Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Formation of a New Geothermal Field in the area of the Nizhne (Lower)-Koshelevsky Geothermal Deposit (South Kamchatka): a Natural or Man-Made Phenomenon?

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Keywords: South Kamchatka, Nizhne-Koshelevsky thermal anomaly, temperature and geochemical areal mapping, argillization of deluvial deposits, gas-vapour fluid, high-dynamic geothermal processes

ABSTRACT

Formation of new geothermal anomalies in historical time is rather a rare phenomenon. For the most part, such anomalies are formed due to activation of magma activity (e.g., heating of active volcanoes' slopes) or hydrothermal processes (emergence of new thermal water springs, fumaroles, funnels from hydrothermal explosions). Thermal anomalies most frequently form within the known geothermal fields due to natural reasons; sometimes it occurs due to drilling or field development. In most cases the nature of such phenomena is obvious. Starting increasingly from the 1960s, geological-geophysical, geochemical, geobotanical and other works have been carried out within the Nizhne (Lower)-Koshelevsky vapour-dominated geothermal deposit and the thermal anomaly of the same name, already known in the 18th century. In 2008, an occurrence of a new thermal anomaly named as Nizhne (Lower)-Koshelevsky New Thermal Field (NKN) was recorded. Vegetation and soil was scorched in an area of 200 x 200 meters, the temperature of soils in the central part of the field reached 100-107 ^{o}C. In 2009-2013, we carried out temperature and geochemical (Hg-metering) mapping on this site; composition and properties of deluvial sediments in the most heated part of the field and its outskirts were studied; magnetometric survey and electrical exploration were conducted, i.e. everything for monitoring of NKN parameter changes and resolution of the origin question.

It was determined that a sudden heating of soils was followed by their rapid cooling. The temperature in the most heated sections has decreased from 100 to 40 ^{o}C in a 5-year period. Anomalously elevated contents of Hg in deluvial deposits are clearly correlated with positive temperature anomalies. Hydrothermal-metasomatic alteration of rock sections took place in five years – from weak argillization of sand clay (clay loam) and rock fragments to formation of hydrothermal clays characterized by a high level of Hg concentration. All this testifies in favour of NKN emergence due to inflow of a heat- and chemical ore element-carrying gas-vapour fluid from some depth. A subvertical zone of rocks with reduced resistance which, probably, acts as a channel for the ascending gas-vapour fluid was identified in geoelectrical cross-sections. The data acquired cannot unambiguously answer the question about the nature of this phenomenon: NKN formed owing to the development of high-dynamic geothermal processes in the interior of the main thermal anomaly or an influx of a heat-carrying medium is caused by disruption of a bore casing in one of exploration drill holes located near the field. In any case, the field formation is connected with the sudden penetration of the gas-vapour heat-carrying medium into the zone of elevated permeability of rocks due to an outcome of some physical mechanism: an earthquake event, hydrothermal explosion in the interior of the hydrothermal system, etc. Further monitoring of changes in NKN physical-chemical parameters may give answers to the questions of great scientific and practical meaning for geothermics: what actual heat and matter transfer rates are in the rocks, how much time is needed for the conversion of pyroclastics and deluvial deposits into clays, what possible rates and mechanisms of formations of large geochemical anomalies (Hg, Au, Cu, Zn, etc.) impacting the regional geoecology are.

1. INTRODUCTION

Nizhne (Lower)-Koshelevsky New Thermal Field (NKN) is located on the western slope of the largest on Kamchatka Koshelevsky volcanic massif (Dolgozhivischii…, 1980). The famous Gremutchiye (‘Rattling’) Springs which form the Nizhne-Koshelevsky and Verkhne (Upper)-Koshelevsky thermal anomalies with an estimated capacity of 25 and 50 GW respectively (Vakin et al., 1976). Many geologists, geophysicists and hydrogeologists have contributed to the study of this area: N.I. Lazarenkov, B.I. Piip, S.E. Aprelkov, S.I. Naboko, V.V. Ivanov, G.A. Gonsovskaya, A.I. Serezhnikov, M.I. Zubin, E.A. Vakin and many others. In 1970-80th, wells were drilled in the Nizhne-Koshelevsky thermal anomaly area to a depth of 1,500 m and a vapour-dominated geothermal deposit of the same name was found. The inferred resources the deposit equated to electric capacity are 90 MW (Pisareva, 1987). At the same time all thermal manifestations of the area were identified and described: Promezhutochniye (‘Intermediate’), Skazka (‘Fairy Tale’), Kalderniye (‘of caldera’), Sivuchinskiye and other thermal springs. However, during the survey period of South-Kamchatka-Kuril surveying company of Institute of Volcanology and Seismology FED RAS in 2006-2013, some previously known thermal manifestations were not found but new ones were identified (Rychagov, 2008). Particularly, a rare natural phenomenon such as formation of a new thermal field was observed some 300-400 m to the south from the Nizhne-Koshelevsky thermal anomaly in the interstream area of the Gremutchiy (‘Rattling’) and Priamoi (‘Straight’) streams. Usually, surface is heated on the slopes of active volcanoes or on active geothermal fields and accompanied by the formation of explosion craters, fumaroles, new springs and other thermal outflows (Kotenko et al., 2006; Terada, Sudo, 2012). In 2008, researchers from the surveying company recorded vegetation scorching (grass and alder shrubs) on an area of approximately 40 thous. m^2 and heating of the ground at a depth of 30-50 cm up to 100-107 ^{o}C, **Figure 1**. No other surface manifestations of any geothermal activity (water springs, mud-water pots, discharge of thermal waters near the field) were found on this site. This territory was named as the Nizhne-Koshelevsky New Thermal Field (NKN). A sudden heating of the area comparable to a size of a usual thermal field is of a great importance for the study of speed of geothermal processes and rate of alteration of rocks in real-time, for mapping of heat-conducting channels and heat sources, for solving other fundamental scientific questions of geothermics. Besides, the territory belongs to the South

