PROCEEDINGS, Thirty-Third Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 28-30, 2008
SGP-TR-185

HEAT DISCHARGE OF THE MUTNOVSKY VOLCANO

A. Kiryukhin[1], M. Ramsey[2], V. Droznin[1], A. Carter[2], S. Rose[2],
V. Dvigalo[1], I. Dubrovskaya[1]

[1]- Institute of Volcanology and Seismology FEBRAS, Russia

[2]- University of Pittsburgh, USA
e-mail: avk2@kscnet.ru

ABSTRACT

Mutnovsky volcano's thermal output (≈1122 MWt with temperatures above 600^{o}C) (B.G. Polyak, 1985, is exceptional for a volcano in repose, and suggests robust magma convection within Mutnovsky's conduit. In summer 2007 helicopter's infra-red (IR) survey was done, thermal surface distribution of the Mutnovsky crater floor and adjacent geothermal field areas were obtained, and thermal heat output of the Mutnovsky volcano currently re-estimated as ≈825 MWt.

INTRODUCTION

At Mutnovsky Volcano, Kamchatka, Russia, geothermal production is from a single fracture plane that strikes towards the volcano's crater and taps fluid containing a component whose isotopically appropriate source is the Crater Glacier (Fig.1). Mutnovsky's thermal output (≈1000 MWt with temperatures above 600^{o}C) imply convection magma at a rate at least 1000 kg/s. This is exceptional for a volcano in repose, and suggests robust magma convection within Mutnovsky's conduit. With a system geometry characterized by transition from magmatic vapor to dilute hydrothermal fluid at <2 km depth, Mutnovsky is an attractive drilling target for understanding magma-hydrothermal interactions. Mutnovsky Scientific Drilling Project (MSDP) project will attempt to penetrate Mutnovsky's active conduit (Fig.2). Before drilling, a comprehensive research program, including reassessment of the heat and mass discharge of the Mutnovsky volcano, will play an increasingly important role.

MUTNOVSKY VOLCANO GEOLOGICAL CONDITIONS AND THERMAL OUTPUT

The volcanic geology, structure, and eruptive history has been described in detail by O.B. Selyangin (1993). The volcano has gone through four stages spanning late Pleistocene through Holocene time.

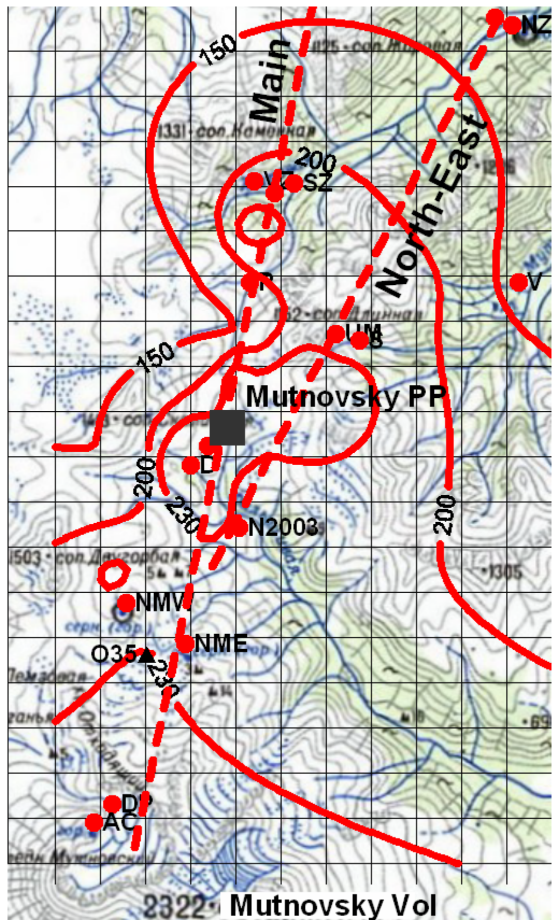

Figure. 1. Hot springs and fumarole fields of the Mutnovsky area (filled circles). Counters are temperature distributions at -250 masl. Dashed lines are high permeability plane zones projections, included production zones of geothermal field and surface thermal manifestations. High permeability plane zones: «Main» (trace at -250 masl) and «North-East» (Kiryukhin et al., 1998, 2005). Triangle-well 035, closest to the Mutnovsky crater well. Grid size is 1 km.

