ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 414, No. 4, pp. 605–608. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © V.Yu. Lavrushin, B.G. Polyak, V.P. Strizhov, F. Italiano, A. Rizzo, 2007, published in Doklady Akademii Nauk, 2007, Vol. 414, No. 2, pp. 239–242.

GEOCHEMISTRY

# The $^3He/^4He$ Halo of the Kazbek Volcanic Center, Northern Caucasus

**V. Yu. Lavrushin[a], B. G. Polyak[a], V. P. Strizhov[b], F. Italiano[c], and A. Rizzo[c]**

Presented by Academician Yu.G. Leonov June 26, 2006

Received July 7, 2006

**DOI:** 10.1134/S1028334X07040253

Manifestations of recent volcanism in the Greater Caucasus are grouped in the El'brus and Kazbek volcanic areas [1]. The last episodes of activity in the majority of their eruptive centers date back to the Late Holocene or even first centuries of the recent era (El'brus Volcano) [2]. This implies potential volcanic hazards in the Greater Caucasus. Therefore, it is important to outline contours of this potentially hazardous region with the maximal possible accuracy. The region is characterized by indications of geodynamic stress, such as recent eruptions, crustal deformations, seismic activity, geothermal anomalies, and others. The $^3He/^4He$ value in natural gases can serve as one of such indications.

The study of the He isotopic composition provides insight into the participation of mantle emanations in the formation of fluid systems. It is known that the $^3He/^4He$ ratio is ~$1200 \cdot 10^{-8}$ in the mantle helium and three orders of magnitude lower in crustal helium [3]. The mantle helium enters upper layers of the crust with magmatic melts [4]. Helium released from the melts is mixed in variable proportions with the crustal helium and dissolved in gaseous-water fluids. Subsequently, the helium is transported along with the fluids to the surface. The data on the helium isotopic composition in natural gases offer the opportunity to determine areas with magmatic activity even in regions lacking its surface manifestations and positive geothermal anomalies and, thus, outline regions with potential volcanic hazard. Systematic gathering of such data can serve as an efficient tool for the monitoring of the volcanic hazard.

The study of gases from mineral waters of the Caucasian region demonstrated long ago the presence of the mantle helium in their gases [5]. The distribution of $^3He/^4He$ values is best studied in the El'brus volcanic area located north of the Main Range of the Greater Caucasus [6–8]. Helium isotope signs of the discharge of mantle derivatives spread far beyond this region and reach the northern slope of the Stavropol Arch [9]. Maximal $^3He/^4He$ values ($>300 \cdot 10^{-8}$) trace the El'brus Caldera area identified by Bogatikov et al. [10]. The diameter of the caldera is close to that of its intermediate magma chamber outlined by gravimetric data [11]. The $^3He/^4He$ values exceeding $150 \cdot 10^{-8}$ encompass a spacious area (Fig. 1) corresponding to the projection of a deeper "parental magmatic source" (see, for example, [12]).

In the Kazbek volcanic area, which comprises several volcanic subareas, the helium isotopic composition

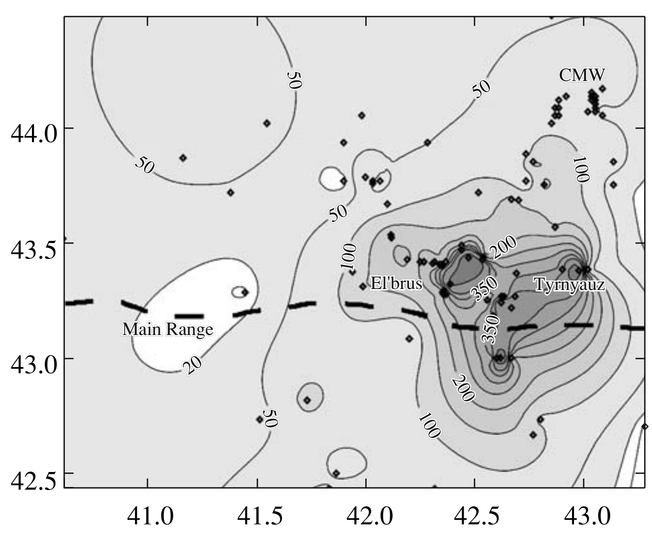


**Fig. 1.** Distribution of $^3He/^4He$ values ($\times 10^{-8}$) in subsurface fluids of the El'brus region. (CMW) Caucasian Mineral Waters. Diamonds designate sampling sites.

