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INVESTIGATION OF RECHARGE OF MUTNOVSKY GEOTERMAL FIELD WITH USE THE ISOTOPE OXYGEN (O^{18}), HYDROGEN (D) AND TRITIUM (T) DATA.

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ABSTRACT

Based on the isotopic analysises of fluids from wells and meteoric waters of Mutnovsky geotermal field (O^{18}, D and T) is drawn a conclusion that water from melting glacier of the crater of the Mutnovsky volcano may be a source of recharge of geotermal fluids of Dachnny and Verhne-Mutnovsky site of the Mutnovsky geotermal field of Kamchatka.

1. INTRODUCTION

Development of the Kamchatka geothermal fields : Mutnovsky (from 12 MWe to 80 MWe) and Pauzhetsky (from 11 MWe to 25 Mwe) should be accomplished with appropriate stable isotope (D , O^{18}) monitoring programme to identify recharge of cold and reinjected water , high temperature fluid up-flow zones in geothermal reservoir and to design optimal exploitation load.

T,D and O^{18} sampling of the Dachny site of the Mutnovsky geothermal field was performed in 1986-1990 (including long term multi-well flow tests period) [2,5,6,8]. New production wells (048, 049N and 055) were drilled last years in Verkhne-Mutnovsky site of the Mutnovsky geothermal field, where pilot plant 12 MWe was decided to build based on wells aforementioned above. So , our studies in Mutnovsky field were focused on Verkhne Mutnovsky site , where additional flow tests and corresponding fluid sampling were performed (Fig.1).

2. DESCRIPTION OF RESEARCH CARRIED OUT

Following studies were conducted :

Fluid sampling from production wells 049N and 048 was performed during flow test period , as well as sampling of snow , and meteoric water , and well 014 (Dachny site) was made (Table 1,2,3) . D O^{18} and chemistry analysis were executed in Geothermal Department of the Geological Survey of Japan. Analysis of all available D , O^{18} and T data (Taran, 1986 ,Table 4, Kiryukhin,1993,1995) was performed to understand possible mechanizm of recharge in the Mutnovsky geothermal field.

D, O^{18} and chemistry data (Table 1) from wells 045 , 01, 014, 1, 24 (Dachny) and 037, 048 , 049N (Verkhne-Mutnovsky) were used too to identify high temperature upflow zones in geothermal reservoir and to confirm possible flows directions.

3. RESULTS OBTAINED

3.1 MECHANIZM OF RECHARGE IN THE MUTNOVSKY GEOTHERMAL FIELD

All sampling from wells was performed using liquid part of two phase mixture derived from James tank after single step separation under atmospheric conditions. According to Arnason, 1976 , we used the following correction for steam losses:

$$\delta_0 O^{18} = \delta_L O^{18} - 0.975\,(t_0/100 - 1)$$

$$\delta_0 D = \delta_L D - 4.63\,(t_0/100 - 1)$$

-where o - index of initial value of D or O^{18}, L - the same in liquid part after separation under atmospheric conditions , t_0 - initial temperature of fluid . In case of boiling in reservoir due to fracture/matrix interaction fluid is getting some heat through heat conduction mechanizm from matrix, so in that case Arnason formulaes were modified:

$$\delta_0 O^{18} = \delta_L O^{18} - 0.2105\ 10^{-2}\,(h_0 - 419.4)$$

$$\delta_0 D = \delta_L D - 0.9996\ 10^{-2}\,(h_0 - 419.4)$$

where h_0- discharge enthalpy of well.

So, to avoid overestimations of D and O^{18} values modified Arnason formulaes were used . Table 2 shows isotope composition of fluids from wells of Mutnovsky geothermal field with steam losses corrections.

Tables 3 and 4 shows isotope composition of meteoric waters of Mutnovsky geothermal field.

