Resources of Curative Mud of the Crimea Peninsula

Elena Kayukova

Abstract This chapter deals with the curative mud resources of salty lakes and mud volcanoes in Crimea Peninsula. There are unique resources of salt lakes brine, salts, curative muds, as well as mineral and thermal water. The medicinal potential of salt lakes of Crimea is very high in which there are 35 salt lakes and 33 mud volcanoes within Kerch Peninsula. Most of the lakes of the Crimea are of marine origin with a permanent infiltration of water from the sea. They are sulphatic type. Total capacity of mud deposits of the Crimea is estimated at about 32,279 mln m^3.

Keywords Crimea Peninsula · Salt lakes · Mud volcanoes · Curative muds

1 Introduction

The Autonomous Republic of Crimea (from 1954 to 1991 it was the Crimean Region) is part of the Ukraine. The Crimean peninsula is in the southern part of Ukraine, washed by the Black and Azov seas and connected to the continent with a narrow Perekop isthmus. The administrative border is located along the Perekop Swell and the Sivash, a shallow bay of the Sea of Azov.

Crimean climate is characterized by its location between the temperate and subtropical geographical zones, contributing to the mild climate of the peninsula and a large number of hours of sunlight (2,180–2,470 h per year). The region is famous for its healing factors: healthful climate, warm sea, mineral waters, mud of salt lakes and volcanoes (that are underestimated). Sometimes the Crimea is called "the small continent," because of its different landscapes and very rich nature. This is also a popular seaside resort; however, the recreation potential of other

E. Kayukova (✉)
Faculty of Hydrogeology, Department of Geology, University of St. Petersburg, Universitetskaya nab. 7/9, St. Petersburg, Russia 199034,
e-mail: epkayu@gmail.com

W. Balderer et al. (eds.), *Thermal and Mineral Waters*, Environmental Earth Sciences,
DOI: 10.1007/978-3-642-28824-1_6,

water resources still has not been studied properly and has not had its complex ecological economic assessment.

During the centuries people have been using natural resources for medical purposes, and curative qualities of many natural factors have been known since ancient times. The Crimean peninsula began to be considered as a perspective resort region after the Empress Catherine II visited in 1787. Later the south coast of Crimea was developed into the most beloved recreation place for Russian aristocracy and leaders (Stalin, Khruschev, Brezhnev, Gorbachov, Yeltsin).

2 Geological and Hydrogeological Settings of the Study Area

The Crimea Peninsula is located at the southwest of the East European Plain. The largest part of its territory has the plain shape. In the west, the plain turns into the lime terraces of the Tarkhankut, running their steep edge into the sea line. The hilly ridges of the Kerch Peninsula dominate the eastern part. The chain of the Crimean Mountains occupies the southern part of the peninsula and tectonically is part of Crimea-Caucasus mountain system.

The Crimea Mountains obtained their shapes in the Alpine fold era. They stretch from west to east for 180 km. There are three ridges: the Main one (the First one, located in the southern margin of the Peninsula) has a height of 1,200–1,500 m; the Interior one (the Second one) has a height of 400–600 m; and the Exterior one (the Third one) has a height of 250–350 m. The Main ridge is the highest and its forestless mountain-massifs are called yayla. Roman-Kosh Mountain (1,545 m) is the highest peak of Crimea located at Babugan-yayla. Coastal hills of the Main ridge end on the southern coast of Crimea.

Geologically, the Crimea Peninsula is situated on the border of the south of the East-European Platform, Skythian plate and Crimea-Caucasian orogenic system. It is subdivided into three parts: southern mountainous part, northern plain part and Kerch peninsula.

Mesozoic and Cenozoic rocks of marine, lagoon and continental origin mainly constitute the geological structure of this region. Within the Main ridge and southern coast, Triassic-Jurassic flysch series and Upper Jurassic—Lower Cretaceous carbonates and terrestrial-carbonates are mostly developed. Within the Second Ridge, Upper-Cretaceous marine clayey carbonates are overlain by Paleogene carbonates. Only Neogene and Quaternary sediments occur in the Pre-Mountainous northern parts and within the Plain Crimea (Muratov 1960; Fig. 1).

