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HIDDEN TRENDS IN PRESSURE TIME SERIES MEASURED IN A GEOTHERMAL RESERVOIR IN KAMCHATKA AND ITS CONNECTION WITH SEISMIC ACTIVITY

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ABSTRACT

Hidden trends in pressure time series measured in a geothermal reservoir of Mutnovsky geothermal field situated near the active crater of volcano Mutnovsky and the caldron of volcano Gorely in Kamchatka are revealed.
During 1995 - 2001, monitoring of hydrodynamic regime has been conducted. It included pressure registration at the depth of 950 m, the data being taken every five minutes.
Intervals of hidden periodicities are detected. Correlation between the pressure variations and the time of seismic activity is revealed.
The obtained results are useful for the detection of short-term pre-seismic and post-seismic anomalies.

INTRODUCTION

It is a common knowledge that high-temperature geothermal reservoirs are dated for active fractures of deep site, by which the transportation of magma materials to the surface of the Earth, and accordingly the changes of the tensity of mountain rock, following up by earthquakes and (or) eruptions of volcanoes are carried out. The pressure of geothermal fluids is closely connected to pressure in mountain rocks, controlling disclosing of breaks and relative volume of crack-gangue of space, and the changes of the tensity in local volume of geothermal reservoirs can be carried over with enough high speed (thousand m/day) in "global" hydrodynamical volume of geothermal reservoir [1]. In this connection the monitoring of thermal-hydrodynamical parameters in the geothermal reservoirs can be useful for the indication of the preparation of seismic and volcanic event.
There is some information showing the connection of a hydrodynamical regime of geothermal reservoir Krabla (Iceland) with eruptions of title volcano [2]. The continual observations for hydrodynamical regime of wells, which are done in the Geological service of Japan during 10 years in the 6 wells, show that in some wells during some hours before earthquake the variations of a hydrodynamical regime begin, and radius of the hydrodynamical echo D (distance from the epicenter up to the point of observation, km) is connected with magnitude M by the formula $M = 2.45 \cdot IH \cdot D + 0.69$, where M is the magnitude of the earthquake [3]. Recently the continual observations with using of “capillary tube” system in high-temperature geothermal well (temperature 194°C, depth 1005m) in the caldera Nigorikava (Hokkaido island) within the limits of the title geothermal deposit (it should be noticed that geothermal electro station has been already used for a long time there, capacity 50 MW) are done. By results of the observation (1993-1995) the hydrodynamical variations which are connected with seismic events (earthquake in Koba, 01.1995 etc.) are marked.

The observations in Kamchatka, which are done by Institute of Volcanology (Far East Branch Russia AS) on the sources and well GK-1 (station Pinachevo, acentric part of Ketkino geothermal deposit, 40°C) show enough postseismic reaction (increase of the charge and connected macrocomponents of chemical structure) in most cases [2], however, frequency of registration of observable parameters (once in 3 days) does not allow to answer a question about the existence of short-term pre-seismic anomalies.

With the account of aforesaid, the statement of works on monitoring of hydrodynamical regime in Mutnovsky geothermal reservoir which is not far from two active volcanoes: Mutnovsky and Gorely, is of interest. In the district of geothermal deposit 89 wells were bored hardly with the average depth about 1.5 km, and some areas of a deposit will be hardly exploited in the future (Volcany area), while the commissioning of other areas (Dachny, Verhne-Mutnovsky) is postponed for uncertain time due to financional problems - that has created the preconditions for finding the mechanism of thermal-hydrodynamical anomalies in conditions of non broken operation of the regime, and using of the revealed legitimacy during the operation.

The continual observation over the changes of hydrodynamical pressure in high-temperature geothermal reservoirs of Kamchatka in connection with the forecast of volcanic and seismic activity have begun to be carried out for the first time since September 1995. In the Mutnovsky geothermal deposit in the well 30 on the depth of 950 m the system for continuous registration of pressure in the geothermal reservoir - "capillary tube " was installed (works were carried out together with the Geological Service of Japan within the framework of the Russian-Japanese project "Volcanoes and volcanic energy").
The time series were analyzed for the first time in works [4-5]. In these works two strong hydrodynamical anomalies with the amplitude of pressure variations more than 6σ, synchronized with seismic events with magnitude 4.1-4.5 in the distance of 82-112 km from the observation point, were revealed. Strong earthquakes with K_s>11were taken as examples. This work is a continuation of these investigations. In this work correlation of pressure variations not only with strong earthquakes, but also with the weak seismic events with K_s>7 is shown. Besides the limits on the coordinates of seismic events, influencing researched geothermal system, will be stated here.

