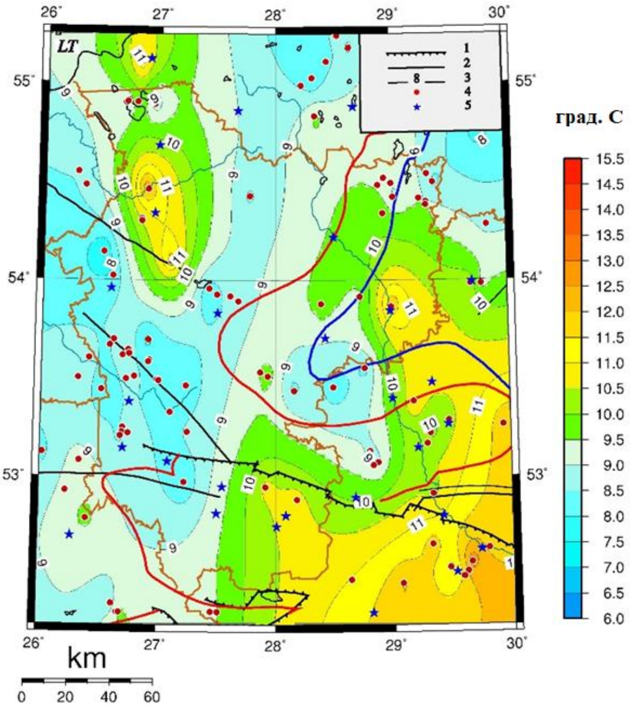

Рисунок 6 – Карта распределения температуры на гл. 200 м для Минской обл.
[2, 3, с изменениями]

Библиографические ссылки

1. *Павловская О. А., Зуй В. И.* Применение ГИС для моделирования особенностей распределения температуры в пределах нейтрального слоя Минской области // ГИС-технологии в науках о Земле : Материалы конкурса ГИС-проектов студентов и аспирантов ВУЗов Республики Беларусь, проведённых в рамках празднования Международ. дня ГИС-2011, 16 нояб. 2011 г. / Отв. ред. Д. М. Курлович. Минск, 2012. С. 35–39.
2. *Зуй В. И.* Тепловое поле платформенного чехла Беларуси. Минск : Экономпресс, 2013.
3. Геотермический атлас Беларуси / Под общ. ред. В. И. Зуя. Минск : Национ. б-ка Беларуси, 2018.
4. *Зуй В. И.* Основы геотермии (пособие). Минск : Изд-во БГУ, 2018.
5. *Зуй В. И.* Тепловой поток в зоне активного водообмена на северо-востоке Беларуси / Проблемы геологии Беларуси и смежных территорий : материалы Международ. науч. конф., посвящ. 100-летию со дня рожд. акад. НАН Беларуси А. С. Махнача (Минск, 21–22 нояб. 2018 г.). Минск : СтройМедиаПроект, 2018. С. 49–53.

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A LOOK AT THE GEOTHERMAL FIELD AND GEOTHERMAL ENERGY IN THE CAUCASUS REGION

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The surface heat flow density varies from 20–30 to 100 and 150 mW/m^2. The increased heat flow values predominant. Abnormally low heat flow (20–40 mW/m^2) is found in sedimentary basins. Zones of young tectonic and volcanic activity are distinguished.

Key words: geothermal field; geothermal energy; Caucasus region.

