

Integrated ammonoid, conodont and radiolarian zonation of the Triassic and some remarks to Stage/Substage subdivision and the numeric age of the Triassic stages

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Abstract: An integrated Triassic ammonoid-, conodont and radiolarian zonation is presented. Ammonoid- and conodont zonations are generally well worked out and well correlatable. The radiolarian zonation is well established in the Middle Triassic, lower and middle Carnian as well as in the upper Norian and Rhaetian.

The Induan (Kiparisova & Popov, 1956) was more than 60 years later established than the Brahmanian (Mojsisovics et al., 1895) and its scope was two times drastically changed. After the latest shift of its lower boundary, the Induan get a perfect synonym of the original Brahmanian and should be therefore rejected, the more, as even its name is incorrect. The Dienerian Substage (Tozer, 1967) is a junior synonym of the Gandarian Substage (Mojsisovics et al., 1895) which should be used for priority reasons. The Gangetian Substage (Mojsisovics et al., 1895) was defined by the *Otoceras-Ophiceras* faunas of the Himalaya. The Griesbachian Substage (Tozer, 1967) included originally the Boreal *Otoceras concavum* and *O. boreale* zones which are older than the *H. parvus* Zone and belong therefore to the Permian after definition of the base of the Triassic with the base of the *H. parvus* Zone. Only the upper Griesbachian belongs to the Triassic but should not more used as Triassic substage both for priority reason and for different definition. Also its upper boundary must probably be re-defined. The biostratigraphic priority boundary for the Ladinian with the FAD of *Reitziites reitzi* is preferred against the definition with the FAD of *Eoprotrachyceras curionii*. A compromise boundary is possible (especially the FAD of *A. avisianum*), but this boundary has not the correlation potential of the two other boundaries.

The numerical age of the Triassic stages and substages is discussed.

INTRODUCTION

The ammonoid- and conodont biostratigraphy of the Triassic is well elaborated for the entire Triassic, and also the radiolarian zonation is well known for most of the Triassic. Despite of this fact only the base of the Triassic is finally defined and approved by the International Stratigraphic Commission. In the present paper the correlation of the ammonoid-, conodont- and radiolarian zonation is shown to facilitate the definition of the Triassic stages and substages. However, other fossil groups (e.g. bivalves, especially pelagic bivalves, holothurian sclerites, dasycladaceans, conchostracans, sporomorphs) are also

widely used for stratigraphic correlation within the Triassic. Many reliable data about the numerical age of the Middle Triassic are present, but nearly no reliable numerical ages are known for the Upper Triassic, except for the Triassic-Jurassic boundary. However, the numerical ages can be applied also for most of the Upper Triassic by astronomic calibration in the of the Tuvanian to Rhaetian interval in the Newark Basin (e.g., Kent & Olson, 2000). Channell et al. (2002, 2003) correlated the palaeomagnetic subdivision of the Newark Basin with the marine scale and made by this the astronomic calibration also available for the marine Tuvanian and Norian.

REMARKS TO THE PERMIAN-TRIASSIC BOUNDARY

The base of the Triassic at the FAD of *H. parvus* is the only officially confirmed boundary of the Triassic. *H. parvus* occurs both in deep-water deposits without ammonoids (e.g. Sicily, Oman), in ammonoid-bearing moderately deep deposits (e.g. South China, Kashmir, Greenland, Arctic Canada) both of the Tethyan and Boreal realms, and in shallow water deposits without ammonoids (e.g. Southern Alps, Hungary, Salt Range, western North America). For better understanding of the causes of the Permian-Triassic biotic crisis, a very precise correlation of this boundary is necessary also to continental deposits. For this reason and for evaluation of the conditions around the Permian-Triassic boundary (PTB) also sequence stratigraphic, palaeomagnetic, stable isotope and microsphaerule investigations have been carried out around the PTB, and the presence and onset of anoxia, the radiometric ages as well as the Milankovitch cycles have been investigated by many authors, especially in the Meishan GSSP (e.g. Claoue-Long et al., 1991, Yin Hongfu et al., 1992, 1996, 2001, Wang Cheng-yuan et al., 1996, Bowring et al., 1998, Jin Yugan et al., 2000, Mundil et al., 2001), but also in other sections. They yielded not only interesting data for the understanding of the Permian-Triassic crisis, but are also - in combination with biostratigraphic data - a good tool for very detailed correlation. Some remarks are necessary. Magnetostratigraphic investigations in combination with detailed biostratigraphy are very important for correlation. However, at the PTB the trend can be observed to fit the data by compilation into the PTB which was accepted or generally used at the time of publication. The Boundary Clay was generally not investigated in the Chinese section because the soft, weathered and fissile clays are unsuitable for getting

samples for reliable investigations. However, the beginning of the normal polarity close to the PTB was often shown at the base of the Boundary Clay. Only in Heller et al. (1988, 1995) was shown a short level of unknown polarity in the Boundary Clay of the Shangsi section. In the other papers the beginning of the normal polarity was shown at the base of the Boundary Clay which was formerly assumed to be the PTB. In the compilation by Jin Yugan et al. (2000) the normal polarity which is even not proven for the Boundary Clay was then assigned to the *H. parvus* Zone in the Meishan and Shangsi sections whereas the reversed polarity which was in all original papers shown for the beds below the Boundary Clay was assigned to the *C. meishanensis* Zone, from where it is nowhere in the world proven. By this again the reversal was fit into the new, internationally adopted PTB without any new data. This is especially dangerous because by this was created the impression that in the GSSP (Meishan) and in other well investigated sections at the PTB (e.g. Shangsi) the reversal coincides with the adopted PTB (FAD of *H. parvus*) what is nowhere in the world the case. This has caused in the Germanic Basin discussions to lower the PTB to the lower part of the upper Bröckelschiefer (uppermost Zechstein), where this reversal occurs.

All reliable palaeomagnetic data in the world have shown that the change from reversed to normal polarity around the PTB occurs distinctly below the PTB which lies within the lower third of a normal Zone. In the section Dorasham II on the Azerbaïdzhan side of the Araxes river the normal polarity begins 0.5 m below the top of the *Paratirolites* beds (Zakharov & Sokarev, 1991). In the Jolfa sections on the Iranian side of the Araxes river, this level corresponds to the upper *C. yini* fauna of the uppermost *C. changxingensis-C. deflecta* Zone. In the Iranian sections two further zones follow in the Permian red ammonoid-bearing limestones, the *C. iranica* Zone and the *C. praemeishanensis* Zone (missing in the Chinese intraplateau basins) before the *C. meishanensis-H. praeparvus* Zone begins at the base of the overlying Boundary Clay. Thus, the beginning of the normal polarity zone around the PTB is undoubtedly within the upper Dorashamian below the *C. meishanensis-H. praeparvus* Zone. This is confirmed in other parts of the world. In Scholger et al. (2000) the beginning of the normal polarity Zone is shown in the Bulla section (Southern Alps) distinctly below the FAD of *H. parvus*. This *H. parvus* is even not *H. parvus*, but partly a form, similar to *H. eurypyge* Nicoll, Metcalfe & Wang which begins within the uppermost Permian, partly an indeterminable juvenile form, probably of *H. praeparvus*. In the Shangsi section, the normal polarity zone begins at the base of Bed 28, Bed 27 has unknown polarity and below, Bed 26 has reversed polarity (Peng Yuanqiao et al. (2001). The FAD of *H. parvus* in this section is in Bed 30, about 4.6 m above the beginning of the normal polarity zone. In the Griesbach Creek in Arctic Canada, both the *O. concavum* and the *O. boreale* Zones have normal polarity. The FAD of *H. parvus* in the Arctic is above the *O. boreale* Zone s.s. within the *T. pascoei* Zone. Gallet et al. (2000) have shown in Abadeh (Iran) the beginning of the normal polarity zone around

the PTB at the base of the Triassic above a long gap comprising the entire *C. changxingensis-C. deflecta* Zone of the upper Dorashamian. However, the upper Dorashamian gap is not present. *C. changxingensis*, *C. deflecta*, *C. parasubcarinata* are very common in this section and the upper Dorashamian part is even longer than the lower Dorashamian *C. subcarinata* Zone. *C. yini* is present in the upper part of the *C. changxingensis-C. deflecta* Zone. Above this *C. yini* level which lies in the same position as in Meishan, two further conodont zones are present which are missing in Meishan, the *C. iranica* Zone and the *C. praemeishanensis* Zone, the latter of which contains only very few conodonts. Then the *C. meishanensis-C. praeparvus* Zone follows in the Boundary Clay as in Meishan. By dissolving of 10 kg samples in very short distances (after re-sampling every 5-10 cm in the critical interval) the FAD of *H. parvus* could be very well established at 1.10 m above the Boundary Beds, that means 1.38 m above the PTB which is indicated by Gallet et al. et the base of the Boundary Beds, as Gallet et al. (2000) did not yet use the base of the Triassic with the FAD of *H. parvus*. This may be overlooked in using the paper of Gallet et al. (2000) because in 2000 no other paper used the old PTB at the base of the Boundary Clay and the FAD of *H. parvus* is shown within the upper Boundary Clay and so it appears that the PTB is placed at the FAD of *H. parvus*. This low occurrence of *H. parvus* is not confirmed. All clayey-marly samples from the Boundary Clay have a poor *Hindeodus* fauna with *H. praeparvus* and *H. typicalis*. A thin limestone bed within the upper Boundary Clay has an unusually rich *Hindeodus* fauna which does not contain any *H. parvus*. This species may be misinterpreted for the similar *H. eurypyge*, but even this species is very rare in this bed which is dominated by *H. praeparvus*. As correctly stated by Gallet et al. (2000) no palaeomagnetic investigations were carried out from the unsuitable boundary Clay. Thus, the first sample with normal polarisation is from the first limestone above the Boundary Clay, but also this level lies 1.10 m below the base of the Triassic (see above). It is not quite clear what is the highest sample with reversed polarity in the Hambast Formation because *C. subcarinata* is shown to occur until the top of the Hambast Formation. However, this species is not present in the uppermost metres of the Hambast Formation. Nevertheless, the Gallet et al. (2000) paper is important to show that the normal event begins distinctly below the PTB despite the fact that it is shown to begin at least at the PTB. Correct evaluation of reliable palaeomagnetic data as in the Gallet et al. (2000) paper needs to revise the stratigraphic subdivision, especially the formerly used PTB. In the Germanic Basin the normal zone around the PTB begins in the lower third of the upper Bröckelschiefer (upper Fulda Formation) of the uppermost Zechstein. This fits well with the biostratigraphically defined PTB at the Oolithbank Alpha 2 of the overlying Calvörde Fm. (Kozur, 1999) of the lowermost Buntsandstein. The beginning of the normal zone in the uppermost Permian is in combination with biostratigraphic data an important tie-point for a very detailed correlation of the marine and continental Triassic.