METODOLOGY OF MEASUREMENT

The system " capillary tube " which is made by Pruett Inc. includes the following components: 1. Tube from corrosion-proof steel, 3.2 mm in diameter and 1500 m length, which is established on the winch with the drum 300 mm in diameter; on the end of the tube, lowered in the well, there is a camera which length is 3 m and centralizator, 2. Transduser (device for transformation of changes of pressure to electrical signal on input of cable RS232), 3. The portable personal computer for record of the indications of pressure on the diskette, 4. The storage battery 12 V (60 A*h), 5. The solar battery (SP) (20 V, 3 A at the maximal lightness), 6. A cylinder with helium (1500 PSI = 10.5 MPa), device for the recharge of the accumulator from the solar battery. For lowering of capillary tube in the well 30 special lubricator was used also. The registration of pressure is carried out on the depth of 950 m, the record is made every 5 minutes, and the result records on a magnetic disk. The system "capillary tube " is made by firm Pruett Inc (USA) and is given to Institute of Volcanology by Geological Service of Japan within the framework of the project of the international scientific and technical cooperation. The technology of operation of the system "capillary tube" provides periodic pumping of system by helium, which are carried out once per 2-3 weeks and the moments of pumping are fixed by short-term (up to 30 mines.) increase of pressure in the system at the appropriate moments of time.
The well 30 is in the central part of Verhne-Mutnovsky area of Mutnovsky geothermal field in 13.5 km from an active crater of volcano Mutnovsky and in 8 km from the caldera of volcano Gorely (Fig. 1). The well 30 is dated for a productive zone northeast extension and southeast accordant. The well opens two zones of the increased permeability: first - on the depth of 825 m (temperature 217 - 228°C), second on the depth of 950 m (temperature 231 - 233°C) (data GP ”Mutnovka”).

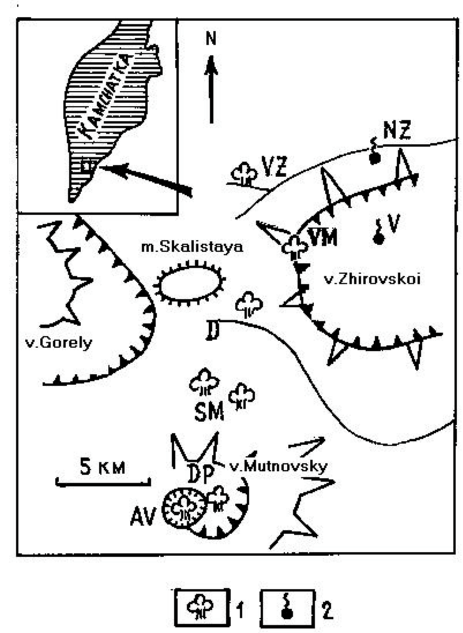

Figure. 1. Mutnovski geothermal field.
1- naturally outlet of steam:
AV – active funnel;
DP – Ground-field;
SM – Severo- Mutnovskie ;
D - Dachnye;
VM – Verkhne-Mutnovskie;
VZ – Verkhne-Zhirovskie
2- thermae:
V -Voinovskie;
NZ – Nizhne-Zhirovye

Since November 27 1995 till May 7 1996 in 250 m from the well 30 another well 049-H with the constant charge 12 kg/s had worked, further since September 16 1996 till August 29 1997 on the Verhne-Mutnovsky area practically not broken natural regime (short-term switching -on of the well 055 11.16.1996 from 14:30 till 21:00, 12.5.1996, and from 04.19.97 20:25 till 04.22.97 15:30 with the charge up to 20 kg/s, and also longer periodic switching on with the charge less than 1 kg/s for heating of the houses with equipment) was supported, it is possible not to consider, as the experience shows the well 30 does not react significantly to the switching of the well 055. The well 30 had been working all time since December 1995 with the insignificant charge of steam (0.005 kg/s - September 1996, 0.012 k/s - September 1997), that is necessary for heating of the house in which the equipment is placed.

Thus, a subject of the analysis is the interval of time since September 16, 1996 till August 29, 1997, when in the deposit the natural non- broken hydrodynamical regime practically was supported.

