given evidence for the increased solubility of actinides in oxidation states IV, V, and VI as a result of CO_3^{2-} complexation. We have attempted to quantify the effect of CO_3^{2-} complexing through the use of computer models but have been frustrated by the lack of suitable thermodynamic data on actinide complexes. Simulations of the solution equilibrium chemistry by means of the computer program MINEQL (*20*), incorporating removal processes similar to those in the ocean (*2*), were made with and without the effect of CO_3^{2-} complexing. Let us consider the case of thorium, for which the solubilizing effect is largest (Table 1). In the absence of CO_3^{2-} complexing, the dominant thorium species is $Th(OH)_4$ (*21*), which would lead to rapid removal by adsorption. The simplest carbonate species we could invoke which would compete effectively with $Th(OH)_4$ is $Th(CO_3)(OH)_2$. If we assign $\log K = 6$ for the formation constant of this species, then 98 percent of the dissolved thorium would be in this form. Our educated guess is that this is a lower limit and that $\log K > 6$ is likely.

We believe, therefore, that the elevated concentrations of actinides in Mono Lake could be maintained largely by complexation with CO_3^{2-}. Other ligands may also be important. The effective solubilities of actinides in oxidation states IV, V, and possibly VI in this lake are greatly enhanced relative to seawater by complexation with natural ligands at the concentrations found in Mono Lake. The solubilities of trivalent actinides are not as strongly enhanced. The marked solubilizing effect of natural alkaline brines on the actinide elements has important implications for the management of radioactive waste and its transport in ground water. Our ability to model this effect would be greatly enhanced by the availability of thermodynamic data on actinide carbonate species.