The new palaeomagnetic data in the Meishan section by Zhu Yanming and Liu Yugan (1999) repeated by Yin Hongfu et al. (2001) are problematical for the magnetostratigraphy around the PTB. In these papers the entire Bed 27 is shown to have a reversed polarity and the normal polarity zone is shown to begin more than 5 m below the Boundary Clay. Both these features cannot be confirmed in many section outside Meishan, also not in the well dated sections of the Central and Western Tethys. Bed 27 comprises more than the upper half of the *C. meishanensis*-*H. praeparvus* Zone and the entire *H. parvus* Zone. Exactly this time interval is well investigated in several sections (Abadeh of Iran, Bulla and Siusi of Southern Alps, Griesbach Creek in Arctic Canada, Germanic Basin, see Gallet et al., 2000, Scholger et al., 2000, Ogg & Steiner, 1991, Szurlies, 2001) and nowhere a reverse interval was found in the *H. parvus* Zone and time equivalents. Moreover, in well dated marine sections, the normal Zone does not begin so deep within the upper Dorshamian *C. changxingensis*-*C. deflecta* Zone, but only in its uppermost part (Zakharov & Sokarev, 1991 in Dorasham II, Gallet et al., 2000 in Abadeh, Scholger et al., 2000 in the Southern Alps).

Stratigraphic importance has also the drop in $\delta^{13}\text{C}$ close to the PTB (e.g., Baud et al., 1989, Xu & Yan, 1993, Bowring et al., 1998, Jin Yugan et al., 2000, Yin Hongfu & Zhang Kexin, 1996, Yin Hongfu et al., 2001). In Meishan generally a first minimum is indicated within the Boundary Clay (lower part of Bed 26) and after a short increase in the uppermost part of the Boundary Clay, a second stronger drop occurs in Bed 27 with a minimum just before the base of the Triassic (e.g., Yin Hongfu & Zhang Kexin, 1996, Bowring et al., 1998). The two minima are with -5 to -6 very strong. Only Jin Yugan et al. (2000) gave an other picture with only one minimum (around -1) close to the base of the Boundary Beds (basal parts of Bed 25) and no minimum in the *H. parvus* Zone (values between 0 and $+1$). Korte, Kozur, partly with other co-authors (in press and in prep.) investigated in detail the development in $\delta^{13}\text{C}$ in several sections in Iran which are well dated by conodonts. In two sections (Abadeh and Jolfa) there are two minima, one in the Boundary Clay and an other in the uppermost *C. meishanensis*-*H. praeparvus* Zone, similar to the picture shown by Bowring et al. (1998) and Yin Hongfu et al. (2001) and other papers for Meishan, but the values for the minima do not go below -2 . However, the first minimum within the Boundary Clay may be an artifact both in Meishan, Abadeh and Jolfa. Especially in Meishan, the beds contain very few carbonate which is often dominated by carbonate from ostracod shells. This may strongly alter the values for $\delta^{13}\text{C}$. In Shahreza and Zal, where the Boundary Clay contain more CaCO_3 , there is no minimum in the Boundary Clay. In Shahreza, the values vary between $+1.27$ and $+2.12$, in Zal so far only one value at the very base of the Boundary Clay with *C. meishanensis* and *H. praeparvus* yielded a value of $+1.31$. The second minimum at the PTB or a little before can be everywhere found and it is surely not an artefact. It is characterised by a drop to values <0 within the uppermost *C. meishanensis*-*H. praeparvus* Zone, but

in pelagic sections not below -2 . The minimum lies either a little below the PTB or at the PTB. After a slight increase in the upper *H. parvus* Zone, there is generally a second drop within the lower *I. isarcica* Zone.

The minimum of the $\delta^{13}\text{C}$ values in the uppermost *C. meishanensis*-*H. praeparvus* Zone immediately below the PTB or at the PTB is a good stratigraphic marker. In the Shangsi section this minimum was assumed to be somewhat higher, in Bed 30 (Baud et al., 1989). However, after re-study of the conodonts in this section by Nicoll et al. (2002), the FAD of *H. parvus* was found in Bed 30, indicating that the PTB was drawn in this section too low. Also in this section the first minimum in the Boundary Clay is not present. The re-evaluation of the conodont stratigraphy has shown in this section the outstanding stratigraphic importance of the $\delta^{13}\text{C}$ minimum around the PTB.

First testing of the application of the $\delta^{13}\text{C}$ minimum for determination of the continental PTB were successful. Dr. Ch. Korte (Bochum) determined $\delta^{13}\text{C}_{\text{carb}}$ from the Oolite Bank Alpha 1 (-2.22 to -2.65 in different levels) which is a time equivalent of the lower part of the Boundary Clay, and from the Oolite Bank Alpha 2 (-4.00 to -4.22) which is situated around the PTB. A stromatolitic limestone bed, about 1.35 m above the base of Oolite Bank Alpha 2 yielded the value -3.81 . Despite the fact that only 3 levels of limestones are present in this interval, the Oolite Bank Alpha 2 represents the minimum in $\delta^{13}\text{C}$ because just in this level is the minimum in $\delta^{13}\text{C}_{\text{org}}$ (Prof. Dr. H.J. Hansen, pers. comm.).

A further tool for stratigraphic correlation around the PTB is a horizon with rich occurrences of microsphaerules. They were first reported from the Meishan section and other sections in China (e.g., He Jinwen, 1985, Yin Hongfu et al., 1992, Yin Hongfu & Zhang Kexin, 1996), but we have found them also in the Abadeh, Jolfa, Shahreza and Zal sections of Central and NW Iran and in the Bükk Mts. of Hungary. The interval with increased frequency of microsphaerules occur from the uppermost *C. changxingensis*-*C. deflecta* Zone (horizon with *C. yini*) until the *H. parvus* Zone. The richest occurrences are derived from the lower, but not lowermost Boundary Clay. Such microsphaerules were also found in continental beds of the Germanic Basin (Bachmann & Kozur, 2002) with a distinct maximum from the Oolite Bank Alpha 1 up to grey clays about 1.5 m above the base of Oolite Bank Alpha 1. This indicates that the base of the Buntsandstein which is characterised by a distinct climatic change from a dry to wet climate coincides roughly with the base of the Boundary Clay.

By consideration of different tools for stratigraphic correlation, a rather detailed correlation between the marine and continental Triassic around the PTB is possible. In the continental deposits of the Germanic Basin, the Milankovitch cycles are well recognisable. From the beginning of the normal zone below the PTB in the lower third of the upper Fulda Fm. until the PTB in the Germanic Basin at the Oolite Bank Alpha 2 two $\sim 100\text{kyr}$ eccentricity cycles can be discriminated. From the base of

the Buntsandstein (corresponding to the base of the Boundary Clay) up to the PTB only one ~100kyr eccentricity cycle and one 20 kyr precession cycle is present. This is very important for dating of the PTB from radiometric data from Bed 25 (lower Boundary Clay) in the Meishan section (see below).

