

ALBERTIANA



42

DECEMBER 2014

ISSN 0619-4324

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Cover Image: Waagen's (1895) lithographic plate of the *Ceratite* limestone from Khoora section, Salt Range. See Baud, p. 3

THE GLOBAL MARINE PERMIAN-TRIASSIC BOUNDARY: OVER A CENTURY OF ADVENTURES AND CONTROVERSIES (1880–2001)

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FOREWORD

Different views have been recounted on the Permian-Triassic boundary story. Here are considered only some aspects of a long story and for a more full account, especially of the early development of the Permian-Triassic boundary, I refer to some parts the Tozer's (1984) book. As researcher in IGCP projects from 1974, vice-chairman, chairman and past-chairman of the Subcommittee on Triassic Stratigraphy (1984–2000), I provide here an insider point of view.

INTRODUCTION

FROM GRIESBACH TO DIENER: THE DISCOVERY OF THE OTOCERAS AMMONOID IN THE HIMALAYA

Carl Ludolph Griesbach

The story starts in 1880, when Carl Ludolph Griesbach (Fig. 1) was publishing a note on the Paleontology of the Lower Triassic of the Himalaya: during his Survey of the Central Himalaya, he discovered the *Otoceras* ammonoid (Fig. 1) and he was the first who understood the importance of this fossil to mark the base of the Triassic Series and the Permian-Triassic boundary. His Central Himalaya's studies were published in 1891.



Carl Ludolph Griesbach

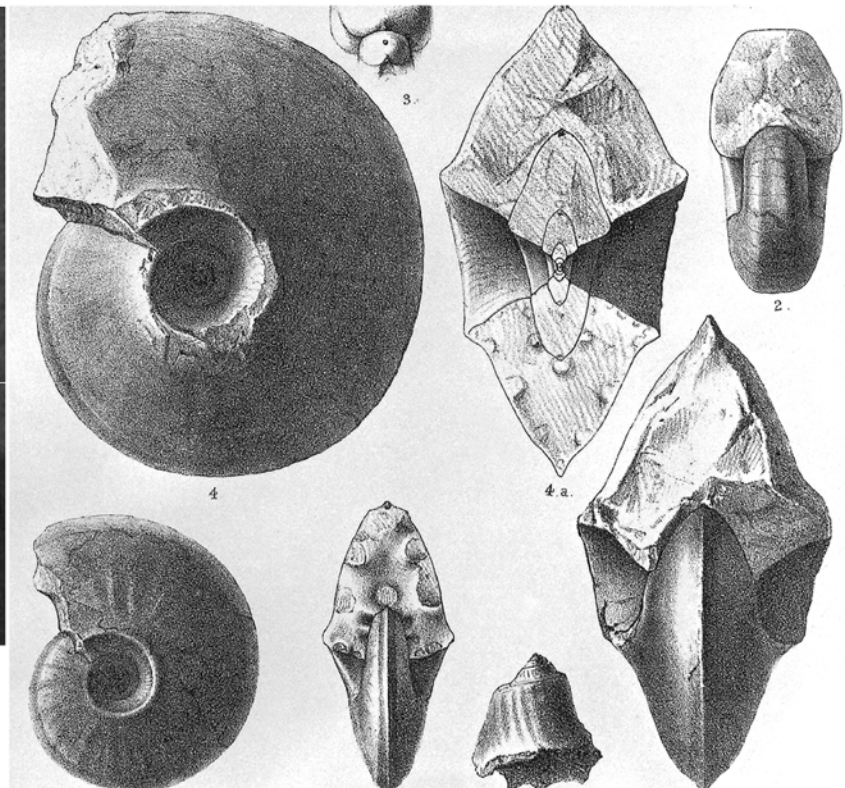


Figure 1 – Carl Ludolph Griesbach with its *Otoceras* original plate (Griesbach, 1880).

Edmond von Mojsisovics, Wilhelm Waagen and Carl Diener

Shortly after Griesbach's publication came out the Mojsisovics, Waagen and Diener 1895 paper with the Lower Triassic subdivision proposal made by Waagen and Diener (Fig. 2) in which they strongly advised the use of the *Otoceras* Beds described in the Central Himalaya to define the base of the Triassic. In the same year, Wilhelm Waagen published an impressive paleontological work on the Salt Range fossils (Fig. 3). This was soon followed by the contributions of Carl Diener who explored

the Central Himalaya and published his survey in 1895 (Fig. 4). Like Waagen before him, Diener visited the Salt Range, then the Permian-Triassic sections in Kashmir. He discovers also *Otoceras* specimens in Spiti Valley sections and made correlations with the Shalshal Cliff section in the Central Himalaya (Diener, 1912). All these extensive paleontological collections have been carefully stored at the Geological Survey of India in Calcutta.

The first controversy starts with von Krafft (1901), Frech (1902) and Noetling (1905) who assumed the Permian age of *Otoceras* with references to the Transcaucasia sections.

Untere Trias nach W. Waagen und C. Diener.

Serien	Stufen	Unterstuften	Mediterrane Triasprovinz		Indische Triasprovinz		
			Zone (der pelagischen Facies)	Schichtbezeichnung (verschiedenartiger örtl. Entwicklung)	Zone (der pelagischen Facies)	Schichtbezeichnung (verschiedenartiger örtlicher Entwicklung)	
Dinarisch	Anisiisch	Bosnisch	10. Z. des <i>Ceratites trinodosus</i>	Oberer Muschelkalk	Z. des <i>Ptychites rugifer</i>	Muschelkalk des Himalaya	
		Balatonisch	9. Z. des <i>Ceratites binodosus</i>	Unterer Muschelkalk	Z. des <i>Sibirites Pruhlada</i>	Brachiopoden-Schichten mit <i>Rhynchonella Griesbachi</i> (Himalaya)	
	Hydaspisch				8. Z. des <i>Stephanites superbus</i>	Oberer Ceratiten-Kalke der Salt Range	
Skythisch	Jakutisch		Z. des <i>Tirolites Cassianns</i>	Werfener Schichten	7. Z. des <i>Flemingites Flemingianus</i>	Ceratiten-Sandstein der Salt Range	Subrobustus Beds des Himalaya
					6. Z. des <i>Flemingites radiatus</i>		
	Brahmanisch	Gandarisch	der Ostalpen	5. Z. des <i>Ceratites normalis</i>	4. Z. des <i>Proptychites trilobatus</i>	Ceratite Marls der Salt Range	
		Gangetisch		3. Z. des <i>Proptychites Lawrenceanus</i>			
			2. Z. des <i>Gyronites frequens</i>	1. Z. des <i>Otoceras Woodwardi</i>	Untere Ceratiten-Kalke der Salt Range	Otoceras Beds des Himalaya	

Figure 2 – The Lower Triassic scale according to Waagen and Diener in Mojsisovics et al. (1895).

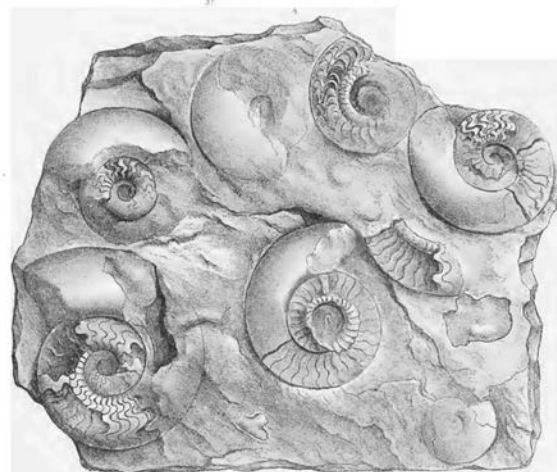
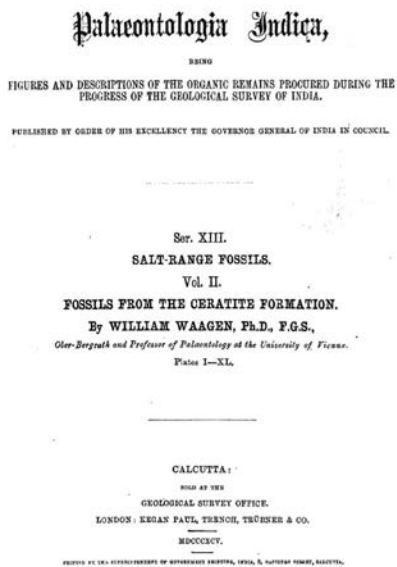


Figure 3 – Left, cover of the Salt Range fossils by Waagen (1895); right: plate XL of Waagen (1895) showing a limestone slab of the Lower *Ceratite* limestone, Khoora section.



Carl Diener

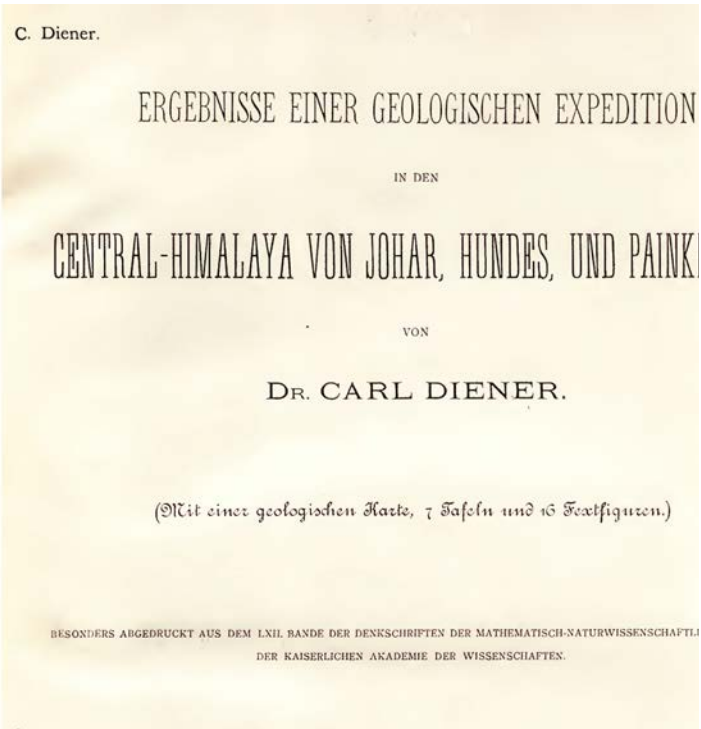


Figure 4 – The cover of the Central Himalaya paper of C. Diener (1895).

THE ARCTIC ADVENTURES, AMMONOIDS AND MIXED FAUNA

The Permian-Triassic succession and boundary of three main areas of the Western Arctic have been intensely studied (Fig. 5, left): Jameson Land on East Greenland with the expeditions of

Lauge Koch in the 1930's (Fig. 5, right), of R. Trümpy in the 1950's, and of C. Teichert and B. Kummel at the end of the 1960's; Axel Heiberg and Ellesmere Islands surveyed by E.T. Tozer; and Spitsbergen (Svalbard) Islands studied during three expeditions of a Japanese team led by Nakamura (1984) and by K. Nakazawa in 1986.

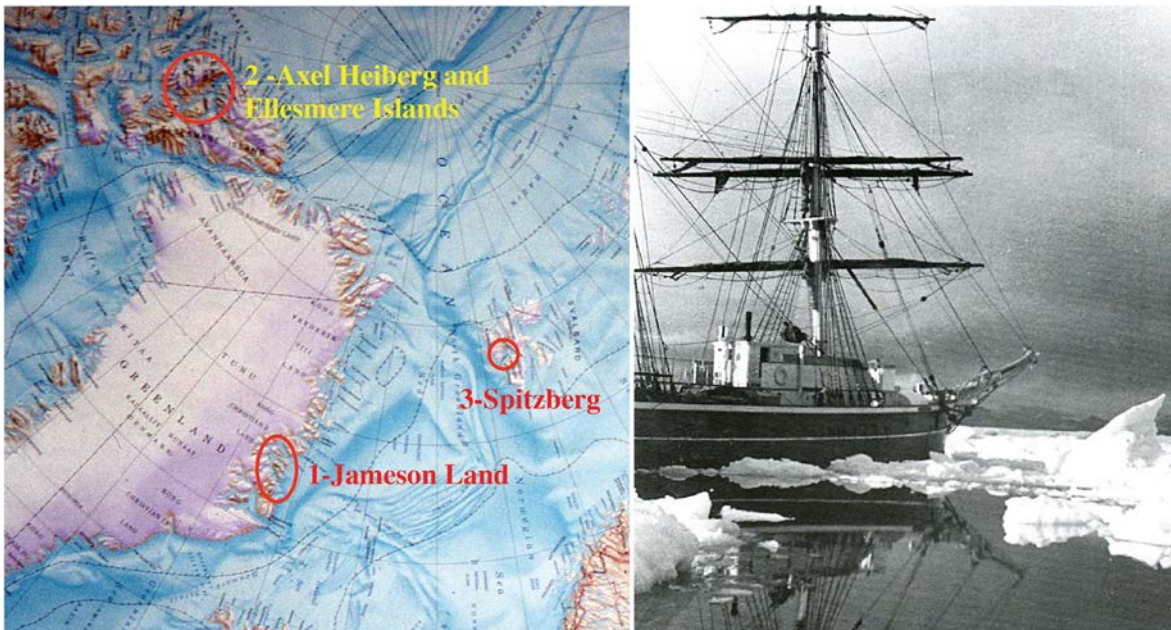
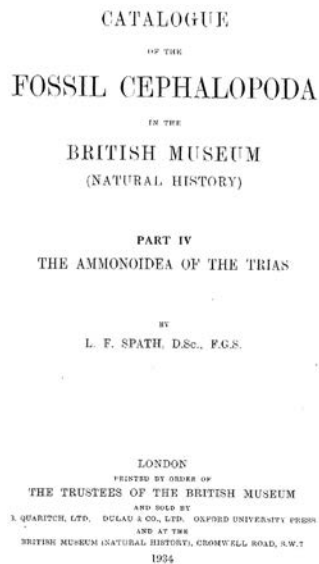


Figure 5 – Left, Western Arctic map: 1– Jameson Land, 2- Axel Heiberg and Ellesmere Islands, 3- Spitsbergen (Svalbard) Islands; right: the “Gustave Holmes” boat of the Lauge Koch Expedition close to Jameson Land (photo from Augusto Gansser, a young geologist of the expedition).

Lauge Koch collections and Leonard Frank Spath

Between 1930 and 1950, large Cephalopod collections from Eastern Greenland made by Lauge Koch (1931) were carefully studied by Leonard Frank Spath (Fig. 6), allowing him to publish a new and very fine subdivision of the Lower Triassic from the Arctic region. Working on ammonoid biochrones, his basal Triassic was called Otoceratan (Spath, 1934, Spath et al., 1951).



Rudolf Trümpy

At the end of the 1950s, Rudolf Trümpy, Professor in Lausanne and Zürich, Switzerland went to East Greenland (Jameson Land, Kap Stosch), studied the late Permian to basal Triassic macrofossils and, in 1960, he wrote an interesting study about the problematic of the mixed fauna at the Permian-Triassic transition. Later, in 1969, Trümpy published his work on the Lower Triassic Ammonites from Jameson Land (Fig. 7) with refined subdivisions of the local basal Triassic.

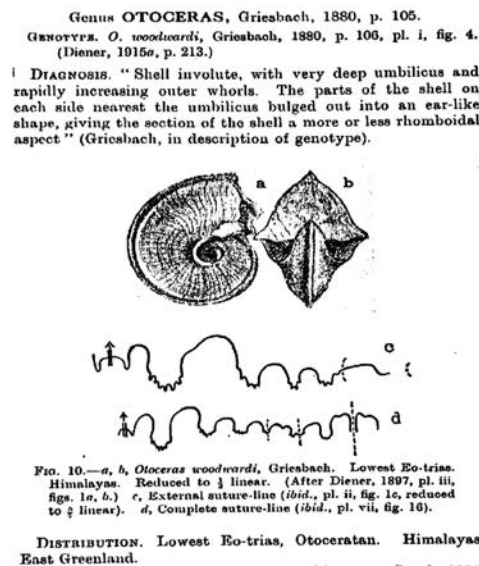


Figure 6 – Left, cover of the Spath's catalogue; right, his *Otoceras* description (Spath, 1934).



Rudolf Trümpy

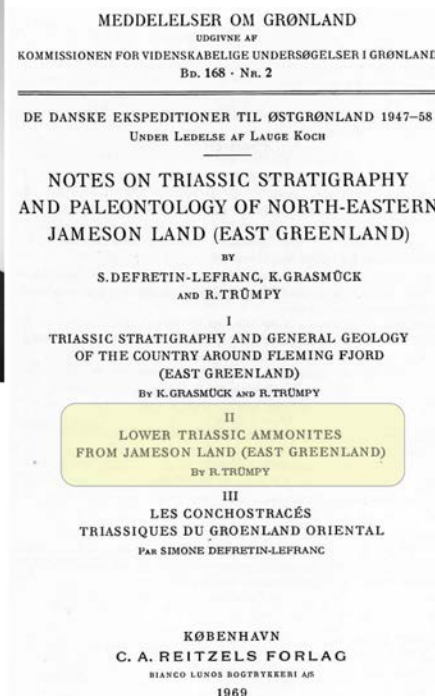


Figure 7 – Cover of the 1969 Jameson Land Triassic paper with the Trümpy's ammonites study.

Edward Timothy Tozer

In the sixties, a Canadian paleontologist ammonoid specialist, Edward Timothy Tozer (Fig. 8, left), started his famous Triassic studies in the High Arctic, for the Geological Survey of Canada (Fig. 8, right). As only geographic names are allowed for stage name, Tozer gave the name of the pioneers of the Triassic studies to small gullies or creeks, both on Axel Heiberg and on Ellesmere Island (Fig. 9). That is why, in 1965, he took the opportunity to

subdivide the Lower Triassic Series in four stages, named from these creeks: Griesbachian, Dienerian, Smithian and Spathian.

With Norman Silberling, the ammonoid specialist from Denver (USA), Tozer extended the Arctic lower Triassic subdivisions to the whole of North America and published (Tozer and Silberling, 1968), as point of reference, the biochronological scale and the subdivisions of the Western North America Triassic (Fig. 10).

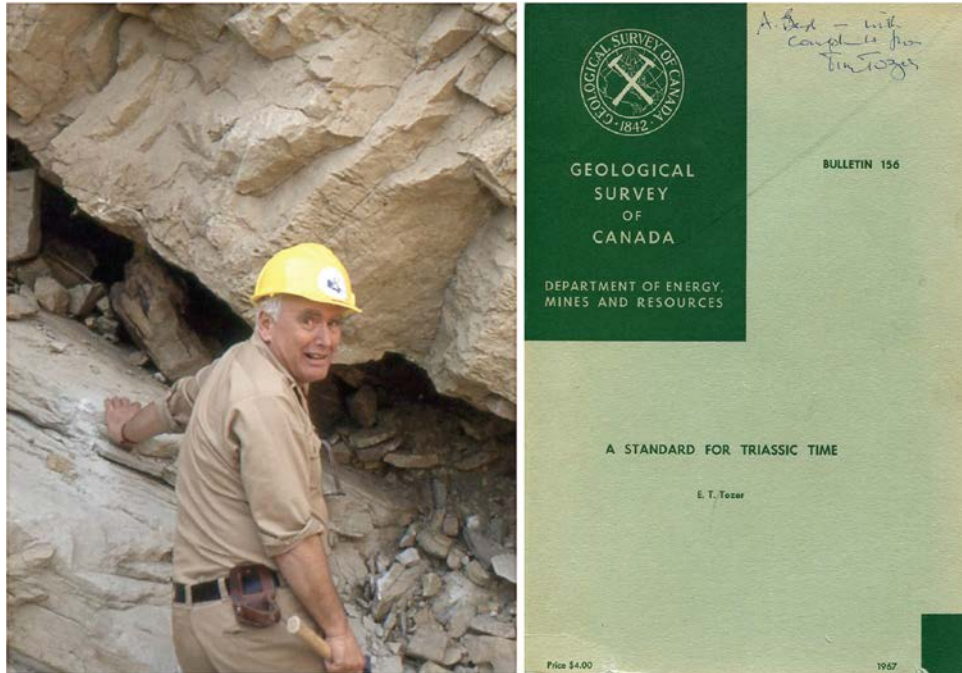


Figure 8 – Left, Tim Tozer surprised at the PTB in Nammal Gorge (Salt Range, Pakistan, December 1987); right, cover of the Tozer's (1967) Triassic book.

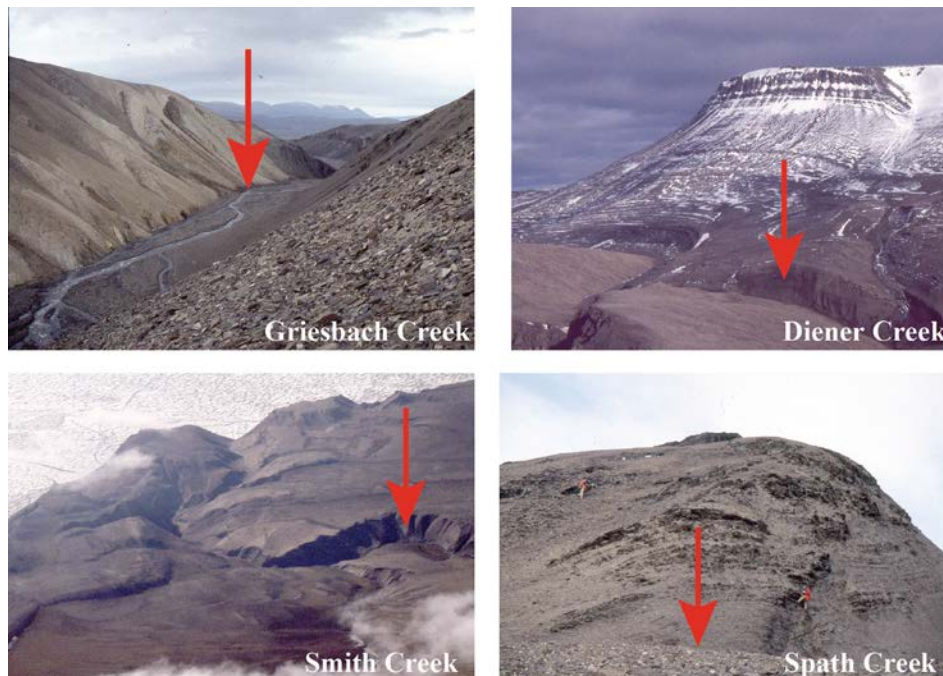


Figure 9 – The four remote gullies (Creeks) used by E.T. Tozer as lower Triassic stages stratotypes.

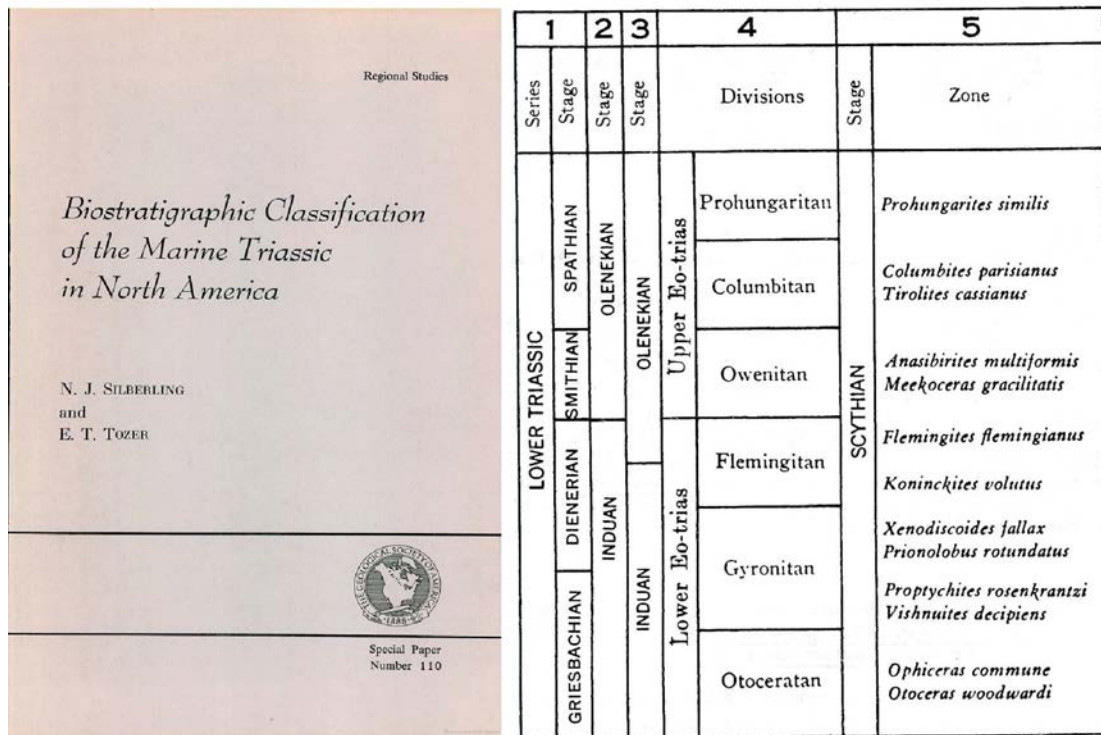


Figure 10 – Left, cover of the Silberling and Tozer (1968) basic Triassic paper; right, Tozer's (1965, table 2) Lower Triassic comparative classification with: 1 = Silberling and Tozer (1968), 2 = Kiparisova & Popov (1956, 1961), 3 = Kiparisova & Popov (1964), 4 = Spath (1934), 5 = Kummel (1957).

Curt Teichert and Bernhard Kummel

During the 1967 Summer, Curt Teichert specialist of Permian Cephalopods and Bernhard Kummel specialist of Triassic ammonoids get the opportunity to go and work on the Permian Triassic transition in the famous Kap Stosch area. They finally went to the conclusion that the Permian fossils with brachiopods

and bryozoans are reworked within the basal Triassic *Ophiceras* beds (so called mixed fauna). The first paper was published in 1972 (Fig. 11), and the detailed description of the sections appear in their 1976 paper with the conodont description in an appendix written by Walter C. Sweet.

BULLETIN OF CANADIAN PETROLEUM GEOLOGY
VOL. 20, NO. 4 (DECEMBER, 1972) P. 659-675

PERMIAN-TRIASSIC BOUNDARY
IN THE KAP STOSCH AREA, EAST GREENLAND

CURT TEICHERT¹ AND BERNHARD KUMMEL²

ABSTRACT

Study of a number of Permian-Triassic sections in the Kap Stosch region in the summer of 1967 has provided a number of new observations. First, the Permian-Triassic sections southwest of Kap Stosch are of homogeneous shale, silty shale, and siltstone facies. None of the rock units are highly indurated, but all are markedly "soft." Solifluction has so badly affected all outcrops that meaningful stratigraphic sections are next to impossible to obtain. The lowest Triassic beds in these regions do contain thin (1-5 cm) hard bands consisting of coquinas of ammonoids (*Glyptophiceras* and *Otoceras*) and containing fragments of productids, bryozoans, and other fossils of "Permian" affinities.

Southeast of Kap Stosch (e.g., between Rivers 6 and 14) the lowest Triassic strata encompassing the *Glyptophiceras* Zone are about 200 m thick. They are predominantly arkosic sandstone and conglomerate. A number of horizons yield fragmentary and whole specimens of productid brachiopods, fragments of crinoid stems, bryozoans and other fossils in coarse sandstone and conglomerate matrix, occurring as much as 100 m above the base of the Triassic sequence.

These strata, containing mixed associations, by their thickness, sedimentary structures, and composition, clearly indicate very rapid rates of deposition. These environmental considerations lead to the conclusion that the "Permian" faunal elements almost certainly did not actually live and form part of the benthos during earliest Triassic time. The underlying Permian formations are of diverse facies among which richly-fossiliferous biohermal banks are present elsewhere. Some of these banks weather easily, yielding nearly perfectly preserved fossils free of matrix. We consider it most probable that some of the Permian faunal elements in the lowest Triassic formations have been brought into that environment as argillaceous boulders, that once coming to rest, dissolved, leaving well-preserved fossils that were rapidly buried in the coarse sediment and in a free state were transported very little. The majority of fossils, however, were washed out of soft rocks and were badly broken during transportation.

We conclude that the Permian-Triassic sequence in the area encompasses a break equivalent to at least the Dzulfian Stage.



Figure 11 – Left, first page of the Teicher and Kummel's (1973) Kap Stosch paper; right, their plate with Ophiceratids accumulation.

