Geochemical and sedimentary records across Precambrian/Cambrian boundary, Elburz Mountains, North Iran: implications for a breakup of ocean stratification before the Cambrian Explosion

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Geological Setting: Complete upper Proterozoic to lower Cambrian successions are exposed in the Elburz Mountains, North Iran (Hamdi et al., 1989; Matsumoto et al., 1995). The successions consist of Dolomite Members and Shale Members.

Dolomite Members consist mainly of dolomite, and are characterized by microbial mat sediments, tempestite, rhythmic lamination produced by tidal currents, and gypsiferous horizons, which indicate a shallow water tidal flat environment. Shale Members consist mainly of shale which rhythmically contains carbonate layers. Shale members are characterized by slumps and micritic carbonate formed in an open marine subtidal environment in relatively deep water near the shelf break. Shale just below the PC/C boundary is characterized by organic-rich dark gray shale and abundant acritarchs (phytoplankton). The horizon on the lower Tommotian of Lower Cambrian is characterized by shale with white-weathering which reflects high phosphate contents, and also characterized by phosphate-rich carbonate associated with iron oxides and cherts. Small shelly fossils that first appear in the Vendian increase in frequency just above the boundary. Their highest abundance is in the phosphatic horizon. There is also a marked increase of trace fossils in both frequency and size near the boundary, however they can be identified only in the shale, which makes it difficult to identify the timing of the increase.

Results: These isotopic and chemical profiles show the same stratigraphic variations in both sections as follows. The strong negative shift up to -15‰ and then rapid increase of δ¹³C below the boundary is associated with high concentrations of manganese, phosphorus, and barium in shales. The second positive excursion of δ¹³C on the Tommotian is associated with a high concentration of phosphorus and also moderately high concentrations of manganese. The general pattern of δ¹³C fluctuates around -2‰ with low amplitudes in the LDM. In the Cambrian strata, on the contrary, δ¹³C fluctuates around +1‰ with high amplitudes, and the four positive excursions also show upsection increases in both amplitudes and periods. Barium is generally more enriched in the LSM than in the USM. These chemical and isotopic anomalies are also associated with the following changes in lithology and in fossil occurrences in the Iranian sections. The strong negative excursion of δ¹³C at the end of Precambrian is associated with carbonaceous shale and abundant acritarchs. The second positive excursion of δ¹³C in the Tommotian stage is associated with the maximum occurrences of phosphorites and small shelly fossils.

Discussion: Diagenetic effects on δ¹³C carb did not significantly alter original carbon isotopic ratios, and the strong negative excursion below the boundary is a global event (Kimura et al., submitted). The negative δ¹³C excursion associated with abundant phytoplankton fossils, high concentrations of P, Mn, and Ba, and the carbonaceous shale indicates mixing of surface water and deep water as follows. A global warm climate (Green House condition) is inferred from the paucity of glacial deposits after the last Precambrian glaciation (Meert and Voo, 1994). During the Green House Earth, the latitudinal thermal gradient was small and oceanic circulation is not as vigorous as present-day (Tucker, 1992). Organic matter produced by photosynthesis in the surface photic zone was bacterially degraded during passage to the sea floor. The transportation of organic matter from surface to deep water resulted in preservation in deep water of abundant dissolved carbon and nutrient-related elements including phosphorus and barium. δ¹³C TDC in deep water is negative which reflects extremely negative organic-derived CO₂. The consumption of oxygen in the...
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deep water by degradation of organic matter accelerated formation of anoxic or dysonic bottom water. Manganese is highly soluble as Mn$^{2+}$ under dysonic conditions, which leads to high concentration of dissolved manganese in deep water. Thereby nutrient enriched dysonic deep water masses developed below oxic surface water. Sudden breakup of the stratified ocean caused the following changes which are recorded in the horizon just below the PC/C boundary. (1) $\delta^{13}$C$_{\text{carb}}$ precipitated in shallow water shows a strong negative excursion due to contributions of CO$_2$ having the extremely negative values derived from deep water. (2) The deep water-derived manganese and barium precipitated as oxide and sulfate, respectively in the oxic surface environment, which resulted their high concentrations in sediments deposited in shallow water environments. (3) Phytoplankton in the photic zone flourished because of upwelled nutrient-enriched deep water, which resulted in carbonaceous sediments and occurrences of its abundant fossils. A possible analogous oceanic condition is the present-day Black Sea. Our model of the breakup of ocean stratification is therefore consistent with all of our data of $\delta^{13}$C, chemical anomaly, carbonaceous shale, and abundant phytoplankton fossil. Metazoa live in oxic conditions above 1% PAL $P_O_2$ in present-day (Knoll, 1992), which implies that the low oxygen level in Precambrian restricted metazoan evolution. Increased organic burial where the negative $\delta^{13}$C excursion occurs below the PC/C boundary means increased free oxygen production rate, which may have contributed to increased atmospheric oxygen. Explosive diversification began at the lowest Cambrian just above the negative excursion of $\delta^{13}$C. This is interpreted to mean that low $P_O_2$ conditions that had suppressed Metazoan evolution during Proterozoic era were lost. We conclude that the "Cambrian Explosion" was initiated by the breakup of ocean stratification at the end of Precambrian.

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