Fig.2 summaries data of Tables 2,3 and 4. All high temperature fluids sampled from geothermal wells belongs to the region -13.6‰ $<\delta_0 O^{18}<$ -15.2‰ and -109.3‰ $<\delta_0 D<$ -115.8‰ in D-O^{18} diagram. Generally, fluids from Verkhne Mutnovsky (wells 049N and 048) have a positive shift in D-O^{18} diagram (about 1.5‰ in $\delta_0 O^{18}$) compare to wells from Dachny (wells 01, 1 , 24) , which may indicate that Verkhne Mutnovsky fluids spent more time in geothermal reservoir , compare to Dachny fluids . Meanwhile , possible original meteoric water source (recharge fluid) defined as intersection of meteoric line and "hot fluids" line seems to have similar isotope composition (about ($\delta_0 O^{18}$, $\delta_0 D$) = (-15.7‰, -115‰)) for both sites: Verkhne-Mutnovsky and Dachny.

Meteoric waters widely distributed along "meteoric water" line. Especially wide range is for snow and rain samples (δO^{18}, δD) $\subset$ (-21.77‰, -10.61‰) x (-163.4‰, -62‰) (which may explain very strong wind conditions in area), contrary meteoric water samples from cold streams and springs , which "averaged" snow and rain distributions , occupy more close range along "meteoric line" (δO^{18}, δD) $\subset$ (-17.4‰ , -12‰) x (-124‰, -84‰). Note , that meteoric waters from cold streams and springs of Dacny and Verkhne-Mutnovsky ((δO^{18}, δD) $\subset$ (-14.3‰ , -12.0‰) x (-100‰ , -87‰)), average δO^{18} = - 13.5‰, δD=-93.5‰ - are heavier than geothermal fluids from wells. That means, recharge area for geothermal fluids has higher elevations, than + 800 - +900 masl. Arnason (1976) found that D Increase rate is about 3%0 per 100 m of elevation per Iceland conditions. If similar rate appropriate for Kamchatka, about 700 m additional elevation needed for recharge area to be consistent with isotopic data . So , possible recharge area should be about +1500 masl. Another necessary requirement for the recharge area - a low tritium concentrations,since deep wells an Mutnovsky geotermal field show in average 2.7 TE , though average values for meteoric water form 15.1 TE (1986-1988 ye.)[5]. Sufficiently high real velocities to filtrations in the geotermal reservoir (16 - 28 м/day [5]) be indicative of that even when moving a fluid from the area of discharge before the geotermal reservoir on paths by the length 15-20 km - a time of stay a fluid in the system will form not more than 3,5 years , i.e. source concentration a tritium must not greatly change to the account of natural disintegration (half-decay of tritium 12,33 years).

One of the possible places to be considered as a recharge area for geothermal fluids may be the glacier in the crater of Mutnovsky volcano , melting part of which is located at elevations +1400 - +1500 masl. The rate of melting is enough to feed the Vulcannaya river with discharge 150 - 1500 kg/s, so its may cover 55 kg/s of high temperature ascending flow in Dachny and Verkhne Mutnovsky (ascending flow estimations were made by Kiryukhin, 1996). Moreover , ice water should be low tritium concentrations (Kiryukhin,1993), that is satisfy mentioned above requirement for possible recharge area too.

(Though Vulkannaya river on output from the crater of Mutnovsky vulcan and is not "sterile" on 100% in respect of the tritum and has 12 TE (test selection is executed in 1986 , analysis - V.V.Romanov in IWP AS USSR) , it is necessary to take into account that this products of hiding a glacier , diluted by the atmospheric precipitation .)

Note, there is no other possible places in area to be considered as recharge areas for geothermal fluids of Dachny and Verkhne Mutnovsky. Although Gorely volcano top is 1812 masl , almost all caldera floor is lower than +1200 masl, and there is no low tritium source inside caldera (17 TE) , because there is no glaciers in caldera. Other mountains in area : Skalistaya and Dvugorbaya are to low (less than 1.4 km) to be considered as possible recharge areas , and there is no glaciers (low tritium sources) on those mountains too.

