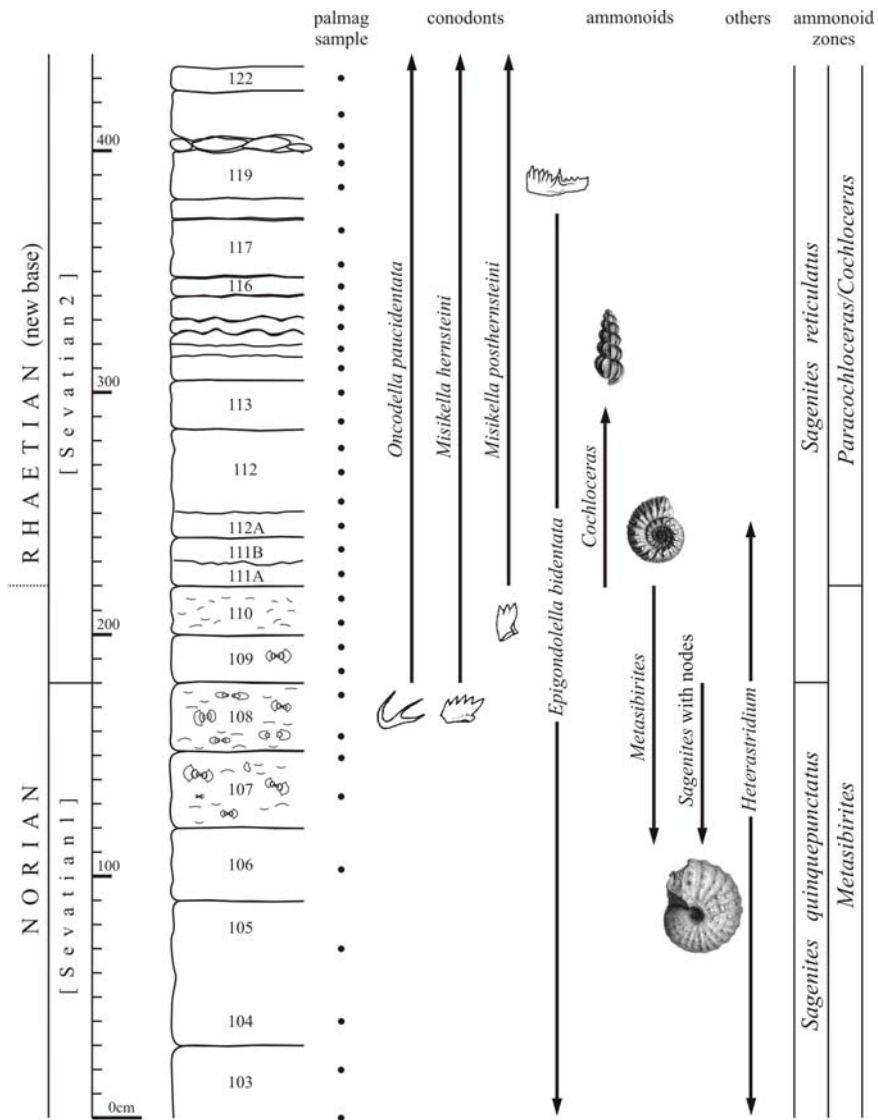


# ALBERTIANA



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The primary aim of ALBERTIANA is to promote the interdisciplinary collaboration and understanding among members of the I.U.G.S. Subcommittee on Triassic stratigraphy. Within this scope ALBERTIANA serves as the newsletter for the announcement of general information and as a platform for discussion of developments in the field of Triassic stratigraphy. ALBERTIANA thus encourages the publication of announcements, literature reviews, progress reports, preliminary notes etc. - i. e. those contributions in which information is presented relevant to current interdisciplinary Triassic research. An electronic version of ALBERTIANA is also available in PDF format at the

### ALBERTIANA website

at <http://www.bio.uu.nl/~palaeo/Albertiana/Albertiana01.htm>.

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Cover: Ammonoids and conodonts in the new Steinbergkogel section (Austria). See also paper by Krystyn and Kuerschner pp. 17-20

## Executive Notes

## From the Secretary

### From the Chair

The 55th Executive Committee meeting of IUGS was held in Vilnius, Lithuania in late March of this year where financial and other decisions were finalized. Two decisions will be of interest to, or will have an impact on STS members. The good news is that the proposal for the Anisian-Ladinian GSSP, having successfully passed the vote within the ICS, was ratified by the IUGS. This brings to a close the long process of defining one Triassic boundary. ***We now have 5 more GSSPs to define and less than 3 years to do it!*** I urge the collective STS, and particularly the task force members, to focus on this task and to contribute to and bring forward the necessary proposals as quickly as possible. The emphasis should be on practicality, not perfection. The bad news from IUGS is that they have severely trimmed the budget allocations to constituent commissions, and the ICS has received the lowest level of funding since the 1990's. In turn, the STS has been given very little to help disseminate information and to subsidize meetings where working groups gather to discuss GSSPs. This comes after recent news that the IGCP program is also being drastically reduced. Our task becomes that much harder in the absence of these resources, so I encourage you all to make use of the GSSP discussion forums that can be accessed through the STS website at <http://paleo.cortland.edu/sts> (Login: STS; Password: tropites). I populated these bulletin boards in December with items from my annual reports on behalf of both STS and IGCP467 (which can be viewed at their respective web sites), but no other comments have been added! You are encouraged to do so and utilize this medium in order to expedite the process of Triassic time scale definition.

### Revision of Subcommittee on Triassic Stratigraphy Membership

*Christopher A. McRoberts, STS Secretary*

Over the past several months, the executive of the Subcommittee on Triassic Stratigraphy has revised its voting and corresponding membership (below). The new voters list was arrived at by considering previous years of service as voters (8 years is ICS recommended maximum), current activity within task groups, non-response to recent ballots, and geographic and discipline representation. The corresponding members list is based largely on responses to several emails on that subject over the last several months. Former corresponding members who have been inadvertently excluded should contact the Secretary. Updates of these lists will be made to the STS website (<http://paleo.cortland.edu/sts/>).

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## In Memoriam

Professor Dr. Erik Flügel (1934 – 2004) contributed to Triassic studies, particularly through his work on Triassic reefs. He founded the Institute of Palaeontology in the University of Erlangen-Nuremberg and the journal *Facies*. André Freiwald (Erlangen-Nuremberg) prepared obituaries, including lists of Erik's scientific publications, which have appeared in *Facies* (2004), 30: 149-159, and *Geologia Croatica*, 57 (2): 209-219.

Professor Jürgen Remane (1934 – 2004) established, during his involvement with the ICS, revised guidelines governing the selection of GSSPs by the Subcommittee of Triassic Stratigraphy (STS) and other ICS stratigraphic subcommittees (Remane et al., 1996. *Episodes*, 19 (3): 77-81). His considered and objective counsel on such matters was always helpful at meetings of the STS and of the intersystem (Triassic-Jurassic) boundary working group of the Subcommittee on Jurassic Stratigraphy. An obituary by Adatte (Neuchâtel) and Gradstein (Oslo) appeared in *Episodes* (2004), 27 (4): 395; there will certainly be others.

*Geoff Warrington*

*9 February 2005*



## Future Meetings

### COME TO NEW ZEALAND

All Triassic workers are encouraged to gather in New Zealand in March 2006, and especially those involved in IGCP 467 (Triassic time and trans-Panthalassan correlations) and the Subcommittee on Triassic Stratigraphy.

The occasion is not to be missed!! Among other things, we shall be celebrating the many contributions and achievements of Jack Grant-Mackie to global Triassic research and especially in the context of Panthalassa. Jack retired from the University of Auckland seven years ago but is as active as ever, and is on the organising committee for this meeting!

Plans for the meeting are well advanced and a Second Circular with Registration Form and other details will be made available shortly in March or April. In the meantime please consult the following website for current detail and correct costs: <http://www.gns.cri.nz/interrad/>

Remember that this meeting is a joint meeting of the following two conferences:

- 1) 'Circum-Pacific Triassic Stratigraphy & Correlation', a symposium hosted by IGCP 467 and STS, and
- 2) 'InterRad XI: Radiolarians in Stratigraphy and Paleooceanography', 11<sup>th</sup> Meeting of the International Association of Radiolarian Paleontologists.

### Provisional symposia

The conference will be arranged as a series of symposia, which will begin with plenary talks. Each day will finish with a general talk open to the wider scientific community. Suggestions for additions or changes to symposia are welcome and should be emailed to the convenors.

#### A. Triassic stratigraphy and biogeography

A1. Triassic catastrophes: P/T, T/J and intra-Triassic boundary events

A2. Paleobiogeography and terrane analysis

A3. Trans-Panthalassan correlation and radiolarian evolution

#### B. Paleontological and stratigraphic methods and results

B1. Quantitative stratigraphic methods (BIOGRAPH, CONOP, GRAPHCOR, etc.)

B2. Quantitative paleoecological analysis

B3. Advances in processing and examining microfossil samples

#### C. Correlation and interpretation of Cretaceous-Cenozoic biosiliceous facies

C1. Biostratigraphy of deep-water facies

C2. Paleoenvironmental interpretation of biosiliceous facies

D. Biological indicators of ocean productivity

D1. Climate and ocean productivity interactions in the modern ocean

D2. Interrelations between Quaternary climate cycles and ocean productivity

D3. Plankton response to aberrant climate events in a greenhouse world

E. Plankton biology and phylogenetics

E1. Phylogenetic methods

E2. Advances in plankton classification

The meeting will be held at Te Papa, the National Museum of New Zealand, in Wellington, March 19-24, 2006. The pre-conference and post-conference excursions will provide the best possible opportunities to see Triassic rocks and sequences of New Zealand and you are all urged to participate. Of particular note is the pre-conference excursion to Arrow Rocks, Northland (north of Auckland), to visit a Permian-Triassic boundary sequence with radiolarian and conodont bearing cherts, coloured argillites and tuffs.

Convenors: Hamish Campbell (Triassic) and Chris Hollis (InterRad)

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*Institute of*  
**GEOLOGICAL  
& NUCLEAR  
SCIENCES**  
*Limited*



## The Boreal Triassic

Longyearbyen, Svalbard, Arctic Norway 2006



*Svalbardiceras spitzbergense* invites you to:

***The 2006 Boreal Triassic Conference at Longyearbyen (78° N), Svalbard, Arctic Norway,***

Arranged at UNIS, the World's northernmost University during late August 2006. Sponsored by the  
**Subcommission on Triassic Stratigraphy (STS)**

**Svalbard** has one of the most complete and accessible Triassic successions in the Arctic. The Boreal Triassic will be the focus of the conference, although comparisons between the Boreal and other Triassic successions are welcome.

Despite its high latitude Longyearbyen is easy accessed by daily flights from mainland Norway. There are modern hotel facilities and the modern campus of UNIS (University Centre on Svalbard, <http://www.unis.no/>) will host our conference.

We hope to arrange a full day excursion to the famous FESTNINGEN section where vertical beds along the shore of Isfjorden display the complete Permian to Tertiary succession. We will concentrate on the 1100 metre thick, complete, Triassic exposures. The excursion will hopefully take place with a large coastal steamer (following its use by a university course), Exact dates can not be fixed before winter 2006.

There will be a published conference volume with extended abstracts and a fully refereed post conference proceedings volume of Polar Research, for research papers with Arctic affiliations.

For planning purposes we need to know approximately how many will attend the conference and excursion, please give us a response via email or preferably on the Web page: <http://natmus.uio.no/triassic-2006/>

Organizing Committee

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**Présentation de la manifestation**

Le groupe marocain du Permien et du Trias G.M.P.T. organise, depuis sa création à Rabat en 1995, des réunions bisannuelles dans les différentes universités marocaines.

Depuis cette date, ces réunions ont pris de l'importance et sont devenues un rendez vous incontournable dans les Sciences de la Terre au Maroc. Suite à la précédente réunion tenue à Fès en 2004, il a été décidé que l'organisation de la 5<sup>ème</sup> réunion du GMPT aura lieu à l'Université Chouaib Doukkali, El Jadida en 2006.

A cette occasion, nous sommes particulièrement honorés de pouvoir assurer la relève de cette manifestation afin de maintenir le contact et permettre les échanges scientifiques entre les différents chercheurs dans le domaine de la géologie du Stéphanien, du Permien et du Trias.

Cette manifestation a également comme objectifs le renforcement des liens de coopération entre les chercheurs des différents établissements et universités marocains et étrangers.

**Lieu / Address of scientific session**

Université Chouaib Doukkali,  
Faculté des Sciences,  
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B.P. 20, 24000, El Jadida, MAROC.  
Tel. : 212 23 34 23 25 / 34 30 03 Poste 105  
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**Appel à communications**

Le comité d'organisation de la 5<sup>ème</sup> Réunion du Groupe Marocain du Permien et du Trias (GMPT-5) a le plaisir de vous inviter à participer massivement et à contribuer à la réussite de cette manifestation scientifique.

Les présentations peuvent se faire sous forme d'une communication orale et/ou de poster.

Une seconde circulaire fournira les instructions nécessaires aux auteurs pour la réalisation des résumés.

**Thèmes du colloque  
Themes of the symposium**

- A- Géodynamique des bassins sédimentaires
- B- Stratigraphie, Paléontologie et Paléogéographie
- C- Magnétisme, Pétrographie et Géochimie
- D- Géologie appliquée

**Excursion / Field trip**

Une excursion de deux jours sera organisée dans le bassin permien de Chougrane et son voisinage (Meseta centrale marocaine).

*A field trip of two days will be organized in the Permian basin of Chougrane and its neighborhood (Moroccan central Meseta).*

**Langues officielles / official languages**

Français ou Anglais / French or English

UNIVERSITE CHOUAIB DOUKKALI  
FACULTE DES SCIENCES  
EL JADIDA



EN COLLABORATION AVEC LE GROUPE  
MAROCAIN DU PERMIEN ET DU TRIAS  
ORGANISE

LA CINQUIEME REUNION DU GROUPE  
MAROCAIN DU PERMIEN ET DU TRIAS  
(GMPT-5)

El Jadida, du 26 au 29 Avril 2006



Première circulaire / First Circular



**Bulletin de pré-inscription  
Pre-registration form**

Prénom / Firstname: .....  
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Titre (s) provisoire (s) / Title (s) :

1) .....  
 2) .....

participer éventuellement à l'excursion

Oui Non

**Bulletin à retourner avant**  
 le 31 Mars 2005

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Executive Committee**

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**Abdellatif JOUHARI**  
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**Échéances / Schedule**

Retour du bulletin de pré-inscription  
 Deadline for return of pre-registration form  
**31 Mars 2005 / Mars 31, 2005**

Envoi de la 2<sup>ème</sup> circulaire / 2<sup>nd</sup> circular mailed  
**15 Mai 2005 / Mai 15, 2005**

Inscription définitive et envoi des résumés  
 Final registration and deadline for submission of  
 abstracts  
**31 Janvier 2006 / January 31, 2006**

Envoi de la 3<sup>ème</sup> circulaire / Sending of the 3<sup>rd</sup> circular  
**31 Mars 2006 / March 31, 2006**

*Please to communicate this circular to all colleagues susceptible of being interested*

*Please forward this program to colleagues who might be interested in.*

**Correspondance / Correspondence**

Toute correspondance concernant le colloque doit être adressée à.  
 All correspondence concerning the colloquium should be sent to:

**Prof. Hafid SABER**  
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 Faculté des Sciences  
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Title: ..... Surname: .....

First Names: .....

Institution: .....

Postal Address: .....

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Country: ..... Code: .....

e-mail address: .....

Fax: .....

Telephone: .....

Author(s) and Title(s) of Paper(s): .....

.....

.....

Author(s) and Title(s) of Poster(s) .....

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I am interested in the excursion:      **Yes**                      **No**

\_\_\_\_\_  
Signature

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IV SYMPOSIUM ON STRATIGRAPHY and  
PALAEOGEOGRAPHY OF THE PERMIAN AND TRIASSIC  
SYSTEMS IN SPAIN

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Further information can be found at [www.cidarismpe.org](http://www.cidarismpe.org)

If you are considering to attend it or need more information please contact to [Ana.Marquez@uv.es](mailto:Ana.Marquez@uv.es) or [info@esoc.es](mailto:info@esoc.es)

Sincerely

Ana Marquez

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## Definition of the Triassic-Jurassic boundary

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**Abstract** - The criterion for definition of the Triassic-Jurassic boundary should be a marker event of optimal global correlateability. Only an ammonite event meets this criterion, and the lowest occurrence of *Psiloceras tilmanni* in the New York Canyon area of Nevada, USA provides the most globally correlateable datum. Other potential marker events for definition of the Triassic-Jurassic boundary (bivalve, conodont and radiolarian bio-events, mass extinction and a carbon isotope excursion) have less correlation potential.

### Introduction

As the time for selection of a GSSP for the Triassic-Jurassic system boundary (TJB, base of Hettangian stage) approaches (Fig. 1), there is a need to discuss the criterion for definition of the boundary. Since the 1960's, the LO (lowest occurrence) of the ammonite *Psiloceras* (usually the species *P. planorbis*) has provided the working definition of the TJB (e.g., Lloyd, 1964; Maubeuge, 1964; Cope et al., 1980; Warrington et al., 1994; Gradstein et al., 2004). However, rather recently, other criteria for boundary definition have been advocated. These include a change in the bivalve fauna (essentially the LO of *Agerchlamys*), a sudden negative excursion of carbon isotopes and the LO of *Psiloceras tilmanni*, which precedes the LO of *P. planorbis*. Other criteria that have been or can be advocated include the supposed TJB mass extinction, the HO (highest occurrence) of conodonts or a significant evolutionary turnover of radiolarians.

What must underlie discussion of the definition of the TJB is the well accepted concept that global correlateability should be the main emphasis in the selection of a GSSP (e.g., Cowie et al., 1986; Remane et al., 1996; Gradstein et al., 2004; Walsh et al., 2004). As Remane et al. (1996: 79) expressed it, "the boundary definition will normally start from the identification of a level which can be characterised by a marker event of optimal correlation potential." Thus, our goal here is to evaluate the possible marker events that could be used to define the TJB and to argue that an ammonite-based marker event has optimal correlation potential. This marker event is the LO of *Psiloceras tilmanni* in the New York Canyon section of Nevada.

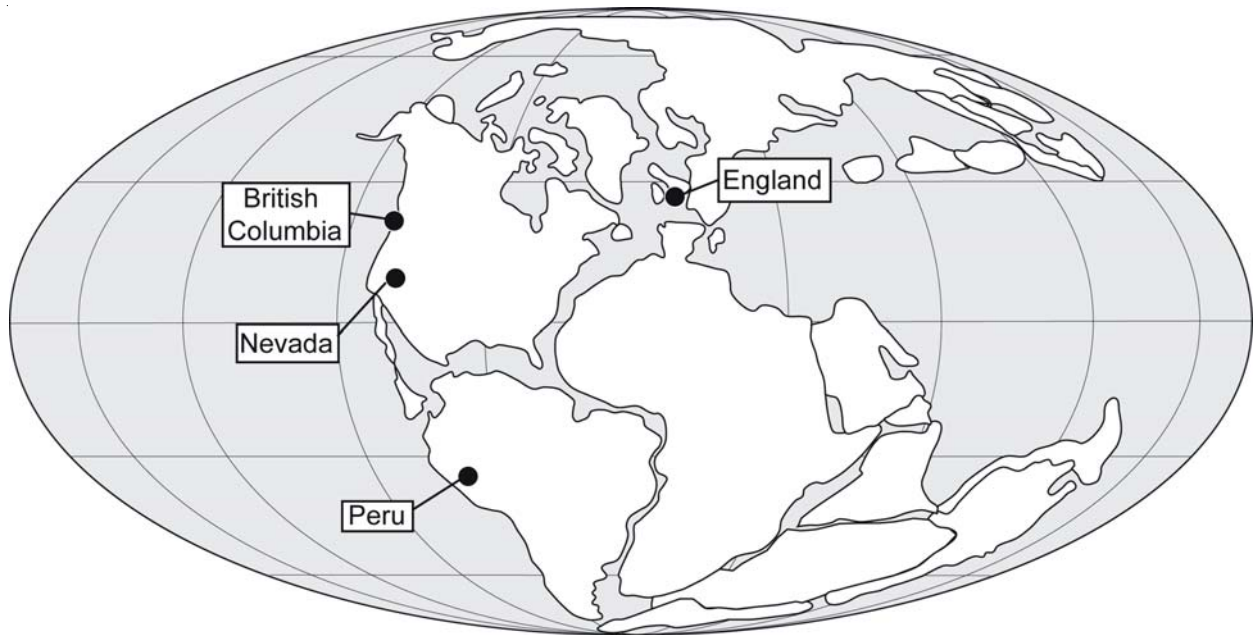
### Ammonite criteria

Distinction of the Triassic and Jurassic systems in marine biostratigraphy has a long tradition rooted in ammonite biostratigraphy. This is because the ceratite-dominated ammonite faunas of the Triassic virtually disappeared across the system boundary and were totally replaced by the smooth-shelled psiloceratids of the Early Jurassic. Because of the long history of study of this ammonite turnover, its details are extremely well documented on a global scale, especially in western North America, South America and Western Europe. This ammonite turnover thus provides wide-ranging correlations that are intensively studied, extensively published and documented. No other bio-event associated with the TJB can claim such investigation, and no bio-event is comparable to the ammonite turnover to provide a *globally correlateable* criterion for boundary definition.

The most complete and completely known succession of ammonites across the TJB is in the New York Canyon area of western Nevada, USA (Fig. 1) (e.g., Taylor et al., 2000; Guex et al., 2004). This succession presents two possible choices of an ammonite marker event: ( 1) the LO of the psiloceratid *P. tilmanni*, the stratigraphically lowest smooth-walled psiloceratid; or 2) the LO of *P. pacificum* and other entirely smooth walled psiloceratids (Fig. 2).

Using the LO of *Psiloceras tilmanni* as the boundary marker event has the advantage that it would place all the smooth-shelled psiloceratids in the Jurassic, a concept long adhered to by paleontologists who study ammonites. Furthermore, Bloos (2004) has noted that the LO of *P.*





**Figure 1.** Late Triassic paleogeographic map showing location of the four candidates for a GSSP of the Triassic-Jurassic boundary (base of Hettangian). They are: Queen Charlotte Islands, British Columbia, Canada; New York Canyon area, Nevada, USA; Utcubamba Valley, Peru; and St. Audrie's Bay, England.

*tilmanni* is only slightly younger than most of the other criteria used to identify the TJB, such as the extinction of typical Triassic taxa of ammonites and bivalves and the HO of Conodonts (Fig. 2). For example, in the New York Canyon area, the HO of *Choristoceras marshi*, a widely distributed terminal Triassic ammonite, is only a few meters below the LO of *P. tilmanni*. This means that in strata that lack *Psiloceras tilmanni*, these other criteria can act as proxies for placement of the TJB.

In the New York Canyon area, the LO of *Psiloceras pacificum* is stratigraphically higher than the LO of *P. tilmanni*, so it does not as closely approximate those proxies that can be used to identify the TJB. The LO of *P. planorbis* also is higher than the LO of *P. tilmanni*, and it might approximate the LO of *P. pacificum*, though this is uncertain. Continued definition of the TJB by the LO of *P. planorbis* (or equating it to the LO of *P. pacificum*) thus defines a boundary farther removed from the other bioevents that are proxies for identifying the TJB than does a TJB boundary defined by the LO of *P. tilmanni* (Fig. 2).

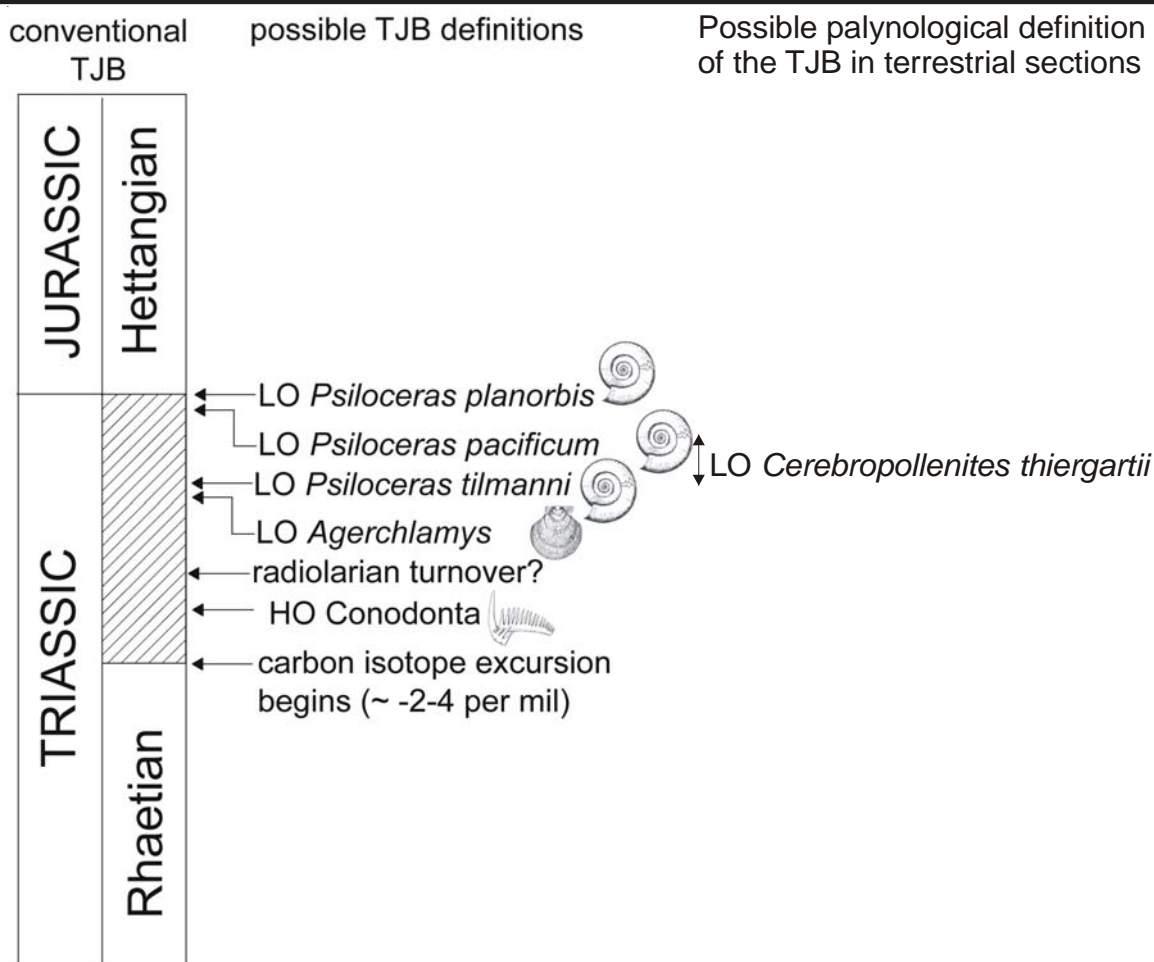
Claims that the LO of *Psiloceras planorbis* (or of any other *Psiloceras* species) are not useful for TJB definition because of the diachroneity of the LO of *P. planorbis* in Western Europe (e.g., Hesselbo et al., 2002) are based on a lack of conceptual and methodological understanding of how boundaries are defined. The LO of *P. planorbis* is diachronous in Western Europe largely because of the lack of open marine facies across the TJB boundary. Furthermore, older *Psiloceras* (such as *P. tilmanni*) are known elsewhere. The LO of *P. tilmanni* at a single place (the GSSP) can be used to define the TJB. If the LO of *P.*

*tilmanni* elsewhere is shown not to be the same age as at the GSSP, this will introduce some imprecision into using *only* the LO of *P. tilmanni* to identify the TJB, but it will not change the definition of the TJB. Clearly, no species of organism had an instantaneous appearance globally, so we should expect some diachroneity in the LO of any index fossil when viewed over a broad enough geographic area.

