Pb isotopes in Circum-Antarctic Mn nodules: a tracer of oceanic circulation?

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Introduction

The degree that isotope ratios of trace elements vary geographically within the oceans to a large extent reflects their residence times. Nd isotope ratios are distinct in different oceans but nearly uniform within each ocean (Piepgras *et al.*, 1979; Goldstein and O'Nions, 1981) reflecting a residence time longer than the mixing time of individual oceans but shorter than the whole ocean ($\sim$1500yrs) (Elderfield and Greaves, 1982). Pb has a residence time about an order of magnitude shorter than Nd, about 80–100 yrs (Craig *et al.*, 1973). Because of their short but different oceanic residence time, Pb and Nd are useful to study mixing processes involved in the oceans through water masses movement. Sr and Nd isotopic studies of Mn nodules have shown that these trace elements are primarily derived from ambient seawater and is likely also to hold for Pb. Since the pioneering studies of Chow and Patterson (1959; 1962), few Pb isotopic data have been reported on marine Mn nodules, although Pb is the most sensitive to variations in local inputs and changes through time.

We report Pb isotope ratios of Mn nodules from the Circum-Antarctic ocean, which is the link between the Atlantic, Indian and Pacific through the Antarctic Circumpolar Current (AAC) which flows eastward around Antarctica.

Results

Pb isotopes in Mn nodules display large-scale isotopic variations, with lower Pb isotopic ratios in the Pacific sector ($^{206}Pb/^{204}Pb$ = 18.7–18.9) compared to those in the Atlantic-Indian sectors ($^{206}Pb/^{204}Pb$ = 18.7–19.1). This distinction is consistent with the subdivision of the Circum-Antarctic ocean into two large geographical Nd isotopic domains, one south of the Pacific and one south of the Atlantic and Indian oceans (Albarède and Goldstein, 1992). However, in contrast to Nd isotopes, Pb isotope ratios show regular fine-scale geographical variations within each domain, characterized by a gradual eastward decrease through the Pacific followed by an increase starting at around 30°W in the southwest Atlantic into the eastern Atlantic and Indian sectors. Pb isotope ratios also show positive correlations with an eastward evolution from nearly MORB-like Pb isotopic ratios in the eastern Pacific sector toward continental-type in the Atlantic-Indian sectors.

Discussion

The geographical distribution of Pb isotopic variations reflect the variability of continental fluxes to the oceans and progressive variations in the local sources of Pb. Both particulates fluxes around the Circum-Antarctic and the oceanic circulation could explain the isotopic features of the Mn nodules. The relationships between Pb and Nd isotopic ratios provide constraints on the processes controlling these elements. In the Pacific sector, absence of a clear correlation between the Pb and Nd isotopic ratios combined to the low eolian flux indicates that Pb and Nd are not controlled by local particulates but rather vary independently as a result of their short and different residence times. In contrast, the systematic geographical covariations of Pb and Nd isotope ratios in the Atlantic-Indian sectors are consistent with control by local particulates added to the water column. The geographical variation of Pb and Nd isotopic ratios might also be explained through mixing of water masses (Fig. 1). The AAC is continuously renewed by North Atlantic Deep Water (NADW) added at the Argentine Basin. The similarity of Pb and Nd isotopic ratios from the eastern Pacific and the SW Atlantic suggest that the route of return flow into the Northern Atlantic to feed NADW production is accomplished via the Drake Passage. The crustal Pb and Nd isotopic signature of the eastern Atlantic and Indian Mn nodules is consistent with the addition of NADW, a potential source of unradiogenic Nd, to the Circumpolar Ocean. A common control of Pb and Nd by water masses is indicated by the striking similarity between Nd isotopes in the nodules and water masses at corresponding depths observed along a profile at 35°E, south of Africa and Madagascar. Inferring the Pb isotopic characteristics of the water masses, we estimate that 70% of NADW+Weddel Sea

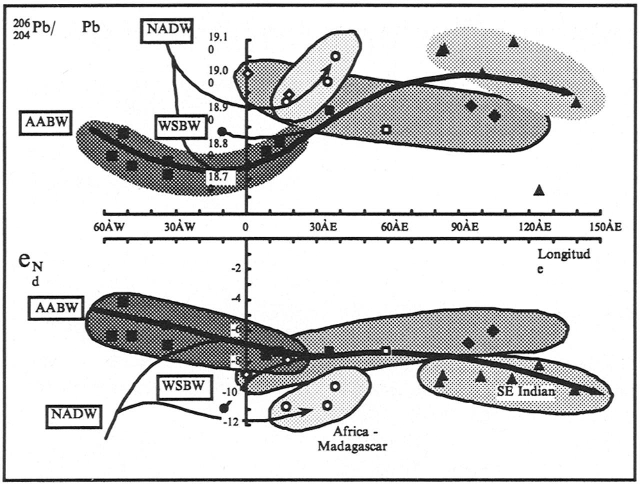

FIG. 1. εNd and $^{206}Pb/^{204}Pb$ variations with longitude showing the possible relationships of isotopic provinces in the Atlantic-Indian sector to oceanic circulation. Antarctic Bottom water (AABW) flowing eastward through Drake Passage into the SW Atlantic is altered near 0° longitude by mixing with North Atlantic Deep Water (NADW), flowing southward, and Weddell Sea Bottom Water (WSBW) flowing northward. Both of these water masses have similar, low ε_{Nd}. However, NADW has higher $^{206}Pb/^{204}Pb$ than WSBW, which is higher than the AABW. Thus addition of NADW results in lower ε_{Nd} and higher $^{206}Pb/^{204}Pb$ ratios in the SE Atlantic and Africa-Madagascar provinces where it is then blocked by the Madagascar Ridge, as well as in the Circum-Antarctic. The effect of addition of WSBW shows up more strongly in the south. The addition of these water masses results mainly in higher Pb isotope ratios compared to the SW Atlantic province. Nd isotope ratios of the water masses are from Piepgras and Wasserburg (1980; 1982) Pb isotope ratios of the water masses are inferred from our data.

Bottom Water (ε_{Nd} = –12; $^{207}Pb/^{204}Pb$ = 15.69) and 30% of PDW (ε_{Nd} = –3; $^{207}Pb/^{204}Pb$ = 15.61) contribute to the formation of AABW (Antarctic Bottom Water) (ε_{Nd} = –9; $^{207}Pb/^{204}Pb$ = 15.67), in agreement with the estimate of Piepgras and Wasserburg (1982). However, glacial-interglacial changes have affected these proportions. The high ε_{Nd} values of Mn nodules from the Pacific and SW Atlantic compared to the present-day ε_{Nd} value (–9) of AABW may reflect growth of Mn oxides layers during glacial intervals.

Conclusion

We conclude that Pb isotopic variations in Circum-Antarctic Mn nodules mirror the integrated evolution of Circum-Antarctic water. Despite major glacial-interglacial reorganizations, particulate flux and bottom water circulation has been, on average, stable through the Pleistocene. A similar conclusion was reached by AlbarÅde and Goldstein (1992) based on Nd isotopes. Moreover, the short residence time of Pb makes it a potentially powerful tool to investigate the effects of changes in Pleistocene-Holocene ocean circulation through glacial-interglacial periods.

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