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## Remarks to the base of Olenekian

**Heinz. W. Kozur**

*Rézsü u. H-1029 Budapest, Hungary*

### General remarks

#### Lower Triassic stages and substages

Mojsisovics et al. (1895) introduced the stage subdivision for the Tethyan Triassic, except the Rhaetian stage, which was introduced earlier by Gümbel, 1861 and adopted by Mojsisovics et al. (1895). Best defined from all stages was the Brahmanian Stage, with the Gangetian and Gandarian Substages defined in the Salt Range and in the Himalayas (Gangetian Substage). The Mojsisovics et al. (1895) paper was well known to all Tethyan workers and there established Middle and Upper Triassic stages were accepted with some modifications (Ladinian Stage replaced the Norian Stage and the Norian Stage replaced the Juvavian Stage). The Scythian Series by Mojsisovics et al. (1895) was, however, lowered to a Scythian stage. According to our present knowledge about the short duration of the Scythian (5.6 myrs according to Bachmann & Kozur, 2004) this was not a bad decision. In the 50ies of the last century, the Mojsisovics et al. (1895) paper was either unknown to the majority of the Soviet and some American workers or intentionally not regarded. Kiparisova & Popov (1956) introduced the Induan and Olenekian stages for the Lower Triassic, without regarding the fact that already Mojsisovics et al. (1895) had introduced and well defined a Brahmanian and Jakutian Stage for this time interval. The Olenekian was defined in the Boreal Realm of Russia. The Induan Stage has got its name from the Indus River, flowing through the Salt Range which its excellent, ammonoid- and conodont rich Lower Triassic sections. The Salt Range is also the type area of the Brahmanian Stage, which has clearly the priority. More important, however, is that the Induan was several times drastically changed in its scope. One of the reason for this is that it was named after its type area in the Salt Range, but Kiparisova & Popov (1956) had not studied this area and only a restricted literature knowledge about this area (they did even not know the Mojsisovics et al., 1895 paper). In reality, the Induan was defined with Lower Triassic Boreal ammonoid faunas from the base of the Boreal *Otoceras* faunas (later defined as the base of the *O. concavum* Zone). A lot of problems with the definition of the Olenekian base came from the original definition of the Induan and Olenekian. The exact equivalents of the Perigondwanan Lower Triassic ammonoid faunas of the Salt Range and of the Boreal ammonoid faunas was unknown in 1956, and thus Kiparisova & Popov (1956) assigned the largest part of the Lower Olenekian to the original Induan. Later, Kiparisova & Popov (1964) removed the lower Olenekian part from the original Induan and this was the first drastic change of the scope of the Induan. With the definition of the base of the Triassic

with the FAD of *H. parvus* (Kozur & Pjatakova) the entire lower part of the Griesbachian, the Boreal *O. concavum* and *O. boreale* Zone s.s. belongs to the Permian (Kozur, 1998a, b). By this a distinct part of the original Induan get Permian. After this second big change of both the upper and lower part of the Induan, the Induan finally corresponds fully to the Brahmanian which has more than 50 years priority. For these reasons, I furthermore use the unchanged term Brahmanian instead of the several time drastically changed term Induan.

Two substages were assigned to the Brahmanian, the Gangetian and the Gandarian substages. The Gangetian was defined by the Perigondwanan *Otoceras woodwardi* Zone s.l. which starts with the Perigondwanan *Otoceras* fauna and included also the *Ophiceras* faunas s.l. that means all the ammonoid fauna from the level of the present base of the Triassic (FAD of *H. parvus*) to below the base of the Dienerian. It corresponds therefore exactly to the lowermost substage of the Triassic. The term Gangetian has not only 60 years priority against the Griesbachian (Tozer, 1965), but can be used unchanged, whereas the Griesbachian is half of Permian (lower Griesbachian), half of Triassic age (upper Griesbachian). Therefore also here I use the term Gangetian instead of Griesbachian for the lowermost substage of the Triassic. The Dienerian (Tozer, 1965) fully corresponds to the Gandarian (Mojsisovics et al., 1895). Except the priority, the advantage of the Gangetian and Gandarian is the definition in the Tethyan realm (Perigondwanan margin of the Tethys), whereas both Griesbachian and Dienerian are defined in the Boreal Realm with lower diversity than the Tethyan faunas. In the present discussion, the Brahmanian Stage (= strongly revised Induan Stage) with Gangetian (= upper Griesbachian) and Gandarian (= Dienerian) substages are used (Figs. 1, 2).