REMARKS TO THE NUMERICAL AGE OF THE PERMIAN-TRIASSIC BOUNDARY

Two sets of radiometric data were published recently for the PTB at Meishan. Bowring and others (1998) reported 251.4 Ma \pm 0.3 for Bed 25 of Meishan (lower *C. meishanensis*-*H. praeparvus* Zone) and 250.7 Ma \pm 0.3 for Bed 28 (basal *I. isarcica* Zone). From these data an age of the PTB of about 251 Ma can be concluded. Mundil and others (2001), on the other hand, reported values slightly older than 254 Ma for Bed 25 and 252.5 Ma \pm 0.3 for Bed 28, concluding 253 Ma for the PTB. There are problems with both sets. 251 Ma for the PTB seems to be inconsistent with the 247 Ma for the base of Anisian (Lehrmann et al., 2002). 4 myrs for the entire Scythian (Brahmanian + Olenekian stages) is too short considering the Milankovitch cycles of the Germanic Basin as well as the number of biozones and sedimentation rates in the marine Lower Triassic. Approximately 253 Ma for the PTB (Mundil et al., 2001) is a reliable value, when 247 Ma is used for the base of the Anisian. However, Mundil and others mentioned that > 254 Ma for Bed 25 is a very weak value. The time span from the base of Bed 25 to the base of the Triassic (PTB) cannot be >1 myrs. As shown by correlation with the Germanic Basin (Bachmann & Kozur 2002), this interval has a duration of about 0.12 myrs (see above). A solution to this problem may be found in the basic data of Bowring and others (1998). They recorded two data clusters in Bed 25, one at 251.4 Ma \pm 0.3 and one at 252.7 Ma \pm 0.4. They rejected the older cluster as inherited and used the younger one which fit in their other data. But as correctly stated by Mundil and others (2001), the older data cluster inferred an equally plausible age assignment. If we use 252.7 Ma for Bed 25 and 0.12 myrs for the duration of the *C. meishanensis*-*H. praeparvus* Zone (interval between the event boundary and the biostratigraphic PTB), we get an age of 252.6 Ma for the PTB, close to the value of 253 Ma (Mundil et al., 2001), and a duration of about 100 kyrs for the *H. parvus* Zone, as 252.5 Ma for Bed 28 (Mundil et al., 2001) corresponds to the base of the overlying *I. isarcica* Zone. If we use this estimated PTB of 252.6 Ma and the 247 Ma for the base of Anisian (Lehrmann et al., 2002), we get a duration of 5.6 myrs for the Lower Triassic. This is nearly identical with the Scythian duration estimated by astronomic calibration of the Brahmanian to Lower Olenekian and estimation of the Upper Olenekian (see below).

LOWER TRIASSIC STAGE/SUBSTAGE SUBDIVISION

Most of the Triassic stages were established by Mojsisovics et al. (1895). Only the Rhaetian Stage was introduced already by Guembel (1859, 1861) and over-

taken by Mojsisovics et al. (1895). The stage subdivision by Mojsisovics et al. (1895) was generally overtaken for Middle and Upper Triassic and only the Juvavic Stage was re-named into the Norian Stage originally introduced for the Ladinian Stage which was named already by Bittner (1892). However, the Lower Triassic stages were not used, but the Scythian Series, also introduced by Mojsisovics et al. (1895) was regarded as the Scythian Stage for more than 50 years. This was rather well founded as even a Scythian Stage would belong to the shortest stages of the Triassic (compare the duration of the Lower Triassic with the other stages, see figs 1-3). However, in the former Soviet Union and in North America prevailed for long time the opinion that one stage for the Lower Triassic would have a too long duration. Unfortunately, the paper of Mojsisovics et al. (1895) was not taken into consideration and thus not the Lower Triassic stages established by Mojsisovics et al. (1895) were used but new stage names were introduced, the Induan and Olenekian by Kiparisova & Popov (1956) and the Griesbachian, Dienerian, Smithian and Spathian by Tozer (1965). This was the more curious as the Brahmanian Stage, the lowermost stage of the Triassic (introduced by Mojsisovics et al., 1895) is the originally best defined stage of the Triassic.

The Induan and Olenekian were originally defined by Kiparisova & Popov (1956) with faunal successions in the Boreal realm, but the Salt Range was taken as the type of the Induan which got its name from the Indus river. By this even the name of the Induan is incorrect, the correct name would be Indusian. The base of the Induan was defined by the base of the Boreal *Otoceras* faunas that means with the base of later established *O. concavum* Zone which is not present in the Salt Range (gap). The top of the Induan was placed in the type area Salt Range at the top of the Ceratite Sandstone which was erroneously correlated with pre-Olenekian Boreal faunas. However, the ammonoid fauna of the Ceratite Sandstone comprises the largest part of the Lower Olenekian (Smithian Substage). This was recognised by Kiparisova & Popov (1964), and they who excluded the Ceratite Sandstone from the Olenekian. This was the first big change in the scope of the Induan.

By the final definition of the base of the Triassic (finally ratified by the IUGS Executive Committee in March, 2001) with the first appearance datum (FAD) of *Hindeodus parvus*, first proposed by Kozur & Pjatakova (1976) and later followed by Yin Hongfu et al. (1988), the lower part of the Induan became Permian by definition. After this second revision of the Induan, a large part of the original Induan belongs now to the Permian and Lower Olenekian. After these two big revisions, it corresponds now perfectly to the Brahmanian established by Mojsisovics et al. (1895) more than 60 years before the introduction of the Induan. Therefore, there is no reason, furthermore to use the "remnant Induan" instead of the Brahmanian which has the priority and must not be re-defined.

The Brahmanian was defined by Mojsisovics et al. (1895) by the *Otoceras*-*Ophiceras* faunas of the Himalaya (Gangetic Substage) and the Lower Ceratite Limestone

My	Stage/Substage	Ammonoid Zone	Conodont Zone	Radiolarian Zone	
247	OLENEKIAN	Neopanoceras haugi	Chiosella gondolelloides	Hozmadia ozawai	
		Prohungerites-Subcolumbites	Triassospathodus sosioensis		
		Procolumbites	Triassospathodus triangularis		
		Columbites parisianus	Triassospathodus homeri		
		Tirolites cassianus	Ictiospathodus collinsoni		
	250,7	Early Olenekian (Smithian)	Anasibirites kingianus	Triassospathodus hungaricus	Radiolarians unknown
			Flemingites flemingianus	Neospathodus waageni-Scythogondolella milleri	
		Gandarian (Dienerian)	Prionolobus rotundatus	N. waageni-Scythogond. meeki	Stigmospaerostylus turkensis
			Pleurogyromites planidorsatus	Chengyuania nepalensis	
				Neospathodus dieneri	
252,5	GANGETIAN	Ophiceras tibeticum	Sweetospathodus kummeli	Radiolarians unknown	
		Otoceras woodwardi-Ophiceras bandoi	Clarkina postcarinata		
		Otoceras fissicellatum	H. postparvus- H. carinata		
			H. sosioensis		
			Isarcicella isarcica		
	BRAHMANIAN (=INDUAN)	Otoceras woodwardi-Ophiceras bandoi	Hindeodus parvus	Radiolarians unknown	
		Otoceras fissicellatum			
			T. pascoei		
252,6	UPPER DORASHAMIAN	Hypoph. changxingense	Clarkina meishanensis - H. praeparvus	Radiolarians unknown	
		Pleuronodoc. occidentale	Clarkina praemeishanensis		
252,7	LOPING				

Figure 1: Lower Triassic stages, substages, ammonoid, conodont and radiolarian zonations

and Ceratite Marls (Gandarian Substage) of the Salt Range. The *Otoceras-Ophiceras* faunas of the Himalaya are younger than the Boreal *Otoceras* faunas (Krystyn & Orchard, 1996, Kozur, 1996, 1998a, b). They begin with the *H. parvus* Zone. As the biostratigraphic base of the Triassic was originally not defined by the FAD of the genus

Otoceras, but with the FAD of *O. woodwardi* (*Otoceras* was in the late 19th Century used in a much wider sense than today, including Dzhulfian and Dorashamian Otocerataceans), the FAD of *H. parvus* is close to the original base of the Triassic at the base of the *O. woodwardi* Zone. The Boreal *O. concavum* Zone and *O. boreale* Zone

s.s. do not contain *H. parvus*, but *H. praeparvus* and *H. typicalis*. *H. parvus* begins in the uppermost Boreal *Otoceras* faunas within the *T. pascoei* Zone (Kozur, 1998a, b). Thus, in contrast to the Induan the lower boundary of the Brahmanian must not be changed. The same is true for the upper boundary. The Ceratite Marls have a rich conodont fauna of the upper *N. dieneri* Zone (*N. cristagalli* Zone sensu Sweet, 1970). The overlying Ceratite Sandstone belongs to the Lower Olenekian *Flemingites flemingianus* ammonoid zone and was never included into the Brahmanian, in contrast to the original Induan which was defined by inclusion of the Ceratite Sandstone (*Flemingites flemingianus* Zone).

The Gangetian can be used as lowermost substage of the Triassic without change of its original scope (see above). The base of the Himalayan *Otoceras-Ophiceras* faunas coincides with the base of the *H. parvus* Zone (Krystyn & Orchard, 1996, Kozur, 1998a, b). The following Gandarian begins with the *Sweetospathodus kummeli* Zone. By this the Gangetian comprises the lowermost substage of the Triassic in the present scope. When the term Griesbachian (introduced 70 years later than the Gangetian) is used for the lowermost substage of the Triassic, this would require a total revision of the Griesbachian by removing of the entire lower half of this substage which belongs to the Permian according to the definition of the base of the Triassic. For this reason the term Gangetian is preferred against a totally revised Griesbachian which has, moreover, not the priority. The Ellesmerian Substage (Kozur, 1972) has the same scope as the Gangetian, but is a junior synonym of the Gangetian.