Kamchatka State Sanctuary of the federal level and it is apparent that the heating of a new area may significantly influence the region's environment. In view of the said above, the researchers from the surveying company conducted integrated geological-geophysical studies in NKN.

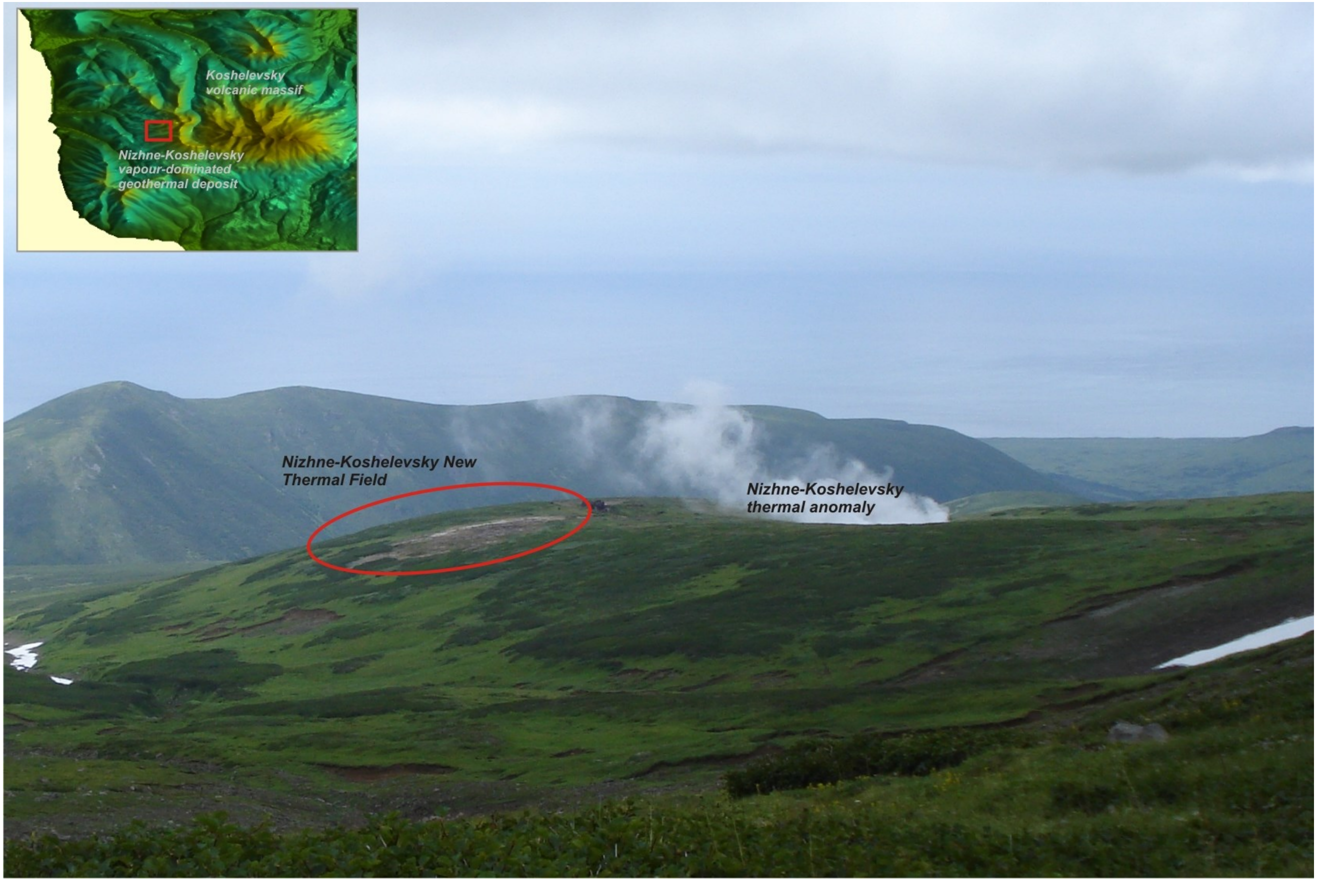

Figure 1: General view in the area of research (photo by V. Shanina)

