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WELL CONSTRUCTION AND DRILLING TECHNOLOGY FOR THERMAL WATER PRODUCTION IN CHALLENGING GEOLOGICAL CONDITIONS

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КОНСТРУКЦИЯ И ТЕХНОЛОГИЯ БУРЕНИЯ СКВАЖИН В СЛОЖНЫХ ГОРНО-ГЕОЛОГИЧЕСКИХ УСЛОВИЯХ С ЦЕЛЬЮ ДОБЫЧИ ТЕРМАЛЬНЫХ ВОД

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The paper considers special aspects of well construction and drilling technology aiming to produce thermal water. The practice of exploration, prospecting and production of thermal water in challenging geological conditions of Central Mongolia and analysis of the results from earlier drilled wells suggest that the approved and implemented ground water well construction and drilling technology does not provide reliable protection of opened thermal springs from cooling in the course of water movement along the wellbore from its bottom to the wellhead. The reason for this is a significant heat loss due to high thermal conductivity of well construction elements (steel pipes). The developed and proposed promising well construction includes several sequentially run casing strings with mandatory cementing of outer annulus with cement slurry. This helps reduce total heat flow loss and increase wellhead temperature of thermal springs by 10–15 °C. It is also suggested to use double-wall casing (“pipe-in-pipe” system) with heat insulating material (polyurethane foam) filling the interstring annulus. Use of this technology will help reduce heat loss along wellbore by 20–30 %. For drilling in this region, it is advisable to use pneumatic and hydraulic hammers for drilling a pilot wellbore and further expand it using a roller-cone bit. URB-2A-2 drilling rig can be advised as a drilling machine. Successful thermal water exploration and prospecting operations in the territory of Mongolia is an important future-oriented goal. The technology of well casing with pipes using polyurethane foam will help reduce heat loss along wellbore by 20–30 %, thereby enabling production of water with wellhead temperature approximating formation temperature. The suggested groundwater well construction improves cost effectiveness of production.

Ключевые слова:
бурение, термальные воды Монголии, конструкция скважины, технология бурения, цементирование, температура, обсадные колонны, пенополиуретан, минерализация, коллектор.

Рассматриваются особенности конструкции и технологии бурения скважин для добычи термальных вод. Практикой поисков, разведки и добычи термальных вод в сложных горно-геологических условиях Центральной Монголии и анализом результатов по ранее пробуренным скважинам установлено, что принятой и реализуемой конструкцией и технологией бурения гидрогеологических скважин не обеспечивается надежная защита вскрытых терм от охлаждения при движении из них вод по стволу скважины от забоя до устья. Причиной этому являются значительные теплопотери вследствие высокой температуропроводности элементов конструкции скважины (стальные трубы). Разработана и предлагается перспективная конструкция скважины, включающая несколько последовательно спущенных обсадных колонн с обязательным цементированием заколонного пространства тампонажным раствором. При этом снижаются суммарные потери теплопотока и на 10–15 °С повышается температура терм на устье скважины. Предлагается также использовать обсадные колонны с двойной стенкой (технология «труба в трубе»), в межколонном пространстве которых находится теплоизолирующий материал – пенополиуретан. Использование этой технологии позволит уменьшить теплопотери по стволу скважины на 20–30 %. Для бурения в данном регионе целесообразно применение пневмо- и гидроударников с целью бурения пилотного ствола с дальнейшим расширением его шарошечным долотом. Буровым станком может быть принята буровая установка УРБ-2А-2. Успешное проведение работ по поискам и разведке термальных вод на территории Монголии является крайне перспективной и важной целью. Технология крепления скважины трубами с применением пенополиуретана позволит сократить теплопотери по стволу скважины на 20–30 %, что обеспечит возможность получения на устье температуру воды, максимально приближенную к пластовой. Предложенная конструкция гидрогеологической скважины повышает экономический эффект.

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Introduction

The expanse of Mongolian territory is abundant in fresh and mineral ground thermal waters with different compositions [1–10 and others]. Multiple nitric mineral thermal springs are mostly located in its western and north-western parts, whereas cold springs prevail in the north-eastern and eastern parts of the country. Hydrogeology, hydrogeochemistry, thermal water genesis are vastly debatable and require further research [3–10, 11–27]. Presented below is some information concerning geothermal fields and occurrences in the Central Mongolia, identified and surveyed within Khangai arched uplift [6, 7, 10].

General information concerning thermal water fields. Geological structure

Saikhan Khulzh thermal water field

The field is located 350 km to the west and north-west of Ulaanbaatar, in the territory of Bulgan aimag, 2 km to the west and south-west of the Mogot somon administrative center [2, 3, 8]. The field area's absolute elevation is about 1450 m. Occurrences of sodium-sulfate thermal springs in Saikhan Khulzh were first described by V.A. Smirnov in 1927. Over the years the springs have been visited by F.K. Shipulin (1941), V.N. Popov (1946), O. Namnandorzh, Sh. Tseren (1958) and G.M. Shpeiser, B.I. Pisarsky (1973), Narangerel, N. Lkhagva (1974) and others. During exploration and prospecting drilling operations, new information concerning this field was obtained, which can be summarized as follows.