The Gandarian in its original definition begins with the *Gyronites* ammonoid faunas of the Lower Ceratite Limestone which contain at its base conodonts of the *Sweetospathodus kummeli* Zone, which marks the base of the upper substage of the Brahmanian. Tozer (1978, p. 32) pointed out that "Gandarian is an approximate synonym of Dienerian." It has to be pointed out that the Dienerian is the junior synonym of Gandarian which was established 70 years before the Dienerian. In the interest of stability in the stratigraphic nomenclature, such clear priority should be in all cases regarded in favour of the senior synonym, in this case in favour of the Gandarian. Moreover, the Gandarian was established on the Perigondwana margin of the Tethys, the Dienerian in the Boreal realm. If possible (priority, well defined and applicable), stages/substages established in the highly diverse Tethyan faunas should be preferred against stages/substages established in low diversity Boreal faunas. The Gandarian base in the Tethys is best to place at the base of the *S. kummeli* Zone in the Salt Range (base of the *P. planidorsatus* Zone s.s.) in agreement with the original definition of the Gandarian. This coincides with the Dienerian base in the Boreal realm where the Dienerian was originally defined by the boundary between the *Bukkenites strigatus* Zone and the *Proptychites candidus* Zone. According to Orchard & Tozer (1997) *S. kummeli* occurs in the *P. candidus* Zone of the Arctic Canada and begins roughly at the base of this zone. *Bukkenites* from the underlying *B. strigatus* Zone occurs also within the

Perigondwanan Tethyan *Ophiceras* faunas, but only in condensed deposits (Krystyn & Orchard, 1996). However, *S. kummeli* does not occur in this level and, therefore, it should not yet present in the Perigondwanan *Bukkenites* faunas. An other Dienerian base is used by Krystyn & Orchard (1996). They assigned their ammonoid association between the upper *O. tibeticum* Zone (with *Bukkenites*) and the *P. planidorsatus* Zone s.s. with *S. kummeli* into the lowermost Dienerian. This Dienerian base is lower than the Boreal type Dienerian base. The ammonoid fauna of association 5 is very poor, no specimen can be determined in species level and in 4 out of 5 genera even the generic determination is questionable. The conodont fauna of this level with last *H. typicalis* is a typical Gangetian fauna and *S. kummeli* is not yet present. According to its conodont fauna (Krystyn & Orchard), this horizon should belong to the Gangetian, also in the interest of the correlation with the Boreal fauna.

The base of the Olenekian is well defined by the base of the *Flemingites flemingianus* ammonoid Zone. In this level the ancestor form of *Paragondolella* Mosher begins with *Chengyuania nepalensis* (Kozur & Mostler) in pelagic deposits, a little later is the FAD of *Neospathodus waageni*. In shallow water deposits the characteristic *Pachycladina* begins in this level and *Claraia* disappeared. This boundary can be well correlated with continental deposits by conchostracans which occur in brackish intercalations of marine beds, e.g. in the Werfen Beds of Hungary and in marine sections with ammonoids in northeastern Siberia. At the base of then Olenekian, the characteristic *Cornia germari* fauna (spined conchostracans) with *Estheriella* (radially ribbed conchostracans) disappeared and the *Magnietheria subcircularis-M. truempyi* fauna begins. *M. truempyi* was found in Madagascar at the base of the Olenekian between *Claraia*-bearing beds below and the *F. flemingianus* beds above. As in the entire Brahmanian of the Germanic Basin the Milankovitch cycles are well recognisable and no distinct gaps are present in the basin facies of the Germanic Basin, the duration of the Brahmanian can be well fixed (see below).

Remarks to the numerical age of the Lower Triassic stages

Radiometric data are only present around the PTB and from the base of the Anisian. As pointed out above, a duration of 5.6 myrs is assumed for the Lower Triassic. the numeric age of the Lower Triassic stages can be only estimated by investigation of the Milankovitch cycles. As they can be much better recognised in continental beds, the astronomic calibration was carried out in the continental sequence of the Germanic Basin. The correlation of the continental beds in the Germanic Basin with the marine scale was mainly carried out by conchostracans (e.g., Kozur, 1993, 1999, Kozur & Mock, 1993). During the Brahmanian, the conchostracan zonation is as detailed as the ammonoid- and conodont zonations in pelagic marine deposits (Kozur & Seidel, 1983). The Brahmanian-Olenekian boundary marks the most pronounced faunal turnover in the conchostracan faunas. The biostratigraphic control for the Milankovitch cycles in the Germanic Ba-

sin is very good.

Szurlies (2001) subdivided the Calvörde Formation, the lowermost formation of the Germanic Buntsandstein, into 10 cycles, interpreted as ~100 kyrs Milankovitch eccentricity cycles. However, his cycle 4 comprises two ~100 kyrs cycles, which means 11 Milankovitch eccentricity cycles are present in the Calvörde Fm. The biostratigraphic PTB at Oolite Alpha 2 lies within the lowermost part of cycle 2, only one precession cycle above its base, leaving about 10 cycles (approximately 1 myrs) for the Brahmanian part of the Calvörde Fm. The overlying Bernburg Fm. comprises up to 11 eccentricity cycles in the basin centre (borehole Halle-Süd, Solling Mts., in the latter area found by studies of Kozur and Lepper, in prep.). Cycle 11 corresponds to the well dated Lower Olenekian *Magnietheria truempyi* and the lowermost part of the *M. quellaensis-L. radzinskii* conchostracan zones. This number is between the view of Szurlies (2001), who recognised maximally 10 cycles (but had not investigated any section with the two youngest conchostracan zones of the Bernburg Fm.), and that of Röhlings (1993), who discriminated maximally 14 cycles in the basin centre (including Solling Mts.) which are apparently not all eccentricity cycles. The youngest Brahmanian faunas occur in cycle 9, resulting in $1.0 + 0.9 = 1.9$ myrs for the total Brahmanian. By this the base of the Olenekian is estimated with 250.7 Ma.

The base of the Olenekian (base of the *M. ? subcircularis* Zone) is close to the base of cycle 10, and is marked by the most prominent change within the Lower Triassic conchostracan faunas (Kozur & Seidel, 1983). Thus, the two upper cycles of the Bernburg Fm. belong to the Lower Olenekian (Smithian). The overlying Volpriehausen Formation has a typical Smithian conchostracan fauna which is well correlated with the marine scale (Kozur & Mock, 1993). As in the uppermost Volpriehausen Fm. the first Upper Olenekian (Spathian) element (*M. deverta*) appears in the conchostracan fauna, and the upper part of the first cycle in the overlying Detfurth Fm. has already a rich Spathian conchostracan fauna, the top of the Smithian can be assigned to the top of the Volpriehausen Fm. It consists of up to 14 cycles (about 1.4 myrs). Thus, 1.6 myrs of the Smithian are represented by sediments in the Germanic Basin. However, there is a short gap between the Bernburg and Volpriehausen Formations. The gap had a short duration as no faunal change can be observed between the topmost Bernburg Fm. and the Volpriehausen Sandstone. Both belong to the *M. quellaensis-L. radzinskii* Zone. Thus, the gap is much shorter than one conchostracan zone which have an average duration of about 400 kyrs during the Brahmanian-Smithian interval. Thus, we assign approximately 200 kyrs for the gap between the Bernburg and Volpriehausen Formations (including the local Quickborn Sandstone which partly filled the gap in the centre of the Germanic Basin). Thus, we get a total duration of the Smithian of $1.6 + 0.2 = 1.8$ myrs. From this results a numeric age of 248.9 Ma for the base of the Upper Olenekian (Spathian).

In the Upper Olenekian (Spathian) of the Germanic Basin there are several gaps, which currently prevent a time es-

timation based on Milankovitch cycles. However, it can be concluded from marine sections that the Spathian has a similar duration as the Smithian or it is a little longer. This is in good agreement with the above mentioned estimation of 248.9 Ma for the base of the Spathian which gives a duration of 1.9 myrs for the Spathian using the 247 Ma for the base of the Anisian.

MIDDLE TRIASSIC – THE PROBLEM OF THE ANISIAN-LADINIAN BOUNDARY

As shown in the Veszprém conference 2002, there is a good agreement between most ammonoid workers and all conodont workers to place the base of the Anisian at the base of the *Chiosella timorensis* Zone. *C. timorensis* (Nogami) has evolved in a phylomorphogenetic cline from *C. gondolelloides* (Bender). This cline can be traced in all pelagic deposits of the Tethys, the Circum-Pacific realm and North America. At this boundary distinct changes can be observed also in other fossil groups, e.g. holothurian sclerites which allow correlation into slightly hypersaline deposits, such as in the Germanic Basin. 247 Ma were reported for the base of the Anisian (Lehrmann et al., 2002).

An open question is the Anisian-Ladinian boundary, the problem has to be solved by agreement. From the *P. trinodosus* Zone up to the lower *E. curionii* Zone the conodonts are in a phase of slow phylomorphogenetic changes which does not allow a very detailed stratigraphic subdivision by conodonts of this level. Moreover, some of the stratigraphically important forms have an occurrence restricted to Tethys or Tethys and western Panthalassa, and do not occur in North America and by this beside the relatively low stratigraphic value of conodonts for this stratigraphic interval also correlation problems with conodonts are present. Only ammonoids and radiolarians of the Anisian-Ladinian boundary level can be well used for a high-resolution biostratigraphy. For ammonoids, this is also the case for many other stratigraphic levels within the Triassic. Radiolarians have in the upper Anisian-Ladinian interval their strongest stratigraphic resolution power in the entire Mesozoic. The reason for this is the recovery pattern after the Permian-Triassic biotic crisis. Radiolarians belong to the strongest affected fossil groups. They almost disappeared at the PTB and only very few radiolarians are present from the uppermost Dorashamian *C. meishanensis-H. praeparvus* Zone until the top of the Smithian. During this time even a world-wide radiolarite gap is present, an unique feature since the Ordovician. For unknown reasons, the recovery of the radiolarians began very late, contemporaneous with the beginning of the recovery of the warm water benthos and of the land plant communities, whereas nekton and nektobenthonic animals, like ammonoids and conodonts recovered fast, after the short *H. parvus* conodont Zone (after about 100kyrs). The recovery of the radiolarians began at the base of the Late Olenekian (base of the Spathian), but the diversity remained low. However, in Panthalassa the first radiolarites re-appeared in the Spathian. The radiolarian diversity remained low during the lower Anisian and be-

