Excess ^{3}H in the volcanic lakes: evidence for natural nuclear fusion *

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Abstract The excess ^{3}H (tritium) have been observed in the volcanic lakes Nemrut (Turkey), Laacher (Germany) and Pavin (France). The ^{4}He and ^{3}He concentrations in Lakes Nemrut, Laacher, and Pavin were determined to be 25 and 190, 10 and 50, and 70 and 500 times larger than the atmospheric saturation value respectively. The isotopic ratio of the helium excess, $^3He_{ex}/^4He_{ex}$, in Lakes Nemrut, Laacher and Pavin was $(1.032\pm0.006)\times10^{-5}$, $(7.42\pm0.03)\times10^{-6}$ and $(9.09\pm0.01)\times10^{-6}$ respectively. The ^{3}He/^{4}He ratio of helium isotopes in the lake can help us to identify the origin of gas fluxes from the interior of the Earth. The ^{3}He/^{4}He ratios in the Lakes Nemrut, Laacher and Pavin clearly indicate that a large amount of helium isotopes were released to the lakes from mantle source. The excess ^{3}H at the bottom of Lakes Nemrut, Laacher and Pavin have a good correlation with mantle ^{3}He. We consider that the excess ^{3}H might be also released from mantle source and both ^{3}H and ^{3}He might be produced by nuclear fusion (d-d reaction) in an environment rich in H atoms and (U+Th) at high temperature and high pressure condition in deep Earth.

Key words ^{3}H(tritium), ^{3}He, natural nuclear fusion, volcanic lakes

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1 Introduction

^{4}He in the Earth is produced by the natural radioactive decay of U and Th. However, ^{3}He is still a mystery in the deep Earth. Lacking knowledge of deep source production mechanism, deep-Earth ^{3}He has been assumed to be of primordial origin, trapped within the Earth at the time that the Earth formed, and reserved in the primitive reservoir[1] However, the hypothesis of primordial origin of ^{3}He have been met challenges in the explanation of ^{3}He paradoxes in the Earth[2].

The hypothesis of natural nuclear fusion (geofusion) occurring in the deep Earth goes back to 1980s. Jones et al. supposed that under a non-equilibrium conditions, d-d and p-d fusion reactions might occur in the deep Earth according to the reactions[3],

p+d$\rightarrow^3$He+γ (5.4 MeV),
d+d$\rightarrow$p(3.02 MeV)+^{3}H (1.01 MeV),
d+d$\rightarrow$n(2.45 MeV)+^{3}He (0.82 MeV),

here ^{3}H and ^{3}He are the products of d-d reaction. However, ^{3}He is already known to be released from deep Earth, but this could be of primordial origin. Since tritium decays with a half-life of 12.4 years, a good test of hypothesis of d-d reaction in the Earth would be detection of tritium emanating from deep Earth and found in magmatic gases and fluids. ^{3}H induced by other nuclear reactions in the Earth was estimated to be less than 0.01 TU (1 TU=1 tritium atoms per 10^{18} hydrogen atoms), the value under detectable limit.

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Extensive tritium measurements in the volcanic products were taken to search for evidence for natural nuclear fusion in the Earth. Ouick et al tried to measure the tritium concentration in the action P'pO'o crater at Kilauea in Hawaii[4], they found that the tritium concentration of the samples from inner crater was lower than that of the samples taken simultaneously from the nearby upwind crater rim. The results provide no evidence in support of natural fusion in the Earth's interior. Another experiment by Goff and McMurtry[5], who collected magmatic water samples from 11 active volcanoes around the world, the results reveal that the magmatic tritium values were generally as small as background level, which concluded no evidence that the natural fusion in the Earth can emit an ^{3}H content >0.05 TU.

The volcanic lakes rich in mantle helium, for example: the excess ^{3}He concentration at the bottom of Lake Nemrut is about 1-2 orders of magnitude higher than the ^{3}He concentration in volcanic crater at Kilauea. If excess ^{3}H come from mantle together with ^{3}He, the high ^{3}He concentration and high ^{3}He flux might indicate high ^{3}H concentration in the end-member magamatic fluid. Therefore, the concentration of mantle ^{3}H in the Lake Nemrut should be higher than the volcano areas (e. g. Kilauea). We consider that the volcanic lakes with high mantle-helium concentration might be the idea sites for testing magmatic gases released from the mantle source.

2 Mantle ^{3}He and excess ^{3}H in the volcanic lakes

Tritium, with a half-life of 12.4 years, is usually input into lake from surface by precipitation. It is naturally produced in the atmosphere by spallation of nitrogen and oxygen interaction, but an increase of the global tritium inventory by a factor of more than 100 due to atmosphere nuclear test in the 1950's—1960's was detected. In the lake, under the circumstance of fairly well vertical mixture of water, a nearly homogeneous tritium distribution will be presented from the surface to the bottom of the lake water, or, with un-uniform vertical mixture, the tritium concentration will decrease while the depth increases in the lake water[6].