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References and Notes

1. V. M. Goldschmidt, *Geochemistry* (Clarendon, Oxford, 1954); K. B. Krauskopf, *Geochim. Cosmochim. Acta* **9**, 1 (1956); K. K. Turekian, *ibid.* **41**, 1139 (1977).
2. P. W. Schindler, *Thalassia Jugosl.* **11**, 101 (1975); L. Balistrieri, P. G. Brewer, J. W. Murray, *Deep-Sea Res.* **28A**, 101 (1981).
3. H. C. Whitehead and J. H. Feth, *Geol. Soc. Am. Bull.* **72**, 1421 (1961); H. J. Simpson and T. Takahashi, *Init. Rep. Deep Sea Drill. Proj.* **20**, 877 (1973).
4. H. J. Simpson, R. M. Trier, C. R. Olson, D. E. Hammond, A. Ege, L. Miller, J. M. Melack, *Science* **207**, 1071 (1980).
5. J. B. Andelmann and T. C. Rozzell, in *Radionuclides in the Environment*, R. F. Gould, Ed. (American Chemical Society, Washington, D.C., 1970), pp. 118–137.
6. C. N. Murray and R. Fukai, in *Impacts of Nuclear Releases into the Environment* (International Atomic Energy Agency, Vienna, 1975), pp. 179–192; D. M. Nelson and M. B. Lovett, *Nature (London)* **276**, 599 (1978); J. M. Cleveland, in *Chemical Modeling in Aqueous Systems: Speciation, Sorption, Solubility, and Kinetics*, E. A. Jenne, Ed. (Symposium Series 93, American Chemical Society, Washington, D.C., 1979), pp. 321–338; E. A. Bondietti and J. R. Trabalka, *Radiochem. Radioanal. Lett.* **42**, 169 (1980).
7. F. P. Cotton and G. Wilkinson, *Advanced Inorganic Chemistry* (Interscience, New York, ed. 3, 1972).
8. The concentrations of actinides in Table 1 are lower than those reported by H. J. Simpson *et al.*, *Science* **216**, 512 (1982). Our sample, taken near the edge of Mono Lake, was apparently diluted with fresh water from a nearby spring. The sample had a chlorinity of 13.2 per mil as compared with an average chlorinity of ~ 20 per mil for the samples taken by Simpson *et al.* from the center of the lake. The concentrations of actinides in Table 1 normalized to a chlorinity of 20 per mil are in good agreement with the concentrations determined by Simpson *et al.* The major conclusions of this report are not changed by the fact that our sample was diluted with fresh water. Furthermore, the values of τ_{Th} and τ_{Pa} are unaffected by this dilution since they are calculated from the $^{230}Th/^{234}U$ and $^{231}Pa/^{235}U$ ratios, respectively. We learned of the full extent of the work of Simpson *et al.* on the isotopes of the uranium and thorium series in Mono Lake after the initial draft of this report had been prepared. This report and the accompanying one by Simpson *et al.* were written without reference to each other in order to identify the original contributions of each group.
9. R. F. Anderson, thesis, Woods Hole Oceanographic Institution–Massachusetts Institute of Technology (1981).
10. D. W. Scholl, R. Von Huene, P. St. Amand, J. B. Ridlon, *Geol. Soc. Am. Bull.* **78**, 583 (1967).
11. W. S. Moore and W. M. Sackett, *J. Geophys. Res.* **69**, 5401 (1964).
12. B. L. K. Somayajulu and E. D. Goldberg, *Earth Planet. Sci. Lett.* **1**, 102 (1966).
13. P. G. Brewer, Y. Nozaki, D. W. Spencer, A. P. Fleer, *J. Mar. Res.* **38**, 703 (1980).
14. W. S. Broecker, A. Kaufman, R. M. Trier, *Earth Planet. Sci. Lett.* **20**, 35 (1973); E. Matsumoto, *Geochim. Cosmochim. Acta* **39**, 205 (1975); Y. H. Li, H. W. Feely, J. R. Toggweiler, *Deep-Sea Res.* **27A**, 545 (1980).
15. K. G. Knauss, T. L. Ku, W. S. Moore, *Earth Planet. Sci. Lett.* **39**, 235 (1978).
16. R. Aller and J. K. Cochran, *ibid.* **29**, 37 (1976); Y. H. Li, H. W. Feely, P. H. Santschi, *ibid.* **42**, 13 (1979); P. H. Santschi, Y. H. Li, J. Bell, *ibid.* **45**, 201 (1979); M. Minagawa and S. Tsunogai, *ibid.* **47**, 51 (1980).
17. H. D. Livingston, D. L. Schneider, V. T. Bowen, *ibid.* **25**, 361 (1975).
18. H. D. Livingston and V. T. Bowen, in *Environmental Toxicity of Aquatic Radionuclides: Models and Mechanisms* (Ann Arbor Science, Ann Arbor, Mich., 1976), p. 107.
19. M. H. Kurbatov, H. B. Webster, J. O. Kurbatov, *J. Phys. Colloid Chem.* **54**, 1239 (1950); M. R. Scott, unpublished results; I. E. Starik and L. B. Kolyadnin, *Geochemistry* **2**, 245 (1957); D. Langmuir, *Geochim. Cosmochim. Acta* **42**, 547 (1978).
20. J. C. Westall, J. L. Zachary, F. M. M. Morel, *Technical Note 18* (Water Quality Laboratory, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, 1976); in our calculations we assumed a CO_3^{2-} concentration of 0.187*M* and a *p*H of 10 (*3*).
21. C. F. Baes, Jr., and R. E. Mesmer, *The Hydrolysis of Cations* (Wiley, New York, 1976).
22. A. Kaufman, *Geochim. Cosmochim. Acta* **33**, 717 (1969).
23. T. L. Ku, K. G. Knauss, G. G. Mathieu, *Deep-Sea Res.* **24**, 1005 (1977).
24. V. T. Bowen, V. E. Noshkin, H. D. Livingston, H. L. Volchok, *Earth Planet. Sci. Lett.* **49**, 411 (1980).
25. Discussions with H. D. Livingston during the early stages of this work led to the inclusion of plutonium and americium measurements in this study. We thank L. Surprenant for performing the ^{241}Am analysis. H. J. Simpson arranged for the comparison of the chlorinity of our sample with that of the samples analyzed by Simpson *et al.* (*8*). S. Smith assisted with the use of the MINEQL program calculations. Financial support was provided by NSF grant OCE 78-26318, Department of Energy contract EY-76-S-02-3566, and a fellowship to R.F.A., from the Woods Hole Oceanographic Institution Education Office. This is Woods Hole Oceanographic Institution Contribution 4962.
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14 September 1981; revised 29 December 1981

