FORMAÇÃO DA COMPOSIÇÃO QUÍMICA DE DEPÓSITOS DE ÁGUA MINERAL DO TIPO INJEÇÃOCOMO EXEMPLIFICADOS PELO CAMPO DE CHAPAEVSKOYE NO DISTRITO DE KORSAKOV DA REGIÃO DE SAKHALIN

FORMATION OF CHEMICAL COMPOSITION OF INJECTION-TYPE MINERAL WATER DEPOSITS AS EXEMPLIFIED BY CHAPAEVSKOYE FIELD IN KORSAKOV DISTRICT OF SAKHALIN REGION

ФОРМИРОВАНИЕ ХИМИЧЕСКОГО СОСТАВА МЕСТОРОЖДЕНИЙ МИНЕРАЛЬНЫХ ВОД ГИДРОИНЖЕКЦИОННОГО ТИПА НА ПРИМЕРЕ МЕСТОРОЖДЕНИЯ «ЧАПАЕВСКОЕ» В КОРСАКОВСКОМ РАЙОНЕ САХАЛИНСКОЙ ОБЛАСТИ

SAKHAROV, Valerii A.*; MOROZOVA, Olga A.; VYPRYAZHKIN, Evgeniy N;, IKENKHI; POLIAK, Hanna S.

Federal State Budget Educational Institution of Higher Education “Sakhalin State University”, Laboratory of physical and chemical research
68 Pogranichnaya St., Yuzhno-Sakhalinsk, 693008, Russian Federation

** Corresponding author*
sakhsakh@yandex.ru

Received 02 October 2018; received in revised form 11 November 2018; accepted 11 November 2018

RESUMO

A água mineral subterrânea é amplamente utilizada na balneologia e na indústria alimentícia. Os depósitos conhecidos são geralmente afastados do consumidor, o que afeta negativamente sua acessibilidade. Uma certa combinação de condições climáticas, hidrologia, tectônica e hidrologia de águas subterrâneas em algumas regiões permite que depósitos de água mineral do tipo injeção se formem nas áreas livres de seus indicadores externos. Os dados necessários podem ser obtidos a partir de fontes literárias disponíveis, o que amplia significativamente as áreas para a pesquisa de depósitos nas proximidades de potenciais consumidores. Os depósitos do tipo injeção apresentam uma estrutura muito complexa, razão pela qual sua exploração e operação têm suas especificidades. Esses aspectos foram abordados em um exemplo específico.O objetivo da pesquisa foi estudar os fatores que permitem a formação de depósitos de água mineral tipo injeção e os fatores que afetam as mudanças na composição química da água subterrânea no curso da exploração da água.O artigo oferece uma visão geral bastante detalhada dos dados sobre o clima, hidrologia, tectônica, geologia e hidrologia de águas subterrâneas da região. A análise de dados nos permite concluir sobre uma possibilidade em princípio da formação de depósitos do tipo injeção na área de estudo. Levantamentos geofísicos de campo, de perfuração e hidrogeológicos foram usados para desenvolver um modelo de depósito bastante detalhado na área escolhida e para mostrar o mecanismo de formação da composição química da água subterrânea.

Palavras-chave: *Água mineral, depósito de água mineral tipo injeção.*

ABSTRACT

Underground mineral water is widely used in balneology and food industry. Known deposits are usually away from the consumer, which negatively affects their accessibility. A certain combination of climatic conditions, hydrology, tectonics and groundwater hydrology in some region makes it possible for injection-type mineral water deposits to form in the areas free of their outer indicators. Required data may be obtained from available literary sources, which significantly expands the areas for the search of deposits in close proximity to potential consumers. Injection-type deposits feature very complex structure, which is why their exploration and operation have its specifics. These aspects have been addressed on a particular example. The research

DOI: 10.52571/PTQ.v16.n31.2020.463_Periodico31_pgs_457_471.pdf

objective is to study the factors that enable the formation of injection-type mineral water deposits in the first place and factors that affect changes of groundwater chemical composition in the course of water exploitation in the second place. The article offers a quite detailed overview of data on the climate, hydrology, tectonics, geology and groundwater hydrology of the region. Data analysis allows us to conclude on a possibility in principle of the formation of injection-type deposits in the study area. Field geophysical, drilling and hydrogeological surveys were used to develop quite a detailed deposit model in the chosen area and to show the mechanism of formation of groundwater chemical composition.

Keywords: *Mineral water, injection-type mineral water deposit.*

АННОТАЦИЯ

Подземные минеральные воды имеют широкое применение в бальнеологии и пищевой промышленности. Известные месторождения, как правило, находятся на значительном удалении от потребителя, что затрудняет их доступность. Определенное сочетание климатических условий, гидрологии, тектоники, геологии и гидрогеологии в каком-либо районе обусловливает возможность формирования месторождений минеральных вод гидроинжекционного типа на территориях, где отсутствуют их внешние признаки. Получить необходимые сведения возможно из доступных литературных источников, что значительно расширяет площади, перспективные для поисков месторождений в непосредственной близости от потенциального потребителя. Месторождения гидроинжекционного типа имеют весьма сложное строение, поэтому их разведка и эксплуатация имеют специфические особенности. Указанные аспекты разобраны на конкретном примере. Цель исследования – изучение факторов, определяющих, во-первых, возможность формирования месторождений минеральных вод гидроинжекционного типа, во-вторых, влияющих на изменение химического состава подземных вод в процессе их эксплуатации. В статье представлен достаточно подробный обзор данных о климате, гидрологии, тектонике, геологии и гидрогеологии района. Анализ данных позволяет сделать вывод о принципиальной возможности формирования месторождений гидроинжекционного типа в рассматриваемом районе. На основе полевых геофизических, буровых и гидрогеологических работ разработана достаточно детальная модель месторождения на выбранном участке, показан механизм формирования химического состава подземных вод.

Ключевые слова: *Минеральные воды, месторождение минеральных вод гидроинжекционного типа.*

INTRODUCTION

Mineral water is widely used in balneology and food industry. However, mineral springs are usually away from the consumer, so water delivery to healthcare centers, mineral water plants, etc. is very costly. That said, review of prospecting results suggests that when natural conditions are combined in a certain way, mineral water deposits develop much more often than assumed, even in the areas free of any outward appearances. These deposits include injection-type mineral water deposits that result from mixing of highly mineralized water that circulates in permeable zones of tectonic faults with fresh water of the hydrogeological section top (Kharitonova, 2013; Posokhov and Tolstikhin, 1977; Vartanyan, 1997; Vartanyan and Yarotskiy, 1972). Identification of the natural factors that enable the formation of injection-type deposits allows to significantly increase perspective areas and, thus, bring their search and exploration sites as close to the consumer as possible. Sure enough, this approach will yield cost advantages.

