Correlation of the Germanic Triassic with the international scale

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

1. Introduction

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

2. International scale and numerical ages

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

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

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

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

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

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

Figure 1: ■ Normal polarity ☐ Reversed polarity ▨ No reliable data
Lower Triassic stages, substages and numerical ages. Low latitude biostratigraphic zonations from Kozur (2003a, b). Magnetostratigraphy (M) of low latitude marine sediments after Scholger et al. (2000), Tong Jinnan (2005) and Muttoni et al. (1996). Chronostratigraphic correlations of magnetozones of Scholger et al. and Muttoni et al. modified according to text. Compiled radiometric ages in normal text, extrapolated numerical ages in italics.

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

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

The International Subcommission on Triassic Stratigra-

Ma			Stage/Substage	Ammonoid Zone/Subzone		Conodont Zone		Radiolarian Zone/Subzone	
	LATE TRIASSIC→	CARNIAN ↑	Julian ↑	Trachyceras aonoides		Gladigondolella tethydis- ↑ Paragondolella polygnathiformis I.Z.		Tetraporobrachia haeckeli ↑	
			Cordevolian	Trachyceras aon				unnamed radiolarian zone	
				Daxatina canadiensis- Frankites sutherlandi		Budurovignathus diebeli- Paragondolella polygnathiformis		Tritortis kretaensis	
237	MIDDLE TRIASSIC	LADINIAN	Longobardian	Frankites regoledanus		Budurovignathus supralongobardica		M. cochleata	T. kretaensis dispiralis
238 237.9				Protrachyceras archelaus		Budurovignathus mungoensis			Spongoserrula fluegeli Spongoserrula rarauana Pterospongus priscus
238.8				Protrachyceras gredleri		Budurovignathus hungaricus		Muelleritortis firma	
			Fassanian	Eoprotrachyceras curionii	E. recubariense	Budurovignathus truempyi		unnamed radiolarian fauna	
240.5					E. curionii	Paragondolella ? trammeri- Neogondolella aequidentata		Ladinocampe multiperforata	Ladinocampe vicentinensis
241.5 241.2		ANISIAN	Illyrian	Nevadites secedensis					
						Paragondolella ? trammeri trammeri- Paragondolella alpina			Ladinocampe annuloperforata
242.6				Reitziites reitzi	Aplococeras avisianum			Spongosilicar. italicus	O. inaequispinosus
240.4 240.5 *242.9*					Reitziites reitzi	Paragondolella alpina – Paragondolella trammeri praetrammeri			Oertlispongus primitivus
241.1				Kellnerites felsoeoersensis	K. felsoeoersensis	Neogondolella mesotriassica		Spongosilicar. transitus	Yeharaia annulata
					L. pseudohungaricum				Tiborella florida
				Paraceratites trinodosus	Asseretoc. camunum	Neogondolella constricta		Tetraspinocyrtis laevis	
					Semiornites aviticus				
					Schreyerites abichi	Paragondolella bifurcata		no dated radiolarians	
			Pelsonian	Schreyerites binodosus	S. binodosus		Nicoraella germanica- Nicoraella kockeli	Parasepsagon robustus	
					Bulogites zoldianus	Paragondolella bulgarica		Baratuna cristianensis	
				Balatonites balatonicus	Beyrichites cadoricus	N. shoshonensis			
					B. balatonicus				
			Bithynian	Agdharbandites ismidicus			Nicoraella germanica	Paroertlispongus diacanthus	
				Nicomedites osmani					
				Lenotropites caurus					
				Silberlingites muelleri					
			Aegean	Pseudokeyserlingites guexi		Neogondolella ? regalis		Hozmadia gifuensis	
247				Japonites welteri		Chiosella timorensis			