Introduction. The Caucasus is situated in between the Black Sea and the Caspian Sea. Its area belongs to Russia, Georgia, Azerbaijan, and Armenia. It is a mountainous region including the Greater Caucasus mountain range, which has considered historically as a natural barrier between Eastern Europe and Western Asia, but is today accepted by the majority of scholars as being a part of Asia [1]. The European highest mountain the Elbrus, at 5,642 m is located in the west part of the Greater Caucasus mountain range. On the southern side, the Lesser Caucasus includes the Javakheti Plateau and grows into the Armenian highlands, a part of which is located in Turkey [2]. The Caucasus region is separated into northern and southern parts: the North Caucasus (Ciscaucasus) and South Caucasus (Transcaucasus), respectively. The Greater Caucasus mountain range in the north is a border of the Russian Federation with trans Caucasian republics, while the Lesser Caucasus mountain range in the south is occupied by several independent states, namely Georgia, Armenia, Azerbaijan [2]. The Caucasus is a large mountainous area covering about 440,000 km between the Black, Azov and Caspian seas (Fig. 1). The mountains are more than 1,000 km long, in a WNW-ESE striking range between the Caspian and Black seas and reach elevations over 5 km above the sea level.

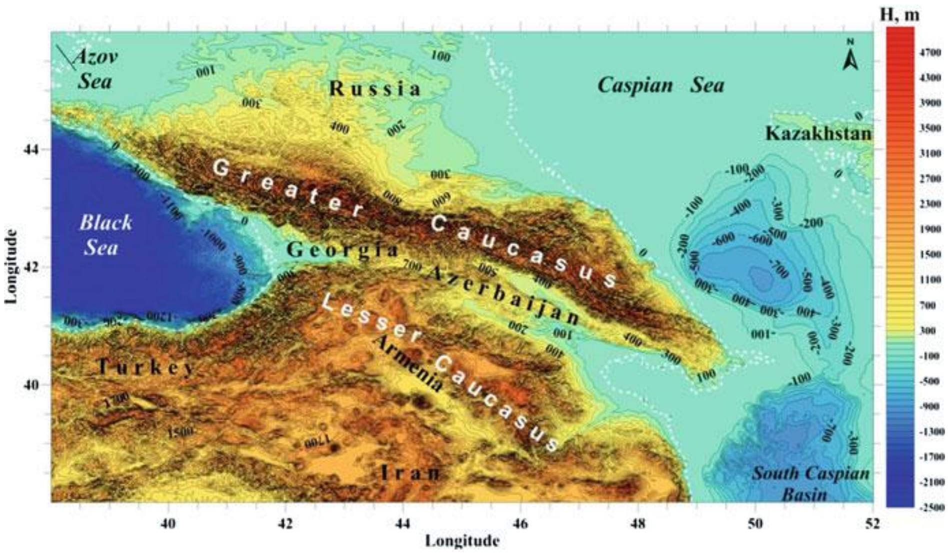

Figure 1 – Caucasus region map with topography and bathymetry data
(constructed on the basis of the World Topography Database [3]

The geology of Caucasus. The structure and geological history of the Caucasus are determined largely by its position between the still converging Eurasian and Africa-Arabian lithospheric plates, within a wide zone of continental collision. During the Late Proterozoic–Early Cenozoic, the region belonged to the Tethys Ocean and its Eurasian and Africa-Arabian margins, where there existed a system of island arcs, intra-arc rifts, back-arc basins, characteristic of the pre-collisional stage of the evolution of the region. The region, along with other fragments, that are now exposed in the Upper Precambrian – Cambrian crystalline basement of the Alpine orogenic belt, was separated from the western Gondwana during the Early Paleozoic because of back-arc rifting above a south-dipping subduction zone. Continued rifting and seafloor spreading produced the Palaeotethys Ocean in the wake of northward migrating peri-Gondwanan terranes. Around 350 Ma the displacement of the Caucasian and other peri-Gondwanan terranes completed to the southern margin of Eurasia. Widespread emplacement of microcline granite plutons along the active continental margin of southern Eurasia during 330–280 Ma occurred above a north-dipping Palaeotethyan subduction zone. However, Variscan and Eo-Cimmerian–Early Alpine events did not lead to the complete closing of the Palaeozoic Ocean. The Mesozoic Tethys in the Caucasus was inherited from the Palaeotethys.

