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Erosion and deposition from bottom currents during the Givetian and Frasnian: Response to intensified oceanic circulation between Gondwana and Laurussia

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Abstract

Calcareous bottom-current deposits in otherwise pelagic and hemipelagic successions of the Harz Mountains in Germany (Herzyn Limestone Formation), the eastern Moroccan Central Massif (Ziar-Mrirt Nappe), and the Carnic Alps in Austria/Italy (Valentin and Pal Limestone Formation) show strong evidence of bottom-current reworking of carbonate ooze during Givetian and early Frasnian. Associated phosphates confirm that higher hydraulic energy temporarily prevailed. The bottom-current deposited facies builds up strongly condensed and reduced successions with stratigraphic gaps, which also occur with similar features in other areas of central Europe and northwest Africa at the same stratigraphic interval.

The widespread current-induced reworking of calcareous sediments and phosphate formation during the Givetian and early Frasnian as well as the associated erosional processes marked by pronounced hiatuses all signal a major circulation event. The temporal and spatial positions of these fossil calcareous contourites in the Devonian are discussed. Research concluded that thermohaline currents were intensified by the acceleration of flows constricted in the narrow oceanic passages between the approaching continental plates Laurussia and Gondwana. Areas affected were the southeastern Rhenish Sea shelf, the disintegrated northern continental margin of Gondwana, and deep marginal plateaus of the Noric Terrane in the western part of the Prototethys. The disposition of the fossil calcareous contourites and faunal data corroborate palaeogeographic reconstructions that show an advanced convergence between Gondwana and Laurussia and the smaller continental plates such as the Armorican and Noric terranes during Givetian and Frasnian times.

Keywords: Givetian; Frasnian; Bottom currents; Fossil calcareous contourites; Oceanic circulation; Palaeogeography

1. Introduction

In Devonian times, the palaeoceanographic situation is characterized by a narrow NE-trending ocean bounded by Laurussia in the northwest and Gondwana in the southeast. While Laurussia was located at equatorial latitudes, Gondwana drifted across the south pole. Rifting at the continental margins of Laurussia and Gondwana led to a separation of minor terranes from the continents during Early and Middle Devonian, whereas the first contact between Laurussia and the Central European promontory of Gondwana during latest Devonian marks the onset of Variscan Orogeny (Golonka, 2002). A low-stand of sea level prevailing during Early Devonian changed to global continental flooding, reaching a high stand at the transition from

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Frasnian to Famennian, then receding cyclically to reach a temporary low-stand at the end of the period (Johnson et al., 1985). It is expected that for much of the greenhouse Devonian, oceanic thermohaline stratification was more stable than today (Copper, 2002).

Devonian pelagic carbonates (Cephalopodenkalk, Griotte) were deposited over a wide range of settings from continental margins on drowned carbonate platforms to slopes and to basins (Bandel, 1974; Tucker, 1973, 1974; Wendt and Aigner, 1985). The biota are dominated by pelagic fauna of cephalopods, thin-shelled bivalves, styliolinids and tentaculitids, ostracods, radiolarians, and conodonts. Widely distributed microfacies types common in the Devonian are grey and red, often burrowed bioclastic wackestones and cephalopod wackestones. Styliolinid packstones exhibit one distinctive microfacies (Tucker and Kendall, 1973; Wendt and Aigner, 1985; Walliser and Reitner, 1999). The origin of the micrite matrix is unclear, but is commonly explained as resulting from break-up of macroskeletons rather than from calcareous microfossils or nannofossils that are rare or missing in the Devonian (Tucker, 1990). Consequently, comparisons with modern analogues do not work convincingly.

Stratigraphically condensed and expanded successions have been recognized (Jenkyns, 1971; Tucker, 1990). The first were commonly accumulated upon pelagic carbonate platforms (see Santantonio, 1993, 1994), whereas the second deposited in adjoining basins. In condensed pelagic limestones, there is abundant evidence of discontinuous sedimentation and of early diagenetic lithification. Hardgrounds have surfaces encrusted by sessile foraminifera, corrosional and corrasional surfaces can be distinguished, and lithoclasts are common (Tucker, 1974). Expanded pelagic limestones are commonly nodular with interbedded marls, and include resedimented units of various origins.

Phosphorites, black shales and organic-rich limestones are intercalated within the Devonian pelagic limestone successions, indicating that bottom-water hypoxia or anoxia temporarily prevailed. Phosphates and phosphatic hardgrounds locally form thin interbeds within the condensed pelagic limestones deposited between Laurussia and Gondwana (Schönlaub, 1980, 1985; Hüneke, 1995, 1997; Hüsken, 1993; Hüneke and Reich, 2000). The environments of phosphate deposition exhibit very low or zero sediment-accumulation rates and are generally described as areas of current-induced sediment reworking. Phosphates from upwelling-related environments are known in western North America in the northern Sierra Nevada range of California, and the Cordillera of Alberta and southeastern British Columbia. The mode of occurrence of these phosphorites and their association with black shale and chert clearly suggest that they may have formed along the western continental margin of Laurussia that experienced strong equatorial or trade wind belt upwelling (Varga, 1982). Devonian black shales were deposited in a number of settings (Copper, 2002), such as (a) deep marine waters below the continental-margin slope waters in highly stratified oceans below the carbonate compensations depth, (b) tropical back-reef lagoons, (c) wide, rimmed shelf areas within areas of upwelling, or (d) shallow platforms with poor internal circulation. The nutrient-trapping equatorial current system of the globe-encircling Panthalassa ocean was probably anoxic and may have been sulphate-reducing (Jewell, 1995). Nutrient-rich, anoxic water from the undercurrent would have had direct consequences for the genesis of phosphate and black shale facies in Devonian oceanic and epicontinental seaways as well as possibly providing the source water for coastal upwelling. With respect to the oxygen reservoirs, the Panthalassa ocean can be roughly compared to the modern global ocean, whereas the Proto-Tethys basin can be seen as a huge lake, relatively stratified, with less oxygenated conditions as depth increases (Goddéris and Joachimski, 2004).

Devonian pelagic carbonates typically exhibit the continuum of the five major lithofacies categories recognized by Tucker (1990). Pelagic skeletal calcarenites (category E) originated in places where current winnowing removed lime mud, leaving the larger pelagic bioclasts to comprise the sediment. This facies is genetically related to bottom-current deposits, which have been rarely documented in ancient series (see Stow et al., 2002). Because of process interaction and process continuum, their distinction based on sediment characteristics alone will only be possible to a limited extent and requires further work. In addition, there are only a few systematic studies that reveal the chronological and spatial distribution of such current-influenced lithofacies in Devonian pelagic successions (e.g. Franke and Walliser, 1983; Wendt et al., 1984; Wendt, 1991). Contourites is the generally accepted term for those sediments deposited by or significantly affected by the action of bottom currents (Stow et al., 2002).

Based on a combination of sedimentological evidence, facies and microfacies interpretations, taphonomic observations, biostratigraphic age control and correlation, Hüneke (2001, submitted for publication-a,b) presented evidence of fossil bottom-current deposits from different palaeogeographic settings of the oce-