The hydrogeological settings of the Crimea Peninsula are different in the northern platform (platform artesian basins) and southern folded part (fissured waters and karstic basins). Kerch Peninsula also has a complex hydrogeology: its southwestern part is an aquiclude: Paleogene Maykop clays 3,000 m thick; its northeastern part is a system of small artesian basins.

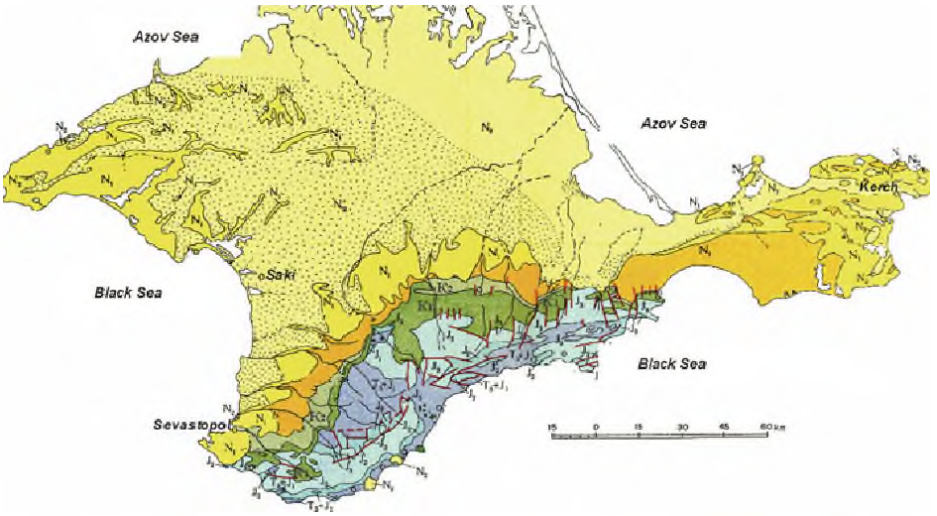

Fig. 1 Geological sketch of the Crimea peninsula (after Muratov 1960). N_2 Pliocene marine sediments; N_1 Pliocene continental deposits; N_1 Miocene deposits; Pg Paleogene deposits; K_2 Upper Cretaceous deposits; K_1 Lower Cretaceous sediments; J_3 Upper Jurassic deposits; J_2 Middle Jurassic deposits; J_1 Lower Jurassic deposits; T_3-J_1 Tavricheskaya Series (Upper Triassic–Lower Jurassic); Faults and thrusts

High plateaus of Crimean Mountains (1,200–1,500 m above sea level) are the main recharge area of the whole Peninsula. Groundwater is formed within the Main Ridge, then it comes through surface runoff and underground flow to the north, recharging the artesian basins of plain parts of the region. The close hydraulic connections between the hydrogeological structures of the Crimean Mountains and the northern parts of the peninsula are responsible for the good quality of water in artesian basins, which became an important source of drinking water supply.

The Main Ridge of the Crimea Mountains hydrogeologically belongs to Crimea Mountains' hydrogeological massif, but the Exterior and Interior Ridges are part of the recharge area of Alma and Indolsky artesian basins. Rainfall waters (up to 1,000 mm per year) are accumulated in limestones forming the karstic aquifers.

Apart from the rare landscapes and special natural beauties, nature also endowed Crimea with springs and lakes with important therapeutic properties.

3 Mineral Resources of the Salt Lake and Mud Volcanoes

Mineral resources of the Crimean Peninsula include mineral waters, thermal springs, curative muds in salt lakes and volcanoes and many touristic landmarks. More than 300 salt lakes, lagoons and gulfs are situated along the seacoast. They

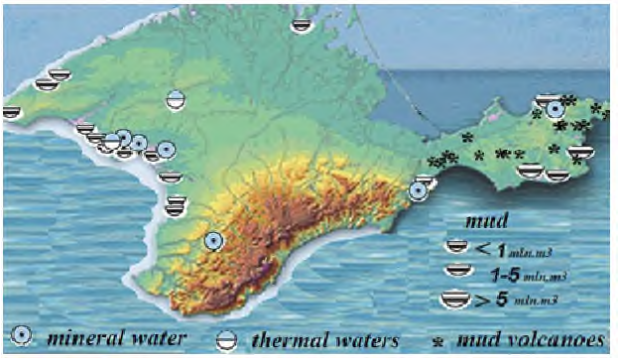

Fig. 2 Position of the main resources of mineral waters and therapeutic muds

contain brines and curative muds; many salt lakes are used for extraction of table or bathing salts.

