Late Jurassic $\delta^{13}C$ stratigraphy: carbon cycle and paleoceanography

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High resolution stable isotope analysis of Tethyan carbonates provides insight into the Late Jurassic carbon cycle and paleoceanographic history. The Late Jurassic $\delta^{13}C$ record can be divided into a unstable Oxfordian featuring a rapid 2 per mil negative excursion, followed by a gradual rise to a Kimmeridgian maximum and gradual decrease towards the Jurassic-Cretaceous boundary (**figure 1**). The Oxfordian negative excursion may be explained by paleoceanographic changes and/or significant volcanic activity. The most positive values in the Kimmeridgian coincide with extensive organic deposition and the $\delta^{13}C$ decline in the Tithonian is consistent with evidence of increasingly oligotrophic conditions in the Tethyan seaway.

The five sections studied are located in the Swiss Jura mountains, the Swiss Alps and the Southern Alps of northern Italy. The Auenstein section, an inner carbonate ramp section, is located in the Swiss Jura mountains which features a series of hardgrounds followed by a thick series of alternating marl and thin micritic limestone beds (**figure 2**). Chronological control is provided by ammonite stratigraphy (Gygi and Persoz, 1987).

The two Helvetic nappe sections from the Swiss Alps, Nissibach and Ortstock, feature outcrops of the hemipelagic Oxfordian Schilt Fm deposited in an outer ramp environment. The lowermost sandy limestone member is succeeded by an extensive marly interval with isolated limestone beds. The marly intervals become thinner and less frequent higher in the section and the uppermost Schilt Fm features thin-bedded micritic limestones with relatively few marl stringers. The scarcity and poor preservation of index fossils at this site make biostratigraphic dating tentative.

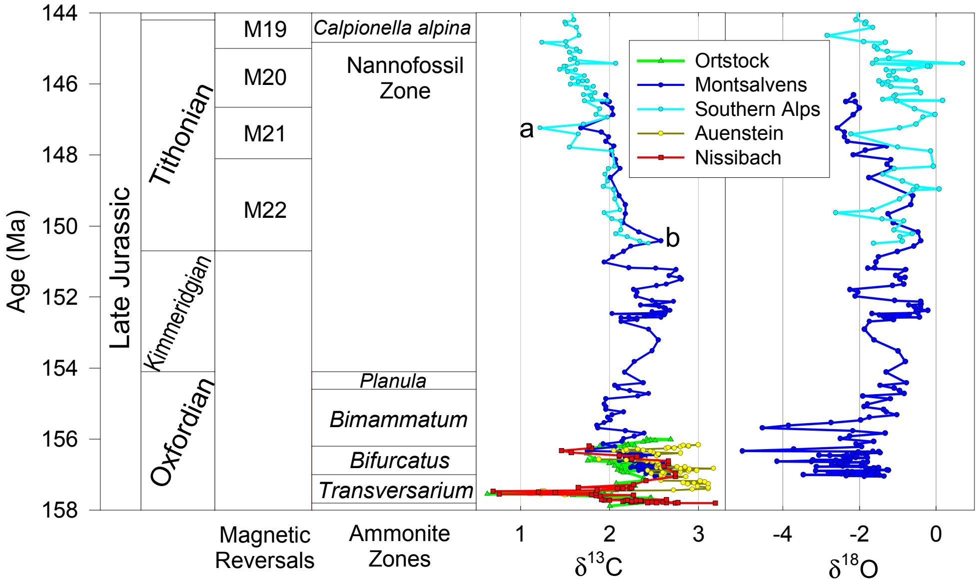

Figure 1 Composite bulk carbonate isotope curves and stratigraphic control of studied sections.

