Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Geothermal Resources of the Chukchi Peninsula

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Keywords: thermal waters, H-O-S-He isotopes, exploration, resources, Chukchi Peninsula

ABSTRACT

Nine groups of mineral springs with temperature of discharged waters from 14 to 97 °C were sampled by the authors in the July-September of 2002 in the eastern part of the Chukchi Peninsula. Besides temperature measurements, we refined the positions of each group by GPS, sampled them for chemical and isotopic analyses of water and gas phases including He isotopes, estimated "base" temperatures of thermal water by means of Si-, Na/K-, Na/Li-, Mg/Li- and Na-K-Ca-geothermometers, and evaluated their flow rates considering open and hidden discharge. Geothermal resources of each group were estimated and the possible ways of their use are considered.

1. INTRODUCTION

Hydrothermal manifestations are known in some places of the Chukchi Peninsula since the end of XVIII century. Crossed by the Arctic Circle, the peninsula is located in severe climatic conditions characterized by permafrost and has much need for electric and thermal energy. These demands could be met by geothermal resources to one or another extent. In order to estimate the prospects of geothermal development and use in the eastern part of the peninsula, in summer of 2002 we investigated 9 groups of thermal and mineral springs: Chaplino Spr. (C) with temperature of the water amounting up to 87,5°C, Senyavin Spr. (S), 79,7°C, Arakamchechen Spr. (A), 38°C, Kivak Spr. (K), 43°C, Kukun' (Lorino) Spr. (L), 58°C, Mechigmen Spr. (M), 97°C, Tuman (Upper Mechigmen) Spr. (T), 56°C, Babushkiny Ochki (Grandmother Glasses) Spr. (BO), 21°C, and Dezhnev Spr. (D), 59,5°C.

Our research was aimed at revealing the nature of these fluids and evaluating their geothermal resources for possible future use in one way or another. With this aim in view we determined the chemical composition of water and gas phases of fluids under study, as well as isotopic composition of the H_2O, S_{SO4}, Ar and He. Water temperatures and flow rates were measured in each group, and the "base" temperatures of thermal waters were calculated by means of Si-, Na/K-, Na/Li-, Mg/Li- and Na-K-Ca-geothermometers. The schematic maps in 1: 2 500 or 1: 5 000 scale were compiled for each grope of the springs sampled.

2. TECTONIC SETTING

The studied area is the part of the marginal Bering Sea volcano-plutonic belt. As Fig. 1 shows, the belt is superimposed on the older tectonic units of Pz-T-K_1 island arcs and Pcm-Pz Chukchi-Seward microcontinent.

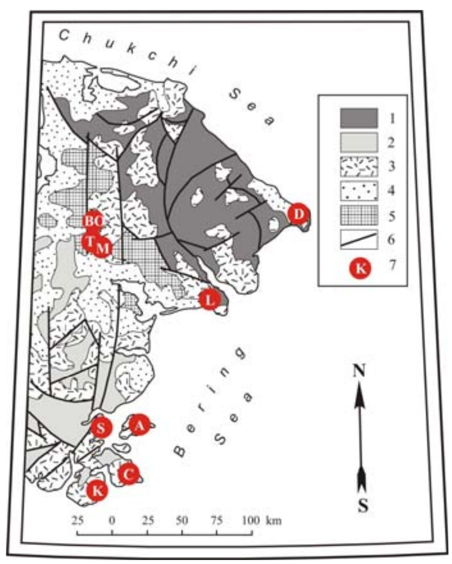

Figure 1: Tectonic sketch of the eastern part of the Chukchi Peninsula (from [State…, 2001], simplified). 1 – Pcm-Pz units of the Chukchi-Seward mikrocontinent, 2 – Pz-T-K_1 island arc units, 3 – the units of the K_2-N_1 marginal Bering Sea volcano-plutonic belt, 4 – Q intracontinental depressions, 5 – Kolyuchin-Mechigmen zone of maximal seismicity and density of the crust, 6 – faults, 7 – the 2002 sampling sites.

[†] Deceased

Pcm-Pz rocks are metamorphized up to amphibolite facies and presented by granites, gneisses, and schist. The island arc units are composed by volcano-carbonate-terrigenous rocks, whereas the belt consists of Upper Cretaceous riolite and dacite lavas and tuffs and Lower Miocene (~ 18 Ma) basalts and dolerites [State…, 2001]. These basic volcanics are located in Kolyuchin-Mechigmen Depression (KMD) coincided with the zone of elevated seismicity, enhanced density of the crust, and a sharp bench in the gravity field. The intrusive rocks in the studied area are presented by granitoid massifs and acid extrusions are no younger than 58 Ma [State…, 2001].