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

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

The biggest problem of the Upper Triassic international scale is currently the base of the Rhaetian although the priority is rather clear. The Rhaetian was introduced already by Gümbel (1861), long before any other stage of the Triassic, and its base has therefore the clear priority over any later assignment of faunas to the Norian. Furthermore, a stage is defined by its base and the base of the overlying stage, and not by the upper boundary of the underlying stage. Gümbel (1861) defined the Rhaetian with the Kössen Beds, and *Rhaetavicula contorta* (Portlock) was used in the 19th century in and outside the Alps (e.g. Germanic Basin) as a Rhaetian guideform. Most of the Kössen Beds begin close to the base of the *M. posthernsteini* Zone (Ga|´dzicki et al., 1979), a boundary used by Channell et al. (2003) and Muttoni et al. (2004) for their correlation of the marine Rhaetian base with the continental Newark Basin. However, as shown by Golebiowski (1986, 1990) and Krystyn (1990), in some places the Kössen Beds begin already within the *M. hernsteini* Zone. Thus, according to the priority, the base of the Rhaetian is either at the base of the *M. posthernsteini* Zone or at the base of the *M. hernsteini* Zone. According to Golebiowski (1990), *R. contorta* begins within Unit 2 of the Hochalm Member of the Kössen Formation. In Unit 2 is also the FAD of *M. posthernsteini*. A similar deep occurrence of *R. contorta* reported Ga|´dzicki et al. (1979) from the Kendelbach section. The Rhaetian of Krystyn (in Gallet et al., 2003) comprises only the upper part of the original Rhaetian and, moreover, this boundary cannot be well correlated to North America and Panthalassa.

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

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

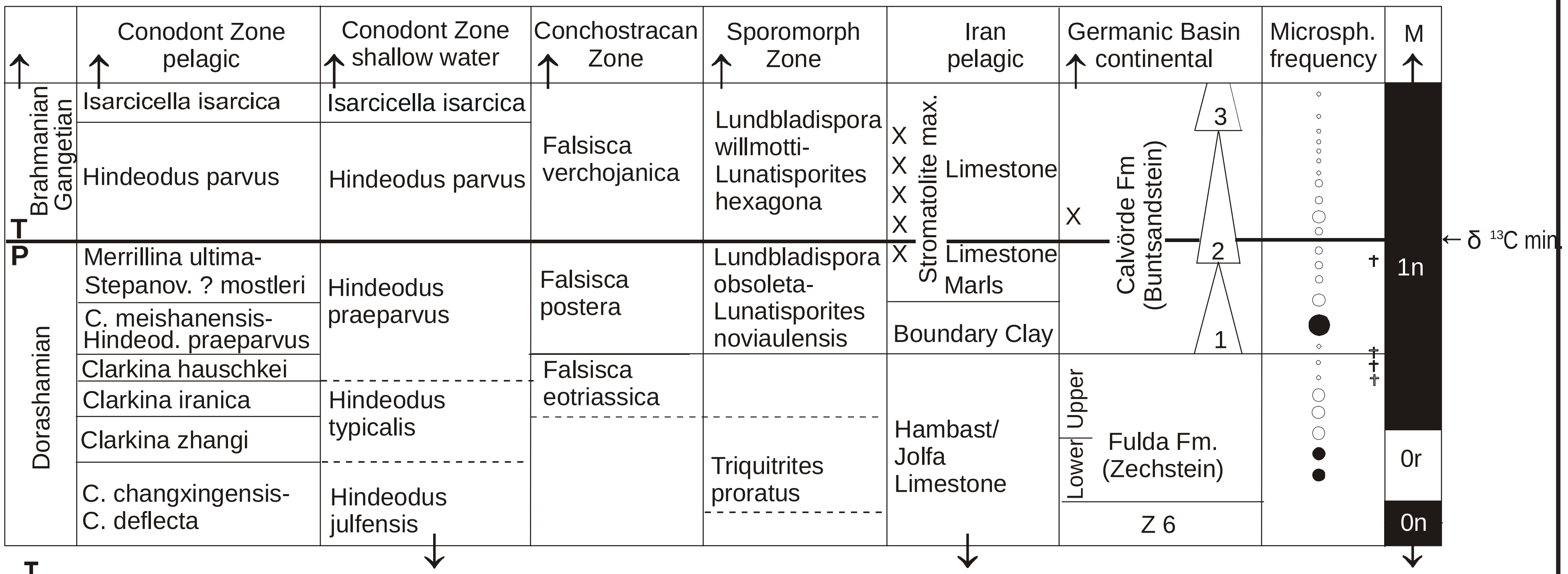
Ma		Stage/Substage		Ammonoid Zone/Subzone Standard		Conodont Zone/Subzone			
						Tethys/Western Pacific		North America	
199.6	UPPER TRIASSIC	RHAETIAN	Upper Rhaetian	Chor. marshi	Choristoceras marshi	Misikella ultima		Norigondolella sp.	
					Chor. ammonitiforme	Misikella posthernsteini	Misikella koessenensis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

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

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

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

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



$\frac{T}{P}$ = Permian-Triassic boundary. † = levels of mass extinction. Frequency of microsphaerules: ● = very common, • = common, ○ = moderately common, ◦ = rare, ∘ = very rare (sporadic occurrence).

