenekian and Anisian (see Atudorei, 1999, Fig. 38). Therefore, it appears that the amplitude of the positive carbon isotope excursion in this area is up to 3‰. In addition, the carbon isotope excursion is recorded in two different sections in the vicinity of Deşli Caira, in different lithological settings: at Dealul cu Cununa (6 km southeast of Deşli Caira), and Uzum Bair (1 km southwest of Deşli Caira).

The proposed OAB is located close to the end of the gradual increase in $\delta^{13}\text{C}$ values; however, there is no distinct feature of the carbon isotope curve just across the proposed boundary. The highest values are recorded in an interval 3 to 5 meters above the proposed boundary, although the entire middle and upper part could be considered as a plateau. The gradual increase in $\delta^{13}\text{C}$ values just across the boundary suggests that no significant gaps occur at Deşli Caira within the proposed boundary interval.

In addition to the current Dobrogea data, previous carbon isotope studies showed the presence of a marked positive carbon isotope excursion across the OAB in Spiti (India), Kçira (Albania), and South China (Atudorei, 1999; Payne et al., 2004; Galfetti et al., 2007). Outside the Tethys, a



A



B

Figure 6: A. Thermal demagnetization of samples from the Değli Caira section B. The closed (open) symbols refer to the horizontal (vertical) plane. B. a. Equal-area projection of directions isolated in the low to middle temperature range (LTC component) and b. in the high temperatures (HTC component). c. Mean normal and reversed polarity directions computed after bedding correction from the HTC component. The closed (open) symbols refer to directions in the lower (upper) hemisphere.

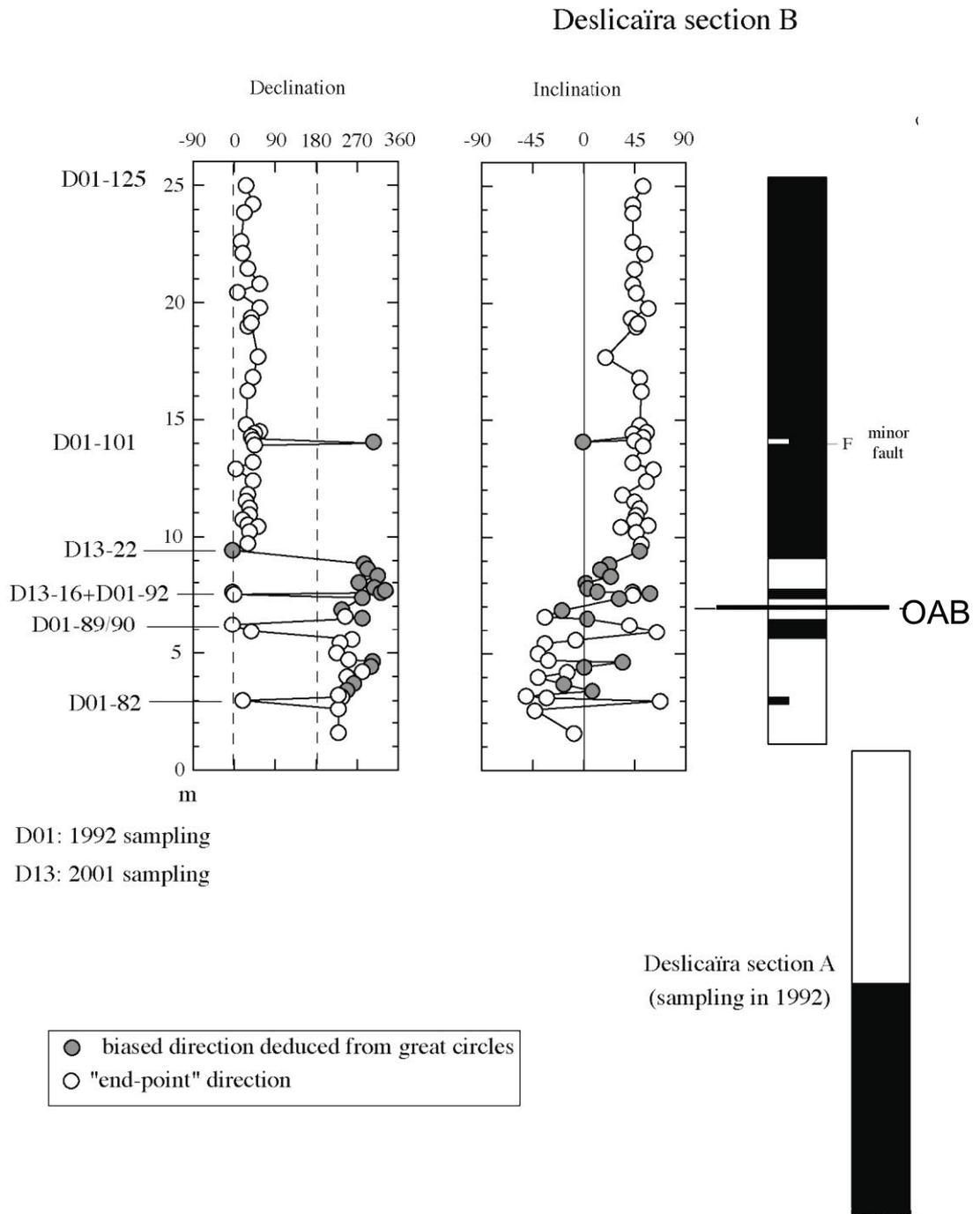


Figure 7: Magnetostratigraphic sequence of the Deșli Caïra section B combining the results obtained in 1992 and 2001. We also indicate the sequence we obtained from section A (sampling in 1992).

positive excursion near the OAB has recently been reported at Ursula Creek (northeast British Columbia, Canada), proving its global extent (Atudorei et al., 2007). This excursion clearly has considerable correlation potential.

Summary

The Olenekian-Anisian Boundary GSSP is proposed between beds GR6 and GR7 (between 203/204 and G7A, respectively) at Deşli Caira Hill Section B, in northern Dobrogea, Romania.

This boundary is recognized by major faunal turnover in widely distributed ammonoids, nautiloids, conodonts, and foraminiferids within continuous fossil sequences. It is characterized further by distinctive magnetostratigraphic and chemostratigraphic profiles.

Amongst the ammonoids, the latest Olenekian is characterized by the *Deslicairites* Beds, which contain a very abundant and diversified ammonoid fauna including species of well-known latest Spathian genera. The base of the Anisian contains the *Paracrochordiceras-Japonites* Beds, and these are followed by the *Aegeiceras ugra* Beds. Some of the ammonoid taxa permit correlation between the Tethyan and the Boreal realms.

The orthocerids of the topmost Olenekian are characterized as the *Paratrematoceras abundans* Beds whereas the nautilids are differentiated as two successive assemblages, *Deslinautilus limatulus* Beds and *Syringoceras mediocre* Beds, respectively. In the basal Anisian, virtually the entire fauna differs in strata characterized as the *Paratrematoceras conspicuum* Beds for the orthocerids, and *Syringoceras exiguum* Beds for the nautilids, respectively.

Conodonts show a profound turnover about the OAB involving the disappearance of four genera, amongst which *Triassospathodus* is dominant in the late Olenekian. The successive appearance and rise to dominance of five other taxa, notably *Chiosella*, characterizes early Anisian strata.

Amongst the foraminiferids, the typical Lower Triassic *Rectocornuspira kalhori* - *Cornuspira mahajeri* assemblage extends to the top of the Olenekian and is succeeded by a different foraminiferal assemblage diagnostic for the lowermost Anisian.

The paleontologically defined OAB is located in between two short normal magnetic polarity intervals, and close to the end of a gradual increase in $\delta^{13}\text{C}$ isotope values; both can be recognized globally.

The proposed GSSP is a multifaceted datum that can serve to identify the OAB and base of the Middle Triassic Series in the standard Triassic timescale.

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Plate 1

All specimens are housed in the Faculty of Geology and Geophysics, University of Bucharest.
All figures natural size, if otherwise stated.

Fig.1. *Japonites* sp.; GE 211 (level 821, lower Anisian)

Fig.2. ?*Karangatites* sp.; GE 189 (level G7A, lower Anisian)

Fig.3. *Paracrochordiceras* sp.; GE 190 (level G7A, lower Anisian)

Fig.4. '*Romanites*' cf. *simionescui* Welter; GE 215 (level 822, lower Anisian)

Fig.5-6. *Deslicairites simionescui* Grădinaru, n.gen.n.sp.; GE 135 (level 820, uppermost Olenekian); Fig. 6 - x 2

Fig.7-8. *Deslicairites simionescui* Grădinaru, n.gen.n.sp.; GE 123 (level 820, uppermost Olenekian); Fig.8 - x 2

Fig.9-10. *Deslicairites kittli* Grădinaru, n.gen.n.sp.; GE 98 (level 820, uppermost Olenekian); Fig.10 - x 2

Fig.11-12. *Deslicairites kittli* Grădinaru, n.gen.n.sp.; GE 91 (level 820, uppermost Olenekian); Fig.12 - x 2

Fig.13. *Procladiscites* sp.; GE 120 (level 820, uppermost Olenekian)

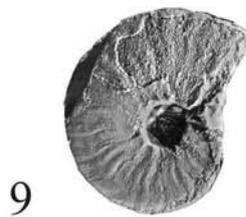
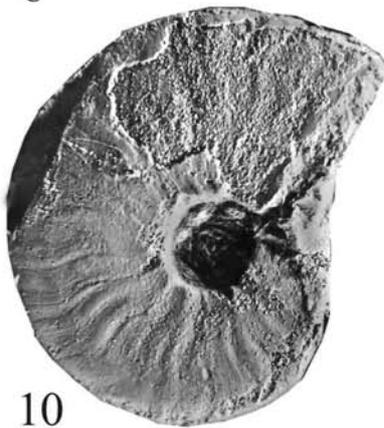
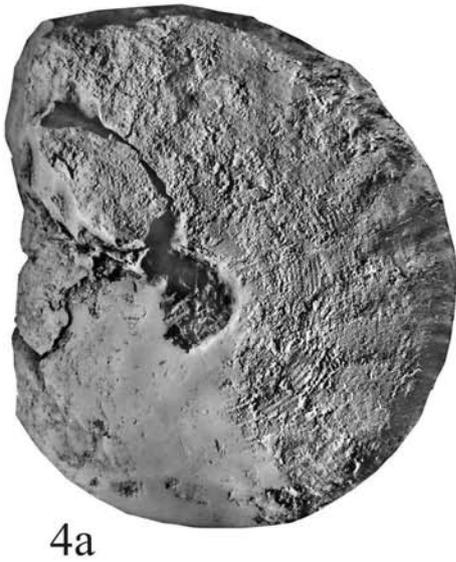
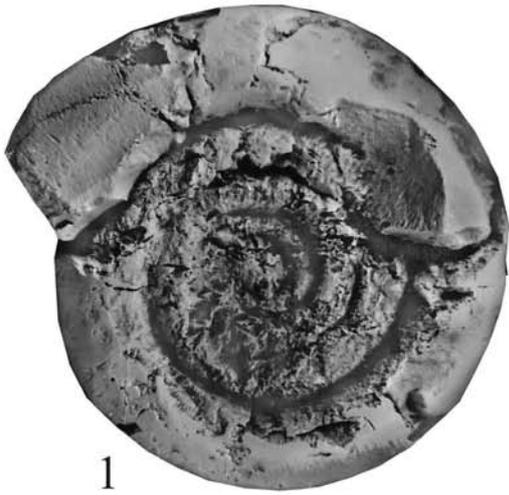


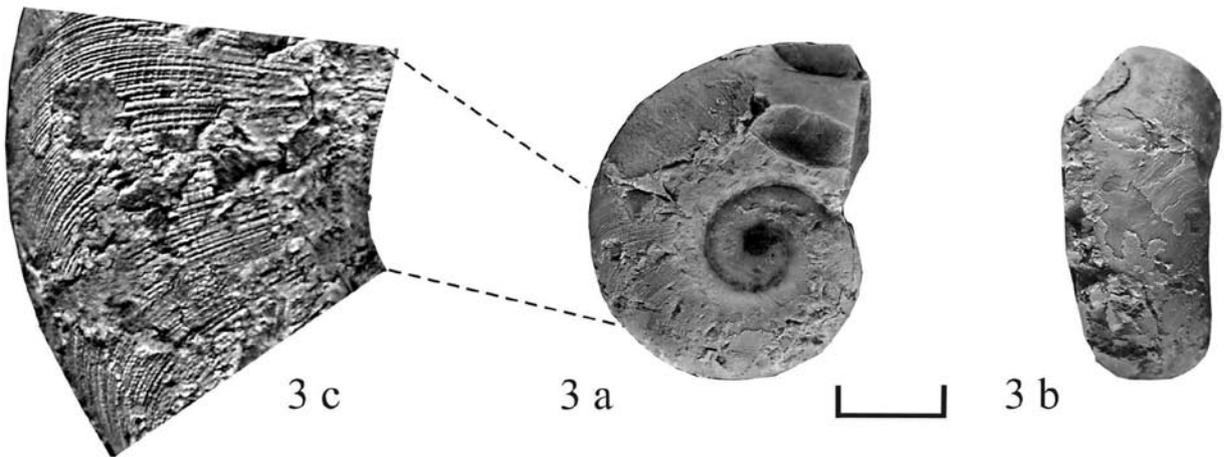
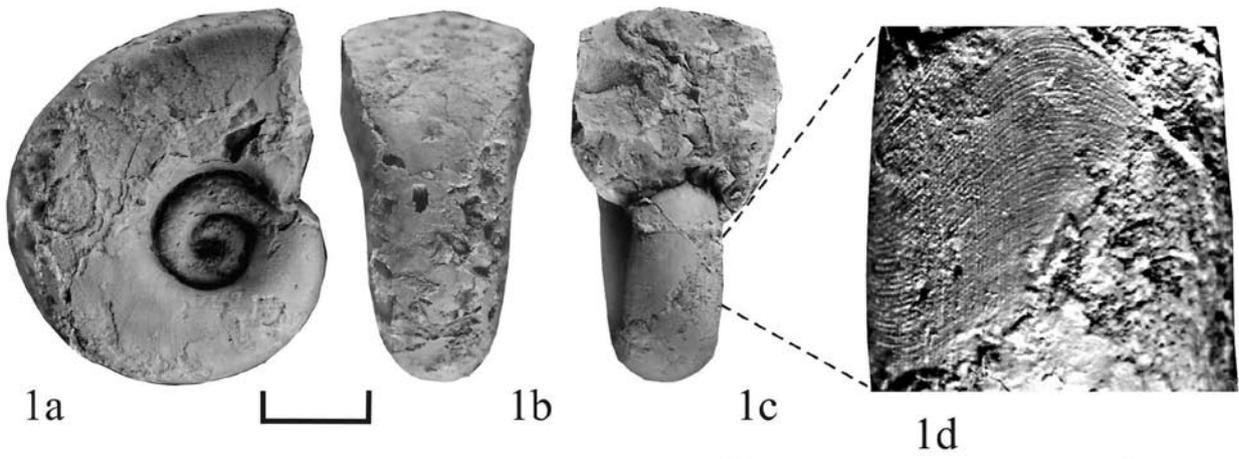
Plate 2

All specimens are housed in the Faculty of Geology and Geophysics, University of Bucharest. The bar corresponds to 1 cm; Fig.1 d - x 5; Fig.3 c - x 3.

Fig.1. *Deslinautilus limatulus* Grădinaru & Sobolev, n.gen.n.sp.; GE 7 (level 202a, uppermost Olenekian).

Fig.2. *Syringoceras mediocre* Grădinaru & Sobolev, n.sp.; GE 41 (level 203, uppermost Olenekian)

Fig.3. *Syringoceras exiguum* Grădinaru & Sobolev; n.sp.; GE 51 (level 208/209, lower Anisian)



The magnetostratigraphy of the Olenekian-Anisian boundary and a proposal to define the base of the Anisian using a magnetozone datum

Mark W. Hounslow¹, Michael Szurlies², Giovanni Muttoni³, and Jerzy Nawrocki⁴

¹CEMP, Geography Dept., Lancaster University, Bailrigg, Lancaster, UK. LA1 4YB (m.hounslow@lancs.ac.uk).

²GeoForschungsZentrum Potsdam, Telegrafenberg Haus C, D-14473 Potsdam, Germany (szur@gfz-potsdam.de).

³Department of Earth Sciences, University of Milan, Via Mangiagalli 34, 20133 Milan, Italy (giovanni.muttoni1@unimi.it).

⁴Paleomagnetic Laboratory, Polish Geological Institute, Rakowiecka 4, 00-975 Warsaw, Poland (jerzy.nawrocki@pgi.gov.pl).

Introduction

There exist many magnetostratigraphic studies across the boundary of the Lower and Middle Triassic, from both low and high-palaeolatitude marine sections (Muttoni et al., 1995, 1996, 2000; Lehrmann et al., 2006; Hounslow et al., 2007, inpress-b), and non-marine sections (Steiner et al., 1993; Nawrocki & Szulc, 2000; Huang & Opdyke, 2000; Hounslow & McIntosh, 2003; Dinarès-Turell et al., 2005; Steiner, 2006; Szurlies, 2007). These many studies now supply excellent independent assessment of the sequence of polarity reversals across the Olenekian-Anisian boundary (OAB), providing a potentially high-detail of correlation using magnetostratigraphy. This is supplemented by well-established magnetostratigraphies through the remainder of the Lower and Middle Triassic (Muttoni et al., 2000, 2004; Steiner, 2006; Szurlies, 2007; Hounslow et al., inpress-a).

Correlation using magnetostratigraphic normal/reverse polarity 'bar-code' patterns relies on a reasonable, within-section consistency of sedimentation rate. Comparison between sections with large sedimentation rate differences is best accommodated by stretching or shrinking the entire magnetostratigraphic scale, using other correlation constraints (biostratigraphic, radiometric etc) as a guide. Similarly, hiatus can distort the magnetostratigraphic pattern unless properly identified using biostratigraphic, or sedimentological data. For the most part use of these 'sedimentation rate principles' have provided sound solutions for magnetostratigraphic correlation in most marine and terrestrial settings, except perhaps where sedimentation rates are very low (e.g. some pelagic settings). These principles provide the basis of the correlations in Figures 1 and 2, constrained by the biostratigraphy, which is sometimes conflicting, perhaps in part due to the 'first-occurrence versus first presence problem'.

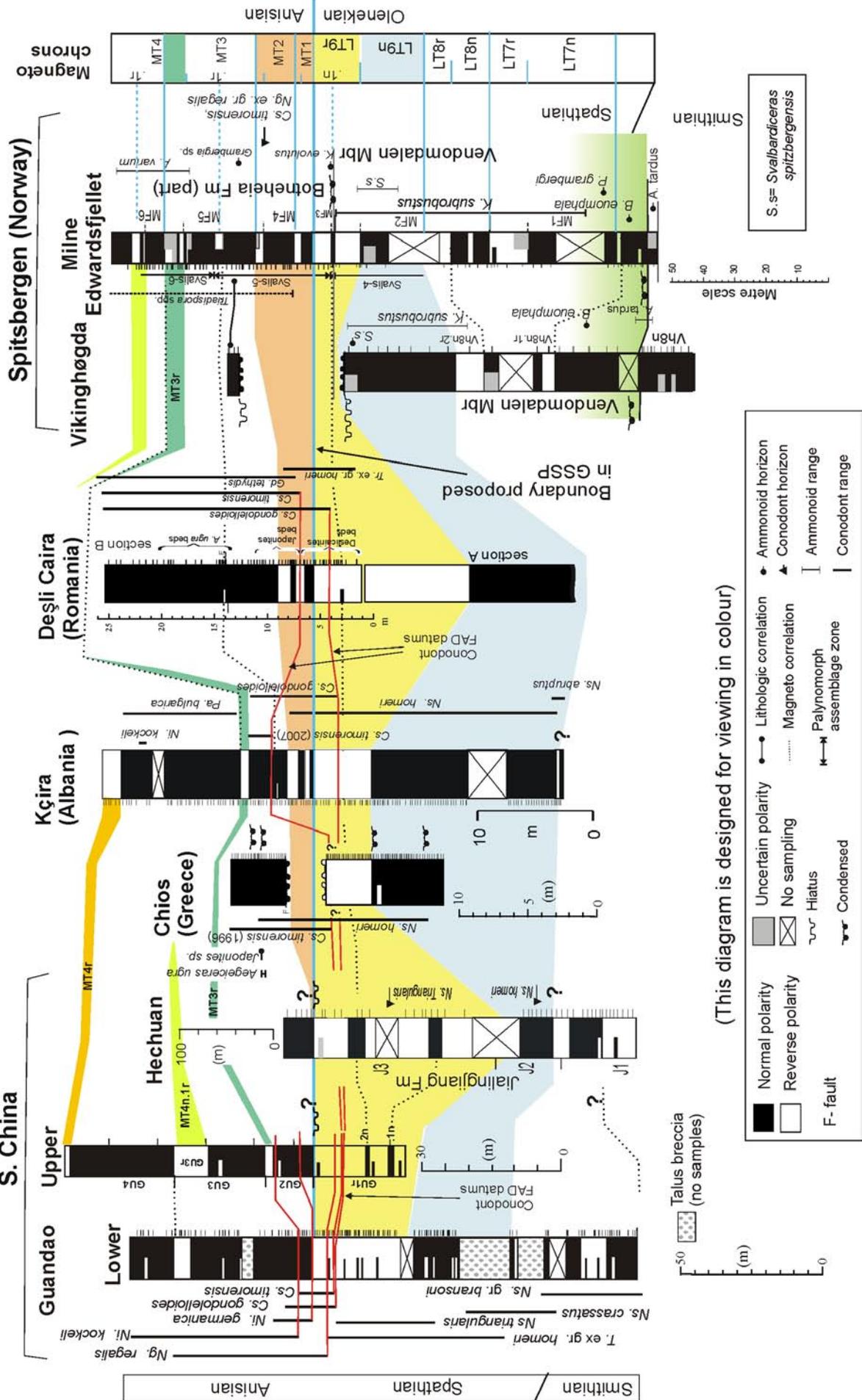
Magnetostratigraphy across the Olenekian-Anisian boundary

The main features of the polarity pattern across the Olenekian-Anisian boundary (OAB) interval can be summarised thus:

a) Magnetozone LT9r (i.e. reverse polarity upper part of LT9) can be confidently detected in marine sections at Kçira, Chios, Deşli Caira, Guandao, Milne Edwardsfjellet (Fig. 1) and in the upper part of the Middle Buntsandstein (Fig. 2). With less confidence (in part due to the limited biostratigraphic constraints), it can be detected in the Hechuan section and in some other non-marine sections (Figs.1,2). The reverse magnetozone has at least one normal submagnetozone (LT9r.1n), found at Milne Edwardsfjellet, Deşli Caira, upper Guandao and probably in the Solling Fm as well (Szurlies 2007: Karlshafen and Bockenem A100 sections; Figs. 1 & 2). There is some evidence of a second normal polarity submagnetozone within LT9r, at the upper Guandao (i.e. GU1r.1n) and Hechuan sections, although the magnetostratigraphic data from both Guandao sections is 'noisy' due to many 'half-bar' putative submagnetozones (i.e. intervals identified by only a single specimen; Fig. 1).

b) Magnetozone chrons (i.e. a normal-reverse couplet) MT1 and MT2 characterise the base of the relatively-long normal polarity interval which occurs in the Lower Anisian, probably extending into the early Pelsonian (Muttoni et al., 2000; Nawrocki & Szulc, 2000; Fig. 2). The reverse and

Figure 1 (next page): Summary bio-magnetostratigraphy of important marine Olenekian-Anisian boundary sections. Guandao sections from Lehrmann et al. (2006) and Orchard et al. (2007a); conodont ranges apply to Lower Guandao. Hechuan section from Steiner et al. (1989). Chios section is a composite from Muttoni et al. (1995, 1996). Kçira from Muttoni et al. (1996; 2000). Deşli Caira from Gallet in Grădinaru (2003); Grădinaru (pers. comm., 2007) and Orchard et al. (2007b). Vikinghogda and Milne Edwardsfjellet sections from Hounslow et al (2007, inpress-a, inpress-b). Magnetostratigraphy is coded LT for the Lower Triassic (from Hounslow et al., inpress-a) and MT for the Middle Triassic. Ticks adjacent to polarity columns indicate the magnetostratigraphic sampling levels. Concurrent range zones of Vigran et al. (1998)-Svalis₄= *J. punctispinosa* - *C. pustulatus* - *C. ologogranifer* - *V. jenensis*- *D. nejburgii*; Svalis₅=*S. seebergensis*- *A. circumdatus*- *A. spiniger*- *Pretricolpitolenites* spp.; Svalis₆= *A. macrocavatus* - *T. plicata* - *J. punctispinosa*- *K. punctatus*.



normal parts of the magnetochrons MT1 and MT2 appear to vary somewhat in relative thickness, probably due to sedimentation rate changes in the different sections near the OAB. Nonetheless, magnetozone chrons MT1 and MT2 can be confidently correlated between Kçira, Deşli Caira, and Milne Edwardsfjellet. Magnetochrons MT1 and MT2 are also clearly present in the Riera de Sant Jaume section in the Spanish Buntsandstein, and the Middle-Upper Buntsandstein boundary interval from the German Basin (Fig. 2). In some other European sections, part of MT2n (and MT1) is probably missing, due to a minor unconformity (at about the level of the so-called S-unconformity of the German nomenclature; Fig. 2). MT1 and MT2 were not detected at Chios due to faulting and hiatus at the top of LT9r (Muttoni et al., 1996, 2000). This situation may also be similar at Guandao (and Hechuan?) where MT3n (of Bithynian age) appears to rest directly on LT9r (Fig. 1).

These suggest that the Deşli Caira proposed GSSP and the Kçira section contain a relatively complete magnetostratigraphic record across the OAB, with Kçira being more condensed than Deşli Caira, probably accounting for the undetected submagnetozone(s) in LT9r. The Guandao sections appears to have magnetochrons MT1 and MT2 missing, but appear have a considerably expanded latest Spathian LT9r, compared to any other marine sections.

A 2nd correlation possibility of the Guandao sections could place GU2 being equivalent to MT3, which would make the 'full-bar' normal submagnetozones in GU1r (i.e. GU1r.1n and GU1r.2n; Fig. 1) the equivalent of MT1n and MT2n. This is the original correlation proposed by Lerhmann et al. (2006), in which GU2n is the equivalent of MT4n, a correlation which is driven by with the conodont biostratigraphy, but largely ignores the magnetostratigraphy. This 2nd correlation possibility for the Guandao sections would suggest submagnetozones GU1r.1n and GU1r.2n are the equivalent of MT1n and MT2n, a possibility which is only valid if there are order of magnitude fluctuations (on a metre to 10 m scale) in the sedimentation rate in this part of the section. There is not evidence in the lithology of these sections that such sedimentation rate changes have occurred (cf. Lehrmann et al. 2006; Orchard et al., 2007).

In addition, the correlation problems of relating Guandao to other sections relates to the fact that *Ni. kockeli* and *Ni. germanica* appear very low in the section compared to the magnetostratigraphy in other comparable sections. Both these conodont forms appear to start high up in MT4n at Kçira and in the Polish and German Muschelkalk (Figs. 1, 2). The upper range of *Cs. timorensis* and *Cs. gondolelloides* terminates at or below the level of MT3r at Kçira, but within GU3n (equivalent of MT4n) in the Upper Guandao section. For these reasons it is not clear if GU2r or GU3r in the Upper Gaundao section is the equivalent of MT3r. However, it is more probable that GU2r is the equivalent of MT3r, and GU3r is MT4n.1r, seen at Milne Edwardsfjellet and in the Polish Muschelkalk (Figs. 1 & 2). This suggests that the equivalent of MT1 and MT2 are either missing or highly condensed in the Guandao sections. Perhaps some evidence for this is that the FAD of *Ni. kockeli* and *Ni.*

germanica step higher into magnetozone GU2n, at the Upper Guandao section compared to the Lower Guandao section- evidence of a missing or condensed interval at Lower Guandao?

The position of magnetochrons MT1 and MT2 in the non-marine sections of the Central European Basin (i.e. Poland, Obernsees core, Central Germany composite) around the OAB is largely constrained by the excellent and vast amount of well-log coverage across this basin from the UK in the west to Poland in the east (e.g., Geluk, 2005; Fig. 2). Hitherto, conchostracan zonations, vertebrates and palynostratigraphy from these successions do not allow such basin-wide unambiguous detailed correlation at this level. However, based on a palynological study, Brugman (1986) already placed the OAB within the uppermost Middle Buntsandstein. Magnetochron MT2 also appears to have been detected by Huang & Opdyke (2000) in the Badong Fm in South China. One of the features at this level, which supports the magnetostratigraphic construction in Figure 2, is the appearance of *Triadispora* sp., which in the Milne Edwardsfjellet section are consistently present from magnetochron MT2 (Hounslow et al., In press-b), the correlated approximate level at which they become common to abundant in the Upper Buntsandstein sections.

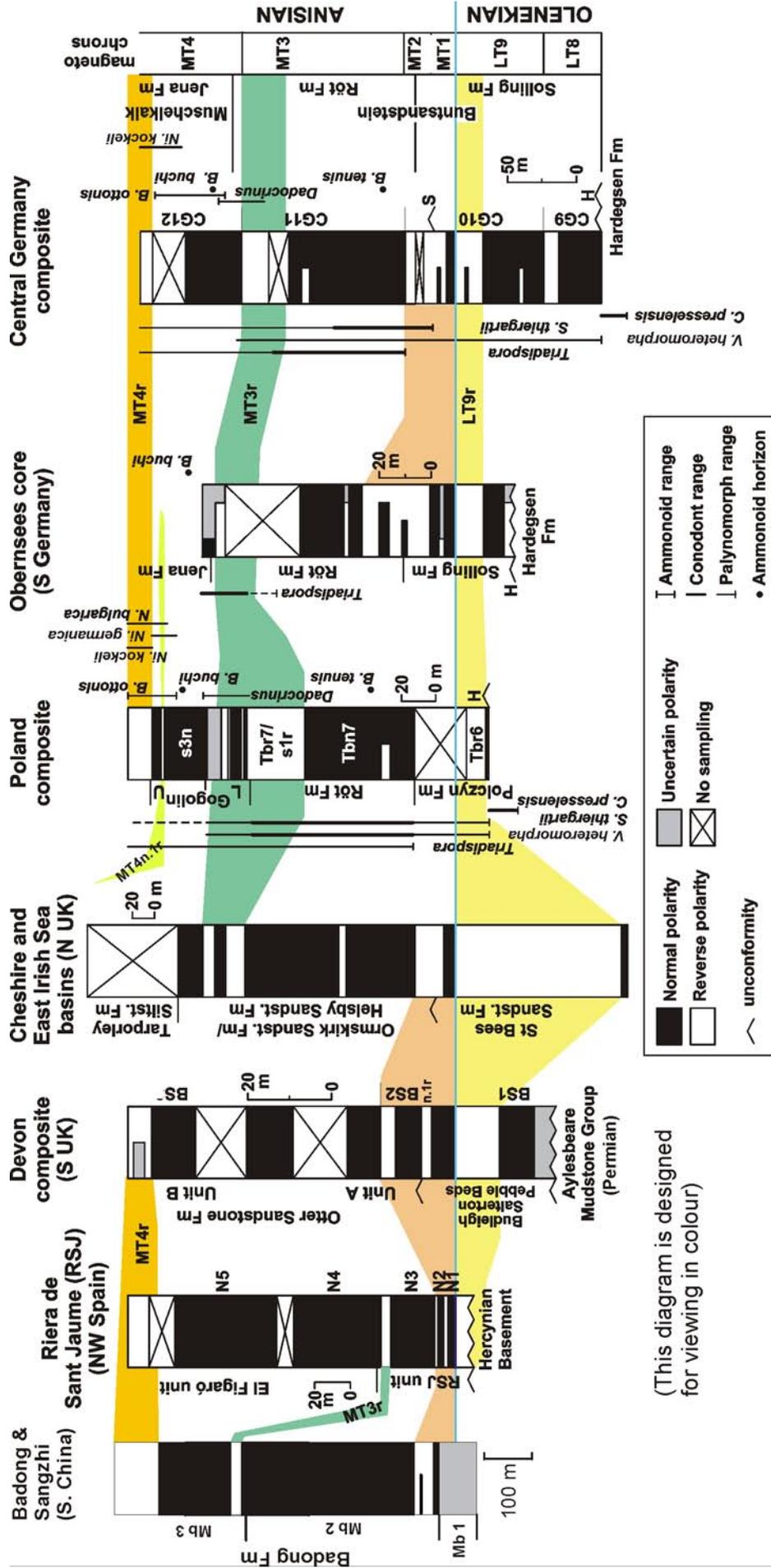
Correlation of biostratigraphic datums at the Olenekian-Anisian boundary

Following publication of the magnetostratigraphic and biostratigraphic results from Chios and Kçira, in 1995, 1996 the acceptance of a solid taxonomic definition of *Chiosella timorensis* has taken place (Grădinaru et al., 2006; Orchard et al., 2007b). Examination of photos of the conodont collections from the Kçira section has revised the FAD of *Cs. timorensis* some 4.4 m higher in the section (at 26.5±0.2 m) than its 1996 level (A. Nicora pers. comm. to M.J. Orchard, 2007), to be located within Kç2n (equivalent to MT3n (Fig. 1). A similar up-wards revision is presumably needed for Chios, but in the absence of a detailed re-study, we have used that level originally published in Fig. 1.

The magnetostratigraphic correlations outlined above, along with the revisions pertinent to *Cs. timorensis* suggest a number of important points about the actual distribution of age diagnostic fossils across the OAB:

The appearance of *Cs. timorensis* appears to be diachronous relative to the magnetostratigraphy between the Guandao, Chios, Kçira and Deşli Caira sections. At Guandao and

Figure 2 (next page): Summary of bio-magnetostratigraphies of important mainly non-marine sections from the Central European Basin across the Olenekian-Anisian boundary. Badong Fm (S. China) from Huang and Opdyke (2000); Riera de Sant Jaume from Dinarès-Turell et al. (2005), Devon from Hounslow & McIntosh (2003), Irish Sea from Mange et al. (1999). Central Germany from Szurlies (2007), Obernsees core from Soffel & Wippen (1998) re-interpreted by Szurlies (2007), Poland composite modified from Nawrocki (1997) and Nawrocki & Szulc (2000) according to Szurlies (2007). Unconformities: H=Hardegsen, S=Solling.



Chios (1996 definition) this datum occurs within the upper part of LT9r, at Deşli Caira within MT1r, and at Kçira within MT3n (Fig. 1). At Kçira, the original (i.e. 1996) definition of *Cs. timorensis* placed the first occurrence within the uppermost part of LT9r. The magnetostratigraphic sampling at the lower and upper Guandao sections, is particularly closely-spaced in the upper part of correlated LT9r (Lehrmann et al., 2006; Orchard et al., 2007a; Fig. 1), which indicates no evidence of magnetochrons MT1 and MT2 at about the level of *Cs. timorensis*. Similarly, magnetostratigraphic sampling density is high at the Chios, Kçira and Deşli Caira sections. What is the origin of this apparent diachroneity- is it caused by multi-regional evolution of *Cs. timorensis*? Is the magnetostratigraphy compromised in one or more of these sections? Are there problems of adequate sampling of the conodont faunas in some of these sections to solidly recognise a FAD? We can see no substantiated argument to nullify any of these possibilities, and as such choosing the *Cs. timorensis* datum to define the base of the Anisian could turn out to be a poor decision.

A much more consistent datum, relative to the magnetostratigraphy is the appearance of *Chiosella (Neospathodus) gondolelloides*, which at Kçira, Deşli Caira and Guandao occurs in the upper part of LT9r. This 'datum-1' of Orchard et al. (2007b) is also closer to the traditional Boreal ammonoid-based Spathian-Anisian boundary (i.e. between the latest Spathian *Svalbardiceras spitzbergensis* Subzone and the *Grambergia taimyrensis* Zone; Dagys & Weitschat, 1993; Dagys & Sobolev, 1995), which is located between LT9r.1n and the mid parts of the immediately underlying reverse magnetozone LT9r.1r (Fig. 1). In the Milne Edwardsfjellet section this transition is bracketed by the occurrence of *Karangatites evolutus* (index form for 2nd subzone of Siberian *G. taimyrensis* Zone) close to the top of LT9r.1n, overlying the ammonoid *S. spitzbergensis* in LT9r.1r. This relationship is to some extent confirmed by the occurrence of *?Svalbardiceras* and *Karangatites* from Deşli Caira (Grădinaru & Sobolev, 2006). Hence, 'datum-1' provides better low to high-latitude correlation potential than that of the (diachronous) FAD of *Cs. timorensis*. Datum-1 is also close to the boundary between the *Svalis*₄ and *Svalis*₅ palynomorph assemblages of Vigran et al. (1998), which occurs in the 1st metre of the Botneheia Fm (i.e. base of MF3r; Fig. 1) in the Milne Edwardsfjellet section (Fig. 1; Hounslow et al. In press-b). In the Central European Basin, the correlated datum-1 level probably falls within the upperpart of the Solling Fm (i.e. the uppermost Middle Buntsandstein, Fig. 2).

If either of these conodont datums should become the 'golden-spike' level in the Deşli Caira proposed GSSP, some of the Boreal ammonoids traditionally considered Anisian, will have first appearances in the latest Olenekian.

Base of magnetozone MT1n as the datum for the Olenekian-Anisian boundary

The Deşli Caira provides a well-defined and continuous magnetostratigraphy tied to a range of relevant biostrati-

graphic markers. We propose that the base of magnetozone MT1n in the Deşli Caira section can provide a robust and globally correlatable datum for defining the base of the Anisian. If choosing a magnetostratigraphic datum, in place of a succession of validated sequential faunal evolutionary changes, our case has to demonstrate a consistent pattern of polarity reversals (Remane et al., 1996). We have done this above, using data from marine and non-marine successions, which is also constrained and related to faunal-ranges and FAD events. Use of a magnetic polarity boundary as the primary GSSP correlation datum has parallels in the Quaternary, Neogene, Palaeogene and Lower Cretaceous, as both proposed and actual datums (<http://www.stratigraphy.org/gssp.htm>), a reflection of the high correlation potential using magnetozone boundaries. Whilst magnetostratigraphy in Triassic successions has not such a historical pedigree as in earlier systems, its potential is clear for high resolution sub-division of geological time in future studies.

Selecting the base of MT1n for defining the base of the Anisian has a number of advantages.

- The global correlation potential of a magnetostratigraphic datum is far greater than any biostratigraphic datum, since it is not restricted by facies or climate, having the potential to be recognised at low and high-palaeolatitude and in marine and non-marine successions. Magnetozone boundaries probably provide the closest to a true chronostratigraphic datum available in stratigraphy (Remane et al., 1996).
- The documentation and correlation potential of the base of MT1n has been clearly demonstrated in multiple studies, in multiple sections, with multiple lithofacies. These studies document a clear pattern of repeatable magnetozones and submagnetozones across the OAB (Figs. 1 and 2)
- Magnetozone MT1n marks the base of the predominantly normal polarity interval which characterises the Lower Anisian, and as such is a distinctive part of the Triassic magnetic polarity pattern. The magnetozone hierarchy of MT1r and MT2r overlain by the remainder of the Lower Anisian, dominantly normal polarity MT3n (Figs. 1 & 2), provides a distinctive 'bar-code' for recognition. This extends to recognition of hiatus and erosional loss of sediment at the OAB, if the MT1r and MT2r magnetozones are missing in correlated sections (Figs 1 and 2).
- The underlying reverse magnetozone LT9r has a demonstrable pattern of finer-scale submagnetozones with at least one (i.e. LT9r.1n) and possible two short duration submagnetozones, for finer scale subdivision of underlying boundary strata. These illustrate, through correlation, how it is possible to map the proposed OAB in the Deşli Caira section (with its Tethyan fauna) into the Boreal ammonoid zonation.
- The base of MT1n at Deşli Caira falls between

two of the other strongest proposed datums for defining the base of the Anisian, namely FAD of *Cs. timorensis*, and FAD of *Cs. gondolelloides*. Both of these could act as secondary markers for the base of the Anisian.

- With the magnetostratigraphy it is possible to demonstrate, through correlation, that palynological proxies could also be utilised near to the boundary, in the absence of other information. The Svalis₄-Svalis₅ boundary, occurring just prior to MT1n, is a useful and clearly documented marker in Boreal regions (Vigran et al., 1998). The incoming of consistently present *Triadispora* sp. appears to characterise a level within magnetochron MT2, and may be a useful additional marker above the proposed OAB in low latitude sections containing a palynological record (Figs. 1, 2).

Conclusions

The OAB interval is characterised by a well-documented pattern of magnetic polarity reversals that has been observed in different sections at varying levels of detail. We propose to place the base of the Anisian in the Deşli Caira proposed GSSP section at meter level 5.7 m (Section B) at the base of normal polarity magnetozone MT1n. We believe that such a magnetostratigraphic datum, provides better than any single conodont datum, the requirements of global exportability that are fundamental to a GSSP definition. Secondary correlative markers would be the FAD of *Cs. timorensis*, just above the boundary and the FAD of *Cs. gondolelloides*, just below the boundary. This choice would provide a key means for linkage of marine and nonmarine strata, and provide for other sections, that for climatic or paleogeographic reasons, do not share the same paleontological content. The magnetostratigraphic correlation herein illustrated, supports the existence of a number of other palynostratigraphic and ammonoid proxies that could be utilised to help define the base of the Anisian in both low and high latitude sections, in the absence of magnetostratigraphy.

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A Candidate Of The Global Boundary Stratotype Section And Point For The Base Of The Carnian Stage (Upper Triassic):

GSSP at the base of the canadensis Subzone (FAD of Daxatina) in the Prati di Stuoeres/Stuoeres Wiesen section (Southern Alps, NE Italy)

Mietto P.¹, Andreetta R.², Broglio Loriga C.², Buratti N.³, Cirilli S.³, De Zanche
V.¹, Furin S.², Gianolla P.², Manfrin S.¹, Muttoni G.⁴, Neri C.⁵, Nicora A.⁴,
Posenato R.², Preto N.^{1,6}, Rigo M.¹, Roghi G.⁶, Spötl C.⁷

¹Università degli studi di Padova, Dipartimento di Geoscienze, via Giotto 1, I-35137 Padova

²Università degli studi di Ferrara, Dipartimento di Scienze della Terra, via Saragat 1, Blocco B, I-44100, Ferrara

³Università degli studi di Perugia, Dipartimento di Scienze della Terra, Piazza dell'Università 1, I-06123 Perugia

⁴Università degli studi di Milano, Dipartimento di Scienze della Terra "Ardito Desio", via Mangiagalli 34, I-20133
Milano

⁵Università della Calabria, Dipartimento di Scienze della Terra, via P. Bucci, I-87036 Arcavacata di Rende (Cs)

⁶C.N.R., Istituto di Geoscienze e Georisorse, C.so Garibaldi 37, I-35137 Padova

⁷Institut für Geologie und Paleontologie, Universität Innsbruck, Innrain 52, A- 6020 Innsbruck

Introduction

This paper is a slightly modified version of the proposal for the GSSP of the base of the Carnian Stage presented by Broglio Loriga et al. (1998, 1999) for discussion among the members of the L/C working group of the STS (M. Gaetani chairman), concerning the Prati di Stuoeres/Stuoeres Wiesen candidate section.

This proposal and its contents follow the guidelines published on p. 61 of Albertiana 26. Of the items listed in these guidelines, the discussion of cycle stratigraphy and point 4B are excluded here. About the latter, no other candidate sections have been proposed.

1. Stratigraphic Rank Of Boundary

Base Of The Carnian Stage And The Upper Triassic Series

2. Proposed Gssp - Geographic And Physical Geology

2a Geographic Location

The GSSP candidate at Prati di Stuoeres/Stuoeres Wiesen (Province of Belluno, Veneto Region, NE Italy) is located on the left side of the Cordevole Valley, on the southern slope of the crest separating the Badia/Abtei and the Cordevole valleys (Dolomites, Southern Alps).

The Prati di Stuoeres section (German: Stuoeres Wiesen) lies few hundreds meters east of Pralongià, a locality sited NE of Arabba (Cordevole Valley). The section extends from an altitude of 1980 m and reaches the crest at 2150 m a.s.l., within a vast gully-eroded depression, deeply incised

within the slope. Upwards, it continues inside the overlying meadows and ends at the toe of the vertical walls of the Piccolo Settsass (the well-known Richthofen Riff of Mojsisovics, 1879) and of the Settsass (Fig. 1).

The section can be easily reached from Rif. Pralongià following C.A.I. footpath n. 23 towards Settsass, a few hundreds meters ESE of Piz Stuoeres (2181m). Pralongià is easily attainable by many footpaths (C.A.I.n.22, n. 23, n.3) from all the surrounding localities, San Cassiano/St. Kassian, Corvara/Kurfar (Badia/Abtei Valley) and from Campolongo Pass, but also by gravel roads from Corvara/Kurfar (intersection at km 35, SP 244) and Renaz (intersection at km 88, SR 48) and by chair-lift from Rifugio Chertz near Campolongo Pass.

2b Geological Location

The Prati di Stuoeres/Stuoeres Wiesen section (Fig. 2) is located in the Dolomites that constitute the central-northern portion of the Southern Alps (Doglioni, 1987; Castellarin and Cantelli, 2000). The Southern Alps derived from the comparatively gentle deformation of the passive continental margin of the Mesozoic Tethys Ocean into a non metamorphic, south-vergent thrust belt belonging to the Alpine Belt. In the Dolomites, the sedimentary succession spans from late Permian to Cretaceous time, but it is a worldwide reference area for the Triassic (Bosellini et al., 2003).

The Dolomites stratigraphy records several tectonic and magmatic events including the Late Ladinian emplacement of epicrustal intrusions (Monzoni, Predazzo, Cima Pape) and shoshonitic volcanism (Sloman, 1989). This is a key event in the stratigraphic record of the Dolomites and it

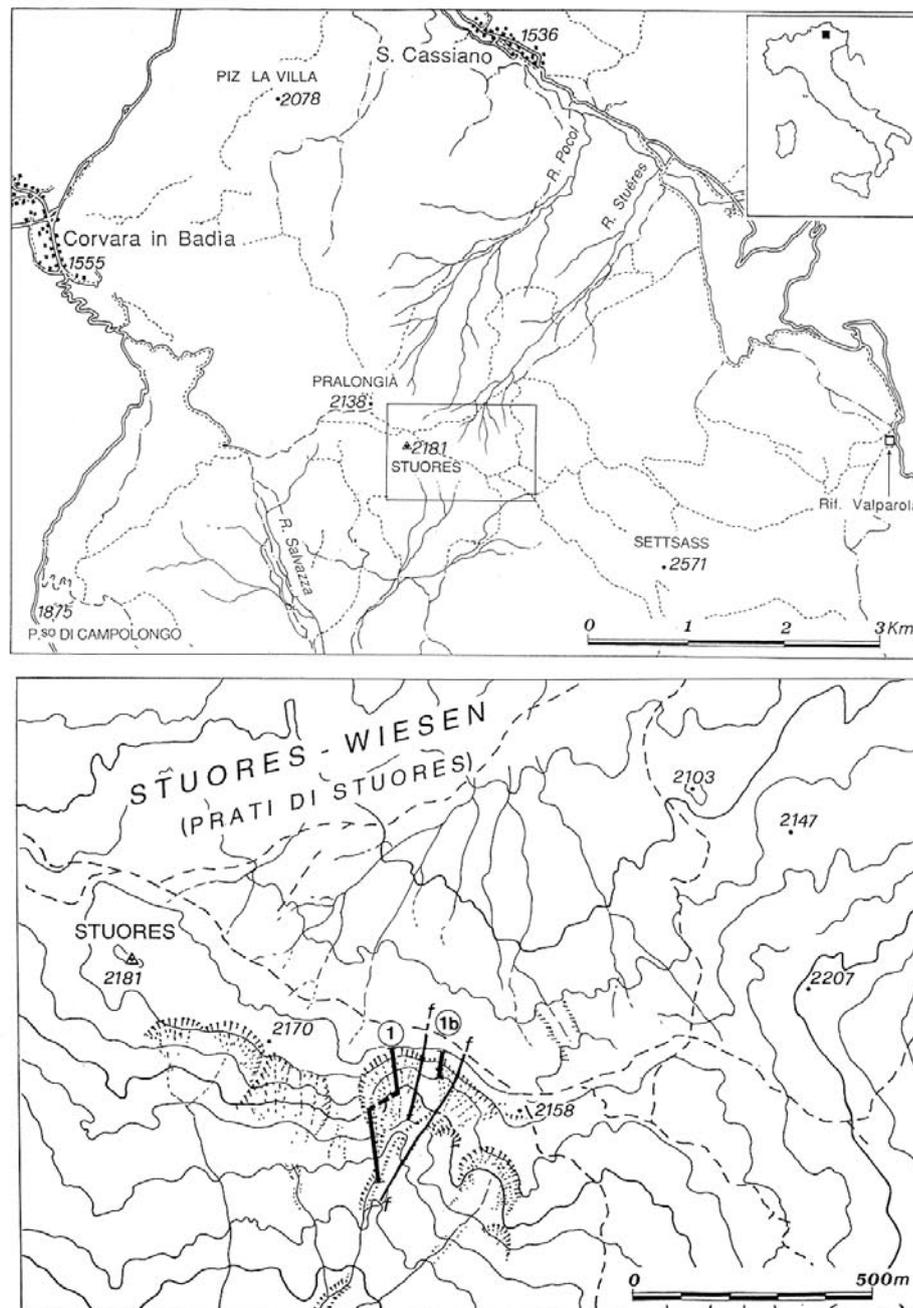


Figure 1: Location map of the Prati di Stuores/Stuores Wiesen section (from Broglio Loriga et al., 1998, mod.).

is responsible of huge input of volcanoclastics and lava flows both in subaerial and marine conditions (Fernazza Fm). The tectonic activity related to the volcanic event also triggered submarine collapses of the pre-volcanic succession, and their embodying as megabreccias into the coeval volcanoclastics. These units constitutes the base of the described succession at Prati di Stuores (Broglio Loriga et al., 1999). After the rapid emplacement of the volcanic edifices, the stratigraphic succession records their erosion as a thick volcanodetritic unit (Wengen Fm) enhanced by a sea level fall. The Wengen Fm shows an internal organisation controlled by the progradation of turbiditic lobes towards deeper basins, lithofacies are thus controlled by the distance from source areas. Locally, small carbonate platforms are documented (mostly with fringing reef geometries):

they are responsible for the exportation of carbonatic boulders called “Cipit” as well as finer biocalcarenes. The reduced rates of erosion, related to the sea level rise and the start-up of rimmed carbonate platforms (Cassian Dolomite), lead to a reduced siliciclastic input in favour of carbonate sediments in the basins (San Cassiano Fm). The typical organisation of this interval, exhibiting strong volcanoclastic input, sharp reduction and again increase in siliciclastic and shallow water-derived carbonates, is well documented in the area of Prati di Stuores/Stuores Wiesen. The subsequent basin evolution is characterized by a progressive shallowing, resulting in a complete closure of the basin itself during Late Carnian time (Heiligkreuz, Travenanzes Fms).