The sampled springs are located to tectonic fractured zones cut igneous rocks mainly of Cretaceous age and the older gneisses and fillites. Altitudes of the springs don't exceed 100 masl. The most of discharge foci are located no further than 1-10 km from the sea coast, whereas three group situated in KMD are offset by about 50 km from the Bering Sea (Fig. 1 and 2).

Figure 2: Senyavin Springs. Senyavin Strait of Bering Sea on the background

3. RESULTS

The research showed that different constituents of the studied fluids–water phase, components of dissolved solids and gases evolved from the springs–have different origin.

3.1 Genesis of water

Cl-Na thermal waters discharged along the coast of the Chukchi Peninsula were traditionally identified with recent or some metamorphized seawater [Ponomarev, 1936; Kalabin, 1959; Stremyakov, 1967; Zelenkevich, 1970]. However, an unequivocal criterion of water origin is only the isotopic composition of H_2O unknown before our research. This research showed that thermal waters under study differ sharply from recent seawater. δD- and δ^{18}O-values measured in thermal fluids were found to lie in the following ranges (in relation to SMOW standard): from -93 to -134 ‰ (δD) and from -11.1 to -17.6 ‰ (δ^{18}O), whereas the Bering Sea water is characterized by δD = -10 ‰ and δ^{18}O = - 1.3 ‰.

The studied springs are subdivided into two groups in isotopic composition of water (Fig. 3). The first group (A) includes all "coastal" springs except for Senyavin ones. Thermal waters of these springs are almost identical to fresh water from local rivers in δD- and δ^{18}O-values. The

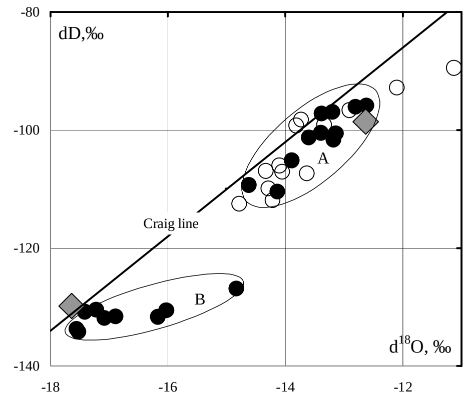

Figure 3: δD- and δ18O-values in the fresh (open dots) and thermal (solid dots) waters of the Chukchi Peninsula. Diamonds denote the Alaska Peninsula precipitates (Yurtsever and Gat, 1981).

data points corresponding to these springs are coincided with the "Craig line" on the δD–δ^{18}O plot.

The second group (B) unites the KMD springs and Senyavin ones; these springs issue the waters with the lower δD- and δ^{18}O-values than those in local fresh waters (the latter are similar in this respect with their counterparts from the first group). This feature of the KMD springs can be resulted from different reasons: I) the higher altitude of recharge areas for mineral waters as compared with those for fresh ones, 2) the colder climate of the formation of mineral waters than that in the modern epoch, and/or 3) an addition of water due to permafrost thawing or from underlying aquifers. The problem needs further research.

Thermal waters of the second group are characterized by the well-pronounced "^{18}O shift" resulting from rock–water interaction and indicating the long duration of water circulation in the crust.

3.2 Dissolved solids

Thermal waters contain from 1300 to 20000 ppm of dissolved solids among which NaCl predominates. However, the TDS content in mineral waters cannot be explained by simple mixing of recent seawater with local fresh waters of atmogenic origin. Such a mixing cannot provide the observed combinations of isotopic composition of water and TDS content in the studied fluids. If the Cl content (11 000 ppm) in the Chaplino water were result from mixing of 40-45 % of seawater having SMOW isotopic composition and 60-55 % of fresh one from the same site (δD = 100 ‰, δ^{18}O = 13-14 ‰), the resulting values of δD and δ^{18}O should be equal to ~40 ‰ and ~6 ‰, respectively, instead the observed values.

