New Insight into Formation of Tskaltubo Radon-Containing Healing Springs, Georgia, the Caucasus

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***Abstract*— The world-famous Tskaltubo spa-resort is located in western Georgia 250 km from the city of Tbilisi, and 90 km from the Black Sea.The healing component of this spa-resort, is warm (30–34 ℃) natural springs containing the noble gas radon. The current view of the waters is that they are of hydrothermal origin, and their radon enrichment occurs in the quaternary sediments (1–8 m thick) of the Tskaltubo depression. The content of uranium and thorium (parent elements to radon) in Quaternary sediments of the Tskaltubo depression was studied under both field and laboratory conditions. The results indicate that the Quaternary sediments of Tskaltubo have relatively low radiation (less than 0.17 μSv/h), and typical crustal levels of U and Th (less than 1.4 ppm and 5.3 ppm, respectively. Therefore, the Quaternary sediments cannot be the source of elevated radon. We believe that Bajocian porphyritic igneous rocks located at a depth of 700–800 meters beneath the Tskaltubo depression, do have radiation levels from (120 mkr/h to 220 mkr/h) that are close to that expected from the radon concentration in the spa waters. From this zone, the upward flow of radon mixes with the groundwater of the Lower Cretaceous limestones, which flows into the Tskaltubo depression through a diabase dike barrier. The heating of the springs to a temperature of +30–34 ℃ is still unclear: the waters become warmer as they get closer to the surface unlike a more typical deep geothermal source. Although thermal energy released during the radioactive decay of radon (^{222}Rn) to the stable isotope of lead (^{206}Pb) would increase water temperature, radiation levels do not account for the full thermal range observed.**

***Keywords*—Tskaltubo spa-resort, healing springs, radon, thorium, uranium**

I. Introduction

The Republic of Georgia is located between the Greater and Lesser Caucasus Mountains, across along the eastern coast of the Black Sea. This country is rich in natural resources, including mineral water springs. There are more than 2,000 known mineral water springs, some producing water sold worldwide, and others supporting health and wellness centers. Typically, these springs are located in the mountains, and due to the good climate and natural beauty, many of these locations create excellent resort environments. Among them, the Tskaltubo spa resort, known for its radon-containing warm springs, stands out as a prime example where the harmonious combination of stunning nature and healing springs are found (Fig. 1).

Fig. 1. General view of the Tskaltubo spa-resort area.

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The world-famous Tskaltubo spa-resort is located in western Georgia 250 km from the city of Tbilisi, 8 km from the city of Kutaisi, and 90 km from the Black Sea. Nestled between the valleys of the Rioni and Tshkenistskali rivers, there is a subtropical, very pleasant climate. This resort was highly popular during the Soviet period in Georgia, and many sanatoriums were built here at this time for those needing to convelesce from chronic health conditions. Because the radon volitalizes from water, the perceived healing properties of the spring water dissipaits in 3–4 minutes. As such, patients were taken directly to the radon-containing warm springs for their treatments. There are several such well-equipped springs in Tskaltubo, however, the most popular is source 6 (Fig. 2), where famous people were treated, including Joseph Djugashvili (Stalin).

Fig. 2. Building of the 6th source bathroom in Tskaltubo spa-resort.

In Tskaltubo, radon-containing springs flow in a small stream depression of ~3 km long and ~1.5 km wide, at an altitude of 100–150 meters above sea level. This depression is bounded from the east, north and west by the 600–800 m high Samgural ridge, built up of fractured and karstified lower Cretaceous limestones. In the central part of this depression, in the bed of Tskaltubostskali river, at a distance of about 800 m, warm springs containing radon rise, which are fed by the ground waters of this ridge. The resort area is crossed by Upper Cretaceous gabbro-diabase dykes, part of which is exposed directly in Tskaltubo depression and the radon-rich warm springs most likely follow the barrier created by these dikes.

