NATURMUSEUM SÜDTIROL
MUSEO SCIENZE NATURALI ALTO ADIGE
MUSEUM NATÖRA SÜDTIROL

AUTONOME PROVINZ BOZEN - SÜDTIROL

PROVINCIA AUTONOMA DI BOLZANO - ALTO ADIGE

PROVINZIA AUTONOMA DE BULSAN - SÜDTIROL

Amt für Geologie und Baustoffprüfung
Ufficio Geologia e Prove Materiali

planetearth® Earth Sciences for Society

The Triassic climate

Workshop on Triassic palaeoclimatology

Abstract book

Bolzano/Bozen (I), June 3-7, 2008

Workshop on Triassic palaeoclimatology

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"The climate during the Triassic? That's easy... everything was warm and dry…"
...or, at least this is what you generally find when, in textbooks, you look for a description of the Triassic climate. But it wasn't probably so. Although valuable studies on Triassic climate exist, researchers from various regions and fields of Earth Sciences worked alone or in small groups, dealing mostly with short time intervals. There is a need of a more comprehensive picture of the Triassic climate through time and space, which could only stem from the interaction of research groups that worked, so far, isolated.
The aim of this workshop is to provide a forum for researchers interested in the Triassic paleoclimate. Participants will be invited to present methodological approaches and significant case histories of paleoclimatic and paleoenvironmental reconstructions at regional and global scale. Studies involving new interdisciplinary methods are particularly welcome.

The workshop is supported by the Museum of Nature South Tyrol and the Office for Geology and Building Material Testing.

THE MUSEUM

Bozen/Bolzano city, at the western margin of the Dolomites, is the capital of the province of South Tyrol, one of the northernmost provinces of Italy.
The small airport of the city permits only flights to Munich (D) and Rome (I), better served airports, however, are located in nearby localities, to the North (Munich, Innsbruck) and South (Verona). Bolzano is easily reached by train, from all of these cities.

The workshop is held at the Museum of Nature South Tyrol, in Bozen / Bolzano, Bindergasse / Via Bottai 1.

<u>Organising and Scientific Committee</u>

Evelyn Kustatscher (Museum of Nature South Tyrol)

Piero Gianolla (University of Ferrara)

Lorenz Keim (Geological Survey of South Tyrol)

Nereo Preto (University of Padova, and IGG-CNR, Padova)

Guido Roghi (IGG-CNR, Padova)

PROGRAMM

Arrival on Tuesday, June 3, 2005

3.00 p.m.	Arrival at the Museum with registration (posters and presentations may be handed in)
4.00 p.m.	Guided visit through the Museum of Nature South Tyrol
5.00 p.m.	Icebreaker-party

Workshop, Wednesday, June 4, 2005

8.30p.m.	Registration
9.00 a.m.	Opening ceremony
	Morning session, Chairman: Guido Roghi
9.20 a.m.	**Keynote lecture**: Paul B. Wignall: MASS EXTINCTION, CLIMATE CHANGE AND VOLCANISM
10.00 a.m.	Valentin Krassilov: FLORAL CHANGE OVER THE PERMIAN – TRIASSIC TRANSITION AND PHYTOGEOGRAPHIC EVIDENCE OF TRIASSIC CLIMATES
10.20 a.m.	Sylvain Richoz, Leopold Krystyn, Aymon Baud, Rainer Brandner, Micha Horacek & Parvin Mohtat-Aghai: PERMIAN-TRIASSIC BOUNDARY INTERVAL IN MIDDLE EAST (TURKEY, IRAN AND N. OMAN): PROGRESSIVE ENVIRONMENTAL CHANGE FROM DETAILED CARBONATE CARBON ISOTOPE MARINE CURVE AND SEDIMENTARY EVOLUTION.
10.40 a.m.	Tea and Coffee break
11.00 a.m.	Micha Horacek & Leopold Krystyn: OXYGEN ISOTOPIC EVIDENCE FOR CLIMATE CHANGE ACROSS THE PERMIAN-TRIASSIC BOUNDARY – FROM COOL-HOUSE TO HOT-HOUSE
11.20 a.m.	Michal Krobicki & Jan Golonka: PERMIAN/TRIASSIC VIETNAMESE EMEISHAN VOLCANISM AND THEIR RELATION TO PALAEOGEOGRAPHY OF SE ASIA AND MASS EXTINCTION
11.40 a.m.	Elke Hermann: EARLY TRIASSIC RECORDS IN LOW PALAEOLATITUDES – EVIDENCE FOR A GLOBAL AND MAJOR CLIMATIC CHANGE AT THE SMITHIAN/SPATHIAN BOUNDARY
12.00	Sara Pruss & Aymon Baud: LOWER TRIASSIC ANOMALOUS CARBONATE FACIES AND CARBON CYCLE INSTABILITY
0.20 p.m.	Josef Paul: PALAEOCLIMATE OF THE BUNTSANDSTEIN (LOWER TRIASSIC, CENTRAL EUROPE)
0.40 p.m.	Lunch

Afternoon session, Chairman: Nereo Preto

2.00 p.m.	**Keynote lecture**: Peter Hochuli: TRIASSIC CLIMATE – INFERRED FROM PALYNOLOGY
2.40 p.m.	Marcelina Łabaj: PALEOENVIRONMENTAL RECORDS IN ANISIAN REEFS FROM UPPER SILESIA (SW POLAND)
3.00 p.m.	Evelyn Kustatscher, Johanna H.A. Van Konijnenburg-Van Cittert & Guido Roghi: MACROFLORAS AND PALYNOMORPHS AS POSSIBLY PROXIES FOR PALAEOCLIMATIC STUDIES: THE CASE STUDY OF THE FOSSILLAGERSTÄTTE KÜHWIESENKOPF
3.20 p.m.	Tea and Coffee break
3.40 p.m.	Manuel Rigo, Nereo Preto, Michael M. Joachimski: PALEOECOLOGY OF TRIASSIC CONODONTS: CONSTRAINTS FROM OXYGEN ISOTOPES OF BIOGENIC APATITE
4.00 p.m.	Franco Russo: DOES BIOCONSTRUCTOR ORGANISM EVOLUTION REFLECTS THE CLIMATIC CHANGES DURING THE TRIASSIC OF THE DOLOMITES?
4.20 p.m.	Dorit Korngreen & Chaim Benjamini: TECTONIC VS. CLIMATIC FORCING OF CYCLICITY IN THE SEDIMENTARY PATTERN OF THE TRIASSIC OF NORTHERN ISRAEL
4.40 p.m.	Tea Kolar-Jurkovšek & Bogdan Jurkovšek: NEW PALEONTOLOGICAL EVIDENCE FOR THE CARNIAN STRATA OF THE MEŽICA AREA (KARAVANKE MTS, SLOVENIA)

Workshop, Thursday, June 5, 2005

Morning session, Chairman: Lorenz Keim

8.40 a.m.	**Keynote lecture**: Kiessling: ENVIRONMENTAL CONTROLS ON EARLY MESOZOIC REEF DEVELOPMENT
9.20 a.m.	Aaron Meilijson, Dorit Korngreen & Chaim Benjamini: PALEOECOLOGICAL SIGNIFICANCE OF SUBTIDAL MICROBIALITES, UPPER LADINIAN TO LOWER CARNIAN OF ISRAEL
9.40 a.m.	Heinz W. Kozur & Gerhard H. Bachmann: THE MID-CARNIAN POLYPHASE WET CLIMATE INTERMEZZO (SCHILFSANDSTEIN, GERMANIC BASIN)
10.00 a.m.	Nereo Preto, Piero Gianolla & Guido Roghi: THE CARNIAN PLUVIAL EVENT: CAUSES AND EFFECTS
10.20 a.m.	Guido Roghi, Piero Gianolla, Nereo Preto, Luca Minarelli & Claudio Pilati: PALYNOLOGY OF THE "RAIBLER SCHICTEN" NEAR RUBLAND (AUSTRIA) AND COMPARISON WITH OTHER UPPER TRIASSIC PALYNOFLORAS
10.40 a.m.	Tea and Coffee break
11.00 a.m.	Fabrizio Berra, Flavio Jadoul, Andrea Anelli & Maria Teresa Galli: ENVIRONMENTAL CONTROL ON THE END OF THE DOLOMIA PRINCIPALE DEPOSITIONAL SYSTEM IN THE CENTRAL ALPS: EVIDENCE OF CLIMATE CHANGE
11.20 a.m.	Michael Hautmann: THE ROLE OF OCEAN ACIDIFICATION IN THE END-TRIASSIC MARINE MASS EXTINCTION EVENT
11.40 a.m.	Nina R. Bonis, Wolfram M. Kürschner & Leopold Krystyn: FLORAL AND PALAEOENVIRONMENTAL CHANGES ACROSS THE TRIASSIC AND JURASSIC BOUNDARY INTERVAL
12.00	Micha Ruhl: HIGH RESOLUTION CARBON ISOTOPE DATA OF TRIASSIC-JURASSIC KEY SECTIONS IN EUROPE
0.20 p.m.	Bas van de Schootbrugge: ACID RAIN AND THE DEMISE OF TERRESTRIAL ECOSYSTEMS AT THE TRIASSIC-JURASSIC BOUNDARY
0.40 p.m.	Lunch

Afternoon session, Chairman: Piero Gianolla

2.00 p.m.	Poster session
3.00 p.m.	Tea and Coffee break
3.20 p.m.	Round Table discussion

Poster session:

Jacopo Dal Corso, Evelyn Kustatscher, Paolo Mietto, Nereo Preto, Guido Roghi: NEW PALYNOLOGICAL DATA FROM THE ANISIAN (MIDDLE TRIASSIC) OF SOUTHERN ALPS

Chiara Guaiumi, Nereo Preto & Hildegard Westphal: WHAT WAS THE PRECURSOR OF THE TRIASSIC MICRITE?

Thomas Hornung & Rainer Brandner: THE NW TETHYAN 'CARNIAN CRISIS'

Aernout Korevaar, Cees van Oosterhout & Keith Gerdes: THE GLOBAL SIGNIFICANCE OF PERMO-TRIASSIC HYDROCARBON SYSTEMS AND THE ROLE OF PLATE RECONSTRUCTION AND PALEOCLIMATOLOGICAL MODELLING IN RESOURCE ASSESSMENT

Christoph Korte, Stephen P. Hesselbo & Heinz W. Kozur: TRIASSIC AND TRIASSIC-JURASSIC BOUNDARY CLIMATIC VARIATIONS INDICATED BY OXYGEN ISOTOPES FROM LOW-MG-CALCITE FOSSILS

Michele Mazza & Manuel Rigo: WHY GENERIC TURNOVERS IN THE CARNIAN/NORIAN CONODONTS?

Barbara Meller: FACIES DEPENDENCE OF PLANT ASSEMBLAGES FROM THE CARNIAN LUNZ FORMATION (AUSTRIA)

Christian Pott, Hans Kerp & Michael Krings: THE LATE TRIASSIC FLORA FROM LUNZ IN LOWER AUSTRA – PALEOECOLOGICAL CONSIDERATIONS

Alberto Riva, Raffaele Di Cuia & Andrea Scifoni: UPPER TRIASSIC DOLOMITIZATION CONTROLLED BY CLIMATE: PRELIMINARY RESULTS FROM MOUNT PELMO (EASTERN DOLOMITES, ITALY)

Micha Ruhl, Nina R. Bonis & Wolfram M. Kürschner: STOMATALY FREQUENCY ANALYSIS AND CARBON ISOTOPE STRATIGRAPHY FROM THE GERMAN BASIN: CHANGING CO_2 LEVELS DURING THE END-TRIASSIC

Natalia Zavialova, Nicoletta Buratti & Guido Roghi: EARLY HISTORY OF CIRCUMPOLLES GROUP

LIST OF PARTICIPANTS

Marco Avanzini
Museo Tridentino di Scienze Naturali
Via Calepina 14
38100 Trento
Italy
e-mail: Avanzini@mtsn.tn.it

Gerhard H. Bachmann
Martin-Luther-Universität Halle–Wittenberg
Institut für Geologische Wissenschaften
Von-Seckendorff-Platz 3
06099 Halle (Saale)
Germany
e.mail:gerhard.bachmann@geo.uni-halle.de

Marco Balini
Dipartimento Scienze della Terra “A. Desio”
Università degli Studi di Milano
Via Mangiagalli 34
35137 Milano
Italy
e-mail: marco.balini@unimi.it

Aymon Baud
Geological Museum
UNIL_BFSH2
Parc de la Rouvraie 28,
1018 Lausanne
Switzerland
e-mail: aymon.baud@unil.ch

Fabrizio Berra
Dipartimento Scienze della Terra “A. Desio”
Università degli Studi di Milano
Via Mangiagalli 34
20194 Milano
Italy
e-mail: fabrizio.berra@unimi.it

Nina R. Bonis
Palaeoecology, Institute of Environmental Biology
Utrecht University
Laboratory of Palaeobotany and Palynology
Budapestlaan 4
3584 CD Utrecht
The Netherlands
e-mail: n.r.bonis@bio.uu.nl

Rainer Brandner
Institute for Geology and Palaeontology
University of Innsbruck
Innrain 52f
6020 Innsbruck
Austria
e-mail: rainer.brandner@uibk.ac.at

Anna Breda
Dipartimento di Geoscienze
Università degli Studi di Padova
via Giotto 1
35137 Padova
Italy
e-mail: anna.breda@unipd.it

David Bressan
Himmelreichstraße Nr.6
39031 Bruneck
Italy
e-mail: David.Bressan@uibk.ac.at

Francesco Buia
c/o Andrea Marzoli
Dipartimento di Geoscienze
Università degli Studi di Padova
via Giotto 1
35137 Padova
Italy
e-mail: iacta@hotmail.it

