Helium isotope studies of the Central Tien Shan

B G Polyak 1, E A Bataleva 2, A K Rybin 2

1 Geological Institute of the Russian Academy of Sciences, 119017, Pyzhevskiy Pereulok, 7c1, Moscow, Russia
2 Research station of Russian Academy of Sciences in Bishkek city, 720049, Bishkek-49, Kyrgyzstan

E-mail: bataleva@gdirc.ru; rybin@gdirc.ru

Abstract. The research shows new results of isotope-helium studies carried out in the Tien Shan - Naryn and Atbashi basins. Sampling of thermal mineral springs in the Eastern Tien Shan was carried out in order to identify traces of mantle emanations in fluids and to assess the degree of permeability of the Earth's crust for the introduction of deep masses, which would make it possible to clarify the nature of the interaction of the crust and mantle in the zone of recent orogeny. Concentrations of helium isotopes were measured in gas and water samples from 6 thermal mineral springs in the Central Tien Shan. It was found that fluids from three sources contain an abnormally high amount of mantle helium. In the gases of the Narzan source, the ratio $\frac{^3\text{He}}{^4\text{He}}$ in the gas phase ($597\times10^{-8}$) reaches the Central Asian maximum found earlier on the Fergana ridge in the Kyzyl-Beles source ($510\times630\times10^{-8}$). The obtained results support the ideas on the existence of two sub-latitude positive helium isotope anomalies on the northern and southern flanks of the Eastern Tien Shan - in the zones of junction of the epiplatform neo-orogene with more ancient tectonically stable structures.

1. Introduction

According to modern concepts of the origin of helium isotopes in the Earth's crust and upper mantle, it is assumed that the $^4\text{He}$ isotope (light helium) was captured by the Earth's matter during the accretion of the planet as the primary helium present in meteorite matter, while the $\frac{^3\text{He}}{^4\text{He}}$ (R) ratio was on the order of $1.5\times10^{-4}$. In the modern Earth's crust, as a result of the influx of the radiogenic isotope $^4\text{He}$, which occurs during the decay of uranium (U) and thorium (Th), this ratio has significantly decreased, and for the ancient continental crust it fluctuates within $(2\pm1)\times10^{-8}$ [1, 2]. In the atmosphere, due to the constant influx of helium from the bowels of our planet, sphaelogenous reactions and due to the constant dissipation of both helium isotopes into outer space, the R value of $140\times10^{-8}$ was established. Thus, samples of thermal mineral springs can contain helium, which includes three components - crustal, mantle, and atmospheric, which makes them a favorable object for regional studies (Fig. 1).

Variations in the $\frac{^3\text{He}}{^4\text{He}}$ value in geological objects are not accidental. There is a difference in this ratio in the gases of sedimentary rocks of different ages, and during regional comparisons it was found that these variations obey a more general pattern, reflecting the tectonic specifics of the regions under study [3-10]. The emerging trend in the distribution of helium isotopic ratios in natural gases was thus very similar to the dependence previously established in the distribution of heat flux. Since this flux, to one degree or another, is undoubtedly genetically related to the process of radioactive decay, which also forms the isotopic composition of terrestrial helium, a direct comparison of both parameters is of particular interest. Already the first attempt in this direction, undertaken on
comparatively limited material, showed on a qualitative level the existence of a positive relationship between these parameters. With an increase in the number of determinations of the isotopic composition of helium in different geotectonic provinces and new measurements of the heat flux, it becomes possible to clarify and detail the previous ideas about the spatial regularities in the distribution of $^{3}\text{He} / ^{4}\text{He}$ in terrestrial gases and the nature of its correlation with the heat flux. In subterranean fluids, the presence, in addition to crustal fluids, is also clearly seen of the isotopically lighter helium. This helium could have formed under the influence of radioactive decay only in the deep bowels of the Earth, where the primary (cosmic) $^{3}\text{He}$ is still partially preserved.