Geological structure of the Saikhan Khulzh thermal water field profile involves Upper Triassic and Lower Jurassic effusive and undivided quaternary deposits. Effusive rocks comprise light-gray to dark-gray andesite-basalts and andesite-porphyries, tuffs, which are drilled to the depth of 36.0–62.0 m in the prospecting area. Quaternary deposits comprise mostly inequigranular sands with inclusions and individual beds of boulders, gravel and pebbles up to 2.0–4.0 m thick. It has been established [7, 8] that thermal waters are associated with the tectonic fracturing zone of Upper Triassic and Lower Jurassic effusive rocks. The total area of mineral water discharge focus and spread area reaches 0.3 km^2.

Exploratory thermal water wells have been drilled at the depths of 6.0 (in unconsolidated deposits) to 202.0 m (in parent rock) with the temperature of 20–55 ^{o}C and yields of 0.3–4.6 L/s, at drawdowns of 2.0–2.6 m respectively. Thermal waters of Saikhan Khulzh field belong to the so-called khulzh type [5, 14, 18] and exhibit low salinity (maximum 0.83 g/L), sodium sulfate composition, high temperature (45–57 °C) and alkaline reaction (pH = 8.45–8.65). Presently these sodium sulfate thermal springs provide a basis for a seasonal local health resort. High therapeutic value and significant estimated reserves of thermal waters, along with favorable natural and economic conditions of the location, are prerequisites for further expansion of Khulzhi mineral water facility [8].

Otgontenger thermal water field

The reservoir is located in the territory of Dzabkhan aimag, 75 km to the east of aimag's administrative center Uliastai, in a strongly broken mountainous area of Khangai. The deposit area lies at the northern foot of Mount Otgontenger whose summit is the highest elevation point in the Khangai range (4031 m above sea level). First information about occurrence of Otgontenger thermal waters was recorded by chemist V.A. Smirnov (1926). Later the reservoir was explored by O. Namnandorzh, Sh. Tseren (1957), Z.P. Kozlovskaya (1964), G.M. Shpeizer, B.I. Pisarsky (1973), Z. Narangerel, N. Lkhagva and others.

Geological structure of Otgontenger mineral water field [1–3, 7] consists of Paleozoic intrusive rocks and quaternary deposits. The intrusive rocks comprise granites, subalkaline granites and medium- and coarse-grained clearly porphyraceous leucocratic granites. The rock mass exhibits an intensive erosive breakdown and overlapping fracturing [3, 10, 16 and others]. Quaternary deposits are represented by gravel and pebble material and micaceous sand with boulders of glacial origin. Visible thickness of glacial deposits is 10–15 m [1, 8].

It has been established that thermal waters are associated with the intrusive rocks' tectonic fracturing zone [16, 28, 29]. Discharge of thermal waters is associated with waterlogged feathering and transverse secondary multidirectional fractures [7, 10, 28, 30–32]. The main fault passes across Arshaan River valley, has a north-western direction and is accompanied by a fracturing zone. Total area of thermal water discharge in the daylight surface reaches 0.13 km^2 (650×200 m). The most high-temperature zones (50–55 °C – discharges No. 9, 23) are associated with intersections of tectonic faults waterlogged by thermal springs and are located in the central part of the area.

The field area has 40 registered hot discharges with a temperature of 28–55 °C. Water temperature in 60 % registered springs amounts to 42–47 °C on average, and in the rest does not exceed 23–38 °C. Total yield of hot springs with the temperature of 42–55 °C equals 6.0 L/s.

As a result of monitoring observations within one-year cycle, no changes have been registered in the chemical composition, temperature, or yield, as a function of atmospheric precipitation. Hot water discharges are located at an altitude of up to 40 m over the river's edge at a distance of 0.5 km from the riverbed. In terms of chemical composition, thermal waters belong to the khulzh type of sodium sulfate thermal springs and exhibit low salinity (up to 0.29 g/L) and alkaline reaction (pH = 7.0–9.0) with silicic acid content of 32–74 mg/L.

Presently the Otgontenger thermal waters are used as seasonal republican health resort based on natural discharges of thermal springs with temperature up to 57 °C [7, 8, 10]. Mineral waters of Otgontenger field are used for treating disorders of joints, nervous system, blood circulation organs, gastrointestinal tract, skin, and gynecological diseases.

Shargalzhuut thermal water field

The field is located in the territory of Bayankhongor aimag, 60 km to the north-east from the aimag's administrative center Bayankhongor, 30 km to the east of the somon center Erdenetsogt. Absolute elevation of the arshan's discharge is 2500 m.