Injection-type deposits normally feature very complex geological structure and groundwater conditions. This is why water quality issues often occur when these deposits are developed. These issues are mainly caused by two reasons: 1) prospecting shortcomings; 2) operator’s non-compliance with the mineral water production method.

The research objective is to study the

factors that enable the formation of injection-type mineral water deposits, factors that condition the formation of groundwater chemical composition in natural and disturbed conditions.

MATERIALS AND METHODS

Information sources are data on natural conditions in the study area (https://meteoinfo.ru/climatcities; Hydrogeology of the USSR, 1972; Resources…, 1973; Scientific and applied…, 1990; State water register, 1972; Zharov, n.d.) and results of oil, gas and groundwater prospecting and research conducted in the Sakhalin region. Chapaevskoye deposit data was used as a reference.

Chapaevskoye mineral water deposit is situated in Korsakov district of Sakhalin region, on the right bank of the Komissarovka river valley, on the second bottom, 100 meters to the south of boundary houses of Chapaevo settlement (Fig. 1).

History of deposit discovery. The deposit was discovered by accident. In 1990, search for fresh groundwater was conducted for Chapaevo settlement water supply. A few wells were bored in its suburbs that tapped bedrock base and turned out to contain virtually no water. Only two wells, No. 280 and 270 (Fig. 3), tapped fractured reservoirs and had high yields: 5/6-10 l/s and 3-7 m at lows, correspondingly. The chemical composition of the well water revealed its conformity to GOST 2874-82 “Drinking water” (1984). The wells were tapped to the network; water was supplied to the settlement for household needs. Quite soon, water mineralization in well No. 270 increased to 2.9 g/dm^3, and the water was no longer suitable for household use. Water in well No. 280 has remained fresh until now. Sometimes, mineralization in the well gets up to the critical level caused by a change in the balance of fresh and salty water in good yields.

Results of the chemical analysis of the water from well No. 270 were submitted to the All-Union Research Center for Medical Rehabilitation and Physical Therapy. The center provided the report signed by Professor L. F. Nikolaeva stating that …pursuant to GOST 13273-88 (1988), this water belonged to medicinal drinking water (by its boron content) that could be recommended for internal use at health establishments and for bottling. Indications for use are chronic normal-, hyper- and subacid gastritis, gastric and duodenal ulcer, chronic colitis and enterocolitis, chronic liver and bile passage diseases, chronic pancreatitis, metabolic diseases. In pursuance of this report, authorities decided to use the water from well No. 270 as mineral water.

The following tasks had to be addressed as part of the feasibility study for the arrangement of commercial bottling of medicinal mineral water: - identify the main factors affecting deposit formation; - locate natural boundaries of mineral water surface and depth spread; - assess the scope of mineral water natural resources; - determine the share of resources that may be extracted without detriment to the environment; - obtain data to develop a sustainable deposit exploitation method.

Methods to address the set tasks

Literary sources were collected and reviewed to study the normative documents that regulate criteria of classifying groundwater as mineral medicinal table water, reference materials about the climate, hydrology, stratigraphy, tectonics, geological structure and groundwater conditions of the study area, published data about the structure and development experience of such deposits, repository and archive materials about results of prospecting in Sakhalin region.

Surface geophysical studies were conducted to determine the salty water location and its migration channels towards the ground surface. To this end, the following tasks were solved:

- determination of the geological and tectonic pattern of the deposit area to the depth of 150 m; - determination of mineral water confinedness to tectonic faults and lithologic reservoirs. By analogy with proven mineral water deposits, mineral water is assumed to be confined to the fault zones that normally stand out due to their geoelectric field conduction anomaly. This explains the choice of the work method. The work was conducted by vertical electrical sounding.

Drilling was conducted after areal geophysical investigations. Well locations, depth, and design were based on interpretation of geophysical investigation results — drilling comprised specification (verification) of deposit boundaries and building a test well cluster for pumping and production test. The wells were arranged along beams in the line of designed anisotropic axes: wells No. 2,3,4 – parallel to a meridian fault; wells No. 1,5 – perpendicular to it (Fig. 3). The distance from the center well (producer) No. 270 to well No. 1 is 60.0 m; to well No. 2 – 10.0 m; to well No. 3 – 15.0 m; to well No. 4 – 20.0 m; to well No. 5 – 32.0 m. The well pattern and distance between the center and inspection wells were chosen subject to the possible radius of the cone of influence during the pumping and production test. Logging was performed in all wells to determine the detailed breakdown of the exposed geological cross-section; identify rock filtration properties; determine sections with the highest water abundance; and determine differentiation of groundwater salt content by the well depth.

Pumping and production test was conducted to determine the main hydrogeological parameters of the deposit's aquifer system. A total of 10 interval pumping tests from 5 inspection wells and one pumping and production test were conducted. Pumping followed the common method; pumping test took 48 hours each, pumping and production test lasted for 1,128 hours. Pumping and production test was conducted from well No. 270.

Hydrochemical tests of water-bearing formations and systems were conducted to study groundwater chemical composition at varying occurrence depths. Water quality was assessed as per GOST 13273-88 "Mineral drinking medicinal and medicinal table water" (1988). Sampling and chemical tests followed by validated methods.

RESULTS

Main natural factors in the study area.

Climate and hydrography.

The region has a maritime monsoon climate with the mean annual temperature ranging from +1.5 to +3.0oC. The coldest month is January, and the warmest is August (https://meteoinfo.ru/climatcities; Scientific and applied…, 1990). The mean daily temperature shifts through 0oC to the negative area in November, to the positive area – in April. The air temperature in winter reaches minus 26oC, in summer – plus 30oC. The frost-free period varies from 116 to 138 days a year. The mean annual precipitation is 814 mm. Yearly precipitation is unevenly distributed; 15-20% of precipitation occurs in winter. Minimum precipitation is observed in February (20-30 mm), maximum – in August-September (80-100 mm). The warm period (April-October) sees from 400 to 500 mm of precipitation, winter (November-March) sees 150-200 mm (Fig. 2). The first snow falls in late October – early November. Snow cover breaks up in mid-late April. Most snow falls in February-March. The thickness of snow cover across the deposit is uneven. On crags, it normally does not exceed 10 cm, while in topographic lows, it reaches 3-4 m. The frost depth is up to 0.5 m.

