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HELIUM - 3 DISTRIBUTION IN WESTERN TURKEY

Nilgün Güleç*

ABSTRACT . — In this study, to investigate the mantle-crust interaction in Western Turkey, geothermal fluids from various locations are analyzed for their $^3He/^4He$ ratios. The results reveal a mixing between mantle - and (continental) crustal - helium components. The distribution of mantle-helium, which is characterized by high $^3He/^4He$ ratios, does not show any correlation with the spatial and/or temporal distribution of the surface volcanics in the region, but appears to be governed by the distribution of tectonic deformation. The lack of any correlation between the distribution of mantle-helium and surface volcanism suggests that helium, now degassing from mantle, has most probably entered the crust in association with the melts emplaced at deeper levels. The fault systems of the present extensional tectonics are thought to have had an efficient role in the escape of helium to the surface through the brittle parts of crust.

INTRODUCTION

The determination of $^3He/^4He$ ratios in continental fluids provides valuable contributions to the understanding of mantle - crust interactions. ^3He is essentially primordial, that is to say, trapped in the Earth's interior at the time of its accretion from the solar nebula (Ozima and Podosek, 1983). Therefore, the presence of any excess ^3He at the surface indicates that volatiles have been transported from mantle. Mantle-helium is characterized by $^3He/^4He$ ratios of about 10^{-5} (Mamyrin and Tolstikhin, 1984). On the other hand, ^4He is produced by the a -decay of ^{238}U, ^{235}U and ^{232}Th. Since U and Th are mostly concentrated in the continental crust relative to mantle and littlte3He is retained in the crust, continental crust is enriched in ^4He and (continental) crustal - helium is characterized by $^3He/^4He$ ratios of about 10^{-7} - 10^{-8} (Andrews, 1985). The isotopic composition of helium in the atmosphere is rather constant over the globe ($^3He/^4He = 1.4 \times 10^{-6}$ (Craig and Lupton, 1981; Lupton, 1983)). Because of this uniform composition atmospheric - helium is used as a standard in most laboratories and it has become convention to express He-isotope compositions relative to that of atmospheric - He ($R/R_a = (^3He/^4He)_{samble}$ $(^{3He}/^{He}{}_{atm}$.

The bulk of ^3He loss from mantle takes place in ocean basins through processes associated with the generation and cooling of oceanic lithosphere. However, a small proportion of ^3He is also lost through continental crust undergoing contemporary deformation. Although the mechanism of transport of helium from mantle into crust is not well-understood, the spatial association of mantle-helium and volcanics in various settings (Craig et al., 1978; Condomines et al., 1983; Kurz et al., 1983) suggests a relationship between mantle melts and transport of mantle - He.

The aim of the present study is the investigation of the mantle-crust interaction in Western Turkey through the He-isotope analyses of geothermal fluids. With the exception of one sample taken from a drilling well (Ömerbeyli - Germencik), all the other samples are collected from natural springs either as water and/or a gas phase bubbling through the water The majority of samples are groundwater discharges associated with the faults bounding the major grabens in Western Turkey. These samples are likely to represent mixtures of a deep cfrculating hydrothermal system and cold, meteoric waters infiltrating through the graben filling sediments (IUTF, 1971, 1975). The temperature of the fluids range from 35°C to 100°C. The sampling locations are shown in Figure 1 along with the measured He-isotope compositions.