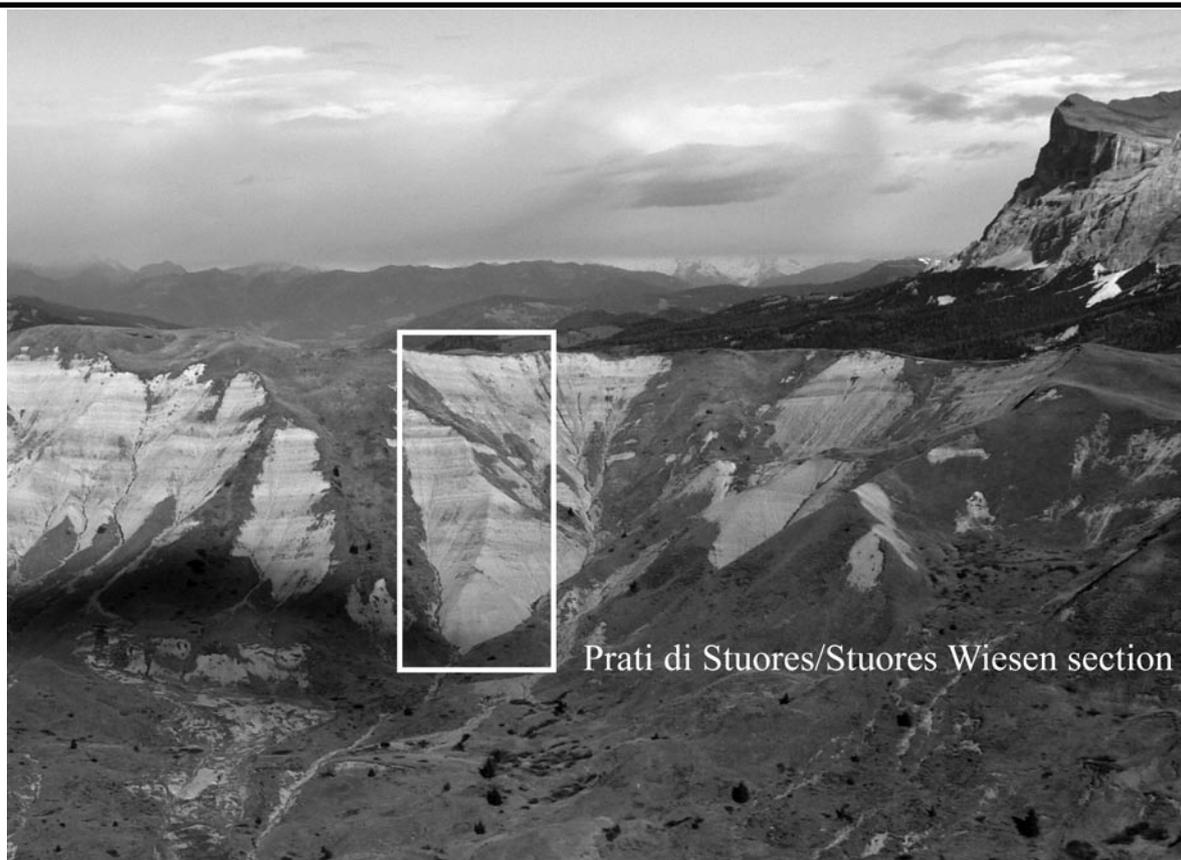


Figure 2: Picture of the Prati di Stuores/Stuores Wiesen section.

2C Location of level and specific point

Several outcrops exposing the upper Wengen and the San Cassiano Formations are present at Prati di Stuores/Stuores Wiesen. Most of them expose long sections, which are easily correlated by tracing conspicuous beds. The section, exposed at 46°31'37"N and 11°55'49"E; 1980 m a.s.l., WGS84 datum, is indicated as Standard Section, because it exposes the longest succession (Figs 1, 3). This section is represented on Italian topographic map at scale 1:25000 number 11-I-SE "Corvara in Badia", 5th ed., 1963, published by the Istituto Geografico Militare Italiano.

The proposed GSSP is located at the base of bed SW4, at 45 m from the base of the San Cassiano Fm in the Prati di Stuores/Stuores Wiesen stratigraphic section (Figs 1, 4, 5). Bed SW4 is a marly limestone immediately underlying an arenite bed in the lower San Cassiano Formation. The bed yields ammonoids, including *Daxatina canadensis* (Whiteaves), proposed as the principal marker to identify the boundary.

2D Stratigraphic completeness

The Prati di Stuores/Stuores Wiesen section is characterized by a thick interval of marine sediments deposited below storm wave-base. The depositional motif consists of hemipelagites and thin turbidite beds (both siliciclastic and from nearby carbonate platforms) documenting high but variable sedimentation rates. In detail, a slight increase in sedimentation rate is noticed towards the upper part of the section accordingly to the overall regressive trend. Taking as a whole, terrigenous sedimentation seems to decrease

upwards in favour of the carbonate supply coming from the progradation of carbonate platforms (Cassian Dolomite).

Slumps and slump scars are recognized in the upper part of the section, but are absent around the proposed GSSP level. Such slumps-slump scars do not involve considerable thickness and therefore do not correspond to significant stratigraphic gaps. Hard-ground and non-depositional and/or condensed levels are absent in the studied interval.

2E Adequate thickness and stratigraphic extent

The Prati di Stuores/Stuores Wiesen section encompasses 180 meters of hemipelagic beds of the Wengen and San Cassiano Fms, which become more than 200 once the physically correlated section 1bis is considered (Fig. 5). Lateral continuity of the outcrops is also in the order of many hundreds of meters (Fig. 3). Ammonoids are common throughout the section.

Below the proposed GSSP, 45 m of marls and arenites referred to the San Cassiano Fm and ca. 20 m of Ladinian shales are exposed in the section; this interval represent the top of the Upper Ladinian *regoledanus* Subzone.

The first biozone of the Carnian, the *canadensis* Subzone, is well represented in the section up to m 194.30, where the boundary with the overlying *aon* Subzone is documented in section 1bis.

The Prati di Stuores/Stuores Wiesen section thus encompasses three ammonoid subzones. This stratigraphic interval is relatively short, if compared with the thickness of the succession; this is a consequence of the high sedimentation

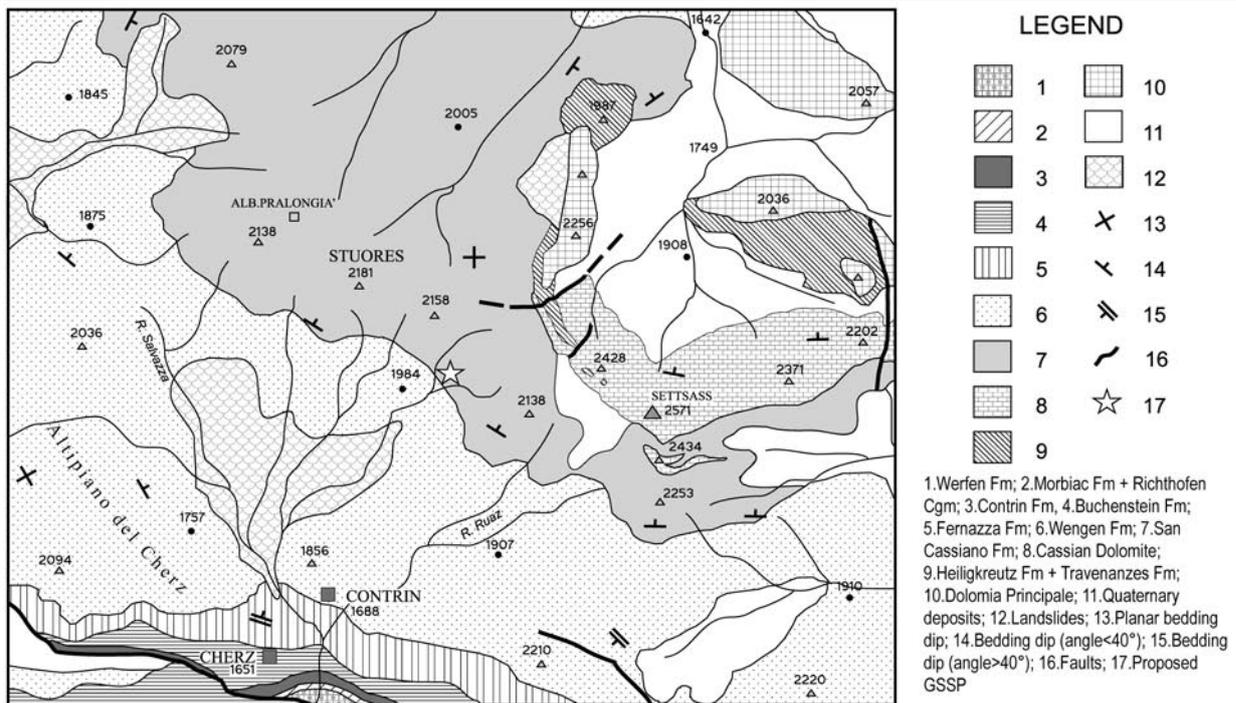


Figure 3: Geologic map of the type area of the proposed GSSP for the base of the Carnian.

rate that characterized the Cassian basin between the late Ladinian and early Carnian. The considerable stratigraphic extent below and above the proposed boundary level is then sufficient to ensure a stable definition of the GSSP.

2F Provisions for conservation and protection

The accessibility of the Prati di Stuoers/Stuoers Wiesen section is historically documented from the early XIX Century, thanks to the classical works by Münster (1834), Wissmann and Münster (1841), Klipstein (1845), Laube (1869), Mojsisovics (1882), Ogilvie (1893), Ogilvie Gordon (1900, 1929), Urlichs (1974, 1994), and others. This historical record clearly documents a long-lasting persistence of the natural outcrops. The section area is involved in small but frequent landslides, due to the steep exposure and the lithological nature of the involved unit, consisting of marls, volcanoclastic arenite and thin bio-calcarenite alternations. The chosen section, however, lies on a steep rise, about 75 metres above the slope base, a high-standing location preventing the landslide and debris flow deposits from accumulating on the section outcrop. The large lateral continuity of the outcrop also support a good preservation potential of the proposed GSSP.

The Prati di Stuoers/Stuoers Wiesen area belongs to a Dolomites area nominated for subscription to the UNESCO World Heritage List. The area benefits from significant degree of environmental protection, supporting its long-lasting preservation. The area is protected by the Law 8/8, 1985, n. 431 (Galasso), preserving the whole of the territories above 1600 m, and it extends within the Col di Lana - Settsass - Chertz protected area (ZPSIT3230086), related to the directive Natura 2000 (92/43/CE, 79/409/CE). The local administrations (Comune di Livinallongo del Col di Lana and Provincia di Belluno) intend to maintain and label the section access and to disseminate the related information to the general public.

3. Primary and secondary markers

3A principal correlation event (marker) at gssp level

The proposed GSSP-level at Prati di Stuoers/Stuoers Wiesen is defined by the first appearance of the ammonoid genus *Daxatina* (i.e. *Daxatina canadensis*), as recognized in the bed SW4.

The genus *Daxatina* is documented in several sections of the Southern Alps: Prati di Stuoers/Stuoers Wiesen, Bec de Rocces near Campolongo Pass, Antersass in Badia Valley, Rio Cuzze near Borca di Cadore and Pista Nera near Sappada (Mietto and Manfrin, 1995a, 1995b; Broglio Loriga et al, 1998, 1999; Manco et al., 2004; Mietto et al., 2007). After the early findings in British Columbia (Whiteaves, 1889), in the Svalbard Archipelago (Böhm, 1903, 1904) and in Alaska (Martin, 1926), more recently the new occurrences in the Himalayas region (Spiti valley: Balini, Krystyn and Torti, 1998; Krystyn, Balini and Nicora, 2004) and in Nevada (New Pass Range: Balini and Jenks, 2007; Balini et al., 2007) testify the worldwide distribution of the quoted genus.

For this reason the proposed GSSP-level provides an excellent tool for trans-Panthalassan correlations, between low to middle-high palaeolatitude domains.

3B Other stratigraphy

3B.1 Biostratigraphy

Ammonoids

In the Prati di Stuoers/Stuoers Wiesen section, three ammonoid subzones have been recognized: *regoledanus*, *canadensis* and *aon*. The *regoledanus* Subzone is documented from the base of the section (Wengen Fm) to 45 m

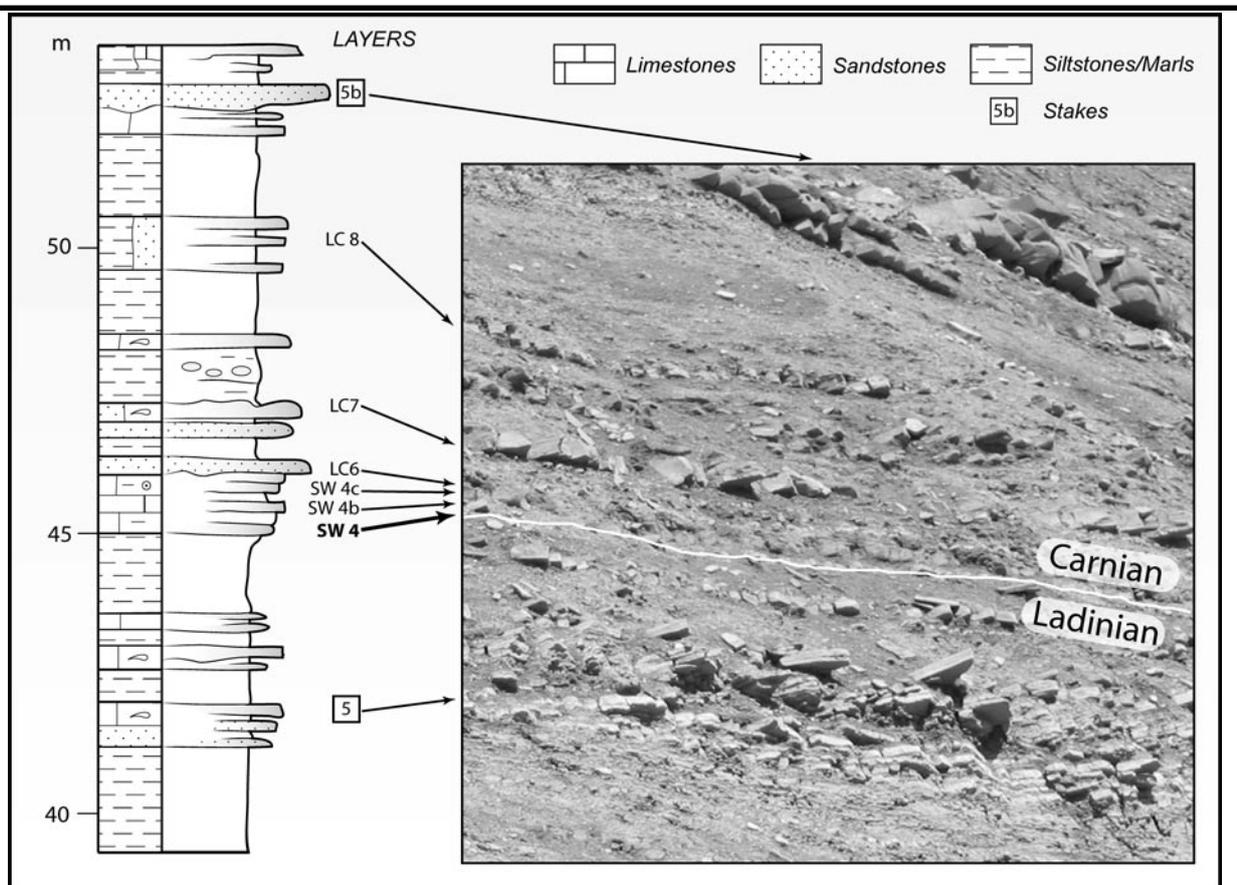


Figure 4: Log and photograph of the Prati di Stuores/Stuores Wiesen section showing the Ladinian/Carnian boundary in detail.

from the base of the San Cassiano Fm. Within this interval (Fig. 5) cf. *Protrachyceras* and *Zestoceras* cf. *enode* Tozer occur. The latter species is also documented in other stratigraphic sections of the Southern Alps, always associated with longobardian ammonoid fauna (Mietto et al., submitted). The *canadensis* Subzone starts from the base of the bed SW4 in which, with the strongly ornamented species *Daxatina canadensis*, the genus *Daxatina* firstly appears. Successively, 16.50 m above the same bed a finely ornamented trachyceratid specimen occurs. This specimen was previously attributed to *Trachyceras bipunctatum* (Münster) (Mietto and Manfrin, 1995a, 1995b; Broglio Loriga et al., 1999; Mietto et al., 2007) but is now attributed to *Daxatina* cf. *laubei* Tozer, 1994 (Mietto et al., submitted). Above, representatives of *Daxatina* (chiefly *D. canadensis*) are scattered along 145 m of the Prati di Stuores/Stuores Wiesen section. Above this interval, the first appearance of *Trachyceras* cf. *aon* (Münster) is checked in bed SW24. The interval zone comprised between the first occurrence of *D. canadensis* and the first occurrence of *T. aon* was originally defined as *Daxatina* cf. *canadensis* Subzone. Later on, based on the direct comparison with type material from Canada, this unit is formally named *canadensis* Subzone. In the past, this biozonal interval was considered equivalent to the *sutherlandi* Zone (Urlichs, 1974, 1977) then comprised in the tethysian *regoledanus* Zone (Urlichs, 1994). Almost 34 m above the bed SW4, the first occurrence of genus *Trachyceras* is recorded by the species *T. muensteri* (Wissmann). In particular, this taxon is characterized by a subammonitic suture line, but less indented

than, e.g., in *T. aon*. After the attribution of most specimens to *D. cf. laubei*, the occurrence of *T. bipunctatum* in the *canadensis* Subzone at Prati di Stuores/Stuores Wiesen cannot be confirmed anymore. Nevertheless, this species has been found in the Antersass section, in the uppermost part of the biozone (Mietto et al., 2007, submitted).

Two species of *Frankites* are documented at Prati di Stuores/Stuores Wiesen: the most abundant and widespread is *Frankites apertus* (Mojsisovics). This taxon, which is considered synonymous of *Frankites sutherlandi* (McLearn) from North America by Mietto et al. (submitted), occurs from the upper part of the *regoledanus* Subzone to the lower part of the *canadensis* Subzone at least. A second species, *Frankites johnstoni* Mietto and Manfrin (in Mietto et al., submitted), occurs sparsely in the lower part of the latter subzone, but its total range comprises, in other sections, also most of the *regoledanus* Subzone.

The best documented genus in the *canadensis* Subzone is *Zestoceras*. In bed SW5b, 7.40 m above SW4, *Zestoceras lorigae* Mietto and Manfrin (in Mietto et al., submitted) occurs. This species is widespread along the *canadensis* Subzone, where its seems to be confined. A second species, *Zestoceras barwicki* (Johnston), originally assigned by Johnston (1941) to the genus *Clionites* (sic!), is equivalent to *Zestoceras cerastes* Tozer. We consider these taxa as synonyms (Mietto et al., 2007, submitted).

Moreover, the bed SW4 yields also *Sirenotrachyceras thusneldae* (Mojsisovics), which is scattered, at present,

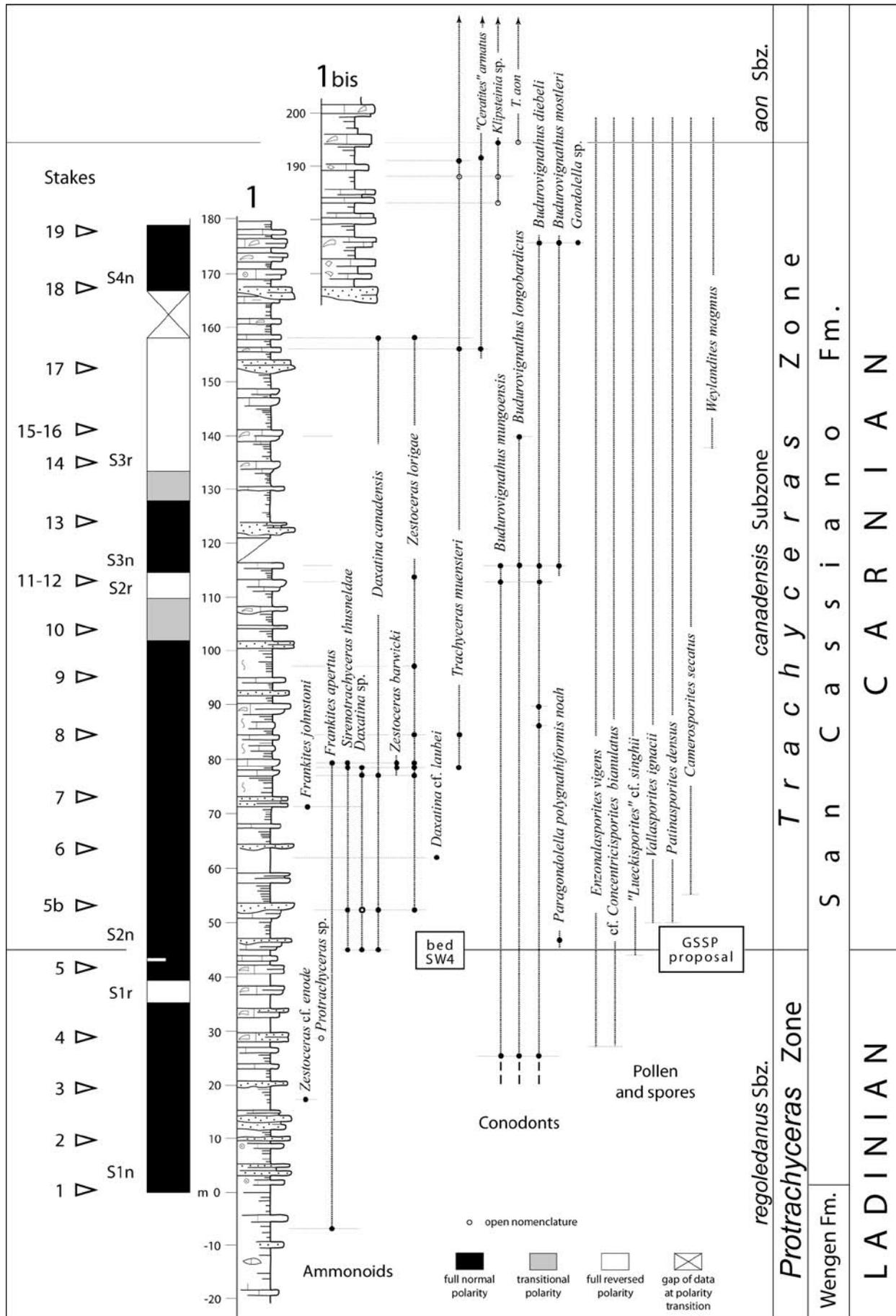


Figure 5: Stratigraphic column of the Prati di Stuores/Stuores Wiesen section with distribution of main fossils and magnetostratigraphy (from Broglio Loriga et al., 1998, mod.).

within the lower part of the subzone.

In the last ten meters of the biozone, taxa documented also in the *aon* Subzone [e.g. *Klipsteinia* cf. *achelous* (Münster), “*Ceratites*” *armatus* (Münster)] occur. In a bed of a nearby section (SW 11), correlated with the uppermost part of the Prati di Stuoeres/Stuoeres Wiesen section, *Badiotites eryx* (Münster) is also recorded. The *canadensis* Subzone is directly overlaid by the *aon* Subzone; the latter is marked by *Trachyceras* cf. *aon* (Münster), as documented in the section 1b (Fig. 5), at 194,30 m from the base of the San Cassiano Fm (bed SW24). The *canadensis/aon* subzones boundary is better exposed in the Antersass section (Fig. 10) and is marked, in particular, by *Trachyceras aon* (Münster), *Brothotrachyceras* spp. and *Hannaoceras* sp. (Mietto et al., 2007; submitted).

Conodonts

Although the Prati di Stuoeres/Stuoeres Wiesen section has been investigated several times for conodont biostratigraphy, a poor fauna has been recorded. This fauna is composed of *Budurovignathus mungoensis* (Diebel), *Budurovignathus mostleri* (Kozur), *Budurovignathus diebeli* (Kozur and Mostler), *Budurovignathus longobardicus* (Kovács) and by the long-ranging species *Gladigondolella malayensis malayensis* Nogami and *Gladigondolella tethydis* (Huckriede) (Mastandrea in Broglio Loriga et al., 1999). All these species range at least from the upper part of the Longobardian (late Ladinian) to the lower part of the Julian (early Carnian).

Other coeval sections, Antersass and Bec the Rocces sections, have been studied both for ammonoid and conodont biostratigraphy (Mietto et al., 2007). A similar conodont fauna have been recovered from both sections with the addition of *Paragondolella foliata* Budurov and the two subspecies *Pseudofurnishius murcianus praecursor* Gullo and Kozur and *Pseudofurnishius murcianus murcianus* Van den Boogaard from Antersass section (Mietto et al., 2007). Recently, *Paragondolella polygnathiformis noah* (Hayashi) has been recovered in the Prati di Stuoeres/Stuoeres Wiesen section (Manco et al., 2004; Mietto et al., 2007; and Fig. 5).

Paragondolella polygnathiformis noah (Hayashi) lies on the phylogenetic lineage of *Paragondolella inclinata* – *Paragondolella polygnathiformis polygnathiformis* – *Paragondolella polygnathiformis noah*, a branch of the *excelsa*-stock which evolved during the late Ladinian – early Carnian (Kovács, 1983). During the last years, the species here named *Paragondolella polygnathiformis* (Budurov and Stefanov) has been ascribed into different genera by various authors, e.g. *Neogondolella*, *Paragondolella*, *Metapolygnathus*. Considering the phyletic evolution and considering the peculiarities which distinguish the above-mentioned genera, as summarized by Kozur (1989), this species has been here interpreted as belonging to genus *Paragondolella*.

Paragondolella polygnathiformis noah (Hayashi) is characterized by a geniculation point or an abrupt anterior step on both the anterior lateral margins. The presence of this

feature on only one of the anterior margins is typical for the transitional forms between *Paragondolella inclinata* (Kovács) and *Paragondolella polygnathiformis polygnathiformis* (Budurov and Stefanov) during the latest Ladinian. *Paragondolella polygnathiformis polygnathiformis* (Budurov and Stefanov) differs from *Paragondolella polygnathiformis noah* (Hayashi) for the absence of a free blade since the platform tends to reach the point of the blade.

Historically, the FO of *Paragondolella polygnathiformis* has been used to define the base of the Carnian, the occurrence of which was considered coincident with the base of the *Trachyceras aon* Subzone (Krystyn, 1983). Later, it has been demonstrated a downward extension of the range of *Paragondolella polygnathiformis* below the FAD of *Trachyceras aon* (Kozur, 1980, 1989; Kovács et al., 1991; Gallet et al., 1998; Rigo et al., 2007), that means within the *canadensis* Subzone. At Spiti (India), the FO of *Paragondolella polygnathiformis noah* along with *Paragondolella polygnathiformis polygnathiformis* is some meters below the FO of *Daxatina canadensis*.

At Prati di Stuoeres/Stuoeres Wiesen, *Paragondolella polygnathiformis noah* (Hayashi) has been collected from sample SW 4c, 70 cm above the first occurrence of *Daxatina canadensis* (Whiteaves) in bed SW 4. The FAD of *Paragondolella polygnathiformis noah* (Hayashi) is practically coincident with the FAD of *Daxatina canadensis*, and might be an useful additional marker event for the base of the Carnian stage.

Halobiids and other macrofossils

The lower San Cassiano Fm deposited within a deep basin, well below the photic zone, with a high sedimentary rate and oxygen-deficient bottom conditions (e.g. Fürsich and Wendt, 1977; Broglio Loriga et al., 1999). These conditions only permitted the proliferation of posidonioids, an opportunistic bivalve group, well adapted to low-oxygen benthic habitats (e.g. Wignall, 1994; Aberham, 1994). Posidonioids are common throughout the whole *canadensis* Subzone, where they generally occur in the laminated dark grey clay and argillaceous marls alternated with turbidites. For these reasons, bivalves of the lower San Cassiano Fm of Prati di Stuoeres/Stuoeres Wiesen section (uppermost *regoledanus* and *canadensis* subzones) are mainly represented by members of the superfamily Posidonioidea (sensu Waller in Waller & Stanley, 2005), while gastropods and brachiopods are rarer. Specimens of the latter two groups mostly occur since the middle *canadensis* Subzone (Posenato in Broglio Loriga et al. 1999: tab. 6).

The posidonioids of the *canadensis* Subzone were distinguished into three groups (Posenato in Broglio Loriga et al., 1999): a) “*Posidonia*” *wengensis* (Wissmann); b) “*Posidonia*” cf. *wengensis*; c) ?*Halobia* sp.

On the base of the recent revision of T. R. Waller (in Waller & Stanley 2005), the first species is attributed to *Bositra*, although this author include in the Family Posidoniidae those posidonioids with the “hinge line generally much shorter than shell length” (op. cit., p. 19), while “*Posidonia*” *wengensis* is characterized by a long hinge margin (see

also Wissmann in Münster 1841, pl. 16, fig. 12), thus the attribution of Wissmann's species to *Bositra* is not completely convincing. The species is common in the Longobardian Wengen beds Auct. of the Dolomites, from which the type-material was found (Wissmann in Wissmann and Münster, 1841). The second group (b) yields "*Posidonia wengensis*" - like valves with weak radial costellae. Radial plications characterise *Daonella* and *Halobia* and for this reason the hypothesis that the group B) "could represent juvenile stage of *Daonella* or a transition to *Halobia*" was proposed (Posenato in Broglio Loriga et al., 1999: p. 60). Both the just above quoted genera have species groups which show transitional features to "*Posidonia*" such as the *Gruppe der posidonoiden Daonellaformen* and *Gruppe der schwach verzierten Halobien* and *Gruppe der Halobia styriaca* (Kittl, 1912). Also the specimens reported by Mietto et al. (2007) from the *canadensis* Subzone of Bec de Rocces section, and classified as "praehalobids", belong to this group. However, radial ribbing may also occur in the family Posidoniidae, to which *Bositra* belongs (Waller and Stanley, 2005). Fine radial ribs were also noted by Kittl (1912: p. 19) in some shells by him referred to Wissmann's species. However, in absence of an abundant population, which depicts the sculpture variability and in absence of unquestionable features of possible derived genera (i.e. the anterior auricle/tube of *Halobia*), we again refer to *Bositra* both the groups and distinguish them only at specific level (*Bositra wengensis* and *Bositra* cf. *wengensis*).

The third group (c) consists of very rare specimens collected from two beds (7SW6.1 and 5SW8.0, see Broglio Loriga et al. 1999: tab. 6). The reason of this classification is discernible in the left specimen of pl. 9, fig. 2 of Broglio Loriga et al. (1999): it is a left valve with prevailing comarginal folds and a slight curved anterior tube/ear - like process, which induced us to refer tentatively it to *Halobia* (?*Halobia* sp., Posenato in Broglio Loriga et al., 1999).

According to several authors (e.g. Mojsisovics, 1874; Kittl, 1912; Gruber, 1976; Mc Roberts, 2000), *Halobia* (an halobiid with the anterior auricle -or tube- separated from the disk), derived directly from *Daonella* (a D-shaped and radially plicated halobiid lacking of the anterior auricle), or through the intermediate genus *Aparimella* Campbell, 1994. According to this hypothesis, the ancestral species have well developed radial plications, which have to be considered a primitive, plesiomorphic feature of the Halobiidae, considering this family as a natural, monophyletic taxon (Campbell, 1994; McRoberts, 2000). However, *Halobia* contains more than 300 species and subspecies (McRoberts, 1993), and many authors consider this genus a polyphyletic group (e.g. Kittl, 1912; Ichikawa, 1958; Gruber, 1976; Polubotko, 1988; McRoberts, 2000). Among the eleven *Halobia* species-groups proposed by Kittl (1912), two are characterized by a reduced radial ribbing. They are the *Gruppe der schwach verzierten Halobien* and *Gruppe der Halobia styriaca*. Some species of the former group (e.g. *H. disperseinsecta* Kittl) are closely related to species of the second group [e.g. *H. lenticularis* (Gemellaro): Cafiero and De Capoa Bonardi (1980, 1982)] for which the new genus *Perihalobia* Gruber, 1976 was

proposed. According to Gruber (1976), *Halobia* derived from *Daonella*, while *Perihalobia* from "*Posidonia*" as indicated by the outline and sculpture pattern of the early species *H. lenticularis* from the late Carnian - lower Norian of Sicily and Montenegro (Cafiero and De Capoa Bonardi, 1980, 1982). A direct origin of *Halobia* from "*Posidonia*" was also sustained by Polubotko (1984, 1988), who considered *Halobia*, with seven subgenera, as derived from "*Posidonia*", while he erected the new genera *Zittelhalobia* and *Indigirohalobia*, and respectively two and three subgenera, for those halobiids derived from *Daonella*. A group of halobiids with feeble or without radial plications was also recognized by Campbell (1994), who classified it as *Halobia* (*Parahalobia* Yin and Hsu).

The early sure Halobiids of the Prati di Stuoeres/Stuoeres Wiesen occur in the middle *aon* Subzone (*Halobia cassiana* Mojsisovics, bed 13b) and across the *aon-aonoides* subzones boundary (*Halobia fluxa* Mojsisovics, beds 18-19) (Urlich 1974, 1994). The latter species belong to the *Halobia rugosa* group of Kittl (1912), which also contains *H. zitteli* Lindström and *H. vixaurita* Kittl, two species with a well developed radial ribbing, and restricted, in the western Tethys, to the *aon* Subzone (Gruber, 1976; Krystyn, 1978). Both the *Halobia* species from the upper San Cassiano Fm of Prati di Stuoeres/Stuoeres Wiesen have a well developed radial sculpture, thus the early sure Halobiids of the Prati di Stuoeres/Stuoeres Wiesen section do not belong to a group with reduced sculpture, hypothetically derived from "*Posidonia*". In conclusion, the lacking of posidonoids with an undisputable anterior ear impedes the sure identification of *Halobia* in the *canadensis* Subzone of the Prati di Stuoeres/Stuoeres Wiesen, although the specimen of the group c) could contribute to the debate on the phyletic connection between *Bositra*, *Daonella* and *Halobia*.

Palynomorphs

The distribution of spores, pollen grains and marine elements (acritarchs, foraminiferal linings and tasmanites) in the Prati di Stuoeres/Stuoeres Wiesen section reflects the evolution of the terrestrial and marine flora before and after the proposed boundary. Thirtyfour samples have been studied in order to define the distribution and the main LADs and FADs present along the succession.

Typical upper Ladinian-lower Carnian sporomorphs as *Uvaesporites gadensis*, *Kuglerina meieri*, *Ovalipollis pseudoalatus*, *Todisporites* spp., *Aratrisporites* spp., *Reticulatisporites dolomiticus*, *Sellaspora rugoverrucata* and the circumpolles form *Partitisporites novimundanus* are present throughout the section.

In the upper part of the *regoledanus* Subzone, *Concentricisporites* cf. *C. bianulatus*, *Enzonasporites vigens*, *Kyrtomisporis ervii*, *Gordonispora fossulata* and *Duplicisporites granulatus* have their first occurrence (Fig. 6). "*Lueckisporites*" cf. *singhii* firstly appears very close to the top of the *regoledanus* Subzone.

Moreover, *Nevesisporites vallatus*, *Todisporites marginales*, *Calamospora* sp. A, *Apiculatisporites parvispinosus* and *Densosporites* cf. *variomarginatus* are, in the Prati di

Stuores/Stuores Wiesen section, restricted to the *regoledanus* Subzone. *Nevesisporites vallatus* has its last occurrence at the proposed boundary.

Above the proposed boundary, in the lower part of the *canadensis* Subzone, *Vallasporites ignacii*, *Patinasporites densus* and *Aulisporites* cf. *A. astigosus*, together with *Duplicisporites verrucosus* and *Camerosporites secatus*, have their first occurrence.

In the samples from the uppermost part of the *canadensis* Subzone, the first occurrences of *Weylandites magnus*, *Camerosporites pseudoverrucatus* and *Samaropollenites speciosus* are found. No other significant bioevents are documented in the overlying *aon* Subzone.

The palynological content of the Prati di Stuores/Stuores Wiesen section supports the proposal to place the boundary at the FAD of *Daxatina canadensis*. This ammonoid event occurs very closely to significant changes of the palynological association, consisting in the replacement of upper Ladinian sporomorphs by typical Carnian microflora.

The first appearance of *Patinasporites densus* marks the base of the *vigens-densus* phase and is associated with the first appearance of *Vallasporites ignacii* (Van der Eem, 1983); their common occurrence has been traditionally considered to be close to the base of the Carnian (Van der Eem, 1983, Fisher, 1972; Visscher and Brugman, 1981; Fisher and Dunay, 1984; Warrington, 1996; Hochuli and Frank, 2000; Roghi 2004).

On the base of a previous palynological work (Van der Eem, 1983), the Ladinian/Carnian boundary was placed in the Prati di Stuores/Stuores Wiesen section at sample Stu 2-09 AL, corresponding to the base of the author's *vigens-densus* phase and, always in the same section, to sample 3 of Urlichs (1994). Van der Eem's sample Stu 2-09 AL is located above our uppermost sample (sw af, metres 193.5), thus, the base of the *vigens-densus* phase in the Prati di Stuores/Stuores Wiesen section is lowered by at least 130 metres with respect to Van der Eem (1983). In fact, the occurrence of the typical Carnian species *Vallasporites ignacii* and *Patinasporites densus* very close to the proposed GSSP boundary, in association with *Enzonalasporites vigens*, allows to refer the palynological associations from the lower part of the *canadensis* Subzone to the *vigens-densus* phase of Van der Eem (1983). These data reinforce the proposal to place the base of the phase close to the base of the *canadensis* Subzone (Broglia Loriga et al., 1999).

On the basis of the first occurrence, in the Prati di Stuores/Stuores Wiesen section, of *Concentricisporites* cf. *C. bianulatus* within the *regoledanus* Subzone, the base of the *Concentricisporites* cf. *C. bianulatus* assemblage (Roghi, 2004) is late Ladinian (Longobardian) in age.

Other microfossils

There are no new data about foraminifers, microcrinoids and holothurian sclerites besides those exposed in Broglia Loriga et al. (1998, 1999). Benthic foraminifers in particular were studied by C. Broglia Loriga, R. Rettori

and D. di Bari (Broglia Loriga et al., 1999). In a preliminary proposal (Broglia Loriga et al., 1998), these authors concluded that:

1. A Carnian affinity in the portion of section belonging to the lower *canadensis* (m. 45 to 145) ammonoid subzones is suggested by taxa observed in thin sections.
2. The assemblages recognized in isolated material and thin sections in this lower interval are, however, closely comparable to those of the upper *canadensis* Subzone (m 145 to 180).
3. Most of the species occurring in the Prati di Stuores/Stuores Wiesen section 1 (Fig. 4) are quoted in the Carnian of the Taurus, Carpatho-Balkans, Transadnanubian Central Range, Serbia, Northern Calcareous Alps, Julian Alps, China and Israel.
4. Change in taxonomical compositions may strongly depend on ecological factors.

Microcrinoids and holothurian sclerites were studied by G.F. Laghi and M. Rechichi (Broglia Loriga et al., 1999). Again, the conclusions of the preliminary proposal (Broglia Loriga et al., 1998) can be summarized as follows:

1. Between m 20 to 45, the first occurrences of many microcrinoids are documented.
2. From m 120 to 150, a short peak of abundance in both microcrinoids and sclerites can be recognized.
3. Above this peak, the taxonomic diversity decreases. According to Bizzarini (1993), holothurian sclerites increase again upwards.
4. Close to the top of the section, a few species disappear. The last occurrence of *Osteocrinus acus* is the most prominent event.

The microcrinoid and holothurian sclerites association seems to be rather typical of the *canadensis* Subzone; with minor modifications, it also extends upwards into the *aon* Subzone.

The variations in taxonomic diversity can probably be referred to ecological factors.

3B.2 Magnetostratigraphy

A total of 96 paleomagnetic core samples were analyzed for magnetostratigraphy (Broglia Loriga et al., 1999). A bipolar characteristic component of magnetization oriented in geographic coordinates north and positive or south and negative was isolated in 72% of the specimens in the temperature range comprised usually between about 200°C and 450°C up to 550-580°C. In 10% of the specimens the characteristic component could be followed up to maximum unblocking temperatures of 600-630°C. An additional 11% of the samples show transitional directions associated with polarity excursions or acquired during field polarity reversals. The bipolar and transitional characteristic component directions become shallower upon correction for bedding tilt. Rock-magnetic experiments point to magnetite as the main carrier of the magnetic remanence; subsidiary sulphurs and haematite are occasionally present. The

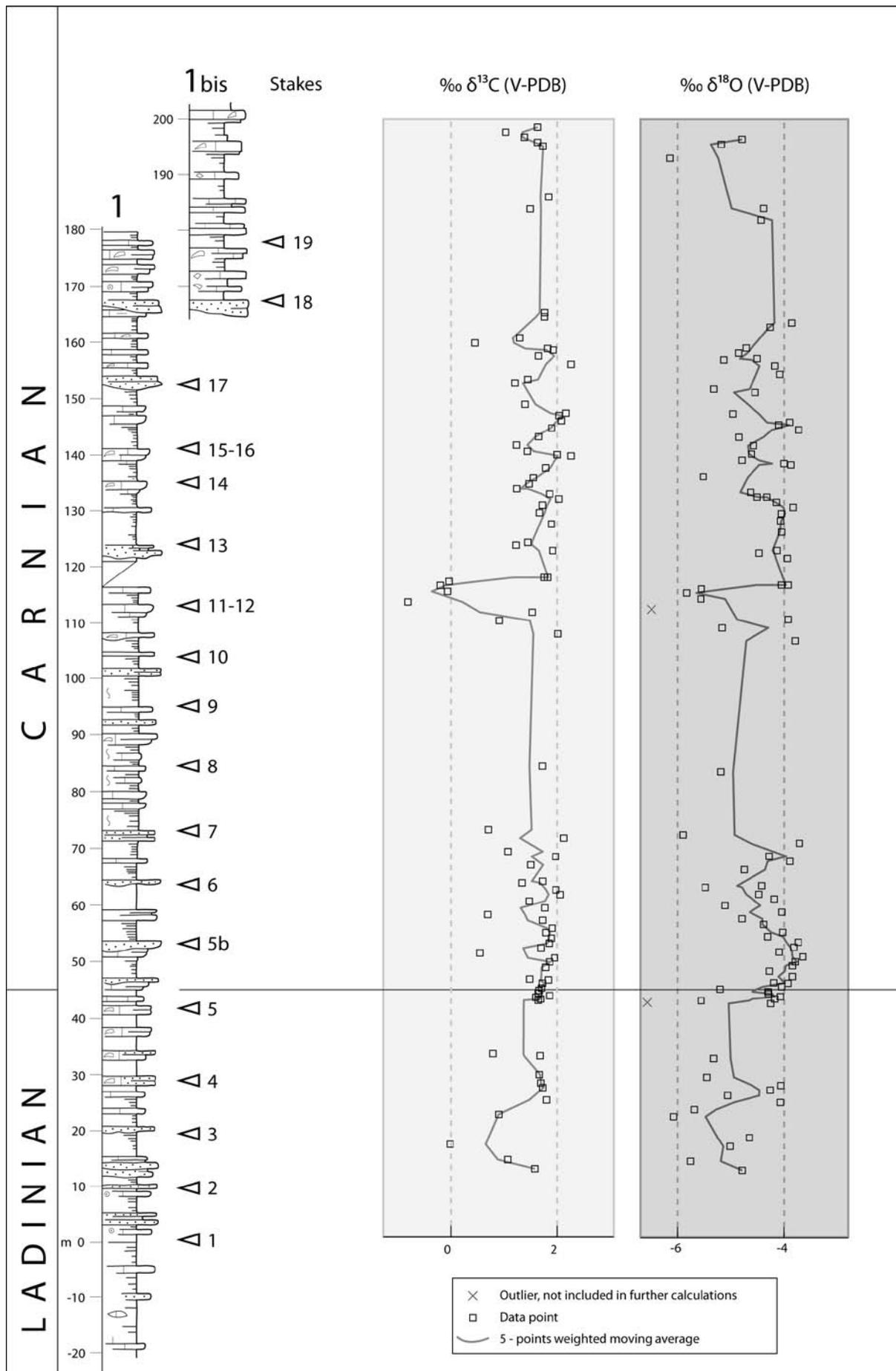


Figure 7: Chemostratigraphic data from the Prati di Stuoeres/Stuores Wiesen section

latitude of the specimen virtual geomagnetic pole (VGP) with respect to the overall mean north paleomagnetic pole was used to delineate magnetic polarity stratigraphy. The latitude of the VGPs defines, from bottom to top, a lower normal (S1n)-reverse (S1r)-normal (S2n)-reverse (S2r)-normal (S3n)-reverse (S3r)-normal (S4n) polarity sequence. The base of the Carnian, as defined by the FAD of *Daxatina canadensis*, falls towards the base of S2n. The Prati di Stuores/Stuores Wiesen section can be tentatively correlated with the coeval Mayerling section from Austria of Gallet et al. (1998). According to this correlation (Broglia Loriga et al., 1999), the first appearance of *Daxatina canadensis* at Prati di Stuores/Stuores Wiesen would fall at Mayerling within the *diebeli* conodont Assemblage Zone.

3B.3 Chemical stratigraphy

Prati di Stuores/Stuores Wiesen section has never been investigated in detail with the purpose of describing stable Carbon, Oxygen, and Strontium isotopes variations. To improve our knowledge in this time interval 102 samples have been collected so far along the whole section of Prati di Stuores/Stuores Wiesen for analyse Carbon and Oxygen stable isotopes' ratios. Samples are unequally spaced (see Fig. 7), being collected exclusively from siltitic marls that were not potentially involved in turbidites. From each sample, a small amount of rock (few grams) has been hand-drilled, avoiding macrofossils (like bivalves shells), intraclasts or fractures filled by calcite. The drilled powder is thus considered representative of the bulk composition of the sample.

Powders were reacted with phosphoric acid and analyzed using an automated continuous-flow isotope ratio mass spectrometer at the University of Innsbruck. Results were calibrated against NBS and IAEA standards and have been reported relative to VPDB scale. The long-term analytical uncertainties are $\pm 0.07\%$ for $\delta^{13}\text{C}$, and $\pm 0.08\%$ for $\delta^{18}\text{O}$ (reported at the 1σ level, Spötl and Vennemann, 2003).

Preliminary results of our analyses are plotted in Fig. 7: for graphical purposes, in $\delta^{13}\text{C}$ box seven *mild* outliers* are not shown being lower than -2% and clearly isolated from the data cloud. For the same reason, six mild outliers are not shown in $\delta^{18}\text{O}$ box, being lower than -7% or greater than -2% $\delta^{18}\text{O}$. Oxygen isotopes values are strongly drifted towards very low values, being potentially overprinted by diagenesis. $\delta^{13}\text{C}$ values appear to be constant albeit sensibly scattered along the whole section, with no evidence of excursions close to the proposed Ladinian/Carnian boundary, or anywhere else throughout the section except close to Stakes 11-12. $\delta^{13}\text{C}$ values, ranging between $0 \div 2\%$ VPDB, seem compatible with the expected values for this time interval (Korte et al., 2005, Veizer et al., 1999). It is necessary, however, to highlight the preliminary nature of these data: further analyses both at Prati di Stuores/Stuores Wiesen and in correlated sections seem necessary to identify diagenetic influences and ultimately unravel the primary geochemical trend within this interval.

*: *mild* outliers are defined as data points whose values are $< Q_1 - 1.5 \cdot (Q_3 - Q_1)$ or $> Q_3 + 1.5 \cdot (Q_3 - Q_1)$, where Q_1 and

Q_3 are the first and third quartiles for the given dataset, respectively.

3B.4 Sequence stratigraphy

Comparing to Broglia Loriga et al. (1999), there are no significant variations of the sequence stratigraphic interpretation across the proposed boundary, as well as its global correlation (Fig. 8). The only differences are related to the slightly younger age of the supposed sequence boundary defining the base of the sequence Car 1. New biostratigraphic data from the Southern Alps (Dolomites and Lombardy) and Transdanubian Range (Hungary), allows us to put it in the lower part of the *regoledanus* Subzone instead of the *neumayri* Subzone.

The proposed GSSP is placed at the beginning of the regressive trend just after the Car 1 (sensu Gianolla et al., 1998) or Lad 3 (sensu Hardenbol et al. 1998) maximum flooding surface (*mfs*), dated to the upper *regoledanus* Subzone, in a section presenting very high sedimentation rates (Gianolla, 1995). This *mfs* is one of the best traceable surfaces for basin-wide correlation. Thus the potential for correlation of the proposed boundary is enhanced by sequence stratigraphic interpretation, specially when compared with sections characterized by lower sedimentation rates.

3B.6 Other event stratigraphy

Up to now, no other physical or chemical surfaces have been recognized that could be used for correlations outside the Dolomites area. Tephra layers of latest Ladinian age have been discovered recently in some sections of the Dolomites (cf. chapter 3B.8), but are not yet been identified at Prati di Stuores/Stuores Wiesen. Their correlation potential, however, should be limited to the eastern Southern Alps. No cyclostratigraphic analyses have been carried out in Prati di Stuores/Stuores Wiesen section. Masetti et al. (1991) studied a slightly younger succession of the San Cassiano Fm. some kilometres from Stuores (Lavarella section, near San Cassiano village). There, these authors recognized a cyclic organisation of stratal patterns. Such regular organization was not observed at Prati di Stuores/Stuores Wiesen, probably because of the greater distance of this section from carbonate slopes of the Cassian carbonate platforms.

3B.7 Marine-land correlation potential

The palynological association of Prati di Stuores/Stuores Wiesen allows correlation of the proposed boundary in terrestrial sections.

In Switzerland, *Vallasporites ignacii* and *Patinasporites densus* appear in the upper part of the middle Gipskeuper (interval F in Scheuring, 1970 and Mostler and Scheuring, 1974). In south Germany (Franken), *Vallasporites ignacii* appears in the upper "Myophorienschichten" both in outcrop and in the Obersees borehole, while *Patinasporites densus* in the overlying "Estherienschichten". On the base of these first appearances, the proposed GSSP level can be correlated to in the upper part of the Myophorienschichten (Van den Berg, 1987, Brack et al., 1999).

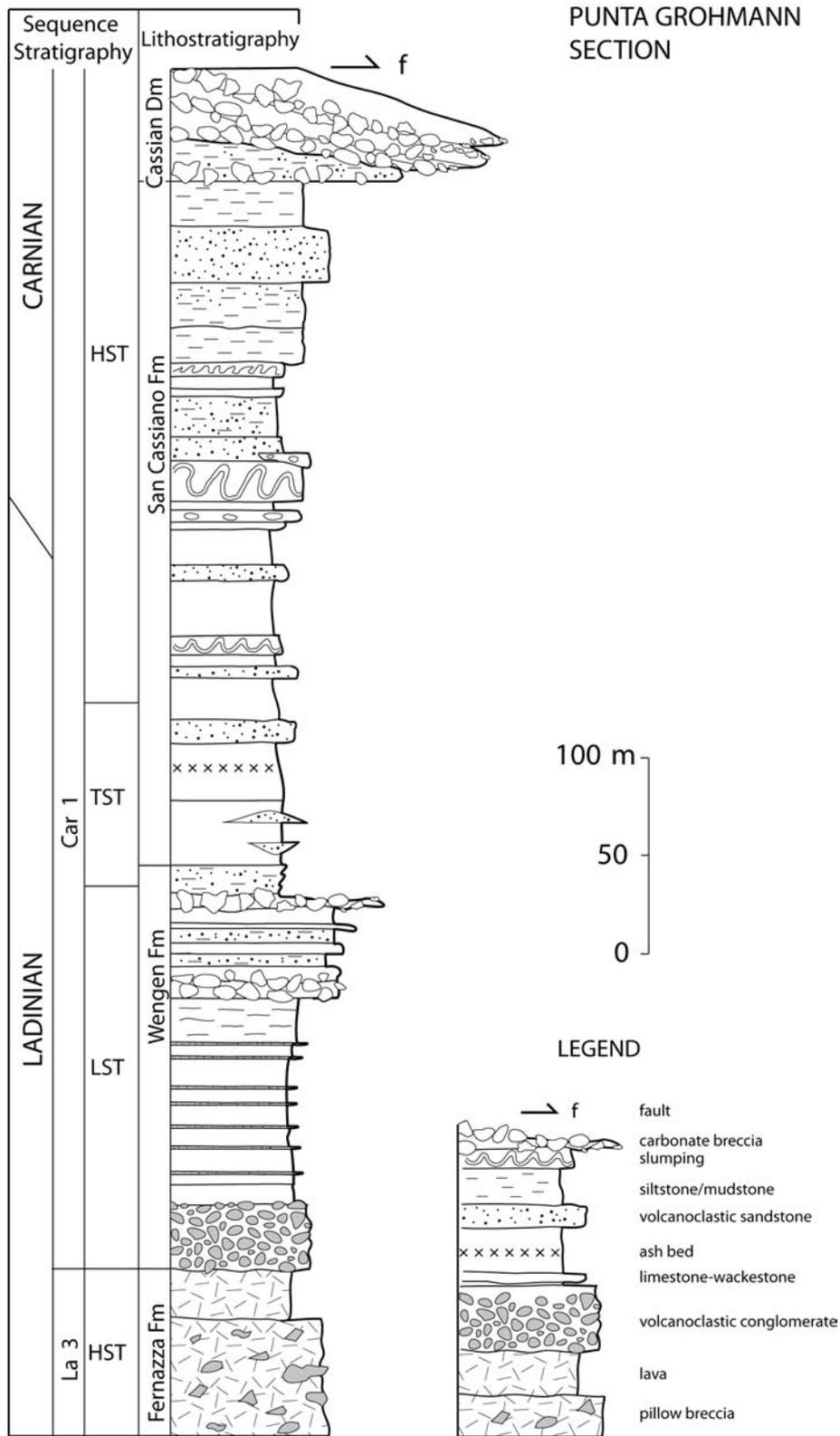


Figure 8: Lithostratigraphy and sequence-stratigraphic interpretation around the Ladinian/Carnian boundary at the Punta Grohmann section, 14 km westward from Prati di Stuares. This section is representative of the sedimentary evolution in this time interval in the Dolomites.

