ALBERTIANA

NOVEMBER 1999

23

ISSN 0619-4324

ALBERTIANA

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ALBERTIANA 22 was compiled and edited by Hans Kerp with the help of an editorial committee consisting of: Aymon Baud (Lausanne), Spencer G. Lucas (Albuquerque) Mike Orchard (Vancouver), Tim Tozer (Vancouver) and Henk Visscher (Utrecht). The editorial committee does not review contributions but provides - when needed - linguistic help to non-English speaking contributors.

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

CONTENTS ALBERTIANA 23

Cover: from O.A. Welter (1922): Paläontologie von Timor. XI. Lieferung

SEE PAGE 35 FOR METHODS OF PAYMENT OF ALBERTIANA

BALLOT FOR THE EXECUTIVE OF THE ICS SUBCOMMISSION ON TRIASSIC STRATIGRAPHY

In accordance with ICS requirements the Chairman of the Subcommission on Triassic Stratigraphy has asked Voting Members of the Subcommission to vote on the officers who will form the Executive of the Subcommission for the period from 2000 until 2004. The present Chairman (M. Gaetani) and one Vice-Chairman (H. Rieber) wish to retire from the Executive in 2000.

The following were proposed as officers of the Subcommission for 2000-2004:

- Chairman: M. Orchard, Geological Survey of Canada, Vancouver
- Vice-Chairman: Yu. D. Zakharov, Vladivostock, Russia
- Vice-Chairman: Yin Hongfu, China University of Geosciences, Wuhan
- Secretary-General: G. Warrington, British Geological Survey, Nottingham

The results of the ballot are as follows:

- Responses: 18 (Y= For; N = Against; A = Abstention)

• Proposed Chairman:	(M. Orchard)	Y (18)	N (0)	A (0)
• Proposed Vice-Chairman:	(Yu. D. Zakharov)	Y (16)	N (1)	A (1)
• Proposed Vice-Chairman:	(Yin Hongfu)	Y (16)	N (1)	A (1)
• Proposed Secretary-General:	(G. Warrington)	Y (16)	N (1)	A (1)

M. Gaetani
Chairman, Subcommission on Triassic Stratigraphy

G. Warrington
Secretary-General, Subcommission on Triassic Stratigraphy

October 1999

From the editor

The publication of this issue of Albertiana is delayed considerably because some important contributions were received very late. By the time they arrived the rest of the issue had already been edited and made ready for the press. Nevertheless, teaching obligations and administrative duties caused an extra delay and therefore I was unable to finish this issue timely.

As you may have noticed ALBERTIANA has also been issued on the worldwide web. However, due to the limited amount of server space available, only No. 21 and No. 22 (partly) have been launched. Anyone who has server space available for hosting the online edition of Albertiana is requested to contacted the editor.

Hans Kerp
Editor of Albertiana

REPORT ON THE INTERNATIONAL CONFERENCE ON PANGEA AND THE PALEOZOIC-MESOZOIC TRANSITION

WUHAN, PEOPLE'S REPUBLIC OF CHINA, 9-11 MARCH, 1999

This conference was held at the China University of Geosciences, Wuhan, People's Republic of China, and was attended by 66 geoscientists from 11 countries. Some delegates participated in pre-conference excursions to examine the Permian and Triassic sequences at Meishan in northern Zhejiang, Xifanli in southeastern Hubei or Penglaitan in eastern Guangxi, or attended a post-conference excursion to the Yangtze Gorges area.

During the three days' symposium in Wuhan, 44 contributions, including 5 keynote addresses and 17 posters, on the stratigraphy, palaeontology, geochemistry, plate tectonics, palaeogeography and sedimentology of the Permian-Triassic transition period were presented. The range and diversity of the contributions was such that it is beyond my capacity to summarise them all. However I would like to take this opportunity to mention just a few; I beg your pardon if I omit reference to many of the valuable contributions.

One interesting aspect of the talks concerned eastern Pangea and especially the Tethys. Was the Tethys a vast ocean which disappeared during later subduction, was it an archipelagic ocean or, a third possibility not considered during the conference, was it merely a seaway, especially between Karakorum and Turkey? Was South China, for example, an integrated microplate or a mosaic of blocks? Several authors mentioned a polycyclic orogeny or 'riftogenesis' in the Kunlun, Yidun and Three Rivers regions, and a non-Wilson cycle characterized by an archipelagic ocean, a soft collision and a multi-phased orogeny was suggested; these possibilities need further investigation.

The paleobiogeography of Pangea attracted interest. Cool water conodonts were mentioned, especially Vjalovognathus. The cosmopolitan distribution of Hindeodus parvus evoked some suggestions. Occurrences of elements of the Glossopteris flora in South Primorsk, SE Mongolia, and probably North China, and of a temperate fauna in Kitakami were discussed; do these represent a bipolar distribution, or a biotic expansion due to some factors, or are they evidence of Gondwanan dispersal and Eurasian accretion? Answers to these questions will probably result in a radical reinterpretation of eastern Pangea and the Tethys, and in reconstructions very different from the traditional ones found in current literature.

The Permian-Triassic transition, extinction and boundary formed a highlight of the conference. Permian-Triassic boundary sections in Arctic Canada, Oman, Australia, Iran, China and other countries were discussed with reference to the Meishan section, using many methods other than bio- and lithostratigraphy, such as isotope studies (carbon, cerium and other elements), isotopic dating, palaeomagnetism, studies of peat-mire ecosystems, and bed by bed high-resolution interregional correlation. The development, extinction and recovery of ammonoids, foraminifera and conodonts, as well as radiolarians and other deep-water fauna elements, was indicated and discussed. The isotopic dating of the boundary in the Meishan section is consistent from bed by bed according to one recent publication but less so according to other authors. Two points of the extinction were emphasized; (a) the causes were mainly terrestrial, though a recent

publication suggesting an extraterrestrial impact cannot be ignored; (b) that it occurred in stages rather than at one stroke. However, how many steps were involved, two or many and, more importantly, was there a major extinction episode at the level taken as the Permian-Triassic boundary? If these two points are real, we still need to know whether extinction was due to a global stress-release event or, as indicated by ammonoids, to eustatic control. Why did volcanism, anoxia, the $\delta^{13}C$ excursion, the great R-T turning point, a palaeomagnetic anomaly and the grandfather of all extinctions occur together? Among the possibilities the anoxia theory appears unlikely because of oxygen-dependent bioturbation at the Permian-Trassic boundary. Clarification of the causality of these events will enhance our ability to predict our own future in a world which is undergoing another biotic crisis.

Permian and Triassic stratigraphy was another highlight. Permian chronostratigraphic subdivision, sequence stratigraphy, biostratigraphy and biota, including plants, reefs, trace fossils, ammonoids, etc., were discussed in detail. It is worthwhile mentioning the proposal for the Penglaitan section as a candidate GSSP for the base of the Lopingian, with the boundary marked by Clarkina postbittneri. In the Permian 31 conodont zones have been established based on the correlation of South China, USA, Salt Range, Kazakhstan and Iran. This gives a resolution of c.1 Ma per zone, better than achieved by other biostratigraphic schemes for the subdivision of the Permian. The conodont zonation coincides with the amplitude frequencies of sea level change. Some papers cast doubts on the Exxon model of sequence stratigraphy based on passive margin with a slope, emphasizing tectonic control, and relative rather than eustatic sea level changes (i.e. in Spitzbergen), and different tract subdivision within a sequence.

Many paleontological discoveries were presented during the conference, including, for example, the first vertebrate, a fish-like fossil (Cyclostomata?) from the lowermost Cambrian Chengjiang Fauna of SE Yunnan, and the initiation of Mesozoic Pumellina, possible Nassellina radiolarians, in the Late Permian.

This conference has, like other symposia, resulted in more questions than answers but these stimulate research and lead to progress. For example, we need more investigations towards a better understanding of Pangea and Tethys. We need new approaches to high-resolution stratigraphy with the pros and cons of susceptibility being worthy of note. Macrofossils such as ammonoids, which were the main biostratigraphic tool for nearly a century, have been succeeded in importance by microfossils such as conodonts in the last two decades but even these only give a resolution of 1 ma per zone; this is inadequate. Stratigraphy seems to have developed in an upward spiral way, from biostratigraphy-dominated, through a decoupled multidisciplinary stratigraphy to more or less sequence stratigraphy-dominated; what is the post-sequence stratigraphy stage? In the future the most difficult challenge lies in pre-Cambrian strata, mute or dumb strata, and orogenically deformed strata; will geochemical and palaeomagnetic markers Milankovitch cycles, and molecular palaeontology, involving biomarkers and DNA, provide higher resolution and resolve the mute strata problem?

In summary, I hope this meeting has given an impetus to the investigation of these important aspects of geosciences and I would like to mention that our Australian friend John Rigby has suggested that the next Pangea and Tethys meeting should be held in Brisbane within 3-5 years, and that he is also trying to organize a new IGCP project.

This conference was co-sponsored by the National Natural Science Foundation of China (NSFC), the Global Sedimentary Geology Program (GSGP), the Paleontological Society of China (PSC), the ICS Subcommission on Permian Stratigraphy (SPS), the ICS Subcommission on Triassic Stratigraphy (STS), the International Paleontological Association (IPA), and the China University of Geosciences (CUG), and was aided financially by the NSFC, PSC and CUG. The conference

proceedings, including 14 full papers and 58 abstracts, were published by the China University of Geosciences Press, Wuhan. Details of this publication, including how to order it, appear in a separate notice

Professor Yin Hongfu
China University of Geosciences

THE MEISHAN SECTION, GSSP CANDIDATE FOR THE PERMIAN-TRIASSIC BOUNDARY

The State Council of China has approved to set Changxing County, Zhejiang Province as an open region. The Meishan section, GSSP candidate for the Permian-Triassic Boundary, is located in this county. An open region means that any foreigner with valid visa can enter this area and do research work. The openness will satisfy one necessary requirement of GSSP as indicated in the ICS Guide.

Yin Hongfu
Chairman: Permian-Triassic Boundary Working Group

Additions to and corrections of STS membership records published in ALBERTIANA 22

Unfortunaley Dr. Attila Vörös, who was elected as a corresponding member at the STS meeting in Lausanne in 1991, was not listed in ALBERTIANA 22. His records are:

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NEW BOOKS

Proceeding of the International Conference on PANGEA AND THE PALEOZOIC-MESOZOIC TRANSITION Edited by YIN Hongfu and TONG Jinnan (1999), 175 pages, 1 plate

This book consists of two parts, including 14 papers in Part I and 58 abstracts in Part II. The conference gathers contributions of scientists who are interested in the special interval of Pangea and Permian-Triassic transition, for discussing Pangea formation and dispersion; global changes related to Pangea integration and break-up; biotic crisis, extinction, recovery and evolution at the Paleozoic-Mesozoic transition; and Tethys evolution during Pangea interval. It is natural that stratigraphy and paleontology comprise the large bulk.

Copies can be bought by transferring US $ 30.- (includes airmal delivery) the money to "Bank of China Wuhan City, Guang Bu Tun Agency", account no. 4668366-0114-0011334 (Peng Yuanqiao).

Order Form: Send to: Peng Yuanqiao
Faculty of Earth Science
China University of Geosciences
Wuhan 430074, China

Herewith I order ____ copy (copies) of the book "Proceeding of the International Conference on PANGEA AND THE PALEOZOIC-MESOZOIC TRANSITION" (edited by YIN Hongfu and TONG Jinnan, 1999). I include a cheque of $_____ .

Signed _____

Address:

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Proceedings of the 'EPICONTINENTAL TRIASSIC' Symposium, Halle, 1998

The proceedings of this meeting will be published by Schweizerbart'sche Verlag, Stuttgart, and appear, appropriately, in three volumes of Zentralblatt fuer Geologie und Palaeontologie Teil I, bearing the symposium logo. Thee editing was completed in May this year and the proceedings, comprising 52 articles, were delivered to the publisher at the beginning of June. The first volume is expected to appear in December 1999, with volumes 2 and 3 following in January or February 2000. The complete work will comprise about 1200 pages and include 350 figures. Order forms will be distributed to symposium participants.

The appearance of these proceedings will be a memorable Millenium event which everyone involved with studies of the Triassic will be looking forward to; everyone involved with their production is to be congratulated on the rapid progress towards publication.

Norbert HAUSCHKE & Volker WILDE (Eds.) - TRIAS - Eine ganz andere Welt Mitteleuropa im frühen Erdmittelalter.

636 pp., ca. 600 Figs. ISBN 3-931516-55-5.

This book will appear in November-December 1999 and can be ordered from: Verlag Dr. Friedrich Pfeil · P.O. Box 65 00 86 · D-81214 München · Germany. Fax +49 - 89 - 72 42 772 · e-mail: 100417.1722@compuserve.com. The price is: DM 156,47 / Euro 80,-

Contents

Other new books of interest for Triassic workers

- **The Petroleum Geology of NW Europe: Proceedings of the 5th Conference**
  These proceedings (ISBN 1-86239-039-8) have just been published by the Geological Society of London in 2 hardback volumes comprising 1408 pages; many of the articles are relevant to the Triassic of the region.

- **Atlas of Palaeogeography and Lithofacies.** Geological Society Memoir No.13 (Revised A4 format edition, 1999)
  This atlas was first published in 1992 in A3 format. It covers the British Isles region; the Triassic section was contributed by Warrington and Ivimey-Cook.