Deep Advective Transport of Lithogenic Particles in Panama Basin

Abstract. *Sediment traps were deployed at several depths between 660 and 3800 meters in the Panama Basin. The flux of lithogenic particles increased with increasing depth. This increase was due primarily to particles of beidellite (a smectite clay), which was identical to the clay occurring in bottom sediment on the continental slope to the west of the sediment trap mooring. The beidellite vertical flux at the Panama Basin station increased when an easterly current prevailed and decreased when the current reversed, indicating that a major portion of smectite was transported horizontally at mid-water depth to the mooring site from the nearby continental slope.*

Six Parflux Mark II sediment traps (*1*) with 1.5-m^2 openings were deployed at depths of 667 to 3791 m at 5°21′N, 81°53′W in the Panama Basin. This station, which is 3856 m deep, is located at the center of a small, deep basin between the Coiba and Malpelo ridges (Fig. 1) (*2*). Mass flux, measured by this set of sediment traps, increased significantly from 1268 to 3791 m. The increase was due to the increasing flux of lithogenic material, particularly smectite particles (Table 1).

A Parflux trap deployed at 2265 m was equipped with a receptacle changer, which changes the sediment receiving chamber every 30 days, yielding a time series of sediment flux. A cylindrical trap with an opening of 0.05 m^2 was deployed at 1267 m. This trap also had a receptacle changer and was set to collect sediment every 15 days (JZF trap) (*3*). To start a new collecting period in these two traps the timing was synchronized by electronic timers which operated within an error of a few hours (*4*).

Table 1. Flux of material with depth at Panama Basin station accessed by 1.5-m^2 Parflux sediment trap (*1*).

Depth (m)	Mass flux (mg m^{-2} day^{-1})	Total litho-genic* flux (mg m^{-2} day^{-1})	Smectite flux† (mg m^{-2} day^{-1})
667	114.1	11	10
1268‡	104.5	14	12
2265‡	127.5	24	19
2869	158.0	32	27
3769	179.3	50	42
3791	179.6	50	42

*Most of the lithogenic particles were layered and framework silicate; the rest of the mass flux was biogenic particles. †Approximately 80 percent of the lithogenic flux was smectite; more than 95 percent of the smectite was beidellite. The flux of kaolinite and chlorite was constant through the water column and chiefly included in fecal pellets, indicating that they are of shallow-water hemipelagic origin (*6*). ‡This trap was equipped with a time series sampling device. The flux listed here was the average of four increments (see Table 2).

A vector averaging current meter deployed 401 m above the JZF trap indicated that the current velocity was generally eastward at approximately 5 cm sec^{-1}. The current direction changed abruptly to the southwest on 20 September 1979. The southwestward current was maintained during the rest of the period until 20 October, when the instrument stopped functioning. The current meter at 1970 m, 293 m above the Parflux time series trap, also recorded a steady eastward current except for a short reverse flow during the middle of September. The highest velocity during the period, 15 cm sec^{-1}, was recorded in the middle of October. Current direction changed on 17 October and a strong reverse current (up to 15 cm sec^{-1}) prevailed during the last half of October; a weak easterly component was seen at the end of the deployment (Fig. 2).

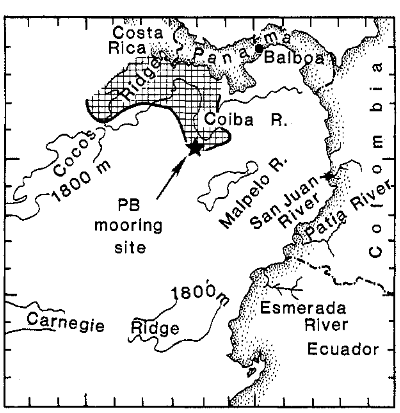

Fig. 1. Location of sediment trap mooring site (*PB*). The hatched area indicates the distribution of beidellite in the bottom surface sediment as published by Heath *et al.* (*6*), who called it anomalous smectite.