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The Montsalvens gorge section in the Ultrahelvetic nappes was deposited in pelagic setting along the western margin of the alpine Tethys and is composed of a basal concretionary limestone and nodular limestones (**figure 2**). The tentative chronology was suggested by Guillaume (1957) based on index ammonites and ammonite assemblages. The accurately dated southern alpine pelagic sections at Xausa and Val del Mis were deposited along the southern continental margin of the alpine Tethys. (Weissert and Channell, 1989). At these sites, the Rosso Ammonitico facies grades into the alternating white limestone and chert beds of the Maiolica Fm. The Montsalvens record was correlated with the S. Alpine data using two $\delta^{13}C$-tie points (a and b in **figure 1**). A constant sedimentation rate is assumed for the data between the *Bifurcatus* negative peak and the early Tithonian positive peak at Montsalvens.

The most striking features of the Late Jurassic $\delta^{13}C$ curves are the two negative excursions in the Oxfordian (**figure 1,2**) which are independent of lithology and depth of deposition. A similar excursion is also found in crinoids of the Swiss Jura platform in an ammonite-dated section (Bill et al., 1995). These data and the $\delta^{13}C$ record from the well-dated series at Auenstein were used to fine-tune the age models of the other 3 sections whose chronology is less well constrained. The estimated duration of the first, most dramatic negative excursion, according to the age model, is 10 ky at condensed and incomplete Ortstock and about 130 ka at both Nissibach and Auenstein. The second, more subtle negative peak occurs over a period of several hundred thousand years. A carbon isotope negative excursion is also recorded in the Oxfordian sediments of the Paris Basin (Casanova and Négrel, 1999) and Vontontian Basin (unpublished data). Bulk carbonate $\delta^{13}C$ results from the Smackover Formation also feature a negative shift of about 1.5 per mil in the Oxfordian (Humphrey et al., 1986). Preliminary results of Late Jurassic bulk carbonate from DSDP site 105 in the eastern Atlantic also display distinctive negative values of 1 per mil (VPDB).

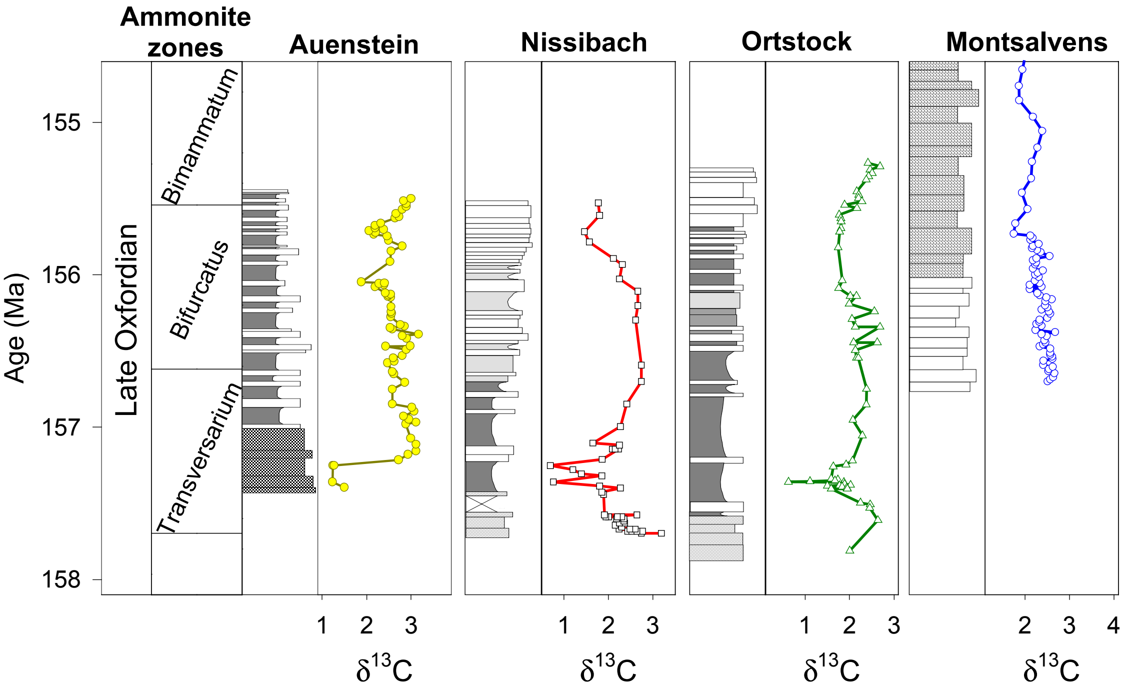

Figure 2 Oxfordian lithological sections with $\delta^{13}C$ stratigraphy. Note that lithology and $\delta^{13}C$ are plotted vs time. White-limestone, light grey-marly limestone, dark grey-marl, check pattern-hardground, wavy pattern-nodular limestone, speckles-calcareous sandstone.