Koji Nakamura, Keiji Nakazawa and the Japanese Group

As reported by Nakamura et al. (1987), a cooperative study between Norsk Polarinstitut and Hokkaido University, Japan was undertaken during the year 1984 in West Central Spitsbergen. The main objective of which was to obtain detailed

stratigraphical and palaeontological informations on the Permian and the Permian-Triassic boundary (Fig. 12). During the Summer 1986, Keiji Nakazawa leaded a Japanese geological expedition to Svalbard with a report of *Otoceras boreale* finding in 1987. Further studies were made in 1990, and the final Report published by Tatsumi (ed.) in 1990 with the Nakamura et al. paper on Permian-Triassic boundary.

THE PERMIAN-TRIASSIC BOUNDARY

Keiji Nakazawa

Introduction

There are two problems with regard to the Permian-Triassic boundary. One is the correlation of the Permian-Triassic transition beds, or mixed fauna beds. The other is the location of boundary itself. An accurate correlation of the transition beds needs first to be cleared before the second problem can be discussed. The correlation of the *Otoceras* Zone is of special importance, because it has classically been defined as the base of the Triassic System. However, its distribution is limited to the arcto-boreal and peri-Gondwana provinces and the correlation with the Tethyan province is still in dispute. The correlation of the so-called mixed fauna beds is also of importance, but these two problems are intimately related with each other.

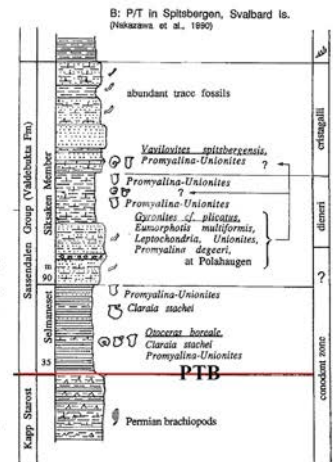


Figure 12 – Left, Introduction of the PTB paper of Nakazawa (1992); right, a Permian-Triassic transition section in Spitsbergen

THE CENTRAL TETHYS

Research on Permian-Triassic transition along the central Tethys margins concerned Transcaucasia (Armenia and Azerbaidjan), Iran, Pakistan, Northern India and Tibet.

In the Salt Range, they started again in the 1950s, with Schindewolf short survey published in 1954 and were followed in the sixties by Curt Teichert, Bernhard Kummel and Walter Sweet, and later by Keij Nakazawa and his Japanese team.

Transcaucasia; from Hermann Abich (1878) to Tim Tozer (1969)

Due to the highly fossiliferous late Paleozoic, the Transcaucasia attracted paleontologists as Abich (1878) and Mojsisovics (1879). For Frech and Arthaber (1900) the Himalayan *Otoceras* were Permian in age as the Armenian one's. Bonnet (1919, Fig.13) found large similarities between the *Otoceras joulfense* Abich and the Himalayan *Otoceras woodwardi*, and fighting against Diener, he strongly claimed a same Eo-Triassic age of the Armenian red "*Otoceras*" beds. Due to the abundance of Xenodiscidae and early Otoceratidae, the area became source of biochronological problems and misplaced correlation. The story continued and later Ruzhentsev and Sarycheva (1965), Russian paleontologists incorrectly determined a basal Triassic *Tompohiceras* zone below the *Dzhulfites* and *Paratirolites* beds. Influenced by this,

D.L. Stepanov, F. Golshani and J. Stöcklin (1969) published, on the Iranian Julfa sections, a wrong correlation with a Permian-Triassic boundary in the middle of the red ammonoid limestone with *Productus*. Fortunately, after carefully studying Armenian specimens, Tozer, the same year (1969), reinterpreted the data and went to the right conclusion that the Permian-Triassic boundary is to be placed above the red ammonoid limestone, at the top of the *Paratirolites* beds. A long controversy was resolved.

Curt Teichert and Bernhard Kummel in association with Walter C. Sweet

In the 1960s, Curt Teichert specialist of Permian Cephalopods, Bernhard Kummel specialist of Triassic ammonoids and Walter C. Sweet conodont specialist started to work together on Permian-Triassic boundary sections of the Tethys: first in the Salt-Range, then in Kashmir and finally in the Julfa section of NW Iran. Both, separately or together, published very detailed reports on examined sections and their macrofossil contents.

Curt Teichert and Bernhard Kummel undertook field work in the Salt Range sections, Pakistan, in 1961 up to 1964, and Kummel published a first report in 1966, followed by an edited book (Teichert and Kummel, 1970) that contains the description of 12 main sections with the Permian-Triassic transition (Fig. 14). Walter C. Sweet (1970) wrote a section on the lower Triassic conodont succession.



Pierre Bonnet

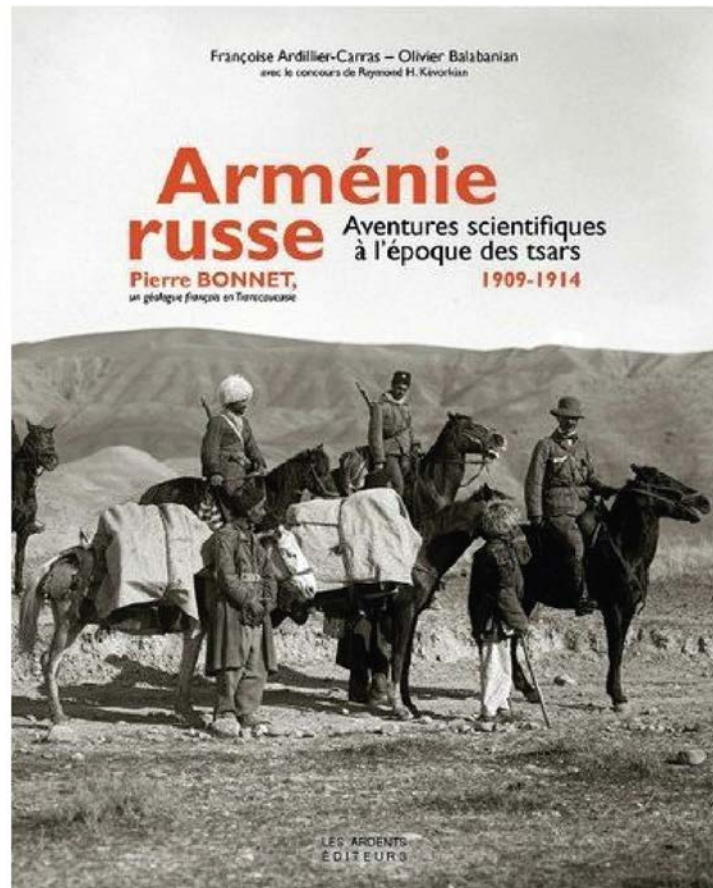


Figure 13 – Cover of the book on the story of the Pierre Bonnet geological explorations in Transcaucasia, from 1909 to 1914.

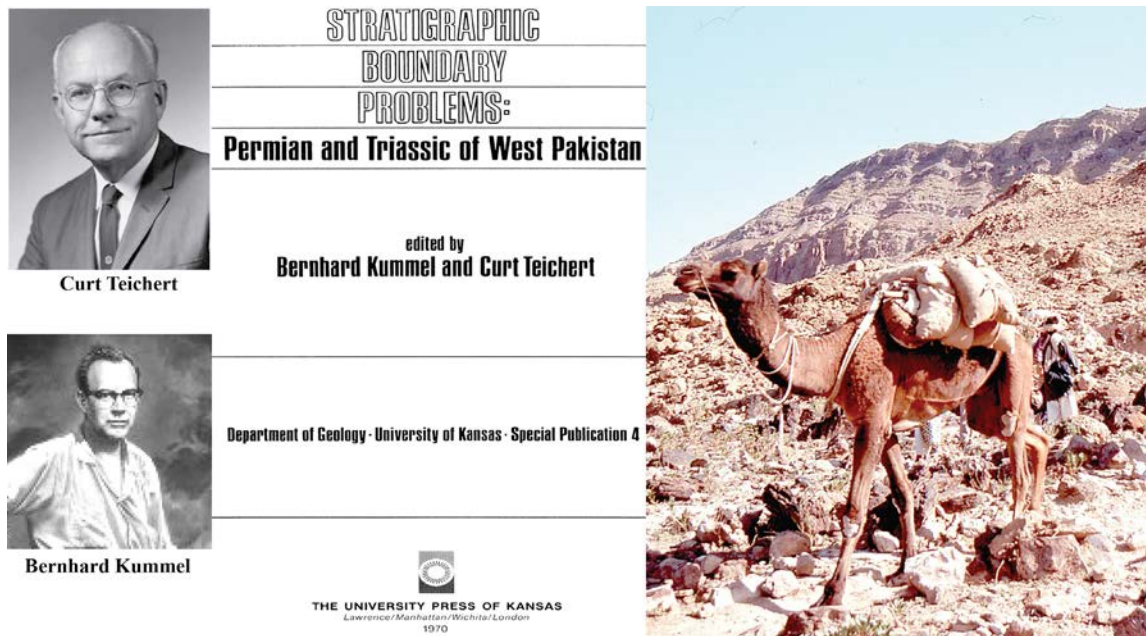
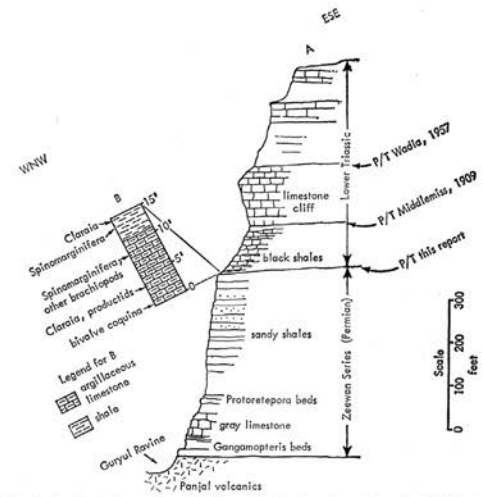


Figure 14 – Left, C. Teichert photo and B. Kummel portrait; middle, cover of the Kummel and Teichert book (1970) on the Salt Ranges; right: slide of the Central part of the Salt Range with, in the foreground, the Lower Triassic strata worked by Teichert and Kummel.



Guryul Ravine section, Indian Kashmir

Fig. 1. Southeast side of Guryul Ravine. (A) Stratigraphic section after Middlemiss (1909) [adapted from Wadia (4)]. P/T, Permian-Triassic boundary. (B) Basal part of Middlemiss's "Black Shale" unit according to our own traverse. (Scale in feet used for compatibility with earlier publications.)

Figure 15 – Left, view on the Guryul Ravine section; right: the Guryul Ravine section drawn by Teichert & Kummel (1970).

In 1968, Curt Teichert and Bernhard Kummel spend 2 days at the Guryul Ravine section, Kashmir, India (Fig. 15), collected samples and wrote a paper (Teichert & Kummel, 1970). The same year, Sweet gave an account on the conodont zonation from late Permian to early Triassic at Guryul Ravine (Sweet, 1970).

After short reconnaissance on Iranian side of the Transcaucasia in 1966, Teichert went back with Bernhard Kummel in Julfa area in 1968 and studied four sections along the slope. The Teichert et al. paper was printed in 1973 (Fig. 16, left) and took account of

the Tozer's views for interpreting the PTB position. The "upper Julfa beds" was sampled in their locality 4 (Fig. 16, right), packed, sent and stored at the Museum of Comparative Zoology, but probably wrongly labeled with the name of the overlying unit "Ali Bashi Formation". This mistake has been the starting point of controversies on the late Permian conodont succession and determination, explained by Henderson et al., 2008 (this story is related by Baud, 2008 and recently by Ghaderi et al., 2013).

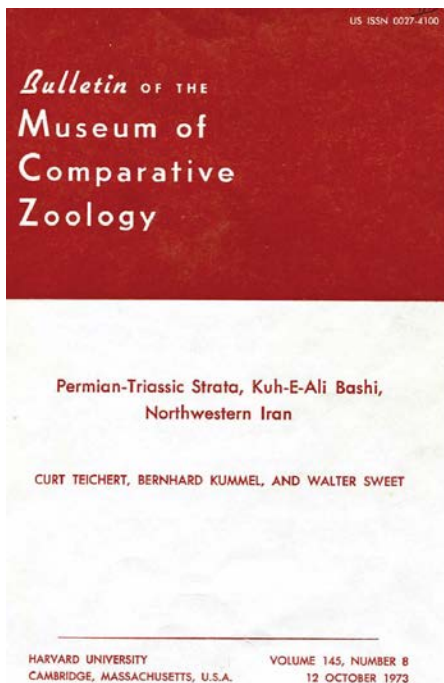


Figure 16 – Left, cover of the Kummel and Teichert (1973) booklet on Julfa sections; right, view on the locality 4 of Kummel and Teichert.

Keiji Nakazawa and the Japanese Group

In 1969 and during the seventies, a Japanese Group led by Keiji Nakazawa, in cooperation with local Survey, started extensive studies of three main Permian–Triassic marine and fossiliferous area of the central Tethys and published bed by bed description and fossil contents.

In 1972, detailed paleontological and sedimentological studies have been carried out in Abadeh, Central Iran (Fig. 17, right) and in Elburz Mountain by geologists of the Geological and Mineral Survey of Iran and by a research staffs of Japanese universities led by Keiji Nakazawa. Supplementary fieldwork was done in 1975 and the extensive results (Fig. 17, left) were published in the Kyoto University Memoirs (Iranian-Japanese Research Group, IJRG, 1981)

With Hari Mohan Kapoor from Indian Survey, the Japanese

Group led by Keiji Nakazawa studied the Guryul Ravine section, (Fig. 18, right) and surrounding sections of the Indian Kashmir, during 1971 and 1972. The extensive results were published in the Kyoto University Memoirs (Nakazawa et al., 1975), the fauna in Nakazawa and Kapoor, 1981 (Fig. 18, left), with the ammonoids systematic description by Bando, and during the 80's, Tetsuo Matsuda (1981, 1982, 1983 and 1984) wrote detailed conodont papers on the Kashmir Permian-Triassic succession.

With colleagues from the Pakistani Geological Survey, the Japanese Group led by Keiji Nakazawa studied in 1975, 1976 and 1979 the Nammal Gorge and seven surrounding sections in the Salt and the Surghar Ranges, Pakistan (Fig. 19, right). The first results were published by Pakistanese-Japanese Research Group (PJRG), first in 1981 (Fig. 19, left) and later in a 90 pages detailed report (PJRG, 1985).

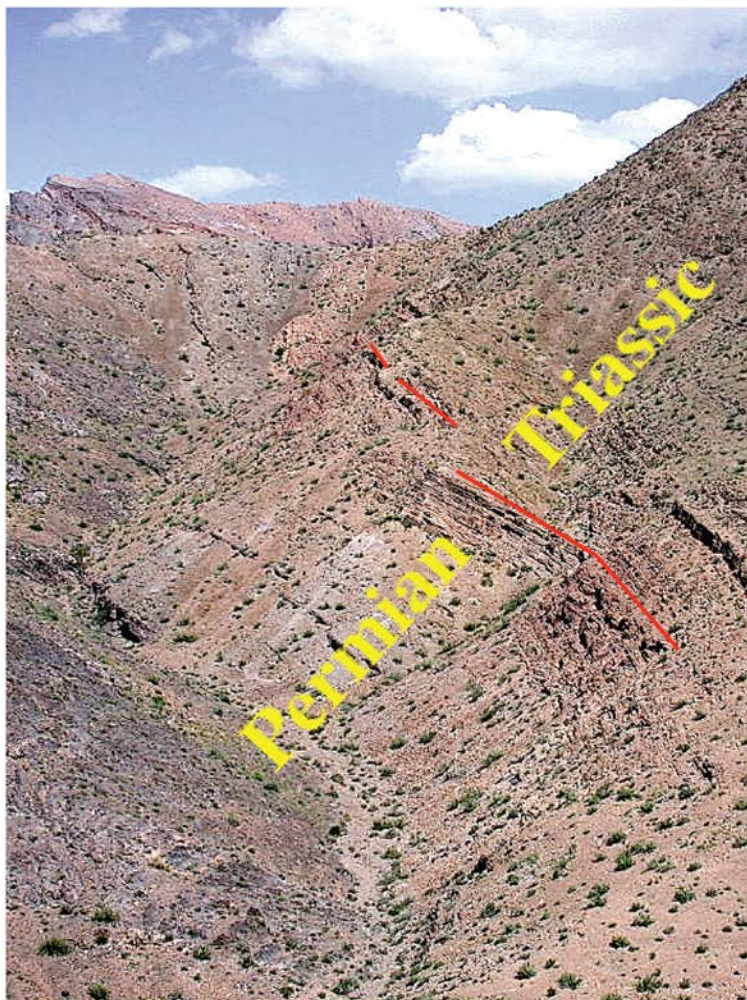
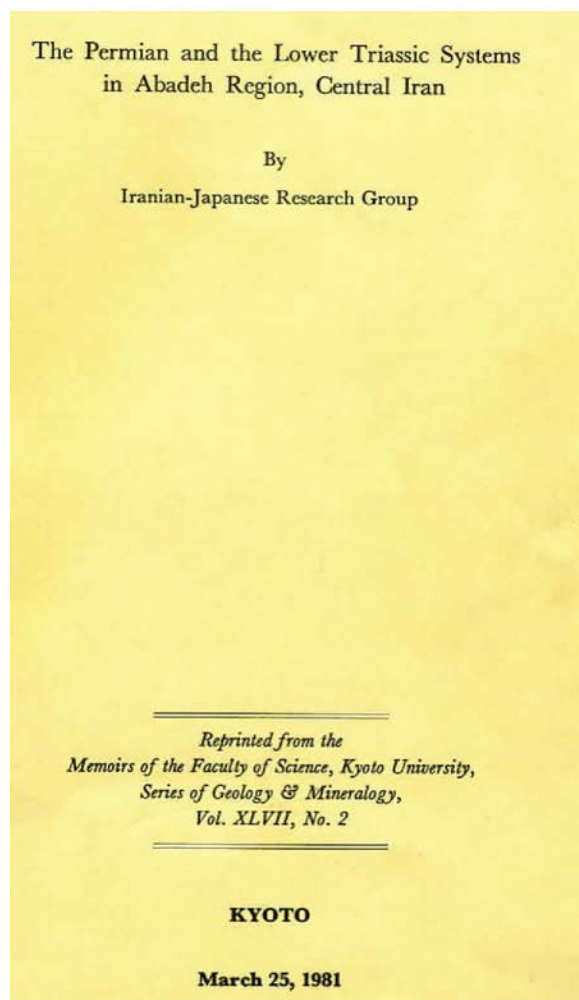


Figure 17 – Left, cover of the Kyoto University Memoirs on Abadeh (IJRG, 1981); right: view of the Abadeh section.

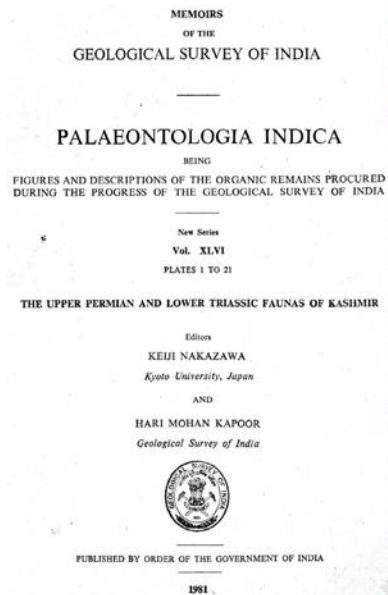


Figure 18 – Left, Cover of the Kashmir book (1981); right: slide of the Guryul Ravine Permian-Triassic section with the Nakazawa beds numbering and PTB (red line).

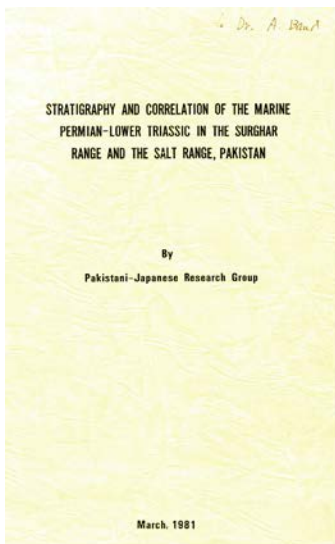


Figure 19 – Left, cover of the first Salt Range paper (PJRG, 1981); right: view on the Surgar Range with upper Permian and lower Triassic in the ground.

THE INTERNATIONAL GEOLOGICAL CORRELATION PROGRAM (IGCP), CONFERENCES AND FIELD WORKSHOPS (1974–2001)

Three years prior to the beginning of the International Geological Correlation Program, a turning point event in the Permian-Triassic boundary studies was the first International Permian-Triassic Conference held August 23-26, 1971 in Calgary (Canada) with over fifty contributions on the paleontology, stratigraphy, sedimentology, radiometric chronology, paleoclimatology and paleomagnetism of this time interval and of the boundary. A. Logan and L. V. Hills edited

the Proceeding entitled “The Permian and Triassic Systems and their Mutual Boundary” in 1972.

For nearly a century, the research of this boundary mainly dealt with macrofossils and associated biochronology as tool for correlation. Microfossils as conodont systematic and geochemical analyses were only at the opening as magnetostratigraphy.

Heller et al. (1988) gave a first study on marine PTB magnetic time scale on Shangsi section (Sichuan, China), a candidate for the Permian-Triassic boundary section. Later on, Ogg and Steiner (1991) published their data on the Lower Triassic stratotype of Ellesmere and Axel Heiberg Islands, showing a normal polarity within the *Otoceras* zones.

IGCP Projects 4 and 106 (1974-1984), Figs. 20 and 21 left.

Sponsored by UNESCO, in 1974 started the International Geological Correlation Program with the Project 4 on “Triassic of the Tethys Realm”, led by Prof. H. Zapfe from Vienna University and Austrian Academy. The Project 106 “Permo-Triassic stage of geological evolution” followed it up to 1984,

led by a Russian team with Dr. A.N. Oleynikov.

Two successful fieldtrips on Permian-Triassic boundary of new areas, the Setorym Creek in Verkoyansk mountains (East Siberia) and the Vedi and Sovetachen sections in Transcaucasia (Armenia) were organized during the 1984 IGC in Moscow. It was a unique opportunity for participants to collect samples of these remote sections (Fig. 20).



Figure 20 – Left, E.T. Tozer between Y. Arkhipov and A. Dagus, field trip leaders, at the lower *Otoceras* beds, Setorym Creek (E Siberia); right: Field trip participants in front of the snowy Ararat summit (Armenia), Zun-Yi Yang is on the right and G. Kotlyar in the middle.

Progress of IGCP Projects*

No. 4/106 TRIASSIC OF THE TETHYS REALM

H. Zapfe, Erdwissenschaftliche Kommissionen der Österreichischen Akademie d. Wissenschaften, A-1010 Wien, Postgasse 7, Austria.

Description. Revision of the biostratigraphy in the Tethyan Triassic. Redefinition of classical stages and substages, their emendation for a worldwide application. Comparison of the scheme with other major faunal realms (North America, Eurasia, Indo-Pacific) aiming at a global Triassic time scale. Once this stage has been achieved, other important topics are to be studied, such as palaeogeography, faunal provinces and palaeomagnetism during Triassic time. An original study was made of the Upper Triassic and during recent years the work has expanded more and more to cover the entire Triassic, and the Project has been expanded to Asia in order to include the Triassic of the Himalayas, China and the Far East.

NO. 203 – PERMO-TRIASSIC EVENTS OF EASTERN TETHYS AND THEIR INTERCONTINENTAL CORRELATION

Yang Zunyi, Beijing Graduate School, Wuhan College of Geology, Beijing 100083, China.

J.M. Dickins, BMR, P.O.B. 378, Canberra City, ACT 2601, Australia.

W.C. Sweet, Department of Geology, Ohio State University, Ohio 43210, USA.

Description : The main objectives of Project 203 include : (1) a detailed study of the Permo-Triassic strata in the Eastern Tethys region and their correlation with equivalent stratigraphic units in Gondwana and Circum-Pacific realms,



Figure 21 – left, IGC Project. 4. 106 and 203 short description; right: Zun-Yi Yang and Norman Newell at the PT boundary, Shangsi section, March 1984.

IGCP Project 203: “Permo-Triassic events in the Eastern Tethys”, 1984-1989

In 1984 began the first Chinese IGCP project 203 (Fig. 21, left) proposed and leaded by Prof. Zun-Yi Yang from Beijing Graduate School, on “Permo-Triassic events in the Eastern Tethys”.

With this project, the large opening of China to Western scientists became operative and a successful conference took place in Beijing, March 1984, followed by the fieldtrip to Shangsi section in northern Sichuan province (Fig. 21, right). This is the start of an active collaboration on Permian-Triassic boundary studies with Chinese colleagues.

In July 1986 at Brescia (northern Italy), our Italian colleagues organized a field conference on Permian and Permian-Triassic boundary of Western Tethys sponsored by the IGCP Project 203. The Proceedings of the Field Conference were published at the “Memorie della Societa Geologica Italiana” (Cassinis, ed., 1988, Fig. 22, left) with new views and aspects on the Permian-Triassic boundary. An invitation was addressed to the members of the International Sub-commission on Triassic stratigraphy (SST) and to the members of the Permian-Triassic Boundary working group to participate to a post conference field trip (Fig. 22, right) on Permian and Triassic of Western and Southwestern Turkey (Visscher, 1986) with the Kemer Gorge and the Curuk Dagh PTB sections and a guidebook was published (Marcoux, ed., 1986).

IGCP Project 199: “Rare events in Geology”, 1984

The IGCP project 199 on “Rare events in Geology” started in 1984 under the leadership of Prof. Ken Hsu (ETH Zurich, Switzerland).

Among “Rare events”, the Permian-Triassic largest extinction was the subject of a Conference in Beijing in 1987, followed by a visit to the Nanjing Geological Institute (Fig. 23) and by an international field workshop to the Meishan section, with the first opportunity to sample the PT Boundary in the Meishan quarries.

Boosted during the 1980’s by the IGCP Project 199, Bill Holser (Fig 24), from Oregon University in Eugene (USA), directed geochemical studies towards Permian and Triassic

successions. With him and Mordekai Magaritz from Rehovot University (Israel), we started in 1985, the first database on stable carbon isotopes of more than twenty Permian-Triassic boundary sites from Southern Alps to South China, from studied sample collections stored in Lausanne Geological Museum. We published (Baud et al., 1989) twelve well dated sections with C isotope curve from bulk rock marine carbonate samples showing, for the first time, the global shift (Fig. 24 right) at the boundary: a new tool for marine Permian-Triassic boundary correlation was open and two main PTB candidate sections, Meishan and Shangsi were concerned and illustrated.

With Viorel Atudorei and Halil Sharp (Lausanne University), we provided a detailed C isotope data on a third PTB candidate, the Guryul Ravine section, Indian Kashmir (Baud et al., 1996). Some years later in Lausanne, Viorel Atudorei was the first to publish a complete C isotope curve of the marine lower Triassic, showing large positive anomalies within the well dated marine succession of the Spiti Valley (Atudorei, 1999) and, Sylvain Richoz (2004) first reported very detailed C isotope curves from PTB sections in Turkey, Iran and Oman.

IGCP Project 272: Late Paleozoic and Early Mesozoic Circum-Pacific Bio-Geological Events, 1988-1992

Succeeding to the IGCP Project 203, the Project 272: Late Paleozoic and Early Mesozoic Circum-Pacific Bio-Geological Events was leaded by J.M. Dickins from Australian Geological Survey.

Just after the Kyoto IGC (end of August 1992), Profs. Yuri Zakharov and Galina Kotlyar organized with my help the first Permian-Triassic conference (Fig. 25, right) and field workshop in Vladivostok (Russia). It was sponsored by the IGCP Project 272 and supported by the STS. The participants get the opportunity to visit four main Permian-Triassic sections of this Far-East Russian area, just open to foreigners’ scientists. A first report was published by Dickins (1993). The proceedings of the field workshop went out in Lausanne (Baud et al., ed., 1997, Fig. 25, left) and the main Project 272 results were published by Dickins et al. (1997).