2. RESEARCH METHOD

Areal Temperature Survey. Measurements of soil temperatures were taken according to a survey grid with a spacing of 40 to 20 m between profiles and a spacing of 20 to 10 m between the measurement points (See below the charts of temperature distribution through different years). The measurements were taken at a depth of 60-70 cm in a bore in which a thermocouple was inserted for a time of ≥ 5-15 minutes whichever was enough to achieve a temperature balance with the ground. Profiles were beyond 15 ^oC temperature isometric lines.

Lithogeochemical (mercury metric) sampling in deluvial soil-pyroclastic deposits of the area was carried out in the same points. Sand clay or clay loam material was taken from subsoil horizons. Samples weighed 0.5-1.0 kg. A sample was dried and sieved through a bronze 1-mm cell strainer to separate organics and large debris. Then a 0.1-0.2 mm 30-50 gram fraction was formed. Mercury content was determined by atomic absorption spectrometry performed on an analytical complex PA-915+ in Vinogradov Institute of Geochemistry SB RAS in Irkutsk (Andrulaitis, 2012).

A magnetometer survey was carried out in 2010-2011 to determine residual magnetism of soil-pyroclastic deposits and bottom rocks in the NKN area and beyond its boundaries. A proton magnetometer MMP-203 designed for measurements of magnetic density modulus T was used. The survey was conducted on a total area of more than 1 km^2. Measurements beyond NKN were taken by a survey grid with a spacing of 100 m between the profiles and a spacing of 10 m between the measurement points. Spacing in the area of NKN was 50 m between the profiles and 5 m between the measurement points. As a result, magnetic anomalies ΔT_a were mapped (Nuzhdayev, Feofilaktov, 2013).

Vertical electrical sounding (VES) in the area of the Nizhne-Koshelevsky t/a and NKN was carried out in 2013. According to the electrical method (Elektrorazvedka…, 2005), measurements of potential difference in the receiver circuit were taken at each sounding point with incremental positioning of transmitter electrodes.

Prospecting pits were dug for the study of soil-pyroclastic sediments and examination of sediment composition changes under influence of the thermal field. In 2010, 2011 and 2013, prospecting pits were dug to penetrate almost the whole thickness of diluvium (180 to 210 cm) in the most heated central part of NKN and on its boundary. Spacing between the pits in both groups was 5-10 m. Cross-sections were sampled layer by layer (every 20 cm on the average) for determination of chemical and mineral composition of sediments, study of mercury distribution in a solid medium (sand clay, clay loam, clay). Each layer was sampled for water extract preparation to analyse the composition of pore solutions.

3. ACTUAL RESULTS

The results of thermal surveys of 2009-2013 are shown in **Figure 2**. The most heated sections are in the central part of the field. The temperature has decreased on all NKN's area in the monitoring period (peak temperature values have decreased by 50 ^oC in the central part) and its area has also decreased (the field has been demarcated by the 20-degree isothermal line). Thus, since a sudden and intensive heating of the surface (in ≤ 1 year, apparently) the area has been gradually cooling off **(Table 1)**. However, configuration and location of the most heated sections remain almost unchanged but their sizes have been decreasing with each year. Falls in temperature, each time by 30 ^oC, took place in two periods in a short time interval (in an interval of ≤ 1 year, see Table 1), which is, probably, directly connected to a change in temperature cycle of a heat-carrying medium at a certain depth underneath NKN.