Other recent publications from the Geological Society of London which contain articles relevant to the Triassic are:

- Development, Evolution and Petroleum Geology of the Wessex Basin Geological Society Special Publication No.133, 400pp, 1998.
- Petroleum Geology of the Irish Sea and Adjacent Areas. Geological Society Special Publication No.124, 408pp, 1998.

Information about these and other Geological Society of London publications may be obtained from:

The Geological Society Publishing House,
Unit 7, Brassmill Enterprise Centre,
Brassmill Lane,
Bath BA1 3JN, UK.

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e-mail: angeld@geolsoc.org.uk
http://bookshop.geolsoc.org.uk

OMAN PANGEA SYMPOSIUM AND FIELD MEETING: 12-16 January 2001

First announcement

On the occasion of the International Conference on the Geology of Oman organized by the Directorate General of Minerals, Sultanate of Oman, at Sultan Qaboos University, Seeb/Muscat, 12-16 January 2001, we are planning an Oman Pangea Symposium and field meeting.

This Oman Pangea Symposium and field meeting will be co-sponsored by the Global Sedimentary Geology Program (chairman Dr. Benoit Beauchamp), by the International Subcommission on Permian Stratigraphy (chairman Dr. Bruce R. Wardlaw) and by International Subcommission on Triassic Stratigraphy (chairman Prof. Maurizio Gaetani). The Symposium will take place within the "Southern Tethys and Arabian Continental Margin" topic of the Conference (Prof. Alastair Robertson).

SCIENTIFIC ORGANISERS OF THE SYMPOSIUM AND FIELD MEETING: Dr. Aymon Baud and Prof. Jean Marcoux with the help of the BRGM and other experts.

OBJECTIVE: With the presentation of new and recent results on Permian and Triassic sediments of Oman, the aim of the Symposium and field meeting are to provide a forum to geologists who are interested in the time interval of Pangea for discussing global changes related to Pangea integration, North Gondwana and Central Tethys evolution; It will be an unique opportunity for sedimentologists, stratigraphers and palaeontologists who are working within the Permian and

Triassic time interval, biotic crisis, extinction, recovery and evolution at the Paleozoic-Mesozoic transition to discuss, to look and to sample at the spectacular Permian and Triassic outcrops belonging to the Oman former continental margin, from shallow shelf to deep marine sediments and sea mounds.

GENERAL THEME: Pangea and Tethys, moving plates and environmental changes.

SECONDARY THEMES: Progress in the Permo-Triassic stratigraphy and palaeontology of the central Tethys and its Gondwana margin; Comparison between the Permo-Triassic continental margins of Oman, Northern India (Himalaya) and Northern Australia.

PROPOSED FIELD EXCURSIONS:

PANGEA PRECONFERENCE EXCURSION 1

Lower to middle Permian sedimentation on the Arabian Platform : the Huqf area (S Central Oman)

Leaders: L. Angiolini, J. Broutin, J. Roger
Date: January 7-11 2001

Located in the south eastern margin of the Arabian plate, the Huqf area (Sultanate of Oman) is a region marked by gentle deformed and uplifted Paleozoic formations.The lower to middle Permian is represented as part of two mega-sequences. The first one consists of a basal succession, beginning with upper Westphalian to Sakmarian glacial deposits, forming the Al Khlata Formation, succeeded by the transgressive marine deposits of the Saiwan Formation marking the complete deglaciation of the region. This latter unit of late Sakmarian age, has yielded a rich and very well preserved brachiopod fauna (studies of L. Angiolini). Overlying unconformably, the upper megasequence is made of a thick fluvial terrigenous unit (Gharif Formation). This sequence terminates with highly fossiliferous (ostracodes, small forams, brachiopods, mollusks, trilobites etc.) marine transgressive deposits of marly carbonate (Khuff Formation), of which only the Kubergandian-Murgabian (Wordian) parts are exposed. This succession represents a key-section for the intercalibration of early to middle Permian marine and continental biostratigraphical scales. The newly named *"Gharif Paleoflora"*, studied by J. Broutin and his students, is erected as a standard for the Arabian Peninsula. This warm humid assemblage is of outstanding paleogeographic significance with associated Gondwanan, Cathaysian and Laurasian floral elements.

PANGEA PRECONFERENCE EXCURSION 2

Permo-Triassic deposits of the Oman margin: from slope to basin and seamounts

Leaders: A. Baud, F. Cordey, L. Krystyn, J. Marcoux
Date: January 8-11, 2001

The mountainous belt located in the eastern part of the Arabian Peninsula, the Oman Mountains, expose a segment of the Gondwanian margin interpreted as a flexural upper plate. During the end of Cretaceous, this segment was sliced and brought on the Arabian continent with the obduction of the ophiolite, part of the Tethyan ocean. Following a lower Permian rifting phase and middle Permian break-up (birth of the Neotethys) a wide carbonate platform developed during late Permian and Triassic times on the inner part of the margin. Carbonates derived from the platform represented the major source for the thick sequence of slope carbonates deposited near the platform margin. On more distal parts, the basinal and oceanic sedimentation resulted in various types of carbonate, of cherts and siliciclastic deposits, presently found in

the Hawasina Nappe. Pelagic sediments deposited on submarine elevated sectors or seamounts are present as blocks of various dimensions, -the Oman Exotics, cropping out both sides of the "Autochtonous" tectonic window. Spectacular and well studied outcrops in the Wadi Wasit, Ba'id, Jebel Musjah and Jebel Misht areas allowed to reconstruct the former geometry of the margin during Late Permian and Triassic time.

PANGEA POSTCONFERENCE EXCURSION 3

Permo-Triassic deposits of the Oman margin: from shallow water to base of slope

Leaders: A. Baud, F. Cordey, J. Marcoux
Date: January 17-20, 2001

The mountainous belt located in the eastern part of the Arabian Peninsula, the Oman Mountains, exposes a segment of the Gondwanian margin, interpreted as a flexural upper plate. The Permian-Triassic sequence deposited on the inner part of this margin is exceptionally well exposed in the Jabal Akhdar Mountains, as part of the "autochtonous" which crops out in a large tectonic window. The Permian and Triassic shallow water carbonate rocks occurring in this area belong to the Akhdar Group, with two main lithologic units: the Saiq and Mahil Formations. The Saiq Formation, about 700m thick and made up of three transgressive - regressive cycles, overlies unconformably Precambrian strata, documenting the upper Permian marine transgression. The following 800m thick Triassic dolomitic Mahil Formation confirms the cyclic and restricted shallow marine environment upward. Carbonates derived from the platform represented the major source for the thick sequence of slope carbonates (the Sumeini Group) deposited near the platform margin, cropping out in the Sumeini area near the border between Oman and the United Arab Emirates. The lower part of this Group (about 1700 m thick) is included in the Maqam Formation, late Permian to late Triassic in age. Key section of the Oman margin architecture, the Wadi Maqam has been re-investigated in terms of biochronology, sequence and isotope stratigraphy.

FURTHER INFORMATION: by Aymon Baud, Geological Museum, UNIL-BFSH2, CH-1015 Lausanne, Switzerland, tel.: xx41 21 692 44 71, fax xx41 21 692 44 75, e-mail aymon.baud@sst.unil.ch and after September 99, directly on the following web site: http://www.geoconfoman.unibe.ch

Friedrich von Alberti-Prize 1999

The Friedrich von Alberti-Prize 1999 has been awarded to Mr. Werner Kugler from Crailsheim near Schwäbisch Hall, Germany. This prize which consists of a sum of DM 20,000.- is given each year by the Friedrich von Alberti Stiftung of the "Hohenloher Muschelkalkwerke", either to a professional scientist or to an amateur palaeontologist. This years recipient, Mr. Werner Kugler, is a hobby palaeontologist who received the prize in recognition of his important discoveries, excavations and preparation of Keuper vertebrates from Baden-Württemberg. For many years Mr. Kugler closely cooperates with several professional palaeontologists and museums. The prestigeous award has been presented on 12 November 1999. On this occasion a special exhibit entitled "230 Millionen Jahre alte Saurierfunde aus Sammlung Werner Kugler" is currently on display in the Muschelkalk-museum Hagdorn in Ingelfingen

MAIN TRENDS IN PERMO-TRIASSIC SHALLOW-WATER TEMPERATURE CHANGES: EVIDENCE FROM OXYGEN ISOTOPE AND Ca-Mg RATIO DATA

(Annual Report 1999 of PTBWG and IOBWG)

Yuri D. Zakharov, Natalia G. Boriskina, Anna K. Cherbadzhi and Alexander M. Popov
Galina V. Kotlyar

Introduction

The first and very scanty isotope paleotemperature studies of the Permian-Triassic were apparently successfully made by Dorman & Gill (1959), Compton (1960) and Lowenstam (1964) in Australia, by Kaltenegger (1967), Fabricius et al. (1970), Morante & Hallam (1996) in the Alps, and by Zakharov et al. (1975) and Golbert et al. (1984) in Arctic Siberia. Results on pre-Permian isotope studies seem to be not very satisfactory (Bowen, 1969).

The objective of the present report is to show the main trends in late Paleozoic and early Mesozoic temperature changes using oxygen isotope and Ca-Mg methods.

Methods

Three methods of paleotemperature measurements are known: (1) oxygen isotope thermometry (Urey, 1948; Epstein et al., 1953; Anderson & Arthur, 1983; Grossman & Ku, 1986), (2) Ca-Mg ratio thermometry (Berlin & Khabakov, 1974), and (3) a paleobotanical method, based on leaf physiognomy (Wolfe & Upchurch, 1987; Spicer et al., 1996; Herman & Spicer, 1997). In this stage only the two first methods have been used for the reconstruction of the Permian-Triassic climate. Isotope thermometry seems to be the most accurate method if carbonate material without any marked diagenetic alteration for analyses is used.

Oxygen isotope, as well as carbon isotope measurements made in the Far Eastern Geological Institute (FEGI), Vladivostok, using a modernized MI-1201B mass spectrometer - «Iskra-1256»-PRM-2 complex. The laboratory gas standard is calibrated to V-SMOW and KH-2 standards. The laboratory standard used in the measurements has been calibrated relatively to calcite NBS (National Bureau of Standards) 19 and equals $+3.98 \pm 0.10$‰ for oxygen relatively to PDB (Pee Dee belemnite) and -0.75 ± 0.10‰ for carbon. Reproducibility of replicate standards was always better than 0.1‰. Two scales were used parallel for interpreting «paleotemperatures» on the basis of $\delta^{18}O$ values: those of Epstein (1953) modified by Anderson & Arthur (1983) and Grossman & Ku (1986).

The Ca-Mg method can not be used, strictly speaking, for paleotemperature measurements in the variant offered by Berlin & Khabakov (1974) because some variations in marine Ca-Mg ratios

recorded in organogenic carbonate may be related to variations in several environmental factors, including the thermal one (Ignatyev et al., 1976; Krasnov & Pozdnyakova, 1982), although the latter is often dominant. Therefore, we show these so-called paleotemperatures values in inverted commas (« »).

For Ca-Mg calculation a chemical analytical method of the complex titration was used. The reproducibility of the analysis was better than 5%.

X-ray analyses were carried out using a DRON-3 diffractometer following the method of Davis & Hooper (1963) for the purpose of determining the phase composition and quantitative calcite-aragonite ratio. The data obtained, together with the results of study of shell microstructure under the SEM, were used as a criterion in determining the degree of diagenetic changes in the original shell material.

Material

Oxygen and carbon isotopes were determined for well-preserved brachiopod shells from the Dorashamian of Transcaucasia (Akhura Suite) and Dorashamian of North Caucasus (Nikitinskaya and Urushtenskaya Suites) and ammonoid shells from the Gzhelian of the Urals, the Lower Olenekian, the Upper Olenekian and the Upper Anisian of Arctic Siberia (Buur River basin, lower reaches of Olenek River and Taimir) preserved as aragonite (Y.D. Zakharov, B.V. Koczirkevicz, A.V. Popov and M.N. Vavilov's collections).

For Ca-Mg analyses were made utilizing limestone material from the Murgabian (Gnishikskaya Suite) of Transcaucasia, the Midian of Transcaucasia (Arpinskaya and Khachikskaya Suites), South Primorye (Chandalaz Suite) and the South Kitakami (Kanokura Formation), the Dzhulfian of Transcaucasia (Akhura Suite), South Primorye (Lyudyanza Suite) and the South Kitakami (Kanokura Formation), Dorashamian of Transcaucasia (Akhura Suite), North Caucasus (Nikitinskaya and Urushtenskaya Suites) and South China (Dalun Formation), Induan and of Transcaucasia (Karabaglyar Suite) and North Caucasus (Yatyrgvatinskaya Suite), and the Anisian of North Caucasus (Malotkhachskaya Suite). All limestone samples were collected by Y.D. Zakharov.

Paleotemperature estimation

Carboniferous

Lowenstam (1961) obtained unusually low $\delta^{18}O$ values for brachiopod shells from the Lower Carboniferous (Mississipian) in Australia, which could be related to an effect of diagenetic alteration (obtained paleotemperatures reach from 24.7° to 30.0°C).

We have investigated aragonitic ammonoids from the Upper Carboniferous of the Urals. Shells of two species of goniatites from the Gzhelian of Sakmara River were isotopically analyzed - one shell of *Aristoceras chkalovi* Ruzhencev of moderate size and three small shells of *Glaphyrites* sp. (A.V. Popov's collection).