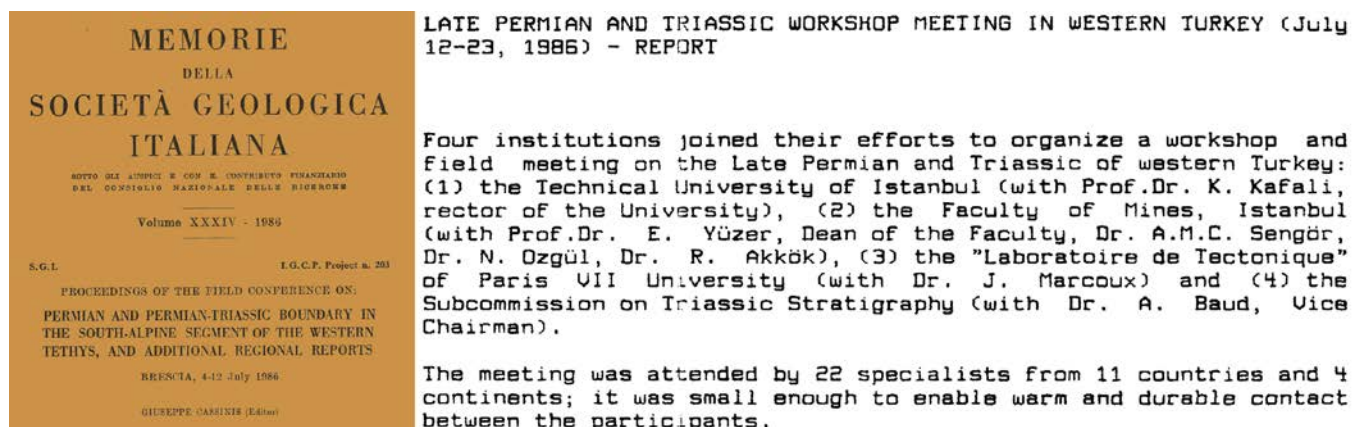


Figure 22 – Left, cover of the Brescia Conference Proceedings; right: report on the PT West Turkey field workshop, 1986.

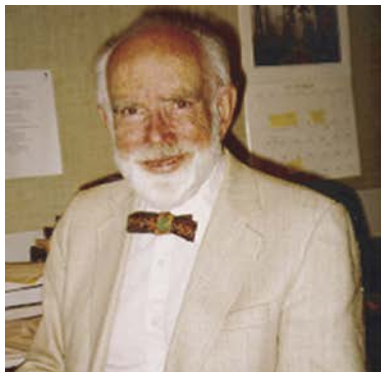
NO. 199 - RARE EVENTS IN GEOLOGY

K.J. Hsü, Geological Institute, ETH-Zentrum, Sonneggstrasse 5, 8006 Zürich, Switzerland.

The Second International Meeting of the project was held in Beijing, China, 3-5 March 1987, with participants coming from ten countries: Austria, Canada, People's Republic of China, France, Italy, Spain, Switzerland, the United Kingdom, U.S.A. and USSR. Some 30 papers were presented followed by two sessions of general discussion on various aspects of rare events and mass extinctions. Chinese geologists reported that biological mass extinctions, stable isotope perturbations, geochemical anomalies and microspherules have been found not only across the Cretaceous/Tertiary boundary, but also the Permian/Triassic, Devonian/Carboniferous, Frasnian/Famennian, Ordovician/Silurian, and Precambrian/Cambrian boundaries in China. However, much work is needed to confirm the preliminary results. Professor K.J. Hsü gave a paper on the use of carbon isotope as a monitor for biomass. D. McLaren emphasized that the mass extinctions in geological history are not only distinguished by the disappearance of many taxa, but more impressive is the nearly total destruction of the biomass by the boundary event. Many participants took part in a five-day post-conference field trip to Changxing in Zhejiang province.



Figure 23 – Left, IGC Project 199 Beijing meeting report; right: the participants of the “rare events” meeting on the steps of the Nanjing Geological Institute, March 1987; in black and in middle front, Ken Hsü, leader of IGC Project 199. Institute, March 1987; in black and in middle front, Ken Hsü, leader of IGC Project 199.



William T. Holser

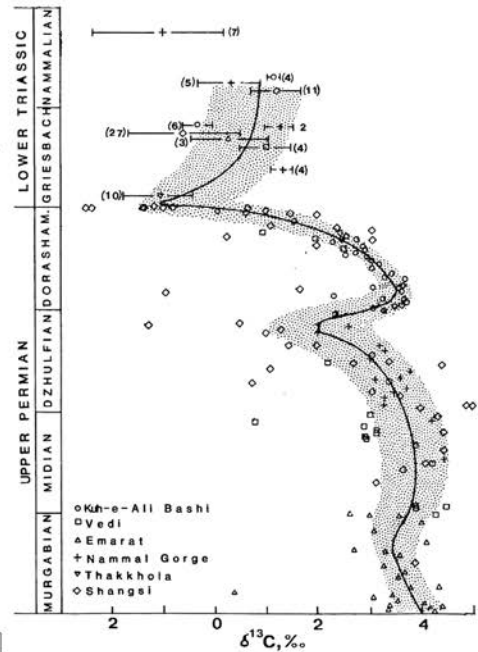
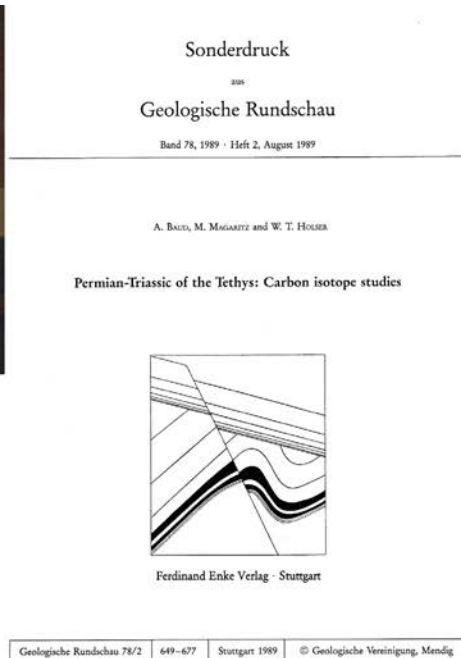


Figure 24 – Left, W.T. Holser photo; middle: cover of the 1989 Baud, Holser and Magaritz Carbon isotope studies paper; right: the Carbon isotope global shift as shown in the last figure.

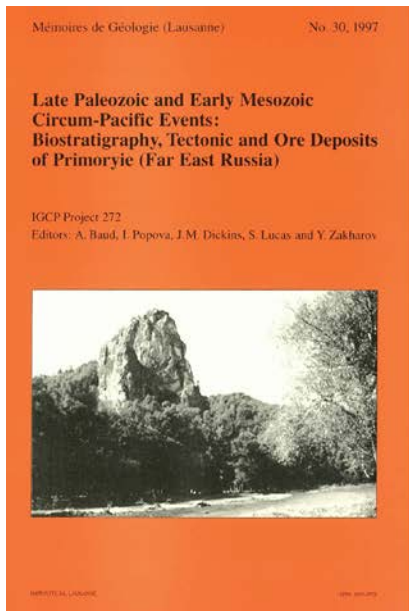


Figure 25 – Left, cover of the Vladivostok Permian-Triassic conference Proceedings; right: round table on IGCP Project 272 during the Vladivostok Permian-Triassic conference with Y. Zakharov, G. Kotlyar, J. M. Dickins, chairman, and the author.

IGCP project 359: Correlation of Tethyan, Circum-Pacific and marginal Gondwanan Permo-Triassic (1993-1998)

Led by Prof. Hongfu Yin (Fig. 26), this project, starting in 1993 and continued through 1997, gave to the participants the

opportunity to participate to specific international meetings with group discussion on the PTB and to visit Permian-Triassic sections in South China, in North Vietnam and in North Caucasus. For the PTB, one of the major achievements was the publication of the Yin's edited book (1996) on the four PTB candidates (Fig. 26, right).



Hongfu Yin

International Geological Correlation Programme, Project no. 359; Correlation of Tethyan, Circum-Pacific and marginal Gondwanan Permo-Triassic

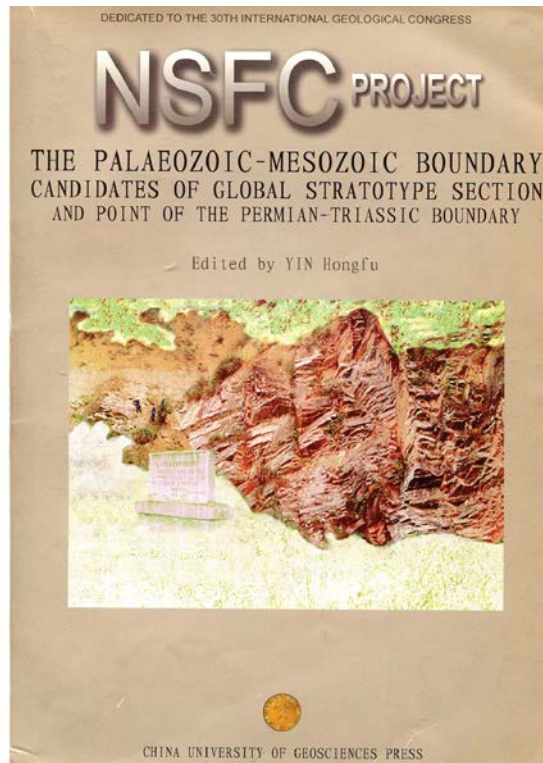


Figure 26 – Cover of Yin's edited book on the four PTB candidates (1985)

THE INTERNATIONAL SUBCOMMISSION ON TRIASSIC STRATIGRAPHY (SST) AND THE PERMIAN-TRIASSIC BOUNDARY WORKING GROUP (PTBWG)

The history of the Subcommittee on Triassic stratigraphy up to 1984 has been well described by Tozer (1985). *Albertiana*, the STS newsletter and platform of discussion publishing preliminary notes, played a very important role in promoting agreement among scientists about criteria fixing the Permian-Triassic boundary, as did *Permophiles*, the Subcommittee on Permian Stratigraphy newsletter (Fig. 27).

Divergent opinions to define the boundary: ammonoid versus conodont

During the 1980's two main camps rose out, the ammonoid workers with Tim Tozer and the new conodont worker group supported by Prof. H. Yin, former student of Prof. Z.-Y. Yang.

In 1984, Tim Tozer asked the PTBWG members about how to define the base of the Triassic. The great majority answered the *Otoceras* beds. But Norman Newell expressed his choice with the base of the Dienerian as published in his 1988 paper. Galina

Kotlyar (1990) was in favor of the *Ophiceras* zone and correlative *Isarcica* conodont zone as Walter Sweet (1988, 1992). The Tozer's proposal was supported by the papers of A. Dagens (1988) and of Nakazawa (1992, 1993).

The conodont specialists get their defender with the H. Yin proposals (Yin, 1988): the first occurrence of the *Hineodus parvus* conodont to define the base of the Triassic, -and the top of boundary clay of Chinese sections as boundary stratotype.

The Lausanne Conference (1991)

Elected STS Chairman during the Washington ICS in 1989, I prepared with my colleagues Jean Guex (Lausanne), Maurizio Gaetani (Milano), Jean Marcoux (Paris) and Hans Rieber (Zurich) a Triassic Conference in Lausanne, Switzerland, for October 1991 with the participation of most of the Subcommittee voting members. This conference was followed by a one day fieldtrip in the Triassic succession of the nearby Prealps (Fig. 28, right). The Triassic Conference proceedings were published 3 years later (Guex and Baud, eds., 1994, Fig. 28 left). Urged by the International Commission on Stratigraphy (ICS) we had, during this conference, to decide how to subdivide the Early Triassic period among four proposals (subdivision in 1, 2, 3 or 4 stages). After a long discussion, the majority of the

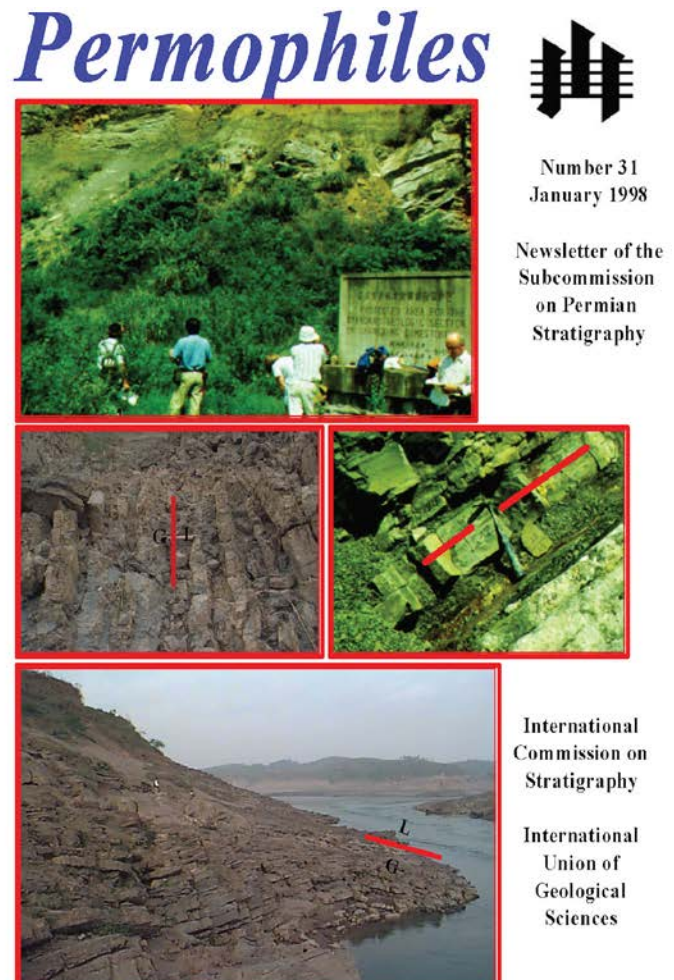


Figure 27 – Left, cover of *Albertiana* 17 with *Ophiceras tibeticum*; left: cover of *Permophiles* 31 with PTB view in Meishan quarry (up and right).

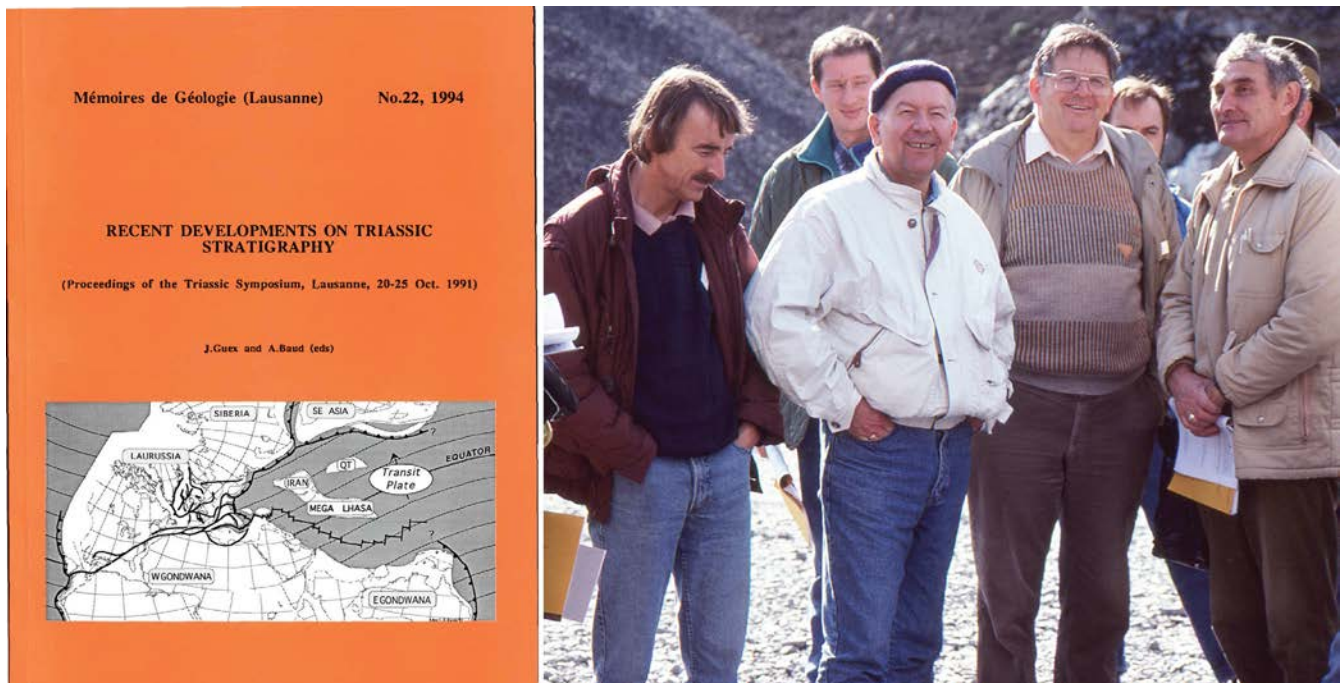


Figure 28 – Left, cover of the 1991 Triassic conference Proceedings (Guex and Baud, Eds., 1994); right: the Triassic ammonite specialists W. Weitschat, A. Dagens, H. Rieber and Y. Zakharov in the Saint-Triphon quarry (post-Triassic conference fieldtrip in Western Switzerland).

voting members proposed the two stage subdivision, named Induan and Olenekian. A detailed report was made by Gaetani (1992). I forwarded the choice to the International Commission on Stratigraphy (ICS) and the new stage names were officially adopted in 1992 during the International Geological Congress (IGC) in Kyoto.

The Permian-Triassic Boundary Working Group (PTBWG) reactivated

The next step of the STS was the setting up of stage boundary working groups on Global Stratigraphic Section and Point (GSSP). As the discussion at the PTBWG was, from 1984, deadlocked, I proposed to H. Yin to reactivate it. Early in 1993, a majority of the voting members elected Yin Hongfu as new chairman. Efficiently, he submitted four GSSP candidates for the boundary: the Meishan section (South China), the Shangsi section (West China), the Selong section (South Tibet) and the Guryul Ravine section (Kashmir, Northern India).

Very active, with the support of the Chinese geological community, he answered point by point to the 1988 Tozer's views, showing the main difficulties when using the ammonoid *Otoceras* to fix the boundary, and the great advantage to move to conodont study for the correlations (Yin, 1994). This was debated during the 1994 PTBWG meeting in Calgary. Yin Hongfu received also a strong support in a 30 pages paper led by H. Kozur, with A. Ramovs, C.Y. Wang and Y. Zakharov, to use *Hindeodus parvus* (Kozur & Pjatakova, 1976) for the PTB definition and to set up the Meishan quarry for the stratotype (Kozur et al., 1994).

In 1995, a majority of the working group approved the Meishan section proposal for Permian-Triassic GSSP. This was

forwarded to the STS members with the new Yin's edited book (Fig. 26) on the four candidates (1996).

Return to High Arctic lower Triassic stratotype

Invited by Benoit Beauchamp I started collaborative work on the Permian-Triassic transition on Ellesmere Island during the summer 1992. Two years later, with Charles Henderson, we sampled High Arctic localities with *Otoceras* for conodont studies, to solve the controversy about the lower *Otoceas* zone correlation. The results were published in the Proceedings of the Beijing IGC 1996 (Henderson and Baud, 1997, Fig. 29, left) showing for the first time that overlying Changxingian conodonts, the *Hindeodus parvus* species appears in the middle of the upper *Otoceras* zone (*Otoceras boreale*).

ACHIEVEMENTS: THE NEW GSSP IN THE MEISHAN QUARRY

At the International Geological Congress (IGC) in Beijing (1996), Yin Hingfu proposed the base of bed 27C at Meishan section D with the first occurrence of the conodont *Hindeodus parvus* for the base of the Triassic GSSP (Yin et al., 1996). But I made the following warning of the very condensed succession of the Permian-Triassic transition at the Meishan locality with a frequent facies changes just below the boundary (not recommended for a stratotype, Baud, 1996). And the long range, with numerous morphotypes of the selected *H. parvus* conodont genus erected by Heinz Kozur on the finding of Pjatakova in Transcaucasia (Kozur and Pjatakova, 1976) can

From *Int'l Geol. Congr.*, Vol. 11, pp. 143-152
Wang Naiswen and J. Remane (Eds)
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CORRELATION OF THE PERMIAN-TRIASSIC BOUNDARY IN ARCTIC CANADA AND COMPARISON WITH MEISHAN, CHINA

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ABSTRACT

Correlation of the Permian-Triassic boundary (P-T) is impeded, in part, by the lack of biostratigraphic correlations between tethyan and boreal settings and the presumed unconformity at many P-T sections in the world. Sequence stratigraphic and biostratigraphic data were collected from six sections of the basal part of the Blind Fiord Formation (Confederation Point Member) on northwestern Ellesmere and Axel Heiberg islands; sequence biostratigraphic data are presented in this paper for only the Griesbach Creek and South Otto Fiord sections. These data address some of these impediments, and allow comparisons to be made with the possible Global Stratotype Section and Point (GSSP) at Meishan, China.



Figure 29 – Left, first page of Henderson and Baud (1997); right: the Permian-Triassic team with the author between Charles Henderson (left) and Benoit Beauchamp at Otto fiord, Ellesmere Island, 1994.

likely brought problems in the determination and consequently in the correlation. Also a detailed discussion on the diachronic *H. parvus* conodont first occurrence was published in Orchard and Krystyn (1998).

Following a positive vote in 1999 by the STS voting members on the Meishan GSSP, the proposal was sent by Maurizio Gaetani, new STS Chairman to the ICS and ratified by the ICS general Assembly, during the Rio de Janeiro IGC in 2000. And the new GSSP final report appears in Episode (Yin et al, 2001). Officially, the Meishan section became the new Erathem boundary with the base of the Triassic Period fixed in the Meishan quarry (Fig.

30, left) .

This was unveiled in this quarry by an opening Ceremony of the GSSP Monument, August 11, 2001 (Fig. 30, right), during the International Symposium on “The Global Stratotype of the Permian-Triassic Boundary and the Paleozoic- Mesozoic Events” held in Changsing City and led by H. Yin.

Thus, after a long time, a successful achievement were done and now the Meishan quarry houses a huge Geopark including an Earth History Museum with giant sculptures and educational exhibitions.

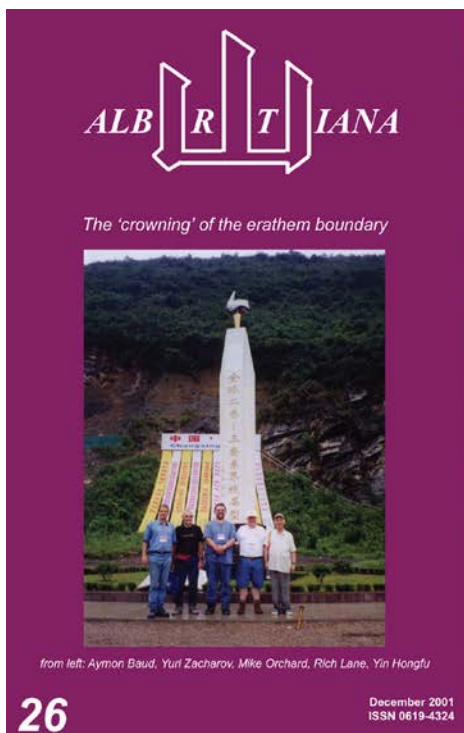


Figure 30 – Left, cover Albertiana 26; right the red ribbon cut ceremony of the Erathem boundary monument, in the Meishan quarry, August 11, 2001 with Charles Henderson (left) and the author.

SOME CONCLUSIONS

During more than a Century were a rash of stage names for the underlying late Permian as Saxonian, Araxian, Chhidruan, Amarassian, Tatarian, Djoulfian / Dorashamian, Changhsingian. Same of plenty stage names happen to the following lower Triassic with successively Buntsandstein, Scythian, Brahamian, Gangetian, Werfenian, Induan or Griesbachian. Finally, the ICS adopted the Changhsingian for the latest Permian stage and the Induan for the Earliest Triassic stage.

With the adoption of the Permian-Triassic GSSP in the Meishan quarry by the ICS and the IUGS, started a boom in Permian-Triassic transition studies, special volumes and publications. Large opening of South China to foreign scientists, new IGCP projects on extinction and recovery were encouraging teams of young researchers in paleontology, biostratigraphy, magnetostratigraphy, geochemistry and absolute dating, with the coming out of hundreds of new papers each year.

But now, with the discover of extended latest Permian sections in South China and extended earliest Triassic sections in Arctic areas, the actual Meishan highly condensed GSSP section shows his borderline. As an extremely short duration of the Induan have been established recently (see Burgess et al., 2014, Ovtcharova et al., 2007), sure a new subdivision of the lower Triassic will be proposed and a new locality for the GSSP will come in the next future.

ACKNOWLEDGEMENTS

Thanks to Prof. Christopher A. McRoberts for his advice and help to improve a first version of this illustrated historical study.

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MARINE *LARIOSAUROS* (SAUROPTERYGIA) RECORDS FROM THE MIDDLE TRIASSIC OF THE GERMANIC BASIN – STRATIGRAPHIC AND PALEOBIOGEOGRAPHIC IMPORTANCE FOR TETHYAN AND GERMANIC BASIN CORRELATION

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Abstract – The stratigraphically oldest *Lariosaurus* skeleton in Europe is of *L. teutonicus* (Diedrich, 1996) from the shallow marine lagoon deposits of the Lower Muschelkalk (Bithynian) of Borgholzhausen (NW Germany) in the Germanic Basin, possibly being synonymous with the (?) Pelsonian Chinese *L. xingyiensis* (Rieppel et al., 2003). Younger remains of *L. buzzii* Tschanz, 1989 were collected as isolated skulls and postcrania in the German Upper Muschelkalk (Illyrian/Fassanian) sites Bad Sulza and Bayreuth, mainly in the oolitic or shallow marine facies. *Lariosaurus buzzii* is also recorded in a few younger (Fassanian/Longobardian boundary) northern Tethys black-shale-lagoon deposits of the Swiss/Italian locality Monte San Giorgio by complete skeletons. The species *L. balsami* Curioni, 1841 seems to represent the stratigraphically youngest records in the late Longobardian of the northwestern Tethys (Austria, Italy, Switzerland). *Lariosaurus* is known from a complete Middle Triassic European record with possibly only three valid species and was distributed along the Pangaeic coasts between Europe and Asia in lagoon and shallow marine paleoenvironments, where they probably smaller hunted fish and juvenile pachypleurosaurs.

INTRODUCTION

The Middle Triassic marine sauropterygian *Lariosaurus*, a close relative of the pachypleurosaurs and nothosaurs (Tschanz 1989), was thought to be present only in the Tethys Ocean and its coasts (Rieppel, 2000) and was never recorded or recognized from the Germanic Basin.

The remains of the Lower Muschelkalk-aged Chinese *Lariosaurus xingyiensis* (Rieppel et al., 2003), for which the exact stratigraphic position remains unclear (possibly Pelsonian: cf. Motani et al., 2008) extended the paleobiogeography of this genus. However, it was not compared to earlier mentioned material from the Germanic Basin, and possibly it represents a Pelsonian aged *Lariosaurus* being synonymous with the few younger, Pelsonian-aged “*P. teutonicus*” (cf. Diedrich, 1996; herein = *Lariosaurus teutonicus*). From the Lower Muschelkalk (Pelsonian) of Germany the oldest record of *Lariosaurus* is revised and further described, which was published preliminarily without detailed descriptions or any figures as “*Paranothosaurus teutonicus*” (Diedrich, 1996).

Already, Meyer (1847-55) figured from the Upper Muschelkalk (Illyrian-Fassanian) a skull and an ischium as “*Nothosaurus*” from the Bindlach locality near Bayreuth. In the Upper Muschelkalk (late Illyrian-Fassanian), *Lariosaurus* published skulls were misidentified as “*Nothosaurus marchicus*” (Rieppel and Wild, 1996) from the Bad Sulza and Bindlach sites and have been

recently identified together with postcranial bones as *Lariosaurus* cf. *buzzii* remains (Diedrich, 2012a, 2013a). A few younger and similar-aged specimens assigned to *L. buzzii* were published by Tschanz (1989), which is best known by skeletons from the black shales of the Swiss Monte San Giorgio (Furrer, 2003) and Italian Perledo localities (Rieppel, 2000; Fig. 2B).

The Lower Keuper *Lariosaurus balsami* skeletal remains were published from the Tethys Ocean from the Partnach-Plattenkalk of the Gailtaler Alpen by Curioni (1847) in the early Longobardian (Ladinian) aged black shale deposits of Austria, which material was discussed (Rieppel, 1994, 1998). New finds of this species were further recorded on the northwestern Tethys from the Pyrenees in Spain (Sanz, 1976), France (Mazin, 1985) and Italy (Ticli, 1984), with different-aged individual skeletons. *L. lavizzarii* Kuhn-Schnyder 1979 represents, based on Rieppel (1994), only a juvenile of *L. balsami*, of which one skeleton from Perledo is discussed by Peyer (1933-34) and figured (Fig. 2A). Possibly, *L. valceresii* (Tintori and Renesto, 1990), which is recently the stratigraphically youngest *Lariosaurus* record from the Meride Limestone (Stöckar, 2010) of the Kalkschieferzone (late Longobardian, Ladinian) of Perledo, Italy (Deecke, 1886), is not validated as a distinct species. Clear identifications of the latter, Lower Keuper species are missing in the Germanic Basin, but might be expected in the Lower Keuper bonebed material of southern Germany after further studies.