Late summer – early fall see cyclones with strong winds and showers in the region that often cause floods. In winter, blizzards causing major snowdrifts are observed. North and north-east dry cold winds prevail in winter and summer mainly sees south and south-east winds. Average wind speed is 3-6 m/s, storm-force winds up to 40 m/s may also occur.

Stream conditions data is based on readings of a water level gauge in Chapaevo settlement (State water register…, 1987), field observations, one-time measurements, and resident interviews.

Komissarovka river is the region's main water course. It is 40 km long, and the watershed area is 500 km2. The average bed width in the study area is 5-6 m. The depth in the low-flow period reaches 1 m. The river valley is U-shaped. The river current speed varies from 0.1 to 3.5 m/s depending on the terrain. The river is mainly nourished by precipitation. The mean annual river flow in the study area is 4-6 m3/s. Ice cover is formed in late November or early December. The freezing period is 120-150 days. Winter levels are 120-130 cm, flow is 0.3-1.1 m3/s. The river breaks up in April. During high water, a significant increase of the river (up to 198 cm) is observed; river flow reaches 55 m3/s. The spring flood period is 6-20 days.

River regime in summer features a stable low water period (130-140 cm) interrupted by steep and short water level rises to 230-373 cm (sometimes catastrophic) as a result of storm rain. The river bursts its banks and floods the floodplain. River flow increases by 3-4 times. The flooding period is 3-5 days.

River temperature conditions depend on the air temperature and range from 7 to 15oC.

Geological structure

Stratigraphy

The region's geological structure is composed of Mesozoic and Cainozoic units universally overlapped by a thin cover of Quarternary deposits.

Mesozoic group

Cretaceous system

Upper section

Bykov formation (K2bk). Bykov formation deposits are the oldest of the study area. The deposits crop out in the east and south-east of the region, in the Komissarovka river basin. They feature north-north-west strike. The formation is made up of alternating silty rock and mudstone with rare thin sandstone and tuff stone streaks.

Silty rock and mudstone are greenish-dark gray in color, both stratified and unstratified. Debris composition: quartz, feldspar, silica rock, rock glass. Sandstone is a polymictic, medium- and coarse-grained, light gray, grey-wacke composition.

The formation is up to 1.600 meters thick.

Cenozoic group

Nummulitic system

Oligocene

Arakay formation (P3ar). Formation deposits strike in a strip of 0.5-0.7 km parallel to Cretaceous formation discharges and make up the Nukhachka-Gremuchka river water parting.

They underlay on Upper Cretaceous deposits with non-conformity. They are mostly represented by coarse rock debris: tuffstone, anisomerous tuff, and tuffite, psammite with tuffaleurolite streaks. Small pebble conglomerates are sometimes found in the formation base.

Tuffstone is gray, yellowish-gray, greenish-gray in color, from fine- to coarse-grained, with prevailing coarse-grained variations, dense, massive broadstone bind rocks. At times, the much tufaceous material is present.

Oval or pillow-like marly noddles from several centimeters to 0.5 meter in diameter are often observed in tufaceous sandstone.

Tuffaleurolite is gray, greenish-gray in color, dense, comprise fine rubbles, often with pillow-like jointing, low silica content, well sorted, with minor bedding in spots.

Tuff and tuffite are dense, massive rocks mostly represented by psammitic variations.

The formation rocks are up to 750 meters thick.

Neogene system.

Lower section.

Kholmsk formation (N1hl) crops out in most of the study area. It lies conformably with gradational contact on underlying Arakay formation deposits. It is represented by a uniform series of unclear alternation of siliceous argillite and silty rocks that contain pyroclastic material with rare thin tuffstone and acidic zeolitized tuff streaks and small pebble conglomerates lenses and streaks.

Siliceous argillite and silty rocks are gray, yellowish-gray, brownish-light-gray in color, comprise fine rubbles, quite dense in debris.

Tuffstone is fine- and medium-grained, gray, greenish-gray or yellowish-gray in color, dense, thin-slabby, well or moderately sorted, sometimes thinly bedded due to some content of tuff.

Tuff is mostly politic or aleurolitic, gray, light-gray or yellowish-light-gray in color, dense, slabby. Tuff contains cement in the form of zeolitized rock glass.

Conglomerates are gray, brown-gray in color, mostly small pebbles, dense, massive. They lie as lenses or lenticular interbeds up to 2 meters deep.

The formation rocks are 1,800 meters thick.

Quarternary system.

Quarternary deposits are represented by eluvial, diluvial and alluvial units.

Eluvio-diluvial units are represented by weathered rock debris. The composition is fully dependant on lithology of the latter. In the Bykov formation discharge field, eluvio-diluvial units are represented by loam and clay, in the Arakay formation discharge field – by rubble-block units. Quarternary rocks in the Kholmsk formation discharge field have a typical appearance. They are represented by gruss-rock series of weathered silica rocks.

Alluvial deposits are found in river and brook valleys and are represented by gravel, sand, clay sand and loam.

Tectonics

Tectonically, the study area is situated in the Cainozoic folding development area. Deposits are combined in the upper structural and formational lift divided into two structural stages: Upper Cretaceous and Paleogene-Neogene (Zharov, n.d.).

The Upper Cretaceous structural stage is represented by Bykov formation deposits that make up the submeridional strike monocline with a west dip at 50-65o. With the formation of the Paleogene-Neogene structural stage, the contact has pronounced unconformity.

The Paleogene-Neogene structural stage is represented by Arakay and Kholmsk formation deposits. The rocks of this stage are contorted to form gentle elongated folds. These are Komissarovka and Odessitka anticlinal and Gaydukov and Odessitka synclinal folds.

Komissarovka upfold in the Komissarovka river basin is traced to 6.5 km, and its width is 2 km. The fold axis in the plan is arched, its convex faces east. The fold plunges southward. The fold is made up of Kholmsk formation rocks. The fold is asymmetrical; its western flank has a lower angle (10-15o), its eastern flank is steep (up to 30o). The southern and northern closings of the Komissarovka upfold are cut off by tectonic faults. Odessitka anticlinal fold is observed in the Odessitka river basin; it is made up of Kholmsk formation rocks. It is traced to 5 km. It is a narrow ctenidium not more than 1 km wide. Rocks on flanks dip at 45o; the eastern flank is steeper than the western one. The southern closing of this structure is cut off by an oblique shift fault, and the northern one lies beyond the study area. The fold axis has a submeridional strike, and the fold has a shallow plunge southward.

Gaydukov synclinal fold is situated between the Komissarovka and Odessitka anticlinal folds. This structure is made up of Kholmsk formation rocks, and it features sharp flank dip. A diagonal break splits it into two blocks.