The *Aristoceras chkalovi* shell has a diameter of 26 mm. Its intact white layer consists in its central part of two well preserved carbonate layers with an outer prismatic and nacreous primary structure (Zakharov et al., 1987). The aragonite content, where the whorl height is 25.8 mm, is 82 ± 3%. An insignificant amount of α-quartz occurs in the shell. The $\delta^{18}O$ value is +0.8‰ and $\delta^{13}C$ value equals +0.5‰ (Table 1).

Sample no.	Ammonoid species	Locality, stage	Location (H, mm)	Aragonite content, %	Admixture (except for calcite)	$\delta^{13}C$ (PDB) ‰	$\delta^{18}O$ (PDB) ‰	T°C
890-3	*Aristoceras chkalovi* Ruzhencev	Sakmara River, Gzhelian	25.8	82 ± 3	α-SiO_2 (little)	-0.5	-0.8	18.9
890-6	*Glaphyrites* sp.	-»-	Side walls of 3 small specimens	87 ± 3	α-SiO_2 (very little)	-2.2	+0.4	36353

Table 1. Isotopic paleotemperatures for the Early Carboniferous of the Urals

The diameter of the analyzed *Glaphyrites* sp. shells is 11-14 millimeters. These shells are also white. Most of the shell fragments have a nacreous layer; an outer prismatic layer was found on only one fragment (Zakharov et al., 1987). A large amount of aragonite (87 ± 3%) occurred in a complex sample of three small shells but the amount of α-quartz was very small. The $\delta^{18}O$ value is +0.4‰ and the value of $\delta^{13}C$ is -2.2‰.

On the basis of data from aragonitic ammonoid shells from Sakmara River $\delta^{18}O$ and $\delta^{13}C$ values close to the real values were for the first time obtained for the Carboniferous. Gzhelian isotopic paleotemperatures for the middle latitudes of the North Hemisphere seem to have fluctuated from 13.7° to 18.9°C.

Early Permian

Compston (1960) and Lowenstam (1961) obtained low isotopic paleotemperature values (6.7-7.7°C) from some brachiopod shells from Sakmarian deposits of glacial origin in Australia and higher temperatures (17.4-23.7°C) from spiriferid shells of the upper Artinskian in Australia. Similar isotopic paleotemperatures (19.4-22.0°C) were recognized from the Permian molluscs of Tasmania (Dorman & Gill, 1959).

Paleotemperature estimates obtained for the Early Permian (Artinskian?) of the northern hemisphere were based only on Ca-Mg ratio method. Paleotemperatures calculated from limestones of the Sakamotozawa Formation (Kabayama member) in Kanokurasawa-Kattisaws Valley area, South Kitakami give values of «15.8°«»- «16.6°C«» (Table 2). As was shown earlier (Zakharov et al., 1997), Kabayama member limestones are characterized by high values of $\delta^{13}C$ (up to 4.7‰) in the middle part.

The investigated brachiopod shells from the Kungurian of South Primorye were found to be useful for isotopic analyses, but only the carbon isotopic composition seems to have been preserved in them as original (Zakharov et al., 1997).

Middle Permian

The results of study of light-colored shells of the three brachiopods *Araxathyris araxensis* Grunt from the Midian and Dzhulfian transition beds (*Pseudodunbarula arpaensis - Araxilevis intermedius* Zone) of the Vedi region in Transcaucasia show that their $\delta^{18}O$ value varies from -3.1 to -3.7‰, corresponding to comparatively high paleotemperatures (25.2°, 25.6° and 27.9°C).

Ca-Mg ratio paleotemperatures obtained from limestones of the Murgabian and the Midian-Dzhulfian transition in Transcaucasia fluctuate from «15.3°C» to «16.9°C» and from «15.1°C» to

«15.9°C» respectively. Midian Ca-Mg ratio paleotemperatures from South Primorye seem to be «14.4-16.5°C», from Kitakami - «15.3-18.3°C» (Table 2).

Sample no.	Brachiopod species	Locality, stage, Zone	Location (L, mm)	$\delta^{13}C$ PDB, ‰	$\delta^{18}O$ PDB, ‰	T°C
522-13-1	*Araxathyris araxensis araxensis* Grunt	Transcaucasia, Vedi, Midian, *Pseudodunbarula arpaensis - Araxilevis intermedius*	12.0	+3.2	-3.2	25.6
522-13-3	-«-	-«-	15.0	+3.3	-3.1	25.2
522-13-4	-«-	-«-	19.0	+4.0	-3.7	27.9
515-1-1	*A. ogbiensis* Grunt	Transcaucasia, Akhura, Dorashamian, *Paratirolites kittli*	11.0	+2.8	-2.9	24.2
515-1-3	-«-	-«-	11.0	+2.4	-2.4	22.0
551-4a	*Linoproductus* sp.	North Caucasus, Nikitian Ravine, uppermost Lower Dorashamian (Nikitinskaya Suite)	40.0	+2.9	-2.8	23.8
571-1	Productida	North Caucasus, Neizvestnaya Ravine, lower Upper Dorashamian (Urushtenskaya Suite)	35.0	+1.0	-2.9	24.2
571-1a	-«-	-«-	30.0	2.2	-2.8	23.8

Table 2. Isotopic paleotemperatures for the Late Permian of Transcaucasia and North Caucasus

Late Permian

Data from study of the isotopic composition of well-preserved shells of the brachiopod *Araxathyris ogbinensis* Grunt from the Dorashamian *Paratirolites kittli* Zone of the Akhura region of Transcaucasia give evidence of some increase in the $\delta^{18}O$ level (up to -2.9‰) in Transcaucasia in the Dorashamian stage in comparison with Midian-Dzhulfian transition time, which illustrates the fall of temperatures from 25.2-27.9°C to 22.0-24.2°C in low latitudes during the two last stages of the Late Permian. From Ca-Mg data the coldest paleotemperatures for that time were recognized for the middle parts of the Dzhulfian *Araxoceras latissimum* («15.2°C») and *Vedioceras ventrosulcatum* («15.3°C») Zones and for the middle Dorashamian *Iranites transcaucasius* («15.2-15.5°C») and *Shevyrevites shevyrevi* (middle part) («15.3°C») Zones (Table 2). Therefore the mentioned fall of temperature during Dzhulfian-Dorashamian time was apparently irregullar.

In addition isotopic paleotemperatures for the end Permian were obtained from a well-preserved light-coloured *Linoproductus* shell from Nikitinskaya Suite of North Caucasus (23.8°C) (Table 2). Kotlyar, Pronina and Nestell (Kotlyar et al., in prep.) consider the Nikitin limestones to be late Changhxingian in age because they are characterized by the foraminifer *Colaniella parva* (Colani) and by some representatives of the fusulinid genus *Palaefusulina.* However, according to Zakharov's opinion, based mainly on the correlation of the positive carbon isotope anomalies recognized in both the *Paratirolites kittli* Zone in Transcaucasia and the Nikitinskaya Suite in the North Caucasus (Zakharov et al., 1999b), they seem to be latest early Dorashamian in age. Besides, according to data from South Primorye, the *Colaniella parva* beds are positioned below the late Changhxingian *Huananoceras qianjiangense* beds (Zakharov & Oleinikov, 1994). In Kitakami, *Colaniella parva* occurs at same level, but no trustworthy latest Changhxingian fossils have discovered there.

The oxygen isotope composition of productid shells from the lower part of the late Dorashamian Urushtenskaya Suite (*Xenodiscus koczirkeviczi - Dushanoceras valeriae* beds) in the North Caucasus is very similar to that of the *Linoproductus* shell from the Nikitinskaya Suite. Their $\delta^{18}O$ values fluctuate from -2.8 to -2.9‰, which corresponds to isotopic paleotemperatures of 23.8-24.2°C, but their $\delta^{13}C$ value significant by lower than $\delta^{13}C$ of the uppermost Lower Dorashamian organogenic carbonates (1.0-2.2‰).

Early Triassic

There is no information on isotopic paleotemperatures for the Induan. At the same time early Induan paleotemperatures were calculated from the Ca-Mg ratio of limestones from Transcaucasia in detail. Three drops in temperature were discovered from limestones of the lower part of the lowermost Induan *Lytophiceras medium* Zone («14.4°C») and («14.0°C») and limestones of the lower part of the overlying *Gyronites* Zone («14.7°C»). The limestone of the middle part of the Induan *Gyronites* Zone shows higher temperature («16.5-16.7°C»). Similar paleotemperatures («16.5°C») show a Ca-Mg analysis of some Induan («16.5°°C») and Olenekian («14.5-16.0°C») limestones of the North Caucasus.

Isotopic paleotemperatures for Olenekian time of the Early Triassic have been obtained only from mollusc shells of Arctic Siberia. A quarter of a century ago they have been calculated by Teiss using aragonitic material mainly of cephalopod shells (Y.D. Zakharov's collection) from the stratotype section of upper Olenekian Substage at Mengilyakh Creek of the Olenek River (Zakharov, 1974; Zakharov et al., 1975; Teiss, 1979). According to Teiss (Zakharov et al., 1975), who applied a water correction (7.52‰) for the approximate computation of paleotemperatures in the late Olenekian shallow sea of high latitudes, paleotemperatures, with respect to extreme figures of hypothetical primary $\delta^{18}O$ quantities, are between 12.7°C and 25.4°C. Teiss' mean value of 14.5°C is consistent with paleotemperatures obtained from bivalve shells that probably lived in some fully saline basin of Arctic Siberia (Kurushin & Zakharov, 1995).

Recently we obtained some new results on both the early Olenekian and the late Olenekian aragonitic ammonoid shells of Arctic Siberia (Zakharov et al., 1999a,b).

Different sectors of a large *Hedenstroemia hedenstroemi* (Keyserling) shell (up to 200 mm in diameter), from the lower substage of the Olenekian (*Hedenstroemia hedenstroemi* Zone) of the Buur River basin were tested. All these shell sectors were cream-coloured and were almost entirely aragonite (96-98 ± 3%) but their $\delta^{18}O$ values did not exceed -4‰. Abnormally low $\delta^{3}C$ values vary from -1.1 to -0.3‰.

Shells of six species of ammonoids from the *Olenikites spinilicatus* Zone of the Olenek River (Mengilyakh Creek) were tested. The aragonite content in the examined shell of *Olenikites spiniplicatus* (Mojsisovics), *Keyserlingites subrobustus* (Keyserling), *Arctomeekoceras rotundatum* (Mojsisovics), *Boreomeekoceras keyserlingi* (Mojsisovics), and *Nordophiceras schmidti* (Mojsisovics) vary from 80 to 96 ± 3%.

The $\delta^{18}O$ quantity in these shells, despite the different degree of recrystallization (0-20%), is rather stable (from -7.9 to -5.1‰) in most of cephalopod shells the $\delta^{3}C$ quantity varies in a narrow range from -5.4 to -2.4‰.

The low content of the heavy oxygen isotope in the shells of cephalopods of different regions of the world, except for a number of regions in Arctic Siberia (Olenek, River, Buur River basin and Taimir), occurs only with complete or, at least, substantial recrystallization of these shells (replacement of aragonite by calcite, loss of primary microstructure). These data make it difficult to doubt the originality of $\delta^{18}O$ values determined from shells of Triassic cephalopods of Arctic

Siberia, which are made up almost entirely of aragonite (98 ± 2%) and characterized by the good preservation of the original microstructure (Zakharov, 1988, 1996; Zakharov et al., 1987).

In acknowledging the priority of the oxygen isotope composition of the well-preserved shells of Triassic cephalopods and the bivalves associated with them in Arctic Siberia we hereby confirm the validity of the conclusion we drew earlier (Zakharov et al., 1975) after Hallam's (1969) interpretation that some Mesozoic molluscs of the Boreal realm evidently lived under reduced salinity conditions. As an additional confirmation of the priority of the detected $\delta^{18}O$ values of the essentially aragonitic shells in Arctic Siberia, it is possible to assume a definite regularity in the distribution of oxygen isotopes (Zakharov et al., 1998): the mean $\delta^{18}O$ quantities for the Early Olenekian, Late Olenekian and Middle - Upper Anisian fall at different levels (-4.5, -5.9 and -4.2‰ respectively), which cannot be attributed to diagenetic changes.

Sample no.	Ammonoid species	Locality, Zone	Location (H, mm)	Aragonite content, %	$\delta^{13}C$ (PDB) ‰	$\delta^{18}O$ (PDB) ‰	Water correction, ‰	T°C (mean value)
890-4-5	*Hedenstroemia hedenstroemi* (Keyserling)	Kyra-Khos, Terek, *Hedenstroemia mojsisovicsi*	105.0 (right side)	97 ± 3	-0.5	-4.9		
890-4-6	same shell	-"-	105.0 (left side)	98 ± 3	-1.0	-4.2	-6.0	8.8 ?
890-4-2	-"-	-"-	90.0	96 ± 3	-1.1	4.8		
890-4-4	-"-	-"-	98.0	98 ± 3	-0.3	-4.0		

Table 3. Isotopic paleotemperature for the Early Olenekian of Arctic Siberia (Buur River basin)

The question what caused the freshening of seas of the Boreal basin in the early and middle Mesozoic, ascertained by different methods (Gramberg & Spiro, 1965; Ivanovskaya, 1967; Hallam, 1969; Saks & Nalnyaeva, 1966, Saks, 1972; Berlin et al., 1970; Ustritsky, 1970; Zakharov et al., 1975, 1998; Dagys & Kazakova, 1984; Zakharov & Radostev, 1975), and what its scales might have been, remains debatable. If its scales were great, it would be most logical to relate it the early Mesozoic freshening to the melting of polar ice, which could arise due to cooling during the transition between the Paleozoic and Mesozoic. Ustritsky (1970) cites indirect data of the existence of Late Permian glacial deposits in the Boreal region. Dickins (1994), on the other hand, doubts the existense of polar glaciers during the Permian-Triassic transition period. Another possible reason for the freshening of the marginal parts of the Boreal Basin could be the entry of fresh water masses from the land as periodically repeating events (Dagys & Kazakov, 1984), since allowance can be made for some deviation in climatic conditions in the Tunguska region during the Triassic against the background of the arid conditions prevailing in the early Mesozoic (Dobzruskina, 1970).