In the Mesozoic and Early Cenozoic, the Great Caucasus and Transcaucasus represented the Northtethyan realm – the southern active margin of the Eurasiatic lithospheric plate. The Oligocene–Neogene and Quaternary basins situated within the Transcaucasian intermountain depression mark the syn- and post-collisional evolution of the region; these basins represented a part of Paratethys and accumulated sediments of closed and semi-closed type. The final collision of the Africa-Arabian and Eurasian plates and formation of the present-day intracontinental mountainous edifice of the Caucasus occurred in the Neogene–Quaternary period. From the Late Miocene (c. a. 9–7 Ma) to the end of the Pleistocene, in the central part of the region, volcanic eruptions in subaerial conditions occurred simultaneously with the formation of molasse troughs. The geometry of tectonic deformations in the Transcaucasus is largely determined by the wedge-shaped rigid Arabian block intensively indenting into the Asia-Minor-Caucasian region. All structural-morphological lines have a clearly expressed arcuate northward-convex configuration reflecting the contours of the Arabian block. However, farther to north, the geometry of the fold-thrust belts is somewhat different – the Achara-Trialeti fold-thrust belt is, on the whole, W–E-trending; the Greater Caucasian fold-thrust belt extends in a WNW–ESE direction (Fig. 2).

Geothermal regime and geothermal energy in the Caucasus

Southern part of Russia. Daghestan Republic at the Northern Caucasus is one of the biggest area for the development of geothermal energy. Total amount of resources at the depth of 0.5–5.5 km allows obtaining approximately 4 million m^3/day of geothermal fluid. At present, more than 7.5 million m^3/year of hot water 50–110 °C is used in Daghestan. Among them, 17 % as hot water; 43 % for district heating; 20 % for greenhouses and 3 % for balneology and mineral water production. Totally in Daghestan about 180 wells have been drilled at a depth from 200 to 5,500 m. The regions of such towns as Kizlyar, Tarumovka and Jushnosukhokumsk, possess unique reserves of hot water. For instance, Tarumovskoye deposit has the reserves of geothermal water of high salinity (200 g/l) with temperature up to 195 ºC. Six wells have been drilled to depths of about 5,500 m, the deepest geothermal wells in this part of Russia. Tests indicate high reservoir permeability with wells producing between 7,500 and 11,000 m^3/day at wellhead pressures of 140–150 bar [5] (Fig. 3).

Republic of Azerbaijan. Geothermal energy is one of the most promising sources of alternative energy. There are different forms of manifestation of the Earth's heat to the surface, e. g. volcanoes, geysers, mud volcanoes, underground water in wells, etc. There are no active volcanoes and geysers at present in Azerbaijan, however there are enough exploration wells where temperatures of thermal water in aquifers are higher than 100 °C. The most interesting area is western part of the South Caspian basin along the Talysh-Vandam maximum [6]. This gravitation maximum reflects buried fragment of Mesozoic island arc, where local volcanic uplifts were explored in details as Muradkhanli oil field was discovered here in 70-s within the weathered and fractured volcanic rocks. The area is characterized by high fluid activity, which promotes the formation of local abnormally high heat flows. The Jarly-3 well is still outflowing to the ground surface with high production rate. The temperature of volcanic rocks here at 2,800–3,000 m depth in some places is higher than 100 °C [7] (Fig. 4). Total energy capacity of thermal waters for hydrogeological areas determined based on their commercial reserves is presented in Tab. 1 [9, 10].

Figure 2 – Tectonic map of the Caucasus [4]
Basement Salients: Dzirula (Dz), Khrami (Kh), Loki (Lo), Tsak uniats (Ts) Akhum (Ah), Asrik hai(As).
Metamorphic complexes: Chugush (Ch), Laba (La), Buulgen (Bu), Kassar (Ka), Dizi (Di).