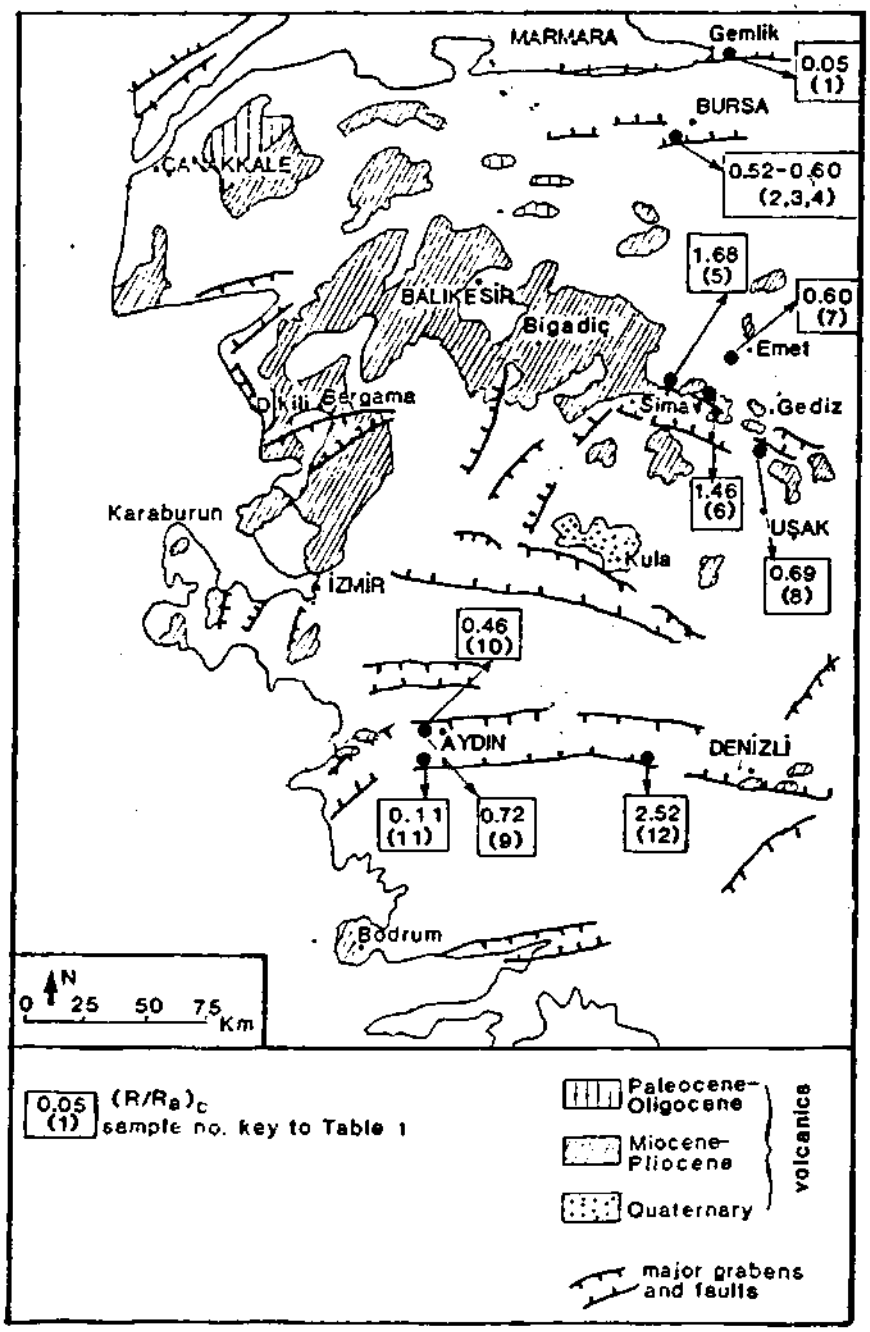

Fig. 1 — Distribution of ^{3}He in Western Turkey in relation to distribution of fault systems and surface volcanics.

ANALYTICAL METHODS

Sample collection

Samples were collected in 10 ml "Weiss" type copper tube devices (Weiss, 1969). The copper tubing is clamped at each end with hinged knife-edged clamps. Copper sample tubes were connected to the spring sources using PTFE tubing and flushed with several volumes of water to ensure that any trapped air bubbles were released. Gas samples were collected at open bubbling pools by means of an inverted funnel which was attached to the copper sample tube and immersed to the maximum possible depth.