Using the LO of *Psiloceras tilmanni* as the marker event for definition of the TJB thus has these advantages: (1) it maintains longstanding tradition of placing the boundary so that all smooth-shelled psiloceratids are Jurassic; (2) it is a boundary above all bio-events traditionally considered Triassic; (3) it provides an ammonite-based definition of broad correlation potential (*P. tilmanni* has a distribution from Nevada to Chile); and (4) it places the boundary close to (just above) other marker events that can be used to identify the TJB in sections that lack ammonites. The LO of *P. tilmanni* thus defines a TJB of optimal correlation potential.

## Bivalves

Hallam (1981) first proposed the idea of a major change in the marine bivalve fauna across the TJB. However, the idea of using a bivalve criterion to identify the boundary is very recent (McRoberts, 2004). It is largely based on a change in the bivalve fauna approximated by the LO of *Agerchlamys* at New York Canyon, which occurs just above the beginning of the negative carbon isotope excursion (Guex et al., 2004, fig. 1, bed N3). According to McRoberts (pers. commun., 2004), the LO of *Agerchlamys* at New York Canyon is an immigration event. If so, then



**Figure 2.** Succession of potential marker events for definition of the Triassic-Jurassic boundary. Succession is based primarily on New York Canyon area, so exact position of radiolarian turnover is uncertain. The LO's of *P. pacificum* and *P. planorbis* may be equivalent, but this is uncertain.

this LO is diachronous, as is the LO of any organism viewed globally.

McRoberts (2004) stated that the bivalve change coincides with a negative excursion of carbon isotopes, but at New York Canyon the isotope excursion begins just before the bivalve change (Guex et al., 2004). The bivalve criterion for TJB definition is little studied and tested, so it lacks extensive documentation. Until it is well documented, its potential for global correlation remains uncertain. However, the LO's of *Agerchlamys* and *Psiloceras tilmanni* in the New York Canyon area are only a few meters apart, and this means that the bivalve change provides another useful proxy for correlation of a TJB defined by the LO of *P. tilmanni*.

**Conodont HO**

To our knowledge, nobody has formally advocated using the HO of Conodonta to define the TJB, even though the extinction of Conodonta has long been seen as a terminal Triassic event, and the presence/absence of conodonts thus is routinely used to distinguish Triassic from Jurassic strata. Rhaetian conodont assemblages are of low diversity and abundance, and conodonts can be easily reworked. Therefore, the HO of Conodonta is not a reliable criterion for TJB definition. However, it is very useful to know

that the presence of autochthonous Conodonta is a pre-Jurassic indicator, and this micropaleontological criterion has been widely used and accepted. So, defining the TJB at a level below the conodont HO is not desirable.

**Radiolarians**

Data from the Queen Charlotte Islands in western Canada (Fig. 1) have been interpreted to indicate a drastic extinction of radiolarians at the TJB (Tipper et al., 1994; Carter, 1994; Ward et al., 2001). Carter (1994) cites the loss of 45 radiolarian species in the top 1.5 m of the *Globolaxtorum tozeri* zone (topmost Rhaetian) on Kunga Island, above which is a low diversity Hettangian fauna in which nasselarians are rare. The radiolarian change as currently understood does not represent a globally correlateable event, though it has recently been identified in Japan. Nevertheless, it is very close in age to the LO of *Psiloceras tilmanni* (Fig. 2) and thus provides another proxy for correlation of a TJB defined by the LO of *P. tilmanni*.

**Mass extinction**

If there is a mass extinction in the TJB interval, why not use the extinction as a datum to define the TJB? Hallam (1990) advocated this, but there is no single mass extinction at or near the TJB (Hallam, 2002; Tanner et

al., 2004; Lucas & Tanner, 2004). Instead, there are a series of extinctions, some local, others global, during the Triassic-Jurassic transition – which extinction should be chosen? A mass extinction criterion for TJB definition thus is problematic simply because no single mass extinction has been identified.

### Carbon isotope excursion

Hesselbo et al. (2002, 2004) advocated using a carbon isotope excursion to define the TJB. This is a negative excursion of ~ 2-4 per mil of organic carbon seen in the St. Audries Bay section in England (Fig. 1). It is stratigraphically below the conodont HO (Fig. 2), and apparently correlative isotope excursions at New York Canyon and in the Queen Charlotte Islands are also in Rhaetian strata (Guex et al., 2004; Ward et al., 2004). The isotope excursion is thus at a level always considered Late Triassic by any biostratigraphic criterion.

A serious drawback to using an isotope excursion to define the TJB is that it needs to be associated with a biostratigraphic datum. As Remane et al. (1996:79) noted, “geophysical and geochemical events are, however, repetitive, and do not allow an unequivocal determination of the age. They need calibration through radioisotopic or biostratigraphic dating.” The datum that corresponds to the Late Triassic isotope excursion in some sections according to McRoberts (2004) is a bivalve change, so the drawbacks of using that change to define the TJB (see above) apply here.

The isotope excursion has additional problems. Thus, despite its apparent widespread consistency, note that the isotope record for the upper Rhaetian through lower Hettangian displays complexities that vary from section to section; therefore, application of the isotope excursion as a non-biostratigraphic marker is not straightforward. Serious questions can be raised about the relative contributions of terrestrial vs. marine organic components in sections characterized by significant changes in sea level and facies (such as St. Audrie’s Bay), and these questions have not been addressed sufficiently. Differences in accumulation rates within and between sections complicate the shape of the isotope excursion curve and the ability to correlate it reliably.

Therefore, the isotope excursion is not a desirable marker event for TJB definition because: (1) it begins at a stratigraphic level always considered Rhaetian, and thus pre-dates the HO of Conodonta and many other bio-events long considered Triassic; (2) it is not a unique event and can only be identified uniquely by its association with a biostratigraphic datum; and (3) the excursion itself is complex and still relatively untested.

### Palynology

One of the problems in a palynological definition of the base of the Jurassic in a terrestrial setting is that there are no major palynofloral breaks that could be correlated precisely with the Triassic-Jurassic boundary (Fisher and Dunay, 1981; Hounslow et al., 2004; Kuerschner et al.,

sub.). The exact stratigraphic age of the microfossil event in the Newark basin is uncertain (Hounslow et al., 2004; Kuerschner et al., sub.). The only morphologically distinct post Triassic taxa, which occur in the *planorbis* beds of the British Rhaeto-Liassic are *Cerebropollenites macroverrucosus* and *C. thiergartii* (Fisher and Dunay, 1981). In the British Rhaetian – Liassic sections, *C. thiergartii* has its FO at the base of the *planorbis* beds, whereas *C. macroverrucosus* has its FO date in the upper part of the *planorbis* beds. New data (Kuerschner et al., sub.) from the Tiefengraben section in the Northern Calcareous Alps (Austria) show, that *C. thiergartii* enters the record in the Tiefengraben Mb. (=pre-*planorbis* beds), within the lower part of the main negative isotope excursion, 8m below of the FO of the first Jurassic ammonite *P. calliphylum*. The first occurrence of *C. thiergartii* approximately coincides with the base of the Hettangian as it would be defined by ammonites. Therefore it may become useful for a correlation of the base of the Jurassic between terrestrial and marine sections.

### Conclusions

The best definition of the TJB will permit precise global correlation. Although no criterion may be ideal, ammonite-based definitions have the advantage of long-term study, testing and documentation. Indeed, for more than a century, the TJB has been defined by an ammonite event, and no other criterion comes close to providing an event of optimal global correlation potential. By that criterion, the LO of *Psiloceras tilmanni* in the New York Canyon area of Nevada appears to be the best marker event for TJB definition.

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# Biotic events around the Norian – Rhaetian boundary from a Tethyan perspective

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## Introduction

This is a progress report on the Norian–Rhaetian boundary interval in marine strat of Austria thought to initiate and stimulate the GSSP discussion process and to facilitate the selection of a single boundary marker which - following the intentions of the Subcommittee on Triassic Stratigraphy - might be chosen in between the ammonoid *Cochloceras/Paracochloceras*, conodonts of the genus *Misikella* (either *M. hernsteini* or *M. posthernsteini*) and the radiolarian *Parvicingula moniliformis* (Orchard, 2003).

The Austrian Salzkammergut region has been known for long as host of the most diverse Tethyan invertebrate faunas found in different basinal environments and lithofacies (Mojsisovics, 1873–1902). Knowledge of their temporal and spatial distribution is now well advanced and should soon arrive at a high-resolution correlation framework of the relevant biomarkers and other stratigraphic tools such as stable isotopes and magnetostratigraphy. Another major issue is the documentation and integration of marine and non-marine palynological events to allow a most widely applicable recognition of the boundary, from deeper offshore settings to marginal marine and terrestrial environments as the latter two are fairly common and cover large areas in the Arctic, in Europe and in south(east)ern Gondwana with presumably high economic potential. Equally of importance is an exact boundary intercalibration of the astrochronologically tuned time scale of the lacustrine Newark basin.

## New section data

Search for boundary interval sections in the Salzkammergut has been concentrated on two different formations, which are extraordinary in the Tethys for their fossil record:

1) on the top of the *Hallstatt Limestone Fm.*, a relatively thin (up to 15m), pure calcareous, deeper marine facies with pelagic bivalves (*Monotis*), ammonoids and conodonts. Several classical places are known (e.g. Sommeraukogel, Steinbergkogel, Rossmoos, Millibrunnkogel, Schneckenkogel – Krystyn et al., 1971) most of them, however, without adequate detailed section description. Scheibelkogel is the only, recently bed by bed studied sequence with a conodont based

biomagnetostratigraphy but a rather spotty ammonoid record (Gallet et al., 1996). To enlarge the ammonoid data base and reduce the problem of stratigraphic condensation (Scheibelkogel: thickness of boundary interval less than 2m) a restudy of classical sections has been started and has led to the discovery of a new, sedimentary more complete locality on Steinbergkogel with an unexpected rich ammonoid and conodont record.

2) on the basal *Zlambach Fm.*, a much thicker (up to 50m), grey limestone and marl intercalations comprising facies with some black (anoxic) shales, found widespread in ravines between Bad Goisern and Bad Aussee. It is less rich in conodonts and megafossils (with specific ammonoids and *Otapiria?* as pelagic bivalve) but important for the presence of radiolarians (under study by H. Mostler), and it provides an exceptional palynological record (Kürschner et al., 2004).

The **Steinbergkogel** is a small isolated summit located on the “Hallstätter Salzberg” about 2 km WNW of the town of Hallstatt (see fig. 1 in Krystyn et al., 1969). It is composed of a steeply (70°) northward dipping sequence of very thick whitish massive and unfossiliferous Lower Norian Hallstatt limestones overlain by about a 30 m thick, well bedded sequence of predominantly red and in the top grey, finegrained pelagic limestones (bioclastic wackestones) of Middle Norian to lowermost Rhaetian age (in new sense), followed by grey marls of the Zlambach Fm. The upper half of the grey limestones develops thin clay interbeds easing the quarrying of stones for dismantling the galleries of the nearby Hallstatt saltmine in the 19. century. As a result an old since more than 100 years abandoned quarry remained opposite of the Ferdinandstollen which exposes the here described section. Most of the classical Steinbergkogel ammonoid fauna may have resulted from that place but there is another locality about 100 m on strike to the W reported in the literature. This is of slightly younger age and nourishes the suspicion that the old faunal record could have been mixed.

A total thickness of 4m has been investigated and preliminary sampled for both megafossils and conodonts, with their vertical distribution illustrated in figure 1. A palaeomagnetic pilot study has shown good magnetic rock properties and should lead to reliable magnetostratigraphic

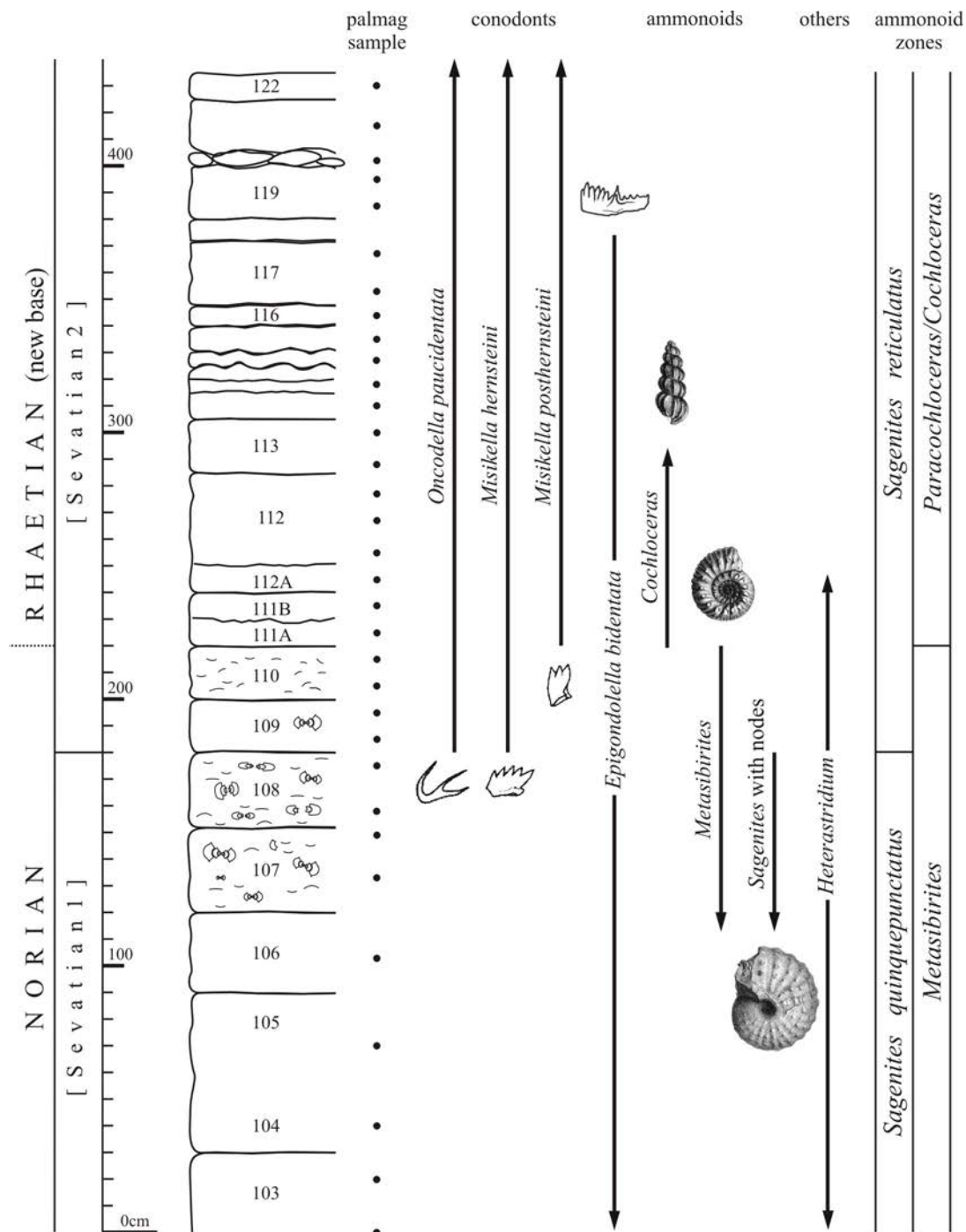


Figure 1: Observed stratigraphic distribution of ammonoids and conodonts in the new Steinbergkogel section.

results (Y. Gallet, pers. comm.). Stable isotope data will be performed from whole rock samples in 2005. With the next excavation campaign the section will be expanded both up- and downwards to

- a) include the transition beds towards the Zlambach Fm. for a palynological cross-correlation,
- b) integrate the *Cycloceltites* and *Vandaites* bearing fauna of the "White Crinoidal Limestone" from Steinbergkogel summit (Mojsisovics, 1873-1902) to demonstrate its stratigraphic position in relation to the FO of *Paracochloceras*
- c) fit the *Monotis* level into sequence.

Of special interest is the 2 m thick interval from bed 107 to 112 where the co-occurrence of all boundary-specific ammonoids and conodonts is recorded in sequence (fig. 1) and where the diagnostic biomarkers are fairly common. Two ammonoid zones/intervals are provisionally distinguished, a lower with *Metasibirites* (bed 107 to 110) and an upper with *Paracochloceras/Cochloceras* (from bed 111A to 112). Further common and represented in all beds are *Rhabdoceras suessi*, *Pinacoceras metternichi*, *Placites*, *Arcestes*, *Cladiscites*, *Rhacophyllites* and *Megaphyllites*. A nodose specimen of *Sagenites* (of *quinquepunctatus* group) in bed 108 testifies the presence of the *quinquepunctatus*-Zone close to the FO of

*Paracochloceras*.

To achieve stratigraphically reliable conodont ranges at least 10 kg of limestone have been dissolved from each bed from 108 to 112. This intense search has led to element recoveries of 50-100 specimens per sample, with *Epigondolella bidentata* dominating up to bed 110 and replaced by a *Misikella* dominance above. *Norigondolella steinbergensis*, usually the leading faunal element in this time interval is fortunately rare as well as ramiform elements. A first conodont event is to be recorded in bed 109 where *Oncodella paucidentata* and *Misikella hernsteini* appear. The latter species is rare in 109 and 110 (5-10 spec.) but gets frequent from 111A (31) onwards. Bed 111A marks the FO of *M. posthernsteini*, as phylogenetic successor of the forementioned species responsible for the most diagnostic conodont datum in the section, and it is probably the worldwide best documented first appearance date of *M. posthernsteini* in co-occurrence with *Paracochloceras*. With just 2 specimens in 111A and 4 in 111B *M. posthernsteini* is unfortunately very rare at the beginning and becomes frequent (30 spec.) only 30 cm above the FO of the species in bed 112. The initial infrequency highlights the problem how to recognize the FAD of *M. posthernsteini* in biofacially less favourable environments. And application of this event without additional (bio)markers may cause uncertainties in regional or intercontinental correlations.

The **Kleiner Zlambachgraben** is located about 2 km east of Bad Goisern and exposes in an altitude of 860 to 880 m along its southern slope a more than 50 meters thick sequence of alternating deep water limestones (mudstones or sponge spicules and radiolarian bearing wackestones) and marls. The section is known since long for its specific ammonoid fauna dominated by choristoceratids (Krystyn, 1987) and has recently become interesting due to its suitability for palynological investigations. By missing of *Sagenites*, *Dionites* and *Epigondolella bidentata* a lower conodont and ammonoid diversity is recorded when compared with Steinbergkogel. But co-occurrence of biostratigraphically diagnostic ammonoid, conodont and radiolarian fauna coupled with a rich marine and terrestrial microflora is uncommon in time-equivalent rocks anywhere in the world and offers a unique opportunity to tie otherwise strongly separated zonal schemes or bioevents together.

From base to top the following FOs of diagnostic biomarkers (in meters above base) have been found: at 1m FO of *M. posthernsteini*, at around 25m occurrence of *Praecitriduma mostleri* and *Livarella densiporata*, at 27m FO of *Vandaïtes saximontanum* and "*Choristoceras*" *haueri*, at 35m FO of *Paracochloceras* (disappearing at 36m), at 39m FO of *Epigondolella slovakensis* (disappearing at 41m) and at 42m FO of *M. rhaetica*.

Preliminary results of the palynological study can be summarized as follows: Throughout the section the pollen and spore assemblages are dominated by *Granuloperculatipollis rudis*, *Corollina meyeriana*, *C. torosus*, and *Ovalipollis pseudoalatus*. Accompanying

elements are *Rhaetipollis germanicus*, *Ricciisporites tuberculatus*, and *Tsugaepollenites pseudomassuleae*. However, two distinct palynological zones can be recognized: sporomorph assemblages from the lower part of the section still include a variety of typical older "Canian" elements (*Enzonalsporites vigens*, *Vallasporites ignacii*, *Patinasporites toralis*, *Ellipsovelatisporites rugosus*, *Partitisporites* spp., *Triadispora* spp.), whereas higher up in the section new elements, such as *Chasmatosporites* sp., *Quadraeculina anaeliformis*, *Limbosporites lundbladii* enter the record. Acritarchs are abundant in the lower part of the section whereas dinoflagellate cysts become more frequent in the higher part (*Rhaetogonyaulax*, *Suessia*, *Dapcodinium*). Intriguingly, the transition between the two zones is characterized by a marked increased spore/pollen ratio, while the marine organic-walled phytoplankton record shows an acme of dinoflagellate cysts (*Rhaetogonyaulax*, *Noricysta*, *Heibergella*). These events in the palynological record coincide approximately with the *Cycloceltites* – *Vandaïtes* event in the ammonoid record mentioned above.

### Biostratigraphic implications

Before discussing the preferred boundary option it may be pointed out that the data signal another correlation level previously not considered. Plotted against other bioevents (i.e. distribution of *M. posthernsteini*, *Cycloceltites* and *Vandaïtes*) occurrence of *Paracochloceras* is evidently different on Steinbergkogel and in the Zlambach. This difference is at best explained by locating them on opposite ends of the genus range and by assuming a stratigraphic range of *Paracochloceras*, which overlaps considerably with many choristoceratids. Joint appearance of *Cycloceltites*, *Vandaïtes* and "*Choristoceras*" *haueri* in the Zlambach (and in the Steinbergkogel-summit fauna) con-committant(?) with the disappearance of *Pinacoceras metternichi* and *Epigondolella bidentata* points to another N-R boundary option close to the *Praecitriduma mostleri* radiolarian date and is related to a significant palynological event that may allow far-reaching intercontinental correlations from the Tethys to the Boreal realm (Kuerschner et al., 2004) and Eastern Gondwana (?).

From Steinbergkogel it now seems clear that the FAD of *M. posthernsteini* correlates to the FO of *Paracochloceras* as it has been supposed by Kozur, 1996. Due to the position in a phylomorphogenetic cline the Steinbergkogel *posthernsteini* date is seen as robust. It is very close to the FO of *M. hernsteini* and obviously much closer then till recently thought (Kozur, 2003). Task of the near future should be to estimate the time duration of the interval between the FADs of the two *Misikella* dates and to figure out how other significant bioevents (FO of *P. monilis*, LO of the genus *Monotis* resp. of *M. salinaria/ochotica* groups) correlate to one or the other of the two dates. In Canada, Carter (1993) for example used the *Monotis* disappearance as argument to correlate the *moniliformis* Zone with the *Paracochloceras amoenum* Zone and to propose their correlative base as new Norian-Rhaetian boundary. A further essential step is the

intercalibration of the two *Misikella* dates in palynostratigraphic scales based on marine and terrestrial taxa for reasons discussed at the beginning. From the viewpoint of ammonoid biochronology both boundaries are acceptable, the *hernsteini* base by maintaining the present *quinquepunctatus-reticulatus* zonal scheme and the *posthernsteini* date by replacing it through a *Metasibirites-Paracochloceras* zonal sequence.

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# Correlation of the Germanic Triassic with the international scale

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**Abstract** - The newest results of Triassic biostratigraphy, uppermost Permian to lowermost Anisian magnetostratigraphy, the numerical ages of the Triassic and of the correlation of the Germanic Triassic with the international scale are discussed. The results are shown in 7 figures. This paper is a contribution to IGCP Project 467

## 1. Introduction

Kozur & Bachmann (2003) presented a poster during the Field Symposium in St. Christina/Val Gardena showing the marine standard scale with numerical ages, ammonoid, conodont and radiolarian zonations as well as correlation charts of the Germanic Triassic with the international scale. The correlation charts include the assumed number of cycles in the Lower and Middle Germanic Triassic as well as the numerical ages of the international chronostratigraphic scale and the Germanic Triassic. A discussion of the international Triassic scale and their numerical ages was already published by Kozur (2003a, b). The aim of this paper is to make available our correlation of the Germanic Triassic and its inferred numerical ages to the community of Triassic workers and to stimulate discussion. A more comprehensive description is published by Bachmann & Kozur (2004).

## 2. International scale and numerical ages

The international scale and the numerical ages of the Triassic stages and substages were discussed by Kozur (2003a, b) using reliable radiometric data and astronomic calibration with Milankovitch cycles.