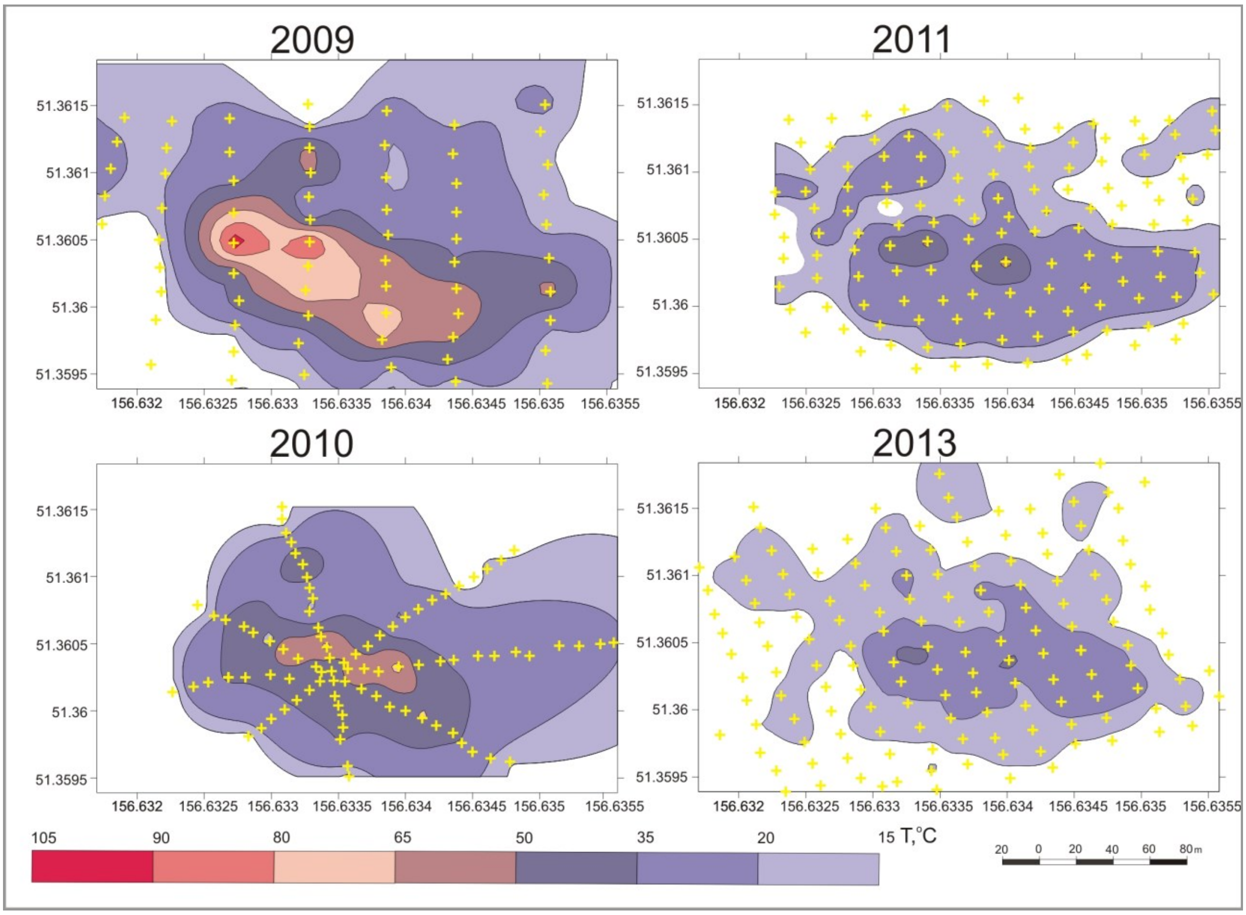

Figure 2: Diagrams of temperature distribution in the area of NKN received by results of areal temperature survey during the period 2009-2013.

Table 1. Change maximal temperatures soil, border area NKN on 20 ^oC isotherm and area barren of growth.

Year	T_{max}, ^oC	S_t, m^2	S_{gr}, m^2
2009	107	39800	-
2010	73	31300	14800
2011	70	17400	11400
2012	40	-	-
2013	41	9400	5800

Note: (S_t, m^2) the area of thermal field due to 20 ^oC isotherm; (S_{gr}, m^2) the area barren of growth.

The mercury distribution across the NKN area correlates well with the temperature fields. Anomalously high contents of mercury in the subsoil layer are representative for the central part of the field, mercury concentrations at the boundaries are close to background values. This indirectly testifies in favour of a single source of temperatures and mercury-metering anomalies, that is, most likely, a geothermal gas-vapour heat-carrying medium.

Based on magnetometer surveys, the magnet anomalies ΔT_a in the central part of Nizhne-Koshelevsky geothermal deposit have been mapped. Three large negative magnet anomalies are delineated on the map: Northern, Central and Southern. The latter traces the fault zone which goes along the valley of the Priamoi stream. The discharge of hydrothermal vapours (Nizhne-Koshelevsky t/a) is connected with the central anomaly. It is assumed that the northern section of reduced values of ΔT_a is confined to a paleo-hydrothermal system (Nuzhdayev, Feofilaktov, 2013). NKN is located in the field of medium values of ΔT_a. This can be apparently explained by a relatively short impact of a geothermal heat-carrying medium on soil-pyroclastic sediments which caused only a partial destruction of ferromagnetic minerals and an incomplete loss of substratum magnetism.