He — analyses

He — isotope analyses (together with the measurements of He and Ne abundances) were carried out on VG MM 3000 mass spectrometer in the Rare Gases Laboratory of the Department of Earth Sciences-University of Cambridge. The $^{3}He/ He$ ratios (= R) were measured against an air standard (= R) and presented as R/R_a values in Table 1. He and Ne abundances were determined by comparison against the air standard. Taking into account the possible air (atmospheric-He) contamination during collection or measurement of the samples, R/R_a ratios were corrected using He/Ne ratios. The correction procedure assumes that all the Ne in the samples is of atmospheric origin; the reason behind this assumption is that the crustal radiogenic processes generate neon in negligible proportion to radiogenic helium and mantle sources are characterized by He/Ne ratios more than 10^3 . The equation used in correction is given in the foot-note of Table 1. The errors associated with the analyses were determined by the consideration of the following factors : 1) the precision related to the performance of the mass spectrometer during the measurements; 2) reproducibility of the measurements; 3) blank corrections An uncertainty of ± 10% is assigned to He — isotope measurements and of ± 20% is assigned to the measurement of He and Ne abundances.

He - ISOTOPE COMPOSITION OF THE FLUIDS

The isotopic composition of He in the geothermal fluids of Western Turkey is given in Table 1 along with the He/Ne ratios and He and Ne abundances. The distribution of ^{3}He in Western Turkey is shown in Figure 1 in relation to the distribution of the fault systems and surface volcanics. Figure 2 compares the He — isotope composition of the Turkish fluids with those from a variety of volcanic settings.

The recorded $(R/R_a)_c$ values range from 0.05 to 2.52. A comparison with mantle-helium (typified by the samples associated with mid-ocean ridges and hot-spot sites) and (continental) crustal-helium, (Fig.2) reveals the presence of a mantle-helium component in Western Turkey. However, the isotopic composition of this mantle-helium is modified as a result of mixing with crustal-helium. Assigning average R/R_a values of 8 and 0.02 for mantle and crustal-helium components, respectively, the involvement of mantle-derived helium in Western Turkey is found not to exceed 30% of the total-He content of any single sample. As far as the comparison with different tectonic settings is concerned the values obtained for Western Turkey are within the documented range of active rifting zones and are rather similar to those reported for the Rhine (graben and the Pannonian basin (Fig. 2).

From Figure 1, ^{3}He appears to be widely distributed in Western Turkey paralleling the distribution of the fault systems of the present extensional regime. In this respect, ^{3}He distribution in Western Turkey seem to be similar to that observed in the Pannonian basin (Fig. 2 of Oxburgh et al., 1986) in contrast to the highly localized distribution pattern seen in the Rhine graben (Fig. 2 of Oxburgh et al., 1986). With regard to the relationship between ^{3}He distribution and tectonic deformation, an important point to note is the low R/R_a values obtained from Gemlik which is located along the extension of the North Anatolian Fault Zone where the dominant strike-slip motion is accompanied by normal faulting. High R/Ra values are concentrated in the normal fault systems of Western Turkey where the N — S extension is much more prominent. On the other hand, there does not seem to be any relationship between the distribution of ^{3}He and surface volcanism. In general, the geothermal systems associated with the youngest volcanic activities are expected to have the highest $^{3}He/^{4}He$ ratios, because the ratio should decrease with time due to the accumulation of radiogenic ^{4}He. However, this is not the case in Western Turkey ; the highest R/R_a value is in the vicinity of Pliocene age Denizli volcanics rather than Quaternary Kula volcanics. In this respect, either Denizli represents an area of high mantle-helium leakage (coupled with low crustal degassing in order to keep this helium in the crust since Pliocene) or the distribution of He is not linked to the surface volcanism.