The Jakutian of Mojsisovics et al. (1895) comprises only a part of the Smithian. Therefore, the name Olenekian can be used. The Smithian and Spathian substages can be discriminated.

#### Fossil groups for definition of the Olenekian base

The stratigraphic resolution potential within pelagic marine Lower Triassic sediments is highest in ammonoids and conodonts. As a conodont specialist, I prefer to use ammonoids for definition of the Olenekian base because the Olenekian conodonts are in a rather preliminary stage of taxonomic investigation. This is best seen in the big oversplitting of *Neospathodus waageni* Sweet in the Chaohou area in Tong Jinnan et al. (2004). Beside *Neospathodus waageni waageni* several species and subspecies has been discriminated within *N. waageni*. The FO of one of them, *N. waageni eowaageni* was chosen to

define the base of the Olenekian. However, this subspecies is rather an ecologically controlled morphotype which appears in different places in different sections and has not too wide regional distribution. Its FO in one of the two GSSP candidates is obviously unsuitable to define the base of the Olenekian. L. Krystyn provided me with the ammonoid and conodont range chart of the Spiti GSSP candidate, in which conodont data of Orchard are involved. They show a much more realistic picture of the intraspecific variability of the *N. waageni* group, subdivided into two species *N. waageni* s.l. with 5 morphotypes, and *N. posterolongus* Orchard in press. Two of the *N. waageni* morphotypes and *N. posterolongus* begin at the same level preferred by Krystyn at the base of ammonoid defined Olenekian. 3 morphotypes begin somewhat later, two of them at the same level. Lumping to very broad species which contain different taxa and oversplitting of variable taxa are common features for early stages of conodont investigation. Every new species within the *N. waageni* group should be also tested in the Salt Range with the stratum typicum of the holotype. It makes not too much sense to use highly oversplit taxa which can be determined by 3-5 specialists (which are often not in full agreement about the separation of these taxa) for definition of any boundary. If conodonts will be used for defining the Olenekian base, the FO of *N. waageni* s.l. in broad not oversplit sense should be used or alternatively, the FO of *N. posterolongus*, but by no means the FO of *N. waageni eowaageni* for which I doubt that it is really a subspecies and not only one of the intraspecific morphotypes of the highly variable *N. waageni*.

However, it seems to me, ammonoids are better suitable to define the base of the Olenekian. If we use the base of the *Rohillites rohilla* Zone, then 7 different species begin at that level. The FO of one of them, best of *R. rohilla* (Diener) may be used. However, according to ammonoids, there are also two other possibilities to define the base of the Olenekian. A little above the base of the *R. rohilla* Zone is the FO of *Flemingites griesbachi* Kraft, which should be also taken into consideration (beginning of 4 ammonoid species in Spiti). *Flemingites* has a wider distribution than *Rohillites* and occurs even in Madagascar. A third horizon is the FO of *Euflemingites* which has also a wide distribution. However, I agree with Krystyn to take the base of the *R. rohilla* Zone as the base of the Olenekian.

To use ammonoids for definition of the Olenekian base bring the question to use Opper Zones, Concurrent Range Zones, Unitary Associations or the FAD/FO of a species for definition of the lower boundary of the Olenekian. This is a general problem what reflects mainly the question of very sharp definition in a point or good correlation potential. The GSSP need a very precise definition in a point, and this requires for definition the FAD of a species (when its forerunner in a phylomorphogenetic lineage is known) or the FO of a species, if its forerunner in a phylomorphogenetic lineage is not definitely known). The correlation can be made by any stratigraphic

method and tool and then the highest potential for correlation should be chosen which may be one of the first three methods. This correlation potential is also given by biopalaeomagnetic correlations and stable isotope trends which, however, should not be the primary tool for definition in a GSSP.