VES indicated that the upper part of the NKN cross-section to a depth of 60 m contained rocks featuring a high apparent resistivity. It is known that this part of the cross-section is composed of a lava-extrusive complex of andesites – andesidacites. A zone of low-resistivity rocks was identified in the lower part of the cross-section (**Figure 3**). The most likely explanation of the physics of this zone is a high conductivity of rocks with respect to hydrothermal solutions or gas-vapour mixture. The drilling data and geological-geophysical surveys indicate that the thermal anomaly area includes a hydrothermal system hypergenesis zone, i.e. a section of strongly argillized rocks with high fissure-pore permeability for hydrothermal vapours is located under the lava-extrusive complex. A channel which communicates with the shared thermal-conductivity zone was identified directly under NKN. Apparently, the formation of the channel explains the heating of the area in the vicinity of NKN.

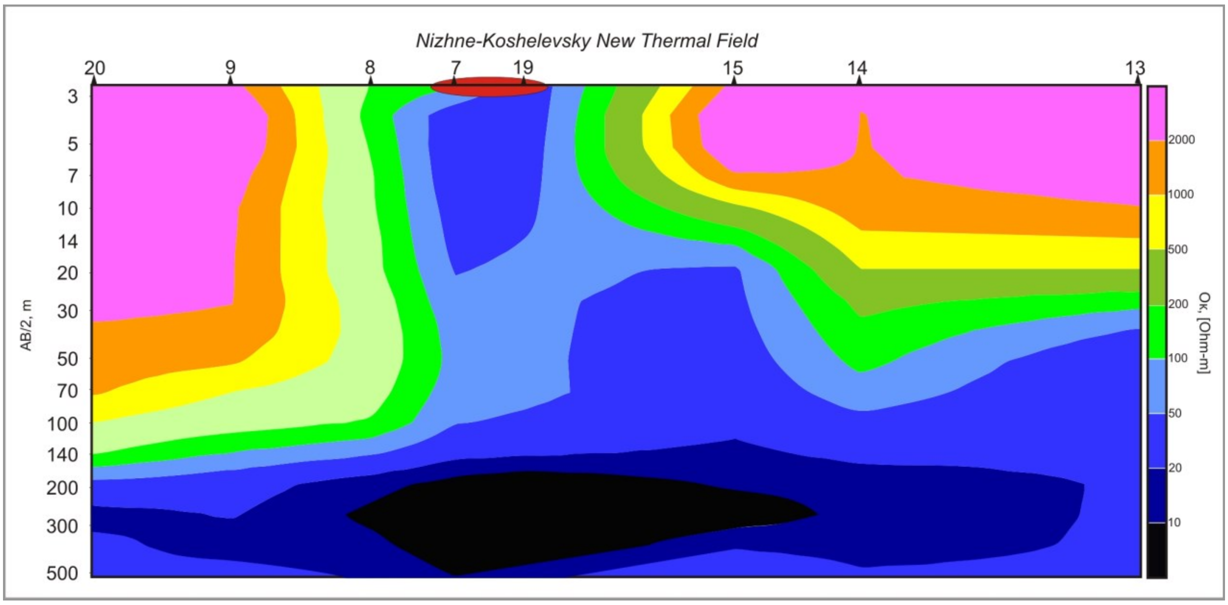

Figure 3: Apparent resistivity section on placement transmitter electrodes based on the results obtained using VES in the area of NKN (points 7, 19 are on the NKN area).

The NKN lithological cross-sections were studied by means of digging prospecting pits with the results stated below. Typically for the field boundaries, there is a 20-cm thick turf layer in the upper part of the sections; in an interval of 35-45 cm, it is followed down by a burnt soil layer containing plant material remains. The layer is underlain by a 20-cm thick boulder bed (in prospecting pits NKN-2/10 and NKN-2/11), below are layers of sand clay and clay loam with gravel, boulders and pebbles. Prospecting pits NKN-2/11 and NKN-2/13 revealed traces of argillization of fine material sediments and decomposition of large debris in the lower layers at a depth of 150 cm (**Figure 4**). This is characteristic of initial stages of hydrothermal-metasomatic rock alterations resulting in the formation of hydrothermal clays. The pits revealed that the upper layer in the central part of the field is composed of clay loam with inclusions of subrounded debris and gravel. Moreover, turf remains and plant roots were observed in the prospecting pit NKN-1/10 but in the following years the layer has degraded due to dynamic erosion processes in this area.

Bands of clay loams and sand clays with gravels and boulders were penetrated below. Layers of argillaceous material were found in the central part of NKN (See Figure 4). An extent of argillization gradually increased from 2010 to 2013. The central part of the cross-section features a layer with distinct boundaries (it is located structurally higher in the pit NKN-1/13). While in 2011 hydrothermal clays form a band within an interval of 120-140 cm (in the footing of this layer), then in 2013 the substratum of the whole layer was converted to hydrothermal clays. This indicates a high rate and intensity of hydrothermal change of sediments in the most heated central part of NKN. Argillization of sediments at the periphery of the field is also related to some heating (up to 37 ^{o}C) of the stratum bottom due to inflow of a geothermal heat-carrying medium (condensate of a gas-vapour mixture).