The relative contents of some components in seawater differ radically from those in thermal waters: the latter are depleted in SO_4 (and Mg) and, in contrast, are enriched in Ca (Fig. 4). The content of Ca correlates with that of Na. The deficit of SO_4 and Mg is usually explained by sulphate reduction and Mg-fixation in clay minerals. In this connection the results of the δ^{34}S measurements should be taken in mind. The δ^{34}S-values inversely correlate with the SO_4 content (Fig. 5). This correlation indicates "sulphide source" of some part of the SO_4 content in thermal waters.

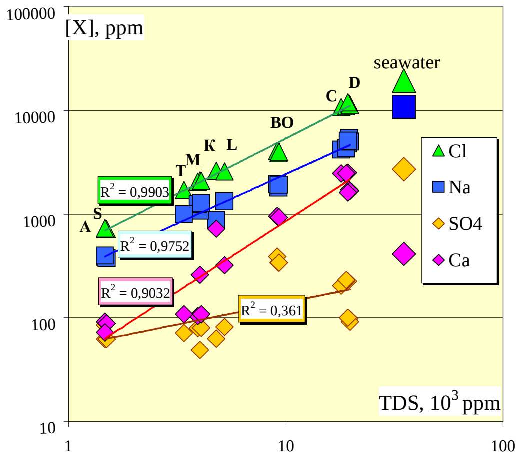

Figure 4: The correlation of TDS and the contents of Na, Cl, SO_4 and Ca in the Chukchi thermal waters.

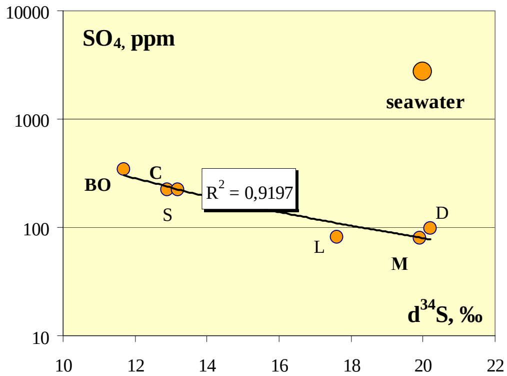

Figure 5: δ^{34}S-SO_4 plot in the Chukchi thermal waters.

One further feature of the Chukchi thermal waters is the higher Br content than that in seawater: Cl/Br in the latter ratio is, as known, ~300, whereas in the studied springs it is of 254 in average and 214 as minimum.

Hence, waters of the studied Chukchi springs cannot be a product of simply dilution of recent seawater by local meteogenic ones, contrary to opinion of some previous researchers. The views by Ivanov [1960], who considered the mud of old marine basins as a source of TDS in the Chukchi thermal waters, seem to be more close to the truth.

3.3 Gas phase

Nitrogen predominates (93-98 % vol.) in free gas phase separated from mineral waters in the most of sampled springs. In 8 spring groups N_2 is completely of atmospheric origin, since the $[N_2]/[Ar_{atm}]$ concentration ratios in their gases are close to those typical for free and water-dissolved air (~80 and ~60, respectively). But in the Babushkiny Ochki gases this ratio amounts to ~170 indicating some excess of N_2 relatively to Ar_{atm}, i.e. an admixture of non-atmospheric nitrogen.

Along N_2 excess, BO Spr. differs in high content of CO_2 (up to 96.3 % vol.). The second CO_2-rich (29.3-57.6 % vol.) group is Mechigmen Spr. Both groups are located in the Kolyuchin-Mechigmen Depression. As noted above, the depression stands out in the peninsula for the most geodynamic activity. Degassing of CO_2-rich waters is accompanied by precipitation of travertine (Fig. 6).

Figure 6: Babushkiny Ochki (Grandmother Glasses) Springs on the summit of travertine dome.

The studied gases contain CH_4 from less 0.001 % vol. to than 1.4 % vol. The CH_4 content positively correlates with spring temperatures (Fig. 7).

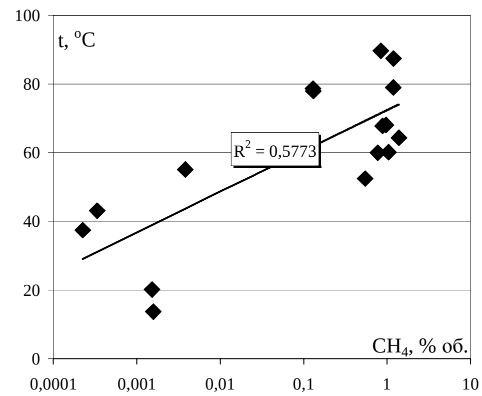

Figure 7: $[CH_4]$-t plot in the Chukchi springs.