Figure 3 – Geothermal resources of the Sothern part of Russia
(Krasnodar and Stavropol regions, Daghestan and Chechen Republics) [21]

Figure 4 – Geothermal energy and mineral water resources of Azerbaijan [8]

Table 1 – Capacity of thermal waters based on their commercial reserves [9, 10]

Hydrogeological areas	Water T, °C	Water flow rate, m^3/day	Energy potential, MW
Absheron Penunsula	20–90	20 000	up to 504
Kur depression	22–95	172 466	up to $47 \cdot 10^3$
Greater Caucasus	30–50	2 000	up to 168
Lesser Caucasus	30–74	4 171	up to 771
Gusar foothill lowlands	30–97	21 654	up to 609
Nakhchivan	40–53	3 000	126–290
Talysh	31–64	14 405	605–778
Lyankaran	42–84	7 908	399–1 129
Total	–	245 604	up to $51 \cdot 10^3$

Georgia. Owing to its geological location, Georgia has considerable resources of middle and high temperature thermal water (33–108 °C). Most of geothermal wells are middle depth and non-operating. On the other hand, the economic development of the country relies largely to energy production. Geothermal potential of Georgia exhibits a promising resource that might be available for energy production. This requires an extensive study to reassess the geothermal potential of the country. Several projects were implemented and some others are underway to achieve this purpose. Georgia has a high potential of geothermal resources, some have been in use since ancient times. The major areas of utilization are balneology resorts, local heating systems, processing industry, and greenhouses. Georgia abounds in geothermal resources, concentrated in 44 deposits. According to preliminary estimations, their heat power is 420 megawatts, and elaboration of thermal energy is maximum 2.7 million megawatt-hour/year [11]. However, the most of the existing 50 geothermal wells in Georgia are of medium depth and supply water at temperatures ranging between 40 to 60 °C. It also should be noted that part of these wells are non-operational. By estimation of the Georgian Geothermal Association, the Georgian energy sector uses about 45,000 m^3/day from a total of 90,000 m^3/day. Therefore, a reassessment of the geothermal potential of Georgia is of major importance from the standpoint of economic development of the country based upon renewable, ecological cleaner energy source [11].

Owing to the high geothermal potential in the South Caucasus and particularly in Georgia, a confirmed total water reserve of 90,000 m^3/day, corresponding to a heat potential of 500,000 tons of equivalent fuel annually, has been recorded [12]. The heat flow for the main parts of Georgia can be listed as follows: 1) The south flank of Caucasus Mountains – 100 mW/m^2; 2) Plate of Georgia: a) For the west zone 40 mW/m^2, b) for the east zone 30 mW/m^2; 3) Adjara-Trialeti folded system: a) Central part 90 mW/m^2, b) the east zone 50 mW/m^2; 4) Artvin-Bolnisi platform 60 mW/m^2.

Fig. 5 shows the main geothermal fields in western Georgia where the reservoir formations are fractured karstic limestones of the lower Cretaceous in the sedimentary trough and at the southeast, where the reservoir formations are volcanic and sandstones of Paleocene-Middle Eocene in the fold system. Thus, we see the following pattern in the distribution of heat flow: its maximum is observed for the central zone of the folded part of Georgia and the minimum is for the plate. The heat flow for the Adjara-Trialeti folded system is characterized by the middle range. The temperature condition of Paleocene – Middle Eocene thermal water bearing complex is better investigated for the Tbilisi region [13–15]. This investigation revealed that the temperature condition of this complex is influenced at depth by a layer of high thermal resistivity upper Eocene rocks as well as their thickness. From the surface of the volcanic-sediment formation of middle Eocene, the temperature of rocks increases to all direction from 20 till 100 °C. To the northeast the increase in temperature is less than to the other direction because of the nearness of the plate. On the contact of Cretaceous – Eocene the temperature has a remarkable variation: to the farthest north and east, where Low Cretaceous is raised to 500 m we have the temperature variation from 100 till 160 °C, when to the west, where the Cretaceous extends to 4,000 m depth, we have temperature about 240 °C.