Several radiometric data are present from around the Permian-Triassic boundary (PTB). The best value is 252.5 Ma from the basal *I. isarcica* Zone of Meishan (Mundil et al., 2001) which has been used as a basic value for astronomic calibration (Kozur, 2003a, b) leading to a PTB of 252.6 Ma. The inferred 252.6 Ma value was independently confirmed by Mundil (2004) on the base of new measurements at at Shangsi and Meishan. As the base of the Anisian is 247 Ma (Lehrmann et al., 2002), the duration of the entire Early Triassic is 5.6 myrs.

Very dense sets of radiometric ages are available from Middle Triassic deposits in the Southern Alps and Hungary, which are rich in biostratigraphically well dated felsic to intermediate tuffs partly with large zircons (e.g. Mundil et al., 1996, Pálffy et al., 2003). The data-set of Mundil et al. (1996) shows generally 2 myrs older ages than that of Pálffy et al. (2003) caused by differences in the methods used. Some values of both data-sets are shown in Fig. 2.

Almost no radiometric data are known from the Upper Triassic. An exception is the biostratigraphically well correlated 199.6 Ma for the base of the Jurassic (Pálffy et al., 2000). This value was the tie-point for the calculation of the numerical ages from the Rhaetian down to the Tuvolian on the base of the excellent astronomic calibration of the beds in the Newark Basin (e.g. Kent & Olson, 1999, 2000, Olson & Kent, 1996, 1999) by Channell et al. (1999, 2002, 2003), Krystyn et al. (2002) and Gallet et al. (2003). Muttoni et al. (2004), on the other hand, used 202 Ma for the base of the Jurassic. This value cannot be excluded as the values measured by Pálffy et al. in the Middle Triassic the are generally 2 myrs younger than those of Mundil et al. (see above). The calculated numerical age for the base of the Norian at 226 Ma by Channell et al. (e.g. 2003) coincides well with the measured 225 Ma for the lowermost Norian (Gehrels et al., 1987), which has, however, a rather large error range ( $\pm 3$  Ma), in which also the assumed Norian base of 227 Ma by Gallet et al. (2003) and 228-227 by Muttoni et al. (2004) would fit.

New results in the marine Lower Triassic are mainly derived from magnetostratigraphy by Liu Yuyan and Naromoto (pers. comm. Yin Hongfu) from the PTB interval of Meishan, and Tong Jin-nan et al. (2005) from the Brahmanian and lower Olenekian of the Olenekian GSSP candidate Chaohu (for Tong Jin-nan et al., 2005, see chapter 3).

Prof. Yin Hongfu, Wuhan, authorised H.W. Kozur in a written communication of February 15, 2005 to publish his following statement. "Dr. Liu Yuyan made an initial research and published the result in 1999 (Liu Yuyan et al., 1999). He did the palaeomagnetic study in Wuhan and in Kobe, Japan. In their paper Liu et al. (1999) found 3 samples (43-45) of Bed 27 at Meishan section bearing reversed polarity. Samples around equivalent layers at Meishan section A gave similar results. These results were quoted by Yin et al. (2001). Later Dr. Liu made a second sampling at sections D and A (sampling whole rock column of P-T boundary strata without interruption). The samples were measured by Dr. Naromoto at the Kyoto University. He found that there was no such reversal around Bed 27. After discussion between Liu and

Ma		Stage/Substage	Ammonoid Zone		Conodont Zone		M
247	MIDDLE TRIASSIC	ANISIAN	Bithynian	Aghardandites ismidicus	Paragondolella bulgarica	Nicoraella germanica	■
				Nicomedites osmani			
				Lenotropites caurus			
		Aegean	Pseudokeyserlingites guexi	Neogondolella ? regalis	■		
			Japonites welteri	Chiosella timorensis	■		
249	LOWER TRIASSIC = SCYTHIAN	OLENEKIAN	Late Olenekian (Spathian)	Neopopanoceras haugi	Chiosella gondolelloides	■	
				Prohungarites-Subcolumbites	Triassospathodus sosioensis		
				Procolumbites	Triassospathodus triangularis		
				Columbites parisianus	Triassospathodus homeri		
				Tirolites cassianus	Icriospathodus collinsoni		
					Triassospathodus hungaricus		
251	OLENEKIAN	Early Olenekian (Smithian)	Anasibirites kingianus	Neospathodus waageni-	■		
			Meekoceras gracilitatis	Scythogondolella milleri	■		
			Flemingites flemingianus	N. waageni-Scythogond. meeki	■		
251.6	BRAHMANIAN (INDUAN)	Gandarian (Dienerian)	Rohillites rohilla	Chengyuania nepalensis	■		
			Gyronites frequens	Neospathodus cristagalli			
		"Pleurogyronites" planidorsatus	Neospathodus dieneri	■			
		Discophiceras	Sweetospathodus kummeli				
252.5	BRAHMANIAN (INDUAN)	Gangetian		Clarkina krystyni	■		
			Ophiceras tibeticum	H. postparvus-H. sosioensis			
			Otoceras woodwardi	Isarcicella isarcica			
252.6			Otoceras fissisellatum	T. pascoei	Hindeodus parvus	■	
252.7	LOPINGIAN	DORASHAMIAN	Upper Dorasham.	Hypoph. changxingense	Otoceras boreale	Merrillina ultima-Stepanovites ? mostleri	■
				Pleuronodoc. occidentale		Clarkina meishanensis -H. praeparvus	
					Clarkina hausehkei		
				Paratirolites kittli, pars	Clarkina iranica		
					Clarkina zhangi		
	Clarkina changxingensis-C. deflecta s.s.	Or					

Figure 1: ■ Normal polarity □ Reversed polarity ▒ No reliable data

Lower Triassic stages, substages and numerical ages. Low latitude biostratigraphic zonation from Kozur (2003a, b). Magnetostratigraphy (M) of low latitude marine sediments after Scholger et al. (2000), Tong Jinnan (2005) and Muttoni et al. (1996). Chronostratigraphic correlations of magnetozones of Scholger et al. and Muttoni et al. modified according to text. Compiled radiometric ages in normal text, extrapolated numerical ages in italics.

Naromoto they decided that the first result by Liu Yuyan et al. (1999) was probably due to secondary magnetisation which had not been eliminated during processing, and that there should not be a reversal around the PT boundary.” This result of Dr. Liu Yunan and Dr. Naromoto is of outstanding importance for the correlation of the continental Permian-Triassic boundary and confirmed the view of Kozur (2004) and Szurlies & Kozur (2004) on the position of the PTB within the palaeomagnetic succession. The PTB lies in the lower third of the normal magnetozone 1n which straddles the PTB (Fig. 1, not to scale). According to the astronomic calibration of the conodont zones (Kozur, 2003a,b, Bachmann & Kozur, 2004) the normal interval from the uppermost *C. zhangi* Zone to the top of the *M. ultima-S. ? mostleri* Zone comprises about 210 000 years, whereas the normal interval from the base of the *H. parvus* up to the top of the *I. isarcica* Zone has a duration of 600 000 years (the *I. isarcica* Zone alone comprises >500 000 years).

In the uppermost Olenekian (upper Spathian) and lower Anisian (Aegean and Bithynian) the detailed palaeomagnetic succession from Muttoni et al. (1996) was used in Fig. 1, but the dating around the Olenekian-Anisian

was somewhat modified by Gradinaru (2003). In his poster presented at the Val Gardena Meeting (2003) it was shown that the base of the Anisian is within a short reversed interval, situated between two short normal intervals, which follow the longer reversed interval Kç1r in the upper Spathian (see Fig. 1). In a discussion between E. Gradinaru and H.W. Kozur on conodont material of Gradinaru it was agreed that Gradinaru’s ammonoid boundary fits perfectly with Kozur’s conodont boundary based on the FAD of *Chiosella timorensis*. Problems with the separation of *C. gondolelloides* and *C. timorensis* which lead often to a somewhat too deep base of the Anisian (e.g. Muttoni et al., 1996) are discussed in Bachmann & Kozur (2004). Gradinaru’s boundary is used in Fig. 1. The disappearance of *Neospathodus abruptus* Orchard in the lower investigated part of the Kçira section shows that the reliable palaeomagnetic record in this sections does not reach deeper than into the *N. triangularis* Zone (Fig. 1). Below this level and above the basal Spathian there are either no reliable palaeomagnetic data present in marine beds or reliable palaeomagnetic data cannot be correlated in detail with the marine scale (see Fig. 1).

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Ma	Stage/Substage	Ammonoid Zone/Subzone	Conodont Zone	Radiolarian Zone/Subzone		
237	LATE TRIASSIC ↑ CARNIAN ↑ Julian ↑	Trachyceras aonoides	Gladigondolella tethydis- ↑ Paragondolella polygnathiformis I.Z.	Tetraporobrachia haeckeli ↑ unnamed radiolarian zone		
		Cordevolian	Trachyceras aon	Budurovignathus diebeli- Paragondolella polygnathiformis	Tritortis kretaensis	
	Daxatina canadiensis- Frankites sultherlandi		Frankites regoledanus		Budurovignathus supralongobardica	M. cochleata
	LADINIAN Longobardian	Protrachyceras archelaus		Budurovignathus mungoensis		
		Protrachyceras gredleri	Budurovignathus hungaricus	Muelleritortis firma		
	238.8	Fassanian	Eoprotrachyceras curionii	Budurovignathus truempyi	unnamed radiolarian fauna	
			E. recubariense E. curionii	Paragondolella ? trammeri- Neogondolella aequidentata	Ladinocampe multiperforata	Ladinocampe vicentinensis
	240.5	MIDDLE TRIASSIC ANISIAN Illyrian	Nevadites secedensis	Paragondolella ? trammeri trammeri- Paragondolella alpina	Ladinocampe multiperforata	Ladinocampe annuloperforata
	241.5		Reitziites reitzi	Aplococeras avisianum Reitziites reitzi	Spongosilic. italicus	O. inaequispinosus Oertlispongos primitivus
	241.2					
242.6	Kellnerites felsoeoersensis		K. felsoeoersensis L. pseudohungaricum	Neogondolella mesotriassica		
240.4			Paraceratites trinodosus	Asseretoc. camunum Semiornites aviticus Schreyerites abichi	Neogondolella constricta	Tetraspinocyrtis laevis
240.5	Pelsonian			Schreyerites binodosus Bulogites zoldianus	Paragondolella bifurcata	no dated radiolarians
242.9			Balatonites balatonicus	N. shoshonensis	Nicoraella germanica- Nicoraella kockeli	Parasepsagon robustus Baratuna cristianensis
241.1	Bithynian		Agdharbandites ismidicus Nicomedites osmani Lenotropites caurus Silberlingites muelleri	Paragondolella bulgarica	Nicoraella germanica	Paroertlispongos diacanthus
			247	Aegean	Pseudokeyserlingites guexi Japonites welteri	Neogondolella ? regalis Chiosella timorensis

Figure 2: Middle Triassic stages, substages; low latitude ammonoid, conodont, radiolarian zonations and numerical ages after Kozur (2003a, b). Further details see Fig. 1.

phy accepted in 2004 the proposal of Brack et al. (2003) to define the base of the Ladinian with the base of the *Eoprotrachyceras curionii* Zone at the GSSP Bagolino in the Southern Alps, ending the uncertainty about the position of the Anisian-Ladinian boundary that lasted for decades.

The biggest problem of the Upper Triassic international scale is currently the base of the Rhaetian although the priority is rather clear. The Rhaetian was introduced already by Gümbel (1861), long before any other stage of the Triassic, and its base has therefore the clear priority over any later assignment of faunas to the Norian. Furthermore, a stage is defined by its base and the base of the overlying stage, and not by the upper boundary of the underlying stage. Gümbel (1861) defined the Rhaetian with the Kössen Beds, and *Rhaetavicula contorta* (Portlock) was used in the 19<sup>th</sup> century in and outside the Alps (e.g. Germanic Basin) as a Rhaetian guideform. Most of the Kössen Beds begin close to the base of the *M. posthernsteini* Zone (Gałdzicki et al., 1979), a boundary used by Channell et al. (2003) and Muttoni et al. (2004) for their correlation of the marine Rhaetian base with the continental Newark Basin. However, as shown by Golebiowski (1986, 1990) and Krystyn (1990), in some places the Kössen Beds begin already within the *M. hernsteini* Zone. Thus, according to the priority, the base of the Rhaetian is either at the base of the *M. posthernsteini* Zone or at the base of the *M. hernsteini* Zone. According to Golebiowski (1990), *R. contorta* begins within Unit 2

of the Hochalm Member of the Kössen Formation. In Unit 2 is also the FAD of *M. posthernsteini*. A similar deep occurrence of *R. contorta* reported Gałdzicki et al. (1979) from the Kendelbach section. The Rhaetian of Krystyn (in Gallet et al., 2003) comprises only the upper part of the original Rhaetian and, moreover, this boundary cannot be well correlated to North America and Panthalassa.

A well applicable Rhaetian base was proposed by Carter (1993). She placed this boundary above the top of the Sevatian *Monotis* beds at the base of the *Paracochloceras amoenum* Zone of North America, which corresponds to the *Cochloceras suessi* Zone and the *Choristoceras? haueri* Zone of the Tethys. The base of both the *C. suessi* and *P. amoenum* Zones coincide. Carter defined the base of the Rhaetian with radiolarians at the base of the *Proparvicungula moniliformis* Zone. Most of the radiolarians of this zone are also present in Panthalassa and in the Tethys, but the zonal index species occurs only in medium (? and high) latitudes, but not in the low latitude Tethys. In Baja California the conodont fauna of the lower *M. posthernsteini* Zone with *M. hernsteini* (Mostler) and *M. posthernsteini* Kozur & Mock occurs together with radiolarians from the lower *P. moniliformis* Zone (Whalen et al., 2003).

The base of the *P. amoenum* Zone can be correlated with the base of the *C. suessi* Zone in the Tethys and would be an good marker for the base of the Rhaetian as it can be

Ma	Stage/Substage	Ammonoid Zone/Subzone Standard		Conodont Zone/Subzone			
				Tethys/Western Pacific		North America	
199.6	Upper Rhaetian	Chor. marshi	Choristoceras marshi	Misikella ultima		Norigondolella sp.	
			Chor. ammonitifforme	Misikella koessenensis		Misikella posthernsteini	
206	Lower Rhaetian	"Ch." haueri	Vandaites stuerzenbaumi			Misikella posthernsteini	
			"Choristoceras" haueri				
			Cochloceras suessi	M. hernsteini-P. andrusovi		Mockina bidentata	
211	Sevatian	Sagenites reticulatus	Mockina bidentata				
		Sagenites quinquepunctatus	Subzone 2				
			Halorites macer	Subzone 1			
216	Alaunian	Mesohimavatites columbianus	Mockina postera		Mockina ? serrulata		
			Mockina ? spiculata		Mockina postera		
			Cyrtopleurites bicrenatus	M. medionorica		Orchardella elongata	
225	Early Norian ("Lacian")	Juvavites magnus	Epigondolella triangularis-Norigondolella hallstattensis		Mockina ? spiculata		
		Malayites paulckei	Epigondolella quadrata		Orchardella multidentata		
226		Stikinoceras kerri	E. orchardi-N. navicula   M. prim.		Epigondolella quadrata		
231	Tuvalian	Klamathites macrolobatus	Carnepigondolella pseudodiebeli		M. primitius   M. comm.		
			Carnepigondolella zoeae		Orchardella ? n. sp. – "Metapolyg. communisti"		
			Paragondolella carpathica		Carnepigondolella zoeae		
	Julian	Tropites welleri	P. postinclinata-P. noah		Carnepigondolella lindae		
			Gladigondolella tethydis-Paragondolella polygnathiformis		Paragondolella polygnathiformis		
	Cordevolian	Tropites dilleri	Budurovignathus diebeli-Paragondolella polygnathiformis				
Austrotrachyceras austriacum							
			Trachyceras aonoides				
			Trachyceras aon				
			D. canadensis-F. sutherlandi				

Figure 3: Upper Triassic stages and substages; ammonoid zonations, Tethyan and North American conodont zonations and numerical ages after Kozur (2003a, b). Further details see Fig. 1.

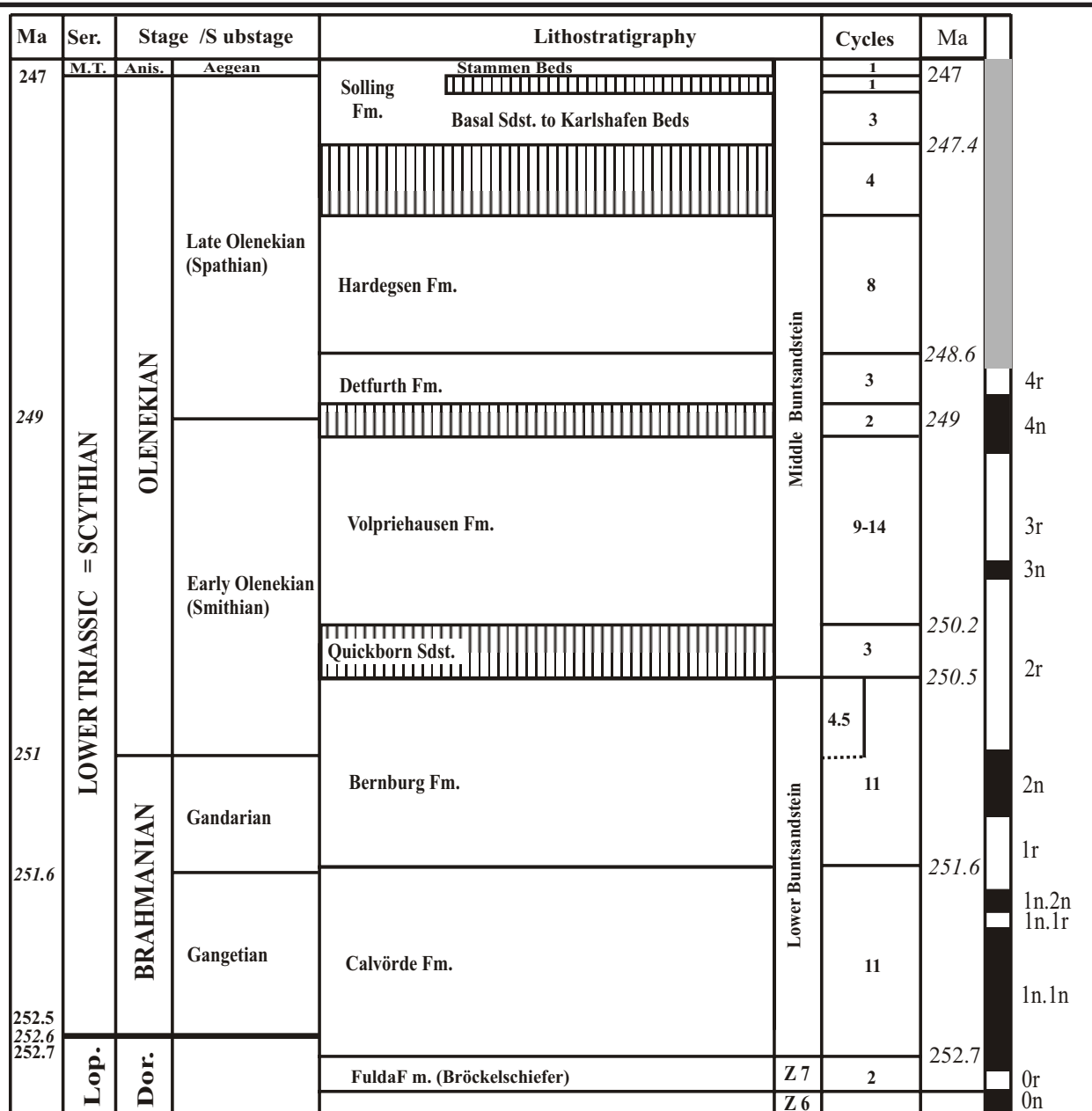
correlated with the base of the *Orchardella mosheri* Zone and the *P. moniliformis* Zone in western North America and the base of the *M. posthernsteini* Zone in the Tethys and Panthalassa.

For the moment, the well correlatable base of the *M. posthernsteini* (= base of the *C. suessi* ammonoid zone = base of the *Paracochloceras amoenum* ammonoid zone = base of the *Orchardella mosheri* conodont zone) is used as the base of Rhaetian, which is in agreement with Channell et al. (2003), Muttoni et al. (2004) and, for North America, also in agreement with Carter (1993) and Orchard & Tozer (1997). However, the base of the *M. hernsteini* Zone is left open as an alternative base of the Rhaetian. Any base of the Rhaetian younger than the base of the *M. posthernsteini* Zone has to be rejected because it violates the priority of the Rhaetian base by Gümbel (1861). Furthermore, it has a low correlation potential with North America and Panthalassa and would lead to a too long Norian of subsystem character. Thus, according to Gallet et al. (2003), the Rhaetian has only a duration of 2 myrs, whereas the Norian is with 25 myrs almost as long as the rest of the Triassic.

Especially misleading is the term Sevatian 2. Originally introduced for the *Sagenites reticulatus* Zone, it was later also used for ammonoid-free deposits and Gallet et al. (1996, p. 116) regarded *Cochloceras* as "Sevatian 2 zonal guide genus". In this case, the entire Sevatian 2 would belong to the Rhaetian *M. posthernsteini* Zone as used in our paper and by Muttoni et al. (2004) because the base of the *Cochloceras suessi* and *M. posthernsteini* zones roughly coincides (Kozur, 1996). However, in Gallet et al. (1996, Fig. 2) is shown that ammonoids occur only in the upper Sevatian 2 at the Scheiblkogel section, where no conodonts are present, whereas in the lower Sevatian 2 *Misikella hernsteini* (Mostler) is present. Thus, against the definition in the same paper, the Sevatian 2 is really defined with the FAD of *M. hernsteini*. Thus, using our Rhaetian base, the Sevatian 2 belongs either entirely to the Rhaetian (ammonoid definition with *Cochloceras*) or the Rhaetian begins within the Sevatian 2 (conodont definition with the FAD of *M. posthernsteini*). When the FAD of *M. hernsteini* is used as base of the Rhaetian, the Sevatian 2 would also belong to the Rhaetian, but in its original definition it contains also upper Sevatian beds







**Figure 5:** Correlation of the Germanic uppermost Zechstein, Lower and Middle Buntsandstein with the biostratigraphic scale, short eccentricity cycles and numerical ages. Compiled radiometric ages from Tethys in normal text, extrapolated numerical ages in italics. Chronostratigraphic correlation of magnetozones of Szurlies (2001, 2004a, b), modified except around the PTB. Magnetozones sn1, sr1 and sn2 of Szurlies (2004a,b) are united into one magnetozone termed 1n (sn1 = 1n.1n, sr1 = 1n.1r; sn2 = 1n.2n), as the duration of sr1 is very short (< 80 000 years) and therefore it was not found in Tethys or in south china sections, with sedimentation rates 10 to100 times less than in the Germanic Basin. Numbers in column “cycles” = inferred numbers of ~100 kyrs short eccentricity cycles in lithostratigraphic units and calculated duration of gaps in 100 kyrs.

below the FAD of *M. hirsteini*. The problem of the Sevatian 2 is very important for the correlation of the Germanic Rhaetian with the marine scale because by use of the Sevatian 2 some Rhaetian faunas would be changed into Sevatian faunas.

The different definition of the Rhaetian base lead to rather different estimations of the length of the Rhaetian (Gallet et al., 2003: 2 myrs; Channell et al., 2003, Muttoni et al., 2004: 7 or 6 myrs; Kozur, 2003a, b: 4 myrs). The palaeomagnetic results by Hounslow et al. (2004) for the Upper Triassic and lower Jurassic of St. Audrie’s Bay,

which allow a good correlation with the Newark Basin, favour a duration of 6 myrs for the Rhaetian.

### 3. Germanic Triassic

#### 3.1. Lithostratigraphic subdivision

There are only few problems with the lithostratigraphic subdivision of the Germanic Triassic. The established lithostratigraphic subdivision of the Buntsandstein, summarised by Lepper & Röhling (1998), and the newly introduced formations of the Muschelkalk and Keuper in

Ma		Stage / Substage	Lithostratigraphy		Cycles		
237.0	<b>MIDDLE TRIASSIC</b>	<b>LADINIAN</b>	Grabfeld Fm (Unterer Gipskeuper) without "Estherienschichten"	Middle Keuper	1 9		
238 237.9			Longobardian	Erfurt Fm (Lettenkeuper)	Lower Keuper	8	
238.8 239.0						2	
			Fassanian	Meissner Fm	Upper Muschelkalk	28	
240.5		<b>ANISIAN</b>	Illyrian	CB Spinosus Zone	Upper Muschelkalk	12	
241.5 241.2				Trochitenkalk Fm		1	
				Diemel Fm	M. M.	7	
				Heilbronn Fm		1	
			Pelsonian	Karlstadt Fm	Lower Muschelkalk	3	
				Schaumkalk Member		9	
				TB Jena Fm		9	
			Bithynian	OB	Lower Muschelkalk	9	
			Aegean	DGB	Upper Buntsandst	2 7	9
247				Röt Fm		2	
		Stammen Beds of Solling Fm		2			

**Figure 6:** Correlation of the Germanic Middle Triassic with the international chronostratigraphic scale, short eccentricity cycles and radiometric numerical ages. Further details see Fig. 5.

the central basin (Hagdorn et al., 1998, Beutler, 1998) are used in Figs. 5-7. The gaps between several Buntsandstein formations are well known since Trusheim (1961a, b, 1963). Several large gaps exist also in the Keuper (Fig. 7). Their significance was especially shown by Wolburg (1969), Beutler (1979, 1995), Duchrow (1984a, b), Dittrich (1989), Aigner & Bachmann (1992), Frisch & Kockel (1999), Nitsch (2002), Nitsch et al. (2002) and Kozur & Bachmann (2003). These gaps are known since long time, but most of them were generally

not shown in lithostratigraphic subdivisions. Their duration is commonly unknown and can only be estimated from the chronostratigraphic interlock of missing intervals, when a good biostratigraphic correlation of the underlying and overlying beds with the international chronostratigraphic scale (with known numerical ages) is established.