[a] Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia; e-mail: v_lavrushin@ginras.ru

[b] Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, ul. Kosygina 19, Moscow, 117975 Russia

[c] National Institute of Geophysics and Volcanology, Palermo, Italy

Helium isotopes and macrocomponents in gases from subsurface fluids of the Kazbek volcanic area

| Index in Fig. 2 | Sample | Sampling site | Sampling date | He, $10^{-4}$ vol % | $^4He/^{20}Ne$ | $^3He/^4He$ meas., $10^{-8}$ | Error, % | $^3He/^4He$ corr., $10^{-8}$ | $H_m/He$, % | $CH_4$, vol % | $CO_2$, vol % | $N_2$, vol % | $O_2$, vol % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 23/99 | Tanadon Spring | 23 Sep 99 | 0.51** | 2** | 145** | | 146 | 12 | 0.27 | 98.65 | 0.95 | 0.078 |
| 2 | 32/00 | Dzinaga Spring | 20 Sep 00 | | 344*** | 17 | 1.49 | 17 | 1 | 2.08 | 86.85 | 10.71 | 0.19 |
| 3 | 6/03 | Zaramag Spring | 20 Jul 03 | | 23*** | 254 | 0.75 | 256 | 21 | 0.58 | 87.71 | 10.68 | 0.28 |
| 4 | 24/99 | Tamisk, Well 3 | 27 Jul 99 | 176** | 12** | 13.8** | | 11 | 1 | 1.09 | 3.43 | 92.84 | 1.18 |
| 5 | 25/99 | Khilag Spring | 25 Jul 99 | 0.54** | 2** | 215** | | 228 | 19 | 0.075 | 97.59 | 1.58 | 0.16 |
| 6 | 4/03 | Verkhnii Karma-don Spring | 15 Jul 03 | | 16*** | 189 | 0.83 | 190 | 16 | 0.036 | 97.33 | 2.46 | 0.26 |
| 7 | 40/00 | Nizhnii Karma-don, Well 29 | 27 Sep 00 | | 962*** | 27 | 0.71 | 27 | 2 | 45.5 | 2.93 | 50.97 | 0.37 |
| 8 | 30/03 | Dzhava Spring | 28 Jul 03 | | 252*** | 384 | 0.3 | 384 | 32 | 0.25 | 8.45 | 89.75 | 0.007 |
| 8 | 136* | Dzhava, Well 44 | <1978 | 150 | | 330 | | | ≥27 | 6.9 | 29.70 | 63.40 | |
| 8 | 136a* | Dzhava, Well 14A | 1988 | 23 | 0.55 | 174 | | 215 | 18 | | 97.70 | | |
| 9 | 34/03 | Khutse Spring | 29 Jul 03 | | 11*** | 319 | 0.59 | 324 | 27 | 1.029 | 82.18 | 16.16 | 0.01 |
| S | 138* | Sadon, Well | <1978 | | | 6.7 | | | <0.35 | | | | |
| T | 139* | Truso Spring | 1983 | 20 | | 260 | | | ≥21 | 0.6 | 97.9 | 1.5 | |
| B | 105* | Bagiata Spring | <1978 | 10 | | 650 | | | ≥54 | | 99.5 | 0.5 | |
| P | 141* | Pansheti Spring | <1978 | | | 250 | | | ≥21 | | 90.8 | 9.2 | |
| N | 140* | Nadibaani Spring | | | | 660 | | | ≥55 | 0.4 | 96.9 | 2.7 | |