The atomic ratio of the two stable helium isotopes, ^{3}He/^{4}He, varies considerably between different components of geosphere. In the atmosphere the ratio is 1.39×10^{-6}. The mantle is characterized by ^{3}He/^{4}He ratio of $\sim 10^{-5}$, while the continental crust is characterized by ^{3}He/^{4}He ratio of $\sim 10^{-8}-10^{-7}$. The analysis of helium isotopes in fluids can help to identify the origin of gas fluxes from the interior of the Earth.

2.1 Excess ^{3}H in lake nemrut

Lake Nemrut is a caldera lake in Turkey, located at the western border of lake Van, the fourth largest closed-basin lake on Earth.

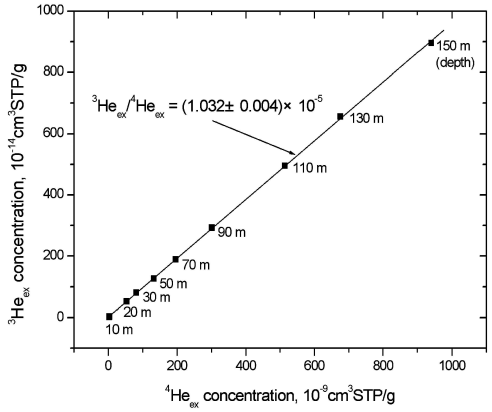

Fig. 1. Vertical profile of $^3He_{ex}/^4He_{ex}$ ratio in Lake Nemrut, $^4He_{ex}$ and $^3He_{ex}$is excess ^{4}He and ^{3}He respectively. The $^3He_{ex}/^4He_{ex}$ ratio remains constant with the depths, $^3He_{ex}/^4He_{ex}$=$1.032\pm0.006\times10^{-5}$, indicating the original ^{3}He and ^{4}He from MORB-like mantle source. Data are adopted from Ref. [7]. The [cm^3 STP/g] equals to [4.47×10^{-2}mol/kg] for helium.

The most striking feature of the helium concentration measured in Lake Nemrut is the large increase of both isotopes with depth. At the depth of 150 m the ^{4}He concentration is 25 times larger than the atmospheric saturation value[7]. For ^{3}He the supersaturation reaches a factor of about 190. The ^{3}He/^{4}He ratio at the bottom of the lake equals to 10.1×10^{-6} and decreases from the bottom to the surface due to mixing. However, the helium excess (i.e. the value subtracted atmospheric helium from measured value) of both isotopes at different depth are linearly related:$^3He_{ex}/^4He_{ex}=(1.032\pm0.006)\times10^{-5}$ (Fig. 1). The ratio is about 7.5 times larger than the ratio in the atmosphere and indicates that the excess helium could be from mantle source.

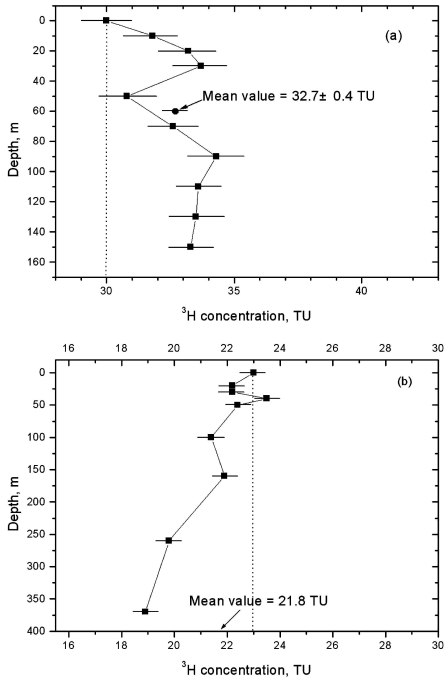

Fig. 2. The vertical profiles of ^{3}H concentration in Lakes Nemrut and Van are given in Fig. 2(a) and Fig. 2(b) respectively. The dash line indicates the ^{3}H concentration in the surface layer. Data are adopted from Ref.[7].

From experimental data in Ref. [7], we have observed the difference between the vertical profiles of ^{3}H concentration in Lake Nemrut and lake Van (Fig. 2(a) and 2(b)). ^{3}H concentration in lake Van decreases with the depth. It decreased by about 20% and 15% respectively in 1989 and 1990 from the surface to the bottom of the lake[7], this could be due to the water in the bottom is not completely mixed. The dashed line in Fig. 2 plots the ^{3}H concentration of the surface layer. It shows that most of the data values below 20 m are smaller than the value of the surface layer and they decrease towards the bottom. On the contrary, the ^{3}H concentration increased by about +10% ($>3\sigma$) from the surface to the bottom in Lake Nemrut and all the data values below 10 m depth is larger than the surface value. The result suggests that besides atmospheric input from surface, the excess ^{3}H (i.e. the measured value subtracted the atmospheric ^{3}H value) may be injected from the bottom analogized to the fact that a large amount of helium isotopes were injected from the bottom of Lake Nemrut. The excess ^{3}H is deduced to be 3.7±1.4 TU

2.2 Excess ^{3}H in Lake Laacher

Lake Laacher is small crater lake in Germany, with a maximum depth of 52 m and a surface area of 3.31 km^2.