Our new calculations, applying a water correction (-6.0‰) for approximate computation of paleotemperatures in the shallow water Olenekian sea of Arctic Siberia, give mean values for early and late Olenekian of 8.8°C and 16.2?°C, respectively. An unusually high late Olenekian temperature in Arctic Siberia is also demonstrated by paleobotanical data (Mogycheva, 1981) and findings of remains of warmth-loving dinosaurs (Kurushin & Zakharov, 1995). Dobruskina (1970) initially considered the Early Triassic *Pleuromeia,* occurring widely at low latitudes, to be the leading vegetation form of the Euramerican region.The finding of *Pleuromeia* in the Lower Triassic in Arctic Siberia, including in the upper Olenekian of Mengilyakh Creek (Krassilov &

Zakharov, 1975), demonstrated that the Angarian flora of the Early Triassic differed less from the Euramerican one than was assumed initially. This illustrates, apparently, the low meridional thermal gradient from Arctic Siberia to low latitudes of North Hemisphere at least during the late Olekekian.

Sample no.	Ammonoid species	Locality, Zone	Location (H, mm)	Aragonite content, %	$\delta^{13}C$ (PDB) ‰	$\delta^{18}O$ (PDB) ‰	Water correction ‰	T°C (mean value)
221-1221	*Olenikites spiniplicatus* (Mojsisovics)	Mengilyach Creek, *Olenikites spiniplicatus*	6.8	96±3	-3.9	-7.9		
221-63	*Keyserlingites subrobustus* (Keyserling)	44.0		95±3	-5.4	-6		
221-113	*Arctomeekoceras rotundatum* (Mojsisovics)	-»-	27.2	80±3	-0.5	-5.9		
221-76-8	*Boreomeekoceras keyserlingites* (Mojsisovics)	-»-	27.0	87±3	-3.4	-6	-6.0	16.2 ?
221-76-6	-»-	-»-	28.0	90±3	-3.5	-5.7		
221-76-5	same shell	-»-	29.9	91±3	-3.9	-5.9		
221-76-4	-»-	-»-	31.0	96±3	-3.1	-5.7		
221-76-3	-»-	-»-	32.3	87±3	-2.4	-6.1		
221-76-2	-»-	-»-	33.4	90±3	-3.2	-7.6		
221-1344-2	*Nordophiceras schmidti* Mojsisovics)	-»-	14.0	83±3	-4.6	-5.1		
221-1123	*Timoceras glacialis* (Mojsisovics)	-»-	11.2	>50±5	-8.3	-6.5		
221-820	-»-	-»-	8.2	23±5	-11.9	-5.6		

Table 4. Isotopic paleotemperature for the Late Olenekian of Arctic Siberia (Olenek River)

Middle Triassic

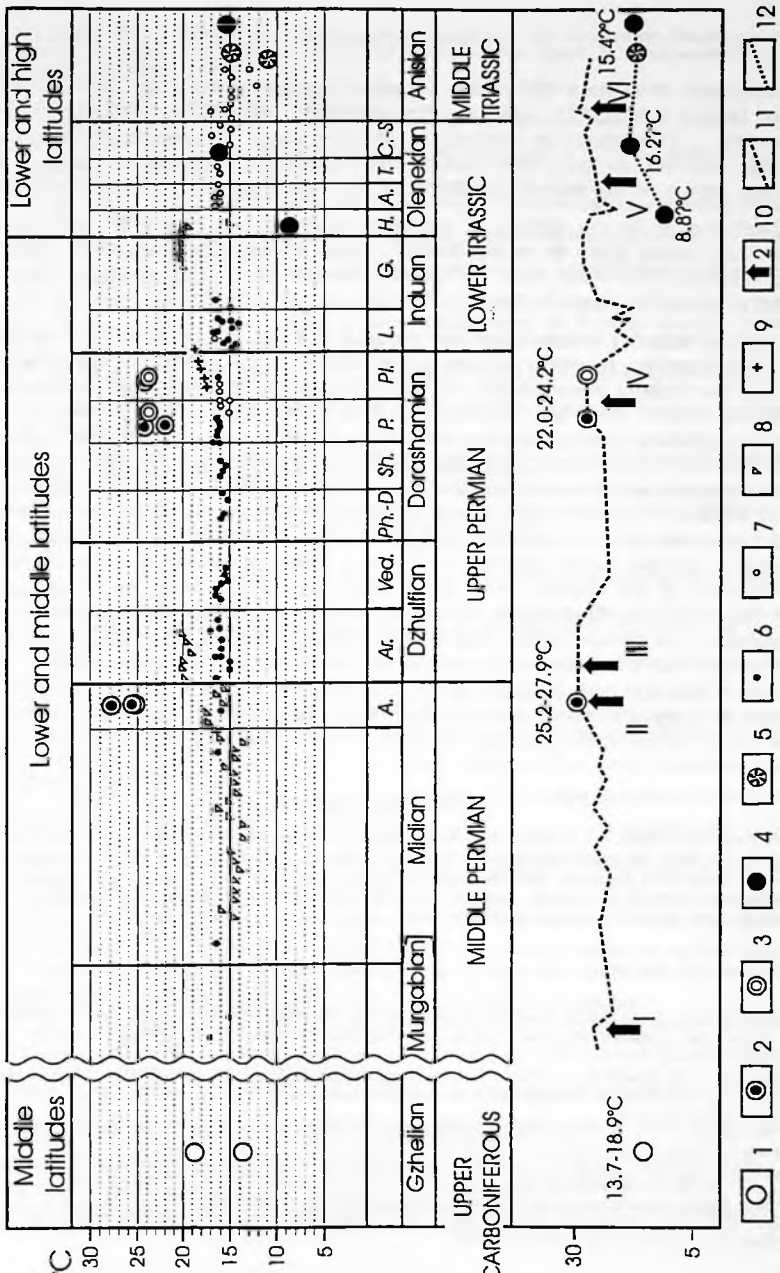
Shells of five ammonoid species from Lower, Middle and Upper Anisian of the Taimir (Tsvetkov Cape and the Keshin Creek)(M.N. Vavilov's collection) were tested. Most well-preserved material was found in the Upper Anisian (*Gymnotoceras rotelliforme* Zone). It is represented by shells of *Arctohungarites* sp. and *Gymnotoceras rotelliforme* (Meek) with a cream colour, with an aragonite content not less than 95±3%. Their $\delta^{18}O$ values fluctuate from -5.8 to -3.7‰, whereas the $\delta^{13}C$ values vary from -2.7 to -1.4‰. According to our calculations, applying a water correction (-4.4‰) the late Anisian mean value of paleotemperature for Taimir sea seems to be 15.4?°C.

Paleotemperatures, obtained for the Anisian of the low latitudes (North Caucasus) by Ca-Mg ratio method, reach only «12.0-17.0°C».

Sample no.	Ammonoid species	Locality, Zone	Location (H, mm)	Aragonite content, %	$\delta^{13}C$ (PDB) ‰	$\delta^{18}O$ (PDB) ‰	Water correction ‰	T°C (mean value)
889-1	*Popanoceras incostans* Dagys et Ermakova	Tsvetkov Cape, Middle Anisian, *Czekanowskites decipiens*	11.0	77 ± 3	-5.2	-4.2		
889-9	*Arctohungarites* sp.	Keshin Creek, Upper Anisian, *Gymnotoceras rotelliforme*	15.8	88 ± 3	-2.3	-4.1		
889-10	same shell	-"-	17.0	88 ± 3	-2.5	-4.4		
889-11	-"-	-"-	18.0	90 ± 3	-3.3	-4.8		
889-13	-"-	-"-	20.0	87 ± 3	-3.1	-3.6		
889-14	-"-	-"-	21.0	95 ± 3	-2.5	-3.9	4.4	15.4?
889-15	*Arctohungarites* sp.	-"-	fragments	95 ± 3	-2.7	-5.6		
889-16	-"-	-"-	12.0	95 ± 3	-2.7	-5.8		
889-17	*A. laevigatus* Popov	Tsvetkov Cape, Upper Anisian, *G. rotelliforme*	12.0	95 ± 3	-5.6	-4.8		
889-21	*Gymnotoceras rotelliforme* (Meek)	Keshin Creek, Upper Anisian, *G. rotelliforme*	22.0	95 ± 3	-1.4	-3.7		
889-22	same shell	-"-	23.0	36 ± 5	-1.8	-3.8		
889-22a	-"-	-"-	25.0	87 ± 3	-1.7	-3.8		

Table 5. Isotopic paleotemperature for the Late Anisian of Arctic Siberia (Taimir)

Fig. 1. Paleotemperatures for the Late Paleozoic and Early Mesozoic. Zones: *A. - Pseudodunbarula arpaensis - Araxilevis intermedius, Ar. - Araxoceras latissimum, Ved. - Vedioceras ventrosulcatum, Ph. - D. Phisonites triangulus, Iranites transcaucasius, Dzhulfites spinosus, Sh. - Shevyrevites shevyrevi, P. - Paratirolites kittli, Pl. - Pleuronodoceras occidentale, L. - Lytophiceras medium, G. - Gyronites, H. - Hedenstroemia, A. - Anasibirites, T. - Tirolites, C. - S. Columbites - Subcolumbites.* 1 - isotopis paleotemperatures from goniotite shells of the Urals, preserved as aragonite; 2 - isotopic paleotemperatures from brachiopod shells of Transcaucasia; 3 - isotopic paleotemperatures from brachiopod shells of North Caucasus; 4 - isotopic paleotemperatures from ceratite shells preserved as aragonite; 5 - isotopic paleotemperatures from bivalve shells (Golbert et al., 1984); 6 - paleotemperatures from Ca-Mg ratio of limestones of Transcaucasia; 7 - paleotemperatures from Ca-Mg ratio of limestones of North Caucasus; 8 - paleotemperatures from Ca-Mg ratio of limestones of South Primorye; 9 - paleotemperatures from Ca-Mg ratio of limestones of South China; 10 - positive carbon isotopic anomaly and its number: I - Wordian (Murgabian) anomaly in Oman (+5.0‰) (Baud et al., 1999), II - latest Midian anomaly in Transcaucasia (+4.0‰) (Zakharov et al., 1998), III - early Dorashamian anomaly on South Primorye (+4.1‰) (Zakharov et al., 1999a), IV - latest Early Dorashamian anomaly in Transcaucasia (+2.8‰) and North Caucasus (+6.9‰) (Zakharov et al., 1999a,b) and South Primorye (Zakharov et al., 1999c), VI - Early Anisian anomaly (+3.5‰) Zakharov et al., 1999a,b); 11 - temperature trends for the late Paleozoic and Early Mesozoic of low latitudes; 12 - temperature trends for the Early and Middle Triassic of high latitudes.


T°C
30
25
20
15
10
5
Middle latitudes
Lower and middle latitudes
Lower and high latitudes
Gzhelian
Murgabian
Midian
A.
Ar.
Ved.
Ph.-D
Sh.
P.
Pl.
L.
G.
H.
A.
T.
C.-S
Dzhulfian
Darashamian
Induan
Olenekian
Anisian
UPPER CARBONIFEROUS
MIDDLE PERMIAN
UPPER PERMIAN
LOWER TRIASSIC
MIDDLE TRIASSIC
13.7-18.9°C
25.2-27.9°C
22.0-24.2°C
8.8°C
16.27°C
15.47°C
I
II
III
IV
V
VI
1
2
3
4
5
6
7
8
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10
11
12

Concluding remarks

One can recognize a marked difference in latest Midian (about 9.3-12.8°C), latest Early Dorashamian (about 5.3-8.5°C), and late Dorashamian (about 7.8-8.2°C) paleotemperatures from carbonates of Transcaucasia obtained in different ways: (1) oxygen isotopic method and (2) Ca-Mg ratio method. Judging from data on the distribution of reefogenic facies in the Upper Permian of the Tethys, in the lowermost Dzhulfian of South Primorye, in the upper Dorashamian of North Caucasus or in the Norian of the Alps (Kaltenegger, 1967) for instance, isotopic paleotemperature values seem to be significantly closer to real ones than those obtained using the Ca-Mg method. The latter may be usefull, apparently, in this concrete case, only for interpretation of the main trends in Permian-Triassic temperature changes.