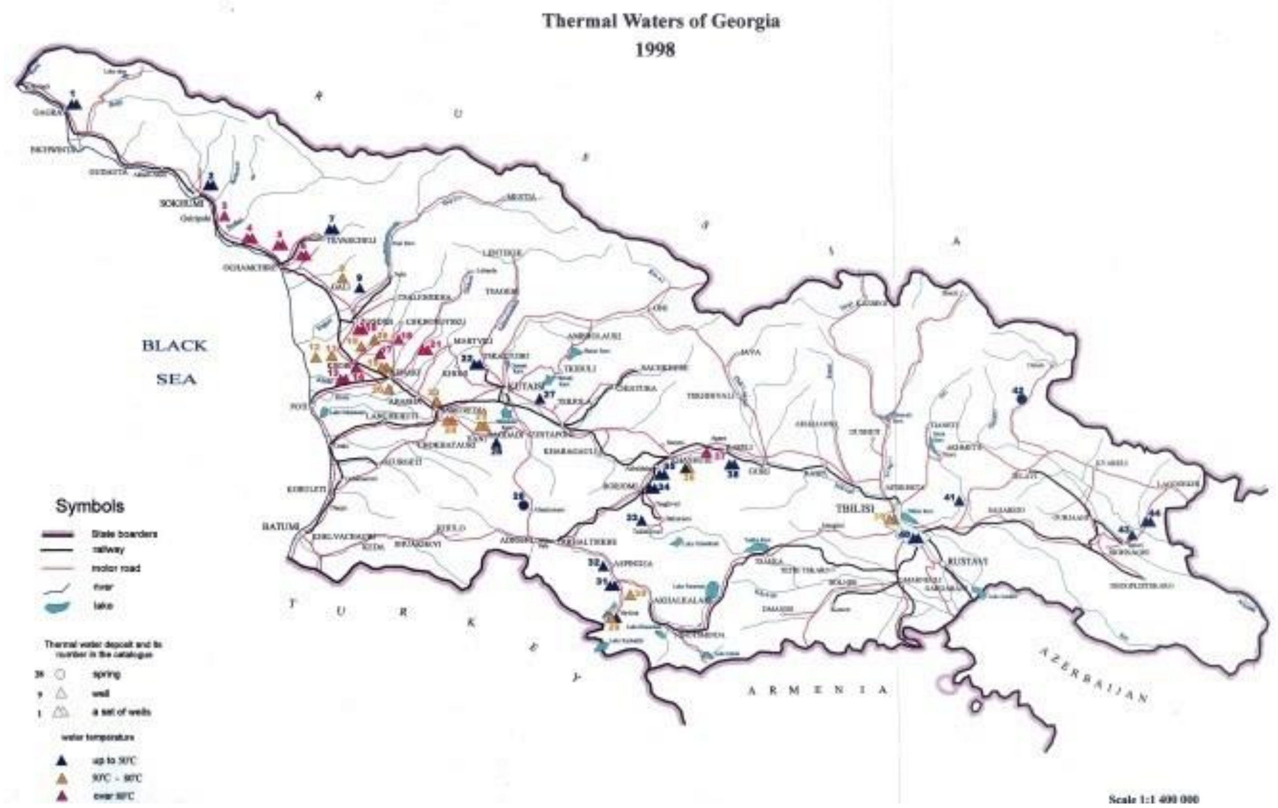

Figure 5 – Main geothermal fields in Georgia [13–15]

Armenia. Although no high-temperature geothermal resources have been identified in the Republic of Armenia, numerous low temperature resource areas (cooler than 100 °C) are present, mostly within a belt of Quaternary volcanism and elevated heat flow that trends northwest-southeast through the central part of the mountainous country. The use of geothermal energy in Armenia is quite limited at present, and mostly takes the form of small-scale and informal applications. However, significant investigations of the country's thermal areas have been undertaken, mostly during the Soviet era. As a result, the information available is more extensive than it might be in some other countries with similar levels of resource utilization. For example, thermal springs have been catalogued and described, and hundreds of shallow wells have been drilled, mostly for investigating of mineral water sources throughout the country [16]. In addition to the investigations and reviews carried out by local specialists, some studies of geothermal resources in Armenia have been funded and carried out by foreign entities [17–19]. Regional heat flow has been interpreted from measurements in numerous drill holes throughout the country, many of them were drilled specifically for measurement of temperatures and rock thermal conductivities. Three heat flow zones have been distinguished based on heat flow data and temperature gradients (Fig. 6).