Table 1– He isotope measurements on Western Turkish fluids

Sample no.	*Locality*	*Key*(1)	*Year*	*Type*	$(^4He)^{(2)}$	$(^{20}Ne)^{(2)}$	$(^4He/^{20}Ne)^{(3)}$	R/R_a	$(R/R_a)_c$
T1	Gemlik	1	1984	water	3.4×10^{-7}	3.6×10^{-7}	0.95 ± 0.2	0 29 ± 0.03	0.05
T3	Çekirge-Bursa	2	1984	water	2.7×10^{-7}	8.1×10^{-9}	45 ± 12	0.52 ± 0.05	0.52
T4	Çekirge-Bursa	3	1984	water	4×10^{-7}	$1\ 2 \times 10^{-8}$	106 + 230/−70	0.52 ± 0.05	0.52
T85-1	Çekirge-Bursa	4	1985	water	6.4×10^{-8}	1.5×10^{-7}	0.42 ± 0.09	0.83 ± 0 03	0.60
T7	Eynal-Simav	5	1984	gas	------	------	300	1.68 ± 0.17	1.68
T8	Ilıcalar	6	1984	water/gas	------	------	100 ± 26	1.46 ± 0.15	1.46
T6	Emet-Kaynarca	7	1984	water	$1\ 5 \times 10^{-7}$	9×10^{-9}	34 + 24/−17	0.60 ± 0.06	0.60
T9	Banaz	8	1984	gas	------	------	17 ± 3	0.70 ± 0 07	0.69
T14	Çamur-Germencik	9	1984	gas	------	------	1.5 ± 0.3	0 77 ± 0 08	0.72
T13	Bozköy - Germencik	10	1984	gas	600 ppb	80 ppb	78 ± 16	0.46 ± 0 05	0.46
T16	Ömerbeyli-Germencik	11	1984	gas	------	------	2.3 ± 0.5	0 22 ± 0.02	0.11
T85-15	Tekke Hamam-Denizli	12	1985	gas	3.1 ppm	39ppb	79 ± 16	2 52 ± 0.08	2.52
Air saturated water 0°C (5)					4.9×10^{-8}	2×10^{-7}	0.24		

(1) Designation on Fig. 1.

(2) (^4He) and (^{20}Ne) concentrations are expressed as ccSTP/g H_2O for water samples and as volume fractions for gas samples. Since details of volumetric splitting were not recorded, (^4He) and (^{20}Ne) concentrations could not be obtained for the gas samples collected in 1984. All determinations ± 20%.

(3) Errors denote scatter typical of successive air runs.

(4) $(R/R_a)_c \simeq ((R/R_a)X - 1)/(X - 1)$

$X = (^4He/^{20}Ne)_{sample} / (^4He/^{20}Ne)_{atm}$

$(^4He/^{20}Ne)_{atm} = 0.288$ (for gas samples)

$(^4He/^{20}Ne)_{atm} = 0.24$ (for water samples)

(the factor, 0.24/0.288 = 0.83 accounts for the differing solubilities of He and Ne in water).

(5) Benson and Krause (1976).