Sara Callegaro
c/o Andrea Marzoli
Dipartimento di Geoscienze
Università degli Studi di Padova
via Giotto 1
35137 Padova
Italy
e-mail: saracallegaro@micso.net

Luca Giacomo Costamagna
Dipartimento di Scienze della Terra
Via Trentino 51
09127 Cagliari
Italy
e-mail: Lucakost@unica.it

Jacopo Dal Corso
Dipartimento di Geoscienze
Università degli Studi di Padova
via Giotto 1
35137 Padova
Italy
e-mail: jacopo.dalcorso@unipd.it

Marco Franceschi
Dipartimento di Geoscienze
Università degli Studi di Padova
via Giotto 1
35137 Padova
Italy
e-mail: marco.franceschi@unipd.it

Stefano Furin
Dipartimento di Scienze della Terra
Università di Ferrara
Blocco "B"
Via G. Saragat, 1
44100 Ferrara
Italy
email: stefano.furin@unife.it

Piero Gianolla
Dipartimento di Scienze della Terra
Università di Ferrara
Blocco "B"
Via G. Saragat 1
44100 Ferrara
Italy
email: glr@unife.it

Nicola Giordano
Università degli Studi di Perugina
Piazza dell'Università
06100 Perugia
e-mail: nikgiordano@hotmail.it

Chiara Guaiumi
Dipartimento di Geoscienze
Università degli Studi di Padova
via Giotto 1
35137 Padova
Italy
E-mail: chiara.guaiumi@unipd.it

Michael Hautmann
Paläontologisches Institut und Museum
Karl Schmid-Strasse 4
8006 Zürich
Switzerland
e-mail: michael.hautmann@pim.uzh.ch

Elke Hermann
Institute and Museum of Palaeontology
University of Zürich
Karl Schmid-Str. 4
8006 Zürich
Switzerland
e-mail: ehermann@pim.uzh.ch

Peter A. Hochuli
Paleontological Institute and Museum
University of Zurich
Karl Schmid-strasse 4
8006 Zürich
e-mail: peter.hochuli@erdw.ethz.ch

Micha Horacek
Institut für Petrologie
Universität Graz
Universitätsplatz 2
8010 Graz
and
Austrian Research Centers GmbH-ARC
2444 Seibersdorf
Austria
e-mail: micha.horacek@arcs.ac.at

Bogdan Jurkovšek
Geološki zavod Slovenije
Geological Survey of Slovenia
Dimičeva ulica 14
SI-1000 Ljubljana
Slovenija
e-mail: bogdan.jurkovsek@geo-zs.si

Lorenz Keim
Autonome Provinz Bozen-Südtirol
Amt für Geologie & Baustoffprüfung
Eggentalerstr. 48
39053 Kardaun /Cardano
Italy
e-mail: Lorenz.Keim@provinz.bz.it

Wolfgang Kiessling
Museum für Naturkunde
Humboldt-Universität Berlin
Invalidenstr. 43
D-10115 Berlin
Germany
e-mail: wolfgang.kiessling@museum.hu-berlin.de

Tea Kolar-Jurkovšek
Geološki zavod Slovenije
Geological Survey of Slovenia
Dimičeva ulica 14
SI-1000 Ljubljana
Slovenija
e-mail: tea.kolar@geo-zs.si

Aernout Korevaar
Shell International E&P
Kessler Park 1
2288GS Rijswijk
The Netherlands
e-mail: aernout.a.r.korevaar@shell.com

Dorit Korngreen
Geological Survey of Israel
Malkhei Israel 30
95501 Jerusalem
Israel
e-mail: doritk@gsi.gov.il

Christoph Korte
Institut für Geologische Wissenschaften
Freie Universität Berlin
Malteserstr. 74-100
12249 Berlin
Germany
e-mail: korte@zedat.fu-berlin.de

Heinz W. Kozur
Rézsü u. 83
1029 Budapest
Hungary
e-mail: kozurh@helka.iif.hu

Valentin Krassilov
Institute of Evolution
University of Haifa
Mount Carmel
Haifa 31905
Israel
and
Paleontological Institute
Profsoyusnaya 129
Moscow 177647
Russia
e-mail: vakrassilov@gmail.com

Michal Krobicki
AGH University of Science and Technology
Department of General Geology,
Environmental Protection and Geotourism
al. Mickiewicza 30
30-059 Krakow
Poland
e-mail: krobicki@geol.agh.edu.pl

Wolfram M. Kuerschner
Institute of Environmental Biology -
Palaeoecology
Laboratory of Palaeobotany and Palynology
Budapestlaan 4
3584 CD Utrecht
The Netherlands
e-mail: w.m.kuerschner@uu.nl

Evelyn Kustatscher
Naturmuseum Südtirol
Bindergasse 1
39100 Bozen/Bolzano
Italy
e-mail: Evelyn.Kustatscher@naturmuseum.it

Marcelina Łabaj
Institute of Geological Sciences Jagiellonian
University
ul. Oleandry 2a
Kraków
Poland
e-mail: marcelina.labaj@uj.edu.pl

Marco Levera
Dipartimento Scienze della Terra "A. Desio"
Università degli Studi di Milano
Via Mangiagalli, 34
20133 Milano
Italy
e-mail: marco.levera@unimi.it

Alessandro Marangon
Dipartimento di Geoscienze
Università degli Studi di Padova
via Giotto 1
35137 Padova
Italy
e-mail. alessandro.marangon@unipd.it

Michele Mazza
Dipartimento Scienze della Terra "A. Desio"
Università degli Studi di Milano
Via Mangiagalli 34
35137 Milano
Italy
e-mail: michele.mazza@unimi.it

Aaron Meilijson
Department of Geological and Environmental
Sciences
Ben-Gurion University in the Negev
P.O.B 653
Beer Sheva 84105
Israel

e-mail: meilijson@gmail.com)

Barbara Meller
Institute of Palaeontology
University of Vienna
Althanstraße 14
1090 Vienna
and
Naturkundliche Station
Austrian Academy of Sciences
Seehof 4
3293 Lunz am See
Austria.
e-mail: barbara.meller@univie.ac.at

Luca Minarelli
Dipartimento di Scienze della Terra
Università di Ferrara
Blocco "B"
Via G. Saragat, 1
44100 Ferrara
Italy
email : mnrlcu@unife.it

Alda Nicora
Dipartimento Scienze della Terra “A. Desio”
Università degli Studi di Milano
Via Mangiagalli 34
35137 Milano
Italy
e-mail: alda.nicora@unimi.it

József Pálfy
Research Group for Paleontology
Hungarian Academy of Sciences-Hungarian
Natural History Museum
POB 137
H-1431Budapest
e-mail: palfy@nhmus.hu

Josef Paul
Zentrum für Geowissenschaften der
Universität Göttingen
Goldschmidt-Str.3
37077 Göttingen
Germany
e-mail: jpaul@gwdg.de

Tadeusz Peryt
Panstwowy Instytut Geologiczny
Rakowiecka 4
00-975Warszawa
Poland
e-mail: tper@pgi.gov.pl

Christian Pott
Naturhistoriska Riksmuseet
Sektionen för Palaeobotanik
Box 50007
S-104 05 Stockholm
Sweden
e-mail: christian.pott@nrm.se

Nereo Preto
Dipartimento di Geoscienze
Università degli Studi di Padova
and
Institute of Geosciences and Georesources
via Giotto 1
35137 Padova
e-mail: nereo.preto@unipd.it

Sara Pruss
Department of Geology
Smith College
44 College Lane
Northampton
MA 01063
USA
e-mail: spruss@email.smith.edu

Sylvain Richoz
FE Paläontologie, Goethe Universität
Frankfurt/Main
Altenhöferallee 1
60438 Frankfurt am Main
E-mail: Richoz@em.uni-frankfurt.de

Manuel Rigo
Dipartimento di Geoscienze
Università degli Studi di Padova
via Giotto 1
35137 Padova
Italy
e-mail: manuel.rigo@unipd.it

Alberto Riva
Dipartimento di Scienze della Terra
Università di Ferrara
Blocco "B"
Via G. Saragat, 1
44100 Ferrara
Italy
e-mail: alberto.riva@unife.it

Guido Roghi
Institute of Geosciences and Georesources
C.N.R.
Dipartimento di Geoscienze
Università degli Studi di Padova
via Giotto 1
35137 Padova
Italy
e-mail: guido.roghi@igg.cnr.it

Micha Ruhl
Palaeoecology, Institute of Environmental Biology, Faculty of Science
Utrecht University
Laboratory of Palaeobotany and Palynology
Budapestlaan 4
3584 CD Utrecht
The Netherlands
e-mail: m.ruhl@uu.nl

Franco Russo
Dipartimento di Scienze della Terra
Università della Calabria
Ponte Bucci 15B
87036 Arcavacata di Rende (CS)
Italy
e-mail: f.russo@unical.it

Marco Stefani
Dip.to di Scienze della Terra
Università di Ferrara
"B" block, Office 317
Via G. Saragat 1
44100 Ferrara (Italy)
e-mail: stm@unife.it

Bas van de Schootbrugge
Institute of Geosciences
Goethe University Frankfurt
Altenhöferallee 1
60438 Frankfurt am Main
Germany
e-mail: van.de.Schootbrugge@em.uni-frankfurt.de

Johanna H.A. Van Konijnenburg-Van Cittert
Laboratory of Palaeobotany and Palynology
Budapestlaan 4
3584 CD Utrecht
The Netherlands.
e-mail: J.H.A.vanKonijnenburg@uu.nl

Paul B. Wignall
School of Earth and Environment
University of Leeds
Leeds LS2 9JT
UK
e-mail: p.wignall@see.leeds.ac.uk

Natalia Zavialova
Paleontological Institute of RAS
Profsoyuznaya ul., 123
117647 Moscow
Russia
e-mail: zavial@paleo.ru

ENVIRONMENTAL CONTROL ON THE END OF THE DOLOMIA PRINCIPALE DEPOSITIONAL SYSTEM IN THE CENTRAL ALPS: EVIDENCE OF CLIMATE CHANGE

Fabrizio Berra, Flavio Jadoul, Andrea Anelli & Maria Teresa Galli

Dipartimento di Scienze della Terra "A. Desio", Università degli Studi di Milano, Italy
e-mail: fabrizio.berra@unimi.it

The Norian in the Western Tethys is characterized by a prevailing early-dolomitized carbonate platform (Dolomia Principale-Hauptdolomit) bordered on one inner side by evaporitic deposits (i.e. Burano Anidrite) and on the other side by open sea sediments. The huge, dolomitic carbonate platform is locally (Lombardy Basin, Carnic Alps, Central Austroalpine) dissected by normal faults with the development of rapidly subsiding, steeply-sided intraplatform troughs. An abrupt environmental change recorded by the sediments which were deposited at the top of the Dolomia Principale system both on the platform top and in the basins.

The top of the Dolomia Principale highs locally emerged (i.e. at the border of the Lombardy Basin; Malga Flavona Mb.) reflecting an important sea-level fall. Emersion is recorded by polycyclic paleosols about 20-30 m thick in the Brenta Massif. Analyses of these paleosoils indicate the presence of a TOT structure of the shale, which is indicative of soil developed in humid climate characterized by alternating humid and arid seasons. After emersion, on the platform top a return to a different carbonate sedimentation is recorded. The upper part of the thick dark fine-grained calciturbidites, debris flow, and talus breccias which were deposited in the basin is characterized by 5 to 10 meters of marly limestones with a high concentration of vertebrates (mainly fishes but also reptiles). This is indicative of reduced sedimentation rates which likely reflect the decreased carbonate production, due to the emersion, of the platform top. These condensed facies are followed by deposition of mixed siliciclastic-carbonate units (i.e. Argillite di Riva di Solto, Koessen beds, *Rhaetavicula contorta* beds).

The observed facies changes are the different effects of an important event that changed the sedimentation style at the top of the Dolomia Principale system. During the deposition of the Dolomia Principale a general arid climate is recorded in all the Western Tethys by the presence of sabkha facies and evaporites toward the emerged lands (Burano, Apennine and Keuper, Germany). Also early diagenetic dolomitization that is peculiar of the Dolomia Principale was likely favoured by arid conditions. On the contrary, the basal layers of the basinal shales are characterised by the presence of palinofacies containing fresh-water forms (Central Austroalpine) as well as insects (dragonflies, Lombardy Basin), that require fresh water during the larval stage.

The end of the long-lasting Norian depositional system is thus related to a sea-level fall which was responsible for the emersion of the platform top and deposition of a condensed horizon in the basins. Facies analyses on the highs and in the basins indicate that it is associated to a transition from arid to humid climate. The observed evolution suggests that a global climate change caused at first the rapid sea-level fall (increased storage of fresh water in continental areas?) and a change in the distribution and entity of rain fall, responsible for the input of shales in the Western Tethys and the abrupt end of the Dolomia Principale depositional system.

FLORAL AND PALAEOENVIRONMENTAL CHANGES ACROSS THE TRIASSIC-JURASSIC BOUNDARY INTERVAL

Nina R. Bonis[1], Wolfram M. Kürschner[1] & Leopold Krystyn[2]

[1]Palaeoecology, Institute of Environmental Biology, Faculty of Science, Utrecht University, Laboratory of Palaeobotany and Palynology, Utrecht, The Netherlands
[2]Department of Paleontology, University of Vienna, Geozentrum, Vienna, Austria
e-mail: n.r.bonis@bio.uu.nl

During the end-Triassic biotic crisis there were major changes in the terrestrial and marine realm but the exact cause, timing and pattern of the extinction is still not clear. We present the results of a high resolution palynological study from two European Triassic-Jurassic boundary key sections: Hochalplgraben (Austria), and St. Audrie's Bay (UK). Both sections show distinct negative shifts (up to 5‰) in the carbon isotope record. Main objective is to document floral changes and infer palaeoenvironmental changes. In both sections palynomorph assemblages below the initial negative carbon excursion show vegetation dominated by conifers (e.g. *Cheirolepidiaceae*) and seed ferns. Just after the initial shift both sections show a distinct increase in fern spores and a decrease in the amount of pollen from *Cheirolepidiaceae*. However, in Austria the dominance of spores persists throughout the section while in St. Audrie's Bay the increase in spores is short-lived and followed by a monotonous assemblage of *Cheirolepidiaceae*. A principal components analysis (PCA) is used to extract climate changes from the palynological records. Results show distinct changes in humidity and temperature at the transition from the Triassic to the Jurassic.