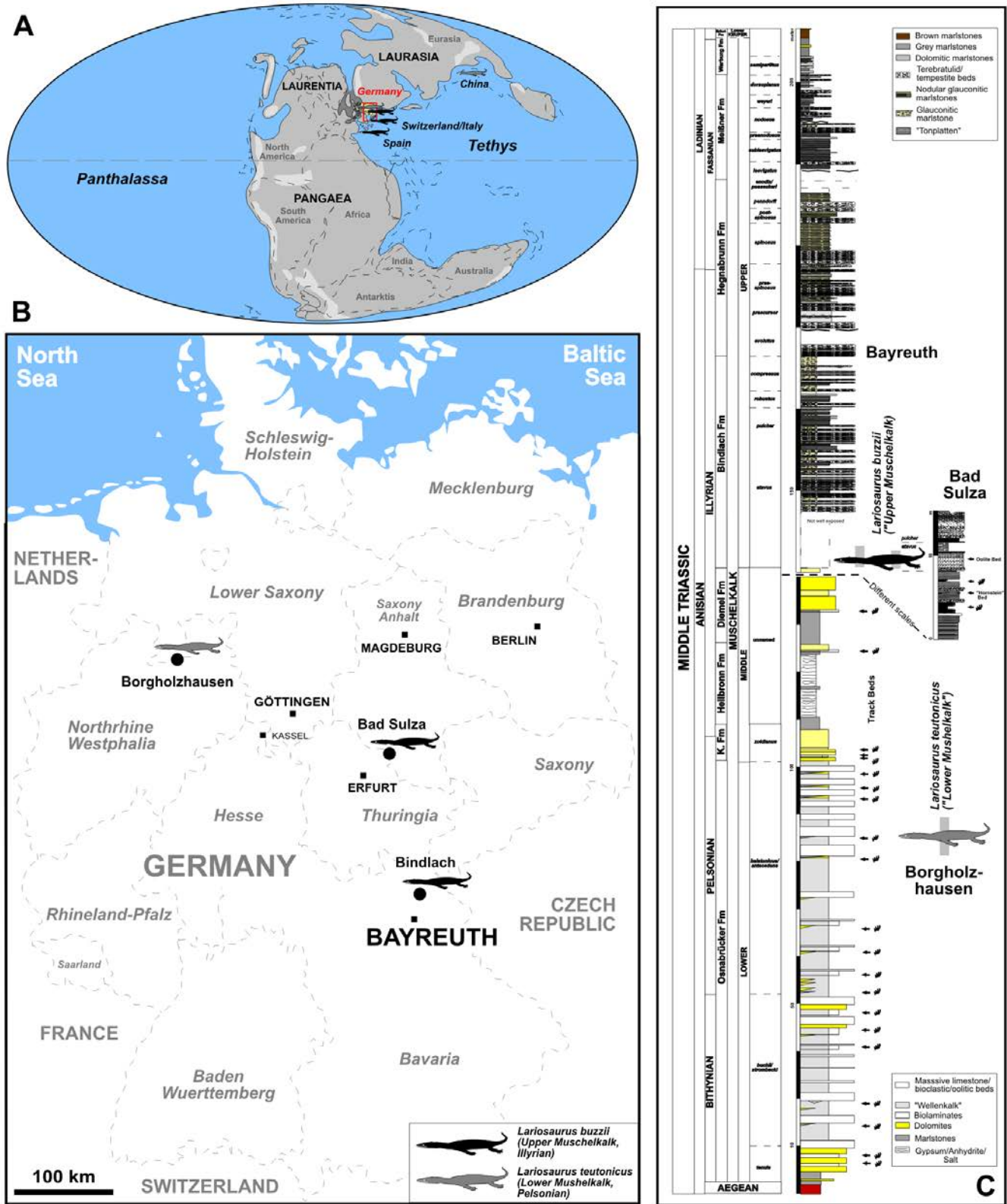


Figure 1 – A, Global distribution of *Lariosaurus* in Europe and China (composed after Curioni, 1841; Sanz, 1976; Tschanz, 1989; Rieppel, 2000; Rieppel et al., 2003). B, Newly identified *Lariosaurus* sites in Germany. C, Biostratigraphy of the Germanic Basin *Lariosaurus* remains from Lower and Upper Muschelkalk layers (Middle Triassic) within different carbonate facies types (composed and modified from Diedrich, 2009, 2012b, 2013d).

MATERIAL AND METHODS

A disarticulated incomplete skeleton from the Lower Muschelkalk was excavated in 1995 by the author at Borgholzhausen (Diedrich, 1996) in Germany at a house construction site, which is in the collection of the Museum Natur und Umwelt Osnabrück (= MNUO). Single skulls and postcranial bones from the Upper Muschelkalk from Bad Sulza (Central Germany) (Diedrich, 2013d) are housed in the Naturkundemuseum Erfurt (= NME), the Saline and Heimatmuseum Bad Sulza (= SHMBS), and the Natural History Museum of the Humboldt-University Berlin (= MB). Skull and postcranial remains from Bayreuth (Diedrich, 2012a) are stored in the Senckenbergmuseum Frankfurt (= SMF) and Urweltmuseum Oberfranken (= UM-O). All available Middle Triassic Germanic Basin material was compared directly with the original skeleton from the University Munich and the cast of *L. buzzii* from Perledo (Figs. 2B-D), which is kept in the University Tübingen (= UT). Finally, all herein described German *Lariosaurus* sites were studied for their stratigraphy, facies/paleoenvironments and vertebrate content, whereas several new studies on skeletons and isolated vertebrate material from the Germanic Basin (cf. Diedrich, 2009a, 2010, 2011a-b, 2012a-b, 2013a-d) allowed identifications of *Lariosaurus* single bones within various German Triassic vertebrate museum collections.

SYSTEMATIC PALEONTOLOGY

Sauropterygia Owen, 1860

Nothosauridae Baur, 1889

Lariosauridae Lydekker, 1889

Lariosaurus Curioni, 1847

Lariosaurus buzzii Tschanz, 1989

Figs. 2, 3

Material. Two skulls and some postcranial remains from Bindlach and Bad Sulza sites in Germany, that include both pectoral and fore limb, pelvic and hindlimb and axial skeletal remains (Fig. 3).

Stratigraphy. *Atavus* zone, *atavus* bonebeds (oolite bonebed) of the lowermost Upper Muschelkalk (middle Illyrian) in Germany (Diedrich, 2012a, 2013d). *Lariosaurus buzzii* is known by skeletons from the Illyrian/Fassanian or Anisian/Ladinian boundary of Monte San Giorgio, Switzerland (Tschanz, 1989, Fig. 2B-E).

Localities. Isolated remains are from Bindlach (Bayreuther localities) and Bad Sulza, Germany (Diedrich, 2012a-b). Skeletons are described from Monte San Giorgio, Switzerland and Italy (Tschanz, 1989; Rieppel, 2000).

Description. This species is well described by skeleton records (cf. Tschanz, 1989).

Lariosaurus teutonicus (Diedrich, 1996)

Figs. 4, 5

Holotype material. Cranial and postcranial elements of a single disarticulated individual skeleton (coll. MNUO).

Stratigraphy. Serpianites antecedens/Balatonites balatonicus cephalopod ceratite biozone, Basal Upper Terebratula bed, Terebratula substage, Osnabrück Formation, middle Lower Muschelkalk, middle Pelsonian, lower Anisian, Middle Triassic.

Locality. Northern corner of the private house grounding of Family Penner, Riesberg in Borgholzhausen, Middle Teutoburg Forst mountain chain, NW-Germany (coordinates Long. 3453,195 and Lat. 5774,350).

Description and differential diagnosis of the skeleton. From the skull only the incomplete lower jaw is represented by the dentary, which was found in close contact to the distal parts, the splenials/angulars/praearticulars indicating a not fully grown or a very old individual (Figs. 4-5). The left side is 66 mm long and has two large anterior teeth, then a small tooth, another large one (fang tooth formula 5/1), and, following, five more 2-4 mm high small teeth. The 17 mm wide symphysis is synostitic, with 12 mm of elongation. It seems, each side has five larger alveolar grooves for the 8-12 mm long fang teeth. All teeth have coarse enamel striations. The alveoli are asymmetrically toothed, whereas on the left side three typically longer (about 3-5 times higher than the other teeth) fang teeth are present. The dental angle is 24°. The splenial overlaps the dentary about 35 mm.

Pectoral girdle - The coracoids are 56 mm long, proximally 31 mm and distally 26 mm wide and are distally partly incomplete (right one) and proximally wide-flattened. One coracoid seems to be pathological on its margin. The 1.5 mm foramina coracoidea are very small. The coracoid angle measures 35°. Distally, the symphysis has only 50% of the margin, which is also found in stratigraphically younger species. The scapula shape fits much more the outline shape of *L. buzzii* (cf. Tschanz, 1989) rather than of *Nothosaurus* (*N. marchicus*). The left, complete 36 mm long scapula is 20 mm in maximum width, and has the typical distinct long processus. Other pectoral bone elements (clavicula, interclavicula) are missing.

Fore limb - The left limb is represented by one incomplete humerus (proximally and distally, estimated 62 mm long), the ulna, radius, the intermedium, distale IV, pisiform, and one phalanx, which allow a reconstruction of the extremity similar to the younger *Lariosaurus* species. The humerus is typically strongly curved in this genus (see Fig. 2C), whereas the non-compressed cross section in the specimen from Germany changes from proximally long-round to oval to distally high-oval. The tuberculus deltoideus is quite large, also seen in other species (*L. buzzii*, Fig. 2C; Tschanz, 1989), whereas the sulcus epicondylaris is deep. The 33 mm long, 14 mm proximal and 13 mm distal and wide, flattened ulna is complete. The inner anterior lateral margin has a convex hump, the outer lateral margin is slightly concave. The ulna outline shape of *L. teutonicus* fits that of *L. buzzii* (Fig. 2C; Tschanz, 1989) best. The length/width index is 4.25. The slimmer and also flattened complete radius is 32 mm long, proximally 9 mm and distally 8 mm wide. The outer margin is irregular. The length/width index is 7.75. Also, this is in general shape and size similar to the radius of *L. buzzii* (Fig. 2C; Tschanz, 1989). The left carpalia are represented by the nearly 10 mm wide intermedium, 4 mm wide and quadratic distale IV,

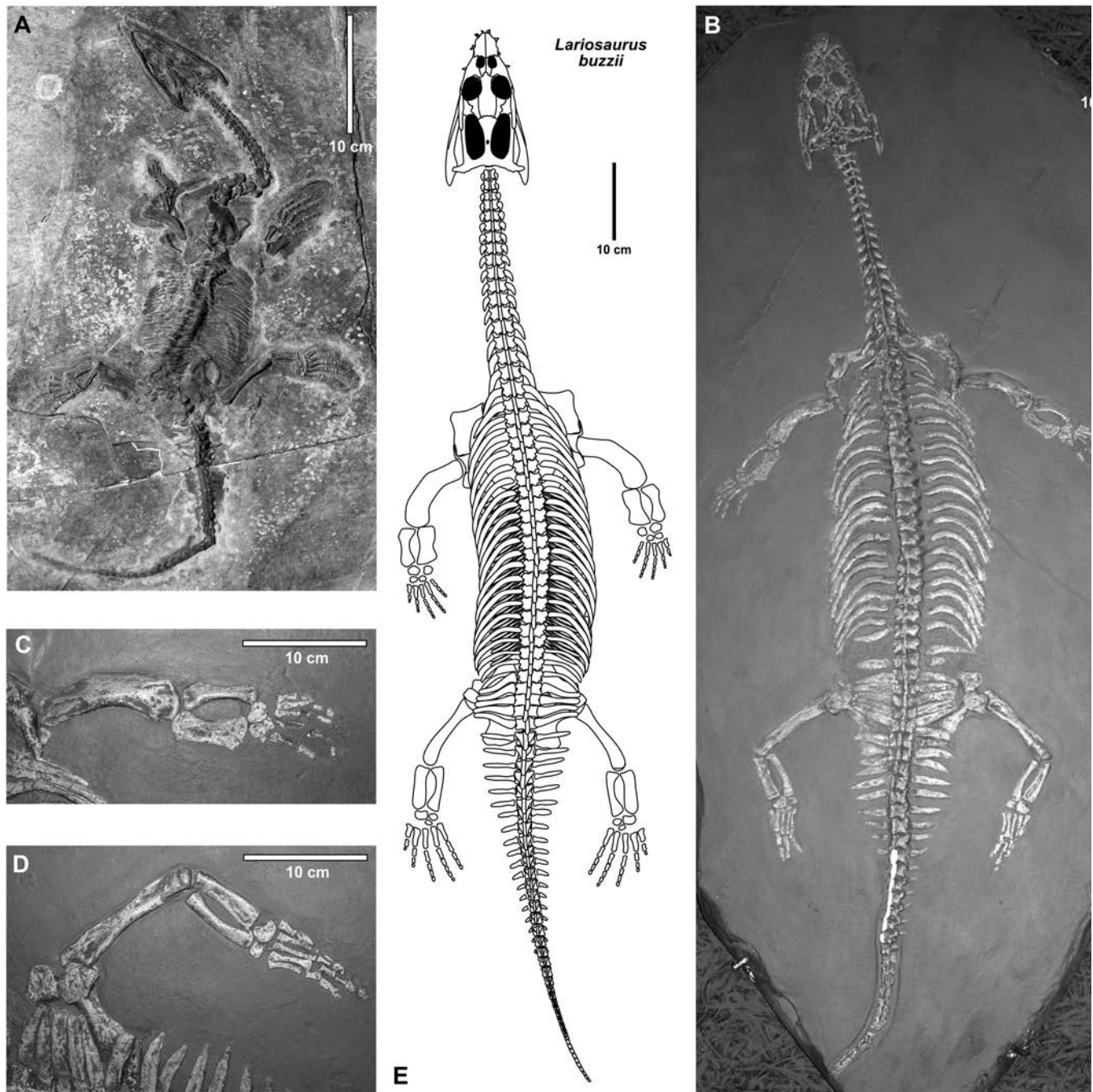


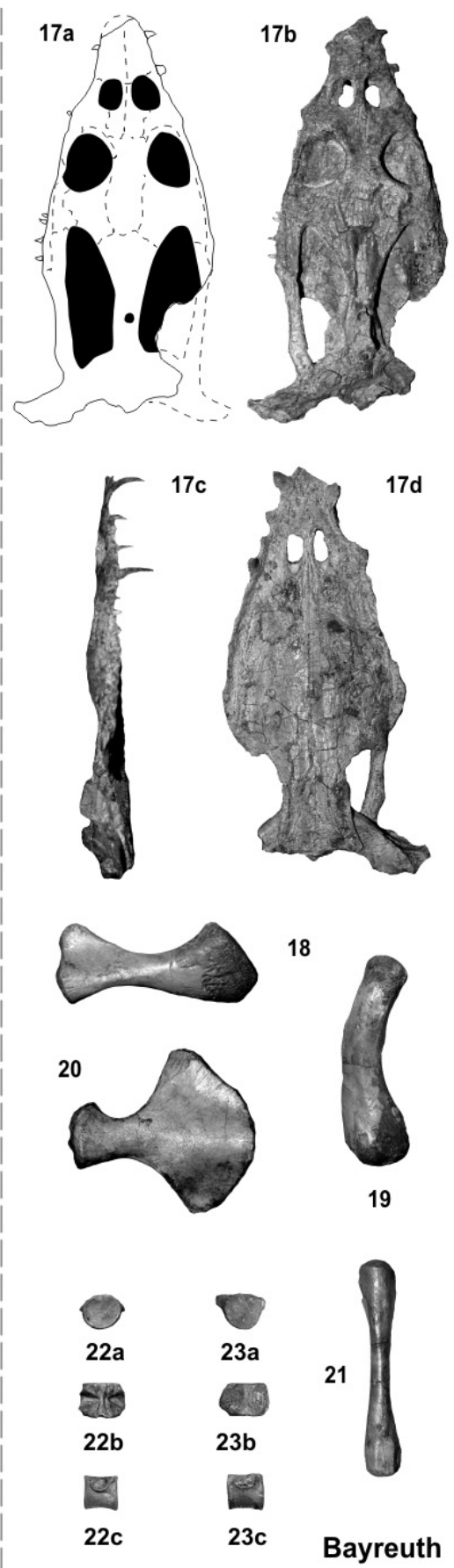
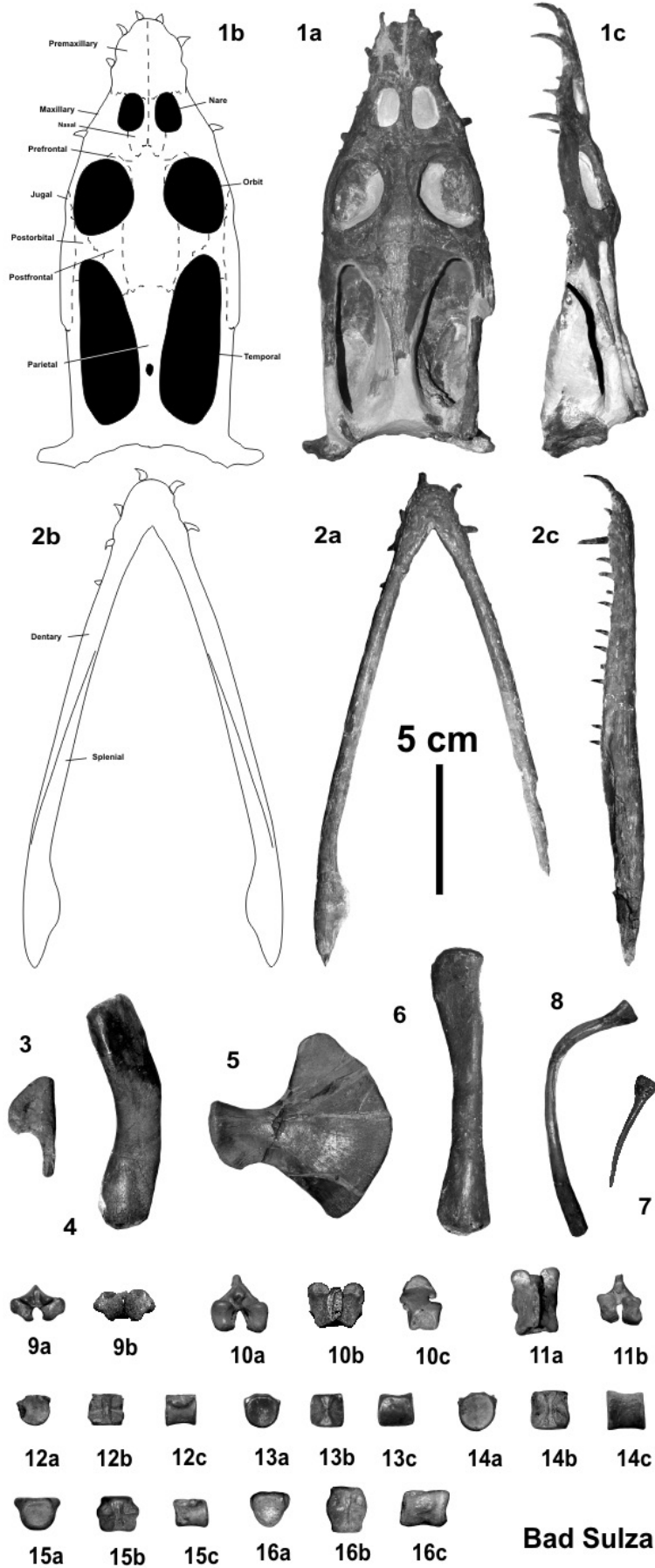
Figure 2 – Marine sauropterygian *Lariosaurus* skeletons from the Middle Triassic of Europe. **A**, Original of a young small individual of *Lariosaurus balsami* Curioni, 1847 from the late Longobardian (Ladinian/Carnian boundary) of Perledo, Italy (SMF without no.), ventral view. **B**, Cast of a large older individual of the neotype of *Lariosaurus balsami* Curioni, 1847 (original figured in Kuhn-Schnyder, 1987) from the late Longobardian (Ladinian/Carnian boundary) of Perledo, Italy (UT without no.), dorsal, **C**, Fore limb, **D**, Hindlimb of *L. balsami* Curioni, 1847 cast, **E**, Skeleton reconstruction after *Lariosaurus balsami* Curioni, 1847, see skeleton of Fig. 2B.

the 6 mm wide oval pisiforme, and one 4 mm wide phalanx.

Axial skeleton – Four dorsal vertebrae are represented, but the neural arches are fused with the centra. The closed sutura neurocentralis indicate an older individual, but not very old compared to the non-fused jaw sutures. The prae- and postzygapophyses are wide and flattened. The distance between the praezygapophyses is 13 mm. The total height of the vertebra

is only 21 mm, whereas the centrum is 10 mm and the dorsal arch 11 mm in height. The cross-section of the neural canal is kidney-formed, with the convex part up. The dorsal vertebrae are similar again to those of *L. buzzii* (Fig. 2C; Tschanz, 1989), whereas they are not isolated and deformed in the skeleton, including the neural arch.

The ribs of the German skeleton specimen are represented by



four cervical (different positions), nine dorsal, and one caudal rib. The four 10–35 mm long cervical ribs are from anterior to posterior and have small caput costae. Also, the dorsal ribs are from anterior to posterior 36–62 mm long. Their rib head is a figure eight in the shape of the articular surface. The 32 mm long flattened caudal rib is from an anterior position. Each of the gastral ribs is composed of five elements. The v-shaped middle gastralia have in the middle and anterior a small spine, whereas the ribs end on both sides in a spine. The angle and length (60 mm to 55 mm) of the middle gastralia increases from caudal to cranial. On this, 32 mm long middle part, the middle gastralia (both sides needle-like) are attached, as are the about 34 mm long end gastralia (one end needle-like, the distal one round). All ribs and gastralia fit descriptions and the skeleton of *L. buzzii* (Fig. 2C; Tschanz, 1989).

Pelvic girdle - Only the left pubis and ilium and fragments of the ischium are represented. The pubis is complete. The distal end of the pubis of *Lariosaurus* has a typically sigmoidal margin (see *L. buzzii*, Tschanz, 1989), but is damaged and clearly not separated into two forked parts as are found in similar aged *Nothosaurus* (*N. marchicus*). The length is 56 mm long, whereas the distal articulation area is 19 mm wide, and the other part measures 28 mm. The foramen obturatum is not open to the margin and only 3 x 4 mm in oval size. In *Nothosaurus* it is open to the margin. The left ilium is typical of *Lariosaurus* (see *L. buzzii*, Tschanz, 1989) in shape and less wide and without an elongated processus, as in *Nothosaurus*, and is complete and 17 mm in height with a length of 23 mm. The facies pubica measures 14 mm, the facies ischiadica 12 mm. The left ilium is fragmentary with the proximal part preserved as a negative impression.

In conclusion, the isolated bone material from an old adult, but not senile animal, in estimated total length of 100–120 cm of *L. teutonicus* fits well to similar and a few larger sized *L. buzzii* (cf. Tschanz, 1989) and is distinct from the similar aged *N. marchicus* in many osteological ways, which have been analyzed already (see Rieppel, 2000). The osteological and taxonomically relevant differences between *L. teutonicus* and *L. buzzii* are mainly found in the shorter dentary symphyses, and different outlined form of the coracoid (compare Figs. 3 and 5). The ulna of *L. teutonicus* is less wide (probably a result of non compaction in the black shale skeletons, in general a problem). The *L. teutonicus* skeleton from Germany is stratigraphically much younger (middle Pelsonian)

than the about two million years younger *L. buzzii* (Illyrian/Fassanian or Anisian/Ladinian boundary, cf. Fig. 6).

DISCUSSION

Previous authors have not been able recognize *Lariosaurus* in the Germanic Basin (Rieppel, 2000), which was in fact widely distributed in the north-western Tethys and the Germanic Basin in the Illyrian, and later in the Fassanian and Longobardian. The claims of Monte San Giorgio endemism (Rieppel, 2000), especially of *L. balsami*, must be revised. Using the new chronostratigraphy of Kozur and Bachmann (2008) and newest stratigraphic results for the Bayreuth and Bad Sulza localities (Diedrich, 2012a-b), such as the updated Triassic time scale (cf. Ogg et al., 2014), and new palaeogeographical maps for the Middle Triassic of Europe, including extensive and changing carbonate intertidal flats (Diedrich, 2009, 2011b, 2012a, b), *Lariosaurus* species occur in different strata and show different distributions changing within the transgression/regression of the Middle Triassic.

Pelsonian – “*Paranotosaurus teutonicus*” (Diedrich, 1996) must be attributed consequently to the genus *Lariosaurus* and represents the oldest record of this genus (Fig. 6), because the Chinese finds are not yet dated well. The facies is a platy dolomite limestone, representing a lagoon deposit (cf. Lukas, 1991; Diedrich, 1996, 2012a, 2013d).

Illyrian – Overlooked cranial and postcranial material (Fig. 3.1-16) comes from Bad Sulza from stratigraphic levels of the *atavus* zone of the oolitic very shallow marine to lagoonal facies, and this material was recently identified as *Lariosaurus* (Diedrich, 2013d). A skull was misidentified by Rieppel and Wild (1996) as “*N. marchicus*” and is reassigned here to *Lariosaurus* cf. *balsami* Curioni, 1847 because the skull shape, nasal, orbit and parietal foramina shapes and measurements match more closely to those of *Lariosaurus* (cf. Tschanz, 1989) than to those of a small *Nothosaurus*. *N. marchicus* has furthermore only been positively identified from the Bithynian to the early Illyrian (“Lower Muschelkalk”) in the Germanic Basin (e.g. Rieppel, 2000).

With the subsequent transgression, *Nothosaurus* appeared as a more highly evolved and few larger form (= *N. juvenilis*) at the end of the Middle Muschelkalk (Edinger, 1921), as has recently been described from a large quantity of cranial and postcranial

← **Figure 3** – *Lariosaurus buzzii* Tschanz, 1989 remains mainly from the **1–16** Oolite Bed (*atavus* biozone, Lower Bad Sulza Fm) of the basal Upper Muschelkalk (Illyrian) of Bad Sulza, Central Germany. **1**, Skull from the Oolite Bed (NME no. 78.234), a. dorsal. b. reconstruction. **2**, Lower jaw from the Oolite Bed (NME no. 78/233), a. ventral, b. ventral reconstruction, c. lateral. **3**, Scapula from the Oolite Bed (NME no. 78/349), lateral. **4**, Humerus from the Oolite Bed (MB no. R.455), lateral. **5**, Ischium from the Oolite Bed (NME no. R.126), dorsal. **6**, Femur from the Oolite Bed (SHMBS no. 45), lateral. **8**, Middle dorsal costa from the Oolite Bed (NME no. R.453), lateral. **9**, Anterior cervical vertebral neural arch (NME no. 78/242), a. lateral, b. dorsal, c. cranial. **10**, Posterior cervical/anterior dorsal vertebral neural arch centrum (NME no. 78/241), a. cranial, b. dorsal, c. lateral. **11**, Middle dorsal vertebral neural arch (NME no. 78/476), a. dorsal, c. caudal. **12**, Middle dorsal vertebral centrum (NME no. 78/240a), a. cranial, b. dorsal, c. lateral. **13**, Middle Dorsal vertebral centrum from the Oolite Bed (MB no. 145.1), a. cranial, b. dorsal, c. lateral. **14**, Middle Dorsal vertebral centrum (NME no. 78/78/240), a. cranial, b. dorsal, c. lateral. **15**, Posterior dorsal vertebral centrum (NME no. 78/240b), a. cranial, b. dorsal, c. lateral. **16**, Anterior caudal vertebral centrum (NME no. 93/12), a. cranial, b. dorsal, c. Lateral. **17–23**, Oolite Bed and Terebratulid tempestitute beds (*atavus* to maximum ?*compressus* biozone, Bindlach Fm) of the basal Upper Muschelkalk (Illyrian) of Bayreuth, South Germany. **17**, Skull from Bindlach, Bindlacher Berg (SMF No. R4572, original in Meyer, 1847-55), a. dorsal, b. lateral, ventral. **18**, Coracoid from Bindlach, Bindlacher Berg (UM-O without no.), ventral. **19**, Humerus from Bindlach, Bindlacher Berg (SMF no. R784), ventral. **20**, Ischium from Bindlach, Bindlacher Berg (UM-O no. BT-670; original to Meyer, 1847-55), dorsal. **21**, Femur from Bindlach, Bindlacher Berg (UM-O no. BT-722), dorsal. **22**, Middle dorsal vertebral centrum (SMF no. R951), a. cranial, b. dorsal, c. lateral. **23**, Posterior dorsal vertebral centrum (SMF without no.), a. cranial, b. dorsal, c. lateral (composed from Diedrich, 2012a, 2013d).