Thus, the isotopic composition of deep (mantle) helium can be evaluated by the $^{3}\text{He} / ^{4}\text{He}$ value in geological objects that are genetically most clearly associated with modern degassing and differentiation of the mantle and, moreover, those in which the contamination of deep helium by crustal ones would be minimal.

Sampling of the thermal mineral springs of the Eastern Tien Shan (Fig. 2) was carried out in order to reveal in these fluids traces of mantle emanations, their scale and localization in different tectonic elements of the orogen, as well as to assess the degree of permeability of the earth's crust for the introduction of deep masses, which would make it possible to clarify the nature of interactions of the crust and mantle in the zone of recent orogeny.

2. Data and method
The isotopic composition of helium in the underground fluids of the Eastern Tien Shan is especially interesting for comparison with that in the regions of the Turan plate not activated by recent orogeny. Previous isotope-helium studies of the region [1, 2, 11] concentrated on its northern margin (in the Kyrgyz and Zailiyskiy ridges) and in the Issyk-Kul basin – “Precambrian microcontinent” according to [11], including its framing (Terskey ridge), and also characterized some sources southeast of the Atbashi-Inylchek (atbashi group) and east of the Talas-Fergana faults. However, the central part of the region, the Naryn basin (naryn group), has practically not been studied. Therefore, it has become the primary object of our research. First of all, we were interested to understand whether new samples taken from newly found mineral springs both in the basins themselves and in the near-side zones of concentrated deformation can serve as a “mantle mark”. In other words, can they be indicators of geodynamic processes and be used to refine complex geophysical models of key objects and at the same time serve as reference points for determining heat and mass transfer zones on the day surface?
When searching and testing the sources, the performers were guided mainly by the work of Polyak and his colleagues [1-3], which contains general information about the sources and wells of the Tien Shan mineral waters. The sampling of gas and water was carried out, as a rule, from ascending thermal mineral springs according to the method described in [12, 13]. This procedure is an extremely important part of research, since during sampling it is necessary to minimize the possible admixture of air in the sample and thereby minimize the contamination of deep noble gases by their atmospheric counterparts. Sampling was carried out into bottles of approximately 300 cm³, which were 1/3 filled with water (water seal). We took free gases from groundwater during their unloading in springs or at wellheads. The hottest spring was sampled within one focus of thermal mineral water discharge.

Analyzes of gas-water samples were performed at the GI KSC RAS (Apatity) on M/S MI 1201 No. 22-78 by Kamensky I.L. For each source, the content of the sum (He + Ne) was determined on a glass mercury device of the Khlopin-Gerling type from a portion of 33 cm³. Of the total amount of this sum, about 100 pv was transferred to a garland of three ampoules, which was soldered into three separate ampoules. Two of them are analyzed, the results are in the above table, and the third ampoule is kept for control.

![Figure 2. Map of helium spring sources](image)

**Figure 2.** Map of helium spring sources: 1 – all He sources, 2 – border of Kyrgyzstan, 3 – main faults (Chl-Chu-II, CT – Central Terskey, NL – Nikolaev line, AI – Atbashy-Inylchek, TF – Talas-Fergana, SF – South Fergana, GK – Gissar-Kokshaal), 4 – He sources investigated in 2019 (the numbers show the ratio \(^3\text{He} / ^4\text{He}\) (R)), 5 – cities, 6 – magnetotelluric soundings points, 7 – water objects: lakes and rivers

### 3. Results

In 2016, within its limits, the Dostuk spring (N 41.36389, E 75.57417, altitude 1818 m, T = 18.9 °C) was sampled, unloading in the zone of tectonic faults limiting the ledge of Paleozoic rocks of the Baibiche-Too ridge at the contact of marbles of the Lower Carboniferous (C₁) with red-colored sandstones and clays of the Oligocene-Miocene (P₃-N₁). Due to the lack of free gas evolution in the source, a water sample was taken for further analysis. For technical reasons, it was not possible to
determine the composition of helium in the same year, but this was done in 2017. The results of isotopic analyzes of gas-water samples are presented in Table 1.