In terms of its hydrogeological structure, Shargalzhuut nitric springs field [30, 32] is associated with the hydrogeological massif of the slope [6, 8] comprising pervasive intrusive Triassic and Permian rocks. It has been established that nitric mineral waters are associated with the Lower Permian rock techtonic fracturing zone. Discharge of nitric springs is related to the regional fault of east-west trending and transverse waterlogged faults [6]. The waterlogged fracturing zone width within the field area amounts to 20–30 m. Total discharge focus area is about 0.25 km^2. Exploration thermal water wells are drilled at the depths from 3.0 m (in alluvial deposits) to 120.0 m (in parent rocks) with temperatures 6–48 °C and yields 1.10–1.92 L/s at drawdowns of 16.0 and 17.7 m respectively. Nitric springs of Shargalzhuut field have sodium bicarbonate chemical composition. They exhibit low salinity (0.2–0.49 g/L), are hyperthermal according to O.K. Lange (above 42 °C), have alkaline reaction (pH = 8.5–9.3) and abnormal content of silicic acid (94.46–174.0 mg/L) and other elements.

Total yield of hot springs with temperature 48–90 °C amounts to 51.0 L/s.

Survey methods.
Well drilling technology
for thermal water production

Technological aspects of drilling [33–37] in regard to wells intended for production of thermal waters are driven by a number of natural factors that have to be taken into account in design of a hydrogeological well [6, 10, 12, 13, 21, 22, 29, 36, 38–42]. These factors include thermal water temperature, formation pressure in the natural reservoir, stratum depth and salinity of thermal waters, and drillability of rocks in which the groundwater well is to be made.

Considered below are the temperature conditions for drilling of ground water wells intended for production of thermal waters (fig. 1). In the conditions of chilled profile of the upper sedimentary sheath of Meso-Cenozoic depressions and river valleys of Mongolia [3, 7–10, 22], the hot underground fluid stream of thermal waters inevitably meets the cold stream of alluvial fresh ground waters of river valleys or streams of cold ground waters of sub-mountain fans.

For the most part, these are the main types of ground water fields which are being studied for decades with the purpose of water supply [3, 6–10, 12, 13, 33, 38, 39, 41, 43 and others]. In some instances, field hydrogeological tests have proven the presence of localized streams of cold ground waters belonging to fissure-vein type and associated with waterlogged faults [6–10, 28, 30–32]. Here one must not exclude concentrated discharge in alluvial deposits of hot thermal and cold potable or nitric mineral waters in certain parts of waterlogged transit fault zones. The existing instances of combined discharge of hot and cold ground waters suggest that hot thermal waters are inevitably diluted and chilled in the zones where they are mixed with cold waters.

Well drilling programme

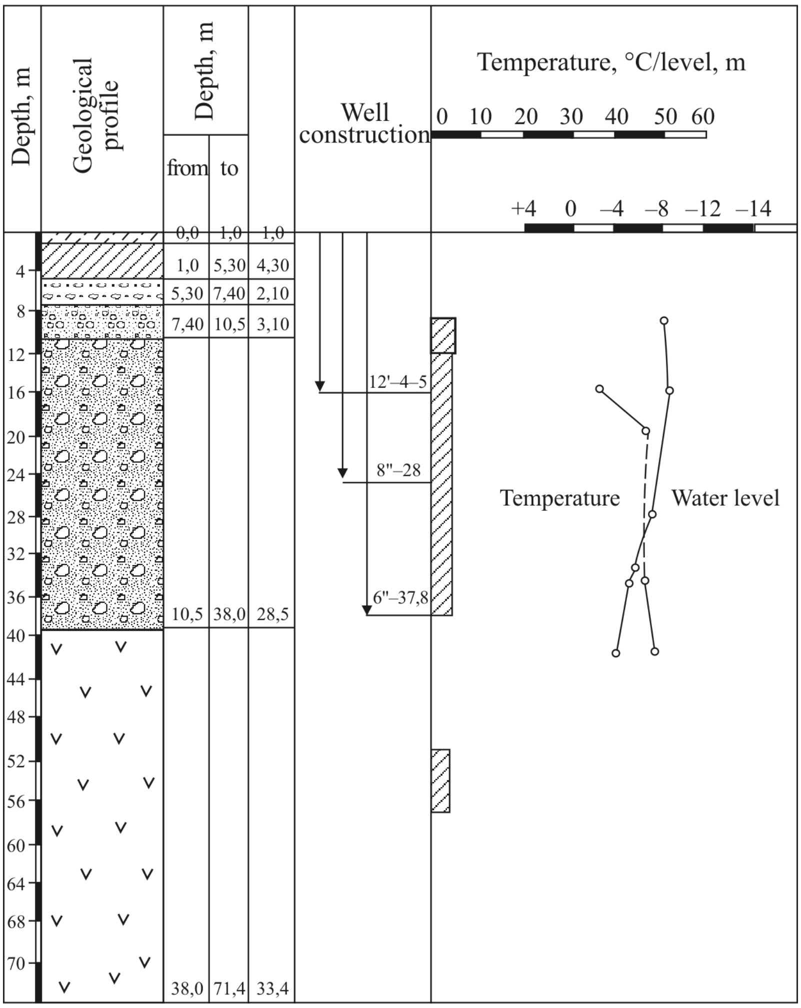

Fig. 1. The approved ground water well construction intended for extraction of thermal waters at Saikhan Khulzh, Mongolia (1974)