In general, at low latitudes temperatures are thought to begin a recurrent warming trend in the Artinskian - Dorashamian, reaching temperature maxima in the Artinskian of Early Permian, early Murgabian and particularly in the Midian - Dzhulfian transition time of Middle Permian, and in the late early Dorashamian - early late Dorashamian time of the Late Permian, which agrees with a placing of the positive carbon isotope anomalies (Zakharov et al., 1999b) and taxonomic diversity of Permian invertebrates. It seems justified to assume that through the course of the early Induan temperature dropped off about three times (twice within the beginning of the *Lytophiceras medium* Zone and once just at the beginning of the *Gyronites* Zone, with a visible warming in the middle part of the latter. A short-term fall of temperature at the beginning of the Induan (volcanic winter) soon followed by a warm period (greenhouse summer) seem to be caused by eruption of the Siberian Traps (Conaghan et al., 1994). A similar situation apparently occurred at the end of the Cretaceous, when extensive flood basalts, known as the Decan Traps erupted. However, the thermal effect seems to be not the main reason of the catastrophic mass extinctions across both the Paleozoic-Mesozoic and Mesozoic-Cenozoic boundaries. At the same time information from the high latitudes of the northern hemisphere helps to understand that the late Olenekian temperatures seem to be significantly higher than those of early Olenekian; on the contrary, a slight temperature decrease appears to have occurred in the Middle Triassic (late Anisian).

Acknowledgements

This research was made under the financial support of Grant PTP95-96/17, RFBR (Russia) Project 97-05-65832 and partly of IGCP project 359. We would like to thank Prof. A.V. Popov and Dr. M.N. Vavilov (S.-Petersburg) for aragonitic material from the Gzhelian of the Urals, and the Lower Olenekian of the Buur River basin and the Anisian of Taimir. Our cordial thanks are due to Dr. V.Y. Vuks (S.-Petersburg and Dr. T.N. Pinchuk (Krasnodar) for help during the field-trip in North Caucasus in 1997 and Prof. K. Tanabe (Tokyo) for some remarks.

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GLOBAL CORRELATION AND CHRONOLOGY OF TRIASSIC THEROPODS (ARCHOSAURIA: DINOSAURIA)

Andrew B. Heckert and Spencer G. Lucas

Theropod dinosaur body fossils are known from Upper Triassic (Carnian-Rhaetian) strata in North and South America, Greenland, Europe, and India. Theropod footprints, usually assigned to the ichnogenus *Grallator* Hitchcock and related ichnotaxa, have been described from the Upper Triassic of North America, Greenland, Europe, and Africa. These theropod occurrences are readily correlated as latest Carnian, Norian, and Rhaetian records. The earliest theropods are among the first dinosaurs and appear essentially synchronously in the Upper Triassic of the United States, the United Kingdom, Brazil, Argentina, and India. These theropods include herrerasaurs, including *Caseosaurus crosbyensis* Hunt, Lucas, Heckert, Sullivan, and Lockley and the ceratosaur *Camposaurus arizonensis* Hunt, Lucas, Heckert, Sullivan, and Lockley from the lower Chinle Group in the southwestern United States, the problematic theropod *Saltopus elginensis* Huene from the Lossiemouth Sandstone in Scotland, the herrerasaurid *Staurikosaurus pricei* Colbert from the Santa Maria Formation in Brazil, the herrerasaurid *Herrerasaurus ischigualastensis* Reig and the basal theropod *Eoraptor lunensis* Sereno, Forster, Rogers & Monetta from the Ischigualasto Formation in Argentina, and the probable basal theropod *Alwalkeria maleriensis* (Chatterjee) from the Maleri Formation in India. All of these occurrences are of late Carnian age, approximately 228 Ma. Thus, the oldest dinosaurs are not from South

America, as commonly claimed, but instead appear synchronously across Pangea in the upper Carnian fossil record of four modern continents.

There are several ceratosaurs and herrerasaurs of Norian age, including the herrerasaur *Chindesaurus bryansmalli* Long & Murry, several unnamed herrerasaurs, and at least four ceratosaurs, including *Eucoelophysis baldwini* Sullivan & Lucas and *Gojirasaurus quayi* Carpenter from the middle Chinle Group, USA, as well as the ceratosaurs *Procompsognathus triassicus* Huene and *Liliensternus liliensterni* (Huene) and problematic theropods such as *Halticosaurus* Huene from the Middle Stubensandstein, Germany. The Rhaetian fossil record of theropods is characterized by abundant tracks, particularly of the ichnogenus *Grallator* Hitchcock, in the USA, Europe, and Africa, and numerous theropods, including the Whitaker quarry theropods *Coelophysis bauri* Cope and *Syntarsus?* Raath from the United States, the ceratosaur *Liliensternus airelensis* Cuny & Galton and other, indeterminate forms from France, and a poorly known theropod fauna from the Los Colorados Formation of Argentina. With the notable exception of the Whitaker Quarry at Ghost Ranch, which preserves dozens of theropod skeletons, Late Triassic theropods never dominated the tetrapod predator guild.

Introduction

Theropods were obligatorily bipedal, predaceous dinosaurs that first appeared in the Late Triassic. In this paper, we document the stratigraphic succession of Triassic theropod dinosaurs worldwide. At this time, all Triassic theropods appear to be endemic, with the possible exception of the Rhaetian Whitaker quarry theropod(s). However, correlations based on other tetrapods, principally aetosaurs, allow us to order chronologically the appearance of theropod taxa. Because most of these taxa are known from relatively few specimens, many from only at a single locality, we cannot discuss their actual stratigraphic ranges in a quantifiable fashion. However, we feel that detailed documentation of the lithostratigraphic and biostratigraphic superposition of these theropods provides important information regarding their early evolution and diversification, and highlights the fact that, at this time, Triassic theropods cannot be used for intercontinental correlation.

Theropods are among the first dinosaurs, and their body fossils occur in Upper Triassic sediments in North and South America, Greenland, Europe, and India, with footprints known from North America, Greenland, Europe, and Africa (Fig. 1). Theropod body fossils are known from rocks as old as late Carnian, and occur throughout rocks of Norian and Rhaetian age. The ichnogenus *Grallator* Hitchcock and related ichnotaxa are widely accepted as the footprints of theropod dinosaurs. These trace fossils are rare in pre-Rhaetian rocks, but are locally abundant in uppermost Triassic rocks in the Chinle Group and Newark Supergroup in North America and in the lower Stromberg Group in South Africa. These fossils are readily correlated using other tetrapods, particularly aetosaurs (Lucas & Heckert, 1996). A corresponding biochronology (Lucas & Hunt, 1993a,b; Lucas, 1998, 1999) of the Late Triassic based on land vertebrate faunachrons (lvf) can be used to order chronologically these fossils as follows: Otischalkian (late early to early late Carnian); Adamanian (latest Carnian:Tuvalian); Revueltian (early-mid Norian) and Apachean (late Norian/Rhaetian).

Western North America

All Triassic theropod body fossils in North America are derived from the Upper Triassic Chinle Group, which encompasses nonmarine deposits from Texas to Idaho and Oklahoma to Nevada

(Lucas, 1993). To date, numerous theropod fossils have been reported from Triassic sediments in Texas, New Mexico, and Arizona, with isolated specimens known from Wyoming.

Theropods are known from strata as old as Otischalkian, but do not become widespread until Adamanian time. Revueltian theropods are similarly diverse and widespread. Apachean theropod body fossils are restricted to the Coelophysis quarry Lagerstätt, but the ichnogenus *Grallator*, which represents the footprints of theropods, is widespread throughout this interval.

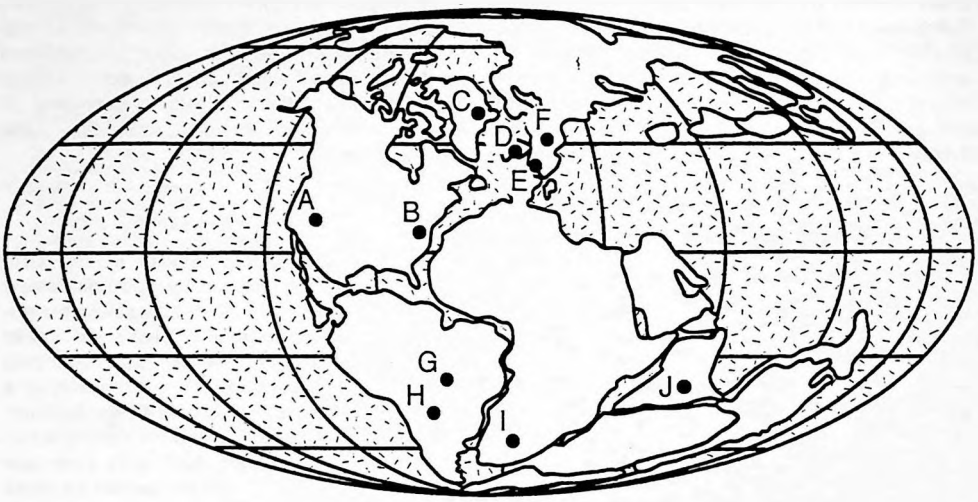

Fig. 1. Upper Triassic theropod localities. A - Chinle Group, southwestern U.S.A. B - Newark Supergroup, eastern U.S.A. and Canada. C - Fleming Fjord Formation, Greenland. D - Lossiemouth Sandstone, Elgin, Scotland. E - Airel layer, Carentan Basin, Normandy, and Grès à Avicula contorta, Nancy, France. F - Keuper, Germany. G - Santa Maria Formation, Brazil. H - Ischigualasto Formation, Argentina. I - lower Elliot Formation, Stormberg Group, southern Africa. J - Maleri Formation, India.

Otischalkian Theropods

A fragmentary centrum from the Salitral Formation of northern New Mexico reported by Hunt & Lucas (1990) may represent a theropod dinosaur. This is the only putative theropod that co-occurs with the aetosaur *Longosuchus meadei* (Sawin). *Longosuchus* is an index taxon of the Otischalkian land-vertebrate faunachron (lvf) of Lucas & Hunt (1993a, 1993b) and is of early-late Carnian age. Hunt et al. (1998) reported a single theropod podial from the Popo Agie Formation of Wyoming, which is also considered Otischalkian based on the presence of the primitive phytosaur *Paleorhinus* Williston (Lucas, 1993, 1994).

Adamanian Theropods

Numerous theropods from the lower Chinle Group co-occur with the aetosaur *Stagonolepis robertsoni* Agassiz, the phytosaur *Rutiodon* Emmons (sensu Ballew, 1989), or both. *Stagonolepis* and *Rutiodon* are index taxa of the lvf, so numerous latest Carnian dinosaurs are known from the lower Chinle. These include a herrerasaurid and the ceratosaur *Camposaurus arizonensis* Hunt, Lucas, Heckert, Sullivan, and Lockley from the Placerias quarry in the Bluewater Creek Formation of Arizona (Lucas et al., 1992; Lucas et al., 1997; Long & Murry, 1995; Hunt et al., 1998), two relatively derived (non-herrerasaurid) theropods from the Bluewater Creek Formation near Fort Wingate, New Mexico (Heckert, 1997), a theropod of unknown affinities (Case, 1922, 1927; Huene, 1932; Hunt et al., 1998) named *Spinosuchus caseanus* by Huene (1932); the herrerasaur *Caseosaurus crosbyensis* Hunt, Lucas, Heckert, Sullivan, and Lockley (Case, 1922, 1927, 1932a; Murry, 1989; Long & Murry, 1995; Hunt et al., 1998) from the Tecovas Formation in Texas and a fragmentary theropod from the Garita Creek Formation in New Mexico (Hunt & Lucas, 1995). Additionally, Hunt et al. (1996) reported two additional theropods from the Blue Mesa Member of the Petrified Forest Formation in the Petrified Forest National Park (PFNP) in eastern Arizona. Therefore, we document numerous theropods from the lower Chinle Group, including three herrerasaurs, a ceratosaur, and as many as four other theropods of unknown affinities.

Revueltian Theropods

Theropods from the middle Chinle Group in Arizona, New Mexico and Texas are generally more fragmentary than the late Carnian dinosaurs. Herrerasaurs include *Chindesaurus bryansmalli* Long & Murry from the Painted Desert Member of the Petrified Forest Formation in the PFNP (Long & Murry, 1995) and several fragmentary herrerasaurids from the Bull Canyon Formation in eastern New Mexico and West Texas (Hunt, 1994; Hunt et al., 1998). Ceratosaurs include *Gojirasaurus quayi* Carpenter from eastern New Mexico (Carpenter & Parrish, 1985; Carpenter, 1997), *Eucoelophysis baldwini* Sullivan & Lucas (Sullivan & Lucas, 1999) and a new ceratosaur (Heckert et al., 1999) from northern New Mexico, and at least one ceratosaur from the PFNP (Padian, 1986). Problematic theropod taxa from the middle Chinle Group include the putative bird *Protoavis texensis* Chatterjee (Chatterjee, 1991) and the putative ornithomimosaur *Shuvosaurus inexpectatus* Chatterjee (Chatterjee, 1993).

These theropods co-occur with the aetosaur *Typothorax coccinarum* Cope and the phytosaur *Pseudopalatus* Mehl, both of which are index taxa of the Revueltian lvf of Lucas & Hunt (1993a, 1993b) and thus of early-mid-Norian age (Fig. 2). Thus, preliminary analyses indicate the presence of at least three herrerasaurs, as many as four ceratosaurs, and several problematic theropods in the middle Chinle Group of early-mid-Norian age.