## 3.2. Cyclicity and possibility of astronomic calibration of the Germanic Triassic

Many sediments of the Germanic Triassic show a well developed cyclicity. The cycles are best recognised in basinal facies, namely in terrestrial playa deposits as well as in shallow marine and hypersaline deposits. They were described in numerous papers, for the Lower and Middle Buntsandstein e.g. by Geluk & Röhling (1999), Röhling (1991, 1993), Szurlies (2001, 2004a, b), for the Upper Buntsandstein by Exner (1999), for the Lower Muschelkalk e.g. by Götz (2002, 2004), Götz & Feist-Burkhardt (2000), Götz & Wertel (2002), Kedzierski (2002), for the Middle Muschelkalk e.g. by Röhling (2002), Brückner-Röhling & Heunisch (2004), for the Upper Muschelkalk e.g. by Aigner (1985), for the Lower Keuper e.g. by Aigner et al. (1990), Aigner & Bachmann (1989, 1992), Pöppelreiter (1998), and for the Grabfeld Fm (Unterer Gipskeuper) of the Middle Keuper by Aigner & Bachmann (1989, 1992) and Nitsch (1997).

The cycles can be assigned to a Milankovitch cyclicity. Best recognisable are, as it seems, the short eccentricity cycles (~ 100 000 years) and the precession cycles (~ 20 000 years), but in continental playa deposits the long eccentricity cycles (~ 400 000 years) show up as well. To identify such sets as Milankovitch cyclicity, five precession cycles should be present in each short eccentricity cycle throughout a continuous succession consisting of several short eccentricity cycles. More convincing is the presence of Milankovitch cyclicity, if long eccentricity cycles can be recognised as well. Figs. 5 and 6 give the inferred numbers of short eccentricity cycles in the respective stratigraphical units. The numbers refer to the most complete sections. In more marginal parts or on swells the number of cycles is less and the gaps become larger. The general problems of Milankovitch cyclicity of the Germanic Triassic are discussed in Bachmann & Kozur (2004).

According to Szurlies (2001) the Calvörde Fm consists of 10 cycles. We interpret 11 short eccentricity Milankovitch cycles by subdividing cycle 4 sensu Szurlies into two. Each of the 11 cycles consists of 5, sometimes 4, smaller ones, interpreted to represent precession cycles. Two complete and 3/4 of a third long eccentricity cycles seem to be present as well.

Szurlies (e. g. 2001), defined 10 cycles in the Bernburg Fm. Conchostracan studies suggest one more cycle to exist in the Halle area and in the Solling Mts, which contains the *M. truempyi* Zone and the base of the *M. quellaensis-L. radzinskii* Zone, resulting in 11 cycles (Kozur & Seidel, 1983a,b, Kozur & Lepper, in prep.). This is important as Röhling (1991, 1993) and Geluk & Röhling (1999) defined 14 cycles in the more central parts of the basin, including the Solling Mountains. Thus, it seems that not all cycles of Röhling are short eccentricity cycles.

Geluk & Röhling (1999) discriminated 18 cycles in the Volpriehausen Fm, Szurlies (2004b) only 9 cycles. As in the Bernburg Fm, the area investigated by Szurlies is not

in the basin centre, where the number of cycles will be somewhat higher than 9. The 18 cycles of Geluk & Röhling are most likely not all short eccentricity cycles. As we have not investigated ourselves a complete section in the Solling Mountains we cannot decide on the exact number of short eccentricity cycles in the basin centre. The best estimate is that the Volpriehausen Fm has between 9 and 14 cycles and we have used 11 cycles for calculation of the numerical age (Fig. 5).

The Milankovitch cyclicity of the Detfurth, Hardegsen and Solling formations is only partly established. Therefore the respective 4, 8 and 5 cycles of these formations are not as precise as in the Lower Buntsandstein. 9 cycles are recognised in the Röt Fm (Exner, 1999). Additionally, the time intervals of the gaps during the Middle Buntsandstein have to be estimated and taken into account for numerical calculations (Fig. 5). This, however, is only possible, if the under- and overlying beds have different sporomorph associations or faunas and the missing biostratigraphic unit is known from outside the Germanic Basin, e.g. *Densoisporites neburgii* association of the Hardegsen Fm - H-"discordance" *Voltziaceasporites heteromorphus* Klaus dominated association with only a few *D. neburgii* (Schulz) Balme of the lower Solling Fm. In the upper, but not uppermost Csopak Marl Fm. between the two sporomorph associations of the Germanic Basin (see above) is a third association with dominating *D. neburgii*, but also with common (11-25 %) *V. heteromorphus* is present corresponding to the *T. homeri-T. triangularis* Zone of middle Spathian age. In this case the duration of the gap between the Hardegsen and Solling Formations can be rather well dated.

Cyclicity is well established in the marine beds of the Lower Muschelkalk (Jena Fm), and we agree with Götz (2004) that the 20 cycles of the Jena Fm and the beginning of a 21th cycle are short eccentricity cycles. We assign the same numbers of cycles as Götz (2004) did to the members of the Jena Fm, i. e. the 3 Wellenkalk Members, subdivided by the Oolithbank Member (OB) and Terebratelbank Member (TB). However, for the Schaumkalk Member which has two cycles and the beginning of a third cycle (Götz (2004), we assigned 3 cycles as Brückner-Röhling & Heunisch (2004) did, to avoid the use of decimals in the cycle numbers of the Schaumkalk Member (and by this in the Jena Fm.) and the overlying Karlstadt Fm of the Middle Muschelkalk. Altogether there are 4 short eccentricity cycles in the Schaumkalk Member and the Karlstadt Fm. One of these cycles straddles the formation boundary. The 9 cycles of the Middle Muschelkalk (e. g. Brückner-Röhling & Heunisch 2004) can all be interpreted as short eccentricity cycles (Fig. 6).

The problems of Milankovitch cyclicity in the Upper Muschelkalk, Lower Keuper and the Grabfeld Fm of the Middle Keuper are discussed in Bachmann & Kozur (2004). 40 short eccentricity cycles are tentatively assigned to the Upper Muschelkalk and 8 to the Lower Keuper (Fig. 6).

In the Upper Triassic the Milankovitch cyclicity is mostly



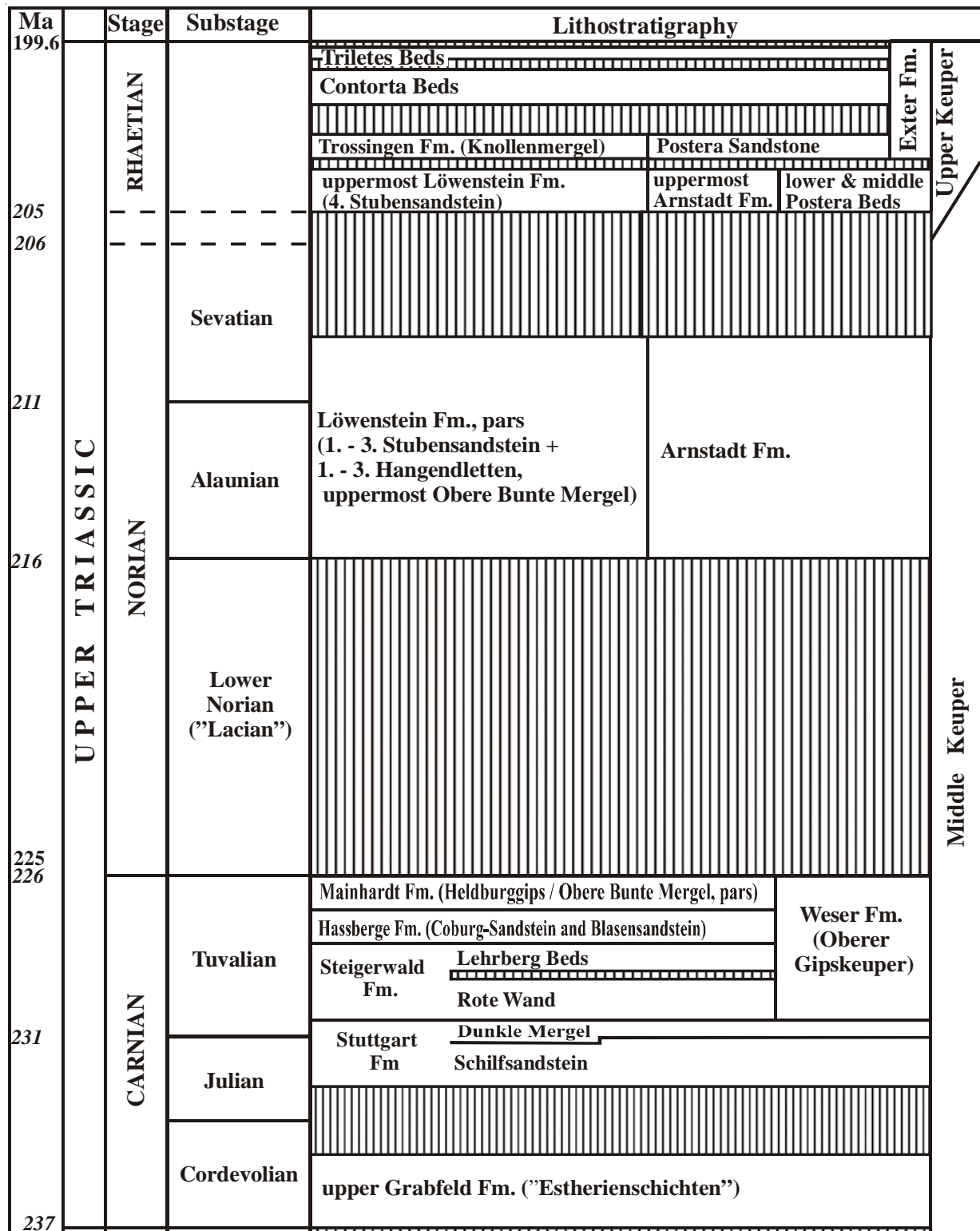


Figure 7: Correlation of the Germanic Upper Triassic with the international scale and numerical ages. Rhaetian base not yet decided upon (probably at 206 to 205 Ma). Further details see Fig. 5.

not yet worked out and a lot of more or less long gaps impede the calculation of the numerical ages (Fig. 7). However, promising attempts have been made to establish Milankovitch cyclicity in some parts of the Upper Triassic (e. g. Reinhardt & Ricken 2000; Tougiannides, 2004, for the Arnstadt Fm).

#### 4. Correlation of the Germanic Triassic with the international chronostratigraphic scale

The correlation of the Germanic Triassic with the international scale is shown in Figs. 4-7 A detailed discussion is given in Bachmann & Kozur (2004). The present paper discusses only a few tie points.

The Permian-Triassic boundary (PTB) was placed by

Kozur (e.g. 1993a,b, 1998 a,b, 1999) at the boundary between the *Falsisca postera* and *F. verchojanica* conchostracan zones. This boundary is found in the entire central part of the Germanic Basin, but is partly also recognisable in more marginal parts (Ptaszyński & Niedźwiedzki, 2004, for the Holy Cross Mts). It is also confirmed by mega- and miospores. The PTB is in the lower part of the so-called Oolith Alpha 2, one precession cycle above the base of the second short eccentricity cycle of the Calvörde Fm, i. e. ~ 120 000 years above the base of the Buntsandstein. This boundary is confirmed by a distinct minimum in  $^{13}\text{C}_{\text{org}}$  (H. J. Hansen, Copenhagen, pers. comm.) and  $^{13}\text{C}_{\text{carb}}$  (Korte & Kozur, in prep.) and supported by a set of events (Bachmann & Kozur, 2003) which are recognisable also in pelagic PTB sections of China and Iran (Fig. 4).

Nawrocki (2004) correlated the PTB with a level inside the short reversed magnetostratigraphic interval in the uppermost Zechstein, which we name "0r" in Fig. 5. The reason for this correlation was an assumed short reversed interval around the PTB of Meishan, which was already rejected by Kozur (2004) and Szurlies & Kozur (2004), and is now shown to be non-existent by new measurements of Chinese and Japanese specialists (pers. comm. Prof. Yin Hongfu, see chapter 2).

The correlation of the Lower and Middle Buntsandstein is mainly based on conchostracans, which are well correlated with marine faunas (e.g., Kozur, 1993b, 1998a, b, 1999, Kozur & Mock, 1993). The base of the Olenekian is especially important. As already shown by Kozur & Seidel (1993a, b) the base of Smithian (in that time named as Jakutian) lies within the upper Bernburg Fm, and Kozur (1993a,b, 1999), Kozur & Mock (1993) and Kozur & Lepper (in prep.) yielded further evidences for this correlation. Most of the Smithian index species are known from sections with the interfingering of marine and brackish to fresh water beds in the Tethys and in Siberia. Shen Yanbin et al. (2002) found *Magnietheria truempyi* Kozur & Seidel, the index species of the second highest conchostracan zone of the Bernburg Fm, even in Madagascar close to marine beds with *Flemingites*, the ammonoid index genus of the lower Smithian. The conchostracan zonation of the Bernburg Fm was slightly modified and correlated with the cyclostratigraphy by Bachmann & Kozur (2004), Kozur et al., in prep., and Kozur & Lepper (in prep.). The upper boundary of the *Estheriella nodosocostata* Zone s. l. is lowered to the level, where the uppermost *Estheriella* was found (middle cycle 7). Between the upper cycle 7 to the top of cycle 9 a fauna occurs, which consists mainly of *Cornia germari* (Beyrich) and *Magnietheria subcircularis* (Chernyshev) and some *Euestheria gutta* (Ljutkevich), *M. ? lerichi* (Marlière) and *M. ? malangensis* (Marlière). For this fauna the new *C. germari*-*M. subcircularis* Zone is established, which is the lowermost Zone of the Olenekian.

Menning (2000) has adopted the base of the Olenekian within the upper Bernburg Fm, which is also shown in Menning & GSC (2002). However, Szurlies (2004a, b)

correlates the lower Volpriehausen Fm with the Gandarian (Dienerian). The reason for this correlation goes partly back to a correlation of respective magnetic reversals by Scholger et al. (2000) who extended the Gandarian (Dienerian) to at least the middle of the Campil Member (upper Smithian). The upper boundary of the only normal zone within the Seis Member was placed into the middle Dienerian. This, however, is close to the upper boundary of the *Claraia aurita* Zone, which corresponds roughly to the Gandarian-Smithian boundary, and the top of the normal zone is situated less than 3 m below sample Bu 45 of Farabegoli & Perri, 1998, which contains a typical Smithian conodont fauna with *Pachycladina obliqua* Staesche). Own investigations of this section have shown that *P. obliqua* is already present in a thin limestone bed around the upper boundary of the normal interval.

Tong Jin-nan et al. (2005) investigated the Lower Triassic palaeomagnetic at the Olenekian GSSP candidate Chaohu in South China. They found that the base of the Olenekian (base of Smithian substage) is insignificantly below the top of a normal zone which begins in the upper *Sweetospathodus kummeli* Zone. Thus, when the palaeomagnetic succession of Scholger et al. (2000) is correctly dated, it coincides with the palaeomagnetic data at the Olenekian GSSP candidate.

According to Szurlies (2001, 2004a,b), the normal interval of the Bernburg Fm ends around the base of cycle 8. Thus, the Olenekian base should be insignificantly deeper, within cycle 7.

The biostratigraphically and magnetostratigraphically correlated base of the Olenekian in continental beds of the Germanic Basin can be also confirmed by carbon isotope investigations. In the Pufels (Bulla) section, somewhat more than 3 short eccentricity cycles above the Olenekian base, a distinct positive excursion of  $^{13}\text{C}$  was found (Korte et al., in press). In the Germanic Basin a distinct positive excursion of  $^{13}\text{C}$  lies in the lower *M. truempyi* Zone, somewhat more than 3 short eccentricity cycles above the base of the Olenekian, too (Korte & Kozur, in prep.).

Our conchostracan studies have shown that the Anisian begins with the Stammen Beds of the upper Solling Fm which has the same Aegean conchostracan fauna as the lower-middle Röt below the Dolomitische Grenzbank. By this we agree with Brugman (1986) who has already shown this correlation based on palynological studies, thus demonstrating the significance of palynological studies in beds, which had not yielded any fauna in that time. His dating was later unfortunately not taken into consideration. The assignment of the Stammen Beds to the Anisian means that the contemporaneous Thüringer Chirotherien Sandstein belongs to the Aegean as well. Until now the tetrapod footprints of the upper Solling Fm were regarded as a typical footprint association of the Lower Triassic. The Bithynian begins in the higher Röt Fm. with the Dolomitische Grenzbank, which is characterised both by marine fauna (bivalves) and conchostracans (Kozur et al., 1993, Kozur, 1999).

According to palynologic data (Brugman, 1986), the entire Röt Fm. belongs to the Anisian. Above the unfossiliferous anhydrite, gypsum and halite of the basal Röt Fm this is also clearly indicated by marine and continental fauna, e.g. ammonoids with the Anisian genus *Beneckeia*, the bivalve *Costatoria* (with higher number of extra-areal ribs than in Olenekian representatives), Aegean holothurian sclerites of the *Theelia mostleri* Zone, Bithynian bivalves and *Beneckeia buchi* (von Alberti) in the upper Röt. Continental Röt yielded lower Anisian tetrapods (*Eocyclotosaurus* fauna) and lower Anisian conchostracans.

Nawrocki & Szulc (2000) presented a different palaeomagnetic correlation of the Röt with the palaeomagnetic succession of condensed pelagic limestones of the Kçira section in Albania (Muttoni et al., 1996), assigning the entire Röt to the Olenekian. This assignment is based on the correlation of the reversed interval in the upper Röt Fm with interval Kç1r (Muttoni et al., 1996) of the uppermost Olenekian. The reversed interval in the upper Röt Fm corresponds actually to the reversed interval Kç2r of the Kçira section straddling the Aegean-Bithynian boundary (Muttoni et al., 1996).

When the palaeomagnetic data of Nawrocki & Szulc (2000) are correctly correlated, they are important for the correlation with the global scale. Below the reversed interval in the upper Röt Fm there is a longer normal interval, beginning after a gap in the dolomites of the lower Röt Fm. These data show that, compared with the marine palaeomagnetic succession (Fig. 1), even the lower Röt dolomites are not older than upper part of lower Aegean. As the lowermost hypersaline Röt below the lower Röt dolomite has a very short duration (not longer than a short eccentricity cycle), there is not enough time for the entire lower *C. timorensis* Zone of the lower Aegean (with 3 reversals, see Fig. 1) in the basal hypersaline Röt. Therefore, the proper correlation of Nawrocki & Szulc's (2000) palaeomagnetic data indicates that the base of the Anisian must be below the base of the Röt (if a gap between Solling and Röt Fm can be excluded), thus confirming the palynological data of Brugman (1986) and the above mentioned Aegean age of the conchostracan fauna of the Stammen Beds.

Vörös (2003) defined the base of the Pelsonian at the GSSP in the Balaton Highland (Hungary) with the base of the *Balatonites balatonicus* Zone s.s., and assigned the *B. ottonis* fauna of the Germanic Basin (lower Wellenkalk Member and Oolithbank Member) to the upper Bithynian. This confirms the conodont correlation by Kozur (e.g., 1974, 1999). It indicates that the correlation of the upper half of the Röt with the Pelsonian by palynologists (e.g., Brugman, 1986, Visscher et al., 1993) must be caused by different FAD of important guide forms in the Alps and in the Germanic Basin.

After the base of the Ladinian was confirmed at the base of the *E. curionii* Zone by the ISTS, most of the Upper Muschelkalk is Anisian in age. The base of the newly defined Ladinian lies above the Cycloidesbank ~ within the

upper *enodis-laevigatus* Zone (or within the *sublaevigatus* Zone sensu Urlichs, 1991).

The Upper Triassic correlation of the Germanic Triassic with the international scale is shown in Fig. 7. The youngest Carnian (late Tuvalian) conchostracan fauna was found by Kelber in the Coburg Sandstone (Kelber & Kozur, in prep.). The oldest conchostracan fauna from the Arnstadt Fm and equivalents contains already the genus *Shipingia*, which begins also in the lowermost Passaic Fm of the Newark Basin, thus giving a good correlation marker. The FAD of *Shipingia* is in the Alaunian. As the Heldburggips (Mainhardt Fm) was rather rapidly deposited, a long gap has to be present between the Mainhardt Fm and the Arnstadt Fm comprising Lower Norian ("Altkimmerische Hauptdiskordanz", Beutler 1979). It may be related to the closure of the Palaeotethys around the Carnian-Norian boundary.

Very important magnetostratigraphic and biostratigraphic data were presented by Hounslow et al. (2004) from the famous Triassic Jurassic boundary sections at St. Audrie's Bay, UK. They allow for the first time a good correlation of the Alaunian to basal Jurassic interval of the Newark Basin with the Germanic Basin.

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## Triassic Ammonoid Succession in South Primorye: 4. Late Olenekian – Early Anisian zones of the Atlasov Cape Section

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**Abstract** – A review of a new data on the Upper Olenekian (*Neocolumbites insignis* and *Subcolumbites multiformis* Zones) and Lower Anisian (*Ussuriphyllites amurensis* and *Leiophyllites pradyumna*) biostratigraphy of the western Ussuri Bay area of South Primorye is given on the basis of new ammonoid, brachiopod and conodont findings. The presence of the *Neocolumbites insignis* zone in the Atlasov Cape section is firstly recognized by the finding of *Olenekoceras meridianus* Zakharov. The representative ammonoid assemblage was recognized for the basal Anisian (*Ussuriphyllites amurensis*) Zone of the Atlasov Cape section: *Parasageceras*, Prionitidae (gen. nov.), *Leiophyllites*, *Megaphyllite*, *Ussuriphyllites* (dominant), *Ussurites*, *Prohungarites*, *Arctohungarites*, *Paracrochordiceras*, *Salterites*, *Paradanubites*, and *Tropigastrites*. Anisian conodonts in the section were discovered in the first time.

### Biostratigraphy

Olenekian and Anisian fossils and lithology and of the western Ussuri Bay area were firstly investigated by I. V. Buriy and N.K. Zharnikova (Buriy, 1959) Korzh (1960), M. Kaplan ( ), L.D. Kiparisova (1961) and Y.D. Zakharov (1968), but the Olenekian-Anisian boundary has not been investigated in detail. This paper contains the description of the Atlasov Cape section on the basis of new paleontological finding.

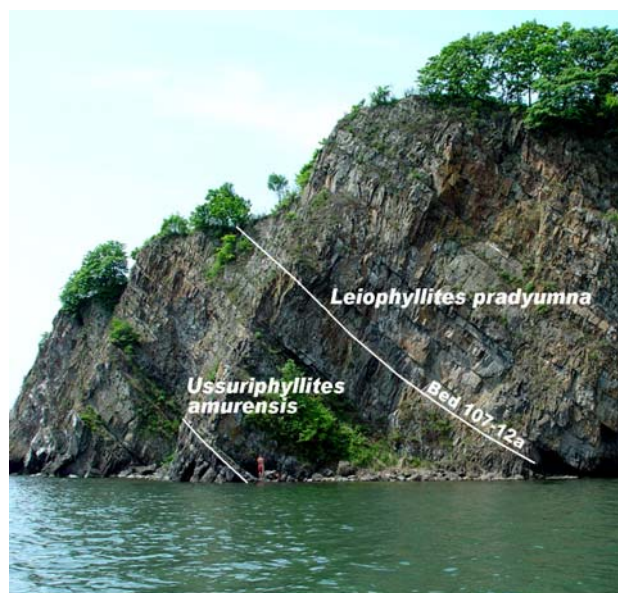
### Lower Anisian (Karazin Suite)

#### *Leiophyllites pradyumna* and *Acrochordiceras kiparisovae* Zones

- 30. Massive sandy siltstone (Fig.1).....about 20.0 m
- 29. Striped sandy siltstone .....7.0 m
- 28. Spotted sandy siltstone .....10.0 m
- 27. Calcareous spotted sandy siltstone .....7.0 m
- Mialinid bivalves, wood fragments (107-13).
- 26. Striped sandy siltstone .....0.9 m
- 25. Massive spotted sandy siltstone .....5.0 m
- 24. Calcareous siltstone .....1.8 m
- Ammonoids – *Balatonites?* sp. (107-12a).

#### *Ussuriphyllites amurensis* Zone

- 23. Spotted sandy siltstone with calcareous sandy siltstone large nodules and short lenses (Figs. 2 and 3).....7 m
- Spiriferid brachiopods, bivalves – *Mutilus* sp., *Eumorphotis* sp., *Bakevellia* sp., Myalinidae, Pinnidae, gastropods, nautiloids – *Trematoceras* sp., *Tainoceras* sp., *Germanonautilus* sp., *Phaedrysmocheilus* sp., *Ph. russkiensis* (Zakharov), *Paranautilus* sp., ammonoids – Prionitidae gen. et sp. nov., *Ussuriphyllites amurensis* (Kiparisova) (dominant), *Megaphyllites atlasoviensis* Zakharov, *Leiophyllites praematurus* Kiparisova, *Leiophyllites* sp., *Paradanubites* sp. indet., *Paracrochordiceras* sp. nov., *Prohungarites popowi* Kiparisova, *Arctohungarites primoriensis* Zakharov, *A. solimani* (Toula), gigantic *Salterites* sp. indet., and



**Figure 1:** Atlasov Cape section (middle portion), Western Ussuri Bay, 1.2 km NE of the Atlasov Cape, South Primorye.



**Figure 2:** *Ussuriphyllites amurensis* Zone in the Atlasov Cape area.





**Figure 3:** *Ussuriphyllites amurensis* (Kiparisova), Lowermost Anisian, Atlasov Cape area (A.M. Popov's photo).

*Tropigastrites sublachontanus* Zakharov (107-4, 4a, 5, 6, 7, 8, 9, 10, 11, 12, 12a, 12b).