In England, on the base of the occurrences of *Camerosporites secatus* and *Enzonasporites vigens*, the boundary lies within the “Keuper marl” (Warrington, 1970).

In the Temple Mountain Member of the Chinle Formation (southwestern U.S.A.), typical Carnian associations are described from the base of the succession but the proposed boundary is not identifiable (Litwin et al., 1991; Litwin and Ash, 1993).

In the Newark Supergroup (eastern U.S.A.), *Vallasporites ignacii* and *Patinasporites densus* appear in the Stockton Formation; on the base of these findings the boundary was placed inside this formation. (Fowell et al., 1994). Recent magnetostratigraphic studies, however, questioned this correlation and rather suggest the GSSP level should lie below the succession of the Newark Supergroup (e.g., Muttoni et al., 2004).

3B.8 Amenability to geochronometry

No datable layers are known from the Prati di Stuoeres/Stuoeres Wiesen section. Recent studies have recognized several primary and reworked ash beds in correlatable sections from the surroundings of the proposed stratotype section (Furin, 2007), further ash beds have been sampled during summer 2007. Among all the studied primary ash beds, only one layer yielded enough zircon crystals for radiometric dating. This bed, collected in the Alpe di Siusi area (24 km west of Prati di Stuoeres/Stuoeres Wiesen) has good biostratigraphic control based on ammonoids and conodonts. With the reference to ammonoids, the ash bed is within the lower part of the *regoledanus* Subzone (sensu Mietto and Manfrin, 1995), below the Car1 sequence boundary (see paragraph 3B.4). Chemical Abraded, ID-TIMS radiometric age of the mentioned layer is expected to be published in 2008. Further ash beds have been collected in the Punta Grohmann section (14 km westward from Prati di Stuoeres) from ash beds between the Car1 sequence boundary and the first occurrence of *Frankites apertus* (Mojsisovics), but data are still preliminary. No radiometric ages are known so far in this area above the proposed boundary. Published radiometric ages bracketing the proposed Ladinian/Carnian boundary are 238.0 +0.4 -0.7 Ma (Mundil et al., 1996) and 230.91±0.33 Ma (Furin et al. 2006). The two ages are excessively older/younger than the proposed boundary (see above) so any interpolation between these two pinpoints is extremely inaccurate (and potentially erroneous). The older age is obtained by U/Pb TIMS analyses on eight air-abraded Zircon crystals from an ash bed collected at Seceda (17 km NE from Prati di Stuoeres/Stuoeres Wiesen). The layers belong to the *archelaus* Zone (sensu Brack and Rieber, 1993, i.e., corresponding to the *longobardicum* to *neumayri* subzones in Mietto and Manfrin, 1995a), based on the presence of *Daonella lommeli*. The younger age is obtained by Chemical Abrasion ID-TIMS technique on eight zircon crystals from a layer collected in the Southern Apennines (Southern Italy – more than 700 Km SE). Biostratigraphic control on the latter layer is given by conodonts and palynomorphs: according to Kozur and Weems (2007) the layer belongs

to the *Carnepigondolella zoeae* conodont zone, leading to middle to upper Tuvalian (Upper Carnian) age. According to many Authors (Gallet et al., 2003; Kozur and Weems, 2007) the expected age for the Ladinian/Carnian boundary should fall approximatively at 237 Ma.

3C Demonstration of regional and global correlation

3C.1 Regional correlation

The litho-, sequence-, magneto- and biostratigraphic correlation of Ladinian/Carnian boundary interval within the Southern Alps is widely illustrated and discussed in De Zanche et al. (1993), De Zanche and Gianolla (1995), Mietto and Manfrin (1995b) and Broglio Loriga et al. (1998, 1999). From a biostratigraphic point of view, several stratigraphic sections and localities in the Southern Alps provide ammonoid faunal assemblages referred to the *canadensis* Subzone. Bed-by-bed distributions of ammonoids, conodonts and palynomorphs in selected key sections are showed in Mietto et al. (2007, submitted).

3C.2 Long distance and global correlation

The succession of ammonoid faunas in the Prati di Stuoeres/Stuoeres Wiesen section and in other correlated localities in the Southern Alps, records some bioevents which occur in homotaxis also in the Tethys and extra-tethysian domains (Himalayas, Nevada, British Columbia, Svalbard). With reference to Mietto and Manfrin (1995b) and Broglio Loriga et al. (1999), the occurrence of taxa with widespread distribution allows the tethysian biozones to be correlated with those defined in British Columbia by Tozer (1967, 1994). In particular, the *canadensis* Subzone has been considered nearly equivalent to the *sutherlandi* Subzone 2 of Canada for the concurrent occurrence of *Daxatina canadensis* and *Frankites apertus* (= *sutherlandi*), and correlatable by the first appearance of the former taxon. Nevertheless, the uppermost Ladinian to lowermost Carnian part of the North America ammonoid Standard Scale needs to be revised because of the partial overlapping between the *sutherlandi* and *desatoyense* Zones, demonstrated in Nevada (Balini, in press). The “*Daxatina canadensis* Zone”, defined in the Svalbard Archipelago (Bjørnøya, see Mørk et al., 1992), is also correlated with the *canadensis* Subzone. Magnetostratigraphic correlation based on ammonoids vs conodonts calibration between Prati di Stuoeres/Stuoeres Wiesen and Mayerling in Northern Calcareous Alps is showed in Broglio Loriga et al (1999), and is now confirmed by the finding of *Paragondolella polygnathiformis noah* in the bed SW4c (Mietto et al., 2007).

The ammonoid succession recently reported from the *canadensis* Subzone in Himalayas (Guling 1 and Muth 3 sections in Spiti Valley: Balini, Krystyn and Torti, 1998; Krystyn, Balini and Nicora, 2004) and in Nevada (New Pass Range: Balini and Jenks, 2007; Balini et al., 2007; Balini, in press) is consistent with the ammonoid succession at Prati di Stuoeres/Stuoeres Wiesen. The correlation is illustrated in detail by Balini et al. (in prep.).

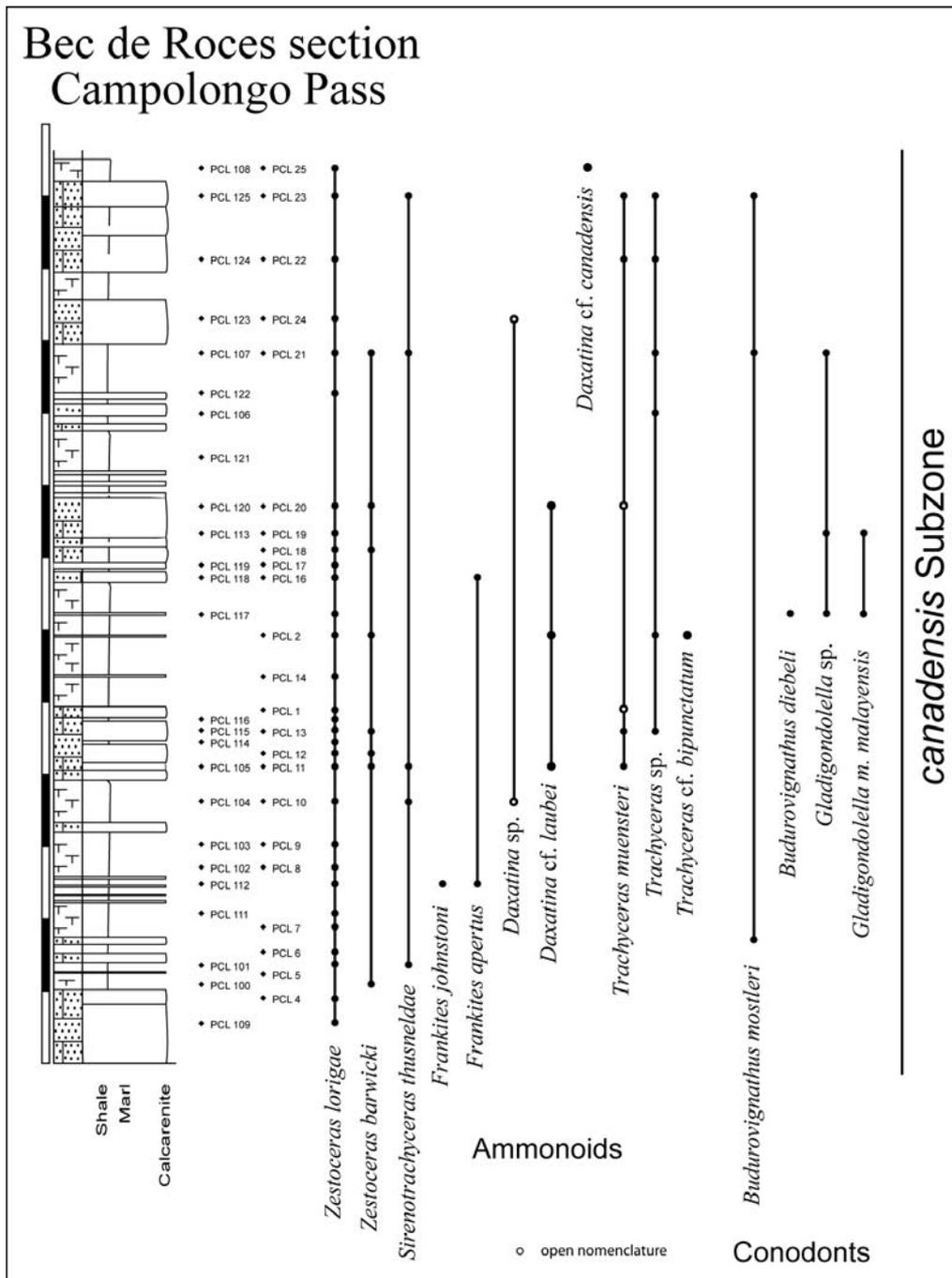


Figure 9: Stratigraphic column of the Bec de Rocès section, with distribution of main fossils.

4. Selection process

4A Relation of the GSSP to historical usage

The history of concepts regarding the Ladinian/Carnian boundary is summarized in Gaetani (1995) and Broglio Loriga et al. (1999). As well known, the base of the Carnian traditionally coincides with the appearance of *Trachyceras aon*, considered the first representative of the genus. *Trachyceras* is documented at Prati di Stuores/Stuores Wiesen by *Trachyceras muensteri* that occurs associated with *Daxatina canadensis*; in the Antersass section *T. bipunctatum* also occurs in the *canadensis* Subzone. This implies the predation of genus *Trachyceras* and allows to consider the *canadensis* Subzone Carnian in age (Mietto and Manfrin, 1995a, 1995b). Also conodonts, palynomorphs and

halobiids corroborate this assumption.

4C votes

During “The Global Triassic” Conference in Albuquerque (23-28 may, 2007), the STS session voted that the primary marker for the definition of the GSSP for the base of the Carnian Stage is the first appearance of the genus *Daxatina*. Voted secondary markers are the first appearance of *Paragondolella polygnathiformis noah* and halobiids. The Prati di Stuores/Stuores Wiesen section in the Southern Alps (NE Italy), and the bed SW4 in which *Daxatina canadensis* firstly appears, were considered a good candidate for the GSSP of the base of the Carnian.

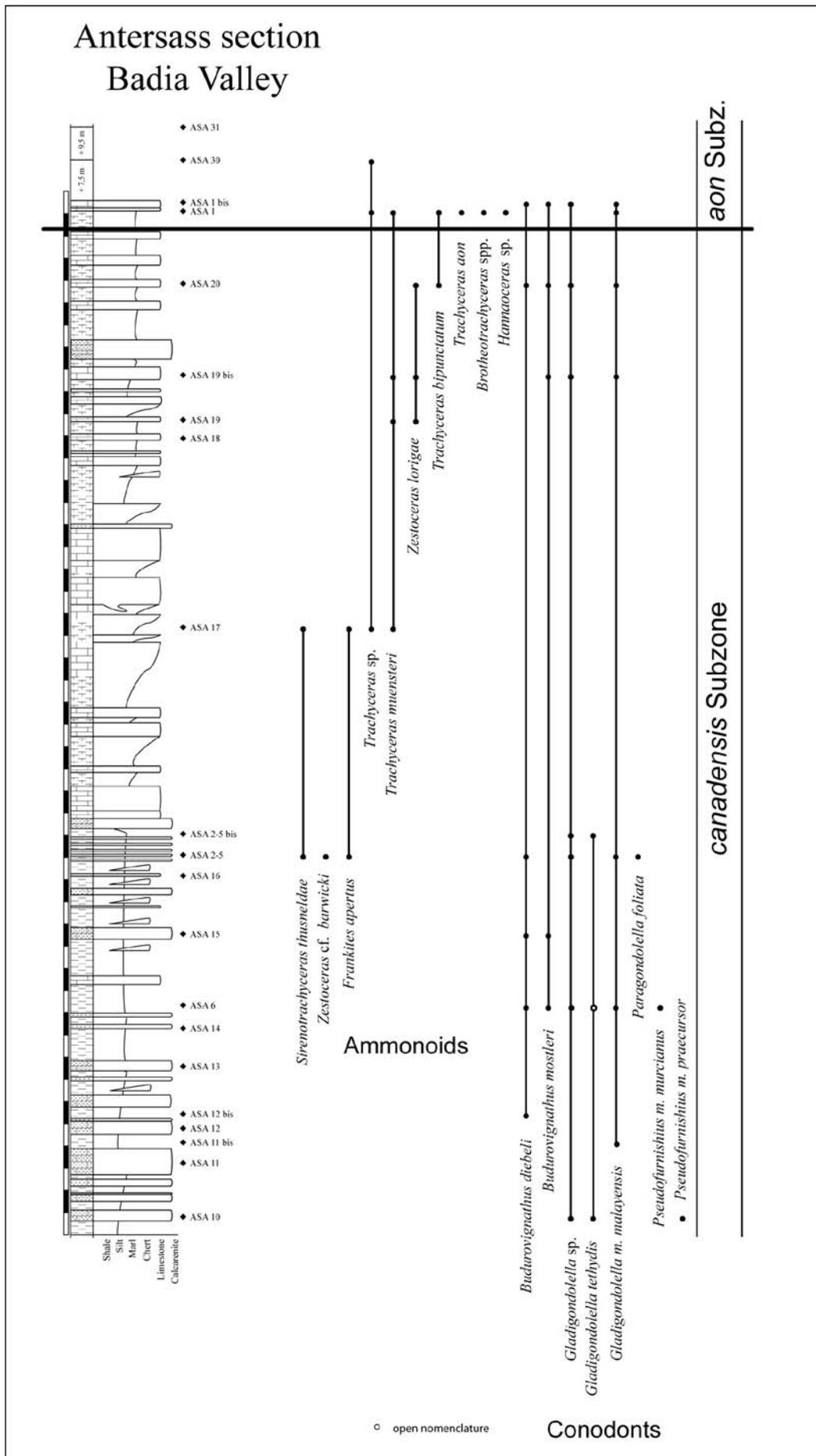


Figure 10: Stratigraphic column of the Antersass section, with distribution of main fossils.

4D selected publications

- Balini, M., in press - Discovery of Upper Ladinian ammonoids at the type locality of the Lower Carnian Desatoyense Zone (South Canyon, New Pass Range, Nevada). *J. Paleont.*, 82/1(2008), 162-168.
- Balini, M., and Jenks, J.F., 2007 - The Trachyceratidae from South Canyon (Central Nevada): record, taxonomic problems and stratigraphic significance for the definition of the Ladinian-Carnian boundary. *New Mex. Mus. Nat. Hist. & Sci. Bull.*, 41, 14-22.
- Balini, M., Jenks, J.F., McRoberts, C.A., and Orchard, M.J., 2007 - The Ladinian-Carnian boundary succession at South Canyon (New Pass Range, Central Nevada). *New Mex. Mus. Nat. Hist. & Sci. Bull.*, 40, 127-138.
- Balini, M., Krystyn, L., Manfrin, S., McRoberts, C.A., Mietto, P., Nicora, A., Orchard, M.J., Richoz, S., and Rigo, M., in prep. - Ladinian/Carnian boundary marine correlation between North America and Tethyan realm.
- Balini, M., Krystyn, L., and Torti, V., 1998 - In search of the Ladinian-Carnian boundary: perspectives from Spiti (Tethys Himalaya). *Albertiana*, 21, 26-32.
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5. Other useful sections

The most relevant complementary sections in the Southern Alps, significative for the definition of the Ladinian/Carnian boundary have been described in Mietto et al. (2007, submitted).

The Bec de Rocces section is located on the eastern flank of the Sella Massif, near Passo Campolongo not far from Stuoeres (**Fig. 9**). It is a short section that best illustrates the ammonoid association typical of the *canadensis* Subzone. The Anterass section is located on the northern flank of Gardenaccia in the middle Badia Valley. This section is noticeable for the abundance of fairly well preserved ammonoids that best records the boundary between the *canadensis* and *aon* subzones (**Fig. 10**).

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First detailed carbon isotope curve through the Ladinian-Carnian boundary : The Weissenbach section (Austria).

S. Richoz¹, L. Krystyn¹, C. Spötl²

¹Department of Palaeontology – Geozentrum, A-1090 Wien, Althanstrasse 14, sylvain.richoz@univie.ac.at

²Institut für Geologie und Paleontologie, Universität Innsbruck, Innrain 52, 6020 Innsbruck, Austria.

Abstract - We present here a preliminary carbon isotope curve of the Ladinian-Carnian Boundary Interval from the Weissenbach-Mayerling section, Northern Calcareous Alps (NCA). The $\delta^{13}\text{C}_{\text{carb}}$ data measured in hemipelagic limestones record two negative excursions of small amplitude immediately below and above the boundary interval. If confirmed by data from other sections these two negative excursions might be relevant chemostratigraphic markers for the Ladinian-Carnian boundary.

1. Introduction

Carbon isotope curves have been widely used as correlation tool and their application is recommended by the ICS within the frame of GSSP definitions. But up to now, there is no detailed carbon isotope curve available for the Ladinian-Carnian boundary (LCB). Prati di Stuoeres/Stuoeres Wiesen in the Southern Alps (Italy), the currently only candidate GSSP (Broglia Loriga et al., 1998; 1999; Mietto et al., 2007), has no published carbon isotopic records. The only available $\delta^{13}\text{C}_{\text{carb}}$ curves for this time slice are from Romania (Atudorei, 1999) and Oman (Hauser et al., 2001), but without adequate biostratigraphic control for this interval and a low isotopic resolution for the Oman section (Hauser et al., 2001). The Weissenbach section in the Northern Calcareous Alps of Austria is important because of its reliable magnetostratigraphy (Gallet et al., 1994, 1998; in these papers the section is named Mayerling) and is approximately correlative to the Stuoeres Wiesen section using conodonts and magnetostratigraphy. We present here a preliminary carbon isotope curve through the LCB.

2. Geological setting

The Weissenbach section is located approximately 30 km southwest of Vienna, in the vicinity of the village of Weissenbach near Mayerling (Fig. 1). Gallet et al. (1994) used the name ‘Mayerling’ (rather than Weissenbach) because of its well-known historical background. From a paleogeographical point of view, this section belongs to the Northern Calcareous Alps (NCA), which are considered as a part of the northwestern Tethyan continental margin (e.g. Bosselini et al., 1980). The section is situated along a railway cutting (1, Fig. 1), with beds dipping 55° towards southeast (Gallet et al., 1994). The section sampled consists of 22 m of thick-bedded, whitish, fine-grained, deep-water pelagic limestones (Fig. 2). This uniform lithology is best suited for carbon isotopic studies (Atudorei, 1999).

3. Method

Twenty-four samples were taken within 15 m of the presumed LCB. For isotopic analyses, powders were produced from selected micritic samples using a diamond-tipped drill. Hand specimens were carefully examined to avoid cracks, veins and weathering features and drilled on the

counterpart of thin sections. The samples were analyzed using an automated carbonate preparation system connected to a Delta^{plus}XL mass spectrometer (Spötl and Venemann, 2003) at Innsbruck University. Reproducibility of replicate analyses was better than $\pm 0.1\text{‰}$ for standards and $\pm 0.15\text{‰}$ for sediment samples for both carbon and oxygen isotope values. All isotope results are reported using the conventional δ notation, defined as per mil (‰) deviation vs. VPDB.

4. Results and discussion

4.1 Biostratigraphy

The biostratigraphy of the sequence is based exclusively on conodonts, a difficult task in absence of a modern revision of Upper Ladinian to Lower Carnian faunas and

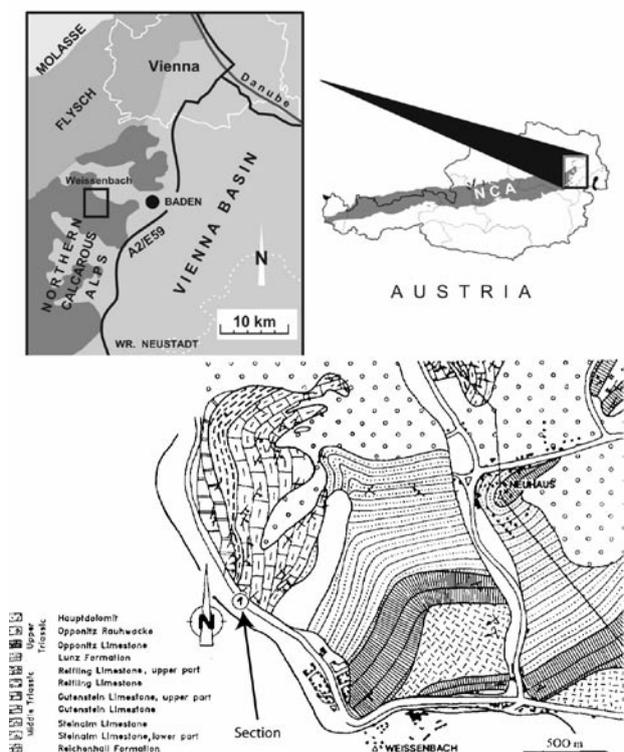


Figure 1: Location, simplified geological and structural maps of the Weissenbach section (modified after Gallet et al., 1994).

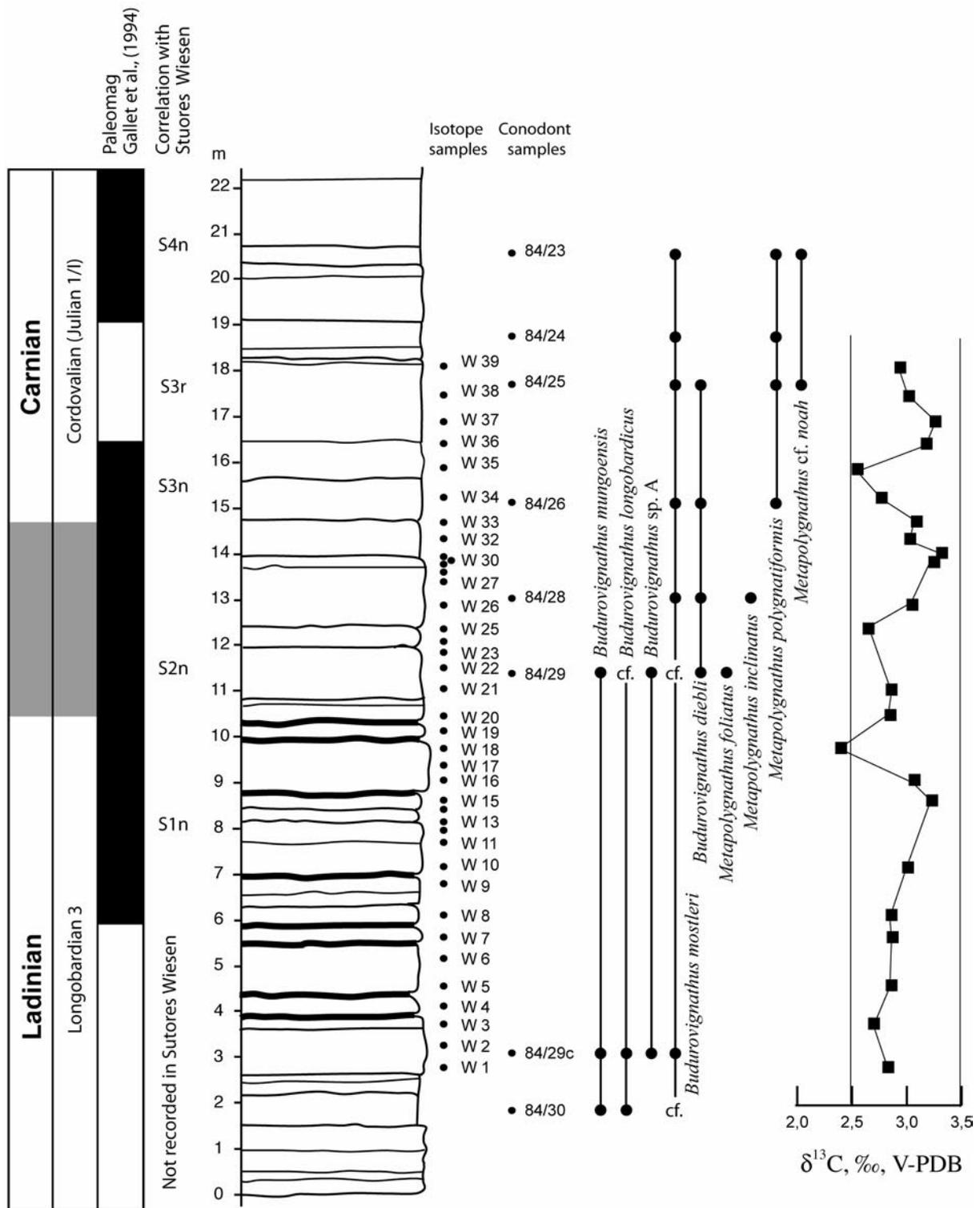


Figure 2: The Ladinian-Carnian boundary interval in Weissenbach showing the possible location of the boundary (in grey), conodont ranges, $\delta^{13}\text{C}_{\text{carb}}$ data and magnetic polarity zones with assumed correlations to the GSSP candidate Stuoeres Wiesen (Italy).

considering the highly contradicting views on the taxonomy of the time-diagnostic genera *Budurovignathus* and *Metapolygnathus*. Published species ranges of the mentioned taxa are therefore highly subjective and may vary considerably rendering a comparison and correlation difficult. A high-resolution stratigraphic interpretation of the Weissenbach section is further hampered by two other factors, i.e. discontinuous data below the indicated LCB interval (Fig. 2), and the apparent difference in faunal

composition of the exclusively *Budurovignathus*-bearing samples in the lower part of the section versus the mixed budurovignathid-gondolellid associations above.

In absence of generally accepted definitions, we provide the here used defining criteria for *Budurovignathus* and *Metapolygnathus* species. Forms with a short rectangular, terminally rounded to slightly squared platform and a lower un-bifurcated keel are included in a morphologically expanded *Budurovignathus longobardicus* (Kovacs)

Sam- ple	meter	d13C, ‰	d18O, ‰
W 1	2.75	2.8	-3.4
W 3	3.70	2.7	-2.8
W 5	4.55	2.9	-1.9
W 7	5.60	2.9	-3.9
W 8	6.10	2.9	-2.0
W 10	7.15	3.0	-2.4
W 15	8.60	3.2	-2.1
W 16	9.05	3.1	-2.8
W 18	9.75	2.4	-2.4
W 20	10.50	2.9	-2.5
W 21	11.10	2.9	-3.8
W 25	12.40	2.6	-3.4
W 26	12.90	3.0	-2.7
W 30	13.85	3.3	-2.4
W 31	13.95	3.3	-1.7
W 32	14.30	3.0	-2.6
W 33	14.70	3.1	-2.9
W 34	15.25	2.8	-3.9
W 35	15.90	2.6	-3.8
W 36	16.40	3.2	-3.3
W 37	16.90	3.3	-2.4
W 38	17.50	3.0	-2.8
W 39	18.10	2.9	-2.9

Table 1: $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of the Weissenbach section.

with an extended range from the Upper Ladinian to the lowest Carnian (cf. *aon*-Zone specimens from Stuores Wiesen figured *Budurovignathus diebeli* in Neri et al., 1995). Specimens with an elongated rectangular, posteriorly squared platform and a well bifurcating, Y-shaped terminal keel are assigned to *Budurovignathus diebeli* (Kozur & Mostler) and might - in this restricted sense - become a valuable marker for the new LCB. The *Metapolygnathus polygnathiformis* group is differentiated in *M. polygnathiformis* s. str. (plus newly described species in Orchard & Balini, 2007), and *M. cf. noah* for morphotypes close to Hayashi's type figure of this species. Orchard & Balini (2007), however, argues to restrict this name to Upper Carnian representatives and not to use it for Lower Carnian ?homoeomorphs.

Neglecting long-ranging species occurring throughout the late Ladinian and basalmost Carnian (*B. mungoensis*, *B. longobardicus*, *M. inclinatus*, *M. foliatus*) there remain three taxa (*B. diebeli*, *M. polygnathiformis*, *M. cf. noah*), which may be of time-significance for the LCB in Weissenbach. These three forms share successive appearances in the section within a 6 m interval starting with *B. diebeli* followed by *M. polygnathiformis* and closely above by

M. cf. noah. Such a low-resolution record does not allow any direct correlation with the Stuores Wiesen sequence, though our gray shaded "boundary interval" (see Fig. 2) may come close to the ammonoid-defined LCB in the candidate GSSP.

4.2 Magnetostratigraphy

The section contains four magnetic polarity intervals with the second one being much longer than the other three (Fig. 2). Muttoni's magnetostratigraphic comparison of Weissenbach-Mayerling with Stuores Wiesen (in Broglio Loriga et al., 1998) lacked a proper chronostratigraphic time frame. He equated a rather long time interval in Weissenbach (complete *regoledanus*-Zone = Longobardian 3 in Gallet et al., 1994) with a much shorter one in Stuores (*Daxatina* cf. *canadensis* Zone = upper part of *regoledanus*-Zone sensu Gallet et al., 1994). The magnetic correlation used in the present paper fits the biostratigraphic data much better. The sedimentation rate, which is 15 to 20 times lower in Weissenbach than in Stuores Wiesen, has as consequence that the sampling interval in Weissenbach (30-60 cm) is in proportion much coarser than in Stuores (< 5-9 m). This might explain the absence of the two thin Stuores Reversals S1r and S2r in the Weissenbach section. Consequently, we correlate the first long Weissenbach Normal with the three Stuores Normals S1n to S3n. At Stuores Wiesen, the base of the *Daxatina* cf. *canadensis* Zone is located low in S2n (Broglio Loriga et al., 1998). Translating this position into the long Normal of Weissenbach would lead to a LCB close to the base of the gray shaded LCB interval in Fig. 2, the probably most realistic value achievable.

4.3 Chemostratigraphy

The lithology, which is rich in carbonate (>99%) and very poor in organic matter, the study of thin-sections, the low thermal overprint (Conodont CAI 1) and the absence of a significant correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values, strongly suggest that diagenesis did not alter the $\delta^{13}\text{C}$ values. The uniform lithology permits to record isotope variations, which would most likely be difficult to identify in a less homogenous limestone. Within the measured interval the $\delta^{13}\text{C}$ values vary between 2.4‰ and 3.3‰. $\delta^{13}\text{C}$ values are slightly increasing from 2.7‰ to 3.2‰ in the first 6 m. The curve then records two negative excursions of 0.7‰ in amplitude, one beginning just below the interval presumably comprising the LCB (shaded interval in Fig. 2) and the second one beginning immediately above it. If confirmed by subsequent studies the suggested position of the LCB at the base of the shaded interval will provide a possibility to correlate this boundary within the first negative excursion.

In Dobrogea (Romania) Atudorei (1999) showed constant values in the two lower thirds of the Ladinian followed by an increase of 1.5‰ to 2‰ and again constant values in the Lower Carnian. Unfortunately, the available biostratigraphic data do not allow to decide if this increase occurred in the Upper Ladinian or in the Lower Carnian. Our results suggest that this increase did not occur around the boundary, but either below or above it and thus cannot serve as marker for the LCB. Further isotope studies are

necessary to 1) define the exact biostratigraphic position of the $\delta^{13}\text{C}$ increase recorded in Dobrogea, and 2) confirm the reproducibility and the wider correlation of the two small negative excursions around the LCB in the Weissenbach section.

Acknowledgments

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The Carnian/Norian boundary interval at Pizzo Mondello (Sicani Mountains, Sicily) and its bearing for the definition of the GSSP of the Norian Stage

Nicora A.¹, Balini M.¹, Bellanca A.², Bertinelli A.³, Bowring S.A.⁴, Di Stefano P.⁵, Dumitrica P.⁶, Guaiumi C.⁷, Gullo M.⁸, Hungerbuehler A.⁶, Levera M.¹, Mazza M.¹, McRoberts C.A.⁹, Muttoni G.¹, Preto N.⁷, & Rigo M.⁷

¹Dipartimento di Scienze della Terra "A. Desio", Via Mangiagalli 34, 20133 Milano, Italy.

²Dipartimento di Chimica e Fisica della Terra ed applicazioni alle Georisorse, Via Archirafi 36, 90123 Palermo, Italy.

³Dipartimento di Scienze della Terra, Piazza Università, 06123 Perugia, Italy.

⁴Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge MA 02139, U.S.A.

⁵Dipartimento di Geologia e Geodesia, Università di Palermo, via Archirafi 22, 90123 Palermo, Italy.

⁶Istitut de Géologie et Paléontologie, UNIL, BSFH-2, 1015 Lausanne, Suisse.

⁷Dipartimento di Geoscienze, Università degli Studi di Padova, via Giotto 1, 35137 Padova, Italy.

⁸INAIL-CONTARP Piemonte, Corso Orbassano 366, 10137 Torino, Italy.

⁹Department of Geology, SUNY at Cortland, P.O. Box 2000, Cortland, NY 13045, USA.

Introduction

Pizzo Mondello in the Sicani Mountains (Western Sicily, Italy) is one of the best sites in the world for the study of the Carnian/Norian boundary. At this site, a 450 m thick pelagic-hemipelagic limestone succession is exposed. The succession belongs to the Cherty Limestone (*Calcari con selce* or *Halobia limestone Auctorum*), and is impressive for the combination of great thickness, almost uniform facies, good exposure and easy accessibility.

Besides fulfilling these basic conditions for the examination as GSSP candidate section, Pizzo Mondello is located in an area that is very important for the paleontology for the Upper Triassic pelagic facies. The Cherty Limestone of Western Sicily, and especially of Sicani Mountains, is well known all over the world for the exceptionally rich and well preserved Late Carnian to Early Norian ammonoid faunas studied by G.G. Gemmellaro (1904) and for the very rich halobiid record (Gemmellaro, 1882; Montanari & Renda, 1976; Cafiero & De Capoa Bonardi, 1982; De Capoa Bonardi, 1984).

Although Sicani Mountains have been known in literature since XIX century, the Pizzo Mondello section is a rather new locality presented in international journals in mid '90s (Bellanca et al., 1995; Gullo, 1996). In the second half of the '90s, integrated paleomagnetic, isotopic and conodont stratigraphic investigations were carried out, and Pizzo Mondello soon became one of the world references for the unusual combination of Late Carnian-Early Norian magnetostratigraphic, stable isotope and conodont record (Muttoni et al., 2001; 2004).

However, the investigations carried out in the late '90s were not detailed enough from the paleontological point

of view to support the presentation of a GSSP proposal, as pointed out by Krystyn & Gallet (2002). For this reason a new multidisciplinary research programme started in 2006. Aims of this programme, which involves researchers from Milano, Padova, Palermo, Perugia and Lausanne Universities, are, besides the sedimentology, the high resolution integrated bio-chronostratigraphy based on conodonts, ammonoids, halobiids and radiolarians, and the recalibration of magnetostratigraphy and of stable isotope curves.

Here we present the new data available. Two new very dense conodont samplings were carried out in fall 2006 and spring 2007. The first ammonoid and halobiid bed-by-bed sampling was done in spring 2007, and radiolarian sampling was done in 2005 and summer 2007.

Geological setting

Pizzo Mondello is located in the Sicani Mountains, about 4 km SE of the worldwide known Permian megablocks of the Sosio Valley (Fig. 1.1).

The Sicani Mountains belong to the western Sicily segment of the Maghrebian thrust and fold belt. The structural setting of this area consists of a pile of south-verging thrust sheets formed by Permian to Cenozoic deep-water sediments. They are known as Sicanian structural units (Catalano et al., 1995), and are regarded as to be derived from the Neogene contraction of a deep-water basin (Sicanian basin) located along the southern margin of the Ionian Tethys (Di Stefano, 1990; Muttoni et al., 2004). Pizzo Mondello is the exposed part of a large thrust sheet that overthrusts upper Tortonian-Messinian clays. The roughly East-West trending thrust front is dissected by a later (Pliocene) NW-SE right transpressional fault separating the Pizzo Mondello ss. from Pizzo Scavarrante to the West (Fig.

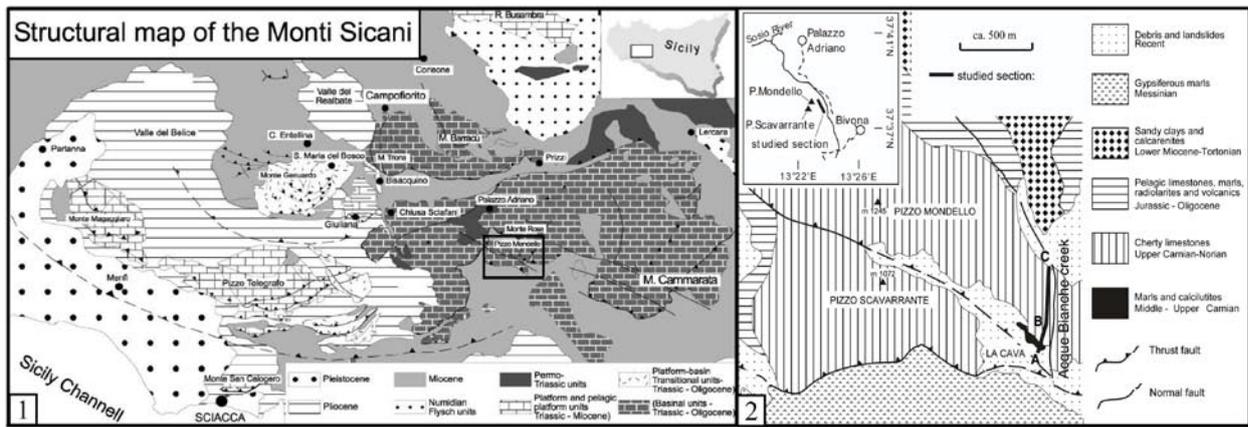


Figure 1: Location map of Pizzo Mondello (Sicani Mountains, Sicily). 1. Geological map of the Sicani Mountains (from Di Stefano et al., 1996). 2. Detailed map of Pizzo Mondello area (from Muttoni et al., 2004).

1.2). Late Miocene-Pliocene thrusting and transpressional movements, associated to clockwise rotations (Muttoni et al., 2001), resulted in a polyphasic folding of the Pizzo Mondello Meso-Cenozoic succession. Northward the Pizzo Mondello unit is in turn overthrusts by another Sicani-type structural unit known as Monte Rose Unit (Masclé, 1979; Di Stefano & Gullo, 1997).

Stratigraphic setting

The Pizzo Mondello succession consists of deep-water Upper Triassic to Eocene calcilutites with a Middle Jurassic intercalation of radiolarites and pillow lavas, covered by Oligo-Miocene clays and glauconitic sandstones. The total thickness can be estimated at about 1500 m.

The Carnian to Rhaetian succession can be easily subdivided into three lithostratigraphic units (Di Stefano, 1990; Gullo, 1996; Di Stefano & Gullo, 1997). The lowermost unit (Fig. 3) consists of a few meters of Upper (p.p.) Carnian dark gray marls alternating to marly limestones. These beds are assigned to the Mufara Formation (Schmidt di Friedberg, 1962), an about 200 m thick lithostratigraphic unit well known from the deep water successions in western Sicily. The Mufara Formation has played the role of major décollement level during the Neogene Maghrebien accretion. At Pizzo Mondello this formation lies tectonically on Tortonian-Messinian clays. An upsection change from marls-calcilutite alternations to monotonous calcilutite beds marks the transition from the Mufara Formation to the next thick unit, informally known as Cherty Limestone or *Halobia* limestones (=Scillato Formation [Schmidt di Friedberg et al., 1960]). In the Sicani Mountains well known sections of this unit, more than 400 m thick, are described at Monte Cammarata and Monte Triona (Masclé, 1979; De Capoa, 1984). At Pizzo Mondello (Fig. 2.1, 2.2) the lower part of this unit is very well exposed in an old quarry (“La Cava”) active until 30 years ago. The intermediate and upper part outcrop extensively along a small creek bounding the eastern slope of Pizzo Mondello: the Acque Bianche creek. In the whole the unit consists of about 450 m of evenly-bedded to nodular *Halobia*-bearing cherty calcilutites. White marly calcilutites (similar to the Maiolica) reaching a thickness of about 20 m follow by a sharp conformable contact. These beds were described by

Gullo (1996) as Portella Gebbia Limestone.

The lower part of the Cherty Limestone, straddling the Carnian/Norian boundary (unit 2 of Muttoni et al., 2001; 2004), is studied in detail.

Lithofacies and sedimentology

Muttoni et al. (2001, 2004) divide the Cherty Limestone of Pizzo Mondello into four parts or lithozones (Fig. 3):

- I. The basal 3 m, above the Mufara Formation, is characterized by calcilutites with rare cherty nodules;
- II. 143.5 m of dm-thick, well-bedded white-yellow calcilutites with black chert nodules, intercalated with cm-thick marly levels, follow. In the calcilutites of this lithozone, thin-shelled bivalves (halobiids), foraminifers, radiolarians, sponge spicules, sparse ammonoids and ostracods (Gullo, 1996), as well as calcispheres and calcareous nanofossils (Bellanca et al., 1993; 1995) are present;

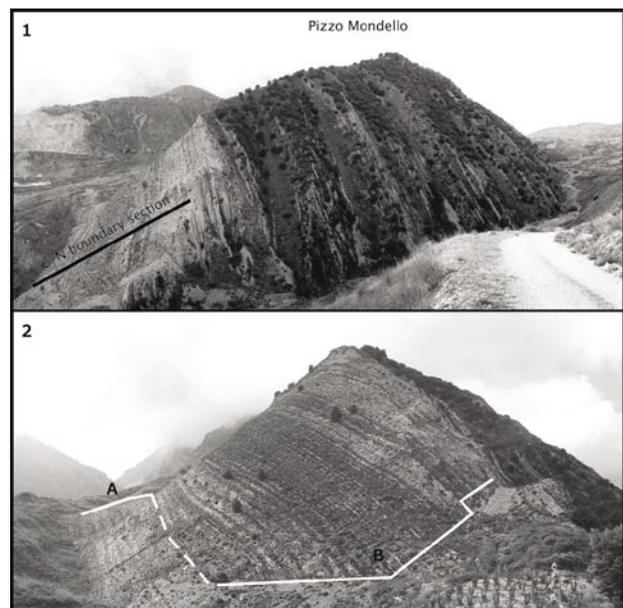


Figure 2: General view of Pizzo Mondello (La Cava) section showing 1) the entire succession of the Cherty Limestone; 2) the interval under study, with the position of the two sampling sites (A and B).

Pizzo Mondello (Muttoni et al., 2004)

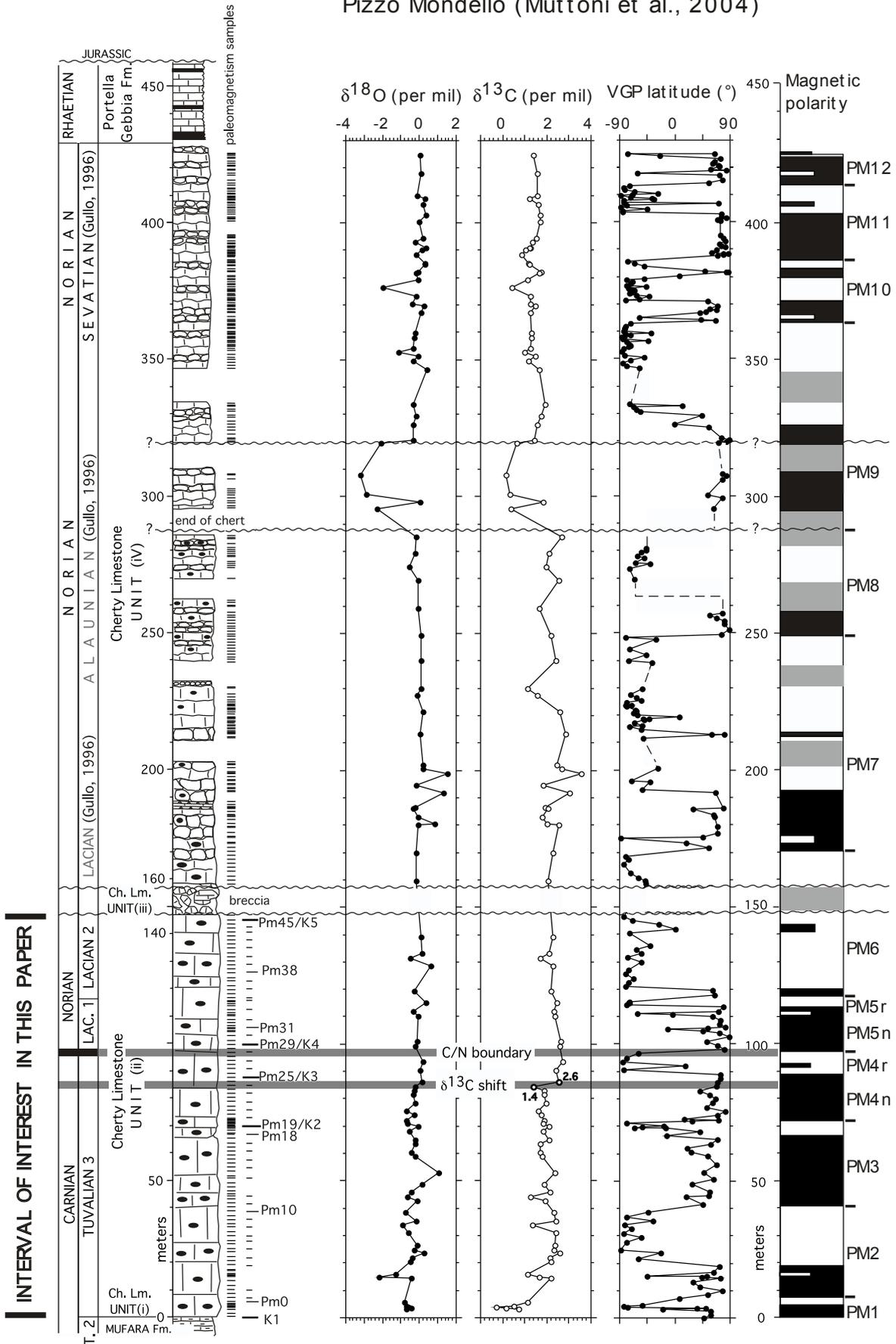


Figure 3: Pizzo Mondello section from Muttoni et al. (2004), with $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotope curves and magnetostratigraphy. The lower part of the log, representing the Carnian/Norian boundary interval, is studied in detail in this paper (Fig. 4 and 5).

III. 11.5 m of brecciated limestones, hereafter referred to as the “*slump-breccia*” level;

IV. 267.5 m of dm- to cm-thick, well-bedded to nodular whitish calcilutites with cherty nodules are found above the “*slump-breccia*” level. Chert disappears at meter 290 ca.

The interval II of Muttoni et al. (2004), ca. 140 m thick, was subject to a high-resolution sedimentological analysis. The succession was logged at cm scale and densely sampled (ca. 2 samples/m). Most of the samples were studied with optical microscope, while selected samples were analyzed at SEM. As a result three facies are recognized (Fig. 4; Pl. 1):

Facies A: well-bedded, dm-thick, white calcilutites with black-brown cherty nodules more abundant in the interlayers. Calcilutite layers are composed mostly of micrite, with thin-shelled bivalves (halobiids), radiolarians, ammonoids, foraminifers and calcispheres; bioturbations and laminations are rare. Bivalve coquinas also occur. The interlayers are composed of mm-thick brownish clays, which are rarely laminated (Pl. 1 A1-3).

Facies B: it is similar to facies A, but layers are nodular, up to 1 m thick, and characterized by stylolitic joints. Thin-shelled bivalves, calcispheres and coquinas are more abundant. Bioturbations and laminations are common (Pl. 1 B1-3).

Facies C: calcilutite layers are even more nodular than in facies B but generally thinner (8-15 cm), and always laminated. Thin-shelled bivalves and calcispheres are very common. Silicified coquinas are very abundant. Cm- to dm-scale interlayers, composed of brown-black dolomitized clay-marls, are more common than in all other facies. This facies is rich in black chert, occurring in 5-7 cm thick beds (Pl. 1 C1-3).

In the logged section (Fig. 4), these three facies alternate following the scheme A-B-C-B-A with interval C centered at m 73 ca.

This facies alternation may represent a combination of oscillations in the carbonate sediment supply from surrounding carbonate platforms, varying dissolution rates at the sea-bottom, and different autochthonous carbonate productivity (e.g., benthic thin-shelled bivalves or calcispheres, supposed to be pelagic according to Bellanca et al., 1993; 1995).

Ammonoid distribution

The biostratigraphic analysis of ammonoids and halobiids started in May, 2007. Two segments of Muttoni et al. (2001) interval II (lower half and upper part of the section in Fig. 4) were selected to test a bed-by-bed sampling for megafossils (Fig. 4). This sampling yielded sparse ammonoids together with very common halobiids. The occurrence of

ammonoids is especially interesting because it solves a problem of apparent inconsistency in literature. Gemmellaro (1904) described a large collection of about 4,000 well preserved ammonoids from Cherty Limestone of several localities in western Sicily. However, since that time only very few citations of ammonoids have been done (i.e., De Wever et al., 1979; Mascle, 1979; Gullo, 1996; Krystyn & Gallet, 2002), but no description of new specimens has never been provided.

The ammonoids are sparse within the beds, but the collection is possible because of the very good exposure of the succession. The beds can be easily followed along strike for tens or even hundreds of meters and some specimens can be recognized on surface.

At the present some tens of ammonoids have been collected. Most of them are of small size. Sometimes the specimens are hard to extract from the matrix. However, some medium- to large-sized very well preserved specimens can also be found (Pl. 2). Preliminary examination of the collection lead to identify some stratigraphic markers.