Figure 4: Conodont, conchostracan, sporomorph zonation and microsphaerule frequency around the PTB in Iran and Germany. Not to scale. Arrows 1, 2, 3 = short eccentricity cycles.
M = Magnetostratigraphy after Szurlies (2004). max = maximum, min. = minimum

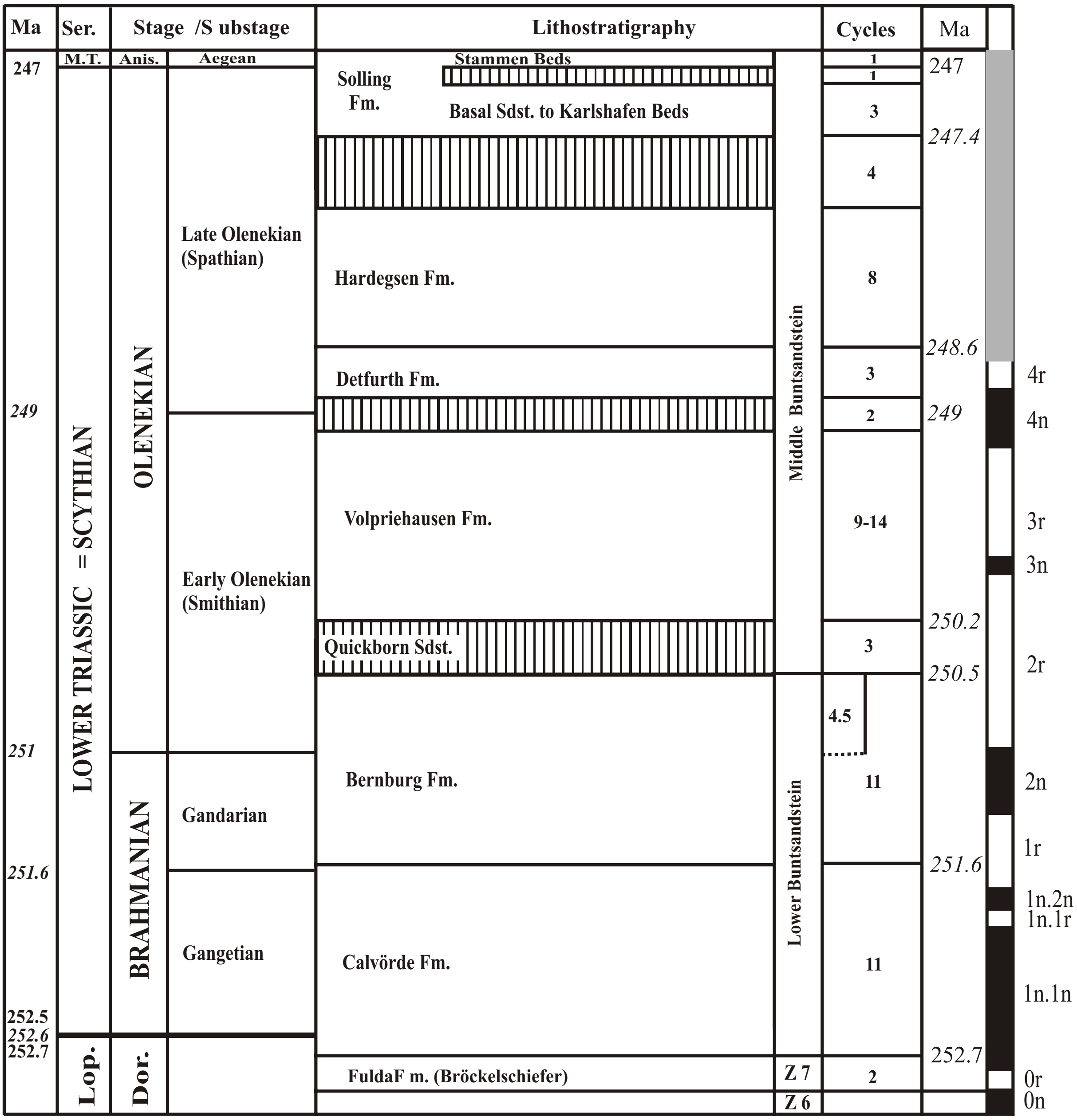


Figure 5: Correlation of the Germanic uppermost Zechstein, Lower and Middle Buntsandstein with the biostratigraphic scale, short eccentricity cycles and numerical ages. Compiled radiometric ages from Tethys in normal text, extrapolated numerical ages in italics. Chronostratigraphic correlation of magnetozones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

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

The different definition of the Rhaetian base lead to rather different estimations of the lenght of the Rhaetian (Gallet et al., 2003: 2 myrs; Channell et al., 2003, Muttoni et al., 2004: 7 or 6 myrs; Kozur, 2003a, b: 4 myrs). The palaeomagnetic results by Hounslow et al. (2004) for the Upper Triassic and lower Jurassic of St. Audrie's Bay, which allow a good correlation with the Newark Basin, favour a duration of 6 myrs for the Rhaetian.