My	Stage/Substage	Ammonoite Zone/Subzone	Conodont Zone	Radiolarian Zone/Subzone
237	Julian ?	Trachyceras acroides Trachyceras aon	Cladigondolella tethydis? Paragondolella polygnathiformis I.Z.	Tetraponobrachia haeckeli ? unnamed radiolarian zone
238 237.9	Cordevolian	Daxalina canadiensis- Frankites suherlandi	Budurovignathus diebeli- Paragondolella polygnathiformis	Tritortis kretaensis
238.8	Longobardian	Frankites regoledanus	Budurovignathus supralongobardica	T. kretaensis dispiralis Spongoseriula fluegeli Spongoseriula rarauana Pterospongius priscus
239.5	Fassanian	Protrachyceras archelaus	Budurovignathus mungoensis	M. cochleata
241.2	Ladinian base (base of the reizi or of the curionii zones) not decided by the ISTS	Protrachyceras grelleri Eoprotrachyceras curionii Nevadites secedensis	Budurovignathus hungaricus Budurovignathus truempyi Paragondolella ? trammeri- Neogondolella aquidentata	Muellerfortis firma unnamed radiolarian fauna
240.4 240.5 241 241.1	Illyrian	Reizites reizi K. felsceoerensis L. pseudohungaricum Asseretoc. camunum Paraceratites trinodosus	Paragondolella alpina Paragondolella alpina Paragondolella alpina — Paragondolella trammeri praetrammeri Neogondolella mesotriassica Neogondolella constricta	Ladinocampe vicentinensis Ladinocampe annuliferolata O. inaequispinosus Spongosilicar. italicus Spongosilicar. transitus Tetrapsinocyrtis laevis
	Pelsonian	Schreyerites binodosus Balatonites balatonicus Nevadiscultites taylori	Paragondolella bifurcata Nicoeraella germanica- Nicoeraella kockeli	no dated radiolarians Parasepsagon robustus Baratuna cristianensis Paoertlispongius diacanthus
	Bithynian	Agdharbandites ismidicus Nicomedites osmani Lenotropites caurus Silberfingites muelleri	Paragondolella bulgarica	Hozmadia gifuensis
247	Aegean	Pseudokeyserlingites guexi Japonites welleri	Neogondolella ? regalis Chiosella timorensis	Stigmospaerostylus ? phattalungensis

Figure 2: Middle Triassic stages, substages, ammonoid, conodont and radiolarian zonations

came distinctly higher during the Pelsonian. In the Illyrian an explosive radiation of radiolarian taxa began. In the same time, radiolarites became again widespread throughout the world. This explosive radiation of radiolarians continued from the *P. trinodosus* Zone to the *A. avisanum* Zone. The radiation of radiolarian taxa became much slower during the *N. secedensis* Zone and was very low in the *E. curionii* Zone. A second phase of rapid radiation occurred throughout the Longobardian and, to a somewhat lower rate, in the Cordevolian. During the two phases of explosive radiation very much, partly very short-living radiolarians appeared and also the extinction rate was

rather high. Thus, a very detailed biostratigraphic subdivision can be made with radiolarians, as detailed as with ammonoids and much more detailed than with conodonts of this stratigraphic level. By this and the fact that in the Middle Triassic radiolarites are very widely distributed in the Tethys and in Panthalassa, in which ammonoids will be never found and conodonts occur only sporadically, the upper Anisian and Ladinian radiolarians have an outstanding stratigraphic importance. For priority and traditional reasons, the upper Anisian and Ladinian stratigraphic units, among them the Anisian-Ladinian boundary should be defined by ammonoids, but the radiolarians should be

taken into consideration very seriously. For this reason, ammonoids and radiolarians should be common in a GSSP candidate for the base of the Ladinian.

Presently two levels for the boundary are discussed, the base of the *Reitziites reitzi* Zone s.s. (FAD of *R. reitzi*) and the base of the *Eoprotrachyceras curionii* Zone. Brack et al. (2003) summarized the advantages for using the FAD of base of the *E. curionii* Zone in the Bagolino composite section (Southern Alps, Northern Italy) as GSSP for the base of the Ladinian and Vörös et al. (2003) did the same for using the FAD of *R. reitzi* (base of the *R. reitzi* Zone s.s.) in the Felsöör section (Balaton Highland, Hungary) as the base of the Ladinian. Both sections have advantages and some disadvantages of different degree. The advantage of the Bagolino section is that throughout the section rich ammonoid faunas and moderately rich conodont faunas are present. The conodonts are not especially well suitable for definition and correlation of the Anisian-Ladinian boundary level, but the ammonoids are most important. The FAD of *Eoprotrachyceras curionii* is said by all ammonoid workers as a marker which can be traced throughout the Tethys and low latitude ammonoid faunas of western North America in contrast to the FAD of *Reitziites reitzi* which has a much more restricted occurrence. However, this is not correct. *R. reitzi* occurs from the western Tethys until Japan. *E. curionii* is only known from the western Tethys, especially from the Southern Alps, and it was not yet reported east of Greece. For good reasons, stages are defined in GSSP with the FAD of a species which is requested to have a wide regional distribution. This is not the case for *E. curionii*. In North America two other species occur, *E. subasperum* in Nevada and *E. matutinum* in British Columbia (Tozer, 1994). It is not very probable that all these three species begin exactly in the same level, at least, it cannot be proven. Neither conodonts nor radiolarians show any change at the FAD of *E. curionii*. Thus, really, *E. curionii* is a very restricted species, much more restricted than *R. reitzi*.

The disadvantages of Bagolino and the *E. curionii* datum are that no radiolarians are present and that the section is thermally altered. No direct ammonoid-radiolarian correlation can be carried out in the Bagolino section, a serious disadvantage, if we regard the above mentioned importance of radiolarians in this stratigraphic level (see above). The thermal alteration (CAI = 4-5) prevent any reliable magnetostratigraphic investigation in this section. Moreover, also stable isotope investigations are not so easy to carry out in thermally altered sections and there is a danger that the data may be not reliable. Thus, the physico-chemical stratigraphic investigations can be either not carried out (magnetostratigraphy) in the Bagolino section or they must be regarded with reserve (stable isotope investigations). Thermally altered sections should not be chosen as GSSP, if alternative, unaltered sections are present. Physico-chemical stratigraphic data in combination with biostratigraphic data will be more and more important in future investigations and it is therefore not good to choose a GSSP with thermally altered beds in which also in future such investigations can partly not carried out, partly cannot be carried out under optimal conditions.

In this connection a discussion in Veszprém was made that the high thermal alteration of the Bagolino section is not a serious disadvantage because a good correlation with unaltered sections can be made, where palaeomagnetic investigations can be carried out. This is not an appropriate discussion of the advantages and disadvantages of a GSSP candidate. By this kind of argumentation any section can be elevated in the rank of a very suitable GSSP without disadvantages. For instance, the disadvantage of the Felsöör section that only very few conodonts are present around the FAD of *R. reitzi* would be no longer a disadvantage because the FAD of *R. reitzi* can be well correlated with sections in the Southern Alps which contain moderately common conodonts in this level. The above discussion is the more inappropriate as there is an other discussion that the palaeomagnetic data of Felsöör cannot be used because they were made only from limestone intercalations in tuffs (see below). In the end, this lead to a picture that Bagolino (in which palaeomagnetic investigations cannot be carried out because of thermal alteration) is better suitable for palaeomagnetic correlations (through other sections) than Felsöör (where such investigations can be carried out, CAI = 1).

A more formal disadvantage of the proposal to use the FAD of *E. curionii* as base of the Ladinian is that the Fassanian would be a very short substage, comprising only one ammonoid zone or two zones, if the *gredleri* Zone is put into the Fassanian and not into the Longobardian. This is too few for a substage (about 1 m.y.). In the same time, the Illyrian would be very much expanded. This would mean a reduction of the Fassanian used since more 100 years by more 50 %. This is not a refining or slight modification but a very strong change in the traditional scope of the Fassanian. Directly connected with the strong reduction of the traditional Fassanian by using the FAD of *E. curionii* for definition the base of the Ladinian is the fact that this boundary lies high above the appearance of the typical Ladinian *Diplopora annulata* dasycladacean association. Very thick Middle Triassic carbonate platforms with dasycladacean algae are widespread in the Tethys and among them, the Ladinian association with *D. annulata* is well distinguished from the Anisian association with *Oligoporella*, *Physoporella* and *D. annulatissima*. The beginning of the *D. annulatissima* association is well dated by ammonoids in the Germanic basin (Kozur, 1974). The *D. annulatissima* association begins at the base of the Middle Muschelkalk and ranges through much of the Middle Muschelkalk which contains also in its upper part Anisian dasycladaceans (Kozur, 1974). Immediately below an ammonoid fauna from the basal Illyrian is present and also *Neogondolella bifurcata* begins, whereas *N. bulgarica* and *Nicoraella kockeli* disappear. The FAD of the *D. annulata* association is not so well dated, but lies in all cases far below the FAD of *E. curionii*. By this the typical Ladinian *D. annulata* association would be to an Anisian-Ladinian association. According to Bystrický (1964 and later papers), the *D. annulata* association begins in the *R. reitzi* Zone, but it is not clear, whether at its base or inside this zone. A similar problem exists with the sporomorphs. The Ladinian

vicentinense-scheuringi phase (Brugman, 1986) begins close to the base of the *Kellnerites felsoeoersensis* Zone. From all discussed base of the Ladinian, the FAD of *R. reitzi* is closest to and the FAD of *E. curionii* most distant from this event.