The traditional explanation of these warm springs is that the waters are heated at depth by a hydrothermal source, and that they are enriched in radon by transport through the 1–8 m thick Quaternary sediments of the Tskaltubo depression [1, 2]. The healing springs of Tskaltubo are also enriched with helium (^{2}He), which is also a product of radioactive decay of uranium and thorium but is not radiogenic.

Within the framework of a larger regional study of the Rustaveli National Science Foundation project FR-18-8122 (“Thorium—Future Energy: Investigation of Thorium Occurrences in Georgia”), we conducted fieldwork in the Tskaltubo region as well. These efforts included studying the area using modern radiodosimeters (POLIMASTER, INSPECTOR, and FAG-FH40F2), as well as performing chemical analyses of samples, which were carried out at the MSALAB laboratory in Vancouver, Canada, using an ICP-MS device. This study revealed that there are no anomalous concentrations of uranium or thorium in the Tskaltubo area, including the Quaternary sediments of the Tskaltubo Depression [3]. Following this, we sought to determine which rocks are the source of radon in Tskaltubo’s healing waters and why these waters are warm. The results of this research are presented in this publication.

II. Brief Geology of the Region

Georgia is situated in the central part of the Caucasus mountain-building area and covers all major structural units of this Orogen: The Greater and the Lesser Caucasus fold systems and intermountain depression lying between them (Rioni, Enguri, Kura and Alazani basins) (Fig. 3). The Tskaltubo area is located on the border of the southern slope of the Greater Caucasus and of the Rioni basin of the intermountain depressions, between the valleys of Rioni and Tskhenistskali rivers. The region represented an active continental margin in the Mesozoic, which has been exhumed very rapidly during the last ~5 Ma [4, 5].

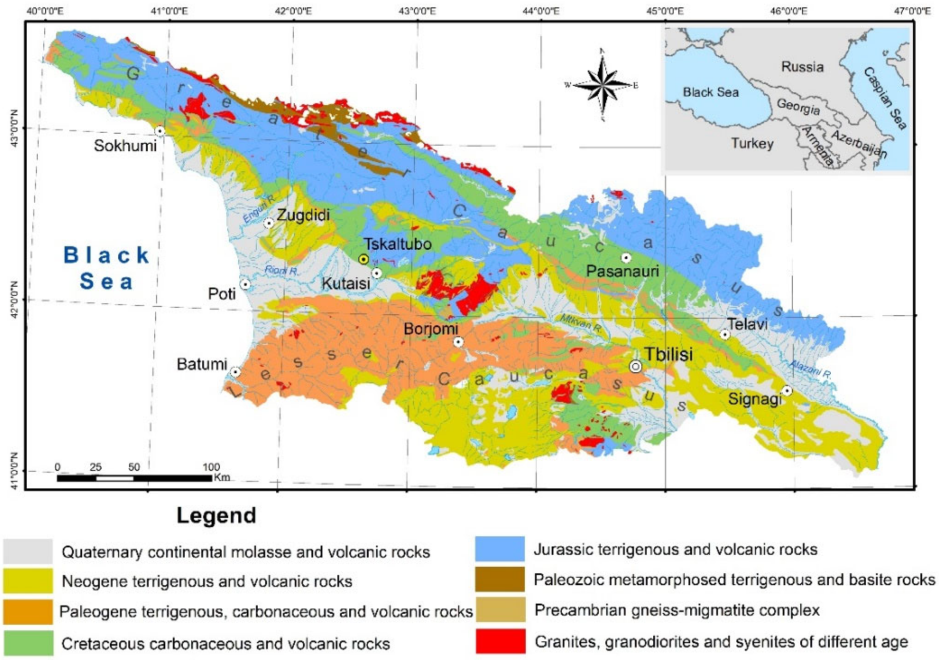

Fig. 3. Simplified Geological map of Georgia with Tskaltubo spa-resort. The map modified after map of [6].