Discotropites plinii (Mojsisovics) has been collected from level PMAM17 (Pl. 2.5), in the lower part of the studied interval (Fig. 4). This species is index of the *D. plinii* subzone (Krystyn, 1974, 1980), first subzone of the uppermost Carnian *Anatropites spinosus* Zone.

In the middle part of the studied interval, in level PMAM7 a well preserved *Gonionitites maurolicoi* Gemmellaro has been found (Pl. 2.6). The genus *Gonionotites* ranges across the Carnian/Norian boundary in both the Tethyan realm and North America. In the Tethys it can be found from the *Gonionotites* cf. *italicus* subzone (Krystyn, 1980) of the *Anatropites spinosus* Zone to the *Guembelites jandianus* Zone (Krystyn, 1982), while in North America it is found in the *Macrolobatus* and *Kerri* zones (Tozer, 1994). At the rank of species, the Upper Carnian *Gonionotites* differ from the Lower Norian ones (Krystyn, 1982; Tozer, 1994). Unfortunately *G. maurolicoi* Gemmellaro has been reported only by Gemmellaro from western Sicily, then the stratigraphic position of this species has never been calibrated with respect to the Carnian/Norian boundary.

Probably the most interesting specimen for the identification of the Carnian/Norian boundary is at present a single specimen of *Dimorphites* sp. (Pl. 2.7) which was found unfortunately from debris. This specimen obviously cannot be used to trace any bio-chronostratigraphic boundary, but it demonstrates that in the Pizzo Mondello succession the ammonoid record documents also the very base of the Norian Stage. *Dimorphites* is restricted to the first zone of the Norian in both the Tethyan realm (*Guembelites jandianus* Zone: Krystyn, 1982) and North America (*Kerri* Zone: Tozer, 1994).

Halobiid distribution

At present, about 300 halobiid specimens (from 44 beds) have been collected (Fig. 4).

Halobiids have a wide distribution within the succession, ranging from almost the base (sample PM6), to the top of

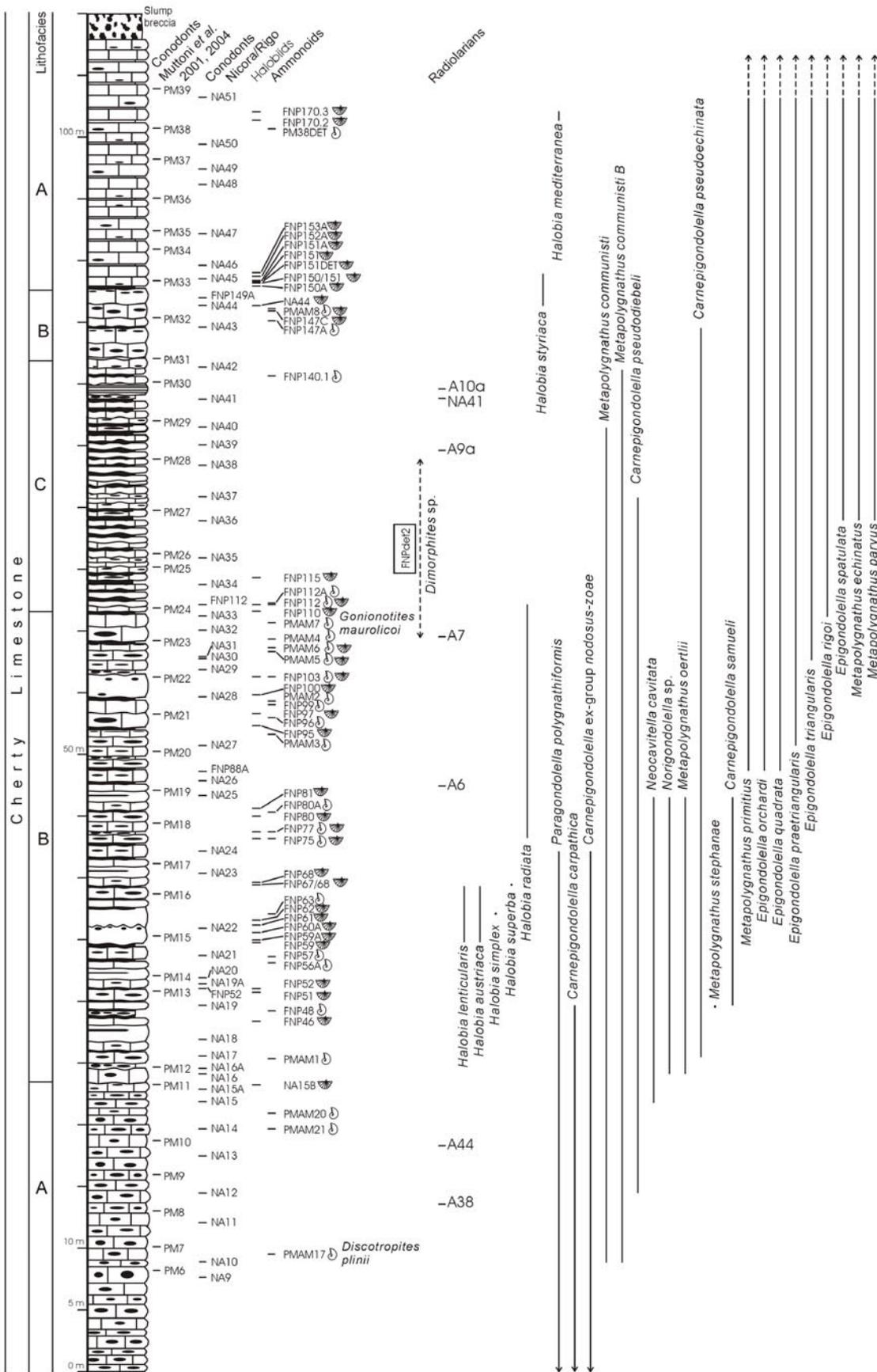


Figure 4: Detailed log of the Carnian/Norian boundary interval with the distribution of ammonoids, halobiids, radiolarian samples and conodonts. Acronym PM: conodont sample from Muttoni et al. 2001 and 2004; NA: conodont sample 2006 and 2007; FNP: lithofacies/halobiid/ammonoid sample 2007; PMAM: ammonoid sample 2007; A: radiolarian sample 2005 and 2007. The increment of the sampling resolution for conodonts might allow the re-calibration of the FOs of some species.

age	LATE CARNIAN				EARLY NORIAN		
	A38	A44	A6	A7	A9a		
taxa							
samples							
Acanthocircus (?) sp. A PESSAGNO, 1979					x	x	x
Braginastrum curvatus TEKIN					x	x	x
Bulbocyrtium reticulatum KOZUR & MOSTLER					x	x	x
Capnodoce sp. cf. C. anapetes DE WEVER					x	x	
Capnodoce sp. cf. C. longibrachium TEKIN							x
Capnuchosphaera deweveri KOZUR & MOSTLER					x	x	x
Capnuchosphaera triassica DE WEVER		x					
Capnuchosphaera lea DE WEVER		x			x	x	
Capnuchosphaera sp. cf. C. lea DE WEVER	x	x	x	x	x	x	
Capnuchosphaera theloides DE WEVER		x			x	x	x
Capnuchosphaera sp. aff. C. crassa YEH	x	x	x	x			
Capnuchosphaera tricornis DE WEVER					x	x	x
Capnuchosphaera sp. indet.	x	x	x	x			
Carinaheliosoma carinata (KOZUR & MOSTLER)					x	x	
Dumitricasphaera (?) sp.					x		
Entactinosphaera (?) sp.1 BRAGIN	x	x	x	x	x	x	x
Enoplacampe sp.					x		
Kahlerosphaera sp. cf. Eptingium sp. A DE WEVER					x		x
Icrioma tetrancistrum DE WEVER					x	x	x

Figure 5: Radiolarian distribution in the studied samples.

the succession below the *slump breccia* (sample PM39). Within this interval, we recognize different distribution patterns for fossils.

The base and the first half of the succession show a quite homogeneous alternation of levels bearing only halobiids or levels bearing only ammonoids, with some intercalated levels bearing both halobiids and ammonoids (e.g. levels FNP52, FNP75, FNP112 in Fig. 4). The halobiids are recorded as small prints of single valves (frequently not more than 1-1.5 cm in diameter for lenticular forms, and not more than 1.5-2 cm in length for elongated forms). The skeletal material is very rarely preserved –mostly recrystallized shells.

The second half of the succession is characterized by a thick beds-set of levels bearing halobiids only, with ammonoids distributed below and over it (i.e. levels from NA44 to FNP153). The halobiids from these levels are larger (mostly more than 3-4 centimeters in diameter), heavily compressed and reduced to thin films or laminas. They occur both as isolated specimens (single valves) and as coquina-like levels, mostly at the base or at the top of beds. In the beds-set comprised between levels NA44 and FNP153A, more than 70% of the levels are made of halobiids' remains. No imbrication could be recognized, while even 70-80% of halobiids are oriented convex-up.

At the moment, the study of the collection is in progress, but we recognize seven species, and four assemblages.

The lower part of the succession is dominated by *Halobia lenticularis* and *H. austriaca*, with rare *H. simplex* and only one specimen of *H. superba* (levels from NA15B to FNP67/68; Fig 5). The middle part is dominated by *H. radiata* forms (levels from FNP75 to FNP115; Fig. 4). The halobiids from levels NA44 to FNP153A are *H. styriaca* (Mojsisovics, 1874) or *H. styriaca*-group specimens (levels from FNP150 to FNP153A; Fig. 4). Finally, the uppermost part of the succession (levels FNP170.2 and FNP170.3; Fig. 4) contains few specimens of *H. mediterranea*.

We identify four halobiid assemblages, named for their dominant species, from bottom to top: *H. lenticularis* (with subordinate *H. austriaca* and *H. simplex*), *H. radiata*, *H. styriaca*, and *H. mediterranea*.

Among these species, five are reported from Upper Carnian to Lower Norian (*H. lenticularis*, *H. superba*, *H. austriaca*, *H. simplex* and *H. radiata*; (Gruber, 1975, 1976; Cafiero & De Capoa Bonardi, 1984; Campbell, 1994) and two as Lower Norian (*H. styriaca* and *H. mediterranea*; Krystyn and Gallet, 2002; Krystyn et al., 2002). In particular, *H. styriaca* is considered in North America and Tethys as marker of the upper part of Lacion 1 (upper *Kerri* Zone in North America; *Jandianus* Zone in the Tethyan realm; Krystyn and Gallet, 2002; Krystyn et al., 2004).

Conodont distribution

At Pizzo Mondello, conodont samples were collected at different times and by different researchers in the past

(Gullo, 1996; Muttoni et al., 2001; Krystyn et al., 2002; Nicora et al., 2006; Guaiumi et al., 2007). A detailed sampling has been carried out in two sites (A and B; Fig. 2.2), because the middle part of the outcrop is rather steep. A bed-by-bed correlation between the two sites guarantee the uniform density of sampling.

Sample numbers are labelled with different capitals referring to the various researchers and times of sampling (reference column in Fig. 4). Sample spacing is minimal in the interval supposed to contain the Carnian/Norian boundary, and the distribution of conodonts is shown in Fig. 4

The number of conodonts in each sample is generally high. With few exceptions, samples from lithofacies A turned out to be particularly poor in conodonts, while lithofacies C is particularly rich in specimens. The conodonts have a Conodont Alteration Index (CAI) of 1.

The nomenclature of the conodont zones is reported according to Moix et al. (2007) and Orchard (1991 a). The most relevant occurrences are here emphasized in roughly chronological order.

- From sample NA10 *Metapolygnathus communisti* (Hayashi) (Plate 4.7) and *Metapolygnathus communisti* B Krystyn (Plate 3.3) are also present. Samples PM0-10 are characterized by the association *Paragondolella polygnathiformis* (Budurov & Stefanov), *Carnepigondolella carpaticha* (Mock), *Carnepigondolella nodosa* (Hayashi) along with *Carnepigondolella* ex gr. *zoeae* (Orchard).

- From sample NA10 *Metapolygnathus communisti* (Hayashi) (Plate 4.7) and *Metapolygnathus communisti* B Krystyn (Plate 3.3) are also present.

- *Carnepigondolella pseudodiebeli* (Kozur) (Plate 3.4) is from NA12 up to NA37.

- *Carnepigondolella pseudoechinata* (Kozur) and *Metapolygnathus stephaniae* Orchard occur from NA17.

- *Neocavitella cavitata* Sudar & Budurov appears, along with the aforementioned species, in NA15 and ranges up to NA25.

- *Norigondolella* sp. (Plate 3.1) and *Metapolygnathus oertlii* (Kozur) (Plate 3.2) occur in NA16.

- *Carnepigondolella samueli* (Orchard) (Plate 3.5) is present from NA19.

- *Metapolygnathus primitius* (Mosher) (Plate 3.10), *Epigondolella quadrata* Orchard (Plates 3.8, 3.9) and *E. orchardi* Kozur (Plates 3.7, 3.11) are rather abundant from FNP88A.

- *Epigondolella praetriangularis* Kozur & Moix (Plate 4.5) occurs in NA27.

- *Epigondolella triangularis* (Budurov) (Plates 4.8, 4.9, 4.10) is present from NA30 upwards.

- *Epigondolella rigoi* Kozur (Plates 3.12, 4.6) was obtained from NA33 upwards.

- *Metapolygnathus parvus* Kozur (Plates 4.2, 4.3), *Epigo-*

ndolella spatulata (Hayashi) and *M. echinatus* (Hayashi) (Plates 4.1, 4.4) characterize the conodont fauna from NA36 upwards.

According to the recent literature, the bio-chronostratigraphic value of the species proposed to determine the Carnian/Norian boundary is here briefly discussed.

- The first conodont association [*Paragondolella polygnathiformis* (Budurov & Stefanov), *Carnepigondolella carpaticha* (Mock), *Carnepigondolella nodosa* (Hayashi) along with *Metapolygnathus stephaniae* Orchard and *Carnepigondolella* ex gr. *zoeae* (Orchard)] can be related to the Middle-Late Tuvallian according to Orchard (1991a,b), Orchard & Tozer (1997), Carter & Orchard (2000), Orchard et al. (2001), Muttoni et al. (2001), Krystyn et al. (2002), Channell et al. (2003), Kozur (2003), Moix et al. (2007)].

- *Metapolygnathus communisti* Hayashi (Muttoni et al., 2001) seems to have a regional distribution (Kozur, 2003; Channell et al., 2003). In the Northern Tethys it appears just before the FAD of *Norigondolella navicula* (Huckriede) and disappears just before the FAD of *Epigondolella quadrata* Orchard, while in Neotethys and North America it occurs significantly earlier below the FAD of *Norigondolella navicula* (Huckriede) (Kozur, 2003).

- *Neocavitella cavitata* Sudar & Budurov range is restricted to the upper part of the Carnian according to Sudar and Budurov (1979), Budurov and Sudar (1990).

- *Norigondolella navicula* (Huckriede) has been regarded as marker for the base of the Norian Stage by Krystyn (1980) and Orchard (1991, b). According to Carter & Orchard (2000) and Kozur (2003), *Norigondolella navicula* seems to be facies controlled and thus not usable as boundary marker.

- *Metapolygnathus oertlii* (Kozur) according to Kozur (1980) and Krystyn et al. (2002) is a short-ranged species of the Latest Tuvallian that ends at the FAD of *Metapolygnathus communisti* Hayashi. But a clear overlapping of *Metapolygnathus communisti* Hayashi with *Metapolygnathus oertlii* (Kozur) has been recently illustrated in Rigo et al. (2007).

- The FO of *Carnepigondolella samueli* (Orchard) identifies the Upper *nodosus* Zone sensu Orchard (1991, a) of Middle-Late Carnian age.

- *Metapolygnathus primitius* (Mosher) straddles the Carnian/ Norian boundary (Orchard, 1991, a,b; Orchard & Tozer, 1997; Muttoni et al., 2001). According to Kozur (2003), in North America the FAD of *M. primitius* is partly coincident with the FAD of *Norigondolella navicula* while in the Neotethys it is coeval to the FAD of *Epigondolella orchardi* Kozur. However the occurrence of *Metapolygnathus primitius* is very close to the base of the Norian. At Pizzo Mondello *M. primitius* occurs along with *E. orchardi* and *E. quadrata*, and become very abundant after the FO of *M. echinatus* and *M. parvus*.

- *Epigondolella orchardi* Kozur is Latest Carnian-Low-

er Norian in age according to Kozur (2003) and Moix et al. (2007). It occurs along with *Metapolygnathus communisti* and *Metapolygnathus primitius* in the Neotethys while in the Northern Tethys it is associated with *Norigondolella navicula* and transitional forms to *Carnepigondolella pseudodiebeli* (Kozur), as well argued in Kozur (2003).

- *Epigondolella quadrata* Orchard (= *Epigondolella abneptis* subspecies A; Orchard, 1991, b) is Early Norian in age according to Orchard (1991 a, b), Krystyn et al. (2002), Channell et al. (2003), Kozur (2003) and Moix et al. (2007).

- *Epigondolella praetriangularis* Kozur & Moix occurs from the uppermost Tuvalian to the Earliestmost Laciian (Latestmost Carnian-Early Norian; Moix et al., 2007).

- *Epigondolella triangularis* (Budurov) (= *Epigondolella abneptis* subspecies B sensu Orchard, 1991 a) is Late Laciian (Early Norian) according to most of the Authors (e.g.: Orchard, 1991 a, b; Krystyn et al., 2002; Channell et al., 2003; Kozur, 2003 and Moix et al., 2007).

- *Epigondolella rigoi* Kozur ranges from Earliestmost Norian to Alaunian (Middle Norian; Moix et al., 2007)

- *Metapolygnathus parvus* Kozur, according to Kozur (1972), is restricted to the Tuvalian (Late Carnian).

- *Metapolygnathus echinatus* (Hayashi): Orchard (1991b) refers this species to *Metapolygnathus pseudoechintus* (Kozur) and assigne it to the Latestmost Tuvalian.

Radiolarian distribution

The radiolarian faunas from the latest Carnian to Early Norian interval are fairly well to very well preserved in the Pizzo Mondello section and show a rather high diversity. Common spumellarian genera include *Capnuhosphaera* De Wever, *Spongortilispinus* Kozur, Moix & Mostler, and *Kahlerosphaera* Kozur & Mostler. Nassellarians are usually less abundant and are often represented by various Xiphothecidae and Pseudodictyomitridae.

Many of these forms are well known from coeval sections in the Tethys (De Wever et al., 1979; Kozur & Mostler, 1972, 1978, 1979, 1981; Tekin, 1999, etc.), as well as from British Columbia (Carter & Orchard, 2000) and Oregon (Blome, 1984; Yeh, 1989) and can represent useful markers for global correlations. There are, however, some differences between the faunas known in North America and in Western Tethys, as for example, the abundance of genus *Xiphothecaella* De Wever & O'Dogherty in Western Tethys and its scarcity in North America.

As can be seen in Tekin (1999) and was pointed out especially by Carter (in Carter & Orchard, 2000), radiolarians show a gradual change across the Carnian/Norian boundary. However, Carter & Orchard proposed several potential radiolarian datums for the boundary calibrated with conodont zonation.

The study of the present radiolarian sequence is in a preliminary state. A closer sampling around the Carnian/Norian boundary was done quite recently and the study of the new

samples around the boundary is in progress. Anyway, this preliminary study shows that some taxa, previously known as having their LAD in the Late Carnian (*Praeorbiculiformella*, *Spongortilispinus*, *Weverella*, *Dumitricasphaera*, *Monospongella*) range till the Early Norian, and other taxa known until present from the Early Norian (Tekin, 1999) are still present in the latest Carnian.

In the present state of knowledge, A9a (located 1 m above the sample PM28, see Fig. 4, and around 12 meters above the $\delta^{13}\text{C}$ shift, see Fig. 3) is the oldest sample showing noticeable Norian affinities by containing the FAD of certain taxa known only to appear in the lower Laciian: for example some species of *Mesosaturnalis*, and especially *Monocapnuhosphaera* (*M. inflata* Tekin, Pl. 6 fig. 9), etc. (Pl. 5, figs. 14-16 and Pl. 6, figs. 8-16). This sample and some upper samples (A10a, NA41) contain numerous new taxa besides many already known species typical of Early Norian assemblages as reported in particular in Turkey (Tekin, 1999). Other species, as for example *Carinaheliosoma carinata* (Kozur & Mostler) (Pl. 6 fig. 13), known as having their LAD in the Early Norian, are present in this sample. A detailed content can be seen in the occurrence table (Fig. 5).

The sample A10a (2 meters above the sample PM29) is Early Norian on the basis of the presence of *Kahlerosphaera kemerensis adentata* Tekin (Pl. 6, fig. 1), known so far only from the Early Norian. Besides it there are species ranging from the Late Carnian to Early Norian (*Capnuhosphaera deweveri* Kozur & Mostler, *C. tricornis* De Wever, *Kahlerosphaera norica* Kozur & Mock, etc., see Plates 6-7).

The sample NA41 (18 metres above the $\delta^{13}\text{C}$ shift and just above the A10a) is Early Norian on the basis of the presence of the same taxa yielded in A10a (Pl. 6) and of *Icrioma tetrancistrum* De Wever (Early-Middle Norian), *Xiphothecaella longa* (Kozur & Mock) (Early Norian-Middle Norian), and *Xiphothecaella rugosa* (Bragin) (Late Carnian-Early Norian, *Braginastrum curvatum* Tekin, *Podobursa akayi* Tekin, *Capnodoce* sp. cf. *C. longibrachium* Tekin, and *Senelella triassica* Tekin, almost all referable to Early Norian (Pl. 7).

Magnetostratigraphy

A total of 410 paleomagnetic core samples were analysed for magnetostratigraphy (Muttoni et al., 2001; 2004). Rock magnetic experiments showed the presence in all sampled lithologies of dominant magnetite as carrier of the natural remanent magnetization (NRM). The results of stepwise thermal demagnetization of the NRM showed a multi-component structure. There is an initial magnetization component along the north and steep positive present-day field direction, isolated between room temperature and ~200-300°C in the majority of the specimens. At higher demagnetization temperatures, from ~200-300°C to ~400°C up to a (rare) maximum of 500-550°C, about three-quarters (73%) of the specimens show the presence of a southeast-and-down or northwest-and-up (in geographic coordinates) characteristic component, interpreted as acquired during normal and reverse geomagnetic polarity,

respectively. After correction for the homoclinal bedding tilt, the mean normal and reverse characteristic component directions become more easterly and westerly, respectively. Although normal and reverse populations are clearly seen, their means depart from antipodality by $\sim 36^\circ$, which we attribute to residual contamination from present-day field overprinting. The effect of the contaminating bias and/or transitional components on the mean direction can be minimized by first inverting all directions to common polarity, which results in a tilt corrected mean direction of Dec. = 107.0° , Inc. = 34.5° . The corresponding overall paleomagnetic pole, calculated by averaging the virtual geomagnetic pole (VGP) for each characteristic component direction, is located at Long. = 78.0°E , Lat. = 0.4°S .

The latitude of the sample VGP relative to the north pole of the paleomagnetic axis was used for interpreting the polarity stratigraphy. An overall sequence of 27 polarity intervals, labeled from magnetozone PM1 to PM12n has been established starting at the base of the Cherty Limestone (Fig. 3); delineation of magnetozones PM1 to PM6 is from Muttoni et al. (2001). Each magnetozone is subdivided into a lower predominantly normal and an upper predominantly reverse portion, in which submagnetozones can be embedded. The conodont Carnian-Norian boundary was placed at the PM4r/PM5n boundary, whereas the $\delta^{13}\text{C}$ positive shift falls within the upper part of magnetozone PM4n (Fig. 3) (Muttoni et al., 2004 and references therein).

Chemostratigraphy

Stable isotopes ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) data were already presented in literature, but a new detailed sampling of the boundary interval is scheduled. The data by Bellanca et al (1995) for the lowermost part (Carnian) of the section, were complemented by Muttoni et al. (2004), who reported the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves for the whole Cherty Limestone succession (Muttoni et al. 2004, fig. 3; Fig. 3). A 1.2 per mil shift of $\delta^{13}\text{C}$ is reported from the upper part of the magnetozones PM4n and immediately below sample PM25 (Muttoni et al., 2004, fig. 3; Fig. 3). As suggested by Muttoni et al. (2004) this shift could be a proxy for the Carnian/Norian boundary, but further investigation are necessary to better calibrate this physical event.

Tuffitic layers

The upper part of the boundary interval (upper lithofacies A) is under study in order to find tuffitic layers. If the occurrence of tuffitic layers is confirmed, we will process samples to separate and date zircons.

Correlations and possible marker events

The Carnian/Norian boundary Working Group has not yet decided on the guide event of the boundary, however, most of the debate is focused on conodonts (Muttoni et al., 2001; 2004; Channel et al., 2003; Krystyn & Gallet, 2002; Kozur, 2007; Orchard, 2007a, b). For this reason here we discuss the main conodont events potentially useful for the selection of the GSSP marker event.

The following stratigraphically important platform conodont occurrences have been recognized at Pizzo Mondello section from base to top (Fig. 4). A particular attention has been focused to those species which have been historically considered to mark the base of the Norian Stage.

- ***Metapolygnathus communisti* Hayashi, 1968:** *Metapolygnathus communisti* was first stated by Hayashi (1968) from Japan. Subsequently Krystyn (1980) differentiated the *Metapolygnathus communisti* population into two different subspecies: *Metapolygnathus commuinisti* s.s. and *Metapolygnathus communisti* B attributing to *M. communisti* s.s a range Latest Carnian-Earliest Norian and to *M. communisti* B only Early Norian. As suggested by Kozur (2003), *Metapolygnathus communisti* recovered in the Northern Tethys are always advanced forms, while transitional forms between *M. communisti* and its forerunner *P. polygnathiformis noah* (Hayashi) were restricted to North America and Neotethys, allowing the assumption that the FOs of *M. communisti* are diachronous in between the Northern Tethyan-Western Pantalassa and North America and Neotethys. However the occurrence of *M. communisti* is world widely below the FADs of *Norigondolella navicula* and the *Epigondolella* spp. (e.g. *Epigondolella orchardi*, *Epigondolella quadrata*) and at Pizzo Mondello section *M. communisti* Hayashi occurred below the ammonoid *Discotropites plinii*, which is a guide species for the base of the upper Tuvallian (Krystyn 1974, 1980 and Krystyn et al., 2002). With this consideration the first occurrence of *M. communisti* is surely Late Carnian in age.

- ***Metapolygnathus comministi* B Krystyn, 1980:** this species never described and only illustrated in Krystyn (1980) has been proposed by Gallet et al. (1992, 1994) as a guide species for the base of the Norian. Unfortunately, *Metapolygnathus communisti* B is absent in North America and only sporadically present in the Tethys (Krystyn, 1980; Gallet et al., 1992, 1994; Rigo et al., 2007). At Pizzo Mondello section, the FO of *Metapolygnathus communisti* B is below the occurrence of *Discotropites plinii*, an Upper Carnian ammonoid (see above). Thus, the sporadic occurrence, its stratigraphical range and the absence of a clear description makes the FAD on *M. communisti* B not ideal for defining the base of the Norian.

- ***Norigondolella* sp.:** for many years, the FAD of genus *Norigondolella* with the species *Norigondolella navicula* (Huckriede, 1958) has been considered by different authors working both on North American and Tethyan sections to mark the base of the Norian. Krystyn (1980) first supported this occurrence for the definition of the base of the Norian. But genus *Norigondolella* is often rare throughout the Neotethys suggesting it is a facies-controlled taxon (Kozur, 2003) and also in North America, according to Orchard et al. (2000), the mass occurrence of *N. navicula* would confirm this hypothesis. Furthermore, according to Kozur in Channell et al. (2003), the FAD of *Norigondolella navicula*, which is the first representative of genus *Norigondolella*, is close to FAD of *Metapolygnathus communisti* B which in Pizzo Mondello section has been recovered from surely Carnian strata (see above). The species recovered at Pizzo Mondello section and illustrated

in Plate 3, Figure 1 a-c belongs for sure to the genus *Norigondolella* but it is not possible to ascribe this species to *Norigondolella navicula* (Huckriede). It might be a precursor of *Norigondolella navicula* from an ancestral forerunner not yet well identified. Thus it means that the genus *Norigondolella* occurred from Carnian strata but the species *Norigondolella navicula* might even appear somewhere around the Carnian/Norian boundary as first suggested by Krystyn (1980).-

- ***Metapolygnathus primitius* (Mosher, 1970)**: according to Orchard (1983, 1991 a, b) and Kozur (2003), a set of different species have been gathered in *Metapolygnathus primitius*. Orchard (1991 a, b) defines a *M. primitius* Zone subdivided into lower and upper. The lower *M. primitius* Zone is characterized by the development of *M. primitius* from *Metapolygnathus nodosus* Hayashi and it is attributed to the uppermost Carnian. The upper *M. primitius* Zone is defined by the co-occurrence of *Norigondolella navicula* and *M. primitius* and attributed to the *kerri* Zone (Lower Norian). This association is regarded as definitive of the basal Norian.

Krystyn (1980) locates his *Metapolygnathus primitius* Assemblage Zone within the upper *Anatropites* Zone (~*Macrolobatus* Zone, Upper Carnian) and to the Lower Norian *Jandianus* (~lower *Kerri* Zone) ammonoid Zones considering "this zone of worldwide utility because the index species is distributed in the Tethyan region as far as Canada and Western North America".

After Kozur (2003) the FAD of *M. primitius* occurs contemporaneously or a little earlier than the FAD of *E. orchardi*, which is common in the Northern Tethys and in the Neotethys and represents a good correlation biomarker. Furthermore, real *Metapolygnathus primitius* occurs only from the Neotethys (Sicani, Lagonegro and Mersin area) and the Western North America, sometimes as transitional forms between *Metapolygnathus communisti* and *Metapolygnathus primitius* in the Sicani Basin (Muttoni et al., 2001) as suggested by Kozur (2003). Instead, in the Northern Tethys only rare *Metapolygnathus* cf. *primitius* are present but no transitional forms occurred.

The base of the *M. primitius* Zone both in North America and in the Neotethys is close to the base of the *Stikinoceras kerri* Zone. It corresponds to the FAD of *M. primitius* in North America and in the Neotethys, while in the Northern Tethys it corresponds to the FAD of *E. orchardi* and, insignificantly later, the FAD *Norigondolella navicula* (Kozur, 2003).

Moix et al. (2007), refer the *M. pimitius* Zone to the lower part of the *Kerri* Zone, but assign this interval to the uppermost Carnian.

At Pizzo Mondello, *M. primitius* appears in sample FNP88A, 27m below *Gonionotites maurolicoi*, along with *Epigondolella orchardi* and *Epigondolella quadrata*.

- ***Epigondolella praetriangularis* Kozur & Moix, 2007**: this species was recently described by Moix et al. (2007) and its range straddles their *E. orchardi* Zone and *E.*

quadrata Zone. *Epigondolella praetriangularis*, which represents a transitional form from *Carnepigondolella pseudodiebeli* (Kozur) to *Epigondolella triangularis* (Budurov) (Moix et al., 2007), even if not common, may suggest the interval around the Carnian/Norian boundary. At Pizzo Mondello, stratigraphically older representatives of this species occurs, along with *Halobia radiata*, about 11 meters below *Gonionotites maurolicoi*.

- ***Metapolygnathus parvus* Kozur, 1972**: this species has been considered for long time as a juvenile stage of the *Metapolygnathus communisti* (Budurov and Sudar, 1991) probably due to the short platform and the absence of nodes on the anterior margins of the platform. But juvenile forms of metapolygnathids are characterized by a more posterior position of the pit respect to the adult forms, which is situated in or just before the middle of the platform (Kozur, 2003). Instead, in *Metapolygnathus parvus* the position of the pit is strongly shifted forwards, and this is a very peculiar feature for a *Metapolygnathus* species. Thus, *Metapolygnathus parvus* should be considered as an independent species, and a possible biomarker for the base of the Norian.

- ***Epigondolella triangularis* (Budurov, 1972)**: this species is an advanced *Epigondolella*, subdivided by Orchard (1991, b) into two subspecies (*E. triangularis triangularis* (Budurov) and *E. triangularis uniformis* Orchard). It ranges the middle-upper part of the Lacian (Early Norian). At Pizzo Mondello, this species occurs 3m below *Gonionotites maurolicoi*.

- ***Epigondolella orchardi* (Kozur, 2003)**: this species has been established by Kozur in 2003, and it is described as a primitive *Epigondolella*, the perfect transition form between *Carnepigondolella* and *Epigondolella*. In detail, *E. orchardi* is considered to be the transitional species between *Carnepigondolella pseudodiebeli* (Kozur) and *Epigondolella quadrata* Orchard (Kozur, 2003). This species is common in the lower Lacian (upper *Kerri* Zone, Early Norian) of the Northern Tethys together with *Norigondolella navicula* (Huckriede) while it is rare in the Latest Carnian, immediately below the *kerri* Zone (Kozur, 2003).

At Pizzo Mondello, *E. orchardi* appears together with *Epigondolella quadrata* Orchard, 10 meters below the finding of *Gonionotites maurolicoi*.

- ***Epigondolella quadrata* Orchard, 1991**: this species has been called for many years *Epigondolella abneptis*, since 1991, when Orchard described it as a new species and named it *Epigondolella quadrata*. It is considered to be one of the most suitable conodonts to define the base of the Norian. In 2003 Channell et al. still considered *E. quadrata* as a junior synonym of *E. abneptis*, and replaced the name *E. quadrata* Zone by the name *E. abneptis* Zone. They used this zone to indicate the base of the Norian Stage (Channell et al., 2003), placing it within the *Stikinoceras kerri* ammonoid Zone, but close to the upper boundary of this zone. The base of the *E. abneptis* Zone (= *E. quadrata* Zone) seemed to be ideal to define the Carnian/Norian boundary, because it corresponded closely to the appear-

ance of *Halobia styriaca* (Krystyn, 2002), and it was well defined by the FAD of *E. abneptis* both in the Tethys and in North America (Channel et al., 2003).

Also in Moix et al. (2007), *E. quadrata* is used to mark the base of the Norian, which begins with the FAD of this species and corresponds to the base of the *E. quadrata* Zone.

According to the new biostratigraphic data collected at Pizzo Mondello, *E. quadrata* can be considered a possible biomarker for the base of the Norian. The FAD of *E. quadrata* has been found 10 meters below *Gonionotites maurolicoi*, together with the FAD of *E. orchardi*.

- ***Epigondolella rigoi* Kozur, 2007**: this species has been recently established by Moix et al. (2007). It defines the homonymous zone (*E. rigoi* Zone, between the *E. quadrata* Zone and the *N. halstattensis* Zone- *E. triangularis* Zone), and it occurs from the Early Norian to the Alunian. The species is widespread throughout the entire Tethys (Moix et al., 2007).

The stratigraphic position of *E. rigoi* and its zone (above *E. quadrata* Zone), and its wide distribution through all the Tethys, make this conodont a suitable species as candidate to indicate the base of the Norian. At Pizzo Mondello, *E. rigoi* has been found 1.50m above *Gonionotites maurolicoi*.

- ***Metapolygnathus echinatus* (Hayashi, 1968)**: the species was regarded as an early growth stage of *M. communisti* and referred to *Carnepigondolella pseudoechinata* by Kozur (1990). Orchard (1991, a) refers *Metapolygnathus echinatus* as a very important index species of his *Metapolygnathus communisti* Zone and interpretes this species as “the end member in the lineage *M. lindae*- *M. samueli*”. Subsequently, Orchard (1991, b) reviewed *Metapolygnathus echinatus* and included it in *Metapolygnathus pseudoechinatus* (Kozur) a “short-ranging species in the Carnian-Norian boundary interval”. According to Orchard (1991, b), *M. pseudoechinatus* (= *M. echinatus*) is characterized “by a long blade up to two thirds total unit length, and a short subquadrate platform that bears small, usually sharp marginal denticles, particularly on the anterior part.”

At Pizzo Mondello section, *Metapolygnathus echinatus* is associated with *M. parvus*, *M. communisti* and abundant *Carnepigondolella pseudodiebeli*. Our specimens present a shorter blade and platform in respect to those specimens described by Orchard (1991, b). *M. echinatus* occurs 8m above *Gonionotites maurolicoi* and 7m below a Norian radiolarian assemblage (A9a). Thus this species seems to be a good proxy for the Carnian/Norian boundary in agreement with Orchard and Kozur proposals at Albuquerque (2007).

Conclusions

On the basis of the new bio-chronostratigraphic studies, the following points can be emphasized.

1) The Pizzo Mondello succession yields ammonoids.

The record is fully consistent with the faunas described by Gemmellaro (1904) and spans from the Late Carnian *Discotropites plinii* Zone to the Early Norian *Guembelites jandiaunus* Zone.

2) The succession also provides very good Halobiids. Six out of the seven identified species (*H. lenticularis*, *H. superba*, *H. austriaca*, *H. simplex*, *H. radiata*, and *H. styriaca*) occur also in North America with the same distribution. This provides a very good tool for correlations. *H. mediterranea* is documented only from the Tethyan realm. *H. radiata* spans from Late Carnian to earliest Norian, while *H. styriaca* is traditionally considered Early Norian in age.

3) The conodont studies allow to recognize two main events (Fig. 4):

- the first one is represented by the FO of *Metapolygnathus primitius*, *Epigondolella quadrata* and *E. orchardi* in FNP88A where *Halobia radiata* is also present.

- the second one is represented by the FO of *Metapolygnathus echinatus* and *M. parvus* in NA36, 8m above *Gonionotites maurolicoi* and 7m below a Norian radiolarian assemblage (A9a).

At present, we consider the second event, in accordance also with Orchard and Kozur (Albuquerque meeting, May, 2007) and Orchard (2007b), as more suitable to define the base of the Norian Stage.

4) The studies on radiolarian assemblages show that most species cross the C-N boundary, but a few species could have their FAD in the Early Norian as for example *Kahl-erosphaera kemerensis adentata* Tekin, *Podobursa akayi* Tekin, *Senella triassica* Tekin, or *Monocapnuhosphaera inflata* Tekin. We do hope to have many more data when all the new samples will be processed and studied.

In summary, Pizzo Mondello section not only provides a very good magnetostratigraphic and chemostratigraphic records as well described in literature (Bellanca et al., 1995; Muttoni et al. 2001; 2004), but also the best integrated bio-chronostratigraphic record across the Carnian/Norian boundary of the Tethyan realm. Further investigations are necessary to better calibrate the conodont events with ammonoids, halobiids and radiolarians. A high resolution sampling for all the fossil groups of the intervals PM19 to PM22 and PM26 to PM33 of the section is scheduled for spring 2008. New paleomagnetic and chemostratigraphic high resolution samplings will also be done, in order to increase the calibration of the conodont events with the magnetostratigraphic scale and stable isotope curves and to select possible proxys (PM4n boundary $\delta^{13}C$ shift).

The final goal is the presentation of the GSSP proposal for the Norian Stage at Pizzo Mondello.

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Plate 1.

Main lithofacies of the Pizzo Mondello section. C1: thin, plane-bedded layers of limestone and siliceous limestones of facies C in outcrop, m 78 ca. C2: concentration of densely packed thin-shelled bivalves (*Halobia* sp.) of facies C in thin section. Sample FNP 151 (m 80). C3: abundant calcispheres in sample FNP 145 (m 74), facies C, as seen at SEM. B1: dm-scale nodular beds of facies B, outcrop exposure, m 47 ca. B2: wackestone with abundant radiolarian moulds and thin-shelled bivalves, sample 110 (m 51), facies B, thin section. B3: calcispheres are abundant also in facies B; note radiolarian mould filled with large calcite crystals to the right, diameter 50 μ m ca. (sample FNP 126, m 62). A1: dm-scale beds with plane to undulate joints and brown chert nodules, outcrop exposure, m 15 ca. A2: wackestone with radiolarian moulds and thin-shelled bivalves, sample FNP 11 (m 29), facies A. Facies A and B are indistinguishable in thin section. A3: calcispheres and fine calcite crystals, sample FNP 11 (m 29), facies A. Calcispheres are usually rarer in facies A. Samples observed at the SEM were etched with 10% HCl for 5 to 10 seconds to highlight crystal boundaries, and coated with graphite.

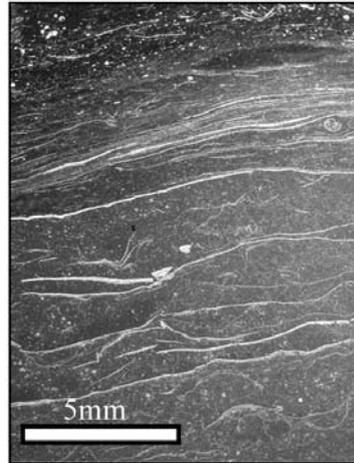
OUTCROPS

THIN-SECTIONS

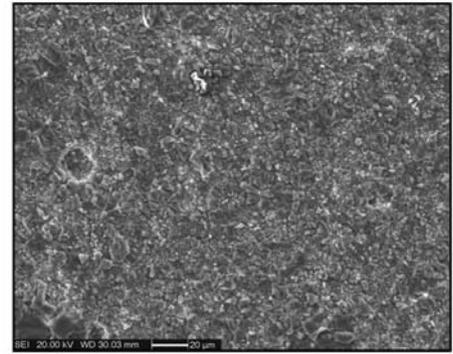
SEM PICTURES



C1



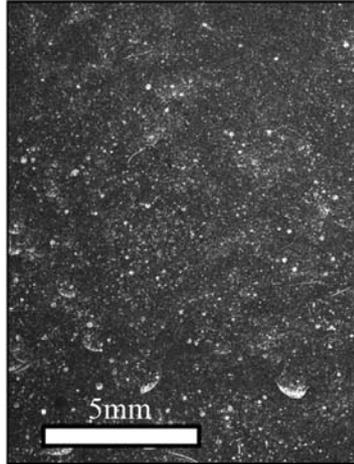
C2



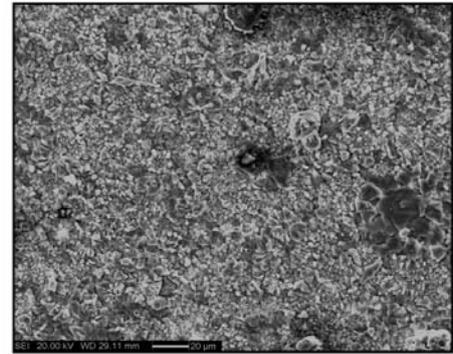
C3



B1



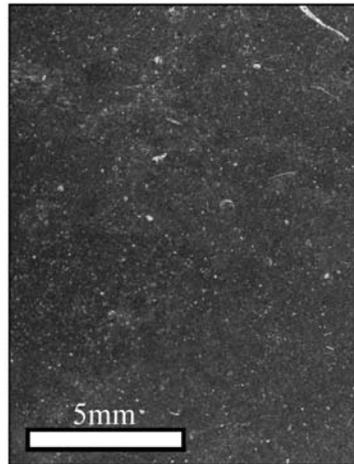
B2



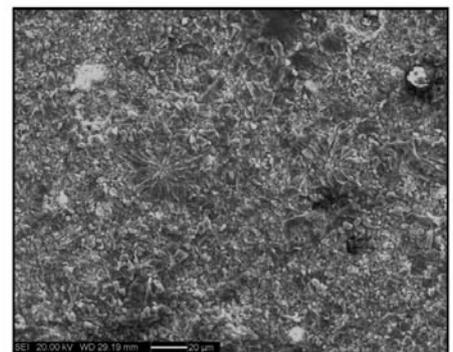
B3



A1



A2



A3

Plate 2

1: *Halobia lenticularis* Gemmellaro; FNP67/68.

2: *Halobia radiata* Gemmellaro; FNP95.

3: *Halobia styriaca* Mojsisovics; NA45.

4: *Halobia mediterranea* Gemmellaro; FNP170.2.

5: *Discotropites plinii* (Mojsisovics), lateral view; PMAM17.

6 a-b: *Gonionotites maurolico* Gemmellaro, a) oral view, b) lateral view; PMAM7.

7: *Dimorphites* sp., specimen from debris (FNPdet2), lateral view.

Bar scale always 1 cm. All specimens whitened with Ammonium Chloride, except for fig. 5.

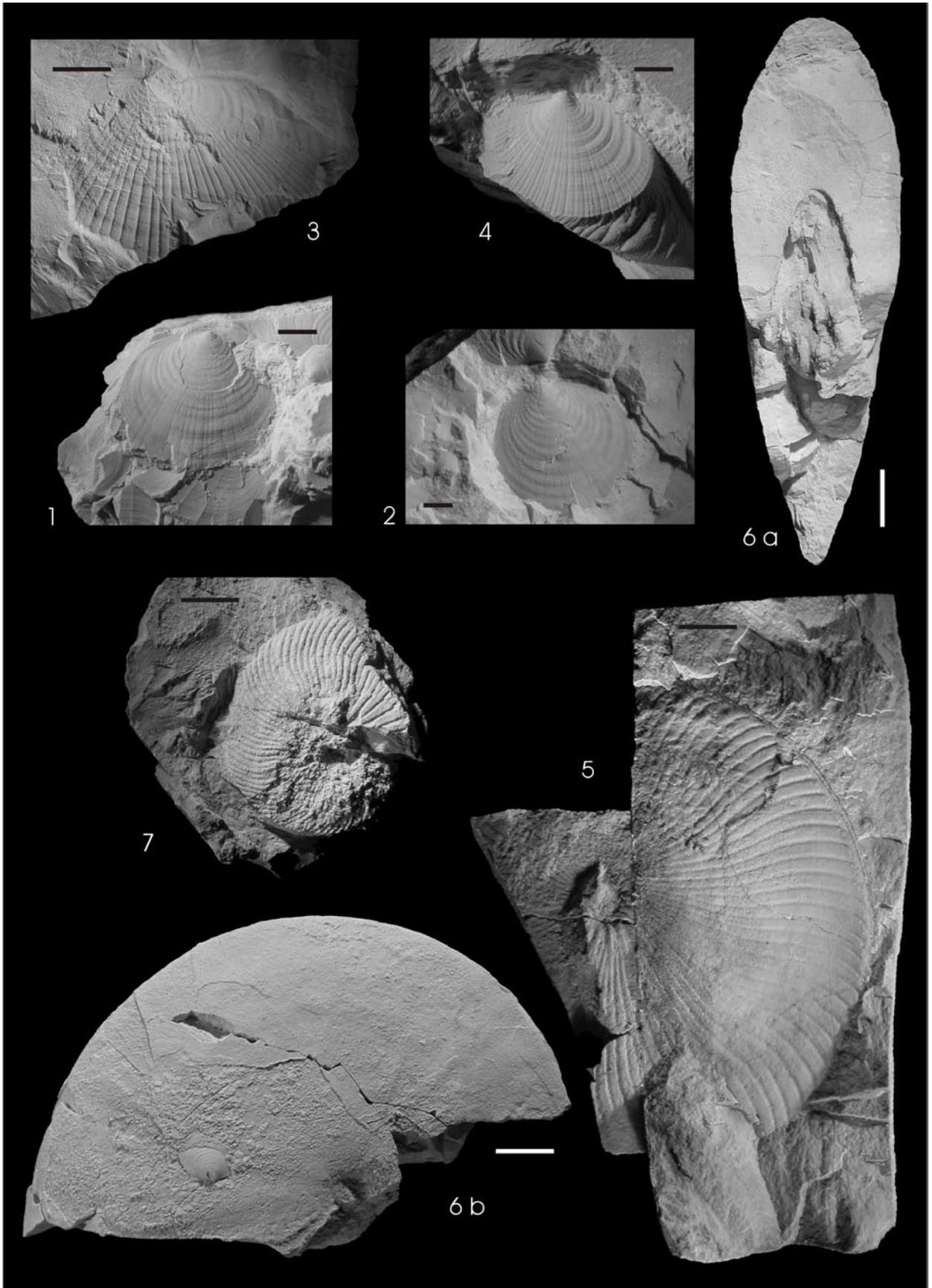


Plate 3

1a-b: *Norigondolella* sp., NA16.

2a-b: *Metapolygnathus oertlii* (Kozur), NA16.

3a-b: *Metapolygnathus communisti* B Krystyn, NA22.

4a-b: *Carnepigondolella pseudodiebeli* (Kozur), NA22.

5a-b: *Carnepigondolella samueli* (Orchard), PM19.

6a-b: *Carnepigondolella zoeae* (Orchard), PM19.

7a-b: *Epigondolella orchardi* (Kozur), juvenile specimen, FNP88A.

8a-b: *Epigondolella quadrata* Orchard, FNP88A.

9a-b: *Epigondolella quadrata* Orchard, juvenile specimen, NA30.

10a-b: *Metapolygnathus primitius* (Mosher), NA34.

11a-b: *Epigondolella orchardi* (Kozur), NA33.

12a-b: *Epigondolella rigoi* Kozur, NA33.

a= upper view, b= lateral view, c= lower view.

All the bars are 200 μ m.

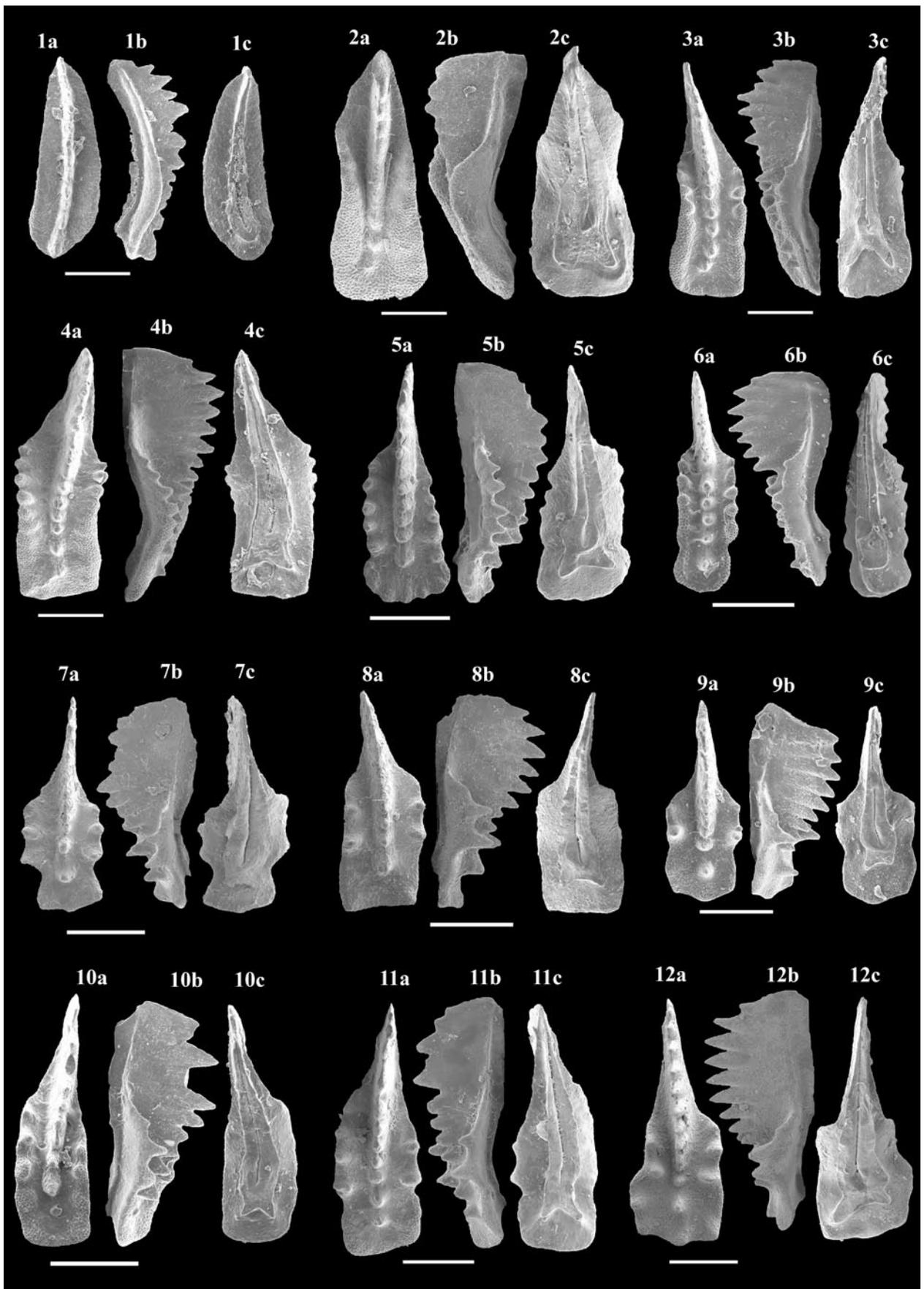


Plate 4

- 1a-b: *Metapolygnathus echinatus* (Hayashi), NA 33.
2a-b: *Metapolygnathus parvus* (Kozur), NA36.
3a-b: *Metapolygnathus parvus* (Kozur), NA 37.
4a-b: *Metapolygnathus echinatus* (Hayashi), NA38.
5a-b: *Epigondolella praetriangularis* (Kozur & Moix), NA37,
6a-b: *Epigondolella rigoi* Kozur, PM28,
7a-b: *Metapolygnathus communisti* Hayashi, PM29.
8a-b: *Epigondolella triangularis* (Budurov), NA42.
9a-b: *Epigondolella triangularis* (Budurov), NA42.
10a-b: *Epigondolella triangularis* (Budurov), NA68.
a= upper view, b= lateral view, c= lower view.
All the bars are 200 µm.

