MUTNOVSKY SCIENTIFIC DRILLING PROGRAM TARGETS

A.V. Kiryukhin

Institute of Volcanology and Seismology Far East Branch Russia AS (avk2@kscnet.ru)

Conventional geothermal energy use in Kamchatka

The total number of thermal springs in Kamchatka estimated as 236 (G.F. Pilipenko, 2004, pers. com.). High temperature thermal manifestations occur adjacent to active volcanoes (total number of active volcanoes estimated as 30). Most of the geothermal reservoirs occur are Quaternary volcanogenic rocks (layer-type fractured reservoirs) and in Neogene volcanogenic and sedimentary rocks (vein type fractured reservoirs). A few geothermal reservoirs found in metamorphic Cretaceous and Paleozoic rocks.

Conventional geothermal energy use include high temperature geothermal fields Mutnovsky and Pauzhetsky, and low temperature geothermal fields: Paratunsky, Essovsky, Anavgaisky and Malkinsky. Mutnovsky geothermal field capacity include Verkhne-Mutnovsky PP (12 MWe installed in 1999) and Mutnovsky (50 MWe installed in 2002). Pauzhetsky PP started exploitation in 1966 with 5 MWe installed capacity, at this time 14.5 MWe total capacity installed, as well as 2.5 MWe binary PP feasibility study is on-going. Another attractive possibilities of high temperature geothermal reservoirs use are Bolshe-Banny (where 30-40 MWe binary PP may be installed), Kireunskaya (where 10-20 MWe binary PP may be installed) and Nizhne-Koshelevsky (where 50 MWe PP is feasible) (V.M. Sugrobov et al, 2004). Paratunsky geothermal field operated mostly under free discharge conditions of hot 85-95 ^{o}C water with flow rates 220-230 kg/s used for swimming pools, district heating, greenhouses and fish farming. Essovsky and Anavgaisky geothermal fields produce 190 kg/s at 70-80 ^{o}C with similar use. Malkinsky geothermal field operated with pumps deliver 20-30 kg/s at 80-90 ^{o}C. Verkhne-Paratunsky geothermal field use with 280 kg/s of 80^{o}C confirmed capacity is a very promising for heat supply of Elisovo city (30,000 population) located 50 km apart.

The total potential of Kamchatka high temperature geothermal fields for electricity generation is estimated by volumetric method as 1130 MWe x 100 years (excluding national park located Semyachik, Uzon and Geyserny geothermal fields), and total potential of Kamchatka low temperature geothermal fields (less then 150^{o}C) for direct heat use is estimated as 1345 MWh x 100 years (V.M. Sugrobov et al, 1976, 2004).

History of development of the Mutnovsky geothermal field

The Dachny fumarole field was discovered in 1960 by I.T. Kirsanov, and described in details by E.A. Vakin (1976). Exploration works began in 1978, including delineation of surface manifestations, temperatures, soil gas surveys, resistivity surveys, T-gradient drilling, and drilling of the exploration wells. Eighty nine exploration wells were drilled by 1991 (G.M. Assaulov et al, 1987, V.M. Sugrobov et al, 1986). Flow tests from production wells conducted during 1983-1987 time period, which confirmed the possibility of the 50 MWe production based on a sum of the single well flow rate values. A Mutnovsky 50 MWe power plant feasibility study performed by WestJec (1996-1997) was based on TOUGH2-modeling of different exploitation scenarios (A.V. Kiryukhin, 1996) confirmed 50 MWe potential of Mutnovsky geothermal field. Hence since 1999 a pilot 12 MWe Verkhne-Mutnovsky PP, and since 2002 the Mutnovsky 50 MWe PP put into operation. Recent developments of the Mutnovsky project were implemented by SC Geotherm. Fig.1 show principal features of the Mutnovsky geothermal field and Mutnovsky volcano area.

