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CARBON ISOTOPE EVENTS DURING THE TRIASSIC

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Introduction

Over the last decade, the use of geochemistry and especially stable isotopes in stratigraphy has become commonplace. Recent reviews of the stratigraphic applications of the carbon, oxygen, sulfur and strontium isotopic systems can be found in Holser (1996), Popp et al. (1997), McArthur (1994), Veizer et al. (1997a,b) and Strauss (1997).

Many stable isotope studies have focused on the Permian/Triassic boundary and the lower part of the Lower Triassic. However, much less attention has been paid to the remainder of the Triassic. The Triassic segment of the widely cited Phanerozoic curves (Holser, 1988; Burke et al., 1982; Veizer, 1997b) is poorly constrained for both carbon and strontium isotopes, although a number of papers treated various aspects of origin, paleoclimate or diagenesis using carbon and oxygen isotopes from Triassic carbonates (Scherer, 1977; Henrich and Zankl, 1986; Frisia-Bruni and Weissert, 1989; Spötl and Burns, 1991; Litnerova, 1992; Bernasconi, 1993; Bellanca, 1995; Al-Aasm, 1995; Mutti and Weissert, 1995; Loreau, 1995).

There are basically two approaches employed for reconstructing pre-Jurassic secular variations of carbon isotope ratios, discussed in Grossman (1994) and Scholle (1995). The first considers only the data recorded from carefully selected carbonate components, like marine cements and mainly nonluminescent brachiopod shells, which are more likely to preserve primary signatures. The second one relies on the use of whole-rock micritic limestones or dolomites assuming, through mass-balance criteria, that inorganic carbon isotopes are affected to only a small degree by diagenetic alteration in carbonate rich and organic carbon poor sediments; oxygen isotopes have been, in most cases, reset during diagenesis.

The scarce occurence of thick shelled brachiopods in Triassic deposits seriously limits the acquisition of "high-confidence" carbon and oxygen isotope data. In addition, due to the current correlation problems that are posed (mainly to the Lower and Middle Triassic), an isotopic curve with a good chronostratigraphic coverage must be obtained from sections that are well calibrated by biostratigraphical means.

One of the few studies that present in detail carbon isotope variations along measured Triassic profiles are given by Steuber (1991) and Simon and Steuber (1993). The data were obtained on a Middle Triassic to Lower Jurassic section from the Helicon Mountains, Greece. No well defined fluctuations were observed in d13C values of the carbonates, instead, a gradual increase in d13C values of organic matter from Ladinian to Norian was found. More recently, Böhm and Gawlick (1997) reported a positive carbon isotope excursion in the Upper Triassic based on data obtained on a section from the Northern Calcareous Alps.

During the last three years, we have studied the carbonate carbon and oxygen isotope variations in several marine Triassic sections, under close biostratigraphic control, in order to detect any systematic fluctuations that would potentially serve for chemostratigraphical correlations. Here below we briefly overview some Triassic carbon isotope events, some of them already described elsewhere, others are newly described.

Carbon isotope events

Permian/Triassic boundary

The sudden drop in d13C values that accompanied the end-Permian extinction event have been documented worldwide (Baud et al., 1989; Magaritz and Holser, 1991; and many others). Regardless of the cause of the shift, it can be used in correlating Upper Permian to Lower Triassic

sections that lack fossils. However, fine scale correlations are limited (partly) by uncertainities related to the precise biostratigraphical correlations near the Permian/Triassic boundary interval.
Magaritz and Holser (1991) reported for the Gartnerkopfel core (Carnic Alps) a multiple minima carbon isotope profile in the lowermost Triassic. Scholle (1995) questioned the primary nature of this multiple minima pattern, arguing that there is a good correlation with the organic carbon content. Although a similar d13C pattern with two minima has been reported from the Guryul Ravine section (Baud et al., 1996), it is not clear whether it is "real" and, at the present state of knowledge, their use for fine scale correlations is not recommended.

In many sections covering the Lower Triassic there is organic material present, that could account for an input of 13C depleted components. It is also likely that the ocean stratification that characterized part (if not all) of the Early Triassic (Hallam, 1994a; Isozaki, 1997) resulted in marked vertical gradients in d13C values of the seawater. Consequently, the interpretation of the carbon isotope record for this time interval is not straightforward. Therefore, there are some uncertainities as to the carbon isotope pattern following the end-Permian drop.
Our data-set confirm an earlier observation that Triassic d13C values are generally lower than their Permian counterparts (Holser, 1987; Grossman, 1994), the high Permian d13C values are encountered only occasionally during the Triassic.

Smithian/Spathian boundary

A well marked positive excursion of d13C values has been found by Guex and Menoud (unpublished) and further described by Baud et al. (1996), just bellow the Smithian/Spathian boundary in the classical section from Nammal Gorge, Salt Range, within the *Anasibirites pluriformis* Zone (Guex, 1978). It was reproduced in another section from Salt Range, Landu Nala, situated about 70 km far to Nammal Gorge section. Its global extent has yet to be demonstrated. However, an increase in d13C values at the Smithian/Spathian boundary can be explained by an increase in ocean productivity, in agreement with the radiation event that took place simultaneously (Hallam, 1996).