22. Calcareous siltstone with interbeds of sandy limestone .....2.7 m

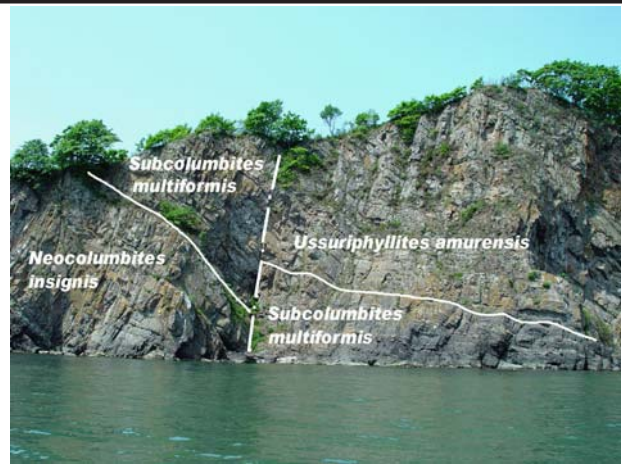
Spiriferid brachiopods, ammonoids - *Ussuriphyllites amurensis* (Kiparisova), conodonts (107-3a,b).

21. Spotted and striped sandy siltstone with short and thin lenses of calcareous siltstone and coarse sandstone.....0.5 m

Bivalves – *Posidonia* sp., gastropods, nautiloids – *Trematoceras* sp., ammonoids - *Parasageceras* sp. nov., Prionitidae gen. et sp. nov., *Ussuriphyllites amurensis* (Kiparisova), *Megaphyllites atlasoviensis* Zakharov, *Ussurites* sp., *Prohungarites popowi* Kiparisova, *Arctohungarites primoriensis* Zakharov, *Arctohungarites solimani* (Toula), *Tropigastrites sublachontanus* Zakharov, conodonts – *Neospathodus* cf. *homeri* (Bender), amphibian remains (107-2, 2a, 3, 3b).

20. Calcareous siltstone.....0.25 m

18. Calcareous coarse sandstone with small pieces of siltstone (Figs. 4 and 5).....0.15 m



**Figure 4:** *Ussuriphyllites amurensis* / *Subcolumbites multiformis* Zones boundary in the Atlasov Cape section.



**Figure 5:** Anisian basal bed in the Atlasov Cape section.

Rare brachiopods (shell fragments), ammonoids – *Prohungarites* ? sp., abundant shark teeth (107-1).

## Olenekian

### *Subcolumbites multiformis* Zone (Zhitkov Suite)

17. Sandy siltstone with small calcareous-marly nodules and lenses (Fig. 6)..... 13 m  
Small bivalves, gastropods *Bellerophon* sp., nautiloids, ammonoids – *Subcolumbites multiformis* Kiparisova, *Megaphyllites immaturus* Kiparisova (106-2, 2a, 2b, 3, 4, 4a, 5).

### *Neocolumbites insignis* Zone (Atlasov Suite)

16. Fine grained silty sandstone with small nodules and lenses of calcareous sandstone .....1 m

15. Fine grained, calcareous sandstone with lenses of calcareous sandstone-coquina.....3.8 m  
Small bivalves.

14. Striped, fine grained, silty sandstone .....1.5 m

13. Fine grained, silty sandstone, striped in some places .....2.6 m





Figure 6: Anisian-Olenekian boundary beds in the Atlasov Cape section.



Figure 7: *Neocolumbites insignis* Zone in the Atlasov Cape section.

- 12. Fine grained silty sandstone with lenses of calcareous sandstone-coquina.....20 m Bivalves (106-1).
- 11. Thin intercalation of fine grained, striped sandstone and siltstone with lenses of calcareous sandstone....7 m Bivalves – *Bakevella* sp., Pectinaceae (105-2), ammonoid – *Olenekoceras meridianus* (Zakharov) (105-3) (Figs. 7 and 8).
- 10. Striped, fine grained sandstone .....6 m
- 9. Fine grained sandstone .....8 m
- 8. Striped, fine grained sandstone.....0.8 m
- 7. Fine grained sandstone ..... 4 m
- 6. Striped, fine grained sandstone..... 0.6 m
- 5. Fine grained sandstone.....1 m
- 4. Striped, fine grained sandstone .....1 m
- 3. Fine grained sandstone.....1.8 m
- 2. Striped, fine grained sandstone.....0.7 m
- 1. Fine grained sandstone with lenses of calcareous sandstone-coquina.....4 m Bivalves – *Bakevella* sp. (105-1).

Closed interval (about 200 m in thickness).



Figure 8: *Olenekoceras meridianum* (Zakharov), Upper Olenekian, Atlasov Cape area (A.M. Popov's photo).

**Induan**

**(Lazurninskaya Suite) *Gyronites subdharmus* Zone**

a. Conglomerate and sandstone .....more than 50 m  
Rare bivalves.

**Conclusions**

The *Neocolumbites insignis* Zone of the Atlasov Cape section western Ussuri Bay area in South Primorye characterized by typical Late Olenekian fossils (*Olenekoceras meridianum*) differs in its lithology from the same zone of Russian Island, where the Zhitkov Suite has been recognized (Zakharov, 1997; Zakharov et al., 2004). Therefore there is a ground to describe *Neocolumbites insignis* Zone sequences of the Atlasov Cape section in the present paper as a new formation in South Primorye (Atlasov Suite), consisting mainly of fine grained, striped sandstone, 60-70 m thick.

Basal beds of the Karazin Suite, overlaying the Latest Olenekian *Subcolumbites multiformis* Zone in the Atlasov Cape section, are characterized by a typical earliest Anisian ammonoid assemblage. The latter contains representatives of *Parasageceras*, Prionitidae (gen. nov.),



Figure 9: Earliest Ladinian crinoid from the Atlasov Cape section (Bed 107-14) (A.M. Popov's photo).

*Leiophyllites*, *Megaphyllites*, *Ussuriphyllites* (dominant), *Ussurites*, *Prohungarites*, *Arctohungarites*, *Salterites*, *Paracrochordiceras*, *Paradanubites* and *Tropigastrites*.

The Atlasov Cape seem to be one of most representative sections in South Primorye, which can be proposed as a candidate GSSP of the Olenekian-Anisian boundary in the case of positive results in the detailed investigation of its conodont succession.

### **Acknowledgments**

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# Palaeobiogeographic Zoning of Triassic Seas of Northeastern Asia Based on Conodontophoridae

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## Introduction

It is believed today that a single supercontinent Pangea existed in the Early Triassic and was surrounded by the Panthalassa proto-ocean. In the east, a giant gulf, the Tethys ocean, was deeply indented into this supercontinent (Fig. 1).

On the basis of differences in the biotas (molluscs, brachiopods, etc.) that inhabited northern and southern basins, explorers have recognized the Boreal and Tethyan paleobiogeographic zones (Dagys, 1974, 1976; Dagys et al., 1979; Dagys and Shevyrev, 1981; Sobolev, 1989).

To study the geographic differentiation of Conodontophoridae in the Triassic is rather difficult. First, microfossils from separate regions (Tethyan and Boreal) are explored poorly and unevenly; second, there is no consensus as to the volume of many genus-ranked taxa. Until recently, conodonts have been little used for paleobiogeographic zoning of Triassic basins. Only one publication was dedicated to regularities of geographic distribution of Early Triassic conodonts (Dagys and Dagys, 1989). In northeastern Russia, some new microfossil localities have recently been established and its monographic study has supplemented general regularities of their vertical and lateral occurrence (Klets, 1998, 2000; Klets and Yadrenkin, 2001; Klets and Kopylova, 2004). To disclose regularities of geographic distribution of conodonts in northeastern Asia, we used the faunal (areal-genetic) principle of zoning. The taxonomic composition of genera

and species was determined more accurately for certain periods of time: epochs and ages. Geographic ranges of some taxa (genera, species) were mapped. Criteria for recognition of paleobiogeographic units (or zoochores) are rank and degree of endemism of microfossils. Criteria and factors were revealed which control the paleogeographic differentiation of conodonts.

The data obtained by analyzing similarities or differences in assemblages of conodonts from various paleoclimatic environments were supplemented with statistical data. Long's coefficients of community were calculated using the formulas  $R=C*(N1+N2)/2*N1N2$ , where R is the coefficient, N1 is the number of taxa in a smaller assemblage, N2 is the number of taxa in a larger assemblage, C is the number of common taxa for two areas (Long, 1963). Matrices of likelihood of faunal descriptions were constructed on the basis of overlapping coefficient matrices.

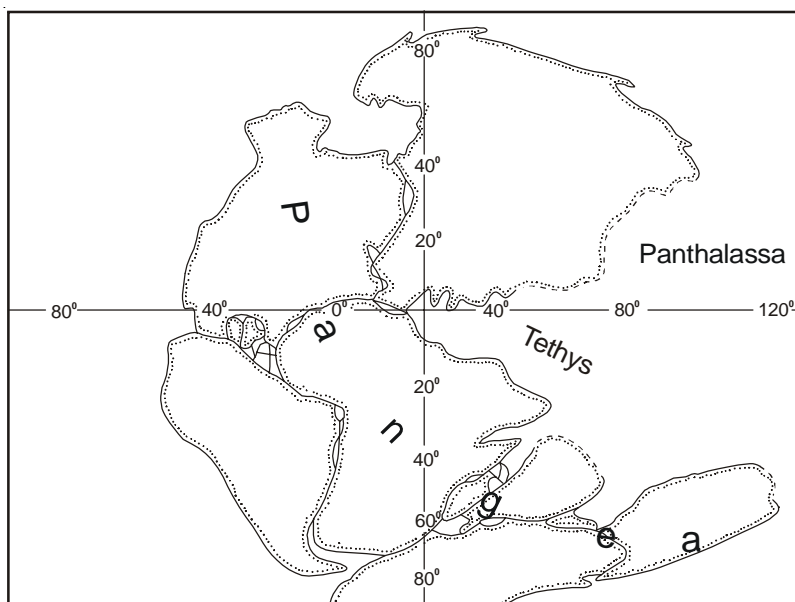
The obtained data on paleobiogeographic conodont zoning of Triassic seas of northeastern Asia were discussed with B.N.Shurygin and A.B.Kanygin, whose comments and recommendations are greatly appreciated.

## Palaeobiogeographic analysis

### Early Triassic

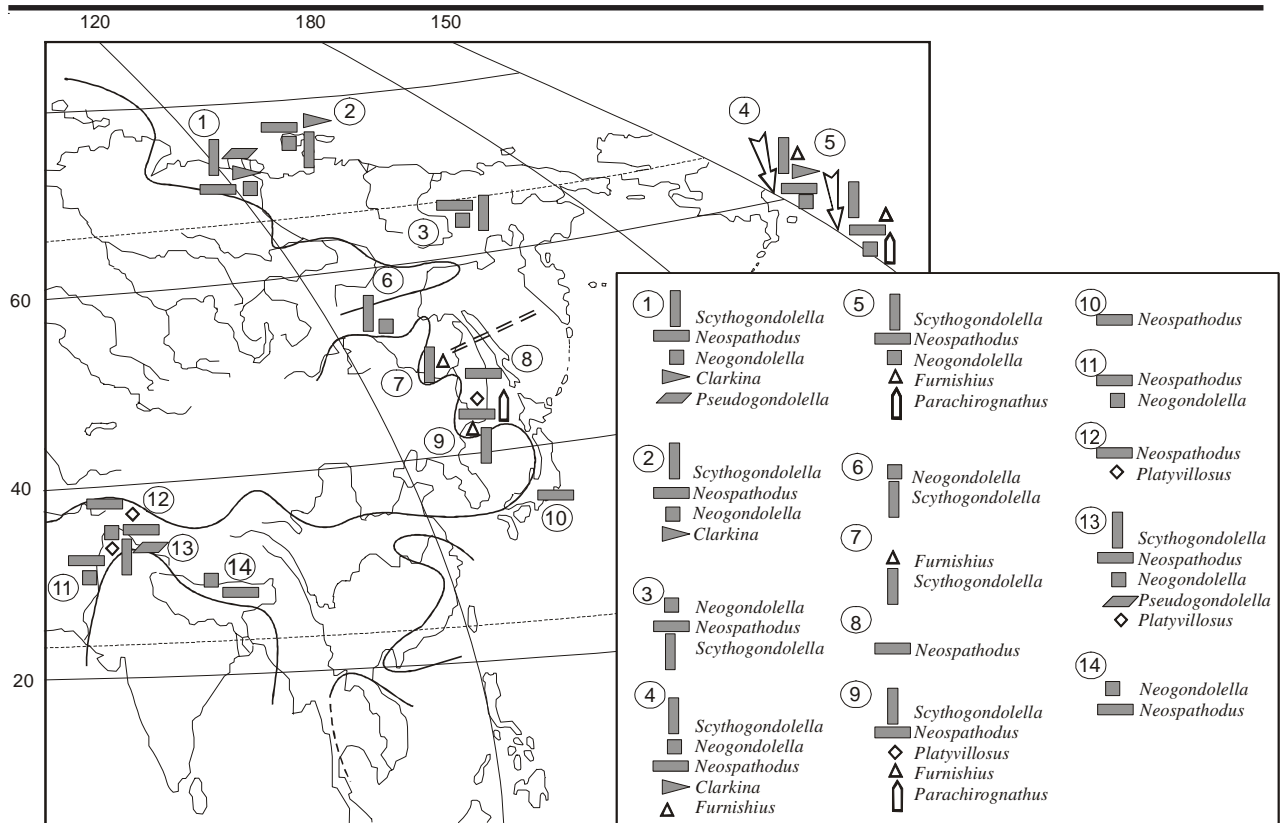
#### Induan Age

In the Induan Age the Tethys basin was inhabited by con-



**Figure 1:** Position of the continents of the beginning of the Triassic Period (from Shevyrev, A.A., 1986).





**Figure 2:** Reference localities of the Lower Olenek conodontophorid in the North-East Asia (geographic zoning on figs. 2, 3, 5, 7, 8 from Shevyrev, 1986). Note: see table 1.

odonts inherited from the Permian: *Hindeodus*, *Isarcicella*, *Clarkina* and, in the second half of the Induan, *Platyvillosus*, *Neospathodus* (Wang, 1995; Yang et al., 2001; Koike, 1996). Finding of the Induan species *Clarkina* cf. *changxingensis* Wang et Wang and *Hindeodus typicalis* (Sweet) in the northern latitudes is known from (Zakharov, 2002). The available data on this group of microfossils are evidently insufficient for biogeographic analysis.

### Olenek Age

#### Early Olenek time

In Early Olenek time, the conodont assemblages were considerably renewed in southern basins. This time is characterized by the Triassic-greatest specific and generic diversity. Conodont assemblages are represented by 32 (of 37) species from eight genera: *Neospathodus*, *Neogondolella*, *Scythogondolella*, *Pseudogondolella*, *Clarkina*, *Parachirognathus*, *Furnishius*, *Platyvillosus*. In addition to the cosmopolites, there existed the thermophile genera *Furnishius*, *Platyvillosus*, and *Parachirognathus*, whose geographic range is restricted to the low latitudes. The richest Early Olenek conodont assemblages have been described from sections of India (Goel, 1977; Matsuda, 1984), China (Yang et al., 2001), West Pakistan (Sweet, 1970), Japan (Igo, Koike, 1983), southwestern USA (Mosher, 1968; Sweet et al., 1971; Solien, 1979), Britain Columbia (Mosher, 1973), Tajikistan (Dagys, 1990), Russia: Far Eastern maritime

(Buriy, 1979, 1989; Bragin, 1991), and central Sikhote Alin' (Bragin, 1991; Klets, 1995) (Fig. 2, Table 1).

The northern conodont assemblages were separated from the southern ones. At that time, only the cosmopolitan genera *Neospathodus*, *Neogondolella*, and *Scythogondolella* existed within the Boreal belt. Endemism was recorded at the species level: *Neogondolella buurensis* Dagys, *N. composita* Dagys, *N. jakutensis* Dagys. The richest Early Olenek conodont assemblages are known and described from sections at the lower reaches of the Lena River, on the island of Kotel'ny, in the Dzhugadzhak River basin, and in the Shevli River basin (Dagys, 1984; Kuz'min and Klets, 1990; Klets and Yadrenkin, 2001; Klets and Kopylova, 2004) (Fig. 2, Table 1).

Statistical coefficients confirm the isolation of southern and northern conodont assemblages (Table 2). The highest and closest Long's coefficients are recorded in the assemblages within the Boreal belt: lower reaches of the Lena River and island of Kotel'ny, Dzhugadzhak and Shevli basins (0.57-0.62). The coefficients of community are very low or even equal to zero in the assemblages in the Lena River basin and southeastern Pamir, Tajikistan, (0.2), in the Lena basin and China (0), Lena basin and Far Eastern maritime (0.24). At the same time coefficients of community are close in some conodont assemblages from the Boreal and Tethyan basins. Coefficient for the lower reaches of the Lena River and Dzhugadzhak River basin (0.62) is close to the coefficient for the Lena lower reaches

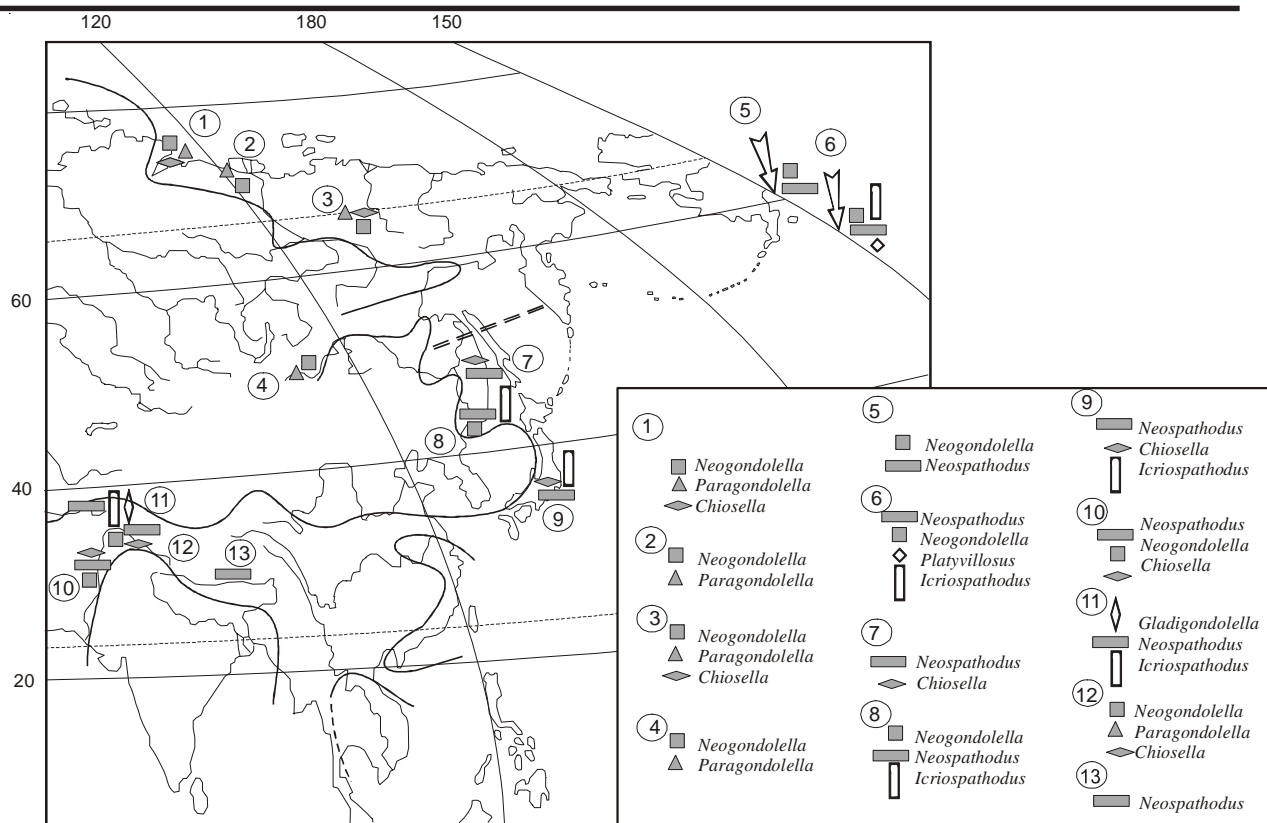


Figure 3: Reference localities of the Upper Olenek conodontophorid in the North-East Asia. Note: see tabl 4.

and central Sikhote Alin' (0.56) and Japan (0.6). Some smoothing of statistics can be likely explained by migration of conodonts from Tethys, from the far-shore pelagic paleoenvironments in connection with the Triassic greatest transgression of the Boreal basin (expressed in Early Olenek time) and higher paleotemperature of sea water up to 24-29 C (Kurushin and Zakharov, 1995).

The climatic isolation of northern and southern assemblages is confirmed by data from the likelihood matrix (Table 3). The high and highest likelihood percentages (50% to 80%) are observed in conodont assemblages from three Siberian regions.

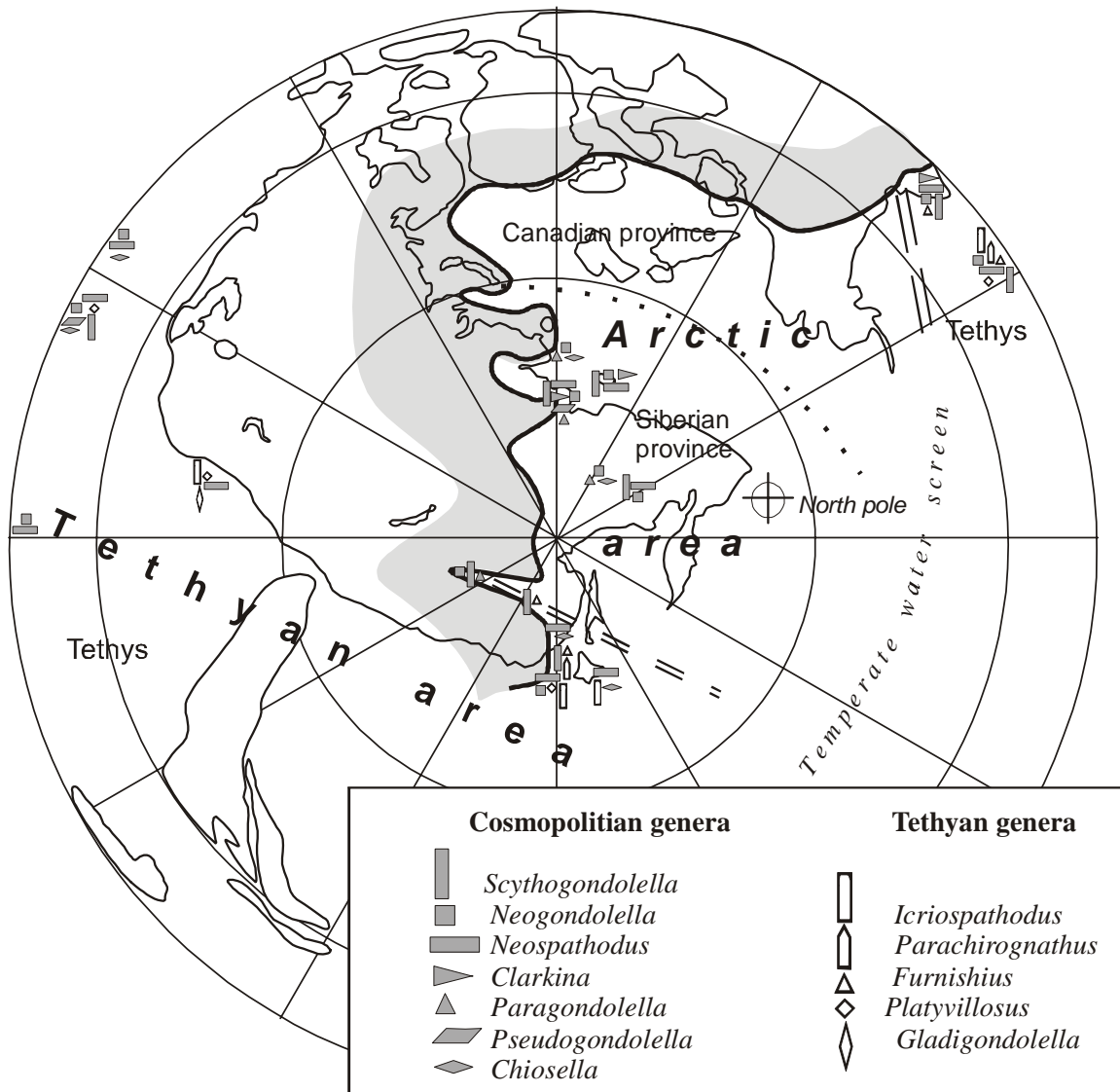
Late Olenek time

In Late Olenek time, the species diversity of Conodontophoridae is considerably diminished. Assemblages include 21 species of seven genera: *Neogondolella*, *Paragondolella*, *Chiosella*, *Gladigondolella*, *Neospathodus*, *Icriospathodus*, and *Platyvillosus*. A great generic and specific diversity persists in southern basins, where the taxonomic composition is renewed. The genera *Gladigondolella* and *Icriospathodus*, typical of the Tethyan belt only, appear, while the Early Olenekian genera *Furnishius* and *Parachirognathus* disappear. They are known from India (Goel, 1977; Matsuda, 1984), China (Yang et al., 2001), West Pakistan (Sweet, 1970), Japan (Igo and Koike, 1983; Igo, 1989), southwestern USA (Mosher, 1968; Sweet, 1970; Sweet et al., 1971; Solien, 1979), Tajikistan (Dagys and Dronov, 1989; Dagys, 1990), and from Russia: Far Eastern maritime (Buriy, 1979;

Bragin, 1991), central Sikhote Alin'" (Bragin, 1991; Klets, 1995) (Fig. 3, Plate 4).