3. Germanic Triassic

3.1. Lithostratigraphic subdivision

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

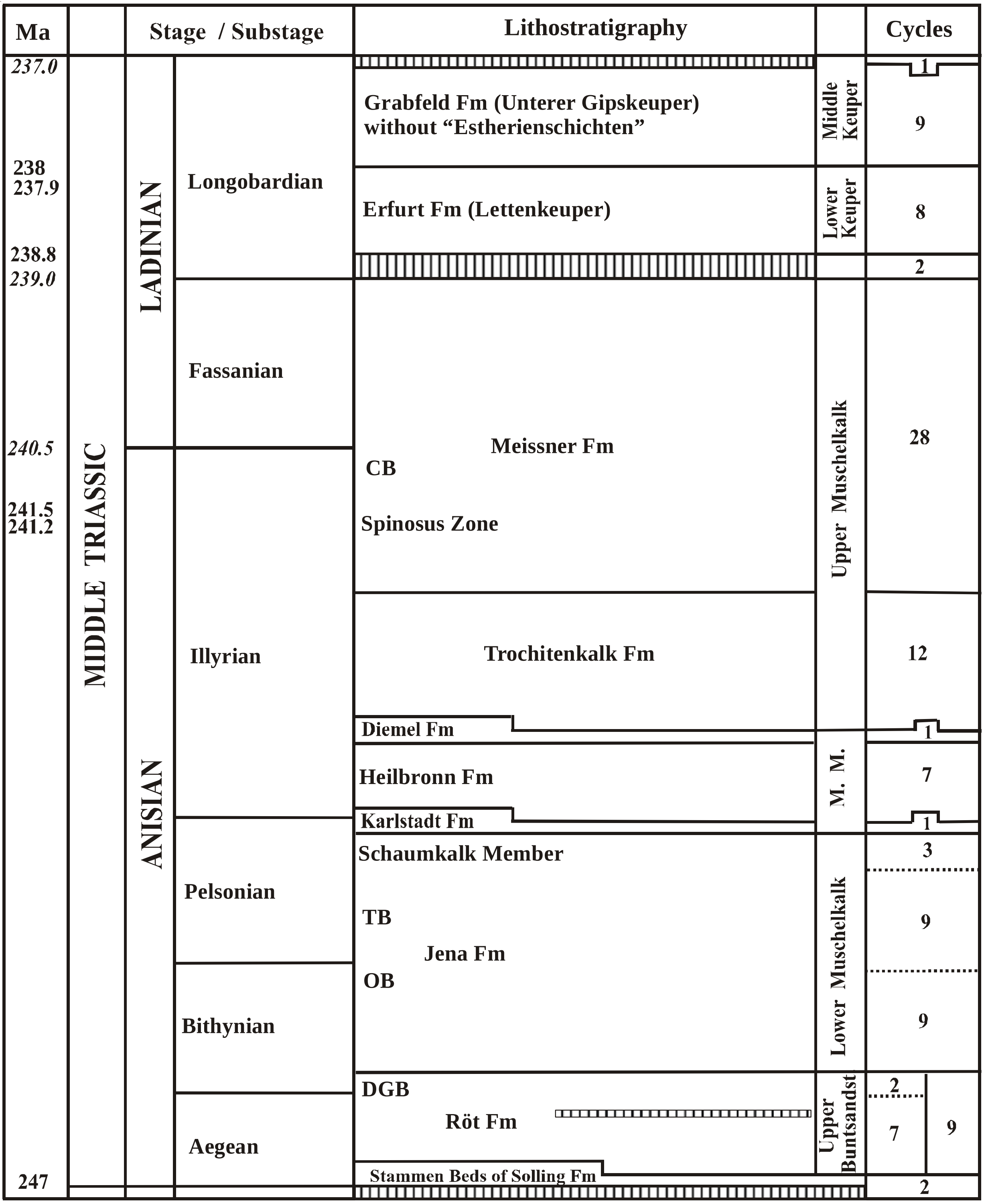


Figure 6: Correlation of the Germanic Middle Triassic with the international chronostratigraphic scale, short eccentricity cycles and radiometric numerical ages. Further details see Fig. 5.

the central basin (Hagdorn et al., 1998, Beutler, 1998) are used in Figs. 5-7. The gaps between several Buntsandstein formations are well known since Trusheim (1961a, b, 1963). Several large gaps exist also in the Keuper (Fig. 7). Their significance was especially shown by Wolburg (1969), Beutler (1979, 1995), Duchrow (1984a, b), Dittrich (1989), Aigner & Bachmann (1992), Frisch & Kockel (1999), Nitsch (2002), Nitsch et al. (2002) and Kozur & Bachmann (2003). These gaps are known since long time, but most of them were generally not shown in lithostratigrapohic subdivisions. Their duration is commonly unknown and can only be estimated from the chronostratigraphic interlock of missing intervals, when a good biostratigraphic correlation of the underlying and overlying beds with the international chronostratigraphic scale (with known numerical ages) is established.

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

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

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

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

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

Geluk & Röhling (1999) discriminated 18 cycles in the Volpriehausen Fm, Szurlies (2004b) only 9 cycles. As in the Bernburg Fm, the area investigated by Szurlies is not in the basin centre, where the number of cycles will be somewhat higher than 9. The 18 cycles of Geluk & Röhling are most likely not all short eccentricity cycles. As we have not investigated ourselves a complete section in the Solling Mountains we cannot decide on the exact number of short eccentricity cycles in the basin centre. The best estimate is that the Volpriehausen Fm has between 9 and 14 cycles and we have used 11 cycles for calculation of the numerical age (Fig. 5).