The process of dilution and chilling of hot thermal streams when mixed with cold fresh and mineral waters in natural conditions impedes gaining full benefit from the energy potential of a thermal water discharge focus [36, 40]. The task of preserving maximum possible natural temperatures of thermal waters requires a solid package of engineering and technological solutions for practical implementation. In terms of well construction improvement [17, 33–35], this task can be solved by suggesting that each intermediate casing string in the ground water well bore should perform a double function. Apart from securing the wellbore walls against caving-in or collapsing in unconsolidated and semi-consolidated deposits, the casing string isolates the working space of the well and natural ground water reservoirs from the zones already drilled and can be regarded as a heat-insulating well casing element which separates heat flows of the hot and cold fluid hydrogeological systems.

Results of the study

In natural reservoirs with high values of filtration environment parameters (filtration factor, pressure conductivity etc. [12, 33, 38]) it is of special importance to ensure reliable separation of the two types of hydrogeological structures: alluvial deposits that contain and redistribute the flows of cold fresh waters, and thermal mineral waters contained in waterlogged faults. Apparently, several sequentially run casing strings with mandatory cementing of the outer annulus with cement slurry help reduce total loss of heat flow obtained from the well. In order to additionally reduce the loss of thermal mineral water temperature on the way along the wellbore to the surface within the well construction, it is suggested to use casing strings (including production casing) manufactured from composite heat insulation materials. This will result in up to 10–15 °C higher temperature values of the thermal springs captured by the well compared to temperature values in the natural discharge focus passing through alluvial deposits. Use of thermal cases (heat insulation solution) has proved to be highly effective in construction of wells in the interval of permafrost rocks in the oil and gas field of the Tyumen Oblast, the Sakha Republic (Yakutia) and in the north of Krasnoyarsk Krai. In these instances, the permafrost rock masses are isolated from heating due to the contact through casing with the drilling mud in the well [23]. Conversely, the authors of this paper propose using thermal cases to avoid chilling of thermal waters in the wellbore on the way from its bottom to the wellhead.

One of the promising directions of reducing the thermal conductivity of well casing is use of polyurethane-based polymeric materials in its structure. The authors suggest using double-wall casing strings (“pipe-in-pipe technology”), with a heat insulating filler material (polyurethane foam). It helps achieve the established goal mainly due to the low thermal conductivity factor (0.019– 0.03 W/m·K), whereas for the steel of the casing string it amounts to 27–40 W/m·K, and low weight of polyurethane foam does not require any additional equipment to run the casing.

Use of this technology will help reduce heat loss along the wellbore by 20–30 %, ensuring that surface temperature is as close as possible to the formation temperature.

Generally, the geologic conditions of Shargalzhuut field are favorable for drilling thermal water producing wells [6]. The only challenge in drilling such wells is quartz diorites which are a common occurrence throughout the thermal water field area. In these conditions, it is advisable to use pneumatic and hydraulic hammers for drilling a pilot wellbore and further expand it using a roller-cone bit. [43]. URB-2A-2 drilling rig mounted on all-terrain chassis (URAL, KAMAZ) with a drilling capacity of 200-250 m can be advised as a drilling machine. The well construction can be as follows (fig. 2).

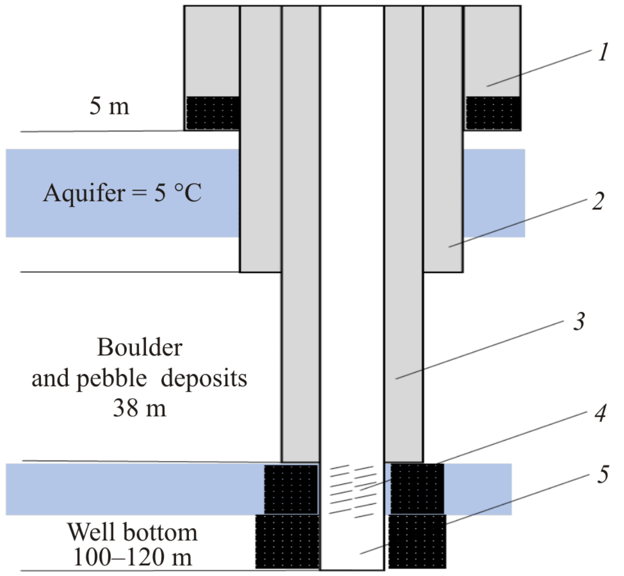

Fig. 2. New hydrogeological well construction for thermal water extraction in Mongolia: *1* – surface casing, 324 mm, with cemented casing shoe; *2* – intermediate casing I-219 mm, cemented; *3* – intermediate casing II-168 mm, cemented; *4* – slotted filter in the producing formation; *5* – production string, 127 mm, drilling diameter 151 mm

Fig. 2 shows an interval of unconsolidated reservoir rocks, top of crystalline rock, and fault zone logged with thermal waters. The proposed new hydrogeological well construction solves the above mentioned tasks of effective geothermal resources development for reservoirs with overlying alluvial deposits.

