

# ALBERTIANA



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## Message from the STS Chair

**Marco Balini**, STS Chair, *Department of Earth Sciences "Ardito Desio", University of Milan, Via Mangiagalli 34, 20133 Milan, Italy*

The 2016 is the last year of my second term of service as chairman of the STS and this issue of *Albertiana* provides me the opportunity to share with all of you some considerations on this experience. I do not want here to focus on my personal experience (positive in all respects), but I would like to emphasize some problems in the life and organization of the STS encountered over the past years. Some changes have been made, but to my opinion the future of the STS is still unclear. In order to be short and straight I am going to stress specific points.

### No GSSP defined since 2008, which perspective on the future?

The mission of the STS is to support the ICS in the definition of World standards in Stratigraphy. In this general framework the specific duty of the STS is to define the GSSP (Global Stratotype Section and Point) of the Triassic stages. Since the ratification of the GSSP of the Carnian Stage at Prati di Stuoeres/Stuoeres Wiesen in 2008, no Triassic GSSP has been defined. Quite a lot of work has been done on some Stage boundaries (see below) but, as a matter of fact, in the past 8 years no GSSP has been defined within the Triassic System, while quite a significant number of GSSPs have been selected by other Subcommissions, and voted by the ICS. As a matter of fact, the STS cannot be anymore considered one of the most productive Subcommissions of the ICS!

There are several reasons for the slowing down in the GSSP selection, then I am not surprised of the result. However, I worry about the future.

The selection of a GSSP is a long lasting procedure, from 11 years for the Ladinian/Carnian boundary to the nearly 20 years for the Permian/Triassic and the Anisian/Ladinian boundaries. The selection of the 3 GSSPs between the 2001 and 2008 is the result of a huge investment of time by several specialists with long experience on Triassic, who devoted a significant part of their scientific career to study potential candidate sections since the 1970s. Many of these specialists are now retired, or passed away.

We are in the middle of a generational turnover, but with nearly no replacements for the full positions that are left. The number of specialists in several key-groups or tools has dramatically decreased in few years. If we do not perform our duty in the next 5 years, I wonder if we can accomplish our mission.

### Liveliness of the STS

The retirement of the historical members who joined the STS in the 1970s is not the only problem we are facing now. Some senior members do not seem to be very interested in the activities

of the STS, while some young members seem to be reluctant to invest time on long term research projects such as those aimed at selecting GSSP candidates. In order to better explain these statements, I report here some facts.

The Triassic Subcommittee is presently consisting of 24 Voting Members and 118 Corresponding members. A major update of the list of the corresponding was done in 2011, when 34 new members accepted the invitation to join in the STS. In term of number, the STS has never been so large, but if we take into account the participation of the member to the life of the STS, the situation is more than depressing. There is no interexchange between a major part of the Voting Members and the Chair, the Voting Members seem to delegate all the decisions to the Chair.

The Voting Members are crucial for every Subcommittee, because of their wide experience. They form the core of the Subcommittee. They should have to provide ideas, suggestions and support to the Chairman, Vicechairman and Secretary. If they are not active, the Executive Committee is left alone.

### International projects

Since its beginning, the STS has benefit from IGCPs, (e.g. IGCP 458 and 467), but after the end of IGCP 467, the STS activities lack of any support from UNESCO through IGCP. This lack is a severe limitation, especially after the beginning of the world economic crisis of 2009, that resulted in a severe cut of budget for scientific research in many countries.

To tell the truth, the IGCP 630 ("Permian-Triassic climatic & environmental extremes and biotic response") includes in its wide range of goals some goals overlapping with the mission of STS [e.g. Integrated stratigraphic (biostratigraphy, cyclostratigraphy, magnetostratigraphy, and geochronology) correlations between marine and terrestrial P-Tr and Early Triassic successions]. This IGCP, however, was not conceived, designed and scheduled in cooperation with the Executive Committee of the STS. As result, there is no integration between the activities and deadlines of the Working Groups of the STS (namely the Induan/Olenekian Working Group) and the schedule of meetings of IGCP 630.

I do not want to emphasize here a controversy, but as a matter of fact, despite of the huge investment of money and people, as well as the high number of workshops and excursions, no significant improvements to the solution of the Induan/Olenekian boundary thus far resulted neither from the IGCP 630, nor from the previous IGCP 572 ("Restoration of Marine Ecosystems following the Permian-Triassic Mass Extinction: lessons for the present").

### Is everything going bad?

Of course not. A tremendous amount of work has been done in the past years on several aspects of Triassic stratigraphy. Especially on the Induan-Olenekian, and on the Carnian-Rhaetian intervals. A significant part of this work is done by relatively few groups of stratigraphers, but they are very active. Few workshops and field workshops have been organized, but they have always been successful. Albertiana has been revitalized by the new Editor Chris McRoberts. There are several new entries in the Subcommittee, this is an investment on the future.

### Which future for the STS?

I hope the Voting Members will react to my shaking remarks. As I already wrote, the Voting Members are crucial for the life of the Subcommittee. I am asking them to motivate and stimulate their researchers and PhD students to participate to the STS activities. I will also do my best to motivate some young specialists through the selection of some of them as new Voting Members.

Membership must be active. The ideal member of the subcommittee is not a specialist who is publishing many papers on Triassic, but is a person who is actively participating to the life of the Subcommittee, no matter if his/her H-index is low, medium or high. One of the easiest ways to participate to the life of the Subcommittee, is by submitting contributions to the Albertiana. All the STS members as well as all the Triassic specialists non members of the STS, are warmly invited to submit contributions to our newsletter. Albertiana is the reference journal for the discussions on Triassic stratigraphy in broad sense. Albertiana is not an ISI or Scopus journal, however, it is a scientific journal in all respects and it publishes short communications, papers, and discussions that will never be published on ISI or Scopus journals. Even more important, the time you need to write a manuscript suitable for publication on Albertiana is usually few days.

I am going to finish this report by emphasizing that investing time on the STS (as in every other Subcommittee of the STS) is worth for. The goals of the Subcommittee are not old fashioned or not up-to-date. It is exactly the opposite. The time scales (and their definition) are one of the most popular topics in Geology. Just to give you crude numbers, in the last 5 years about 241,000 papers have been published on “time scale” and “Geology” (data source: Google Scholar). In the same time interval 20,700 papers have been published on “time scale” and “Stratigraphy”. This striking difference of one order of magnitude between the two statistics, is a basic demonstration of the strategic importance of Stratigraphy in Earth Sciences.

The time scales are calibrated by rather small group of stratigraphers, but their results are crucial for a much wider community of Earth Scientists.

One additional solution to motivate Triassic specialists to take part of the life of the STS, could be the organization international congress on the Triassic System, every 4 years. The specialists on Carboniferous, Permian, Jurassic, Cretaceous and Paleogene (only to report those in my mind) know that every 4 years there is an international congress dedicated to all the aspects of Stratigraphy, Paleontology, Paleoclimate and Paleogeography of their specific system. These congresses are big events, with one or two hundreds participants, on average. We had some big events on Triassic in the past (Lausanne, 1991; Halle, 1998; Albuquerque, 2007), but not on a regular basis. I do not think the Triassic is better known than the Carboniferous and the other, above mentioned, systems. It is mostly a matter of finding people and groups volunteering for the organization, and this is exactly the crucial problem. In the past years it has been difficult even finding volunteers for the organization of quite specific and logistically easier workshops. Hopefully this trend will be reversed in the near future.

**Marco Balini**

Università di Milano, Italy



## SUBCOMMISSION ON TRIASSIC STRATIGRAPHY: EXECUTIVE VOTE

**Christopher McRoberts**, STS Secretary, *Geology Department, State University of New York at Cortland, Cortland, New York, 13045 USA*

According to ICS/IUGS statutes, every four years, the subcommissions should hold an election for its executive. The previous term for the executive of the STS was set to expire in December 2015 and a call for nominations and election new executive for the period 2016-2020. A solicitation for the new executive (Chair and vice Chair) was send via email to the existng STS voting and corresponding membership. The call for nominations resulted in single nomination for Chair of the Subcommission, Mark Hounslow (Lancaster Environment Centre, Lancaster University, UK) and two nominations for Vice Chair: Zhong-Qiang Chen (China University of Geosciences at Wuhan) and Wolfram Kürschner (University of Oslo).

Balloting was conducted via email to voting members between December 8 and December 18, 2016. The results of the first round of balloting is as follows: 22 ballots were returned (from 23 voting members) resulted in a 96% return rate.

M. Hounslow for STS Chair  
18 Yes votes, 1 No vote, 3 Abstentions

Z.-q. Chen for STS Vice Chair: 10 Yes votes  
W. Kürschner for STS Vice Chair: 12 Yes votes  
0 Abstentions

Mark Hounslow was duly elected as Chair of the STS with 81.8% of returned ballots. Z.-q.Chen received 45.5% of cast ballots and W. Kürschner received 54.5% of cast ballots. The leading vice chair candidate, W. Kürschner, failed to achieved the 60% majority to successfully complete the election as stipulated in ICS statutes.

A second round of balloting was necessary to affirm the leading candidate of the first ballot, and was held via email to voting members between December 18 and and December 30, 2016. The results of the second round of ballots is as follows: 20 ballots cast (23 voting members) resulted in a 87% return rate.

W. Kürschner for STS Vice Chair  
18 Yes votes, 1 No vote, 1 Abstention

Wolfram Kürschner was duly elected as Vice Chair of the STS with 90% of returned ballots.

## REPORT OF THE NORIAN/RHAETIAN BOUNDARY WORKING GROUP

**Marco Balini**, STS Chair, *Department of Earth Sciences "Ardito Desio", University of Milan, Via Mangiagalli 34, 20133 Milan, Italy*

Leo Krystyn, who chaired this Working Group for many years, in 2014 step back from this position because he was directly involved in the group working on the candidate section Steinbergkogel (Austria). I took on the coordination of the WG, that was re-activated on October 20, 2014. The 20 members were requested to confirm their interest on taking part of the GSSP selection procedure, then on December 16, 2014, the WG members were requested to suggest possible new members. Fifteen members answered the call and suggested 8 possible new members. On the basis of the number of votes, Manuel Rigo, Dave Taylor and Simonetta Cirilli were invited to join the WG. They accepted the invitation between February and March, then the final composition of the Working Group includes the following 24 members:

Bachman, Gerhard, *Halle, Germany;*  
*gerhard.bachmann@geo.uni-halle.de*  
Balini Marco, *Milano, Italy;*  
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## STS Report

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With the new members, the WG does not conform with the composition of 20 members suggested in the ICS Statute, but the base of the Rhaetian stage is one of the most complex of the Triassic system, then it is reasonable to involve some more specialists. This is a rather common practice, followed also by other Subcommissions of the ICS.

At the end of December 2014 Manuel Rigo informed me that a second proposal of GSSP, with Pignola-Abriola as candidate section (Lagonegro basin, Southern Italy), was submitted to Lethaia. The review process and the technical editing of the accepted manuscript took quite a lot of time, then Rigo et al. proposal was presented as talk during the session S 17 of STRATI 2015 congress in Graz, Austria. The pre-print of the paper was available only in September, 2015.

The congress STRATI 2015 (July 19-23, 2015, Graz, Austria) was advertised since 2014 as the most important opportunity to discuss the Norian/Rhaetian boundary. The GSSP candidate section Steinbergkogel was visited during the pre-congress field trip FT 5 2 "End-Triassic crisis events recorded in platforms and basins of the Austrian Alps. The Triassic/Jurassic GSSP and the Norian/Rhaetian GSSP candidate". Unfortunately no one of the members of Rigo's group attended the field trip, then the discussion on the N/R boundary took place during the session S17 and the Business meeting of the STS (see the report). Four talks out of 17, and 3 posters out of 6 were on Norian-Rhaetian stratigraphy. The talks included the updated proposal for Steinbergkogel (Krystyn et al.) and the new proposal for Pignola-Abriola (Rigo et al.).

The second proposal of GSSP for the Rhaetian stage, by Rigo et al., is based on a prominent negative shift of ca. 6‰ of the  $\delta^{13}\text{C}_{\text{org}}$ , while Krystyn et al. proposal for Steinbergkogel is based on the FAD of the conodont *Misikella posthernsteini*. The latter event was already formally voted as primary marker event by the N/R boundary WG, several years ago.

At the end of STRATI congress, I asked Rigo to organize

a field trip to Pignola-Abriola, because this section has not yet been visited by many specialists. A first option was for October 2015, but it was delayed to 2016, because there was not time enough to advertise WG.

## BUSINESS MEETING OF THE STS, GRAZ, JULY 22, 2015

**Marco Balini**, STS Chair, *Department of Earth Sciences "Ardito Desio", University of Milan, Via Mangiagalli 34, 20133 Milan, Italy*

Participants: Marco Balini, Claudia Agnini, Annachiara Bartolini, Aymon Baud, Jacopo del Corso, Bruno Galbrun, Silvia Gardin, Piero Gianolla, Steve Hesselbo, Dennis Kent, Ali Murat Kilic, Leo Krystyn, Marco Levera, Gerhard Mandl, Michele Mazza, Jozsef Palfy, Camille Peyberne, Sylvain Richoz, Manuel Rigo, George Stanley, Tong Jinnan, X. Zhang.

Agenda: At the beginning of the meeting, M. Balini proposed to change the original agenda, consisting of 3 points (1. from the chair; 2. Albertiana and 3. State of the art of the discussion on Norian/Rhaetian boundary), and to dedicate the whole business meeting to the discussion of the item #3. This suggestion was accepted by all the participants.

Report: The meeting started at 12,30. All the participants accepted the proposal to dedicate the meeting to the discussion on the Norian/Rhaetian boundary.

In the first part of the meeting L. Krystyn and M. Rigo illustrated with the help of Powerpoint presentations a summary of the data from the two GSSP candidate sections, Steinbergkogel and Pignola-Abriola. Krystyn gave a short presentation, while Rigo illustrated Pignola-Abriola proposal in details, because his presentation during session S17 was strongly influenced by technical problems.

The second part of the meeting was devoted to the discussion of the following items:

a) the two different proposal of marker events (FAD of *Misikella posthernsteini* at Steinbergkogel and a negative shift of the  $\delta^{13}\text{C}_{\text{org}}$  at Pignola Abriola);

b) the different views of the correlations of Steinbergkogel with Pignola-Abriola, especially as regard the calibration of magnetostratigraphy.

The discussion of the latter point was quite lively. Krystyn and Rigo showed two different interpretations of the morphology of *Misikella posthernsteini*, within the lineage *M. hernsteini*-*M. posthernsteini*. At the end of the meeting M. Balini proposed to the leaders of the groups working on Steinbergkogel and Pignola-Abriola to submit their views to the next Albertiana and also suggested Rigo to organize a field trip to Pignola-Abriola.

No further point were raised, then the meeting ended at 14:00.

## THE NORIAN/RHAETIAN BOUNDARY INTERVAL AT PIGNOLA-ABRIOLA SECTION (SOUTHERN APENNINES, ITALY) AS A GSSP CANDIDATE FOR THE RHAETIAN STAGE: AN UPDATE

**Bertinelli, A.<sup>1</sup>, Casacci, M.<sup>1</sup>, Concheri, G.<sup>2</sup>, Gattolin, G.<sup>3</sup>, Godfrey, L.<sup>4</sup>, Katz, M.E.<sup>5</sup>, Maron, M.<sup>3</sup>, Mazza, M.<sup>6</sup>, Mietto, P.<sup>3</sup>, Muttoni, G.<sup>6</sup>, Rigo, M.<sup>3,7</sup>, Sprovieri, M.<sup>8</sup>, Stellin, F.<sup>7</sup>, & Zaffani, M.<sup>3</sup>**

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**Abstract** – The Pignola-Abriola section (Southern Apennines, Italy) fulfills all the qualifications required by the Subcommittee on Triassic Stratigraphy to be proposed as Global Boundary Stratotype Section and Point (GSSP) candidate for the Norian/Rhaetian Boundary (NRB). The Pignola-Abriola section consists of pelagic basal strata, well exposed and very well preserved with minimal tectonic stress and deformation, outcropping along the SP5 “della Sellata” road in a very accessible location in a protected natural Park, which assures a long-time preservation of the site. The main marker event proposed to define the NRB is the First Appearance Datum (FAD) of the conodont *Misikella posthernsteini* s.s. at level PIG 24 (m 44.9), which in the study section is associated to other events, useful proxies for the identification of the base of the Rhaetian: 1) the base of the radiolarian *Proparvicungula moniliformis* Zone; 2) a strong negative shift of the  $\delta^{13}\text{C}_{\text{org}}$ , which is documented as a global marker. Both the  $\delta^{13}\text{C}_{\text{org}}$  negative shift and the FAD of *M. posthernsteini* s.s. occur within the magnetozone MPA-5r of Pignola-Abriola at ~205.7 Ma. In this work we discuss *M. posthernsteini* taxonomy, phylogenesis, and global correlations with other fossil groups and physical events. Furthermore, we update the already existing conodont and radiolarian biostratigraphy with new data, providing better constraint of the age interval determined by the conodont species.