The northeastern zone of Armenia (Zone I) is characterized by low heat flow (less than 60–75 mW/m^2) and low temperature gradients (less than 43 °C/km). The central zone (Zone II), which coincides closely with the belt of Quaternary volcanoes, is one of high heat flow (75 to more than 90 mW/m^2) and elevated temperature gradients (generally greater than 50 °C/km). The southwestern zone (Zone III) has low heat flow (less than 60–75 mW/m^2) and generally low temperature gradients (less than 33 °C/km), but higher gradients occur locally (Tab. 2)

Conclusion. There are several heat flow levels in the Caspian–Caucasus–Black See region defined by the structure and time of tectonic activity of the lithosphere.

The surface heat flow density varies from 20–30 to 100 and 150 mW/m^2. The increased heat flow values predominant. Abnormally low heat flow (20–40 mW/m^2) is found in sedimentary basins. Zones of young tectonic and volcanic activity are distinguished.

Characteristic features are heat flow anomalies, running transversal to the main course of the Alpine units. They are related to deep fault zones crossing these structures (from the Arabian Plate to peri-Caucasus region).

From an analysis of the heat flow distribution on maps, a conclusion can be drawn on the genetic relationship between the heat flow pattern and the tectonic evolution of the Caspian Sea – Caucasus – Black Sea region, its position between the still converging Eurasia and Arabian – Africa lithosphic plates within the wide zone of continent-continent collision.

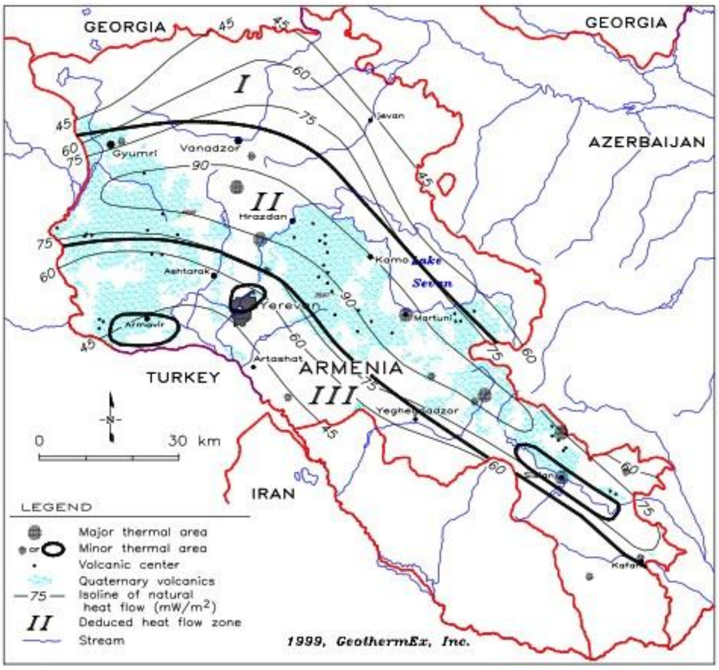

Figure 6 – Contours of heat flow with deduced heat flow zones [20]

Table 2 – Characteristics of principal geothermal resource areas, Republic of Armenia [20]