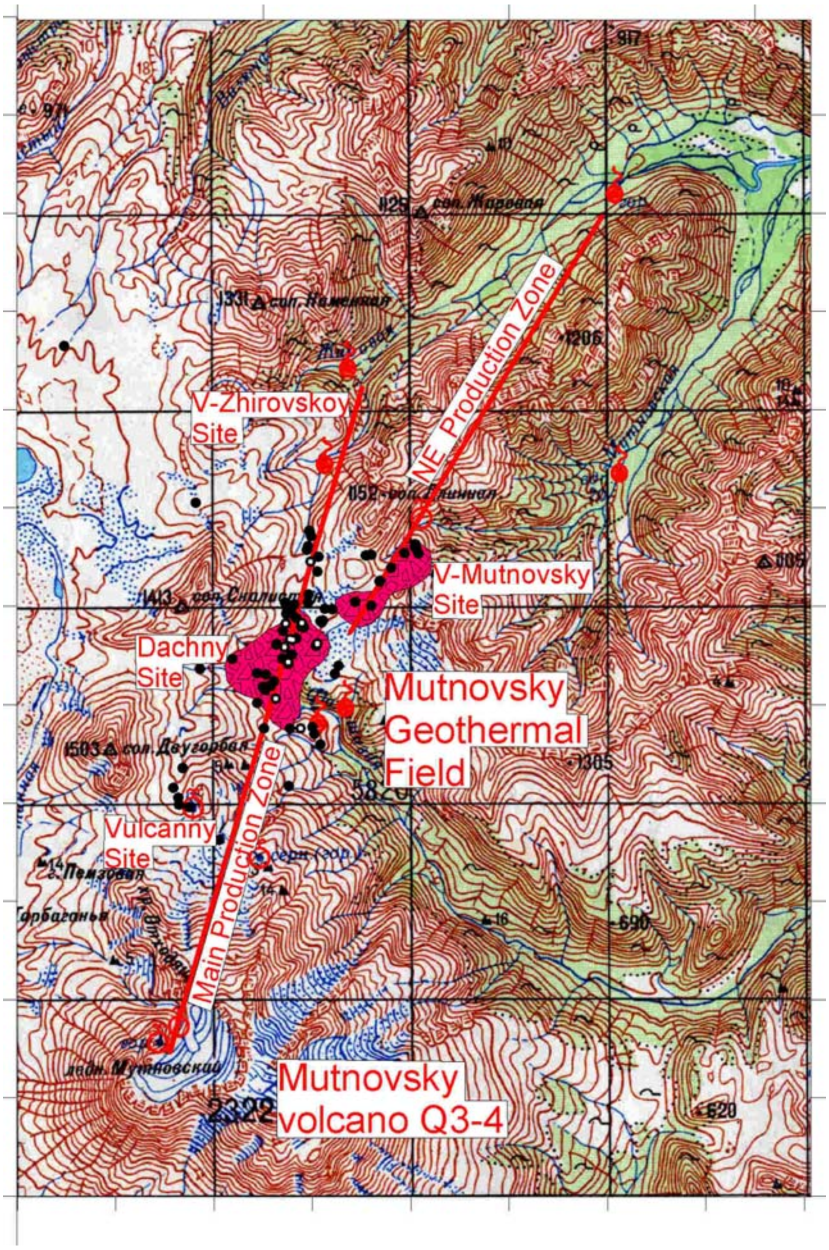

Fig.1. Mutnovsky geothermal field area, including Mutnovsky volcano, steam and hot spring discharges, traces of principal production zones and 250^{o}C counters of geothermal reservoirs at -250 masl. Grid size is 4 x 4 km^{2}.

Conceptual hydrogeological model of the Mutnovsky geothermal field.

The current conceptual hydrogeological model of the Dachny site is based on mapping of active fracture zones, circulation losses and production zones distribution data, gas and fluid chemistry data, and secondary minerals distributions (Fig. 2). Recent results of drilling and application of data from geothermal analogs reveal the “single fault” nature of reservoir. The main production zone in Dachny site is 120 m thick strikes north-north-east and dips east-east-south at an angle of 60^{o} within the North-Mutnovsky volcano-tectonic zone. Host rocks of the production zone are: diorites, Miocene-Pliocene sandstones, and rhyolite and andesite tuffs and lavas. Nevertheless, there is no explicit lithologic control of the production zone. The roof of the production zone is identified by circulation losses during drilling along the plane of main production zone, and the connectivity of the zone has been confirmed by tracer tests. The plane of the main production zone intersects the active magma feeding chamber of Mutnovsky volcano at elevations of +250 - +1250 m at a distance of 8 km from production site.