Conclusion

The technological solutions proposed above help reduce heat loss along the wellbore by 20–30 %. Further research in this area will be undertaken. The technological solutions integrated in the cycle of drilling and casing the hydrogeological well for production of thermal waters bring real economic effect measured in heat flow units and in cash equivalent.

References

1. Geologiia MNR [Geology of Mongolian People's Republic]. Moscow, Nedra, 1973, vol.1, 582 p.

2. Pinneker E.V., Pisarskii B.I., Dorzhsuren P. et al. Geokhimiia podzemnykh mineralnykh vod mnr [Geochemistry of underground mineral waters of the Mongolian People's Republic]. Moscow, Nauka, 1976, 79 p.

3. Marinov N.A., Popov V.N. Gidrogeologiia Mongolskoi Narodnoi Respubliki [Hydrogeology of the Mongolian People's Republic]. Moscow, 1963, 452 p.

4. Orgilianov A.I., Kriukova I.G., Badminov P.S., Ganchimeg D. Sravnitelnaia kharakteristika izotopnogo sostava termalnykh vod Baikalskoi riftovoi zony i smezhnykh svodovykh podniatii [Comparative characteristics of the isotopic composition of the thermal waters of the Baikal rift zone and adjacent vaults]. *Materialy vserossiiskogo soveshchaniia po podzemnym vodam Vostoka Rossii*. Irkutsk, Geograf, 2012, p. 218-221.

5. Pinneker E.V., Pisarskii B.I., Pavlova S.E., Lepin V.S. Izotopnye issledovaniia mineralnykh vod mongolii [Isotopic studies of mineral waters of Mongolia]. *Geologiia i geofizika*, 1995, vol.36 (1), pp.94-102.

6. Surmaazhav D., Lkhagva N. Mestorozhdeniia termalnykh vod shargalzhuut [Shargalzhuut thermal water deposits]. *Gidrogeologiia, Inzhener-naia geologiia i ekologiia*. Ulaanbaatar, 2016, pp. 20-25.

7. Surmaazhav D. Usloviia formirovaniia termalnykh vod Mongolii [The conditions for the formation of thermal waters of Mongolia]. *Materialy vserossiiskogo soveshchaniia po podzemnym vodam Vostoka Rossii*. Novosibirsk, 2017, pp. 50-54.

8. Surmaazhav D. Gidrogeologicheskie usloviia tsentralnoi Mongolii [Hydrogeological conditions of central Mongolia]. *Materialy mezhvuzovskoi Kerulenskoi geologicheskoi ekspeditsii*. Irkutsk, 2015.

9. Surmaazhav D. Usloviia i raspredeleniia podzemnykh vod v merzlykh zonakh Mongolii [Groundwater conditions and distribution in the frozen zones of Mongolia]. *Materialy vserossiiskogo soveshchaniia po podzemnym vodam Vostoka Rossii.* Iakutsk, 2015.

10. Surmaazhav D. Raspredeleniia termalnykh vod v razlomakh Mongolii [Distribution of thermal waters in the faults of Mongolia]. *Materialy mezhvuzovskoi Kerulenskoi geologicheskoi ekspeditsii*. Ulaanbaata, 2017.

11. Altynnikova M.A., Didenkov Iu.N. Usloviia formirovaniia sovremennykhgidroterm raiona Severo-Muiskogo tonnelia BAM [The conditions for the formation of modern hydrothermal areas of the North Mui tunnel BAM]. *Sbornik nauchnykh trudov*. Irkutsk, izdatelstvo Irkutskogo gosudarstvennogo tekhnicheskogo universiteta, 2005, pp.7-12.

12. Bondarenko S.S. Izuchenie i otsenka resursov mineralnykh, termalnykh i promyshlennykh vod [Study and assessment of mineral, thermal and industrial water resources]. Moscow, Nedra, 1975, 243 p.

13. Vartanian G.S. Mestorozhdeniia uglekislykh vod gorno-skladchatykh regionov [Deposits of carbon dioxide in mountain-folded regions]. Moscow, Nedra, 1985, 286 p.

14. Genezis uglekislykh i termalnykh vod MNR po izotopnym dannym [Genesis of carbonic and thermal waters of the Mongolian People's Republic according to isotope data]. *Prirodnye usloviia i resursy nekotorykh raionov MNR*. Ulan-Bator, 1982, p.41.

15. Ivanov V.V., Nevraev G.A. Klassifikatsiia podzemnykh mineralnykh vod [Underground Mineral Water Classification]. *Trudy Tsentralnogo instituta kurortologii i fizioterapii*, 1964, iss.1.