The mass flux of each increment in the JZF trap steadily increased until the increment that ended on 21 September, when it dropped sharply. The trap collected consistently smaller flux during the rest of the deployment. The timing of this decrease of mass flux coincided with the change of current direction at this site. The mass flux also increased in the Parflux time series trap until the 30-day increment ended on 19 October 1979, when it was as much as 221 mg m^{-2} day^{-1}. The flux then dropped to 3.5 mg m^{-2} day^{-1} during the last increment (*5*). This decrease was also associated with a strong and abrupt reversal of the current component at the Parflux site.

The bulk of the lithogenic flux collected during the first three increments by the Parflux time series trap was beidellite, a form of authigenic smectite clay (Table 2) (*6*). The sediment collected during the 30-day increment between 19 October and 16 November by the same trap was considerably different from that collected during other increments; it was dominated by relatively large, consolidated particles such as planktonic shells, pteropod tests, and zooplankton fecal pellets. The percentage of fine lithogenic particles in the total mass flux during this increment was less than one-fifth of that in the previous increments. Heath *et al.* (*6*) found that high concentrations of beidellite were distributed in the bottom surface sediment along a well-defined area of the continental slope between Coiba Ridge and north of Cocos Ridge (Fig. 1). The distribution of beidellite in bottom sediments reached our sediment trap mooring site.

The evidence suggests that the smectite caught by the traps originated from the continental slope to the northeast of the station and was transported laterally at mid-water depths, not through surface current or bottom nepheloid layers. It is unlikely that the smectite flux consisted of clay resuspended from the bottom in the vicinity of the trap. Nephelometer and suspended particle concentration profiles indicated no significant nepheloid layer near the mooring site (*7*). Current meters at 3292 and 3671 m recorded no current velocities adequate to produce resuspension (Fig. 2). The relatively strong currents in the upper layers were probably blocked by a topographic sill surrounding the basin.

Increasing aluminosilicate fluxes with depth have been observed at all the stations where we have set sediment trap moorings, including the Sargasso Sea, the tropical North Atlantic Ocean, and the central North Pacific Ocean (*8*). A model to explain this consistent increasing flux with depth has been proposed (*9*). It assumes resuspension of fine clay particles in the energetic boundary regions of the continental slopes and isopycnal transport of the fine particles into ocean basin interiors, accompanied by aggregation to larger, faster settling particles.

Table 2. Flux of material at 2265 m, in time series experiment from 29 July to 16 November 1979; Tr, trace.

Increment, 1979	Mass flux (mg m^{-2} day^{-1})	Total litho-genic* flux (mg m^{-2} day^{-1})	Smectite flux† (mg m^{-2} day^{-1})
29 July to 24 Aug.	120.3	23	16
25 Aug. to 21 Sept.	163.6	31	24
22 Sept. to 19 Oct.	221.6	42	36
20 Oct. to 16 Nov.	3.5	1	Tr
Average	127.5	24	19

*A detailed mineralogical analysis of each time series sample collected by the JZF trap was not made because of the restriction of the total sample size.

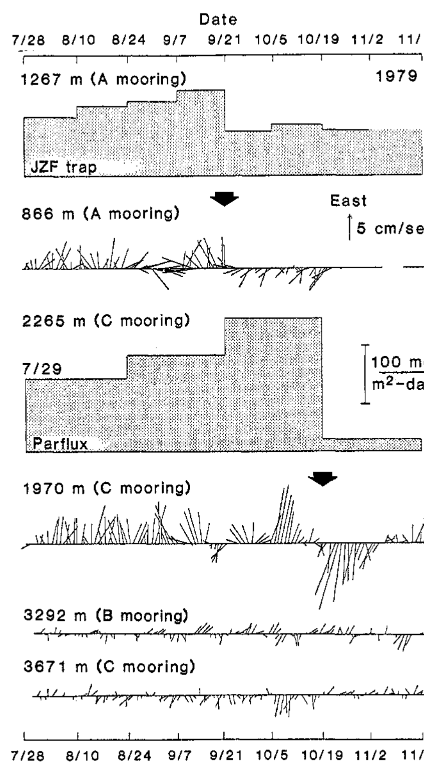

Fig. 2. Relation between currents and material flux at the Panama Basin site measured by two time series sediment traps (JZF and Parflux) between 28 July and 16 November 1979. No current meter data at 866 m are available after 21 October. The JZF trap malfunctioned during the period 2 to 16 November. Prominent changes of material flux were associated with a change of current direction, as indicated by arrows.