Area	Maximum known resource temperature, °C	No. of wells drilled	Typical well depth, m	Maximum well depth, m	Estimated combined production rate, l/sec
Jermuk	63	>30	150–500	642	>17
Vorotan River valley	43	14+	150–250	1 158	100–200
Ankavan	42	11+	50–100	410	>40
Arzakan	45	2	?	800	7 + ?
Martuni	40+	3+	500–900	971	>6
Jermukpur	99	2	600–1 000	1 000	0

References

1. «Caucasus – region and mountains, Eurasia». Encyclopedia Britannica. Retrieved 2018-11-26. «The watershed of the Greater Caucasus, the backbone of the system, traditionally has been part of the line dividing Europe and Asia; but the whole region is so subject to Asian influences that there is now general agreement on assigning the Caucasus to Asia». Wikipedia.

2. «Caucasus – region and mountains, Eurasia». Encyclopedia Britannica. Retrieved 2018-11-26. «West of the Kura-Araks Lowland rises the Lesser Caucasus range, which is extended southward by the Dzhavakhet Range and the Armenian Highland, the latter extending southwestward into Turkey». Wikipedia.

3. *Smith W. H. F, Sandwell D. T.* Global seafloor topography from satellite altimetry and ship depth soundings // Science. 1997. Vol. 277. P. 1957–1962.

4. *Adamia Sh., Chabukiani A., Chkhotua T., Sadradze N., Zakaraia D., Zakariadze G.* Geology of the Caucasus and adjacent areas, 1 : 250 000 scale geological map // Proc. XIX Congr. of the Carpathian-Balkan Geol. Assoc. Thessaloniki, Greece, 23–26 Sept. 2010. P. 19.

5. *Magamedov K. M., Alkhasov A. V., Aliyev R. M*. Geothermal energy prospects in Daghestan // IGA News. 1999. N 36. P. 3–4.

6. *Nadirov R. S.* Geology and Oil-Gas Potential of the area of the Talysh-Vandam gravity maximum: Thesises of Ph. D dissertation. Baku, 1985.

7. *Aliyev S. A., Mukhtarov A. Sh., Aliyev Z. A., Bagirli R. C.* Geothermal investigations in Azerbaijan. Azerbaijan Geology. 2002. Vol. V.

8. *Nabiyev N. D., Bashirov M. M., Safarov J. T., Shahverdiyev A., Hassel E.* Thermodynamic Properties of the Geothermal Resources (Khachmaz and Sabir-Oba) of Azerbaijan // J. Chem. Eng. Data. 2009, Vol. 54, P. 1799–1806.

9. *Mukhtarov A. Sh., Khammedov A. M.* Geothermal resources of Azerbaijan // Materials of Int. Workshop «Problems of geothermal energy development in the CIS countries and the activities of international Geofond: Materials of «Geofond-2003». Project of Worldbank and Global Environmental Fond for development of geothermal energy in Europe and Central Asia: with participation of CIS countries. Moscow, 2003. P. 27–32 (in Russian).

10. *Tagiyev I. I., Ibrahimova I. Sh., Babayev A. M.* Mineral and Thermal water resources of Azerbaijan. Baku : Chashyoglu, 2001 (in Russian).

11. SEEC (South East Europe Consultants) 2007. Georgia: Strategic Environmental Assessment of Power Sector Development, Final Rep. 2007.

12. *Tsertsvadze N., Buachidze G., Vardigoreli O., Vashakidze B., Inaishvili T., Kotrikadze N., Tsertsvadze L.* Thermal waters of Georgia. Tbilisi, 1998.

13. *Buntebarth G., Chelidze T., Melikadze G.* Hydrodynamic and microtemperature monitoring in seismic areas // Georgian Eng. News. 2004. N 3. P. 12–132.

14. *Jimsheladze T., Kapanadze N., Melikadze G*. Microtemperature observation in Tbilisi seismoactive region // J. Georgian Geophys Assoc. 2008. Vol. 12. P. 75–81.