PALEOCLIMATIC RECONSTRUCTION OF THE UPPER ANISIAN (MIDDLE TRIASSIC) OF SOUTHERN ALPS THROUGH QUANTITATIVE PALYNOLOGICAL ANALYSES

Jacopo Dal Corso[1], Evelyn Kustatscher[2], Paolo Mietto[1], Nereo Preto[1], Guido Roghi[3]

[1]Dipartimento di Geoscienze, Università degli Studi di Padova, Padova, Italy
[2]Naturmuseum Südtirol, Bozen/Bolzano, Italy
[3]Istituto di Geoscienze e Georisorse-CNR-Sezione di Padova, c/o Dipartimento di Geoscienze, Università degli Studi di Padova, Padova, Italy
e-mail: jacopo.dalcorso@unipd.it

Quantitative and qualitative palynological analyses are an important tool to understand past floral changes and climatic variations. Middle Triassic palynomorph assemblages from ammonoid-rich marine sections of the Tethys are known from the Southern Alps and are well calibrated with detailed biochronostratigraphic scales.

Palynological quantitative analyses have been carried out on three Upper Anisian sections of the Dolomites and Adige Valley (Southern Alps). The Late Anisian (Pelsonian and Illyrian) is traditionally considered an arid period.

The Monte Prà della Vacca - Kühwiesenkopf section encompasses the Dont Fm. and was dated to the middle Pelsonian – lower Illyrian by palynological assemblages calibrated with ammonoids at the coeval Dont section. The Palus – San Marco section comprises the middle – upper Illyrian basinal succession of the Dolomites (Mt. Bivera Fm., Ambata Fm. and the Knollenkalke Mb. of the Livinallongo Fm.) and has been correlated to the Marne della Val di Centa Fm., sampled at the Val di Centa section (Adige Valley), by palynomorphs and ammonoids.

At least 200 palynomorphs have been counted in each sample. Sporomorphs have been subdivided into xerophytic and hygrophytic groups based on their botanical affinity and the relative percentage of each group has been calculated.

Pelsonian – lower Illyrian assemblages are strongly dominated by hygrophytic elements (mostly trilete acavate spores), whereas those of the middle and upper Illyrian are characterized by a pronounced increase of xerophytic groups (bisaccate pollen grains) and low percentage of hygrophytic groups. Therefore, an early and/or middle Illyrian shift from humid to arid environmental conditions can be inferred.

WHAT WAS THE PRECURSOR OF THE TRIASSIC MICRITE?

Chiara Guaiumi[1] , Nereo Preto[1,2] & Hildegard Westphal[3]

[1]Dipartimento di Geoscienze, Università degli Studi di Padova, Padova, Italy
[2]Istituto di Geoscienze e Georisorse, CNR, Padova, Italy
[3]Department of Geosciences, Bremen University, Bremen, Germany
E-mail: chiara.guaiumi@unipd.it

New petrological data on mineralogy of precursors of the Middle-Upper Triassic micrites from Tethys Ocean are presented. Hemipelagic limestone-marl alternations of the Middle Triassic of the Dolomites (northern Italy) and of the Upper Triassic of the Sicani Basin (Sicily), and carbonate-clastic ramp deposits of the Upper Triassic of the western Julian Alps (northern Italy) were analysed with Optical and Scanning Electron Microscopy. In order to discriminate micrites with aragonite-dominated and calcite-dominated precursor, morphological parameters (average crystal dimension and presence/absence of elongated pits) were considered.

The origin of Triassic carbonate mud is still unclear. Calcareous nannoplankton originated during the Late Triassic, but its low abundance cannot supply sufficient carbonate to build up hundred-meters-thick successions as those of the Triassic. Micrite was thus mostly derived from carbonate shelves. The Triassic period is considered a time of "Aragonite Sea", but the mineralogy precursor of Triassic micrite is still unknown.

The fine carbonate fraction from Sicani Basin (Calcari con Selce Fm.) shows lack of aragonite needles or pits and small micrite crystals (2-5 µm). Abundant calcispheres (20-30 µm) are present. Middle Triassic hemipelagites (preserved as limestones) of the Dolomites also exhibit small calcite crystals (<= 5 µm) in the nodular facies but pitted large (10 µm) microspar crystals in the plane-bedded facies. Rare calcispheres are also present. The lower Carnian of the Julian Alps (Rio del Lago Fm.) shows large (10 µm) pitted microspar crystals. Thus the precursor sediment of upper Carnian to Norian Calcari con Selce Fm. was composed mainly by calcite, and calcareous nannoplankton provided a significant contribution to carbonate sedimentation. To the contrary, the lower Carnian fine carbonates of Julian Alps clearly had an aragonite-dominated precursor. The Middle Triassic of the Dolomites shows rapid oscillations between calcite-dominated and aragonite-dominated precursors. Our data imply that the relative portions of aragonite and calcite were variable for the Tethyan Middle-Upper Triassic micrites. These changes in mineralogy of marine Triassic carbonates are poorly studied, but likely linked up to seawater chemical variations (Mg/Ca ratio, pCO_2, temperature and salinity).

THE ROLE OF OCEAN ACIDIFICATION IN THE END-TRIASSIC MARINE MASS EXTINCTION EVENT

Michael Hautmann

Paläontologisches Institut und Museum, Zürich, Switzerland
e-mail: michael.hautmann@pim.uzh.ch

Palaeobotanical and geochemical evidence indicate a sudden rise in atmospheric CO_2 across the Triassic-Jurassic (T-J) boundary, probably reflecting the combined effect of extensive volcanic degassing and thermal dissociation of marine gas hydrates. It has been proposed that hydrolysis of the emitted CO_2 (plus volcanogenic SO_2) had led to acidification of seawater and a corresponding decrease of the $CaCO_3$ saturation state of seawater, which particularly harmed organisms with hypercalcified and/or aragonitic and high-Mg calcitic skeletons (Hautmann, 2004). A new analysis of the extinction pattern across the T-J boundary confirms selectivity against such taxa (Hautmann et al., in press). Aragonitic scleractinian corals and aragonitic/high-Mg calcitic hypercalcified sponges were among the most adversely affected groups during the end-Triassic mass extinction event. By contrast, groups with non-calcareous skeletons such as radiolarians and scolecodonts were only little affected. The predicted pattern of selectivity also holds within clades that use variable materials for skeletal biomineralization. Aragonitic bivalves were significantly more extinction-prone than bivalves with partly or completely calcitic shells, and foraminifers with calcareous tests suffered higher extinction rates than those with agglutinated tests. Within calcareous foraminifers, the extinction risk increased according to the mineralogy of the test from low-Mg calcitic via high-Mg calcitic to aragonitic taxa. These patterns of selectivity suggest that ocean acidification was an important killing mechanism during the end-Triassic marine mass extinction, which might act as a test-case for predicting future effects of anthropogenic ocean acidification on life in the sea.

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EARLY TRIASSIC RECORDS IN LOW PALAEOLATITUDES – EVIDENCE FOR A GLOBAL AND MAJOR CLIMATIC CHANGE AT THE SMITHIAN/SPATHIAN BOUNDARY

Elke Hermann[1], Peter A. Hochuli[1], Hugo Bucher[1], Ghazala Roohi[2]

[1]Institute and Museum of Palaeontology, University of Zürich, Zürich, Switzerland
[2]Pakistan Museum of Natural History, Garden Avenue, Islamabad 44000, Pakistan
e-mail: ehermann@pim.uzh.ch

The Early Triassic is characterized by a delayed recovery of terrestrial and marine ecosystems. Especially the Smithian/Spathian boundary is marked by a significant global ammonoid and conodont turnover as well as a change in the palynological associations of the Boreal realm. There, the Smithian/Spathian transition is marked by a conspicuous change from a hygrophyte dominated assemblage in the Smithian to a xerophyte dominated Spathian spore/pollen association. (Galfetti et al., 2007 Geology).

In order to test the global significance of this signal, it is necessary to gain a better knowledge of palynological records from the low palaeolatitudes. Here, we present the composition of the Early Triassic microfloras of Nammal Nala, Salt Range, Pakistan. Ammonoids and conodonts provide the high resolution age control at Nammal Nala.

The Smithian palynological assemblage is characterized by a general dominance of hygrophytic elements. The proportion ranges between 80% in the lower Smithian, 60 % in the middle Smithian and 95% in the upper Smithian. Slightly below the Smithian/Spathian boundary, between the *Anasibirites/Wasatchites* horizon and the *Glyptophiceras* horizon, the composition changes dramatically. The assemblages show an increased proportion of xerophytic elements, which varies between 40 % and around 95% within the Spathian. This event coincides with the onset of a positive shift in the $\delta^{13}C$ record which marks the Smithian/Spathian boundary (Galfetti et al., 2007 EPSL). The Smithian/Spathian boundary climatic event can thus be traced from high to low latitudes, thus demonstrating its global significance.

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CLIMATE VARIATIONS IN THE TRIASSIC – INFERRED FROM PALYNOLOGY

Peter A. Hochuli

Palaeontological Institute and Museum, University Zürich, Zürich, Switzerland
e-mail: peter.hochuli@erdw.ethz.ch

The Triassic climate is generally known to be hot and arid. The lack of continuous fossil plant records and the widespread occurrence of red beds lead to the general belief that during the Triassic continents represented extremely hostile environments. Little is known about climatic variations in space and time during this period. However, changes in the distribution of sediments (e.g. coal, evaporites) and changes in the palaeontological record prove the existence of long and shorter term variations. Palynological data are considered good proxies for climatic changes, although used so far for Triassic assemblages essentially to trace relative humidity.

Coined by the marine record around the Permian Triassic boundary (PTB) where 90% of marine animal species disappeared similar effects have been inferred for land plants. This led to speculations that the entire record of Early Triassic land plants was reworked (Utting et al. 2004). Here, we present palynological evidence covering almost the entire Triassic, with the main focus on the Boreal realm where marine sediments represent the best possible archives allowing for direct correlations with the marine realm and corresponding time calibration. Palynological records from the Barents Sea area document several climatic shifts. The global significance of some of those can be proven by a multiproxy approach (Galfetti et al. 2007); others are more disputed. The significance of most of the observed changes remains to be assessed.

The best calibrated records come from shallow cores drilled in the context of stratigraphic research in the Barents Sea and in the Norwegian Sea (Vigran et al., 1998 and unpublished results). These sediments are fully marine and well dated; however, they cover selected stratigraphic intervals only. A continuous record comes from an exploration well in the Barents Sea representing 1300m of marginal marine sediments of Middle and Late Triassic age. Here, the drawback is a lack of independent age control and the use of cutting samples.

The records from northern Norway show significant shifts in the composition of floral elements. Interpretations are based on grouping of individual taxa into climatically relevant groups (hygrophytes versus xerophytes). Comparison of these records with data from the Alpine and the Germanic realm show significant differences, documenting variations in latitudinal distribution of plant assemblages and also opening new perspectives for future climatic interpretations of Triassic palynomorph assemblages.

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OXYGEN ISOTOPIC EVIDENCE FOR CLIMATE CHANGE ACROSS THE PERMIAN-TRIASSIC BOUNDARY – FROM COOL-HOUSE TO HOT-HOUSE

Micha Horacek[1] & Leopold Krystyn[2]

[1]Institut für Petrologie, Universität Graz, Graz, Austria and Austrian Research Centers GmbH-ARC, Seibersdorf, Austria
[2]Institut für Paläontologie, Universität Wien, Vienna, Austria
e-mail: micha.horacek@arcs.ac.at

The Permian-Triassic Boundary (PTB) is the most severe mass extinction event in Earth history. More than 90% of all skelleton producing species got extinct. To explain this event, many different extinction mechanisms have been proposed, including bolide impact, global anoxia, sudden climate change and ocean poisoning. However, rigorous testing of these hypotheses is hampered by the lack of reliable proxy paleoenvironmental data. Thus, the processes that led to the catastrophy have still not been completely unraveled. Previous studies of oxygen isotopic variation across the PTB have relied on isotopic analyses of whole-rock samples because of the absence of suitable calcareous fossils spanning the interval. Unfortunately, the oxygen isotopic compositions of carbonate sediments are easily modified by post-depositional alteration (diagenesis). An attempt to produce from brachiopods a reliable oxygen isotopic record of the events leading up to the end-Permian extinction (Gruszczinsky et al., 1989) was not successful, as their Western Spitsbergen sections have not been demonstrated to be latest Permian, and the isotopic results have been shown to mirror mainly diagenetic signals (Mii et al., 1997). Using measurements of conodont phosphate, we present δ^{18}O records from four different localities giving evidence of a significant change in oxygen isotope composition across the boundary. We interpret the data as a climate change towards warmer temperatures at the PTB.