The exact coincidence of an ammonoid FAD/FO with changes in other fossil groups should not influence the selection of a certain level for definition. For biological reason perfect coincidence of the FAD in different fossil groups will be rarely found. It is possible at ammonoids and conodonts because of similar facies preference, but the coincidence of the FAD/FO in different fossil groups should be always regarded with caution because it generally rather indicates abrupt facies changes, gaps, condensation and other negative factors in definition of a boundary. On the other hand, a level should be preferred close to which but not necessarily in exactly the same level changes in different fossil groups can be observed. This is the case for all three potential ammonoid boundaries mentioned above.

### GSSP candidates

Sections in the Chaohu area and in Spiti were proposed as GSSP candidates. Both have shortcomings and advantages. Unfortunately, sections in the Salt Range were not taken into consideration despite the fact that the Salt Range is the classical area of the Lower Triassic stratigraphy. The Salt Range sections are rich in well preserved ammonoids, contain very much conodonts, the CAI is 1, palaeomagnetic works well and the stable isotope results are very good for the investigated Lower Triassic part of the sections but were unfortunately not yet carried out just for the interval around the Olenekian base. Additionally sporomorphs are present and of good preservation in the Salt Range sections. According to ammonoid specialists, the preservation of the ammonoids in Chaohu is bad and ammonoids can be therefore surely not used for definition of the Olenekian base, if Chaohu is chosen as GSSP. Moreover, genera occur together in Chaohu and have there the same FO (e.g. *Flemingites* and *Euflemingites*) which have in Spiti distinctly different FO and ranges. Below the FO of *Flemingites* and *Euflemingites* in Chaohu, there is a longer interval without ammonoids (Tong Jinnan et al., 1974). Either condensation (not probable for the facies in Chaohu) or this longer ammonoid-interval in Chaohu or problems with determination because of bad preservation may explain the obvious differences in ammonoid ranges in Chaohu compared with other sections.

Compared with our material from Nepal and the data from Spiti, the conodont control of Chaohu is incomplete. Some important taxa are missing, others have a very different range from other sections in the world. *Chengyuania nepalensis* (Kozur & Mostler), a widely distributed gondolellid genus with rudimentary platform, is absent Chaohu. This species partly has been assigned in recent time to *Borinella* Budurov & Sudar, 1994. This, however, is both against the intention of the authors and

also not confirmed by the morphological features. *Borinella* Budurov & Sudar, 1994 is a replacement name for *Kozurella* Budurov & Sudar, 1993, a junior homonym of the holothurian *Kozurella* Mostler. *Borinella buurensis* (Dagis), the type species of *Borinella* and all other assigned species are forms with a broad platform, assigned by Kozur (1989) to primitive earliest *Paragondolella* Mosher. *Chengyuania nepalensis* has a Pa element with strongly reduced rudimentary platform. Budurov & Sudar (1993) assigned this species to *Kashmirella*, likewise with reduced platform, but from another lineage. They pointed out that “*K.*” *nepalensis* is distinctly different from *Borinella* what is correct. In all Triassic lineages genera with strongly reduced platform of the Pa element are treated as different genera then gondolellids with broad unreduced platform, and this brings inconsistency in the Triassic conodont taxonomy, if *C. nepalensis* is assigned to a genus which has per definition and holotype an unreduced broad platform. The separation of gondolellids with rudimentary platform from gondolellids with unreduced platform is clearly confirmed by their apparatuses. All gondolellids with strongly reduced rudimentary platform have a distinctly different apparatus from gondolellids with unreduced platform. This is even the case when a form with rudimentary platform evolved from a form with unreduced platform and vice versa and the apparatuses of the immediate forerunner and successor are compared. This is best demonstrated in the Germanic Basin, when *Celsigondolella watznaueri praecursor* (Kozur) with reduced platform evolved from *Neogondolella haslachensis* (Tatge) with unreduced platform. Despite the fact that *C. watznaueri praecursor* gradually evolved from *N. haslachensis*, in *Celsigondolella* the apparatus is more different from the *Neogondolella* apparatus than any apparatus from genera with unreduced platform. Even the Pb element changed into another form genus (*Pollognathus* Kozur). Likewise *Chiosella* with rudimentary platform has an apparatus different from all gondolellid apparatuses with unreduced platform. Thus, the argument that *Borinella buurensis* (as already known to Kozur 1989) evolved from *C. nepalensis* does not confirm that *Chengyuania nepalensis* is a *Borinella*, because otherwise *Celsigondolella* with totally different apparatus must be a *Neogondolella* despite the fact that the *Celsigondolella* apparatus is more different from the *Neogondolella* apparatus, than all apparatuses of not so closely elated gondolellids with unreduced platform