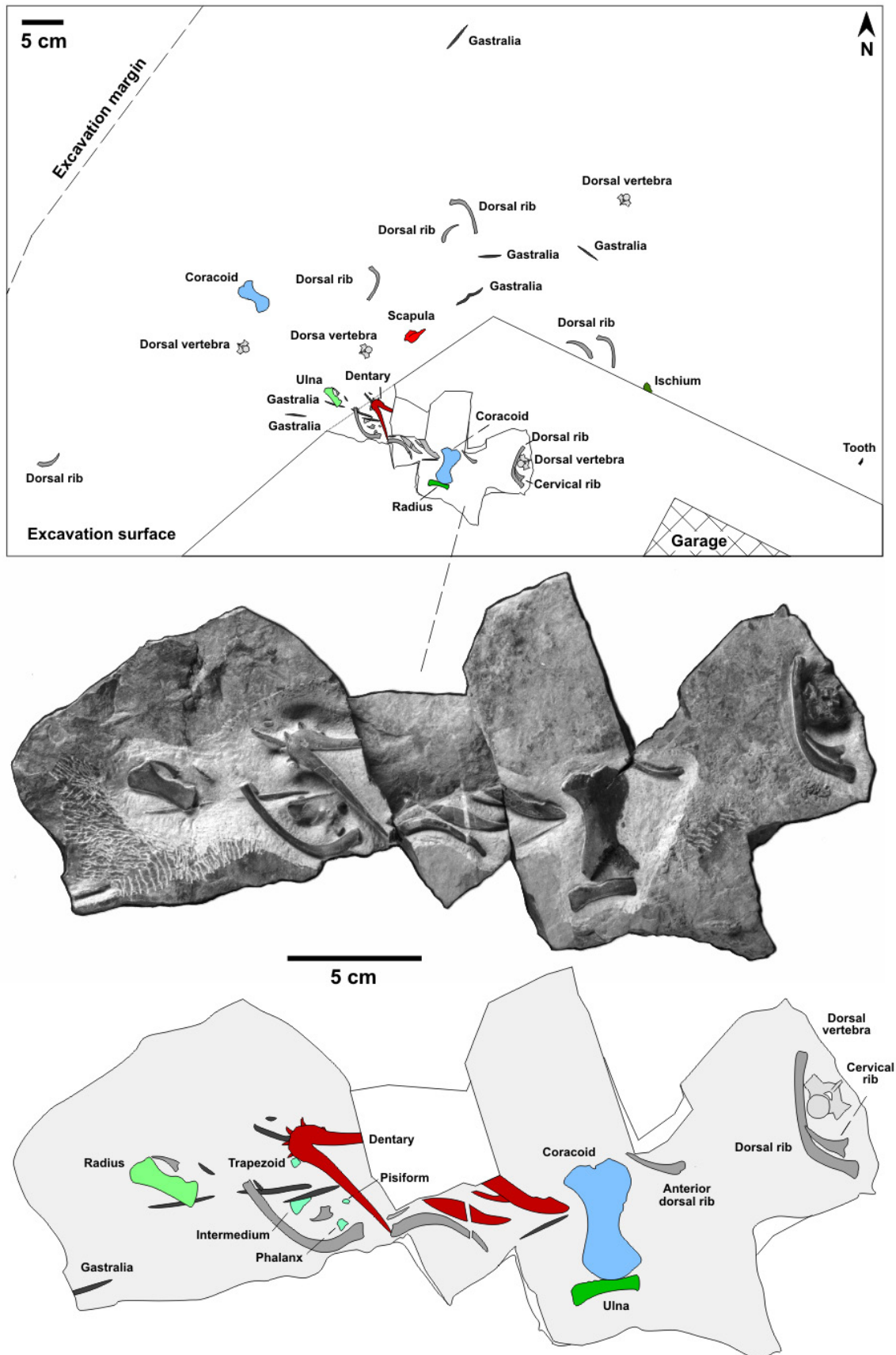


Figure 4 – *Lariosaurus teutonicus* (Diedrich, 1996), holotype skeleton from the Lower Terebratula Bed (Terebratula substage) of the Lower Muschelkalk (Pelsonian) of Borgholzhausen, NW Germany (coll. MNUO).

material from Bad Sulza (Diedrich, 2013d). Also, the skull from Bindlach (Fig. 3.17) illustrated in Edinger (1921) as *Nothosaurus* sp., and identified by Rieppel and Wild (1996) again as “*N. marchicus*,” was revised in Diedrich (2012a) to *Lariosaurus* cf. *buzzii*, which was also found in the atavus oolite bonebeds of Bayreuth/Bindlach (Germany, Fig. 6, Map A). In addition to the cranium from the Bayreuth sites, the postcranial remains include a humerus, coracoid, femur and ischium, and also possibly a dorsal vertebra centrum (Figs. 3.18-23), which all are quite characteristic of *Lariosaurus* compared to a skeleton cast in the BSP (from Perledo, Italy, Fig. 2B), the descriptions of Curioni (1847) and Ticli (1984) and the figures of Tschanz (1989). Those remains from Bayreuth and Bad Sulza thus support the presence of this genus, as would be expected, in the Germanic Basin.

Other new evidence comes from a skull of similar age from Bad Sulza (Fig. 3.17) that was misidentified as “*N. marchicus*” in Rieppel and Wild (1996), which is in fact a similar *Lariosaurus* skull (Diedrich, 2013d). Also, from Bad Sulza, several postcranial bones with similar proportions, from all parts of the body, again indicate the presence of *Lariosaurus buzzii* Tschanz, 1989 in the Germanic Basin during the late Illyrian (?Fassanian). Also, the *L. buzzii* remains from the Anisian/Ladinian boundary of the northwestern Tethys (Fig. 6 Map B) are from lagoons and strata that formed during the maximum high stand of the Anisian/Ladinian boundary (intraplatform lagoons: Furrer, 1995).

Longobardian – *Lariosaurus balsamii* (early Longobardian, Ladinian) skeletons are from the Kalkschieferzone (Uppermost Ladinian), such as those recorded at Valceresio (Varese, northern Italy (Tintori and Renesto, 1990) to which the herein juvenile Frankfurt specimen (Fig. 2A) is assigned. Also from Perledo (It), similar material was described (Curioni, 1847). This species seems to be represented by different aged individual skeletons, and is recently limited in the northern Tethys, but must also be expected in the Germanic Basin at least in the Bavarian-Hessian depression lagoons in southern Germany (Fig. 6 Map C).

CONCLUSIONS

In the Middle Triassic of Europe *Lariosaurus* is present not only in the northern Tethys as suggested before, it also occurs in the Germanic Basin, and these are even the oldest records (middle Pelsonian, middle Lower Muschelkalk, Anisian) with the herein described holotype skeleton of *L. teutonicus* Diedrich, 1996, which was found in dolomite platy limestones of a lagoon facies. This is validated herein taxonomically with a detailed description and figures of the material. From the Germanic Basin the next records are isolated skulls and postcranial bones of similar age from the atavus bonebeds (middle Illyrian, basal Upper Muschelkalk, Anisian/Ladinian boundary) and similar oolitic, very shallow marine to lagoonal facies of Bad Sulza and Bayreuth, Germany. This material is dated in more detail, whereas this can be attributed to the about two million year younger species *L. buzzii* Tschanz, 1989, which is therefore represented starting with the new transgression in both the Germanic Basin and the northern Tethys, whereas a clear facies related (lagoon) occurrence of this genus can be demonstrated. The stratigraphically

youngest record species is present somehow in the Lower Keuper (Longobardian, Ladinian), whereas in the Germanic basin those seem to have been disappeared (regression) and remained only in the northern Tethys with *L. balsamii* Curioni (1841).

ACKNOWLEDGMENTS

The Naturkundemuseum Osnabrück (A. Leipner) made the studied specimens available, and supported this work with the preparation of the *L. teutonicus* holotype specimen and with photos. I thank Dr. G.R. Riedel for the possibility to study the main collection in the Naturkundemuseum Erfurt, and Dr. J.M. Rabold for the study of the historical Meyer collection in the Urwelt-Museum Oberfranken Bayreuth. Dr. R. Brocke from the Senckenberg Natural History Museum, Frankfurt, provided access to the historical bone collection from the Bayreuth sites. Dr. O. Hampe supported the collections work in the Natural History Museum of the Humboldt-University Berlin. The sponsor of this research, as part of the “Middle Triassic Megatracksite and Reptile Project of the Germanic Basin,” was the Palaeologic Private Research Institution (www.paleologic.eu). I thank D. Surmik for a review of the first draft. Comments by an anonymous reviewer and S. G. Lucas improved the manuscript.

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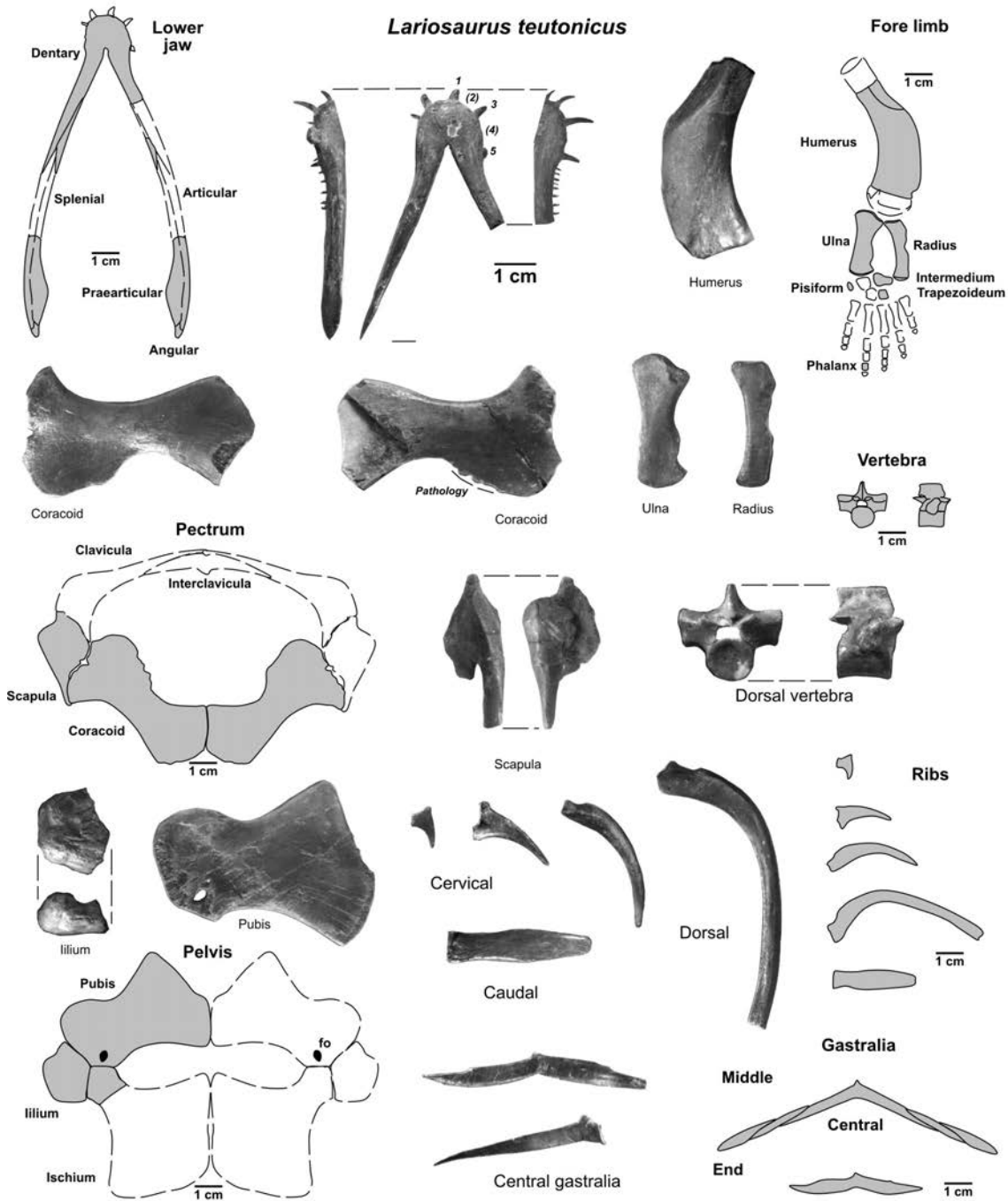


Figure 5 – *Lariosaurus teutonicus* (Diedrich, 1996) holotype skeletal elements (coll. MNUO) from the Lower Terebratula Bed (Terebratula Substage) of the Lower Muschelkalk (Pelsonian) of Borgholzhausen, NW Germany.

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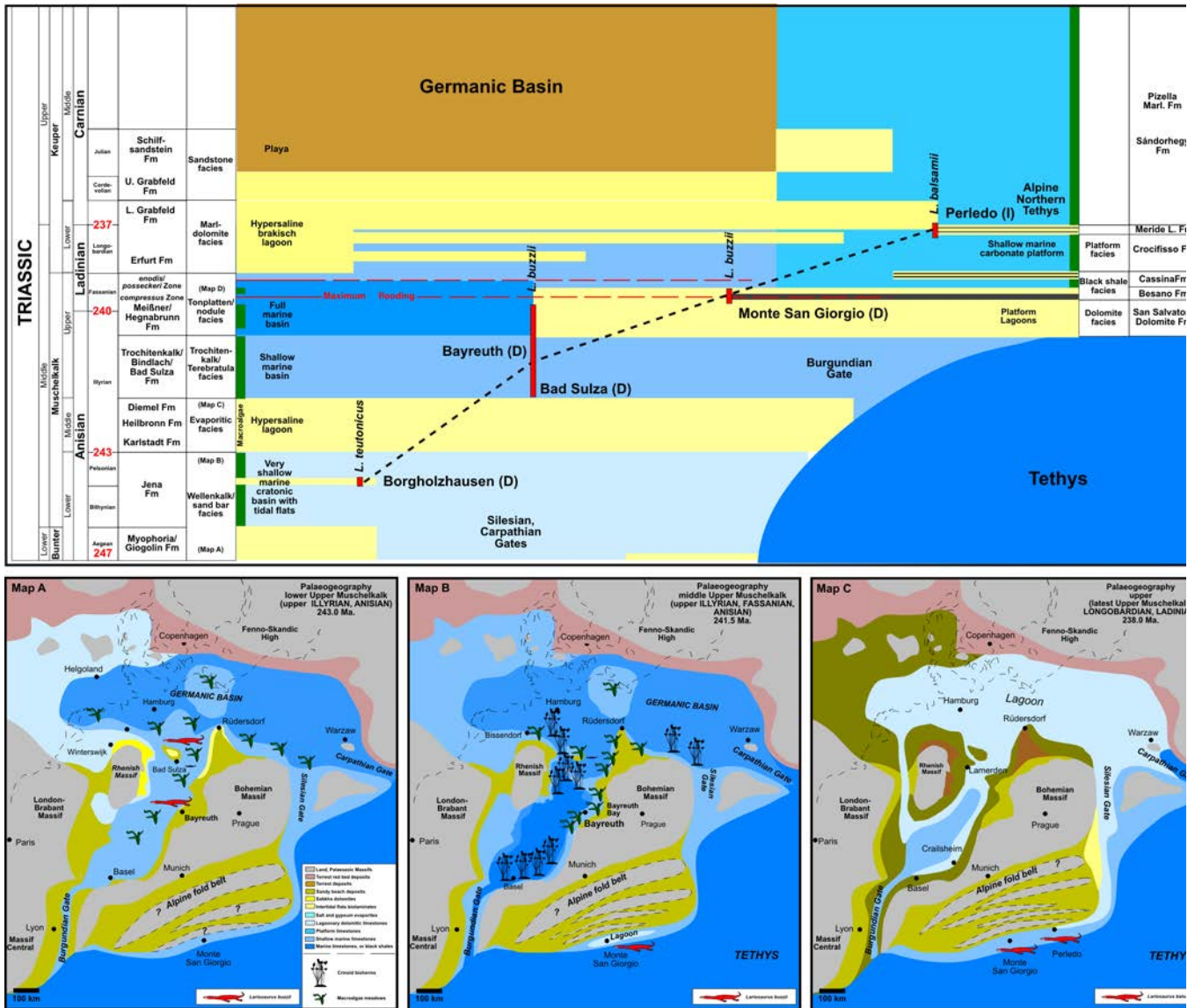


Figure 5 – Palaeobiogeography and biostratigraphy of the three very shallow marine/lagoonal-adapted *Lariosaurus* species. *L. teutoncus*, *L. buzzii*, *L. balsami* in Europe (maps and stratigraphy from Diedrich, 2009b, 2012a, 2013d).

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A SUMMARY OF NEW CONODONT BIOSTRATIGRAPHY AND CORRELATION OF THE ANISIAN (MIDDLE TRIASSIC) STRATA IN BRITISH COLUMBIA, CANADA

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Abstract – New conodont collections from both outcrop sections and subsurface drill core improve the correlation of Anisian (Middle Triassic) strata in British Columbia. New conodont species and morphotypes identified in these collections are used to define new informal conodont faunal assemblages. This preliminary biostratigraphical scheme allows correlation of the Anisian between surface and subsurface sections in British Columbia for the first time, as illustrated by four of the sections studied. Improved correlation has led to a revision of the interpretation of the depositional environment of Anisian rocks in British Columbia, from that of a continental margin to that of a restricted basin. The recognition of some of the new conodont taxa in collections from Nevada and the Canadian Arctic indicates that some of the faunal assemblages may prove useful for regional correlation and placement of the sub-stage boundaries of the Anisian.

INTRODUCTION

This paper introduces new conodont taxa from the Anisian of northeastern British Columbia, and new biostratigraphical correlations based on their distribution. This work both summarises and expands upon observations and conclusions made by Golding (2014).

Ammonoids and conodonts are the two most useful and widely used taxonomic groups for biostratigraphical subdivision of the marine Anisian. The base of the Anisian has not yet been defined by a Global Boundary Stratotype Section and Point (GSSP; Ogg et al., 2014). The only candidate section so far proposed is at Desli Caira in Romania, where the boundary has been proposed at the first appearance of the conodont *Chiosella timorensis* (Nogami) (Gradinaru et al., 2007; Orchard et al., 2007 a). However, the first appearance of this species is now known to occur with Spathian (upper Olenekian) ammonoids of the *Neopopanoceras haugi* Zone in Nevada and China (Ovtcharova et al., 2010; Goudemand et al., 2012), therefore its use as a definitive index species for the base of the Anisian is questionable, and would require the *Neopopanoceras haugi* Zone to be re-defined as Anisian in part. The complementary section at Guandao in China (Lehrmann et al., 2006) provides a superior conodont record (Orchard et al., 2007b), but lacks good ammonoid control

		Ammonoid and Conodont Zones (Orchard and Tozer, 1997)		
ANISIAN	U	chischa	aldae	excelsa
		deleeni	constricta	
	M	minor	"n. sp. P"	regalis
			shoshonensis	
		hayesi	"n. sp. N"	
		hagei		
	L	americanum	"n. sp. M"	
		caurus		
		mulleri		
		germanica		
		timorensis		

Figure 1 – Existing ammonoid and conodont biozonation of the Anisian in British Columbia based on Orchard and Tozer (1997). L = Lower, M = Middle, U = Upper.

(Ogg et al., 2014). The upper boundary of the Anisian is formally defined by the first appearance of the ammonoid *Eoprotrachyceras curionii* (Mojsisovics) at the base of the Ladinian, in the section at Bagolino in Italy (Brack et al., 2005).

In British Columbia, the Anisian ammonoid record is fairly well developed, with eight ammonoid zones and two subzones recognized (Fig. 1; Tozer, 1967, 1994; Silberling & Tozer, 1968; Bucher, 2002). However, the Anisian sequence in British Columbia appears rather incomplete by reference to that of Nevada, where 13 ammonoid zones and 31 subzones are recognized (Silberling & Wallace, 1969; Silberling & Nichols, 1982; Bucher, 1988, 1989, 1992 a, b, 1994; Bucher & Orchard, 1995). Lowermost Anisian ammonoids appear to be missing in British Columbia, and there are large gaps in the ammonoid record of the Middle and Upper Anisian (Monnet & Bucher, 2005). The reasons for this discrepancy between the two areas are unclear, but may be due to unconformities in the Anisian succession of British Columbia, or the difference may simply be a reflection of the higher ammonoid diversity in Nevada (Monnet & Bucher, 2005).

The conodont record of the Anisian in British Columbia is generally poor in resolution compared with that of the ammonoids. Eleven partially overlapping conodont zones have been outlined for the Anisian (Orchard & Tozer, 1997), although several of these were based on undescribed taxa. In the upper part of the Middle Anisian and in the Upper Anisian the precision of the existing conodont zonation is comparable to that of the ammonoids, however, within the Lower Anisian and lower part of the Middle Anisian, the precision is not as good (Fig. 1).

The deficiency in the existing conodont biozonation is due, in part, to an underdeveloped taxonomy for Anisian conodonts in North America, particularly the ubiquitous Neogondolellins and Paragondolellins (*sensu* Orchard, 2005). In an attempt to improve the stratigraphic utility of the conodonts, new conodont samples were collected from both surface outcrop and subsurface drill core in British Columbia, and examined together with existing collections which are calibrated with ammonoid zones (Orchard & Tozer, 1997). This has resulted in the taxonomic revision of a number of conodont species groups, the refinement of the faunal succession that is tied to the existing ammonoid biozonation, and improved correlation between outcrop and subsurface Triassic.

GEOLOGICAL SETTING

The Anisian rocks of British Columbia belong to two major tectonic settings: some were deposited on the continental margin of North America, whilst others were deposited on pericratonic and exotic terranes that lay to the west of the continent during the Triassic. These terranes have subsequently accreted onto the margin of North America, and rocks of Anisian age are preserved throughout British Columbia (Orchard, 1991). Those that were deposited on the continental margin form a near-continuous outcrop belt running along the eastern margin of the Canadian Rocky Mountains (Fig. 2). To the east of this outcrop belt, Anisian rocks are present in the subsurface of British Columbia and the

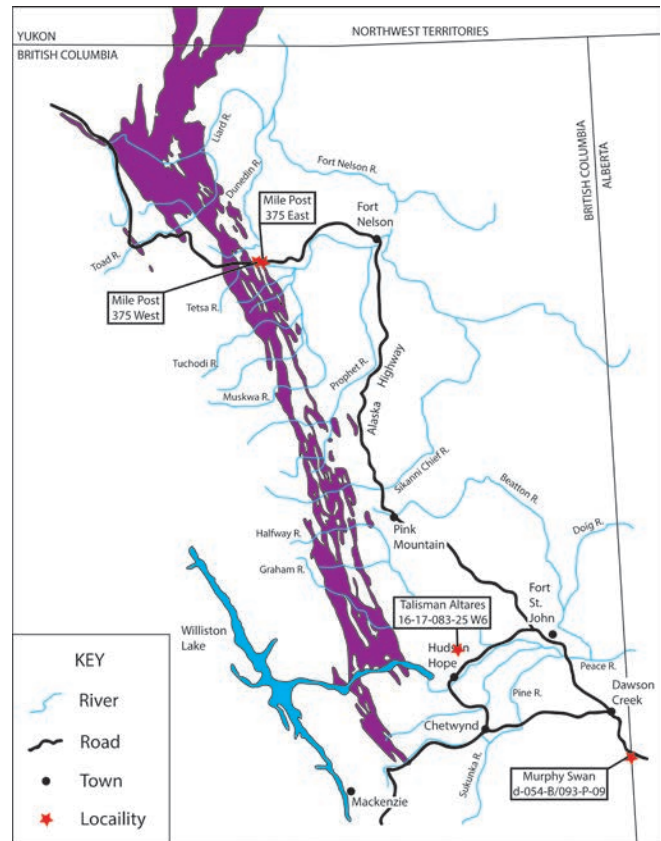


Figure 2 – Map showing the distribution of Triassic outcrop in northeastern British Columbia and the location of the four sections mentioned in the text. Triassic outcrop is in purple.

neighboring province of Alberta.

The Anisian rocks of the subsurface and eastern outcrop belt were deposited in the Western Canada Sedimentary Basin (WCSB), which was made up of a complex series of sub-basins formed by a combination of transtension and extension (Davies, 1997). The basin initiated during the Mesoproterozoic and persisted as a continental margin basin until terrane accretion began in the Triassic (Ross et al., 1989; Beranek and Mortensen, 2011). During the Anisian, the WCSB was located on the western margin of North America at mid-latitudes (Smith et al., 1995), and experienced an arid climate influenced by trade winds and upwelling (Davies, 1997).

Anisian rocks of the outcrop belt belong to the Toad Formation. This unit was named by Kindle (1944) and it consists of up to 800 m of siltstone, shale, fine-grained sandstone and carbonate (Gibson, 1975). The formation is thought to range in age from the Smithian (lower Olenekian) to the Ladinian on the basis of ammonoid and conodont collections (Tozer, 1961, 1994; Orchard & Tozer, 1997; Zonneveld, 2010). In the subsurface, the Anisian rocks belong to the Montney and Doig formations, both defined by Armitage (1962). The Montney Formation consists of up to 450 m of siltstone and sandstone with very minor amounts of shale and carbonate (Armitage, 1962; Davies et al., 1997). The formation is thought to range in age from Changhsingian to Anisian (Zonneveld, 2010; Zubin-Stathopoulos et al., 2012). The Doig Formation unconformably

overlies the Montney Formation, and consists of up to 150 m of siltstone, fine sandstone and carbonate (Armitage, 1962; Evoy & Moslow, 1995). The age of this formation is uncertain, but has been estimated as Spathian to Ladinian (Hunt & Ratcliffe, 1959; Qi, 1995; Zonneveld, 2010). Both the Montney and Doig formations contain economically important reserves of natural gas (Adams, 2013).

A total of 42 conodont collections from 11 outcrop sections and 7 subsurface wells, all representing the ancestral North American continental margin, were examined for this study; the location of those discussed in this paper are shown in Fig. 2. A full description of all of the localities is available in Golding (2014).

NEW CONODONT SPECIES

Previously, the majority of conodont species from the Anisian of North America have been assigned to one of six named species: *Neogondolella regalis* Mosher, *N. constricta* (Mosher and Clark), *N. bulgarica* (Budurov and Stefanov), *N. shoshonensis* Nicora, *N. momburgensis* (Tatge), and *Paragondolella excelsa* Mosher (Mosher & Clark, 1965; Mosher, 1973; Nicora, 1976, 1977; Nicora & Kovács, 1984; Ritter, 1989; Orchard, 1994), although Nicora et al. (1980) and Orchard (2010) also differentiated several other less common taxa from Nevada. The current taxonomic revision has resulted in the recognition of a number of new morphotypes of some of the common species from British Columbia, which have been re-classified as species groups. Previous reports of *N. momburgensis*, the type species of *Neogondolella*, from North America (e.g. Ritter, 1989) are regarded as erroneous, and the existence of this species outside of Tethys is questioned (Bucher & Orchard, 1995; Orchard & Rieber, 1999). In addition to 18 new morphotypes of four species groups assigned to *Neogondolella* and *Paragondolella*, a further nine new species of *Neogondolella* have been differentiated; these new taxa will all be fully described in future publications. A selection of some of the most stratigraphically important new taxa are shown in Fig. 3.

The Canadian succession of these new conodont taxa has allowed the recognition of 11 new, informal faunal assemblages that are useful for local correlation. These assemblages are groups of species that will hopefully define biozones, once the variations in morphology, and geographic and stratigraphic ranges of the constituent species have been fully determined. Seven of these assemblages are introduced informally here to illustrate their use in correlation (Fig. 4). Currently, the new biostratigraphical scheme is a hybrid, with the *N. ex gr. shoshonensis* faunal assemblage equivalent in concept to an assemblage biozone, whilst the others are akin to interval biozones, defined by first appearances of taxa.

CORRELATION OF THE ANISIAN IN B.C.