### INTRODUCTION

The formulation of the Rhaetian as a stage was proposed for the first time by Carl Wilhelm Ritter von Gümbel in 1891 to indicate all strata containing *Avicula contorta*, a shallow-water bivalve typical of western Tethys facies. Since then, intense debate over the definition of the Rhaetian has focused on: 1) recognition as an independent Stage (e.g., Pearson 1970; Ager 1987); 2) assignment to the Jurassic System (e.g., Slavin 1961, 1963); 3) inclusion in the Norian Stage, as recommended by Tozer (1967) and Silberling & Tozer (1968) and adopted by Zapfe (1974) and Palmer (1983); or 4) complete removal from the geological time scales (e.g., Tozer 1984, 1990). Even though it was not formally

accepted at that time, many publications on Tethyan successions refer to the Rhaetian as a Stage of the Upper Triassic Series (e.g., Kozur & Mock, 1974; Gazdzicki, 1978; Gazdzicki, et al. 1979; Krystyn, 1980, 1990; Fåhræus & Ryley, 1989). It took exactly 100 years before the Subcommittee on Triassic Stratigraphy (STS) finally formalized the Rhaetian as an independent Stage in 1991. However, even if nowadays the Rhaetian is universally recognized as the last stage of the Upper Triassic, its base still awaits formal definition.

Several markers have been proposed by Krystyn (2010) in an activity report of the Norian/Rhaetian Working Group, also reported by Ogg in Gradstein et al. (2012) and by Rigo et al. (2015). These markers are:

1. The First Appearance Datum (FAD) of the conodont *Misikella posthernsteini*
2. The base of the *Proparvicungula moniliformis* radiolarian Zone
3. The FAD of the conodont *Mockina mosheri* morphotype A
4. The Last Occurrence (LO) of the ammonoid genus *Metasibirites*
5. The FAD of the ammonoid *Paracochloceras suessi*
6. The disappearance of the standard-size bivalve genus *Monotis*
7. The prominent change from an extended normal-polarity magnetozone upward into a reversed polarity magnetozone (UT23n to UT23r), from the composite scale illustrated by Hounslow & Muttoni (2010)

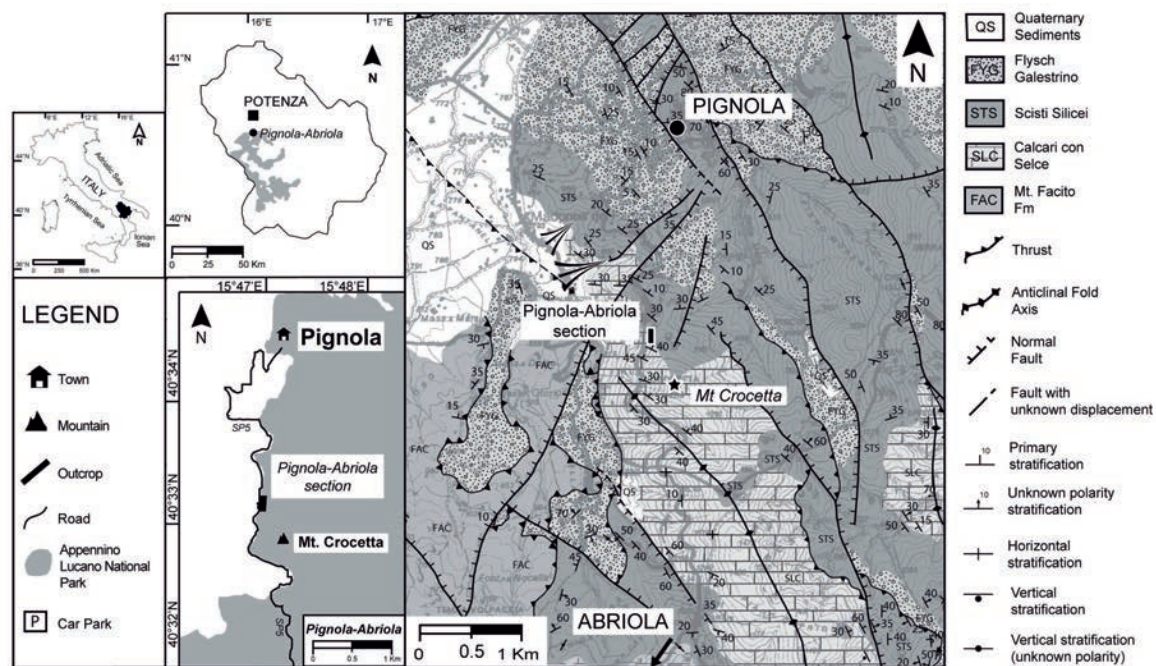
The FAD of the conodont *Misikella posthernsteini* is now the more suitable bioevent recommended by the Task Force of the Subcommittee on Triassic Stratigraphy as the marker for the base of the Rhaetian (Krystyn, 2010).

To date, there are two possible GSSP candidates for the NRB. One is the Steinbergkogel section, near Hallstatt, Salzkammergut (Austria), a composite section consisting of three sub-sections named STK-A, STK-B and STK-C, with STK-A correlative to STK-C, and STK-B stratigraphically coeval. The boundary is defined in bed 111 of section A, at meter 2.20, with the FAD of *M. posthernsteini* (Krystyn et al., 2015). The other GSSP candidate is the Pignola-Abriola section (Southern Apennines, Italy; Fig. 1) (Rigo et al., 2015), a well-exposed Upper Triassic pelagic/hemipelagic section of the western Tethyan realm, which crops out near Potenza city (Southern Italy). The boundary here is defined at sample PIG24, at 44.9 m, with the FAD of *M. posthernsteini* s.s. (Rigo et al., 2015).

The aim of this paper is thus to present an improved and updated set of biostratigraphic (conodonts and radiolarians), magnetostratigraphic, geochemical, and sedimentological data of the Pignola-Abriola section, in support to its candidature for the GSSP of the Rhaetian stage. Because the FAD of *M. posthernsteini* is the main marker event proposed, its exact definition is of primary importance: a discussion on the original diagnosis by Kozur & Mock (1974) and biostratigraphic significance of this species is thus also presented.

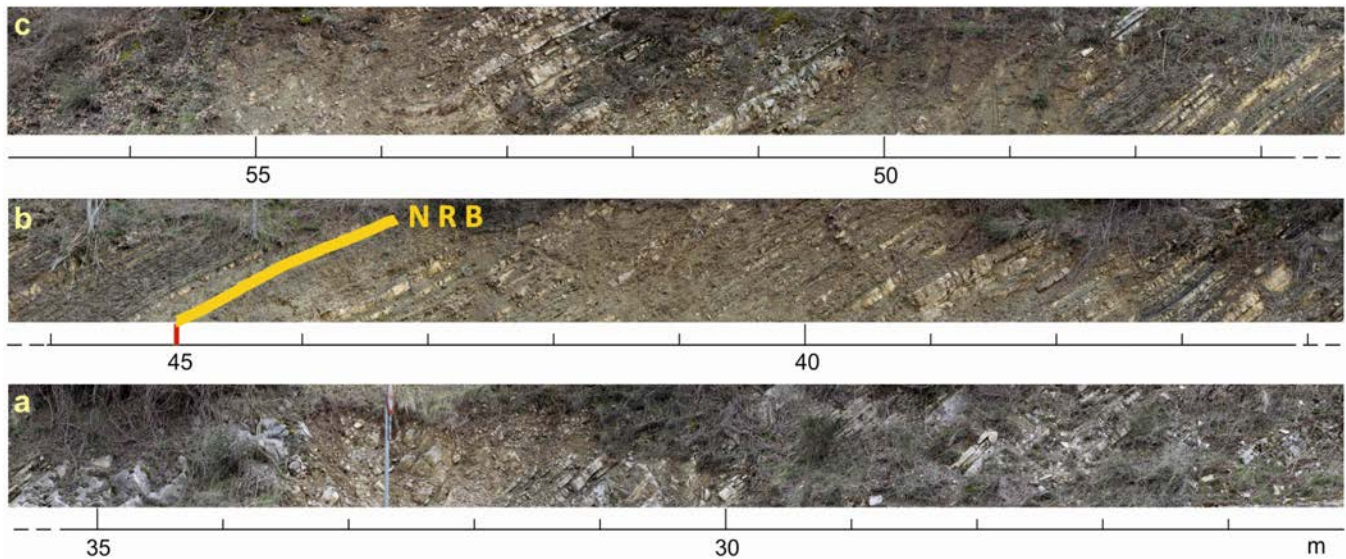
## GEOLOGICAL SETTING AND STRATIGRAPHY

The Pignola-Abriola section belongs to the Lagonegro Basin (Southern Apennines), which is considered part of the south-western branch of the Tethys Ocean, and it was bordered northward by the Apenninic and Apulian carbonate platforms system (e.g., Şengör et al., 1984; Stampfli et al., 1991; Stampfli & Marchant 1995; Catalano et al., 2001; Ciarapica & Passeri, 2002, 2005). The Lagonegro Basin succession is characterized by Permian to Miocene deposits deposited in shallow to deep basinal environments. The lower part of the succession is represented by the “Lagonegro Lower Sequence” (e.g., Mostardini & Merlini, 1986; Ciarapica et al., 1990; Ciarapica & Passeri, 2005; Rigo et al., 2005) and includes the following formations (from oldest to youngest): Monte Facito Formation (Permian to upper Ladinian); Calcarei con Selce (upper Ladinian to Upper Norian/Rhaetian); Scisti Silicei (Upper Norian/Rhaetian to Tithonian) and Flysch Galestrino Formation (Tithonian to Lower Cretaceous). The “Lagonegro Lower Sequence” is everywhere detached from its basement and dissected into several tectonic units, piled up



**Figure 1** – Geological map and location map of the Pignola-Abriola section (Southern Apennines, Italy), outcropping in the protected area of the Parco Appennino Lucano - Val d’Agri - Lagonegrese. The Pignola-Abriola section crops out along the main road SP 5 ‘della Sellata’, on the western flank of Mt. Crocetta (Lat: 40°33’23,50” N; Long: 15°47’1,71” E) (modified after Rigo et al., 2015).





**Figure 2** – General view of Pignola-Abriola section showing the succession of the Cherty Limestone and the NRB position.

between the Apenninic and Apulian carbonate platforms (e.g., Mostardini & Merlini, 1986) during the Apenninic orogenesis.

The Upper Triassic–Middle Jurassic Calcarei con Selce and Scisti Silicei consist of pelagic carbonates and siliceous deposits (i.e., cherts and radiolarites) bearing conodonts, pelagic bivalves (e.g., genus *Halobia*), radiolarians and rare ammonoids. The Calcarei con Selce displays different features in the Lagonegro Basin area: in proximal paleogeographic settings, this formation persisted from the Late Triassic to the Early-Middle Jurassic (e.g., Scandone, 1967; Bertinelli et al., 2005b; Passeri et al., 2005), whereas in more distal settings, a transition from carbonate sedimentation of the Calcarei con Selce to siliceous deposition of the Scisti Silicei occurred between the latest Triassic and the earliest Jurassic. This difference in the time-transition between the two formations is interpreted as a response to the different subsidence rates of the ocean floor below the CCD (e.g., Amodeo, 1999; Giordano et al., 2010; Casacci et al., in press). A previous shift from carbonate to siliceous deposition is documented during the Carnian (Rigo et al., 2007), most likely due to a gradual transition towards warm and more humid climate conditions (Rigo & Joachimski 2010; Rigo et al., 2012b; Trotter et al., 2015). Owing to difficulties in placing a boundary between the Calcarei con Selce and the Scisti Silicei, Miconnet (1983) first introduced the term ‘Transitional Interval’ to characterize that part of the Calcarei con Selce Formation; this ‘Transitional Interval’ bears increasingly red radiolaritic intercalations, which are typical of the overlying Scisti Silicei Formation (Amodeo, 1999; Bertinelli et al., 2005a; Passeri et al., 2005; Reggiani et al., 2005; Rigo et al., 2012a). The base of the ‘Transitional Interval’ is conventionally marked by a 2.5–4.0-m-thick interval of red shales (Amodeo, 1999; Bertinelli et al., 2005b; Reggiani et al., 2005; Rigo et al., 2012a) Sevatian 1 in age (conodont *Mockina bidentata* Zone – late Norian) (Rigo et al., 2005; 2012a). However, this red shale interval has been claimed to be missing from the Pignola-Abriola section, whereas it is easily recognized in all the

other Lagonegro Basin sections. Because of the presence of carbonatic resedimented deposits (e.g., calcarenites and calcirudites) (Bertinelli et al., 2005a,b; Casacci et al., in press), the Pignola-Abriola section is considered to be one of the most proximal section with respect to the coeval adjacent carbonate platforms.

### LITHOSTRATIGRAPHY OF THE PIGNOLA-ABRIOLA SECTION

The Pignola-Abriola section was measured on the western side of Mt. Crocetta along the road SP5 ‘della Sellata’ connecting the villages of Pignola and Abriola (Geographic coordinate system, datum WGS 84: 40° 33’ 23.50”\_N, 15° 47’ 1.71”\_E) (Fig. 1). The Pignola-Abriola section is subject to minimal structural deformation and is located within the protected area of the Appennino Lucano-Val d’Agri-Lagonegrese National Park (Fig. 1). The section is about 60 m thick and exposes the Calcarei con Selce Formation encompassing the Norian/Rhaetian boundary (Amodeo et al., 1993; Amodeo, 1999; Bazzucchi et al., 2005; Rigo et al., 2005; 2012a; Giordano et al., 2010) (Fig. 2). Thinly bedded cherty limestones (partially dolomitized in the lowermost part of the section) constitute the dominant lithology, sometimes intercalated with centimeter-thick calcarenites due to sporadic gravity flows/turbiditic events (e.g., Amodeo, 1999; Bertinelli et al., 2005a; Giordano et al., 2011). The siliciclastic input increases in the upper part of the Calcarei con Selce Formation at the transition to the overlying Scisti Silicei Formation, where shales, radiolarites and subordinate marls are dominant. The lower portion of the section (ca. 0–6.5 m) (Figs. 2 and 3) consists mainly of thin-bedded cherty dolostones; a few cherty nodules are present in the first 3.5 m ca., and become frequent in the upper part of the section. Calcarenitic horizons containing fragments of benthic organisms, linked to gravity flow events, are subordinate. From

ca. 6.5 up to meter 13, repeated thick shale intercalations are present. Cherty layers become abundant at ca. 13 m from the base of the measured section. Between ca. 13 and 22.5 m, limestones gradually replace dolostones and consist mainly of mudstone – wackestone, and less commonly packstone, with abundant radiolarians and rare bivalves (e.g., genus *Halobia*). From 22.5 m up to ca. 39 m, the frequency of shaley intervals decreases and centimeter-thick chert bands in limestone beds become common. In addition, three decimeter-thick graded calcarenitic layers, often amalgamated and partially dolomitized, occur between ca. 34 and 35.5 m and provide a useful lithomarker (Maron et al., 2015). Between 39 and 43.5 m, nodules and especially layers and bands of black radiolarian cherts become abundant. An increase in terrigenous input can be registered up to meter 56 with the appearance of shale horizons. The shales are typically dark and rich in organic matter, often interbedded with silicified limestones and thin calcarenites, deposited in low oxygen (dysoxic to anoxic) paleoenvironmental conditions. This frequent alternation of shales, limestones, fine-grained calcarenites, marls and chert beds constitute the so-called ‘Transition Interval’ (Miconnet, 1983; Amodeo, 1999), separating the Calcarì con Selce from the Scisti Silicei, although at Mt. Crocetta the lower part of Scisti Silicei does not crop out. The uppermost part of the Pignola-Abriola section (ca. m 56–58) is characterized by decimeter-thick micritic limestone beds with few clayey intercalations, testifying a return to more abundant carbonate deposition.

## BIOSTRATIGRAPHY

The Pignola-Abriola section has been subjected to many biostratigraphic studies, and in particular was deeply investigated for conodonts and radiolarians (Amodeo, 1999; Bazzucchi et al., 2005; Rigo et al., 2005, 2012a; Giordano et al., 2010; Rigo et al., 2015) (Figs. 4 and 5).

### Conodonts

Conodonts are common throughout the section and have a Color Alteration Index (CAI) of 1.5, suggesting that burial temperatures did not exceed 100 °C (sensu Epstein et al., 1977; Bazzucchi et al., 2005; Giordano et al., 2010; Maron et al., 2015). According to Krystyn et al. (2007a, b), conodonts are generally rare around the NRB. However, the detailed studies on the Pignola-Abriola samples across the boundary reveal that in our section, conodonts occur in this interval in sufficient abundance to provide constraints on the NRB interval (significant new data are presented in this paper, Figs. 3 and 4).