In the northern basins, the genera *Neogondolella* and *Neospathodus* persist, new cosmopolites, *Paragondolella* and *Chiosella*, appear, while *Clarkina* and *Pseudogondolella* disappear. Findings of Late Olenekian Conodontophoridae are known from eastern Taimyr (Dagys, 1984), lower reaches of the Lena River (Dagys, 1984), basin of the Zyryanka River (Klets, 1998), eastern Transbaikalia (Klets, 2002) (Fig. 3, Table 4).

Statistical coefficients are not in conflict with the evidence of increasing isolation of conodont assemblages from the Boreal and Tethyan basins. The highest Long's coefficients (0.58 to 0.75) are between regions of northern latitudes: eastern Taimyr and lower reaches of the Lena River, eastern Taimyr and basin of the Zyryanka River, eastern Taimyr and eastern Transbaikalia (Table 5). The maximum likelihood (80%) is recorded between complexes of the lower reaches of the Lena River and eastern Transbaikalia. The assemblages of southeastern USA and Far Eastern maritime, central Sikhote Alin' and Japan, Far Eastern maritime and Japan display a 75% likelihood. It is possible that relatively cool waters of the southern Tethys are responsible for the close coefficient of community and high degree of likelihood between the assemblages of eastern Taimyr and lower reaches of the Lena River (0.75 and 66%) and eastern Taimyr and India (0.75 and 75%). The assemblages at the northern latitudes show a very low or zero likelihood with the assemblages of southeastern Pamir, China, and Japan (Table 6).



**Figure 4:** Distribution of conodontophorid in the Olenekian boreal basin of the North-East Asia (zoning of water area on figs 4, 6, 9 from Zakharov, 2002).

Thus, throughout the Olenekian Age there was a latitudinal differentiation of conodont assemblages, which was expressed in disproportion of a systematic composition by comparison of microfossils of the Tethyan and Boreal paleobasins. Analysis of their geographical distribution suggests the presence of two biochores. **Arctic Realm** is characterized by the cosmopolitan genera *Neogondolella*, *Neospathodus*, *Paragondolella*, and *Chiosella* and endemic species *Neogondolella buurensis* Dagys, *N. composita* Dagys, *N. jakutensis* Dagys, *N. altera* Klets. It covers only high-latitude basins, including eastern Taimyr, lower reaches of the Lena River, island of Kotel'ny, Dzhugadzhak River basin, and Zyryanka River basin. A large gulf was indented into the continent from the east, reaching the basin of the Shevli River, a tributary of the Uda River, in Early Olenek time, and eastern Transbaikalia, in Late Olenek time. The **Tethyan Realm** is characterized by a high taxonomic diversity, with the genera *Furnishius*, *Platyvillosus*, *Parachirognathus*, *Gladigondolella*, and *Icriospathodus* living exclusively at the southern latitudes, and is traceable from West Paki-

stan to southwestern USA, including Tajikistan (south-eastern Pamir), China, India, Sikhote Alin', and Japan (Fig. 4). The conodont assemblages that inhabited northern and southern parts of the realm display some differences in taxonomic composition.

### Middle Triassic

More drastic differences in conodont assemblages in the Middle Triassic Boreal and Tethyan basins are due, first of all, to a drastic decrease in number of taxa at the northern latitudes. The available materials on the microfauna under study permit paleobiogeographical analysis only for the Middle Triassic as a whole.

At that time, the Tethys was inhabited by about 30 species of conodonts of eight genera: *Budurovignathus*, *Chiosella*, *Gladigondolella*, *Mosherella*, *Neogondolella*, *Neospathodus*, *Nicoraella*, and *Paragondolella*. Four genera are typical of southern basins. Findings of Middle Triassic conodonts are known from India (Goel, 1977), China (Zhao and Zhang, 1991), Japan (Igo, Koike, 1983;

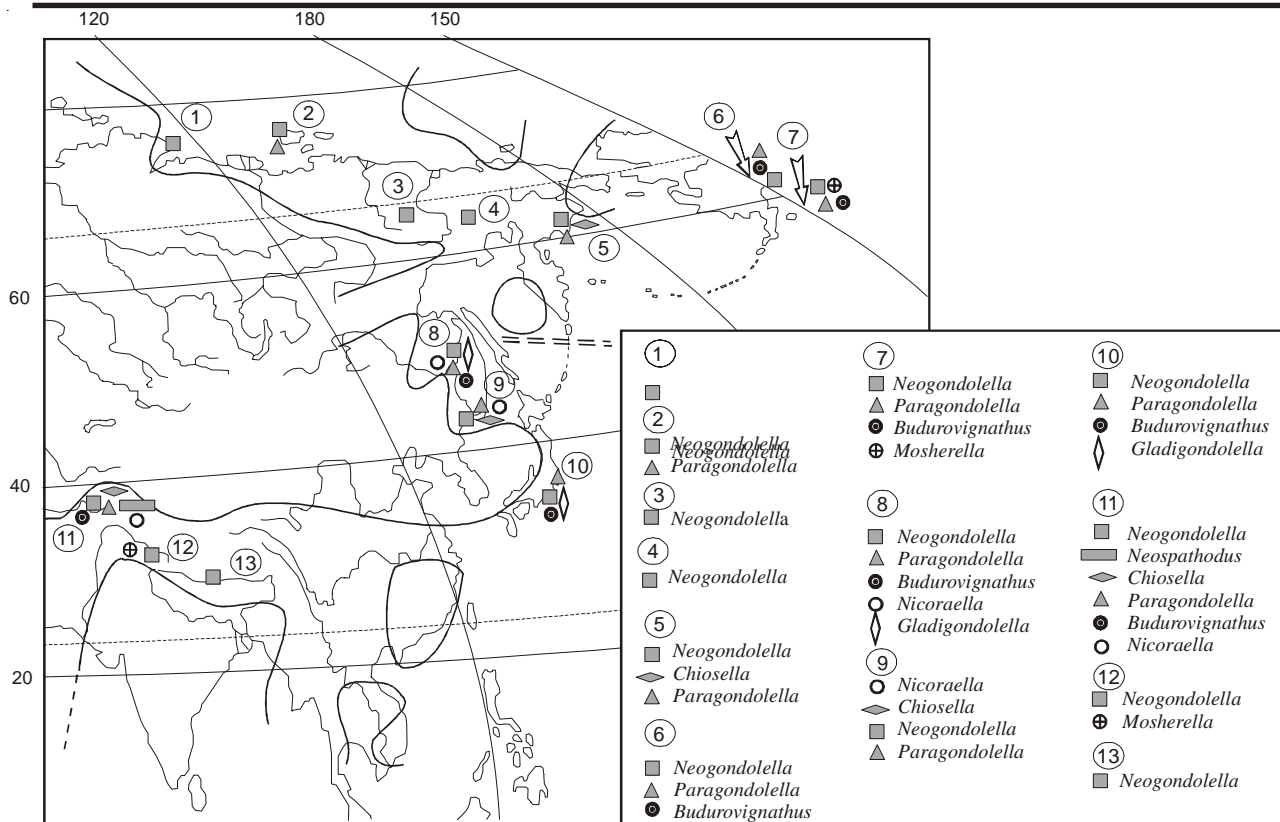


Figure 5: Reference localities of the Middle Triassic conodontophorid in the North-East Asia. Note: see Table 7.

Igo, 1989; Koike et al., 1991; Nakazawa et al., 1994), southeastern USA (Mosher, 1968; Sweet et al., 1971; Wardlaw and Jones, 1980), Britain Columbia (Mosher, 1973), Tajikistan (Dagys and Dronov, 1989), and from Russia: in central Sikhote Alin' and Far Eastern maritime (Buriy, 1989; Bragin, 1991; Klets, 1995) and Koryak upland (Bragin, 1991) (Fig. 5, Table 7).

In the Anisian, the polar basins were inhabited by as little as three cosmopolitan genera: *Neogondolella*, *Paragondolella*, and *Chiosella*. It should be noted that the last representatives of the genus *Chiosella* were extinct as early as the Early Anisian. In northern Siberia findings of the Anisian conodonts are known from eastern Taimyr (Dagys et al., 1979), Kotel'ny, Zyryanka basin (Klets and Kopylova, 2004) and Dzhugadzhak basin (Dagys, 1991) (Fig. 5, Table 7). Ladinian microfossils are extremely rare and have been found in the Zyryanka basin (Klets and Kopylova, 2004) and on eastern Taimyr (oral communication by N.I.Kurushin).

The maximum percentage overlap of species in microfossil assemblages of central Sikhote Alin' and Japan is 83%, central Sikhote Alin' and southeastern Pamir, 66.6%, central Sikhote Alin' and Far Eastern maritime, 58.0% (Table 8). The minimum species likelihood is demonstrated by the conodont assemblages of central Sikhote Alin' and eastern Taimyr (16.6%), central Sikhote Alin' and Zyryanka basin (16.6%). The assemblages of central Sikhote Alin' and Dzhugadzhak basin, Koryak upland and India are equally similar, by 25%.

The increased isolation of conodont assemblages in the Middle Triassic is, probably, related to the early Anisian decrease in paleotemperature of sea water in the Boreal basin down to 16-18 C (Kurushin and Zakharov, 1995). The extremely low similarity between assemblages of central Sikhote Alin' and China (8.3%) and depletion of some assemblages of northern latitudes and China seems to indicate that the waters in southern Tethys were relatively cool. The conodont assemblage established in siliceous rocks of the Koryak upland is represented by three genera, *Chiosella*, *Paragondolella*, and *Neogondolella*, and in other localities of northern Siberia, by one genus *Neogondolella* (eastern Taimyr, Zyryanka and Dzhugadzhak river basins) or by two genera – *Neogondolella* and *Paragondolella* (island of Kotel'ny).

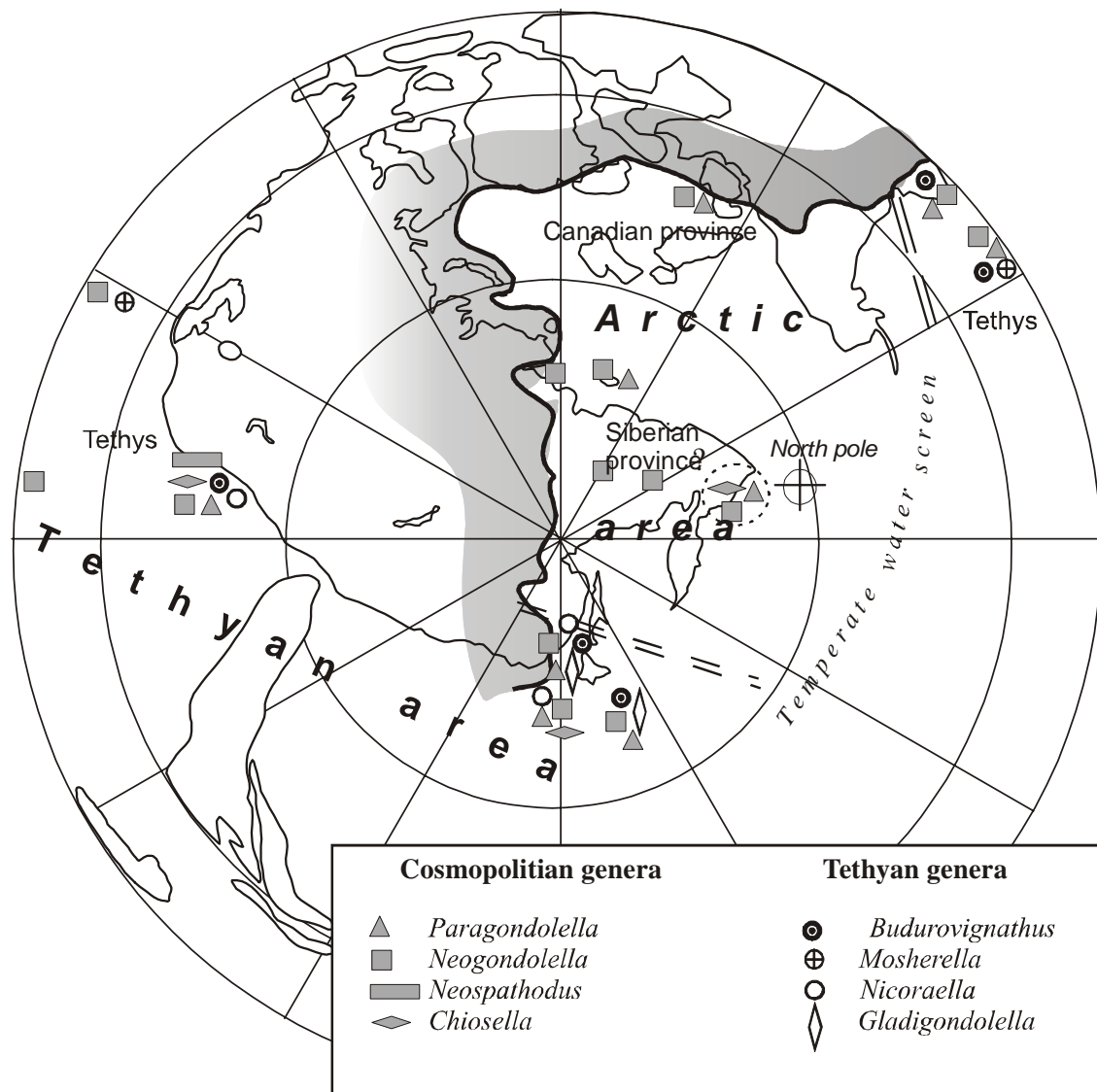
Latitudinal geographical differentiation of conodont assemblages established in the Early Triassic is also traceable in the Middle Triassic (Fig. 6). The **Boreal Realm** from eastern Taimyr to Dzhugadzhak basin is represented exclusively by smooth cosmopolitan forms of the genera *Neogondolella* and *Paragondolella*. The **Tethyan Realm** from West Pakistan to southwestern USA is characterized by distinct genera, including highly sculptured (*Budurovignathus*) ones.

**Late Triassic**

*Carnian Age*

The Carnian Age is characterized by a general decrease





**Figure 6:** Distribution of conodontophorid in the Middle Triassic boreal basin of the North-East Asia.

in systematic diversity of species-ranked taxa to 16. Generic diversity remains the same. Seven genera of Conodontophoridae (*Paragondolella*, *Epigondolella*, *Metapolygnathus*, *Gladigondolella*, *Mosherella*, *Mockina*, *Metapolygnathus*) are widespread in the Tethys, six of them being indicators of southern latitudes. They were dominated by smooth paragondolelids and heavily sculptured epigondolelids. In northeastern Asia, Carnian conodonts have been established in Britain Columbia and on the Queen Charlotte Islands (Mosher, 1973; Orchar, 1991), in the southwestern USA (Mosher, 1968; Sweet et al., 1971), in Japan (Koike et al., 1991; Igo, 1989; Nakazawa et al., 1994), in China (Yang et al., 20022), in Tajikistan (Dagys and Dronov, 1989), and in Russia: on the Koryak upland (Bragin, 1991), in central Sikhote Alin' and in the Far Eastern maritime (Bragin, 1991; Buriy, 1989; Klets, 1995) (Fig. 7, Table 9).

Only one cosmopolitan genus, *Paragondolella*, was developed in the north. Its occurrences have been established on Kotel'ny and in the Zyryanka basin (Klets, 2000) (Fig. 7, Table 9).

Statistical coefficients corroborate the drastic isolation of southern and northern assemblages of conodonts. The highest Long's coefficients (0.75) and a high degree of likelihood (66%) are observed in assemblages within the Boreal belt: Kotel'ny and Zyryanka basin (Tables 10 and 11). The assemblages from Kotel'ny and other study areas of northeastern Asia show lower or zero coefficients. Within the Tethyan zone, the greatest similarity is observed between assemblages of central Sikhote Alin' and Japan (80%), Far Eastern maritime and southwestern USA (75%).

The boundaries of zoogeographical realms established for earlier periods using conodonts retain their position in the Carnian Age. There is also latitudinal differentiation of microfossil assemblages with the Tethyan belt. A high coefficient of community (0.62) between assemblages of Kotel'ny and China is a stable indicator of a relatively low temperature of waters in the southern Tethys.

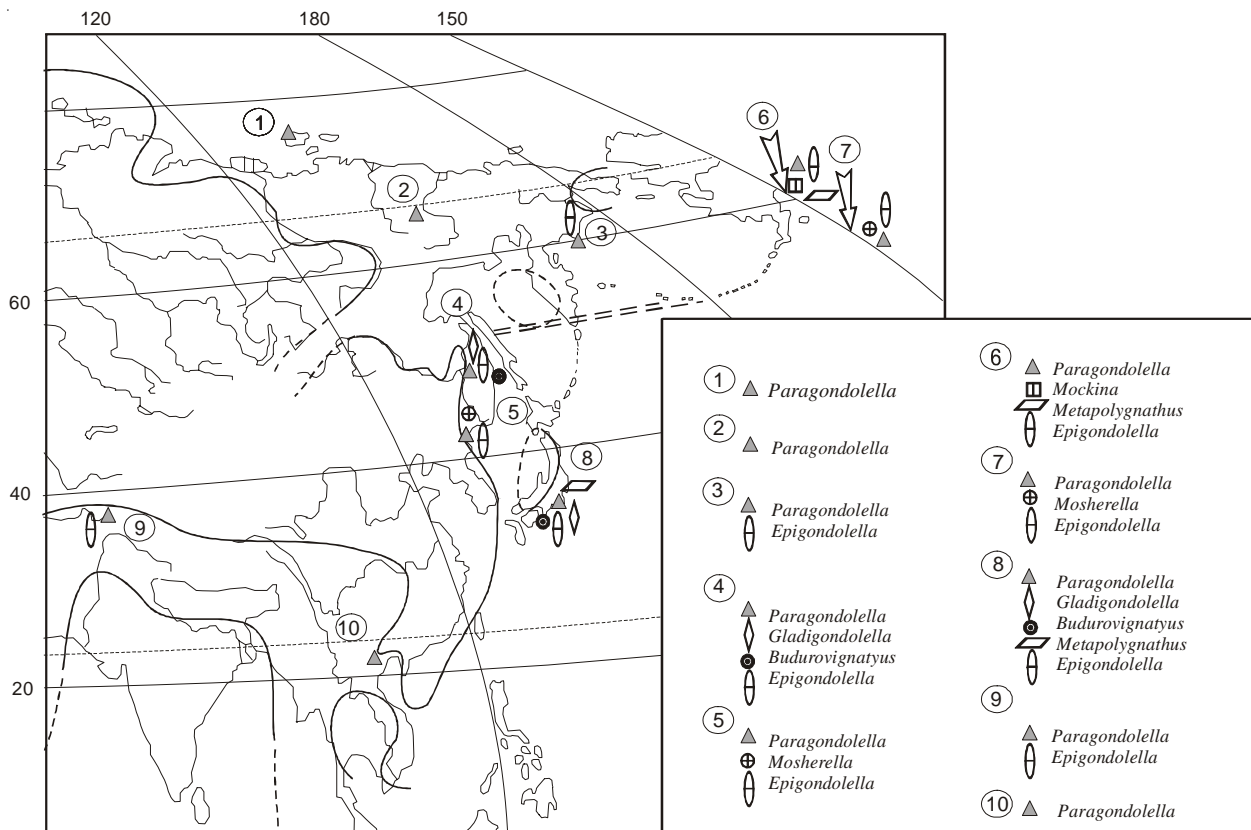


Figure 7: Reference localities of the Carnian conodontophorid in the North-East Asia. Note: see Table 9.

*Norian-Rhaetian*

In the Rhaetian, Conodontophoridae seemed no longer to exist in the polar latitudes. The available materials permit a biogeographic analysis for the Norian-Rhaetian as a whole.

In the late Triassic, the conodont assemblages of north latitudes and Tethys were utmost different. The total number of genera at this stage of development reduces to seven taxa. During this period, taxonomically different assemblages of conodonts remained in southern seas but their composition essentially changed. Paragondolellids disappear, while sculptured mockinides and heavily sculptured erigondolellids are obviously predominant. In the Rhaetian, the specific genus *Misikella* was widespread throughout the Tethys. It had a very simple characteristic morphology. In northeastern Asia, the Norian and Rhaetian conodonts are known from Russia: Koryak upland (Bragin, 1991), central Sikhote Alin' and Far Eastern maritime (Bragin, 1991; Buriy, 1989; Klets, 1995); from Tajikistan (Dagys and Dronov, 1989), from China (Yang et al., 2002), from Japan (Koike et al., 1991; Igo, 1989; Nakazawa et al., 1994), from Britain Columbia and Queen Charlotte Islands (Mosher, 1973; Orchar, 1991) and from the southwestern USA (Mosher, 1968; Sweet et al., 1971) (Fig. 8, Table 12).

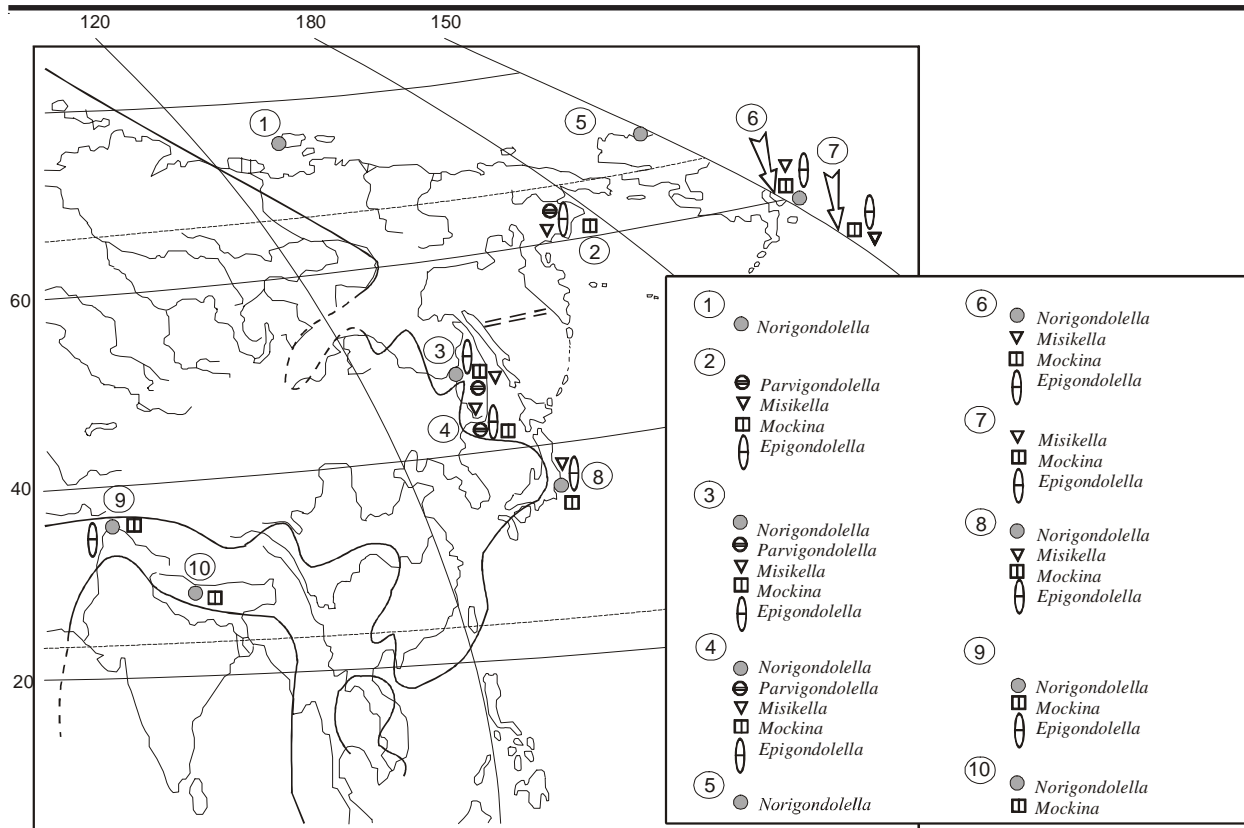
At that time, the Boreal basins were inhabited by only one cosmopolitan genus, *Norigondolella*, represented by two species. In subpolar regions, Norian conodont locali-

ties are known on Kotel'ny (Klets, 2000) and on the Alaska Peninsula (oral communication by B.N.Shurygin) (Fig. 8, Table 12).

Statistical coefficients confirm a drastic disproportion of conodont assemblages from Boreal and Tethyan basins and a high similarity within the same biochore. The highest Long's coefficient of community (0.75) is recorded between conodont assemblages of Kotel'ny and Alaska, and the lowest one (from 0 to 0.29), between those of Kotel'ny and Koryak upland, Kotel'ny and central Sikhote Alin' and Kotel'ny and Far Eastern maritime (Table 13).

The maximum likelihood is observed between the assemblages of the Far Eastern maritime and Britain Columbia (81%), central Sikhote Alin' and Japan (72%), Britain Columbia and Japan (70%). The least likelihood (0 to 18%) is recorded for assemblages from different paleoclimatic environments: island of Kotel'ny and Koryak upland, central Sikhote Alin', Far Eastern maritime, southwestern USA and Japan, Alaska and Central Sikhote Alin', Far Eastern maritime, southwestern USA, southeastern Pamir, Japan and China (Table 14).

The boundaries of the *Tethyan* and *Boreal zoochores* established according to Conodontophoridae in earlier times retain their position until the end of the Triassic (Fig. 9). Rather high coefficient of community (0.5) and high degree of likelihood (50%) between the assemblages of Kotel'ny and China seem to be indicative of the existing



**Figure 8:** Reference localities of the Norian and Rhaetian conodontophorid in the North-East Asia. Note: see Table 12.

latitudinal inhomogeneity of conodont assemblages within the Tethys basin and relatively low temperature of the waters in southern Tethys.