The Mutnovsky volcano crater glacier apparently acts as a meteoric water recharge area for the fluids producing by exploitation wells. Meteoric recharge is accelerated by melting of the glacier due to high heat flows in the crater (Bottom Field). Thermal input to the production zone may also come from other magmatic bodies accumulated in the North Mutnovsky volcano-tectonic zone. It is not clear whether or not such bodies are directly connected to magmatic system of the active Mutnovsky volcano, or just isolated remains of magma intruded into the plane of hydro-magma-fracturing created by Mutnovsky volcano. Upflow of high temperature fluids occurs in the south-east part of the Main production zone, where conditions are liquid-dominated at 300°C occurs. Upflow rates estimated based on numerical models as 50-60 kg/s with enthalpies 1270-1390 kJ/kg. Ascending fluids transform to two-phase conditions in the shallow parts of the production zone (above 0 m.a.s.l.), where production coincides with the wairakite-chlorite secondary minerals association.

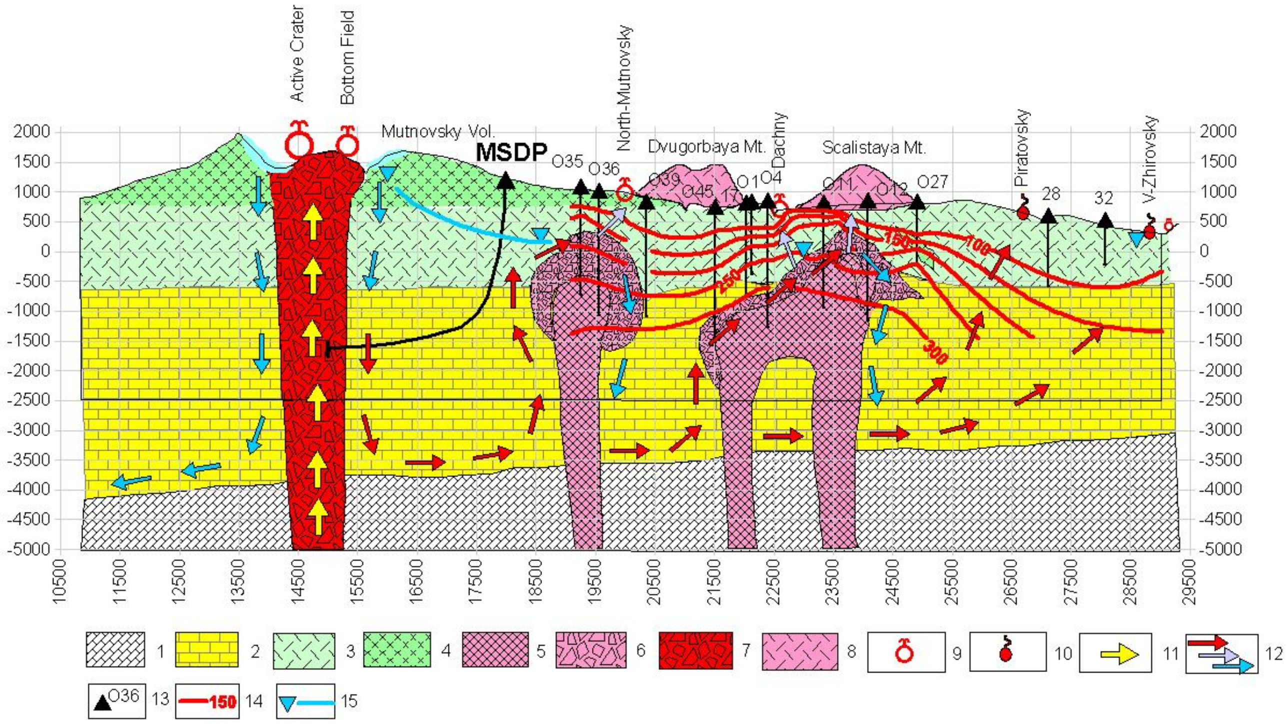

Fig. 2 Cross-section and conceptual hydrogeological model of the Mutnovsky volcano – Mutnovsky geothermal field system: 1 – Crystal basement, 2 – Cretaceous basement and Miocene sandstones, 3- Neogene volcanogenic and sedimentary rocks, 4 – Mutnovsky stratovolcano (Q_3-Q_4), 5 – Diorite intrusions, 6 – Diorite contact zone, 7 – Mutnovsky volcano magmatic system, 8- Acid extrusions (Q_3-Q_4), 9- fumarole fields, 10 – Hot springs, 11- Magma and magmatic fluids, 12 – Hydrothermal fluids, 13 – Geothermal wells, 14 – Temperature distribution (Mutnovsky geothermal field), 15 – Water levels in Mutnovsky hydrothermal system (referenced to m.a.s.l.).
MSDP – potential drilling site for the Mutnovsky Scientific Drilling Program.