In ascending stratigraphical order, the following main bioevents are recognized:

1. Meter 7, sample PI5, the FO of *Mockina bidentata*
2. Meter 21.4, sample PR16, the FOs of *Misikella hernsteini*, *Parvigondolella andrusovi*, and *Norigondolella steinbergensis*
3. Meter 29.8, sample PIG 16 (=PR 12), the FO of *Parvigondolella lata*
4. Meter 32, sample GNC3, the FOs of *Misikella buseri* and *Misikella hernsteini posthernsteini* morphocline

5. Meter 44.9, in sample PIG24, the FAD of *Misikella posthernsteini* s.s. (marking the base of the Rhaetian in this section) in association with the FO of *Misikella koessenensis*
6. Meter 54.2, sample PIG 38, the FOs of *Misikella ultima* and *Misikella kovaci*

### Radiolarians

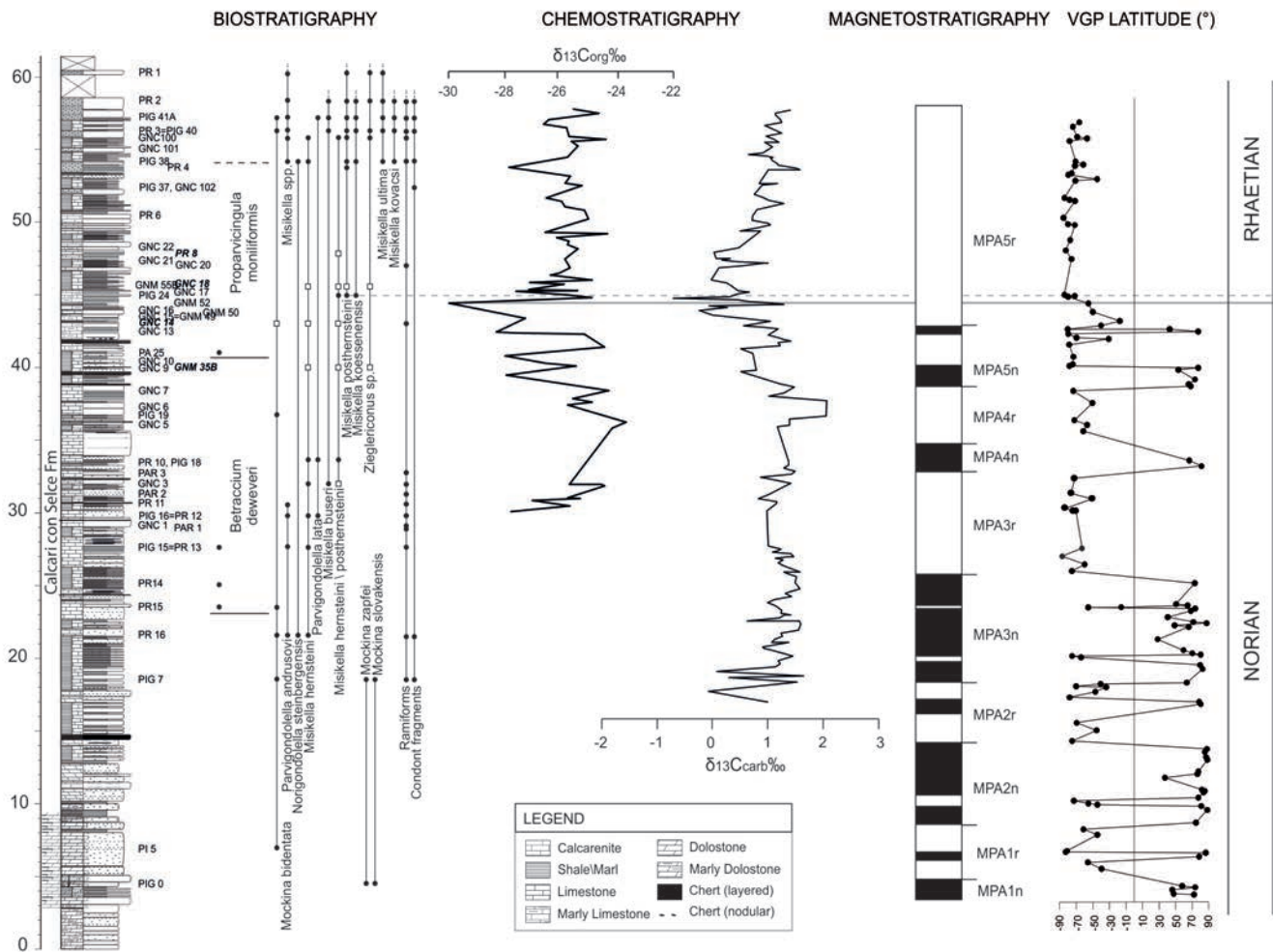
The radiolarian associations (Figs. 3 and 5) are well preserved and conform to the biozonation proposed by Carter (1993), which consists of radiolarian assemblage zones biochronologically correlated to the North America ammonoid zonation proposed by Tozer (1980). Sample PR14 at meter 25 yields a radiolarian assemblage referable to the *Betraccium deweveri* Zone (U.A. 1, Carter, 1993) based on the presence of *Betraccium deweveri* Pessagno & Blome, *Praemesotaturnalis gracilis* Kozur & Mostler, *Tetraporobrachia* sp. aff. *T. composita* Carter, *Ayrtonius elizabethae* Sugiyama, *Citriduma* sp. A sensu Carter (1993), *Lysemela* sp. cf. *L. olbia* Sugiyama, *Livarella valida* Yoshida and *Livarella* sp. sensu Carter (1993) (Giordano et al., 2010); a similar assemblage was also found in sample PR15 at meter 23.5 and sample PR13 at meter 27.5. Sample PA25 at meter 41 yields a radiolarian assemblage referable to the *Proparvicungula moniliformis* Zone, Assemblage 1 and Assemblage 2, Subassemblage 2a (U.A. 2–8 Carter 1993), for the presence of *Fontinella primitiva* Carter, *Praemesotaturnalis* sp. cf. *P. sandspitensis* Blome, *Globolaxtorum* sp. cf. *G. bullae* (Yeh & Cheng), *Livarella densiporata* Kozur & Mostler and *Livarella valida* Yoshida (Bazzucchi et al., 2005; Giordano et al., 2010).

## CHEMOSTRATIGRAPHY

### Carbon analyses

The Pignola-Abriola section has been analyzed at high-resolution (cm-scale) for organic carbon isotope ( $\delta^{13}\text{C}_{\text{org}}$ ) and total organic carbon (TOC). Seventy-six rock samples were collected, washed in deionized water and eventually reduced to a fine powder using a Retsch RM0 grinder, then dried overnight at 40°C. Samples with clear alterations were avoided (e.g., fracture-filling mineralization, bioturbation, diagenetic alterations). For the TOC investigation, the powders were leached with a 10% HCl solution in silver capsules, then dried on a hot plate at 50°C (Schlanger & Jenkyns, 1976). All samples were analyzed using a Vario Macro CNS Elemental Analyzer at the University of Padua. Results were calibrated against Sulphanilamide standard (N = 16.25%; C = 41.81%; S = 18.62%; H = 4.65%). The analytical uncertainty of the instrument is  $\sigma = 0.5\%$  (%RSD, relative standard deviation). For the  $\delta^{13}\text{C}_{\text{org}}$  measurements, pulverized rock samples were acid-washed with 10% HCl overnight, then neutralized in deionized water, dried at 40°C overnight and wrapped in tin capsules. Forty-one samples were analyzed through a GVI Isoprime CF-IRMS mass spectrometer at the Rutgers University: multiple blank capsules and isotope standards (NBS 22 = -30.03‰; Coplen et al., 2006; and an in-house standard) were added for every batch of isotopic analyses (standard





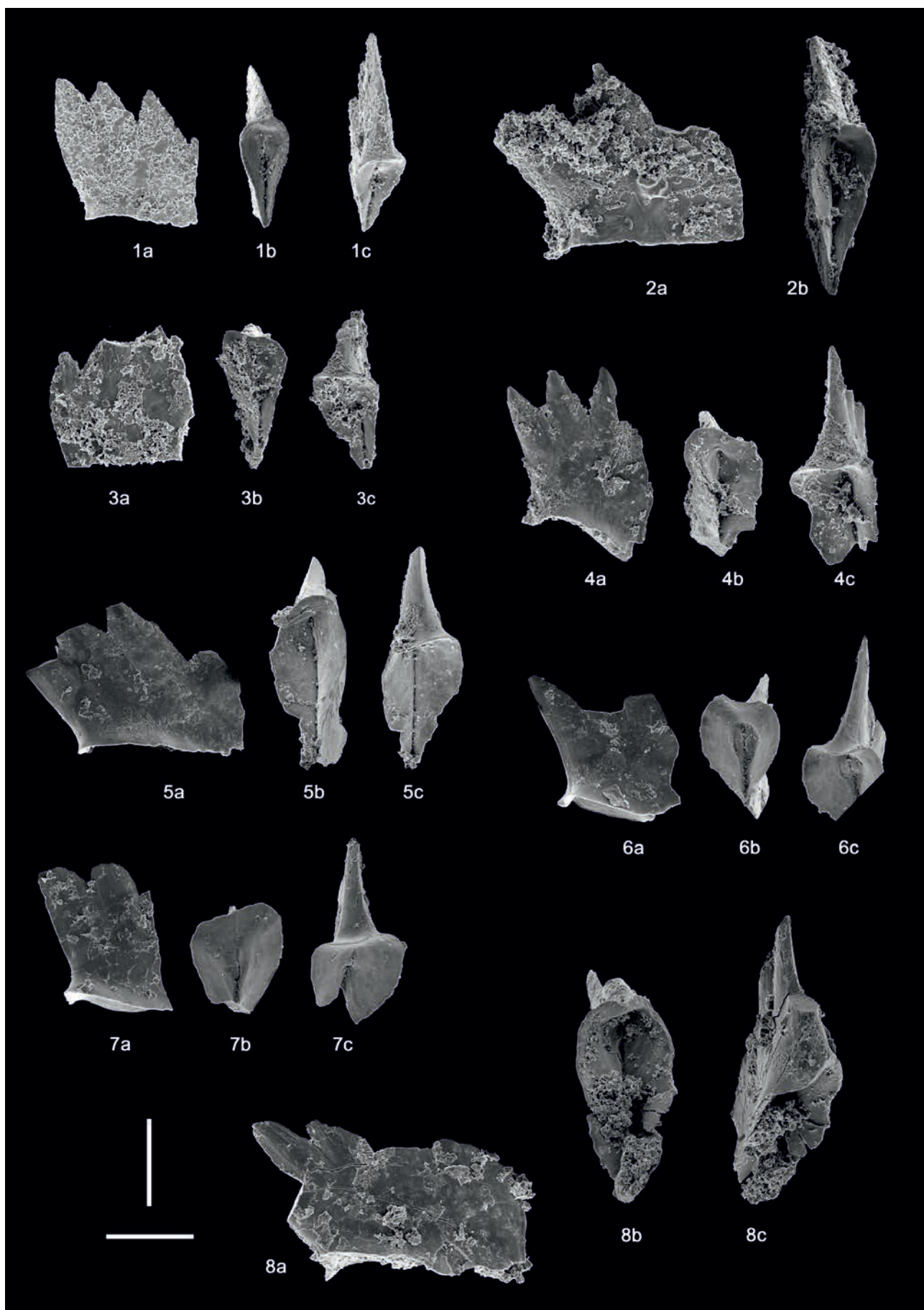
**Figure 3** – The Pignola-Abriola section, from left to right: stratigraphical log, radiolarian and conodont biostratigraphy,  $\delta^{13}\text{C}_{\text{org}}$  and  $\delta^{13}\text{C}_{\text{carb}}$  curves, magnetostratigraphy and the virtual geomagnetic poles (VGP) (after Rigo et al., 2015, modified). The prominent  $\delta^{13}\text{C}_{\text{org}}$  negative shift is located close to the FAD of conodont *Misikella posthernsteini* s.s., here reported as primary proxy for the base of the Rhaetian. The  $\delta^{13}\text{C}_{\text{org}}$  negative peak occurs within the base of the radiolarian *Proparvicinula moniliformis* Zone.

deviation  $\sigma = 0.2\text{‰}$ ). Fifteen samples were analyzed using a Delta V Advantage mass spectrometer connected to a Flash HT Elemental Analyzer at the University of Padua. For every set of analyses, multiple blank capsules and isotope standards (IAEA CH-6 =  $-10.45\text{‰}$ , IAEA CH-7 =  $-32.15\text{‰}$ , Coplen et al., 2006) were included (standard deviation  $\sigma = 0.3\text{‰}$ ).

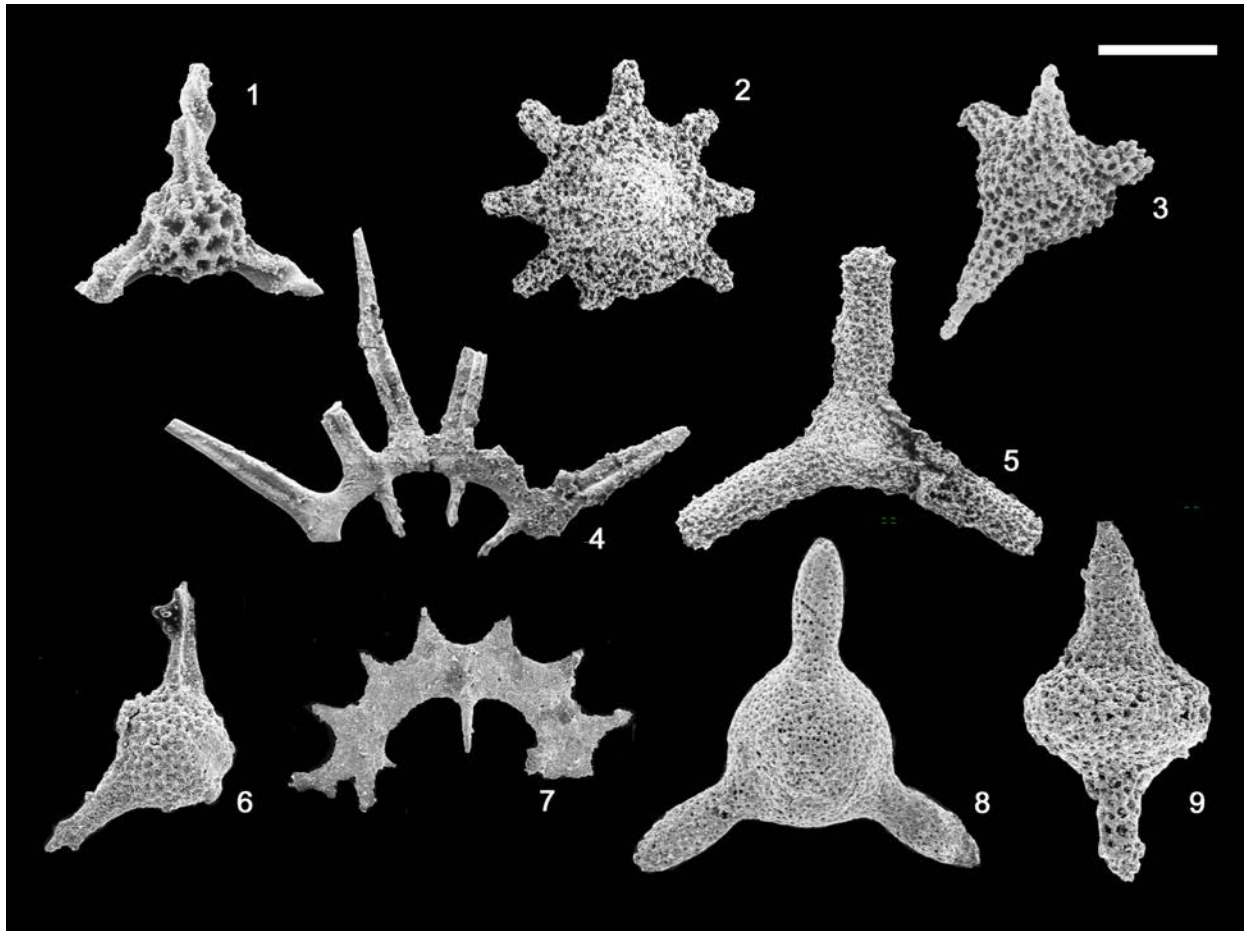
The obtained high-resolution  $\delta^{13}\text{C}_{\text{org}}$  profile of the uppermost portion of the Pignola-Abriola section (from 30 m to 57.5 m circa) shows a ca. 6‰ negative shift between meter 36 and meter 44.4, reaching its minimum ( $\delta^{13}\text{C}_{\text{org}} = -29.95\text{‰}$ ) at meter 44.4 (Fig. 3), just 50 cm below the FAD of the conodont *Misikella posthernsteini* s.s., the main marker event proposed for the identification of the base of the Rhaetian (Krystyn, 2010; Ogg in Gradstein et al., 2012). This prominent negative peak

has been proposed as a valuable geochemical marker for the base of the Rhaetian (Rigo et al., 2015) as an alternative to the FAD of *Misikella posthernsteini* s.s., which in fact is not particularly abundant in the North America realm and appears at a younger stratigraphic interval than in the Tethys, complicating its value as a global marker. In stark contrast, the  $\delta^{13}\text{C}_{\text{org}}$  negative shift has been recognized and well calibrated on biostratigraphic grounds in different sections in the Tethyan and North America realms (Rigo et al., 2015; Zaffani et al., submitted), including Pignola-Abriola, Mt. Volturino (Italy, Rigo et al., 2015), Kennecott Point (Canada, Ward et al. 2001, 2004), Frederick Island (Canada, Whiteside & Ward 2011) and Williston Lake, Canada (Wignall et al., 2007). The negative excursion at the base of the Rhaetian is recorded also in the  $\delta^{13}\text{C}_{\text{carb}}$  profile of different Tethyan geological

**Figure 4** (opposing page) – SEM micrographs of Upper Norian to Rhaetian conodonts from the Pignola-Abriola section (Southern Apennines, Italy). Scale bar = 100  $\mu\text{m}$ . All the specimens are at the same scale. a: lateral view; b: lower view; c: posterior view. 1. Transitional form *Misikella hernsteini*/*Misikella posthernsteini* (GNC 3); 2. *Misikella hernsteini* (GNC 14); 3. Transitional form *Misikella hernsteini*/*Misikella posthernsteini* (GNM 35B); 4. Transitional form *Misikella hernsteini*/*Misikella posthernsteini* (GNM 55B); 5. *Misikella hernsteini* (GNM 55B); 6. *Misikella posthernsteini* (GNM 55B); 7. Transitional form *Misikella hernsteini*/*Misikella posthernsteini* (GNM 55B); 8. *Misikella hernsteini* (GNM 55B).