The study of mercury distribution in the sediments of NKN cross-section demonstrated that its content exceeded background values for the rocks of the Kuril-Kamchatka region (Leonova, 1979) by 1-3 orders. High concentrations of mercury in argillized fine clastic sediments (sand clay and clay loam) and a marked increase of mercury content in the near-surface layers of the cross-section (**Figure 5**) are characteristic of the central part of the field. Pore solutions are characterized by high and sometimes outstanding values of Hg. There is a budding tendency of increase of mercury concentrations in the pore solutions of the most argillized layers of sediments as well as the near-surface layer rich in organic matter. Mercury contents in the solid substratum are relatively high and reach (100-120) x 10^{-6}%, in the pore solutions mercury concentrations are high. On the whole, mercury contents in the solid and aqueous phases of fine clastic deluvial sediments clearly increase towards the footing of cross-section at the periphery of NKN.

The highest concentrations of Hg are typical for the lower most argillized layer. It is well known that mercury in modern hydrothermal systems comes up to the surface with a geothermal heat-carrying medium. Hg is particularly transported by means of a gas-vapour phase (Trukhin et al., 1986). The distribution of Hg in the cross-sections of the deluvial sediments of Nizhne-Koshelevsky New Thermal Field says for the following mercury transport pattern during the NKN formation: mercury's ascending with a gas-vapour phase in the central part of the field and its coming to the field periphery when the vapour condensate spreads.

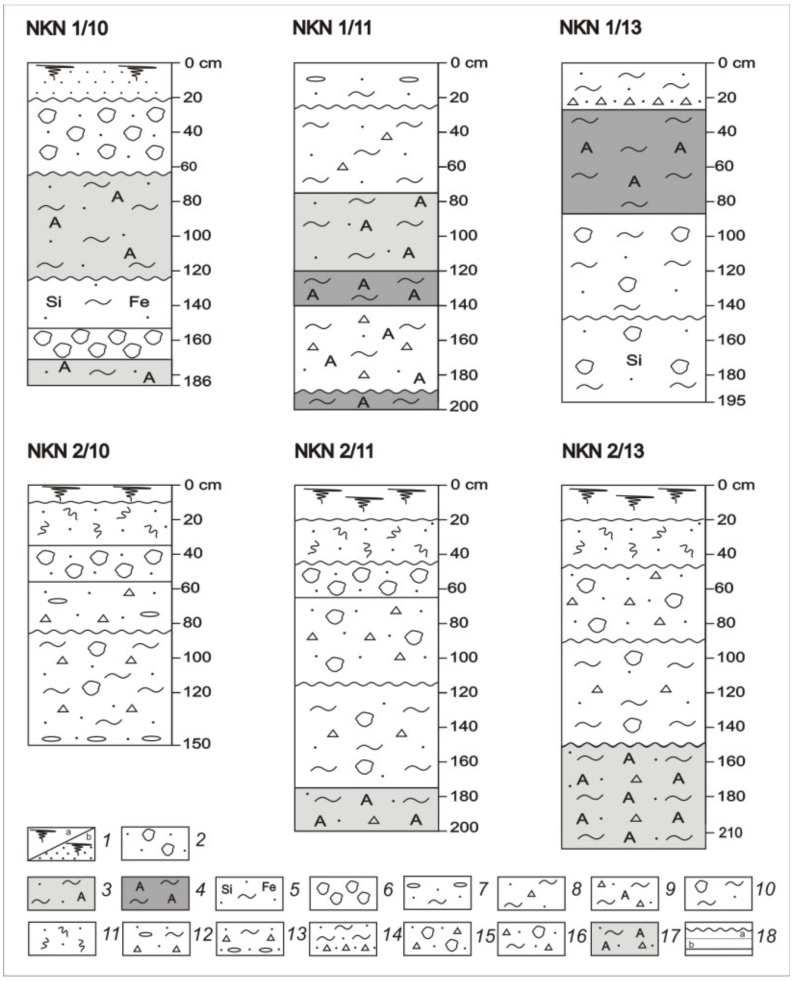

Figure 4: Lithological cross-sections of prospecting pits digging in the area of NKN. (1) soil: (a) turf, (b) turf with sandy clay; (2) boulder bed with sandy clay; (3) plastic argillization sandy clay; (4) bright-purple (hydrothermal) clays; (5) boulder bed stained with silication and hematite; (6) boulder bed; (7) sandy clay with pebbles; (8) sandy clay with gravel; (9) argillization sandy clay with gravel; (10) sandy clay with some boulder bed; (11) burnt soil-vegetable layer; (12) sandy clay with pebbles and gravel; (13) sandy clay with gravel and pebbles at the bottom of layer; (14) sandy clay with gravel at the bottom of layer; (15) clay loam with gravel, boulders; (16) sandy clay with gravel and boulder bed; (17) sandy clay with gravel some argillization; (18) boundary between layers: (a) gradual, (b) sharp boundary.