*C. nepalensis* does not define the base of the Olenekian, but it is a widespread marker for the Gandarian-Smithian boundary interval. *Eurygnathodus costatus* Staesche is a species which occur both in pelagic and shallow water deposits and is therefore important for correlation of the ammonoid-bearing pelagic deposits with ammonoid-free shallow water deposits of the Werfen facies. This species characterizes the uppermost Gandarian and lower Smithian, but in Chaohu it begins only considerably above the base of the Olenekian.

The published palaeomagnetic data (Tong Jin-nan et al.,

2005) are an advantage of Chaohu. From the Permian-Triassic boundary to the lower Smithian these data seems to be reliable and can be well correlated with the Germanic Basin and Tethys (Bachman & Kozur, 2004). In younger beds no good correlation is possible. Orchard (discussion in Longyearbyen, August 2006), who studied the conodonts in Chaohu determined the CAI in the Lower Triassic of Chaohu with 3-4. No reliable palaeomagnetic data can be obtained in beds with CAI = 3.5 and higher. At CAI = 3 partly reliable data are possible, partly not. At this CAI often a part of the section or a part of the samples yield reliable data, others not. Tong Jin-nan (pers. comm.) stated that the palaeomagnetic data from the base of the Triassic up to the Lower Olenekian were confirmed by investigation of two different sections. Thus, seemingly, at least a part of the palaeomagnetic data of Chaohu (base of the Triassic to lower Smithian) seems to be reliable data, but in levels, where they contradict biostratigraphic correlations (higher Olenekian), they should be regarded with reserve.

Stable isotope data were published from Chaohu (Tong Jinnan et al., 2004, 2005), but compared with other sections they are difficult to interpret around the base of the Olenekian, if this base is placed at the right place.

If ammonoids are chosen to define the base of the Olenekian, Chaohu is unsuitable. A conodont definition can be only placed at the FO of *N. waageni* n. subsp. A (= *N. waageni eowaageni*), if taken the conodont range chart by Tong Jinnan et al. (2004), but this would be a very weak definition.

Spiti has a very good ammonoid-control and also the conodonts are more numerous than in Chaohu. As the conodonts have CAI = 5, no reliable palaeomagnetic data can be obtained. The carbon isotope data (Krystyn, written comm.) show a distinct maximum close to the base of the Olenekian, whereas in general this maximum lies somewhat above the base of the Olenekian.

Both an ammonoid and conodont definition is possible in Spiti independent from the level which is chosen. For the moment, the base of the *R. rohilla* Zone can be favored, a level which is not well correlatable with Chaohu.

Unfortunately, no newer studies were made in the Salt Range. There, ammonoids are numerous and well preserved. Conodonts are extremely frequent and have CAI = 1. Thus, reliable palaeomagnetic and carbon isotope data can be obtained, the latter are partly present (Atudorei, 1998), but unfortunately not for the level around the Olenekian boundary. Sporomorphs are present as well.

If the GSSP will be chosen between Chaohu and Spiti, then Spiti has the better potential. However, additionally the Salt Range sections should be investigated. A correlation with ammonoids and conodonts will be easy in the Salt Range and palaeomagnetic data will be reliable, like for the underlying Permian. Moreover, sporomorphs may give a good possibility for correlation with continental beds, especially in Gondwana.



### Correlation with continental sequences

The continental Lower Triassic can be subdivided by conchostracans as detailed as the pelagic marine sediments by ammonoids and conodonts (e.g. Kozur, 1993, 1999). Conchostracans occur also in brackish sediments and can be therefore rather well correlated with the marine scale in intercalations of ammonoid-bearing beds (e.g. northern and northeastern Siberia) and in brackish intercalations in very shallow water beds (e.g. Werfen Beds of Hungary, Kozur & Mock, 1993, Kozur, 1999). Conchostracan guide forms from the low latitude Lower Triassic are also present in high northern latitudes (northern and northeastern Siberia, Greenland) and in northern and central Gondwana (northern India, Central and Eastern Africa, western Africa, Madagascar).