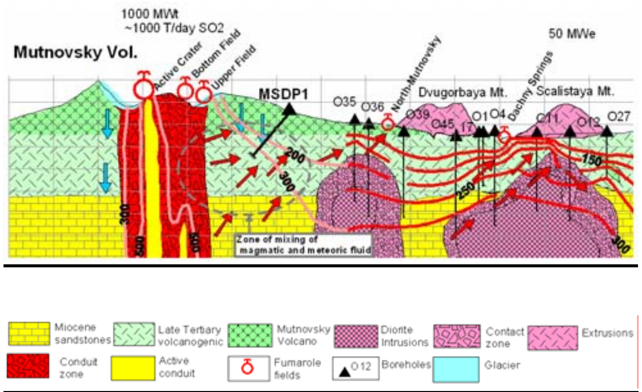

Figure. 2. Sub-meridional cross-section and conceptual geothermal-hydrogeological model of the Mutnovsky volcano – Mutnovsky geothermal field system. MSDP – potential drilling site for the Mutnovsky Scientific Drilling Program.

Each stage 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. 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, probably the main recharge source of the hydrothermal system. Enlargement of the crater has exposed a magnificent dike swarm. If dikes are continuing to intrude the system, either as feeders from depth or as "magma-fractures" off the central conduit, this would provide another means by which heat could be transported beyond the edifice to the zone of geothermal production.

The crater of Mutnovsky III 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. This event appears to have been caused by a dike propagating upward and intersecting the hydrothermal system centered beneath Mutnovsky III, as a crack system opened over a length of a few kilometers, transecting the Mutnovsky III and IV craters and the west flank of Mutnovsky IV.

Fumaroles of the volcano are localized within three fields: Upper Field, Bottom Field and Active Crater, hereafter UF, BF and AC (Fig. 3). UF and BF are situated 200 m from each other inside Mutnovsky III crater. The active crater of Mutnovsky IV is situated 600 m southwestward, with a variety of high-temperature and powerful fumaroles on its floor and western wall. The maximum temperature of gases was 620°C in 2005. 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 must maintain the vigorous upward gas flux by sustained magma convection within the conduit.

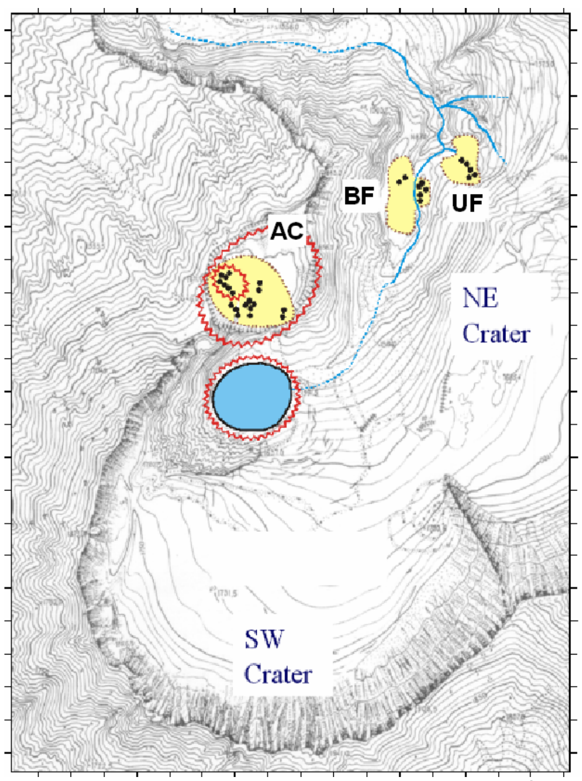

Figure. 3. Mutnovsky volcano thermal fields (Zelensky, 2006): UF – Upper Field, BF – Bottom Field, AC – Active Crater. Blue lake – site of the phreatic explosion 2000. Grid scale – 100 m.