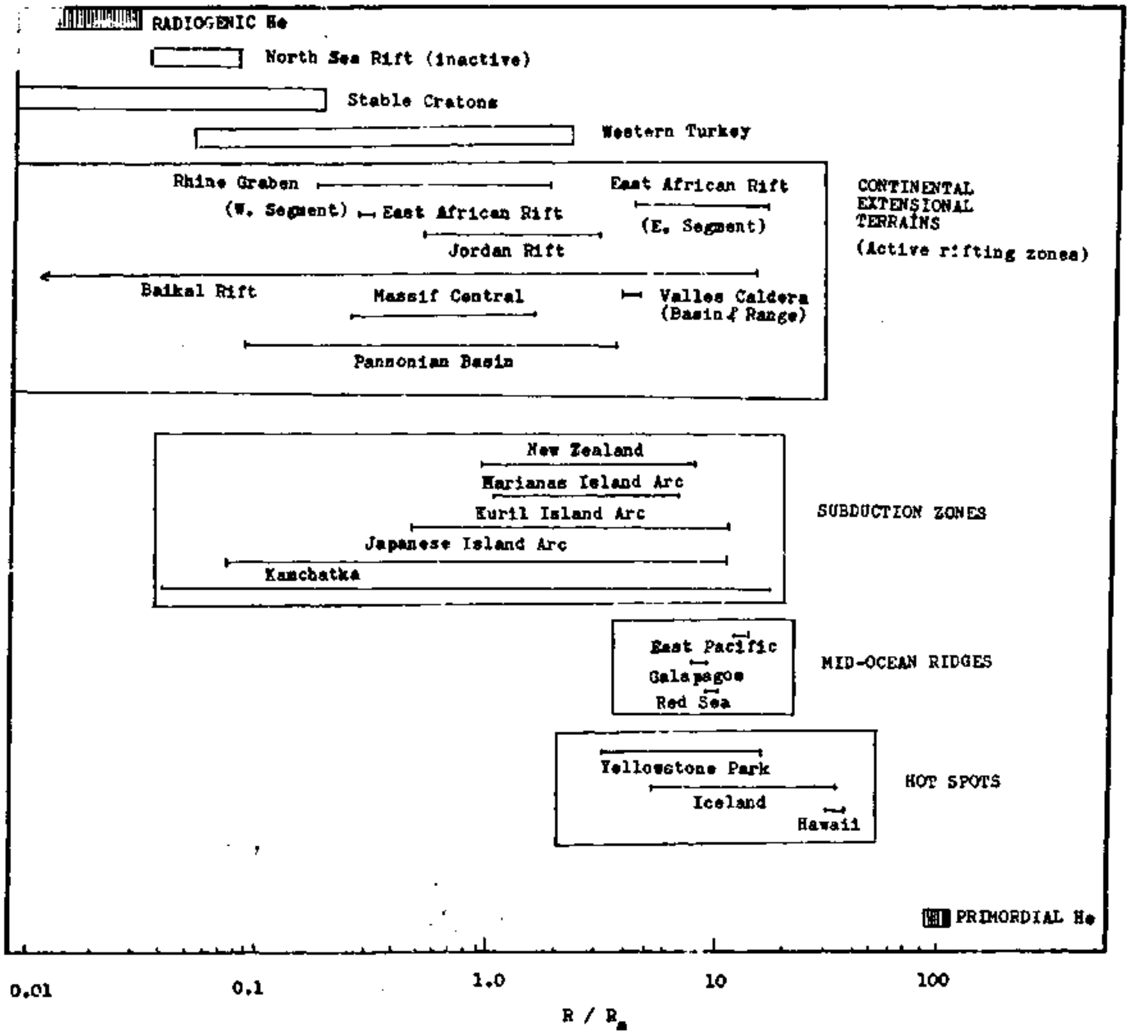

Fig.2— The isotope composition of He from different tectonic settings compared with results obtained for Western Turkish fluids.

Data sources : 1) Kennedy et al., 1985 (Yellowstonepark); 2) Hooker et al., 1985(Rhine Graben and North Sea rift); 3) Oxburgh et al., 1986 (Pannonian basin); 4) Smith and Kennedy, 1985 (Valles caldera); 5) Polyak and Tolstikhin, 1985 (the others).

Bars represent the ranges of R/R_a values for 1, 2, 3 and 4 and 95% limits of log-distribution for 5.

DISCUSSION

The present study confirms the presence of ^3He enrichments in Western Turkey over that expected from normal crustal lithologies. The discussion presented here are directed towards answering the following questions:

1-Do the ^3He enrichments necessarily indicate a mantle contribution ?

2- If so, what are the possible mechanisms responsible for the transportation of mantle-helium to the surface?

^{3}He and possible sources

Although ^{3}He is essentially primordial, it can also be produced by the radioactive decay of ^{6}Li and ^{3}H isotopes. ^{3}He produced from ^{6}Li and ^{3}H is known as radiogenic ^{3}He and tritiugenic ^{3}He, respectively. The rate of radiogenic ^{3}He production is dependent on the Li content of the material. However, since most rocks have Li abundances less than 50 ppm, the R/R_a values of the helium produced by ^{6}Li decay does not exceed 0.02 (Mamyrin and Tolstikhin, 1984; Andrews, 1985). Therefore, radiogenic ^{3}He can not be an adequate source for the ^{3}He observed in the Western Turkish fluids.