**Figure 5** – SEM micrographs of Upper Norian–Rhaetian radiolarians from Calcari con Selce Formation of the Pignola-Abriola section. Samples PR13 and PR14 are referred to the *Betraccium deweveri* Zone; sample PA25 is referred to the *Proparvicungula moniliformis* Zone, Assemblages 1 and Assemblage 2, Subassemblage 2a. Scale bar = 100  $\mu\text{m}$  for 1, 6–9; 150  $\mu\text{m}$  for 4; 200  $\mu\text{m}$  for 2, 3, 5 (after Rigo et al. 2015, modified). 1. *Betraccium deweveri* Pessagno & Blome (PR14); 2. *Citriduma* sp. A, sensu Carter (1993) (PR13); 3. *Tetraporobrachia* sp. aff. *T. composita* Carter (PR14); 4. *Praemesotaturnalis gracilis* (Kozur & Mostler) (PR14); 5. *Livarella* sp., sensu Carter (1993) (PR14); 6. *Fontinella primitiva* Carter (PA 25); 7. *Praemesotaturnalis* sp. cf. *P. sandspitensis* (Blome) (PA25); 8. *Livarella densiporata* Kozur & Mostler (PA25); 9. *Globolaxtorum* sp. cf. *G. hullae* (Yeh & Cheng) (PA25).

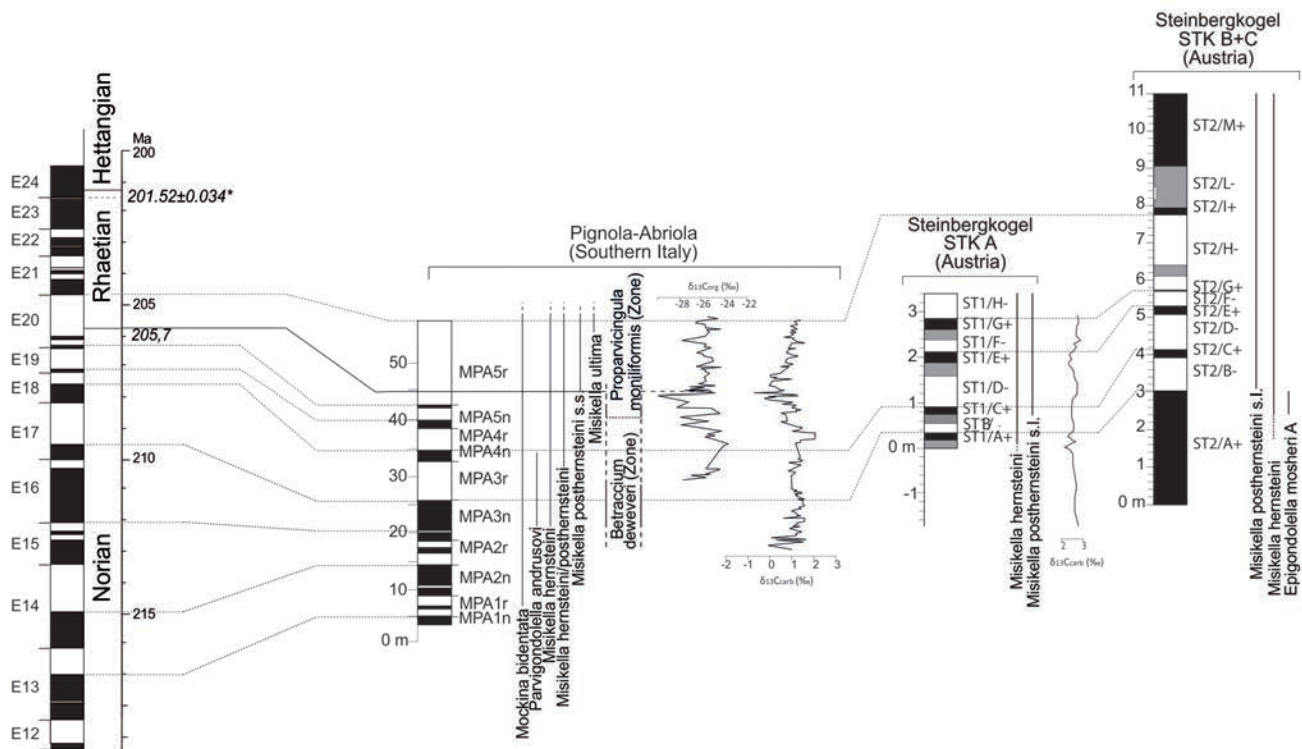
sections, for example Pignola-Abriola (Preto et al., 2013) and the composite succession illustrated by Korte et al. (2005). This  $\delta^{13}\text{C}_{\text{carb}}$  decrease appears to be absent from Steinbergkogel STK-A section (Austria, Krystyn et al., 2007a, b; Fig. 6), whose record is almost flat (likely due to the highly condensed section). The occurrence of the Norian-Rhaetian boundary  $\delta^{13}\text{C}_{\text{org}}$  negative shift both in the North America and Tethys realms demonstrates that this negative peak is a global event, and therefore a useful geochemical marker for the base of the Rhaetian stage (Rigo et al., 2015; Zaffani et al., submitted).

## MAGNETOSTRATIGRAPHY

Analysis of the Natural Remanent Magnetism (NRM) has been performed on 220 samples; 9 samples were reserved for rock magnetism experiments (Maron et al., 2015). The analyses were performed at the Alpine Laboratory of Paleomagnetism (ALP) of Peveragno, Italy. The samples were thermally treated up to 675  $^{\circ}\text{C}$  to remove recent magnetization components and analyzed

with a 2G three-axial DC-SQUID cryogenic magnetometer after each demagnetization step. The analysis of the NRM indicates a mean magnetization of the samples of 0.08 mA/m. Hematite and magnetite are the main carriers of the magnetization, as suggested by rock magnetism experiments; subsidiary iron sulphide is also present (Maron et al., 2015). Approximately 55% of the samples (121 of 220) revealed a characteristic component of magnetization (ChRM), isolated mainly up to 450–550 $^{\circ}$  (maximum of 625  $^{\circ}\text{C}$ ), showing north-down and south-up directions. To establish the reliability of the data, the reversal test of McFadden & McElhinny (1990) was applied to the ChRM component directions, obtaining a positive result (Maron et al., 2015). Virtual geomagnetic poles (VGPs) were calculated from the ChRM directions. The sequence of the VGP latitudes has been sorted in stratigraphical order to obtain a sequence of geomagnetic polarity reversals along the Pignola-Abriola section, grouped in 10 magnetozones named MPA (Fig. 6).

The Pignola-Abriola section was then correlated to other Tethyan sections from the literature, choosing the ones with conodont biostratigraphy and magnetostratigraphy (see Maron



**Figure 6** – Correlation of magnetostratigraphy, biostratigraphy and chemostratigraphy of the Pignola-Abriola section with literature data from the Tethyan marine Steinbergkogel section (STK-A and B+C; Hüsing et al., 2011), current GSSP candidate for the Rhaetian Stage (Krystyn et al., 2007a, b). The specimens of conodont *Misikella posthernsteini* in Steinbergkogel (as considered in Krystyn et al. 2007a, b) are here attributed to the *Misikella hernsteini/posthernsteini* transitional form (after Giordano et al., 2010; Rigo et al., 2015). The Pignola-Abriola section is correlated to the Newark Astrochronological Polarity Time Scale (APTS; Olsen et al., 2010) following the correlation of Maron et al., (2015). The level containing the Norian/Rhaetian boundary in Pignola-Abriola is placed with a negative  $\delta^{13}\text{C}_{\text{org}}$  spike of ca. -30‰ and is virtually coincident with the first appearance datum (FAD) of conodont *M. posthernsteini* s.s., dated at 205.7 Ma (Maron et al., 2015), within magnetozone E20r of the Newark APTS.

et al., 2015; Rigo et al., 2015). The other GSSP candidate for the Rhaetian stage, the Steinbergkogel section (Krystyn et al., 2007a, b; Krystyn, 2008), shows a magnetostratigraphic record (Hüsing et al., 2011) comparable with the data from Pignola-Abriola only after a revision in the biostratigraphy of Steinbergkogel (Rigo et al., 2015) (Fig. 6). Observing the conodont specimens of Steinbergkogel (Krystyn et al., 2007b, plate 1, figs. 1-4 from bed 111A and 112), we concluded that the published conodont *Misikella posthernsteini* in Steinbergkogel (Krystyn et al., 2007a) is substantially equivalent to the *Misikella hernsteini/posthernsteini* transitional forms (sensu Giordano et al., 2010) of Pignola-Abriola section (Maron et al., 2015; Rigo et al., 2015).

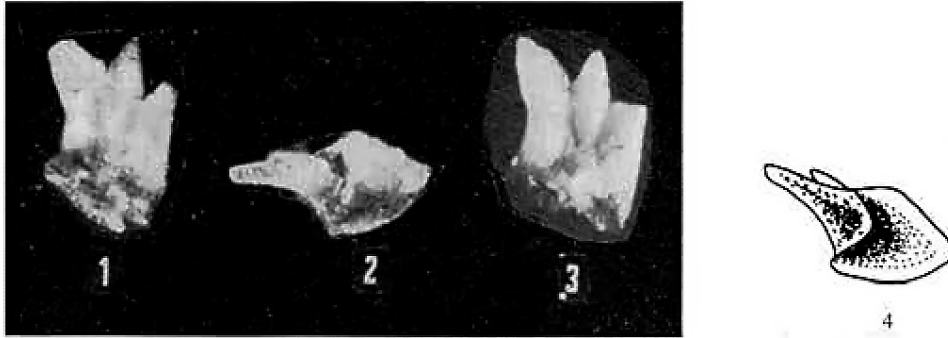
In particular, magnetostratigraphic zones from MPA3r to MPA5r at Pignola-Abriola are considered equivalent to the main reversal interval in Steinbergkogel (ST1/B- to ST1/H- in STK-A subsection; ST2/B- to ST2/H- in STK-B+C subsection) (Fig. 6). Observing Fig. 6, the magnetostratigraphic zones of Steinbergkogel STK-A (officially proposed by Krystyn et al., 2007a) from ST1/B- to ST1/H- are equivalent to the time interval included between E17r to E20r in Newark APTS, as well as the magnetostratigraphic zones from MPA3r to MPA5r in Pignola-Abriola. There is a clear difference between the thickness of the above-listed magnetostratigraphic intervals in the Pignola-Abriola and Steinbergkogel sections: this means that the same time interval is represented by ca. 30

meters in Pignola-Abriola and only ca. 3 meters in Steinbergkogel STK-A. This evidence further supports that the Steinbergkogel section is highly condensed, placing considerable doubt on its suitability and eligibility as the GSSP for the Rhaetian Stage.

Pignola-Abriola is also comparable to the Oyuklu section (Gallet et al. 2007), where interval OyB- to OyD- should correspond to magnetostratigraphic zones MPA4r to MPA5r at Pignola-Abriola (Maron et al., 2015; Rigo et al., 2015). In addition, magnetostratigraphic zones SB-8n to SB-11n of the Carnian-Norian Silická Brezová section (Channell et al., 2003), equivalent to magnetostratigraphic zones PM-8n to PM-12n of the Pizzo Mondello section (Muttoni et al., 2004), should correspond to the lower part of the Pignola-Abriola section from MPA1n to MPA3n (Maron et al., 2015; Rigo et al., 2015). Moreover, the Pignola-Abriola section has been correlated with the upper Rhaetian-Hettangian Brumano/Italcementi Quarry section (Muttoni et al., 2010; 2014), using the base of *M. posthernsteini* s.s. Zone as tie point.

## DISCUSSION

In 2010, the Task Force for the definition of the NRB voted and conventionally decided to adopt the FAD of *Misikella posthernsteini* as marker event for the base of the Rhaetian (as



**Figure 7** – After Kozur & Mock, 1974, modified. 1-2: *Misikella posthernsteini* original holotype (1-2: 82x). 3: *M. posthernsteini* paratype (100x); 4: *Misikella posthernsteini* schematic drawing of the posterior view. The heart shaped basal cavity and the furrow in the posterior side of the last blade denticle, diagnostic characters of the species, are clearly visible.

mentioned in the Introduction). Therefore, it is important that the *M. posthernsteini* morphology and phylogenesis are well defined (according to Remane, 2003); we address this issue in this paper.

### The *Misikella posthernsteini* matter: diagnosis and phylogenesis

*Misikella posthernsteini* was established by Kozur and Mock in 1974. The holotype (Fig. 7) was described from the Upper Triassic section of Maly Mlynsky vrch Hill, in Slovakia (West Carpathians), 1 km east to Silická Brezová, and consisting in Hallstatt Limestones and Zlambach Beds (Mock, 1980 and references therein). According to its original description, *M. posthernsteini* has a relatively simple morphology with well-defined features. We report the original description by Kozur & Mock (1974) below [kindly translated from German by E. Kustatscher, Naturmuseum Südtirol / Museo di Scienze Naturali dell'Alto Adige, Bolzano - Italy]:

“Description: the tiny conodonts show 2 to 3 long teeth, fused together in the half or 2/3 of their length. The posteriormost tooth is slightly longer and especially larger than the others. It forms a clearly visible main tooth whose upper portion is posteriorly bent in the stratigraphically younger (Rhaetian) forms.

The basal cavity covers the whole underside of the conodont and is very deep. The main characteristic is the V-shaped notch in the posterior part of the basal cavity. From this notch starts generally a variable deep groove along the main tooth.”

From this description, it is evident that one of the characters for the classification of *M. posthernsteini* is the presence of no more than 2 to 3 denticles in the blade. Nevertheless, another denticle, usually vestigial or smaller than the others, may occur in the anterior part of the blade (Kozur & Mock, 1991; Giordano et al., 2010; Mazza et al., 2012; Rigo et al., 2015). This 4th denticle is typical of the more primitive (i.e., stratigraphically older) specimens, falling into the intraspecific variability of the species.

Furthermore, Orchard assigned all those specimens characterized by 2 denticles to *Misikella kovacsi* (Pálffy et al., 2007). Because the number of the blade denticles might be slightly variable, the most diagnostic feature of *M. posthernsteini* is the v-shaped notch located in the posterior part of the basal cavity and its extension on the main (posterior) denticle of the blade. This is also stated and illustrated in the original description by Kozur and Mock (1974) (Fig. 7, after Kozur & Mock, 1974, modified).

*Misikella posthernsteini* is the direct phylogenetic descendent of *M. hernsteini* (e.g., Mostler et al., 1978; Kozur & Mock 1991; Giordano et al., 2010). Both species display a similar cusp as the posterior denticle, but they differ in (1) number of blade denticles, which are 3 (rarely 4) in *M. posthernsteini* and 4–6 in *M. hernsteini*; and (2) shape of the basal cavity, which is heart shaped in *M. posthernsteini* and teardrop shaped in *M. hernsteini*.

Considering the original description of *M. posthernsteini* and after a careful investigation of the *M. hernsteini*/*posthernsteini* morphocline, broadly discussed with A. Nicora and H. Kozur (as reported in the acknowledgments in Giordano et al., 2010), the real *M. posthernsteini* (here referred to as *M. posthernsteini* s.s.) are to be considered as only those specimens with a visible and clear inflexion on the posterior margin of the basal cavity (heart shape) and with an evident notch on the backside of the main posterior denticles (Kozur and Mock, 1974; Giordano et al., 2010). Thus, all the other specimens without the v-shaped posterior margin of the basal cavity and the notch on the posterior denticle should be interpreted as transitional forms between *M. hernsteini* and *M. posthernsteini* s.s. (i.e., *Misikella hernsteini*/*posthernsteini* morphocline), and not considered as true *M. posthernsteini*. However, the FAD of *M. posthernsteini* s.s. does not coincide with the acme of radiation of the species, and the specimens are quite scarce, in agreement with Krystyn et al., (2007a).

The *M. posthernsteini* specimens figured from Steinbergkogel by Krystyn et al. (2007a, pl. 1, figs. 1–4), in the first proposal for the section as GSSP of the Rhaetian, show significant differences from the holotype. Other specimens in Krystyn et al. (2007a, pl. 1, figs 1-2), are from bed 111A (the NRB level); they have a slightly heart-shaped basal cavity, typical of *M. posthernsteini*, and the number of denticles fall into the intraspecific variability of the species, but no furrow occurs on the terminal denticle.