Previously performed studies of the Mutnovsky volcano craters thermal output yield the following results.

North crater of Mutnovsky volcano (Bottom and Upper Fields) heat output was estimated as 373 MWt (B. Polyak, 1966) based on direct field measurements of the steam jets rates and heat flows. Description of the AC fumaroles chemistry and flow characteristics was made by E.A. Vakin et al (1966). Estimates of the thermal output from Active Crater (AC) based assumption specific steam rate at the crater floor is 27 g/s (similar to UF values) and area of steam discharge 18000 m2, that yield 1432 MWt, and total Mutnovsky heat discharge 1814 MWt (B. Polyak, 1966).

Heat discharge from Active Crater (AC) of Mutnovsky Volcano estimated as 1676 MWt (Vakin et al, 1976), but no any details of estimations mentioned.

Later heat and mass flows discharge Bottom Field (BF) and Upper Field (UF) estimations (Muraviev et al, 1983) based on individual fumaroles rate measurements data, shallow (0.15-1.0 m) temperature measurements distributions data, hot lakes and streams temperature measurements (most measurements conducted in 1980 year). Heat output from UF estimated as 281 MWt, from BF - 93 MWt. It was found that 85% of the heat discharges from fumaroles, 8.6% carried out by Volcannaya river, 3.4% from surface of hot lakes, 2.6% from steam grounds and less than 1% by conductive heat transfer. Fig. 4 shows temperature distribution at depth 0.15 m obtained as one of results of this survey.

Ground based IR-survey (Polyak et al, 1985) performed (infra-red camera СМОГ-1К used) to obtain surface temperature distribution of the BF, UF and Active Crater. Total IR emission of the BF and UF estimated as 4 MWt with thermal area of 40000 m^2. Fig. 4 shows IR estimated temperature distribution of the UF. Active Crater walls IR emission estimated as 7 MWt with thermal area 37000 m^2, not including bottom parts of the Active Crater, located outside of the ground IR-survey area scope (Fig. 5). It was found that ground surfaces under 50°C yield 59% of the total emission, surfaces with temperature range 50-200°C yield 36% emission, and high temperature areas above 200°C yield just 5%. It was concluded by authors (Polyak et al, 1985), that if the fraction of IR emission is the same in the heat output balances of the BF, UF and Active Crater, then total heat discharge from Active Crater should be around double of them, e.g. 748 MWt. That is significantly lower, than assumed before (Polyak, 1966), but nevertheless the total heat discharge of Mutnovsky volcano estimated as 1122 MWt. Its worth to note, that according to Fig.5 the most steam/gas discharge in AC seems to be from a single area ≈75 m x 10 m (horizontal x vertical dimensions) above 150°C located in the western (280-310 deg NWW) part of the crater wall. This area known as "Comb of Tamara" is a site of the dyke emplacement during eruption 1960.

Note also, that recently performed satellite SO_2 emission observations yield a range of 74 - 488 T/d (S. Carn, pers. com. 2007). If SO_2 mass concentration assumed to be 2.9 wt%, then steam discharge rate estimated as 29.5 - 194.8 kg/s, which correspond to heat discharge rate 104 – 689 MWt, if 3000 kJ/kg steam enthalpy used and 85% of heat discharge assumed to be convective. But these SO_2-based estimations are preliminary and should be verified.