The oldest rocks in the area is represented by Bajocian alkaline and subalkaline volcanic formation (Bajocian porphyry series). The thickness of this series exceeds 1000 m and it crops out to the east of Tskaltubo, in the river Rioni valley. In the Tskaltubo area, the Bajocian porphyry series is overlain by Lower Cretaceous limestones suite, of the 600–700 m thick. This suite continues above Mtavari suite (200–250 m thick), which is built up by tuff breccia and basaltic flows of the Turonian age. This complex of rocks, in Upper Cretaceous, is intersected by gabbro-diabase and diabase-porphyry dykes, which are related to the volcanic and subvolcanic rocks of the Mtavari suite (Fig. 4).

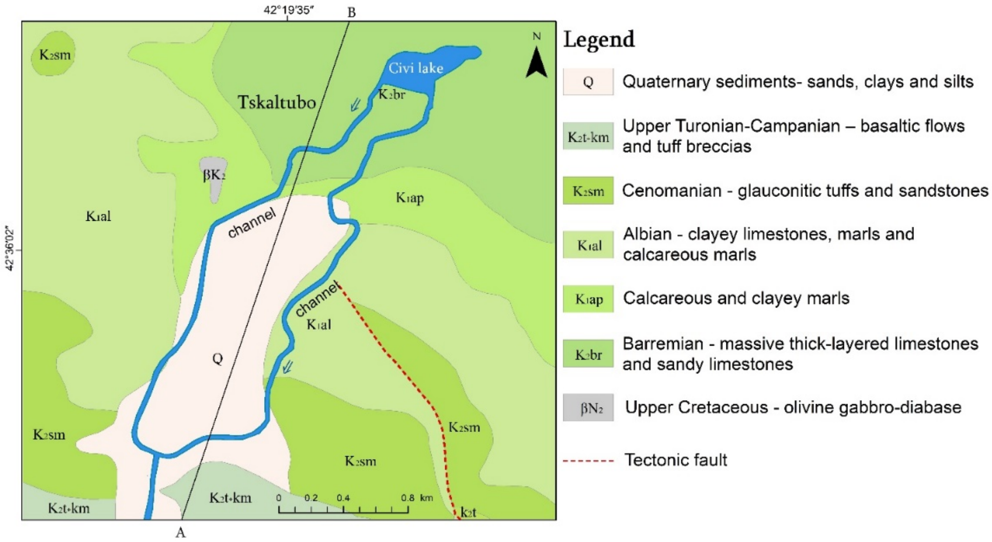

Fig. 4. Schematic geological map of Tskaltubo depression. The map modified after [2].

Quaternary sediments are widely distributed in the study area, but their most important outcrops relevant to this study are in the valleys of Tskaltubosskali, Tskarostskali and Tavukugma rivers. These sediments in the Tskaltubosskali river basin are represented by light-brown clays and sands, the thickness of which is ~8 m in the central part, and decreases to ~1 m towards the periphery. The old bed of the Tskaltubostskali River passed through these sediments, however, it is currently artificially filled with waterproof, so-called “fatty clays” [7]. In order to block radon containing water channels and increase its reserves bed, two artificial water channels have been laid around the former natural bed of the Tskaltubostskali River.

Currently, the resource exploitation wells are located along the old river bed, in the NE-SW direction, at a distance of 850 m. Their depth does not exceed 95 meters, from which warm radon waters flow byunder artesian conditions towards the Tskaltubo resort. The traditional view is that the high amount of precipitation in the region infiltrates to the deep lower Cretaceous limestones, where they are heated. Radon enrichment is thought to occur in the Quaternary alluvial sediments of the Tskaltubo depression [1, 2].

The older drilling work for the resource showed that the Lower Cretaceous limestones of the Tskaltubo Depression are intruded by Upper Cretaceous gabbro-diabase dykes. These dykes are exposed on the surface under Quaternary sediments, therefore, it is considered that they represent the barrier along which radon waters flow on the Tskaltubo depression [7].