3.2 HIGH TEMPERATURE UPFLOW ZONES IN GEOTHERMAL RESERVOIR AND POSSIBLE FLOWS DIRECTIONS

The Truesdell Na/K geothermometer (Fournier, 1981) and Cl/SO_4 ratio were used to identify possible high temperature upflow zones in the field and to trace circulation patterns, by following the path of increasing temperatures (Table 1) . At current time , two such zones were confirmed : 1). Main upflow zone (around wells 01 and 045) with T_{Na-K} up to 303 °C, Cl/SO_4 up to 4.83 and 2) North-East-2 upflow zone (around well 048) with T_{Na-K} up to 270 °C, and Cl/SO_4 up to 2.04.

Wells 01--> 1 --> 014 --> 24 are tracing ascending part of circulation pattern from Main upflow zone (Cl/SO_4 decrease from 3.06 to 0.93) . Circulation patterns around North-East 2 upflow zone are not clear at current time : there may be in two directions : 048 --> 049N and 048 --> 037 (Cl/SO_4 decrease from 2.04 to 1.83 - 2.01)).

CONCLUSIONS

1.Water from melting glacier in the crater of the Mutnovsky volcano is a very possible recharge area of geothermal fluids of Dachny and Verkhne Mutnovsky site of the Mutnovsky geothermal field.

2.Additional isotopic (D , O^{18} and T) studies of meteoric waters in the crater of Mutnovsky volcano may be usefull to completly confirm idea, concluded above.

3. Simulation of more reliable recharge conditions in the model - allow us to more realistic 3-D numerical model and geothermal poteintial assesment of the Mutnovsky field.

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Table 1. Some Chemistry and Termodynamic Properties of Fluids (water after separation in James tank at atmospheric conditions) from Wells of Mutnovsky Geothermal Field **(in ppm).**

Date	Well	Enthalpy, Kj/kg	SiO_2	Na	K	SO_4	Cl	TDS*	T_{SiO2}	T_{Na-K}	Cl /SO_4
11.91	045**	2320	890	320	70.0	90	435	1805	311	291	4.83
08.88	01	1500	1340	230	54.0	100	306	2030	304	303	3.06
09.88	014	2050	666	247	46.0	182	238	1379	280	266	1.31
09.95	014			226	39.1	120	242			255	2.00
09.88	1	1450	1050	247	49.0	192	240	1778	279	276	1.25
09.88	24	1400	1002	247	49.0	235	218	1751	274	276	0.93
07.93	037	1665	742	243	41.3	134	244	1406	291	253	1.82
07.96	048	1506		259	49.4	129	261			270	2.04
07.93	049N		965	250	42.5	154	237	1659	270	253	1.54
12.95-05.96***	049N	1260		256	49.5	129	260			270	2.01

Notes: 1.Enthalpy-Discharge data and Chemistry data of well 045 from Asaulova N.P. et al (1994)

2.Chemistry analysis (1988-1993) were made in the Central Chemistry Laboratory of the Institute of Volcanology by V.Marynova

3.Chemistry analysis (1995-1996) were made in the Geological Survey of Japan by Mr. Takahashi

4.Sampling of wells except of mentioned in 1). were made by A.V.Kiryukhin (1986-1993)

Table 2. Isotope composition of fluids from wells of Mutnovsky geothermal field (water after separation in James tank at atmospheric conditions)