On the other side, the conodont ranges in the Bagolino section can be somewhat improved by own investigations. Brack et al. (2003) discriminate only the *P. alpina* group. The species *P. alpina* (Kozur & Mostler) has in our material its FAD in the same bed in which *R. reitzi* begins. This species is also present in North America (Orchard, pers. comm. Veszprém Meeting 2002), where it occurs in the upper Rotelliformis and Meeki Zones, and has therefore a good correlation potential. It is not correct that only *N. praeungarica* (Kovács), which begins in the upper *N. secedensis* Zone has a correlation potential between the Tethys and North America as pointed out by Brack et al. (2003). *P. alpina* has the same correlation potential. The same is true for *N. aldae* which is very common in North America, where it begins in the upper Meeki Zone. It is common in the more open sea development in the Tethys, but unfortunately not present in Bagolino. The FAD of this latter species in the Tethys is not yet well dated. It lies between the base of the *R. reitzi* Zone and the base of the *E. curionii* Zone, most probably in the upper *A. avisianum* Zone and does therefore not support either of the two discussed Anisian-Ladinian boundaries. Under *P. aff. eotrammeri* (Krystyn) several taxa were united by Brack et al. (2003), among them *P. trammeri praetrammeri* which begins in Bagolino immediately above the FAD of *R. reitzi*. The FAD of this species is important for the Tethys, but not for the open sea development.

The base of the *Reitzi* Zone with the FAD of *R. reitzi* in the Felsöors section in Hungary was used as proposal for the base of the Ladinian (*Reitzi* Zone sensu Kozur, 1995a, b, corresponding to the original *Reitzi* Zone) by Vörös et al. (2003). *Trinodosus* Zone, *Felsoeoersensis* Zone, *Reitzi* Zone and *Avisianum* Zone occur in a continuous succession with good ammonoid control. Above this level ammonoids are rare. Conodonts are very common in the Pelsonian, rare in the *Trinodosus* Zone and very rare in the *Felsoeoersensis* and *Reitzi* Zones. From the *Avisianum* Zone onward, conodonts are moderately common in about the same amount as in the Bagolino section. The advantage of this section is good ammonoid control, the very good radiolarian control and the absence of thermal alteration which allows both palaeomagnetic and stable isotope studies (Vörös et al., 2003, Korte, 1999). Radiolarians are common and well preserved from the *Trinodosus* Zone up to the *Avisianum* Zone and occur both in the limestones and in tuffs. Above this level well preserved radiolarians can be extracted only from the common chert nodules. Also deep water ostracods are common. A further advantage is the very low thermal alteration (CAI = 1) which allows both palaeomagnetic and stable isotope investigations.

Ammonoids, conodonts, radiolarians, ostracods, and stable isotopes are well studied in this section. In Márton et al. (1997) not all limestone beds were palaeomagnetically

investigated, but in Vörös et al. (2003) data from all limestone beds were present. As indicated by radiolarians, the tuffs were deposited very rapidly and the time is in the limestone beds. Only at the base or within the limestone beds changes in radiolarian faunas can be observed, whereas the tuffs have the same radiolarian fauna as the underlying limestone bed. Therefore the investigation of all limestone beds gives a very dense palaeomagnetic control. The beds in the critical interval have largely normal polarity. Only in the upper *Felsoeoersensis* Zone and in the lower *Avisianum* Zone a short reversed interval is present. Thus, also the palaeomagnetic investigations are in a good stage in the FelsQörs section.

The FAD of *R. reitzi* has a good correlation potential because exactly in the same level the first primitive *Oertlispongus*, *O. primitivus* appears and with this species also the genus *Oertlispongus*, one of the most prominent Ladinian genera and the basic form of numerous Fasnian and Longobardian advanced Oertlispongidae. In the immediately underlying beds, as in the entire *Felsoeoersensis* Zone the immediate forerunner of *Oertlispongus primitivus* are present within the genus *Pseudoertlispongus* which were erroneously put into the genus *Oertlispongus* by Dosztály (1993) and therefore the *Oertlispongus inaequispinosus* Zone was shown in Hungarian publications (e.g. Márton et al., 1997) in a wrong place. *Oertlispongus inaequispinosus* is a more advanced form than *O. primitivus* and has its FAD only in the *Avisianum* Zone. At the base of the *Reitzi* Zone (contemporaneous with the FAD of *R. reitzi*) a strong faunal turnover in the radiolarian faunas occurred (Kozur 1995a). Numerous Illyrian guideforms disappeared and numerous Ladinian forms appeared which partly ranges up to the upper Fasnian or Longobardian. This faunal turnover is not local or facies-controlled because it can be also found within radiolarite sequences throughout the Tethys, and in Panthalassa (Japan, Philippines). It can be also correlated with high latitude radiolarian faunas from the Omolon Massif (NE Siberia) and New Zealand (Kozur, 1995 a).

The FAD of *R. reitzi* has also a high potential for correlation with continental beds by the base of the *Dijkstrastrisporites beutleri* Zone, a megaspore Zone which is present both in the marginal marine and continental beds of the Germanic Basin and in the Pricaspian depression where it characterises the entire Ladinian. The FAD of *D. beutleri* can be well correlated with the base of the *Ceratites compressus* ammonoid zone, but the correlation with the Tethys is not quite clear. *Chirodella tiquetra* begins in the Germanic Basin a little below the FAD of *Dijkstrastrisporites beutleri* and *C. compressus*, *Neohindeodella triassica aquidentata* begins in the *C. compressus* Zone. In the Felsöors section both species begin in the *Avisianum* Zone of the Felsöors section. Unfortunately, the *Reitzi* Zone of the Felsöors section is very poor in conodonts and therefore it cannot be excluded, that these species begin in the Tethys already during the *Reitzi* Zone. In older deposits they are not yet present. Characteristic miospores of the *Reitzi*- and *Avisianum* Zone are *Kuglerina meieri*, *Cananoropollis scheuringi* and *C. brugmani* (Góczán & Oravecz-Scheffer, 1993). They are

typical Ladinian sporomorphs which ranges through much of the Ladinian. Their first appearance, however, is close to the base of the *Felsoeoersensis* Zone, that means earlier than the base of the *Reitzi* Zone. Nevertheless, from all levels for the base of the Ladinian, the FAD of *R. reitzi* is closest to this sporomorph event. In the same level some typical Illyrian foraminifers disappeared, like *Meandrospira dinarica* and several Ladinian forms appear, like *Oberhauserella ladinica*, *Pseudonodosaria loczyi* and "*Pilaminella*" *gmerica* appeared, but this event may be facies-controlled. Nevertheless, some of these foraminifers occur also in the shallow-water platform carbonates. Also this foraminifer event is somewhat older than the *Reitzi* Zone, but again the FAD of *R. reitzi* is closest to this event among the candidates for the base of the Ladinian..

The disadvantage of the *R. reitzi* boundary is that the index species can be only recognised in the Tethys and in Japan, but not in North America. However, as discussed above, *R. reitzi* is much wider distributed than *E. curionii*. A further disadvantage is that conodonts are very rare in the *Reitzi* Zone. However, conodonts are of subordinate importance for the definition of the Anisian-Ladinian boundary because only gradual changes within smooth *Neogondolella* and *Paragondolella* occur, which are difficult to determine even for conodont specialists.

As a whole, the correlation potential for the *R. reitzi* boundary is much higher than that of the *E. curionii* boundary, if we regard all faunal and floral element. A correlation with the high latitude fauna is possible by radiolarians (Kozur, 1995b) and the FAD of *R. reitzi* is close to a distinct changes in palynomorphs (both megaspores, base of the *D. beutleri* Zone and miospores, base of the *Cannanoropollis scheuringi* association).

In the St. Christina Meeting September 2003 a vote will be made in the Anisian-Ladinian Boundary Working Group between the FAD of *R. reitzi* and the FAD of *E. curionii* for definition of the base of Ladinian. If both proposals will not get 60 % of the votes as in former votings, a compromise proposal should be chosen. The former proposal of the base of the *N. secedensis* Zone is unsuitable because at this boundary no change can be observed in conodonts and radiolarians and therefore the correlation potential is very low. The former view of Krystyn (1983) that this boundary is characterised by a distinct change in conodonts is caused by strong condensation in the Epidaurus section, where at least the *Avisianum* Zones is condensed into the *Nevadites* fauna. The base of the *N. secedensis* Zone has the lowest correlation potential from all proposed Ladinian boundaries and, therefore it cannot be used as a compromise boundary.