15. *Bunterbarth G., Kapanadze N., Kobzev G., Melikadze G.* Re-assessment of the Geothermal Potential of Tbilisi region: The Hydrodynamic Digital Model Project // «Environment and Recourses», Assoc. of Acad. of Science in Asia Workshop, 25–27 Sept. 2009, Izmir, Turkey. P. 154–161.

16. *Mkrtchian S. S.* Geology of the Armenian SSR (Vol. IX – Mineral Waters). Yerevan : Acad. of Science of the Arm. SSR, Inst. of Geol. Sciences, 1969 (in Russian).
17. Lahmeyer International GmbH. Development Planning in the Armenian Power Subsector. 1994.
18. Lahmeyer International GmbH. Update of Least Cost Power Investment Program, Armenia. 1996.
19. Petroleum Geology Investigators ApS. Armenian Geothermal Project Reconnaissance Study – Final Rep. Rep. for Int. Bank for Reconstruction and Development. 1998.
20. *Henneberger R., Cooksley D., Hallberg J.* Geothermal resources of Armenia // Proc. World Geothermal Congr. 2000, Kyushu–Tohoku, Japan, May 28–June 10, 2000. Geothermex, Inc., Geothermal Exploration Development And Operation 5221 Central Ave, Suite 201, Richmond CA 94804 (510). P. 1217–1222.
21. *Svalova V., Povarov K.* Geothermal Energy Use in Russia. Country Update for 2010–2015 [Electronic resource] // Proc. World Geothermal Congr. 2015 Melbourne, Australia, 19–25 April 2015. URL: https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2015/01061.pdf (date of access: 02.01.2020)

УДК 556.31

ОЦЕНКА КАЧЕСТВА ПОДЗЕМНЫХ ВОД БЕЛАРУСИ ПО ГИДРОХИМИЧЕСКИМ ПОКАЗАТЕЛЯМ

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Представлены данные о ресурсах и эксплуатации подземных вод Беларуси. Охарактеризован их химический состав. Дан анализ гидрогеохимических данных по гидрологическим бассейнам за период 2011–2020 гг. Установлено, что в целом по республике основными показателями загрязнения подземных вод являются NH_4^+ и NO_3^-. Рассмотрено влияние отвалов добычи солей и отвалов фосфогипса на подземные воды. Прослеживается сильное химическое загрязнение Cl^- и SO_4^{2-} в Солигорском горнодобывающем районе, а также PO_4^{3-} и SO_4^{2-} в зоне расположения отвалов фосфогипса Гомельского химического завода.

Ключевые слова: подземные воды; питьевое водоснабжение; гидрогеохимические показатели; загрязнение; отвалы фосфогипса; вредные выбросы терриконов.

В Беларуси практически весь объём хозяйственно-питьевого водоснабжения базируется на эксплуатации пресных подземных вод, в связи с чем проблема качества подземных вод является сегодня наиболее актуальной.

Подземные воды Беларуси представлены тремя классами: пресными, солоноватыми и солёными водами, а также рассолами [8].

На территории Беларуси мощность слоя пресных вод питьевого назначения колеблется в пределах от 100 до 1 000 м [7]. Основными водоносными горизонтами являются 3 повсеместно выдержанных комплекса (верхнепротерозойских отложений и верхней трещиноватой зоны кристаллического фундамента, девонских отложений, отложений четвертичной системы), а также водоносные комплексы кембро-силурийских, силурийско-ордовикских, каменноугольных, пермско-триасовых, юрско-меловых и палеоген-неогеновых образований фрагментарного распространения [4].

В ненарушенных условиях на территории Беларуси формируются пресные подземные воды гидрокарбонатного кальциевого и магниево-кальциевого состава с минерализацией 0,2–0,5 г/дм^3. На участках разгрузки глубинных минерализированных вод, приуроченных к региональным тектоническим разломам и солянокупольным структурам в Припятском прогибе, наблюдается увеличение минерализации до 4–6 г/дм^3, и воды приобретают хлоридный натриевый состав [6].