There are 33 mud volcanoes discovered within Kerch Peninsula (the host rocks are Paleogene Maykop clays). A map of mud reserves and mud volcanoes is presented on Fig. 2.

All lakes in Crimea are divided into 7 subgroups: I—Perekop subgroup, II—Tarkhankut subgroup, III—Evpatoriya subgroup, IV—Yaila lakes, V—Khersones subgroup, VI—Kerch subgroup, VII—Chongar-Arabat subgroup (Fig. 3).

Salt lakes in the Crimea peninsular have the total surface area of about 27,000 km^2. Those with TDS of the water of more than 35 g/l occupy more than 15 % of this area. Only a few of them have continental origin and never had a connection with the sea. The most widespread are lakes of sulphate type water (Ponizovsky 1965). These types of lakes are divided into sulfate-sodium and sulfate-magnesium (or chloride magnesium). The lakes of sulfate-magnesium water of marine origin are dominant types of lakes. Lakes of continental origin are mostly sulfate sodium.

A great majority of the salt lakes are situated along the coast in the steppe parts. Most of them are shallow and sometimes dry up during the summer.

There are 26 lakes where deposits of therapeutic mud and brine as well as over 100 mineral springs of different chemical compositions have been distinguished. According to the decision of Ukrainian authorities, 15 places with mud deposits and 13 large resources of mineral water were granted by therapeutic category (Khmara et al. 2001). That is one of the priorities in the development of the Crimean resort area. Data characteristic features concerning deposits of therapeutic mud are presented in Table 1. There are only three large salt lakes (with an area of more than 10 km^2) in this table, such as Sasyk-Sivash, Uzunlarskoe, Tobechikskoe due to the fact that not all lakes and their mud deposits are of medicinal importance.

Geological reserves of curative mud in Crimea are about 30 mln m^3 (Khmara et al. 2001). At present, the world market price of curative mud is about 5 USD per kg. The most known natural salt lakes are: Sakskoye (near Saki), Moynaki (near Evpatoriya), Sasyk-Syvash (east Evpatoria). Other important lakes

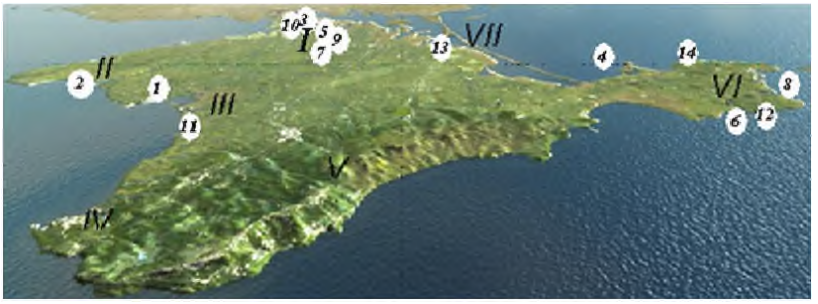

Fig. 3 Position of the main salt lakes of the Crimean peninsula, *1* Sasyk, *2* Donuzlav, *3* Aygulskoe, *4* Aktashskoe, *5* Krasnoe, *6* Uzunlarskoe, *7* Kirleutskoe, *8* Tobechikskoe, *9* Kiyatskoe, *10* Staroe, *11* Sakskoe, *12* Koyashskoe, *13* Genicheskoe, *14* Chokrakskoe

Table 1 Salt lakes and mud volcanoes of medicinal importance (after Khmara et al. 2001)