4. DISCUSSION OF RESULTS

A rare natural phenomenon was observed on the western slope of the Koshelevsky Volcanic Massif (South Kamchatka) near the well-known Nizhne (Lower)-Koshelevsky thermal anomaly: a new geothermal field (NKN) was formed at 750-800 m elevations in the interstream area of the Gremutchiy ('Rattling') and Priamoi ('Straight') streams. The field was discovered thanks to vegetation scorching (grass and alder shrubs) caused by increase of the ground temperature up to 100-107 ^{o}C. In 2009, the field has an area of 40 thous. m^2. Further on, after such a sudden heating of the area, the temperatures of soils decreased (down to 40 ^{o}C in the centre in 5 years) and the field area decreased as well. The study of the temperature pattern of NKN and mercury distribution in soil-pyroclastic sediments throughout the field area and in the cross-sections of deluvial sediments has demonstrated that formation of a new thermal anomaly and change of composition and structure of sediments occur owing to a geothermal heat-carrying medium. It is unlikely that a heat-carrying medium are hydrothermal solutions since no evidence of circulation of hydrothermal fluids has been found within the field or in its close vicinity. Most likely, formation of a thermal field and alterations of sediments occur under influence of a gas-vapour phase which, at a certain depth, is separated from superheated hydrothermal solution. This is confirmed by the metasomatic alteration character of soil-pyroclastic (deluvial) sediment substratum, i.e. their argillization beyond the zone of active circulation of solutions. The study of an extent of sediments argillization and mercury distribution indicates that within the field area Hg comes to deluvial sediments with a geothermal heat-carrying medium. The geophysical data also indirectly point to the metasomatic type of sediments alteration (a decrease of rocks' magnetism) and the presence of a heat source connected to the main gas-vapour zone of the Nizhne-Koshelevsky geothermal deposit. Apparently, a gas-vapour heat-carrying medium comes through a subvertical channel which is rather clearly manifested on geoelectrical sections and is characterized by medium electric conductivity parameters of the environment. These data cannot unambiguously answer the question whether the field was formed

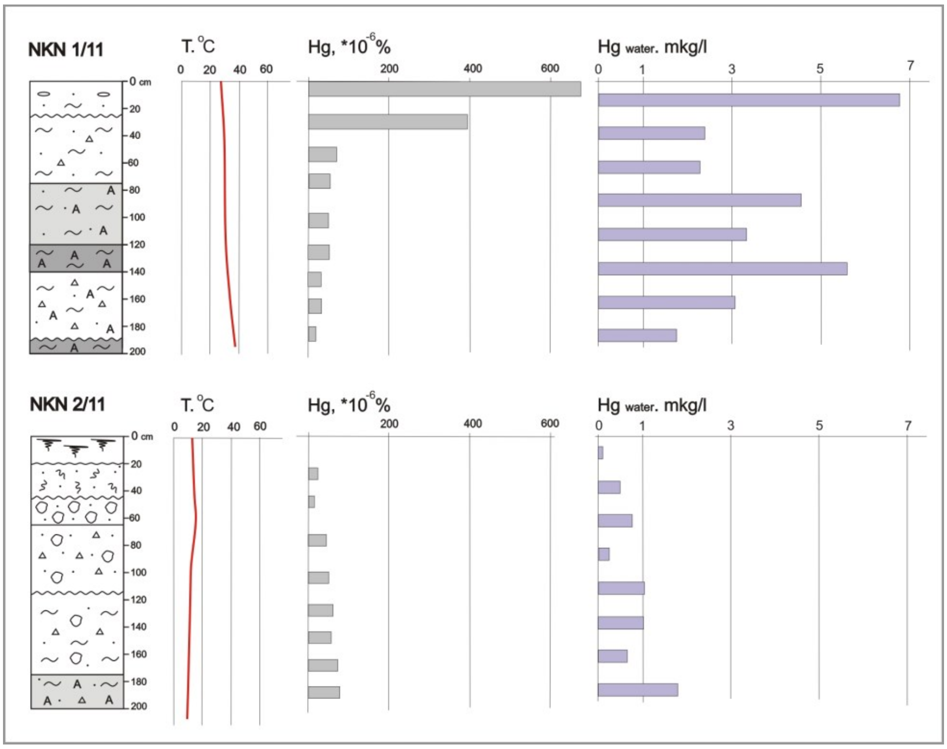

Figure 5: Diagrams of temperatures and mercury distribution in soil-pyroclastic deposits and pore- cross-sections of prospecting pits digging in the area of NKN.