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THE NW TETHYAN 'CARNIAN CRISIS'

Thomas Hornung[1] & Rainer Brandner[2]

[1] GWU Geologie-Wasser-Umwelt GmbH, Salzburg, Austria
[2] Institute for Geology and Palaeontology, University of Innsbruck, Innsbruck, Austria
e-mail: thomas.hornung@gwu.at

The 'Carnian Crisis' is characterized by one of the most severe ecological crisis of the Triassic well recognized in many basinal, shallow-marine and epicontinental NW Tethyan facies areas by, successively, 1) a demise of carbonate platforms and reefs in Julian 1/IIc, 2) a major faunal and floral turnover in Late Julian and 3) a significant extinction event affecting conodonts and ammonoids at the Julian/Tuvalian boundary (e.g., Hornung, 2007; and references therein). Recently, Carnian sediments have been studied intensively in the Northern Calcareous and the Southern Alps (Hornung, 2008), where large carbonate platforms flourished at the beginning of the stage. Based on a comprehensive and multistratigraphic study of 19 successions from the NW Tethys, the presence of short-lived ammonoid and conodont taxa and the sudden absence of reef-derived debris in basinal and shallow-marine successions document a strict synchroneity in latest Julian 1 of a carbonate productivity crisis. The demise of these carbonate platforms marked a severe cut in Triassic reef development (Flügel, 2002) and has been well-dated by short-lived conodont and ammonoid taxa (*Metapolygnathus carnicus*; *Trachyceras* n. sp. 1) into the uppermost *aonoides* Zone representing the Julian 1/IIc (Fig. 1, Tab. 1; see also Hornung and Brandner, 2005; Hornung et al., 2007a, b). The platform demise was followed by a turnover of faunal and floral assemblages in marine and epicontinental environments (reef builders, bivalves, crinoids, bryozoans: Simms and Ruffell, 1989, 1990; Hallam, 1996; flora: Pott et al., 2007; tetrapoda: Benton, 1991). Subsequently, a major extinction event affected many ammonoid and conodont taxa at the Julian-Tuvalian boundary (Krystyn, 1983, 1991; Rigo et al., 2006).

The ultimate causes for the biotic crisis are still a matter of discussion, but have been often related to a drastic change to more humid climatic conditions. The onset of intensified siliciclastic input to wide parts of the epicontinental basins and marginal Tethyan environments (e.g., Enos et al., 1998; Geyer, 2002; Lehrmann et al. 2005a; Hornung and Brandner, 2005; Rigo et al., 2006; Furin et al., 2007; Hornung et al., 2007a, b) have been called as the 'Carnian-Pluvial Event' by Simms and Ruffell (1989).

In order to put evidence on a possible climate trackway, we measured the $\delta^{18}O_{phos}$-ratio of conodont apatite. Using this very stable isotope proxy and the methodology of Wenzel et al. (2000), we evidenced a major negative shift of 2.0 ‰ [V-SMOW] in latest Julian 1 and Julian 2 indicating climate warming and a change in seawater salinity. This interpretation fits with changes in lithofacies and argues for humidification and enhanced freshwater runoff (sensu Simms and Ruffell, 1989), resulting in higher nutrient levels as the main factors of both reef disease and decline of nektonic biodiversity in late Early Carnian time.

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ENVIRONMENTAL CONTROLS ON EARLY MESOZOIC REEF DEVELOPMENT

Wolfgang Kiessling

Museum für Naturkunde, Humboldt-Universität Berlin, Berlin, Germany
e-mail: wolfgang.kiessling@museum.hu-berlin.de

Climate, nutrient concentrations and sea-level fluctuations are commonly discussed as prevalent environmental controls of reef development on a variety of temporal and geographic scales. Determining the role of each factor on early Mesozoic reef development is complicated by their complex interactions. In addition evolutionary processes may mask the influence of environmental factors. The long recovery periods from two devastating mass extinctions (end-Permian and end-Triassic) provide an exceptional macroevolutionary framework that must be considered when assessing the influence of environmental factors.

A further issue is sampling bias. Sampling issues are especially relevant for such important measures as reef abundance and palaeogeographic distribution, which are commonly used for palaeoclimatic inferences. I used the PaleoReefs database (PARED) and the Paleobiology Database (http://paleodb.org) to trace early Mesozoic reef evolution and to control for sampling.

There are just two significant metazoan reef booms in the Triassic-Jurassic periods after sampling-standardization: one in the Norian-Rhaetian and one in the Oxfordian-Kimmeridgian. Both significant peaks are followed by substantial declines. The boom and burst pattern of reef growth suggests that self-organized criticality (perhaps through biotic interactions such as acquisition and loss of photosymbiosis) might play are more important role in reef development than a linear response to environmental change. Similarly, most of the reported higher-latitude excursions of early Mesozoic reefs may not be real. This is not to say that reefs were not often situated outside the modern reef zone, but that the apparent widening and shrinking of the reef zone is largely a sampling artifact. There is, however, an interesting difference between the Triassic and Jurassic: While Triassic reefs were strongly concentrated in northern equatorial latitudes, Jurassic reefs were suspiciously rare near the palaeo-equator, which might indicate unusual warmth.

In sum, the reef patterns currently remain equivocal with regard to environmental forcing. A multidisciplinary approach should permit rapid progress, however.

NEW PALEONTOLOGICAL EVIDENCE FOR THE CARNIAN STRATA OF THE MEŽICA AREA (KARAVANKE MTS, SLOVENIA)

Tea Kolar-Jurkovšek & Bogdan Jurkovšek

Geološki zavod Slovenije, Ljubljana, Slovenia. e-mail: tea.kolar@geo-zs.si

Carnian carbonate succession of the »Raibl group« in the Mežica region (Karavanke Mts., Slovenia) includes three clastic horizons of marly-shaly rocks. An increase of carbonate amount is evidenced from the first to the third clastic horizons (Pungartnik et al., 1982). Similar differences were observed also by Jelen and Kušej (1982): palynological assemblage from the first clastic horizon reflects a fluviatile-deltaic environment containing abundant pterydophyte spores, the second horizon is characterized by the spores of mangrova trees, and the third horizon is marked by prevailing xerophytic elements. Jelen and Kušej (1982) interpreted these beds as a retrograded deltaic system and its cyclicity is explained by Hagemaister (1988) as eustatic sea-level fluctuations. Most probably the first and third clastic horizons correspond to the two Carnian third order transgressive-regressive cycles of Haq et al. (1987) as stated by Bechstädt and Schweizer (1991).

Rich invertebrate fauna includes ammonoids, bivalves (Jurkovšek, 1978), gastropods (Kaim et al., 2006), crinoids (Jurkovšek and Kolar-Jurkovšek, 1997), and thecideide brachiopods (Jurkovšek et al., 2002). Conodont sampling was conducted over last two decades. The most interesting part is the second clastic horizon where occur particular layers or lenses of micritic limestone. A single sample produced conodonts. It is marked by well preserved conodont fauna of the monospecific *Nicoraella ? budaensis* that enables apparatus reconstruction. The recovered conodont fauna confirms the Julian age and it is important data for making regional correlation.

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THE GLOBAL SIGNIFICANCE OF PERMO-TRIASSIC HYDRO-CARBON SYSTEMS AND THE ROLE OF PLATE RECONSTRUCTION AND PALEOCLIMATOLOGICAL MODELLING IN RESOURCE ASSESSMENT.

Aernout Korevaar, Cees van Oosterhout & Keith Gerdes

Shell International E&P, Rijswijk, The Netherlands. e-mail: aernout.a.r.korevaar@shell.com

The amalgamation of Pangea generated large uplifted areas separated by broad intracratonic depressions. The break up of this continental landmass commenced during the Permian period and continued throughout the Triassic period. The sediments derived from the denudation of Pangea and along the margins of the fragmenting continental landmass formed Permo-Triassic reservoirs that are estimated to contain more than 600 Billion boe i.e. one sixth of the total global hydrocarbon reserves (2P Recoverable, source: IHSE). Forty percent of these reserves are gas and condensate. Gross depositional environment maps created for discrete tectono-stratigraphic intervals during the continental break up illustrate the development of both carbonate and siliciclastic sequences with reservoir and seal potential and the widespread occurrence of organic rich lithologies with the potential to have formed hydrocarbon source rocks.

The shelfal carbonate 'Khuff' play of the Middle East accounts for approximately 400 Bboe of the reserves attributed to Permo-Triassic reservoirs. Siliciclastic sequences of Triassic age include the TAGI reservoirs of North Africa and the Mungaroo formation reservoirs of the N.W. Shelf of Australia. The lithologies within which hydrocarbons are accumulated in these reservoirs allude to specific paleogeographical and paleoclimate conditions.

The modelling of the global break up of Pangea, and the mapping of the gross depositional environments created, has been the subject of numerous studies by various researchers (Scotese, Stampfli, Smith, Golonka etc.). Hydrocarbon accumulations restored to their chronostratigraphically correct positions by paleo-rotation of the Scotese 2004 plate model show strong temporal alignment with the opening of Neo-Tethys. These initial studies illustrate that a better understanding of the critical factors controlling the development of hydrocarbon accumulations can be obtained from the modelling of paleogeographic and paleoclimatic settings. The predictive potential of the gross depositional environments generated are largely dependent upon the accuracy of the plate reconstructions used.

TECTONIC VS. CLIMATIC FORCING OF CYCLICITY IN THE SEDIMENTARY PATTERN OF THE TRIASSIC OF NORTHERN ISRAEL

Dorit Korngreen[1] & Chaim Benjamini[2]

[1]Geological Survey of Israel, Jerusalem, Israel
[2] Department of Geological and Environmental Sciences, Ben-Gurion University in the Negev, Beer Sheva, Israel
e-mail: doritk@gsi.gov.il

Five transgressive/regressive cycles, superposed upon higher order sea level fluctuations, were identified in the Middle to Upper Triassic from two boreholes, 100 km apart, representing similar positions on the palaeo-shelf in northern Israel. These cycles can be correlated between the two boreholes, despite some unique depositional features of each. The first cycle is Pelsonian. The transgressive part commences with a moderately energetic near- to offshore ramp margin. The sea level high is indicated by facies shift to more proximal, shallower inner ramp, but no evaporites. The cycle terminates beneath a restricted open marine lagoonal facies with terrigenous clastic influx. The second cycle (upper Pelsonian to Longobardian), displays a gradual environmental change, from an open marine energetic regime constituting most of the cycle, terminating at the first evidence of marginal marine gypsum/anhydrite evaporites. The third cycle (Cordevolian) represents a more dramatic change in which lagoonal environments predominate, and open marine carbonates are minor. The highstand is dominated by pulses of subsidence, reflected in cyclic occurrence of halite pseudomorphs within the gypsum/evaporite lagoon. Exposure features mark the end of the third cycle. The fourth cycle (Carnian) is characterized by marginal sabkhas and deeper salina conditions, terminating at the uppermost occurrence of supratidal and exposure features. The fifth cycle belongs to the Norian – Rhaetien, and evaporitic conditions gradually become reduced, and the carbonates again become dominant.

Backstripping of the sections of northern Israel indicate underlying tectonic movements in the first, second and fourth cycles, suggesting a relationship with contemporary tectonic movements belonging to Tethyan rifting phases known from the NE & NW Dolomites, Paris Basin and western Southern Alps. Backstripping of the second and fifth cycles, of the Ladinian and Norian-Rhaetian, do not indicate an underlying tectonic pulse. These two cycles are related to development, and subsequently elimination of, extreme evaporative conditions, from the Ladianian through the Norian. The intervening tectonic event augments the effects of the evaporative regime, but does not initiate these conditions. We conclude that there is a significant climatic component to the tectonically inactive cycles, yielding effects subsequently enhanced by tectonic activity.

TRIASSIC AND TRIASSIC-JURASSIC BOUNDARY CLIMATIC VARIATIONS INDICATED BY OXYGEN ISOTOPES FROM LOW-MG-CALCITE FOSSILS

Christoph Korte[1], Stephen P. Hesselbo[2] & Heinz W. Kozur[3]

[1]Institut für Geologische Wissenschaften, Freie Universität Berlin, Berlin, Germany
[2]Department of Earth Sciences, University of Oxford, Oxford, United Kingdom
[3]Rézsü u. 83, Budapest, Hungary
e-mail: korte@zedat.fu-berlin.de

Oxygen isotope values of calcite and phosphate fossils are useful proxies for past seawater temperatures and the reconstruction of climate changes. To acquire the primary geochemical signal of past oceans, the proxies must be free of diagenetic alteration. Low-Mg-calcite shells from articulate brachiopod and oysters can serve as suitable material that retains the oxygen isotopic compositions of the past seawater, because the LMC of their shells is relatively resistant to diagenetic alteration. Such material has the advantage that their textural preservation and chemical integrity can be checked by optical microscopy, SEM and ICP-AES and to select the samples for isotopic studies or to evaluate their isotope data. Only texturally excellently preserved samples with less than 250 ppm Mn and more than 400 ppm Sr were classified as acceptable and are discussed in this study. Two periods are of increased interest: (1) the early to middle Carnian and (2) the Rhaetian-Hettangian transition.

For the Early Carnian brachiopod oxygen isotope values from South Alpine St. Kassian (San Cassiano, Dolomites, Italy) a rise of about 2 ‰ occurs within the Cordevolian, from -3 ‰ in the early/middle *aon* Zone to -1 ‰ in the late *aon*/early *aonoides* Zone (Korte et al., 2005). These data indicate a rapid temperature decline of virtually 10°C, or alternatively, a combination of a moderate temperature drop with a moderate increase in seawater salinity, if one takes into account the increase of salinity that took place in this region at that time (Mutti and Weissert, 1995). A decrease in brachiopod oxygen isotope values throughout the Julian, indicating a subsequent warming, is reported by a few brachiopod data (Korte et al., 2005) and confirmed by conodont $\delta^{18}O$ (Hornung et al., 2007).

Oxygen isotope values from the Triassic–Jurassic (T–J) transition originate from oysters of the Lavernock Point (Glamorgan, South Wales) succession. They are about 0 ‰ in the lower Langport Member, increase somewhat to highest values of more than +1.6 ‰ in the higher Langport Member, and decline quickly (with some reversals) to values of about –2 ‰ in the *portlocki* Subzone in the Blue Lias Formation. These data indicate that a pronounced cooling of more than 5 °C followed by a distinctly warming of about 10 °C. For the T–J transition it is unlikely that the oxygen isotope fluctuations are controlled by a eustatic sea-level rise due to waning ice sheets or by freshwater influence because this is at odds with geologic observations.