No.	Deposit		Reserves (m^3)	Recommendation for use
1	Kizil-Yar	mud	10,000,000	Central and peripheral nervous system (neuralgia, neuritis); cardiovascular system; musculoskeletal system, the effects of trauma; diseases of the joints (arthritis, arthrosis, hondrozy); digestive; gynecological diseases; skin diseases
2	*Uzunlarskoe*	mud	6,930,000	
3	*Tobechikskoe*	mud	5,500,000	
4	*Bulganakskoe*	mud	5,000,000	
5	*Chokrakskoe*	mud	4,660,000	
6	Sakskoe	mud, brine	4,500,000	
7	*Koyashskoe*	mud	3,369,000	
8	Dzharylgach	mud	3,100,000	
9	Sasyk-Sivash	mud	976,000	
10	Bagayly	mud	120,000	
11	*Djau-Tepe*	mud	32,000	

Deposits of Kerch Peninsula are emphasized in italics

are: Chokrak, Uzunlarskoe, Koyashskoe, Tobechikskoe (Kerch peninsula). There are a lot of legends about the healing power of these lakes.

The curative muds are divided into two main types depending on the physical and chemical properties: silt sulfide type and Sopochnaya type (hill mud; Ponizovsky 1965; Fig. 4). They are distinguished by smell, texture, temperature, content of organic substances (e.g. the silt sulfide muds contain up to 28 % organic matter whereas the sopochnaya muds contain practically no organic matter).

Sulfide silt muds are rich in iron sulfides and water-soluble compounds. Uzunlarskoe Lake is the largest reservoir of sulfide silt mud in the Kerch region. The potential resources of therapeutic muds of lakes Kizil-Yar, Uzunlar, Chokrak, Koyash, Dzharilgach, Sakskoe and others are very large; however, not all of them are utilized by the spa industry, presumably due to very bad road infrastructure. The first mud-cure resort in Russia was Saki, which was founded in 1827. The

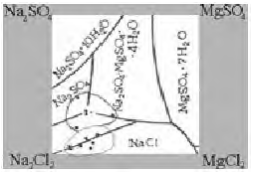

Fig. 4 Diagram showing the chemical composition of salt lakes in the Crimea peninsula (after Ponizovsky 1965)

waters of Saki Lake are recognized as the saltiest in the world with the high concentration of medicinal mud. Now the resources of mud have decreased from 21 to 5.5 mln m^3.

3.1 Silt Sulphide Mud (Lakes of Marine Origin)

Chokrakskoye Lake (marine origin) is a unique reservoir of mud and brines. The mud reserves are estimated at 4,660,000 m^3. The lake is recharged from time to time by seawater, usually during stormy weather, when the water from the sea can reach the lake through the narrow bar that divides both reservoirs (Fomichev 1948; Figs. 5 and 6). On the bottom of the lake there are mud volcanoes, mineral springs and gas emanations. Chokrak Lake mud is of sulfate–chloride-magnesium-sodium type with high sulfides content. The mud contains: hydrogen sulfide, iron sulfide, nitrogen, hydrogen, hydroxides of aluminum and iron salts of fatty acids, traces of precious metals (e.g. silver, gold, platinum), bitumen-like compounds, lignin, cellulose, organic retinoid substances, most of the known amino acids, fulvic acids, organic acids, aromatic derivatives, various biologically active substances, vitamins, biogenic stimulants, substances such as antibiotics, and the entire set of sea salt.

New substances and chemical compounds are formed also as a result of algae and other micro-organism activity. Chokrak muds are counted among those of high therapeutic activity and are used for healing of many diseases.

Chokrak Lake is located in the northern part of Kerch Peninsula. The water in this lake has TDS of about 80–300 g/l, depending on the season: Cl^-—72,500 mg/l; SO_4^{2-}—38,000 mg/l; HCO_3^-—1,100 mg/l; CO_3^{2-}—300 mg/l; Ca^{2+}—300 mg/l; Mg^{2+}—24,700 mg/l; $(Na+K)^+$—60,300 mg/l; pH—6.8. The brines are chloride magnesium-sodium. They contain up to 750 mg/l of bromine and up to 300 mg/l of boron (as H_3BO_3).