Conceptual model of the Mutnovsky volcano magma system

The volcanic geology, structure, and eruptive history has been described in detail by O.B. Selyangin (1993), J. Eichelberger (2005, pers. com.). The volcano has gone through four stages spanning late Pleistocene through Holocene time. Each stage probably reflects the evolution of a small shallow magma reservoir, and the transition from one stage to the next has involved a shift of the eruptive center by as much as 1 km. All stages except for the current incompletely developed stage have produced magmas ranging from basalt to dacite. Mutnovsky IV is characterized by basaltic andesites. Although Mutnovsky grew contemporaneously with nearby Gorely Volcano, there is little or no evidence of interaction between the two magma systems. Mutnovsky III ended its eruptive cycle with Holocene eruption of dacitic pyroclastic flows and emplacement of a dacite dome within its crater. This crater has been enlarged by explosion, collapse, and/or erosion and is now occupied by a crater glacier, the main recharge source of the hydrothermal system. The crater is the scene of intense fumarolic activity, modestly superheated and arranged in a ring, apparently defining the conduit margin of the late dacite dome. A powerful phreatic explosion in 2000 at the edge of the Mutnovsky III "caldera" and adjacent to Mutnovsky IV reopened a large pre-existing crater that had been covered by the crater glacier. The resulting lake was still hot in 2003 but was ice-covered in 2004.

Mutnovsky active crater (Mutnovsky IV) has fumaroles as hot as 507^{o}C and emits a continuous SO_2-rich plume. Total heat output estimated as 1700 MW (B.G. Polyak, 1988, Y.P. Trukhin, 2003)), discharging fumaroles fluids include steam (92.8 wt%), CO_2 (3.3 wt %), SO_2 (2.9 wt %), H_2S (0.6 wt%), HCl (0.3 wt%), HF (0.1 wt%) and H_2 (Y.P. Trukhin, 2003, M. Zelensky, 2003). Clearly, the magma column is very close to the surface and/or maintains a vigorous upward gas flux from degassing sustained by magma convection within the conduit.

Rough estimations of the natural steam upflow rate based on assumed heat output (B.G. Polyak, 1988, Y.P. Trukhin, 2003)) yield to 566 kg/s steam rate with the enthalpy of 3000 kJ/kg. That is equivalent of 480 MWe geothermal Power Plant (if 1.17 kg/s per MWe conversion rate applied to steam at 230-260 bars and 500 ^{o}C, O. Fridleifsson, pers. com., 2005). Based on analysis of the 37 geothermal fields case history sustainable exploitation rate is 5.3 times greater than natural upflow rate (S. Sanyal, 2005), that mean possibility of the 2544 MWe sustainable production from Mutnovsky volcano conduit zone.

Mutnovsky volcano magma chambers modeling studies performed recently by S.A. Fedotov (2005), I.S. Utkin et al (2005) show the following estimations of the shallow Mutnovsky IV magma chamber parameters: elevation -1.7 km, radius 1.5 km, temperature 900-1250 ^{o}C, heat capacity of the chamber and host rocks estimated as 0.3 10^{20} J.

Targets of the Mutnovsky Scientific Drilling Program (MSDP).
Mutnovsky 62 MWe power plants taps a productive zone that strikes toward the highly active vent of the Mutnovsky volcano, 8 km away. Geochemical data supports the view that hydrothermal fluids are derived from the environment of Mutnovsky conduit. This lateral arrangement provides an ideal geometry for exploring the magma-hydrothermal connection by drilling. Objective of this scientific drilling project to be include:

- Identifying magmatic components in fluids proximal to the conduit and their relationship to fluids of producing system.
- Monitoring physical parameters to assess the hydraulic connections of the volcanic and geothermal systems.
- Acquiring and interpreting in terms of magma evolution a nearly complete eruption and chemical history of Mutnovsky volcano.
- In-situ measurement of response of magma-hydrothermal system to frequent earthquakes.
- Determining the overall volatile and thermal budget of the volcano by assessing subsurface hydrothermal convection as well as emission to atmosphere.
- Identifying technical and economical feasibility of the sustainable steam production from Mutnovsky volcano conduit zone.
- Steam contribution to the Mutnovsky PP, in case of significant steam production from scientific well.