To the east of the Odessitka anticlinal fold, there is a syncline structure of the same name. It has a steep (up to 35o) western flank and a more gently sloping eastern flank. It is made up of Kholmsk formation rocks.

Fractures were identified by aerial photo interpretation. The principal fractures of the study region are meridional and submeridional faults with steep dips of fault planes close to vertical. They are observed in the Kholmsk formation deposit development field and along the Oligocene Arakay formation contact with Miocene Kholmsk formation and Upper Cretaceous Bykov formation units and they predetermine the horst type of Arakay formation rock yields.

North-western rhumb faults complicate submeridional tectonic faults and often displace them to the left. They have relatively low dips and are, perhaps, upcasts or upthrow-shifts.

North-eastern faults are locally developed. When crossing north-western faults, they form strong crush zones favoring the accumulation of gravitational water, often with higher mineral and trace element content. Chapaevskoye mineral water deposit is confined to such zone.

Hydrogeological conditions

The deposit is situated within the Yuzhno-Sakhalinsk hydrogeological massif that accommodates aquifer systems represented by rocks of various origin and lithologic and petrographic composition aged from Upper Cretaceous to Quarternary (Hydrogeology of the USSR, 1972). Geological structure, structural and tectonic features of the massif conditioned the formation of groundwater classified as interstitial, fissure and fissure-vein water in terms of circulation conditions.

The following aquifer systems are common in the region:

- Quarternary deposit aquifer system (Q);
- Kholmsk formation Lower Miocene deposit aquifer system (N1hl);
- Arakay formation Oligocene deposit aquifer system (P3ar);
- Bykov formation Upper Cretaceous deposit aquifer system (К2bk).

The quarternary deposit aquifer system is scattered due to the low thickness of Quarternary deposits. Mostly, alluvial deposits of river and brook valleys are water cut; other genetic types of Quarternary deposits are little water cut.

Alluvial deposits are represented by poorly sorted field stone, pebble, sand, and loam not more than 5-6 meters thick.

Groundwater forms a common aquiferous nonartesian water column, in which levels come close to the day surface (1-2 m). The aquifer system is nourished through inflow seepage of precipitation and river floodwater. Water discharges into rivers and brooks.

Source yield is 0.3-0.4 l/s, and the specific well yield is 0.76-2.6 l/s*m. The system’s water is colorless, odorless and tasteless, cold, fresh (total dissolved salts – up to 0.5 g/dm3), hydrocarbonate, sodium, calcium, very soft, pH = 7.0-7.6.

The water is used for household needs. It is exploited by local communities using shallow wells. In terms of mineral water search, the Quarternary deposit aquifer system is of no importance.

Kholmsk formation Lower Miocene deposit aquifer system (N1hl) is well developed in most of the study area.

Water-bearing rocks are represented by silty rocks, tuffaleurolite, sandstone, tuffstone, mudstone that feature very low permeability, due to which the aquifer system has very low filtration properties. Water abundance of the system rises considerably within tectonic fault zones where well yield reaches 700 m3/day, unlike nearly water-free rocks outside of crush zones.

Groundwater chemical composition is controlled by the tectonic faults it is confined to. Freshwater within crush zones is usually of infiltration origin. It is nourished at its outcrops and by inflow from adjacent water-bearing formations and systems. Water discharges into surface watercourses or underlying water-bearing formations. In certain cases, tectonic faults act as a transit zone for the mineralized water with trace elements coming from depth.

In favorable conditions, the mixing of two water types – fresh infiltration and deep mineralized – results in low-salt water, medicinal table water valuable in terms of balneology.

Arakay formation Oligocene deposit aquifer system is common in the east of the region; it extends in a strip 0.5-0.7 km wide from north-east south-westward.

Water-bearing rocks are represented by silty rocks and sandstone with a considerable share of tufaceous material. The water is classified as a fissure and stratal-fissure in terms of water circulation and nourishment conditions.

Well yields vary from nearly water-free to 8.0 l/s. Source yields range from 0.01 to 0.5 l/s. Water is nourished by precipitation. The flow is directed from water partings towards rivers. Water discharges into rivers and creek valleys. Overall, the aquifer system is little water cut.

Groundwater chemical composition is characterized by various content of main components and mineralization. Within the study area, the system’s water is fresh with mineralization of 0.2-0.4 g/dm3. In terms of anionic composition, the water is mainly hydrocarbonate, and chloride type is less common. The cationic composition is sodium or sodium-calcium.

Bykov formation Upper Cretaceous deposit aquifer system is commonly found in the eastern part of the region. Water-bearing deposits are represented by mudstone, silty rocks with rare sandstone streaks. Groundwater is of fissure type only. At the section top, near the day surface, soil water occurs to the depth of 10-20 meters, rarely deeper. Water abundance of the system is very low, and spring yield does not exceed 0.1 l/s. The water is fresh, sodium bicarbonate type.

Groundwater of deep layers is of high-pressure type. Measured surplus pressure reaches 220 m above ground. Water abundance is low, well yield does not exceed 0.05 l/s at a depression to 100-500 m. In terms of its chemical composition, the water is of sodium chloride type with mineralization of up to 30 g/dm3. The water has a high content of iodine, bromine, boron.

Due to its low water abundance, the system is of no interest for water supply or other needs. Still, certain crush zones are relatively water-abundant, and it is probable that the water they contain may be of balneological value.

DISCUSSION

The study of literary sources on the climate, hydrology, tectonics, geology and groundwater conditions of the study area has shown that, by a set of features, the area is prospective in terms of the formation of injection-type mineral water deposits. Firstly, the study area has developed bedrocks that have low filtration properties in an undisturbed condition. Fissure-vein water with high mineralization may accumulate within fractures, while low rock permeability prevents mineralization attenuation in these local zones. Secondly, wet and mild climate ensures year-round ingress of fresh water from the land surface into water-bearing formations.

Interpretation of surface geophysical survey results allowed to outline the mineralized water spreading dome and specify the drilling procedure. A detailed deposit model was built based on drilling and groundwater inflow testing results.

Two aquifer systems are developed directly at the deposit (Fig. 3):

1. Quarternary deposit aquifer system (Q);
2. Kholmsk formation Miocene deposit aquifer system (N1hl).

The quarternary deposit aquifer system is found all over the deposit territory; it is up to 12 meters thick and is represented by dense loam, gravel, pebble with sand and sandy-loam aggregate.

Kholmsk formation Miocene deposit aquifer system (N1hl) is found all over the deposit territory. The system is studied to the depth of 120 meters. In the interval of 0-40 meters, beyond the tectonic fault zone, it is mostly represented by poorly sorted dense silty rocks and quar. Rocks have low filtration properties, well yields range from 0.01 to 0.05 l/s at depressions from 3 to 15 m. Static levels were established at a depth of 6-14 from the ground.

