Redox variations indicated from rare earth elements of the authigenic carbonates from cold seeps of the Gulf of Mexico

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The anaerobic oxidation of methane (AOM), which is mediated by consortia of methane-oxidizing archaea and sulfate-reducing bacteria, is the key biogeochemical process at cold seeps. This process leads to an increase of carbonate alkalinity and consequently the precipitation of carbonate minerals. The AOM leads to sulfate depletion in sediment pore water, which induces a change in redox conditions. Rare earth elements (REE) of seep carbonates that as an reliable indicator of this redox variations.

The total REE of the matrix of the carbonate samples from Bush Hill (GC 185), Alaminos Canyon lease area 645 (AC 645), and Green Canyon lease area 238 (GC 238) is from 7.1 to 20.8 ppm, which is higher than that of cements and bivalve shells ranging from 0.4 to 3.1 ppm.

The shale-normalized REE patterns of two Bush Hill seep carbonate samples show pronounced negative Ce anomalies, suggesting precipitated under oxic conditions. However, the patterns of the other five seep carbonate samples show no or slightly positive Ce anomalies, indicating formed under anoxic conditions. Thus, it seems that the redox conditions at Bush Hill seep site is variable spatially. The shale-normalized REE patterns of the seep carbonate from GC 238 shows no Ce anomaly, indicating formed under reduced condition. In contrast, all samples including the matrix, cement, and bivalve shell from AC 645 all show pronounced negative Ce anomalies, indicating that the formation condition for Alaminos Canyon seep carbonates is distinct oxic.

Overall, our results show that apart from anoxic, oxic conditions are common at seep environments. It is suggested from our data that formation conditions of authigenic carbonates at cold seeps are variable and complex.

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