An other compromise boundary would be the base of the *A. avisianum* Zone. This level was used for many years by Kozur (e.g. 1972, 1974, 1975, 1980) and correlated with the base of the *N. pseudolonga* Zone. This boundary was permanently criticized mainly by ammonoid workers and seems, therefore, from the view of the ammonoid workers not a very good boundary. According to Assereto (1969) *Aplococeras vogdesi* is a junior synonym of *A.*

avisianum. If this view would be correct, *A. avisianum* would be the only stratigraphically important species which is present in both Tethys and in North America. However, this view is not accepted by all ammonoid workers and the similarity of the two species may be only caused by the scarcity of taxonomic characters in the genus *Aplococeras*. An other disadvantage of *A. avisianum* is that this species is very rare or absent in distal basinal facies, like in Felsöors, where the presence of the *Avisianum* Zone is indicated by the *Latemarites* fauna. In terms of conodonts this boundary is not well correlatable but as pointed out earlier, conodonts are not important for definition of the Anisian-Ladinian boundary, as the real big change in conodont fauna, the FAD of *Budurovignathus truempyi*, is only in the middle part of the *E. curionii* Zone. The FAD of *P. trammeri* in the *Avisianum* Zone is a rather facies controlled event as the very similar *P. trammeri praetrammeri* is already present in the lower *Reitzi* Zone and the difference between the two subspecies is not distinct. With *N. pseudolonga*, a Ladinian type of *Neogondolella* with slightly forward shifted basal cavity and upturned posterior lower margin appears in the *Avisianum* Zone. Also *N. transita* begins in this level or slightly higher, but many different *Neogondolella* species have been assigned to *N. transita* and its junior synonym *N. excentrica*. As the FAD of *N. pseudolonga* shows an important step in conodont evolution, Kozur (1980) discriminated the *N. pseudolonga* Zone with a base around the base of the *Avisianum* Zone, but *N. pseudolonga* is often so rare that it is not a good index fossil. it was not reported from North America. An important conodont species for correlation is *N. aldae* which has its FAD in the upper Meeki Zone in North America, but it is not known, where exactly it begins within the *Avisianum* Zone (rather only in its upper part). In intra shelf basins such as Bagolino, this species was not yet found. The changes in the radiolarian fauna at the base of the *Avisianum* Zone is not so pronounced as at the base of the *Reitzi* Zone because no turnover in the fauna occurs and most of the typical Ladinian genera begin already at the base of the *Reitzi* Zone. However, the base of the *Avisianum* Zone is recognisable by radiolarians. In the *Avisianum* Zone of FelsQörs is the FAD of *Oertlispongus inaequispinosus*, an advanced *Oertlispongus* with wide distribution in the Tethys and western Panthalassa. Also some other species appear in this level and a little higher is the FAD of *Ladinocampe*. A rough correlation is also possible with *Daonella elongata* which occurs in the middle Meeki Zone of North America. As the FAD of *A. avisianum* is not much higher than the FAD of *R. reitzi*, the base of the *Avisianum* Zone is close to the priority base of the Ladinian. Many authors regard the *Avisianum* Zone even as a Subzone of the *Reitzi* Zone. The FAD of *A. avisianum* is therefore close to the above discussed sporomorph boundary, not as close as the FAD of *R. reitzi*, but not too much apart. The same is true for the beginning of the Ladinian *D. annulata* dasycladacean association. A little above the base of the *Avisianum* Zone in the FelsQörs section a short reversed interval is present within the normal Zone. If this short reversed interval can be also found

in other sections it would be a good correlation marker. Summarizing it can be stated that the correlation potential of the *Avisianum* Zone is not as good as that of the *Reitzi* Zone, but correlation in different facies is possible. As a “political” compromise, it would be acceptable, if no other (better) compromise boundary will be found.

Numerical age of the Middle Triassic

As mentioned above, the base of the Anisian was dated with 247 Ma (Lehrmann et al., 2002). Numerous reliable radiometric data are known from the upper Anisian to Ladinian interval measured in the Southern Alps by Mundil et al. (1996, 2003) and Brack et al. (1996, 2003) and in the FelsQoörs section by Pálffy et al. (2003). The oldest data are from the lower and upper *Felsoeoersensis* Zone with 241.1 ± 0.5 Ma and 241.2 ± 0.4 Ma indicating a very short duration of this zone what is also indicated by radiolarians which are almost unchanged throughout the *Felsoeoersensis* Zone. The lowermost *Reitzi* Zone yielded a value of 240.5 ± 0.5 Ma, the upper *Reitzi* Zone a value of 240.4 ± 0.5 Ma. Somewhat higher values were measured by Mundil et al. (1996, 2003) in the Southern Alps for the *Avisianum* Zone (*Latemarites* fauna) of the Latemar platform (242.6 ± 0.7 Ma) and of $241.2 \pm 0.8/-0.6$ Ma for the base of the *Secedensis* Zone. For the *Gredleri* Zone they reported $238.8 \pm 0.5/-0.2$ Ma. In this level Pálffy et al. got a very similar value (238.7 ± 0.6 Ma) for the boundary *Gredleri/Archelaus* Zones. Both set look reliable, but the South Alpine set is about 1-2 myrs older for the *Avisianum-Secedensis* level. It is difficult to decide, which set is right. Taking into consideration the 247 Ma for the base of the Anisian, an age around 241 Ma for the base of the *Reitzi* Zone is more probable than an age around 242-243 Ma, which would result from the South Alpine set. Values around 238 Ma for the *archelaus* Zone (Mundil et al., 1996, 2003) speak for the base of the Carnian around 237 Ma.

UPPER TRIASSIC STAGES

The Carnian was long time defined by the FAD of *Trachyceras* and subdivided into 3 substages, the Cordevolian, Julian and Tuvalian (Mojsisovics et al., 1895). Later the Cordevolian and Julian was partly united to the Julian s.l. (Krystyn, 1980). This was not a good decision both for questions of priority and common use and from the faunistic viewpoint. The Cordevolian contain in all fossil groups a mixture of Carnian forms with genera and partly species which range up from the Ladinian. In the Julian the Ladinian types are no longer present. In ammonoid faunas *Trachyceras* and *Daxatina* occur together with *Frankites*, in conodont faunas *Paragondolella polygnathiformis*, a very characteristic guideform of the entire Carnian occurs together with the Ladinian genus *Budurovignathus* and in the Neotethys with advanced *Pseudofurnishius* which also ranges up from the Ladinian, in pelagic bivalves the genus *Haloibia* is present and occurs together with *Daonella* which ranges up from the Middle Triassic, in radiolarians the first Upper Triassic and younger Saturnalidae are present together with the last Oertlispongidae which dominate the Ladinian, and similar Carnian-Ladinian mixed faunas are present at ho-

lothurian sclerites and ostracods. These mixed faunas have often lead to wrong assignment of ammonoid faunas. Thus, the *Frankites sutherlandi* Zone was generally assigned to the Ladinian because it did not contain *Trachyceras*, but Kozur (1976) assigned it to the Carnian assuming that its upper part (*Daxatina* fauna) is a time-equivalent of the (lower) Cordevolian *Trachyceras* faunas. He pointed out that *Trachyceras* has a diachronous FAD, related to the palaeolatitude, and is therefore not suitable to define the base of Carnian.

Broglio Loriga et al. (1999) proposed to use then FAD of *Daxatina canadiensis* in the locality Prati di Stuoeres Wiesen Section (Dolomites, Italy) as base of the Carnian. They have shown a clear overlap of *Frankites* and *Trachyceras* as assumed by Kozur (1976). This boundary is close to that proposed by Kozur (1976) and is here accepted. However, studies in more pelagic sections must show, where begin the typical Carnian faunal elements, like *P. polygnathiformis* and *Halobia*. They seem to begin within the *F. regoledanus* Zone, which is here assigned to the uppermost Ladinian, but there is a clear overlap of *Frankites apertus*, generally regarded as guide form of the *F. regoledanus* Zone, *Daxatina* and *Trachyceras* (Broglio Loriga et al., 1999).

The FAD of *Daxatina canadiensis* as base of the Carnian has a good potential for correlation with the continental facies. *Patinasporites densus* and *Vallasporites ignacii* begin a little above the FAD of *Daxatina cf. canadiensis* in the Prati di Stuoeres section. In the Germanic Basin, *V. ignacii* begins somewhat below the base of the “*Estheria* Beds” of the upper Grabfeld Formation, whereas *P. densus* begins in the upper “*Estheria* Beds”. At the base of the “*Estheria* Beds” the conchostracan *Laxitextella multireticulata* begins which occurs according to Kozur & Mock (1993) and Kozur (1999) in the “Kalkschieferzone” of the uppermost Meride Limestone, indicating a level around the base of the Carnian.

Rather problematic is the Carnian-Norian boundary because around this boundary the metapolygnathid conodonts split into two main lineages, a North American and a Tethyan-western Panthalassa lineage. Faunal invasions of North American forms occur in the Tethys, e.g. *Metapolygnathus communisti* which always begins with advanced forms in the Tethys, without transitional forms to its forerunner *P. polygnathiformis noah*. Such transition forms are illustrated from the *Communisti* Zone of North America (Orchard, 1991a). This zone seemingly does not contain real *M. communisti* with strongly forward-shifted basal cavity (both with respect to the platform and to the end of the keel; the pit in *M. communisti* is situated in or before the middle of the platform). Especially characteristic are the juvenile forms of *M. communisti* which have the pit at the anterior platform margin. This is unusual because all other juvenile metapolygnathids have the pit in more posterior position than in adults. Perhaps these juvenile forms are in reality an independent species (*M. parvus*). Real *M. communisti* are illustrated from North American material only from the *E. primitia* Zone together with advanced (real) *E.*