The water is used on a case-by-case basis for household needs.

In tectonic fault zones, rock filtration properties increase significantly.

Fault tectonics plays a key role in the formation of the Chapaevskoye mineral water deposit. Three late Pliocene-Miocene tectonic faults are identified at the deposit.

The overthrust type sublatitudinal fault was identified by aerial photo interpretation in the scale of 1:50 000 and completed by exploratory wells. The fracture zone crops out in the Komissarovka river valley as a strip 70 m wide. Drilling revealed that the fault was represented by a crush zone up to 40 m thick. Within this zone, sandstone and silty rocks are strongly fractured; in the west – to breccia comprising debris and ballast with sand and sandy-loam aggregate, in the east – to mylonite.

The second system of submeridional strike faults is represented by two parallel upcasts heavy pitching south-westward. They are younger; they complicate the sublatitudinal fault and split the crush zone confined to it into three blocks.

Fault tectonics affects the deposit formation as follows. The sublatitudinal fault crush zone is heterogeneous within site. Block I is made up of heavy fractured rocks; in block II, rocks feature high fracturing, but individual cracks are filled with calcite and clay matter; in block III, rocks in the fracture zone are ground to mylonite. Most likely, the sublatitudinal thrust crush zone at individual sites (blocks I, II) was under tension stress exposed to meridian upcasts, which resulted in rock decompaction and increased permeability. Thus, both north-south strike faults are represented by heavy fractured rocks and are hydrogeologically active.

The most favorable conditions for accumulation of gravitational water are observed in fault junction zones.

Pumping tests yielded the following

results. When the Kholmsk formation deposit aquifer system was tested outside of tectonic fault zones (0-40 m interval), all the wells had minor groundwater inflow. Yields ranged from 0.01 l/s (well No. 5) to 0,05 l/s (wells No. 2,3) at depressions of 13.9-15.1 m, specific yields were 0.001 l/s*m and 0.01 l/s*m. The submeridional strike tectonic fault was tested by wells No. 3 and 4. Yields were 0.8-0.95 l/s at depressions of 2, and 4.9 m, correspondingly, specific yields were 0.32 l/s*m and 0.125 l/s*m. The sublatitudinal fault was tested by wells No. 1 and 2. Pumping rates were 1.0 l/s and 1.6 l/s at depressions of, correspondingly, 9.5 and 7.25 m, specific yields were 0.11 l/s*m and 0.21 l/s*m.

Pumping and production test of well No. 270 with a yield of 10 l/s was started with operating well No. 280, from which fresh water was extracted with a yield of 4-6 l/s. All inspection wells responded to pumping. During pumping (47 days), no level stabilization was attained in the center and inspection wells. The level in the center well at the working end went down by 16.5 m. Pumping and production test confirmed high water abundance of the area. Results of pumping graphical analytic processing and depression cone developmental character allow to conclude that hydrodynamic conditions of the area follow the “strip aquifer” pattern. The response of inspection wells No. 2,3 to the outage of well No. 280 implies that wells No. 280 and 270 capped one aquifer system and were in close hydrodynamic interaction.

Chemical composition formation

The following conclusions were drawn from the scientific literature on boron geochemistry (Gasanova and Bykova, 2015; Ivanov, 1994; Kraynov, 1964, 1973; Kraynov and Zakutin, 1994; Kraynov *et al.*, 2004; Posokhov, 1975; Shvartsev, 1982, 1998; Zakutin, 2010; Zakutin and Palkin, 2000) and experience of exploring mineral water deposits in the Russian Far East (Chelnokov *et al.*, 2010; Kharitonova, 2013). In Neogene deposits below the active water exchange zone, sedimentation water of marine origin with sodium chloride composition and mineralization of up to 20 g/dm^3 is commonly found. Hydrocarbonate-ion in the deposit water apparently develops during decalcification subject to high carbonate content of igneous-sedimentary rocks; boron is of thermometamorphic origin. Boron originally added to sandy and clay rocks through volcanism later on partially leached out from the rocks subject to a sufficiently high temperature accompanied by carbonic acid release. The direct relationship between boron content and mineralization was established at the deposit (Fig. 4).

The deposit is of “injection” type (Vartanyan, 1977). It was formed as a result of mineral water penetration along the zone of fracture of the submeridional strike in the fresh water circulating in Quarternary deposits and the tectonic fault of the sublatitudinal strike.

Freshwater in the zone of fracture was exposed by well No. 280. The water is clear, colorless, odorless, cold. Water mineralization ranges from 0.53 to 1 g/dm^3. The water is of sodium bicarbonate type, slightly alkaline (pH – 8.1-8.9), very soft (total hardness – 0.45-1.05 meq/dm^3).

Typical ion composition formula described in Equation 1:

$$M_{0,53}\ \frac{HCO_3\ 87\ Cl12\ SO_4\ 1}{Na\ 93\ Ca\ 5\ Mg\ 2}\quad \begin{matrix} pH\ 8,1 \\ O_2 1,76 \end{matrix}$$

(Eq.1)

Mineral water was sampled in the interval of 40 to 100 m. The water is clear, cold, colorless, with a slight vague smell. The water is of chloride-hydrocarbonate and sodium composition with high boron content. Typical ion composition formula is presented in Equation 2:

$$M_{2,3}\ \frac{\begin{matrix} HCO_3 61 Cl28 \\ CO_3\ 18 \end{matrix}}{\begin{matrix} Na\ 98\ M \\ g2 \end{matrix}}\quad pH\ 8,5\ O_2 1,96\ B71,5\ J1,3\ Br0,4$$

(Eq.2)

The water is very soft (total hardness – 0.25-0.97 meq/dm^3), slightly alkaline (pH – 8.6-8.9).

Content range of the main chemical components for well 270 is provided in Table 1.

Water microcomponent composition is extremely poor. The maximum content of trace elements for well No. 270 is shown in Table 2.

No boron, beryllium, tantalum, niobium, indium, stannum, wolframium, cobalt, silver, bismuth, cadmium, mercury, antimony, gallium, germanium, hafnium, lanthanium, cerium, tellurium, aurum, yttrium, iterium, scandium, phosphorus were found in water.

In terms of its quality characteristics, the water fully conforms to GOST 13273-88 (1988) that applies to medicinal mineral water and is classified as group I-a, “Sodium bicarbonate boron water”, “Nelepinsky” type.