Specimen of Pl. 1, fig. 4 (level 112), instead, has a more evident heart shaped basal cavity and a posterior furrow, but the blade consists of five denticles, falling completely outside the variability of the species, and they are much narrower than those of the holotype. Thus, the specimens figured in Krystyn et al. (2007a) cannot be considered as *M. posthernsteini* s.s., because none of them completely satisfy the original description of the species; instead, they represent the morphocline between *M. hernsteini* and *M. posthernsteini* s.s.

Whereas the critical *M. posthernsteini* s.s. is not illustrated from Steinbergkogel, it is clearly documented at Pignola-Abriola, together with the transitional forms from *M. hernsteini* (Fig. 4). *Misikella hernsteinilposthernsteini* transitional forms occur in sample GNC 3. *Misikella posthernsteini* s.s. first occurs in sample PIG24, and is also present less than 50 cm above in sample GNM55B (Fig. 4, n. 7). Documentation of the *M. hernsteinilposthernsteini* morphocline in the Pignola-Abriola section is complete and thus, the first occurrence of *M. posthernsteini* s.s. should be considered a real first phylogenetic occurrence (FAD), because it occurs along its phylogenetic lineage (as suggested by Remane, 2003). In contrast, Bed 111A of Steinbergkogel does not bear the diagnostic *M. posthernsteini* s.s.; rather, only elements of the transitional *M. hernsteinilposthernsteini* morphocline are present, and it should thus be considered still Sevatian 2 in age.

Calibration with radiolarian biostratigraphy (Giordano et al., 2010) reveals that only those specimens of *Misikella posthernsteini* characterized by a heart shaped basal cavity and a distinct notch along the backside of the cusp occurred within the radiolarian *Proparvicungula moniliformis* Zone (sensu Carter 1993). As already argued by Giordano et al. (2010), these specimens were interpreted as *Misikella posthernsteini* s.s.

In the Pignola-Abriola section, the FAD of *M. posthernsteini* s.s. occurs about 50 cm above a marked negative  $\delta^{13}\text{C}_{\text{org}}$  excursion of about 6‰, within the base of the radiolarian *Proparvicungula moniliformis* Zone. This negative shift is also documented within the *P. moniliformis* Zone of the Monte Volturino section, about 50 km south to the Pignola-Abriola section, in the Lagonegro Basin (Rigo et al., 2015). In North America (British Columbia, Canada), the *P. moniliformis* Zone is biochronologically equivalent to the North American ammonoid *Paracochloceras anoenum* Zone (e.g., Carter, 1993; Orchard & Tozer, 1997; Longridge et al., 2007), later confirmed by Orchard et al. (2007). In Kennecott Point (British Columbia, Canada) a negative shift of  $\delta^{13}\text{C}_{\text{org}}$  coincides with the disappearance of the standard-size *Monotis* bivalves (Ward et al., 2004; Whiteside & Ward, 2011; Zaffani et al., submitted). This correlation is further confirmed by a  $\delta^{13}\text{C}_{\text{org}}$  negative shift recorded after the end-Norian extinction of monotids at Lake Williston (British Columbia, Canada) (Wignall et al., 2007).

The fact that a  $\delta^{13}\text{C}_{\text{org}}$  negative excursion is documented at the base of the *Proparvicungula moniliformis* Zone in both the western and eastern sides of the Panthalassa Ocean, clearly demonstrates that this excursion is an important geochemical/physical proxy for correlations at global scale.

Around the NRB, important bioevents (listed in Rigo et al., 2015) support (and are supported by) the  $\delta^{13}\text{C}_{\text{org}}$  negative excursion documented at Pignola-Abriola section at the NRB.

These events occurred in a very short time interval and therefore are important, nearly coeval proxies (see Rigo et al., 2015 for details on global biostratigraphic correlations of these bioevents). Furthermore, the age model developed for the Pignola-Abriola section, derived from the statistical correlation with the Newark APTS, placed the level containing the NRB (FAD of *Misikella posthernsteini* s.s.) at ca. 205.7 Ma (see Maron et al., 2015 and Rigo et al., 2015 for details). This age is in agreement with the high-precision U-Pb geochronology age of  $205.70 \pm 0.15$  by Wotzlaw et al. (2014) for the NRB, which was marked by the disappearance of the standard-size *Monotis* bivalves, thus further confirming the right correlations between the NRB bioevents.

## CONCLUSIONS

With this update, we provide additional documentation and detail in support of the Pignola-Abriola section as GSSP candidate for the Rhaetian Stage. In fact, the Pignola-Abriola section fulfills all the qualifications required by the Subcommittee on Triassic Stratigraphy, as listed by Rigo et al. (2015) and briefly summarized here:

1. Good exposure
2. Cropping out in a minimal structural deformation area
3. Easy access along the SS 5 road 'la Sellata'
4. Located in the protected area of the Parco Appennino Lucano - Val d'Agri - Lagonegrese
5. It is a continuous basinal succession
6. The section is fossiliferous, with distinctive and well-preserved conodont and radiolarian cosmopolitan fauna
7. The FAD of the conodont *Misikella posthernsteini* s.s. is readily distinguishable from the *Misikella hernsteinilposthernsteini* transitional forms. The FAD of *M. posthernsteini* s.s. is the STS-voted biomarker for the definition of the Rhaetian base. Level PIG24 at Pignola-Abriola, where the FAD of *M. posthernsteini* s.s. is placed, is thus proposed here as GSSP of the Rhaetian stage
8. The base of the radiolarian *Proparvicungula moniliformis* Zone, which is a second bioevent proposed to mark the base of the Rhaetian, is well documented and calibrated with the FAD of *M. posthernsteini* s.s.
9. The Pignola-Abriola section depicts a marked  $\delta^{13}\text{C}_{\text{org}}$  negative shift of ca. 6‰, mirrored by a decrease in the  $\delta^{13}\text{C}_{\text{carb}}$  curve, occurring ca. 0.5 meters below the FAD of *M. posthernsteini* s.s. and within the radiolarian *P. moniliformis* Zone. This negative carbon isotope shift is suggested by Rigo et al. (2015) as the primary physical marker for the NRB because it is a large geochemical signal that has been documented in both the western and eastern sides of the Panthalassa Ocean
10. The Pignola-Abriola section is subdivided into 10 magnetostratigraphic zones, calibrated with conodont and radiolarian biostratigraphy and statistically correlated with the Newark APTS, allowing the dating of litho-, bio- and chemo-events
11. The age model developed for the Pignola-Abriola section, placed the NRB (FAD of *M. posthernsteini* s.s.) at ca. 205.7 Ma, in agreement with recent high-precision U-Pb



geochronology age.

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## STRATIGRAPHIC SIGNIFICANCE OF THE EARLY RHAETIAN OSTRACODS FROM THE PROPOSED NORIAN/RHAETIAN GSSP AT STEINBERGKOGEL (LATE TRIASSIC, UPPER AUSTRIA)

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**Abstract** – The ostracod associations from the *Paracochloceras suessi* Zone (Early Rhaetian, Late Triassic) of the proposed Norian/Rhaetian GSSP at Steinbergkogel (Upper Austria) are listed and compared with those from the *Vandaites stuerzenbaumi* and *Choristoceras marshi* zones (Middle and Late Rhaetian). The associations from these three zones are closely related, and the differences in diversity between each other are caused by different ecological conditions. The alleged mass extinction in ostracods at the base of the *Vandaites stuerzenbaumi* Zone, the former base of the Rhaetian, cannot be confirmed.

### INTRODUCTION

The ostracods from the Rhaetian Zlambach and Kössen formations of the Northern Calcareous Alps (Austria and Upper Bavaria) are well known (Bolz, 1969, 1970a, 1970b, 1971; Kozur, 1971; Kollmann, 1969, 1963; Kristan-Tollmann, 1970, 1971a, 1971b, 1971c, 1973; Urlichs, 1972). However, different stratigraphic classifications of the Zlambach Formation have been published in the literature on ostracods: Late Norian (Kozur, 1971a), Late Norian and Rhaetian (Kollmann, 1963; Kristan-Tollmann, 1970, 1971a, 1971b, 1971c, 1973), Rhaetian (Kollmann, 1960), or Late Norian to Rhaetian (Bolz, 1969, 1970a, 1970b, 1971, 1974). To obtain a reliable ostracod stratigraphy calibrated to the standard ammonoid zones, the biostratigraphic positions of the most important ostracod-bearing Rhaetian localities from the Northern Calcareous Alps, especially those from the Hallstatt region (Upper Austria and Styria), are updated based on new ammonoid findings (provided by L. Krystyn and M. Maslo) and on ammonoids recorded in literature. However, the subdivision of the Rhaetian underwent some changes in the last few decades. The early classifications have been summarized by Wiedmann et al. (1979) and Krystyn (1980: 74, 2007a, fig. 1). It is unnecessary to discuss in detail the follow-up changes which happened to the latest Triassic chronostratigraphic scale with up- and down-scaling of the Norian-Rhaetian boundary respectively revisions in the ammonoid zonal and subzonal scheme (Krystyn, 1990). After an intensive discussion within the Norian-Rhaetian boundary working group of the Subcommittee on Triassic

Stratigraphy, the base of the Rhaetian has been proposed at the first appearance of the conodont *Misikella posthernsteini*. By this, the Rhaetian includes now three ammonoid zones (*Paracochloceras suessi*, *Vandaites stuerzenbaumi*, and *Choristoceras marshi*) of which the oldest corresponds to part of the former classical Upper Norian of the Hallstatt Limestone Formation. This stratigraphic subdivision in *Paracochloceras suessi*, *Vandaites stuerzenbaumi*, and *Choristoceras marshi* zones (= Early, Middle, and Late Rhaetian) is adopted here. By incorporating the *Paracochloceras suessi* Zone to the Rhaetian, no terrigenous sediments from which ostracods could easily be extracted were left in the Northern Calcareous Alps and elsewhere in the western Tethys to the Norian. There are also no reports of Late Norian ostracods extracted from limestones by acidic dissolution. Therefore, we are without any knowledge of the immediate pre-Rhaetian ostracod fauna and without any idea on eventual changes in the ostracod fauna at the new Norian/Rhaetian boundary.

### STRATIGRAPHIC DISTRIBUTION OF THE OSTRACODS AT STEINBERGKOGEL

Five samples comprising moderately preserved ostracods are at hand from thin marl beds of the uppermost Hallstatt Limestone Formation (*Paracochloceras suessi* Zone) which consists of grey well-bedded limestone beds at the Steinbergkogel locality (near Hallstatt/Upper Austria) (Fig. 1). The taxonomy of the Bairdiidae is adopted from Bolz (1971), and the taxonomy of

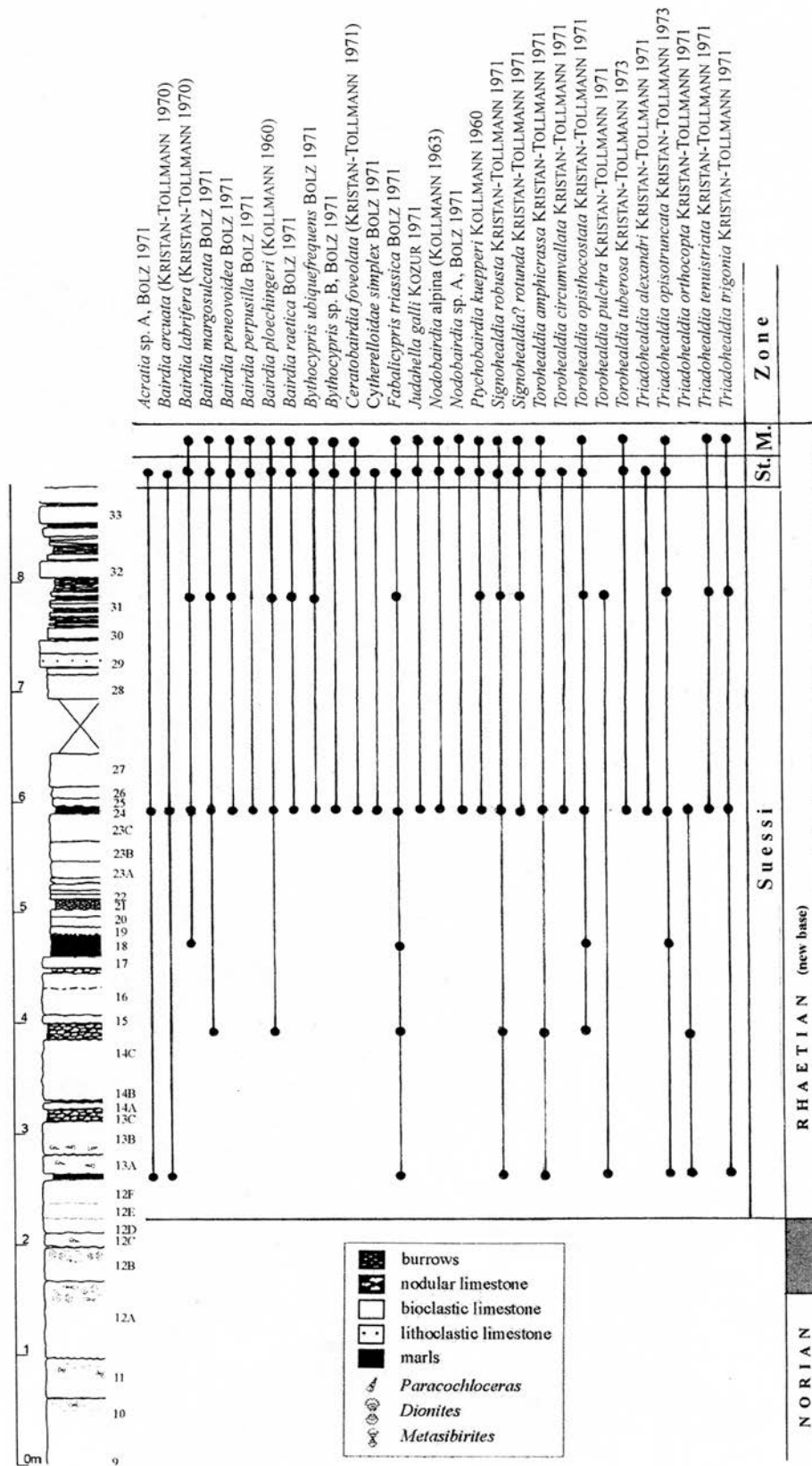


Figure 1 – Stratigraphic ranges of the ostracods from the *Paracochloceras suessi* Zone (Early Rhaetian) of Steinbergkogel (Upper Austria, section). Section from Krystyn et al., 2007b, fig. 6: section B+C). M. = *Choristoceras marshi* Zone, St. = *Vandaites stuerzenbaumi* Zone.