Apachean Theropods

Unlike the underlying rocks, strata of Apachean (Rhaetian) age in the Chinle Group contain abundant tetrapod footprints and relatively few body fossils. Outside of the extremely prolific Whitaker quarry, which yields abundant ceratosaur skeletons, almost all theropod fossils from the upper Chinle Group are trace fossils assigned to the ichnogenus *Grallator* Hitchcock.
The Whitaker quarry produces abundant remains of the ceratosaur *Coelophysis* (Colbert, 1989) and, possibly, individuals of the genus *Syntarsus* (Paul, 1993; Sullivan, 1994; Hunt et al., 1998). These are the most derived ceratosaurs and are among the most derived Triassic theropods known (e.g. Rowe & Gauthier, 1990; Holtz, 1994).

LATE TRIASSIC (KEUPER)						SERIES
CARNIAN		NORIAN			RHAETIAN	AGE
Julian	Tuvalian	Lacian	Alaunian	Sevatian		Sub-age
	multiple herrerasaurs, ceratosaurs, and other theropods (see text)	unnamed herrerasaurs (3) *Chindesaurus bryansmalli* unnamed ceratosaurs (2) *Eucoelophysis baldwini* *Gojirasaurus quayi* *Protoavis /Shuvosaurus*			*Coelophysis bauri* *Syntarsus* ? *Grallator* spp.	North America (Chinle)
		Grallator spp.			*Grallator* spp.	North America (Newark)
		unnamed theropod *Grallator* sp.				Green-land
	Saltopus			Fissure-fill theropods "Coelurosaurs"		Europe (UK)
		Procompsognathus triassicus *Halticosaurus longotarsus* *Halticosaurus orbitoangulatus*	*Liliensternus liliensterni*		*Liliensternus airelensis*	Europe (Continental)
	Staurikosaurus *Herrerasaurus* *Eoraptor*				unnamed theropods (ceratosaur)	South America
	Alwalkeria					India
					Grallator spp.	Africa

Fig. 2. Biochronology of Late Triassic theropods.

Various workers have assigned tridactyl tetrapod tracks in the Chinle to the ichnogenera *Grallator* Hitchcock, *Agialopous* Branson & Mehl, *Coelurosaurichnus* Kuhn, and *Atreipus* Olsen & Baird. With the possible exception of *Atreipus*, these tracks represent theropods of varying sizes, and we agree with Leonardi & Lockley (1995) that *Agialopous* and *Coelurosaurichnus* are probably junior subjective synonyms of *Grallator*. The vast majority of Chinle Group theropod footprints occur in rocks of, or correlative to, the Rock Point Formation (Lucas & Hunt, 1993a, 1993b; Lockley & Hunt, 1995). Therefore, the upper Chinle Group is depauperate in theropod body fossils outside of the Whitaker quarry, but has a rich ichnofossil record of theropod footprints.

Eastern North America

The Newark Supergroup in eastern North America yields no body fossils of Triassic theropods. The holotype of *Podokesaurus holyokensis* Talbot and casts of theropod bones attributed to Coelophysis sp. (Colbert & Baird, 1958), originally considered to be Triassic in age, were probably derived from the Portland Formation and thus are of Jurassic age (Olsen et al., 1989).

With the relatively recent recognition that much of the uppermost Newark Supergroup is of Jurassic, not Triassic age, most of the famous Newark Supergroup theropod footprint localities are now part of the Early Jurassic ichnofauna (Olsen, 1980; Olsen et al., 1982; Olsen et al., 1989; Silvestri & Szajna, 1993). However, unlike the Chinle Group, theropod footprints are known from nearly the entire stratigraphic section of the Newark Supergroup. Footprints of *Grallator* and related ichnotaxa occur in rocks of late Carnian to Rhaetian age throughout much of the Newark Supergroup and have been reported by numerous workers (e.g., Baird, 1957; Olsen & Baird, 1986; Weems, 1987, 1992; Olsen, 1980; Olsen & Flynn, 1989; Olsen et al., 1989; Olsen et al., 1998) (Fig. 2). Thus, the entire Triassic theropod fossil record of the Newark Supergroup consists of a variety of *Grallator* and *Grallator*-like footprints from strata ranging from late Carnian to Rhaetian in age.

Greenland

Jenkins et al. (1994) first reviewed the Upper Triassic tetrapod fauna of Greenland. So far, the only theropod body fossil this assemblage contains is an indeterminate theropod consisting of "disassociated vertebrae and ribs, a partial pelvis and hind limb, including a femur (length, 33 cm) and phalanges" (Jenkins et al., 1994:14) from the upper Bjergkronerne beds in the Ørsted Dal Member of the Fleming Fjord Formation. They also reported numerous trackways assignable to *Grallator* sp. from the Ørsted Dal Member. The occurrence of *Aetosaurus* with the theropod fossils of the Ørsted Dal Member indicates an early-mid Norian age for this fauna (Fig. 2).

Europe

The Triassic theropod fossil record of Europe includes body fossils from the United Kingdom, France, and Germany, with numerous footprints from several localities. The Lossiemouth Sandstone of Elgin, Scotland, has produced theropod fossils assigned to *Saltopus elginensis* Huene. The Lossiemouth Sandstone is the type stratum of the aetosaur *Stagonolepis robertsoni* Agassiz, which is of Adamanian (latest Carnian) age. Ostrom (1981) and Norman (1990) reviewed the problematic theropods, and Norman (1990) considered *Saltopus elginensis* to be a nomen dubium. Because of its strong theropod affinities and latest Carnian age, we include it in this review as one of the oldest known theropods. The fissure-fill assemblages developed in Carboniferous limestone around the Bristol Channel area and in South Wales also produce fragmentary Triassic coelurosaurs (Fraser, 1994).

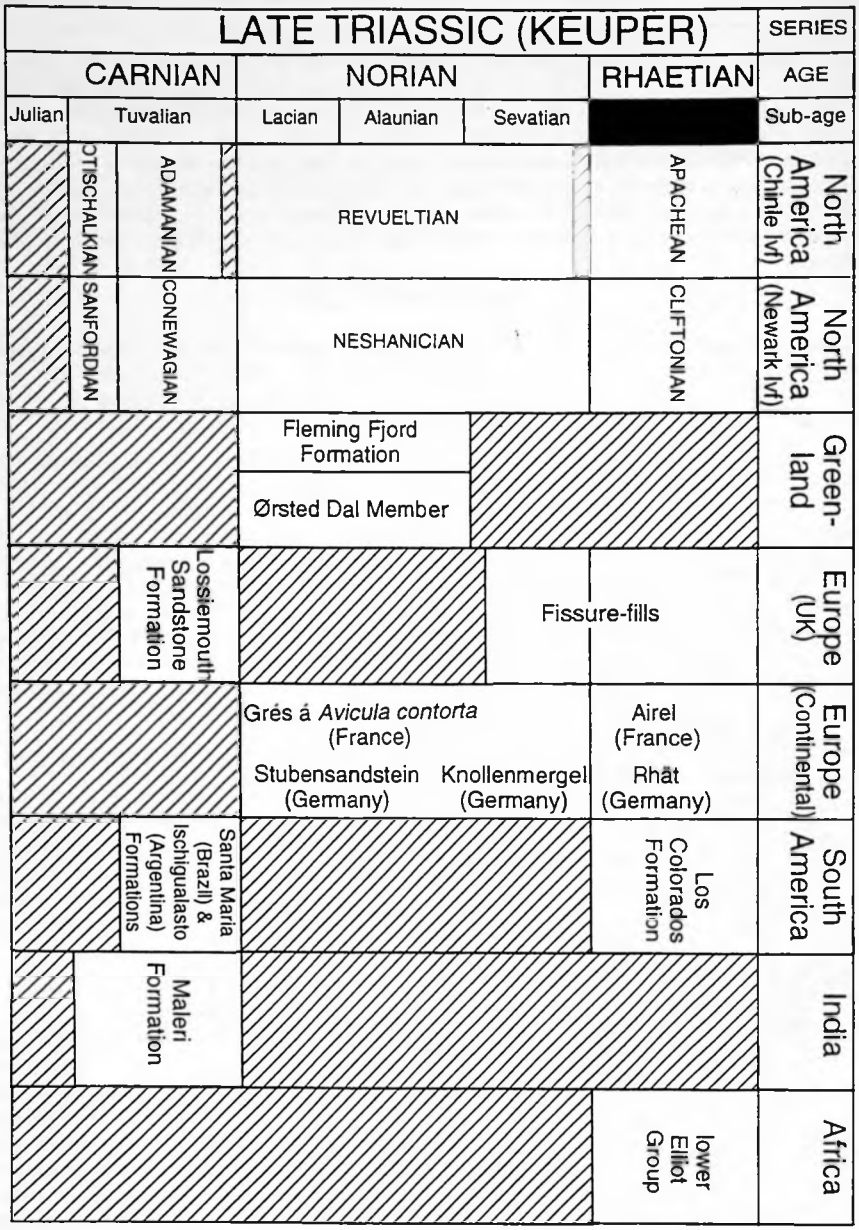

Fig. 3. Correlation of Upper Triassic theropod-bearing units. Chinle and Newark Supergroup faunachrons follow Lucas & Hunt 1993a) and Lucas & Huber 1999).

Revueltian Theropods

In Germany, the holotypes of the ceratosaur *Procompsognathus triassicus* Huene and the problematic taxa *Halticosaurus longotarsus* Huene and *H. orbitoangulatus* Huene were found in a marly interval just above the Middle Stubensandstein (Huene, 1908, 1921, 1932; Sereno & Wild, 1992), strata of undisputed Norian age (Aigner & Bachman, 1992). The co-occurrence of these forms with numerous taxa, particularly the aetosaur *Aetosaurus*, indicates an early-mid Norian age for the Triassic theropods of the Keuper, with the ceratosaur *Liliensternus liliensterni*, found in the Knollenmergel, representing the youngest Keuper Norian theropod.

Apachean Theropods

The holotype of the ceratosaur *Liliensternus airelensis* (Larsonneur & Lapparent, 1966; Cuny & Galton, 1993) was derived from the Airel layer of the Carentan Basin in Normandy, France. This locality and the Saint-Nicolas-de-Port locality near Nancy, in the "Grès à *Avicula contorta*", which has also produced fragmentary theropod material (Godefroit & Cuny, 1997), are of Rhaetian age (Lucas & Huber, 1999).

South America

The Triassic theropods of South America are well-studied, and consist of the herrerasaurids *Staurikosaurus pricei* Colbert from the Santa Maria Formation of Brazil and *Herrerasaurus ischigualastensis* Reig from the Ischigualasto Formation of Argentina, which co-occurs with the basal theropod *Eoraptor lunensis* Sereno, Forster, Rogers & Monetta. *Ischisaurus cattoi* Reig is a junior subjective synonym of *Herrerasaurus* (Novas, 1992, 1993; Sereno & Novas, 1992, 1993). Some fragmentary theropods are known from the Los Colorados Formation in Argentina (Arcucci & Coria, 1997). The Ischigualasto theropods and *Staurikosaurus* are of Adamanian age, and the new theropod from the Los Colorados Formation is of probable Apachean age.

Adamanian Theropods

In the Santa Maria Formation of Brazil, *Staurikosaurus* Colbert co-occurs with the rhynchosaur *Scaphonyx* Woodward and the aetosaur *Stagonolepis* Agassiz (= *Aetosauroides* Casamiquela) and thus is the same age as the Ischigualasto fauna, which also includes *Scaphonyx* and *Stagonolepis* (= *Aetosauroides*) (Brinkman & Sues, 1987; Sues, 1990). *Stagonolepis* is known to occur in rocks of latest Carnian age (Adamanian lvf of Lucas & Hunt, 1993a, 1993b) in the Chinle Group and the Lossiemouth Sandstone (Walker, 1961). Therefore, we correlate the Ischigualasto and Santa Maria formations with these units (Lucas & Heckert, 1996). Rogers et al. (1993) reported a date of 227.8 ± 0.3 Ma from an ash 80 m below the dinosaur occurrences in the Ischigualasto Formation. Therefore, we consider 228 Ma to be a useful date for both the lower Chinle and for the Lossiemouth Sandstone, indicating that a diverse theropod assemblage existed on several continents by this time.

Apachean Theropods

The Los Colorados Formation produces fragmentary theropods, none of which are named. At least one of these theropods is a moderately large (3-4 m body length) ceratosaur (Arcucci & Coria, 1997). Correlation of the Los Colorados Formation to other Triassic strata remains difficult due to the endemic nature of the fauna. Currently, we favor an Apachean age for the Los Colorados, based in part on the prevalence of prosauropods.

Africa

There are no body fossils of Late Triassic theropods known from Africa, and the entire Late Triassic theropod record consists of footprints from the lower Elliot Formation in the Stormberg Group. Ellenberger (1970, 1972, 1974), originally described this theropod ichnofauna, recognizing at least three ichnogenera and a minimum of nine ichnospecies. Olsen & Galton (1984) re-examined this assemblage and considered all of the tracks to pertain to *Grallator* spp. Precise correlation of the lower Elliot to other Triassic strata is problematic due to a high degree of endemism in the fauna, although preliminary lines of evidence indicate that it is probably of late Norian age (Cooper, 1982; Lucas & Huber, 1999), not late Carnian age, as argued by both Gauffre (1993a) and Galton & Heerden (1998), who mistakenly thought that traversodontids, present in the upper Elliot, do not occur in post-Carnian strata.