References:

Assaulov G.M. et al, 1987, Report on exploration works on Dachny site Mutnovsky geothermal field and feasibility study of the 50 MWe PP (in 7 volumes). *Termalny (in Russian).*

Fedotov S.A., 2005, Magmatic Feeding Systems and Mechanizm of Volcanoes Eruptions. Moscow. *Nauka Publ.,* 300 p.

Kiryukhin A.V., 1993, High-Temperature Fluid Flows in the Mutnovsky Hydrothermal System. Kamchatka, *Geothermics, v.23, No. 1,* pp.49-64.

Kiryukhin A.V., 1996, Modeling Studies: Dachny Geothermal Reservoir, Kamchatka, Russia. *Geothermics, v.26, No.1*, pp.63-90.

Кирюхин А.В., Такахаши М., Поляков А.Ю. и др., 1998, Исследование условий водного питания Мутновского геотермального месторождения с использованием данных по изотопии кислорода (O^{18}) и водорода (D). *Вулканология и сейсмология, №4-5,* с.54-62.

Кирюхин А.В., Лесных М.Д., Поляков А.Ю., 2002, Естественный гидродинамический режим Мутновского геотермального резервуара и его связь с сейсмической активностью, *Вулканология и сейсмология, №1,* С.51-60.

Kiryukhin A.V., Leonov V.L., Slovtsov I.B., Delemen I.F., Puzankov M.Y., Polyakov A.Y., Ivanysko G.O., Bataeva O.P., Zelensky M.E., 2005, Modeling of the exploitation of the Dachny geothermal field in relation to steam supply to Mutnovsky PP. *Volcanology and Seismology Journal , #5*, p.19-44. (in Russian)

Kononov V.I., Povarov O.A., 2005, Geothermal Development in Russia: Country Update Report 2000-2004. *Proceedings World Geothermal Congress 2005*, 7 p.

Polyak B.G., 1988, Heat and mass flux in the main structures of the earth crust. *Moscow, Nauka Publ.*

Sanyal S., 2005, Sustainability and Reniewability of Geothermal Field Capacity. *Proceedings World Geothermal Congress 2005*, 12 p.

Selyangin O.B., 1993, New Data of Mutnovsky Volcano: Structure, Development, Forecast. *Volcanology and Seismology Jour.*, #1, p.17-35.

Sugrobov V.M., 1976, Geothermal Resources of Kamchatka and Possibility of Use. in: *Hydrothermal Systems and Fields of Kamchatka, FEB RAS, Vladivostok*, p.267-291 (in Russian).

Sugrobov V.M.(editor), 1986, Geothermal and Geochemical Studies of High-Temperature Hydrothermal System (Using the Pattern of the Mutnovsky Geothermal Field). *Moscow, Science*, p. 305 (in Russian).

V.M. Sugrobov, V.I. Kononov, O.B. Vereina Possibilities of Kamchatka Geothermal Resources Use, 2004, *IGW, P-Kamchatsky*, 14 p. (in Russian).

Trukhin Y.P., 2003, Geochemistry of the active geothermal processes and geotechnologies applications. *Moscow, Nauka Publ.,* 376 p.

Zelensky M.E., 2003, Transport of the Elements and Minerals Formation in the High Temperature Fumaroles of the Mutnovsky Volcano (Kamchatka) *PhD Thesis,* Novosibirsk, 20 p.

Utkin I.S., Fedotov S.A., Delemen I.F., Utkina L.I., 2005, Dynamics of the Development of Flowing Magmatic Chambers on Mutnovsko-Gorelovsky Group of Volcanoes, their Thermal Fields and Underground Heat Capacity. *Volcanology and Seismology Journal, #5,* 30 p. (in Russian).

Vakin E.A., Kirsanov I.T., Kirsanova T.P, 1976, Thermal fields and hot springs of the Mutnovsky volcanic area, in: *Hydrothermal Systems and Fields of Kamchatka, FEB RAS, Vladivostok*, p.85-115 (in Russian).