During production studies and tests under various water withdrawal conditions, no noticeable change in the water chemical composition was observed. It yielded conclusion on stable water quality for further exploitation of the deposit. However, according to consumers, sizeable fluctuations of water mineralization and chemical composition are observed in operation both in well No. 280 (“fresh”) used for household purposes and in well No. 270 – mineral. In well No. 280, water sometimes tastes a little salty during low water, while in well No. 270, water mineralization noticeably decreases during floods, and the water gets bitterish during low water. Thus, conclusions on the stable chemical composition of groundwater are not supported.

It is due to wrong interpretation of the results of groundwater inflow testing and lack of such tests.

The authors concluded that the boundary with block III has fixed rate flow, but they did not specify its value. Most likely, well No. 5 does not respond to pumping, and its recorded level fluctuations are caused by natural factors; thus, it is a no-flow boundary – Q=0. Moreover, melinite with clay is found in block III. This assumption is also supported by a slow level recovery in well 270. Thus, water flows into the wells along the sublatitudinal fault from the Komissarovka river (fresh) and from the western submeridional fault (salty). Water intermingles. Its chemical composition depends on the rate of water inflow from the above sources, and it must vary subject to well yields, which is actually the case. During low water, the share of salty water increases in well No. 270 following reduction in surface nourishment (freshwater) and mineral content in the well water increases (sometimes with a slight hydrogen-sulfide odor). During floods, correspondingly, the share of freshwater increases and mineralization attenuates.

The same situation is observed in “freshwater” well No. 280. The only difference is the distance to the salty water source. This is why, when water is low, mineralization may increase, and the water gets a little salty.

Since wells No. 280 and 270 expose the same aquifer system and are situated close to one another, they naturally operate in close hydrodynamic interaction. Flow rates of both wells must be adjusted (with regard to the above operation factors) so as to preserve the quality of both fresh and mineral water.

CONCLUSIONS:

1. Comprehensive analysis of literary sources on natural conditions allows us to conclude on a possibility in principle of the formation of injection-type mineral water deposits in the study area.

2. The chemical composition of both fresh and mineral water at the deposit is formed during its operation as a result of the mixing of mineralized water coming from the tectonic fault and fresh water coming from the ground water-bearing formation and Komissarovka river.

3. Composition and mineralization of well water depend on ratios of deep and surface water, which, in their turn, are subject to well yields.

4. Monitoring over the operation of the “fresh” and “mineral’ wells is recommended (Rules…, 1998).

5. Well yields must be adjusted subject to seasonal fluctuations in order to maintain the chemical composition in production wells, both “fresh” and “mineral”, within quality requirements.

ACKNOWLEDGEMENTS

Materials of Sakhalin Hydrogeological Company were used. Hydrogeology engineers V. A. Furman, O. P. Troshkin, L. I. Zhukova, E. A. Spalilo took part in the work. Drilling and test surveys were conducted by a crew headed by drilling foreman V. A. Kudashkin, organizational supervision was exercised by A. F. Pryadko and I. G. Zavadskiy. The results were obtained as part of the execution of the state task of the Russian Ministry of Education

and Science: 5.9560.2017/8.9.

REFERENCES:

1. Chelnokov, G. A.; Kharitonova, N. A.; Taran, Y. A.; Geochemistry of mineral water and associated gases from the lotus aquifer Primorye, Far East Russia; *Global Ground-water Resources and Management;* Paliwal, B. S., ed.; Scientific Publishers: Jodhpur, 2010.
2. Gasanova, E. R.; Bykova, V. V.; Importance of the boron geochemistry for the groundwater of Tomsk region, *Rogov readings. April 7-9, 2015.\,* Tomsk, 2015.
3. *GOST 13273-88 Mineral drinking medicinal and medicinal table water. Specifications*, Nedra: Moscow, 1988.
4. *GOST 2874-82 Drinking water. Specification,* Publishing house of standards: Moscow, 1984.
5. https://meteoinfo.ru/climatcities; Accessed on 20/12/2018.
6. *Hydrogeology of the USSR. Volume XXIV. Sakhalin island*, Nedra: Moscow, 1972.
7. Ivanov, V. V.; *Environmental geochemistry of elements. Manual in 6 books. Book 2. Basic p-elements,* Moscow: Nedra, 1994.
8. Kharitonova, N. A.; *Acidulous water of the northeast of Asia: origin and evolution, Doctoral thesis,* Tomsk, 2013.
9. Kraynov, S. R.; *Geochemistry of rare elements in groundwater (related to geochemical search for deposits),* Nedra: Moscow, 1973.
10. Kraynov, S. R.; *Hydrogeochemical method of prospecting for boron deposits*, Nedra: Moscow, 1964.
11. Kraynov, S. R.; Ryzhenko, B. N.; Shvets, V. M.; *Geochemistry of groundwater. Theoretical, practical, and environmental aspects*, Nauka: Moscow, 2004.
12. Kraynov, S. R.; Zakutin, V. P.; Geochemical and environmental condition of Russia's groundwater (reasons and trends for the change of chemical content of underground water); *Geochemistry* **1994**, 3, 321.
13. Posokhov, Ye. V.; *General hydrogeochemistry*, Nedra: Leningrad, 1975.
14. Posokhov, Ye. V.; Tolstikhin, N. I.; *Mineral water: medicinal, industrial power*, Nedra: Leningrad, 1977.
15. *Resources of the USSR surface water. Vol. 18. Far East. Issue 4. Sakhalin and Kuril Islands,* Gidrometeoizdat: Leningrad, 1973.
16. *Rules for the development of the deposits of mineral water and therapeutic muds,* Gosgortekhnadzor: Moscow, 1998.
17. *Scientific and applied reference on climate of the USSR. Series 3. Long-term data. Parts 1-6. Issue 34. Sakhalin region,* Gidrometeoizdat: Leningrad, 1990.
18. Shvartsev, S. L., ed.; *Basics of hydrogeology. Hydrogeochemistry*, Nauka: Novosibirsk, 1982.
19. Shvartsev, S. L.; *Hydrogeochemistry of hypergenesis zone,* Nedra: Moscow, 1998.
20. *State water register. Long-term data on surface water mode and resources. Vol. 1. RSFSR. Issue 22. Sakhalin Region river basin,* Leningrad: Gidrometeoizdat, 1987.
21. Vartanyan, G. S.; *Acidulous water deposits in fold-mountain regions,* Nedra: Moscow, 1977.
22. Vartanyan, G. S.; Yarotskiy, L. A.; *Exploration, prospecting, and appraisal of useful resources of mineral water deposits*, Nedra: Moscow, 1972.
23. Zakutin, V. P.; Palkin, S. S.; Boron-containing fresh groundwater (patterns of regional distribution and formation); *Forth international congress Water: Ecology and Technology. Ecwatech-2000. May 30 - June 2, 2000;* Moscow, 2000.
24. Zakutin, V. P.; The main geochemical specifics of boron in fresh groundwater; *Environmental geology. Engineering geology. Hydrogeology. Geocryology* **2010**, 1, 30.
25. Zharov, A. E.; *Geologic map of the Russian Federation. Scale 1:200000, Sakhalin series.*