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THE MID-CARNIAN WET INTERMEZZO OF THE SCHILFSANDSTEIN (GERMANIC BASIN)

Heinz W. Kozur[1] & G. H.Bachmann[2]

[1] Rézsü u. 83, Budapest, Hungary

[2] Institut für Geologische Wissenschaften, Martin-Luther-Universität Hallen –Wittenberg, Halle (Saale), Germany

e-mail: kozurh@helka.iif.hu

In Carnian times the Germanic Basin was situated north of the Tethys Ocean around the Tropic of Cancer, i. e. in the northern low latitude dry girdle. Because of this palaeolatitude location hypersaline deposits are to be expected during the entire Carnian. Such is indeed the case in the late Longobardian to middle Cordevolian Grabfeld Fm as well as in the Tuvalian Weser Fm, both containing a high percentage of anhydrite and halite deposits. On the other hand, the Julian Schilfsandstein (Stuttgart Fm) is without any evaporites, except for some nodular gypsum in the uppermost part. This mid-Carnian "evaporite gap" is rather enigmatic and suggests a relatively short period of wet climate. The change from the arid climate of the Grabfeld Fm to the humid climate of the Schilfsandstein was rather abrupt. Both formations, however, are separated by a long late Cordevolian to early Julian hiatus. The end of the wet climatic interval is also rather abrupt. We name this wet interval the "Mid-Carnian Wet Intermezzo" (MCWI).

The MCWI is observed in the low palaeolatitudes of the entire northern hemisphere including the northern dry girdle around the Tropic of Cancer (e.g., Kozur, 1972, 1975; Simms & Ruffel, 1989 for the Germanic Basin; Hornung, 2007 for the Tethys; Kozur & Weems, 2007 for the Newark Supergroup). In the Germanic Basin three distinct phases can be observed within the MCWI (Shukla & Bachmann, 2007). (1) Beds of phase 1 unconformably overlie evaporitic playa and sabkha deposits of the Grabfeld Fm from which up to 10–20 m of upper *Estheria* beds and parts of the middle *Estheria* beds may have been removed by pre-Schilfsandstein erosion. This erosion seems to have started already during the uppermost Grabfeld Fm and continued during the pre-Schilfsandstein hiatus (Hauschke, 1988). Lake deposits of phase 1 are up to a few meters thick and consist of thin-bedded shales, siltstones and sandstones as well as limestone beds in the basal part in NE Germany. From NE Germany to Thuringia there occurs a brackish to brachyhaline marine ostracod fauna of the upper Julian *Simeonella alpina* Zone suggesting some marine ingression from the southeast. (2) Sediments of phase 2 (main phase) are several 10's of meters thick and consist mainly of thick sandstone bodies or shales and siltstones ("flood facies" or "normal facies", respectively) thought to be mostly of fluvial or estuarine origin with some marine and tidal influence in S Germany (Shukla & Bachmann 2007). The sandstones are thickest in generally NNE-SSE trending strings and have strong erosional bases. Such erosion often removes the deposits of the first phase and frequently cuts down into the uppermost Grabfeld Fm as deep as the middle part of middle *Estheria* Beds, i. e. close to the deepest pre-Schilfsandstein erosion. (3) The third phase has an unconformable, minor erosional base and consists of sandstones and reddish shales of dominantly fluviatile origin.

Kozur (1972, 1975) explained the facies of the Schilfsandstein and of the contemporaneous Tethyan Lunz Beds by a wet mid-Carnian climatic interval interrupting the overall arid Carnian climate, and the Lunz Beds were additionally influenced by tectonic movements. Simms & Ruffel (1989) explained the Schilfsandstein facies by a "pluvial event". Hornung (2007) recognised a strong warming and wet climate period throughout the Tethys. Kozur & Weems (2007) pointed out that the base of the MCWI coincides with a fundamental plate tectonic reorganisation in connection with the closure of the Palaeotethys. Especially important seems to be the disintegration of the Tauride-Apulian ridge between the Neotethys and the Tethyan Ocean to the north (Kozur, 2000; Stampfli & Kozur 2006). With this disintegration the much warmer waters of the equatorial Neotethys could flow northwards, thus warming the subtropical northern Tethys by several degrees Celsius. It is thought that this effect caused a shift of the monsoonal regime. More moisture brought northwards is the result and so causing large amounts of precipitation at the uplifted shoulders of a rift system between Scandinavia and Greenland – the likely main source area of the large amount of Schilfsandstein clastics transported south into and across the Germanic Basin. This effect would explain the dominance of Caledonian age micas in the Schilfsandstein (Paul et al. 2008). More difficult to explain is the rather sudden end of the MCWI. The monsoonal regime must have been totally changed because the MCWI and the clastic influx from the north both ended almost instantaneously.

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FLORAL CHANGE OVER THE PERMIAN – TRIASSIC TRANSITION AND PHYTOGEOGRAPHIC EVIDENCE OF TRIASSIC CLIMATES

Valentin Krassilov

Institute of Evolution, University of Haifa, Mount Carmel, Haifa, Israel and Paleontological Institute, Moscow, Russia. E-mail: vakrassilov@gmail.com

Major evolutionary events in the earth's history seem to have been accompanied, and perhaps causally related, to latitudinal shifts of vegetation zones. The appearance of temperate Angarian floristic elements in the latest Permian of China (Krassilov, 2000) may suggest a cooling near the Permian – Triassic Boundary (PTB), although terrestrial transboundary sequences are insufficiently studied. In the Volga River Basin, the historical stratotypic area of the Upper Permian, a widespread hiatus occurs at the base of the Lower Triassic (the Vetlugian Series). Few recently described PTB sequences contain plant macrofossil and palynological assemblages representing a mixture of Permian survivors and short-lived derived forms of a high morphological plasticity peculiar for this time interval (Krassilov et al., 1999). These co-occur with *Tympanicysta*, a microfossil previously assigned to the PTB "fungal spike", but re-interpreted as a green alga spreading with eutrophication of estuarine waters at the PTB. The transitional sequence is correlated with the interval of mixed occurrences of Permian and Triassic forms in the stratotypic uppermost Changxingian. Arthropod traces (histoid leaf galls and the oldest known leaf mines) testify to a contribution of plant – arthropod interactions to terrestrial biotic changes over the PTB.

A subsequent warming is marked by the spread of *Pleuromeia* and allied semiarboreal lycopsids producing the boat-shaped sporangia supposedly dispersed by sea currents and often deposited with ammonoid shells. Their taphonomy indicates a tidal flat semiarboreal growth characteristic of termophylic coastal vegetation, the exceptionally wide latitudinal range of which during the Early Triassic included the type Olenekian in the North Siberia (Krassilov & Zakharov, 1975). No evidence of contemporaneous temperate vegetation has ever been found. Climatic situation changed drastically in the late Middle to Late Triassic, with temperate Mesozoic vegetation first appearing in Siberia. It was dominated by *Phoenicopsis* maintaining its prominence through the Mesozoic. The temperate/subtropical boundary is marked by the joint or adjacent occurrences of *Phoenicopsis* leptostrobaleans and *Scytophyllum* peltasperms. In Eurasia, the boundary extended over the Urals, the major climate controlling orographic feature of the time.

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PERMIAN/TRIASSIC VIETNAMESE EMEISHAN VOLCANISM AND THEIR RELATION TO PALEOGEOGRAPHY OF SE ASIA AND MASS EXTINCTION

Michal Krobicki & Jan Golonka

AGH University of Science and Technology, Department of General Geology, Environmental Protection and Geotourism, Krakow, Poland. e-mail: krobicki@geol.agh.edu.pl

The Emeishan basalts in southwest China belong to the Late Permian worldwide volcanic episodes on area of 250 000 km^2. The most intensive volcanism effect in NW Vietnam occurs between Song Ma and Song Da suture zones. In this region volcanic rocks of the very thick (up to 1000 m) sequence of the Camthuy Formation (e.g. with pillow lava flows) construct narrow (20 km) and long (250 km) belt (e.g. Son La and Quynh Nhai area). There is probably SE branch of magmatic region of Emeishan Large Igneus Province (ELIP), which has been moved to present position during Oligocene-Miocene time as tectonic extrusion in SE direction, along Ailao Shan–Red River Fault Zone. Radiometric data indicate close to Permian/Triassic boundary age of this volcanic event, both on Ar-Ar method (251-253 Ma) and U-Pb one (259 Ma). At this time the Neotethys Ocean was already opened and had Arabia, Greater India and Australia on one side and Lut–Qiangtang–Sibumasu on the other. The fast movement of Cimmerian continents and incoming Indosinian orogeny suggest closer proximity of Sibumasu and Indochina during Late Permian times. The strong volcanic episode started in Indochina at this time, and probable has been connected with back-arc spreading and the hot spots could also play a role in formation of this volcanism. Plate tectonic reorganization of this part of SE Asia have been connected with break-up of Gondwana and rapid northward movements of Sibumasu, Lhasa and Qiangtang terranes as an eastern end of Cimmerian Continent. Late Permian climatic conditions, like steep polar-equatorial temperature gradients, dry continental interiors, and high-latitude wet belts existed. The warming which followed seems, to correspond closely with the extinction event at the Permian/Triassic boundary. From the geodynamical point of view this climatic change and biological extinction was perhaps related to the plate reorganization and mantle plume activity. Paleoclimatic changes in this time, as effect both of such geotectonic revolution and simultaneously origin of LIP provinces (including ELIP) has presumable been main reason of P/T global mass extinction. The change of palaeocirculation within Tethyan-Panthalassa Ocean and suggested superanoxia event during this time has been result of these interactions.

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MACROFLORAS AND PALYNOMORPHS AS POSSIBLE PROXIES FOR PALAEOCLIMATIC STUDIES: THE CASE STUDY OF THE FOSSILLAGERSTÄTTE KÜHWIESENKOPF / MONTE PRÀ DELLA VACCA (OLANG DOLOMITES, N-ITALY)

Evelyn Kustatscher[1], Johanna H.A. Van Konijnenburg-Van Cittert[2] & Guido Roghi[3]

[1] Naturmuseum Südtirol, Bozen, Italy
[2] Laboratory of Palaeobotany and Palynology, Utrecht, The Netherlands.
[3] Institute of Geosciences and Earth Resources - CNR- Padova, Italy
e-mail Evelyn.Kustatscher@naturmuseum.it

In 1999, the discovery of a rich plant deposit at Kühwiesenkopf gave rise to integrated biostratigrafic, palaeoclimatic and palaeoenvironmental studies of this area. The 200m thick stratigraphical sequence belongs to the Dont Formation and is characterised by an important fossiliferous horizon rich in well preserved plant fossils. Brachiopods, ammonoids and palynomorphs dated it to the middle Pelsonian - lower Illyrian. The fossiliferous deposit originated probably from rapid burial events due to gravity flows or very high sedimentary rate, connected with heavy storms causing flooding in the nearby terrestrial domain (for more information see Broglio Loriga *et al*. 2002).

The outcrop provided not only a rich palynoflora but also a taphonomically only slightly selected macroflora. These two sources of information permit us to get a better picture on the palaeoenvironmental and climatic conditions during this time period. The macroflora is composed of both sterile and fertile organs belonging at least to 28 genera of lycopods, horsetails, ferns, seed ferns, cycadophytes and conifer. The conifers are the most abundant group, closely followed by ferns and cycads, whereas horsetails are rare. The abundance of ferns and cycads with some relatively large leaves, as well as the high taxonomical diversity both in richness and abundance, suggests a general warm and humid climate. However, the discontinuous growth of some conifer shoots suggests periodical or casual variations in the rainfall during the plant life.

In the palynomorph analysis, 84 samples collected along the whole section, have been studied: 149 sporomorph species, 7 megaspores, 3 acritarch and 3 algal cyst genera, microforaminiferal linings have been determined. For the palynomorph quantitative analysis, the methods proposed by Visscher & Van der Zwan (1981) and Abbink (1998) have been applied. Both show a predominant high percentage of hygrophytic groups, which suggests a humid and warm climate. However, throughout the section some oscillations in the palynological composition become visible, also on short time intervals. The cause of these variations could be either due to variations of the climate conditions and/or sea-level fluctuations or ground water table fluctuations. Additionally, the lowermost, middle and uppermost parts of the section record an increase of the pollen fraction. The palynofacies indicate that the succession was deposited in a marine area near to emerged lands and subjected by occasional fresh water influx.

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PALEOENVIRONMENTAL RECORDS IN ANISIAN REEFS FROM UPPER SILESIA (SW POLAND)

Marcelina Łabaj

Institute of Geological Sciences, Jagiellonian University, Kraków, Poland.
e-mail: marcelina.labaj@uj.edu.pl

Anisian reefs, known from the Upper Silesia were formed by sponge- coral- microbial assemblage. Reefs grew up during the highstand phase of the global maximum transgression in Anisian time (Szulc, 2000). They formed 150 km-long belt, in barrier form, separating the tethyan open marine zone from the backreef area (Germanic Basin) (Szulc, 2000).

Fluctuating environmental conditions determined composition of reef constructors and affected their morphology. Two biohermal complexes featuring the succession reflect two stages in shallowing trend in basin (Szulc, 2000). The first complex began with biostroms built by prostrate colonies of Hexactinellida sponges which fragile character indicates low energy. During the periods of increasing energy and input of bioclastic material, sponges were buried under sediment cover. Shallowing basin and environmental stabilisation favoured sponge development, which dominated the shallow zones with high energy. Massive sponges built large colonies up to 7 m in height. Sponges provide stabilised ground, which was colonized by branched *Volzeia szulci* corals. Well preserved, delicate twigs of corals and lack of detrital sediment, suggest relatively quiet environment, and high rate of sedimentation. The complex is capped by lamellar colonies of *Pamiroseris silesiaca.* Platy character of corals colonies indicates a relatively high energy of the environment which means that reefs reached their shallowest growth phase. Detrital material abounds in between colonies indicate that the coral growth was disturbed by storm events.