16. Kropotkin P.N., Valiaev B.M. Glubinnye razlomy i degazatsiia zemli. Tektonicheskoe razvitie zemnoi kory i razlomy [Deep faults and degassing of the Earth. Tectonic development of the earth's crust and faults]. Moscow, Nauka, 1979, pp.257-267.

17. Kurbanov M.K. Geotermalnye i gidro-mineralnye resursy vostochnogo kavkaza i predkavkazia [Geothermal and hydro-mineral resources of the East Caucasus and Ciscaucasia]. *Nauka/Interperiodika*, 2001, 260 p.

18. Pinneker E.V., Pisarskii B.I., Shvartsev S.L. et al. Osnovy gidrogeologii. obshchaia gidro-geologiia [Fundamentals of hydrogeology. General hydrogeology]. Novosibirsk, Nauka, 1980, 225 p.

19. Pliusnin A.M., Zamana L.S., Shvartsev S.L., Tokarenko O.G., Cherniaevskii M.K. Gidrogeokhimicheskie osobennosti sostava azotnykh term baikalskoi riftovoi zony [Hydrogeochemical peculiarities of the composition of nitric thermal waters in the Baikal Rift Zone]. *Geologiia i geofizika*, 2013, vol.54/(5), pp.647-664.

20. Poliak B.G., Prasolov E.M., Tolstikhin I.N., Kozlovtseva S.V., Kononov V.I., Khutorskii M.D. Izotopy geliia vo fliuidakh Baikalskoi riftovoi zony [Helium isotopes in fluids of the Baikal rift zone]. *Izvestiia AN SSSR*, 1992, no.10, pp.18-33.

21. Khutorskoi M.D. Geotermiia tsentralno-aziatskogo skladchatogo poiasa [Geothermy of the Central Asian fold belt]. 1985.

22. Frolov N.M. Gidrogeotermiia [Hydrogeothermy]. Moscow, 1976, 280 p.

23. Shananenko V.V. Burenie v vechnoi merzlote bolshe ne problema [Permafrost drilling is no longer a problem]. *Territoriia neftegaz*, 2014, no.8, pp.16-17.

24. Shvartsev S.L. Vzaimodeistvie podzemnykh vod s gornymi porodami [Groundwater interaction with rocks]. *Osnovy gidrogeologii: Gidrogeokhimiia*. Ed. S.l. Shvartsev. Novosibirsk, Nauka,1982, pp.92-117.

25. Shvartsev S.L. K probleme samoorganizatsii sistemy voda-poroda [To the problem of self-organization of the water-rock system]. *Geologiia i geofizika*,1995,

26. Shvartsev S.L. Geologicheskaia sistema “voda – poroda” [Geological system “water – rock”]. *Vestnik RAN*, 1997, vol.67, no.6, pp.518-524.

27. Faif U., Prais N., Tompson A. Fliuidy v zemnoi kore [The fluids in the Earth's crust]. Moscow, Mir, 1988, 438 p.

28. Stepanov V.M. Obvodnennye razlomy [Watered faults]. Irkutsk, 1988.

29. Chernyshev S.N. Treshchiny gornykh porod [Rock cracks]. Moscow, Nedra, 1989.

30. Stepanov V.M. Vvedenie v strukturnuiu gidrogeologiiu [Introduction to structural hydrogeology]. Moscow, Nedra, 1989, 229 p.

31. Stepanov V.M. Gidrogeologicheskie struktury Zabaikalia [Hydrogeological structures of Transbaikalia]. Moscow, Nedra, 1981.

32. Stepanov V.M. O printsipakh sistematizatsii gidrogeologicheskikh struktur [On the principles of systematization of hydrogeological structures]. *Izvestiia vuzov. Geologiia i razvedka*, 1985, no.3, pp.88-93.

33. Auzina L.I. Poiski i razvedka podzemnykh vod [Groundwater prospecting and exploration]. Irkutsk, Izdatelstvo irkutskogo gosudarstvennogo tekhnicheskogo universiteta, 2014, 120 p.

34. Bashkatov D.N., Rogovoi V.L. Burenie skvazhin na vodu [Water well drilling]. Moscow, 1976, 206 p.

35. Kalinin A.G., Levitskii A.Z., Nikitin B.A. Tekhnologiia bureniia razvedochnykh skvazhin na neft i gaz [Oil and gas exploration drilling technology]. Moscow, Nedra, 1998

36. Metodicheskie rekomendatsii po poiskam, razvedke i otsenke ekspluatatsionnykh zapasov termalnykh vod [Guidelines for the search, exploration and evaluation of operational reserves of thermal waters]. Moscow, 1982, 121 p.

37. Sulakshin S.S. Napravlennoe burenie [Directional drilling]. Moscow, Nedra, 1987.

38. Borevskii B.V., Drobnokhod N.I., Iazvin L.S. Otsenka zapasov podzemnykh vod [Groundwater reserves assessment]. Kiev, Vyshcha shk. Golovnoe izdatelstvo, 1989, 407 p.