Note: (*) Data from [9]; (**) measured by I.L. Kamenskii (Geological Institute, Kola Scientific Center, Russian Academy Sciences); (***) He/Ne (National Institute of Geophysics and Volcanology, Palermo).

in subsurface fluids is less investigated. The previous data concern only its southern (Georgian) segment, where several tens of small eruptive centers are located in the Kel, Kabardzha, and Dzhava volcanic subareas [1] and $^3He/^4He$ values ranging from ~$200 \cdot 10^{-8}$ to $700 \cdot 10^{-8}$ were recorded in gases of mineral waters [9]. This $^3He/^4He$ level, which corresponds to 60% of the mantle component in the total helium, is as high as in the nearest vicinity of the El'brus Volcano.

The segment located north of the Main Range forms the Kazbek volcanic subarea that extends from the upper reaches of the Cherek River to the Terek River. The Kazbek Volcano, the most known eruptive center in this subarea, was active in the Quaternary. The Tepli, Kubus, and other "neointrusions" in its western part are dated back to the Late Pliocene [1].

In this area, the $^3He/^4He$ value of $6.7 \cdot 10^{-8}$ was previously determined only in gases sampled in the Sadon ore field [5]. Such a value indicates the virtual absence of mantle derivatives in these gases. However, one determination is insufficient for outlining the "helium isotope boundary" of the region with intense magmatism.

Therefore, we sampled mineral springs in the northern (Kazbek area) and southern (Bol'shaya Liakhva River basin) segments of the study region in 1999–2003. The samples of bubbling gases were analyzed by the Group of Geochemical Monitoring of Seismoactive Areas at the National Institute of Geophysics and Volcanology (Palermo, Italy). The table and Fig. 2 present the obtained data.

Sampling of the Dzhava and Khutse springs in the Liakhva River basin confirmed the previous results. In addition, springs located at upper reaches of the Urukh, Ardon, Fiagdon, and Genaldon rivers in the northern segment yielded $^3He/^4He$ values as high as $(190–256) \cdot 10^{-8}$. They indicate unambiguously a substantial admixture of the mantle helium in gases and, thus, mark the Kazbek volcanic subarea. At the northern sampling sites (Dzinaga, Tamisk, and Nizhnii Karmadon), the $^3He/^4He$ ratio sharply decreases (approximately by an order of magnitude) to values typical for crustal helium.

The decrease in the share of mantle helium in the gaseous phase of fluids is accompanied by variations in the chemical composition of the gaseous phase: drastic decrease in the content of carbon dioxides and increase in contents of nitrogen and methane (table). This fact supports the concept that $CO_2$-rich waters of volcanic areas, the Kazbek and El'brus ones included, are genetically related to magmatism.

The sole exception is provided by the sample taken from the well in the Dzinaga Camping. The sample is characterized by a $^3He/^4He$ value ($17 \cdot 10^{-8}$) close to the crustal one, although the gas released in this area is