My	Stage/Substage	Ammonoid Zone/Subzone Standard		Conodont Zone/Subzone		
				Tethys/Western Pacific	North America	
199.6	Upper Rhaetian	Chor. marshi	Choristoceras marshi	Misikella ultima		
			Chor. ammonitifforme	Misikella koessenensis		
205 ? 207 ?	Lower Rhaetian	"Ch." haueri	Vandaites stuerzenbaumi	Misikella posthernsteini	Misikella hernsteini- Misikella posthernsteini	
			"Choristoceras" haueri			Orchardella mosheri
			Cochloceras suessi			
211	Sevatian		Sagenites reticulatus	M. hernsteini-P. andrusovi		
			Sagenites quinquepunctatus	Mockina bidentata	Subzone 2	Mockina bidentata
			Halorites macer		Subzone 1	
216	Alaunian		Mesohimavatites columbianus	Mockina postera		
			Cyrtopleurites bicrenatus	Orchardella ? spiculata	Orchardella ? spiculata	
225 226	Early Norian		Juvavites magnus	Epigondolella triangularis- Norigondolella hallstattensis		
			Malayites paulckeii	Epigondolella quadrata		
			Stikinoceras kerri	E. ? primitia-M. communisti		
231	Tuvanian		Klamathites macrolobatus	Epigondolella pseudodiebeli		
			Tropites welleri	Epigondolella nodosa		
			Tropites dilleri	Paragondolella carpathica	upper lower	Epigondolella nodosa lower
			Austrotrachyceras austriacum	P. postinclinata-P. polygnathifor.		
231	Julian		Trachyceras aonoides	Gladigondolella tethydis- Paragondolella polygnathiformis		
			Trachyceras aon	Budurovignathus diebeli- Paragondolella polygnathiformis		
	Cordevolian		D. canadiensis-F. sutherlandi	Paragondolella polygnathiformis		

Figure 3:Upper Triassic stages, substages, ammonoid zonation, Tethyan and North American conodont zonations

primita (Carter & Orchard, 2000). Thus, seemingly the *M. communisti* Zone of North America has only the fore-runners of *M. communisti*, a new species in the transitional field between *Paragondolella* and *Metapolygnathus* (illustrated "*M. communisti*" in Orchard, 1991a). As real *M. communisti* occurs only in the *E. ? primitia* Zone or insignificantly earlier, the North American *Communisti* Zone has to be abandoned. This range is also confirmed by the range of *M. communisti* in Europe. In the northern Tethys it occurs in a very short interval, which begins a little before the FAD of *Norigondolella navicula* and ends just before the *E. quadrata* Zone (Krystyn, 1980 and own data) and co-occurs with rare *E. ? primitia*. As *E. ? primitia* has to be restricted to the advanced forms in the former scope of this species and true *M. communisti* and advanced *E. ? primitia* occur together in North America (Carter & Orchard, 2000), the *M. communisti* Zone and the *E. ? primitia* Zone fall largely together. In the Neotethys *M.*

communisti is more common than in the northern Tethys (Muttoni et al., 2001, own data from a section NE of Pietra di Salomone in the Sosio Valley, Sicily). It occurs together with common *E. primitia* s.s. (see below), and in the upper range also a few *E. quadrata* occur. One form illustrated by Muttoni et al. (2001, Fig. 10, 4a) under *M. communisti* looks like transition form between *M. communisti* and *E. ? primitia*, whereas on the other hand in the northern Tethys there are forms which look transitional between *E. ? nodosa* and *E. ? primitia*. Orchard (1983) illustrated the intraspecific variability of *E. ? primitia* in North America in the scope as the species is until now used. It is clearly to seen that 3 different species belong to *E. ? primitia*. True *E. ? primitia* (holotype refigured in Orchard, 1991 b) are slender with marginal denticles on the anterior platform, and the platform is posteriorly not narrowed. Their pit is strongly forward-shifted in the same manner as in true *M. communisti*. This

form occurs in the *S. kerri* Zone of North America which belongs according to Tozer (1984) to the basal Norian and the conodonts obviously confirm this view. More primitive forms with subterminal pit (e.g. Orchard, 1983, Fig. 2F) and rather nodes than platform denticles which are mostly transversally elongated (e.g. Orchard, 1983, Fig. 2, Figs. A-C) are an independent species which seems to be identical with *E. pseudodiebeli* or may partly belong to a new taxon, transitional between *E. nodosa* and *E. primitia*. This form is common in the uppermost Carnian of the Tethys and North America. A third form (e.g. Orchard, 1983, Fig. 2 M, N, O, Q) are rather different in having a very narrow posterior platform, mostly with a pointed posterior. These forms, which are not present in the Tethys, represent a new form restricted to North America. They represent the basic forms of the North American genus *Orchardella*.

The above mentioned taxonomic problems and uncertainties about the origin of some conodont species around the Carnian-Norian boundary are a big obstacle for definition this boundary with conodonts. For this reason a definition by ammonoids (base of the *S. kerri* Zone) is preferred. Close to this boundary a distinct faunal turnover can be observed in the conodont fauna, to which belong the FAD of *N. navicula*, the FAD of *M. communisti* s.s. (probably a little below the base of the *S. kerri* Zone, within the uppermost *Macrolobatus* Zone), and the FAD of *E. ? primitia* s.s. (probably a little below this boundary, within the uppermost *Macrolobatus* Zone). By correlation of this boundary with the magnetostratigraphic scale of the continental Newark Basin (Channell et al., 2003), this boundary lies insignificantly below E7r sensu Kent & Olson (2000). Therefore, this boundary can be well correlated with the continental scale. It lies at the end of the lower third of the Conewagian (Adamanian) land vertebrate faunachron (LVF) in the level, where the typical upper Carnian *Paleorhinus* of the Otischalkian and lower Adamanian LVF became extinct.

The only base of the Rhaetian which can be well correlated between the Tethys and North America is the FAD of the conodont *Misikella posthernsteini* proposed for the first time by Kozur (1996). This species evolved in a phylomorphogenetic cline from *M. hernsteini*. The FAD of *M. posthernsteini* is at or close to the base of the *Cochloceras suessi* ammonoid Zone which can be well correlated with the *Paracochloceras amoenum* Zone. Therefore this Rhaetian boundary coincides with the base of the *C. suessi* Zone in the Tethys, the base of the *Paracochloceras amoenum* Zone in North America and roughly with the base of the *Orchardella mosheri* conodont zone in North America. This North America Rhaetian boundary was first established by Carter (1993) and also applied by Kozur (1996) and Orchard & Tozer (1997). *M. posthernsteini* occurs in shallow water and pelagic limestones, as well as in shales and radiolarites of the Tethys and in western Panthalassa. It is absent on the North American shelf and occurs in North America only in terranes (Orchard, 1991b). As the *Cochloceras suessi* Zone and the *Paracochloceras samoenum* Zone can be correlated, the *M. posthernsteini* datum, can be well cor-

related with North America by ammonoids. This base of the Rhaetian is also recognisable by radiolarians (Fig. 4, Carter, 1993). This Rhaetian is also characterised by the disappearance of the bivalve *Monotis* and Norian brachiopods, such as *Hallorella*, *Hallorelloidea*, *Austriellula*, *Pedixella*, *Crurirhynchia camerothyris*, as well as by the appearance of Rhaetian brachiopods, such as *Austrirhynchia cornigera*, *Labella suessi*, *Oxyclopella oxycolpos*, *Rhaetina pyriformis*, *Zugmayerella koessenensis*. But for many of these forms the exact appearance in correlation with the ammonoid and conodont zonations is not yet precisely known.

Numeric ages of the Upper Triassic

Almost no radiometric data are known from the Upper Triassic. A well dated radiometric age is 199.6 ± 0.4 Ma for the Triassic-Jurassic boundary (TJB, Pálffy et al. 2000). Kent & Olson (2000) took a similar age for the continental TJB in the Newark Basin (202 Ma) and calculated the following by astronomic calibration with Milankovitch cycles: base Rhaetian 208 Ma (Rhaetian duration 6 myrs), base Norian 217 Ma (Norian duration 9 myrs) and base Carnian about 232 Ma (Carnian duration 15 myrs). The value obtained for the base Carnian does not fit with the 237 Ma based on the dense set of radiometric data in the Southern Alps. This is, however, not due to the method of astronomic calibration, but by errors in the current correlation of the continental Newark sequence with the marine scale. Channell et al. (2002, 2003) used the same method, but assigned an age of approximately 200 Ma for the TJB and correlated the palaeomagnetic scale of the Newark sequence (Kent & Olson, 2000) with the marine Upper Triassic palaeomagnetic scale. They recognised that the base of the Carnian at the base of the Stockton Fm., as assumed by Kent & Olson (2000), corresponds actually with a level slightly above the base of the Tuvallian, for which they calculated a value of 231 Ma. This fits nicely with the vertebrate stratigraphy by Huber et al. (1993), who correlated the base of the Stockton Fm. with the lower Tuvallian as well. It also fits with the 237 Ma for the base of the Carnian, as 6 myrs duration for Cordevolian + Julian is a realistic value.

The base of the Norian was changed by Channell and others (2002, 2003) from the lower part of the Passaic Fm. to the middle part of the Stockton Fm. at 226 Ma. This gives the Tuvallian a duration of 5 myrs. The base of the Rhaetian was left at about the same level as shown by Kent & Olson (2000), but in the Newark Basin it is biostratigraphically not well constrained. Unfortunately, the palaeomagnetic correlation is also weak, as the marine section of Silická Brezová (Slovakia) ends in the uppermost Norian, immediately below the Rhaetian, and only in the Scheiblkogel section (Austria) palaeomagnetic data are known from the immediate base of the Rhaetian (Gallet et al., 1996). Most of the marine Rhaetian has not yielded any palaeomagnetic data. Channell and others (2003) tentatively placed the lowermost possible base of the Rhaetian at 207 Ma. Along with the considerably lowered base of the Norian in the Newark Basin, this yields a minimum duration of the Norian of about 19 myrs, and a maximum duration of the

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