| <i>P. suessi</i>           | <i>V. stuerzenbaumi</i>  | <i>Ch. marshi</i>   | Zone  |                       |
|----------------------------|--|---|---|-----------------------|
| Roßmoos,<br>Steinbergkogel | Grünbachgraben,<br>Höllgraben,<br>Mühlgraben,<br>Weißloferbach | Ampelsbach<br>Fischerwiese,<br>Rotwandl,<br>Weißloferbach | Localities recorded by BOLZ (1970, 1971),<br>supplemented by Steinbergkogel |                       |
| X                          | X  | X   | <i>Bairdia acerta</i> BOLZ 1971   | <b>Bairdiidae</b>     |
|                            | X  |   | <i>Bairdia arcuata</i> (KRISTAN-TOLLMANN 1970)                              |                       |
| X                          | X  | X   | <i>Bairdia austriaca</i> (KOLLMANN 1963)                                    |                       |
|                            | X  |   | <i>Bairdia bicostata</i> (KRISTAN-TOLLMANN 1969)                            |                       |
| X                          | X  |   | <i>Bairdia cincta</i> (KOLLMANN 1963)                                       |                       |
|                            | X  | X   | <i>Bairdia fastigata</i> BOLZ 1971  |                       |
|                            | X  |   | <i>Bairdia hians</i> (KOLLMANN 1963)  |                       |
|                            | X  | X   | <i>Bairdia labrifera</i> (KRISTAN-TOLLMANN 1970)                            |                       |
| X                          | X  | X   | <i>Bairdia margosulcata</i> BOLZ 1971                                       |                       |
|                            | X  |   | <i>Bairdia marginotumida</i> (KRISTAN-TOLLMANN 1969)                        |                       |
| X                          | X  | X   | <i>Bairdia penevoidea</i> BOLZ 1971   |                       |
|                            | X  | X   | <i>Bairdia perdata</i> BOLZ 1971  |                       |
| X                          | X  | X   | <i>Bairdia perpusilla</i> BOLZ 1971   |                       |
| X                          | X  | X   | <i>Bairdia ploechingeri</i> (KOLLMANN 1960)                                 |                       |
| X                          | X  |   | <i>Bairdia raetica</i> BOLZ 1971  |                       |
|                            | X  | X   | <i>Bairdia salisburgensis</i> (KOLLMANN 1963)                               |                       |
| X                          | X  |   | <i>Bairdia ventriosa</i> BOLZ 1971  |                       |
| X                          | X  | X   | <i>Bairdiacypris multidentata</i> BOLZ 1971                                 |                       |
| X                          | X  | X   | <i>Bythocypris ubiquefrequens</i> BOLZ 1971                                 |                       |
|                            | X  | X   | <i>Ceratobairdia triassica</i> BOLZ 1971                                    |                       |
| X                          | X  | X   | <i>Fabalicypis triassica</i> BOLZ 1971                                      |                       |
| X                          | X  | X   | <i>Lobobairdia salinaria</i> KOLLMANN 1963                                  |                       |
| X                          | X  | X   | <i>Lobobairdia triassica</i> (KOLLMANN 1963)                                |                       |
| X                          | X  | X   | <i>Lobobairdia umbonata</i> (KOLLMANN 1963)                                 |                       |
| X                          | X  | X   | <i>Nodobairdia alpina</i> (KOLLMANN 1963)                                   |                       |
| X                          | X  | X   | <i>Nodobairdia dentata</i> BOLZ 1971  |                       |
|                            | X  |   | <i>Nodobairdia nodata</i> BOLZ 1971   |                       |
|                            | X  |   | <i>Nodobairdia triassica</i> BOLZ 1971                                      |                       |
|                            | X  |   | <i>Ptychobairdia circumvallata</i> KRISTAN-TOLLM.1970                       |                       |
| X                          | X  | X   | <i>Ptychobairdia kuepperi</i> KOLLMANN 1960                                 |                       |
|                            | X  |   | <i>Ptychobairdia oberhauseri</i> KOLLMANN 1963                              |                       |
|                            | X  | X   | <i>Triebelina bicornuta</i> (KOLLMANN 1963)                                 |                       |
|                            | X  | X   | <i>Triebelina longiforma</i> BOLZ 1971                                      |                       |
|                            | X  | X   | <i>Triebelina ornata</i> (KOLLMANN 1963) *)                                 |                       |
|                            | X  |   | <i>Triebelina parva</i> BOLZ 1971 **)                                       |                       |
|                            | X  | X   | <i>Triebelina reticulata</i> (KRISTAN-TOLLMANN 1970)                        |                       |
| X                          | X  | X   | <i>Cytherelloidea circumscripta</i> (BLAKE 1876)                            | <b>Cytherelloidea</b> |
|                            | X  | X   | <i>Cytherelloidea latereticulata</i> BOLZ 1970                              |                       |
|                            | X  | X   | <i>Cytherelloidea percostata</i> BOLZ 1970                                  |                       |
| X                          | X  | X   | <i>Cytherelloidea plana</i> BOLZ 1970                                       |                       |
| X                          | X  | X   | <i>Cytherelloidea pulchella</i> BOLZ 1970 ***)                              |                       |
| X                          | X  |   | <i>Cytherelloidea simplex</i> BOLZ 1970                                     |                       |
| X                          | X  | X   | <i>Cytherelloidea triassica</i> BOLZ 1970                                   |                       |
|                            | X  | X   | <i>Cytherelloidea unicastata</i> BOLZ 1970                                  |                       |
| X                          | X  | X   | <i>Cytherelloidea valida</i> BOLZ 1970                                      |                       |

**Table 1** – . Updated ranges of the ostracod species of the Bairdiidae and Cytherelloidea recorded by Bolz (1969, 1970a, 1971), except those in open nomenclature. \*) junior synonym: *Dicerobairdia variolaria* Kristan-Tollmann (1971). \*\*) junior synonym: *Dicerobairdia trinodosa* Kristan-Tollmann (1971). \*\*\* = *Cytherelloidea buisensis* Donze (1966).



Kristan-Tollmann (1970, 1971a, 1971b, 1971c, 1973) is still used here, though the healdiid genera and species introduced by her should be revised. The ostracod assemblages from Steinbergkogel are dominated both in diversity and abundance by Healdiidae. Smooth-shelled Bairdiidae are also highly diverse but poorly abundant, and ornamented Bairdiidae are merely represented by single *Ptychobairdia* specimens. The bairdiid species found at Steinbergkogel have been furthermore recorded from the lowermost Zlambach Formation just above the Hallstatt Limestone Formation (*Paracochloceras suessi* Zone) at the locality Roßmoos north-east of Bad Goisern (Upper Austria) by Bolz (1974: 327). Most species of the Bairdiidae and Healdiidae recorded from these localities range from the *Paracochloceras suessi* Zone into the younger *Vandaites stuerzenbaumi* and *Choristoceras marshi* zones (Fig. 1, Tab. 1). Merely, some species of the genera *Triadohealdia* and *Torohealdia* are hitherto unknown from younger zones, probably because they are still not investigated from there.

The ostracod assemblages from the Zlambach Formation which are dominated in diversity by Healdiidae and smooth-shelled Bairdiidae represent deep-water conditions. The water depth of the Hallstatt Basin has been supposed to be below 250 and 300 m estimating the height of the palaeoslope from the platform to the basin at Gosaukamm/Salzburg (Krystyn, 1991: 66). Ostracod assemblages from the Alpine Late Anisian with a similar faunal content have been interpreted as representatives of deep-shelf or even bathyal environments (Kozur, 1971b, 1972: 634). Another association, also with an abundance especially of ornamented Bairdiidae (*Ptychobairdia*) and furthermore of smooth-shelled Bairdiidae (*Bairdia*, *Bairdiacypris*, *Bythocypris*) has been described from the Early Pliensbachian of the Pontides/Turkey (Lord & Lambourne, 1991: 382). It represents deep-water, perhaps bathyal conditions. In contrast, ostracod genera indicating neritic environments are very rare in the *Paracochloceras suessi* Zone at Steinbergkogel. Only single specimens of *Nodobairdia* and *Judahella* are recorded from there.

### IS THERE AN END-NORIAN BIOTIC CRISIS IN OSTRACODS?

McRoberts et al. (2008: 726) stated that “it has long been recognized that an extraordinary event took place around the Norian/Rhaetian boundary that primarily affected the pelagic fauna dominated by monotid bivalves and ammonoids.” This mass extinction has been also alleged in ostracods at the former Norian/Rhaetian boundary (Kozur, 1971b: 4, 1972: 627, 1980: 122; Kozur & Mostler, 1972: 349). To check up this assumption, the stratigraphic ranges of the Bairdiidae and Cytherelloidea from the Zlambach Formation described by Bolz (1969, 1970a, 1970b, 1971) are updated. Not only a decrease in diversity is missing at the boundary from the *Paracochloceras suessi* Zone to the *Vandaites stuerzenbaumi* Zone, but in contrast an increase in diversity has been observed from 18 species of Bairdiidae in the *Paracochloceras suessi* Zone to 36 species in the *Vandaites stuerzenbaumi* Zone and a decrease to 24 species in the *Choristoceras marshi* Zone (Tab. 1). The reason for this increase is first of all the first appearance of

*Nodobairdia* and *Triebelina* species in the *Vandaites stuerzenbaumi* Zone besides a higher diversity in smooth-shelled Bairdiidae. *Nodobairdia* and *Triebelina* which originally lived in the neritic zone have been transported downslope and redeposited in deeper water of the adjacent Hallstatt Basin. Allogenic beds with an input of neritic associations are rare in the basal sediments of the *Paracochloceras suessi* Zone at Steinbergkogel, but frequent in the *Vandaites stuerzenbaumi* and *Choristoceras marshi* zones at other localities. The decrease in diversity in the *Choristoceras marshi* Zone mainly results from a lower diversity of smooth-shelled *Bairdia* species which had a high diversity in deep-shelf and bathyal environments. Therefore, the differences in the ostracod diversity between the three Rhaetian zones result from different ecological conditions. The stratigraphic distribution of the Cytherelloidea is similar. After Bolz (1970a), six species have been recorded in the *Paracochloceras suessi* Zone, nine in the *Vandaites stuerzenbaumi* Zone, and eight in the *Choristoceras marshi* Zone (Tab. 1). However, Cytherelloidea are very rare in the Zlambach Formation and thus insignificant for ecological interpretations.

### CONCLUSIONS

The faunistic relationships between the ostracods of the *Paracochloceras suessi*, *Vandaites stuerzenbaumi*, and *Choristoceras marshi* zones are very close: All ostracod species recorded from the *Paracochloceras suessi* Zone, except few *Triadohealdia* and *Torohealdia* species, range into the *Vandaites stuerzenbaumi* Zone and most of them also into the *Choristoceras marshi* Zone (Fig. 1, Tab. 1). This stratigraphic distribution of the ostracods corroborates the formal incorporation of the *Paracochloceras suessi* Zone to the Rhaetian Stage. Ostracods from the Late Norian in the revised sense are unknown, and therefore, a comparison with ostracod associations older than *Paracochloceras suessi* Zone (Early Rhaetian) is impossible.

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## BASE OF THE RHAETIAN AND A CRITIQUE OF TRIASSIC CONODONT-BASED CHRONOSTRATIGRAPHY

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**Abstract**—Recent analyses render problematic a Rhaetian base defined by a GSSP at Steinbergkogel, Austria, that has the lowest occurrence of the conodont *Misikella posthernsteini* as its primary signal. This problem well exemplifies taxonomic issues and stratigraphic range extensions of Triassic conodonts that have rendered problematic the base Induan GSSP and proposals for the GSSPs of the bases of the Olenekian, Anisian and Norian. Triassic chronostratigraphy should abandon conodont biostratigraphy and return to the ammonoid biostratigraphy upon which the Triassic timescale was originally built.

### INTRODUCTION

The Triassic chronostratigraphic scale was built primarily on two centuries of ammonoid biostratigraphy (Lucas, 2010). However, in the 1990s, a movement began to define Triassic chronostratigraphic (stage) boundaries that were correlated primarily by conodonts. At present, one stage boundary (Induan) has a GSSP and four (Olenekian, Anisian, Norian and Rhaetian) are likely to be defined by GSSPs that have their primary signals based on the LOs (lowest occurrences) of conodont species.

Nevertheless, I see diverse problems with conodont-based Triassic chronostratigraphy, including: (1) the relative youth of Triassic conodont taxonomy, which remains unstable for many taxa; (2) the youth of stratigraphic studies of Triassic conodont taxa, so that many Triassic conodonts do not have well-established stratigraphic ranges; (3) reworking of conodonts, which is not easily recognized and rarely addressed (Macke and Nichols, 2007); (4) problems of facies restrictions, diachroneity and provinciality, which do affect Triassic conodont distributions (Clark, 1984); and (5) the invisibility of conodonts on outcrop, so that they cannot be used in the field to determine the ages of strata (Lucas, 2010, 2013).

To a large extent, I believe that Triassic conodont-correlated GSSPs were an answer to longstanding disagreements over taxonomy and correlation among ammonoid specialists (Lucas, 2010, 2013). Thus, as a relatively newly studied taxonomic group (extensive study of Triassic conodonts did not begin until the 1970s), Triassic conodonts did not have the perceived drawbacks of ammonoids—a long history of taxonomic changes and disagreements as well as known provinciality and demonstrably diachronous distributions of some taxa. Furthermore, the ubiquity and perceived cosmopolitanism of conodonts as well as the retirement in the 1990s of the main Triassic ammonoid workers fueled the rise of Triassic conodont-

based chronostratigraphy. Nevertheless, it is increasingly clear that Triassic conodonts have all of the drawbacks of the ammonoids and are not inherently superior biostratigraphic tools with which to define Triassic chronostratigraphy.

In the light of recently published work on Rhaetian conodonts, the proposal to use a conodont biostratigraphic datum as the primary signal for a basal Rhaetian GSSP (Krystyn et al., 2007a, b) exemplifies the drawbacks of using conodonts in Triassic chronostratigraphic definitions. These drawbacks support my contention that we should abandon conodonts as a tool for the chronostratigraphic definition of Triassic stages and continue to build the Triassic timescale using ammonoid biochronological events (Lucas, 2013).

### SOME HISTORY

Gümbel (1859) used the term “Rhätische Gebilde” to refer to the uppermost Triassic strata (Kössen beds) in the Bavarian Alps. No type locality was specified, but Gümbel did refer to the “Schichten der *Rhaetavicula contorta*” (beds with the bivalve *R. contorta*). Thus, in the first “finished” Triassic chronostratigraphic scale, Mojsisovics et al. (1895) referred to the Rhaetian as the “Zone der *Avicula contorta*.”

In ammonoid biostratigraphy, the Rhaetian was long considered equivalent to one or two ammonoid zones (see reviews by Krystyn, 1990 and Krystyn et al., 2007b). Because of this, Tozer (1967, 1988, among others) argued that the Rhaetian was “too short” to be recognized as a stage and should be reduced to a substage of the Norian, a proposal that was followed by some workers during the 1970s and 1980s. However, short stages are superior to long stages because they discriminate short intervals of geological time, one of the primary goals of timescale research (Lucas, 2010, 2013). Therefore, Tozer’s argument to eliminate the Rhaetian as a stage because it is “too short” should have been



immediately rejected. The real problems of the Late Triassic chronostratigraphic scale should focus on the Carnian and Norian, both very long stages that need to be subdivided. As I have already argued, elevating their substages (Julian, Tuvalian, Alaunian, etc.) to stage status would be a major step forward in development of a Triassic chronostratigraphic scale (Lucas, 2013).

The Subcommittee on Triassic Stratigraphy (STS) began its published discussion (in the first issues of the STS journal *Albertiana*) with a lively debate over whether or not to recognize the Rhaetian as a separate stage. This effectively ended by the 1990s, when the STS agreed on a stage nomenclature of the Triassic that recognizes a distinct Rhaetian as the youngest Triassic stage (Visscher, 1992).

At present, the only fully published GSSP candidate for the Rhaetian base is the Steinbergkogel section near Hallstatt, Austria (Krystyn et al., 2007a, b). The favored definition of the Rhaetian base has as its primary signal the LO (lowest occurrence) of the conodont *Misikella posthernsteini* (Fig. 1). This produces a so-called “long” Rhaetian composed of two ammonoid zones. The youngest substage of the Norian, the Sevatian, is thereby reduced to one ammonoid zone.

### CONODONTS AND THE BASE OF THE RHAETIAN

The proposal of Krystyn et al. (2007a, b) to define a GSSP for the Rhaetian base at Steinbergkogel offered two possible conodont biostratigraphic datums (and a stratigraphically higher,

ammonoid-based level) as candidates for the primary signal of the GSSP--the LO of the conodont *Misikella hernsteini*, and the slightly higher LO of the conodont *M. posthernsteini* (Fig. 1). The working group voted on the GSSP level, and a majority (61%) chose the *M. posthernsteini* datum (Krystyn, 2010). However, the formal proposal to ratify the base Rhaetian GSSP never went to the ICS.

Some would say that was a fortunate delay, as Giordano et al. (2010) concluded that the LO of *Misikella posthernsteini* is actually younger at Steinbergkogel than it is in the section they studied in the Lagonegro basin in southern Italy. Thus, the LO of *M. posthernsteini* at Steinbergkogel is not the FAD (first appearance datum) of the species. As part of their work, Giordano et al. (2010) presented a chronomorphocline of the species transition from *M. hernsteini* to *M. posthernsteini* (Fig. 2).

However, I see the chronomorphocline of *Misikella hernsteini* to *M. posthernsteini* presented by Giordano et al. (2010) as very incomplete (Fig. 2). Thus, unlike chronomorphoclines proposed in the paleontological literature for some other taxa, such as foraminiferans and fossil mammals (e.g., Hayami & Ozawa, 1975; Bookstein et al., 1978), Giordano et al.’s (2010) conodont chronomorphocline is known only from photographs of supposedly representative steps in the lineage. There are no data on sample sizes, no documentation of variation in samples, no metric data, indeed, none of the detailed information and analyses we should see to convince us that the data robustly support the hypothesized chronomorphocline. Indeed, the lack of any data on variation in the sample at each step in the chronomorphocline makes it an unconvincing portrayal of the evolution of the species.