**Table 1.** Results of isotopic analyzes of a water sample from the Dostuk spring (analyst I L Kamensky, GI KSC, June 12 - July 1, 2017)

| Taken for analysis (cm³) | He+Ne concentration (ppm) | He quantity in the ampoule (10⁶ cm³ STP) | ³He/⁴He *10⁻⁸ | ³He²⁰Ne | He concentration (ppm) | Ne concentration (ppm) |
|--------------------------|---------------------------|----------------------------------------|-----------------|---------|-----------------------|-----------------------|
| 33                       | 26                        | 14                                    | 75±7            | 0.48    | 8                     | 18                    |
| 19                       | 19                        | 73±6                                  | 0.50            | 8.1     | 17.9                  |

The ³He / ⁴He values indicated in this table are two times less than in the atmosphere (140 × 10⁻⁸), but much higher than those found in the Issyk-Kul basin sources: ~ (3.3÷7.5) × 10⁻⁸, which characterize helium from the so-called "Turanian" (Hercynian) continental crust, which has not experienced epiplatform tectonic-magmatic activation. At the same time, the ratios of ⁴He / ²⁰Ne concentrations indicated in the next column of the same table are 0.48 and 0.50, which are close to the atmospheric value of ~ 0.3, indicate an obvious admixture of air the value of the isotope-helium ratio measured in the gas of the Dostuk source. One can only be sure that such a value is significantly lower than the measured ones (73-75) × 10⁻⁸ and much closer to the “Issyk-Kul” ones. That is why it was necessary to re-try the Dostuk source, which was done later.

Due to the absence of free gas evolution in this source, a water sample was again taken from it for analysis of the isotopic composition of water-dissolved helium. A similar sample was taken from the Karabuk spring (N41.16248, E75.25594, altitude 2560 m, T°С = 6.5, Fig. 2), as well as samples of spontaneously released gases from the Narzan (N40.76054 E76.29954) and Arashan 1, 2 (1 - N41.11603 E76.50965; 2 - N41.11530 E76.50981) springs. The results of the analysis of all these samples are shown in Table 2.

**Table 2.** Results of isotopic analyzes of spontaneous gas samples for 5 sources of the Kyrgyz Republic in 2018 (analyst I L Kamensky GI KSC, November, 2019)

| Spring name, probe No | Sampling date | T °С | ⁴He ppm | ³He/⁴He E⁻⁸ | ³He²⁰Ne |
|-----------------------|---------------|------|---------|-------------|---------|
| Water                 |               |      |         |             |         |
| Dostuk                | 26.06.2018    | 18.9 | 470     | 19±4        | 82      |
| Karabuk              | 27.06.2018    | 6.5  | 12      | 82±6        | 0.76    |
| Narzan               | 29.06.2018    | 4.8  | 10      | 600 ± 20    | 270     |
| probe 1               |               |      |         |             |         |
| probe 2               |               |      | 14      | 597 ± 30    | 353     |
| Arashan 1, 2         | 29.06.2018    | 18.8 | 18      | 300 ± 19    | > 31    |
| Arashan 2             | 29.06.2018    | 14.5 | 15      | 280 ± 17    | 122     |
| Arashan 1             | 30.06.2018    | 18.9 | 170     | 271 ±15    | 791     |

The estimate of the ³He / ⁴He ratio obtained in the water of the Dostuk spring indicates a very small admixture of the mantle component in the water-dissolved helium. Apparently, it can, as a first approximation, be considered characteristic of the Naryn basin, which adjoins the Terskey ridge and the Issyk-Kul microcontinent from the south, where the ³He / ⁴He values are close to those characteristic of the radiogenic helium of the ancient crust [9, 12]. The much higher value of the ³He / ⁴He ratio measured in a sample from the Karabuk spring in the same Naryn basin is accompanied by a low value of the ⁴He / ²⁰Ne ratio = 0.76. This value indicates a large admixture of air He in this sample, not allowing, as in the previous sample from the Dostuk source, to reliably estimate the degree
of this atmospheric contamination and calculate the true depth value of the isotope-helium ratio, which should be much lower than the measured one.