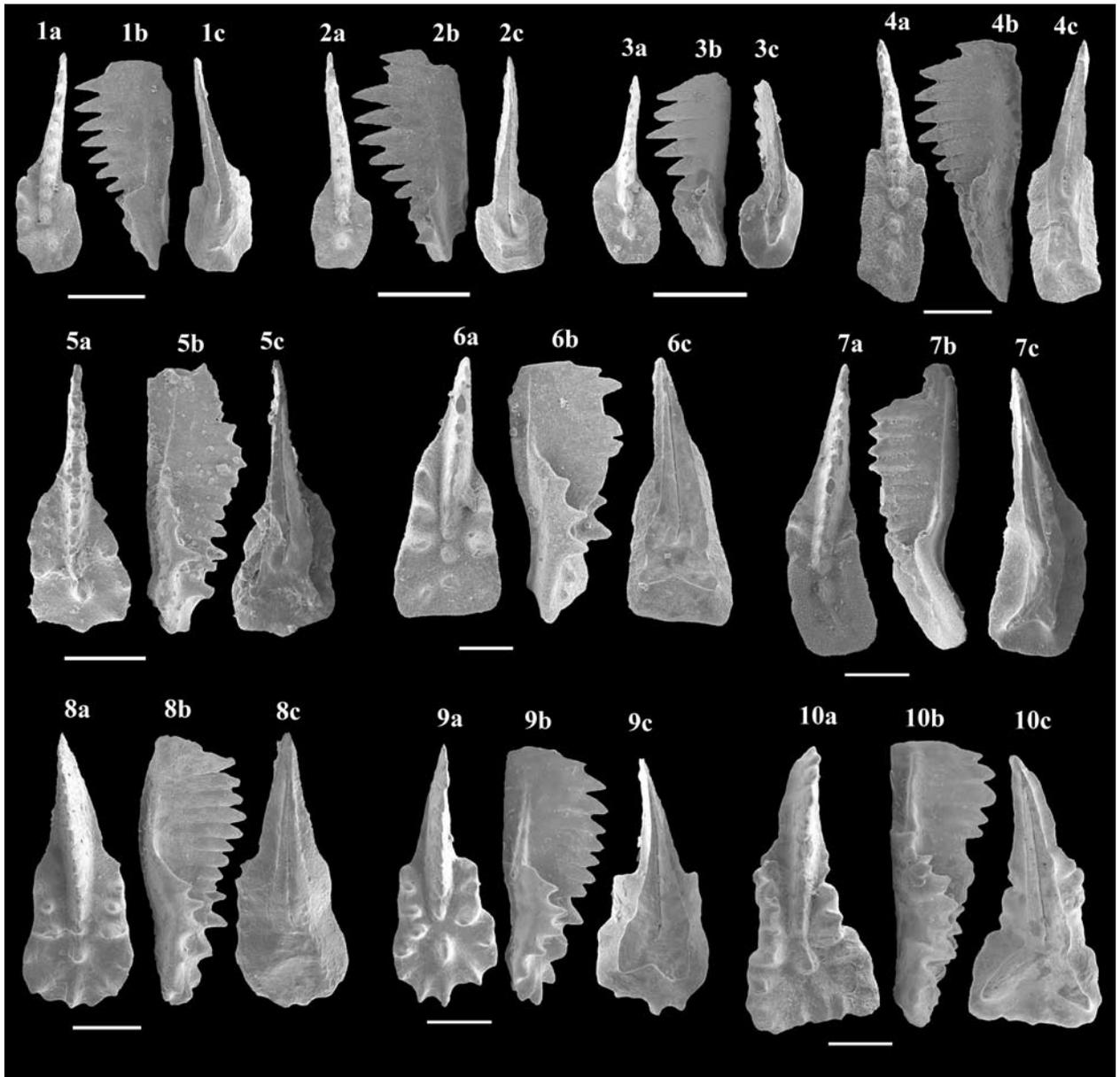


Plate 5

All scale bars equal 100 μ m. Scale A applies to 1-5 and 9-16. Scale B applies to 6 and 7.

Late Carnian:

- 1: *Capnuchosphaera* sp. indet., A7.
- 2: *Triassocampe baldii* Kozur Group, A38.
- 3: ? *Pachus* sp. indet., A7.
- 4: *Xiphoteccaella longa* Kozur & Mock, A6.
- 5: *Paronaella* (?) sp., A38.
- 6: *Capnuchosphaera* sp. aff. *C. crassa* Yeh, A38.
- 7: ? *Weverella* sp. A, A38.

Early Norian, sample A11:

- 8: *Pachus multinodosus* Tekin.
- 9: *Pachus multinodosus* Tekin.
- 10: *Corum perornatum* Blome.
- 11: *Corum* sp.
- 12: ? *Castrum* sp. indet.
- 13: *Latium mundum* Blome.

Early Norian, sample A9a:

- 14: *Dumitricasphaera* (?) sp.
- 15: *Entactinosphaera* (?) sp.1 Bragin.
- 16: *Enoplocampe* sp.

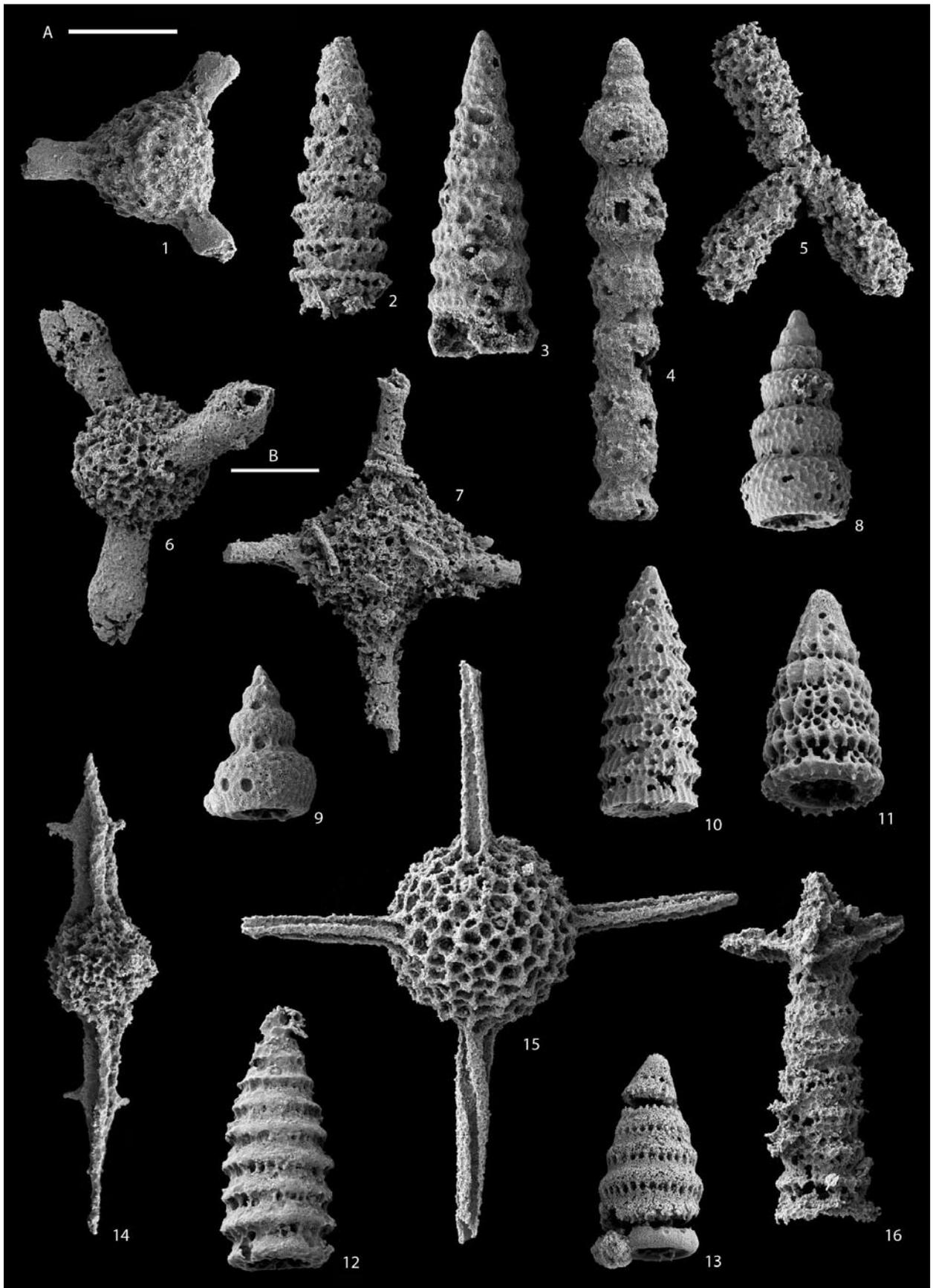


Plate 6

Sample A10a:

- 1: *Kahlerosphaera kemerensis adentata* Tekin.
- 2: *Kahlerosphaera norica* Kozur & Mock.
- 3: *Capnuchosphaera tricornis* De Wever.
- 4: *Capnuchosphaera deweveri* Kozur & Mostler.
- 5: *Capnuchosphaera theloides* De Wever.
- 6: *Vinassaspongius* (?) sp.
- 7: *Capnuchosphaera* sp.cf. *C. lea* De Wever.

Sample A9a:

- 8: *Capnuchosphaera lea* De Wever.
- 9: *Monocapnuchosphaera inflata* Tekin.
- 10: *Capnodoce* sp. cf. *C. anapetes* De Wever.
- 11: *Zhamojdasphaera rigoi* Kozur, Moix & Mostler.
- 12: *Cryptostephanidium* sp.
- 13: *Carinaheliosoma carinata* (Kozur & Mostler).
- 14: *Weverella tetrabrachiata* Kozur & Mostler.
- 15: *Spongortilispinus* sp. aff. *S. turkensis* Kozur, Moix & Mostler.
- 16: *Spongortilispinus tortilis* Kozur & Mostler.

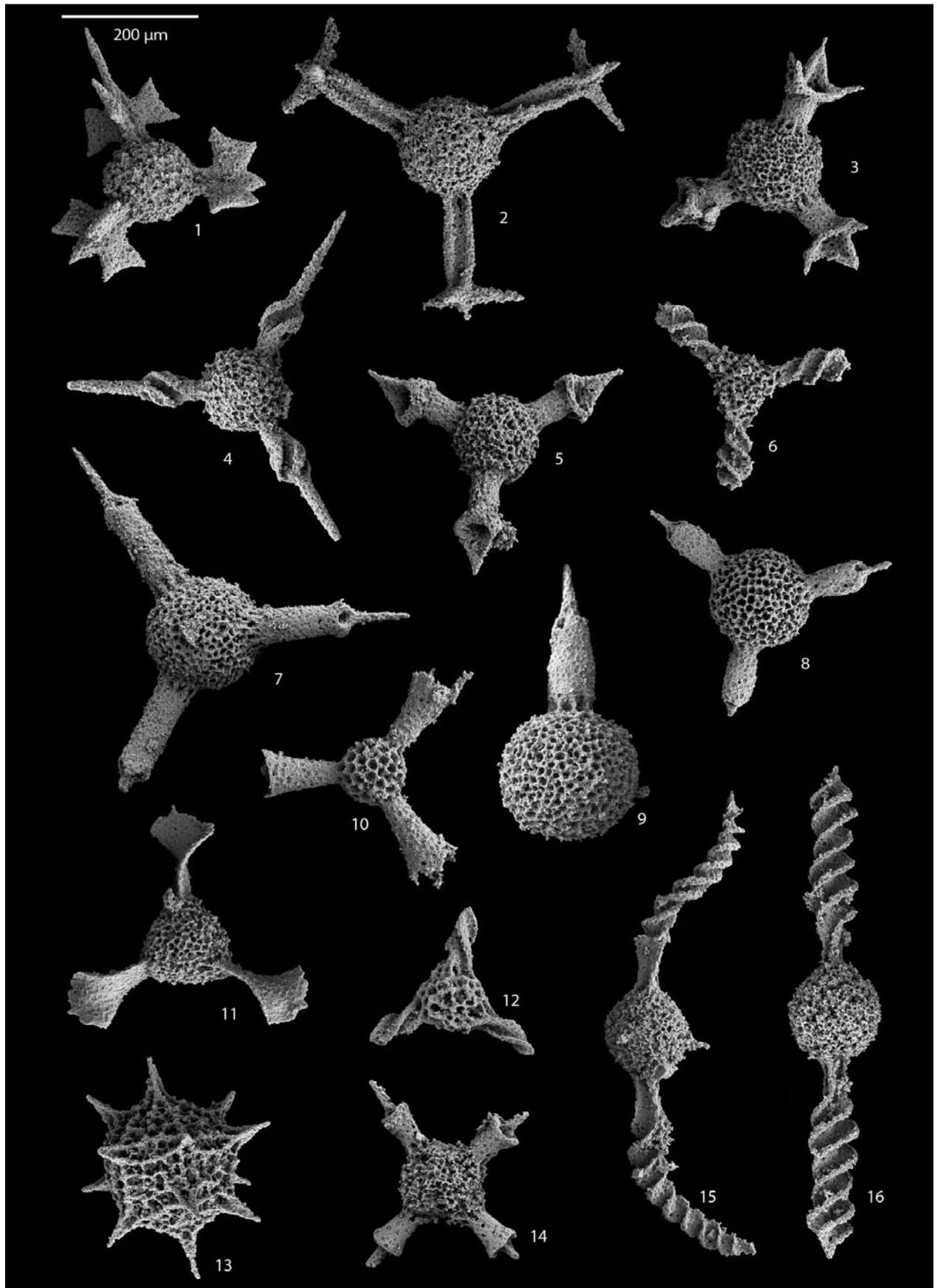
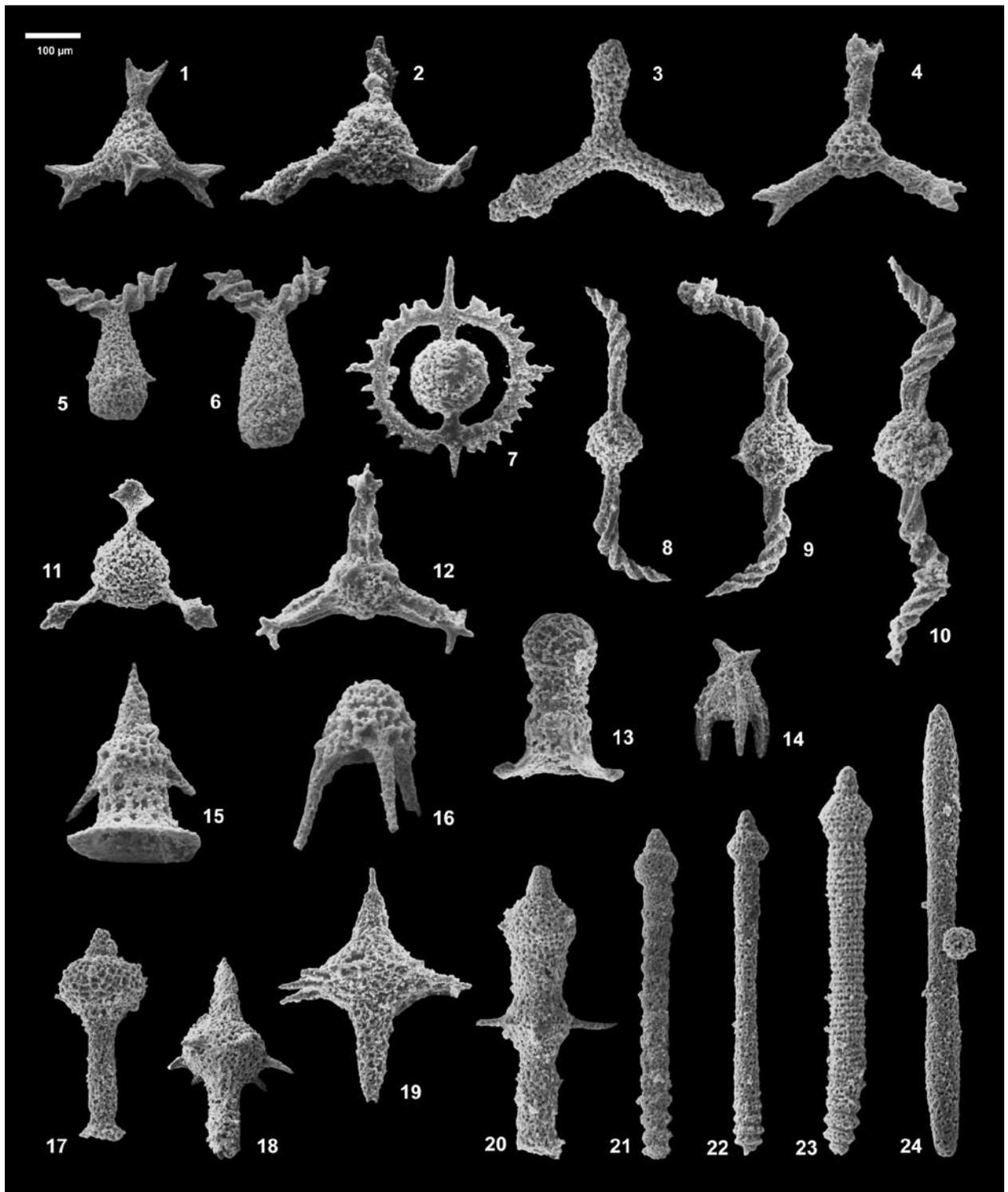


Plate 7

Sample NA 41:

- 1: *Icrioma tetrancistrum* De Wever.
- 2: *Braginastrum curvatus* Tekin.
- 3: *Paronaella* (?) sp. cf. *P. norica* Kozur & Mostler.
- 4: *Capnodoce* sp. cf. *C. longibrachium* Tekin.
- 5: *Karnospongella capricornis* Bragin.
- 6: *Karnospongella multispinosa* Kozur, Moix & Mostler.
- 7: *Acanthocircus* (?) sp. A Pessagno, 1979.
- 8: *Spongotortilispinus carnicus* (Kozur & Mostler).
- 9: *Spongotortilispinus* sp. cf. *S. aequicurvistylus* (Lahm).
- 10: *Spongotortilispinus* sp. cf. *S. turkensis* Kozur, Moix & Mostler.
- 11: *Zhamojdasphaera latispinosa* Kozur & Mostler.
- 12: *Kahlerosphaera* sp. cf. *Eptingium* sp. A De Wever.
- 13: *Bulbocyrtium reticulatum* Kozur & Mostler.
- 14: *Picapora* sp. cf. *P. robusta* Kozur & Mostler.
- 15: *Sanfilippoella* sp. B Carter, 2000.
- 16: *Spinopoulpus noricus* Kozur & Mock.
- 17: *Podobursa akayi* Tekin.
- 18: *Podobursa turriiformis* Tekin.
- 19: *Podobursa* sp. A Tekin, 1999.
- 20: *Senelella triassica* Tekin.
- 21: *Xiphothecaella longa* (Kozur & Mock).
- 22: *Xiphothecaella* sp. cf. *X. rugosa* (Bragin).
- 23: *Xiphothecaella rugosa* (Bragin).
- 24: *Mostlericyrtium sitepesiforme* Tekin.



A proposed Carnian-Norian Boundary GSSP at Black Bear Ridge, northeast British Columbia, and a new conodont framework for the boundary interval.

M.J. Orchard

Geological Survey of Canada, 625 Robson St., Vancouver, B.C., V6B 5J3, Canada.

morchard@nrcan.gc.ca

Introduction

Black Bear Ridge lies on the north shore of Williston Lake (Fig. 1), 4 km northeast of the mouth of Nabesche River (NTS Map 94 B/3; zone 10, UTM 497670E, 6215500N). A continuously exposed section begins within the upper Carnian Ludington Formation, extends through the largely Norian Pardonet Formation, and ends in the Lower Jurassic Fernie Formation. The Carnian-Norian Boundary (CNB) interval lies within the basal parts of the Pardonet Formation *sensu* Gibson and Edwards (1995), or within a transitional zone between the two formations as recognized by Zonneveld (in Orchard et al., 2001). These strata represent uninterrupted accumulation in a stable distal slope and basinal environment on the western edge of Pangaea. They preserve an abundant and continuous faunal record for the CNB interval and the section is consequently a strong contender for the Global Stratigraphic Section and Point (GSSP). A newly proposed conodont datum coincides with a profound conodont faunal turnover as well as significant changes in bivalve and ammonoid faunas and is favoured as the definitive datum for the CNB.

Previous work

Various suggestions have been made about the placement of the Carnian-Norian Boundary in terms of a defining

conodont event. The traditional CNB in North America ammonoid chronology has long been placed at the base of the Kerri Zone, a position that falls within the range of the conodont *Metapolygnathus primitius* (Mosher 1970) and close to the incoming of *Norigondolella navicula* (Huckriede 1958), i.e. at the base of the Upper *primitius* Zone of Orchard (1983). Although the latter is a good approximation of the boundary, there is no established phyletic lineage for *N. navicula*, whose appearance is apparently facies controlled. Hence, Carter and Orchard (1999) and Orchard et al. (2000) sought a correspondence between ammonoid, conodont, and radiolarian datums about the CNB on Queen Charlotte Islands and concluded a more recognizable boundary might fall at the base of the *Macrolobatus* Zone, which precedes the Kerri Zone and is more or less coincident with the base of a broadly defined *communisti* conodont Zone. However, this proposition was not widely accepted and recent conodont taxonomic work demonstrates that typical *M. communisti* is rare or absent in North America. Recently, the suggestion to define a CNB at the appearance of the conodont *Epigondolella quadrata* Orchard 1991, the zone of which post-dates the *primitius* Zone, gained currency amongst conodont workers because the event is widespread, apparently free from provincialism, and easily recognizable. However, this event does not correlate with an ammonoid zone boundary in North

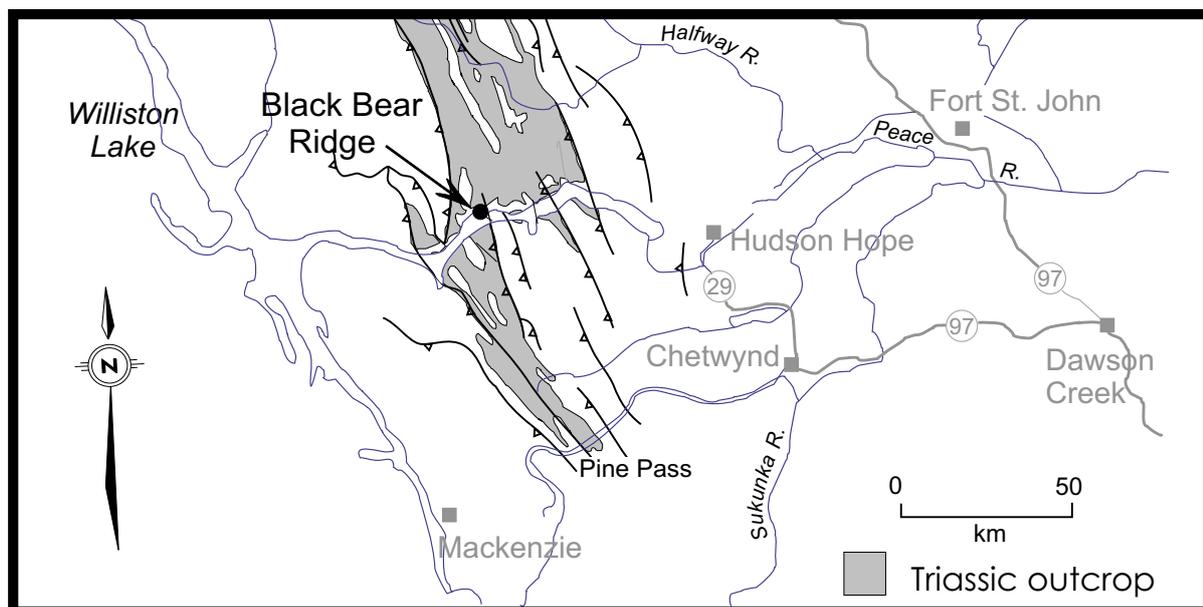


Figure 1: Locality map of northeast British Columbia showing location of Black Bear Ridge.

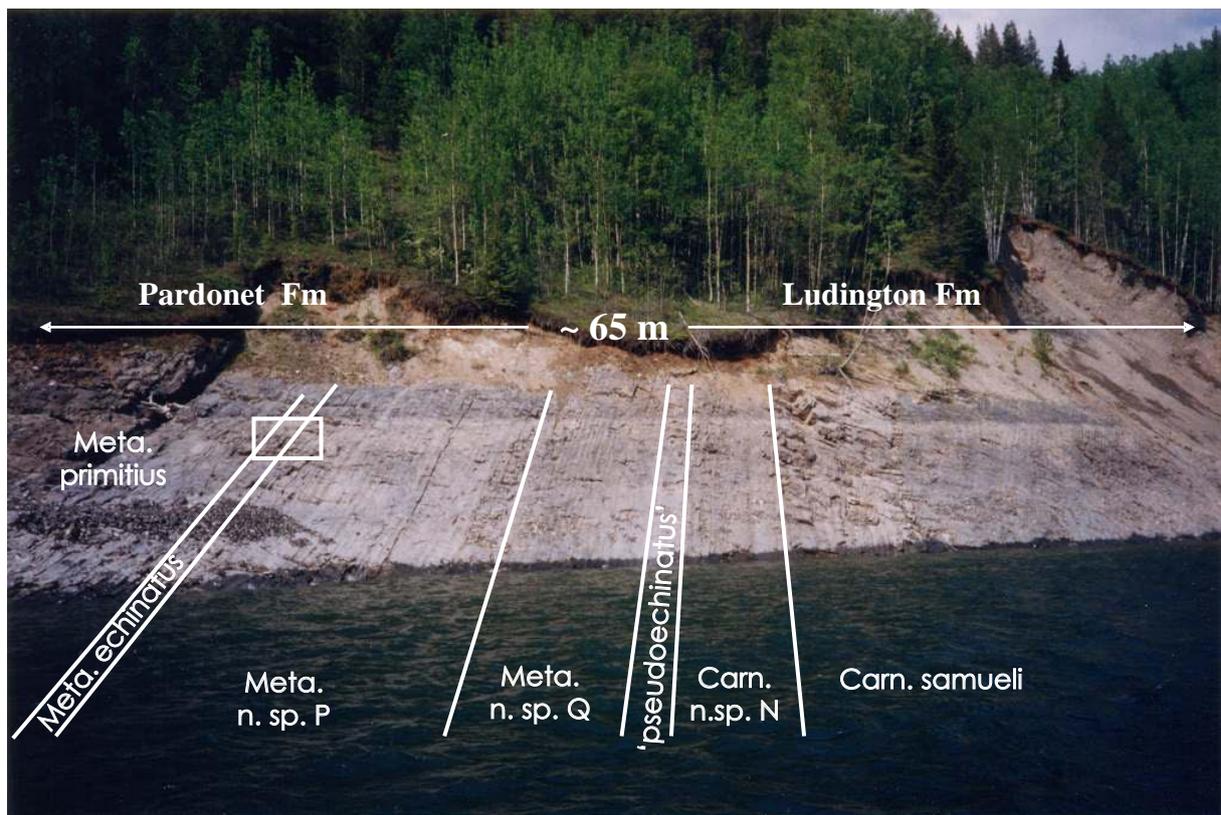


Figure 2: Photograph of the basal part of the Black Bear Ridge section showing the position of new conodont zones. Carn. = *Carniepigondolella*; Meta. = *Metapolygnathus*. Inset is area of Fig. 4.

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Detailed re-sampling and re-examination of the Black Bear Ridge succession and the nearby Pardonet Hill sections, combined with further taxonomic refinements, have revealed a more suitable conodont-based definition for the CNB that has good macrofossil control and appears to lie close to the base of the Kerri Zone and a change in the bivalve fauna. This conodont horizon is the first appearance datum (FAD) of *Metapolygnathus echinatus*

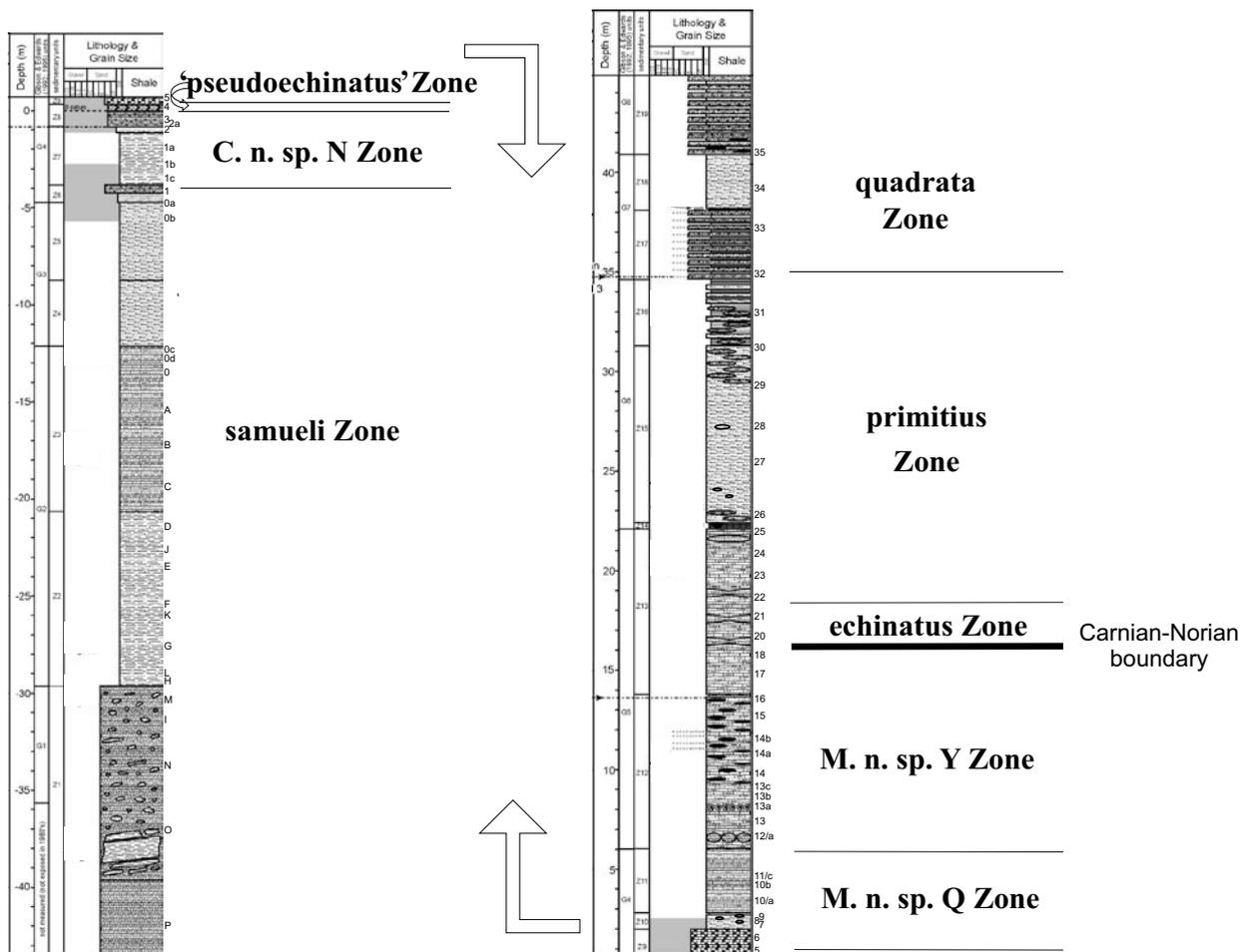


Figure 3: A lithostratigraphic section of lower Black Bear Ridge adapted from Zonneveld (2007) showing conodont sample numbers, conodont zones, and position of the proposed CNB.

(Hayashi 1968), which coincides with a dramatic decline in typical Carnian metapolygnathid stocks and their substantive replacement with *M. primitius*. Macrofossils from these boundary strata are currently being examined, and chemostratigraphy samples analysed. This summary includes the latest available conodont data on continuous, bed-by-bed sampling of the proposed CNB strata.

Conodont groups and succession

Black Bear Ridge provides an exceptional record of late Carnian through late Norian conodonts, which are well preserved (CAI~3) and occur in great abundance (commonly several hundred specimens /kg). This succession begins with diverse metapolygnathid faunas centred on *Metapolygnathus carpathicus* and *M. nodosus* accompanied by elements now referred to *Carniepigondolella*, progressive evolutionary changes within which is allowed the recognition of three faunal intervals (see Orchard, 2007b, and below). More or less concurrent with the disappearance of *Carniepigondolella*, the first members of the *M. primitius* group appear, as do a second metapolygnathid stock characterized by high anterior platform parapets. Morphological change in both these stocks permits further subdivision into two faunal intervals (see below). Higher in the succession, *M. echinatus* appears as the final development in the largely unornamented metapolygnathid

stock coincident with most species other than *M. primitius* becoming rare or disappearing. A little higher in the succession, *Norigondolella navicula* becomes abundant in some beds, and higher still *Epigondolella quadrata* replaces *M. primitius* as the dominant element (see Orchard et al., 2001). Below, the diagnostic conodont groups and their morphogenesis during the CNB interval are summarized.

***Metapolygnathus carpathicus* - *M. nodosus* group (Plate 1, figs. 9-31; Orchard, 2007b, Fig. 1: 1-3, 10-12, 19-21).**

This group encompasses perhaps the most commonly identified elements of late Carnian age. Traditionally, the group has been regarded as evolving from the ubiquitous lower Carnian species *Metapolygnathus polygnathiformis* (Budurrov & Stefanov 1965), which typically lacks platform ornament, through progressive development of anterior platform nodes, first on the anterior margins of the anterior platform, as in *M. carpathicus* (Mock 1979), and then on the upper margins, as in *M. nodosus* (Hayashi 1968). Quite apart from the difficulties surrounding the identity of *M. polygnathiformis* (see Orchard, 2007a), these criteria do not work well in the present material. Rather, more useful morphological criteria that have stratigraphic utility are the relative lengths of the platform and blade, and the

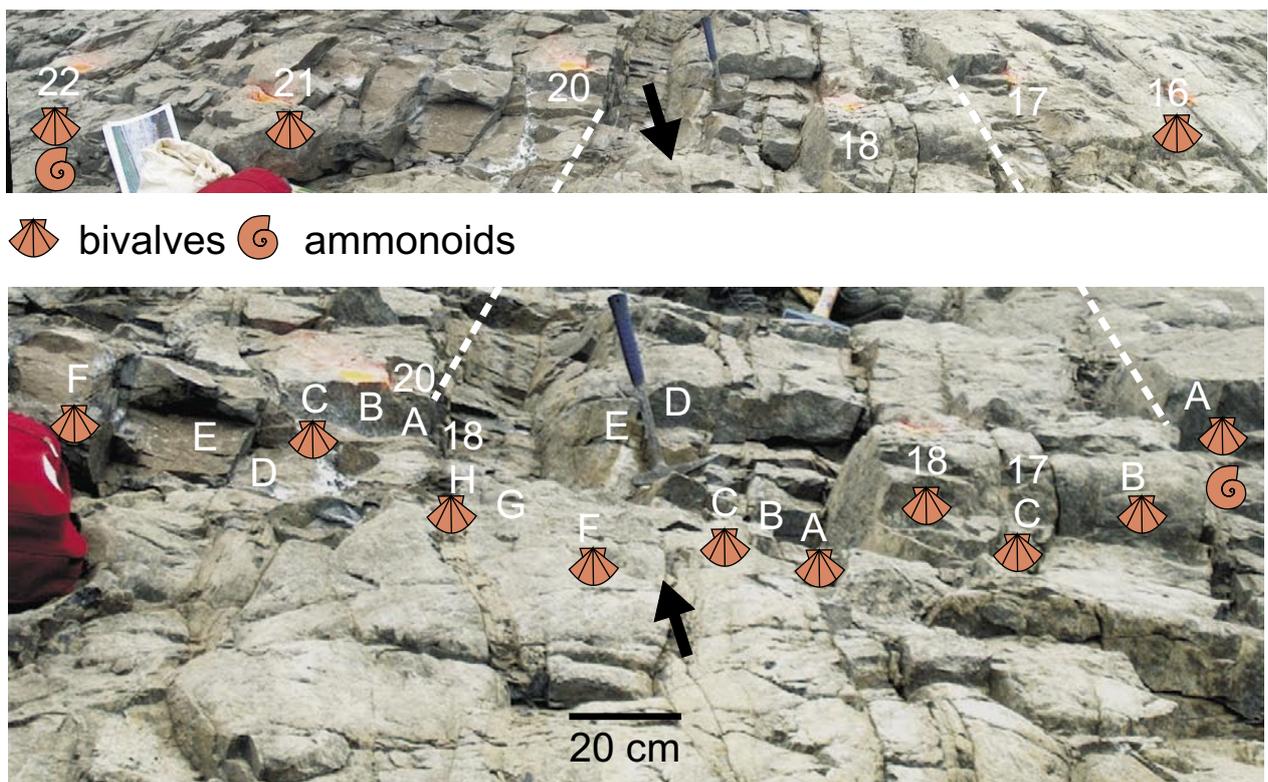


Figure 4: Two photographs showing detail of CNB strata at Black Bear Ridge and bed numbers during reconnaissance sampling (above), and subsequent bed-by-bed sampling (below). Correspondence between photos indicated by bed numbers and dashed lines. The proposed CNB GSSP lies between beds 18 and 20 in the upper photo, and between (18)E and (18)F in the lower photo, as indicated by black arrows. Macrofossil bivalve and ammonoid collections under study are shown by symbols.

relative height of the anterior platform. As can be observed in the holotype of *M. carpathicus*, the blade is relatively short and the anterior platform is not raised. In the rather poorly preserved (anteriorly incomplete?) holotype of *M. nodosus*, the anterior platform is raised and, in the present material, this is accompanied by shortening of the platform and concomitant lengthening of the (free) blade. The difference is especially noticeable in small growth stages of the two species (Plate 1).

As in other metapolygnathids, there is a wide range of platform shapes represented in populations of the present group. Subquadrate outlines are typical but elements may vary in platform length: width ratio, and the posterior platform may be constricted, laterally expanded, pointed, rounded, or deflected ('linguiform'). Some of these 'shapes' may be stratigraphically restricted, but all variations seem to be present in elements in which relative blade length, anterior platform height, and the posterior position of the pit are constants. Elongate forms appear to close to *M. noah* (Hayashi 1968).

***Carniepigondolella* spp. (Orchard, 2007b, Fig. 1: 4-6, 13-15, 22-24).**

This genus is characterized by a lineage of robustly noded or minutely denticulate species (Orchard, 1991a; Kozur, 2003). *Carniepigondolella* has a range within the upper Carnian in British Columbia and includes some elements that are homeomorphs of Norian *Epigondolella*. This has led to them being grouped in loosely defined and alleg-

edly long-ranging species such as "*E. abneptis* (Huckriede 1958)" (Orchard, 1983). On the contrary, species of this group are valuable short-ranging indices that evolved rapidly and disappeared in British Columbia prior to the appearance of *Epigondolella*.

The first species of *Carniepigondolella* is *C. zoeae* (Orchard 1991), which appeared early in the Welleri Zone (Orchard, 1991a) and is characterized by well-defined, marginal platform nodes that are generally well rounded in both upper and lateral views. Early forms of *C. zoeae* have nodes developed on a relatively flat platform and not on a raised anterior parapet, as in *M. nodosus*. The holotype, from Queen Charlotte Islands, is more advanced with higher anterior platform margins as well as a more anterior pit. At both east Pardonet Hill on Williston Lake and on Queen Charlotte Islands, *C. zoeae* stratigraphically precedes *C. samueli* (Orchard 1991), in which small but sharp denticles rather than rounded nodes are developed. Intermediate specimens occur with sharp denticles in the anterior-most platform of otherwise typical specimens of *C. zoeae*.

The lowest ~38 m of strata exposed at Black Bear Ridge contain *Carniepigondolella samueli*, which has a short free blade, ornament that typically surrounds the entire platform margin but which is often stronger in the anterior part, and a pit that is located to the posterior of platform mid-length. Contemporaneous and otherwise very similar forms in which the posterior platform bears only incipient nodes or are unornamented are assigned to *Carniepigondolella*

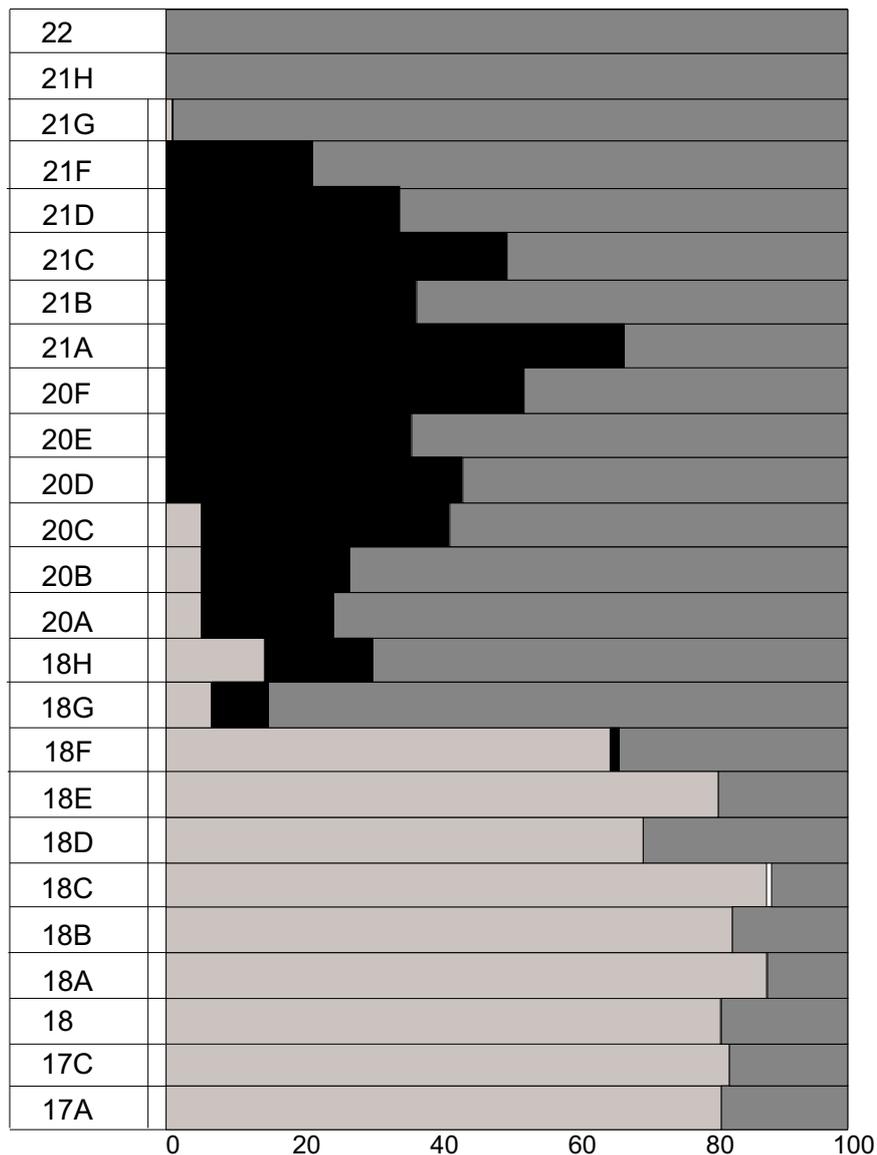


Figure 5: Graphical illustration of the conodont faunal turnover at the proposed CNB at Black Bear Ridge. Percentage of fauna on horizontal axis; sample numbers on vertical axis. Pale grey = ‘Carnian metapolygnathids’, medium grey = *primitius* group, dark grey = *M. echinatus*. The latter, the proposed index, appears in sample 18F and is immediately followed by a dramatic faunal turnover.

n. sp. E. The latter is a homeomorph of the lower Norian *Epigondolella quadrata* and may be assignable to ‘*E. orchardi*’ Kozur 2003; it differs in having a shorter blade, lower anterior platform denticles, and a pit that is located further to the posterior than its central or anterior position in the Norian species. *Carniepigondolella pseudodiebeli* (Kozur 1972) is similar to *C. samueli* and may be conspecific, but both the stratigraphic context and variability of the Austrian species are unknown.

The beds with *C. samueli* are succeeded by ~4m of strata characterized by very similar elements referred to *Carniepigondolella* n. sp. N. These differ from the former in having a relatively short platform and a more distinctive free blade. The same trend continues in conodont elements from the next ~0.5 m of overlying strata and results in elements with diminutive platforms, long free blades, and a pit that is central or anterior in position. These are tentatively referred to *C. ‘pseudoechinatus’* (Kozur 1990).

The holotype of the latter, inadequately defined species has a shorter free blade than the Black Bear specimens, and its variability is unknown. Platform shapes and ornament vary in all *Carniepigondolella* species, but the progressive morphogenesis in platform: blade ratio and the anterior migration of the pit are distinctive.

***Metapolygnathus* spp. with high parapets** (Plate 1, figs. 1-8; Plate 2, figs. 25-42).

Beginning in the *Carniepigondolella* n. sp. N Zone (see below), metapolygnathids show a progressive trend to increased anterior parapet development. This is evident in the emergence of *Metapolygnathus nodosus* wherein one or more raised anterior platform margins may be incised forming often irregular, poorly defined nodes (Orchard, 1983, Pl. 3, Fig. A). In unornamented elements assigned to *Metapolygnathus* n. sp. C (e.g. Orchard, 2006, Pl. 7, figs. 8-10), the anterior end of only

one unornamented platform margin is conspicuously raised. Later, forms in which both anterior margins are strongly elevated become abundant and this is accompanied by a migration of the pit to a position at or a little posterior to platform mid-length. In these forms, referred to *Metapolygnathus* n. sp. Q, the platform margins rise steeply and progressively from the posterior end and pass into anterior parapets. At a higher stratigraphic level, the posterior and anterior platform margins of similar unornamented elements become more differentiated and the elevated anterior parapet may be more triangular in profile, as in *Metapolygnathus* n. sp. Y, or terminate in a sharp apex and a precipitous anterior edge, as in *Metapolygnathus* n. sp. K. These last two species also have narrower, often pointed platforms and a pit that is sub-central or anterior in position.

The diversification in this Carnian conodont stock that includes elaboration of anterior parapets also results in a subgroup, presumably derived from *M. nodosus*, in which well differentiated parapets bear incipient or weak nodes and the posterior platform is somewhat reduced in width, especially in smaller growth stages. Such forms are assigned to *Metapolygnathus* n. sp. P, which also has a sub-central pit. Large elements of *M. n. sp. P* resemble *M. communisti* Hayashi 1968 and were formerly determined as such by Orchard (1991a, b; see below). *Metapolygnathus* n. sp. P dominates latest Carnian conodont faunas in British Columbia.

***Metapolygnathus primitius* group** (Plate 2, figs. 1-3, 13-15; Orchard, 2007b, Fig. 1: 7-9, 16-18, 25-27). This group embraces those metapolygnathids with well differentiated nodes on both anterior platform margins. *Carniepigondolella* species have generally smaller, sharper, and usually more widely distributed platform denticles, whereas *M. nodosus* has less developed and poorly differentiated nodes on the raised anterior platform. The *primitius* group also shows progressive migration of the pit to a central or anterior position.

The first representatives of this group are referred to *Metapolygnathus* n. sp. G (Orchard, 2007b, Fig. 1: 16-18) wherein the anterior-most denticles are discrete and those to the posterior less so. This species shows much stronger node formation than is typical of the *M. nodosus* group, from which they also differ in having a more anteriorly located pit (i.e. a little posterior to the platform mid-length).

More or less concurrent with the appearance of *Metapolygnathus* n. sp. G, uncommon slender elements appear with relatively narrow posterior platforms and smaller and more numerous anterior platform nodes similar to those of some *Carniepigondolella* species. These elements quickly lead to *Metapolygnathus* n. sp. I, a species in which the platform is largely confined to the middle of the element, the posterior part being a narrow flange bordering a high carina which extends close to the posterior end of the element; the pit is central or anterior in position. Such forms were assigned to the new genus *Orchardella* by Kozur

(2003) and regarded as an ancestor of the middle Norian *Epigondolella multidentata* Mosher 1970, which has a similar high carina. Stratigraphic linkage to the middle Norian species is weak and the two species are currently regarded as homeomorphs.

Rare subquadrate elements with discrete platform denticles resembling *M. primitius* also appear at about the same time as *M. n. sp. I*. The oldest elements have a pit that lies a little posterior of the platform mid-length but more common specimens from stratigraphically higher beds have a pit that is centrally located or anterior of that position, as in the holotype (Orchard, 1991b, Pl. 1, figs. 13-15). Platform shape variation in *M. primitius* includes uncommon rounded and pointed forms as well as those with relatively long and narrow platforms. The latter resemble *Metapolygnathus* n. sp. I but the posterior carina is lower and a posterior platform brim is present. Other variants of the *M. primitius* population illustrated as line diagrams by Orchard (1983, Fig. 2) were regarded by Kozur (2003, p. 70) as including examples of *Carniepigondolella*, but this is not the case.

***Metapolygnathus echinatus* (Plate 2, figs. 7-12, 19-24).**

The trend toward platform reduction appears to be a common feature of CNB conodont taxa, as discussed under both the *carpathicus* - *nodosus* group and *Carniepigondolella* spp. The same trend within *Metapolygnathus* n. sp. P is thought to lead to *M. echinatus*. This species has been regarded as a small growth stage and hence junior synonyms of *M. communisti*, but the rarity or absence of the latter species in northeast B.C. signals that the two are in fact distinct taxa. The published type material of *M. echinatus* are difficult to evaluate, but the essential feature of the present specimens are a reduced, sometimes vestigial platform that is about one-third total element length, and a pit that lies close to the junction of the platform and blade.

In some *M. echinatus*-bearing collections, there are small elements that completely lack a platform. These appear to be the ultimate expression of platform reduction in this lineage, comparable to that seen in the development of latest Triassic *Parvigondolella* from *Epigondolella*. The basal Norian elements are assigned to *Metapolygnathus* n. sp. R and are reminiscent of juvenile *Norigondolella navicula*, which led to the earlier suggestion that a metapolygnathid stock gave rise to *Norigondolella* (Orchard, 1991a). Differences in the arching of the elements and the position of the pit could be reconciled if the entire posterior portion in *M. n. sp. R*, representing the vestigial platform, was lost.