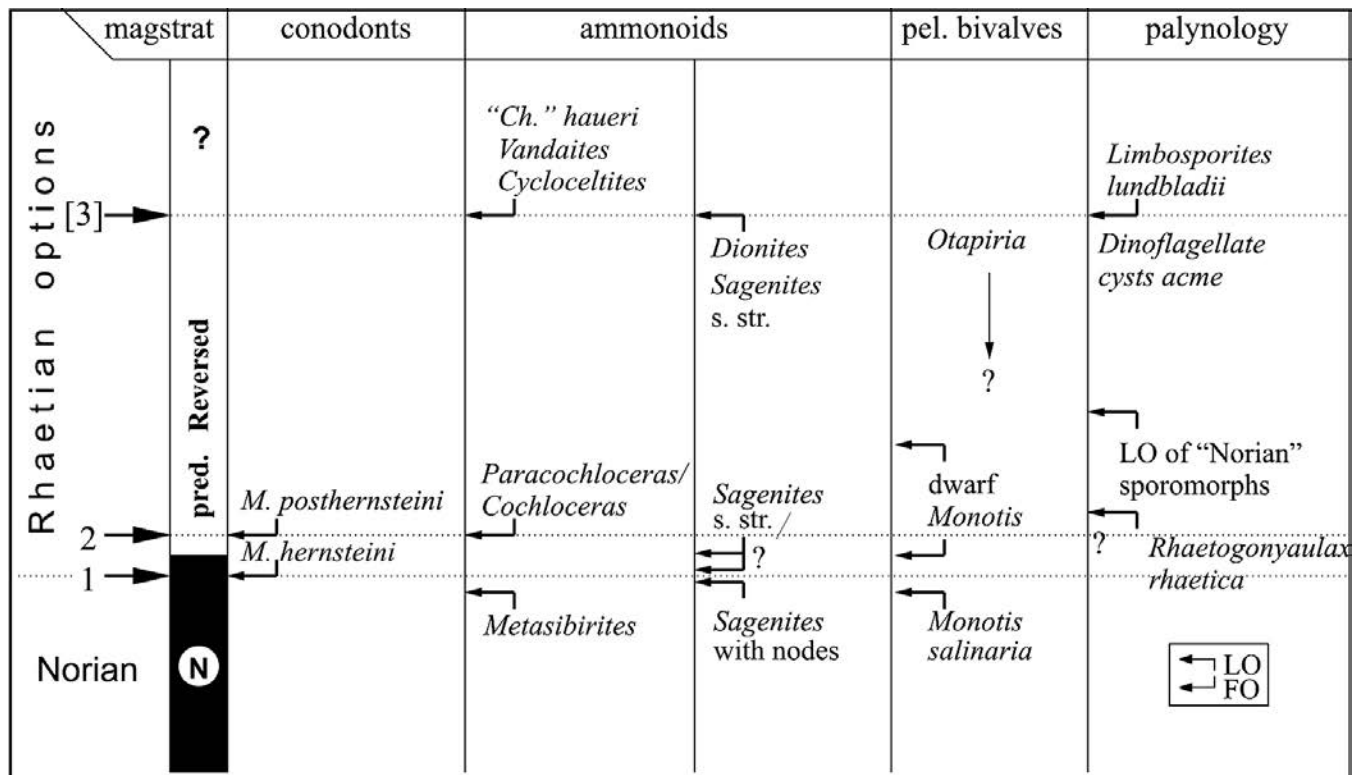
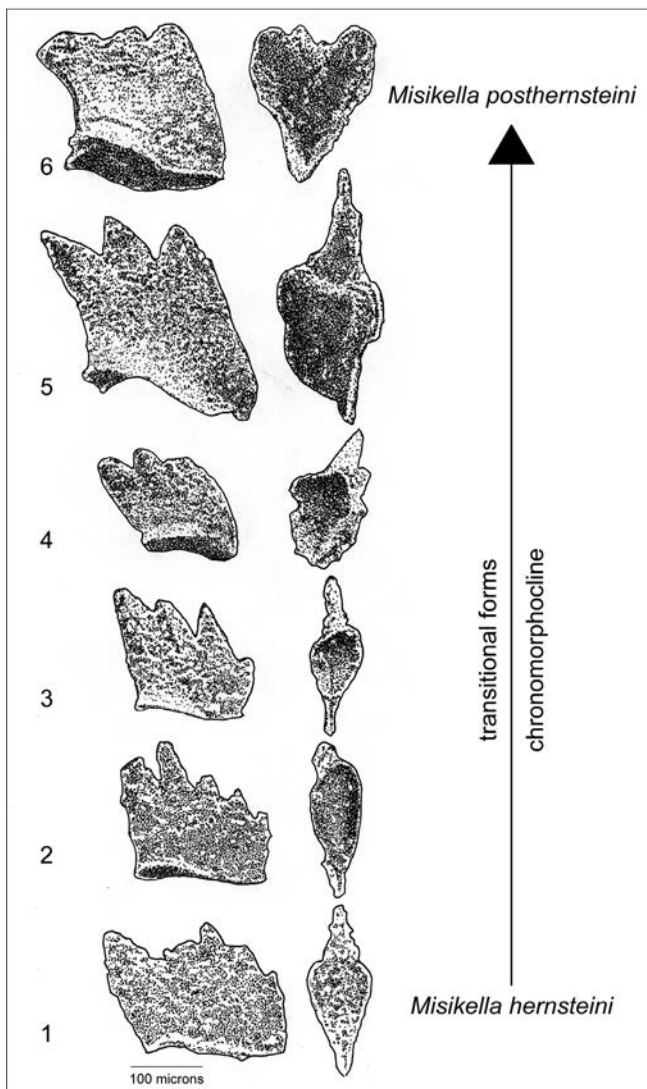


Figure 1—Possible GSSP levels (1, 2, 3) and proxies for the base of the Rhaetian Stage at the Steinbergkogel, Austria, section (from Krystyn et al., 2007a).



**Figure 2** – Hypothesized chronomorphocline from *Misikella hernsteini* to *M. posthernsteini* from the Lagonegro basin in Italy. Conodont images redrawn by Tom Suazo and diagram slightly modified from Giordano et al. (2010, fig. 5). Conodont views on right are basal views of conodonts shown in lateral views on left.

Instead, all we are shown is a succession of ideal morphotypes that may capture the actual chronomorphocline, but without other data and analysis the chronomorphocline must be considered incompletely documented.

Because of this, it is easy to question various aspects of this chronomorphocline. For example, the fact that conodont 4 is similar to 5 (Fig. 2) but only about half its size raises interesting questions about possible conodont ontogeny and heterochronic evolution not addressed by Giordano et al. (2010). Also, why isn't the species-level change from *M. hernsteini* to *M. posthernsteini* between conodonts 4 and 5, and doesn't 4 more resemble 6 in certain morphology than does 5? Furthermore, because we don't know the range of variation at each step of the chronomorphocline, how can we evaluate whether the only conodont illustrated at each level well represents the sample from which it was taken?

In fairness to Giordano et al. (2010), I note that the

chronomorphocline of *Misikella hernsteini* to *M. posthernsteini* they present is just as inadequate as conodont chronomorphoclines being proposed in conjunction with Permian stage GSSPs (e. g., Chernykh et al., 2014). To me, it seems that the “corporate culture” of conodont micropaleontologists is to produce chronomorphoclines akin to “connect-the-dots art,” instead of the rigorously and metrically documented chronomorphoclines proposed in evolutionary studies of other taxonomic groups. I urge conodont micropaleontologists to document their chronomorphoclines more extensively and more rigorously before they are considered for use in chronostratigraphy.

### PROBLEMATIC TRIASSIC CONODONT CHRONOSTRATIGRAPHY

The problems with using conodonts for Triassic chronostratigraphic definitions are growing rapidly. Thus, recent work on conodont records across the Permo-Triassic boundary indicate that the LO of *Hindeodus parvus* at Meishan in south China, which is the primary signal associated with the base of the Induan (= base Triassic) GSSP, is a relatively young occurrence of this taxon (Jiang et al., 2011; Brosse et al., 2015). Thus, the primary signal to correlate the base of the Triassic is diachronous.

In 2007, the working group of the STS voted to favor (though not by a significant majority) a basal Olenekian GSSP at the Mud section in Spiti with its primary signal the LO of the conodont *Neospathodus waageni*. Not long after the vote, *N. waageni* was found to have older occurrences at Mud than previously known, derailing the effort to define this GSSP (Zakharov, 2010).

For at least a decade, the LO of the conodont *Chiosella timorensis* at the Deşli Caira section in Romania was considered the primary signal for a base Anisian GSSP (e.g., Orchard et al., 2007). However, discovery of that species in Spathian strata (Goudemand et al., 2012) extended its stratigraphic range and has derailed definition of a basal Anisian GSSP.

Several conodont datums have been proposed as the primary signal for a GSSP for the Norian base (e.g., Orchard, 2014). Disagreements over conodont taxonomy in this interval seem to impede a decision here (e.g., Mazza et al., 2009, 2012). And, if you disagree with my assertion that Triassic conodont taxonomy is young and untested, examine how many new conodont taxa Orchard (2013, 2014) has just named in his monumental studies of the Carnian-Norian boundary GSSP candidate section at Black Bear Ridge in British Columbia, Canada.

As noted above, the conodont signal for a basal Rhaetian GSSP is problematic. Unfortunately, this has opened the door to those who propose non-unique events as primary signals for GSSPs, such as chemostratigraphy and magnetostratigraphy (e.g., Maron et al., 2015), proposals that should be summarily rejected.

In 2007, at the Global Triassic meeting in Albuquerque, the STS seemed very close to defining GSSPs with conodont signals for the bases of the Olenekian, Anisian, Norian and Rhaetian. Now, nearly a decade later, these GSSPs remain undefined because of stratigraphic range extensions and/or taxonomic problems with the conodonts. I think the time is long past due to abandon conodonts and return to ammonoids as the primary signals upon

which to correlate Triassic chronostratigraphic boundaries.

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## BASE OF THE RHAETIAN AND A CRITIQUE OF TRIASSIC CONODONT-BASED CHRONOSTRATIGRAPHY: COMMENT

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### INTRODUCTION

Elsewhere in this volume, Spencer Lucas has argued for the “abandonment of conodonts as a tool for chronostratigraphic definition”, and a “return to ammonoids as primary signals”. He fails to explain or propose which ammonoids would be more suitable primary signals, but rather he supports this view by listing five disadvantages of the microfossil group, and by citing several cases where our knowledge of boundary conodonts has recently improved, which he claims renders them unreliable. On the contrary, conodonts are becoming ever more useful in the geological sciences, including Triassic biochronology, as I shall attempt to show here.

From the outset it needs to be stated that GSSP proposals are considered on their merits in terms of both the fossil record and the “non-unique” physical and chemical signals rejected outright by Lucas (Walsh et al., 2004). There is no a priori use of conodonts for this purpose, or any “movement” to towards doing so, they just happen to be extremely useful. In contrast to the alleged ‘tyranny of conodonts’, the last decade has, in fact, seen the choice of an ammonoid as a primary datum for the only two defined intra-Triassic GSSPs, the Anisian-Ladinian Boundary and the Ladinian-Carnian Boundary. The Permian-Triassic Boundary remains the only datum defined by a conodont. As Lucas writes, two other conodont datums have been proposed but these GSSPs have not been concluded pending clarification of some specific taxonomic and biostratigraphic issues, which are being addressed.

Of course, ammonoids do provide the essential historical framework for the present Triassic time scale: stage boundaries were broadly established by very visible (and sometimes mixed!) ammonoid fossils long before the advent of conodonts. The relative novelty of these microfossils cannot be denied, but nor can the tremendous progress that has been made. We now have a rather complete fossil record for the group through the Triassic, as in the Paleozoic where they have been studied longer, and where conodonts frequently serve as boundary indices. The conodont fossil record lends itself to phyletic and evolutionary studies much more than that of less resilient fossils. Calcareous fossils rarely enjoy this advantage, although they certainly provide some superb successions. Lucas’s facetious comment about “joining the dots” reveals an ignorance of how clearly displayed morphogenesis often is in the conodonts.

### CONODONT-BASED CHRONOSTRATIGRAPHY

Lucas lists five diverse problems with conodont-based chronostratigraphy. I comment on each one below.

#### **Taxonomic & stratigraphic instability**

Yes, Triassic conodonts have been studied for only 50 years. During that time, our knowledge has gone through a revolution in terms of SEM micro-imagery and multielement taxonomy. Much remains to be done, but for which fossil group is that not the case? – Jurassic ammonite zonations have undergone constant revision since Opper developed the concept of a biostratigraphic zone 150 years ago! My perspective after 45 years of conodont research is that both conodont taxonomy and biostratigraphy has reached a solid level of maturity and stability. If progress is slow it is simply that there are too few conodont researchers working on boundary definitions. Lucas argues that recent taxonomic and stratigraphic revisionism render the group less useful, whereas I regard such work - which generally involves larger and denser sampling of key intervals - as taking us exactly where we need to be.

#### **Reworking**

In spite of examples cited by Mack & Nichols (2007) from often dated literature on Devonian-Mississippian lag deposits, the reworking phenomenon is uncommon in my experience. It is generally easy to recognize when it does occur, and resulting ‘derived’ data adds considerably to geological interpretations: e.g. recognition of ‘ghost stratigraphy’ and erosional history. Reworked conodonts are, like reworked zircons, obvious in lacking pristine ‘facets’ and are not selected to provide dates. In cases of extreme condensation, one must take great care of course – as is equally true of ammonoids: stratigraphic admixture and leakage of ammonoids in Alpine Hallstatt limestones originally led to far more erroneous chronostratigraphy than any cited by Lucas! (see historical review in Tozer, 1994).

In some clastic successions, e.g. the Triassic Liard Formation in B.C., rare eroded conodont elements are corroded and discoloured (and perhaps have a different Color Alteration Index) compared with contemporaneous elements. A more common reworking phenomenon is where coarse clastics contain clasts from which conodonts can be isolated, sometimes separately,

to reveal the source rocks. One may run into a problem only if the clast-bearing nature of the rock is not realized and a contemporaneous microfauna is absent. It should also be noted that conodonts are well enough known now to recognize admixtures of differing ages (contra Macke & Nichols, 2007).

### Facies, provinciality

To portray conodonts as in some way uniquely deficient in this area is misleading. Non-paleontologists point to all fossils as sharing this drawback, and therefore insist on truly global, instantaneous events as integral to definition (Smith et al., 2014). We can point to the differing habitats occupied by all creatures, past and present, to demonstrate temporal lag in migration, or absence from some facies. We can be confident that active predators, like most conodonts and ammonoids, were more widespread than most, and became widespread rapidly. I see no merit in presenting either fossil group as in some way superior in this particular regard. Of course, when there is demonstrable facies dependency or paleobiogeographic partitioning, the conodonts (and other fossils) become a different kind of tool – very useful in basin and terrane analysis.

### Invisibility

This is a moot point. I have spent much of my time in the field in the company of macropaleontologists and I am delighted when they are able to proclaim the age of strata on the spot! The late Tim Tozer guided me through Triassic successions for many years, and I was able to collect conodont samples that were tightly intercalibrated with his ammonoid zones (Orchard and Tozer, 1997). Furthermore, I collected samples from beds between his preserved ammonoid faunas, and in doing so I was able to delineate biozones in intervening strata. A more complete conodont succession and, consequently, a more refined chronology resulted, and this is often the scenario in integrated ammonoid - conodont stratigraphy. Obviously these advances can hardly be achieved in the field but require laboratory extraction. However, the issue is the value of conodonts in chronostratigraphy, not as an aid in field geology (but see Cordey & Krauss, 1990). It should be added that the careful preparation of macrofossils in the laboratory is often necessary prior to precise determination.

## GSSPS OLD AND NEW

Lucas makes the point that a decade has passed since the 2007 Albuquerque meeting when the status of outstanding GSSPs was discussed, and he presents this as a further reason to abandon conodonts. He notes several examples of how conodont range has been modified, and criticizes some of the science that has been published as lacking rigour. With a single paragraph on each of several Triassic boundaries, Lucas offers the reader a stark summary of conodont shortcomings to date. His broad dismissal of conodonts demands a more thorough review of not only the problems that have emerged, and also the considerable progress made to address them as we move close to resolution of

the Triassic time scale.

### Permian-Triassic Boundary (PTB)

Choice of the first Triassic GSSP resulted from a multidisciplinary study of all the then available data to identify a sequence of biological, physical, and chemical events at the erathem boundary (Yin et al., 2001). The well-studied Meishan succession incorporated many biotic and non-biotic signals, one of which, the first appearance of *Hindeodus parvus*, was selected as an index: this is a common and globally distributed conodont that occurs in a wide variety of facies.

The PTB has continued to receive intensive study in recent years. The chemostratigraphy is now much better understood, as is the conodont taxonomy. Numerous new species of the related *Hindeodus* and *Isarcicella* have been differentiated since the GSSP was defined (see Orchard, 2007 for list), and there have been taxonomic advancements in morphometric analysis of *H. parvus* morphotypes (Chen et al., 2009), and cladistical analysis of the entire *Hindeodus-Isarcicella* clade (Jiang et al., 2010, 2011). Refined conodont and carbon isotope data from more expanded sections than that at Meishan support the view that the appearance of *H. parvus* at the GSSP is younger than its appearance elsewhere (Jiang et al., 2011; Brosse et al. 2015; Zhang et al., 2014; Yuan et al., 2015). This progress arises directly from the refinement of conodont biostratigraphy which has proven to be self-correcting as more intensive studies focused on the boundary interval. The facts may represent a shortfall for the relatively condensed type section at Meishan with its dissolution phenomena (Chen et al., 2009), but not for *H. parvus* as a correlative tool and useful index.

### Induan-Olenekian Boundary (IOB)

As shown by Goudemand (2014), new fossil collections from Mud, Waili, Chaohe, and Nammal Gorge enable further taxonomic revision of the *Neospathodus waageni* group and have resulted in both a consistent conodont succession, and a tighter calibration with ammonoid faunas. Although unpublished in detail, this work continues the modern revisionism of the conodont group that dates from a decade earlier (Zhao et al., 2004). More thorough sampling of the Mud section, supplemented by new data from Chinese and Pakistan sections, yielded and replicated new conodont taxa within the waageni group (Goudemand, 2014). The decision to define the IOB on the appearance of this species spectrum, characterized as *N. ex gr. waageni*, was not without merit even if it was, in retrospect, premature and imprecise. As Goudemand states, the newly differentiated conodonts “can be used to define the base of the IOB”, and are fully consistent with the ammonoid data.