The water flow rate is quite hitgh: 13–15 million liters in 24 hours (9,000 to 10,000 liters per minute). The mineral content of the water is ~ 0.7 g/l and the temperature ranges from +30 ℃ to +34 ℃. Radon concentration ranges from 30±15 bq/l to 90±35 bq/l. Chemically, it is characterized as weakly radon, nitrogenous, chloride-sulphate-hydrocarbonate, sodium-magnesium-calcium mineralized water, with a weak alkaline reaction (pH = 7.1–7.6) [2]. Its main healing component is the noble gas radon, whose weak radiation is believed to have a positive effect on many diseases, and high temperature makes it possible to use it without heating.

The radon source and the water heating mechanism are not currently known with certainty. Before discussing these issues, we briefly familiarize ourselves with the physical properties of radon.

III. Brief Description of Radon

Radon is a colorless, potentially life-threatening, radioactive substance under standard pressure and temperature. Inhalation of this gas damages the bronchial system, and ~10% of lung cancer in the world is caused by exposure to this gas [8]. In nature, radium is c produced by the natural decay of ^{238}U, ^{235}U and ^{232}Th. These elements are first converted to radium (^{226}Ra, ^{223}Ra, ^{228}Ra respectively), which then decays to release the radioactive gas radon. Radon has four natural isotopes, but the most abundant is ^{222}Rn.

Radon's half life is short: 3 days, 19 hours and 12 minutes (approximately 3,822 days). Through alpha decay, ^{222}Rn is converted first to ^{214}Po, then to ^{210}Bi and finally to the stable isotope ^{206}Pb. As a result of the radioactive decay of ^{238}U, ^{235}U and ^{232}Th, helium (^{2}He) is also produced, although unlike radon, the latter is not a radioactive element [9]. Due to its mobility and chemical inertness, radon easily leaves its primary structure and dissolves both in water and gases. The gas released from the primary structure undergoes vertical migration through tectonic faults, fissures and microcracks, and enters soil, water and air [10].

The migration rate of radon in rocks and the solubility coefficient in groundwater are not precisely established, since these processes are complex and depend on many factors [9–11]. In particular, on the type of rocks, their fissures, degree of porosity, water pressure, temperature and many other factors. It is known that free radon atoms in the earth's crust move about 100–200 meters based on the half life, Dissolved radon in water moves more rapidly with fractured waters, although their velocity is highest in karst waters [12]. In summary, radon production and transport through the heterogenous subsurface of this area is likley to be complex and subject to the many different factors encountered.

IV. Discussion

The data provided in this work sheds light on the factors leading to the warm waters containing radon in Tskaltubo area:

1. The results indicate that the Quaternary sediments of Tskaltubo have relatively low radiation (less than 0.17 μSv/h), and typical crustal levels of U and Th (less than 1.4 ppm and 5.3 ppm, respectively). Therefore the Quaternary sediments cannot be the source of elevated radon. However, borehole radiation data from the deeper Bajocian porphyritic igneous rocks, located at a depth of 700–800 meters beneath the Tskaltubo depression, do have radiation levels that are close to that expected from the radon concentration in the spa waters. From this zone, the upward flow of radon mixes with the groundwater of the Lower Cretaceous limestones, which flows into the Tskaltubo depression through a diabase dike barrier. The heating of the waters to a temperature of +30–34 ℃ is still unclear: the waters become warmer as they get closer to the surface unlike a more typical deep geothermal source. Although thermal energy released during the radioactive decay of uranium, thorium and radon (^{222}Rn) and related daughter products would increase water temperature, radiation levels do not account for the full thermal range observed. In addition, the relatively short half-life of ^{222}Rn means that if there is excess ^{222}Rn, above that expected from decay of thorium and uranium in the source area, then this upward flow and mixing must occur on timescales of days if all of the radon is derived from the deeper volcanic rock source zone.