The results of the analysis of the spontaneously released gas phase at the sources of Arashan and Narzan are fundamentally different. These sources exit southeast of the Atbashi-Inylchek fault, and the composition of helium in them is completely different: their gases are practically not contaminated with atmospheric helium and, on the contrary, contain a significant contribution of mantle helium. The Arashan springs (N 41.11530, E 76.50981, 3302 m and N 41.11603, E 76.50965, altitude 3310 m) are located at the base of terrace Q3, east of the D3-C1 marble outcrops, lithology is sand, boulders, pebbles of poor roundness. The Narzan spring (N 40.76054, E 76.29953, altitude 3366 m) is located in channel Q4 sediments, at the base of the D (?) Basalt scarp, lithology is represented by Q4 boulders and deluvium mafic rocks.

In the Arashan spring, the values of \( R = (280-300) \times 10^{-8} \) exceed those previously encountered not only in the Beshbelechir-Arashan spring \((210 \times 10^{-8})\), but also in the Chatyrkel spring coming out to the southwest \(- \sim 250 \times 10^{-8} \) [1]. In the gases of the Narzan source, the \( ^{3}\text{He} / ^{4}\text{He} \) ratio in the gas phase \((597\div600) \times 10^{-8} \) reaches the "Central Asian" maximum found earlier on the Fergana ridge in the Kyzyl-Beles spring \((510\div630) \times 10^{-8} \) [1].

4. Conclusion

The concentrations of helium isotopes, as well as Ne and Ar, were studied in gas and water samples from 6 thermal mineral springs in the Central Tien Shan. The performed studies are an important addition to the new magnetotelluric soundings carried out along the 75th meridian [14, 15]. The results obtained support the idea [1,2] about the existence of two sublatitudinal positive isotope-helium anomalies on the northern and southern flanks of the Eastern Tien Shan - at the junctions (in the junction zones) of the epiplatform neoorogen with more ancient tectonically stable structures - the Caledonian Kazakh shield and the Precambrian Tarim plate. The northern anomaly (in the Zailiyskiy ridge) has lower \(^{3}\text{He} / ^{4}\text{He} \) ratios and seems to be "thinner" in diameter than the southern one. The value of \(^{3}\text{He} / ^{4}\text{He} \sim 6\times10^{-6} \) found in the last samples of the gas-water mixture of the Narzan source, as in the Kyzyl Beles source, is close to the maximum not only in Central Asia, but also outside the areas of active volcanism in general, so it is worth considering the possibility revision of the age of volcano-plutonic formations rare in the region, the existence of which is assumed near the Narzan source, according to its coordinates and Figure 3 in [16].

Taking into account the importance of isotope-helium studies for an objective characterization of the geodynamic environment not only in the Eastern Tien Shan [1,2, 17], but also in other regions [18-20], they should be continued with a more representative sampling of the gas phase of thermomineral sources and taking into account the literature data. It is especially important to determine the ratio \(^{3}\text{He} / ^{4}\text{He} \) (R) in the Naryn basin.

5. References

[1] Polyak B G, Kamensky I L, Sultankhodzhaev A A, Chernov I G, Barabanov L N, Lisitsyn A K, Khabarovskyaya M V 1990 Submantle helium in fluids of the southeastern Tien Shan Doklady Earth Sciences 312(3) 721–725
[2] Polyak B G, Cheshko A L, Gordienko V V, Tarasov V N, Kamenskii I L, Prasolov E M 1999 Helium isotopes, heat flow, and tectonics of the eastern carpathians Doklady Earth Sciences 367 332-337
[3] Mamyrin B A, Tolstikhin I N, Anufriyev G S, Kamenskii I L 1972 Isotopic composition of helium in icelandic hot springs Geochemistry International 11 1396
[4] Rykhkova K M, Duchkov A D, Lebedev V I, Kamenskii I L 2007 Helium isotopes in underground sources of Eastern Tuva Doklady Earth Sciences 417(6) 814-817
[5] Grieshaber E, O’Nions R K, Oxburgh E R 1992 Helium isotope systematics in crustal fluids from the Eifel, Rhine Graben and Black Forest, FRG Chem. Geology. 99 213-235
[6] Duchkov A D, Sokolova L S, Rykhkova K M, Lebedev V I, Kamenskii I L 2010 Estimation of
heat flow in Tuva from data on helium isotopes in thermal mineral springs Russian Geology and Geophysics 51(2) 209-219