### Olenekian-Anisian Boundary (OAB)

The story of the OAB revolves around *Chiosella timorensis*, a common species in lower Anisian strata worldwide. For example, it is common in the *Japonites welteri* beds in Nevada (Orchard, 1994), and more recently was found to be abundant in the early Anisian of Deşli Caira, Romania (Orchard, Grădinaru et al., 2007); its common occurrence in Guandao, China lacks

independent fossil control but the succession of conodont taxa is the same as in Romania (Orchard, Lehrmann, et al., 2007). On the basis of its consistent occurrence and age, it was proposed as an index for the OAB at Deşli Caira, where it is very well aligned with the other fossil elements (Grădinaru et al., 2007). This proposal was initially supported by the fact that conodont samples from the late Spathian *Haugi* Zone of Nevada (mostly collected and identified by Hugo Bucher) failed to produce a single specimen of *C. timorensis* until very recently when a single float sample did so (Goudemand et al., 2012). So, we now know that – in terms of ammonoid stratigraphy – the conodont species straddles the traditional ammonoid boundary; it remains to be seen if this is true at Deşli Caira, where we have long awaited a full account of the ammonoid succession and its correlation with Nevada.

Tentatively, the *Haugi* Zone may be divisible into lower and upper parts based on the presence of *C. timorensis* and, setting aside ‘tradition’, the conodont could be used as an index to the OAB and some part of the *Haugi* Zone may be assigned to the Anisian! (anathema to ammonoid workers no doubt!). That is not something I am advocating, but the main point to make is that *C. timorensis* remains an important guide fossil to recognize, if not define the base of the OAB. Other conodont taxa, some new, were reported by Orchard et al. (op. cit.) from both Romania and China in studies intended to stabilize the taxonomy around the OAB. Using this taxonomic base, Ovtcharova et al. (2015) recently recast the conodont data from Romania and China and compared new data from China. Through the application of Unitary Association they recognize two laterally reproducible maximal associations/ conodont biozones between which the ‘traditional’ OAB falls. They conclude that, with adequate sampling, there is no detectable diachronism in the first occurrence “of a nektonic or a pelagic species”; good news for both conodonts and ammonoids. The conodonts of the OAB provide excellent characterization of the boundary interval and in conjunction with other criteria can provide an appropriate GSSP definition.

### Carnian-Norian Boundary (CNB)

This boundary was the subject of a recent monograph on conodonts from the CNB GSSP prospect at Black Bear Ridge (BBR) in British Columbia. As Lucas notes, many new taxa are described in this work, which largely reflects the relative novelty of the rich and partly endemic North American tropical fauna. The work was also designed to provide the taxonomic basis for a thorough comparison with Tethyan taxa, an advance made possible through lavish illustration in Lucas’s museum publication series! Cosmopolitan species also occur at BBR and these were used by Orchard (2014) as a basis for correlations with Pizzo Mondello, an alternate Sicilian candidate. The contemporaneous conodonts from the latter area (Mazza et al., 2012) are presently less differentiated, and also partly endemic, but the two GSSP candidate sections can be correlated with both conodonts and carbon isotopes anomalies. Both ammonoid and bivalve faunas in these sections provide broad age constraints but are less useful than the conodonts in providing bed-by-bed correlation, or chronomorphoclines (see Orchard, 2014, fig. 30).

### Norian-Rhaetian Boundary (NRB)

The *Misikella* chronomorphocline that features in current proposals for the NRB involves the development of an indentation/ re-entrant in the posterior margin of the P1 element in stratigraphically younger elements. This morphogenesis is seen in many sections worldwide. Lucas (this volume) criticizes the work by Giordano et al. (2010) as providing incomplete documentation of this morphogenesis, although that does not make it any less real. Lucas suggests that the re-illustrated *Misikella* chronomorphocline is flawed, and suggests that elements illustrated as figs. 4 and 6 are morphologically closer than figs. 5 and 6. I see no basis for such a suggestion: the re-entrant can be seen to develop progressively through the illustrated elements. I believe Krystyn et al. (2007a, b), well understood this, and the limitations of using alternative ammonoid indices in their proposal for the NRB. There appears to be no superior ammonoid index option for the NRB, and nor does Lucas suggest one. His urging “for conodont micropaleontologists to document their chronomorphoclines ... more rigorously” is not without merit, but to imply this is not an issue for ammonoid researchers to address for their group (around any Triassic boundary) leaves much unsaid! The first appearance of *M. posthernsteini* needs to be resolved, as does correlation with North America, where *Misikella* is rare (but see Orchard, Whalen, et al., 2007; Orchard, Carter, et al., 2007).

### SUMMARY

Conodonts are a valuable tool for application in stratigraphical, paleoenvironmental, and other geological problems. Their role in biochronology has become increasingly important and they will continue to be an essential ingredient, if not a primary signal, for all Triassic GSSPs. The choice of definition requires an assessment of ALL available criteria and the choice of a single datum needs to be set in the context of a replicable succession of events. To suggest that conodonts cannot be reliably factored into such deliberations, or serve as primary indices, is nonsense.

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## BASE OF THE RHAETIAN AND A CRITIQUE OF TRIASSIC CONODONT-BASED CHRONOSTRATIGRAPHY: REPLY

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My article emphasizes recent and current problems in using conodonts for Triassic chronostratigraphic definitions. I concluded that Triassic conodont stratigraphic ranges are so poorly established and their taxonomy is so new and unstable that they are hindering, not helping definition of a Triassic chronostratigraphic scale. Not surprisingly, Mike Orchard, who has devoted much of his career to developing Triassic conodont biostratigraphy and chronostratigraphy, disagrees with me. Yet, much of Orchard's text explaining the disagreement reiterates (in greater detail than did I) the reasons why Triassic chronostratigraphic boundary definition based on conodont biostratigraphy is a shambles. Thus, he concedes that *Hindeodus parvus* is diachronous, so that its LO (lowest occurrence) at the Meishan GSSP is younger than some other records; he concludes that the recent attempt to use *Neospathodus waageni* as the primary signal of a base Olenekian GSSP was "premature and imprecise;" he explains that *Chiosella timorensis* cannot be a primary signal for an Anisian base unless that base is move downward to capture recent range extension of that species into Spathian strata; he acknowledges that his recent publications on a possible base Norian GSSP in western Canada introduced very many new conodont taxa; and Orchard concedes that "the first appearance of *Misikella posthernsteini* needs to be resolved" to use it to define a Rhaetian base.

I agree with Orchard that what we have been learning about Triassic conodonts during the last decade is progress. Indeed, this progress demonstrates how poorly established are the stratigraphic ranges of many Triassic conodont species, and how many new Triassic conodont taxa remain to be found/identified. Furthermore, this progress should lead us to realize that there has been little to no progress on many chronostratigraphic definitions of the Triassic timescale because whenever somebody proposes a conodont taxon LO as the primary signal of a Triassic GSSP, we soon find that conodont taxon in older strata or its taxonomy is revealed to be in need of an overhaul.

Orchard also agrees with me that Triassic conodont taxonomy is young, that conodonts can be reworked, that they are subject to restriction by facies and provinciality and that conodonts are invisible on outcrop. That is good, because it means that conodonts have all the problems we face with other fossils used in biostratigraphy, and more—nobody can see them on outcrop, so they are of no use to geologists in field studies. Orchard concludes that "my perspective after 45 years of conodont research is that both conodont taxonomy and biostratigraphy has reached a solid level of maturity and stability." Yet, most of the rest of his text (as stressed above) contradicts that conclusion by recounting stratigraphic range extensions and taxonomic changes/new taxa that have pervaded the study of Triassic conodonts during the last decade.

Orchard is not bothered by undocumented conodont chromomorphoclines such as the chromomorphocline of *Misikella hernsteini* to *M. posthernsteini* presented by Giordano et al. (2010) because he somehow "knows" they are real. His point of view on this well represents what I called the "corporate culture" of conodont micropaleontologists, which is to produce chromomorphoclines akin to "connect-the-dots art," instead of the rigorously and metrically documented chromomorphoclines proposed in evolutionary studies of other taxonomic groups. Again, I urge conodont micropaleontologists to document their conodont chromomorphoclines more extensively and more rigorously before they are considered for use in chronostratigraphy.

The Triassic timescale was built on ammonoid biostratigraphy. I have, very explicitly, pointed out one way forward using ammonoids to define all Triassic chronostratigraphic boundaries (Lucas, 2013). I agree with Orchard that conodonts are valuable to the development of a Triassic timescale as one of several tools by which we correlate Triassic strata. But, if we continue to propose Triassic GSSPs for which conodonts are the primary signal, then we will continue to see those primary signals fail.

## NEW TRIASSIC LITERATURE

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## Publication Announcement

**Conodonts from the Carnian-Norian boundary (Upper Triassic) of Black Bear Ridge, northeastern British Columbia, Canada by Michael J. Orchard. New Mexico Museum of Natural History and Science, Bulletin 64: 1-139. 2014.**

This 139-page volume presents a comprehensive taxonomic and biostratigraphic analysis of the Late Triassic conodont record at one of the world's most important Carnian-Norian boundary sections. Extensively illustrated, the monograph names 71 new species and will be an essential reference to all further research on Late Triassic conodonts. If you are interested in ordering Bulletin 64, it costs \$20 and you can contact Beth Ricker, Store Manager for the NMMNH&S, at [beth@naturalhistoryfoundation.org](mailto:beth@naturalhistoryfoundation.org) to place orders.

**Abstract**—Conodonts from the Carnian-Norian Boundary (CNB) interval at the Global Stratigraphic Section and Point (GSSP) candidate section at Black Bear Ridge (BBR), British Columbia, Canada, include five previously introduced genera (*Acuminatella*, *Kraussodontus*, *Parapetella*, *Primatella*, *Quadralla*), 71 new species (plus nine previously named, and 13 more in open nomenclature), and 47 new morphotypes. These elements, and others previously known, display progressive morphogenesis through the strata of the Ludington and Pardonet formations, which represent a continuous Upper Triassic slope-basin succession at the western edge of Pangea.

Two conodont zones and nine subzones are defined for the interval, in ascending stratigraphic order: *Carnepigondolella samueli* Zone with the subzones of *C. eozoa*-*Kraussodontus ludingtonensis*, *C. zoa*, *C. medioconstricta*, and *C. spenceri*; the *Primatella primitia* Zone with the subzones of *Acuminatella sagittale*-*Parapetella beattyi*, *A. angusta*-*Metapolygnathus dylani*, *A. acuminata*-*Pa. prominens*, *M. parvus* (three subdivisions), and *Primatella asymmetrica*-*Norigondolella* sp. These strata are capped by the Early Norian *Epigondolella quadrata* Zone.

Conodont faunal turnovers are identified at the boundary between the *samueli* and *primitia* zones with the extinction of *Carnepigondolella*, and between the *primitia* and *quadrata* zones with the extinction of *Acuminatella* and *Primatella*. However, the most significant turnover is in the boundary interval of the *acuminata*-*prominens* and *parvus* subzones where, respectively, 16 and 46 taxa disappear, including all *Quadralla*, *Kraussodontus*, and most *Parapetella* species. This turnover falls within a 5 m boundary interval bracketed by diagnostic ammonoids of the Upper Carnian *Klamathites macrolobatus* Zone and those of the Lower Norian *Stikinoceras kerri* Zone. The undated boundary interval includes an organic carbon isotope minimum, and the first occurrences of the bivalve *Halobia austriaca*, and the ammonoid *Pterosirenites*. Conodonts from this boundary interval are also identified in association with *H. austriaca* and *Pterosirenites* at nearby Pardonet Hill east (PHE). Matrix from archival ammonoid collections of the

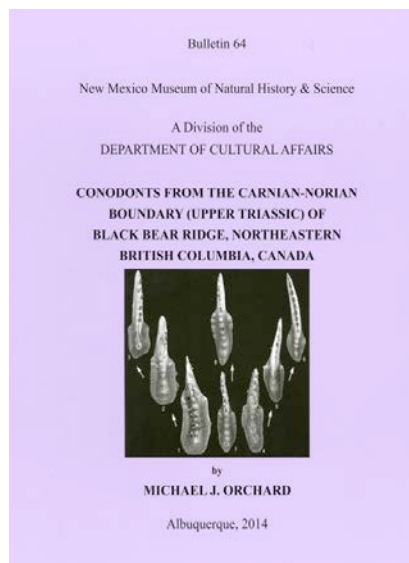
*Macrolobatus* Zone has also yielded the boundary conodont faunas, implying that the entire boundary interval at BBR is equivalent to the *Macrolobatus* Zone.

Broad correlation with the GSSP candidate section at Pizzo Mondello (PM) in Sicily can be achieved at several levels around the *parvus* Subzone: at its base with the appearance of the name-giver; at levels within it based on the appearances of *Parapetella destinae*, *Parapetella irwini*, and *Primatella bifida*; and at its top where typical Carnian taxa disappear (equivalent to event T3 at PM). At BBR, the *parvus* Subzone documents the decline and extinction of Carnian conodont genera, the bloom of diminutive taxa, and the ascendancy of the *Primatella* stock, precursor of *Epigondolella*. The *parvus* Subzone includes significant conodont, ammonoid, and bivalve appearances that could serve as indices or proxies for the CNB, but use of any of them would have the effect of assigning some *Macrolobatus* Zone collections to the Norian Stage.

The base of the *asymmetrica*-*Norigondolella* Subzone of the *primitia* Zone offers a CNB position that is most closely aligned with the traditional base of the Norian, i.e. at the base of the Kerri Zone, and only that position assigns all *Anatropites*-bearing collections to the Carnian. At BBR, this level is defined by the disappearance of *Metapolygnathus parvus* and its diminutive associates rather than by new appearances. Uncommon taxa that appear at that time may be endemics: *Acuminatella curvata* at BBR, and *Primatella? gulloae* at PM. The disappearance of *M. parvus* and its associates close the Carnian chapter in conodont evolution, and their extinction may be favored as a natural boundary. Such a position for the CNB does, however, remove *Halobia* species as definitive indices, and places the range of *Pterosirenites* on both sides of the Carnian-Norian Boundary. Subsequent floods

of *Norigondolella*, initially *N. norica*, provide a strong and definitive Norian signal at BBR and nearby sections.

In addition to five new genera and nine new species previously introduced from BBR, the following new taxa are named: *Acuminatella binodosa*, *A. constricta*, *A. curvata*, *A. denticulata*, *A. longicarinata*, *A. sagittale*, *A. sinuosa*, *A.? extensa*, *A.? prima*, *Carnepigondolella anitae*, *C. gibsoni*, *C. milanae*, *C. postsamueli*, *C. spenceri*, *Kraussodontus ludingtonensis*, *K. margaretae*, *K. roberti*, *K. rosiae*, *K. urbanae*, *K. vancouverense*, *K. wendae*, *Metapolygnathus dylani*, *Norigondolella norica*, *Parapetella beattyi*, *P. broatchae*, *P. clarae*, *P. columbiense*, *P. cordillerense*, *P. destinae*, *P. elegantula*, *P. hillarae*, *P. irwini*, *P. johnpauli*, *P. lanei*, *P. posterolata*, *P. prominens angulare*, *P. p. circulare*, *P. pumilio*, *P. riteri*, *P. rubae*, *P. willifordii*, *Primatella bifida*, *P. circulare*, *P. elongata*, *P. mclearnii*, *P. oblonga*, *P. ovale*, *P. postero globosa*, *P. rectangulare*, *P. rhomboidale*, *P. rotunda*, *P. stanleyi*, *P. subquadrata*, *P. triangulare*, *P. vanlierae*, *Quadralla deflecta*, *Q. karenae*, *Q. kathleena*, *Q. mcrobertsi*, *Q. pardoneti*, *Q. posteroexpansa*, *Q. postlobata*, *Q. praecommunisti curvata*, *Q. p. ornata*, *Q. roysi*, *Q. sigmoidale*, and *Q. willistonense*.







## 35<sup>TH</sup> INTERNATIONAL GEOLOGICAL CONGRESS

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### **Theme. Phanerozoic Earth History, Stratigraphy and the Geologic Time Scale**

**Theme Champions:** *J. Ogg, Zh.-Q. Chen, W. Altermann, & F. Gradstein*

This theme is comprised of several symposia and technical sessions on all aspects related to global stratigraphy. Among these, two sessions are of particular interest to readers of *Albertiana*: **IGCP 630: Permian and Triassic integrated Stratigraphy and Climatic, Environmental and Biotic Extremes** (*Zh.-Q. Chen and M. Benton*) and **Recent Developments in the Geological Time Scale** (*F. Gradstein, J. Ogg and Laurence Robb*).



### **Abstracts deadline: 12 July, 2016**

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### **Theme Session 104. The Permian-Triassic Crisis and Its Aftermath: Biotic, Climatic, and Environmental Upheavals**

**Conveners:** *Hugo Bucher, Thomas J. Algeo, Peter Roopnarine*

This multidisciplinary session aims at a better understanding of the nature of environmental perturbations and of the evolutionary responses of repeatedly and profoundly disturbed ecosystems during the Permian-Triassic transition.

### **Theme Session 145. Volcanism, Mass Extinctions, and Environmental Change**

**Conveners:** *Thierry Adatte, Stephen E. Grasby, Gerta Keller, Blair Schoene*

Important new data and observations increasingly link four of the five major mass extinctions directly to LIPs, as well as PETM and OAEs, particularly based on the fields of paleontology, stratigraphy, geochronology, geochemistry, climate, sedimentology, mineralogy, and volcanology.