Unlike in marine sediments, a very big faunal turnover can be observed in the conchostracan faunas close to the base of the Olenekian. A fauna dominated by spined conchostracans (e.g. *Cornia*) is replaced by a fauna dominated by *Magnietheria* (large conchostracans without spines and vertical ribs). *Magnietheria* begins already with relatively small forms within the upper Gandarian, but it is there never dominating. This faunal turnover was regarded by Kozur (1993, 1999) as the base of the Olenekian. The spined *Cornia* is very common in some bedding planes (indicating brackish conditions in the very shallow marine Werfen Beds with *Claraia aurita*, upper Gandarian) of Hungary, whereas *Magnietheria*-dominated faunas are known from the lower part of the *Pachycladina* conodont fauna of undoubtedly Smithian age (Kozur & Mock, 1993) in the same area. *M. truempyi* (Kozur & Seidel) occurs in Madagascar in beds with ammonoids (unfortunately without modern investigation) and bivalves above undoubtedly Gandarian *Claraia*-bearing beds) and below lower Smithian *Flemingites*-bearing beds (Shen et al., 2002). Rather an early Smithian age can be assumed for *M. truempyi* from Madagascar. No direct dating is known for the *M. subcircularis* Zone but because it lies above the faunal turnover, it was regarded as the first Olenekian conchostracan zone by Kozur (1993, 1999), variant B in Fig. 2. Korte & Kozur (2005) insignificantly lowered the base of the Olenekian using the palaeomagnetic data by Tong Jinnan et al. (2005) for Chaohu. This boundary lies within the uppermost part of the Gandarian conchostracan complex (variant A) in Fig. 2. Taking into consideration that the Olenekian base is not yet finally fixed in Chaohu and the palaeomagnetic data must be regarded with some caution (but seemingly they are reliable around the base of the Olenekian) because the CAI is 3-4 (see above), variant B is still regarded as an option of the continental Olenekian base.

According to Korte & Kozur (2005) stable carbon isotope data from fresh water limestones in the Germanic Basin show a distinct maximum about 350 000 years above the palaeomagnetically correlated Olenekian base (100 000 years above the conchostracan faunal turnover), if Milankovitch cyclicity is applied (Bachmann & Kozur,

2004). In the Southern Alps this maximum lies within the lowermost part of the Lower Olenekian *Pachycladina* conodont fauna, also there about 350 000 years above the palaeomagnetically correlated Olenekian base and insignificantly closer to the FO of the Lower Olenekian *Pachycladina* fauna. In both cases, the maximum in  $\delta^{13}\text{C}_{\text{carb}}$  lies within the lower Smithian, like in the continental beds of the Germanic Basin. In Spiti, the maximum in  $\delta^{13}\text{C}_{\text{carb}}$  lies a little above the base of the *R. rohilla* Zone (Krystyn, written comm.). In the rather condensed sequence in Spiti the distance between the base of the *R. rohilla* Zone and the maximum in the carbon isotope curve could be well in the range between 100 000 and 350 000 years but rather closer to the first value. The maximum is defined by two values within the *R. rohilla* Zone. The older value is according to the data of Krystyn from the *R. rohilla* Zone in the lower bed with *R. rohilla*, a little above the FO of *R. rohilla*. This level is probably not further away from the base of the *R. rohilla* Zone than 100 000 years, rather closer to this boundary. In that case, the strong faunal turnover in the continental conchostracan faunas (variant B of the Olenekian base in the continental conchostracan succession) would coincide with the base of the *R. rohilla* Zone, making the view of Krystyn a very good decision. This speaks in favour of Spiti and in favour of the boundary proposed by Bhargava et al. (2004) as the lowest Olenekian base. The second and insignificantly higher value lies according to the data of Krystyn in the second bed of the *R. rohilla* Zone, in the level where the first *Flemingites griesbachi* appears in the *R. rohilla* fauna. If the maximum in the Germanic Basin corresponds to this level, then in the highly condensed Spiti succession a distance of more than 300 000 years to the base of the *R. rohilla* Zone would be possible and this would be a further confirmation that the palaeomagnetic data of Chaohu are reliable around the Olenekian base (see above), which would elevate the value of the Chaohu section and by this confirm variant A of the continental Olenekian in the conchostracan succession.