In order to demonstrate the utility of the new conodont faunal assemblages in the correlation of the Anisian of northeastern British Columbia, four sections are chosen. Two of these are outcrop sections located on the Alaska Highway, at Mile Post

375 East and Mile Post 375 West (Fig. 2). The Toad Formation is exposed at these sections on the two limbs of an anticline, and they represent the type sections of the *Lenotropites caurus*, *Hollandites minor*, and *Eogymnotoceras deleeni* ammonoid Zones (Tozer, 1967, 1994); Bucher (2002) also differentiated the *Paracrochordiceras americanum* beds at the Mile Post 375 East section. At these sections, the age of the conodont faunal assemblages has been directly tied to the ammonoid biozonation (Fig. 4). The other two sections are drill core from hydrocarbon wells drilled in the vicinity of Fort St. John, named Talisman Altares 16-17-083-25W6 and Murphy Swan d-054-B/093-P-09 (Fig. 2). The drill core from these wells belongs to the Montney and Doig formations, and conodont collections from the wells can be assigned to the same faunal assemblages as in the outcrop sections. However, no ammonoids were collected from the drill core. The correlation between this drill core and the outcrop sections is shown in Fig. 4. The stratigraphy and conodont zonation of the Talisman Altares 16-17-083-25W6 well is discussed in detail in another manuscript (Golding et al., in press).

The geographical separation of these sections is quite large, nevertheless it is possible to draw firm correlations between them, particularly around the Lower-Middle Anisian boundary. This is placed between the *Paracrochordiceras americanum* and *Buddhaites hagei* ammonoid zones (Tozer, 1994) and, although no conodont fauna was recovered from the *Buddhaites hagei* Zone (the presence of which was reported from the Mile Post 375 East section by Bucher, 2002), the division between the *Neogondolella ex gr. regalis* morphotype D and the *Neogondolella ex gr. regalis* morphotype B faunal assemblages is inferred to approximate the boundary. The recognition of these faunal assemblage in the subsurface drill core allows the correlation of the Lower-Middle Anisian boundary between the outcrop and the subsurface (Fig. 4).

IMPLICATIONS OF THE NEW CORRELATION

The correlation of the Anisian using new conodont faunal assemblages allows some of the previously accepted ideas about the Anisian of British Columbia to be tested. The boundary between the Montney and Doig formations has previously been thought to be diachronous, with estimates for its age ranging from Spathian to Ladinian (Hunt & Ratcliffe, 1959; Qi, 1995; Zonneveld, 2010), however neither the degree nor pattern of diachroneity has been well understood. The new correlation described herein shows that the formational boundary is oldest in the center of the study area, just west of Fort St. John, and becomes younger both to the west and to the east (Golding, 2014). The base of the Doig Formation is Spathian in age in the Altares area of British Columbia, and ranges into the Middle Anisian in the Dawson area. This pattern of diachroneity is not what would have been expected if the sediment of the Montney and Doig formations was deposited on a west-facing continental margin. Instead, it implies that the depositional basin was restricted during the Anisian, with localized palaeo-highs present to the west as well as to the east of the depocentre (Golding, 2014). The new correlation also shows that the basal Doig Formation is condensed, with

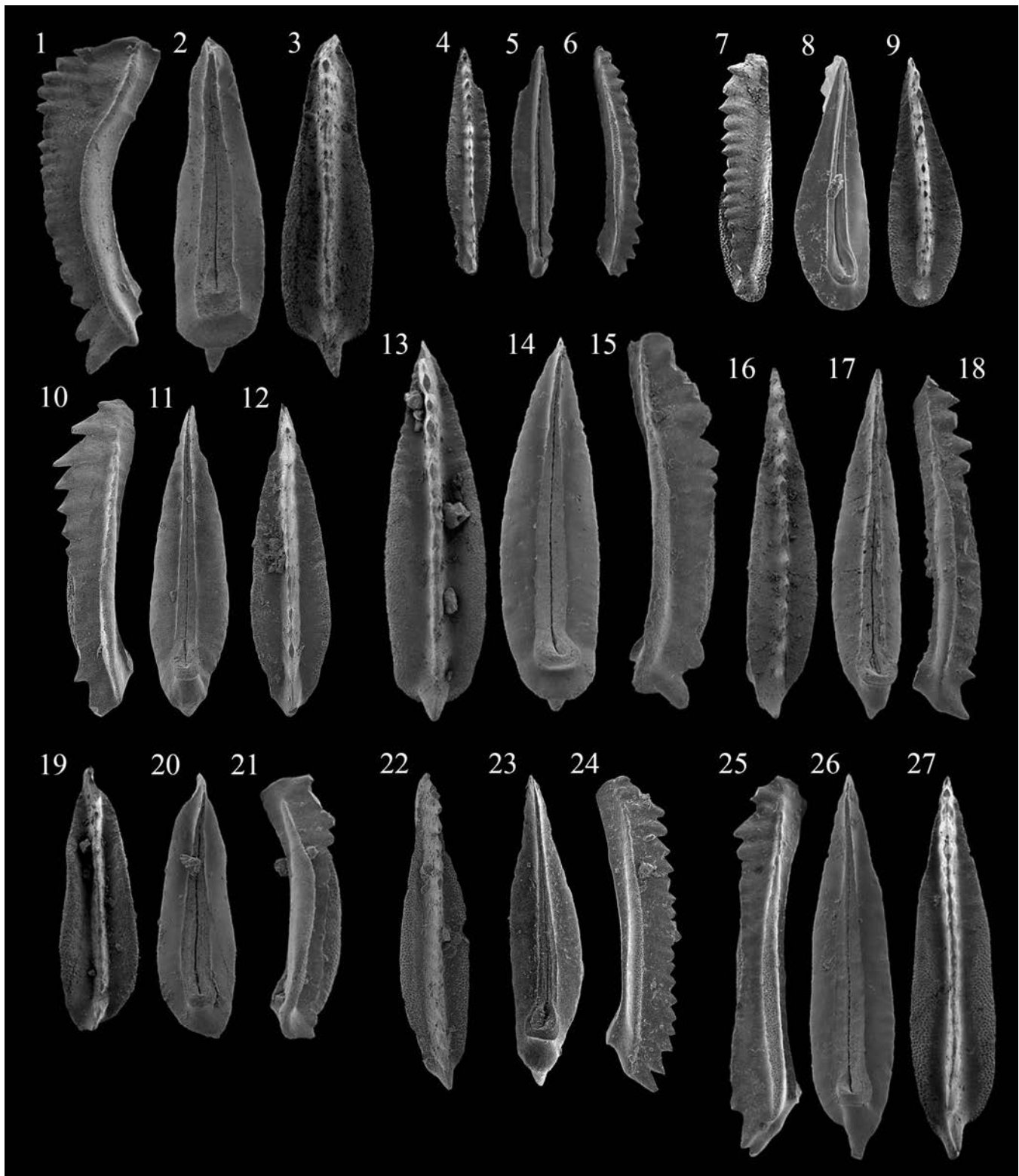


Figure 3 – Some stratigraphically important conodonts from the Anisian of northeastern British Columbia. **1–3**, *Neogondolella* ex gr. *regalis* Mosher, morphotype A nov., GSC 131502, *Tetsaoceras hayesi* Zone, Toad Formation, Mile Post 375 West (GSC cur. no. 68294). **4–6**, *Neogondolella* ex gr. *shoshonensis* Nicora, GSC 131503, *Hollandites minor* Zone, Toad Formation, Mile Post 375 West (GSC cur. no. C-201926). **7–9**, *Paragondolella* ex gr. *liebermani* Kovács and Krystyn, morphotype A nov., GSC 131504, *Eogymnotoceras deleeeni* Zone, Toad Formation, Mile Post 375 West (GSC cur. no. C-201925). **10–12**, *Neogondolella* ex gr. *regalis* morphotype B nov., GSC 131505, *Tetsaoceras hayesi* Zone, Doig Formation, Murphy Swan d-054-B/093-P-09 well (GSC cur. no. V-002957); **13–15**, *Neogondolella* ex gr. *regalis* morphotype C nov., GSC 131506, *Tetsaoceras hayesi* Zone, Toad Formation, Mile Post 375 East (GSC cur. no. 68204). **16–18**, *Neogondolella* n. sp. N sensu Orchard and Tozer, 1997, GSC 131507, *Tetsaoceras hayesi* Zone, Toad Formation, Mile Post 375 East (GSC cur. no. 68204). **19–21**, *Neogondolella* n. sp. M sensu Orchard and Tozer, 1997, GSC 131508, *Lenotropites caurus* Zone, Toad Formation, Mile Post 375 East (GSC cur. no. C-201922).

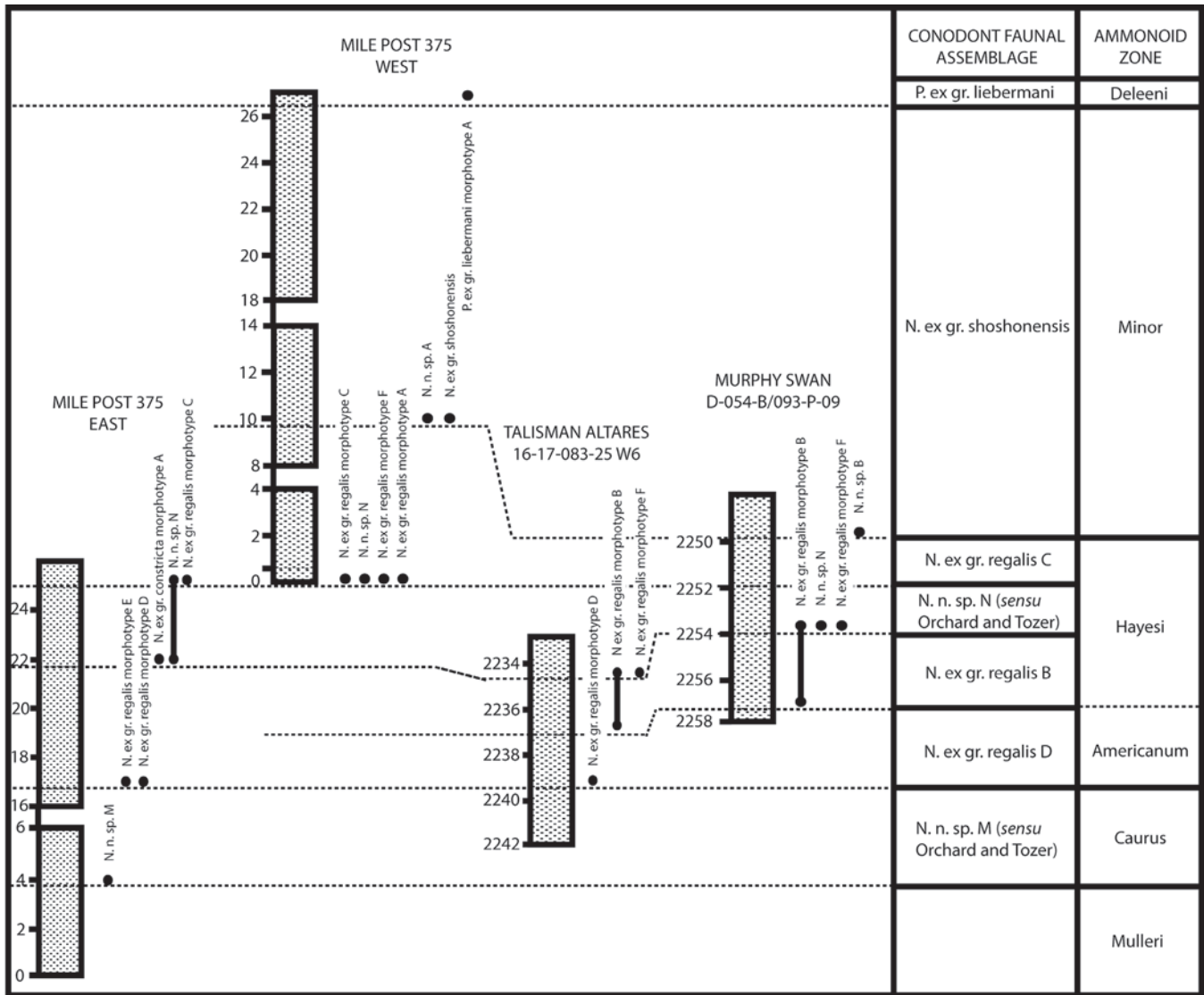


Figure 4 – Correlation of the sections at Mile Post 375 East, Mile Post 375 West, Talisman Altares 16-17-083-25 W6 and Murphy Swan d-054-B/093-P-09 using seven of the new conodont faunal assemblages, that are in turn calibrated to the existing ammonoid biozonation. Dashed line between *Paracrochordiceras americanum* and *Tetsaoceras hayesi* zones indicates the absence of the *Buddhaites hagei* Zone. N. = *Neogondolella*, P. = *Paragondolella*. In outcrop sections, the scale is in meters above the base of the section, and in subsurface drill core, the scale is in meters below kelly bushing.

the highest degree of condensation occurring where the base of the formation is youngest, and the least where it is oldest. This pattern of condensation again suggests the presence of localized paleo-highs within the basin (Golding, 2014).

The large number of new conodont species and morphotypes used to define the new faunal assemblage scheme currently precludes correlation beyond the local area. Anisian collections of conodonts from Nevada contain rich faunas of *Neogondolella* ex gr. *constricta*, and it is probable that some of the new species recognized in British Columbia can also be recognized amongst this diverse fauna. Morphotypes of *N. ex gr. shoshonensis* have been identified in Nevada (Nicora, 1976) and may be useful

for stratigraphic correlation between the two areas; this species group appears to be restricted to the Middle and Upper Anisian (Nicora, 1976; Golding, 2014). *Neogondolella* n. sp. C sensu Orchard, 2008 appears in the Lower Anisian in British Columbia and similar forms seem to occur at the same level in Nevada and in the upper Spathian of the Canadian Arctic (Orchard, 2008). Further investigation of Anisian faunas from Nevada and the Canadian Arctic is required to determine the degree to which these new faunal assemblages are suitable for regional correlation, or to what extent they may be useful for correlation with sub-stage boundaries used in Tethys.

◀ **Figure 3 (continued).** 22–24, *Neogondolella* ex gr. *regalis* morphotype D nov., GSC 131476, *Paracrochordiceras americanum* Zone, Doig Formation, Talisman Altares 16-17-083-25 W6 well (GSC cur. no. V-002978). 25–27, *Neogondolella* ex gr. *regalis* morphotype E nov., GSC 131509, *Paracrochordiceras americanum* Zone, Toad Formation, Mile Post 375 East (GSC cur. no. C-209952). Magnification is × 80.

CONCLUSIONS

The recognition of new conodont taxa from the Anisian of British Columbia has improved the resolution of the conodont biozonation for this time period. The new faunal assemblages allow more precise correlation between sections, including from the outcrop to the subsurface for the first time. The correlation of the subsurface sections has allowed the depositional environment of the Anisian rocks to be re-assessed; it is suggested that these rocks were not deposited on a continental margin, but within a semi-restricted basin. A number of the new conodont taxa identified within the Anisian of British Columbia are also present in Nevada and the Canadian Arctic, suggesting the potential for recognizing the conodont faunal assemblages throughout North America.

ACKNOWLEDGEMENTS

Charles Henderson (University of Calgary) and Chris McRoberts (SUNY Cortland) are thanked for their helpful reviews of the manuscript. Financial support for this study was provided in part by the Yukon Basins Project of the Geological Survey of Canada GEM Program, and by Geoscience B.C.

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TIME CALIBRATED EARLY TRIASSIC $\delta^{13}\text{C}_{\text{carb}}$, $\delta^{18}\text{O}_{\text{apatite}}$ AND SST CURVES FROM SOUTH CHINA: AN UPDATE

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Abstract – Since Sun et al. (2012) published the first $\delta^{18}\text{O}_{\text{apatite}}$ data of conodonts from sections in the Nanpanjiang Basin, South China and used it to reconstruct Late Permian to Middle Triassic eastern Tethyan, equatorial seawater temperatures, errata were published and new radiometric ages became available, which prompted me to reanalyze this unique dataset. In the following I explore how the new data and corresponding modifications impact the shape of the Early Triassic $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves from South China, their implications for the evolution of sea surface temperatures, and their relationship with the biotic recovery in the aftermath of the Permo-Triassic crisis.

INTRODUCTION

In 2012, Sun et al. published the first $\delta^{18}\text{O}_{\text{apatite}}$ data of conodonts from sections in the Nanpanjiang Basin, South China and they used this data to reconstruct Late Permian to Middle Triassic eastern Tethyan, equatorial seawater temperatures. Since then, new information and mistakes have come to light. Goudemand et al. (2013) wrote a technical comment and proposed corrections to Sun et al.'s (2012) figures 2 and 3. As admitted by Sun et al. in their reply (2013), some data points were erroneous (their table S4 does not match their figs. 2 and 3). Goudemand et al.'s (2013) figure 1 was drawn after figure 4 in Galfetti et al. (2007), however, which referenced an incorrect age of ca. 247.9 Ma for the Early-Middle Triassic boundary instead of the new age of 247.2 Ma proposed by Lehrmann et al. (2007). This age (247.2 Ma) remains valid with the new (but still informal) boundary definition by Goudemand et al. (2012), which places the boundary between the 'carinata beds' and the 'tethydis beds', clearly above the FAD of *Chiosella timorensis*. Furthermore, Burgess et al. (2014) proposed a new radiometric age of 251.9 Ma for the base of the Triassic as well as new absolute time constraints. In the following I explore how these findings impact the shape of the Early Triassic $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves from South China and their implications for the relationship between seawater temperatures and biotic recovery in the aftermath of the Permo-Triassic crisis.

Stratigraphic sequence in Zuodeng

Sun et al.'s (2012) figure 2 shows that most $\delta^{18}\text{O}_{\text{apatite}}$ and $\delta^{13}\text{C}_{\text{carb}}$ data for the Early Triassic of the Nanpanjiang basin is from Zuodeng section, and it spans from the base of the Dienerian to the late Spathian. Hence, I used the data from

Zuodeng section as a basis for the time calibration. Once this data was calibrated, the biochronological correlations could be used to fit the data from other sections.

Figure 1 displays the raw data from Zuodeng II section from Sun et al. (2012, tab. S4). The y-axis represents here the stratigraphical position of the samples. The light and dark green bands indicate the extent of each biozone as given by Sun et al., taking into account that ZDC50 and ZDC51 have been reassigned to the *Novispathodus pingdingshanensis* Zone (Sun et al., 2013).

ABSOLUTE AGE CONSTRAINTS

In order to plot the corresponding biozones on an absolute timescale, the following absolute ages were taken into consideration:

(1) An age of 252.0 Ma for the middle of bed 23 in Meishan (Burgess et al., 2014). This age constrains the position of the *Neogondolella yini* Zone (C2 in Fig. 2), which starts from bed 24 in Meishan (Joachimski et al., 2012).

(2) An age of 251.9 Ma for the Permo-Triassic Boundary (Burgess et al., 2014).

(3) & (4) Two ages at 251.6 Ma and 251.5 Ma respectively from beds 33 and 34 at Meishan (Burgess et al., 2014), which are within the *Neogondolella planata* Zone (Zhang et al., 2007). These two ages constrain respectively the lower and upper ends of a minimum $\delta^{13}\text{C}_{\text{carb}}$ plateau (see Burgess et al., 2014; data from Cao et al., 2010).

(5) An age of 251.2Ma between the *Kashmirites densistriatus* beds and the *Flemingites rursiradiatus* beds (Galfetti et al., 2007, Brayard and Bucher, 2008). This age is late early Smithian but not earliest Smithian sensu the latest definition of the Dienerian/

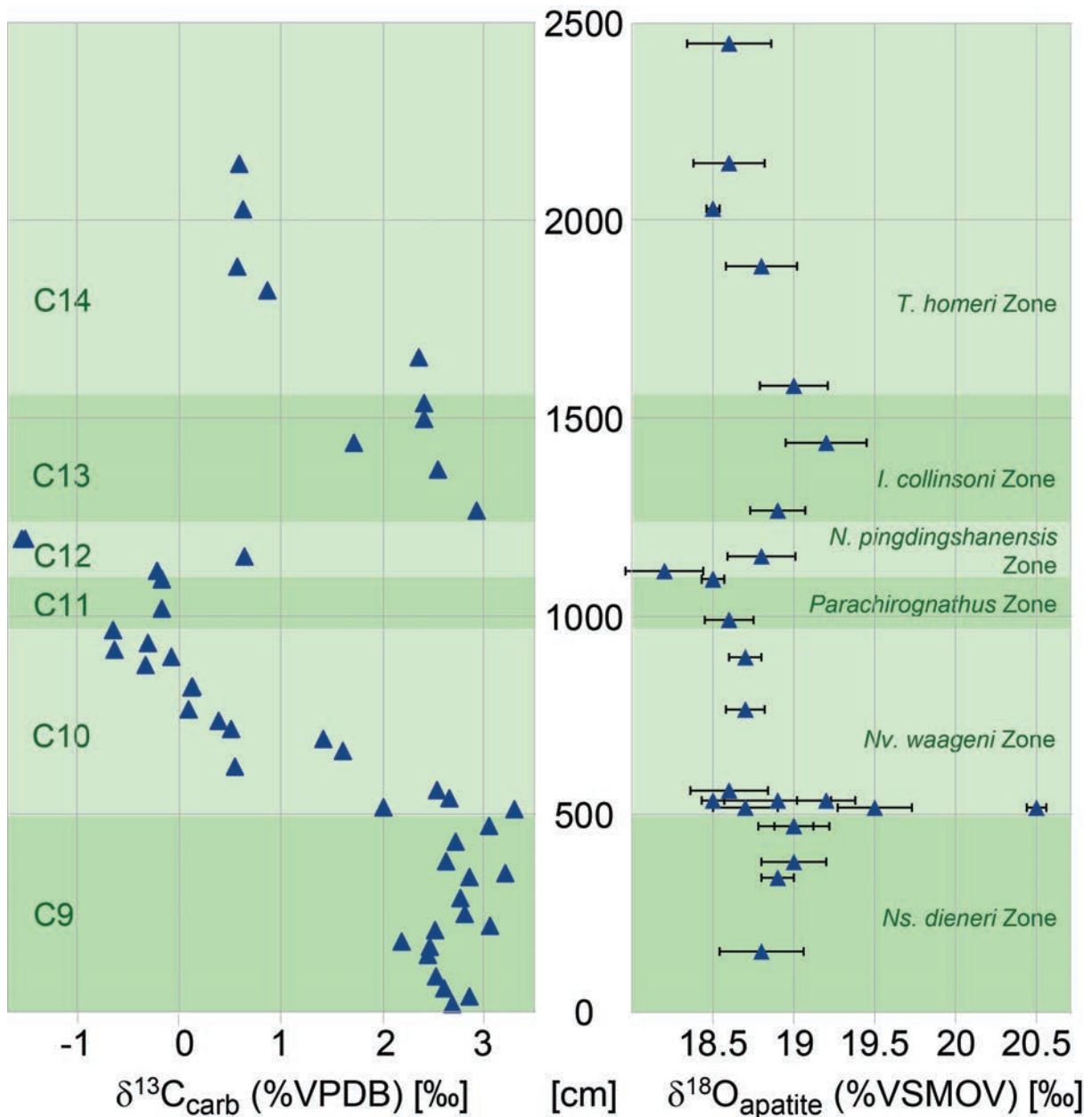


Figure 1 – Stratigraphical evolution of $\delta^{13}\text{C}_{\text{carb}}$ and $\delta^{18}\text{O}_{\text{apatite}}$ data in the Zuodeng II section. Data from Sun et al. (2012). Sun et al. (2012) report that the measurement of NBS 120c was $22.6 \pm 0.16\%$ VSMOW. C9-C14, conodont biozones after Sun et al. (2012). Assignment of samples to corresponding biozones was done after Sun et al. (2012) with corrections from Sun et al. (2013); C9, *Neospathodus dieneri* Zone (Dienerian); C10, *Novispathodus waageni* Zone (early and middle Smithian); C11, *Parachirognathus* Zone (mid-late Smithian); C12: *Novispathodus pingdingshanensis* Zone (early Spathian?); C13, *Icriospathodus collinsoni* Zone (late early Spathian); C14, *Triassospathodus homeri* Zone (middle and late Spathian).

Smithian boundary (Induan-Olenekian boundary, IOB) based on the latest ammonoid results (Brühwiler et al., 2010) that are also corroborated by conodonts and compatible with the latest consensus of the IOBWG about a conodont-based definition of the IOB (Goudemand, this issue). This age does however correlate quite well with the $\delta^{13}\text{C}_{\text{carb}}$ maximum near the base of the Smithian. This shows that the base of the Smithian should not be considered to fall exactly on that $\delta^{13}\text{C}_{\text{carb}}$ maximum, and this is confirmed at the West Pingdingshan section (Chaohu, Anhui province, South China), a GSSP candidate for the IOB (Tong et al., 2007, fig. 2).

(6) An age of 250.5 Ma within the *Tirolites/Columbites* beds (Galfetti et al., 2007). This age correlates roughly with the end of an early Spathian, positive $\delta^{13}\text{C}_{\text{carb}}$ plateau. Given the uncertainty associated with this age, Goudemand et al. (2013) had used the lower bound of this age (about 250.15 Ma) for calibrating the $\delta^{13}\text{C}_{\text{carb}}$ curve (their fig.1).

(7) An age of 248.1 Ma within the late Spathian *Haugi* Zone (Ovtcharova et al., 2006). The corresponding ash layer is found below the maximum $\delta^{13}\text{C}_{\text{carb}}$ plateau that straddles the Early-Middle Triassic boundary, approximately before the Chinese composite $\delta^{13}\text{C}_{\text{carb}}$ curve outreaches +2‰ (see for instance

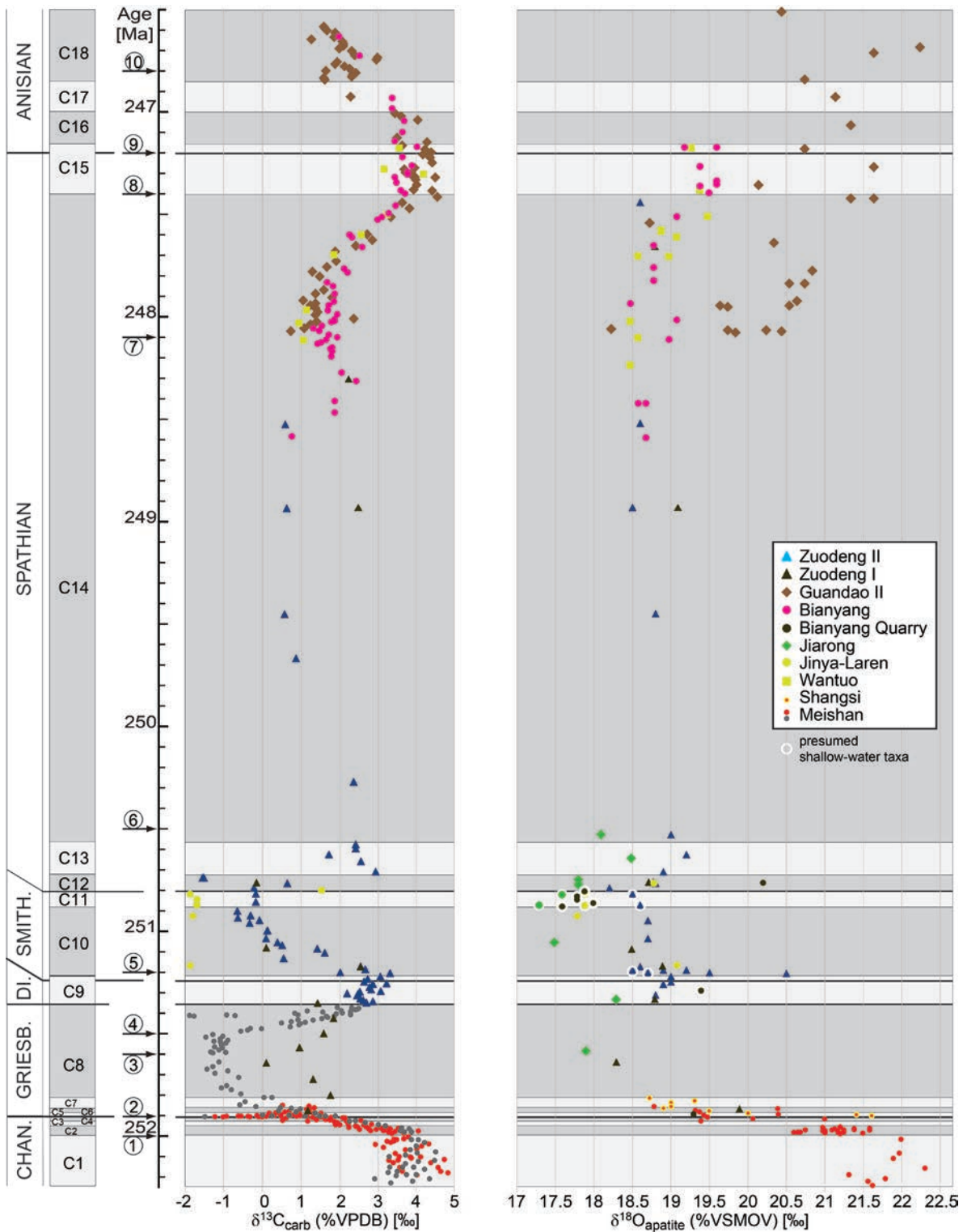


Figure 2 – Temporal evolution of $\delta^{13}\text{C}_{\text{carb}}$ and $\delta^{18}\text{O}_{\text{apatite}}$ data from Meishan. Brown circles: $\delta^{13}\text{C}_{\text{carb}}$ data from Cao et al. (2010); red circles: $\delta^{18}\text{O}_{\text{apatite}}$ data from Joachimski et al. (2012), $\delta^{13}\text{C}_{\text{carb}}$ data from Xie et al. (2007), Shangsi, Wantuo, Jinya, Jiarong, Bianyang, Guandao and Zuodeng (all data from Sun et al., 2012) sections. The $\delta^{18}\text{O}_{\text{apatite}}$ datasets are standardized to NBS 120c=22.6±0.16‰ VSMOW. C1-C18, conodont biozones modified after Sun et al. (2012). C16 and C17 are added because they are used Sun et al. (2012, tab. S4). Assignment of samples to corresponding biozones was done after Sun et al. (2012) with a few corrections (see main text). C1, *Neogondolella changxingensis* Zone; C2, *Neogondolella yini* Zone; C3, *Neogondolella meishanensis* Zone; C4, *Hindeodus changxingensis* Zone; C5, *Hindeodus parvus* Zone; C6, *Isarcicella staeschei* Zone; C7, *Isarcicella isarcica* Zone; C8, *Neogondolella planata* Zone; C9, *Neospathodus dieneri* Zone (Dienerian); C10, *Novispathodus waageni* Zone; C11., *Parachirognathus* Zone; C12, *Novispathodus pingdingshanensis* Zone; C13, *Icriospathodus collinsoni* Zone; C14, *Triassospathodus homeri* Zone; C15, *Chiosella timorensis* Zone; C16, *Neogondolella regalis* Zone; C17, *Nicoraella germanica* Zone; C18, *Nicoraella kockeli* Zone. The arrows with circled numbers 1 to 10 correspond to the absolute time constraints (see main text).