Sample	Date	Well	6D ‰	δO^{18} ‰	Enthalpyk Jlkg	Steam loses corrected	
						δO^{18} ‰	δD‰
MK96-1	13.12.95	049-N	-100.9	-11.91	1260	-109.3	-13.68
MK96-1	**13.12.95**	**049-N**	**-101.5**		**1260**	**-109.9**	
MK96-2	**20.12.95**	**049-N**	**-102.1**	**-12.28**	**1260**	**-110.5**	**-14.05**
MK96-2	**20.12.95**	**049-N**	**-101.9**		**1260**	**-110.3**	
MK96-3	**27.12.95**	**049-N**	**-101.5**	**-12.19**	**1260**	**-109.9**	**-13.96**
MK96-5	**14.02.96**	**049-N**	**-101.3**	**-12.23**	**1260**	**-109.6**	**-14.00**
MK96-7	**22.02.96**	**049-N**	**-102.0**	**-12.34**	**1260**	**-110.2**	**-14.11**
MK96-9	**28.02.96**	**049-N**	**-101.9**	**-12.31**	**1260**	**-110.3**	**-14.08**
MK96-11	**10.03.96**	**049-N**	**-101.1**	**-12.37**	**1260**	**-109.5**	**-14.14**
MK96-12	**18.04.96**	**049-N**	**-101.5**	**-12.16**	**1260**	**-109.9**	**-13.93**
MK96-13	**24.04.96**	**049-N**	**-101.5**	**-12.27**	**1260**	**-109.9**	**-14.04**
MK96-16	**1.05.96**	**049-N**	**-101.7**	**-12.31**	**1260**	**-110.1**	**-14.08**
MK96-17	**7.05.96**	**049-N**	**-101.2**	**-12.35**	**1260**	**-109.6**	**-14.12**
MK96-21	**28.07.96**	**048**	**-101.3**	**-12.25**	**1500**	**-112.2**	**-14.51**
MK96-22	**10.08.95**	**014**	**-98.4**	**-11.34**	**2050**	**-114.7**	**-14.77**
MK96-23	**1.09.95**	**014**	**-96.8**	**-11.17**	**2050**	**-113.1**	**-14.60**
MK88-51	**2.08.88**	**01**	**-102.0**	**-12.8**	**1500**	**-112.8**	**-15.07**
MK88-86	2.07.88	1	-104.0	-13.0	1450	-114.3	-15.17
MK88-129	9.09.88	24	-106.0	-13.0	1400	-115.8	-15.06

Notes: 1.Samples were collected by A.Kiryukhin,A.Polyakov & M.Lesnykh (Institute of Volcanology)

2. Analysis of samples marked as MK95-** & MK96-** was performed by M.Takahashi (Gcoiogical Survey of Japan)

3. Analysis of samples marked as MK88-** was performed by V.Polyakov & A.Bobkov (All Union Hydrogeological Institute , Moskow)

Table 3 Isotope composition of meteoric waters of Mutnovsky geothermal field

Sample	**Date**	**Location**	**δD ‰**	**δO^{18} ‰**
MK96-4	**10.02.96**	**Snow-Dachny**	**-105.0**	**-15.04**
MK96-6	**19.02.96**	**Snow-Dachny**	**-163.4**	**-21.91**
MK96-8	**26.02.96**	**Snow-Dachny**	**-76.8**	**-13.55**
MK96-10	**4.03.96**	**Snow-Dachny**	**-146.8**	**-19.46**
MK96-14	**24.04.96**	**Snow-Dachny**	**-72.6**	**-10.68**
MK96-19	**29.05.96**	**Snow-DachnyF**	**-100.3**	**-13.84**
MK96-20	**31.05.96**	**Snow-VMutnov**	**-100.3**	**-12.07**
MK96-24	**17.08.96**	**Creek-VMutno**	**-87.6**	**-12.10**
MK88-157	**08.88**	**Creek-Dachny**	**-99.0**	**-14.1**

Notes: 1.Samples were collected by A.Kiryukhin,A.Polyakov & M.Lesnykh (Institute of Volcanology)

2. Analysis of samples marked as MK95-** & MK96-** was performed by M.Takahashi (Geological Survey of Japan)

3. Analysis of sample marked as MK88-157 was performed by V.Polyakov & A.Bobkov (All Union Hydrogeological Institute , Moskow)

Sample	Date	Location	δD ‰	δO^{18} ‰
T1	08.83	Falshivaya riv.	-89	-13.6
T2		Well T39	-100	-14.3
T3		Creek-Vulcanny site	-84	-12.6
T4		Vulcannaya riv	-91	-14.1
T5	78	Falshivaya spg	-87	-13.7
T6	04.83	Well V-8	-96	-12.7
T7	08.83	Creek-crater of Mutnovsky	-101	-14.4
T8		Snow-Gorely	-76	-12.1
T9	04.83	Snow-Dachny	-83	-12.9
T10	08.83	Rain-Dachny	-82	-11.0
T11	07.82	Creek-Mutnov -sky glacier	-124	-17.4

Fig. 2 D & O18 distribution in fluids of Mutnovsky geothermal field.