Besides, these gases contain an admixture of He amounting up to 0.4 % vol. The abundance of [He] correlates with that of $[CH_4]$ (Fig. 8).

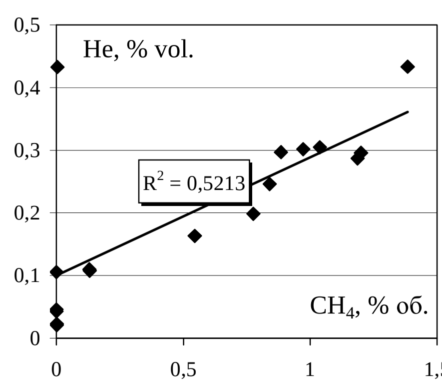

Figure 8: Plot [He] vs. $[CH_4]$ contents in gases.

The $^3He/^4He = R$ ratio values measured in free gas phase lie in the range of (20,2-65,5)×10^{-8}. Such values indicate an admixture the mantle-derived component in studied fluids (Fig. 9). The same range of the *R*-values was found out in other segments of the Pacific margins, in particular, Russian Far East, Southern and Western Mexico [Bogolyubov et al., 1984; Polyak et al., 1991], where magmatic activity occurred in Cretaceous and locally later, i.e. it was subsynchronous wth that in the Chukchi Peninsula.

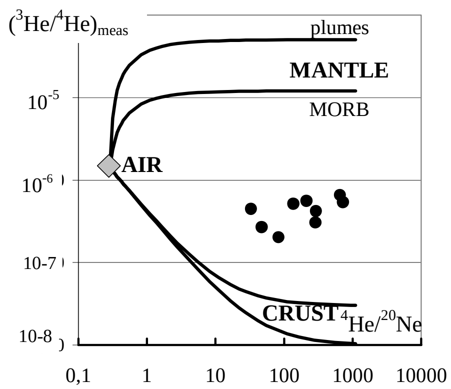

Figure 9: Plot *R* vs. $^4He/^{20}Ne$ contents in gases.

The comparison of [He] and *R* values shed light on the origin of mayor gases. Sinistral deviation of the data points characterizing Kivak, Senyavin, Arakamchechen, and Babushkiny Ochki springs from the crust-mantle mixing line on the Fig. 10 can be explained by or i) solubility-related fractionation of He and mayor gases in the gas–water system, or ii) an addition of mayor gases to mantle-derived CO_2-He mixture.

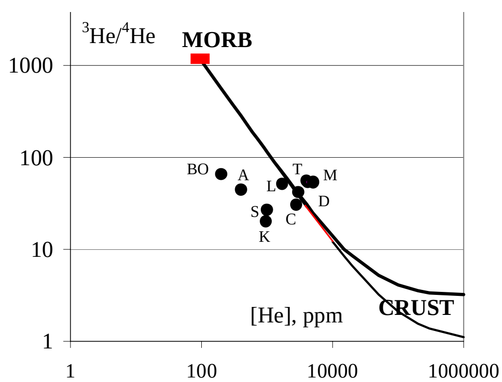

Figure 10: Plot *R* vs. [He] contents in gases.

As this takes place, the *R* values are positively correlated with CO_2 contents (Fig. 11). This trend allows to suggest termometamorphic origin of ten-fold excess of CO_2 in relation to the crust-mantle mixing line. This supposition agrees with a notion on geothermal (geodynamic) activity in the KMD.

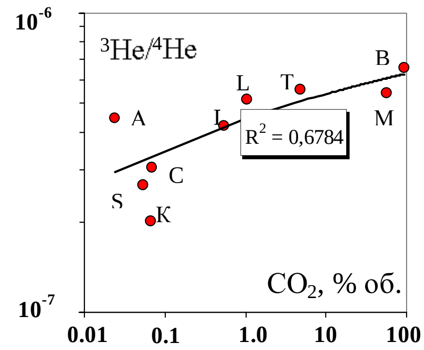

Figure 11: Plot *R* vs. [CO_2] contents in gases.

Using the relationship between He isotope composition in subsurface fluids and terrestrial heat flow [Polyak et al., 1979; Polyak and Tolstikhin], the background conductive heat flow density was evaluated in the studied part of the Chukchi Peninsula. It accounts for 58-65 mW/m^2 that is in a good accordance with the previous estimations [*Geothermal map…*, 1972].