India

Chatterjee (1987, 1994) described the primitive theropod *Alwalkeria maleriensis* (Chatterjee) from the lower Maleri Formation in India. Norman (1990) considered *Alwalkeria* to be a problematic possible dinosaur. For purposes of this analysis, we consider it a theropod, although we recognize that it may represent a lagosuchid. Jain & Roychowdhury (1987) summarized the lower Maleri Fauna and listed among its constituents the phytosaur *Paleorhinus* Williston (= *Parasuchus* Lydekker). The presence of *Paleorhinus* indicates a late Carnian (Tuvalian) age (Hunt & Lucas, 1991b; Lucas & Hunt, 1993a, 1993b). Therefore, *Alwalkeria* Chatterjee is potentially one of the oldest named dinosaurs. No other theropod fossils of Triassic age are known from Asia.

Discussion

Because almost all Triassic theropods appear to be endemic, there are no direct correlations based on theropod dinosaurs. However, other tetrapods, principally aetosaurs, provide a robust biostratigraphy which allows us to divide the Upper Triassic theropod record into three distinct zones, a lower, late Carnian zone that is primarily latest Carnian in age, a Norian zone, and a latest Triassic (Rhaetian) zone (Fig. 3).

Historically, most workers have considered the dinosaurs from the Ischigualasto and Santa Maria Formation in South America to be the oldest known dinosaurs, a concept that has been widely disseminated (Colbert, 1970; Benton, 1990; Novas, 1992, 1993, 1996; Sereno & Novas, 1992, 1993; Rogers et al., 1993; Sereno, 1993, 1995; Sereno et al., 1993). This concept dates back to Romer (1962), who originally considered the abundant rhynchosaurs of the Ischigualasto Formation to indicate a Middle Triassic age. However, a detailed examination of the Ischigualasto and Santa Maria Formation faunas demonstrates that there is no compelling reason to consider them older than late Carnian, and that there is strong evidence supporting correlation of these units with parts of the lower Chinle Group and the Lossiemouth Sandstone, both of latest Carnian age (Lucas & Huber, 1999).

The Ischigualasto and Santa Maria Formations are readily correlated based on the occurrence of the rhynchosaur *Scaphonyx* in both the Santa Maria (Barbarena et al., 1985) and Ischigualasto formations (Sill, 1970; Bonaparte, 1978) and the aetosaur *Aetosauroides* in the Ischigualasto (Casamiquela, 1960, 1961) and Santa Maria (Zacarias, 1982). Recently, we have examined the type material of *Aetosauroides* and concluded that it is congeneric with *Stagonolepis* (Heckert & Lucas, 1996). *Stagonolepis* was originally described from the Lossiemouth Sandstone (Agassiz, 1844) and has long been known (e.g. "new phytosaur," Case, 1932b; = *Calyptosuchus* Long &

Ballew, 1985), if only recently recognized, from the Chinle Group (Murry and Long, 1989; Long & Murry, 1995; Lucas & Hunt, 1993a,b). Therefore, the occurrence of *Stagonolepis* in the Ischigualasto and Santa Maria Formations provides a direct correlation of these units to the Lossiemouth Sandstone and much of the lower, although not lowermost, Chinle Group. Consequently, the South American late Carnian dinosaurs *Eoraptor*, *Herrerasaurus* and *Staurikosaurus* are as old as *Saltopus* from the Lossiemouth and the Adamanian theropods from the Chinle. Detailed biochronology (Hunt and Lucas, 1991b; Lucas and Hunt, 1993a,b) indicates that *Stagonolepis* occurs in rocks of latest Carnian age.

Rogers et al. (1993) reported an Ar/Ar age of 227.8 ± 0.3 for a tuff approximately 60 m below the lowest occurrence of *Stagonolepis* (=*Aetosauroides*) and concluded that the Ischigualasto fauna was thus of middle Carnian age. However, we and others have noted that: (1) there is no official "middle" subdivision of the Carnian; (2) on most recent timescales, including that of Harland et al. (1990) the Carnian spans approximately 235 to 225 Ma, so 228 Ma is a late Carnian age, and (3) the Rogers et al. (1993) date is necessarily a maximum constraint, indicating that the Ischigualasto fauna is slightly younger than 228 Ma old. Although Gradstein et al. (1995) have published a timescale with a Ladinian-Carnian boundary at 227.4 ± 4.5 Ma; this date differs from the Harland et al. (1990) timescale because of the different methods of interpolation used by the two groups. Regardless of this inconsistency, we note here that in the Chinle Group the aetosaur *Stagonolepis* occurs above strata bearing the phytosaur *Paleorhinus*, known from marine strata of undisputed late Carnian age in Austria (Hunt & Lucas, 1991b). Thus, by the correlation we propose here, the co-occurrence of early theropods with *Stagonolepis* indicates that those theropods are of late Carnian age.

Therefore, we note here that the oldest well-known theropods, *Staurikosaurus*, *Eoraptor*, and *Herrerasaurus*, appear at the same time as more fragmentary, yet more derived forms in the Chinle Group and *Saltopus* from the Lossiemouth Sandstone. Accordingly, the oldest known probable theropods are actually those of early late Carnian (Otischalkian) age, including fragmentary remains such as those published by Hunt & Lucas (1990) and Lucas (1994) from the Chinle and, possibly, *Alwalkeria* from the Maleri Formation in India. All of these theropods co-occur with the phytosaur *Paleorhinus*, and are thus of Otischalkian age.

Refining the biostratigraphy of Triassic theropods enables us to make several observations about the nature of the original dinosaur diversification. In addition to the oldest theropods reviewed here, several ornithischians and a prosauropod are known from the same or correlative strata. These include the ornithischians *Pisanosaurus* from the Ischigualasto Formation in Argentina (Casamiquela, 1967), *Pekinosaurus* from the Pekin Formation in North Carolina (Hunt and Lucas, 1994) and the prosauropod *Azendohsaurus* from the Argana series in Morocco (Dutuit, 1972; Gauffre, 1993b). Consequently, we recognize that dinosaurs comprise a very small, yet diverse, component of late Carnian tetrapod faunas. These first dinosaurs had already diversified and included representatives of the ornithischian, prosauropod, and theropod clades. Furthermore, by the latest Carnian the theropods had already diverged from other dinosaurs and included numerous basal forms (Eoraptor and many of the problematic taxa), herrerasaurids, and, rarely, ceratosaurs, as well as several problematic, but apparently derived, forms. This divergence suggests that tetanurine theropods should also be present at this time, although none have yet been identified from Triassic strata. Almost all of these taxa were small, usually considerably less than 2 m long, with the exception of *Azendohsaurus* and some herrerasaurs, which may have reached lengths of 3-4 m.

By Norian time, prosauropod dinosaurs dominated the more terrestrial, dry ecosystems, as evidenced by the abundant specimens of prosauropods known from the Norian portion of the

Keuper (Hunt, 1991). The theropods, however, remained a minor component of all faunas. Ceratosaurs are the best-represented theropod group, with several named genera from the U.S.A. and Germany. Both herrerasaurs and ceratosaurs (notably *Gojirasaurus* and *Liliensternus*) achieved moderately large (5-6 m long) body size during this interval.

By the end of the Triassic (Rhaetian), the herrerasaurs had apparently become extinct, and the vast majority of the theropod fauna consists of moderately to highly derived ceratosaurs, such as *Liliensternus airelensis* and *Coelophysis*. Abundant footprint evidence indicates that small- to medium-sized theropods (1-3 m long) had become common, although, with the exception of the Whitaker quarry, theropods never dominated the Late Triassic body fossil record to the extent that prosauropods did, and they remained a conspicuously rare element in prosauropod-dominated faunas.

Acknowledgments

Dr. A. Arcucci provided useful discussion regarding, and access to specimens of, theropods from the Los Colorados Formation. Reviews by T. R. Holtz Jr. and B. Pérez-Moreno improved a more extensive version of this manuscript. J. Powell and W. Sill provided access to aetosaur specimens from the Ischigualasto Formation and information on South American Triassic reptiles. The New Mexico Museum of Natural History and Science, the Petrified Forest National Park, National Geographic Society, and the Wengerd Traveling Fellowship at the University of New Mexico, supported this research.

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TRIASSIC-JURASSIC BOUNDARY IN THE SIERRA DEL ALAMO MUERTO, SONORA, MEXICO

Spencer G. Lucas and John W. Estep

In the Sierra del Alamo Muerto of northwestern Sonora, Mexico, there is the sequence boundary between Rhaetian and latest Hettangian-Sinemurian strata, where strata equivalent to at least three ammonite zones are missing, so this is not a complete record of the Triassic-Jurassic transition. Furthermore, no evidence of Hettangian dysaerobic/anaerobic conditions is preserved in these strata. A reinterpreted sea-level curve for the Triassic-Jurassic boundary interval in the Sierra del Alamo Muerto has an inflection point at the Rhaetian-Hettangian boundary and is consistent with proposed global sea-level curves.

Introduction

Triassic-Jurassic strata have long been known from Sonora, northwestern Mexico, and the most accessible and well-studied outcrops are those in the Sierra del Alamo Muerto, near Caborca in northwestern Sonora (Fig. 1). González-León (1980) defined the Antimonio Formation in this area as a 3.4-km-thick lithostratigraphic unit of siliciclastic and carbonate strata of presumed Late Triassic-Early Jurassic age. Subsequent research concluded that there is a continuous section through the Triassic-Jurassic boundary, making this one of the few sections worldwide that apparently records such a continuous transition. This section was therefore claimed to be of great importance to understanding the Triassic-Jurassic transition (González-León et al., 1996). Here, we present a review of new data on, and interpretations of, the lithostratigraphy, biostratigraphy and sequence stratigraphy of the Triassic-Jurassic boundary in the Sierra del Alamo Muerto (see Lucas & Estep, 1999 for a more extensive treatment).

Lithostratigraphy

Strata previously assigned to the Antimonio Formation are of Permian, Triassic and Jurassic age and more than 3 km thick (White and Guiza, 1949; González-León, 1980; Stanley et al., 1994; Stanley and González-León, 1995; González-León et al., 1996). However, the Antimonio Formation defined by González-León (1980) may be subdivided into at least three, lithologically distinct and mappable (at the 1:50,000 scale) units. We therefore redefined the Antimonio Formation, restricting it to the section distinguished by red beds, about 1.6 km thick, that ranges in age from Permian to Late Triassic (Lucas & Estep, 1999).

Overlying lower Mesozoic strata in the Sierra del Alamo Muerto form a homoclinally-dipping section about 1.5 km thick (González-León 1997a). We divide this section into two lithostratigraphic units, the Rio Asunción Formation (Lucas & Estep, 1999) and the Sierra de Santa Rosa Formation (Hardy 1981). Previously, these rocks were included as the uppermost part of the lower member and all of the upper member of the Antimonio Formation (González-León, 1980, 1997a).

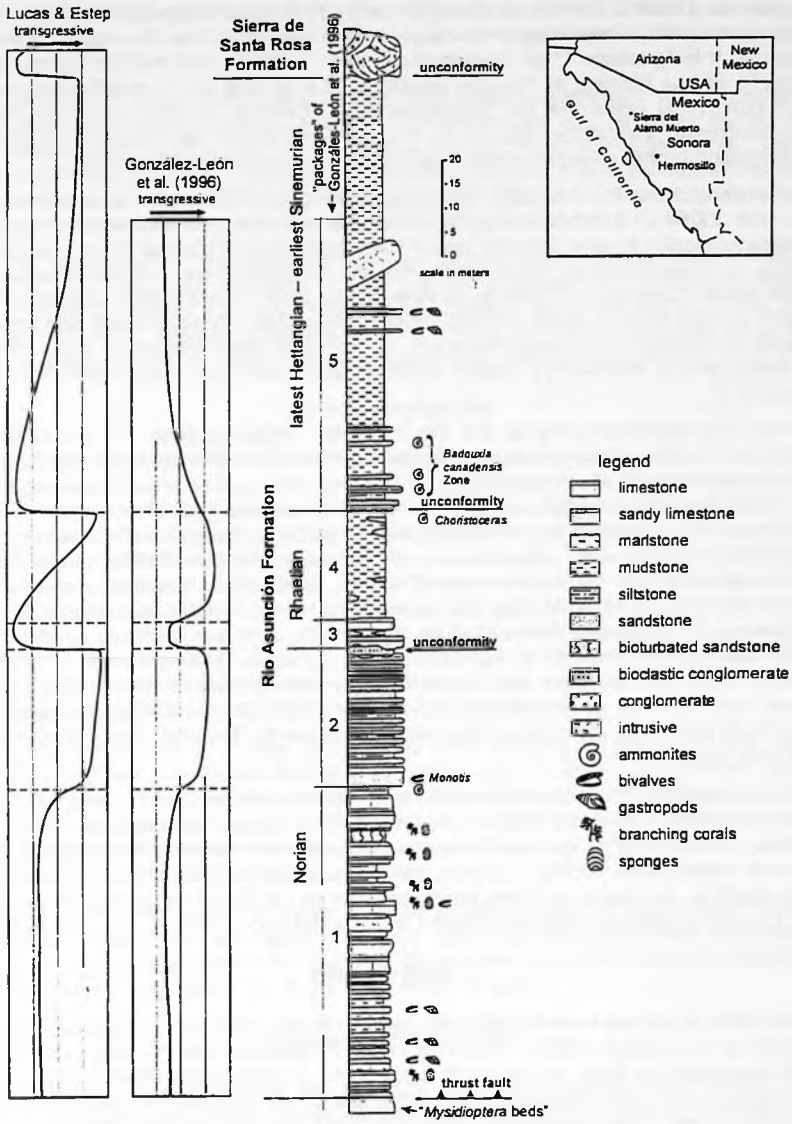

Fig. 1. *Stratigraphic section of the Triassic-Jurassic-boundary interval in the Sierra del Alamo Muerto, Sonora, Mexico with different interpretations of the sea-level curve.*

Stanley et al. (1994), Stanley & González-León (1995), González-León et al. (1996), and González-León (1997a) describe the lower limestone interval of the Rio Asunción Formation in some detail. It is "package 1" of González-León et al.'s (1996) informal terminology (Fig. 1). In brief, the limestone member at the type section is 62.5 m thick and is mostly medium-dark-gray beds of biostromal limestone and packstone with interbeds of gray shale and fine-grained, brown, quartzose, sandstone. Stanley et al. (1994) described its fossils-mostly scleractinian corals, spongiomorphs, disjectoporoids, brachiopods, gastropods and bivalves.