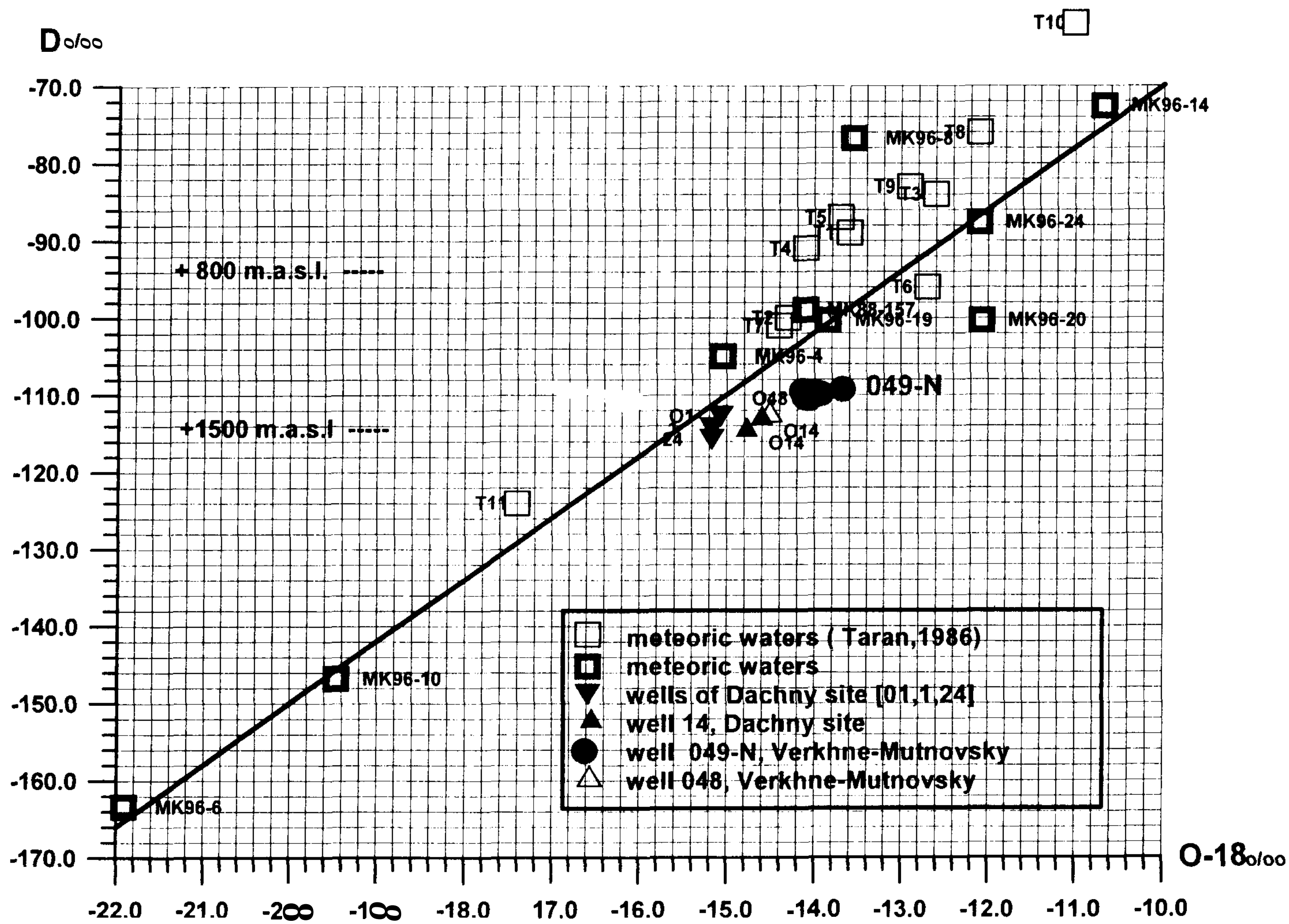

Fig.1 Schematic map of the Mutnovsky geothermal field
● - wells
● -thermal manifestations
---------- - fracture system planes