[7] Craig L C, Chen H C, Taylor W I 1969 Thin Film Dialysis Including Counter-Current Dialysis Journal of Macromolecular Science: Part A Chemistry 3 (1) 133-149

[8] Du J 1992 Works of Gas Geochemistry Gansu Sci. (Technol. Press.) 165-171

[9] Duchkov A D, Shvartsman Yu G, Sokolova L S 2001 Depth heat flow of the Tian-Shan: achievements and challenges Russian Geology and Geophysics 42(10) 1512

[10] Kamensky I L, Tokarev I V, Tolstikhin I N 1991 3He/4He dating: A case for mixing of young and old groundwaters Geochemica et Cosmochimica Acta 55 2895-2899

[11] Batalev V Yu, Bataleva E A, Egorova V V, Matyukov V E, Rybin A K 2011 The lithospheric structure of the Central and Southern Tien Shan: MTS data correlated with petrology and laboratory studies of lower-crust and upper-mantle xenoliths Russian Geology and Geophysics 52(12) 1592–1599

[12] Kamenskii I L, Lobkov B V, Prasolov E M, Beskrovnyi N S, Kudryavtseva E I, Anufriev G S, Pavlov V P 1976 Components of the Earth' upper mantle in the Kamchatka gases (based on He, Ne, Ar and C isotopes). Geochemistry International 5 682–695 (in Russian)

[13] Handbook on the geochemistry of oil and gas 1998 (St. Petersburg., JSC Publishing house Nedra, St. Petersburg branch) 25-36 (in Russian)

[14] Rybin A K, Bataleva E A, Batalev V Y, Matyukov V E, Zabinakova O B, Nelin V O, Morozov Y A, Leonov M G 2018 Specific features in the deep structure of the Naryn basin – Baibichetoo ridge – Atbashi basin system: evidence from the complex of geological and geophysical data Doklady Earth Sciences 479(2) 499-502

[15] Rybin A K, Bataleva E A, Matyukov V E, Morozov YA, Nepeina K S 2021 Deep Structure of the Lithosphere in the Central Tien Shan along the Son-Kul Magnetotelluric Sounding Profile Doklady Earth Sciences 496(2) 101–106

[16] Knauf V I, Mikolaichuk A V, Khristov E V 1980 Seismotectonics and seismicity of the Tien Shan (Frunze: Ilim) 3-17 (in Russian)

[17] Bataleva E, Rybin A, Batalev V, Matyukov V 2009 Models of fluid saturated zones according magnetotellurics and seismics data on Tien Shan crust and mantle along transect MANAS EGU General Assembly 2009 Geophysical Research Abstracts 11 EGU2009-543

[18] Ingebritsen S E 2010 Manning Permeability of the continental crust: dynamic variations inferred from seismicity and metamorphism Geofluids 10 193–205

[19] Hoke L, Lamb S, Hilton D R, Poreda R J 2000 Southern limit of mantle-derived geothermal helium emissions in Tibet: implications for lithospheric structure Earth Planet. Sci. Lett. 180 297-308

[20] Tolstikhin I N 2002 Helium isotopes in nature Geology and minerals of the Kola Peninsula 3 (Apatity: Publishing house MUP Polygraph) 28-50 (in Russian)

Acknowledgements
The research was performed within the framework of the state assignment for Federal State Budgetary Institution of Science Research Station of Russian Academy of Sciences in Bishkek (topic No. AAAA-A19-119020190063-2).