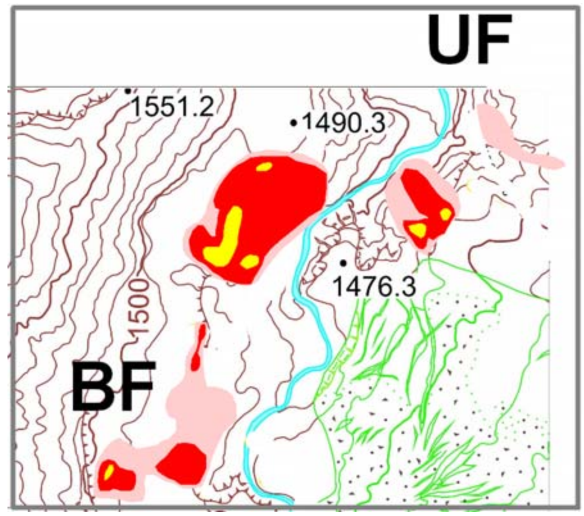

Figure. 4. Bottom Field (BF): temperature distribution at depth 0.15 m in 1981 (Muraviev et al, 1983): pink – above 30°C, red – above 40°C, yellow – above 90°C. Upper Field (UF), IR-estimated temperature distribution at the surface (Polyak et al, 1985) pink – above 30°C, red – above 40°C, yellow – above 50°C. Apparently, north-east part of the UF missed from (Polyak et al, 1985) paper.

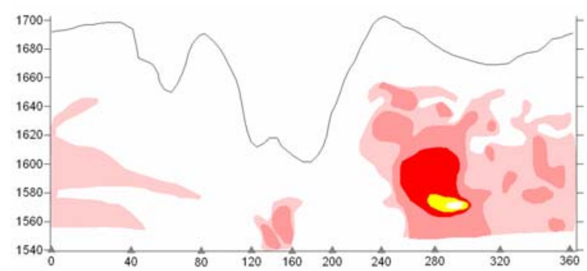

Figure. 5. Active Crater: IR-estimated temperature distribution at the wall surface (Polyak et al, 1985). Horizontal axe is azimuth angle. IR-temperature areas: light pink – above 35°C, dark pink – above 40°C, red – above 100°C, yellow – above 150°C, white inside yellow – above 200°C. The rest area of the crater wall is characterized by 25-35°C IR temperatures.

HELICOPTER IR-SURVEY 2007

In summer 2007 helicopter's MI-8 infra-red survey was done using FLIR camera S40 to identify surface temperature distribution and points of the prominent steam discharges of the Mutnovsky crater floor and adjacent geothermal field areas. IR-survey resolution estimated as 1.6 m. Based on IR-survey performed thermal anomalies of the Active Crater (AC), Bottom Field (BF) and upper field (UF), and a new thermal anomaly WF, located 300 m west to Bottom Field (BF) were detected (Fig. 6).

It also noted, that phreatic explosion-2000 lake disappeared, while cold water still trapped in the fractures of the glacier at the lake bottom.

At this time south part of the BF thermal anomaly significantly shifted eastward (compare Fig. 4 and 6, 7). A new hot spot between south and north parts BF appeared too.

UF thermal anomaly significantly extended into north-east direction and partially warm-up up to 65^{o}C IR temperature, compare to 50^{o}C in 1980 (compare Fig. 4 and 6, 7).

Its difficult to compare ground-based (1983) and helicopter-based (2007) Active Crater IR-images since different projections used, but obviously "Tamara Comb" temperature declined and three new anomalies appeared in the crater floor (compare Fig. 5 and 6, 7).

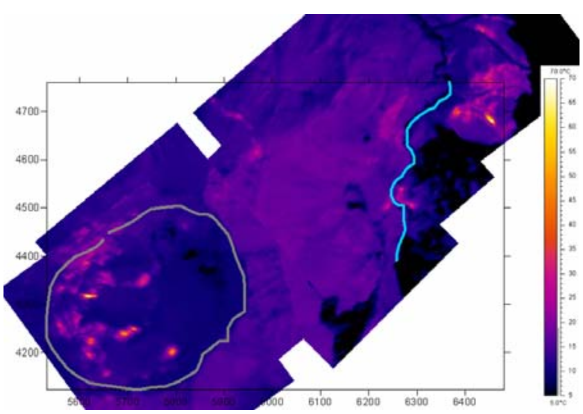

Figure. 6. IR-image of the Mutnovsky Volcano crater's. Active Crater rim shown as a gray circle, Volcannaya river is a blue line.