***Metapolygnathus communisti* group**

This species, which is characterized by a pit that lies well in front of the mid platform, is very common in Tethyan faunas but is rare or absent in those from North America. It has been recorded from Canada by Orchard (1991a) and Carter and Orchard (1999), and used to identify a latest Carnian *communisti* Zone. However, these elements are now referred to other metapolygnathids, e.g. *M. n. sp.*

P and *M. echinatus*. The North American elements differ from *M. communisti* in that they have raised anterior platform margins or parapets, unlike the even margins of latter species, and their pit is located less anteriorly. *M. parvus* (Kozur 1972) has a reduced platform compared with *M. communisti*, but the relative position of the pit is similar. This former may be derived from *M. communisti* or it may be an early growth stage of the same species. Typical specimens appear to be absent from the Canadian succession.

***Norigondolella* spp.** (Plate 2, figs. 16-18)

Norigondolella appears first around the CNB, being represented by *N. navicula*. In British Columbia, this species appears in great abundance within the range of *Metapolygnathus primitius*, often with Kerri Zone ammonoids, and has been used to subdivide the *primitius* Zone, with that upper part containing *N. navicula* being indicative of the Norian (Orchard, 1983). However, the early Norian 'surge' of neogondolellinids is thought to reflect environmental change and the lack of a clear ancestor (although see *M. n. sp. R* above) makes use of *Norigondolella* as the definitive taxon for boundary definition unsatisfactory. There is no established phyletic record bridging the gap between the lower Carnian *Neogondolella liardensis* Orchard 2007a and the Norian species, which is assigned to a separate genus on multielement grounds (Orchard, 2005).

***Epigondolella* spp.** (Orchard, 1991b)

The first species of this genus is here regarded as the lower Norian *E. quadrata*, which the author believes originated in the late Kerri Zone from the *M. primitius* group through significant change in platform length: width ratios, the growth of large and sharp anterior denticles, and change in platform microreticulation (Orchard, 1983, 1991a). These contrast with the smaller and often round-topped nodes of *M. primitius*. It has been suggested by Kozur (2003) that *E. quadrata* evolved from *C. pseudodiebeli* via *E. orchardi* but there is no evidence for this in North American successions.

Carniepigondolella species generally have much smaller and lower platform denticles compared with *Epigondolella*, as well as a more posteriorly located pit.

Conodont Zones

A brief outline of the new conodont zones recognized at Black Bear Ridge is given here and shown in figures 2 and 3. These zones will be more fully described in a future paper along with the new taxonomy.

***Carniepigondolella samueli* Zone**

This zone is characterized by the name-bearer plus *Carniepigondolella zoeae* and *C. n. sp. E*. Among the metapolygnathids, *M. carpathicus* is usually the most common element, along with uncommon *M. reversus* (Mosher 1973) and several distinctive morphotypes with differing platform shapes; *M. aff. communisti* is very rare. This base of this zone is not seen, but it is a minimum of 38 m thick

at Black Bear Ridge.

***Carniepigondolella n. sp. N* Zone**

This zone, which is ~4 m thick at Black Bear Ridge, is marked by both the appearance of the name-giver and several distinctive *Carniepigondolella* variations that differ in platform shape and ornament. Innovative change within *Metapolygnathus* results in the appearance of specimens with raised and nodose platform margins, as in *M. nodosus*, and forms with one raised anterior platform 'parapet', as *M. n. sp. C*. An immigrant stock seems to be represented by the high bladed *Paragondolella?* n. sp. A. Forms close to the holotype of *M. noah* appear in this zone, as do rare specimens of *M. aff. communisti*.

***Carniepigondolella 'pseudoechinatus'* Zone**

This is a thin range-zone that encompasses ~0.5 m of strata at Black Bear Ridge. In addition to *C. 'pseudoechinatus'* (Kozur 1990), it contains many of the species seen in the underlying zone. Many of those species, including all those belonging to *Carniepigondolella*, disappear at the top of this zone, which marks a major faunal turnover. Within the zone, the first representatives of the *primitius* group appear: *Metapolygnathus n. sp. G* and precursors to *M. n. sp. I*. Immediately above the disappearance of *Carniepigondolella*, *M. n. sp. Q* with high parapets appears.

***Metapolygnathus n. sp. Q* Zone**

The base of this ~6m zone is defined by the appearance of the name-giver, which dominates the faunas along with *M. n. sp. G*. Elements close to *M. n. sp. I* and *M. n. sp. P* are rare; these have a more posteriorly positioned pit and a shorter posterior platform than typical specimens of these species, which appear in the next higher zone.

***Metapolygnathus n. sp. P* Zone**

This zone, which is ~10 m thick, is characterized by elements with a relatively elongate and narrow posterior platform, high parapets, and sub-central pits. Distinctive elements of *M. n. sp. I* are more common. *M. n. sp. P* is typical of the zone and its appearance defines the base. *Metapolygnathus n. sp. Y* and, later, *M. n. sp., K* also occur. Examples of *M. primitius* are uncommon but do first occur in this zone. Rare specimens assigned to ?*M. parvus* and possibly *M. stephanae* Orchard 1991 also occur.

***Metapolygnathus echinatus* Zone**

This thin range-zone is ~2.5 m at Black Bear Ridge and about 0.5 m thick at east Pardonet Hill. In both sections, the appearance of this species coincides with a dramatic decrease in typical Carnian conodont elements and the rise to dominance of *Metapolygnathus primitius* (Figs. 4, 5). *M. n. sp. R* and other species are rare. In Orchard et al. (2001, Fig. 2), the base of this zone occurs in the interval between samples 99CM2 with *Halobia ornatissima* and 99CM3 with *Halobia beyrichi*. At both east Pardonet Hill and Juvavites Cove (see Tozer, 1994), large faunas of Kerri Zone ammonoids are known to occur immediately above.

New collections from each locality are under study.

***Metapolygnathus primitius* Zone**

This zone, ~18 m thick (top not shown in Fig. 2) and defined at its base by the disappearance of *M. echinatus*, is frequently monospecific in character, being composed almost entirely of *M. primitius*. Variety in this species is quite pronounced, but all elements have relatively well differentiated anterior nodes and a pit that is either central or anterior to that position (as in the holotype).

***Epigondolella quadrata* Zone**

Defined by the appearance of the name-giver (Orchard, 1991, p. 179), this zone succeeds the *primitius* Zone and extends for ~15 m of strata (not shown in Fig. 2). It is succeeded by the *triangularis* Zone, and higher Norian zones as documented by Orchard et al. (2001).

Summary

The following conodont lineages are recognized in the late Carnian and early Norian:

1. *Carniepigondolella zoeae* s. l. - *C. samueli* - *C. n. sp. N* - *C. 'pseudoechinatus'*.
2. '*Metapolygnathus polygnathiformis*' - *M. carpathicus* - *M. nodosus*.
3. *Metapolygnathus* n. sp. G - *M. primitius* - *Epigondolella quadrata*.
4. *Metapolygnathus* n. sp. C - *M. n. sp. Q* - *M. n. sp. Y* - *M. n. sp. Z*.
5. *Metapolygnathus* n. sp. P - *M. echinatus* - *M. n. sp. R*.

These lineages involve progressive evolutionary change in relative blade: platform length (1, 2, 5), in anterior platform margin profile and ornament (3, 4), and in anterior migration of the basal pit (1, 3, 4, 5). The appearance of *M. echinatus* in lineage 5 is favoured as a definitive event for definition of the CNB (Figs. 3, 4).

Metapolygnathus echinatus is widespread in western Canada (e.g. Carter and Orchard, 1999, Pl. 1, figs. 4-7) where its appearance is closely calibrated with ammonoids, bivalves, radiolarians, and ichthyoliths. Based on older fossil collections we know that the FAD of *M. echinatus* corresponds to a position between *Halobia ornatissima* and *H. beyrichi*, and close to the base of the Kerri Zone. A synthesis of these data is being prepared as part of a full GSSP proposal.

Acknowledgements

This work was initiated with E.T. Tozer who provided invaluable guidance on the ages of ammonoid faunas from Williston Lake and thereby helped in the intercalibration of the two fossil groups. More recent fieldwork was undertaken with the help of J-P Zonneveld, C.M. McRoberts, K. Williford, and T. Beatty, all of whom are working on aspects of a full proposal for the Black Bear Ridge CNB

GSSP currently in preparation. P. Krauss and H. Taylor notably assisted in technical aspects of the study. ESS Contribution number 20070283.

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Plate 1

Conodonts from the upper Carnian of Black Bear Ridge, except those prefixed PHE, which are from Pardonet Hill east. Various growth stages are illustrated. All figures x80; scale is 200 microns.

- Figs. 1-8. *Metapolygnathus* n. sp. Q. 1, 2. GSC 131239; 3-5. GSC 131240; 6-8. GSC 131241; all from bed 5.
- Figs. 9-19. *Metapolygnathus nodosus* (Hayashi). 9, 10. Holotype, re-illustrated from Hayashi, 1968; 11-13. GSC 131242, from bed 7; 14-16. GSC 131243, from bed 8; 17-19. GSC 131244, from bed 8.
- Figs. 20-31. *Metapolygnathus carpathicus* (Mock). 20, 21. GSC 131245, from bed 0; 22, 23. GSC 131246, from bed PHE2-38; 24, 25. GSC 131247, from bed 1A; 26-28. Holotype, re-illustrated from Mock, 1979; 29-30. GSC 131248, from bed 0.

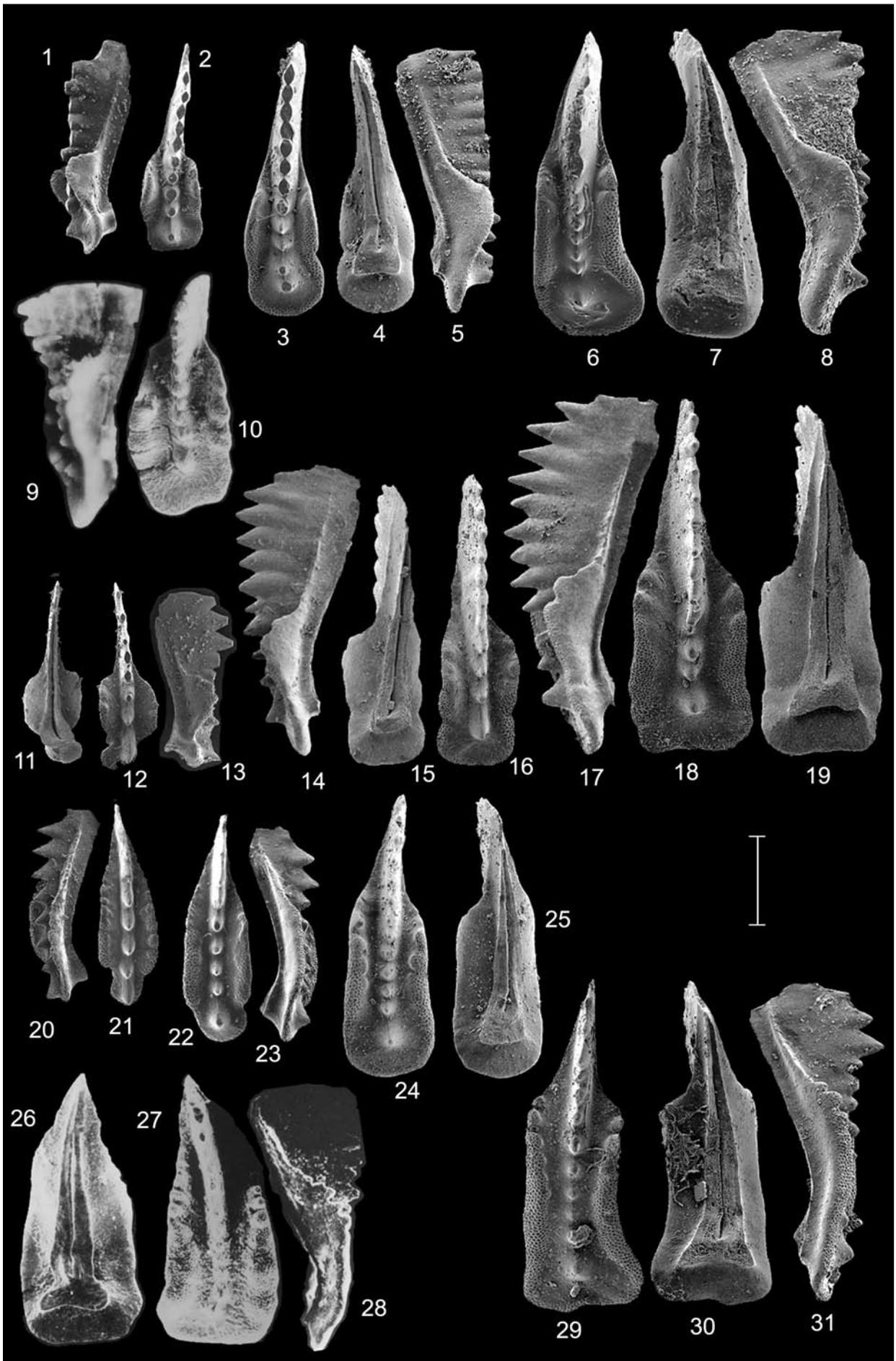
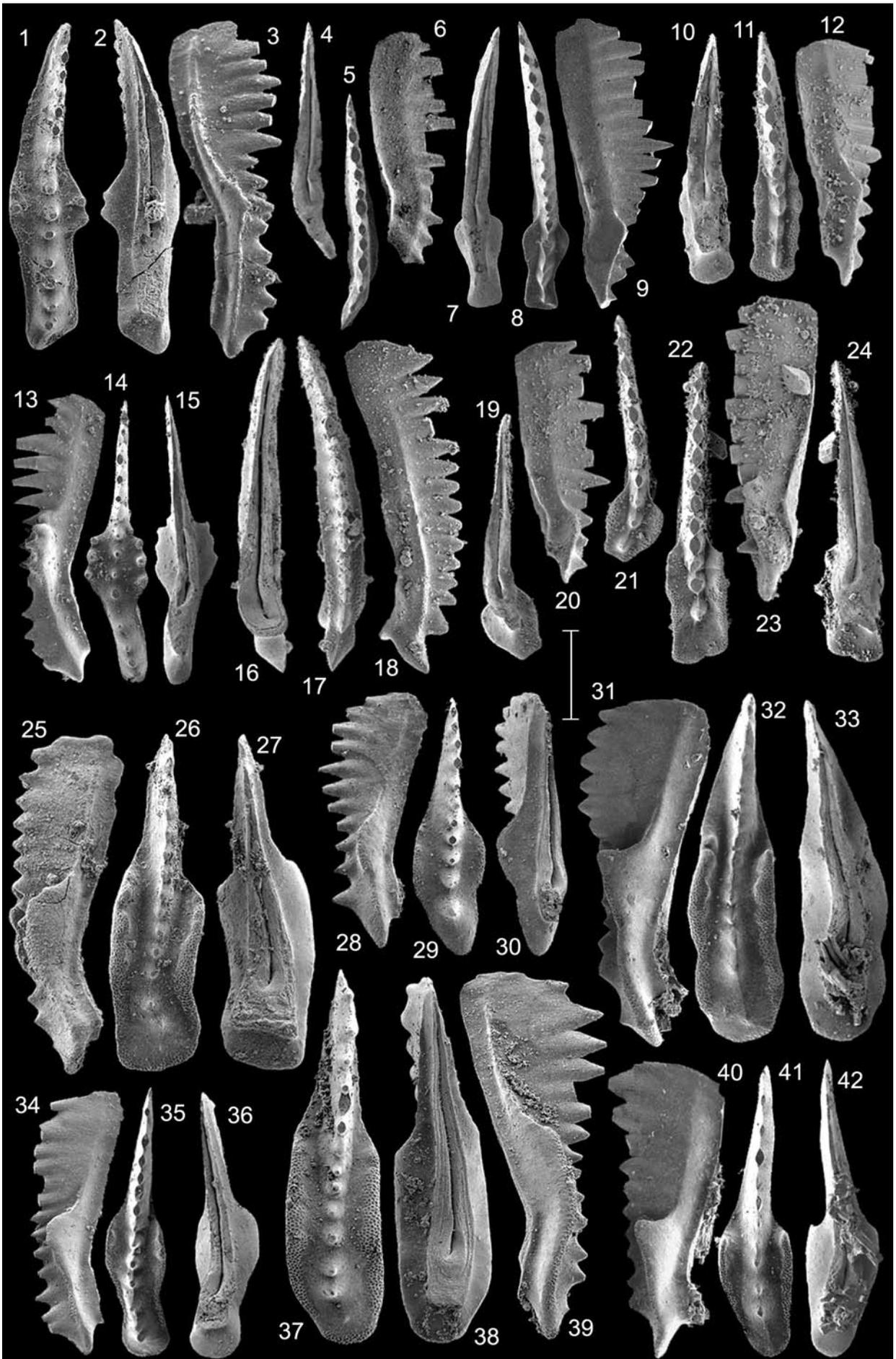


Plate 2

Conodonts from the CNB beds of Black Bear Ridge, except those prefixed PHE, which are from east Pardonet Hill. Various growth stages are illustrated. All figures x80; scale is 200 microns.

- Figs. 1-3, 13-15. *Metapolygnathus* n. sp. I. 1-3. GSC 131165, from bed 14b; 13-15. GSC 131166, from bed 15.
Fig. 4-6. *Metapolygnathus* n. sp. R. 4-6. GSC 131167, from sample PHE-23.
Figs. 7-12, 19-24. *Metapolygnathus echinatus* (Hayashi 1968). 7-9. GSC 131168, from sample PHE-23; 10-12. GSC 131169, from bed 20; 19-21. GSC 131170, from bed 20; 22-24. GSC 131171, from bed 20.
Figs. 16-18. *Norigondolella navicula* (Huckriede 1958). GSC 131172, from bed 26.
Figs. 25-27, 34-36. *Metapolygnathus* n. sp. P. 25-27. GSC 131173, from bed 15; 34-36. GSC 131174, from bed 13A.
Figs. 28-30, 37-39. *Metapolygnathus* n. sp. Y. 28-30. GSC 131175, from bed 16; 37-39. GSC 131176, from bed 16.
Figs. 31-33, 40-42. *Metapolygnathus* n. sp. K. 31-33. GSC 131177, from bed 14A; 40-42. GSC 131178, from bed 15.



The halobiid bivalve succession across a potential Carnian/Norian GSSP at Black Bear Ridge, Williston Lake, northeast British Columbia, Canada

Christopher A. McRoberts

Department of Geology
State University of New York at Cortland
Cortland, New York, 13901 USA

Introduction

The Black Bear Ridge section along the north shore of Williston Lake in northeastern British Columbia represents a continuous exposure from the upper Carnian through upper Norian. This section has been the subject of several biochronologic, stratigraphic sedimentologic, and geochemical studies including a preliminary note on its potential as a Carnian/Norian GSSP (Orchard et al., 2001b). Newly collected biochronologic data along with a reinterpretation of existing fossil data permit a more refined and precise fossil succession across this potential Carnian/Norian GSSP. This short note summarizes the stratigraphic and taxonomic occurrence of halobiid bivalves across this interval. The conodont succession at Black Bear Ridge is documented separately (Orchard, this volume).

The bivalve data herein are derived from field investigations by the author in 1999 and 2001 and supplemented by additional collections made by Orchard and others in 2007. Inasmuch as these specimens are part of a larger systematic work on the halobiid bivalves from the greater Peace River Foothills of northeastern British Columbia currently underway by the author, the taxonomic names are here left in open nomenclature. These somewhat informal names are only meant to convey similarities to closely related taxa which have some biochronologic and correlation value outside of the Western Canada Sedimentary Basin.

Halobiid succession at Black Bear Ridge

Figure 1 shows stratigraphic distribution of halobiid bivalves across a potential Carnian/Norian boundary interval at Black Bear Ridge. In the lower part of the Black Bear Ridge section (Upper Carnian-Lower Norian), five distinct halobiid taxa are recognized and discussed below.

The lower samples (Beds 8 through 18-C) contain *Halobia* cf. *H. septentrionalis* SMITH. This taxon is characterized by its posteriorly elongated shape and exhibits a distinctively fine radial-ribbed ornament and prominent growth-stop after which the ribs become highly disrupted in their course. It is somewhat similar to *Halobia* cf. *H. radiata* GEMMELLARO also from Black Bear Ridge (see below), however *Halobia* cf. *H. septentrionalis* clearly exhibits of growth-stop, disrupted ribbing and has an elongated posterior that is characteristic of specimens Smith (1927) described from Herring Bay, southeast Alaska. It should be noted that the type locality of Smith's species also

produced the type specimens of *H. dalliana* SMITH and *H. symmetrica* SMITH which are here considered to synonyms of *H. septentrionalis* and have often been included within the specific concept of *Halobia radiata* (e.g., McRoberts, 1993). The age-significance and affinity of this form to an established species is not yet known with confidence, but its marked similarity to *Halobia radiata* raises interesting questions regarding the phylogenetic significance of the "growth-stop" ubiquitous among many halobiid species.

Several specimens spanning the Carnian/Norian are referred to *Halobia* cf. *H. radiata* GEMMELLARO. These individuals are characterized by a generally semi-circular outline, densely-packed fine radial ribs that are slightly curved towards the anterior but lack a growth-stop. At Black Bear Ridge, this species first appears in Bed 12-B and ranges up to Bed 21. Elsewhere in North America, similar forms are poorly resolved to upper Carnian (e.g., McRoberts, 1993). In the western Tethys, however, *Halobia radiata* (including its subspecies *H. radiata radiata* and *H. radiata hyatti* KITTIL) are constrained to the upper Carnian (co-occurring with the conodont *Metapolygnathus polygnathiformis*) and possibly lower Norian (see Cafiero and De Capoa Bonardi, 1980, 1982; De Capoa Bonardi, 1984; Gruber, 1976).

At Black Bear Ridge, *Halobia ornatissima* SMITH is common in the lower samples (Beds 10 and 12) and ranges to just above the Carnian/Norian boundary interval (Bed 21 and possibly as high as Bed 25). This species is recognized by its semi-circular outline, with broad and divided ribbing in early growth stages, a pronounced growth stop at around 14 mm from the beak, and strongly disrupted ribbing on the posterior and dorsal sectors of the valves in later growth stages. Although highly variable in form, *Halobia ornatissima* is no doubt related to, but differs slightly from, *Halobia superba* MOJISOVICS in having divided ribs (both secondary and tertiary) prior to the growth stop and the intensity of disrupted ribbing in later growth. Together with *H. superba*, *H. ornatissima* demonstrably occurs in Carnian strata (Welleri, Dilleri, and Macrolobatus Zones) and extends up into the Kerri Zone. Specimens from northeastern British Columbia with a similar growth-stop but with distinctively different outline and/or ribbing characteristics occur higher in the Norian (i.e., above Kerri Zone) are mostly likely attributed to other taxa (e.g., *Halobia cordillerana* SMITH, *Halobia* cf. *H. fallax* MOJISOVICS,

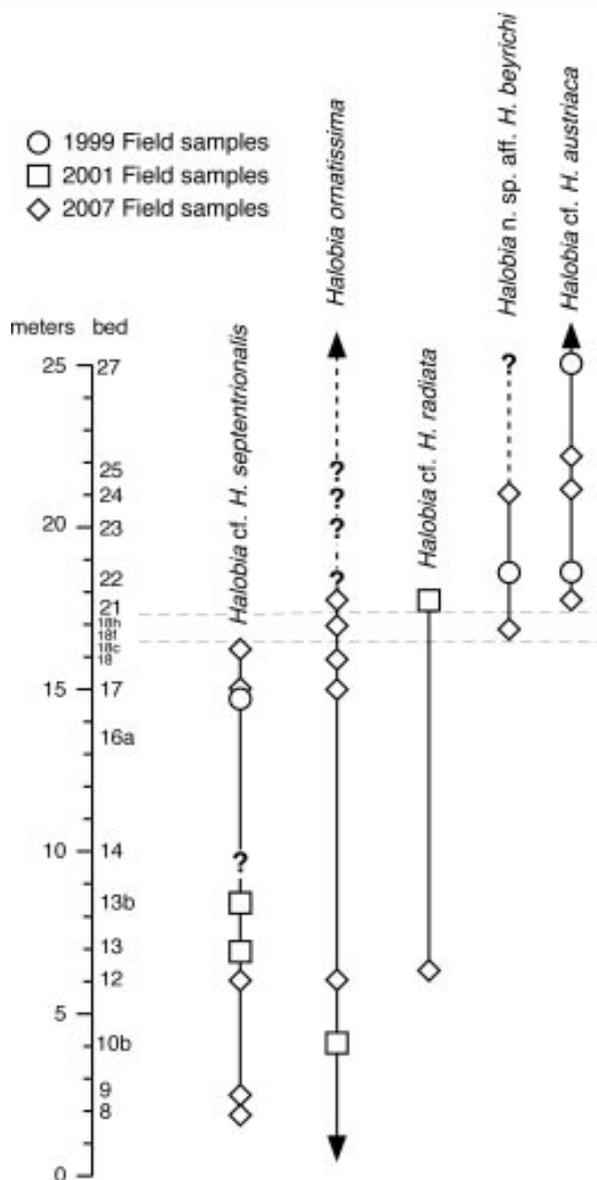


Figure 1: Stratigraphic ranges of halobiid occurrences across the Carnian/Norian interval at Black Bear Ridge. Please refer to Orchard (this volume) for lithologic log and photographs of this portion of the section.

and possibly *H brooksi* SMITH).

Specimens related to *Halobia beyrichi* (MOJSISOVICS) first occur in Bed 18-F. Although a proper evaluation of Mojsisovics' type specimen of *H. beyrichi* from near Bad Ischl Austria is not possible (it cannot be located in the Geologische Bundesanstalt, Vienna), its illustration (Mojsisovics, 1897, Pl. 1, fig. 7) along with topotype specimens provided by L. Krystyn and collected by the author show many similarities and few differences with this new form. The Black Bear Ridge specimens have a slightly more elongated posterior and exhibit finer and more densely-packed radial ribs that warrant designation of a new species. It should be noted, however, that in McRoberts (in Orchard et al., 2001b, fig. 2), younger occurrences referred to this taxon (samples CM99BBR-6 and higher) are now considered to be juveniles of another unrelated taxon. As presently understood, *Halobia n. sp. aff. H. beyrichi* at Black Bear Ridge extends with confidence to Bed 24 and possibly to Bed 27 and is likely restricted to

the early Norian Kerri Zone. This age is consistent with similar occurrences elsewhere in North America where it demonstrably co-occurs with the ammonoid *Stikinoceras kerri* including Vancouver and Fredrick Islands, British Columbia, and Kuiu Island Alaska (McRoberts, in prep) and in the western-Tethys where it is closely associated with *Halobia styriaca* (MOJSISOVICS) and the conodonts *Metapolygnathus abneptis* and *M. nodosus* (e.g., De Capoa Bonardi, 1984)

A few halobiid specimens from the Carnian/Norian interval at Black Bear Ridge are assigned to *Halobia cf. H. austriaca* MOJSISOVICS. Although many of these individuals (occurring primarily in Bed 21 through Bed 22) are rather small, a well-preserved and larger specimen from Bed 27 is approximately equilateral with broad nearly flat-topped ribs that exhibit only a very slight curvature and closely agrees in shape and ribbing characteristics with the type specimens of Mojsisovics (1874). At Black Bear Ridge, the highest occurrence of *Halobia cf. H. austriaca* is in Bed 31 with the conodont *M. primitius*, several meters below the FOD of the ammonite *Malayites* and is therefore likely restricted to the Kerri Zone (although see next section concerning ammonoids at this section). Elsewhere, and particularly in the western Tethys, *Halobia austriaca* is quite common and demonstrably ranges through the uppermost Carnian and lowermost Norian (e.g. Gruber 1975, 1976; Cafiero and De Capoa Bonardi, 1980, 1982; Campbell, 1994).

Discussion

Two potential halobiid-based datums occur in the Carnian/Norian interval at Black Bear Ridge. The lowest occurs just below Bed 18-F with the first occurrence (FOD) of *Halobia n. sp. aff. H. beyrichi* and just above (LOD) of *Halobia cf. H. septentrionalis* which occurs in Bed 18-C. A second potential datum occurs slightly higher than the first and just below Bed 21 with the FOD of *Halobia cf. H. austriaca*.

At Black Bear Ridge, the FOD of *Halobia n. sp. aff. H. beyrichi* is above beds with the ammonoid *Anatropites* (a proxy for the *Macrolobatus* ammonoid zone) and approximately 2 m below the FOD of the ammonoid *Goniontites* (a proxy for the *Kerri* ammonoid zone) that occurs in Bed 22 (see Tozer, 1994, Orchard et al., 2001). The ammonoid *Stikinoceras kerri* has not been found in the Black Bear Ridge section, yet occurs from a similar level (with the conodont *M. echinatus*) at the Pardonet Hill section on the south shore of Williston Lake (see Tozer, 1994; Orchard, this volume).

It is interesting to note that the highest horizons with *Halobia ornatissima* and *H. cf. H. radiata* overlap both *H. n. sp. aff. H. beyrichi* and *H. cf. H. austriaca*-- a relationship that is not known with any confidence elsewhere in the North American Cordillera. At other North American localities investigated by the author including the Shoshone Mountains, Nevada, Fredrick Island, British Columbia, and Kuiu Island, southeast Alaska, the LOD of *Halobia ornatissima* is also below the FOD of *H. n. sp. aff. H. beyrichi* which in turn occurs approximately 1 meter below and extends

upward with well preserved specimens of the ammonoid *Stikinoceras kerri*. *Halobia beyrichi* is however known in other west-Tethyan localities including Sicily, Bosnia and Herzegovina, and Montenegro where it occurs in close association with both *H. styriaca* and *H. superba* and typical Norian conodont assemblages (see Gruber, 1975, 1976; Cafiero and De Capoa Bonardi, 1980, 1982 and De Capoa Bonardi, 1984).

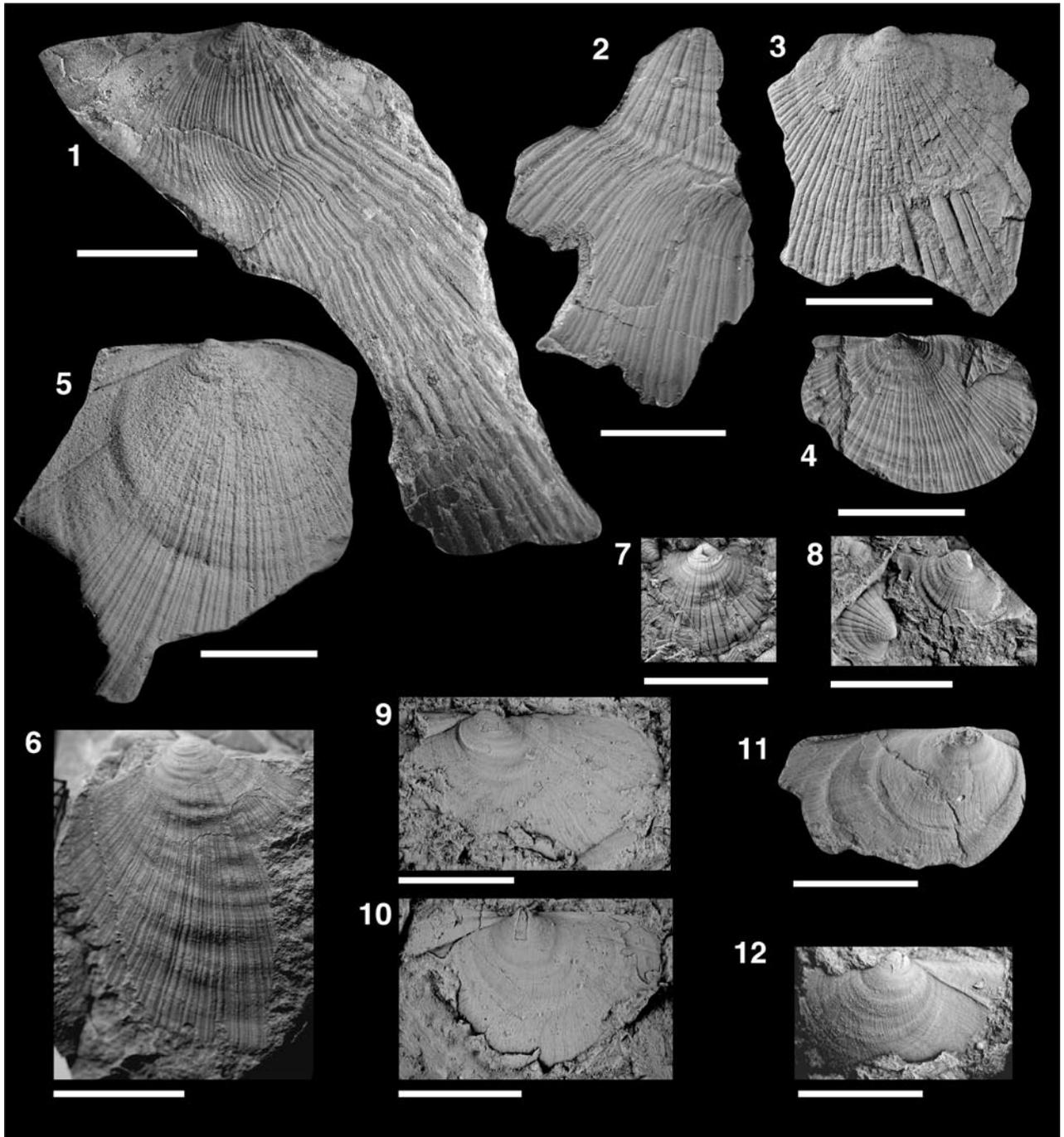
It is further emphasized that the lower datum defined by the FOD of *Halobia* n. sp. aff. *H. beyrichi* corresponds closely with a significant bioevent exhibited by conodonts (Orchard, this volume). Orchard's new conodont zonation across the Carnian/Norian interval at Black Bear Ridge and the section at Pardonet Hill East (on the south shore of Williston Lake). and has identified a major turnover in platform conodont elements beginning with the FOD of *Metapolygnathus echinatus* in bed 18-F and is remarkably complete by bed 18-G. The *Metapolygnathus echinatus* Zone is a relatively short-lived event encompassing approximately 2.5 m of strata and is succeeded by a typical early Norian conodont assemblage dominated by *M. primitius*.

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Platel:

Representative halobiid bivalves from the Carnian/Norian interval at Black Ridge. Scale bar = 1 cm. 1, *Halobia ornatisissima* SMITH, right valve, Bed 20-F; 2, *Halobia ornatisissima* SMITH, left valve fragment, Bed 18-C; 3, *Halobia* cf. *H. austriaca* MOJSISOVICS, right valve, Bed 27; 4, *Halobia* n. sp. aff. *H. beyrichi* (MOJSISOVICS), left valve, Bed 18-F; 5, *Halobia* cf. *H. radiata*, GEMMELLARO, left valve, Bed 21; 6, *Halobia* cf. *H. radiata*, GEMMELLARO, left valve, Bed 12-B; 7, *Halobia* cf. *H. austriaca* MOJSISOVICS, left valve, Bed 22; *Halobia* cf. *H. austriaca* MOJSISOVICS, Bed 22-B; 9, *Halobia* cf. *H. septentrionalis* SMITH, left valve, Bed 17; 10, *Halobia* cf. *H. septentrionalis* SMITH, left valve, Bed 17; 11, *Halobia* cf. *H. septentrionalis* SMITH, right valve, Bed 18; 12, *Halobia* cf. *H. septentrionalis* SMITH, right valve, Bed 17-B.



A record of stable organic carbon isotopes from the Carnian-Norian boundary section at Black Bear Ridge, Williston Lake, British Columbia, Canada

Kenneth H. Williford¹, Michael J. Orchard², John-Paul Zonneveld³,
Christopher McRoberts⁴, Tyler W. Beatty⁵

¹Department of Earth and Space Sciences, University of Washington, Box 351310, Seattle, WA 98195, USA, ammon@u.washington.edu

²Geological Survey of Canada, 625 Robson St., Vancouver, BC V6B 5J3, Canada

³Geological Survey of Canada, 3303 33rd Street NW, Calgary, AB, Canada T2L 2A7

⁴Department of Geology, SUNY Cortland, P.O. Box 2000, NY 13045, USA

⁵Department of Geoscience, University of Calgary, 2500 University Drive Northwest, Calgary, AB T2N 1N4, Canada

Abstract A record of stable organic carbon isotopes from the Carnian-Norian boundary section at Black Bear Ridge on Williston Lake, British Columbia, Canada shows relative stability in carbon cycling across this time interval, with total isotopic variability of 1.12‰. Fine scale sampling around the critical boundary interval reveals a negative isotopic perturbation of 0.5‰ with the most extreme isotope values occurring in the same horizon as the dominant faunal change in conodonts and bivalves. The isotopic change is interpreted to be the result of a decline in net primary production, which would have increased selective pressure on conodonts and bivalves and contributed to the turnover observed across the Carnian-Norian boundary.

Introduction

The Carnian-Norian boundary section at Black Bear Ridge on Williston Lake, British Columbia, Canada was sampled for stable organic carbon isotope analyses in May, 2007 in order to assess the degree to which fossil turnover associated with this time interval was accompanied by changes in biogeochemical cycling. The section at Black Bear Ridge is given a detailed treatment by Orchard (this volume), with special emphasis on the conodont record. This section is a leading candidate for the basal Norian Global Stratotype Section and Point, and the addition of stable carbon isotope data to the growing body of work that exists from this area (e.g. Orchard *et al.*, 2001) makes this candidacy stronger yet. We offer here a preliminary report on the first set of carbon isotope analyses to be completed from this section.

Methods

The ratio of stable carbon isotopes ($^{13}\text{C}/^{12}\text{C}$) in sedimentary bulk organic matter was measured via elemental analyzer continuous flow isotope ratio mass spectrometry in the ISOLAB at the University of Washington. Isotope samples were collected at approximately two-meter intervals through the first 40 m of the section. The interval between beds 18 and 20, thought to contain the conodont turnover event (Fig. 1; Orchard, this volume), was sampled at approximately 10 cm intervals. Conodont samples were subsampled for carbon isotope analysis as well. The data reported here reflect a combination of all three sample

sets.

Care was taken in the field to sample only fresh, unweathered material, and samples were sonicated in deionized water for 45 minutes to remove any exterior contaminants. All glassware was baked for four hours at 500°C, and all tools were cleaned with methanol between uses to avoid organic carbon contamination. Clean isotope samples were ground in a ceramic rotary puck mill cleaned with combusted quartz sand, deionized water, and methanol between each sample. Approximately one gram of each sample was treated with an excess of 10% HCl for 72 h at 50°C. Samples were then triple rinsed with ultrapure (> 18 M Ω) deionized water and dried. Isotope analyses were made with a Costech ECS 4010 Elemental Analyzer coupled to a ThermoFinnegan MAT253 mass spectrometer via a ThermoFinnegan CONFLO III gas interface. Isotope ratios are reported in standard delta (δ) notation relative to Vienna Pee Dee Belemnite (vpdb) where $\delta^{13}\text{C} = [((^{13}\text{C}/^{12}\text{C})_{\text{sample}} / (^{13}\text{C}/^{12}\text{C})_{\text{vpdb}}) - 1] * 1000$. Data reported are the mean of three replicate analyses. Average standard deviation of sample replicates was 0.06 for $\delta^{13}\text{C}_{\text{org}}$ (1 σ ; n = 55). Average analytical precision based on routine analysis of the internal acetanilide reference material was 0.07 for $\delta^{13}\text{C}_{\text{org}}$ (1 σ ; n = 39).

Results

The record of total organic carbon (TOC) and $\delta^{13}\text{C}_{\text{org}}$ from the Carnian-Norian boundary section at Black Bear Ridge is shown in Fig. 1. TOC varies between 0.42 and 27.7%

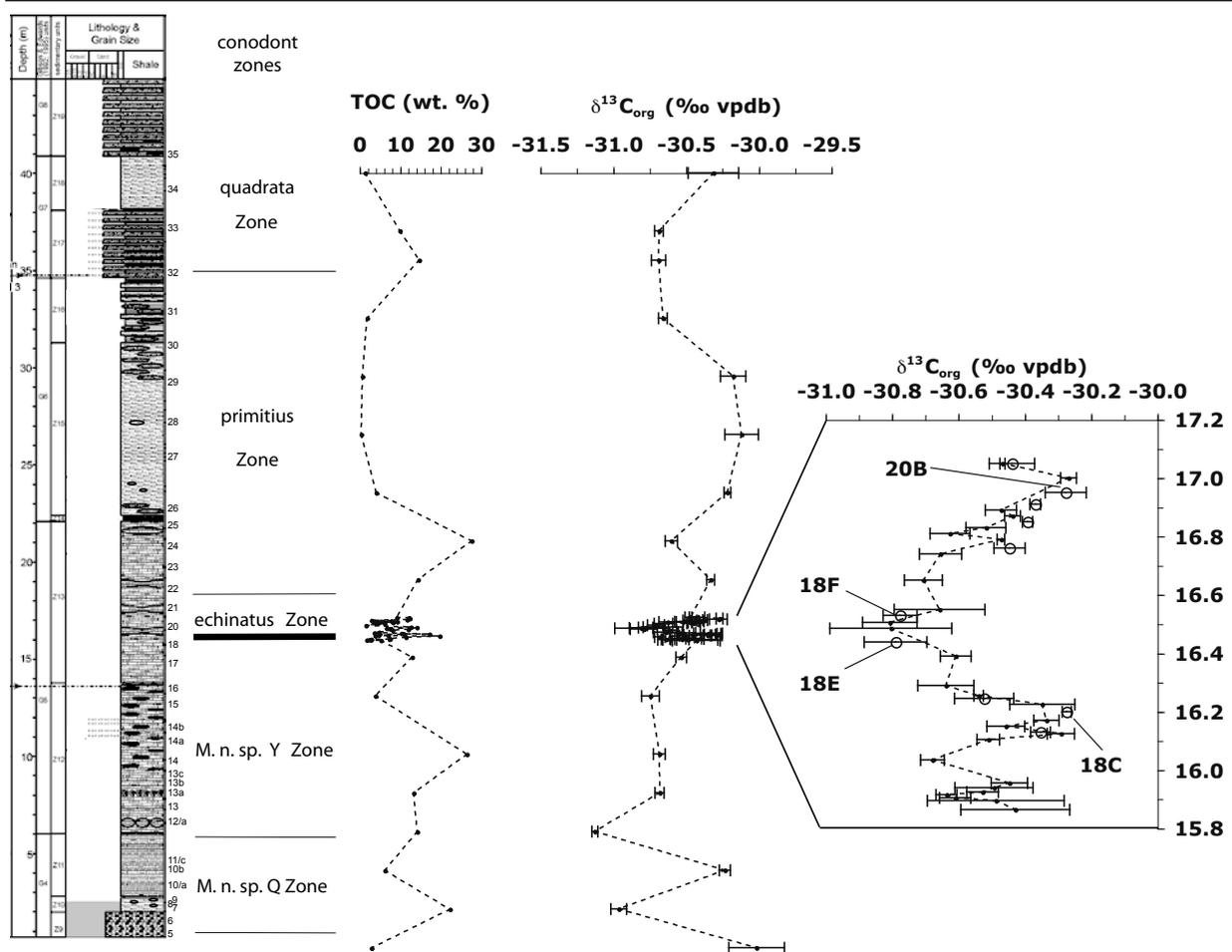


Figure 1: TOC and $\delta^{13}\text{C}_{\text{org}}$ from Carnian-Norian boundary section at Black Bear Ridge. Data points indicate mean values and error bars indicate 2σ of 3 replicate analyses. Inset shows analyses from critical boundary interval between beds 18 and 20. Open circles represent isotopic analyses of matrix from conodont samples discussed in Orchard (this volume). Lithostratigraphy adapted from (Zonneveld, 2007) and conodont zonation from Orchard (this volume).

by weight, with a mean of 6.15%. $\delta^{13}\text{C}_{\text{org}}$ varies between -30.01 and -31.12, with a mean of -30.51 and a standard deviation of 0.21. Overall, this is a small amount of isotopic variability. Within this context, however, the following patterns can be recognized given the high precision and replicability of the isotope analyses. The first 8 m of section is the most variable, with 3 shifts of $> 0.5\text{‰}$. Carbon isotopes then show a positive trend from 8 to 26.5 m, a negative trend from 26.5 to 37 m, and positive again to the highest sampled bed at 40 m. Carbon isotope data for the critical boundary interval between beds 18B and 20C is shown in the inset of Fig. 1. A negative excursion of approximately 0.5 occurs between beds 18C and 20B, or between 16.2 and 17 m in the section, reaching the lowest isotope value of -30.81 at 16.5 m, between beds 18E and 18F. The relationship of TOC to $\delta^{13}\text{C}_{\text{org}}$, with a weak negative trend ($r^2 = 0.1179$), is shown in Fig. 2.

Discussion and Conclusions

The high mean TOC in the Black Bear Ridge section indicates a low oxygen depositional setting conducive to rapid carbon burial, and the weak negative relationship between TOC and $\delta^{13}\text{C}_{\text{org}}$ suggests a low degree of thermal maturation. The Conodont Alteration Index (CAI) from this section is ~ 3 (Orchard, this volume), which also suggests that there may have been some minor thermal alteration

of organic material at temperatures between 110° and 200°C . The low amount of carbon isotopic variability across the Carnian-Norian boundary section at Black Bear Ridge implies relative stability in carbon cycling during this interval and supports the conclusion that there is no significant facies change across this section. Though significant turnover in ammonoids, bivalves, and conodonts has been recognized at this boundary (Carter and Orchard, 1999; Orchard *et al.*, 2000, 2001, this volume), there is no evidence for large scale perturbation in carbon cycling.

Fine scale sampling around the critical boundary interval between beds 18 and 20 reveals a small, negative carbon isotope perturbation which reaches its most negative values between levels 18E and 18F, the exact horizon across which the predominant conodont and bivalve turnover is recognized (Orchard, this volume). While there are slightly larger isotopic shifts lower in the section, they consist only of single points, making paleoenvironmental interpretation tenuous. By contrast, the perturbation between beds 18 and 20 has a smooth and consistent anatomy, and the fact that the most extreme isotopic values in this interval correspond to peak faunal change suggests a potential causative relationship. The negative carbon isotope perturbation could be the result of a short-term drop in net primary productivity and declining algal populations, which would have increased selection pressure on higher trophic levels,

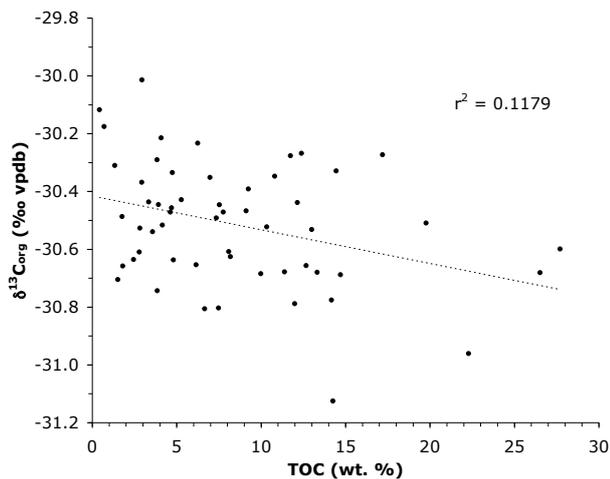


Figure 2: $\delta^{13}\text{C}_{\text{org}}$ vs. TOC from Black Bear Ridge driving evolution in conodonts and bivalves.

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Radiolarian - conodont – ammonoid intercalibration around the Norian-Rhaetian Boundary and implications for trans-Panthalassan correlation

Elizabeth S. Carter¹ & Michael J. Orchard²

¹Portland State University, Portland, OR 97297-0751, USA; mailing address: 69745 Old Wagon Road, Sisters, OR 97759, U.S.A.

²Geological Survey of Canada, 625 Robson St., Vancouver, B.C. V6B 5J3, Canada.

Introduction

Krystyn et al. (2007) have proposed a Global Stratigraphic Section and Point (GSSP) for the Norian-Rhaetian Boundary (NRB) at Steinbergkogel in Austria and presented the attributes of two definitive conodont datum options, namely the appearance of *Misikella hernsteini* and, a little above, that of *M. posthernsteini*. There are ammonoid and bivalve proxies for these two levels, including the disappearance of coquina-forming species of large *Monotis* a little below the first, and the appearance of the ammonoid *Paracochloceras* with the second (Krystyn et al., 2007, Fig. 5). The problem with both these NRB options is that *Misikella* is very rare in the Americas and recognition of the boundary must rely on other criteria. In this paper, we examine the extent to which proxies allow us to correlate American and Tethyan successions. The provincialism of latest Triassic conodonts and the rarity of ammonoids make radiolarians critical for this purpose.

In North America, the NRB has been informally defined between the Deweveri and Moniliformis radiolarian zones (Carter, 1993), a position that has been regarded as approximating a position between the Cordilleranus and Amoenum ammonoid zones. Whereas the association of *Monotis* beds – regarded as a proxy for the Cordilleranus Zone – and Deweveri Zone radiolarians is well established (see below), correlation between the Moniliformis and Amoenum zones rests largely on the evidence provided by conodonts that are associated with each of these at separate localities. Important North American sections where the relationships between these fossil groups are shown are Queen Charlotte Islands (QCI), Vancouver Island, and Baja California (Mexico), where NRB radiolarians and conodonts co-occur, and Williston Lake and Tyaughton Creek (British Columbia), Whitehorse Trough (Yukon Territory), and New York Canyon (Nevada), from each of which NRB ammonoids and conodonts are known. Each of these localities (Fig. 1) is briefly discussed below.

Late Norian and/or early Rhaetian radiolarians are also known from Tethyan areas represented by the Philippines, Japan, Timor, Turkey, Austria, and Italy. This attests to the global distribution of these faunas and underscores their growing potential for helping to define the NRB. See Table 1 for summary of where radiolarians of the Deweveri



Figure 1: Map showing North American localities discussed in text.

and/or Moniliformis zones are present.