Tritiugenic ^{3}He production occurs through the decay of tritium (^{3}H) introduced into the atmosphere during the nuclear testing. If the groundwaters are supplemented by post - 1950 (i.e. after the commencement of nuclear testing) recharges from surface waters, then they are subject to the accumulation of ^{3}He produced by the decay of atmosphere-derived ^{3}H in surface waters. Since there is no information regarding the distribution of bombproduced tritium in Western Turkey or about the groundwater ages, it is difficult to asses the effects of tritiugenic ^{3}He production It should be noted that because the ^{3}He contents of water samples are low (10 ccSTP g), the decay of ^{3}H could potentially increase the He/ He ratios. On the other hand, a comparison between the He contents of water and gas samples reveals that the He contents of gas samples are about an order of magnitute higher than those of water samples. The reason for the low He contents of water samples is the separation of a gas phase into which most of the noble gases partition. However, although the He contents of gas and water samples are different, their ^{3}He/^{4}He ratios are similar to each other. If tritium were introduced into the groundwaters, then as a result of the separation of water and gas phases, the ^{3}He/^{4}He ratios of waters would be enhanced relative to the gas phase (He partitions into the gas phase, whereas ^{3}H is retained in water as a part of water molecule (^{3}H^{1}HO). The retained ^{3}H would produce, in time, ^{3}He in waters). Therefore, in the case of tritiugenic ^{3}He contributions, lower He contents in waters are expected to be accompanied by higher ^{3}He/^{4}He ratios. In Western Turkey, ^{3}He/^{4}He ratios of water samples are not necessarily higher than those of gas samples ; hence, the ^{3}He enhancfcnxents can not be due to H decay.

Transport mechanism of mantle - helium

The transport of helium from mantle into crust is-in general - not well understood, but it is thought to be associated with mantle - derived melts or fluids. If mantle-helium in Western Turkey is transported into the crust by mantle related magmatism, then the fact that no relationship exists between the distribution of ^{3}He and volcanism suggests that plutonic activity may be widespread in Western Turkey. If mantle - derived fluids are responsible for the transportation of mantle-helium, then they must have been injected into the crust over a large area. The association of hot-springs with major fault structures suggests that the fault zones might have acted as conduits for mantle-derived fluids.

One of the problems in determining how mantle-helium is transported into the crust is that it is not known when it was added to the crust. Miocene (or older) volcanism may represent a possible mechanism only if helium can be stored in the crust long enough (i.e. 10^7 years). The relationship between heat flow and He-isotope compositions (Polyak and Tolstikhin, 1985) and the observation that the thermal relaxation time for continental crust is of the order of 10^8 years (Sclater et al., 1981) suggests that crustal storage of helium over such a period may be possible. However, there is not any evidence for deciding when mantle-helium was added to the crust; it might have been added very recently in some areas.

As has already been stated in the foregoing section, the observation of high R/R_a values in the vicinity of Pliocene age Denizli volcanics indicates that either Denizli is a site of prominent mantle - He leakage and that this helium is still being retained in the crust, or that the distribution of ^{3}He is not linked with surface volcanism. In the latter case, the transport of mantle-helium into the crust might result from plutonic activity (much younger than volcanism) or present day loss of fluids from the mantle.

There is an accumulating evidence for mantle-derived melt additions to the continental crust in extensional areas. Geophysical surveys carried out on some of the extensional basins (e.g. Rhine graben , Baikal rift, Rio Grande rift) reveal the presence of highly conductive, anomalously low—velocity zones at sub—crustal (and/or intra—crustal) levels which are interpreted as the zones of magma accumulation (Hermance, 1982 and the references terein). On the basis of these evidences, mantle—derived melts are believed to have had an efficient role in transporting mantle—helium into the crust of Western Turkey where extension is prevailing since about Upper .vliocene. Since mantle — He is widely distributed in Western Turkey, rather than localized plutonic activities, a widespread melt addition to the crust is possibly indicated. The fault systems are thought to have aided the escape of helium to the surface through the brittle parts of crust.

CONCLUSIONS

The main conclusions drawn from the present study can be stated as follows :

1 — The He — isotope composition of the geothermal fluids reveal mixing between mantle —He and crustal—He components.

2 — The distribution of mantle—He does not show any relation to the distribution of surface volcanics but rather appears to be governed by the distribution of the main fault structures.

3 — The lack of any evidence between the distribution of mantle—helium and surface volcanism suggests that helium is degassed from the melts emplaced deeper in the crust.

4 — The fault systems of the present extensional regime are thought to have acted as channelways for the escape of helium to the surface through the crust.

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