MUTNOVSKY VOLCANO CRATERS IR-EMISSION AND HEAT DISCHARGE ASSESSMENT

The surface IR-temperature distributions of the fumaroles fields yield the following estimations of the thermal output areas (Fig.7): Bottom Field: 5075 m^2 with temperatures above 30^{o}C; West Field (located 300 m west from BF): 1420 m^2 with temperatures above 30^{o}C; Upper Field: 12860 m^2 with temperatures above 30^{o}C, 2330 m^2 with temperatures above 40^{o}C, and 115 m^2 with temperatures above 60^{o}C; Active Crater: 17810 m^2 with temperatures above 30^{o}C, 2400 m^2 with temperatures above 40^{o}C, and 90 m^2 with temperatures above 60^{o}C.

Total IR emission in the Mutnovsky volcano craters from surfaces above 30^{o}C is estimated as 4.8 MWt, including 2.1 MW from Active Crater, 1.8 MWt from Upper Field, 0.7 MWt from Bottom Field, and 0.2 MWt from West Field. Ambient temperature 10 ^{o}C and emission coefficient 0.92 was used in these estimations.

If we'll use B. Polyak et al (1985) assumption, that the fraction of IR emission is the same in the heat output balances of the BF, UF and Active Crater, then total heat discharge from Active Crater should be around equal of them, e.g. ≈374 MWt. That is two times lower, than assumed before (Polyak, 1966). Hence, the total heat discharge of the BF, UF and Active Crater estimated as ≈750 MWt. Using the same assumption and adding WF we'll get ≈825 MWt as a total heat output of Mutnovsky volcano craters.

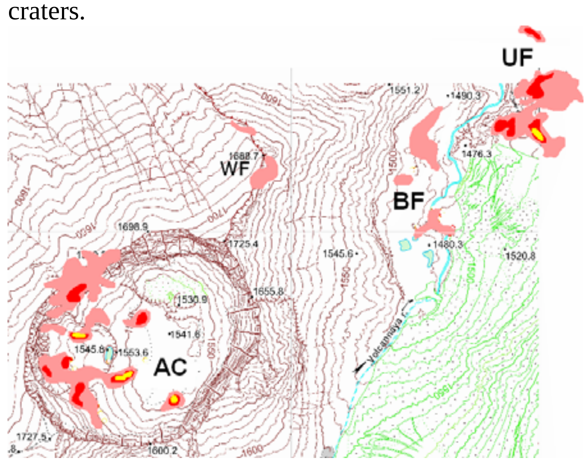

Figure. 7. IR-temperature distribution (August 2007) of the Mutnovsky Volcano craters. AC- Active Crater, BF – Bottom Field, UF- Upper Field, WF – West Field, thermal anomaly 300 m west from Bottom Field. IR-temperature areas: pink – above 30^{o}C, red – above 40^{o}C, yellow – above 60^{o}C.

In spite of similar IR emission rates, the Active Crater steam output visually looks significantly greater, compare to BF and UF (Fig. 8), that may reflect our underestimation of the AC because of difficulties to get IR images from subvertical crater's walls during helicopter IR-survey.

Additional steam may also come from recently erupted lava flows located at the north-western slope of the Mutnovsky-IV and adjacent to the north-western rim of the Active Crater. These lava flows may still release heat.

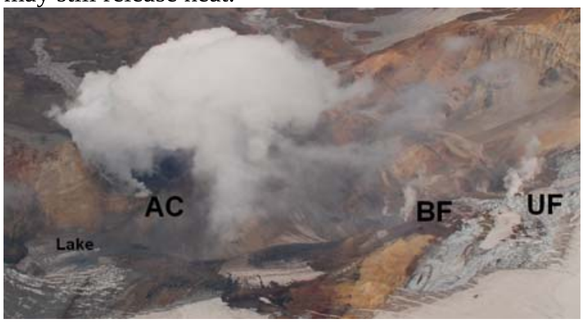

Figure. 8. Mutnovsky Volcano craters aerial view: AC- Active Crater, BF – Bottom Field, UF- Upper Field. Photo's by E. Shushlin.