NRB radiolarian-conodont-ammonoid intercalibration in the Americas

Kennecott Point, Queen Charlotte Islands, British Columbia

The most complete succession of radiolarians and conodonts of late Norian and early Rhaetian age are present at Kennecott Point on northern Graham Island, QCI (Fig. 2). In addition to *Monotis* coquina and other uncommon bivalves, abundant radiolarians, common conodonts, and

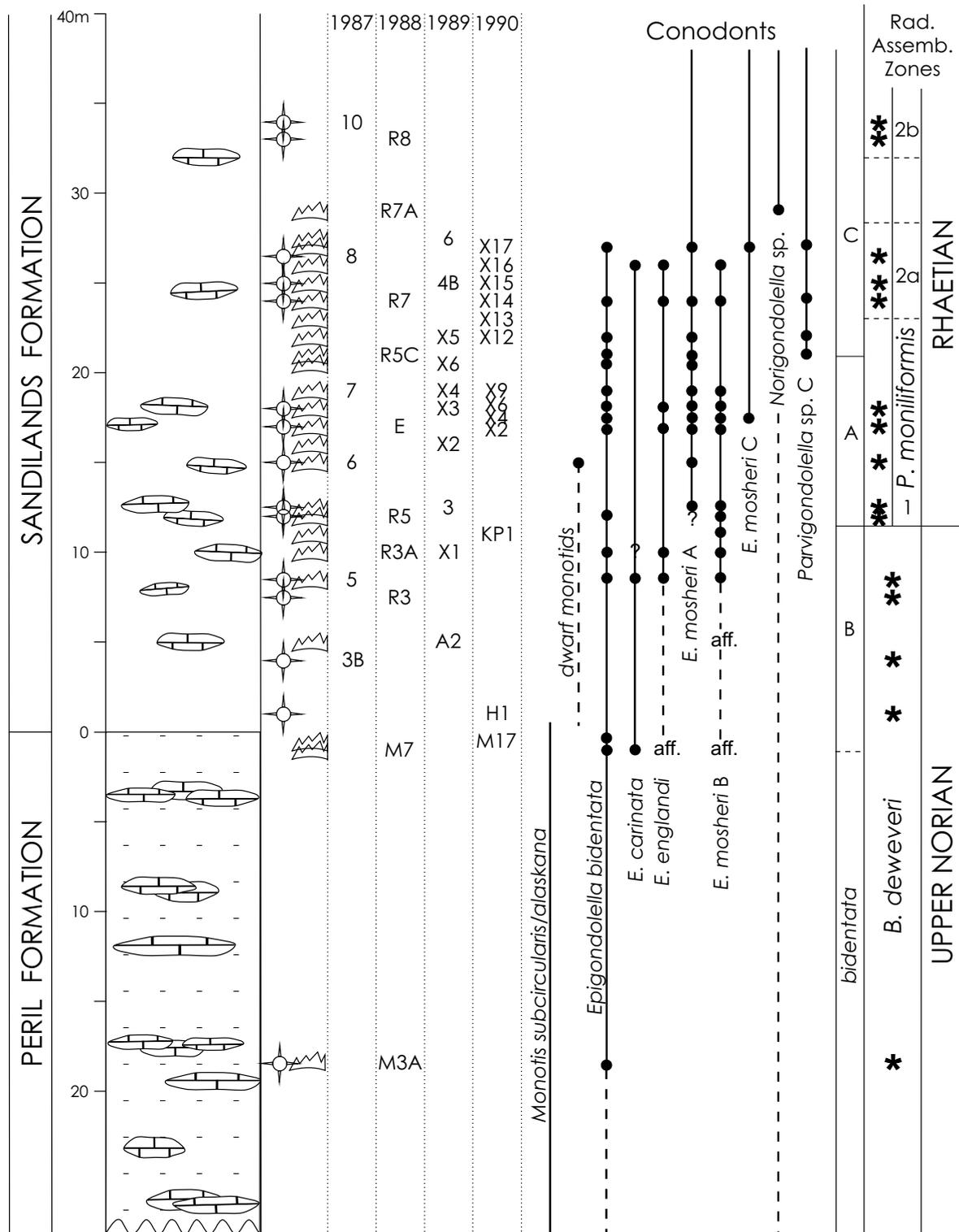


Figure 2: The NRB interval at Kennecott Point on QCI, showing samples taken during four collecting trips, the conodonts recovered, and the ages of radiolarian faunas. Informal conodont intervals shown to left of radiolarian assemblages.

rare ammonoids of late Norian and Rhaetian age are present in the upper Peril and overlying Sandilands formations (Desrochers and Orchard, 1991; Carter, 1993; Tipper et al., 1994; Carter and Orchard, 2004). Other coastal sections, notably on Kunga Island to the south, supplement the Kennecott Point records. Radiolarian zonation for the late Norian and Rhaetian was established in QCI by Carter (1993): (1) the *Betraccium deweveri* Zone; (2) the *Proparvicungula moniliformis* Zone (Assemblages 1 and

2a-d); and (3) the *Globolaxtorum tozeri* Zone (Assemblage 3). These zones have been used extensively as a dating tool for Rhaetian radiolarian faunas, particularly in areas where other means of correlation are absent.

At both Kennecott Point and on Kunga Island, Deweveri Zone radiolarians are associated with *Monotis* beds (Pessagno and Blome, 1980; Blome, 1984; Carter, 1993). At Kennecott Point, diagnostic radiolarians of the Deweveri

Zone are also present in the lower 8.5 m of the Sandilands Formation (Fig. 2, samples 90/H1, 87/3B, 88/R3, and 87/5). The latter are succeeded at 12.0 m by faunas associated with Assemblage 1 of the Moniliformis Zone (Fig. 2, samples 88/R5, 89/3, 87/6, 88/E, 90/X6, and 89/X3). Very rare dwarf monitids have been reported from these levels, as they also have been in Austria (Krystyn et al., 2007). Radiolarian taxa first appearing in Assemblage 1 include *Proparvincingula moniliformis*, *Bistarkum cylindratum*, *Ferresium triquetrum*, *Globolaxtorum hullae*, *Praemeso-saturnalis huxleyensis*, *Nabolella trispinosa*, and *Praecitriduma canthofistula*. These are succeeded at 26 m by faunas associated with Assemblage 2a of the Moniliformis Zone, most notably *Pentaspongodiscus? dihexacanthus* and *Serilla* (formerly *Risella*, see Carter 2007b) *ellisensis*, and at 33m (samples 87/10 and 88 R/8) by Assemblage 2b faunas including *Betraccium kennecottense*, *Cantalum gratum*, *Haeckelicyrtium karcharos*, and *Nabolella desrochersi*. Radiolarians of the overlying *Globolaxtorum tozeri* Zone (Assemblage 3) begin at 65 m in the succession and are characterized by the increasing abundance of *Serilla*, *Globolaxtorum* and species of *Canoptum* and *Laxtorum* with a tube. At 73.5 and 78 m in the succession, Crickmayi Zone age ammonoids occur within the Tozeri Zone. At Kunga Island, Tozeri Zone faunas have played a major role in correlating radiolarians across the Triassic-Jurassic Boundary (Carter and Hori, 2005), and form the basis for proposing Kunga Island as a GSSP candidate for the base of the Jurassic (Longridge et al., 2007).

The conodont succession at Kennecott Point has not been described in modern terms (see taxonomic notes; Plate 1) and only a few specimens have been illustrated (Orchard, 1991; 1994). The fauna of the *Monotis*-beds is dominated by small specimens of *Epigondolella bidentata* sensu stricto. In the overlying Sandilands Formation more elongate forms appear, and these have been referred to *E. mosheri*. Orchard (1994) differentiated two morphotypes of *E. mosheri*, A and B, based on both Canadian and Peruvian collections. Recently, a third, Morphotype C, was added based on material from the Gabbs Formation in Nevada (Orchard et al., 2007a). The ranges of these morphotypes differ and appear to be useful in differentiating NRB strata in Western Canada.

Epigondolella bidentata and *E. carinata* occur in the upper *Monotis* beds and range through the lower Sandilands Formation at Kennecott Point. At first, a few associated elements resemble *E. englandi* and *E. mosheri* Morphotype B, but they lack both the symmetry of the former and the long posterior carina (five posterior carinal nodes) of the latter; these are designated "aff." With the last representatives of Deweveri Zone radiolarians, and for a few metres above those indices but below the first radiolarians of the succeeding Moniliformis Zone, typical *E. englandi* and *E. mosheri* Morphotype B also occur. The first typical *E. mosheri* Morphotype A appears more or less concurrently with radiolarians of Assemblage 1 of the Moniliformis Zone, and thereafter becomes increasingly common with individual elements showing an increasing posterior platform elongation and narrowing. Hence, higher in the

Moniliformis Zone, elements of *E. mosheri* Morphotype C occur. Such forms occupy the same position at Kunga Island too. *Parvigondolella* sp. C also appears at these levels at Kunga Island, and at Kennecott Point it makes its appearance within strata lacking radiolarians but bracketed by Assemblage 1 and Assemblage 2a faunas.

At Kennecott Point, the higher parts of the Moniliformis Zone become increasingly characterized by *Norigondolella steinbergensis*, and the last *Epigondolella* species occur with Assemblage 2b radiolarians. The Tozeri Zone yields *Norigondolella* sp. and from a *Choristoceras*-bearing bed, *Misikella posthernsteini* (Orchard, 1991, Pl. 5, Fig. 21). On Kunga Island, a bed with Assemblage 2a radiolarians yielded a specimen of the Tethyan *Oncodella paucidentata*, whereas a second bed within the Tozeri Zone yielded a single ramiform element interpreted as a possible non-specific M element of *Misikella* (see Pálffy et al., 2007, Fig. 6.20). *Epigondolella mosheri* ranges up through the basal parts of the Tozeri Zone on Kunga Island, whereas *Norigondolella* appears in sub-assemblage 2b and ranges up to within metres of the TJB.

Kyuquot, Vancouver Island, British Columbia

The northwest coast of Vancouver Island south of Kyuquot exposes latest Triassic strata and faunas that have been described by Jeletsky (1950) and Muller et al. (1981, includes faunal lists). The Triassic Parson Bay Formation embraces the informal "Thinly Bedded Member" that includes Norian fossils as young as upper Norian *Monotis*-to *Rhabdoceras*-bearing beds. The overlying "Arenaceous Member" at Mushroom Point contains a diverse shelly fauna in addition to the ammonoids *Rhabdoceras* and *Placites*. Finally, the "Limestone Member", regarded as equivalent to the Sutton Limestone of Cowichan Lake in southern Vancouver Island, yields *Peripleurites*. The coralline Sutton Limestone itself has been assigned by Tozer (1967, p. 78-79) to the Crickmayi Zone based on the occurrence of the ammonoids *Choristoceras*, *Cycloceltites*, *Megaphyllites*, and *Placites*.

A succession of microfossil samples collected in 1992 by MJO from the "Arenaceous Member" at Mushroom Point yielded both conodonts and radiolarians. A diverse collection of radiolarians of Moniliformis Zone Assemblage 1 age occurs both 3.75 m below and with *E. bidentata* and *E. mosheri* Morphotype B. The latter species also occurs 2.25 m higher, and *E. englandi* and *E. carinata* occur 2 m above that, immediately below a 0.5 m thick coral bed. No specimens of *E. mosheri* Morphotype A were recovered, although the conodont faunas are not abundant. In the same area, a rich Deweveri Zone fauna was also recovered from beds with *Monotis* and *Heterastridium*. Rare conodonts recovered from the type locality of the Sutton Limestone, also in strata beneath coral beds, are assigned to *E. bidentata* and *E. mosheri* Morphotype B.

Baja California Sur, Mexico

In common with Queen Charlotte Islands, the Baja succession provides intercalibration of latest Triassic conodonts and radiolarians (Orchard et al., 2007b). Although

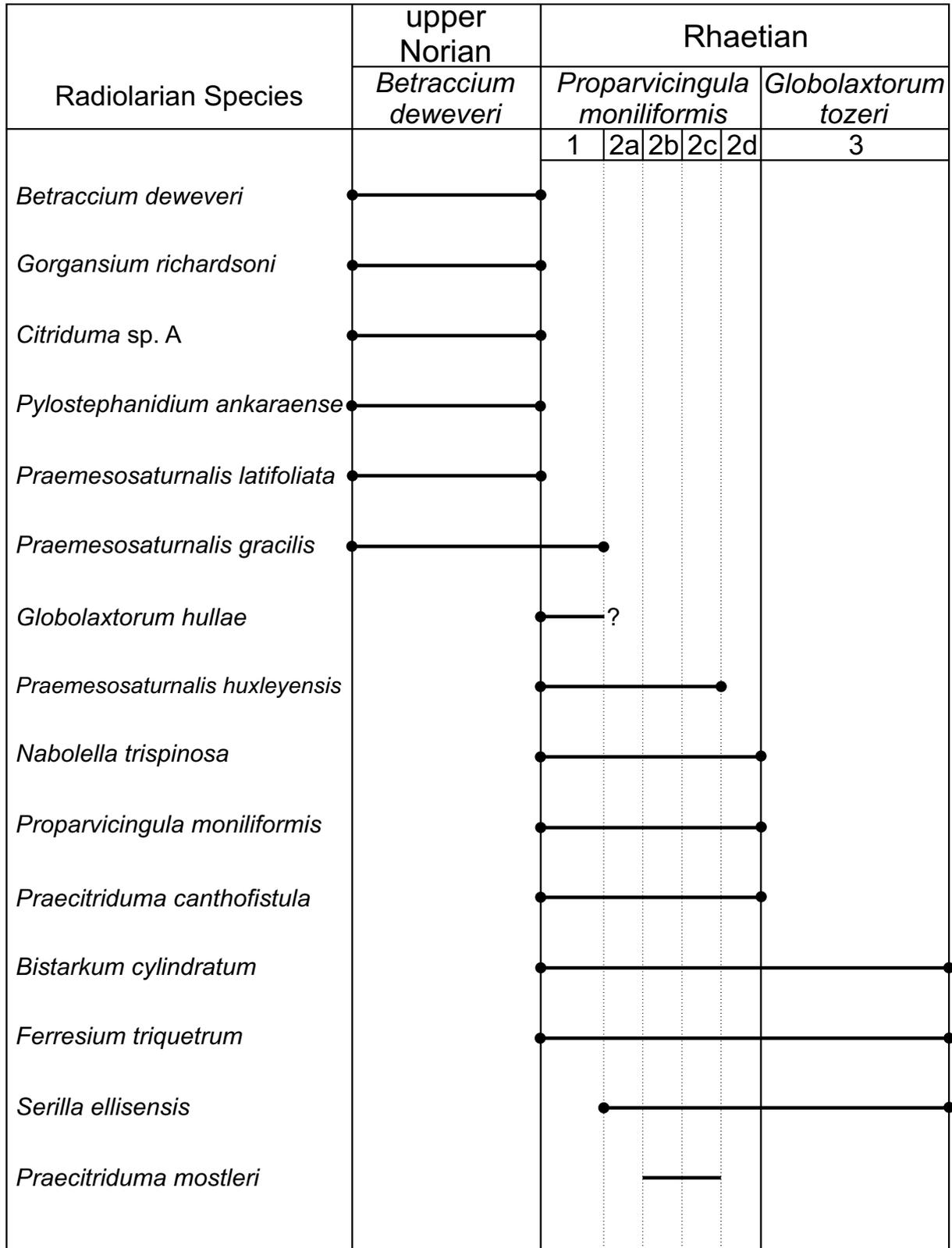


Figure 3: Chart showing ranges of key radiolarian species in relation to the radiolarian zonation of Carter (1993).

generally sparse, the conodont faunas contain many more Tethyan elements than any other North American locality, presumably reflecting a more distant or southerly pre-accretionary paleogeographic location within the Panthalasian Ocean. Similarly, there are some differences in the radiolarian faunas (Orchard et al., 2007b) but the zones based on those faunas are nevertheless recognizable. Hence, both *Misikella hernsteini* and *M. posthernsteini* occur in association with Assemblage 2(b-c) Moniliformis Zone radiolarians, and the former species occurs also with those of the Tozeri Zone. *Oncodella paucidentata*, a typical Rhaetian associate of *M. hernsteini*, also occurs with Assemblage 2a radiolarians. Unfortunately, definitive Assemblage 1 radiolarians have not been found in Baja so we cannot determine whether these *Misikella* species appear earlier than Assemblage 2.

The 'intermediate' nature of the Baja faunas is apparent in the occurrence of *Epigondolella* high into the Rhaetian, in contrast to its earlier demise in Tethys (e.g. at Steinbergkogel), where it is largely replaced by *Misikella* around the NRB (Krystyn et al., 2007). Orchard et al. (2007b) assigned long bidentate *Epigondolella* elements that occurred with both Assemblage 2 and 3 radiolarians in Baja to *E. mosheri* sensu lato, but re-appraisal of these faunas using current criteria places most of these elements in either *E. mosheri* Morphotype B or in advanced (i.e. relatively long) *E. bidentata*. *E. mosheri* Morphotype A may occur with Moniliformis Assemblage 2 radiolarians. In contrast to Queen Charlotte Islands, the Baja succession lacks *Norigondolella* from late Rhaetian strata.

Tyaughton Creek, British Columbia

Tyaughton Creek is the type locality for the North American Amoenum and Crickmayi zones and, although no radiolarians are known, the section is crucial in establishing calibration between the ammonoid chronology and the conodonts and thereby, indirectly, the ammonoid with the radiolarian biochronology. The succession has been described most recently by Umhoefer and Tipper (1998) who provide an account of both the lithostratigraphic succession and its fauna. The Triassic Tyaughton Formation is divided into seven distinct lithological members. From the base these units are: red conglomerate; massive megalodont-bearing limestone; *Monotis* limestone with *Gnomohalorites*; limestone cobble conglomerate; lower green clastics; *Cassianella* beds; and upper green clastics. Tozer (1967) designated the *Cassianella* beds, which have yielded *Paracochloceras amoenum*, as the type locality of the Amoenum Zone, and the upper green clastic unit with its species of *Choristoceras* as the type locality for the Crickmayi Zone.

Conodonts recovered from the Tyaughton Formation include lower Norian *Epigondolella triangularis* in clasts of the basal red conglomerate, and *E. bidentata*, *E. carinata*, and *E. englandi* from the megalodont limestone. Samples from the *Cassianella* beds, which vary between 90 – 120 m in thickness, yield the same species as the limestone below plus *E. mosheri* morphotypes A, B, and C, and *Parvigondolella* sp. C. The upper green clastic unit, ranging from 0

– 74 m in thickness, yielded a single specimen of *Misikella posthernsteini* from close to its top. Hence, although there are no direct associations of ammonoids and conodonts in the same bed, the implication is that diverse *E. mosheri* faunas are diagnostic for the Amoenum Zone.

Lewes River, Yukon Territory

Conodont collections from the Lewes River Group in the Whitehorse Trough of south-central Yukon provided the type material of *Epigondolella englandi* (Orchard, 1991). These strata consist of massive and richly fossiliferous, in part reefoid (including megalodont-bearing) carbonates that have yielded *Paracochloceras* (Tozer, 1958). In addition to *E. englandi*, both morphotypes A and B of *E. mosheri* occur and, although direct ammonoid-conodont association is lacking, the records lend support to the association of the latter conodonts in the Amoenum Zone.

Williston Lake, British Columbia

There are numerous records of conodonts from upper Norian *Monotis* beds in northeastern British Columbia (Orchard and Tozer, 1997), but few localities have Rhaetian strata preserved. Most significant of these is the section at Ne Parle Pas Point where Tozer (1982) documented the *Rhacophyllites* beds overlying the *Monotis* beds at the top of the Pardonet Formation. Therein, the occurrence of *Placites polydactylus* suggests an Amoenum Zone age (Tozer, 1994). Sparse conodont collections from the *Rhacophyllites* beds include *Epigondolella bidentata*, *E. carinata*, *E. mosheri* Morphotype B, and more common *Norigondolella steinbergensis*. These taxa also occur at Black Bear Ridge (Orchard et al., 2001), immediately above *Monotis* beds.

In the Pine Pass area south of Williston Lake, the Bocock Limestone is an aurally restricted unit that also sits above *Monotis* strata. Its pale weathering colour and resistant nature contrast with the dark recessive Pardonet Formation below. The limestone has yielded a rich conodont fauna from its basal parts that consists of *E. bidentata*, *E. carinata*, *E. mosheri* morphotypes A and ?B, and *Norigondolella steinbergensis*.

New York Canyon, Nevada

The conodont succession from the Gabbs Formation was described recently by Orchard et al. (2007b). This area of Nevada, particularly New York Canyon, which is also a candidate for the Triassic-Jurassic Boundary, is important because it permits calibration between conodonts and a highly resolved ammonoid chronology. Furthermore, recent discoveries in the uppermost Triassic also allow intercalibration with some radiolarian faunas. Hence, *E. mosheri* Morphotype A and later *Parvigondolella* sp. C occur within the Nun Mine Member, which is assigned to the Amoenum Zone by Taylor and Guex (2002), and *E. mosheri* Morphotype C occurs in the basal parts of the overlying Mount Hyatt Member. The sampling coverage of this part of the section is not complete but the upper half of the latter formation and the basal parts of the Muller Canyon Member contain the Tethyan conodonts *Misikella posthernsteini* and *Zieglericonus rhaeticus*, ammonoids of

Locality	Radiolarian Zone	Reference
Vancouver Island, B.C.	Deweveri Moniliformis (Assmb. 1)	ESC, internal report to GSC, 1997
Alaska	Deweveri	Blome et al. 1988
Oregon	Deweveri Moniliformis (Assmb. 2; upper part)	from Blome et al. 1988 Yeh 1989
California	Deweveri	from Blome et al. 1988
Nevada	Tozeri	Orchard et al. 2007a
Baja California Sur	Moniliformis (Assmb. 2a-d) Tozeri	Orchard et al. 2007b
New Zealand	Deweveri	Blome et al. 1987; Aita & Spörli 1994
Japan	Deweveri Moniliformis: TR8C, upper ~ = Assmb. 1 TR8D ~ = Assmb 2 + Tozeri Tozeri	Sugiyama 1997 Carter & Hori 2005
Philippines	Deweveri Moniliformis (Assmb. 2b-2c)	Yeh, 1990, 1992; Yeh & Cheng 1996
Tibet	Moniliformis; upper part	Ziabrev et al. 2004
NE China	Deweveri-Moniliformis (undiff.) Deweveri Moniliformis (Assmb. 2a)	Zhang 1990 Yeh & Yang 2006 Yeh & Yang 2006
Russian Far East	= Moniliformis/Tozeri (undiff.)	Bragin 1991
Timor	Deweveri – Moniliformis (undiff)	Rose 1994
Turkey	Deweveri Moniliformis (Assmb. 2b-2c) Tozeri	Bragin & Tekin 1996; Tekin 1999, 2002 Tekin 1999 Tekin 1999, 2002
Austria	Moniliformis (Assmb. 2 undiff.)	Kozur & Mostler 1981, 1994; Kozur 1984, 2003
Italy	Deweveri Moniliformis (Assmb. 1, 2a,2b) Moniliformis (Assmb. 1)	Amodeo 1999 Bazzucchi et al 2005
Hungary	Tozeri	Pálfy et al. 2007
Oman	Tozeri	in Carter 1993
Peru	latest Tozeri/earliest Merum (Hettangian)	in Carter 1993; Von Hillebrandt pers. comm. 2007

Table 1: Global distribution of Upper Norian and Rhaetian radiolarians.

the Crickmayi Zone, and radiolarians of the Tozeri Zone.

Central Peru

Small conodont collections from the lower Pucará Group of central Peru were described by Orchard (1994). This material formed the basis for *Epigondolella mosheri* Morphotype B. Both upper Norian (*Monotis*) and Rhaetian (*Choristoceras*) strata are recognized within the group, but no direct association with conodont fauna is known..

NRB radiolarian-conodont intercalibration in Tethys

Italy

There are two published accounts of conodonts and radiolarians co-occurring in the latest Triassic of Italy. Several radiolarian-conodont correlations are provided in the Lagonegro Basin of southern Italy, where Amodeo (1999) utilized the radiolarian zonation established in

QCI. Deweveri Zone radiolarians, including *Betraccium deweveri*, *Praemesosaturnalis gracilis*, and *Citriduma* sp. A, were found in the Monte Cugnone, Madonna del Sirino, and Sasso di Castalda sections. At Madonna del Sirino, *Epigondolella bidentata* occurred about 13 m below Deweveri Zone radiolarians, and at Sasso di Castalda, unspecified Rhaetian conodonts occurred midway between Deweveri Zone and Moniliformis Zone radiolarians that were separated by ~7.5 m of strata. At Lagonegro, *Misikella hernsteini* occurred ~8 m below the radiolarian *Livarella* of late Norian-Rhaetian age.

Bazzucchi et al. (2005) described the succession in the upper part of the Calcarie con Selce Formation at the Mt. Crocetta section in the Appenines. This included a succession of *Misikella* species with *M. hernsteini* occurring at ~26m and *M. posthernsteini* at ~40.5 m. These bracketed radiolarians of the Moniliformis Zone, including *Fontinella primitiva*, *Praemesosaturnalis sandspitensis*, and *Globolaxtorum hullae* at ~37.5 m (sample PA 25). This

fauna is characteristic of Assemblage 1 and possibly 2a of the Moniliformis Zone. These records are consistent with broad contemporaneity of the base of the Moniliformis Zone and the appearance of *Misikella*.

Turkey

Upper Norian faunas from the Senonian Ophiolitic Mélange near Eryaman, Ankara, Turkey (Bragin and Tekin, 1996), include *Betraccium deweveri*, *B. inornatum*, *Bipedis acrostylus*, *Canoptum triassicum*, *Deflandrecyrtium ithacanthum*, *Fontinella habros*, *Livarella densiporata*, *Phylostephanidium ankaraense*, and *Tetraporobrachia composita*, an assemblage that correlates well with *Betraccium deweveri* Zone faunas in QCI. Tekin (1999) also found Deweveri Zone faunas in the Hacıyunuslar section in the Beyşehir-Hoyran Nappe, and Rhaetian assemblages comparable to the *Proparvicungula moniliformis* and *Globolaxtorum tozeri* zones together with Rhaetian conodonts in the Cataltepe Nappe in the Antalya Nappes. This included *Zieglericonus rhaeticus* with what are interpreted as Moniliformis Assemblage 2 radiolarians. The Tozeri Zone includes *Citriduma asteroides*, *Ferresium triquetrum*, *Icrioma cistella*, *Serilla* spp., *Pentaspogoniscus? dihexacanthus*, *Praecitriduma canthofistula*, *Laxtorum capitaneum*, *Globolaxtorum cristatum*, and *G. sp. C*, herein interpreted as the index *G. tozeri*. The precise transition of radiolarians from upper Norian to lower Rhaetian has not been recognized in Turkey, but the greater sequence of faunas strongly supports zonation established in QCI.

Japan

Some radiolarian species differ between Japan and QCI, but the general trend is similar, as is seen most dramatically in transitional faunas across the Triassic-Jurassic Boundary (Carter and Hori, 2005). The long-ranging *Canoptum triassicum* Zone (Yao, 1982) has long characterized the middle Norian to Rhaetian radiolarian sequence in Japan, but more recently a detailed zonation consisting of twenty biozones was presented for the entire Triassic and basal Jurassic in the Inuyama area (Sugiyama, 1997). Biozones relevant to this discussion are TR8A, TR8B, TR8C, and TR8D, which together span the middle to upper Norian and Rhaetian. Comparison of species suggests the following correlation of these biozones to those in QCI:

1. upper TR8A, TR8B, and lower TR8C are approximately equivalent to the Deweveri Zone; *Betraccium deweveri*, *Praemesosaturnalis pseudokahleri*, *Tetraporobrachia composita*, *Deflandrecyrtium ithacanthum*, and *Citriduma* (not *asteroides* [ESC]) first appear in upper TR8A (at or near the base of the late Norian) and the former two disappear in lower TR8C (approximates top of the late Norian).
2. the upper part of TR8C (base of the Rhaetian?) is marked by the first appearance of *Nabolella trispinosa*, *Betraccium* aff. *inornatum*, and *Paronaella pacofiensis* and may be equivalent to Assemblage 1 of the Moniliformis Zone (see Fig. 2).
3. upper TR8C and lower TR8D are approximately equivalent to Assemblage 2 of the Moniliformis

Zone.

4. upper TR8D correlates with the *Globolaxtorum tozeri* Zone.

According to Sugiyama (1997), many Triassic-type radiolarians disappear at the top of TR 8D. This horizon is evidently very similar to the mudstone bed in the Kat-suyama section studied by Hori (1992) who indicated that the last occurrence of *Misikella posthernsteini* corresponds to this horizon.

Hungary

Although younger than NRB strata, it is noteworthy that Pálffy et al. (2007) recorded *M. posthernsteini*, *M. ultima*, *Zieglericonus rhaeticus*, and *Norigondolella steinbergensis* with Tozeri Zone radiolarians in the Csövár section of Hungary.

Summary

Radiolarians

The greatest change in Upper Triassic radiolarian faunas occurs somewhere in the late middle - early late Norian when all Capnuhosphaeridae (except the genus *Icrioma*) and Capnodocinae disappear. These well known groups dominate the late Carnian to middle Norian fauna and many species are known. Their extinction is not seen in QCI because middle Norian strata are coarsely clastic and have yielded few radiolarians, but representatives of those families have not been found in upper Norian collections of the *Betraccium deweveri* Zone, which are well known and recognized around the world. Amongst these are a few species that are often considered diagnostic of the Rhaetian, but closer examination indicates they actually begin in the upper Norian (or in some cases earlier) and range upward through the Rhaetian. The most widely distributed of these include *Livarella densiporata*, *L. valida*, *Bipedis acrostylus* group, *Betraccium inornatum*, *Deflandrecyrtium ithacanthum*, *Fontinella louisensis*, *F. inflata*, *F. habros*, and *Pentactinocarpus sevaticus*. While these species are useful in assessing the global extent of late Norian and Rhaetian faunas, they cannot be used for detailed biostratigraphy. Thus we focus on species that disappear at the top of the Deweveri Zone and others that begin at the base of the Moniliformis Zone.

The top of the Deweveri Zone in QCI is marked by the final occurrence of *B. deweveri*, *Gorgansium richardsoni*, *Praemesosaturnalis latifolia*, *Phylostephanidium ankaraense*, and *Citriduma* sp. A (Carter, 1993) (Fig. 3). These faunas are succeeded a few metres higher by radiolarians of Assemblage 1 of the *Proparvicungula moniliformis* Zone, whose most diagnostic taxa include *Proparvicungula moniliformis* and *Nabolella trispinosa* along with *Praemesosaturnalis huxleyensis*, *Globolaxtorum hullae*, *Praecitriduma canthofistula*, and *Ferresium triquetrum* (Fig. 3). *Globolaxtorum hullae* is rare in QCI and our data indicate that it may be confined to Assemblage 1, but studies in the Philippines (Yeh, 1990), Japan (Sugiyama, 1997), Italy (Baxxucchi et al., 2005), and Turkey (Tekin, 1999) suggest it may range higher. *Proparvicungula moniliformis*, *Praemesosaturnalis huxleyensis*, *Nabolella trispinosa*,

and *Praecitriduma canthofistula* range to the end of the Moniliformis Zone, whereas *Bistarkum cylindratum*, *Feresium triquetrum*, and *Serilla ellisensis* range to the top of the Triassic. The above taxa are quite widely distributed and useful in furthering worldwide correlation for the base of the *Proparvicingula moniliformis* Zone and/or the base of the Rhaetian. Of note is *Praecitriduma mostleri*, which is relatively rare in Assemblages 2b-2c in QCI (Fig. 3), and also known from Austria, Baja California, Turkey and Japan (Carter 2007a). The informal *Praecitriduma mostleri* Zone, recently designated by Kozur (2003), approximates these same assemblages of the Moniliformis Zone, but no details of this zone or its contents are given. Thus, it appears that *P. mostleri* may provide a useful tie for correlating mid Rhaetian faunas in the Americas with those in Tethys and the Western Pacific, but it cannot aid in defining the Norian-Rhaetian boundary.

Conodonts

In North America, *Monotis* coquinas commonly occur with Cordilleranus Zone ammonoids and *bidentata* Zone conodonts, each of which is regarded as indicative of the late Norian. Data from Tethys, including Baja California, confirms the association of *E. bidentata* and Deweveri Zone radiolarians. Towards the top of the Norian, more elongate *Epigondolella* elements resembling *E. mosheri* appear in QCI, and *E. mosheri* Morphotype B occurs above *Monotis* beds, high in the Deweveri Zone. In Canada, the appearance of typical *E. mosheri* Morphotype A is approximately coincident with the base of the Moniliformis Zone, and Morphotype C appears low in that radiolarian zone.

Data from the type locality of the Amoenum Zone in Tyaughton Creek and from the Gabbs Formation, supported by records from Lewes River in Yukon, suggest that *Epigondolella mosheri* is a useful proxy for the *Paracochloceras amoenum* Zone in North America. This is particularly true of morphotypes A and C. Elsewhere, notably on Williston Lake, Vancouver Island, and in Peru, only *E. mosheri* Morphotype B occurs in strata regarded as lower Rhaetian.

In QCI, *Epigondolella mosheri* Morphotype C and *Parvigondolella* sp. C appear later than the other morphotypes within the lower Moniliformis Zone, suggesting a continuing trend within that stock to posterior platform elongation and narrowing. *Epigondolellids* range into the Tozeri Zone but are uncommon above Assemblage 2a. *Norigondolella steinbergensis* becomes the dominant conodont in Moniliformis Assemblage 2b and extends through the Tozeri Zone.

Crickmayi Zone ammonoids are associated with *M. posthernsteini* at Kennecott Point in QCI, at Tyaughton Creek, and in New York Canyon. In the first and third of these localities, Tozeri Zone radiolarians also occur, as they are known to do in Hungary and Japan. In North America, only in the accreted terrane of Baja does *M. posthernsteini* demonstrably occur in the Moniliformis Zone (assemblage 2b-c), as does *M. hernsteini*.

Discussion and Conclusions

In North America, it had become traditional to consider post-*Monotis* strata as Rhaetian. However, in QCI, the extinction of large monotids occurs within the upper Deweveri Zone and the Rhaetian has been favored to begin at the base of the overlying Moniliformis Zone, which occurs soon after the disappearance of large monotids. The absence of *Misikella* species from these levels in North America prevents direct correlation with Tethys. However, it follows from the above that NRB Option 1 of Krystyn et al. (2007), marked by the FAD of *M. hernsteini* and approximating the last appearance datum (LAD) of large *Monotis*, may occupy a position within the Deweveri Zone. This is supported by data from Italy where lower Moniliformis Zone (1-2a) radiolarians appear above the appearance of *Misikella hernsteini*, and below the appearance of *M. posthernsteini*, that is Option 2 of Krystyn et al. (2007). This may point to an alignment of the Moniliformis Zone and Option 2. However, these data are inconclusive and it remains possible that Option 1 datum, or neither datum, is synchronous with the base of the Moniliformis Zone.

Evidence from the distribution of *Epigondolella* species is similarly ambiguous. Species of that genus are dominant in North American early Rhaetian faunas, but coeval strata in Tethys contain fewer and largely diminutive elements. New data from Austria (Krystyn, pers. comm., 2007) shows that both morphotypes A and B of *Epigondolella mosheri* have a narrow range from uppermost *Monotis salinaria* beds up to the appearance of *M. hernsteini* (Option 1). At Kennecott Point, QCI, only *E. mosheri* Morphotype B is so far known from presumably correlative strata prior to the base of the Moniliformis Zone. This implies that neither morphotype is definitive for the base of the Moniliformis Zone, or alternatively, that the Moniliformis Zone lies close to Option 1 in Tethys.

Elsewhere in North America, strata bearing *Paracochloceras*, an alternate Option 2 index of Krystyn et al. (2007) that defines the Amoenum Zone, are characterized by all morphotypes of *Epigondolella mosheri*, as are most strata bearing Moniliformis Zone radiolarians. However, only *E. mosheri* Morphotype C may be unique to the Moniliformis and Amoenum zones, and perhaps that morphotype also equates with the Option 2 datum index *M. posthernsteini*. The latter species occurs only with Tozeri Zone radiolarians and/or Crickmayi Zone ammonoids in North America, but certainly earlier in Tethyan sequences.

A broader view of trans-Panthalassan correlations may find correlation potential in the dramatic faunal changes that occur both in North America and Tethys near the end of the Triassic. Chief amongst these are the disappearance of large monotid coquina and the slightly later turnover from Deweveri Zone radiolarians to those of the Moniliformis Zone. Speculatively, the appearance of *E. mosheri* in both regions may be aligned with the demise of the large monotids, and the turnover from *Epigondolella* to *Misikella* dominated faunas in Tethys may be related to the turnover in the oceanic realm of radiolarian faunas. If these 'events' are related, then Option 1, the FAD of *M. hernsteini*, may be equivalent with the Moniliformis Zone.

In conclusion, on the basis of the present data, we cannot prove a North American conodont proxy to identify either of the alternate Tethyan datum options, but the appearance of *M. hernsteini* (Option 1) is favored as the equivalent to the base Moniliformis Zone. In general, we can conclude that, in North America, the common occurrence of *Epigondolella mosheri* (uniquely Morphotype C, and typically Morphotype A) and of Moniliformis Zone radiolarians indicate Rhaetian strata.

Conodont taxonomic notes

All the conodont elements mentioned herein are illustrated in Plate 2. Only a brief description of how they have been differentiated is included here. The typical morphology of *Epigondolella bidentata* is a single pair of anterior platform nodes and a narrow posterior platform on which there are three or four carinal denticles. As with other upper Norian populations, some variants have small marginal posterior nodes, and sometimes a second anterior denticle on one side (as in *E. zapfei*). Although *E. bidentata* may grow quite large, the carinal denticles posterior of the denticle-pair rarely exceed four in number, and the length of the posterior platform is comparatively shorter than that of the younger *E. mosheri*. Large bidentate specimens bearing a broad platform and often an unequal anterior denticle pair are excluded from *E. bidentata* and are assigned to *E. englandi*, whereas those with a third anterior denticle and common marginal posterior nodes are assigned to *E. carinata*. Elements of *E. mosheri* differ from the aforementioned taxa by possessing a minimum of five and as many as ten carinal denticles on the posterior platform. The first to appear are Morphotype B, which are relatively long elements with accessory nodes on the posterior platform and, in some cases, a second anterior node on one side. Morphotype A possesses a narrow, unornamented platform, like that of the holotype; Morphotype C has seven or more posterior carinal nodes. *Parvigondolella* sp. C has anterior nodes that are lost but otherwise a similar platform to *E. mosheri* Morphotype A. Similar reduction is sometimes seen in *E. bidentata*, but in those specimens the posterior platform is comparatively short.

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Plate 1.

Upper Norian and Rhaetian radiolarians from QCI. Scale bar = 100 µm for figures 1-3, 6-10, 12 and 16; 150 µm for figures 4-5, 13-14; 250 µm for figure 11; and 165 µm for figure 15.

1. *Betraccium deweveri* Pessagno & Blome. GSC 131223, from GSC loc. C-173346 (=89-KUF-6), Kunga Island, north side.
2. *Gorgansium richardsoni* Pessagno & Blome. GSC 131224, from GSC loc. C-173346 (=89-KUF-6), Kunga Island, north side.
3. *Pylostephanidium ankaraense* Tekin. GSC 131225, from GSC loc. C-158510 (=88-SHB-3), Shields Bay, Graham Island.
4. *Citriduma* sp. A (Carter 1993). GSC 131226, from GSC loc. C-158510 (=88-SHB-3), Shields Bay, Graham Island.
5. *Praemosaturnalis latifolia* (Kozur & Mostler). GSC 131227, from GSC loc. C-158510 (=88-SHB-3), Shields Bay, Graham Island.
6. *Praemosaturnalis gracilis* (Kozur & Mostler). GSC 101905, from GSC loc. C-158510 (=88-SHB-3), Shields Bay, Graham Island.
7. *Nabolella trispinosa* (Carter). GSC 102071, from GSC loc. C-156743 (=88-KPA-E), Kennecott Point.
8. *Proparvicingula moniliformis* Carter. GSC 85919, from GSC loc. C-140373 (=85-SP-9/1), Louise Island.
9. *Bistarkum cylindratum* Carter. GSC 101981, from GSC loc. C-173275 (=89-SKUD-13), Kunga Island, southeast side.
10. *Globolaxtorum hullae* (Yeh). GSC 131228, from GSC loc. C-164737 (=89-KPX-3), Kennecott Point, Graham Island.
11. *Praemosaturnalis huxleyensis* (Carter). GSC 101898, from GSC loc. C-173308 (=89-SKUB-19), Kunga Island, southeast side.
12. *Praecitriduma canthofistula* Carter. GSC 85916, from GSC loc. C-164693/14 (=87-SKUB-14), Kunga Island, southeast side.
13. *Ferresium triquetrum* Carter. GSC 101966, from GSC loc. C-164606/7 (=87-SKUD-7), Kunga Island, southeast side.
14. *Pentaspogodiscus? dihexacanthus* Carter. GSC 102020, from GSC loc. C-127798 (=86-SP-1/1), Louise Island.
15. *Serilla ellisensis* (Carter). GSC 131236, from GSC loc. C-173280 (=89-SKUD-18), Kunga Island, southeast side.
16. *Praecitriduma mostleri* Kozur. GSC 131229, from GSC loc. C-173275 (=89-SKUD-13), Kunga Island, southeast side.

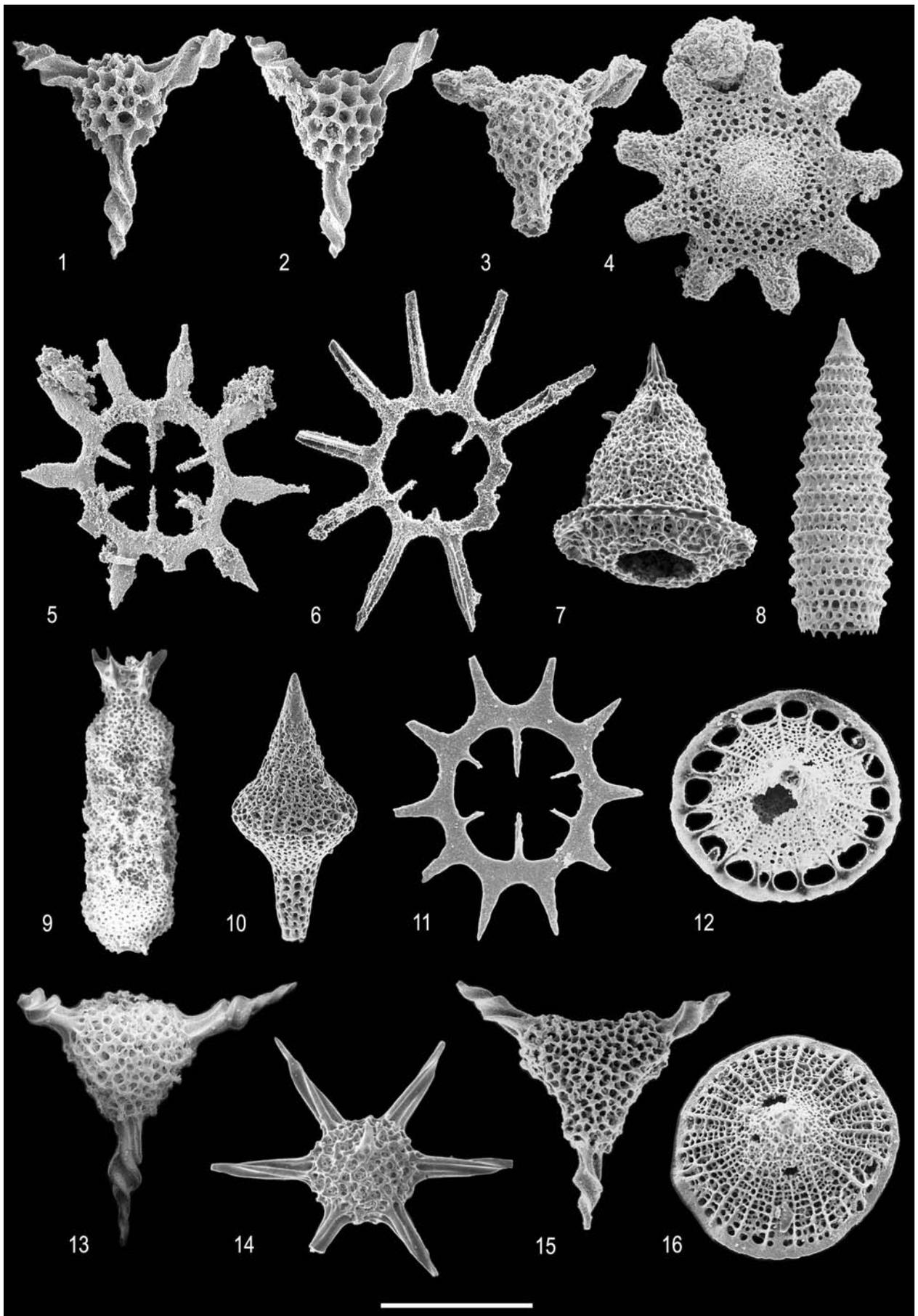
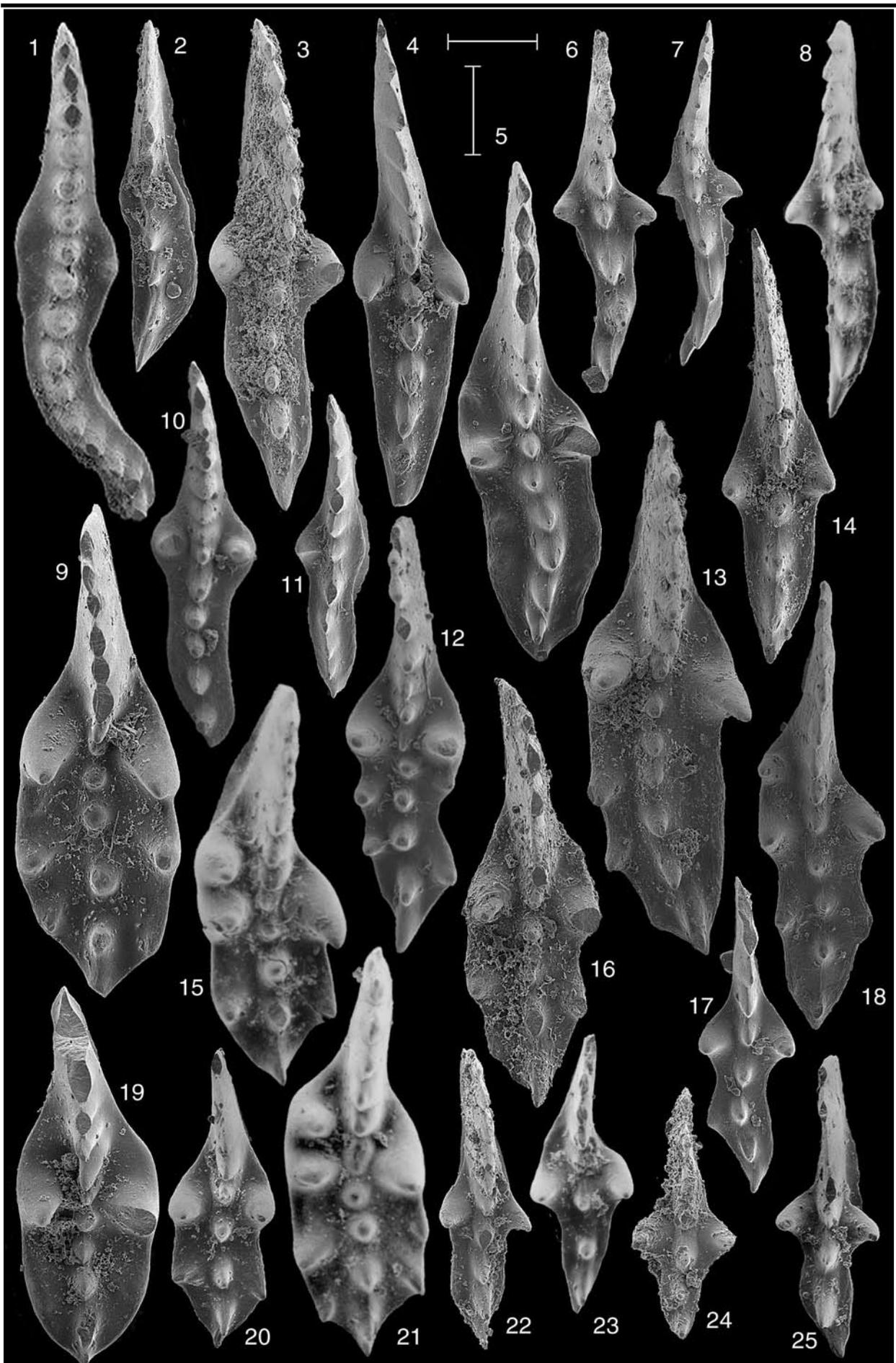


Plate 2.

Upper Norian and Rhaetian conodonts from Kennecott Point, QCI, except fig. 21, from Kunga Island. Scale bar = 100 μm (x160).

- 1, 3, 5, 8, 10. *Epigondolella mosheri* Kozur & Mostler, Morphotype C. 1. GSC 131198, from GSC loc. C-173298 (=SKU-B9), extreme element; 3. GSC 131199, from GSC loc. C-176907 (=90-X17); one node lost; 5. GSC 131200, from GSC loc. C-176908 (=90-X4); 10. GSC 131201, from GSC loc. C-173298 (=SKU-B9).
2. *Parvigondolella* sp. C. GSC 131202, from GSC loc. C-164739 (=89-X5).
- 4, 6, 7, 11. *Epigondolella mosheri* Kozur & Mostler, Morphotype A. 4. GSC 131203, from GSC loc. C-156798 (=88-10); 6. GSC 131204, from GSC loc. C-164737 (=89-3); 7. GSC 131205, from GSC loc. C-156793 (=88-E); 8. GSC 131206, from GSC loc. C-140478 (=87-6); 11. GSC 131207, from GSC loc. C-159349 (=89-10); one node lost.
- 9, 19, 20. *Epigondolella englandi* Orchard. 9. GSC 131208, from GSC loc. C-176906 (=90-X16); 19. GSC 131209, from GSC loc. C-176904 (=90-X14); 20. GSC 131210, from GSC loc. C-140477 (=87-5).
- 12, 13, 16-18. *Epigondolella mosheri* Kozur & Mostler, Morphotype B. 12. GSC 131211, from GSC loc. C-173298 (=SKU-B9); 13. GSC 131212, from GSC loc. C-176901 (=90-X9); 18. GSC 131215, from GSC loc. C-156793 (=88-E).
- 14, 22-25. *Epigondolella bidentata* Mosher. 14. GSC 131216, from GSC loc. C-156792 (=88-5); advanced form; 22. GSC 131217, from GSC loc. C-176895 (=90-M17); advanced form; 23. GSC 131218, from GSC loc. C-140477 (=87-5); 24. GSC 131219, from GSC loc. C-176895 (=90-M17); 25. GSC 131220, from GSC loc. C-158533 (=88-3A).
- 15, 21. *Epigondolella carinata* Orchard. 15. GSC 131221, from GSC loc. C-140477 (=87-5); 21. GSC 131222, from GSC loc. C-173356 (=KU-F7).
- 16, 17. *Epigondolella* aff. *mosheri* Kozur & Mostler, Morphotype B. 16. GSC 131213, from GSC loc. C-176895 (=90-M17); 17. GSC 131214, from GSC loc. C-159340 (=89-2).



Updated bio- and magnetostratigraphy from Steinbergkogel (Austria), candidate GSSP for the base of the Rhaetian stage.

L. Krystyn¹, S. Richoz¹, Y. Gallet², H. Bouquere², W.M. Kürschner³ and C. Spötl⁴

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

leopold.krystyn@univie.ac.at

²Equipe de Paléomagnétisme, Institut de Physique du Globe de Paris, UMR CNRS 7154, 4 Place Jussieu, 75252 Paris cedex 05.

³Palaeoecology, IEB, Laboratory of Palaeobotany and Palynology, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands.

⁴Institut für Geologie und Paläontologie, Universität Innsbruck, Innrain 52, 6020 Innsbruck, Austria.

Abstract For the candidate GSSP section STK-A and a recent, parallel, section STK-B+C new pelagic biodata are presented enlarging considerably the correlational potential of the two proposed Norian-Rhaetian boundary options: 1) FO of *Misikella hernsteini* and 2) FAD of *Misikella posthernsteini*, 70 cm above option 1. Discovery of *Epigondolella mosheri* s.l. considerably below both events reduce the chance to use this species in its broad present concept as a direct boundary proxy in North America. A major turnover in leiostracean ammonoids of the widespread distributed families Arcestidae and Phylloceratidae helps in correlating option 1 to ammonoid-poor Tethyan environments such as reef or other shallow marine environments. A new, 30 m thick magnetostratigraphy from Upper Norian to early Rhaetian strata in Steinbergkogel provides an expanded insight in the magnetic zonal sequence and thereby a better constrained global correlation chance for the principal boundary options 1 and 2.

Historical Review

The Rhaetian stage was introduced by Guembel (1859) about 150 years ago for the Alpine “Schichten der *Rhaetavicula contorta*” that, unfortunately, contained at the base age-insignificant, purely facies dependent shallow-water fossils overlying the virtually fossil-free Hauptdolomite Formation. This led to a longlasting correlation problem of the Norian – Rhaetian boundary and to an unstable and confusing stratigraphic nomenclature. The stage became only recently stabilized when Carter (1993) described in North America a strong radiolarian faunal change that occurs in close temporary proximity to the disappearance of the bivalve *Monotis*, and was supposed to correspond to the appearance of the conodont *Misikella* and of the ammonoid *Paracochloceras*. The last two events, which are closely related in time, (perhaps separated by less than 100 Ka) have later been favored by STS (Orchard, 2003) as future NRB proxies and form the basis for first and second boundary options discussed here. A third, non-competitive boundary option is distinctly higher up and close to the traditional Norian-Rhaetian ammonoid boundary used for many decades. This traditional boundary dates back to Kittl (1903) who was the first to separate Norian *Cochloceras* beds from Rhaetian *Choristoceras* marls (fig. 1). Kozur (1973) adopted Kittl's scheme without making reference to it, and used the Norian age of the *Cochloceras* beds sensu Kittl for another two decades till Carter initiated the change.

