Sedimentologic, Sequence Stratigraphic and Stable Isotopic Study of the Late Cambrian Conococheague Formation, Strasburg, VA

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Abstract

The Late Cambrian Conococheague Limestone near Strasburg, VA, records passive continental margin sedimentation in subtidal, peritidal and supratidal depositional environments. Various short-term cycles, recording rapid sea level changes, are preserved in the outcrop, while the overall increase in sand content of the carbonate sediments upwards in the progression provides evidence for long-term sea level regression (Koerschner and Read, 1998). A general negative-trending $\delta^{13}C$ excursion from +0.7 to -2.7‰ is recorded within the outcrop. High-resolution sampling from the lower stratigraphic section provides a constraint on combined natural and diagenetic variations across the carbonate platform. Based on lithologic, tectonic and temporal similarities, the excursion is most likely equivalent to a Sunwaptan-aged negative $\delta^{13}C$ anomaly, called the HERB event, identified in Australia, Newfoundland, and western North America (Ripperdan et al., 1992; Ripperdan et al., 2002). The C isotope excursion and sea level regression occur during a period of rapid trilobite diversification, further linking strong environmental change with biological evolution. The Sr isotope composition of well-preserved limestone from the sampled outcrop suggests depositional $^{87}Sr/^{86}Sr$ of near 0.70917, which correlates with known Late Cambrian trends to an age of ~500 Ma (Montañez et al., 2000; Ripperdan et al., 1992; Ripperdan, 2002; Saltzman et al., 1998; Ebneth et al., 2001). Sulfur isotopic analyses of structurally bound sulfate in carbonates reveal 34S enrichments of up to +34‰, which match other Late Cambrian bedded sulfates (Claypool et al., 1980) and carbonate associated trace sulfate (Strauss et al., 2000) recording the highest known $\delta^{34}S$ values for the Phanerozoic. Causes of the carbon and sulfur isotope excursions in the Late Cambrian Conococheague Formation and equivalents worldwide are speculative. If primary, these biogeochemical anomalies may be the result of the sudden loss of global oceanic primary productivity (Hoffman et al., 1998), widespread anoxia, and/or rapid deposition of carbonate (Varni, 2002). Given the warm global climate and high sea level, the concentration of continents at low- to mid-latitudes prior to the carbon isotope excursion likely facilitated a change in ocean circulation, which lead to a decrease in oxygen content (Knoll et al., 1996). The coupled anomalies are possibly due to water column bacterial sulfate reduction, which over time would result in ^{13}C depletion in oceanic alkalinity and ^{34}S enrichment in residual seawater sulfate.

Fig. 1. Outcrop photo of subtidal to supratidal cycles in the Late Cambrian Conococheage Formation along the John Marshall Highway near Strasbug, Virginia.

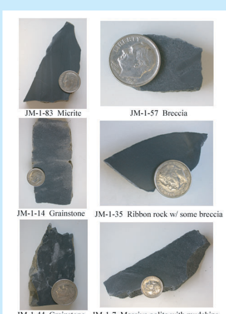

Fig. 2. Polished slabs of Conococheague carbonate lithofacies prior to microdrilling. Darker areas are composed of muddy or silty siliciclastic rich zones that were avoided during sampling.

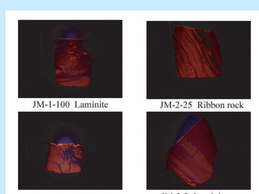

Fig. 3. Catholuminescence photographs of Conococheague carbonates from subtidal and peritidal lithofacies. Carbonates are only moderately luminescent. Drill holes are 1 mm in diameter.

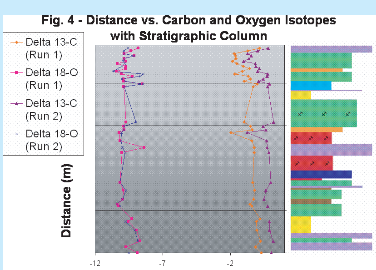

Fig. 4. Stable isotopic compositions of carbonates at the base of the exposed outcrop along the John Marshall Highway. The high resolution sampling of various lithofacies indicates that depositional and diagenetic variability in carbon isotopes is less than 2‰.