A peculiar property of Lake Laacher is a funnel at the sediment surface at depth of 31 m, to the eastern shore near station LA2. The helium isotopes and other rare gases emerging from the funnel were released from mantle that are confirmed by ^{3}He/^{4}He ratios (from 7.23×10^{-6} to 7.33×10^{-6}) in the gases and very low ^{20}Ne concentration (3—60 ppb) compared with atmospheric (16.4 ppm)[8]. The concentration of ^{4}He(^{3}He) increase with depth and reach the values up to 10(50) times to that of the atmospheric equilibrium concentration in the bottom layer of the Lake Laacher. The isotopic ratio of the helium excess, $^3\mathrm{He}_{ex}/^4\mathrm{He}_{ex}$ is $(7.42\pm0.03)\times10^{-6}$. This indicates the presence of helium from the sub-continental mantle at the lake bottom[8].

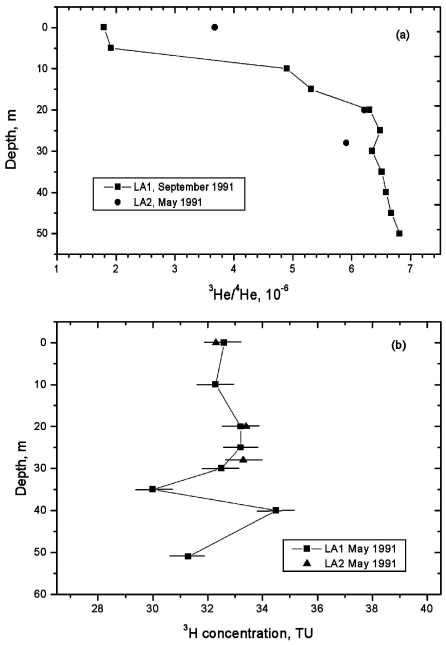

Fig. 3. Comparison of vertical distribution of ^{3}He/^{4}He ratio (Fig. 3(a)) and ^{3}H concentration (Fig. 3(b)) in Lake Laacher, data are adopted from Ref. [8]. A funnel emerging gases was observed at the sediment surface at 31 m, to the eastern shore. The peaks are consistent with existence of the funnel.

The measured ^{3}He/^{4}He ratios (station LA1, near the center of the lake) as a function of the depth presents a peak at around 25 m depth (Fig. 3(a)), which was caused by the existence of the local strong helium emerging from the funnel near station LA2. The peak from the same source can also be observed in the distribution of ^{3}H concentration (station LA1) (Fig. 3(b)). We consider that the excess ^{3}He and ^{3}H

at the both peaks were all released from the funnel. Therefore, the excess ^{3}H, like ^{3}He, might also originate from mantle. The excess ^{3}H concentration released from funnel is estimated to be about 1.1 TU.

In Fig. 4, we summarize all the tritium data in reference[8], including all data from LA1, LA2 and LA3, collected in May and September, 1991. The tritium concentration measured in September is normalized to that in May. It can be seen that the ^{3}H concentration in the surface water is consistent with each other for LA1 and LA2 in May and LA1 in September. The average value is 32.2 TU for surface water, shown as a dashed line in Fig. 4. The average value for total excess ^{3}H concentration between 10—50 m depth is 1.5 TU. The result indicates that the residual excess ^{3}H may be injected into the lake from the bottom and might be released from mantle together with ^{3}He.

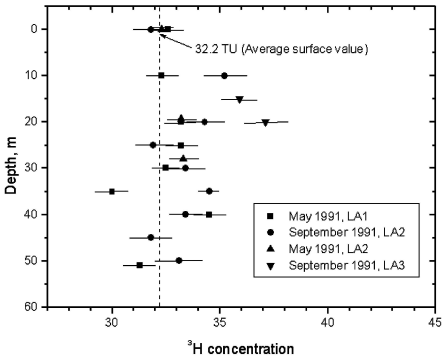

Fig. 4. A summary of data for vertical profiles of ^{3}H concentration in Lake Laacher, data adopted from Ref. [8]. The dash line indicates the ^{3}H concentration in the surface layer.