The question arises of how the advection of resuspended particles is translated into a vertical flux at the Panama Basin mooring site so that smectite particles, which are among the finest clays, can be deposited in the trap. The concentration of suspended clay particles at this station was as small as that at other ocean gyre areas and did not change throughout the water column (*10*). One explanation is that the smectite particles were highly concentrated into small patches or aggregates, which were not caught by ordinary water samples or nephelometer optics because of their relative spatial scarcity. Formation of macroscopic amorphous aggregates, which have been reported from neritic and pelagic environments as "marine snow" (*11*) or "fecal matter" (*12*), is one means by which the settling rate of clay particles may be greatly enhanced. They acquire their clay load by physical scavenging and agglutination. This packaging must occur at mid-depths in the ocean, rather than by surface filter feeders incorporating fine particles into fecal pellets (*13*).

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References and Notes

1. S. Honjo, J. Connell, P. Sachs, *Deep-Sea Res.* **27**, 745 (1980).
2. A sediment trap intercomparison was carried out at this station with 32 sediment traps and 12 different configurations and sizes [D. W. Spencer, Ed., *Woods Hole Oceanogr. Inst. Tech. Memo WHOI-1-81* (1981)].
3. Jannasch, Zafiriou, and Farrington time series sediment trap [H. W. Jannasch, O. C. Zafiriou, J. W. Farrington, *Limnol. Oceanogr.* **25**, 939 (1980)].
4. The JZF trap was deployed during the same period on a separate mooring at 1267 m, 4.8 km east of the Parflux trap, and obtained an average flux of 91 mg m^{-2} day^{-1}, somewhat smaller than the flux of 104 mg m^{-2} day^{-1} at a Parflux trap deployed at 1268 m. However, a comparison of the particle size fractions and contents of the samples from the Parflux and JZF traps indicated similar trapping efficiencies, so that a comparison of flux between these traps was valid. [S. Honjo, *Woods Hole Oceanogr. Inst. Tech. Memo WHOI-1-81* (1981), p. 40].
5. An instrument error was suspected because such a small flux during this period appeared unrealistic compared to the large flux generally observed in the previous increment. However, on replay of the instrument we have not found an indication of mechanical or electronic malfunction in the time series collector in this trap which might have occurred during this increment.
6. G. R. Heath, T. C. Moore, G. C. Roberts, *J. Geol.* **82**, 145 (1974).
7. W. S. Plank, R. V. Zaneveld, H. Pak, *J. Geophys. Res.* **78**, 7113 (1973); W. D. Gardner, P. E. Biscaye, J. Bishop, *Woods Hole Oceanogr. Inst. Tech. Memo WHOI-1-81* (1981), p. 35.
8. S. Honjo, *J. Mar. Res.* **36**, 469 (1980); P. G. Brewer, Y. Nozaki, D. W. Spencer, A. P. Fleer, *ibid.* **38**, 703 (1980).
9. D. W. Spencer and P. G. Brewer, in preparation.
10. S. Honjo, S. J. Manganini, L. Poppe, in preparation.
11. N. Suzuki and K. Kato, *Bull. Fac. Hokkaido Univ.* **4**, 132 (1953); M. W. Silver, A. L. Shanks, J. D. Trent, *Science* **201**, 371 (1978); J. D. Trent, A. L. Shanks, M. W. Silver, *Limnol. Oceanogr.* **23**, 625 (1978); A. L. Alldredge, *ibid.* **24**, 855 (1979).
12. J. K. Bishop, J. M. Edmond, D. R. Ketten, M. P. Bacon, W. B. Silver, *Deep-Sea Res.* **24**, 511 (1977).
13. For example, S. Honjo, *Mar. Micropaleontol.* **1**, 65 (1976).
14. We thank J. F. Connell, S. J. Manganini, and L. Poppe for field and laboratory assistance. W. Gardner's help was indispensable in deploying and recovering the JZP trap. We thank J. Hathaway, I. N. McCave, and J. Cole for their suggestions and discussions. Supported by NSF grant OCE8025429 and ONR contract N00014-74-CO-262-NR-083-009 to S.H. and ONR contract N00014-74-CO-262-NR-083-004 to J.W.F. Woods Hole Oceanographic Institution Contribution 5007.