A group of hydrogen sulfide springs is located on the eastern edge of the lake. The water contains iodine, bromine, boron, iron, titanium, aluminum, barium, manganese, copper, strontium, and lithium. The waters are bicarbonate-chloride-sodium and chloride-sodium.

Koyashskoye Lake (marine origin) is located in the southern part of the Kerch Peninsula within the Opuksky Nature Reserve and Koyashskoe Lake (Fig. 7). Brines of Koyash Lake contain sodium chloride, magnesium and potassium chlorides, sodium iodide, magnesium bromide and magnesium sulfate, calcium

Fig. 5 General view on Chokrakskoe lake of marine origin

Fig. 6 Geological sketch of lake Chokrakskoe lake area (after Fomichev 1948). Explanations, *1* Coastal sands, loess loam, deposits of the lake Chokrak, *2* Caspian and mediterranean terrace, *3* Meotian, *4* Upper Sarmatian and Meotian reefs, *5* Upper Sarmatian, *6* Medium Sarmatian, *7* Middle and Upper Sarmatian clays, *8* Konksky horizon, *9* Karagan horizon, *10* Chokrak horizon, *11* Maikop series, *12* Springs

Fig. 7 General view on Koyashskoe lake

sulfate and organic matter. The brines of Koyash Lake have Cl^-—107,500 mg/l; SO_4^{2-}—19,600 mg/l; HCO_3^-—610 mg/l; Ca^{2+}—200 mg/l; Mg^{2+}—4,480 mg/l; Na^+—69,000 mg/l; K^+—3,900 mg/l. In the summer season the lake salinity is about 200–250 g/l and more. The reserves of high-quality curative mud are more than 3 mln m^3. Valuable compounds in lake waters are mainly potassium, iodine, bromine, boron, arsenic, antimony, mercury, and gold.

One of the interesting features of Koyashskoe Lake is the pink color of the salt crystals formed after substantial evaporation of the lake water. Such color of the

Fig. 8 Crustaccan *Artemia salina* (Koyashskoe lake)

salt crystals indicated the presence of microalgae *Dunaliella Sallina* (Fig. 7). This species, the representative of the plankton community, is the main supplier of provitamine A and products of its transformation in muds, which increases the mud's therapeutic properties. Microalgae *Dunaliella* serves as food for crustacean *Artemia Sallina,* which can live in a highly saline environment up to 250 g/l (Fig. 8). The resources of Koyash Lake are not utilized for curative purposes because of its remoteness and bad roads.

3.2 Silt Sulphide Muds (Lakes of Continental Origin)

The lakes of continental origin (i.e. salt pans) occur in falls of a relief and are not connected with the sea. The local name of such lakes is 'koli' (Fig. 9). Such lakes are formed mainly from waters of atmospheric precipitation. Almost all of them are located on the southwestern plains of the Kerch Peninsula. They are not large and are rather shallow. During the summer season they dry out partially or completely, and a larger area is covered by the mineral crust of white, white and pink or white–gray color, under which there is a very thin layer of brine. This layer is underlain by silts, mostly black or gray, with a significant water content. The chemical composition of the lake water is different from the seawater and is of sulfate type.

3.3 Sopochnaya Mud (Hill Mud)

The mud volcanism on the Kerch Peninsula is manifestation of modern tectonic. There are 33 mud volcanoes on the Kerch Peninsula, and 7 in the Black and Azov Sea (Fig. 10). At present, activity of mud volcanoes is not large; they produce cold