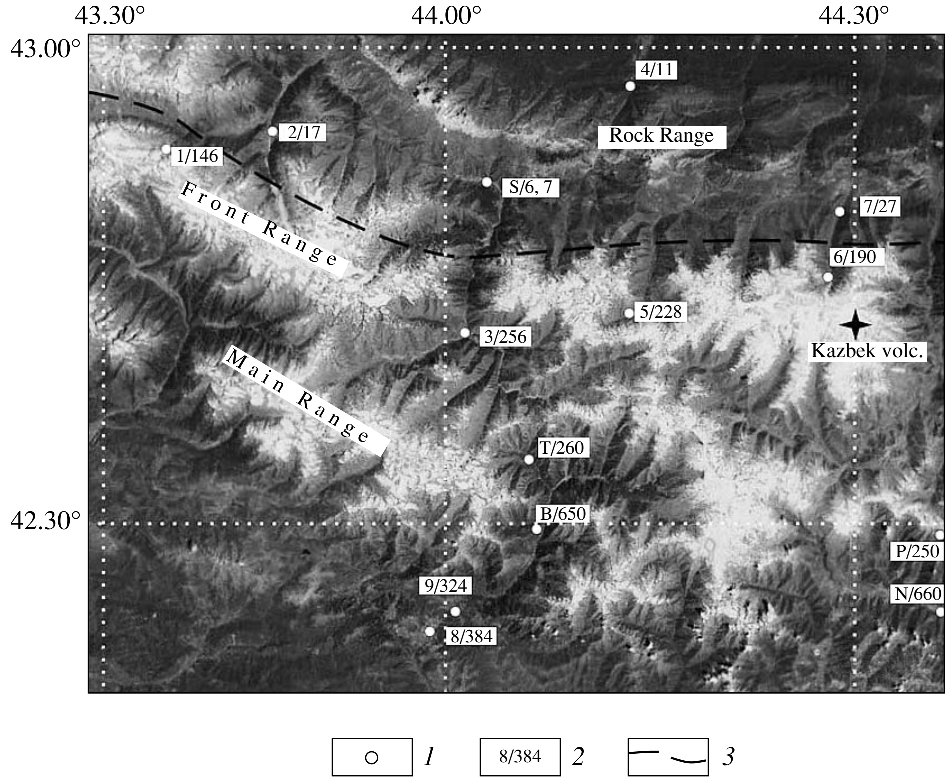


**Fig. 2.** He isotopic composition in gases from the Kazbek volcanic subarea. (1) Sampling sites; (2) numerals and letters to the left of the line are as in the first column of the table ($^3He/^4He$ values, $10^{-8}$ are shown to the right of the line); (3) assumed northern "helium isotope boundary" of the Kazbek volcanic area.

largely composed of $CO_2$. Unfortunately, we failed to determine the $\delta^{13}C_{CO_2}$ value in this sample but the helium isotopic composition in the sample implies the crustal (most likely, metamorphogenic) nature of carbon dioxide. Strong contamination of the mantle $CO_2$-rich fluid by crustal helium seems less probable, although zones of thermal anomalies and tectonic brecciation related to recent tectonomagmatic activity should provide particularly favorable conditions for extraction of radiogenic helium from the rock matrix.

The Genaldon River valley that originates at the northern foothills of the Kazbek Volcano hosts two groups of thermomineral springs: Verkhnii Karmadon (carbon dioxide) and Nizhnii Karmadon (nitrogen–methane). They are located at a distance of approximately 6 and 14 km, respectively, from the Kazbek summit. The $^3He/^4He$ values between these two groups of springs decrease by almost an order of magnitude: from $190 \cdot 10^{-8}$ to $27 \cdot 10^{-8}$. Thus, both the general composition of gases from mineral waters and the isotopic composition of helium in them change drastically over a very narrow (8 km) segment of the Genaldon River valley, suggesting the existence of a sharp boundary between crustal blocks with principally different geochemical compositions of subsurface fluids.

This segment is also marked by variations in the geophysical characteristics of the geological section. According to gravimetric data [13], the area located south of the Nizhnii Karmadon springs is characterized by an increase of negative gravitational anomaly toward the Kazbek Volcano from 0 to –25 mGal at a distance of only 3–4 km. This fact is attributed to the existence of a very shallow magma chamber with the density deficiency up to 0.5 g/cm$^3$ beneath the Kazbek Volcano. The magnetotelluric sounding carried out in the same segment of the valley [14] revealed an object with anomalously low values of electric resistance (0.6–3.0 Om m) at depths of 6–8 km probably related to saturation of rocks with highly mineralized solutions [14].