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

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

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

In the Upper Triassic the Milankovitch cyclicity is mostly

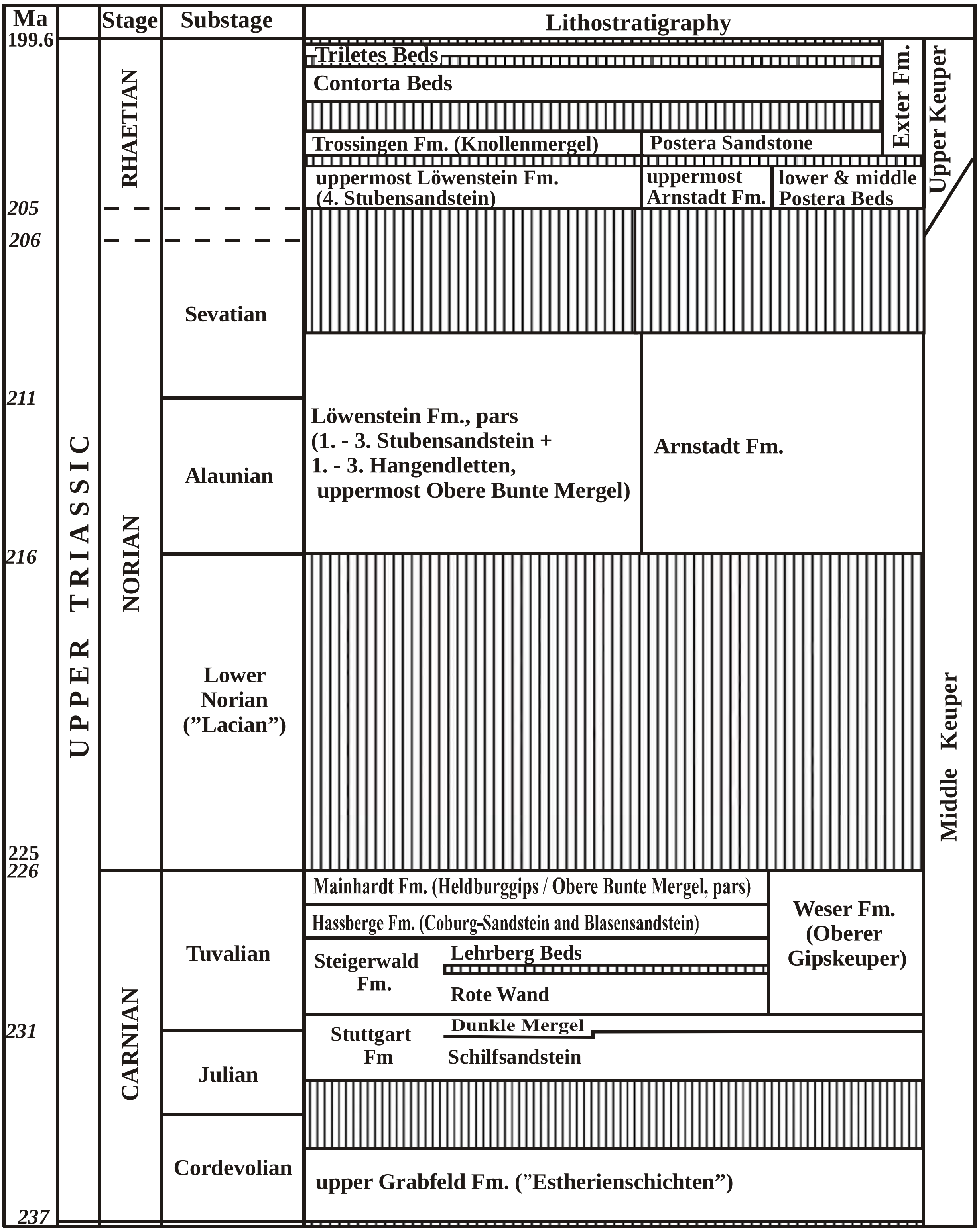


Figure 7: Correlation of the Germanic Upper Triassic with the international scale and numerical ages. Rhaetian base not yet decided upon (probably at 206 to 205 Ma). Further details see Fig. 5.

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

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

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

The Permian-Triassic boundary (PTB) was placed by

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

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

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

Menning (2000) has adopted the base of the Olenekian within the upper Bernburg Fm, which is also shown in Menning & GSC (2002). However, Szurlies (2004a, b) correlates the lower Volpriehausen Fm with the Gandarian (Dienerian). The reason for this correlation goes partly back to a correlation of respective magnetic reversals by Scholger et al. (2000) who extended the Gandarian (Dienerian) to at least the middle of the Campil Member (upper Smithian). The upper boundary of the only normal zone within the Seis Member was placed into the middle Dienerian. This, however, is close to the upper boundary of the *Claraia aurita* Zone, which corresponds roughly to the Gandarian-Smithian boundary, and the top of the normal zone is sitated less than 3 m below sample Bu 45 of Farabegoli & Perri, 1998, which contains a typical Smithian conodont fauna with *Pachycladina obliqua* Staesche). Own investigations of this section have shown that *P. obliqua* is already present in a thin limestone bed around the upper boundary of the normal interval.

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

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

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

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

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

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

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

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

After the base of the Ladinian was confirmed at the base of the *E. curionii* Zone by the ISTS, most of the Upper Muschelkalk is Anisian in age. The base of the newly defined Ladinian lies above the Cycloidesbank ˜ within the upper *enodis-laevigatus* Zone (or within the *sublaevigatus* Zone sensu Urlichs, 1991).

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

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

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