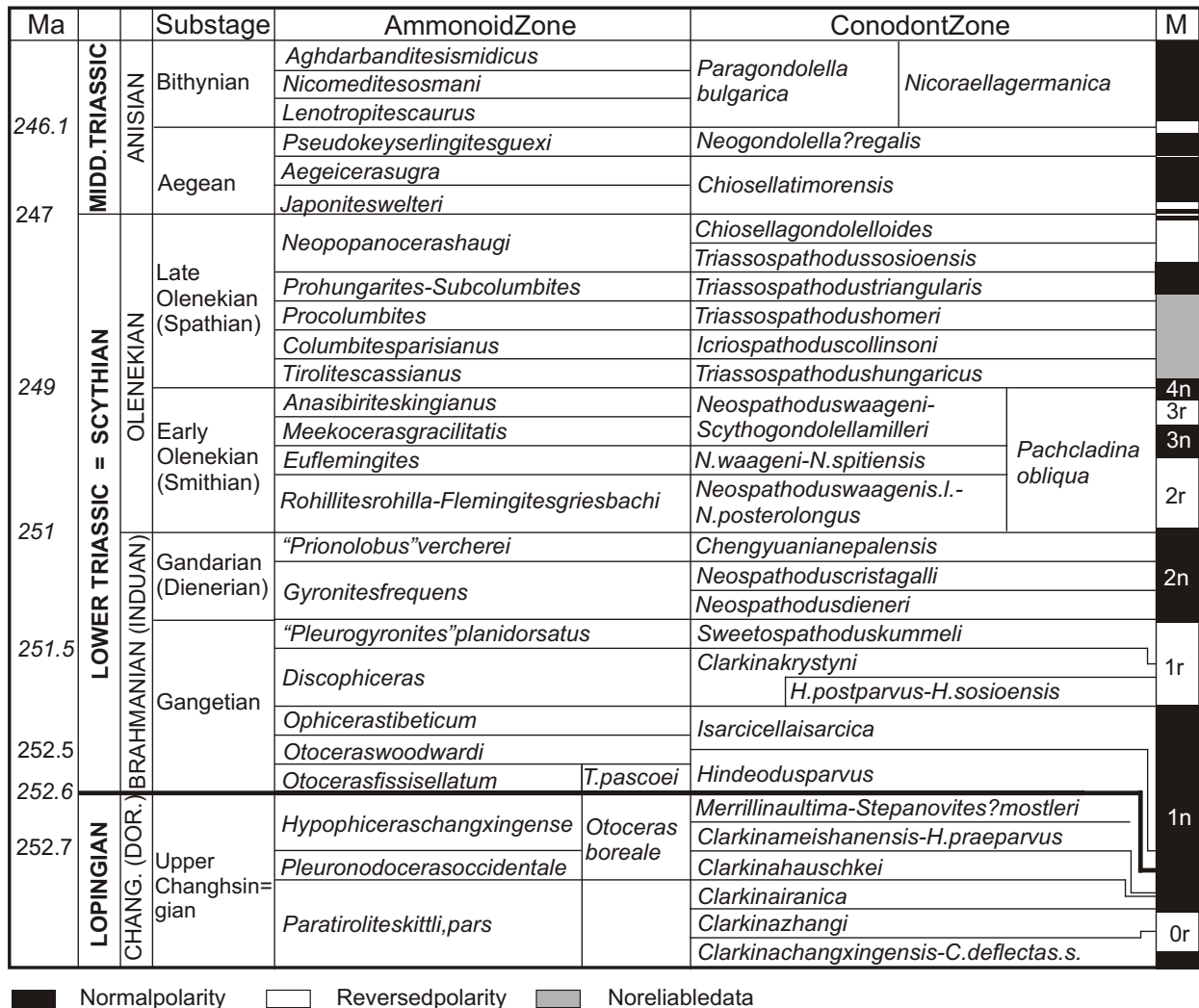
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■ Normalpolarity    □ Reversedpolarity    ▒ Noreliabledata

**Figure 1:** Lower Triassic ammonoid and conodont zonation and palaeomagnetic zonation. Slightly modified after Bachmann & Kozur (2004)  
Full coincidence of base of ammonoid and conodont zones for graphic reasons and only in some cases real.