Galfetti et al., 2007).

(8) An age of 247.4 Ma for the FO of *Chiosella timorensis* in Guandao, South China (age by Lehrman et al., 2007, samples PGD1 and PGD2; revision of conodont ranges in Guandao by Goudemand et al., 2012).

(9) An age of 247.2 Ma for the Early-Middle Triassic Boundary (EMTB, Lehrmann et al., 2007). Note that, since *Chiosella timorensis* has been found in unambiguous Spathian strata, the *C. timorensis* Zone (sensu Sun et al., 2012, that is, based on the FAD of *C. timorensis*) actually straddles this boundary (Goudemand et al., 2012). Except for the position of the FAD of *C. timorensis*, the new EMTB definition (Goudemand et al., 2012) is fully compatible with the previous one (e.g. Lehrmann et al., 2007) and correlates roughly with the lowest part of the maximum $\delta^{13}\text{C}_{\text{carb}}$ plateau.

(10) An age of 246.8 Ma within the *Platycuccoceras* beds (Ovtcharova et al., 2006; sample CHIN29), and associated with the conodont *Nicoraella kockeli* (Lehrmann et al., 2006; sample GDGB-110; see also Galfetti et al., 2007, fig. 4), and hence in the *N. kockeli* Zone (C18, Fig. 2).

Unless constrained by absolute ages, the relative durations of biozones were set to reflect their relative stratigraphical thicknesses in the main section of the corresponding time interval (C1-C8 at Meishan, Joachimski et al., 2012; Zhang et al., 2007; Xie et al., 2007; Cao et al., 2010; C9-C13 at Zuodeng II section, Sun et al., 2012; C15-C18 at Guandao II (Upper Guandao) section, Lehrmann et al., 2007; Orchard et al., 2007). This is a somewhat arbitrary choice since it is unknown whether these thicknesses are a linear function of time. This would be the case if sedimentation rates were constant and no hiatuses were present but this is not necessarily true here (Joachimski et al., 2012; Sun et al., 2012, and references therein). Note that setting a sub-series of unconstrained biozones to be of equal duration would be an equally justified and equally arbitrary option.

The new PTB ages published by Burgess et al. (2014) lead to shorten the duration of the Dienerian considerably. This suggests that the early Smithian and possibly the early Spathian ages by Ovtcharova et al. (2006) should be reassessed too, using the same procedure as Burgess et al. (2014).

CORRELATION OF ADDITIONAL DATA

The data from Shangsi, Jinya, Jiarong, Wantuo, Bianyang Quarry, and Bianyang Hill sections were added using the biochronological correlations and, when available, the chemostratigraphical information. Additionally, if within a given biozone a series of $\delta^{13}\text{C}_{\text{carb}}$ points were associated with the $\delta^{18}\text{O}_{\text{apatite}}$ data, we adjusted the position of the sample series as a whole in order to 'fit' the Meishan-ZuodengII-GuandaoII composite $\delta^{13}\text{C}_{\text{carb}}$ curve. It is possible to do so because it has been shown that the trends of the $\delta^{13}\text{C}_{\text{carb}}$ evolution are the same within the basin (and globally). Yet, caution is warranted as the absolute $\delta^{13}\text{C}$ values and the amplitude of excursions do largely differ even within the same basin from one facies to another (see Meyer et al., 2011).

On the other hand, one could hardly justify adjusting the position of the series (as a whole or otherwise) to 'fit' the $\delta^{18}\text{O}_{\text{apatite}}$ 'curve'. In particular, isolated data points for which the associated $\delta^{13}\text{C}_{\text{carb}}$ data did not help constraining their position on the time axis were arranged so as to reflect the uncertainty on their temporal position: unless further information was provided, single points were placed at the center of the corresponding biozone, the topmost sample of a set of points was placed at the top of the biozone and the bottommost sample at the base of that biozone.

The early Smithian samples from Zuodeng I section (ZDC29, ZDC30) could not be positioned reliably on the time axis. They may or may not confirm a gradual warming within that time interval (compare with Sun et al., 2012). Similarly, it is hard to correlate sample ZDC24 (Sun et al. 2012, reported it from the *Neogondolella carinata* Zone but Sun et al. did not define a *Ng. carinata* Zone; we assigned it to the *Ng. planata* Zone): the associated $\delta^{13}\text{C}_{\text{carb}}$ data suggest that it is coeval to the minimum $\delta^{13}\text{C}_{\text{carb}}$ plateau in the middle of the *Ng. planata* Zone.

Sun et al.'s (2012) $\delta^{13}\text{C}_{\text{carb}}$ data from Jinya is consistent with Galfetti et al.'s (2007) data from Jinya if the early Smithian sample (LRC01) is considered younger than absolute age 5.

Sun et al. (2012) mentioned (their table S4; Sun, personal communication, 2013) that the samples at the Smithian-Spathian boundary from Bianyang Quarry section were ramiform elements, mostly robust ones. If P_1 elements were present, they belonged to *Parachirognathus* spp (an ellisonid conodont). Ellisonids are not known from the Spathian (see for instance Orchard, 2007 for the latest review about Early Triassic conodonts). In my abundant collections from Guangxi, South China, ellisonids are clearly the dominant group in the middle-late Smithian *Owenites koeneni* beds (Galfetti et al., 2007). Yet, none of them survived the Smithian-Spathian boundary crisis. In other words, none is known in the *Novispathodus pingdingshanensis* Zone or in younger strata. Hence, it is doubtful that BYC19-1 (which contains *Parachirognathus* spp.) and BYC16-2 should be displayed in the *Nv. pingdingshanensis* Zone as in Sun et al.'s (2012) figure 2. Instead, I consider samples BYC19-1, BYC16-2, BYC14.3, BYB5 and BYB4 as belonging to the *Parachirognathus* Zone. It may sound trivial to discuss the location of these four points, but displaying them as straddling the Smithian-Spathian boundary gives the (misleading) impression that the evolution of $\delta^{18}\text{O}_{\text{apatite}}$ at Bianyang section parallels that at Zuodeng II section. The evidence for such a parallel (offset) evolution of $\delta^{18}\text{O}_{\text{apatite}}$ in both sections is not available yet.

Figure 2 summarizes the results concerning the time calibration of Sun et al.'s (2012) $\delta^{13}\text{C}_{\text{carb}}$ and $\delta^{18}\text{O}_{\text{apatite}}$ data.

SST CURVE

$\delta^{18}\text{O}_{\text{apatite}}$ data may be interpreted in terms of seawater temperatures, and, more precisely, in terms of Sea Surface Temperatures (SST). Yet, $\delta^{18}\text{O}_{\text{apatite}}$ data may also reflect the different life habits (water depth preferences) of the various conodont genera that were sampled and the corresponding

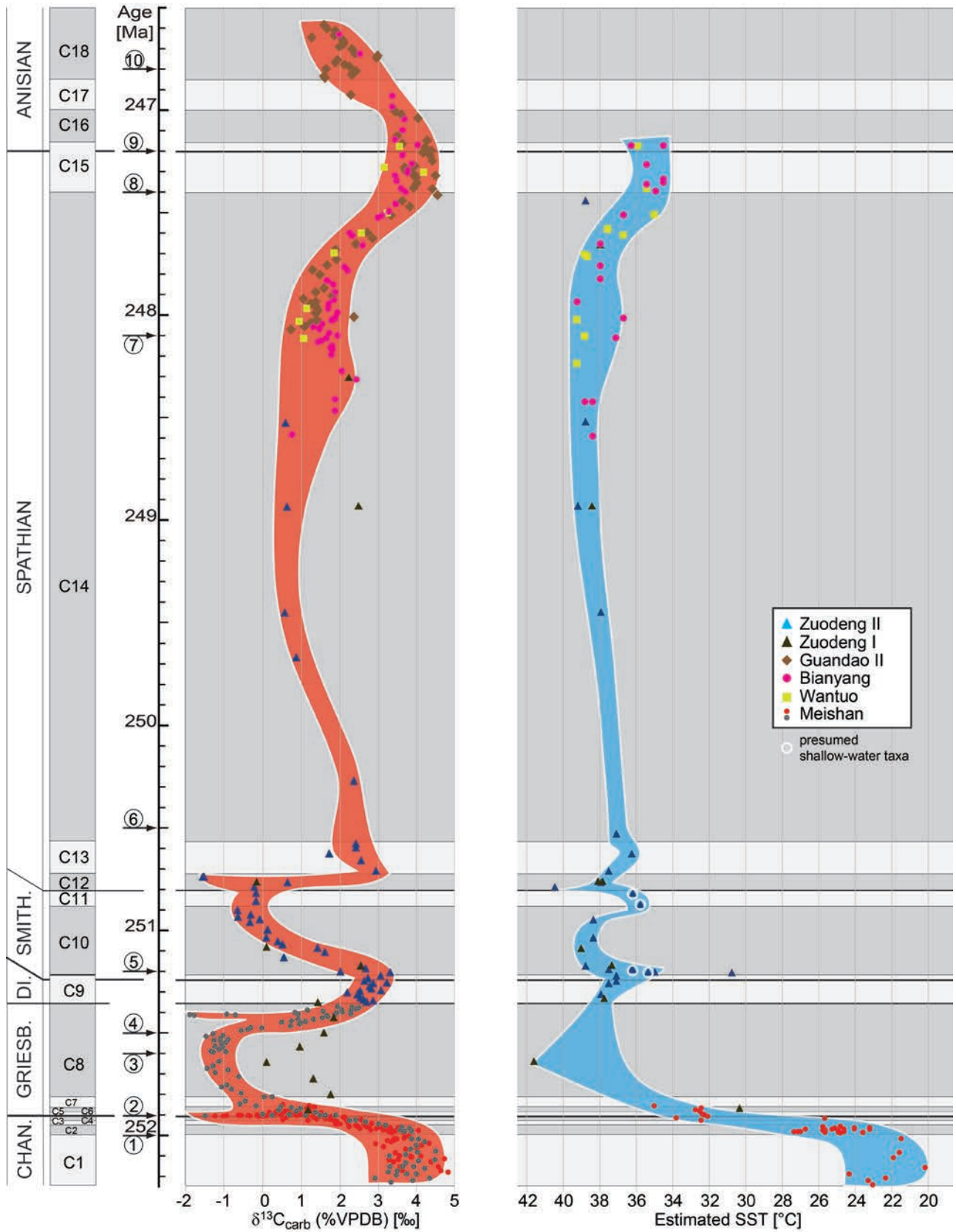


Figure 3 – Temporal evolution of $\delta^{13}C_{carb}$ and estimated sea surface temperatures at Meishan, Zuodeng, Wantuo, Bianyang Hill, and Guandao II sections. For clarity, only the $\delta^{13}C_{carb}$ data is displayed for Guandao II because its $\delta^{18}O_{apatite}$ data is offset from the main trend (see main text and Fig. 4). Data modified after Sun et al. (2012) as described in main text. Samples using hindeodid or ellisonid (*Platyvillosus*, *Pachycladina*, *Parachirognathus*) material are considered as recording the SST. Samples using neospathodid material are corrected by a +3°C offset in order to retrieve the SST. Similarly, samples using neogondolellid material are corrected by a +4.7°C offset. The color bands show the first-order trends.

biases should be corrected for in order to retrieve the SST. Let us first focus on a main composite Meishan-Zuodeng II-Wantuoh/Bianyang Hill curve. In this case, Wantuo and Bianyang Hill sections are preferred to Guandao II because, contrary to Guandao II whose data is clearly offset, the $\delta^{18}\text{O}_{\text{apatite}}$ data from Wantuo and Bianyang Hill is compatible with the data from Zuodeng II. Without comparative samples, one can assume that the data from Meishan is not offset compared to that from Zuodeng II.

The original Meishan $\delta^{18}\text{O}_{\text{apatite}}$ data is from Joachimski et al. (2012) and the data points were obtained by processing either *Hindeodus* or 'Clarkina' (*Neogondolella*) material. For the lower (Permian) part, up to bed 25, both 'Clarkina' and *Hindeodus* are interpreted as recording $\delta^{18}\text{O}_{\text{apatite}}$ data that correspond to the SST (Joachimski et al., 2012, p. 196). Above bed 25, and concurrently with the PTB sea level rise, 'Clarkina' records lower temperatures than *Hindeodus*, which is interpreted as 'Clarkina' migrating to deeper and colder waters while *Hindeodus* remains at the sea surface (ibid).

For the Zuodeng II section, most measurements were performed with material comprising neospathodid elements (Sun et al., 2012, tab. S4). Based on two comparative analyses of *Neospathodus* and *Platyvillosus* (Sun et al., 2012, tab. S1, samples ZDC44 and ZDC B), Sun et al. (2012, supp. text, p. 7) interpreted neospathodids as having lived at a water depth of ca. 70 meters and *Platyvillosus* at sea surface. The case of the middle-late Smithian ellisonids (*Pachycladina*, *Parachirognathus*) is more difficult: ellisonids favored shallow-water environments (e.g. Carr et al., 1984) and their dominance in middle-late Smithian samples may reflect the recorded coeval regression. Yet, without comparative analyses from the same samples, it is not clear by how much their $\delta^{18}\text{O}_{\text{apatite}}$ signal should be offset relative to that of neospathodids. In the following we shall assume, as Sun et al. (2012), that ellisonids lived at sea surface and their $\delta^{18}\text{O}_{\text{apatite}}$ offsets by -0.7‰ compared to that of neospathodids.

The Wantuo and Bianyang Hill data was obtained using either neospathodid or unidentified ramiform material (Sun et al., 2012, tab. S4). Without further evidence, we shall assume most samples correspond to animals that lived like neospathodids at a water depth of ca. 70 meters. One sample from Wantuo (WTC05) was used to compare neospathodid and neogondolellid material and the corresponding 0.4‰ offset suggests that neogondolellids lived at a water depth of ca. 85 meters (Sun et al., 2012, tab. S1 and supp. text p. 7).

The Zuodeng I section was measured using either neospathodids (ZDC28-31), neogondolellids (ZDC24 and ZDC32) or hindeodids (ZDC21). The same offsets as above apply. Namely: samples using hindeodid or ellisonid (*Platyvillosus*, *Pachycladina*, *Parachirognathus*) material are considered as recording the SST; samples using neospathodid material are corrected by a +3°C offset in order to retrieve the SST; and similarly, samples using neogondolellid material are corrected by a +4.7°C offset.

The SST curve for the 'Meishan-Zuodeng-Wantuoh/Bianyang Hill' composite is shown on Figure 3. The temperatures are computed using the equation of Puc  at et al. (2010), assuming constant salinity and an ice-free world ($\delta^{18}\text{O}_{\text{seawater}} = -1\text{‰}$) (Sun

et al., 2012).

On Figure 4, the same procedure is applied to the data from Guandao II, Bianyang Quarry, Jinya and Jiarong sections. The evolution of the SST in Guandao II section is clearly offset (by about -8°C) from that in Wantuo, Bianyang Hill and Zuodeng II sections. Sun et al. (2012) proposed that it is due to higher evaporation in Guandao (salinity offset) since this section is close to the Great Bank of Guizhou. The few data points from Jinya fit with the temperatures in Zuodeng for the early Smithian and the early Spathian but they differ within the *Parachirognathus* Zone. The evolution of the SST in Jiarong seems to parallel that in Zuodeng but it is offset by 2–4°C. Since we are comparing sea surface temperatures, this offset cannot be explained by a difference in water depth (contra Sun et al., 2012). It could instead reflect regional variation but it is puzzling that the offset in Jiarong is opposite to that in Guandao although Jiarong and Guandao are neighboring sections. Sun et al. (2012, fig. 3) suggested that the $\delta^{18}\text{O}$ data from Jiarong, Bianyang and Jinya around the Smithian-Spathian boundary, was reflecting that of Tsoteng and was recording the temporal evolution of the SST: namely the occurrence of a presumed late Smithian thermal maximum.

CONCLUSION

Though based on the same assumptions as Sun et al. (2012) about the life habitats of the measured conodonts, our new calibration offers a significantly different picture for the Early Triassic evolution of sea surface temperatures in South China: the late Smithian *Parachirognathus* Zone may in fact correspond to a decrease of temperatures, while the early Spathian *Novispathodus pingdingshanensis* Zone would correspond to a rebound of temperatures, possibly with a peak in the earliest Spathian. The sea surface temperatures drop again during the *Icriospathodus collinsoni* Zone and then they rise until the middle and late Spathian where they reach levels similar to those observed in the middle Smithian and early Spathian.

ACKNOWLEDGEMENTS

Albertiana's chief editor Chris McRoberts and reviewer Margaret Fraiser are thanked for their comments, which helped to improve this manuscript.

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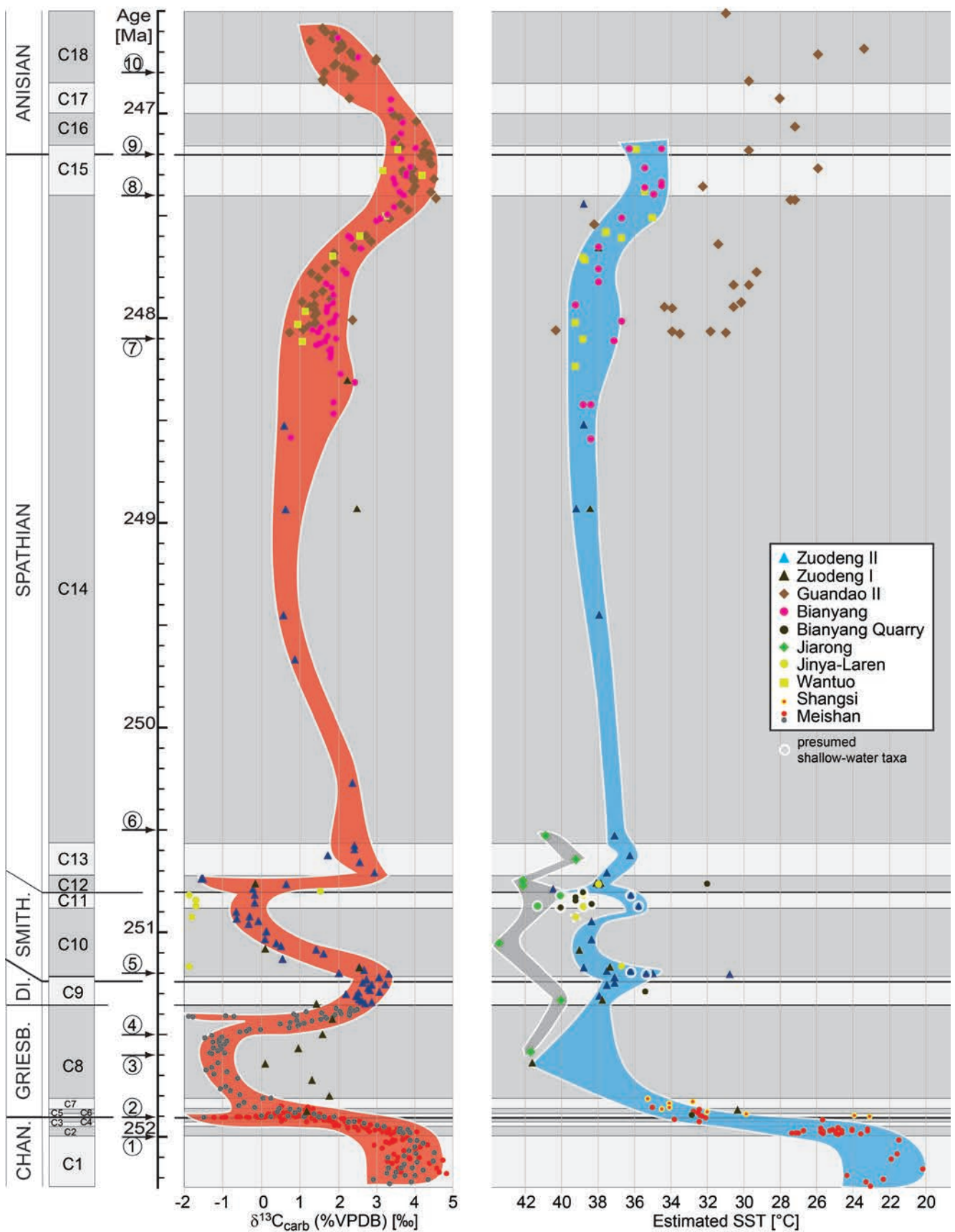


Figure 4 Temporal evolution of $\delta^{13}\text{C}_{\text{carb}}$ and estimated sea surface temperatures at Meishan, Shangsi, Zuodeng, Jinya, Jiarong, Bianyang Quarry, Wantuo, Bianyang Hill and Guandao II sections. Data modified after Sun et al. (2012), see main text and Fig. 3. The SST in Jiarong and Guandao are offset in the opposite way relative to the main composite SST curve.

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NOTE ON THE CONODONTS FROM THE INDUAN-OLENEKIAN BOUNDARY

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INTRODUCTION

A brief summary of results of studies into the Induan-Olenekian Boundary (IOB) conodont material from Waili (Guangxi Province, South China) and Mud (Spiti, Himashal Pradesh, Northern India) is presented (Goudemand et al., in prep. a, b). The latest consensus about the definition of the IOB was to use the FAD of *Neospathodus waageni* sensu lato as an index for the base of the Olenekian (IOB Working Group, as suggested by Tong et al., 2004). Up to now and until the foreseen proposal of the Nammal Gorge section, Pakistan as a GSSP candidate, only two sections have been formally proposed: the Mud section M04 in Northern India (Krystyn et al., 2007a, b), and the West Pindingshan section at Chaohu in Anhui Province, South China (Tong et al., 2003, 2004). Conodont-based correlations between these two sections remain hitherto unclear. Furthermore, new ammonoid data recently questioned the stratigraphic position of the IOB in Mud (Brühwiler et al., 2010). Our new conodont data demonstrates that the northern Indian and south Chinese conodont sequences agree better with one another and with the ammonoid data than was previously thought.

NEW DATA

In the Mud section, the presumed FO of *Neospathodus waageni* was reported in subbed 13A3 (Krystyn et al., 2007a, b). In order to re-assess in details the Mud section, intense bed-by-bed sampling of ammonoids and conodonts was performed below this proposed GSSP. It led first to a revision of the ammonoid biozonation and to the recognition that the most relevant ammonoid turnover occurred between beds 9 and 10 (Brühwiler et al., 2010), about 1m below bed 13 where the boundary was proposed in 2007 (Krystyn et al., 2007a, b). The conodont material led to surprising outcomes too, since 'typical' Smithian forms occurred also below bed 13 (Goudemand et al., in prep. a). In particular, *Ns. waageni* sensu lato was also found in bed 10 (together with the ammonoid *Flemingites bhargavai*), the middle part of which had not been sampled previously. In bed 10 of Mud section, the elements pertaining to *Ns. waageni* sensu lato (see Fig. 1.A) are similar to the specimens of "*Ns. waageni eowaageni*" that were described from beds 24-16, 24-20,

24-21 and 24-22 at Chaohu (Zhao et al., 2008a, fig. 3/ 1–4). *Neospathodus waageni* is a highly variable species that deserves further species differentiation (Goudemand et al., in prep. a, b). These early forms of "*Ns. waageni eowaageni*" were hitherto included in *Ns. waageni* sensu lato and discussed as such during earlier deliberations of the IOBWG. The fact that "*Ns. waageni eowaageni*" had not been recorded from Mud until now had actually led some people to question the completeness of the conodont record in Mud. Our results show that they do occur in Mud too and that they could be used to define the IOB. However, these early forms, which I will refer here to *Novispathodus waageni* new subspecies A, should be distinguished from true *Ns. waageni eowaageni*, a subspecies of '*Neospathodus*' *waageni* whose holotype is from higher up in the Chaohu section (bed 27 at Chaohu, Zhao et al., 2007, pl.1, fig.5; Zhao et al., 2008a, fig. 3/ 5; not pl. 1, fig. 11 from Zhao et al., 2008b, which was published later). Though the two forms are superficially similar, *Ns. waageni eowaageni* is about twice as large and its upper profile is more arcuate. I have many specimens of both forms in my collections (e.g., Waili and Mud) and *Novispathodus waageni* new subspecies A cannot be considered a juvenile form of *Ns. waageni eowaageni*.

Note also that I assign them to the genus *Novispathodus*, whose type species is *Novispathodus abruptus*, an early Spathian species. The P_1 element of *Novispathodus* is segminate and very similar to the P_1 of all neospathodids, but the other elements of the apparatus are different from those of *Neospathodus*, especially the P_2 element, which is characteristically high-bladed. In collections from both Waili and Mud, the P_1 s of *Novispathodus waageni* new subspecies A are found together with similarly denticulated, high-bladed P_2 s, which in my opinion belong also to *Novispathodus waageni* new subspecies A (see Fig. 1.B). Based on further unpublished reconstructions of its apparatus, *Ns. waageni* should be similarly re-assigned to the genus *Novispathodus* (e.g., Orchard & Zonneveld, 2009). This may apply also to all species associated with *Nv. waageni*, such as '*Neospathodus*' *pakistanensis* and '*Neospathodus*' *posterolongatus*.