As is known, inverse problems of geophysics lack solutions. Therefore, interpretation of available gravimetric and electromagnetic data is ambiguous. The ambiguity may be reduced by synthesis of these data based on quantitatively consistent models. In doing so, the spectrum of data should be widened primarily based on "seismic scanning" (a standard procedure in volcanology), i.e., study of the distribution of elastic waves in hypothetical magma chambers. At the present moment, we can only state that geophysical observations record strong variations in the properties of the geological medium north of the Kazbek Volcano in the same area where sharp changes in the helium isotopic composition in subsurface fluids are observed. At the same time, the $^3He/^4He$ values and their sharp changes in the Genaldon River valley have cast some doubt on the existence of a small magma chamber in this area. Judging from helium isotope data, the boundary of the Kazbek volcanic area passes somewhere along the Lateral Ridge (Fig. 2).

Thus, the decrease in the $^3He/^4He$ value north of the Kazbek Volcano appears to be substantially faster than in the El'brus region. In the latter region, the halo of elevated $^3He/^4He$ values extends far into the Scythian Plate. According to the hydrodynamic modeling [6], the fact mentioned above reflects the discharge of the mantle helium through not only the El'brus magmatic feeder, but also other volcanic conduits [6]. Development of such conduits north of the Kazbek Volcano is less probable.

## ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (project no. 00-05-64414), the Division of Earth Sciences of the Russian Academy of Sciences (Program no. 5 "Geophysics of Geosphere Interactions"), and the National Institute of Geophysics and Volcanology, Palermo (Project V5 INGV "Diffusive Degassing in Italy").

## REFERENCES

1. E. E. Milanovskii and N. V. Koronovskii, *Orogenic Volcanism and Tectonics of the Alpine Belt of Eurasia* (Nedra, Moscow, 1973) [in Russian].
2. O. A. Bogatikov, I. V. Melekestsev, A. G. Gurbanov, et al., Dokl. Earth Sci. **363**, 1093 (1998) [Dokl. Akad. Nauk **363**, 219 (1998)].
3. B. A. Mamyrin and I. N. Tolstikhin, *Helium Isotopes in Nature* (Energoizdat, Moscow, 1981) [in Russian].
4. B. G. Polyak, *Heat and Mass Transfer from the Mantle in Major Structures of the Crust* (Nauka, Moscow, 1998) [in Russian].
5. E. S. Matveeva, I. N. Tolstikhin, and V. P. Yakutseni, Geokhimiya, No. 3, 307 (1978).
6. L. E. Yakovlev and B. G. Polyak, Vulkanol. Seismol., No. 6, 3 (1997).
7. B. G. Polyak, E. M. Prasolov, I. L. Kamenskii, et al., Geochem. Int., No. 4, 329 (1998) [Geokhimiya, No. 4, 383 (1998)].
8. V. Yu. Lavrushin, B. G. Polyak, B. G. Pokrovskii, and I. L. Kamenskii, in *Geodynamics, Seismotectonics, and Volcanism in the Northern Caucasus* (OIFZ RAN, Moscow, 201), pp. 272–293 [in Russian] .
9. B. G. Polyak, I. N. Tolstikhin, I. L. Kamenskii, et al., Geochim. Cosmochim. Acta **64**, 1925 (2000).
10. O. A. Bogatikov, I. V. Melekestsev, A. G. Gurbanov, et al., Dokl. Earth Sciences **363A**, 1202 (1998) [Dokl. Akad. Nauk **363**, 515 (1998).
11. M. V. Avdulov, Izv. AN SSSR. Ser. Geol., No. 9, 67 (1962).
12. O. A. Bogatikov, Yu. V. Nechaev, and A. L. Sobisevich, in *Recent Mathematical and Geological Models in Problems of Applied Geophysics* (OIFZ RAN, Moscow, 2001), pp. 249–260 [in Russian].
13. A. V. Kopaev and A. G. Gurbanov, Vestn. Valdikavkaz. Nauch. Tsentra **4** (3), 9 (2004).
14. V. N. Arbuzkin, I. S. Fel'dman, and E. A. Trofimenko, Vestn. Valdikavkaz. Nauch. Tsentra **4** (3), 12 (2004).