These data suggest that the coral fauna grew up in shallow, rather calm-water environment, controlled by severe storm activity.

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WHY GENERIC TURNOVERS IN THE CARNIAN/NORIAN CONODONTS?

Michele Mazza[1] & Manuel Rigo[2]

[1] Department of Earth Sciences “Ardito Desio”, University of Milan, Milano, Italy
[2] Department of Geosciences, University of Padova, Padova, Italy
e-mail: michele.mazza@unimi.it

Conodont biostratigraphy around the Carnian/Norian boundary is rather problematic because of the apparent provincialism of most of the conodont species. New biostratigraphic data from Pizzo Mondello, Western Sicily, Italy (a 400 m thick succession of hemipelagic limestones, belonging to the Cherty Limestone), point out clear relationships among the three most widespread conodont genera *Carnepigondolella*, *Metapolygnathus*, *Epigondolella* and allow to identify particular trends in the genera turnovers which affected the real conodont stratigraphic distribution.

The first 48 meters of the section are largely dominated by the genus *Carnepigondollella*, with some Paragondolellae, only sporadic Metapolygnathids (*M. mersinensis* along with transitional forms *P. noah* - *M. communisti*) and few representatives of *Epigondolella orchardi*. In the overlaying 17 meters, the genus *Carnepigondolella* and transitional forms *P. noah* - *M. communisti* disappear, replaced by the genus *Epigondolella* (several *E. quadrata*). The genus *Metapolygnathus* is still rare. In the following 10 meters, a mass occurrence of the *M. communisti* group along with *M. primitius* is present, while the genus *Epigondolella* disappears. Another genera overturning takes place in the last 30 meters of the section, where advanced Epigondolellae (*triangularis* group) almost replace Metapolygnathids (only few *M. parvus* still occur). After comparisons with sedimentological data (Nicora et al., 2007) and geochemical variations (□^{13}C or □^{18}O; Muttoni et al., 2004), at Pizzo Mondello section, the turnovers of conodont genera around the Carnian/Norian boundary might be likely explained by competition of *Carnepigondolella* versus *Metapolygnathus* and, subsequently, of *Epigondolella* versus *Metapolygnathus*, or by invasions of conodont species from other domains (North America; see Noyan and Kozur, 2007 and references herein).

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PALEOECOLOGICAL SIGNIFICANCE OF SUBTIDAL MICROBIALITES, UPPER LADINIAN TO LOWER CARNIAN OF ISRAEL

Aaron Meilijson [1], Dorit Korngreen [2] & Chaim Benjamini[1,3]

[1]Department of Geological and Environmental Sciences, Ben-Gurion University in the Negev, Beer Sheva, Israel
[2]Geological Survey of Israel, Jerusalem, Israel
[3]Ramon Science Center, Mizpe Ramon, Israel
e-mail: meilijson@gmail.com

Nine microbialite layers, usually of stromatolitic form, were identified in the Ladinian and Carnian Saharonim Fm in the Makhtesh Ramon outcrops of southern Israel. We found that most of these microbialites were deposited in sub-tidal environments within shelf limestone facies, in contrast with previous claims that their depositional environments were peritidal and perievaporitic, and often exposed. To establish the paleoecological conditions for the proliferation of these microbialites, they were compared with Triassic reef microbialites found at the subsurface of northern Israel. The Triassic reefs developed there were a complex system of mixed metazoan framework builders and microbial encrusters growing on the open marine shelf facing an arm of the developing Neo-Tethyan ocean. A series of rifted and tilted blocks separated this shelf edge from inner basins within which the epicontinental Triassic of the Levant interior was deposited. Warm climate, high levels of salinity, and poor mixing with oceanic waters, created stressed conditions poorly suited to metazoon framework builders, but ecologically suitable for microbialites as 'default' carbonate producers in shelf environments. This is an example of how Triassic rifting episodes associated with Pangaean break-up, in suitable climatic belts, often led to similar conditions and ecological consequences. Many circum-Tethyan localities have metazoan reef builders associated with microbialite carbonate producers, while in adjacent restricted inner-shelf basins with variable but high salinity and intermittent hypoxia, the shelf-limestone niche was populated by microbialites, molluscs and serpulids, with metazoan reef growth severely inhibited.

FACIES DEPENDENCE OF PLANT ASSEMBLAGES FROM THE CARNIAN LUNZ FORMATION (AUSTRIA)

Barbara Meller

Institute of Palaeontology, University of Vienna, Vienna & Naturkundliche Station, Austrian Academy of Sciences, Lunz am See, Austria. e-mail: barbara.meller@univie.ac.at

Plant fossils from the Lunz Formation were mainly collected in the 19th century and, to a lesser degree, also at the beginning of the 20th century. Their original discovery was due to the coal mining activities at that time and much of the abundant material stored in several collections in Austria and other countries was taken from the mining waste heaps (Lipold 1865). One waste heap, from the more recent mid-20th century mining activity is now under investigation; heaps from former times are less useful for collecting because the plant-bearing sediments rapidly become strongly weathered. The coal field and the seams from which the material was derived have been established from the original old mining plans. On these, fortunately, the lithology was roughly documented and those parts of the seams where plants remains were observed have been marked. In the waste heap, different types of sediments have been recognized and a correlation between sediment type and plant taxa has been observed.

Grey sandstones, which often contain rhizomes or root-like fossils as well as Sphenophytes (*Equisetites*, *Neocalamites*), very probably represent a paleaosoil horizon; only rarely have *Pterophyllum* pinnae been observed in them. In contrast, the majority of *Pterophyllum* material was found in brown well-bedded shaley silty clay, together with, for example, *Asterotheca*. A third, very hard sediment, with carbonate, mainly contains *Asterotheca*, *Danaeopsis*, and *Pterophyllum* remains. Carbonate-bearing sediments with plant remains have not been described previously here. The characteristic plant fossil-bearing sediments of the Lunz Formation and the basal sandstone are generally described as carbonate-free, although Tollmann (1976) mentioned that carbonate cement occurs in the basal and upper sandstones (“Sandkalke”). In the Pramelreuth profile, drawn by J. Haberfelner at the end of the 19th century (Verloop 1908, Fig. 2), thin carbonates occur in the uppermost part of the section. However, these layers were not indicated by a special signature and have not been noticed. In the generalized profile (Verloop 1908, Fig. 1), thin limestones are marked in the upper part and concretions of a dark blue-grey Kalksandstein are marked at the base of the “Hauptsandstein”, but plant remains were not mentioned from any limestone. Alltogether, it is probable that the mined coal seam and the material in the waste heap derives from one of the uppermost seams. The characteristic dark coaly shale with plant remains, which was collected previously from the main plant layer, has not been observed yet in the waste heap.

At this early stage of the investigations, several hundred reliably identified specimens have been collected in conjunction with sedimentological observations, suitable for palaeoecological reconstructions. This has not been carried out before because typically only the well preserved and most complete plant remains were taken for collections. A palynological investigation of these sediments is planned together with E. Kustatscher (Bozen).

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PALAEOCLIMATE OF THE BUNTSANDSTEIN (LOWER TRIASSIC, CENTRAL EUROPE).

Josef Paul

Zentrum für Geowissenschaften der Universität Göttingen, Göttingen, Germany
e-mail: jpaul@gwdg.de

For a long time the terrestrial Lower Triassic red beds of the Central European Buntsandstein were thought to be formed in a desert environment. Later it was noticed that most of the sandstones were deposited by fluvial waters. Nowadays it became clear that the climate of the Buntsandstein was controlled by a strong cyclicity.

These cycles are in the basin about 10 to 25 m thick and consist of erosive sandstones at the base, followed by cross-bedded sandstones which pass to silty mudstones. The upper part consist of structureless mudstones containing numerous anhydrite nodules. This succession results from alternation of humid and arid climate. The cycles can be traced all over the Buntsandstein basin and can be used as high-resolution stratigraphy. The duration of such a climatic cycle is estimated to 0,1 Ma. The cycles were caused by the excentricity of the orbit (Milankovitch Cycles). In some phases of the excentricity, the tethyal monsoon reached further north to central Europe. The Milankovitch Cycleswere superimposed by long-term climatic changes.

Lower Buntsandstein (Indusian): The first cycles of the lowermost Buntsandstein formation, the Calvörde Formation (10 cycles) were more humid in comparison with the arid Upper Permian climate. Relatively high precipitation led to temporary lakes in the centre of the basin forming laminated sediments and lacustrian ooids. Lower precipitation of the above following cycles resulted in playa lake sediments. In the uppermost cycles, the amount of water was not sufficient to transport sandy material into the basin. With the Bernburg Formation (11 cycles) a long lasting change to a semi-arid climate started. In the centre of the basin, there were slightly salty lakes containing periodically ooids and stromatolites.

Middle Buntsandstein (Olenekian**):** The Volpriehausen Formation (9-14 cycles) and the Detfurth-Formation (3 cycles) are characterized at the margins by ventifacts and arcosic sediments – indications of arid climate - whereas in the centre of the basin, there are fluvial and lacustrine deposits which originated from semi-arid or sub-humid climates. It is assumed that there was a strong cyclic change of dry to humid climates. The Hardegsen Formation (8 cycles) contains more plants, vertebrate tracks, scales of fishes and conchostracans than the antecedent formations indicating a less arid climate. The cyclic monsoonal precipitation in the lower Solling Formation (4-6 cycles) led to a giant lake which temporally filled the complete basin exceeding in size the Great Salt Lake or the Lake Tschad. During a period of some to ten thousand years precipitation compensated the evaporation of such a large lake area. The climate was sub-humid. The above following red mudstones were deposited in a large playa. Frequent vertebrate tracks, calcretes and silcretes point to a warm, semi-arid to humid alternating atmosphere.

Upper Buntsandstein (Olenekian – Anisian): Thick salt deposits in the Roet 1 member indicate a dry climate. The Roet 2 member contains quite a lot of hygrophytic fern spores and sedimentary structures originating from fluvial waters indicating a moderate arid climate. The Roet 3 member is characterized by aeolian clay dunes extending in a large part of the basin. This member is absolutely free of fossils. It was the climax of aridity in the Buntsandstein. In the upper part of the Roet, at the margin of the basin, there were faunas and floras rich in species and numbers. Fishes (Semionotidae) prove permanent flowing rivers. The climate of this period was only moderate dry.

In conclusion, the Lower Triassic climate of Central Europe was controlled by humidity cycles (Milankovitch Cycles). These cycles were superimposed by longer lasting climatic changes which caused giant lakes or deserts.

THE LATE TRIASSIC FLORA FROM LUNZ IN LOWER AUSTRIA – PALAEOECOLOGICAL CONSIDERATIONS

Christian Pott[1], Hans Kerp[2] & Michael Krings[3]

[1]Naturhistoriska riksmuseet, Sektionen för paleobotanik, Stockholm, Sweden.

[2]Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster, Germany
[3]Bayerische Staatssamlung für Paläontologie, Geologie und GeoBio-Center, München, Germany
e-mail: christian.pott@nrm.se

A recently completed systematic macromorphological and cuticular analysis of compressed gymnosperm foliage from the Carnian (Late Triassic) flora from Lunz in Lower Austria has provided detailed circumscriptions of the individual taxa and new information as to their ordinal and generic classification. Although the fossils represent several lineages of gymnosperms, including Cycadales, Bennettitales and Ginkgoales, it appeared that certain idiocuticular and epidermal features such as sunken stomata and papillate surfaces occur widespread among the taxa (Pott et al., in press, 2007a-d). The presence of coal seams indicates that the environmental conditions in the Lunz palaeoecosystem were stable for longer periods and allowed for the accumulation of larger amounts of plant material. The formation of peat generally requires special conditions, including a stable, high groundwater table, reduced oxygen supply and low pH values, which are typically found in swamps or peat-bogs. Many of the idiocuticular and epidermal features recorded for the Lunz plants can be interpreted as adaptations to ecological conditions characteristic of coal-producing peat swamps, e.g., physiological drought, and thus corroborate the interpretation of the Lunz palaeoecosystem as a peat-forming environment (Pott et al., in press).

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THE CARNIAN PLUVIAL EVENT: CAUSES AND EFFECTS.

Nereo Preto[1,2], Piero Gianolla[3] & Guido Roghi[2]

[1]University of Padova, Dept. of Geosciences, Padova, Italy
[2]Institute of Geosciences and Georesources, C.N.R., Padova, Italy
[3]University of Ferrara, Dept. of Earth Sciences, Ferrara, Italy
e-mail: nereo.preto@unipd.it

The term "Carnian Pluvial Event", or CPE, denotes an episode of increased rainfall which had a well recognizable and widespread influence on Carnian marine and continental sedimentary systems. Its onset is dated to the latest Early Carnian (Julian). Initially identified as one of the major turnovers in the stratigraphic evolution of the Northern Calcareous Alps (the "Reingrabener Wende"), it was then interpreted as a shift towards humid climate (Carnian Pluvial Episode).

The CPE is recognized by its effects on sedimentary systems. It corresponds to a sudden increase of siliciclastic sedimentation, temporary demise of rimmed carbonate platforms, widespread oxygen depletion-anoxia in marginal seas and a rise of the carbonate compensation depth in deep basins - a scenario similar to that of Jurassic and Cretaceous Oceanic Anoxic Events. It also corresponds to an apparent biotic turnover and to the occurrence of hygrophytic palynomorph assemblages.

The climatic rather than local environmental nature of the CPE was challenged on the base of palynological studies. Subsequent work however identified the CPE in a variety of environments and localities, and demonstrated its global and climatic nature.