The upper part of the Rio Asunción Formation is 148.5 m thick at the type section (Fig.1). It begins with 27 m of interbedded sandy limestone, siltstone, and sandstone that contain the characteristic Norian bivalve *Monotis* and a few ammonoids ("package 2" of González-León et al., 1996) . A bioclastic limestone conglomerate and sandstone rests with sharp scoured contact on these strata ("package 3") and is overlain by 22 m of mostly thinly laminated tuffaceous shale and sandstone ("package 4") that contain ammonoids (*Choristoceras*) and small pectinacean bivalves (*Chlamys*). A sandy and limey conglomerate rests with sharp scoured contact on these strata and is overlain by almost 90 m of shale with thin interbedded limestone beds ("package 5").

Rocks that rest disconformably on the Rio Asunción Formation form 1.9 km of homoclinally dipping strata dominated by sandstone (González-León 1980, 1997a; Stanley & González-León 1995). These strata include most of the upper member of the Antimonio Formation of González-León (1980). We did not study these strata in detail but note that they are lithologically very different from the Antimonio (redefined) and Rio Asunción formations and are readily mapped as a distinctive, formation-rank unit (see also González-León, 1980, 1997a). In addition, these strata closely resemble the 1.4-km-thick Sierra de Santa Rosa Formation, named by Hardy (1981) for strata exposed in the Sierra de Santa Rosa, about 100 km southeast of the Sierra del Alamo Muerto. The Sierra de Santa Rosa Formation at its type area is mostly sandstone (arkose and lithic wacke) and minor lithic and siliceous conglomerate, olive green shale and biomicritic limestone. Also, in the Sierra del Alamo Muerto, late Sinemurian ammonites occur in the so-called upper member of the Antimonio Formation (Taylor et al., 1996). Ammonites and the bivalve *Weyla* indicate a Sinemurian-Pliensbachian age for the Sierra de Santa Rosa Formation in its type area (Hardy, 1981).

Therefore, because of lithologic and age similarity, we reassign most of the upper member of the Antimonio Formation to the Sierra de Santa Rosa Formation. The basal bed of the Sierra de Santa Rosa Formation (Fig. 1) is conglomerate containing well-rounded clasts mostly of quartzite (along with subordinate porphyry, granite and chert clasts) up to 15 cm in diameter. A more detailed study of the Sierra de Santa Rosa Formation in the Sierra del Alamo Muerto is needed, beyond the useful initial description provided by González-León (1997a).

Biostratigraphy

The biostromal limestone beds of the lower part of the Rio Asunción Formation (Fig. 1) produce late-middle and early-late Norian ammonites of the *Himavatites columbianus* Zone and *Gnomohalorites cordilleranus* Zone, including *Pinacoceras* cf. *P. metternichi* (Hauer) near the base (*G. cordilleranus* Zone), *Catenohalorites*, and *Sagenites* cf. S. *schaubachi* Mojsisovics (González-León et al., 1996). The "hydrozoan" *Heterastridium conglobatum* also indicates an early-late Norian age.

The interval immediately above the biostromes (package 2: Fig. 1) only produces age-diagnostic ammonites from its upper part. González-León et al. (1996, p. 421) reported "A species of

Sagenites, characteristic of the upper part of the Amoenum Zone . . . was also discovered near the top of package 2, so we assign this interval to the Paracochloceras amoenum Zone of late Norian age.

Strata of package 3 yield several Rhaetian-age ammonites characteristic of the *Choristoceras crickmayi* Zone: *Choristoceras crickmayi* Tozer, *Rhacophyllites* sp., *Arcestes* cf. A. *gigantogaleatus* (Mojsisovics), and *A.* cf. *A. nevadanus* (Gabb) (González-León et al. 1996). As González-León (1997b) recently reported, the overlying package 4 also produces *Choristoceras crickmayi*, as high as 1.5 m below the base of package 5 (Fig. 1). Thus, package 4 is Rhaetian, not Hettangian as concluded by Lucas (1993) and by González-León et al. (1996).

Strata of the lower part of package 5 produce an abundant assemblage of ammonites readily assignable to the *Badouxia canadensis* Zone, which straddles the Hettangian-Sinemurian boundary (González-León et al., 1996; Taylor et al., 1996). Two levels higher in the Sierra de Santa Rosa Formation produce age-diagnostic ammonites of the *Asteroceras obtusum* and *Echioceras raricostatum* Zones of late Sinemurian age (D.G. Taylor, oral commun., 1997).

Sequence Stratigraphy

The Rio Asunción Formation includes two sequence boundaries (unconformities), well calibrated by biostratigraphy (Fig. 1). The oldest is at the base of package 3, where bioclastic conglomerate and sandstone rests with sharp contact on much finer-grained limestone and siltstone (Fig. 1). The basal bed of package 3 is a bioclastic conglomerate of bivalves, corals, ammonites, ichthyosaur bones (all shastasaurid), petrified wood, and lithic clasts of limestone and minor cherts. It does not display graded bedding (contra González-León et al. 1996) and has a scoured base with at least 0.5 m of local relief. Therefore, we do not interpret it as a tempestite, as did González-León et al. (1996), but as a transgressive lag or early transgressive systems tract. Although most of the fossils in package 3 are reworked, this package does contain Rhaetian ammonoids and rests directly on late Norian strata. Overlying beds of the Rio Asunción Formation contain *Choristoceras crickmayi* and are also Rhaetian.

Above the Rhaetian strata is a clear stratigraphic break marked by sandstone and bioclastic conglomerate that rest directly on finer-grained strata (Fig. 1). Strata immediately above the sandstone and conglomerate contain ammonites of the *Badouxia canadensis* Zone of latest Hettangian-earliest Sinemurian age, and 1.5 m below the conglomerate and sandstone, Rhaetian ammonites of the *Choristoceras crickmayi* Zone are present. Thus, biostratigraphy indicates a hiatus encompassing most of the Hettangian stage.

The contact of the Rio Asunción Formation with the overlying Sierra de Santa Rosa Formation is another sequence boundary. Here, quartzite-boulder conglomerate rests directly on shale (Lucas 1993, 1996). Overlying strata of the Sierra de Santa Rosa Formation probably include other sequence boundaries, but we did not study these strata in detail.

Triassic-Jurassic Boundary

The lithostratigraphic, biostratigraphic and sequence stratigraphic information from the Triassic-Jurassic strata in the Sierra del Alamo Muerto reviewed above supports a fundamentally different interpretation than that of González-León et al. (1996) of the nature of the Triassic-Jurassic boundary section exposed there. They argued that this section represents a continuous record of sedimentation across that boundary and records a dysaerobic to anaerobic environment during the earliest Jurassic. In contrast, we conclude that this section is very discontinu-

ous across the boundary (most or all of Hettangian time is not represented) and records no dysaerobia.

Two obvious sequence boundaries interrupt the transition from the Triassic to the Jurassic in the Sierra del Alamo Muerto (Fig. 1). At the base of the lower boundary (base of package 3), Rhaetian (*Choristoceras crickmayi* Zone) strata rest disconformably on strata of late Norian age (*Paracochloceras amoenum* Zone), and a negligible hiatus is indicated. However, at the base of the upper sequence boundary (base of package 5), strata of latest Hettangian-earliest Sinemurian (*Badouxia canadensis* Zone) rest disconformably on strata of Rhaetian age. The hiatus at this sequence boundary is equivalent to at least three ammonite zones (*Psiloceras planorbis, P. liasicus* and *Schlotheimia angulata* Zones), which is essentially all of Hettangian time. Clearly, the section preserved in the Sierra del Alamo Muerto does not record a complete Triassic-Jurassic transition.

González-León et al. (1996) argued that package 4 (Fig. 1) was deposited in relatively deep and quiet water in a dysaerobic to anaerobic environment. They identified three features of these strata to support this conclusion: (1) the rocks are laminated, (2) "rich in organics," and (3) pyritic. We agree that the strata in package 4 are laminated and lack bioturbation, but that could merely indicate rapid deposition in relatively quiet water below effective wave base, not dysaerobia/anaerobia. We observed that these strata are not rich in organic material nor do they have sedimentary pyrite. Indeed, they are mostly light colored, tuffaceous (micaceous) sandstones and siltstones that are sparsely fossiliferous. The few dark colors are mostly hematite and manganese weathering stains. Pyrite in these beds is only locally present and may be associated with small igneous intrusions of Cenozoic age that locally cut these strata.

The sea-level curve for the Triassic-Jurassic boundary section in the Sierra del Alamo Muerto and its temporal calibration proposed by González-León et al. (1996) thus needs to be re-evaluated (Fig. 1; see also González-León 1997b). There is strong evidence of an inflection point at the base of package 3, and this is a Norian-Rhaetian break, as they showed. However, a second inflection point in the sea-level curve can be inferred at the top of package 4, where latest Hettangian-earliest Sinemurian rocks rest directly on Rhaetian strata (Fig. 1). Significantly, the reinterpreted sea-level curve for the Triassic-Jurassic boundary section in the Sierra del Alamo Muerto has the same inflection points as the proposed global sea-level curve (Embry, 1988; Haq et al., 1988).

Acknowledgments

Part of this research was supported by Project 3934-T92402 of the Consejo Nacional de Ciencia y Tecnologia. Carlos González-León made field work possible and collaborated in many ways. We benefitted from discussions in the field with Tom Anderson, John Marzolf, Roberto Molina-Garza, Norm Silberling, Maureen Steiner, and Jack Stewart.

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- "The formal name of a biostratigraphic unit should be formed from the names of one, or preferably no more than two, appropriate fossils combined with the appropriate term for the kind of unit in question."
- "The writing and printing of fossil names for stratigraphic units should be guided by the rules laid down in the *International Code of Zoological Nomenclature* and in the *International Code of Botanical Nomenclature*. The initial letter of generic names should be capitalized; the initial letter of the specific epithets should be in lowercase; taxonomic names of genera and species should be in italics. The initial letter of the unit-term (Biozone, Zone, Assemblage Zone) should be capitalized; for example, *Exus albus* Assemblage Zone."
- "The name of the fossil or fossils chosen to designate a biozone should include the genus name plus the specific epithet and also the subspecies name, if there is one. Thus *Exus albus* Assemblage Zone is correct. After the first mention, the genus name may be abbreviated to its initial letter if there is no danger of confusion with some other genus beginning with the same letter; for example, *Exus albus* may be shortened to *E. albus*. On the other hand, the use of the specific epithet alone, in lowercase or capitalized, in italics or not (*albus* Assemblage zone, *Albus* Assemblage zone, albus Assemblage zone, or Albus Assemblage zone), is inadvisable because it can lead to confusion in the case of frequently used species names. However, once the complete name has been cited, and if the use of the specific epithet alone does not cause ambiguous communication, it may be used, in italics and lowercase, in the designation of a biozone; for example, *uniformis* Zone."

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

Deadline for ALBERTIANA 24: April 1st, 2000.

ALBERTIANA is now also available on-line

Several readers and STS member experessed that they would like to see an electronic version of ALBERTIANA on the worldwide web. The editor/webmaster is pleased to inform you that an electronic version of ALBERTIANA is now available under the URL given below.

Comments, suggestions for improvement and information to be posted on the website are most welcome! Because server space is limited, any offer to host the ALBERTIANA website would be greatly appreciated.

http://www.uni-muenster.de/GeoPalaeontologie/Palaeo/Palbot/albomsl.htm

BRITISH TRIASSIC PALAEONTOLOGY: SUPPLEMENT 23

G. WARRINGTON

Since the completion of the writer's previous supplement (No. 22; ALBERTIANA, 22: 41-42) on British Triassic palaeontology, the following works relating to aspects of that subject have been published or have come to his notice:

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This contribution is published with the approval of the Director, British Geological Survey (N.E.R.C.).

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[1] The continuous Help of Mrs. Gaby Schwenzien (Münster) and Dr. Zwier Smeenk (Utrecht) in tracing relevant Triassic literature is gratefully acknowledged. Thanks are also due to all authors who sent information on their recent publications. Some references have been traced from secondary sources. Therefore, diacritical signs may sometimes be missing. Titles of congress abstracts - even those published in regular journals - are not included.

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ALBERTIANA

The production and distribution of ALBERTIANA is sponsored by the LPP Foundation Laboratory of Palaeobotany and Palynology, Utrecht

ALBERTIANA is published by the Laboratory of Palaeobotany and Palynology Utrecht for the Subcommission on Triassic Stratigraphy. It provides a forum for short, relevant articles such as:

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