3.4 Water temperatures

Water temperatures measured in the springs vary in the wide range from 13.7°C (Babushkiny Ochki Spr., southern cauldron) to 97 °C (Mechigmen Spr.). Water temperatures variations in the same discharge focus reflect a dilution of ascending thermal fluids by cold superficial and ground waters.

Until 2002, only two sampling sites, Chaplino and Dezhnev springs, were prospected by shallow boreholes, up to 200 and 140 m, respectively. Temperature measured in the boreholes is close to that in superficial springs. Using Si-, Na/K-, Na/Li-, Mg/Li- and Na-K-Ca-geothermometers [Fournier and Trusdell, 1973; Kharaka and Mariner, 1989; etc], we estimated temperatures on the maximal depth of thermal waters circulation, i.e., the so-called “base” temperatures.

The Si-temperatures calculated correlate both with those measured in springs and calculated by Mg/Li-thermometer and, on the contrary, don’t correlate with Na/K-, Na/Li- and Na-K-Ca-estimations. The latter, in their turn, correlate each other (Fig. 12).

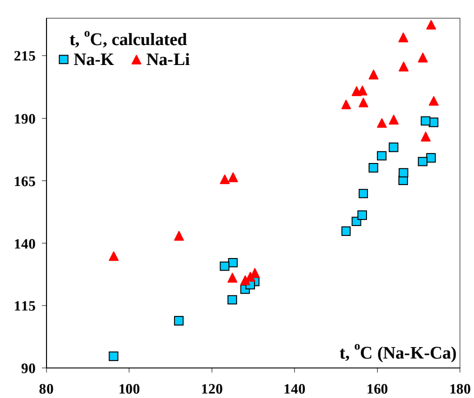

Figure 12: Correlation of Na-K-Ca-, Na/K-, and Na/Li-temperarures.

At the same time, the Si-temperature values agree rather well with the observations in shallow boreholes drilled in Chaplino springs (Fig. 13) as well as in Dezhnev Spr**.**

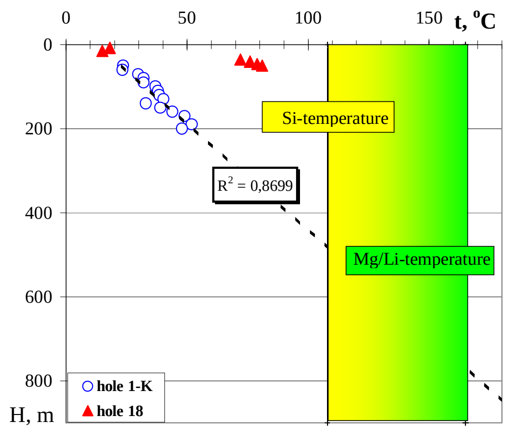

Figure 13: Deep temperatures in Chaplino Spr.

4. THE POSSIBLE USE OF GEOTHERMAL RESOURCES IN THE EAST CHUKCHI PENINSULA

Based on maximal temperature values measured in discharged water and its flow rate, we calculated the natural heat output from each sampled spring group (Table). Besides, we tentatively estimated the local thermal resources, which could be extracted from deep reservoir in the case of its exploitation by boreholes. In so doing, we use Si-temperature as minimal possible value for extracted fluid and proposed, in accordance with experience, the three-fold increase of flow rate as compare with natural productivity. The Table summarizes the results obtained.

Table
Natural and prognostic parameters
of the Eastern Chukchi Peninsula thermal springs

Springs	Natural			Prognostic	
	t, °C	L/s	MW_t	Si-t, °C	≤ MW_t*)
C	88	46	16.8	110	55
S	80	55	18.1	110	68
A	38	≤ 6	< 1	85	
K	43	>10	> 2	86	11
L	58	65	16	116	104
M	97	63	24	144	115
T	56	< 3	0.7	133	
BO	21	~10	< 1	69	
D	60	> 5	1.3	69	4

Geothermal resource development and use depend, first of all, on economic demand and only then on their quality and quantity. Taking into account these factors and the present-day density of population of the Chukchi Peninsula, Chaplino and Kukun' (Lorino) springs are worthy of a prime consideration.