The CPE is recognized globally. Not only its effects are manifest in the western Tethys realm and continental Europe, where they were initially recognized, but are now found also in the southern margins of Tethys (Lagonegro Basin and Spiti valley, Himalayas), south western North America, northern Europe (Svalbard) and, possibly, southern China block.

The CPE is a tropical humid climate pulse, at least within the tropical belt. Climate was wetter in western Tethys during the CPE than in tropical humid tidal flats and marshes of Florida bay, and much dryer earlier and later, as demonstrated by comparison of soil characteristics. In south western North America, paleosols indicate an increase of rainfall from a background of 300-600 mm/yr to 700-1400 mm/yr during the Carnian.

The CPE had short duration. It encompasses a minor portion of the Carnian stage in the Southern Alps, and only barely more than one ammonoid biochronozone. Along with cyclostratigraphic calibration, this evidence suggests the event lasted for less than a million years.

The CPE had a complex internal structure. Humid climatic indicators occur in phases, alternated with short intervals of apparently dryer climate. Each humid sub-phase may deserve a name of its own, provided that biostratigraphic resolution allows their correlation at the interregional scale.

Many possible causes for this event were proposed, including sea-level changes, reorganization of landmasses and consequent changes in atmospheric circulation (e.g., the Carnian eo-Cimmerian collision could have triggered enhanced monsoonal circulation within the Tethys realm), or climate alteration by massive basaltic volcanism (Carnian volcanism of western Tethys, or the Large Igneous Province of Wrangellia). Only those explanations that account for the global and climatic nature of the CPE should be further considered and discussed.

LOWER TRIASSIC ANOMALOUS CARBONATE FACIES, LATITUDINAL EFFECTS, AND CARBON CYCLE INSTABILITY

Sara Pruss[1] & Aymon Baud[2]

[1]Department of Geology, Smith College, Northampton, MA 01063 USA
[2] Geological Museum, UNIL_BFSH2, Lausanne, Switzerland
e-mail: spruss@email.smith.edu

The end-Permian mass extinction continues to serve as the focus of ongoing research, as it is the largest extinction of the Phanerozoic. In recent years, some interest has shifted to the protracted recovery during Early Triassic time. It is well established that diversity of organisms remained low, metazoan reefs were absent, and ecosystems did not fully recover for several million years after the extinction. In addition, a multitude of unusual carbonate facies, facies typically restricted to Proterozoic or Cambrian settings, reappear in abundance in both Tethyan and Panathalassic intertropical realms. Lower Triassic sections in the western United States and in Tethyan carbonates exposed in modern-day Southern Alps, Hungary, Turkey, Armenia, and Iran preserve abundant unusual facies including flat-pebble conglomerates, microbial build ups, and seafloor precipitated fans, suggesting the sedimentary record also reflects environmental and ecological changes associated with the end-Permian mass extinction. On the Gondwana margin (southern higher latitudes) preserved in Oman and North India, the calcimicrobial boundary unit is reduced or absent, and carbonates contain more skeletal material than the equatorial regions.

Previous research has shown that carbon isotopes measured from several sections spanning the Lower Triassic show multiple excursions, suggesting long-term instability in the carbon cycle. A short-term increase in carbon dioxide, perhaps as a consequence of Siberian Trap volcanism, cannot satisfactorily explain carbon cycle instability for millions of years due to fast mixing rates. Rather, a long-term reorganization of carbon cycling in the oceans must have occurred to account for the several million year long delayed recovery of organisms and prevalence of unusual facies in the aftermath of the end-Permian mass extinction.

PERMIAN-TRIASSIC BOUNDARY INTERVAL IN MIDDLE EAST (TURKEY, IRAN AND N. OMAN): PROGRESSIVE ENVIRONMENTAL CHANGE FROM DETAILED CARBONATE CARBON ISOTOPE MARINE CURVE AND SEDIMENTARY EVOLUTION.

Sylvain Richoz[1], Leopold Krystyn[2], Aymon Baud[3], Rainer Brandner[4], Micha Horacek[5] and Parvin Mohtat-Aghai[4]

[1]Institute of Geosciences, Johann Wolfgang Goethe University Frankfurt, Frankfurt, Germany
[2] Institute of Palaeontology, Vienna University, Vienna, Austria
[3] Parc de la Rouvraie 28, CH-1018 Lausanne, Switzerland
[4] Institute of Geology and Paleontology, University of Innsbruck, Innsbruck, Austria
[5] Institute of Mineralogy and Petrology, University of Graz, Graz, Austria
e-mail: Richoz@em.uni-frankfurt.de

The negative end Permian $\delta^{13}C$ excursion is already well studied but causes and chronology are still in question. In an attempt to better undrstand timing and grounds of this strong decrease, we established high resolution sedimentological, biostratigraphical studies and carbonate carbon isotopic curve in four sections in Iran (Abadeh, Shareeza, Zal and Djulfa), two in Oman (Wadi Sahtan, Sumeini) and two in Turkey (Curük dag, Tashkent). This high-resolution chemostratigraphy allow the discrimination of 9 successive isotopic events (IE 0-8) for the PTBI. They were tested for isochrony and compared against an updated high-resolution conodont and ammonoid biostratigraphy. The position of the sections on different margins of the Neotethys has allowed us to decipher between local and global signal. The negative excursion of the PTBI has been separated in four distinct parts. A first drop (IE 0) occurs in the Upper Wuchiapingian with an amplitude of around 1.3‰. A second decrease begins at the base of *Dzhulfites* ammonoid beds and continues gradually until the extinction event (top *jolfensis* conodonte interval, IE 1-2), without important second-order variations. Its amplitude is varying between 1.5‰ to 2.8‰ and its duration has been estimated are around 2.2 Ma and revealed a non-catastrophic phenomenon. The lower *meishanensis-praeparvus* conodonte Zone records stationary to slightly increasing values. A fourth interesting pattern of the curve is recorded from the upper *meishanensis-praeparvus* Zone till the base of the *I. isarcica* conodonte Zone (IE 3-7), with numerous second order variations. These second order variations are well correlatable between the different Iranian sections, but with some uncertainties in and with Oman and Turkey. The limitation to correlate these small peaks with others published sections reveals a higher sensitivity to local perturbations and a lower buffer capacity of the whole ocean. Its amplitude of 1.2 to 3.1‰ could be explained mainly by the breakdown of productivity probably combined with oxidation of organic matter and continuation of the process causing the extinction event. The effect of the causes of the extinction event on the isotopic curve have to be restricted to the alone second part of the carbon curve (IE 1-2) preceding this extinction event. The fatal decrease has thus a maximal amplitude of only 2.8‰ and allows to include some possible mechanisms, which were rejected as unrealistic to cause an excursion of 4‰. E.g. volcanism, change in ratio of organic deposition in land versus ocean, ocean regression, are to be reconsidered as possible mechanisms for PTBI extinction event.

PALEOECOLOGY OF TRIASSIC CONODONTS: CONSTRAINTS FROM OXYGEN ISOTOPES OF BIOGENIC APATITE

Manuel Rigo[1], Nereo Preto[1] & Michael M. Joachimski[2]

[1]Department of Geosciences, University of Padova, Padova, Italy.
[2] Geozentrum Nordayern, University of Erlangen-Nürnberg, Erlangen, Germany
e-mail: manuel.rigo@unipd.it

The oxygen isotopic composition of conodont apatite derived from the Upper Triassic (Carnian to lower Norian) Pignola 2 and Sasso di Castalda sections in the Lagonegro Basin (Southern Apennines, Italy) was studied in order to constrain the habitat of Triassic conodontophorids. Oxygen isotope ratios of conodonts range from 18.5 to 20.8‰ V-SMOV, which translate to paleotemperatures ranging from 22 to 31° C (using equation given by Kolodny et al., 1983), assuming a $\delta^{18}O$ of Triassic subtropical seawater of -0.15 ‰ V-SMOW (Shackelton & Kennett 1975). These warm temperatures, well comparable to those of modern subtropical oceans, suggest that conodonts reflect surface water temperatures and that the studied conodonts lived in near-surface waters. Conodontophorids were early vertebrates with a wormlike body characterized by a finned tail, well-adapted to swimming and predation mode of life. Eye movement was controlled by extrinsic muscles which suggests that conodontophorids throve in the photic zone (Donoghue et al., 2000 and references herein). Furthermore, Triassic gondollelids descended from Paleozoic *Gondolella*, which were recently interpreted as surface water dwellers (Joachimski et al., 2006). It is suggested that Triassic gondollelids had a comparable life habitat. Based the presented oxygen isotope data and considering the anatomical characteristics of the conodont animal, Late Triassic conodontophorids are interpreted as surface dwellers with a nektonic lifestyle, within the euphotic zone. Thus, the oxygen isotopic composition of Triassic conodont apatite is interpreted as a proxy of the temperature and $\delta^{18}O$ of sea surface waters.

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UPPER TRIASSIC DOLOMITIZATION CONTROLLED BY CLIMATE: PRELIMINARY RESULTS FROM MOUNT PELMO (EASTERN DOLOMITES, ITALY)

Alberto Riva[1], Raffaele Di Cuia[2] & Andrea Scifoni[2]

[1]Earth Sciences Department, University of Ferrara, Ferrara, Italy
[2]G.E. Plan Consulting, Ferrara, Italy
e-mail: alberto.riva@unife.it

Some preliminary petrographic and isotopic (d^{18}O and d^{14}C) data from the Mount Pelmo section points to a possible climatic control on the dolomitization processes. The Mount Pelmo section is located in the eastern Dolomites and present a clear transition from the Dolomia Principale (Upper Carnian – Norian) to the Dachstein Limestone (Rhaetian).

The Dolomia Principale is here represented by a 500 m-thick succession of subtidal microcristalline dolomites with Megalodontids, alternated to supratidal stromatolitic dolomites, commonly organized in shallowing upward cycles. The cycle caps are normally marked by the presence of green marls, with tepees and some vadoids.

The Dachstein Limestone shows facies very similar to the Dolomia Principale, but is represented by limestones. This thick succession (500 m) shows an upward decrease in supratidal arid features (tepees, vadoids, etc.), substituted by paleokarst dissolutional features located at the top of each cycle, indicating a probable increase in humidity.

The transition to the overlying Dachstein Limestone is quite rapid and occurs in about 15 m, within the so-called “transitional unit”. The abrupt appearance of limestones is at first confined in the middle of the beds, then expands toward the supratidal and to the subtidal part of the cycle. The dolomites in the subtidal part are normally sucrosic without any sedimentary structure. The supratidal cap is often stromatolitic, sometimes dolomitic, sometimes calcareous. The limestones in this transition are represented by grainstone-packstones with dasycladaceans and foraminifera (*Triasina hantkeni*).

In the transitional unit, just below the dolomitization top, some small mixing-zone features are present, similar to those described by Baceta et al. (2001), indicating the availability of freshwater. Stable isotope analyses shows the presence of meteoric cements inside the mixing zone.

The overall stable isotopic data and the vertical facies evolution point to a dolomitization model for the “transitional unit” directly linked to the influence of freshwater than an “evaporative” model that can be applied to the Dolomia Principale. The dolomites of the transitional unit presents the same isotopic composition of the Dachstein Limestone.

These data suggest an analogy with some coeval stratigraphic sections located in Hungary (Haas and Demeny, 2002), indicating a more humid climate in the Rhaetian than in the Norian.

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HIGH RESOLUTION CARBON ISOTOPE DATA OF TRIASSIC-JURASSIC KEY SECTIONS IN EUROPE

Micha Ruhl[1], M.R. Deenen [2], Wolfram M. Kürschner [1], G.-J. Reichart [3], Leo Krystyn [4]

[1]Institute of Environmental Biology, Utrecht University, Laboratory of Palaeobotany and Palynology, Utrecht, The Netherlands

[2]Laboratory Fort Hoofddijk, Department of Earth Sciences, Faculty of Geosciences, Utrecht University, The Netherlands

[3]Department of Earth Sciences, Faculty of Geosciences, Utrecht University, The Netherlands

[4] Institut für Paläontologie, University of Vienna, Vienna, Austria

e-mail: m.ruhl@uu.nl

Significant fluctuations in organic carbon-isotope values are recognized in key Triassic-Jurassic marine boundary sections in Europe (Hesselbo et al., 2002; Kuerschner et al., 2007) and North America (Ward et al., 2004; Guex et al., 2004). These records are characterized by two pronounced negative excursions that are thought to be related to changes in the global carbon cycle, resulting from massive input of CO_2 during deposition of the Central Atlantic Magmatic Province, the largest igneous province on earth. However, the origin and nature of these excursions are subject to major debate. We show new high resolution stable carbon isotope data from several proximal to distal Triassic-Jurassic boundary sections in the Eiberg Basin (Austria) within the western Tethys realm. The Triassic-Jurassic transition interval in these records is characterized by two distinct negative shifts of up to 7 per mille. A corresponding 2 per mille negative shift is recognized in the carbonate carbon signature. We suggest that perturbations of the carbon isotope signature in these records are only partly related to changes in type of the organic matter.

The Triassic-Jurassic transition interval is also characterized by major biotic turnovers in both the marine and terrestrial realm, which are likely related to major climatic and environmental changes. The duration of extinction and origination patterns and biotic turnover rates in this boundary interval are poorly understood. We present preliminary magnetic susceptibility and C-isotope data of the Tr-J transition at St. Audries Bay (UK) to demonstrate possible astronomical (100 and 400kyr) pacing of the sedimentary sequence. Such a floating astronomical time-scale enables us to better understand timing and mechanisms behind the major Triassic-Jurassic boundary events.