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Although diagenesis may explain a negative excursion, and indeed was invoked to explain the Smackover $\delta^{13}C$ results (Humphrey et al., 1986), the observed negative $\delta^{13}C$ signal persists in different lithological settings and there is no evidence for elevated organic carbon values. A more likely explanation of the carbon isotope data is a significant change in the oceanographic carbon pool. The wide-spread and short-lived nature of the *Tranversarium* negative excursion suggests a sudden addition of isotopically light carbon to the global carbon cycle. Although wide-spread organic dissolution may cause such a response in the oceanic carbon pool, it is unlikely to occur over such a short time scale (Dickens et al., 1995). A dramatic fall in oceanic productivity and/or preservation of organic matter seems equally unlikely in light of coeval deposition of organic rich sediments such as the oil-bearing Smackover Fm in the Gulf of Mexico. An abrupt shift towards more negative $\delta^{13}C$ values may signal a large expulsion of isotopically light volcanic gas into the atmospheric CO_2 pool. The rifting of Antarctica from Gondwana may be a possible candidate of such igneous activity, although the few available dates suggest this event occurred earlier (~ 170 Ma; Rampino and Stothers, 1988) and a recent model suggests that volcanic input alone cannot produce a significant negative excursion (Kump and Arthur, 1999).

Another possibility which may explain a similar $\delta^{13}C$ excursion at the Paleocene Thermal Maximum is the sudden expulsion of gas hydrates along continental shelves. Pelagic sedimentation in the narrow Atlantic ocean started after initial rifting in the Callovian-Oxfordian (Lancelot et al., 1972). A first significant connection between the equatorial Tethys-Atlantic and the Pacific oceans in the Late Jurassic would be consistent with a long term sea level rise throughout the Mesozoic (Haq et al., 1987) and would have affected ocean circulation patterns. The opening of a gateway between Atlantic and Pacific would produce a westward flow of warm and saline Atlantic water, driven by equatorial easterlies. This water most likely sank as it encountered the less saline Pacific ocean just as the modern Mediterranean sinks to form intermediate water upon entering the Atlantic. Modern gas hydrates occur at different types of continental margins but occur in greatest concentration along active margins (Booth et al., 1998). The descent of warm Tethyan water along the western margins of the Americas may have destabilized gas hydrates in the sediments. In analogy to the Dickens et al. (1995) model, resulting turbidites would release large amounts of isotopically light (~60 per mil) methane into the atmosphere and shift the carbon isotope curve to more negative values.

In the Kimmeridgian, carbon isotope values increase gradually to a maximum and then decrease towards the Jurassic-Cretaceous boundary. Three major petroleum provinces occur in the Kimmeridgian: the Persian Gulf, western Siberia and the North Sea which together with the Oxfordian Smackover Fm. in the Gulf Coast form an estimated 25% of the world's petroleum reserves (Heydari and Moore, 1994). The gradual change in $\delta^{13}C$ values may reflect the long term global burial of isotopically depleted organic carbon which starts in the Oxfordian (Smackover Fm), peaks in the Kimmeridgian and decreases through the Tithonian (western Siberia). The $\delta^{13}C$ record may also have been 'buffered' from rapid changes by the large volume of isotopically enriched carbonate being deposited in epicontinental seaways and along the tropical Tethys. A gradual decrease of $\delta^{13}C$ values through the Tithonian corresponds to increasingly oligotrophic conditions in the Tethys interpreted from the spread of nannofossils into the pelagic realm and the evolution of nannofossil assemblages.

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