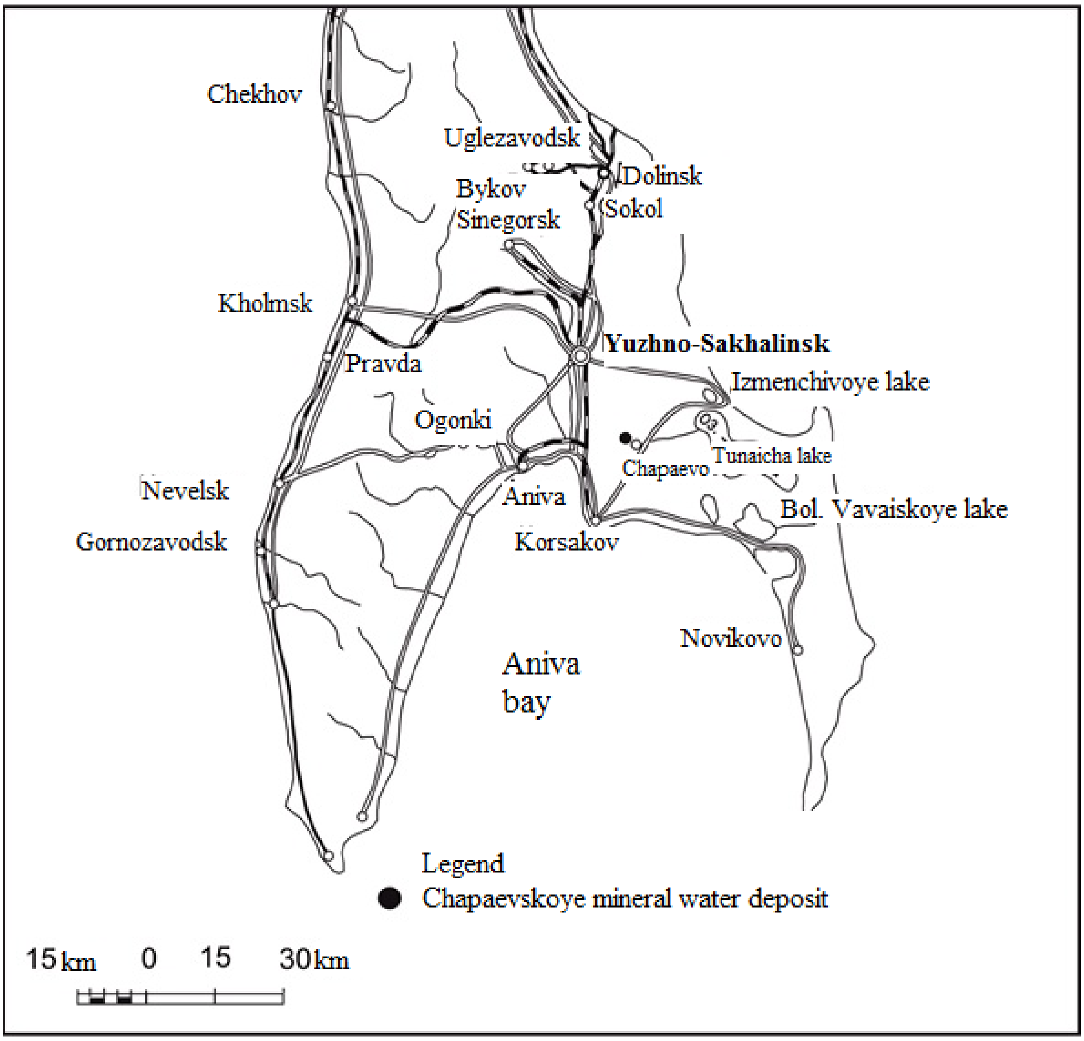

Figure 1. *Chapaevskoye deposit location map*

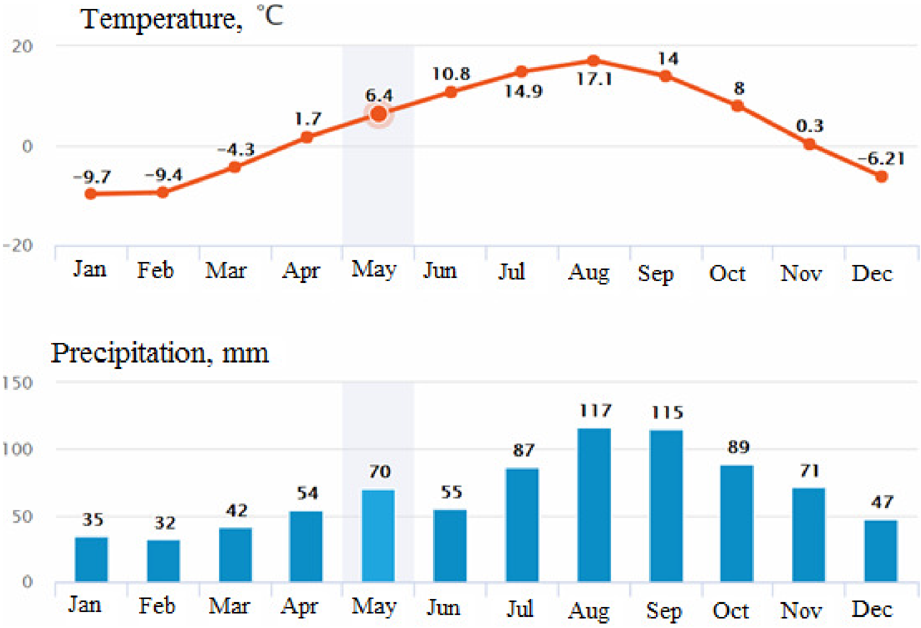

Figure 2. *Monthly average temperature and precipitation characteristics at Korsakov weather station*

