OBSERVATION OF HIGH $^3He/^4He$ RATIO IN OCEAN SEDIMENTS — EVIDENCE FOR EXTRATERRESTRIAL MATERIAL CONTAMINATION

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Abstract. Occurrence of anomalously high $^3He/^4He$ ratio ($> 5 \times 10^{-5}$) is rather common in the Pacific deep sea sediment. The $^3He/^4He$ ratio correlates well with the ^3He content, whereas the ^3He content shows approximate inverse relation with the sedimentation rate. Input of stratospheric dust of about 1 ppm or less which corresponds to about 2000 ton/y fallout rate can explain the above observation.

1. Introduction

We have measured 39 sediments from 12 different sites, 10 sites from the western to central Pacific and 2 sites from the Atlantic Ocean. We found $^3He/^4He$ ratios higher than 5×10^{-5} for 6 sites, well above the values generally observed in common terrestrial materials, in accordance with previous works (1, 2).

All the sediments we studied are piston-cored samples. While two Atlantic sediments (DSDP samples) are of Cretaceous age (3, 4), all the Pacific samples are of Quaternary or at most of late Tertiary age (5, 6). Petrographic descriptions and other data of the samples are given in literatures (3-6). The detailed experimental procedures for the gas extraction and the mass spectrometric analysis were described elsewhere (7).

2. $^3He/^4He$ ratios in sediments

Although because of the small number of the data, it is difficult to draw a general conclusion on the distribution of $^3He/^4He$ ratio in ocean sediments, there appears no clear correlation between the isotopic ratio and geography. However, it is important to note that high $^3He/^4He$ value ($> 5 \times 10^{-5}$) is rather common in the Pacific sediments. Except for diamonds (8), the highest $^3He/^4He$ ever reported for terrestrial materials is 5.2×10^{-5} for Hawaiian olivine xenoliths (9) and the values for common terrestrial rocks such as granites are much less than 10^{-5} (10). ^3He production in the earth is practically negligible

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(11). It is also difficult to attribute the high $^3He/^4He$ ratio to some artificial nuclear fallout or debris, since samples were taken at more than two different levels in a core considerably below the sea water bottom and in several cases the deeper level showed the higher $^3He/^4He$ ratio. Since extraterrestrial materials have $^3He/^4He$ ratio generally higher than 10^{-4} with high helium content ($^4He \geq 10^{-5}$ cm^3STP/g)(10), it is reasonable to assume contamination of some extraterrestrial materials in the sediments to account for the high $^3He/^4He$ ratio ($> 5 \times 10^{-5}$). This assumption is supported by the well-defined correlation between the ^3He content and $^3He/^4He$ ratio shown in Fig. 1. The correlation can be explained as mixing of some materials with high ^3He content and $^3He/^4He$ ratio with sediment which has generally low He content (12).

3. Cosmic dust in sediments

If the global fallout of cosmic dust is responsible for the high $^3He/^4He$ ratio as well as for the high ^3He content, we expect that there is inverse relation between the concentration of the cosmic dust and the sedimentation rate, since in high sedimenting region, the fallout cosmic dust must be diluted by terrestrial materials. In Figure 2, we plot ^3He content against the sedimentation rate which is taken from literatures (3-6). Two Atlantic samples are quite isolated from Pacific samples. This may be due to helium-loss from the Atlantic samples, since they are older by a factor of a hundred than the Pacific sediments. Ignoring the Atlantic samples, there still appears an approximately inverse relation between the ^3He content and sedimentation rate. If we assume uniform fallout rate of cosmic dust and also the initial ^3He content in sediment is negligible, ^3He concentration in the sediment which can be taken as a measure of the amount of the cosmic dust contamination can be expressed as a function of sedimentation rate (r) and flux of the cosmic dust fallout (f),

