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Trace elements deposited with dusts in Southwestern U.S. - -enrichments, fluxes, comparison with records from elsewhere

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Introduction

Modern dusts in the Southwestern U.S. commonly contain, or are accompanied by, larger amounts of ordinarily-rare trace elements than can be explained by the compositions of the common minerals that constitute the dusts, or by the average composition of the earth's crust. Records of deposition of dusts and trace elements from other places and other times give a similar picture (pre-industrial dusts preserved in Antarctic ice, and central European peat bog records). The degrees of enrichment ("enrichment factors") of trace elements in the ancient dusts from those other places, and fine-grained modern dusts from the SW U.S., are similar. In addition to knowing the degrees of enrichment, it is necessary to calculate the amounts of excess trace elements deposited per unit area over time (mass fluxes) as they accompany the dusts, to allow evaluation of the consistency of "source strengths" of trace element supply, through time and across regions. This comparison can be made between regions of the earth, and between pre-industrial and modern times. It is then possible to compare the calculated source strengths with known sources of trace elements to the atmosphere, such as volcanic emissions.

The ordinarily-rare trace elements Pb, Cd, Cu, Se, and others are among those that are present in excess amounts in modern dusts deposited from the atmosphere, and modern atmospheric load material, relative to the rocks and soils that are the sources of the bulk of the dusts (Bowen, 1979). It has been a question whether this enrichment is due to natural processes, or industrial processes, or some combination (Duce et al., 1975; Weiss et al., 1978; Heidam, 1985; Mart, 1983; ref's therein). Analyses of modern dusts we collected in the Southwestern U.S. over several years confirm that many trace elements (Zn, Cu, Pb, Cd, As, Se, Sb, Bi) are much more abundant in at least finer-grained dusts than in the average crust of the earth.

Besides the information from the Southwestern U.S., there are two other studies that contain information on amounts of dust and their accompanying trace elements, and that present or allow extraction of information about the flux rates: a study of dusts in Antarctic ice representing pre-industrial atmospheric deposition (Matsumoto and Hinkley, 2001), and a study of long-term deposition in European peat bogs (Shotyk et al., 2002). In addition, there is a new estimate of the source strength of trace elements from worldwide volcano emissions (Hinkley et al, 1999), one of the natural sources of trace elements to the atmospheric load.

Methods

To obtain winter-season, high-altitude dust, snow pack strata were collected each early Spring from 1997 to 2002 in the Southwestern U.S., under clean conditions. For year-around, low-elevation dust, dry-deposition samples were collected on greased glass plates. Snow samples were reduced in volume in the laboratory under flowing filtered nitrogen, and both kinds of samples were digested and analyzed for a major, minor and trace elements by ICP-MS. Masses of dusts in samples were estimated by summing the masses, as oxides, of elements measured in bulk analyses. Calculations of "enrichment factors" of elements were done by comparing the concentration of an element in dust in a sample to the concentration in average crustal material. Mineral identity, grain size and shape, and an independent check on flux rate and bulk composition were provided by microbeam (SEM) methods.

Results and discussion

SEM analyses of samples indicate that the dusts are composed of common minerals (quartz, feldspars, micas, clays, carbonates; small amounts of pyroxenes and amphiboles; smaller amounts of accessory minerals such as zircon and rare earth minerals; also pollen grains), and that the mode (assemblage of actual mineral species present) is consistent with the bulk chemical results.

In dusts in the U.S. Southwest, "enrichment factors" for trace elements (the factor by which the concentration of an element is greater than in the average crust of the earth) are commonly between 10 and 100, although they range by element and by sample type. Enrichment factors are especially high in finer-grained, farther transported dusts, namely dust in snow pack strata with low concentrations of dust, and in dry deposition samples in which only small amounts of dust are deposited on collection plates per unit time. As for the pre-industrial dust in polar ice and the European peat bog deposits, enrichment factors commonly range between about 10 and more than 100. The polar dust is clearly fine-grained and far-transported, the peat bog dust may be a mixture of near-source and far-transported dust.

A possible argument to dismiss the observed similarity in degree of trace element enrichment in modern SW U.S. dust and pre-industrial Antarctic or European peat bog dusts is that polar dusts and dusts over heavily-vegetated Europe, being fine-grained (large surface/mass ratio) and far-transported, must have been enriched to the maximum extent, because of "exposure" time during atmospheric transport; but that dusts within the dry US Southwest (possibly coarser, more locally transported) could have acquired equivalent amounts of trace elements only if a supplementary (modern; anthropogenic or unique local) source were available. However, this argument cannot be evaluated at present because it is not clear that either of the older dusts had finer grain size than the fine component of U.S. SW dust, and it is not clear that either kind of dust has been transported over greater distances, because it has been shown that fine-grained dusts of uniform composition appear to constitute a hemispheric or global background atmospheric load, which can be identified at low-energy times at both polar and dusty continental interior sites of deposition (Hinkley et al., 1997). The worldwide, "background" atmospheric dust is not dependent on local source regions (Hinkley et al., 1997). This fine dust may be a scavenger of trace metals (possibly from natural sources) during its long residence in the atmosphere, and may account for a large portion of the universality of trace element enrichments in dust.

Industrial trace metal pollution has been documented in northern polar and even Antarctic ice (Sherrel et al., 2000; Rosman et al., 1994). However, these modern increases in elemental inputs have been stated only as concentrations in ice, not as changes in "enrichment factors" of the dusts present in the ice, partly because reliable measurements of both dust content and trace element content have not been made together in the same studies. Those studies, and other documented trace metal pollution in the world today suggest that trace element loadings of S.W. US dusts have likely increased in modern industrial times, but the extent is unknown. Local terranes have been proposed as sources of trace element enrichment for some S.W. dusts collected in specific nearby regions (Reheis et al, 2002).

Conclusions

The finer-grained component of atmospheric dusts in the Southwestern U.S. is significantly "enriched" in many ordinarily -rare trace elements, commonly to factors of 10-100 above the amounts that would be expected if the sources were unaltered average crustal material. This degree of enrichment in dusts in the SW U.S. is about the same as in pre-industrial dusts preserved in Antarctic ice and in European peat bogs, which have natural sources of enrichment. The similar levels of trace element enrichment of the of dusts from the two very different times and among the three locations appear to indicate that naturally-high amounts of trace elements, as seen in the pre-industrial samples, are at the very least a significant component of what is seen today in dust in the Southwest, and that the trace element loads of the modern and ancient dust are indistinguishable at present state of knowledge. The remaining task is to compare the absolute fluxes of key trace elements (mass deposited per unit area per unit time) for such different locations and the different time periods they represent.

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