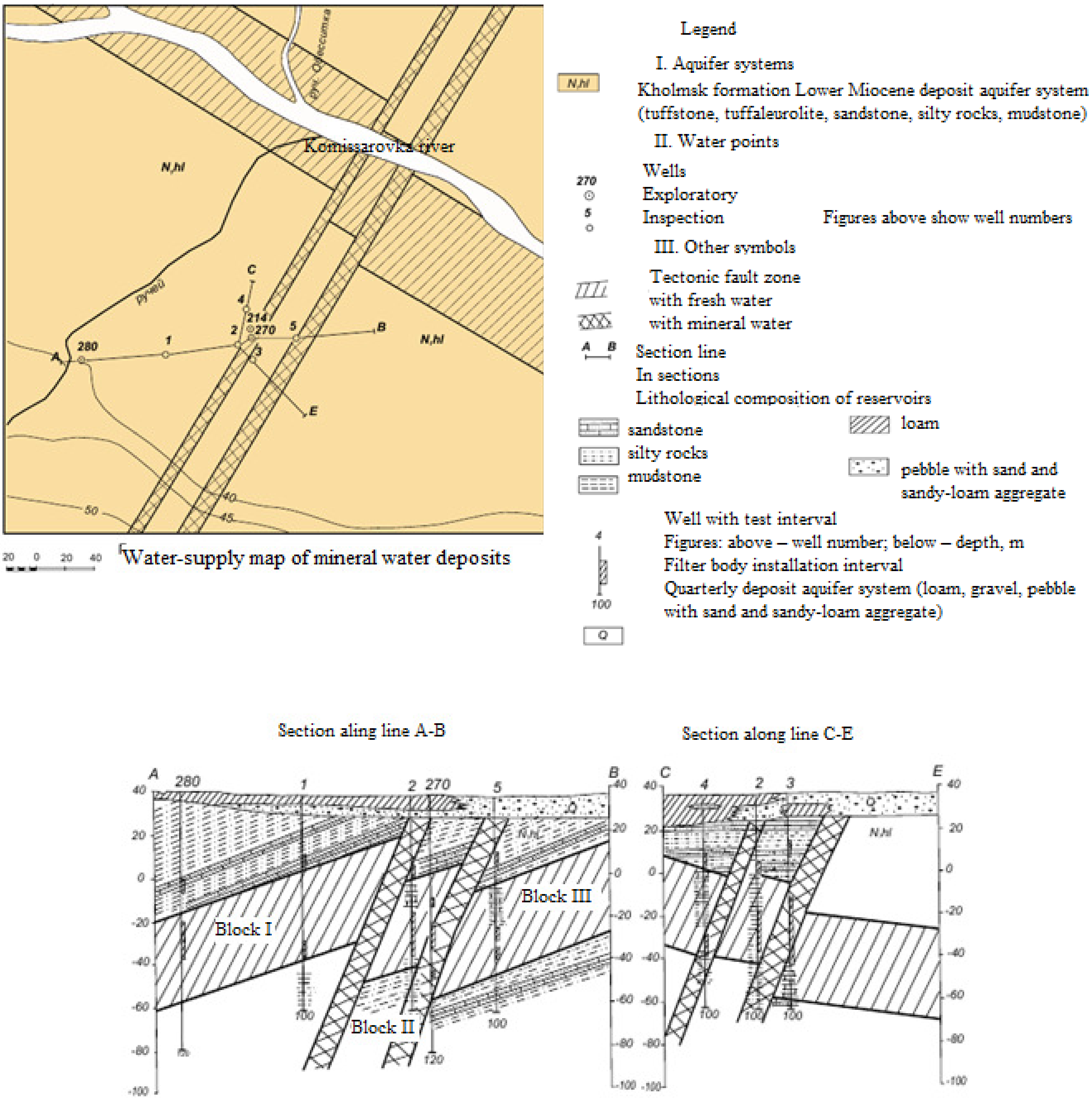

Figure 3. *Water-supply map of the Chapaevskoye mineral water deposit*

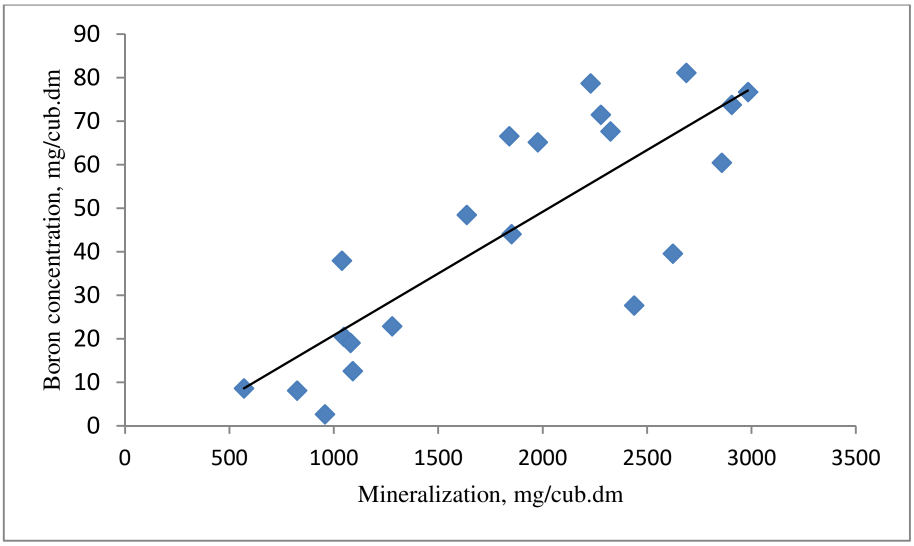

Figure 4. *Water boron concentration – mineralization curve*

Table 1. *Content range of the main chemical components for well 270*

Name	UoM	Contents	
		from	**to**
Total dissolved salts	mg/dm^3	1,636.3	2,721.7
HCO_3^-	mg/dm^3	825.0	1,726.9
SO_4^{2-}	mg/dm^3	3.7	26.7
Cl^-	mg/dm^3	124.0	282.0
Ca^{2+}	mg/dm^3	3.0	22.45
Mg^{2+}	mg/dm^3	2.8	7.0
$Na^- + K^-$	mg/dm^3	535.4	807.9
B	mg/dm^3	48.6	81.1
H_3BO_3	mg/dm^3	220.0	420.0
J	mg/dm^3	0.8	1.3
SiO_2	mg/dm^3	10.4	21.6
Total hardness	meq/dm^3	0.42	1.6
pH	mg/dm^3	8.4	8.7
Oxidability	mgO_2/dm^3	2.92	3.57

Table 2. *The maximum content of trace elements for well No. 270*

Name	**Content, mg/dm^3**	
	limit as per OST 41-05-236-86	**Well 270**
Mn	00.6	0.041
Ti	0.1	0.213
V	0.4	0.002
Cu	0.05	0.002
Ni	-	0.005
Zn	1.0	0.049
Pb	0.03	0.005
Zr	-	0.065
Li	5	0.0418