2.3 Excess ^{3}H in lake pavin

Lake Pavin is a small (0.44 km^2), but deep (92 m), nearly circular lake, in the French Massif Central[9]. A peculiar property of Lake Pavin is the presence of a stagnant deep-water layer, called monimolimnion. The monimolimnion is not affected by seasonal mixing. It is separated from the overlying mixolimnion, the seasonally mixed layer, by a chemocline between about 60 and 70 m depth.

The ^{3}He/^{4}He ratio was $(9.09\pm0.17)\times10^{-6}$ (Fig. 5(a)) and ^{3}He and ^{4}He concentration was 500 and 70 times of air saturation value at the deep-water layer respectively (Fig. 5(b)). The result indicates large mantle helium presence in the bottom water.

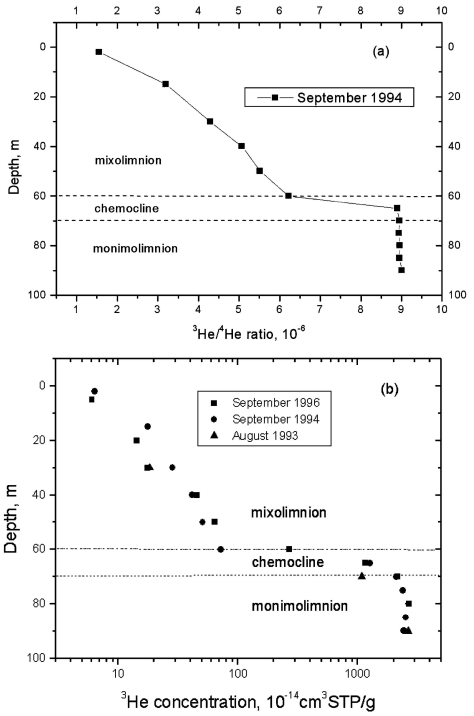

Fig. 5. Vertical profiles of ^{3}He/^{4}He ratio (Fig. 5(a)) and ^{3}He concentration (Fig. 5(b)) in Lake Pavin. The mantle helium was injected to the lake from the bottom. Data are adopted from Ref. [9].

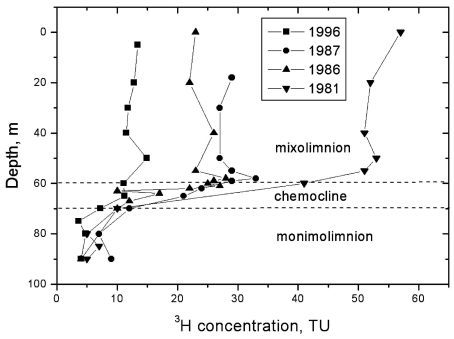

Fig. 6. The vertical profiles of ^{3}H concentration in Lake Pavin, measured in 1996, 1987, 1986 and 1981, data adopted from Refs. [10, 11].

The tritium concentration had large difference in the upper layer of the lake (mixolimnion) for the period between 1981 and 1996[10, 11], the tritium concentration varying from ∼53 TU to ∼12 TU in the mixolimnion., but the tritium concentration in the deep layer of the lake (monimolimnion) only had a slight difference around 5 TU (Fig. 6). The approximate constant ^{3}H concentration in the deep part of the lake indicates no obvious correlation with tritium concentration in the mixolimnion. The mixture of atmospheric ^{3}H concentration is estimated to be less than 1 TU in the deep water. Therefore, an additional tritium source in the deep water should be considered

as about 4 TU. Considering the correlation with mantle helium, the excess ^{3}H might be also released from the mantle.

Data for mantle ^{3}He and deduced excess-^{3}H in Lakes Nemrut, Laacher and Pavin are summarized in Table 1.

Table 1. The observed mantle helium and excess ^{3}H in the volcanic lakes.

Lake	^{3}He/^{4}He,10^{-6}	^{3}He,C_{air}	^{3}He flux, mol/m^2·s	Excess ^{3}H, TU	Reference
Laacher (Germany)	7.42	50	1.2×10^{-16}	$\sim$1.4	[8]
Nemrut (Turkey)	10.1	190	$\sim1\times10^{-16}$	3.7	[7]
Panvin (France)	9	500	9×10^{-18}	$\sim$ 4	[9, 10, 11]

C_{air}: ^{3}He concentration for atmospheric saturation value in the water. Global average ^{3}He flux: 6.6×10^{-20}mol/m^2·s

3 Conclusions

The excess ^{3}H are observed in the three different volcanic lakes, Lakes Nemrut, Laacher and Pavin, and the excess ^{3}H also correlate well with mantle ^{3}He. After origin of excess ^{3}H from atmosphere and known nuclear reaction are excluded[6], we conclude that the excess ^{3}H might be also from mantle source and produced by the nuclear fusion (d-d reaction) in an environment rich in H atoms and (U+Th) at high temperature and high pressure condition in deep Earth.

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