Fig. 9 General view on the Marfovka salt lake of continental origin

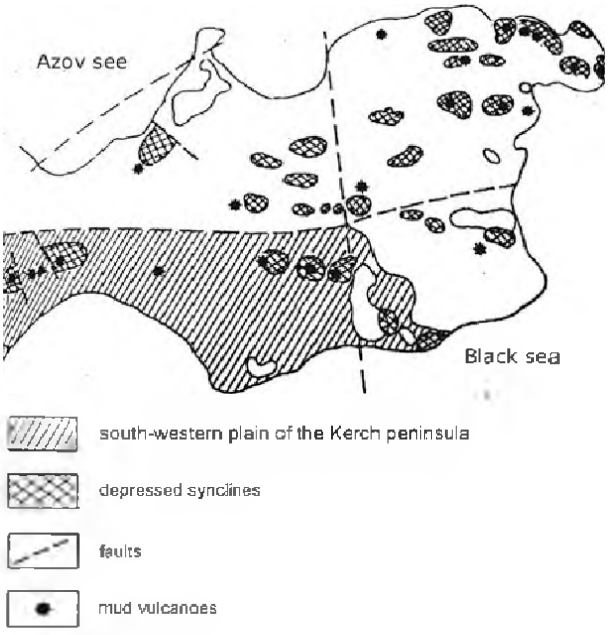

Fig. 10 Sketch presenting the position of mud volcanoes of the Kerch peninsula (after Shnyukov et al. 1992)

mud, water, and emit gases (mostly methane and carbon dioxide). Sometimes powerful eruptions occur, and the volume of produced mud reaches significant values.

Most interesting are volcanoes located at the Bulganakskoe field (Fig. 11). The reserves of the Bulganak muds are estimated at 5,000 m^3. Groundwater of mud volcanoes is usually saline; their TDS reaches 32.6 g/l with ion concentration as follows: Cl^- = 5,453 mg/l, SO_4^{2-} = 1,920 mg/l, HCO_3^- = 15,128 mg/l, Ca^{2+} = 24 mg/l, Mg^+ = 29 mg/l, Na^- = 10,074 mg/l, and pH = 9.

Volcanic mud is a slurry of fine solids suspended in water. The main components of mud are: silica—54.9 %, alumina—15.7 %, iron—6.9 %, water—4.1 %. Other components that can be found in mud are: chlorine, iodine, bromine, fluorine, boron (up to 0.21), lithium, strontium, phosphorus, ammonium, manganese,

Fig. 11 Examples of the mud volcanoes of Bulganakskoe field

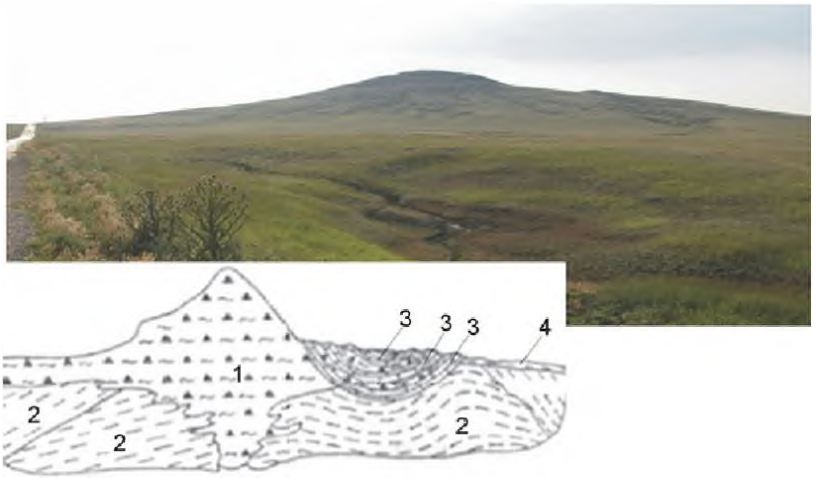

Fig. 12 View on the Djau-Tepe mud volcano and generalized geological cross section (after Shnyukov et al. 1992). Explanations, *1* Sopochnaya formation (clays, slurry, silts, sands), *2* Maykop clays, *3* Limestones, *4* Quaternary sediments

titanium, nickel, cobalt, vanadium, zirconium, copper, zinc, lead, tin, chromium, barium, beryllium, scandium, gallium, arsenic, mercury, silver, organic matter (humic acids, bitumens, volatile fat acids, amine compounds and carbohydrates), and microflora (dies in contact with air). Weak radioactivity and alkaline media are typical features of these muds. In the gas phase methane, hydrogen sulfide and helium are present. The mud is oily and elastic, almost sterile, and has good balneological properties.

