Cosmic dust: Terrestrial accretion rate and solubility in seawater

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Introduction

The Os-isotopic composition of seawater is influenced by three sources: Continental runoff, alteration of oceanic crust, and cosmic dust. We evaluate the importance of the latter by comparing the Os-isotope evolution of seawater, the flux of cosmic dust through time, and differences between the cosmic dust flux-estimates to the Earth's surface and the flux to the deep sea.

Methods and results

We have measured Os-isotope ratios and Os concentrations of bulk pelagic sediments and the hydrogenous (seawater-derived) fraction from DSDP site 596 and other Pacific DSDP/ODP sediments, spanning the past 80 million years. These new data exhibit a general increase in the $^{187}Os/^{186}Os$ of seawater since the K-T boundary, confirming the general shape of the previously reported Cenozoic seawater Os curve (Pegram *et al.*, 1992; Ravizza *et al.*, 1993). In addition these data, in conjunction with Os isotope mass balance calculations, constrain past variations in the terrestrial accretion rate of cosmic dust during the Cenozoic. The model calculations indicate a nearly constant flux which is similar to Os-based estimates from analyses of recent pelagic clays. This stands in marked contrast to the pronounced minimum in the Os isotope ratio of seawater and large cosmic flux inferred from K-T boundary samples. Both the K-T noble metal spike and the constancy of Cenozoic cosmic dust flux are consistent with Ir data from pelagic clays (Kyte and Wasson, 1986). However, the average cosmic dust flux based on Os isotope data (35000 ± 12000 tons/a) is much lower than the Ir-based estimates (96000 ± 32000 tons/a), suggesting that underestimation of terrestrial Ir accumulation in pelagic clays biases Ir-based cosmic dust flux estimates toward high values.

Fig. 1 shows compiled and standardized literature estimates of cosmic dust flux from both the deep sea (filled symbols) and the Earth's surface (open symbols), which can be used to assess the extent of cosmic dust dissolution in seawater or in the sedimentary pile. Various techniques such as mechanical separation of cosmic spherules from sediments or ice, direct space observations and particle collection, trace elements and isotope tracers have been used in more than 50 studies (numbers on the x-axis refer to references below the diagram) to estimate the cosmic flux. Mechanical separations often yield lower bounds (upright triangles) because isolation of all cosmic particles from sediments is impossible. In contrast, some chemical tracers such as Ni give upper bounds (inverted triangles) because the terrestrial contribution is underestimated. The most reasonable flux estimates converge at about 20000 to 60000 tons of cosmic matter accreted each year to the surface as well as the deep sea. Thus, the compiled data do not yield clear evidence supporting significant dissolution.

Discussion

The decrease in the marine $^{187}Os/^{186}Os$ at the K-T boundary, the rarity of glassy and the predominance of iron spherules in deep sea sediments compared with surface deposits argue for some dissolution of cosmic material and - probably - for some effect on the $^{187}Os/^{186}Os$ of seawater.

The K-T event represents an exceptional 'worst-case' because of the enormous amount of cosmic Os (about 5×10^{11}g Os) accreted on the Earth and the possibility that K-T debris is compositionally anomalous. Considerable variation in the marine Os-isotope record and constancy of the terrestrial accretion rate of cosmic dust over the past 80 million years (except during the K-T event) clearly demonstrate that dissolution of cosmic dust is not a driving force in the Os-isotope record of seawater. This is confirmed by the compilation of literature data on the surface and deep sea flux of cosmic dust. The

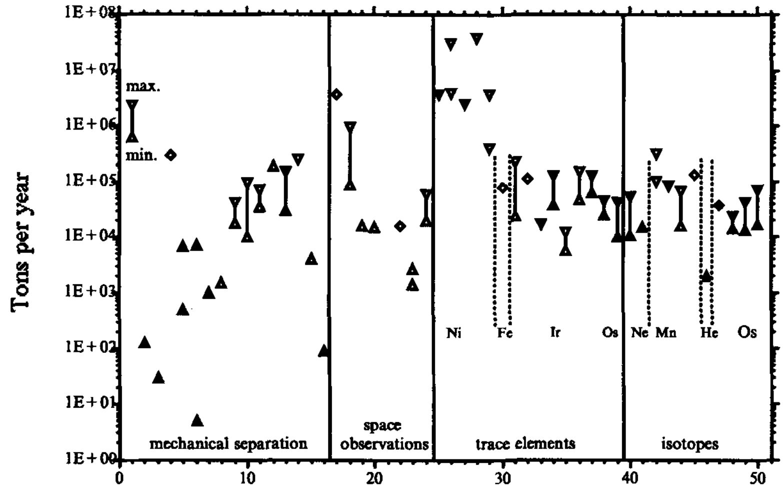

FIG. 1.