30 October 1981; revised 10 March 1982

Endemic Pleural Disease Associated with Exposure to Mixed Fibrous Dust in Turkey

Abstract. *Pleural mesothelioma, lung cancer, pleural calcification and fibrosis, and interstitial parenchymal fibrosis have been observed among inhabitants of several villages in south-central Turkey. Earlier reports have stated that environmental and lung tissue samples from this area contained the fibrous zeolite mineral erionite, and this mineral has generally been assumed to be the agent responsible for these endemic pathological conditions in the absence of asbestos outcroppings and usage. Several different kinds of asbestos minerals in addition to erionite have now been found in environmental samples taken from the villages where these diseases occur. The lung tissues of mesothelioma patients from these villages contain both fibrous zeolites and asbestos minerals.*

In several villages in an area of central Anatolia known as Cappadocia, a very high incidence of pleural mesothelioma has been reported in recent years in a small population. In addition to mesothelioma, other chest diseases, including calcified pleural plaques, pleural fibrosis, interstitial parenchymal fibrosis, and lung cancer, occur frequently. Peritoneal mesothelioma has also been found. Elsewhere the clustering of these diseases generally has been associated with exposure to asbestos, both occupational and environmental (*1*). Geologists and other investigators have not reported the occurrence of asbestos in Cappadocia. Asbestos is not fabricated nor is it used in any manufacturing process in the area (*2–4*), and the household use of asbestos has not been observed.

The focus of this problem is the village of Karain with a population of about 600. Pleural mesothelioma was reported as the cause in 11 out of 18 deaths in the village in 1974. In the preceding 5 years, 25 cases of pleural mesothelioma were reported in Karain (*3*). In the nearby village of Tuzköy, with a population of approximately 3000, the incidence of pleural mesothelioma is approximately six cases per year, or almost three orders of magnitude greater than might be expected (*2*). The ages of these individuals at the time of mesothelioma diagnosis tended to be unusually young, and the incidence occurred with equal frequency in both males and females. These circumstances support the working hypothesis that an etiological agent existed in the environment, with exposures beginning at birth. The occurrence of exceptionally high attack rates of mesothelioma in this rural agrarian society warrants particular attention since (i) mesothelioma in the past has been a "signal" disease indicating prior asbestos exposure, (ii) the high mesothelioma prevalence points to a significant exposure to asbestos fiber, and (iii) the age-sex distribution of tumors (27 to 50 years of age with an equal frequency of male and female occurrence) suggests exposure to an environmental agent beginning in early childhood.

The villages in which mesothelioma was observed, as well as much of Cappadocia, are built upon, and into, tuff, a volcanogenic rock that consists predominantly of volcanic glass, plagioclase feldspars, hornblende, biotite, and pyroxene. Locally, these phases have been altered to form both montmorillonite and a variety of zeolite minerals. The tuff is easily cut into dimension stone and is extensively quarried for building construction. Erosion of the tuff results in conical and beehive-shaped landforms. In Karain, these landforms have been excavated extensively and used for dwellings, animal pens, and storage pens for food and fodder. In the stone houses, contact is made directly with the soft rock surface. It is a common practice in the region for villagers to whitewash their dwellings. Preparation and application of the whitewash produces dust which may persist.

The populations of these villages are exposed throughout their lives to unusually high concentrations of inorganic dust, originating largely from local rocks and soils. Our investigation thus focused