Mud volcanoes are located usually in areas of tectonic activity and where deposits of oil and gas occur at depth. The mud volcanoes on Kerch peninsula are located on the vault of Vulkanovskoy anticline that extends in the latitudinal direction. According to available geological data, the roots of volcanic structures can reach Lower Cretaceous and Jurassic strata. Mud volcanoes are associated with bulged synclines. There is a thick layer of Maikop clay with a considerable quantity of organic matter. In conditions of elevated pressure and temperature the organic matter is decomposed with the release of hydrocarbons (mainly methane).

When the pressure of released gas rises, it goes to the surface through privileged ways pushing ahead fine solids suspended in water. When the pressure drops, the activity of the volcano stops.

The largest mud volcano on the Kerch peninsula is Djau-Tepe (Fig. 12). The height of the hill is 116 m above the sea level. Ejections of Djau-Tepe gases consist of heavy hydrocarbons (83 %) and carbon dioxide. However, most of the mud volcanoes of the Kerch peninsula eject methane. Sulfuric springs occur on the southern side of the Djau-Tepe. The specific components in the spring water are: B—62.2 mg/l, As—0.01 mg/l, Li—0.4 mg/l, P—1 mg/l, Rb < 0.07 mg/l, Sr—2.1 mg/l, F—0.2 mg/l, Br—5.3 mg/l, I—5 mg/l, Cs < 0.05 mg/l (Lagunova 1972).

The mud deposits of Djau-Tepe occupy an area of about 1.5 km^2. The total volume of the mud ejected by this volcano is calculated at 55 million m^3. The reserves of the mud are estimated at 32,000 m^3.

4 Conclusions

Most of the lakes of the Crimea peninsula, especially the largest ones, are of marine origin with a permanent recharge of water from the sea. The majority of lakes are sulphatic type. All the lakes are characterized by high seasonal variation in volume, surface area, salinity and water temperature.

There are many problems in utilization of the therapeutic resources of the salt lakes and mud volcanoes connected with natural and social reasons (e.g. bad road network, remoteness of lakes, etc.). To date many salt lakes of the Crimea peninsula have disappeared (e.g. from 48 lakes to 35 presently); the chemical composition of water in some lakes is changing continuously due to antropogenic contamination (e.g. Lake Donuzlav).

Crimea peninsula is one of the most unique places in the world with respect to occurrence of salt lake brines, curative mud resources, and other salts and chemical compounds, which can be extracted from brines or muds. The muds contain components formed in long-lasting geological, biological, chemical and physical processes. The medicinal and therapeutic potential of salt lakes of Crimea is very high and even exceeds similar products of the Dead Sea.

Total capacity of curative resources (mud and brines) of the Crimea (34 mud deposits and lakes) is: brines—91.2 mln m^3, therapeutic muds—32.279 mln m^3 (data for 1997).

Before 1999, the curative mud was extracted about 15,000 m^3 from salt lakes (Saki and Chokrakskoe). Practically unlimited resources, therapeutic properties and unique quality of the salt lakes brines and muds allow the Ukraine to create health-care and resort facilities of international significance.

References

Fomichev M (1948) Chokrakskoe hydrogen sulfide sources. In: Savarenskii F (ed) Proceedings of the laboratory of the hydrogeology problems, T. 1, USSR Academy of Sciences, pp 221–232 (in Russian only)

Khmara A, Khlebnikov A, Ivanova V, Dyakovich P, Kapinos N (2001) Mineral resources of Crimea and the adjacent waters of the Black and Azov Seas. Atlas: the application to the collection *Problems of development of Crimea.* Simferopol, Tavria—plus, 81 p (in Russian only)

Lagunova I (1972) The chemical composition of mud volcanoes groundwater of the Kerch-Taman region. Dissertation. LSU, 161 p (in Russian only)

Muratov M (1960) A brief sketch of the geological structure of the Crimean peninsula, 208 p (in Russian only)

Ponizovsky A (1965) Salt resources of Crimea. Simferopol, 263 p (in Russian only)

Shnyukov E, Gnatenko G, Nesterov V, Gnatenko O (1992) Mud volcanoes of the Kerch-Taman region. Kiev: Nauk. Dumka, 200 p (in Russian only)

State of the Environment and Natural Resources (Geological Environment) (1998) Issues of development of Crimea, Issue 10, 180 p (in Russian only)