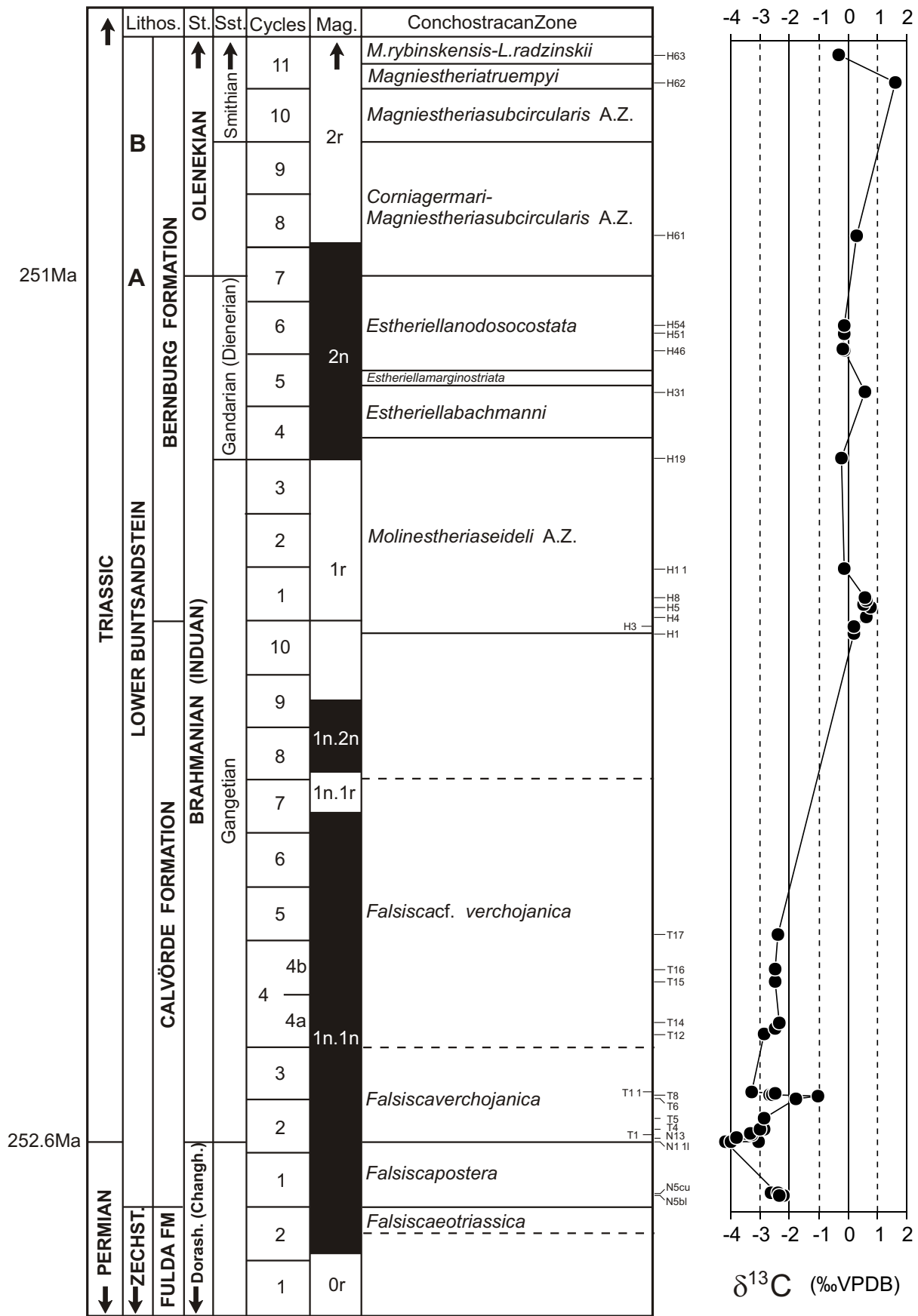


Figure 2: Carbon isotope record of the Lower Triassic Buntsandstein.