CONCLUSIONS

Based on helicopter IR-survey performed in 2007 the thermal anomalies of the Active Crater (AC), Bottom Field (BF) and upper field (UF), and a new thermal anomaly WF, located 300 m west to Bottom Field (BF) were characterized by the total area 37200 m^2 with temperatures above 30^{o}C, 4500 m^2 with temperatures above 40^{o}C, and 210 m^2 with temperatures above 60^{o}C. Total IR emission in the Mutnovsky volcano craters from surfaces above 30^{o}C is estimated as 5.2 MWt.

If B. Polyak et al (1985) assumption, that the fraction of IR emission is the same in the heat output balances of the BF, UF and AC used, then the total heat discharge of Mutnovsky volcano craters estimated as ≈825 MWt.

Nevertheless, that value may reflect our underestimation of the AC because of difficulties to get IR images from subvertical crater's walls. This study is on-going.

ACKNOWLEDGEMENTS

Valuable help from Prof. John Eichelberger, Director of the South Kamchatka Natural Park Anatoly Kargopoltsev, Dr. Boris Polyak and Dr. G. Gavrilenko are highly appreciated. This work was supported by International Continental Drillling Program (ICDP), FEB RAS project 06-I-OH3-109 and RFBR project 06-05-64688a.

REFERENCES

J. Eichelberger, A. Kiryukhin Scientific Drilling Project on Russia's Mutnovsky Volcano EOS, Transactions, American Geophysical Union V.87, #50, 2006.

Kiryukhin, A. V., Leonov, V. L., Slovtsov et al (2005) Modeling the utilization of area Dachny of the Mutnovsky geothermal field in connection with the supply of heat-transfer agent to the 50 MW Mutnovskii Geothermal Power Station. *Volcanology and Seismology Journal,* **5**, 19-44 (in Russian).

Polyak B.G. (1966) Geothermal features of the recent volcanism areas (Kamchatka). Moscow, Nauka Publ., p.108-128 (in Russian).

Muraviev A.V., Polyak B.G., Turkov V.P., Kozlovtseva S.V. (1983), "Reassessment of the Heat Discharge of the Mutnovsky Volcano Fumaroles (Kamchatka)" *Journal of Volcanology and Seismology*, **5**, 51-63 (in Russian).

Polyak B.G., Bezuh B.A., Kaftan V.I., Kuzmin A.I., Kuzmin Y.D., Stelmashok V.E., Turkov V.P. (1985), "Experience of the Ground IR-survey for Temperature and Heat Emission Estimation of the Mutnovsky Volcano Thermal Fields (Kamchatka)," *Journal of Volcanology and Seismology*, **3**, 54-63 (in Russian).

Selyangin O.B. (1993) New about Mutnovsky volcano. *Volcanology and Seismology Journal*, (1), 17-35 (in Russian).

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

Vakin E.A., Kirsanov I.T., Pronin A.A. (1966) Active Crater of Mutnovsky Volcano. *Bulletin of Volcanological Stations*, #40, p. 25-35 (in Russian).

Vakin, E.A., Kirsanov, I.T., Kirsanova, T.P. (1976) Hot areas and thermal springs of the Mutnovskii volcanic region. *Gidroterm. Sist. Term. Polya Kamchatski*, p. 85-114 (in Russian).

Vakin, E.A., Pilipenko, G.F., Sugrobov, V.M. (1986) General characteristics of the Mutnovsky deposit and prediction of resources. *Geoterm. Geokhim. Issled. Vysokotemp. Gidroterm*, p. 6-40, (in Russian).

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.