1: Thomsen (1953), 2: Laevastu & Mellis (1955), 3: Bruun et al. (1955), 4: Hodge & Wildt (1958), 5: Peng et al. (1989), 6: Peng & Lui (1989), 7: Yiou & Raisbeck (1987), 8: Yiou et al. (1989), 9: Crozier et al. (1966), 10: Crozier et al. (1966, all years), 11: Buddhue (1950), 12: Thiel & Schmidt (1961), 13: Crozier (1960), 14: Norris & Hogg (1949), 15: Maurette et al. (1987), 16: Murell et al. (1980) 17: Alexander et al. (1962), 18: van de Hulst (1947), 19: Hughes (1978), 20: Grn et al. (1985), 21: pik (1956), 22: Plane et al. (1991), 23: Kane & Gardner (1993), 24: Love & Brownlee (1993), 25: Bonner & Lourenco (1965), 26: LaViolette (1985), 27: Pettersson & Rotschi (1952), 28: Pettersson (1958), 29: Brocas & Picciotto (1967), 30: Hanappe et al. (1968), 31: Shedlovsky & Paisley (1966), 32: Crocket & Kuo (1979), 33: Harriss et al. (1968), 34: Barker & Anders (1968, Ir), 35: Tuncel & Zoller (1987), 36: Ganapathy (1983), 37: Kyte & Wasson (1986), 38: Barker & Anders (1968, pooled Ir), 39: Barker & Anders (1968, Os), 40: Allegre et al. (1993), 41: Anufriyev et al. (1977), 42: McCorkell et al. (1967), 43: Imamura et al. (1978), 44: Imamura et al. (1979), 45: Bibron et al. (1974), 46: Ozima et al. (1984), 47: Esser & Turekian (1988, 1993), 48: Ravizza & McMurtry (1993), 49: Os-isotope data from GPC-3 (Pegram et al., 1992), 50: Os-isotope data from DSDP 596 (Peucker-Ehrenbrink et al., unpublished).

general agreement of both fluxes places limits on the dissolution in seawater. The most reasonable flux-estimates converge at about 40000 ($\pm$20000) tons per year. Thus, the dissolved fraction must fall within the uncertainty of these estimates and probably does not exceed 20000 tons per year. Assuming chondritic composition, this equals about 1 $\times$ 10^4 g soluble cosmic Os per year. In order to compare this upper limit for the soluble cosmic flux with an estimate of the present-day annual riverine dissolved Os flux, we assume an annual riverine suspended matter flux of $1x10^{16}$ g (Milliman and Syvitsky, 1992) and a mean Os concentration for continent-derived material of 0.05 ng/g (Esser and Turekian, 1993). With this, the global riverine flux is about $5x10^4$ g Os/a, if 10% of the riverine Os is soluble.

Assuming present-day seawater to be a mixture of 5/6 continental runoff ($^{187}Os/^{186}Os$ of about 15) and 1/6 cosmic matter ($^{187}Os/^{186}Os$ of about 1.1), the $^{187}Os/^{186}Os$ would be about 12.7, much higher than the inferred value of 8.6. We cross-check this estimate by considering the present-day mass balance of Os in seawater. Today's seawater is a mixture of continent-derived Os and unradiogenic cosmic and mantle-derived Os ($^{187}Os/^{186}Os$ of about 1.1). The maximum cosmic input can be calculated assuming no mantle-derived input. With this, 90000 tons of cosmic dust must dissolve in seawater each year to balance continental runoff. This value is much too high to be consistent with flux-estimates compiled from the literature and argues for a significant mantle-derived input of Os to seawater. Therefore, we conclude that continental runoff is the main forcing of the Os-isotope evolution of seawater and that alteration of oceanic crust, either by high-temperature hydrothermal convection or low-temperature alteration of marine peridotites, is more important in balancing radiogenic continental runoff than dissolution of cosmic dust.

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