Upper Carboniferous to Lower Triassic carbon isotope stratigraphy of the Western Tethys: evidence from the Southern Alps–Karavanke Mountains and Julian Alps, Slovenia

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The carbon isotope stratigraphy of selected stratigraphic sections from the Karavanke Mountains (Dolžanova soteska, Koutnik Creek, Brsnina) and from the eastern and southern part of the Julian Alps (Straža Hill, Žirovski vrh, Idrijca Valley) spanning an aproximately 1600 m thick stratigraphic interval ranging from Upper Carboniferous to Lower Triassic was used to examine their depositional environment, as well as the changes associated with shifts in carbon isotopes. For this purpose carbon isotope analyses were performed on more than 250 limestone, dolomite and pedogenic carbonate samples from different stratigraphic intervals.

Results and discussion

A schematic representation of the carbon issotope stratigraphy from the Upper Carboniferous to the Lower Triassic is shown in Fig. 1. As evident, the $\delta^{13}C$ signal for the sedimentary sequences of the lower (Late Carboniferous/Early Permian) and upper (Middle-Late Permian to Early Triassic) cycle (see Krainer, 1993, and references therein) is characterized by a series of distinct carbon isotope changes.

There is a distinct positive $\delta^{13}C$ excursion at the C/P transition which most probably records the transgressive trend of the Tethys Sea and a climatic shift from humid to more arid conditions near the C/P boundary. Variations of $\delta^{13}C$ in the lower sedimentary cycle can be correlated with sea level fluctuation probably caused by the Gondwana glaciations, variable $C_{org.}/C_{carb.}$ export ratios changes into the marine sedimentary carbon reservoir (Schidlowski, 1987), as well as by variable changes in the burial rate of organic carbon in more or less isolated intermontane basins of that time. In the Karavanke Mountains, there is an evidence that the key mechanism for $\delta^{13}C$ enrichment were most probably anoxic events and/or high burial rates of organic carbon within periodically isolated more or less stagnant basins. This is supported by an up to 4.5‰ $\delta^{13}C$ enrichment of black and dark grey limestones relative to the light grey, rose, pale red and red massive or bedded limestones from Dolžanova soteska.

The negative $\delta^{13}C$ excursion at the end of the lower cycle could be explained by a regression of the Tethys Sea due to Saalian movements. The carbon isotopic composition of limestone cement from Tarvis breccia in the range between −5.79 and −4.66 ‰ suggests a subaerial exposure on the top of the lower cycle sedimentary sequence.

Pedogenic carbonates, the presence of gypsum and playa lake dolomites from siliclastic sediments of Gröden Formation point to semiarid and arid conditions. The carbon isotopic compositions of pedogenic carbonates cluster between −9.49 to −4.81‰ and are up to 14‰ lighter as compared to the Neoschwagerina limestone – a time equivalent of the Gröden Formation. The $\delta^{13}C$ values of plant remains from the Gröden Formation were found to be between −22.13 and −21.65‰ (Dolenec and Pezdič, 1986). A conceptual model of coupling between marine, atmospheric, and continental carbon (Koch *et al.*, 1995) applied to our data shows that the atmospheric CO_2 $\delta^{13}C$ of the Middle Permian should be close to −5‰. A similar isotopic composition of atmospheric CO_2 is also predicted for the Upper Permian.

The positive $\delta^{13}C$ excursion at the base of the Upper Permian Karavanke Formation indicates a vaste marine transgression to the south in the Tethys. Most $\delta^{13}C$ values of dolomite from the Karavanke Formation fall between +2.00 and +3.10‰, while

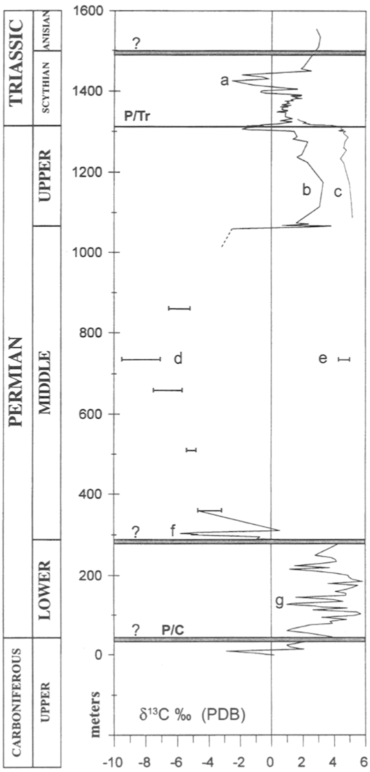

FIG. 1. Upper Carboniferous to Lower Triassic carbonate carbon isotopic record from the Southern Alps–Karavanke Mountains and Julian Alps, Slovenia. **a**: Scythian beds (Karavanke Mountains), **b**: Karavanke Formation (Karavanke Mountains), **c**: Žažar Formation (Idrijca Valley), **d**: Gröden Formation - pedogenic carbonates (Žirovski vrh, Karavanke Mountains), **e**: Neoschwagerina limestone (Straža Hill - Julian Alps, **f**: Tarvis breccia unit - limestone cement (Karavanke Mountains), **g**: Upper Carboniferous limestone, Dolžanova soteska limestone, Rattendorf beds, Trogkofel limestones (Karavanke Mountains).

those of limestone from the Žažar Formation are between +4.07 and +4.67‰.

It appears that the limestone of the Žažar Formation acquired its carbon isotopic composition through isotopic equilibrium with the atmospheric CO_2, while the depletion of $\delta^{13}C$ in the Karavanke Formation could be attributed to biogenic carbon input from surrounding land and/or deceleration in the rate of organic carbon burial in the sedimentary environment of the Karavanke Formation.

The worldwide negative $\delta^{13}C$ excursion at the P/T boundary exibits a multiple character in the Karavanke. The most reasonable explanation for the complex pattern of the $\delta^{13}C$ record is considered to involve multiple interactions of several factors operating on a local scale such as fluctuation of primary productivity, changes in the proportions of continental and marine derived organic matter in the semi- restricted marginal basin of the Karavanke Mountains area, as well as diagenetic processes, which slightly overprinted the primary global palaeoceanographic signal, which marks the well known end Permian boundary events and biotic crisis.

In the Idrijca Valley a negative $\delta^{13}C$ peak at the P/T boundary was not found. However, we can see a more than 4‰ decrease in $\delta^{13}C$ which starts about 5 m below the boundary and accelerates through the boundary to the Lower Scythian. It is important to note that up to 15 m above the boundary, there is no evidence of the $\delta^{13}C$ shift back to its preexcursion values. The absence of a peak can be explained by the result of a condensed section, or unrecognized unconformity. This suggestion is preliminary and must be tested through more detailed isotopic analyses of the investigated boundary section. After the rapid short-term transgression in the earliest Scythian which led to the spread of anoxic water on the epicontinental shelves (Hallam, 1989), the $\delta^{13}C$ signal of the remaining Scythian seems to be controlled by transgressive-regressive events probably caused by different spreading rates of mid-ocean ridges (Krainer, 1993, and references therein), as well as by variable $C_{org.}/C_{arb.}$ export ratios into the marine sedimentary carbon reservoir. The progressive increase in $\delta^{13}C$ values that followed the P/T minimum, continued through Scythian. Superimposed on this long-term trend are short term distinct negative $\delta^{13}C$ excursions, most probably coinciding with the mentioned transgressive-regressive events.

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