39. Lysak S.V. Geotermicheskie usloviia i termalnye vody iuzhnoi chasti Vostochnoi Sibiri [Geothermal conditions and thermal waters of the southern part of Eastern Siberia]. Moscow, Nauka, 1968, 120 p.

40. Metody izucheniia i otsenka resursov glubokikh podzemnykh vod [Methods of study and assessment of deep groundwater resources]. Ed. S.S. Bondarenko, G.S. Vartanian. Moscow, Nedra, 1986, 479 p.

41. Osika D.G. Fliuidnyi rezhim seismicheski aktivnykh oblastei [The fluid regime of seismically active regions]. Moscow, Nauka, 1981, 203 p.

42. Timurziev A.I. Tekhnologiia prognozirovaniia treshchinovatosti na osnove trekhmernoi geomekhanicheskoi i kinematicheskoi modeli treshchinnogo kollektora [Fracturing prediction technology based on a three-dimensional geomechanical and kinematic model of a fracture reservoir]. *Geofizika*, 2008, no.3, pp.41-60.

43. Lysak S.V., Zorin Iu.A. Geotermicheskoe pole baikalskoi riftovoi zony [Geothermal field of the Baikal rift zone]. Moscow, Nauka, 1976.

44. Logachev N.A., Sherman S.I., Levi K.G., Trifonov V.G. Geodinamicheskaia aktivnost litosfery Azii: osnovy analiza i printsipy kartirovaniia [Geodynamic activity of the lithosphere of Asia: the basics of analysis and principles of mapping]. *Geodinamika i razvitie litosfery*. Moscow, 1991, pp.31-39.

45. Seminskii K.Zh., Gladkov A.S., Lunina O.V. et al. Vnutrenniaia struktura continental-nykh razlomnykh zon. Prikladnoi aspect [Internal structure of continental fault zones. Applied aspect]. Novosibirsk, Filial "Geo", 2005, 293 p.

Библиографический список

1. Геология Монгольской Народной Республики. – М.: Недра, 1973. – Т. 1. – 582 с.

2. Геохимия подземных минеральных вод Монгольской Народной Республики / Е.В. Пиннекер, Б.И. Писарский, П. Доржсурен [и др.]. – М., Наука, 1976. – 79 с.

3. Маринов Н.А., Попов В.Н. Гидрогеология Монгольской Народной Республики. – М., 1963. – 452 с.

4. Сравнительная характеристика изотопного состава термальных вод Байкальской рифтовой зоны и смежных сводовых поднятий / А.И. Оргильянов, И.Г. Крюкова, П.С. Бадминов, Д. Ганчимэг // Материалы всероссийского совещания по подземным водам востока России. – Иркутск: Географ, 2012. – С. 218–221.

5. Изотопные исследования минеральных вод Монголии / Е.В. Пиннекер, Б.И. Писарский, С.Е. Павлова, В.С. Лепин // Геология и геофизика. – 1995. – Т. 36 (1). – С. 94–102.

6. Сурмаажав Д., Лхагва Н. Месторождения термальных вод Шаргалжуут // Гидрогеология, инженерная геология и экология. – Улаанбаатар, 2016. – 20–25 с.

7. Сурмаажав Д. Условия формирования термальных вод Монголии // Материалы всероссийского совещания по подземным водам востока России. – Новосибирск, 2017. – 50–54 с.

8. Сурмаажав Д. Гидрогеологические условия центральной Монголии // Материалы межвузовской Керуленской геологической экспедиции. – Иркутск, 2015. – 18–21 с.

9. Сурмаажав Д. Условия и распределения подземных вод в мерзлых зонах Монголии // Материалы всероссийского совещания по подземным водам востока России. – Якутск, 2015. – 11–14 с.

10. Сурмаажав Д. Распределения термальных вод в разломах Монголии // Материалы межвузовской Керуленской геологической экспедиции. – Улаанбаата, 2017. – 12–14 с.

11. Алтынникова М.А., Диденков Ю.Н. Условия формирования современных гидротерм района Северо-Муйского тоннеля БАМ // Гидроминеральные ресурсы Восточной Сибири: сб. науч. тр. – Иркутск: Изд-во Иркутск. гос. техн. ун-та, 2005. – С. 7–12.

12. Бондаренко С.С. Изучение и оценка ресурсов минеральных, термальных и промышленных вод. – М.: Недра, 1975. – 243 с.

13. Вартанян Г.С. Месторождения углекислых вод горно-складчатых регионов. – М.: Недра, 1985. – 286 с.

14. Генезис углекислых и термальных вод Монгольской Народной Республики по изотопным данным // Природные условия и ресурсы некоторых районов Монгольской Народной Республики. – Улан-Батор, 1982. – С. 41.

15. Иванов В.В., Невраев Г.А. Классификация подземных минеральных вод // Тр. Центр. ин-та курортологии и физиотерапии. – 1964. – Вып. 1.