New biodata and boundary options 1 – 3

Detailed mapping of the Steinbergkogel has resulted in an

exact lithostratigraphic localization of all studied sections and fossil localities (fig. 2). Through the excavation of parts of quarry STK it was possible to measure and sample another NRB sequence called as STK-B+C, located along strike of the proposed GSSP candidate STK-A (Krystyn et al., 2007), but separated from it by 30 m of unexposed terrain. An updated summary of bio-, magneto- and chemostratigraphic data for STK-A is shown in figure 3 and for STK-B+C in figure 4. New conodonts from the two sections are figured in plate 1 where the first documented Tethyan record of *E. englandi* (pl. 1, fig. 2-3) and *E. mosheri* (pl. 1, fig. 4-6) is notable. The global correlation potential of boundary options 1 and 2 is discussed in more detail in Orchard et al., this Albertiana volume. A noteworthy result of the newly proposed NRB, especially for extinction related studies, is the fact that most of the hitherto well-known Norian reefs of the Tethys will become Rhaetian in the future.

1) *Option 1*: FO of *Misikella hernsteini*
Pros:

This is an easily recognizable and widely represented species (pl. 1, fig. 8-10) in low palaeolatitude (LPL) regions of the Tethys. Option 1 is marked in section STK-B+C by the FO of both *Oncodella paucidentata* (pl.1, fig. 7), and *Epigondolella mosheri* morphotype A of Orchard et al., 2007 (pl. 1, fig. 6), a form that might occur only rarely in the Tethys. Other proxies are the FO of the phylloceratid *Tragorhacoceras* and a distinct turnover in arcestid ammonoids marked by the appearance of the genus *Rhaetites* (group of *Arcestes gigantogaleatus*) and of new *Stenarcestes* species (of *S. ptychodes* group) most of them widely recorded in LPL Rhaetian faunas, slightly above the FO

		Guembel, 1859 Tollmann, 1967	Mojsisovics, 1869, 1893	Tuchkov, 1962 Dagys, 1988	Krystyn, 1980, 1983, 1987
Rhaetian		Koessen Beds	<i>Avicula Contorta</i>	Post-Monotis Beds	<i>V. stuerzenbaumi</i> <i>Ch. haueri</i> Sz.
Norian/ Sevatian		Hauptdolomite	<i>Cochloceras -Schichten</i>	<i>Cochloceras suessi</i>	<i>S. reticulatus</i> [= <i>Paracochl. suessi</i>]
			+ <i>P. metternichi</i>	(<i>Halorites macer</i>)	<i>Sagenites quinquepunctatus</i>

		Mojsisovics, 1869, 1893	Kittl, 1903	Kozur, 1973-1989	Krystyn, 1980, 1983, 1987
Rhaetian		<i>Avicula contorta</i>	“ <i>Choristoceras- Mergel</i> ” <i>Ch. haueri</i>	<i>Ch. haueri</i>	<i>V. stuerzenbaumi</i> <i>Ch. haueri</i> Sz.
Norian/ Sevatian	<i>P. metternichi</i>	<i>P. mettern. Sz.</i>	<i>Cochloceras -Schichten</i>	<i>Cochloceras suessi</i>	<i>S. reticulatus</i> [= <i>Paracochl. suessi</i>]
		<i>Ch. haueri Sz.</i>	+ <i>P. metternichi</i>	(<i>Halorites macer</i>)	<i>Sagenites quinquepunctatus</i>

Figure 1: Historical review of Rhaetian stage and ammonoid zonal concepts.

of *M. hernsteini*. Additional proxies for option 1 are 1) the corresponding entry of *Sagenites* of the *S. reticulatus* group, 2) the slightly later LO of *Metasibirites*, a pandemic late Norian ammonoid genus, and 3) the worldwide disappearance of big *Monotis* species (*M. salinaria/sub-circularis* in low palaeolatitudes and *M. ochotica* group in the Boreal) a little below the FO of *M. hernsteini*. *Epigondolella mosheri* morphotype B sensu Orchard occurs to early (ST 4, fig. 5) in Steinbergkogel (and Hernstein) to be of boundary relevance, but the FAD of *Epigondolella mosheri* morphotype A sensu Orchard may represent a useful correlative proxy in North America.

Palynological proxies (such as FO of *Rhaetogonyaulax rhaetica* and/or *Rhaetipollis germanicus*) with importance for marginal marine and continental cross-correlations (Batten and Koppelhus, 2002; Warrington, 2002) are more difficult to establish but may appear not far below option 1. To date, palynological samples from the marly intercalations of the transition zone to the Zlambach Formation in the ravine north of the quarry have turned out to be barren. This is compared to the rather rich palynological content of other Zlambach sections (Krystyn and Kuerschner, 2005), an unexpected and unfortunate result.

Several previous palynological studies of Rhaetian reference sections in the Alpine realm, such as Kendelbach, and Weissloferbach (e.g., Morbey, 1975; Morbey and Neves, 1984; Schuurman, 1979) have suggested that the presence of *Rhaetipollis germanicus* may be a valuable biostrati-

graphic marker to characterize the Rhaetian. However, here is the entry level of *R. germanicus* still unknown because of the carbonaceous nature (facies) of the deposits (e.g. Plattenkalk, Fig. x) underlying the Rhaetian deposits (Koessen or Zlambach beds). In Britain *R. germanicus* has its lowest occurrence in the Twyning Mudstone Fm. of the St. Audrie's Bay section (Hounslow et al., 2004) which is approximately of Late Alaunian to Early Sevatian age; while in the German Keuper *R. germanicus* has been observed in the Postera beds (Schulze et al, 2005 and literature cited herein; Lund, 1977, 2003) which are assigned to the Lower Rhaetian and correlate with the Sevatian 2 of the Alpine realm. *R. germanicus* has not yet been reported from the underlying Steinmergelkeuper.

Supra - regional correlation, however, appears to be difficult – with a few exceptions maybe – because of the lateral development of distinct vegetation zones alongside climatic gradients. Similar to the present day situation plant taxa had discrete regional latitudinal and altitudinal ranges which may shift through time as a result of environmental changes. Therefore pollen and spore types can appear diachronously in the stratigraphic record. Their use for stratigraphic correlation may become restricted to a regional scale rather than long-distance or global correlations. For example, *R. germanicus* and *Limbosporites lundbladi* are reported from early to middle Norian successions in the high arctic Canadian sector (Suneby and Hills, 1988) and from Svalbard (Smith, 1982). In the low

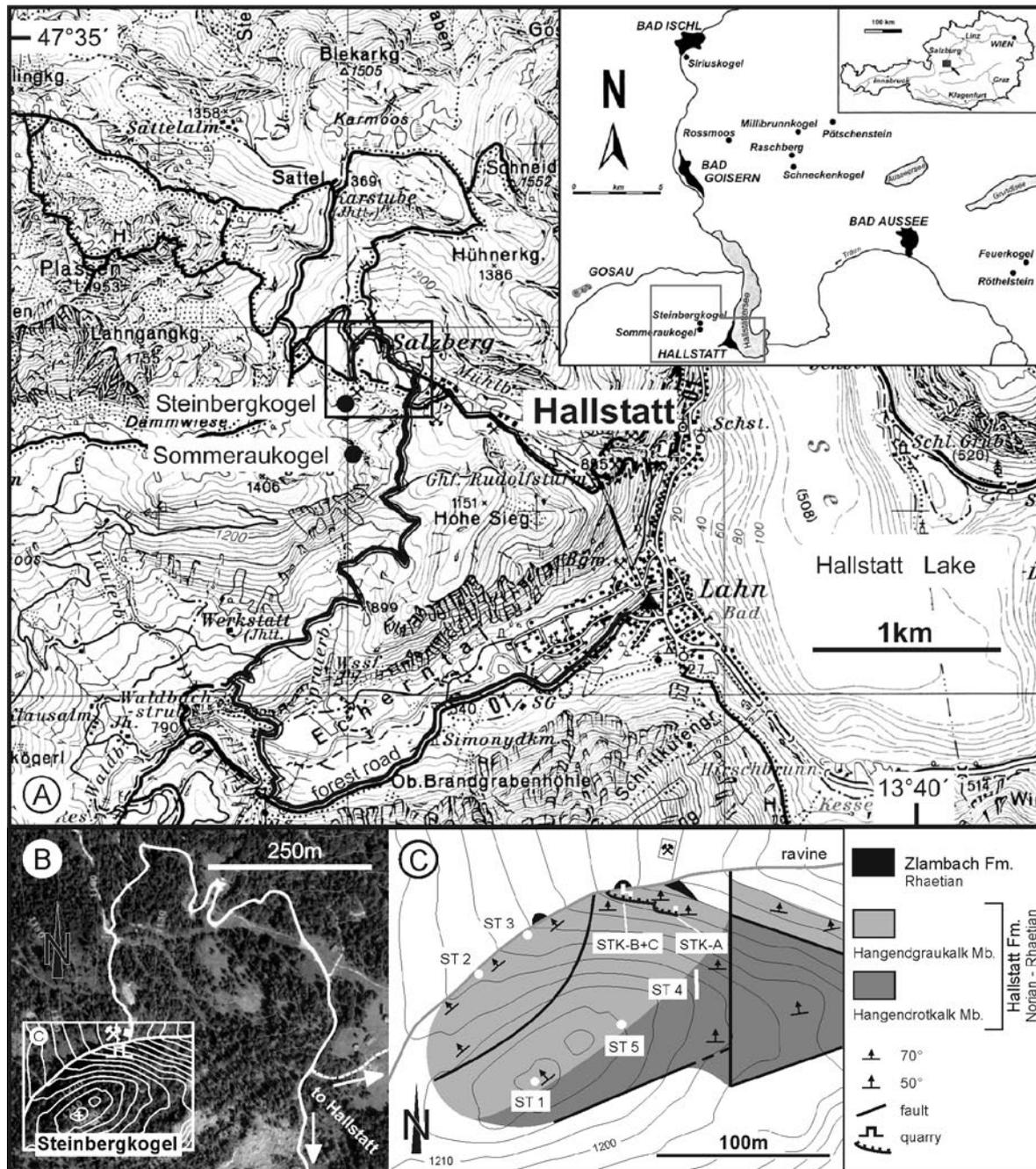


Figure 2: Topographic map of Hallstatt (A) with location of the Steinbergkogel (B) and detailed geographic and geological information on sections and fossil localities (C).

latitudes, *R. germanicus* has not been reported from the Upper Triassic Nayband Formation of central eastern Iran (Ashraf, 1977; Cirilli et al., 2005) but is present in samples from the Alborz mountains of Northern Iran (Achilles et al., 1984; Schweitzer et al., 1987).

Among dinoflagellate cysts, *Rhaetogonyaulax rhaetica* has been found to be useful, but again, the exact lowest occurrence datum is yet unknown. Our preliminary data from Turkey (Kasimlar Formation, Taurus Mountains) suggest that *R. wiggensii*, associated with *Heibergella* sp. occurs in sediments of Sevatian 1 age (dated by Monotis salinaria) while *R. rhaetica* is still absent. In many European sections (incl. borehole data) the FO datum of *R. rhaetica* appears to be facies dependent, as it correlates with a major transgression during the Rhaetian. In the

southern hemisphere *R. rhaetica* is also widely recognized in sediments assigned to a Rhaetian age (Brenner, 1992; Brenner et al., 1992; Backhouse et al. and literature cited herein). However, the exact FO datum is unknown as the underlying older (Norian) rocks are continental and the occurrence of *R. rhaetica* appears to be connected to a marine transgressional phase.

A prominent magnetic polarity change from a long Normal to a distinct Reversal follows soon above the *hernsteini* event (fig. 3-5) and can be recognized in other Tethyan magnetostratigraphies; by a comparable polarity signature it may be identifiable in the lacustrine Newark magneto-chronology too (Gallet et al., 2007).

Cons:

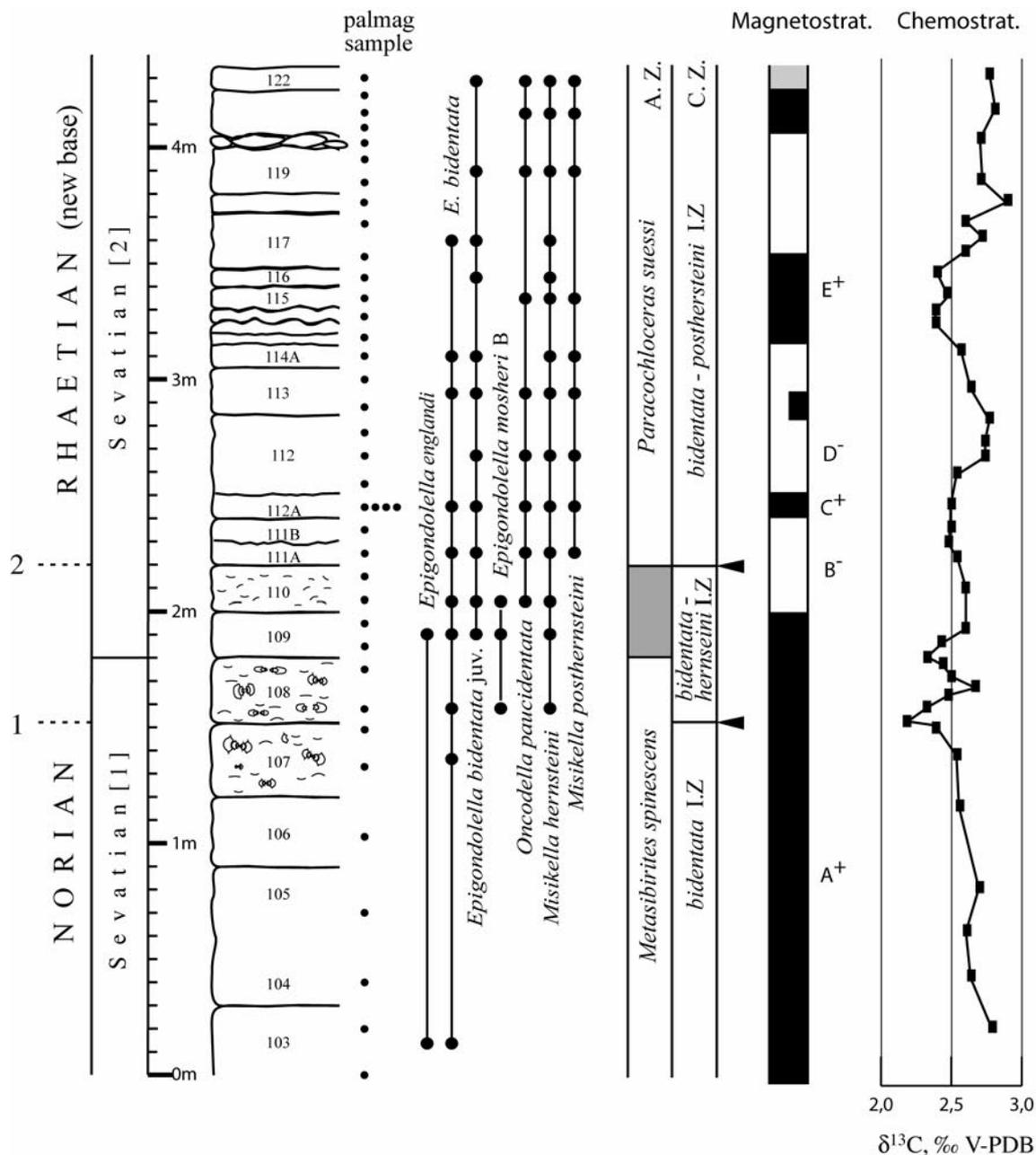


Figure 3: Integrated bio-, magneto- and chemostratigraphy of the candidate section STK-A, note boundary options 1 and 2; Sevastian 1 and 2 refer to previous Upper Norian classification.

No forerunner of the event conodont is known, the species is very rare at the beginning (1 spec. per 5 kg) and not recorded from time-corresponding beds in cratonic America and most of the Panthalassa realm.

2) Option 2: FAD of *Misikella posthernsteini*

Pros:

As phylogenetic successor of the guide species of option 1, *M. posthernsteini* offers a well-established and first appearance date. A corresponding low latitude pandemic proxy is in Steinbergkogel the FO of the heteromorphic ammonoid *Paracochloceras suessi* (and the closely allied genus *Cochloceras*). Option 2 may correlate to the FO of the radiolarian *Proparvicingula moniformis* respectively to the base of this zone (Kozur, 2003) but this is questioned by Orchard et al. (this volume). Of more regional value may

be the entry of dwarf monotids and conodonts (so-called *Parvigondolella*) in parts of the Tethys around this time (fig. 2) as well as the disappearance of the pelagic hydrozoan *Heterastridium* closely above. The *posthernsteini* event follows shortly above the fore-mentioned polarity change within the last major Reversal of the topmost Triassic (Fig. 3, 4).

Cons:

M. posthernsteini is very rare at the beginning, needs large sample quantities (over 5-10 kg) to be recovered and seems to appear later in cratonic America (Orchard et al., 2007). In biofacially less favourable environments, use of this event without additional control may cause uncertainties in regional or intercontinental correlations. A distinct setback of the *posthernsteini* event is the absence of an adequate palynostratigraphic link.

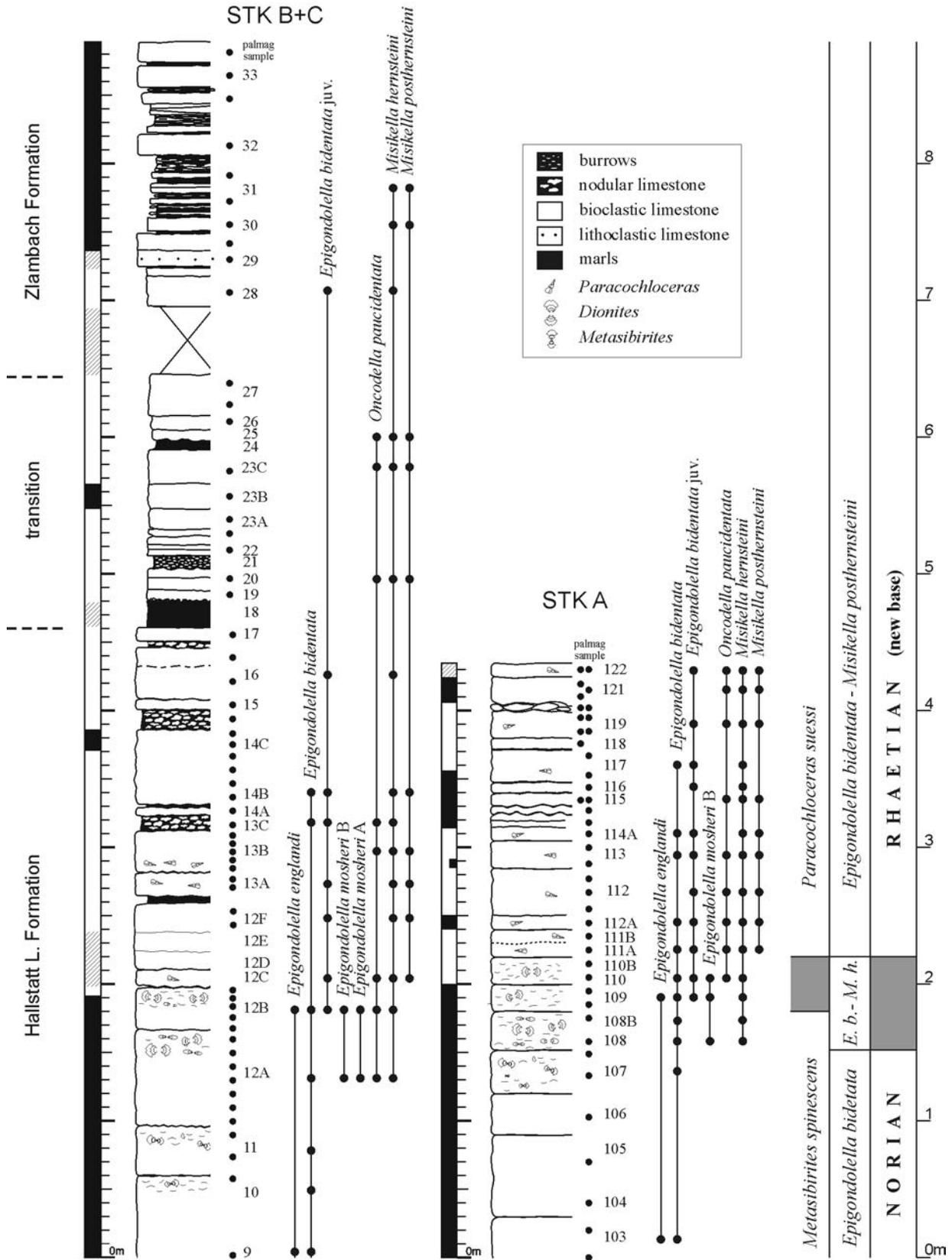


Figure 4: Bio- and magnetostratigraphic correlation of the candidate section A with section B+C in quarry STK; note the high coincidence of bio- and magneto-events between the sections.

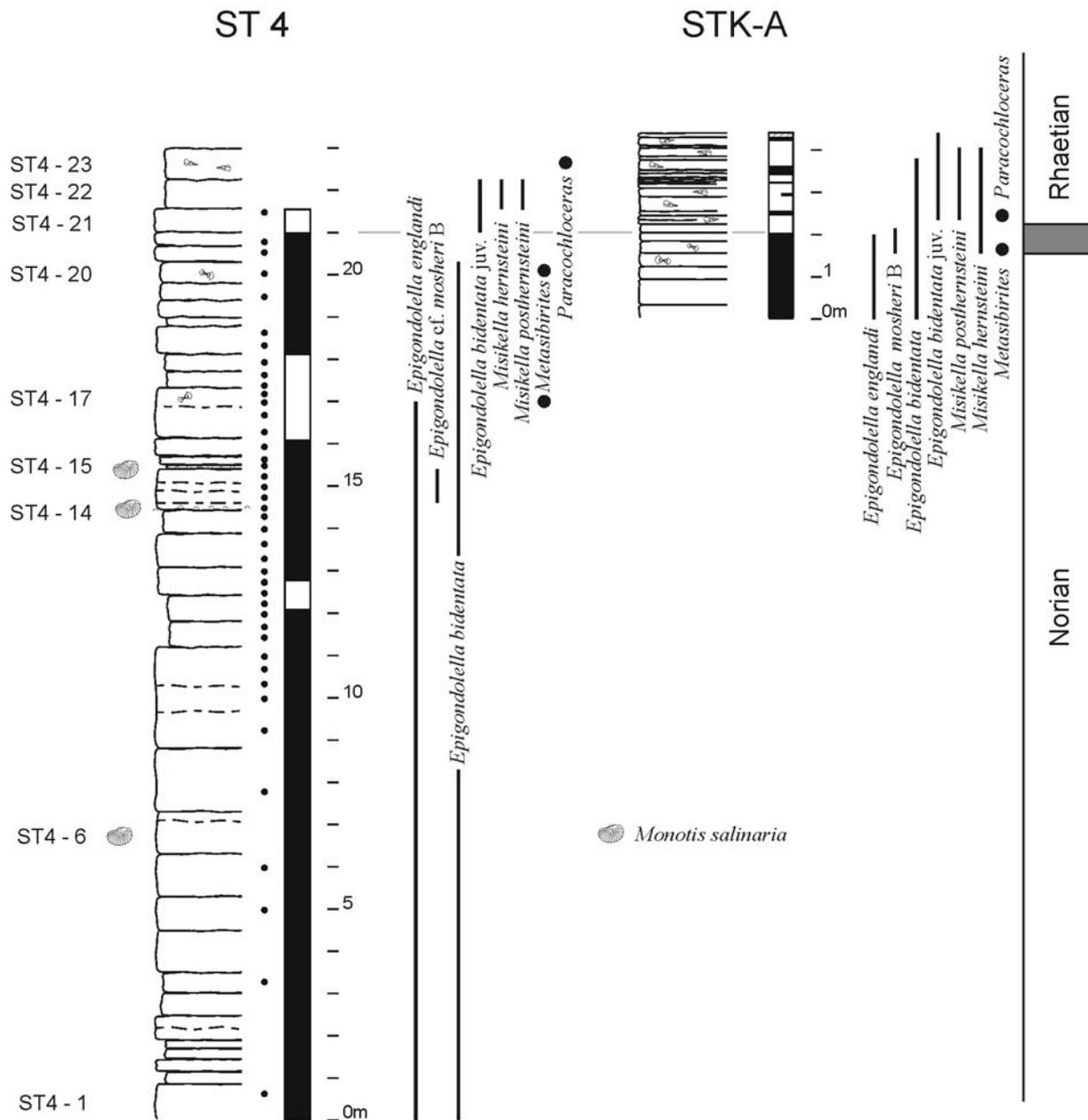


Figure 5: Upper Norian magnetostratigraphy and correlation of section ST 4 with STK-A.

3) Option 3: FA of Vandaites

Pros:

This is a very prominent ammonoid boundary with the additional FO of *Cycloceltites* and *Choristoceras* as well as the disappearance of *Sagenites*, *Dionites* and *Pinacoceras*. Other proxies are the appearance of the cosmopolitan bivalve *Otapiria* and the sporomorph *Limbosporites lundbladii*.

This boundary option is also characterize by a distinct turnover in the pollen and spores and marine palynomorphs. Current research in the Kleiner Zlambach section revealed the top occurrences of several sporomorphs such as *Enzonalaspores vicens*, *Vallasporites ignacii*, *Patinasporites toralis*, *Ellipsovelatisporites rugosus*, *Partitisporites spp.*, *Triadispora spp.*, while higher up in the section new elements, such as *Chasmatosporites sp.*, *Quadraeculina*

anaeliformis, *Limbosporites lundbladii*, enter the record (Fig. 5). These sporomorph assemblages correlate with the transition between the TL and LR concurrent-range zones distinguished by Morbey (1975) within the Karpathian facies of the Koessen beds in the Kendelbach section. The same palynofloral turnover is also easily recognizable in the Germanic Triassic basin within the Exter Formation at the transition between the Postera and Contorta beds (ko1 and Ko2) (Schulze et al. 2005 and literature cited herein)

Intriguingly, the marine organic-walled phytoplankton record shows an acme of dinoflagellate cysts (*Rhaetogonyaulax*, *Noricysta*, *Heibergella*) and coincides approximately with the *Cycloceltites* – *Vandaites* event in the ammonoid record mentioned above (Fig. 5). A similar dinoflagellate cyst event has been found in the middle part of the Heiberg Formation from the Sverdrup basin in the arctic Canada which is assigned to the Upper Norian

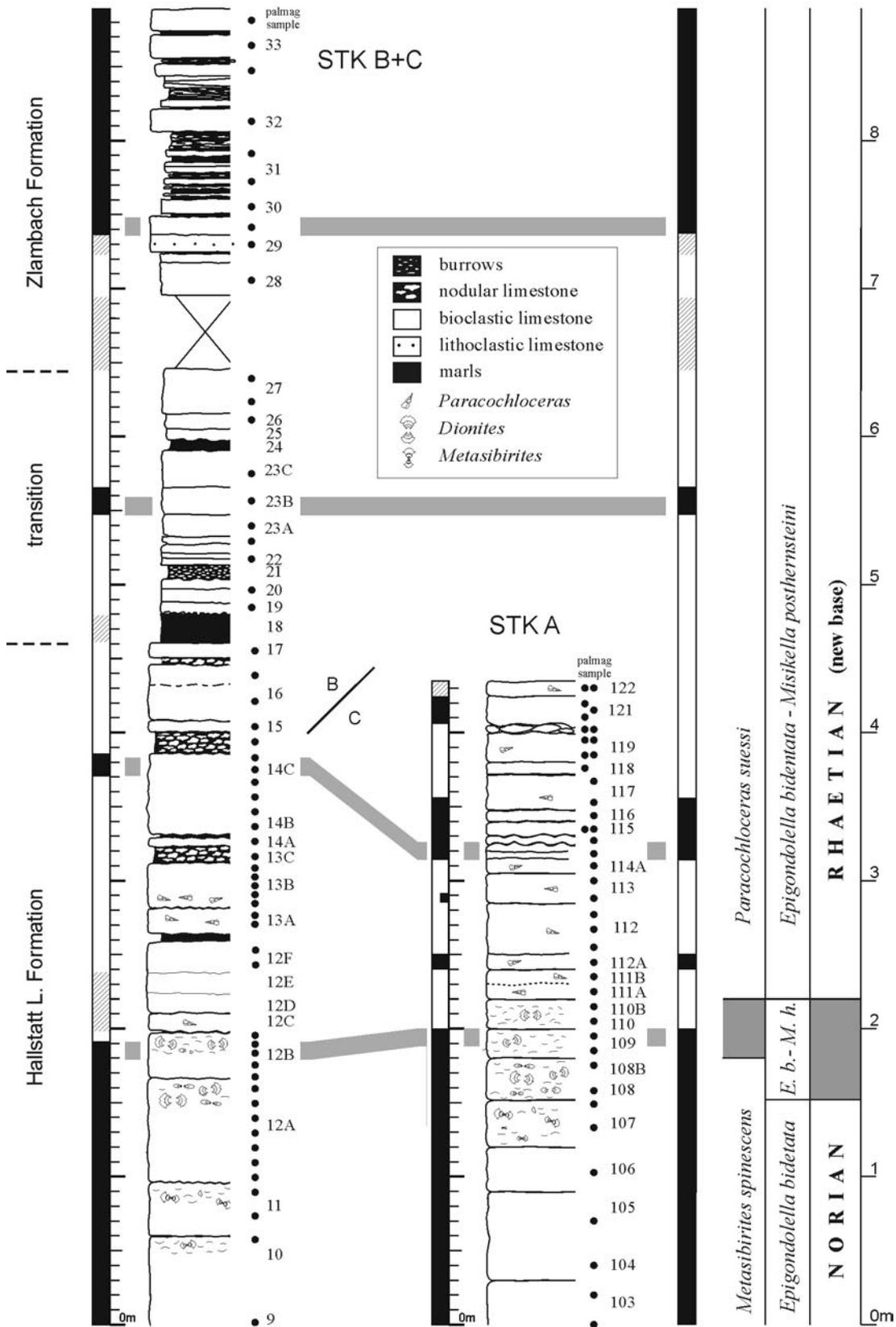


Figure 6: Latest Norian to early Rhaetian magnetostratigraphy from quarry STK.

- Rhaetian (Suneby and Hills, 1988).

Cons:

No changes in conodonts are known with option 3, which is distinctly above the recommended boundary of the STS, and a correlation with the magnetostratigraphy is also not established.

Magnetostratigraphy

The composite magnetostratigraphic sequence obtained from the Steinbergkogel sections ST 4 and STK-B+C contains 13 magnetic polarity intervals (fig. 5, 6). The new data correlate quite well with previous marine Tethyan magnetostratigraphic sequences determined from the Austrian Scheibelkogel, the Italian Pizzo Mondello and the Turkish Oyuklu sections (Gallet et al., 1996; 2007; Muttoni et al., 2001). In Steinbergkogel, the Norian/Rhaetian boundary options 1 and 2 are located in close proximity to a magnetic interval of reversed polarity. This reverse interval is intercalated between a stratigraphically thicker (below) and a significantly thinner (above) normal magnetic polarity interval, which constitutes a relatively distinctive magnetic zonation (Fig. 5). Such a magnetic polarity pattern may be therefore favourable for using magnetostratigraphy as a correlation (and a dating) tool during the late Triassic.

Carbon Isotope stratigraphy

The $\delta^{13}\text{C}_{\text{carb}}$ curve (fig. 3) shows no significant variations across all three boundary options. For a detailed discussion of the carbon isotope record see Krystyn et al. (2007).

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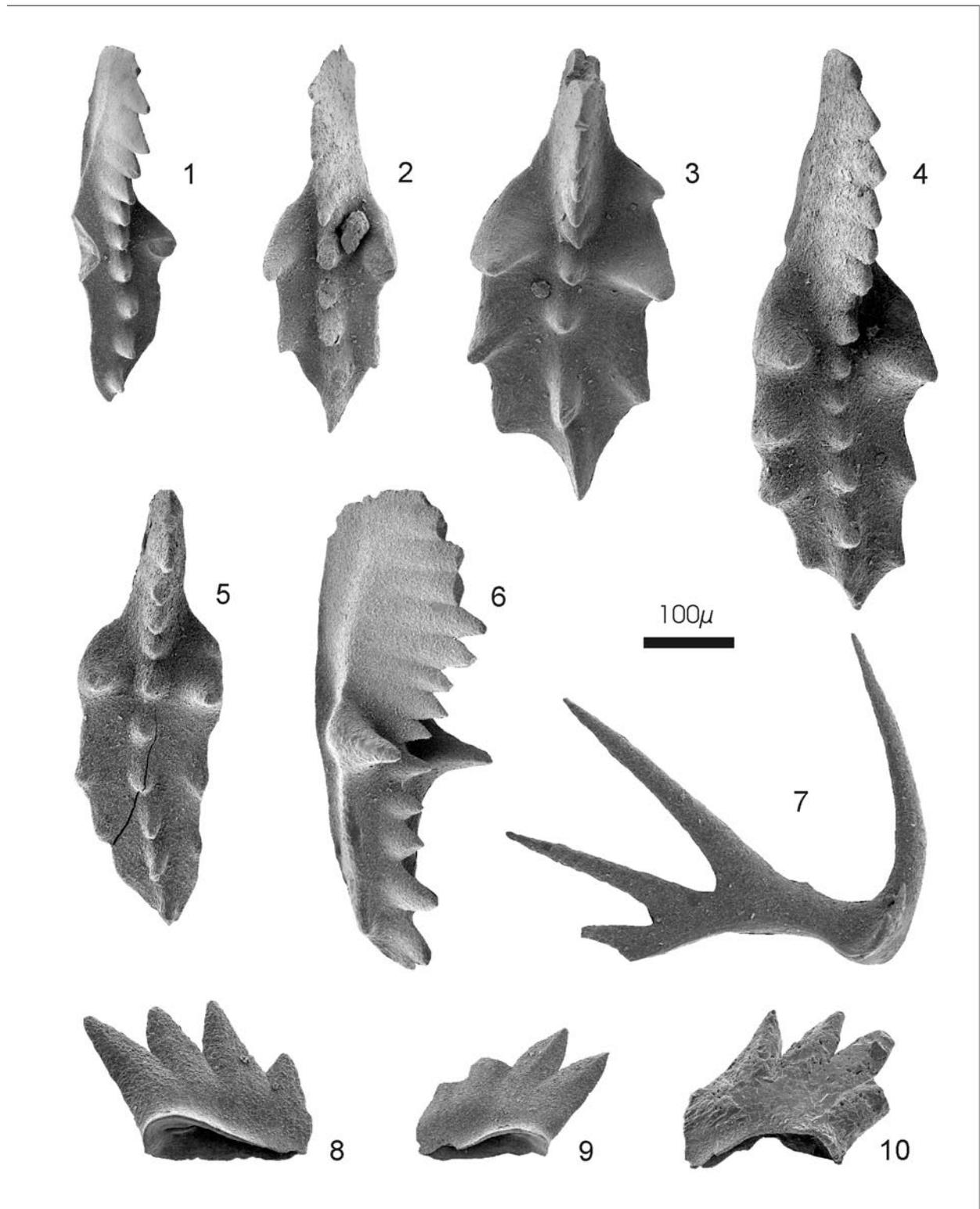


Plate 1

Conodonts from the candidate GSSP section STK-A (Fig. 1, 2, 4-6, 8, 10) and from STK-B+C (Fig. 3, 7, 9). Scale bar = 100µ.

Fig. 1: *Epigondolella bidentata* Mosher, bed 109.

Fig. 2,3: *Epigondolella englandi* Orchard – 2: bed 103, 3: bed 12B.

Fig. 4-5: *Epigondolella mosheri* Kozur & Mostler morphotype B, bed 109.

Fig. 6: *Epigondolella mosheri* Kozur & Mostler morphotype A, bed 109.

Fig. 7: *Oncodella paucidentata* (Mostler), bed 12A.

Fig. 8-10: *Misikella hernsteini* (Mostler) – 8: bed 110, 9: bed 12A, 10: bed 109.

Proxies and Triassic GSSPs

Spencer G. Lucas

New Mexico Museum of Natural History, 1801 Mountain Road N. W., Albuquerque, NM 87104 USA spencer.lucas@state.nm.us

Introduction

The time has arrived to decide on GSSPs (global stratotype sections and points) for the bases of five Triassic stages (Olenekian, Anisian, Carnian, Norian and Rhaetian), and much discussion is now focused on defining these boundaries by August of 2008. The rationale behind and the criteria for GSSP selection have been discussed at length, particularly by the leadership of the ICS (International Commission on Stratigraphy) over the past 20 years (e.g., Cowie et al., 1986; Remane et al., 1996; Walsh et al., 2004). However, I believe these discussions have not sufficiently stressed the significance to GSSP definition of what have been called “other markers” or “secondary markers” of a GSSP. I call these markers “proxies” (e.g., Lucas et al., 2007) and emphasize their significance to Triassic GSSP definition.

What is a proxy?

The word proxy can be defined as “the authority to act for another.” GSSP definitions begin with a primary marker—the event (biotic or non-biotic) used to define the GSSP level (point)—a “marker event of optimal correlation potential” (Remane et al., 1996, p. 79). Proxies are other events (biotic or non-biotic) that are temporally close to the primary marker. Proxies can provide correla-

tions to locations where the primary marker is not present. Furthermore, a temporal succession of proxies can be used to evaluate the synchrony of the primary marker at different localities. Thus, proxies aid in correlation of the GSSP level, especially in places where the primary marker is absent.

Proxies and GSSPs

GSSPs for Phanerozoic strata have been defined in marine strata, almost exclusively by biostratigraphic (biotic events) criteria. As an example, the GSSP for the base of the Ladinian (Brack et al., 2005) is defined by the lowest occurrence of the ammonoid *Eoprotrachyceras curionii*, which is the base of the *E. curionii* zone and the onset of the ammonoid family Trachyceratidae. Proxies of this GSSP (Brack et al., 2005 referred to them as “secondary global markers”) include a conodont lowest occurrence, a very short normal magnetochron and the radioisotopic ages of ash beds that bracket the GSSP. These proxies provide criteria by which to correlate the GSSP level in sections where *E. curionii* is absent. At those sections they are not “secondary,” but actually the primary markers of correlation, which is why I prefer to call them proxies and not secondary markers.

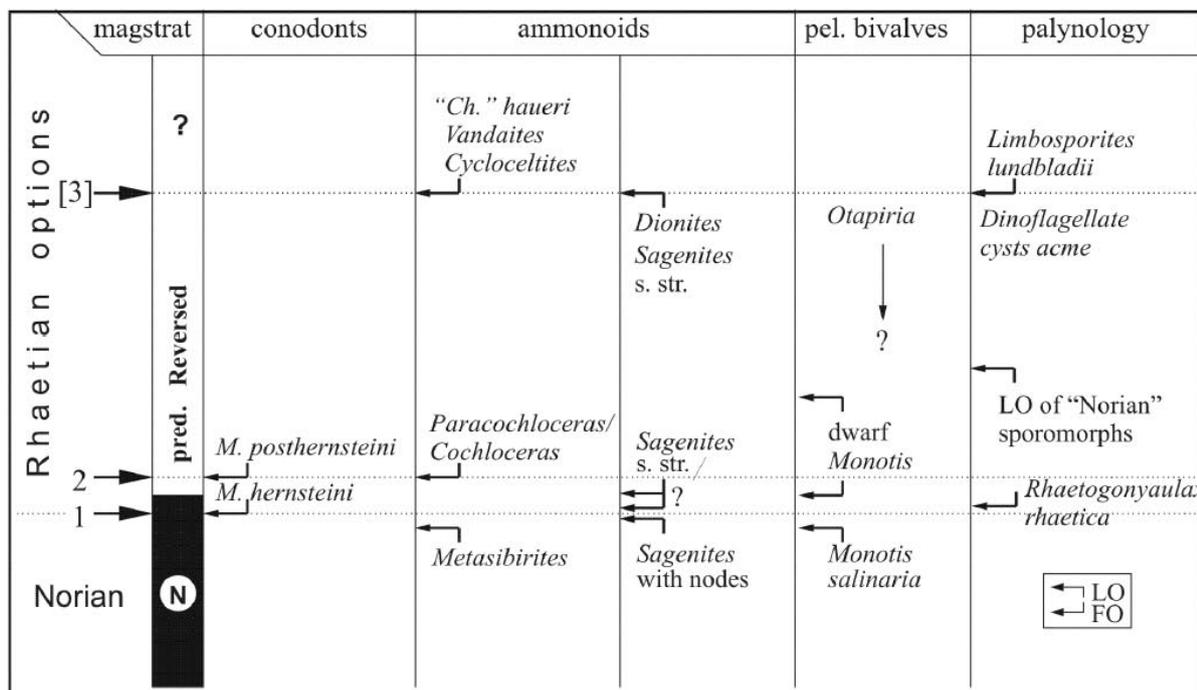


Figure 1: Possible GSSP levels (1, 2, 3) and proxies for the base of the Rhaetian Stage at the Steinbergkogel, Austria, section (from Krystyn et al., 2007).

The main emphasis in GSSP selection is on global correlateability. Walsh et al. (2004, p. 210) well emphasized the importance of proxies to global correlateability by stating that “the boundary level in any specific GSSP should be placed at a horizon correlateable not just by the primary guiding criterion, but by as many lines of independent, age-significant information as possible, such as other fossil groups, radiometrically-dated horizons, chemostratigraphic horizons, polarity reversal horizons, etc.” They (p. 215) more simply stated this as: “GSSPs should be defined so as to be correlateable by as many different lines of age-significant information as possible.”

Thus, proxies are very important, and in some sections just as important as (they replace) the primary marker. An ideal GSSP is defined by a primary marker of optimal global correlation potential closely associated with proxies that are also of broad correlation potential. Choice of a GSSP must place heavy emphasis on the proxies associated with the primary marker.

To demonstrate this in practice, consider the well-crafted proposal for a base Rhaetian GSSP by Krystyn et al. (2007). The proposed GSSP at Steinbergkogel, Austria, presents three possible levels for definition of the Rhaetian base and a variety of proxies (Fig. 1). Thus, levels 1 and 2 have a conodont lowest occurrence as the primary marker. Levels 1 and 2 look preferable to 3 because they have the better proxies. For levels 1 and 2, these include the worldwide disappearance of the bivalve *Monotis*, highest occurrence of the Norian ammonoid *Metasibirites*, and lowest occurrence of the Rhaetian ammonoids *Paracochloceras* and *Sagenites* ss. Magnetostratigraphic and palynostratigraphic events are additional proxies (Fig. 1). Level 3 is less satisfactory—it can be ammonoid defined but lacks conodont or magnetostratigraphic proxies.

The important conclusion is this: an ideal GSSP must have as many good proxies for the primary marker as possible. Proxies allow the GSSP to be correlated where the primary marker is not present, so they make a GSSP more globally correlateable. A GSSP with good proxies is a GSSP with optimal global correlateability.

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Warrington, G¹., Kürschner W. M.² & Kerp, H.³

¹*Honorary Visiting Fellow, Department of Geology, The University of Leicester, U.K. (e-mail: gw47@le.ac.uk). Address for ordinary mail: 3, Lamcote Gardens, Radcliffe on Trent, Nottingham NG12 2BS,*

²*Department of Palaeoecology, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, NL (w.m.kuerschner@bio.uu.nl)*

³*WWU, Abt. Palaeobotanik, Hindenburgplatz 57, 48143 Muenster, Germany (kerp@uni-muenster.de)*

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Future Meetings

“Upper Triassic Subdivisions, Zonations and Events”

Meeting of the late

IGCP 467 and STS co-organized by Austrian Academy of Sciences (Austrian Committee for IGCP), Vienna University (Department of Palaeontology) and Geological Survey of Austria: September, 28 -October, 2, 2008, Bad Goisern (UNESCO world heritage site Dachstein-Hallstatt/Salzkammergut, Austria).

Two session days will particularly focus on all aspects of Upper Triassic stratigraphy (bio-, chrono-, chemo-, event-, cyclo-, magnetostratigraphy); Upper Triassic extinctions and faunal turnovers, marine to non-marine respectively Alpine to Germanic/Western Europe correlations; Upper Triassic palaeobiogeography and Tethys – Panthalassa – Boreal correlations.

Excursions will include visit of the Rhaetian candidate GSSP Steinbergkogel, classical Upper Triassic ammonoid and pelagic bivalve sites, sequence and cyclostratigraphy of lagoonal Dachstein limestone, rise and demise of Upper Triassic reefs.

ORGANIZATION:

W. L. PILLER,

*Austrian National Committee for IGCP, Vienna
Institute of Earth Sciences (Geology and Palaeontology)
University of Graz
8010 Graz, Heinrichstrasse 26
Austria*

L. KRYSZYN,

*Department of Palaeontology, Vienna University
1090 Vienna, Althanstrasse 14
G. MANDL
T. HOFMANN
Geological Survey of Austria
1030 Vienna, Neulingg. 38
Austria*

CORRESPONDENCE:

*L. KRYSZYN
leopold.krystyn@univie.ac.at*

Workshop on Triassic palaeoclimatology

Bolzano / Bozen (I), June 3-7, 2008

“The climate during the Triassic? That’s easy.. everything was warm and dry...”

...or, at least this is what you generally find when, in textbooks, you look for a description of the Triassic climate. But it wasn’t probably so. Although valuable studies on Triassic climate exist, researchers from various regions and fields of Earth Sciences worked alone or in small groups, dealing mostly with short time intervals. There is a need of a more comprehensive picture of the Triassic climate through time and space, which could only stem from the interaction of research groups that worked, so far, isolated.

The aim of this workshop is to provide a forum for researchers interested in the Triassic paleoclimate. Participants will be invited to present methodological approaches and significant case histories of paleoclimatic and paleoenvironmental reconstructions at regional and global scale. Studies involving new interdisciplinary methods are particularly welcome.

The workshop is supported by the Museum of Nature South Tyrol. The scientific sessions will be held at the Museum, in the city of Bolzano/Bozen (Bindergasse 1/Via Bottai, 1).

Program

June 3: Arrival in Bolzano/Bozen, registration and welcome party. The welcome party includes a tasting of local wines; a local producer will give some description of the geographical, pedological and geological characters of the vineyards.

June 4-5: Keynote lectures (Paul Wignall, Peter Hochuli), scientific sessions and round table discussions.

June 6-7: Field trip to Ladinian and Carnian outcrops of the Dolomites. The field trip will focus on the response of carbonate platforms to climate change, and on climate sensitive facies, including paleosols (it might include the Rifugio Dibona section and part of the Ladinian Schlern/Sciliar carbonate buildup).

Scientific Presentations

English is the official language of the workshop. All presentations, including registration forms, oral reports, posters and abstracts should be in English. Participants are invited to give oral and/or poster presentations.

Abstracts will be published in the abstract book. More detailed instructions for authors will be provided in the Second Circular.

Registration

For more informations and registration please use the homepage: <http://trias.geodolomiti.net/>

Registration Fee

The full-registration fee is € 70.00 (reduced rate for students: € 40.00). This amount includes: the abstract book; welcome party at the Museum; coffee breaks and lunches during the workshop.

Organising and Scientific Committee

Evelyn Kustatscher (Museum of Nature South Tyrol)

Piero Gianolla (University of Ferrara)

Lorenz Keim (Geological Survey of South Tyrol, University of Innsbruck)

Nereo Preto and Guido Roghi (University of Padova, and IGG-CNR, Padova)

Workshop on Triassic palaeoclimatology

Bolzano / Bozen (I), June 3-7, 2008

Registration Form

Workshop on Triassic palaeoclimatology

Bolzano / Bozen (I), Museum of Nature South Tyrol

June Thursday 3 – Saturday 7 2008

Surname (last name):

First name(s):

Institution:

City:

ZIP code:

Street, no. / P.O. Box:

Country:

Email :

Phone :

Yes, I wish to participate in the workshop “The Triassic climate”, to be held in Bolzano / Bozen, the 3-7 of June, 2008.

I am interested in giving a presentation as:

poster	talk
---------------	-------------

Title of presentation (provisional):

I wish to participate to the fieldtrip:

yes / no

Please send this preliminary reply form to
Evelyn Kustatscher
Museum of Nature South Tyrol
Bindergasse 1, I-39100 Bolzano / Bozen
e-mail: Evelyn.Kustatscher@naturmuseum.it
tel. 0039 0471 412963 - fax 0039 0471 412969
or register on our homepage <http://trias.geodolomiti.net/>

GUIDELINES FOR THE SUBMISSION OF MANUSCRIPTS TO ALBERTIANA

Albertiana is published twice a year. Contributions should be sent to the editor. In order to facilitate the production of this newsletter and reduce typing errors, authors are kindly requested to submit their contributions electronically, preferably by email. Those who are unable to submit a manuscript in electronic format are kindly requested to send flat (unfolded), clearly typed manuscripts in a 12-point typeface (sans serif) with single line spacing.

Text files can be submitted formatted as *.wpd, *.doc or *.rtf files and illustrations as pixel based graphics (e.g: *.bmp, *.tif, *.gif or *.jpeg) or vector based graphics (e.g: *.ai, *.cdr) that can be directly imported into Adobe PageMaker. Please provide good, clean, flat, printed copies (NOT xerox copies) of any illustrations, which MUST be designed to fit on an A4 page (centered, with at least 2.54 cm wide margins left and right, and 4 cm margins at the top and bottom).

Special attention should be paid to grammar and syntax - linguistic corrections will be minimal. In case of doubt, send your manuscript to a colleague for proof reading. References should be in the format used in the 'New Triassic Literature' section in issue 25 of Albertiana. Please write all Journal titles in full length. The use of names of biostratigraphic units should be in accordance with the International Stratigraphic Guide:

The formal name of a biostratigraphic unit should be formed from the names of one, or preferably no more than two, appropriate fossils combined with the appropriate term for the kind of unit in question."

The writing and printing of fossil names for stratigraphic units should be guided by the rules laid down in the International Code of Zoological Nomenclature and in the International Code of Botanical Nomenclature. The initial letter of generic names should be capitalized; the initial letter of the specific epithets should be in lowercase; taxonomic names of genera and species should be in italics. The initial letter of the unit-term (Biozone, Zone, Assemblage Zone) should be capitalized; for example, Exus albus Assemblage Zone."

The name of the fossil or fossils chosen to designate a biozone should include the genus name plus the specific epithet and also the subspecies name, if there is one. Thus Exus albus Assemblage Zone is correct. After the first

letter; for example, Exus albus may be shortened to E. albus. On the other hand, the use of the specific epithet alone, in lowercase or capitalized, in italics or not (albus Assemblage zone, Albus Assemblage zone, albus Assemblage zone, or Albus Assemblage zone), is inadvisable because it can lead to confusion in the case of frequently used species names. However, once the complete name has been cited, and if the use of the specific epithet alone does not cause ambiguous communication, it may be used, in italics and lowercase, in the designation of a biozone; for example, uniformis Zone."

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

Subcommission on Triassic Stratigraphy

STS Chairman

Dr. Mike Orchard, Geological Survey of Canada, 101-605 Robson Street, Vancouver, British Columbia, Canada.

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*Dr. Marco Balini Professore associato, Paleontology Dipartimento di Scienze della Terra "Ardito Desio"
Universita' degli Studi di Milano Via Mangiagalli 34, 20133 Milano, Italy*

Vice Chairman

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People's Republic of China*

STS Secretary General

*Dr Chris McRoberts Department of Geology State University of New York at Cortland
P.O. Box 2000 Cortland, New York 13045 USA*

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European readers can send a Eurocheque made payable in Euro to Dr. Zwier Smeenk, Laboratory of Palaeobotany and Palynology, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands. Everyone else is kindly requested to send cash in a closed non-transparent envelope to the above Utrecht adress. Because of the high provision costs of other cheques/currencies, other methods of payment cannot be accepted. Institutions can receive ALBERTIANA on an exchange basis.

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