The traditional view that the radon-containing springs of Tskaltubo derive their radon from the shallow Quaternary sediments is not supported by our data. Since here the content of uranium, thorium, and radiation levels are within normal limits. For example, everywhere in these sediments, the parameter μSv/h is within the normal range and does not exceed 0.17. Uranium and Thorium contents determined in 8 samples of this sediments by IMS method at MSLABS laboratory in Vancouver, Canada. In these samples, U concentrations ranged from 0.9 ppm to 1.4 ppm, and Th from 4.5 ppm to 5.3 ppm, which are normal data [13]. Furthermore, the waters are derived from resource wells drilled in the lower Cretaceous limestones at a depth of approximately 95 m. These wells produce water enriched in radon, from below the Quaternary sediments.

2. An early report on water temperature and radioactivity in Tskaltubo wells was published by of the Geological Department of Georgia [14]. It discusses the characteristics of water in wells of different depths (from 75 m to 215 m). According to this report, the water at a depth of about 150 m has a temperature of 22–27 ℃, already contains radon and is quite radioactive. While the temperature of the water at the surface, in Quaternary sediments, at 95 m depth, increases to 30–34 ℃. The observation of water temperature increasing as the surface is approached is anomolous; more typically the water is hotter at depth. In addition the mineralization of Tskaltubo’s thermal springs (~0.7 g/L) is relatively low: mineralized waters in similar settings is typically higher than 1 g/L.

Based on the discussion, a natural question arises as to where the healing waters of Tskaltubo are enriched with radon? and why does this water warm as it moves to the surface?

For the source of radon the Esentuk Kaltsovo expedition in 1997 drilled some deeper wells in the area of Tskaltubo Depression. It crossed the Cretaceous limestones and entered the deeper Bajocian volcanogenic porphyry formation. In this formation, in the interval from 700 m to 800 m, a radiation anomaly of 120 mkr/h to 220 mkr/h was observed, and accordingly, the so-called Tskaltubo radiation anomalous zone was identified [14]. Since during this drilling no chemical analysis of the rocks was carried out and only the radiation anomaly was investigated, It is not known which radioactive elements this zone contain. However, the levels of radiation is spa waters are consistent with the levels of ranges from 30±15 bq/L to 90±35 bq/L.

Therefore, we conclude that the deeper volcanic rocks of this source area are the source of the radon at the spa. The intensively crushed, fissured, and karst geology would allow for relativce rapid transport to shallower levels, where the resource wells would extract the radon-bearing water for use at the spa. Fig. 5 illustrates the conceptual model, of Tskaltubo radon-containing healing springs. Most likely, the upward radon flows from this anomaly are mixing with the waters circulating in the lower Cretaceous limestones, part of which flows to the surface in Tskaltubo depression, due to the presence of the existing gabbro-diabase dyke barrier. The half life of ^{222}Rn is short, so that if the entire source of radon is the deeper volcanic source rocks, and if the source imparts excess ^{222}Rn, above that expected from decay of thorium and uranium in the source area, then this upward flow and mixing must occur on timescales of days.