due to influence of natural sources (inflow of a gas-vapour phase from a geothermal pool of the deposit) or whether this phenomenon has a man-induced character (inflow of a heat-carrying medium due to disruption of a bore casing in one of exploration drill holes which is located on the boundary of the field up the slope). In either case, the formation of the field was caused by a rapid penetration of a geothermal fluid (a gas-vapour phase) in the subvertical zone of highly fractured andesidacites of the upper water-confining complex due to emergence of a trigger mechanism: possibly, an earthquake event, hydrothermal explosion in the interior of the hydrothermal system, etc. (?). A further comprehensive study of NKN will be able to answer the question on the nature of this phenomenon.

5. ACKNOWLEDGMENTS

This work has been carried out with a financial support from the Russian Foundation for Fundamental Research (Projects 13-05-00262a, and 14-05-31158mol_a). The authors deeply appreciate the contribution from all the colleagues from the South-Kamchatka-Kuril surveying company of Institute of Volcanology and Seismology FED RAS who helped to organize and conduct the field works.

REFERENCES

Andrulaitis, L.D., Riazantseva, O.S. Primeneniye sovermennogo rtutnogo fotometra PA-915+ dlia analiza… (Use of a Modern Mercury Photometer PA-915+ for Analysis of Archive Geochemical Samples to Increase Their Informational Value) // *Proceedings of All-Russian Meeting* “Modern Issues of Geochemistry”. Irkutsk: IGC SB RAS, 2012. Vol. 2. P. 158-160.

Vakin, E.A., Dekusar, Z.B., Serezhnikov, A.I., Spichenkova, M.V. Gidrotermi Koshelevskogo vulanicheskogo massiva (Hydrothermal Fluids of the Koshelevsk Volcanic Massif) // Hydrothermal systems and thermal fields of Kamchatka. Vladivostok: FESC AS of USSR, 1976. P. 58-84.

Dolgozhivischii tsentr endogennoy activnosti Yuzhnoy Kamchatki (The Long-Lived Center of Endogenic Activity of the South Kamchatka.) Moscow: Nauka, 1980. 172 p.

Leonova, L.L. Geokhimiya chetvertichnikh i sovremennikh vulcanicheskikh porod… (Geochemistry of Quaternary and Modern Volcanic Rocks of the Kuril Islands and Kamchatka) // *Geochemistry*. 1979. № 2. P. 179-197.

Kotenko, T.A., Kotenko, L.V., Shapar, V.N. Aktivizatsiya vulkana Ebeko v 2005-2006… (Activation of Ebeko Volcano in 2005-2006, Paramushir Ilsand, the Northern Kuril Islands) // *Volcanology and Seismology*. 2007. № 5. P. 3-13.

Nuzhdayev, I.A., Feofilaktov, S.O. Sovremennoye sostoyaniye izuchennosti stroyeniya… (Modern State of Exploration of Nizhne-Koshelevsky Geothermal Deposit (South Kamchatka) and Results of Magnetometer Survey) // *Bulletin of Kamchatka Regional Association “Scientific Training Center”. Earth Sciences*. 2013. № 2 (22). P. 231-241.

Pisareva, M.V. Zona prirodnogo para Nizhnekoshelevskogo geotermalnogo mestorozhdeniya (Natural Steam Reservoir of the Lower-Koshelevsky Geothermal Field.) // *Volcanology and Seismology*. 1987. № 2. P. 52-63.

Rychagov, S.N. Issledovaniya Yuzhnokamchatsko-Kurilskoi ekspeditsiyi… (Studies of South-Kamchatka-Kuril Surveying Company of IViS FED RAS in Pauzhetsky-Kambalny-Koshelevsky Geothermal Region on Kamchatka.) // *Bulletin of Kamchatka Regional Association "Scientific Training Center". Earth Sciences.* 2008. № 2 (12). P. 203-206.

Trukhin, Yu.P., Stepanov, I.I., Shuvalov, R.A. Rtut' v sovremennom gidrotermalnom protsesse (A Role of Mercury in Modern Hydrothermal Process.) Moscow: Nauka, 1986. 199 p.

Elektrorazvedka…(Electrical Method: A Guide for Electric Survey Practice for Students Majoring in Geophysics.) Under the editorship of Khmelevsky, V.K., Modin, I.N., Yakovleva, A.G / Ye., Aleksanov, A., Bobachev, D., Bolshakov, et al. Moscow: GERS, 2005. 311 p.

Terada, A., Sudo, Ya. Thermal activity within the western-slope geothermal zone of Aso volcano, Japan: Development of a new thermal area // *Geothermics*. 2012. V. 42. P. 56-64.