16. Кропоткин П.Н., Валяев Б.М. Глубинные разломы и дегазация Земли. Тектоническое развитие земной коры и разломы. – М.: Наука, 1979. – С. 257–267.

17. Курбанов М.К. Геотермальные и гидроминеральные ресурсы Восточного Кавказа и Предкавказья // МАИК Наука/ Интерпериодика. – Иркутск: Москва, 2001. – 260 с.

18. Основы гидрогеологии. Общая гидрогеология / Е.В. Пиннекер, Б.И. Писарский, С.Л. Шварцев [и др.]. – Новосибирск: Наука, 1980. – 225 с.

19. Гидрогеохимические особенности состава азотных терм байкальской рифтовой зоны / А.М. Плюснин, Л.С. Замана, С.Л. Шварцев, О.Г. Токаренко, М.К. Черняевский // Геология и геофизика. – 2013. – Т. 54 (5). – С. 647–664.

20. Изотопы гелия во флюидах Байкальской рифтовой зоны / Б.Г. Поляк, Э.М. Прасолов, И.Н. Толстихин, С.В. Козловцева, В.И. Кононов, М.Д. Хуторский // Изв. АН СССР. – 1992. – № 10. – С. 18–33.

21. Хуторской М.Д. Геотермия Центрально-Азиатского складчатого пояса. – М., 1996. – 285 с.

22. Фролов Н.М. Гидрогеотермия. – М., 1976. – 280 с.

23. Шананенко В.В. Бурение в вечной мерзлоте больше не проблема // Территория нефтегаз. – 2014. – № 8. – С. 16–17.

24. Шварцев С.Л. Взаимодействие подземных вод с горными породами // Основы гидрогеологии: гидрогеохимия / под ред. С.Л. Шварцева. – Новосибирск: Наука, 1982. – С. 92–117.

25. Шварцев С.Л. К проблеме самоорганизации системы вода – порода // Геология и геофизика. – 1995. – 22–29 с.

26. Шварцев С.Л. Геологическая система «вода – порода» // Вестник РАН. – 1997. – Т. 67, № 6. – С. 518–524.

27. Файф У., Прайс Н., Томпсон А. Флюиды в земной коре. – М.: Мир, 1988. – 438 с.

28. Степанов В.М. Обводненные разломы: учеб. пособие. – Иркутск, 1988. – 314 с.

29. Чернышев С.Н. Трещины горных пород. – М.: Недра, 1989. – 240 с.

30. Степанов В.М. Введение в структурную гидрогеологию. – М.: Недра, 1989. – 229 с.

31. Степанов В.М. Гидрогеологические структуры Забайкалья. – М.: Недра, 1981. – 177 с.

32. Степанов В.М. О принципах систематизации гидрогеологических структур // Изв. вузов. Геология и разведка. – 1985. – № 3. – С. 88–93.

33. Аузина Л.И. Поиски и разведка подземных вод: учеб. пособие. – Иркутск: Изд-во Иркутск. гос. техн. ун-та, 2014. – 120 с.

34. Башкатов Д.Н., Роговой В.Л. Бурение скважин на воду. – М., 1976. – 206 с.

35. Калинин А.Г., Левицкий А.З., Никитин Б.А. Технология бурения разведочных скважин на нефть и газ: учеб. для вузов. – М.: Недра, 1998. – 440 с.

36. Методические рекомендации по поискам, разведке и оценке эксплуатационных запасов термальных вод. – М., 1982. – 121 с.

37. Сулакшин С.С. Направленное бурение. – М.: Недра, 1987. – 272 с.

38. Боревский Б.В., Дробноход Н.И., Язвин Л.С. Оценка запасов подземных вод. – 2-е изд., перераб. и доп. – К.: Выща шк. Головное изд-во, 1989. – 407 с.

39. Лысак С.В. Геотермические условия и термальные воды южной части Восточной Сибири. – М.: Наука, 1968. – 120 с.

40. Методы изучения и оценка ресурсов глубоких подземных вод / под ред. С.С. Бондаренко, Г.С. Вартаняна. – М.: Недра, 1986. – 479 с.

41. Осика Д.Г. Флюидный режим сейсмически активных областей. – М.: Наука, 1981. – 203 с.

42. Тимурзиев А.И. Технология прогнозирования трещиноватости на основе трехмерной геомеханической и кинематической модели трещинного коллектора // Геофизика. – 2008. – № 3. – С. 41–60.

43. Лысак С.В., Зорин Ю.А. Геотермическое поле Байкальской рифтовой зоны. – М.: Наука, 1976. – 288 с.

44. Геодинамическая активность литосферы Азии: основы анализа и принципы картирования / Н.А. Логачев, С.И. Шерман, К.Г. Леви, В.Г. Трифонов // Геодинамика и развитие литосферы. – М., 1991. – С. 31–39.

45. Внутренняя структура континентальных разломных зон / К.Ж. Семинский, А.С. Гладков, О.В. Лунина [и др.] // Прикладной аспект. – Новосибирск: Филиал «Гео», 2005. – 293 с.

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