$$(^3He)_{sed} = \frac{\alpha f}{\rho r} \qquad (1)$$

where α and ρ denote the concentration of ^3He in the extraterrestrial material and density of the sediment. For the ^3He concentration in the cosmic dust, we take the value measured for stratospheric cosmic dust ($\sim$ 10-μm-diameter); i.e., $\alpha \simeq 4 \times 10^{-5}$ cm^3STP/g (see the next paragraph). Putting $\alpha = 4 \times 10^{-5}$ cm^3STP/g and $\rho = 2$ g/cm^3 in Eq.(1), we can construct a family of curves corresponding to different values of f. In Figure 2, we show a curve corresponding to $f = 4 \times 10^{-10}$ $g/cm^2 \cdot y$, which approximates the data. The value f ($= 4 \times 10^{-10}$ $g/cm^2 \cdot y$) corresponds to a cosmic dust fallout rate of about 2000 tons/y. The value may be favorably compared with the estimates made on satellite, radio and visual observations of about a few hundred tons per year for the particle size below 10 μm in diameter (13). Cosmic dust which has a larger than 10-μm-diameter may not be important in the helium inventory in sediments, because the smaller ones occupy only a small fraction of the total mass of the cosmic dust, while the larger one is likely to loose helium due to atmospheric impact heating. We believe that the approximate inverse relation but not random relation between the ^3He content and the sedimentation rate is significant and the relation is attributable to the global cosmic dust fallout.

Assuming that the cosmic dust is responsible to the high $^3He/^4He$ ratio in Figure 1 we also show a mixing curve between the cosmic dust and the sediment. For the cosmic dust, we take $^4He = 0.1\ cm^3STP/g$ (14) and assumed solar wind implanted helium, that is, $^3He/^4He = 4 \times 10^{-4}$. For the uncontaminated sediments, we assumed a typical crustal value 10^{-8} for $^3He/^4He$ ratio (11) and $^4He = 3 \times 10^{-7}\ cm^3STP/g$ (12). From Figure 1, it is evident that less than 1 ppm contamination of the cosmic dust can account for the observed high $^3He/^4He$ as well as the high ^3He content.

Microscopic examination did not show any evidence of extraterrestrial materials. Neutron activation analyses showed slightly higher Ni (200 - 600 ppm) and Co contents (100 - 200 ppm), but Cr (30 - 50 ppm) is slightly lower than that observed in common crustal rocks. We could not detect Ir. Here, it should be emphasized that owing to extremely small amount of ^3He in terrestrial samples ($\lesssim 10^{-12}\ cm^3STP/g$)(10) and to enormous enrichment of helium in cosmic dust ($\sim 10^{-1}\ cm^3STP/g$)(14), even slight contamination of the latter still results in conspicuous anomaly of ^3He content and in $^3He/^4He$ ratio. Since no other element has such enormous contrast in the concentration between the cosmic dust and terrestrial materials in addition to their marked depletion in the earth, it is not surprising if cosmic dust contamination effect is only seen in ^3He content and in $^3He/^4He$ isotopic ratio. Finally, the ubiquitous occurrence of cosmic dust in deep ocean sediment would find important application in oceanography. If the fallout rate is estimated independently, ^3He content in ocean sediments would yield continuous record of the sedimentation rate, or vice versa.

References

(1) Merrihue, C., Annals N.Y. Acad. Sci, 119, Art. 1, 351-367 (1964).

(2) Krylov, A.Ya., Mamyrin, B.A., Silin, Yu.I. and Khabarin, L.V., Geochemistry International, 10, 202-205 (1973).

(3) Initial Report of the Deep Sea Drilling Project, 43, 19-321 (1979).

(4) Ibid, 43, 323-391 (1979).

(5) Kobayashi, K., Tonouchi, S., Furuta, T. and Watanabe, M., Bull. Ocean Res. Inst. Univ. of Tokyo, No. 13, 1-148 (1980).

(6) Preliminary Report of the Hakuho Maru Cruise KH80-3, p209 (1981).

(7) Ozima, M., Zashu, S. and Nitoh, O., Geochim. Cosmochim. Acta, 47, 2217-2224 (1983).

(8) Ozima, M. and Zashu, S., Science, 219, 1067-1068 (1983).

(9) Kaneoka, I. and Takaoka, N., Earth Planet. Sci. Lett., 39, 382-386 (1978).

(10) Ozima, M. and Podosek, F.A., Noble gas geochemistry, p367, Cambridge Univ. Press (1983).