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PALYNOLOGY OF THE “RAIBLER SCHICTEN” NEAR RUBLAND (AUSTRIA) AND COMPARISON WITH OTHER UPPER TRIASSIC PALYNOFLORAS

Guido Roghi[1], Piero Gianolla[2], Nereo Preto[1,3], Luca Minarelli [2] & Claudio Pilati [2]

[1]Institute of Geosciences and Georesources, C.N.R., Padova, Italy
[2]University of Ferrara, Department of Earth Sciences, Ferrara, Italy
[3]University of Padova, Department of Geosciences, Padova, Italy
e-mail: guido.roghi@igg.cnr.it

Palynologycal assemblages are described from the so called Upper Triassic “Raibler Shale” outcropping near Rubland, Austria.

Eighty-eight palynomorph species are recorded and three palynomorph assemblages are established.

The first shale contains *Aulisporites astigmosus, Tigrisporites halleinis, Kraeuselisporites cooksonae, Leschikisporis aduncus* and different species of *Aratrisporites;* typical monosaccoid forms as *Patinasporites, Enzonalasporites* and *Vallasporites*, and circumpolles as *Camerosporites secatus, Duplicisporites granulatus* and *D. verrucosus* are present. The first shale is also very rich of *Lagenella martini* and different *Cycadopites* species.

The second shale shows a similar association, but without any trace of *Lagenella martini* and some forms of *Cycadopites*. The third shale marks the disapparence of *Tigrisporites halleinis, Leschikisporis aduncus, Kraeuselisporites cooksonae, Gordonispora fossulata* and *Gibeosporites* sp. Above the third shale, in some “plattenkalke facies” an association with *Paracirculina quadruplicis* and *Eucommidites* sp. was found.

Quantitative analysis indicates predominance of hygrophytic elements in the first two shales and, in the third shale, a shift toward xerophytic associations (see also Jelen & Kusej, 1982).

On the base of typical Carnian sporomorphs, the “Raibler Schicten” hygrophitic association is correlated to the well know humid shift called “Carnian Pluvial Event” and documented worldwide.

Other palynological assemblages from key sections in Göstlig and Lunz area exhibit differences that allow to define stratigraphical relationships between the so called “Reingraben Shale” and the Raibler Schichten. The Reingraben Shale is, on the base of palynological assemblages, older than the first Raibler shale. This implies that the Carnian Pluvial Event is constituted by at least three humid sub-phases, clearly visible in the Northern Calcareous Alps.

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STOMATAL FREQUENCY ANALYSIS AND CARBON ISOTOPE STRATIGRAPHY FROM THE GERMANIC BASIN: CHANGING CO_2 LEVELS DURING THE END-TRIASSIC

Micha Ruhl, Nina R. Bonis & Wolfram M. Kürschner

Palaeoecology, Institute of Environmental Biology, Faculty of Science, Utrecht University, Laboratory of Palaeobotany and Palynology, Utrecht, The Netherlands. e-mail: m.ruhl@uu.nl

The Triassic-Jurassic transition is a period of major biotic turnovers in both the marine and terrestrial realm. This period is characterized by significant perturbations of marine carbon records in Europe and North America. These perturbations are thought to be related to changes in the global carbon cycle, which result from massive input of CO_2 during deposition of the Central Atlantic Magmatic Province, the largest igneous province on earth. The relationship between large fluctuations in shallow marine carbon records and changes in the global carbon cycle can be equivocal. We present organic carbon isotope data from terrestrial records in the Germanic Basin that show a similar isotope signature as in established marine records, with distinct negative shifts of up to 5 per mille. Turnovers in end-Triassic palynological and paleobotanical records indicate changing climatic conditions on land. A major increase of pCO2 values up to 2400 ppmv is suggested (McElwain et al., 1999) from stomatal frequency analysis on leaves from several plant species. In this study we present stomatal frequency analysis data from leaves of a single plant species, *Lepidopteris ottonis*. Fossil leaves of this extinct seed fern were collected from three stratigraphically different organic rich levels in a single outcrop in the Germanic Basin. Decreasing stomatal index values indicate rising CO2 concentrations in the transition to the Jurassic that may be related to CAMP volcanism.

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DOES THE EVOLUTION OF BIOCONSTRUCTOR ORGANISMS REFLECT THE CLIMATIC CHANGES DURING THE TRIASSIC OF THE DOLOMITES?

Russo F.

Dipartimento di Scienze della Terra, Università della Calabria, Italy.
e-mail: f.russo@unical.it

The Triassic belongs to "Hot House" times. The interior of Pangea was hot and dry during the Triassic. Warm Temperate climates extended to the Poles. There was no ice at either North or South Poles. This is the global climate scenario at very large scale, proposed on the basis of sedimentological, paleontological and geochemical data. The data on oxygen isotope ratios, measured in fossils (Veizer et al., 1999; Veizer, 2004), seem to indicate a slight trend of temperature decrease for the Triassic period. This tendency seems to be confirmed by the finding of fossil resin in the Upper Triassic of Europe and North America (Arizona, Italy, Germany, Austria, Switzerland). The Triassic of the Dolomites includes many carbonate platform generations, ranging from Anisian to Norian-Rhaetian in age (Russo et al., 1998). After the the Permian-Triassic biological crisis "reef" communities reappeared during the Anisian time. These buildups were generally characterised by a limited relief, lacking any primary skeletal framework and evidence of syndepositional cementation. The microfacies are dominated by micrites, mainly allochthonous or detrital in origin. The sparse biota are generally binder and buffler organisms, as dasycladacean algae, sphinctozoans and briozoans. The second generation of carbonate buildups (late Anisian – early Ladinian, Sciliar Fm) are dominated by syndepositional cements (e.g. Marmolada Platform). These cements represent the main component of margin and upper slope facies. They form more or less isolated or laterally linked bodies: the "evinosponges". During the late Ladinian and Carnian p.p., the post-volcanic platforms developed (Cassian Dolomite). The dominating microfacies component (more than 50%) of these platforms consists of automicrites. The metazoan contribution is certainly subordinated to that of skeletal cyanobacteria, like *Cladogirvanella cipitensis*. The primary marine cements provide evidence of a widespread early syndepositional lithification. Towards the top of Julian Substage (Carnian), at the base of the Heiligkreutz-S. Croce/Dürrenstein Formation (i.e. Alpe di Specie), small calcareous bioconstructions (interpreted as patch-reefs) show much more "modern" faunal association. For the first time in the Triassic, a skeletal primary framework developed, largely formed by calcified demosponges and scleractinians. Corals were still subordinated to sponges. Taxonomic diversity increases greatly and the skeletal component exceeds the 50% of the rock volume. This outstanding biological event can be strongly correlated with the climate change indicated by the finding of fossil resin in Heiligkreuz-Santa Croce Formation (Gianolla et al., 1998; Roghi et al., 2006). These biofacies anticipate the "modernization" of the reef-building communities, occurring at a global scale between the Late Carnian and the Norian-Rhaetian. In the Dolomites the complex evolution of bioconstructor organisms seems to be mainly affected by the paleogeography changes rather than climate variations, except for the Carnian humid event marked by the widespread finding of fossil resin, when appeared skeletal organisms capable of developing a primary framework in the bioconstructions.

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ACID RAIN AND THE DEMISE OF TERRESTRIAL ECOSYSTEMS AT THE TRIASSIC-JURASSIC BOUNDARY

Bas van de Schootbrugge[1], Tracy M. Quan[2], Sofie Lindström[3], Carmen Heunisch[4], Heinz-Gerd Röhling[4], Jörg Pross[1], Jens Fiebig[1], Sylvain Richoz[1], Wilhelm Püttmann[1], Yair Rosenthal[2], Paul G. Falkowski[2]

[1] Institute of Geosciences, Johann Wolfgang Goethe University Frankfurt, Germany
[2] Institute of Marine and Coastal Sciences, Rutgers, the State University of New Jersey, USA
[3] GeoBiosphere Science Centre, Department of Geology, Lund University, Lund, Sweden and Geological Survey of Denmark and Greenland, Copenhagen, Denmark
[4] Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) Geozentrum Hannover, Hannover, Germany
E-mail: van de Schootbrugge@em.uni-frankfurt.de

Carbon dioxide released from flood basalt volcanism is increasingly invoked to explain the loss of marine biodiversity at the Triassic-Jurassic boundary, via brief ocean acidification and long-term greenhouse warming. Simultaneously released SO_2 is generally neglected in extinction scenarios, eventhough total volumes are calculated to be enormous and its impact on terrestrial ecosystems would be more severe than the effects of CO_2. Here, based on high-resolution microfloral analyses of the T-J boundary interval from three drill cores from Germany and Sweden, we show that conifer-dominated gymnosperm forests across NW Europe were abruptly replaced by a vegetation composed predominantly of herbaceous ferns and fern allies. This fern spike interval is characterized by abundant Schizaeaceae and Dipteridaceae ferns, plants that are typical early pioneers of disturbed sites. Coinciding with the fern spike, we find abundant remains of Zygnemataceae, freshwater algae that today bloom in lakes that have been experimentally acidified with sulfuric acid. Northern hemisphere deforestation and fern proliferation appears to have occurred downwind from the Central Atlantic Magmatic Provine, which is consistent with the short-term regional effects of acid rain and soil acidification. Following the fern spike, we observe a low-diversity vegetation mainly consisting of cheirolepids, lycopods and corystosperm seed ferns. The dominance of thermophilous conifers during the Hettangian seems to mark the prolonged effects of CO_2-induced greenhouse warming after sulfur emissions had ceased.

MASS EXTINCTION, CLIMATE CHANGE AND VOLCANISM

Paul B. Wignall

School of Earth and Environment, University of Leeds, Leeds, U.K
e-mail: p.wignall@see.leeds.ac.uk

Mass extinctions are the worst biotic crises in Earth history and their correlation with major palaeoenvironmental change has long been known. Initially, emphasis was placed on the link between major sea-level perturbations and extinctions, but more recently the connection between climate change, and especially global warming, has been championed. The cause of global warming is often linked to the contemporaneous eruption of large volumes of carbon dioxide from large igneous provinces. However, these volumes, whilst substantial, are of a similar magnitude to anthropogenic pollution today. Therefore, many climate-extinction mechanisms invoke a triggering affect for the volcanogenic CO_2 with gas-hydrate reservoirs providing the extra impetus needed to create substantial global temperature rise. Newer mechanisms do not rely on mantle CO_2 releases but instead highlight the likelihood that thermal metamorphism, at sites of large igneous province eruptions, is likely to generate orders of magnitude more CO_2 and methane than purely volcanic sources (the Svensen hypothesis).

The Triassic interval is bracketed by two of the best examples of an extinction-global warming-volcanism link. Thus, the Siberian Traps and Central Atlantic Magmatic Province are considered to have been the ultimate cause of the end-Permian and end-Triassic mass extinctions respectively. A similar chain of events has been proposed for both. Volcanic CO_2 release is thought to have caused minor warming that in turn triggered methane release from hydrate reservoirs and so greatly exacerbated the warming trend. Oceanic circulation in a warmer world is then thought to have become more sluggish (and/or increased nutrient flux fostered higher productivity) with the result that marine anoxia became widespread. This provides a proximate mechanism for marine mass extinction but the link to terrestrial extinctions is far from understood. One possibility is that the oceans leaked hydrogen sulphide into the atmosphere and triggered a complex chain of reactions that ultimately decreased ozone production rates. The terrestrial extinction is therefore linked to increased UV radiation. Every aspect of these extinction scenarios is actively debated and “hard” evidence is often lacking. For example, clear evidence for an end-Triassic oceanic anoxic event is absent. Equally controversially Payne and Kump have proposed that repeated eruptions of the Siberian Traps in the Early Triassic created a series of “mini” end-Permian mass extinction events throughout this interval. The Smithian/Spathian crisis is the best documented example in this interval but whether it was caused by exacerbated global warming, in an already warm phase, is far from clear.

EARLY HISTORY OF CIRCUMPOLLES GROUP

Natalia Zavialova[1], Nicoletta Buratti[2] & Guido Roghi[3]

[1]Paleontological Institute of RAS, Moscow, Russia
[2]Department of Earth Science, Perugia, Italy
[3]Institute of Geosciences and Earth Resources - CNR, Padova, Italy
e-mails: zavial@mail.ru

Members of Circumpolles, existed from the Middle Triassic to Upper Cretaceous, were repeatedly used in the context of stratigraphic, paleobotanical, and paleoclimatological reconstructions. The most typical, advanced, and comprehensively studied member of the group, *Classopollis*, has long been considered as an ecological marker. Much less is known about the morphology, botanical assignment, etc. of earlier members. The lack of such knowledge prevents a broader and more confident application of these pollen types. To fill this gap, Carnian (Southern Alps) and Rhaetian (England) Circumpolles have been studied. Carnian *Duplicisporites granulatus* and *D. verrucosus* show a verrucate exine surface, rimula, and small proximal trilete scar. The ectexine is formed of small granules, more numerous and distinct toward the inner hollow. The endexine appears homogeneous, of constant thickness. The rimula is formed by an abruptly thinned ectexine. The general morphology and ultrastructure of Carnian *Diplicisporites* is much more primitive than those of *Classopollis*. The Rhaetian specimens belong to several species of *Corollina* and represent one of the earliest records of this genus. Although they show a certain degree of variability (that, in particular, concerns the presence and development of the endexine), the infratectum is formed by one layer of large and rather widely spaced granules. A transformation is conceivable: an infratectum of numerous and rather small granules (Carnian pollen) could transform in an infratectum of large granules arranged in one row (Rhaetian pollen), which, in its turn, could transform in a columellate-like infratectum, which is the most striking and well-known feature of *Classopollis* and is detected in younger members of the group. The possibility of such morphological transformation implies that, in spite of the absence of data about *in situ* occurrence of non-*Classopollis* members of Circumpolles, the early members of the group most probably were produced by plants of the same conifer family or its ancestor. There are some other indications of cheirolepidaceous affinity of early Circumpolles: in the Carnian of the Julian Alps cheirolepidiaceous shoots are accompanied by numerous Circumpolles in the palynological assemblage.