Chaplino Spr. are discharged at 30 km from Novo-Chaplino Settl. In the 1960-th, target-oriented works including prospecting drilling explored this site. Thermal resources of these hot springs are significant. It would be best to use these resources in cascade succession including a binary power plant, space heating system, greenhouse complex and balneary. However, Chaplino fluids have the high TDS content (up to 20 000 ppm) that can seriously complicate their possible use.

Kukun' Spr. are located at 13 km from Lorino Settl. and at 45 km from Lavrentii Settl. This thermal field prospected as long as in 1970-80s was used for thermal water supply and space heating of greenhouse of 1000 m^2 area, summer recreation campus and four small dwelling houses (Fig. 14). Temperature of issued water is too low for its use in any geothermal power plants or for supplying of distant consumers. But the significant natural resources (16 MW_t) and low TDS content (< 5 000 ppm) are favorable for large-scale agricultural and balneological using of these springs. After our research, geophysical survey and drilling was began in this site by initiative of local administration with participation of Icelandic experts in order to refine the prospects of geothermal developing of Kukun' Spr.

Figure 14: Kukun" (Lorino) Spr. Thermal pipeline on the foreground, greenhouses on the background.

Dezhnev Spr. are situated more close to potential consumer than Chaplino and Kukun' springs, at 8 km only from Uelen Settl. But their low temperature and flow rate along with high TDS content (up to 19 000 ppm) prevent their use. The indirect estimations of base temperature in these fluids are very contradictory: from 69 °C (Si-temperature) to 213 (Mg/Li one). The possibility of geothermal development of this thermal field should be refine by further investigation.

Besides the springs considered above, it should be noted Senyavin and Mechigmen springs. They possess significant geothermal resources (see Table) and could be as bases for large-scale geothermal development. Unfortunately, both groups are located in inhabited places, so their use for any purposes except recreation seems to be problematic.

5. CONCLUSION

1. The different constituents of the sampled fluids – water phase, dissolved solids and gases – have different origin.

2. Waters issued from thermal springs of the Chukchi Peninsula (including those discharged no further than 1-10 km from the sea coast) differ sharply from seawater in H_2O isotopic composition: δD- and $\delta^{18}O$-values measured in these waters vary from -93 to -134 ‰ (δD) and from -11.1 to -17.6 ‰ ($\delta^{18}O$) in relation to SMOW standard, whereas the Bering Sea water is characterized by δD = -10 ‰ and $\delta^{18}O$ = - 1.3 ‰.

3. Although NaCl predominates among dissolved solids, the TDS variations from 1300 to 20000 ppm cannot be explained by mixing of recent seawater with local fresh (atmogenic) water, since this process cannot provide the observed combinations of δD, $\delta^{18}O$ and TDS values.

4. N_2 predominates (93-98 % vol.) in free gas phase from 7 spring groups, whereas gases from Mechigmen Spr. and Babushkiny Ochki Spr. contain from 29.3 to 57.6 % vol. of CO_2 and up to 96.3 % vol. of CO_2, respectively. Both groups are located in Kolyuchin-Mechigmen Depression where the youngest basalts (≤18 Ma) were noted.

5. According to $[N_2]/[Ar_{atm}]$ ratio, N_2 is of pure atmospheric origin in all the gases except those from Babushkiny Ochki Spr., where N_2 excess of non-atmospheric origin is present.

6. The $^3He/^4He$ ratio values varying in the range $(20{,}2\text{-}65{,}5)\times10^{-8}$ indicate an admixture of mantle-derived component in all the gas samples. This ratio correlates positively whith $[CO_2]$ concentration. At the same time, the juxtaposition of He concentration and its isotopic composition shows intracrustal origin of N_2 excess and the most part of CO_2.

7. The eastern Chukchi Peninsula possesses the certain geothermal resources. Their use will depend, first of all, on economic expediency. Taking into account the present-day density of population of the peninsula, Chaplino (natural heat output = 16.8 MW_t) and Kukun' (16 MW_t) springs are worthy of a prime consideration.

Acknowledgements. Authors appreciate the Administration of the Chukchi Autonomy District for the help in the field trip arrangement and the subsidy for the research fulfilled. We thank I.L. Kamenskii (Geological Institute of RAS Kola Sci. Center, Apatity) for cooperation in isotope analyses of noble gases. The work was carried on at the financial support of the RFBR (grant 03-05-64869) and the RAS Dept. of Earth Sci. (BR program # 7, contract 914).

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