At Chaohu, further elements that Zhao et al. (2008a) assigned to '*Neospathodus*' *posterolongatus* were also illustrated from the first 'Olenekian' beds containing *Novispathodus waageni* new subspecies A (Zhao et al., 2008a, beds 24-20 and 24-22, fig. 3/ 7, 8). *Novispathodus posterolongatus* was originally

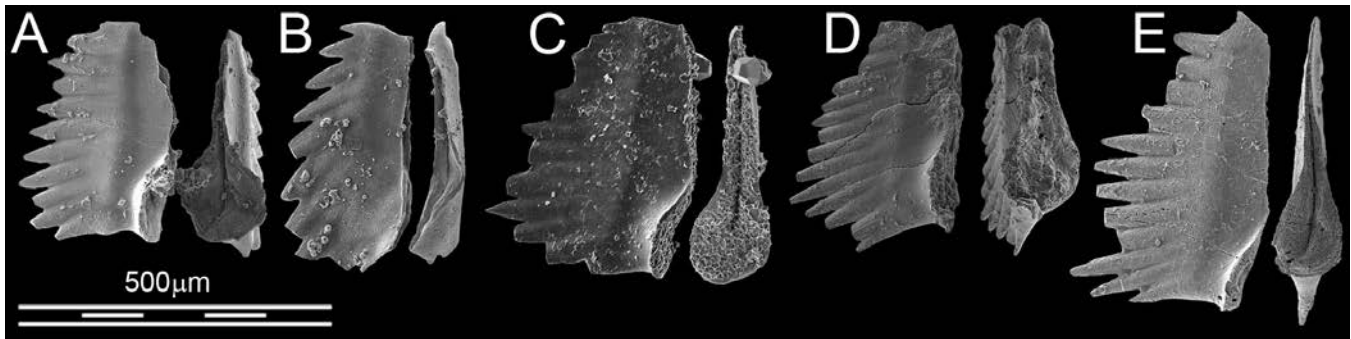


Figure 1 – **A–D**, *Novispathodus waageni* new subspecies A. **A**, P_1 element, Mud, bed 10. **B**, P_2 element, Mud, bed 10. **C**, **D**, P_1 elements, Waili cave section, bed W147 (=bed W235 of Galfetti et al., 2008). **E**, *Novispathodus* n. sp. B. P_1 element, Mud, bed 10. All SEM images, all $\times 80$. All specimens are deposited at the Paleontological Institute and Museum, University of Zurich, Switzerland.

considered a subspecies of *Nv. waageni*. It is also considered as a good secondary proxy for the IOB (IOB Working Group). *Novispathodus posterolongatus* is similar to *Nv. pakistanensis* but differs in the elongated basal cavity of its P_1 element. The holotype of *Nv. posterolongatus* comes from bed 25-25 at Chaohu (Zhao et al., 2007), where it co-occurs with *Nv. waageni waageni*. In Chaohu, Waili and Mud, the FOs of *Nv. posterolongatus* and *Nv. waageni* sensu stricto are sub-contemporaneous. In my opinion, the elements illustrated by Zhao et al. from beds 24-20 and 24-22 are not true *Nv. posterolongatus* and are better differentiated as a new taxon (Goudemand et al., in prep. a, b) that I refer here to *Novispathodus* n. sp. B. In all cases, the very same elements are also found to co-occur with *Novispathodus waageni* new subspecies A in collections from Mud and Waili (see Figs. 1.C–E) and they could also be used as an index for the IOB.

Based on these results, bed 10 in Mud correlates with the upper part of bed 24 in Chaohu (West Pingdingshan section). In accordance with the Chaohu section and the ammonoid data from Mud (Brühwiler et al., 2010), the IOB in Mud should be placed between beds 9 and 10.

The biostratigraphic sequences are very similar in Mud, Waili and Chaohu. In Mud, we find successively: *Novispathodus waageni* new subspecies A and *Novispathodus* n. sp. B (bed 10), *Borinella nepalensis* (from bed 11), *Eurygnathodus costatus* and *Eu. hamadai* (beds 12, 13), *N. waageni eowaageni* (from bed 14). In the Waili cave section in Guangxi, the same sequence is recognized: *Novispathodus waageni* new subspecies A is found (see Figs. 1C–D) about 1 meter below the massive ‘*Flemingites rursiradiatus*’ beds (Brayard and Bucher, 2008), *Borinella*. cf. *B. nepalensis* was found 30 cm above that, *Eu. costatus* and *Eu. hamadai* are restricted to the bed just below the *Flemingites* beds and the lowermost part of the *Flemingites* beds, and *Nv. waageni eowaageni* is found in the middle of the *Flemingites* beds. In Chaohu, and as far as one can tell from the published material, a similar sequence occurs, except that no element of *Borinella* is known. Finally, note that at Nammal section (Salt Range, Pakistan), the type locality of *Nv. waageni waageni*, P_1 and P_2 elements of *Novispathodus waageni* new subspecies A are also found in the earliest ‘Smithian’ strata (Goudemand et al., unpublished), much lower than the FO of *Nv. waageni* sensu stricto.

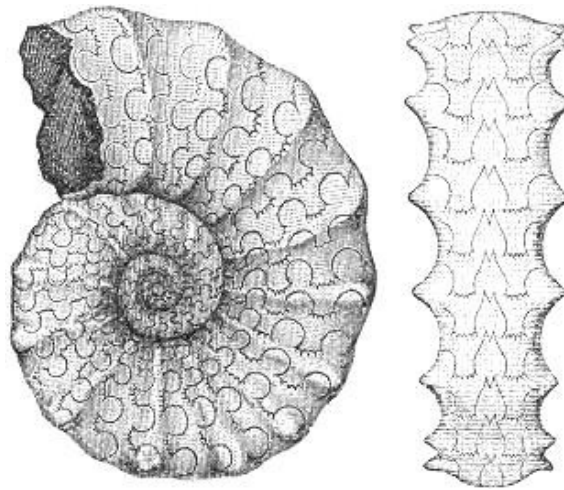
CONCLUSIONS

Based on our new data from Mud and Waili, we differentiate two new taxa (*Novispathodus waageni* new subspecies A and *Novispathodus* n. sp. B) that were previously thought to belong to *Nv. waageni eowaageni* and *Nv. posterolongatus* respectively. In Chaohu these two taxa occur in the earliest Smithian strata (sensu IOBWG). In Mud and Waili (and Nammal), they can also be used to define the base of the IOB. Such definition would be compatible with the ammonoid data from Mud. The conodont biostratigraphic sequences in Mud, Waili, and Chaohu are very similar.

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NEW AND CORRECTED EVIDENCES ON EARLY TRIASSIC BIOSTRATIGRAPHY IN SOUTH PRIMORYE, SIBERIA, KAZAKHSTAN AND VIETNAM (REPORT ON THE IOBWG ACTIVITY IN 2014)

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MAIN RESULTS

1. Global correlation of the Permian-Triassic boundary sequences (*Otoceras* beds) in Siberia has been made on the basis of first carbon-isotope and known palaeontological data (Zakharov et al., 2014a).

2. The integrated approach in palaeontological investigations of the Olenekian (Lower Triassic) of Northern Vietnam was used for the first time: ammonoids (25 species), gastropods (eight species), bivalves (five species), conodonts (43 species), ostracodes (six species, including one new one), and radiolarians (12 species, including five new ones) (Shigeta et al., 2014). As a result, some new subdivisions are recognized in the middle Smithian (*Flemingites rursiradiatus*, *Urdyceras tulongensis*, and *Owenites koeneni* Beds), upper Smithian (*Xenoceltites variocostatus* Beds), and lower Spathian (*Tirolites* cf. *cassianus* and *T.* sp. nov. Beds). Conodonts *Novispathodus* ex gr. *waageni* were found in the middle Smithian in Vietnam.

3. The corrected data on distribution of invertebrates (brachiopods, ammonoids) in the Induan and Olenekian of South Primorye and the Olenekian of Kazakhstan (Mangyshlak) have been obtained (Zakharov and Popov, 2014).

4. First description of well-preserved foraminifera (*Ammodiscus* sp.) from the Lower Triassic (Smithian) of South Primorye was made for the Russian Far East (Bondarenko et al., 2014).

5. Ammonoids of the genus *Churkites*, typical representative of the early Olenekian assemblage (*Anasibirites nevolini* Zone), have been discovered in the upper part of the Tri Kamnya Cape section at the western coast of Ussuri Gulf in South Primorye (Fig. 1) for the first time. *Churkites* cf. *syaskoi* was met in association with ammonoids *Inyoites*, *Chypeceras*, *Owenites*, *Juvenites*, *Prionites*, *Glyptophticeras*, *Brayardites*, *Mianwaliites*, *Pseudoflemingites*, *Aspenites*, *Rohillites*, *Pseudoaspedites*, *Anaxenaspis*, *Anasibirites*, *Monneticerases?*, *Shamaraites*, *Palaeokazakhstanites*, *Xenoceltites*, and *Arctoceras*, most of which are known from the basic section for the *Anasibirites nevolini* Zone (SMID, Artyom). The rarity of ammonoids of the genus *Anasibirites* within the investigated interval and the lack of platform conodonts, including *Schythogondolella milleri* (Müller), within isolated material seem

to be an evidence for the property of fossil-bearing sediments to the upper part of the *Anasibirites nevolini* Zone (upper part of the Smithian Substage of the Olenekian). The lower part of the *Anasibirites nevolini* Zone in South Primorye, correlated with the *S. milleri* conodont Zone, more likely corresponds to the *Wasatchites clistractus* Zone of the Salt Range in Pakistan (Zakharov et al., 2014b).

6. New species of flemingitid ammonoids from the Smithian of South Primorye have been described (Smyshlyaeva and Zakharov, 2013).

Field-work results

Tirolites-bearing sediments located just above the Smithian were discovered in the Kamenushka River basin in South Primorye (new Kamenushka-1 and Kamenushka-2 sections).

Meetings

1. Cephalopod Symposium (Zurich, Sept. 2014). There was business-meeting on the Triassic subcommission in Zurich. Only a single question has been discussed: Induan-Olenekian boundary (IOB). Yuri Zakharov informed about unpublished carbon isotope results, obtained on this topic in Primorye region. Hugo Bucher promised to prepare a presentation on the candidate of global stratotype section of the IOB (Nammal, Salt Range, Pakistan) in nearest future, when conodonts from the Nammal section will be described.

2. 4th International Palaeontological Congress (Mendoza, Sept. 28-Oct. 3, 2014). The poster "Global correlation of *Otoceras* beds in light of the first carbon isotope data on Permian-Triassic boundary in Siberia" (Y.D. Zakharov, A. S. Biakov, S. Richoz, and M. Horachek) was presented.

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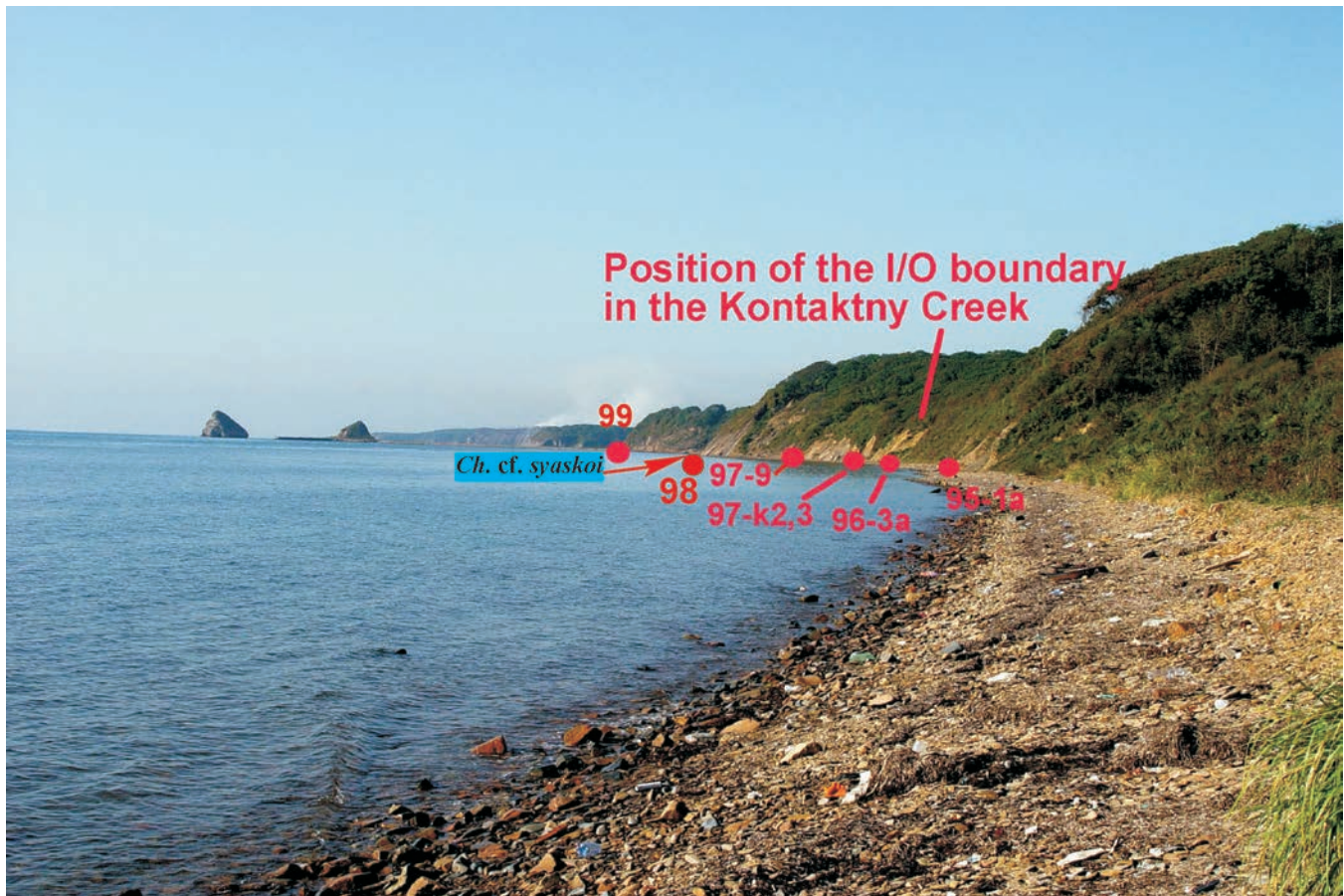


Figure 1 – Image of the Induan/Olenkian boundary Tri Kamnya Cape section at the western coast of Ussuri Gulf in South Primorye

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CARMINA VIRGILI (1927–2014)

Carmina Virgili died in Barcelona on the 21st of November, 2014 where she was born 87 years ago.

During her academic career she lectured in Stratigraphy at Barcelona (1949-1963), Oviedo (1963-1968) and Madrid (1968-1996).

She was a pioneer on the modern studies of the Permian and Triassic in Spain, starting with her Ph.D. Thesis (1956), in which she made the first correct interpretation of the Triassic successions of the Catalan Coastal Ranges and remains the reference work for the Triassic of Northeastern and Central Spain.

In 1968, she created a research team at the Complutense University of Madrid dedicated to the Permian and Triassic stratigraphy and paleogeography, still active. Under her direction, fundamental new data were discovered: the presence of Permian sediments in the Iberian Ranges and Central System (Central Spain), the correct description and dating of Early Permian, Late Permian and Triassic sediments in Central and Eastern Spain, the interpretation of their mutual relationship, boundaries and subdivision into Formations and Members, changing radically the previously accepted interpretations, among many others. Her strong leadership ensured the activity of this group up to now, starting a network of correspondent researchers all over Europe that was at the origin of many collaborative projects.

She introduced in Spain the palynological techniques in collaboration with the Laboratories of the Universities of Strasbourg (France) and Utrecht (Holland) with great success, as all the main continental and shallow marine formations of the Permian and the Triassic were dated and the inter-basinal correlations were refined up to European standards. She encouraged many of the members of the research team to have long periods of study at French and English Universities, a very unusual practice in Spain in the 70's and 80's as part of her concept of international collaborative research effort.

She acted as the Spanish representative in several IUGS-UNESCO Research Programs and in the IUGS-UNESCO Sub-commissions on Permian and Triassic Stratigraphy.

She published more than one hundred scientific articles and books. At the end of her scientific career she became interested in the History of Geology and wrote a book on Lyell and several articles on the relationship of the english



geologist and Spain (See selected publication list below).

She was the first woman to be Professor (1963) and Dean of a Faculty (1977) after the Spanish Civil War. She was Junior Minister for Universities and Research (1982-1985), Dean of the College d'Espagne, Cité Universitaire, Paris (1987-1996) and Senator for Barcelona, Labour Party (1996-2000). She also was a strong militant of women's rights in the society fighting against enormous odds in a male-dominated academic world in the 50' and the 60'.

She will be dearly missed by her former students, disciples, friends and colleagues in different institutions.

Alfredo Arche
Madrid, Spain

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NEW TRIASSIC LITERATURE

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Towards an evolutionary sound definition of 'recovery'?

In the Early Triassic community, 'biotic recovery' is one of the most commonly used terms and a recurring debate is whether the biotic recovery was prolonged in the aftermath of the end-Permian crisis. The problem with this debate is that 'recovery' is understood in different ways by different authors. The latest review about the pattern and tempo of the biotic recovery following the end-Permian mass extinction (EPME) was written by Chen and Benton (2012). Although Chen and Benton are well aware of definition issues with the term 'recovery' (Chen and Benton, 2012, p. 4), their paper still implicitly and alternatively adopts various definitions of 'recovery'. In these regards, their paper illustrates well the wandering of the current literature and this is the reason I am discussing it here. My intention is not to criticize Chen and Benton's paper per se but to draw our attention towards this pervading conceptual issue.

In their 2012 paper, Chen and Benton reviewed the latest results about the biotic recovery following the end-Permian mass extinction (EPME) and they concluded that Triassic ecosystems were rebuilt stepwise from low to high trophic levels. Many of us reacted strongly to that paper, especially to their figure 4 (Chen and Benton, 2012, p. 7) and their claim that "immediate post-extinction ecosystems in the Griesbachian-Dienerian show only the lowest trophic level" (Chen and Benton, 2012, p.7), that is, primary producers, which they equate to microbes. It is obvious (as mentioned several times by Chen and Benton) that many more groups and other trophic levels were represented during this earliest Triassic interval [e.g. ammonoids (Brayard et al., 2009) and conodonts (Orchard, 2007), some being predators presumably (Purnell, 1995); see also Scheyer et al., 2014].

Then, how can we reconcile their figure and claim with the asserted presence of other organisms during that interval? I shall assume that Chen and Benton (2012) implicitly considered a given trophic level to be present only if it has achieved full recovery. This, in turn, raises the issue of defining the term 'recovery' for a trophic level. One recurrent definition used by Chen and Benton (2012) for a group or a community is a low abundance, high diversity and high evenness of that community. Let us take over this definition and have a look again at the Griesbachian data. Where is the evidence for a high diversity and low evenness of microbial communities in the Griesbachian? How do we know that the lowest trophic level had already recovered? The short-lived dominance of microbes in the earliest Griesbachian could also suggest that the corresponding microbes were 'disaster taxa'. The same question applies to the other trophic levels, which, following Chen and Benton, were added sequentially on top of one another. Chen and Benton's figure 4 demonstrates that they did not apply the same definition of 'recovery' consistently throughout their paper.

In fact, like Chen and Benton (2012) we all implicitly and alternatively adopt various definitions of 'recovery'. My intention

here is to stress out our need for either a consensual definition of 'recovery' or the global acceptance by our community that discussions about recovery should be better contextualized. Recovery of a species, of a supra-generic clade, of a community, of an ecosystem or of a trophic level may be defined and quantified in different and possibly contradicting ways. The granularity (spatial, temporal or ecological resolution) we choose for our studies may influence our definition and hence our conclusions about the tempo of recovery. Moreover, although the recovery of a particular taxonomic group can be easily defined in terms of, for instance, its specific diversity, defining the recovery of a complex system with many interacting constituents can be challenging.

A generic, maybe largely approved definition of 'recovery' is "the return to a previous state" (Chen and Benton, 2012, p.3). Yet, this definition does not specify what the 'state' of a clade or of an ecosystem should be. For a given taxon, the most used metric of its state of recovery is its morphological diversity. One could argue that the state of recovery is better characterized by a set of parameters such as diversity, size, and community evenness, as well as the spatial distribution thereof, that is, whether the corresponding recovery signature is observed locally or globally.

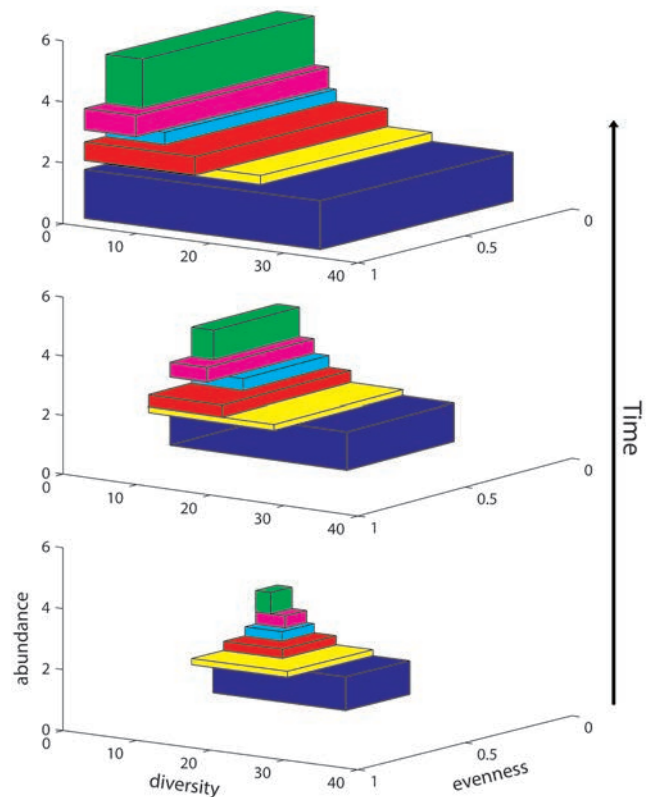


Figure 1 – Fictitious temporal evolution of an ecosystem's trophic pyramid during a recovery.

Yet, what is a good metric for the recovery of an ecosystem? Individual taxonomic groups show major differences in their response to the EPME: ammonoids thrived less than 2 myr after the EPME (Brayard et al., 2009) but corals are unknown from the fossil record until the Middle Triassic. Shall we compute an average of the groups' recoveries? Remember that some groups like the conodonts were positively affected (immediate recovery) and some groups like the trilobites never recovered. How can we appropriately describe the 'state' of an ecosystem?

The familiar way to understand recovery of a given system implies a relative stability (unity) of that system. If the system evolves too fast, we are not able to identify (a) normal, healthy state(s) in comparison with which we can define abnormal, crisis periods. The faster the system evolves in normal conditions, the shorter and tougher the crisis has to be in order for us to detect it and to define its boundaries. In other words, defining ecosystem descriptors that are less prone to variation is key for the identification of healthy steady states and crisis transitional phases.

Recently, Foster and Twitchett (2014) showed that there had been no loss of functional diversity of benthics through the EPME at the global scale. This is not surprising if one considers that the global structure of the network of ecological interactions within an ecosystem is likely to evolve much slower than its individual taxonomic groups: a given group of organisms may disappear but its ecological position or niche will eventually be filled by another group. Even if one expects the network of ecological interactions to co-evolve with the individual taxa, the relative stability of functional ecology makes it a better descriptor of the ecosystem than its ever-changing constitutive organisms. In these regards, Chen and Benton's suggestion (Chen and Benton, 2012) to using a trophic model of recovery for the EPME, a crisis that possibly lasted millions of years, is praiseworthy.

Let us assume that the shape of a particular trophic level is represented in three dimensions by, for instance, the abundance, diversity and evenness of the corresponding community. The state of the ecosystem is then described by a trophic pyramid, whose shape in this three-dimensional space is not necessarily a geometric pyramid (Fig. 1). Using this ecosystem descriptor, recovery could be defined as the restoration of a pre-crisis pyramid shape. As mentioned above, Chen and Benton's bottom-up restoration model is not supported by the data and it calls for a critical reappraisal. Alternative scenarios should be explored. For instance, the recovery trajectory may have instead involved a lateral expansion of the proposed trophic pyramid through increase of both diversity and evenness at all ecological levels (Fig. 1).

Besides the practical issues of identifying the ecological role of past organisms, in particular the role of taxa without extant analogs such as conodonts and ammonoids, one may argue that the term 'recovery' *sensu stricto* implies that the post-crisis steady state (recovery state) is essentially the same as the pre-crisis state. Since the biosphere is likely to evolve drastically during major crises such as the EPME, it is not excluded that, when enough data is gathered, we have to recognize that the ecosystem did not, strictly speaking, recover from the EPME but went through what is called a critical transition: a transition from one equilibrium of the ecosystem to a new, distinct equilibrium.

This work was supported by the Swiss SNF fellowship PA00P1-145314.

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Publication Announcement

Stratigraphie von Deutschland XI: Buntsandstein. J. Lepper und H.-G. Röhlings, Editors. 2013. 657 pp., 275 figs., 45 tab., 1 pl. Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften. vol 69. ISBN 978-3-510-49229-9; € 109,00

As the 11th volume of the series 'Stratigraphy of Germany', the Buntsandstein Monograph has been issued with scientific contributions from 27 authors, mainly from the federal Geological State Surveys. The central theme of the monograph covers the stratigraphy of the German Buntsandstein (Lower Triassic) in the Germanic Basin. It is accompanied by a geoscientific historical review on Buntsandstein research since the 18th Century, followed by a palaeogeographical overview.

The main chapter on the Buntsandstein stratigraphy explains the dual stratigraphy agreed by the German Stratigraphic Commission in 2000. The lithostratigraphic component of the historical units is retained in the seven formations Calvörde, Bernburg, Volpriehausen, Detfurth, Hardegsen, Solling and Röt, whereas the regional geochronological component determines the seven Folgen s1 to s7, which have quasi-isochronous boundaries. In wide areas of the Buntsandstein, the boundaries of these formations and Folgen coincide. The synopsis reflects the combined outcome of several working groups and panels, including those of the German State Geological Surveys.

The dual classification scheme of the Buntsandstein can be correlated throughout the major part of the German section of the Buntsandstein depository. It comprises the following units that are partly separated by unconformities with variable characters:

(Muschelkalk)

Röt-Formation	s7-Folge
Solling-Formations	6-Folge (incl. the S-Unconformity)
----- H-Unconformity -----	
Hardegsen-Formation	s5-Folge
Detfurth-Formation	s4-Folge
----- D-Unconformity -----	
Volpriehausen-Formation	s3-Folge
----- V-Unconformity -----	
Bernburg-Formation	s2-Folge
Calvörde-Formation	s1-Folge

(Zechstein)

The lower boundary of the Buntsandstein Group is in the uppermost Permian Changhsingian stage. Thus a very small portion of the Buntsandstein belongs to the Permian. The upper boundary of the Buntsandstein between the Myophorien beds of the Buntsandstein and the Grenzgelbkalk of the Muschelkalk is of early Anisian age.

The "Bröckelschiefer", which was previously attributed to the lowest Buntsandstein, in fact represents a transitional facies with a saliniferous component. It has been now assigned to the Zechstein Group.

The siliclastic, fining-upward Calvörde Formation (Folge s1) begins in central basin areas with sandy strata, represented by the Heigenbrücken Sandstone or the lower Eck Conglomerate. The base of the Bernburg Formation (Folge s2) begins with a distinct increase in the proportion of sandstone, as well as oolitic

layers. In the coarser clastic proximal-marginal facies this lower boundary can not always be detected.

The Middle Buntsandstein consists of four formations. It starts with the coarse-grained Volpriehausen Sandstone, a member of the Volpriehausen Formation (Folge s3), which is recognizable towards the southern basin margin by a distinct conglomeratic sandstone. A comparable coarse-clastic base and fining upward sequence also characterizes the Detfurth and Hardegsen Formations. Epeirogenetic/taphrogenetic movements were active during sedimentation of the Folge s5 (Hardegsen Formation) and reached a climax towards its end, which lead to differential and widespread erosion of previously-deposited strata. Above this major erosional unconformity, coarse basal sediments of the Solling Formation (Folge s6) were accumulated. In contrast to older layer-cake deposits of the Middle and Lower Buntsandstein, this formation is characterized by local facies changes. It thins out towards the southern basin margin into coarse clastic sediments with multiple pedogenic intervals and extensive hiatuses.

Above the siliclastic Solling Formation (Folge s6) of the Middle Buntsandstein Subgroup there follows the partially-evaporitic Upper Buntsandstein Subgroup. Stratigraphically it is also classified as Röt Formation and Folge s7. It is subdivided into the six members Vitzenburg, Göschwitz, Glockenseck, Karsdorf, Gleina and Dornburg, and in some areas also into the four Subfolgen s7-1 to s7-4. In contrast to the basinal evaporitic facies, the marginal fluvial-lacustrine facies is dominated by a condensed siliclastic succession interrupted proximally by hiatuses and overprinted by stacked palaeosols, which prevent any detailed assignment of lithostratigraphic units.

These central achievements are accompanied by explanations of the biostratigraphic subdivision, of the magneto- and cyclostratigraphy and of the geological time scale, of the climate of the Buntsandstein time, of palaeosols in the Buntsandstein and their stratigraphic relevance, and by a status report on the sequence-, base level- and cyclostratigraphy.

Special insights on regional characteristics of the German Buntsandstein are given by 10 individual contributions. Finally, the Buntsandstein Monograph encompasses further 5 contributions on the lithology and stratigraphy in the adjacent countries of Netherlands and NE-Belgium, Denmark, Poland, NE-France, and eastern Alps.





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