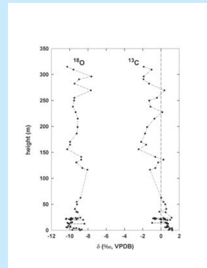

Fig. 5. Carbon and oxygen isotope variations in the Conococheague Formation showing onset of the Late Cambrian negative $\delta^{13}C$ excursion known as the HERB event. The excusion is notably larger than possible depositional and diagenetic variation across the platform recorded in the high resolution sampling from the base of section.

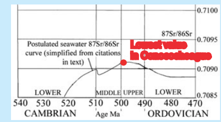

Fig. 6. Known strontium isotope variations in the Late Cambrian period (Ebneth et al., 2001). The lowest $^{87}Sr/^{86}Sr$ determined for the Conococheague falls on the curve at approximately 500 Ma, which is broadly consistent with the known age range of Late Cambrian conodont zones.

Fig. 7. A new calf is born after heavy snows on old MacDonald's Farm, near Strasburg, Virginia

Sulfur isotope composition of trace sulfate in Conococheague carbonates

sample	height (m)	lithofacies	$\delta^{34}S$
JM-1-4	2.7	micrite	+34.39
JM-1-5	3.7	grainstone	+33.06
JM-1-40	14.9	grainstone	+26.23
JM-1-66	21.1	ribbon	+33.06
JM-1-75	23.0	stromatolite	+18.26

Conclusions and a Geochemical Model

Periods of mass extinction, like that evidenced at the end of the Permian (Holser, 1989), have been associated with strong negative carbon isotopic anomalies in seawater proxies. These events have been referred to as Strangelove oceans (Kump, 1991) in that the anomalies suggest a significant loss of primary photosynthetic inputs to the deep ocean, which in turn causes chemical changes in the whole ocean. Mass extinction of animals, including episodic losses of trilobite species in the Cambrian Period (Saltzman et al., 2000), may also be linked to environmental changes that are reflected in negative carbon isotope anomalies due to mass mortality of primary producers.

The carbon and oxygen data together with the age constraint provided by the Sr analysis provide substantial evidence for a negative-trending excursion consistent with the Late Cambrian HERB event. The high-resolution stratigraphy at the base of the outcrop provides a constraint on depositional and diagenetic values. Furthermore, the concentrations of the continents at low- to mid-latitudes, a warm global climate, and high sea level prior to the excursion all suggest that the Conococheague formed during a widespread oceanic anoxic event (OAE).

The coupled C and S isotope anomalies during the HERB event are also likely related to an OAE. Lower productivity would result in attenuated oxygen fluxes to the oceans and atmosphere. Anoxia would facilitate water column dominance of bacterial sulfate reducers, similar to that in the present day Black Sea (Varni, 2002). Long term sulfate reduction in an anoxic deep ocean with abundant iron would cause seawater alkalinity to become increasingly ^{13}C depleted and residual sulfate ^{34}S enriched. Notably, at the onset of the HERB event in the Conococheague Formation, trace sulfate is anomalously enriched in ^{34}S, matching that of Late Cambrian bedded sulfate (Claypool et al., 1980).

One possible model for the coupled biogeochemical events includes:

1. High productivity followed by mass extinction of primary photoautotrophs in the preceding SPICE event.

2. Lowering of oceanic O_2 levels due to restricted circulation and loss of photosynthetic input.

3. Widespread oceanic anoxia allowing bacterial sulfate reducers to populate the water column during the HERB event.

4. Sulfate reduction resulting in the production of ^{13}C depleted alkalinity and ^{32}S enriched sulfide, which would bind with available iron to form insoluble pyrite.

$$C_{106}H_{263}O_{110}N_{16}P + 53SO_4^{2-} + 39CO_2 + 67HCO_3^- + 16NH_4^+ + HPO_4^{2-} + 53HS^- + 39H_2O$$

5. Carbonate precipitated under these conditions is predicted to have negative $\delta^{13}C$ values and residual seawater sulfate, which would be preserved as trace sulfate in the carbonate with ^{34}S enrichment, as observed.

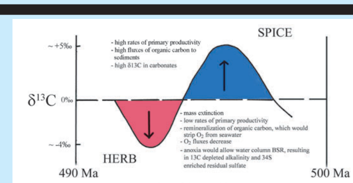

Fig. 8. A geochemical model of Late Cambrian C and S isotope excursions associated with the Conococheague Formation.