(11) Tolstikhin, I.N., in Terrestrial Rare Gases, (Ed. Alexander, E.C.Jr and Ozima, M.) 33-62 (Japan Science Soc. Press., 1978).

(12) Posodek, F.A., Honda, M. and Ozima, M., Geochim. Cosmochim. Acta,

44, 1875-1884 (1980).
(13) Hughes, D.W., in Cosmic dust (Ed. J.A.M. McDonnell), 123-185 (Wiley, 1978).
(14) Rajan, R.S., Brownlee, D.E., Tomandl, D., Hodge, R.W., Farrar, H.IV. and Britten, R.A., Nature, 267, 133-135 (1977).

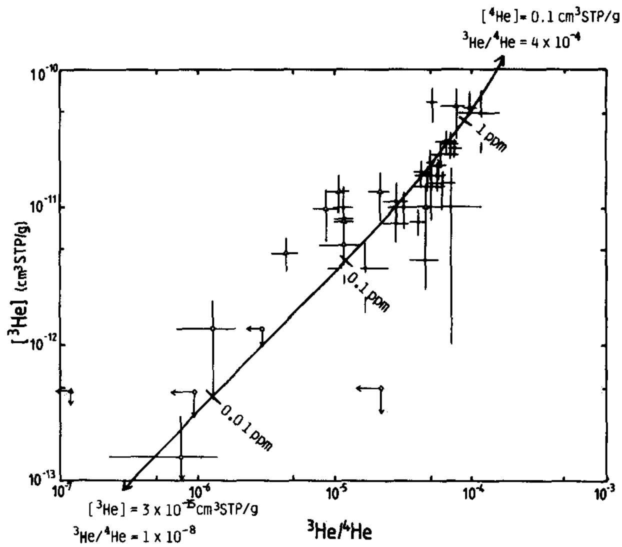

Figure 1. ^3He content in sediments is plotted against $^3He/^4He$ ratio. The curve indicates a mixing curve between He in the cosmic dust (^4He = 0.1 cm^3STP/g, $^3He/^4He = 4 \times 10^{-4}$) and in the sediments ($^3He = 3 \times 10^{-15}$ cm^3STP/g, $^3He/^4He = 10^{-8}$). Numerical figures shown on the curve indicate the degree of the contamination (in ppm) of the cosmic dust in sediments.

Δ : KH-80-3 o : KH68-4 ● : KH75-3-5
□ : KH-75-3-11 ◇ : DSDP

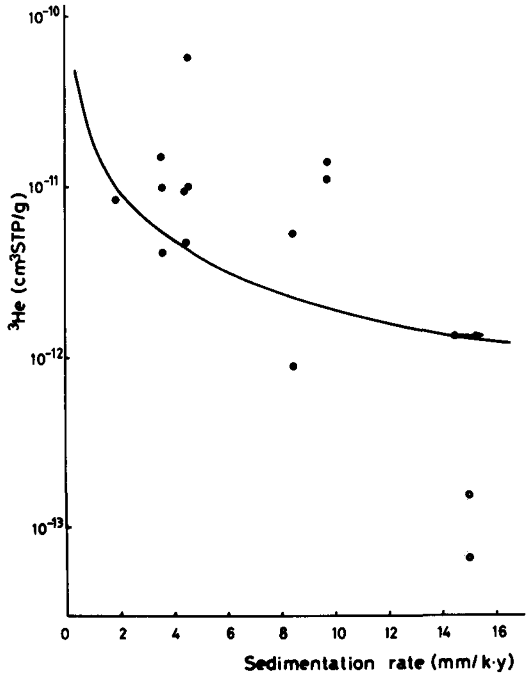

Figure 2. ^3He content is plotted against sedimentation rate. Two hollow circles indicate the Atlantic DSDP samples which are of Cretaceous age. The Pacific samples (solid circles) show approximate inverse relation between ^3He content and sedimentation rate. The curve is constructed by assuming uniform fallout rate (2000 tons/y) of cosmic dust ($^4He = 0.1\ cm^3STP/g$, $^3He/^4He = 4 \times 10^{-4}$).

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