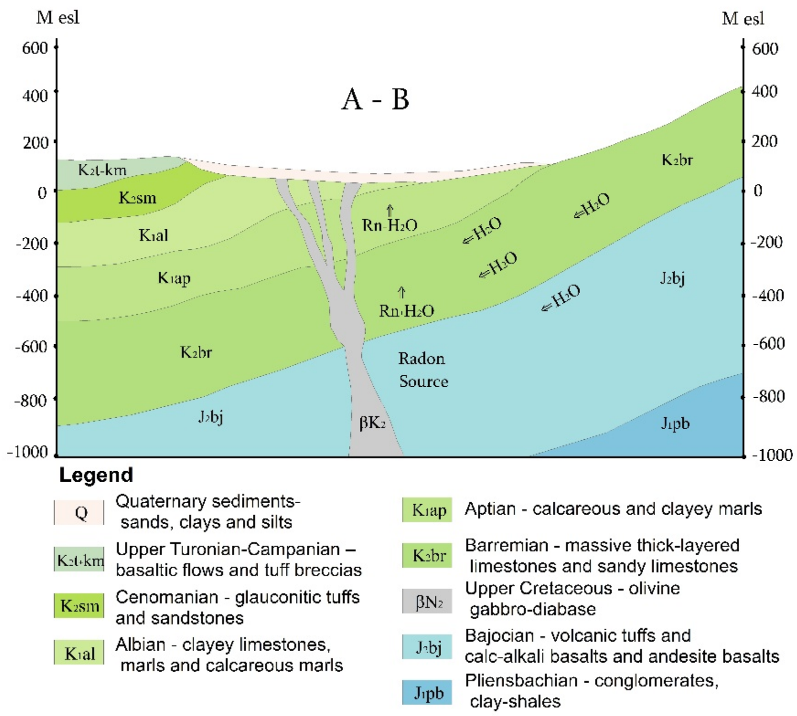

Fig. 5. Conceptual geological model of the formation of Tskaltubo radon-containing healing springs, along the A–B section of the Fig. 1.

As for the question of where the radon-containing springs of Tskaltubo are heated? The radioactive decay would lead to an increased temperature in the water, although the levels measured would not account for the full range of temperature. Radon decay through its daughter products to the stable isotope of lead (^{206}Pb) emits 5.5903 eV [15, 16] and one gram of radon releases about 4400 calories of energy in one hour [17]. More work is needed to quantify the specific case in the subsurface source of the radon to test how much temperature increase can be expected. The starting composition of uranium, thorium, and radon in the source rocks is not known, and is critical to characterization of the range of radioactive heating that may occur. Also, additional work could seek to determine the levels of thorium, uranium and radon isotopes in the source area to determine whether there is excess ^{222}Rn, which could further constrain transport time from the source area to the wells supplying the spa.

In summary, the formation of warm waters containing radon in Tskaltubo is the result of the concurrence of several geological factors, leading to a fortunate setting: 1) the presence of a high radiation activity zone, from which an upward flow of radon is constantly released; 2) the massif of crushed and karstified limestone rocks on top of this flow, which due to intense atmospheric precipitations, contains a large amount of groundwater; 3) due to the geological structure, these groundwaters move from north to south; 4) the barrier of gabbro-diabase dykes in the Tskaltubo depression, part of them rises in this depression; 5) the scale of the geological structure of Tskaltubo depression is such, that while passing through this structure, radon undergoes radioactive decay and heat release; 6) the residual radon in waters of the spa, which at low levels is thought to have healing properties.

V. Conclusion

From the analysis of the results of the conducted research, we conclude that the formation of radon in the healing springs of Tskaltubo-spa resort takes place under its depression, in the anomalously high radiation zone of of the Bajocian volcanogenic porphyry formation (Tskaltubo radiation zone), at a depth of ~700–800 m. The radon formed in this zone, due to its mobility and chemical inertness, moves vertically upwards along karst voids, tectonic faults and fissures and mixes with groundwater of the lower Cretaceous limestones. Part of these radon-enriched groundwater, due to the presence of a barrier of gabbro-diabase dykes, rises in the depression of Tskaltubo. The heating of these springs to a temperature of +30–34 ℃ in part attributable to heat generated by radioactive decay, but more work is required to fully quanitfy the amount of heating that may be attributed to this radioactive source.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Fieldwork was conducted by A. Okrostsvaridze and R. Gabrielashvili. Graphic material was prepared by R. Gabrielashvili. All three authors participated in the discussion. The article was written by A. Okrostsvaridze, and the final version was given by Daniel Tormey. All authors had approved the final version.

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