Spathian/Anisian

For the Spathian to Carnian time interval we have a consistent data set derived from the study of several sections from North Dobrogea. We had the advantage to acquire this data set in a very well-defined biostratigraphical context, due to the generous collaboration with Prof. E. Gradinaru, University of Bucharest, who provided a wealth of unpublished information. In addition, the selected units escaped to a severe tectonic deformation and burial diagenesis, as revealed by field observation, microfacies analysis, low Colour Alteration Index of conodonts and oxygen isotope d18O values from carbonate cements. Further constraints are provided by trace elements geochemistry, studied by S. Zerrari and M. Renard (University Paris VI).
The most interesting feature offered by the Dobrogean record is a pronounced positive excursion in d13C values across the Lower Triassic/Middle Triassic boundary (Atudorei et al, 1996). It is well defined in a composite section made-up exclusively by Halsttatt-type red pelagic limestones, spanning from the Lower Spathian to Lower Carnian. Hallstatt-type limestones are particularly suitable for carbon isotope analysis because of their pelagic nature, their lack of organic carbon and their richness in fossils which offer a good age control. It is noteworthy mentioning that the composite section includes the Desli Caira section, a candidate for the Spathian/Anisian boundary stratotype (Gradinaru, 1993; Gaetani, 1994; Crasquin-Soleau and Gradinaru, 1996).
The rise in d13C values starts in the Uppermost Spathian and the most positive values are attained in the Lowermost Anisian (*Aegeiceras ugra* Zone). The recovery to background values (that are typical to the Lower Spathian and the remainder of the Middle Triassic), takes place somewhere close to the Lower/Middle Anisian boundary. This pattern was reproduced in two other sections from North Dobrogea, in different lithological settings. The Lower/Middle Triassic carbon isotope event has a particular significance (Atudorei et al., in preparation); it may reflect a time when major changes took place in oceanic circulation patterns, a time when the biological recovery after the end-Permian mass extinction was significantly accelerated. Indeed, a major radiation of marine biota was reported for this time (Erwin, 1996). A pronounced global excursion of sulfur isotope ratios from marine sulfates, one of the most striking feature of the sulfur isotopic curve for all the Phanerozoic (Holser et al., 1977; among other) also occur at that time.

Regardless of the implications relating to the recovery from the mass extinction, we believe that the Spathian/Anisian carbon isotope event can be used as a stratigraphical marker and may help in the choice of the Spathian/Anisian boundary stratotype. However, data from other sections spanning this time interval are needed to confirm the d13C pattern.

Carnian to Norian

The carbon isotope record from Hallstatt-type limestones also exhibit a gradual and gentle rise of 1.5 per mil in d13C values during the Carnian. Unfortunately, our data set do not include enough data from the Upper Triassic to better define this trend. Böhm and Gawlick (1997) studied the carbon isotope profile for the Upper Triassic from a section in the Northern Alps, analysing also Halsttatt -type limestones. They reported high d13C values for the Upper Carnian and a positive excursion in the Lower Norian. Combining our data-set with the one reported by Böhm and Gawlick, a consistent trend can be defined, with a gradual rise in d13C values from the Lower Carnian to Lower Norian, followed by a decrease in d13C values starting with the Upper Lower Norian. Certainly, this pattern needs further constraints; however, as a first approximation, it seems to be in agreement with Steuber's (1991) organic carbon isotope record.

Triassic/Jurassic boundary

Most extinction events have been associated with marked carbon isotope excursions (Magaritz,1991). Of the five Phanerozoic major extinction events (Raup, 1986), only for the end-Triassic extinction there is no clear evidence of carbon isotope variations. Hallam (1994b) reported a negative inorganic carbon isotope excursion in the Kendelbach section (Austria), but considered it to be a diagenetic artifact as it is mirrored by the organic carbon isotope curve (Morante and Hallam, 1996). In a preliminary study of the classic New York Canyon section, Taylor et al. (1992) reported some variations of the d13C profile near the boundary, but full data have not been published yet.

Conclusions

Excepting the negative carbon isotope excursion that paralleled the end-Permian mass extinction, three positive carbon isotope events have been recorded during the Triassic. All of them need further confirmation as to their global extent. At least for the Spathian/Anisian event, we have strong reasons to presume his global nature. Positive carbon events are commonly interpreted in terms of the net flux of organic carbon buried and the effectiveness of the "biological pump". For the Smithian/Spathian and Spathian/Anisian events, they may reflect pulses of increased productivity, as they are coincident with reported radiation events. In this respect, the Triassic carbon isotope curve shares much of its Cambrian counterpart, for which a number of isotopic events were correlated with global bio-events (Brasier, 1996).

A review of the actual state of knowledge of the Triassic carbon isotope variations is presented in this note, as well as an evaluation of their potential use for stratigraphic correlations. Our aim is to call the attention of people working in Triassic stratigraphy on a field they may find useful in their research. We did not attempt to discuss here the origin of the proposed carbon isotope excursions, neither did we detail the problems that might be encountered by such studies. It is strongly recommended that stable isotope studies in stratigraphical issues should be coupled with biostratigraphy, carbonate sedimentology, microfacies analysis and other physical or geochemical studies. In the absence of such constraints, the interpretation could be misleading.

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