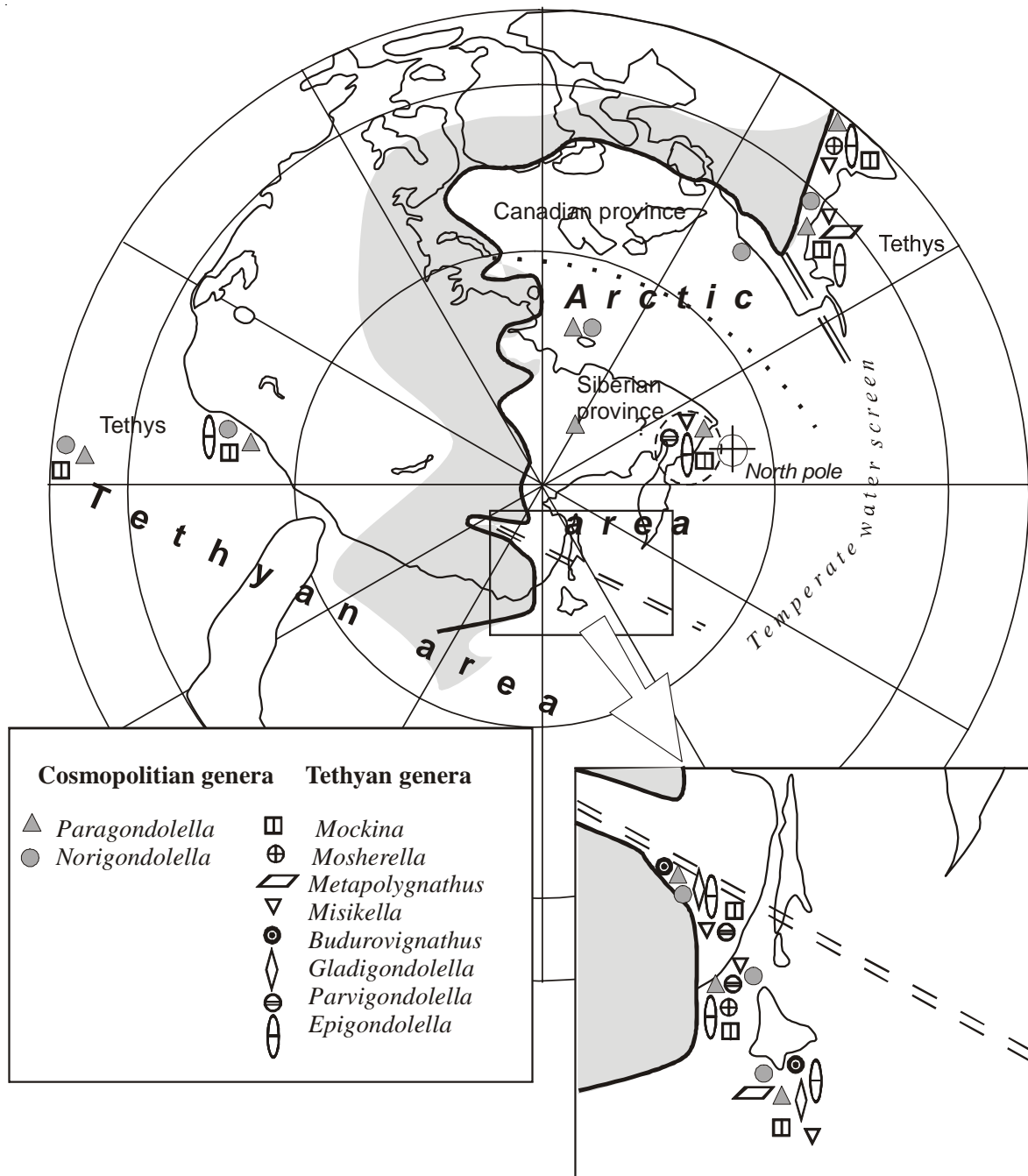
Bragin (1991) has established Late Triassic *Paragondolella polygnathiformis*, *Pa. tadpole*, *Epigondolella abneptis*, *Mockina bidentata*, *M. postera*, *Parvigondolella andrusovi* and *Misikella posthernsteini* in siliceous deep-water deposits in the basin of the Vaamochka River on the Koryak upland (Figs. 7, 8, and 9). Five genera of six (except for *Paragondolella*) are indicators of tropical latitudes. Long's coefficient of community and degree of likelihood between the conodont assemblages on Kotel'ny and Koryak upland equal zero. Findings of a Tethyan assemblage represented by smooth paragondolelides and heavily sculptured erigondolelids not typical of the subpolar latitudes seem to be indicative of the formation of host deposits in the tropics and suggest a horizontal displacement of the Koryak block for thousands of kilometers northward from the initial location.

### Conclusions

1. During the Triassic, reliably since the Early Triassic (Olenekian Age), a latitudinal geographic differentiation of conodont assemblages existed, which was expressed in disproportion of systematic composition when comparing them from different paleoclimatic basins: Tethyan and Boreal. Two biochores are distinguished. The **Arctic Realm** is characterized by drastically depleted composition of conodont assemblages, with only cosmopolitan

genera. Endemism is established at the species level and is traced from eastern Taimyr in the west to Alaska in the east, including the lower reaches of the Lena River, Kotel'ny, Dzhugadzhak and Zyryanka basins. Reliable data show that there was a large gulf in the Early Triassic, which indented into the continent from the east and reached eastern Transbaikalia. The **Tethyan Realm** is characterized by a great taxonomic diversity, with specific genera that lived at the southern latitudes only. It extends from West Pakistan to southwestern USA, embracing southeastern Pamir, China, India, Sikhote Alin', and Japan. The paleogeographic analysis, supplemented with statistical data, shows that during the Triassic, the conodont assemblages of the Tethyan Realm were not uniform, which was expressed in some resemblance of South Tethyan (chiefly, Indian and Chinese) and Boreal assemblages. With new findings available and more detailed conodont-based paleogeographic studies, it is quite probable that the Tethyan Realm will be subdivided into two subrealms: South Tethyan and North Tethyan.

2. Late Triassic (Middle Triassic?) Conodontophoridae from deep-water siliceous deposits of the Koryak upland are evidently similar to the assemblages from the relevant facies of Sikhote Alin' and Japan. The Tethyan southern habit of microfauna in northern regions probably indicates that it is confined to allochthonous terranes of the West Pacific and that the Koryak block moved horizontally northward from its initial location in the tropics. Our data coincide with the results obtained by substantiating the paleobiogeographic criteria of geodynamics of terranes



**Figure 9:** Distribution of conodontophorid in the Late Triassic boreal basin of the North-East Asia.

of northeastern Asia in the Mesozoic based on corals, cephalopods, bivalves, radiolarians, and other faunal groups (Bychkov and Dagys, 1984; Dagys et al., 1989; Zakharov et al., 1996).

3. The paleobiogeographic analysis provides material for and contributes to the further complex zoning of the Triassic seas on the basis of all groups of macro- and microfauna. The recognized basic regularities of lateral differentiation and paleobiogeographic zoning of microfauna are displayed in detailing provincial zonal scales, in constructing intra- and interregional Boreal-Tethyan correlations, and in geodynamic reconstructions.

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Project 467.

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Table 1.

Genera	Species	Localities (regions)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
<i>Scythogondolella</i>	<i>milleri</i>	1	1	1	1	1	0	1	0	1	0	0	0	1	0
	<i>mosheri</i>	1	1	1	0	0	1	0	0	0	0	0	0	1	0
<i>Pseudogondolella</i>	<i>nepalensis</i>	1	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Clarkina</i>	<i>carinata</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>ex gr. carinata</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	<i>planata</i>	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Neospathodus</i>	<i>bicuspidatus</i>	0	0	1	0	1	0	0	0	0	0	0	0	0	0
	<i>bransonii</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	<i>conservativus</i>	1	0	0	0	0	0	0	0	1	1	0	1	0	0
	<i>crisagalli</i>	0	0	0	0	0	0	0	0	1	0	0	1	0	0
	<i>curtus</i>	1	0	0	0	0	0	0	1	0	0	0	0	0	0
	<i>dieneri</i>	1	0	0	0	0	0	0	0	0	1	1	1	1	0
	<i>discreta</i>	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	<i>dissimilis</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>dronovi</i>	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	<i>ex gr. pakistanensis</i>	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	<i>lanceolatus</i>	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	<i>lenaensis</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>novaehollandiae</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	<i>pakistanensis</i>	1	0	0	1	1	0	0	0	0	0	1	0	0	0
<i>pamirensis</i>	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
<i>spitiensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
<i>waageni</i>	1	1	1	1	1	0	0	1	1	1	0	0	0	0	
<i>zarnikovi</i>	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
<i>Neogondolella</i>	<i>altera</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	<i>buurensis</i>	1	1	1	0	0	1	0	0	0	0	0	0	0	0
	<i>composita</i>	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	<i>crenulata</i>	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	<i>elongata</i>	0	0	0	1	0	0	0	0	0	0	1	0	1	0
	<i>jakutensis</i>	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	<i>nevadensis</i>	0	0	0	1	1	0	0	0	0	0	0	0	0	1
	<i>sibirica</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Parachirognathus</i>	<i>ethingtoni</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	<i>inclinata</i>	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	<i>symmetrica</i>	0	0	0	0	1	0	0	0	1	0	0	0	0	0
<i>Furnishius</i>	<i>triserratus</i>	0	0	0	1	1	0	1	0	1	0	0	0	0	0
<i>Platyvillosus</i>	<i>aff. gardinae</i>	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	<i>costatus</i>	0	0	0	0	0	0	0	0	0	0	0	1	1	0
8 genera	38 species	15	8	7	8	8	2	2	2	11	3	3	7	8	2

Species composition of conodonts from Lower Olenekian deposits of northeastern Asia.

Note: 1 – lower reaches of the Lena River; 2 – island of Kotelny; 3 – Dzhugadzhak River basin; 4 – Britain Columbia; 5 – southwestern USA; 6 – Shevli River basin; 7 – Churki Range; 8 – central Sikhote Alin; 9 – Far Eastern maritime; 10 – Japan; 11 – West Pakistan; 12 – southeastern Pamir (Tajikistan); 13 – India; 14 – China; “1” – species is present, “0” – species is not found.

Table 2.

regions	1 и 2	1 и 3	1 и 4	1 и 5	1 и 6	1 и 7	1 и 8	1 и 9	1 и 10	1 и 11	1 и 12	1 и 13	1 и 14
<b>R</b>	0,58	0,62	0,28	0,29	0,57	0,28	0,56	0,24	0,6	0,4	0,2	0,38	0

Long's coefficient of community for the Boreal and Tethyan basins in Early Olenekian time.  
Note: see Table 1.

Table 3.

	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
<b>1</b>		0	0	0	0	0	0	0	0	20	20	0	0	0	<b>14</b>
<b>2</b>	52		27	26	18	11	0	20	20	13	25	26	25	35	<b>13</b>
<b>3</b>	50	80		20	40	22	0	0	0	0	0	0	0	18	<b>12</b>
<b>4</b>	26	25	26		33	0	0	0	0	18	36	0	0	22	<b>11</b>
<b>5</b>	26	25	40	37		29	40	0	0	18	18	20	18	33	<b>10</b>
<b>6</b>	17	40	44	40	0		15	31	0	42	31	22	21	23	<b>9</b>
<b>7</b>	12	20	22	20	40	0		0	0	20	20	22	20	24	<b>8</b>

Matrix of likelihood of Early Olenekian taxa of Conodontophoridae of species rank from 14 localities of northeastern Asia. Note: see Table 1.

Table 4.

Genera	Species	Localities (regions)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	
<i>Chiosella</i>	aff. <i>timorensis</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	<i>timorensis</i>	1	0	0	0	0	0	1	0	1	1	0	1	0	
<i>Gladigondolella</i>	ex gr. <i>tethydis</i>	0	0	0	0	0	0	0	0	0	0	1	0	0	
<i>Icriospathodus</i>	<i>collinsoni</i>	0	0	0	0	0	1	0	1	1	0	1	0	0	
<i>Neodondolella</i>	<i>captica</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	
	<i>elongata</i>	0	0	0	0	0	0	0	0	0	1	0	1	0	
	<i>jubata</i>	1	1	1	1	1	1	0	1	0	1	0	1	0	
	<i>regale</i>	0	0	0	1	0	0	0	0	0	0	0	0	0	
	<i>taimyrensis</i>	1	0	1	0	0	0	0	0	0	0	0	0	0	
<i>Neospathodus</i>	aff. <i>elongatus</i>	0	0	0	0	0	0	0	0	0	0	1	0	0	
	aff. <i>waageni</i>	0	0	0	0	0	0	0	0	0	0	1	0	0	
	<i>curtus</i>	0	0	0	0	0	0	1	0	0	0	0	0	0	
	<i>dieneri</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	
	<i>homeri</i>	0	0	0	0	1	0	1	1	1	1	1	0	1	
	<i>pakistanensis</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	
	<i>spathi</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	
	<i>triangularis</i>	0	0	0	0	0	1	1	1	1	1	1	0	0	
	<i>waageni</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	
	sp. A	0	0	1	0	0	0	0	0	0	0	0	0		
<i>Paragondolella</i>	<i>paragondolellaeformis</i>	1	1	1	1	0	0	0	0	0	0	1	0		
<i>Platyvillosus</i>	<i>asperatus</i>	0	0	0	0	0	1	0	0	0	0	0	0		
<b>7 genera</b>	<b>21 species</b>	<b>4</b>	<b>2</b>	<b>6</b>	<b>3</b>	<b>2</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>9</b>	<b>6</b>	<b>4</b>	<b>1</b>	

Species composition of conodonts from Upper Olenekian deposits of northeastern Asia.

Note: 1 – eastern Taimyr; 2 – lower reaches of the Lena River; 3 – Zyryanka River basin; 4 – eastern Transbaikalia; 5 – Britain Columbia; 6 – southwestern USA; 7 – Sikhote Alin'; 8 – Far Eastern maritime; 9 – Japan; 10 – West Pakistan; 11 – southeastern Pamir (Tajikistan); 12 – India; 13 – China; "1" – species is present, "0" – species is not found.



Table 5.												
regions	1 и 2	1 и 3	1 и 4	1 и 5	1 и 6	1 и 7	1 и 8	1 и 9	1 и 10	1 и 11	1 и 12	1 и 13
<b>R</b>	0,75	0,63	0,58	0,38	0,25	0,25	0,25	0,25	0,36	0	0,75	0

Long's coefficient of community from the Boreal and Tethyan basins in Late Olenekian time.

Note: see Table 4.

Table 6.

	13	12	11	10	9	8	7	6	5	4	3	2	1	
<b>1</b>		0	29	20	40	40	40	0	67	0	0	0	0	<b>13</b>
<b>2</b>	66		0	31	25	25	25	25	33	57	40	66	75	<b>12</b>
<b>3</b>	60	50		27	60	60	40	40	25	0	0	0	0	<b>11</b>
<b>4</b>	57	80	44		46	46	46	31	36	17	13	18	31	<b>10</b>
<b>5</b>	33	50	25	40		75	75	50	33	0	0	0	25	<b>9</b>
<b>6</b>	25	33	20	29	33		50	75	67	29	20	33	25	<b>8</b>
<b>7</b>	25	0	0	0	33	25								

Matrix of likelihood of Late Olenekian taxa of Conodontophoridae of species rank from 13 localities of northeastern Asia. Note: see Table 4.

Table 7.

Genera	Species	Localities (regions)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
<i>Budurovignathus</i>	<i>hungaricus</i>	0	0	0	0	0	0	0	0	0	1	1	0	0
	<i>longobardicus</i>	0	0	0	0	0	0	0	1	0	0	0	0	0
	<i>mostleri</i>	0	0	0	0	0	0	0	0	0	0	1	0	0
	<i>mungoensis</i>	0	0	0	0	0	1	1	1	0	1	0	0	0
	<i>truempyi</i>	0	0	0	0	0	0	0	1	0	0	1	0	0
<i>Chiosella</i>	aff. <i>timorensis</i>	0	0	0	0	0	0	0	0	0	1	0	0	
	<i>timorensis</i>	0	0	0	0	1	0	0	0	1	0	0	0	
<i>Gladigondolella</i>	<i>malayensis</i>	0	0	0	0	0	0	0	0	0	1	0	0	
	<i>tethydis</i>	0	0	0	0	0	0	0	1	0	1	0	0	
<i>Mosherella</i>	<i>newpassensis</i>	0	0	0	0	0	0	1	0	0	0	1	0	
<i>Neogondolella</i>	aff. <i>constricta</i>	1	0	0	0	0	0	0	0	0	0	0	0	
	aff. <i>longa</i>	0	0	0	1	0	0	0	0	0	0	0	0	
	aff. <i>mombergensis</i>	1	0	0	0	0	0	0	0	0	1	0	0	
	<i>auriformis</i>	0	0	0	0	0	0	0	0	0	0	1	0	
	<i>balkanica</i>	0	0	1	1	0	0	0	0	0	0	0	0	
	" <i>navicula</i> "	0	0	0	0	0	1	0	0	0	0	0	1	
	<i>bakalovi</i>	0	0	0	0	1	0	0	0	0	0	0	0	
	<i>bifurcata</i>	0	0	0	0	0	0	0	0	0	1	0	0	
	<i>bulgarica</i>	0	0	0	0	0	0	0	1	0	1	0	0	
	cf. <i>mombergensis</i>	0	1	0	0	0	0	0	0	0	0	0	0	
	<i>consticta</i>	0	1	1	0	0	1	1	1	1	0	0	0	
	<i>cornuta</i>	0	1	0	1	0	0	0	0	1	0	0	0	
	<i>haslachensis</i>	0	0	0	0	0	0	0	1	1	0	0	0	
	<i>mombergensis</i>	0	0	0	0	0	0	1	1	0	1	0	1	
	<i>pridaensis</i>	0	0	0	0	0	0	0	0	1	0	0	0	
<i>regale</i>	0	0	0	0	0	1	0	1	0	0	0	1		
<i>Neospathodus</i>	<i>germanicus</i>	0	0	0	0	0	0	0	0	0	1	0	0	
<i>Nicoraella</i>	<i>kockeli</i>	0	0	0	0	0	0	0	1	1	0	1	0	
<i>Paragondolella</i>	aff. <i>trammeri</i>	0	1	0	0	0	0	0	0	0	0	0	0	
	<i>excelsa</i>	0	0	0	0	1	1	1	1	1	1	0	0	
	<i>foliata</i>	0	0	0	0	0	0	0	0	0	1	1	0	
	<i>inclinata</i>	0	0	0	0	0	0	0	1	0	0	0	0	
	<i>polygnathiformis</i>	0	0	0	0	0	1	0	0	0	0	0	0	
8 genera	33 species	2	4	2	3	3	6	5	12	7	10	8	3	1

Species composition of Conodontophoridae from Middle Triassic deposits of northeastern Asia. Note: 1 – eastern Taimyr; 2 – island of Kotelny; 3 – Zyryanka River basin; 4 – Dzhugadzhak River basin; 5 – Koryak upland; 6 – Britain Columbia; 7 – southwestern USA; 8 – central Sikhote Alin; 9 – Far Eastern maritime; 10 – Japan; 11 – southeastern Pamir (Tajikistan); 12 – India; 13 – China; “1” – species is present, “0” – species is not found.

regions	8 и 1	8 и 2	8 и 3	8 и 4	8 и 5	8 и 6	8 и 7	8 и 9	8 и 10	8 и 11	8 и 12	8 и 13
%	16,6	33,3	16,6	25,0	25,0	50,0	42,0	58,0	83,0	66,6	25,0	8,3

Percentage proportions of species from Middle Triassic deposits of northeastern Asia.  
Note: see Table 7.

Genera	Species	Localities (regions)									
		1	2	3	4	5	6	7	8	9	10
<i>Budurovignathus</i>	<i>mungoensis</i>	0	0	0	1	0	0	0	1	0	0
<i>Epigondolella</i>	<i>abneptis</i>	0	0	1	1	1	0	1	0	0	0
	<i>nodosa</i>	0	0	0	1	1	1	0	1	1	0
	<i>primitia</i>	0	0	0	1	1	1	0	1	0	0
	<i>permica</i>	0	0	0	0	0	0	0	0	1	0
	<i>malayensis</i>	0	0	0	0	0	0	0	1	0	0
<i>Gladigondolella</i>	<i>tethydis</i>	0	0	0	1	0	0	0	1	0	0
	<i>communisti</i>	0	0	0	0	0	1	0	1	0	0
<i>Mockina</i>	<i>echinata</i>	0	0	0	0	0	1	0	0	0	0
<i>Mosherella</i>	<i>newpassensis</i>	0	0	0	0	1	0	1	0	0	0
<i>Paragondolella</i>	<i>aff. foliata</i>	0	0	0	0	0	0	0	0	1	0
	<i>aff. polygnathiformis</i>	0	0	0	1	0	0	0	0	0	0
	<i>foliata</i>	1	1	0	1	0	0	0	1	1	1
	<i>inclinata</i>	0	1	0	1	0	0	0	1	0	1
	<i>polygnathiformis</i>	0	0	1	1	1	1	1	1	1	1
	<i>tadpole</i>	0	0	1	1	0	0	0	1	1	1
<b>7 genera</b>	<b>16 species</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>10</b>	<b>5</b>	<b>5</b>	<b>3</b>	<b>10</b>	<b>6</b>	<b>4</b>

Species composition of Conodontophoridae from Carnian deposits of northeastern Asia.  
Note: 1 – island of Kotelny; 2 – Zyryanka River basin; 3 – Koryak upland; 4 – central Sikhote Alin; 5 – Far Eastern maritime; 6 – Britain Columbia; 7 – southwestern USA; 8 – Japan; 9 – southeastern Pamir (Tajikistan); 10 – China; “1” – species is present, “0” – species is not found.

regions	1 и 2	1 и 3	1 и 4	1 и 5	1 и 6	1 и 7	1 и 8	1 и 9	1 и 10
<b>R</b>	0,75	0	0,55	0	0	0	0,45	0,58	0,62

Long's coefficient of community for Boreal and Tethyan basins in Carnian Age.  
Note: see Table 9.

	10	9	8	7	6	5	4	3	2	1	
1		60	57	28	22	22	57	57	66	40	<b>10</b>
2	66		50	22	36	36	50	44	25	28	<b>9</b>
3	0	0		15	53	40	80	31	33	18	<b>8</b>
4	18	33	46		25	75	31	66	0	0	<b>7</b>
5	0	0	50	53		60	40	25	0	0	<b>6</b>

Matrix of likelihood of Carnian taxa of species-ranked conodonts from ten localities of northeastern Asia. Note: see Table 9.

Table 12.

Genera	Species	Localities (regions)									
		1	2	3	4	5	6	7	8	9	10
<i>Norigondolella</i>	" <i>navicula</i> "	1	0	1	0	1	1	0	1	0	0
	<i>steinbergensis</i>	1	0	0	1	0	1	0	0	1	1
	<i>hallstattensis</i>	0	0	0	1	0	1	0	0	0	0
<i>Epigondolella</i>	<i>abneptis</i>	0	1	1	1	0	1	1	1	1	0
	<i>primitia</i>	0	0	1	1	0	1	0	1	0	0
	<i>spatulata</i>	0	0	1	0	0	0	0	1	1	0
	<i>triangularis</i>	0	0	0	1	0	1	0	0	0	0
<i>Misilella</i>	<i>hernsteini</i>	0	0	1	1	0	0	1	1	0	0
	<i>koessenensis</i>	0	0	1	0	0	0	0	0	0	0
	<i>posthernsteini</i>	0	1	1	1	0	1	1	1	0	0
<i>Mockina</i>	aff. <i>bidentata</i>	0	0	1	0	0	0	0	0	0	0
	<i>bidentata</i>	0	1	1	1	0	1	1	1	0	0
	<i>echinata</i>	0	0	0	0	0	0	0	1	0	0
	<i>multidentata</i>	0	0	0	1	0	1	0	1	0	0
	<i>postera</i>	0	1	1	1	0	1	0	1	1	1
	<i>slovakensis</i>	0	0	1	1	0	0	0	0	0	0
<i>Parvigondolella</i>	<i>andrusovi</i>	0	1	1	1	0	0	0	0	0	0
<b>5 genera</b>	<b>17 species</b>	<b>2</b>	<b>5</b>	<b>12</b>	<b>12</b>	<b>1</b>	<b>10</b>	<b>4</b>	<b>10</b>	<b>4</b>	<b>2</b>

Species composition of Conodontophoridae from Norian and Rhaetian deposits of northeastern Asia. Note: 1 – island of Kotelny; 2 – Koryak upland; 3 – central Sikhote Alin; 4 – Far Eastern maritime; 5 – Alaska; 6 – Britain Columbia; 7 – southwestern USA; 8 – Japan; 9 – southeastern Pamir; 10 – China; "1" – species is present, "0" – species is not found.

Table 13.

regions	1 и 2	1 и 3	1 и 4	1 и 5	1 и 6	1 и 7	1 и 8	1 и 9	1 и 10
<b>R</b>	0	0,29	0,29	0,75	0,6	0	0,3	0,37	0,5

Long's coefficient of community for Boreal and Tethyan basins in Norian and Rhaetian Ages. Note: see Table 12.

Table 14.

	10	9	8	7	6	5	4	3	2	1	
1		66	16	66	33	0	28	14	28	50	<b>10</b>
2	0		42	25	42	0	37	37	44	33	<b>9</b>
3	14	59		20	70	18	63	72	53	16	<b>8</b>
4	14	59	66		42	0	50	50	66	0	<b>7</b>
5	66	0	15	0		18	81	54	53	33	<b>6</b>

Matrix of likelihood of Norian and Rhaetian taxa of species-ranked Conodontophoridae from ten localities of northeastern Asia. Note: see Table 12.



# Studies on the Triassic in Chaohu, Anhui Province, China

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**Abstract** – The Lower Triassic of Chaohu is a classic sequence in the Lower Yangtze region, South China and various studies have been done for the sequence and the chronostratigraphic boundaries. This paper presents a brief summary on the major achievements of the studies, and especially provides a list of the references dealing with the Lower Triassic and the boundaries in Chaohu.

## 1. Introduction

The proposal of the West Pingdingshan Section in Chaohu, Anhui Province in the southeastern China as a GSSP candidate for the Induan-Olenekian boundary (Tong et al., 2003, 2004a) is based upon the following merits:

**Easy accessibility:** All the Lower Triassic sections are located in the suburb of the Chaohu City within two kilometers from the downtown and five kilometers from the center of the town. It is no more than half hour to walk from a hotel at the Chaohu Cement Plant, where we used to stay when working there, to any Lower Triassic sections in the area. You can also take a taxi from the downtown to any sections there at an expense of no more than one US dollar. The Chaohu City is a medium-sized city in the Anhui Province and it has been authorized to be open to all foreigners since 1990's. It is only about 50 km from the Hefei City, the capital of the Anhui Province, and about 100 km from the Nanjing City, the capital of the Jiangsu Province, and has a railway and a freeway connection. All the sections are exposed by quarries or roads to quarries. The West Pingdingshan Section, a candidate of the GSSP, is on a roadside at the foot of Mt. Pingdingshan, so there is no apparent altitude difference from the downtown to the section.

**Unique paleogeography:** During the Early Triassic, Chaohu was in a deep part of carbonate ramp on the Lower Yangtze Block, which was situated in the low-latitude eastern Tethyan archipelago (Yin et al., 1999). The Meishan Section in Changxing, about 180 km from Chaohu by air distance and where the GSSPs of the Permian-Triassic boundary and the base of the Changhsingian Stage are located, was on the same ramp but at a relatively shallower position. So the Lower Triassic of Chaohu contains more fossils and is better for stratigraphic study. In addition, there is a railway and a freeway to connect the Chaohu City with the Changxing County directly and the driving is about three hours.

**Exceptional stratigraphic sequence:** The specific paleogeography made for a Lower Triassic sequence composed of the frequent alternations of mudrock and limestone in Chaohu. In particular the mudrock and limestone are roughly balanceable in the strata from the Permian-Triassic boundary to the lower Olenekian, so the strata are not considerably different or condensed in thickness throughout the sequence. This provides a unique condition for various stratigraphic studies to set up a continuous se-

quence. For instance, the limestone is of great benefit to the investigation of conodonts and inorganic carbon isotopes while the argillaceous rocks usually contain relatively richer ammonoid and bivalve fossils though these fossils are as well common and probably preserved better in limestone. A well-solidified hard rock would be better sampled for the magnetostratigraphic study, so limestone is more favorable than mudrock though it might contain weak magnetic signals and a superconductor instrument is necessary. In addition, the apparent multiple lithologic cycles of mudrock and limestone are regarded as the imprint of the Milankovitch orbital periods. Several tuffaceous clay beds are meanwhile observed in the base of the Olenekian at the West Pingdingshan Section. Thus a high-resolution chronostratigraphy might be established based upon the study in Chaohu.

**Extensive researches:** Various scales of general geological survey, especially the 1:200,000 and 1:50,000 geological maps had been done early in 1980's, and many special topics dealing with the Lower Triassic of Chaohu performed in the early years. Recent years an emphasis has been laid on the Induan-Olenekian boundary strata and repeated investigations involve nearly all aspects related to the definition of the GSSP. The following paragraphs will mainly provide a summary for these studies and list the references.

**Comfortable working conditions:** The Anhui Province is located in the rapid-developing zone of eastern China with a good economic environment and living condition. However, Anhui is a province predominated by agriculture and its economic development is not so speedy as the neighboring Jiangsu and Zhejiang Provinces, thus the living and working expenses are not so high as the relatively more developed provinces in the economic zone. Chaohu is in the lower reaches of the Yangtze River with a subtropical monsoon climate. It is usually warm and humid. The temperature is occasionally over 36°C in summer and rarely below -5°C in winter, thus the field work can be well performed there all the year round. But the better time is spring, autumn and winter as it might be relatively hot and the vegetation is luxuriant during summer. Cement is one of the major economic industries in Chaohu. The quarries and the roads to quarries provide us many wonderful geological outcrops. However, the active quarrying destroys some new-exposed rare and novel geological records as well if the protection is not applied in time. Meanwhile, the cement industry results in certain envi-

ronmental pollution.

In a word, Chaohu has a good objective condition for studying the Lower Triassic and defining the GSSP of the Induan-Olenekian boundary. This paper is designed to provide a summary and a reference list of the studies on the Triassic in Chaohu.

## 2. General Geology

The following is a list of reports on the general geology (geological survey) in Chaohu:

- Xu Keqing, 1934, Report on the Geology in the Northern Chaoxian\*, Anhui Province (Scale: 1/50,000);
- Chaoxian Geological Team of Huadong Geological Bureau, 1956.1, Report on the Geological Survey of Coal Mine in Hanshan, Chaoxian and Huaining, Anhui Province (Scale: 1/100,000);
- Luo Qingkung, 1956.6, General Geology in the Northern Chaoxian, Anhui Province (Scale: 1/50,000);
- Petroleum Team of Anhui Geological Bureau, 1956.12, Report on the Regional Geological Survey in the Area between Chaohu Lake and Hanshan, Anhui Province (Scale: 1/200,000);
- Hefei City Geological Team of Anhui Geological Bureau, 1959.4, Report on the Evaluation of the Sedimentary and Metamorphosed Iron Ore in Feidong and Chaoxian, Anhui Province (Scale: 1/10,000, 1/15,000);
- Hefei City Geological Team of Anhui Geological Bureau, 1959.4, Report on the Evaluation of the Fenghuangshan Iron Ore in Chaoxian, Anhui Province (Scale: 1/10,000);
- Team No. 324 of Anhui Geological Bureau, 1961.7, A Brief Report on the Geological Survey in Mt. Yangshan, Chaoxian, Anhui Province (Scale: 1/10,000).

During 1975-1978 a systematical geological survey of Scale 1/200,000 was performed by the Anhui Geological Surveying Team. A few years late (1980.7-1983.9) the geological survey of Scale 1/50,000 took place in Chaohu. At the same time (1980.10-1982.9) an experimental lithostratigraphic "Formation Map of Scale 1:50,000" was carried out there.

- Anhui Geological Surveying Team, 1978 (1981), Report on the 1:200,000 Regional Geological Survey of Map Hefei and Map Dingyuan (Scale: 1/200,000);
- Zhang Suoxin, 1983, A Summary on the Geology of Map Chaohu City (Scale: 1/50,000, Formation Map);
- Anhui Geological Surveying Team, 1984 (1989), Report on the 1:50,000 Regional Geological Survey of Map Chaoxian (scale: 1/50,000).

In the stratigraphical provincialism Chaohu belongs to the Lower Yangtze Stratigraphical Province. The

stratigraphical sequence is preserved from the Upper Sinian (Ediacaran) to Middle Triassic except for the Lower and Middle Devonian though evident parallel unconformities exist between the Silurian and Devonian and between Lower and Upper Carboniferous. Since the area was on a stable platform (Lower Yangtze Block), the total sequence is not very thick, less than 3,000 meters. In lithology the strata from the Upper Sinian to Middle Ordovician and from Carboniferous to Middle Triassic are mainly composed of carbonate rocks while the Silurian and Upper Devonian are predominated by clastic rocks. All the strata were folded synchronously during the Indosinian Movement (Middle and Late Triassic). Since the Middle Triassic the marine sedimentation had been ended and the area received terrestrial sediments or eroded.

The Lower Triassic in Chaohu is exposed mainly in Mt. Majiashan and Mt. Pingdingshan north to the Chaohu Lake and the Yingping-Qingshuitang area south to the Chaohu Lake and it usually forms the cores of synclines. The best-studied Lower Triassic sections are in the north of the Chaohu Lake. The Majiashan-Pingdingshan Syncline is a synclinorium with an axis in NE 30°. The syncline becomes broader southwards from Mt. Pingdingshan to Mt. Majiashan. The youngest rock in the core is the Middle Triassic, which exists only in the southern part of the syncline. The limbs are composed of the strata from the Lower Triassic to Lower Silurian with different modes of occurrence. The strata in both limbs incline westward in the southern part of the syncline and the dip angle of the west limb is over 68° while the angle of the east limb is 50-60°. The limbs are of a normal occurrence in the northern part of the syncline. Thus in the studied Lower Triassic sections the complete sequence from the Upper Permian to Middle Triassic occurs only in Mt. Majiashan, the southern part of the syncline but the Upper Permian - Lower Olenekian sequence also exists in Mt. Pingdingshan.

Due to the well-developed stratigraphic sequences and good regional geological records, Chaohu is selected by some universities and colleges as a field-education base for geological students.

## 3. Lower Triassic Sections

The most famous and well-studied Lower Triassic sequence in the area is the (South) Majiashan Section at the south of Mt. Majiashan. It has been intensively studied since the Regional Geological Survey of Scale 1:200,000 in the late 1970's. The lower part from the Upper Permian to Lower Olenekian was exposed by a big man-made trough because it is composed mostly of mudrocks of poor outcrop, while the upper part is exposed on a series of quarries. This section is the type section of the Chaohuan Stage, a Chinese Lower Triassic stage (Tong et al., 2001a; China National Stratigraphical Commission, 2002; Yin and Tong, 2002). There have been a lot of researches done in the section (Guo and Xu, 1980; Wang, 1984; Xu, 1987; Yang et al., 1987; Tong et al., 2001b). Since the trough was completely filled up and the vegetation heavily covers the lower part of the section, no more work can be done there currently. In the meantime, some newly built

road uncovered new sections in the area. A section at the north of Mt. Majiashan was exposed by the highway from Hefei to Chaohu and the section covers the strata from the Upper Induan to the Lower Anisian but the lower part of the Lower Triassic and the Upper Permian are not well exposed there. This section is no difference from the upper part of the (South) Majiashan Section exposed in the quarries and so not many works have been done at it.

Some sections of the lower part of the Lower Triassic were exposed last decade in Mt. Pingdingshan by the roads to quarries, among which two have been actively studied in recent years (Tong et al., 2002a, 2003). One is at the north of Mt. Pingdingshan, namely North Pingdingshan Section, while the other one at the west of Mt. Pingdingshan, West Pingdingshan Section. These sections cover the strata from the Upper Permian to Lower Olenekian. The West Pingdingshan Section has been proposed as a candidate stratotype of the global Induan-Olenekian boundary (Tong et al., 2003, 2004a, 2005c). The upper Permian and lower Triassic sequence is also well exposed at the south of Mt. Pingdingshan. But the rock in the core of Mt. Pingdingshan is the lower Olenekian and the upper part has been eroded.

#### 4. Fossils

Fossils are very rich in the Lower Triassic of Chaohu. Bivalves, ammonoids, conodonts are very common throughout the Lower Triassic while fish fossils are generally rich in some beds of the upper part. Various fossils are studied in early years, e.g. ammonoids (Guo and Xu, 1980; Guo, 1982a, 1982b; Wang, 1984), bivalves (Li, 1979; Li and Ding, 1981; Wang, 1984), conodonts (Ding, 1983; Wang, 1984), ichthyosaurs (Young and Dong, 1972; Chen, 1978; Motani et al., 1996; Motani and You, 1998a, 1998b) and ichnofossils (Liu and Wang, 1990; Bi et al., 1996). Recent years when the GSSP of the Induan-Olenekian boundary is explored and the stratotype of the Chinese Chaohuan Stage studied, some more collections have been done from the Lower Triassic in Chaohu with the emphasis on the lower part of the Lower Triassic because most of the early reported fossils were from the upper part. About two thousand bivalve and ammonoid specimens are collected though most of them are mould fossils and more or less hard to be precisely identified at a specific level. Around three thousand conodont specimens have been retrieved by the repeated analyses of samples. Meanwhile, decades of bony fish fossils, including some coelacanth specimens, and a few ichthyosaur specimens were collected. Most of these specimens have been studied though only few results have been published (e.g. Zhao et al., 2003a, 2003b, 2004 for conodonts; Tong et al., 2004b for ammonoids) or in preparation of publication (for conodonts, fish and ichthyosaur fossils and bivalves).

#### 5. Stratigraphy

**Lithostratigraphy:** The Lower Triassic lithostratigraphical sequence of Chaohu was first systematically studied during the geological survey of Scale 1/

200,000 and it was divided into three formations in ascending order: Yinkeng Formation, Helongshan Formation and Biandanshan Formation, among which the latter was later renamed Nanlinghu Formation. The underlying Upper Permian is the Dalong Formation composed of cherty beds and cherty mudrocks while the overlying Middle Triassic is named the Dongma'anshan Formation of carbonate and evaporate rocks. The Yinkeng and Helongshan Formations are mostly composed of close-spaced alternations of thin-bedded limestone and mudrock with a domination of argillaceous component, while the Nanlinghu Formation is predominated by limestone of various bedding thicknesses alternated by shale (Guo and Xu, 1980; Wang, 1984; Xu, 1987; Yang et al., 1987; Tong et al., 2001a).

**Biostratigraphy:** Based on the rich collections at the South Majiashan Section, Gu and Xu (1980) first proposed the Lower Triassic **ammonoid** zonation of the area in ascending order: *Lytophicerias-Ophicerias* Zone, *Prionolobus* Zone, *Flemingites* Zone, *Anasibirites* Zone, *Tirolites-Columbites* Zone and *Subcolumbites* Zone. Late studies in the adjacent areas had basically confirmed this zonation except for only few revisions, e.g. the *Prionolobus* Zone was expanded as *Gyronites-Prionolobus* Zone (Gu, 1982b; Xu, 1987; Tong et al., 2003) and the *Flemingites* Zone as *Flemingites-Euflemingites* Zone (Tong et al., 2003). Tong and Zakharov (2004b) provided a summary for the ammonoid sequence in the area. Having studied the conodonts collected from the South Majiashan Section, Ding (1983) established the Lower Triassic **conodont** zonation of the area in ascending order: *Neogondolella carinata* Assemblage, *Neospathodus dieneri* Assemblage, *Neospathodus cristagalli* Assemblage, *Neospathodus waageni* Assemblage, *Neospathodus collinsoni* Assemblage and *Neospathodus anhuiensis-Neospathodus homeri* Assemblage. These assemblages were later referred to as corresponding zones (Yang et al., 1987; Cao and Wang, 1993). This zonal scheme was clearly defined by following the "Standard Triassic Conodont Zonation" proposed by Sweet et al. (1971). Recent study based upon many more collections from the Lower Triassic of Chaohu indicates that the zonal scheme might be necessarily revised. Tong et al. (2003) and Zhao et al. (2003b) listed a new zonation in ascending order: *Hindeodus typicalis-Neogondolella planata* Zone, *Neogondolella krystyni* Zone, *Neospathodus kummeli* Zone, *Neospathodus dieneri* Zone, *Neospathodus* n. sp. C-N. n. sp. D Zone, *Neospathodus waageni* Zone, *Neospathodus* n. sp. M Zone, *Neospathodus eotriangularis* Zone, *Neospathodus homeri-N. abruptus* Zone and *Neospathodus anhuiensis* Zone. This zonation includes some unnamed new species as the zonal fossils and its availability for a biostratigraphic correlation desiderates proof. Considering the correlation of the index fossils, Tong et al. (2005a, 2005b) further revised the conodont zonation as follows: *Hindeodus typicalis* Zone, *Neogondolella krystyni-N. planate* Zone, *Neospathodus kummeli* Zone, *Neospathodus dieneri* Zone, *Neospathodus waageni* Zone, *Neospathodus* n. sp. M Zone, *Neospathodus homeri* Zone, and *Neospathodus*



*anhuinensis* Zone. The **bivalves** are one of the common fossil groups throughout the Lower Triassic of Chaohu but the biostratigraphic importance is not so notable as the conodont and ammonoid that few studies dealt with the bivalve zonation in the area. However, a four-zone bivalve sequence is evident in the Lower Triassic of Chaohu (Tong et al., 2003, 2005b): *Claraia griesbachi*-*C. concentrica* Zone, *Eumorphotis inaequicostata*-*E. huancangensis* Zone, *Guichiella angulata* Zone and *Periclaraiia circularis* Zone, which are of more or less stratigraphic importance.

**Ecostratigraphy:** Ding and Wei (1991) and Wei and Ding (in Yin et al., 1995) established a Lower Triassic ecostratigraphic scheme of Chaohu, including five community sequences (CS) (*Claraia* CS, *Neospathodus dieneri* CS, *Flemingites* CS, *Neospathodus triangularis* CS and *Periclaraiia* CS) and 12 community zones (CZ) (*Claraia* cf. *stachei* CZ, *Claraia griesbachi* CZ, *Claraia aurita* CZ, *Prionolobus* CZ, *Neospathodus dieneri* CZ, *Xenodiscoids* CZ, *Anasibirites kingianus* CZ, *Flemingites* cf. *ellipticus* CZ, *Neospathodus waageni* CZ, *Neospathodus triangularis* CZ, *Posidonia* CZ and *Periclaraiia circularis* CZ).

**Sequence stratigraphy:** Tong (1997) and Tong and Yin (1998) studied the Lower Triassic sequence stratigraphy of Chaohu and divided the Lower Triassic into four third-order sequences with type II sequence boundaries (SB<sub>2</sub>), which are roughly corresponding with the four Lower Triassic substages though the sequence boundaries were proven to be clearly under the chronostratigraphic boundaries but the transgressive surfaces closed to the boundaries (Yin and Tong, 1995).

**Carbon isotope stratigraphy:** The Lower Triassic carbonate carbon isotope stratigraphy has been intensively studied in Chaohu recent years and a complete Lower Triassic carbon isotope excursion established based upon about a thousand data from three section (Tong et al., 2002b, 2003, 2005b; Zuo et al., 2003b, 2004). The data from two Pingdingshan sections have been reported in detail while the data from the South Majiashan Section is in preparation of publication. The carbon isotope curves from the three sections can be precisely correlated, which well accords with the biostratigraphic correlation (Tong et al., 2005b). The values are very negative at the Permian-Triassic boundary, which is clearly coinciding with the results from the other P-T sections over the world, and in the basal part of the Lower Triassic. The excursion gently climbs throughout the Induan and reaches around zero at the Induan-Olenekian boundary. A big negative valley occurs in the lower part of the Olenekian while the values rapidly rise to very positive in the middle part of the Olenekian (lower Spathian). Then the excursion goes downward slowly but the values are never so negative as the early time, and the next positive value occurs in the Middle Triassic.

**Magnetostratigraphy:** The Chinese Lower Triassic Working Group collaborated with Dr. Hans J. Hansen at the Copenhagen University (Denmark) to study the

magnetostratigraphy in recent years. The magnetostratigraphic sequence of the lower part covering the whole Induan and the base of the Olenekian at the Pingdingshan sections has been briefly reported in Tong et al. (2002a, 2003). The result indicates that the Induan consists of two normal polarity zones and one reversed zone and both the Permian-Triassic and Induan-Olenekian boundaries are located in the normal polarity zones. The upper part of the Lower Triassic at the Pingdingshan and Majiashan sections were sampled and measured in 2003-2004. The pattern is shown in Tong et al. (2005a, b) but the detailed results are in the preparation of publication.

**High-resolution cyclostratigraphy:** Some attempts have been done for a high-resolution cyclostratigraphy at the Chaohu sections since the Lower Triassic appears quite distinct multiple cyclicity in lithology. The rhythmic lithological cycles express very excellent parasequences in sequence stratigraphy and they are god-given good clues to retrieve the system tracts (Tong, 1997; Tong and Cui, 2002). Based upon the analysis of the high-resolution samples of magnetic susceptibility and geochemical elements, Peng et al. (1999, 2000a, b, 2001a) groped for a cyclic analysis to relate the cyclicity to the Milankovitch periods. Recent years a group has been focusing on a cyclostratigraphic study at the sections on the basis of the data of lithology, magnetic susceptibility and organic and inorganic carbon isotopes (Tong et al., 2005c).

## 6. Other Studies

Some studies on the Lower Triassic of Chaohu also dealt with other aspects such as the lithology and lithofacies (Han, 1983; Li and Wu, 1988; Guo, 1989), storm and earthquake deposits and structures (Wang, 1990; Qian and Guo, 1995; Chi et al., 1999), volcanic rocks and events (Li, 1996, 2000), etc.

## 7. Permian-Triassic Boundary

Chaohu is situated about 180 km from Meishan where the GSSP of the Permian-Triassic boundary is located and they were both on the Lower Yangtze Block, thus the Permian-Triassic boundary sequence in Chaohu has been intensively studied with the exploration of the stratotype of the Permian-Triassic boundary (Sheng et al., 1987; Yang et al., 1987, 1991). Actually the Permian-Triassic boundary sequence in Chaohu is classic due to its facies difference from that in Meishan. The lithostratigraphic unit of the uppermost Permian in Chaohu is the Dalong Formation of cherty beds and cherty mudrocks, which indicates a deeper depositional condition than the Changxing Formation of limestone in Meishan. But the Permian-Triassic boundary stratigraphic set composed of two clay beds and one limestone bed is clearly correlated (Peng and Tong, 1999; Peng et al., 2001b). The lowermost of the Triassic is the same unit, Yinkeng Formation, as in Meishan and predominated by mudrocks. No conodont *Hindeodus parvus* has been found at the Chaohu sections so far though the Permian brachiopods and ammonoids and the Triassic bivalves and ammonoids are very common around the boundary. The conodonts retrieved from



the boundary limestone are not very rich and only *Hindeodus typicalis* and some indeterminate species of the genus are identified. The boundary limestone and the calcareous rocks at the base of the Triassic yield very negative values of inorganic carbon isotopes ( $d^{13}C$ ). All rocks around the boundary including three samples from the cherty beds at the top of the Dalong Formation produce signals of a normal geomagnetic polarity (Tong et al., 2005b).

### 8. Induan-Olenekian Boundary

Recent research has paid more attention to the Induan-Olenekian boundary and major results were summarized in Tong et al. (2003, 2004a). Zhao et al. (2002) also presented a preliminary discussion on the Induan-Olenekian boundary of Chaohu. A more detailed statement is presented in Tong et al. (2005a). The conodont *Neospathodus waageni* is suggested as the index fossil to define the boundary and the ammonoids *Flemingites* and *Euflemingites* (as well as *Hedenstroemia*) are as reference markers. The West Pingdingshan Section is proposed as one of the candidate stratotype sections for the Induan-Olenekian boundary. At the West Pingdingshan Section the FAD of *Neospathodus waageni* is in Subbed 24-16 while the base of the *Flemingites-Euflemingites* Zone at the base of Subbed 24-21, which is 26 cm above the FAD of *Hindeodus waageni*. The Induan-Olenekian boundary defined by the conodont at the West Pingdingshan Section is located in the upper part of the second Triassic magnetostratigraphic polarity zone and around the first Triassic positive peak of carbon isotope excursion (Tong et al., 2003, 2004a).

Based upon the conodonts from Chaohu, Zhao et al. (2004) subdivided *Neospathodus waageni* into three subspecies, i.e. *N. waageni* n. subsp. A, *N. waageni* n. subsp. B and *N. waageni waageni*. At the West Pingdingshan Section these three subspecies have their FADs in an ascending order within a 72-cm interval. Albeit their evolutionary lineages are to be studied, *N. waageni* n. subsp. A looks more primitive. Thus *N. waageni* n. subsp. B and *N. waageni waageni* would also be good index fossils for the boundary (Tong et al., 2005a).

### 9. International Symposium on Triassic Chronostratigraphy and Biotic Recovery. May 23-25, 2005, Chaohu, Anhui, China

An international symposium titled "Triassic Chronostratigraphy and Biotic Recovery" co-sponsored by the Subcommittee on Triassic Stratigraphy, Induan-Olenekian Task Force, IGCP-467 and others has been scheduled in Chaohu on May 23-25, 2005. The symposium is designed to provide a forum to all kinds of scientists who are interested in the Triassic chronostratigraphy, esp. the Lower Triassic, and the ecosystem reconstruction and biotic recovery in the early Triassic, as well as the related biotic and environmental events following the mass extinction. It provides a unique chance to closely view and examine the Lower Triassic sequence in the area

and discuss the related issues. The first and second circulars of the symposium have been posted in Albertiana.

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**(Footnote)**

\* **Chaoxian** (meaning Chao County) is the previous name of the **Chaohu** (meaning Chao Lake) **City**.



**New Triassic Literature**

**Triassic Bibliography**

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**Hans Hagdorn, 2004. Muschelkalkmuseum  
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All Triassic workers are familiar with the term Muschelkalk. Several will know the Muschelkalkmuseum in Ingelfingen, in southern Germany where the Triassic and the Muschelkalk were defined by Friedrich von Alberti in 1834. Those who do not, better should. The name Muschelkalk refers to fossils and fossils are the life-long passion of Hans Hagdorn. Started as an amateur collector, he is now recognised as one of the world's leading specialists on Triassic crinoids and Muschelkalk stratigraphy. Over the years he gathered an impressive collection of fossils and he has published numerous papers, especially on Triassic crinoids. His efforts are not only recognised by scientists but also by the local authorities, who helped to realise a museum entirely devoted to the Muschelkalk. In this museum the visitor gets an excellent overview of Hans Hagdorn's impressive collection of Muschelkalk fossils, which is completed by fine specimens from other passionate collectors. This book is not just a museum guide. It is much more than just a guide. It is a real book, lavishly illustrated with numerous excellent colour pictures and diagrams, telling the story of the Muschelkalk. The book not only deals with fossils, but also gives information on the geology, stratigraphy, palaeogeography and even on the use of Muschelkalk limestone as street pavement and building stone. Historical aspects are included also. Fossil groups illustrated range from palynomorphs to vertebrates. It will be no surprise that ammonoids and crinoids are well represented. The text is in German, which may be a handicap for non-Germans, but the illustrations alone are a good reason for ordering this book. Once you have seen the book, a visit to Ingelfingen to see this spectacular collection will be the next logical step.

The book can be ordered via the Museum's web site: <http://www.muschelkalkmuseum.de> or directly from the publisher <http://www.edition-lattner.de>



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The name of the fossil or fossils chosen to designate a biozone should include the genus name plus the specific epithet and also the subspecies name, if there is one. Thus Exus albus Assemblage Zone is correct. After the first

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From: Salvador, A. (ed.), 1994. International Stratigraphic Guide. Second Edition. International Commission on Stratigraphic Classification of IUGS International Commission on Stratigraphy. IUGS/GSA, Boulder, Co, p. 66.



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