ANALYSIS OF THE RECEIVED RESULTS

The goal of the analysis is to state the limits of the influence of seismic events at the hydrothermal system on the influence intensity (klass K_s of earthquakes) and the radius of the hydrothermal echo (distance between the epicenter and observation point).

The analysis of time series without visible strong deviations of the amplitude lets us understand what earthquakes do not influence pressure variations.
For the analysis, intervals with minimized variations of pressure amplitude ($\sigma = 0.1$) with 10-15 days' periods have been chosen. For the period of 1996 six similar intervals could be observed.
The period of July 1996 is of most interest. After a series of strong earthquakes during 4 days quiet period started which then was gradually turning to the period of seismic activity. (Table 1)

Time series from 07.06.96 to 07.21.96 is shown on picture 2. Two seismic events (07.09.96, 2:02, M=2.3, D=102 and 07.15.96, 12:27, M=1.7 D=92) are marked by vertical lines. Both events were accompanied by low-pressure increase two hours before the earthquake and the increase of the oscillation amplitude after it. For the period from 07.10.96 to 07.10.96 within the radius of 105 km from the observation point there were no earthquakes with K_s>7. At the same time on the distance more than 105 km there were 2-6 earthquakes with K_s<=11every day, but they did not influence pressure changes. Comparative analysis lets us conclude that seismic events with K_s>7 within the radius of 105 km from the observation point have the most comprehensive echo of pressure variations in geothermal reservoir. The other seismic events will apparently have an echo if K_s>11.

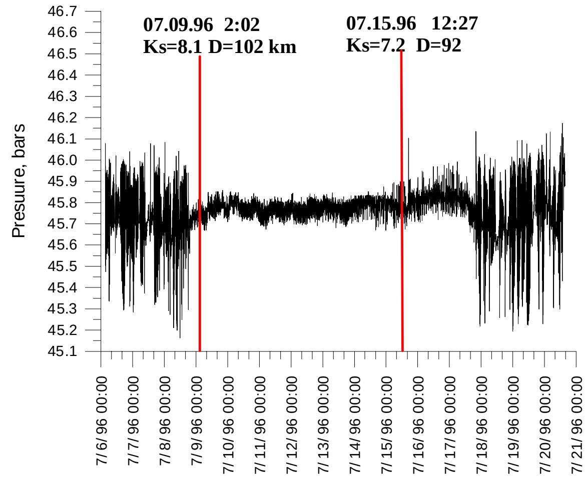

Figure. 2. Change of pressure in the well 30, July 6-21, 1996, Mutnovsky geothermal field.

One more time series from 09.18.96 to 09.28.96, which demonstrates similar behavior, is shown on Fig. 3. Seismic events with the limits are shown in Table 2. Two events with the interval of two seconds on 09.23.96 cause the echo which is similar to the ones in [4].

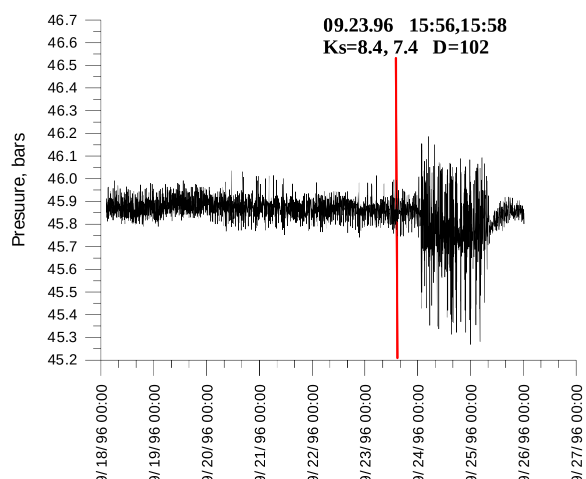

Figure. 2. Change of pressure in the well 30, September, 1996, Mutnovsky geothermal field.

From 09.14.96 to 09.23.96 there were no earthquakes in the specified radius, excluding the events of 09.21.96, when the epicenter was on the depth 114 km. We can see on Fig. 2 that this event did not influence pressure variations, possible reason is that the epicenter was too deep. The other seismic events of this period fell outside the limits the specified radius.

Together with the investigation the radius of the hydrodynamical echo, preliminary spectral analysis has been carried out.
The spectral analysis of days time series has shown that on the eve of the seismic event new frequency components appear. For more detailed analysis it is required to increase frequency of observation, for example up to 1 record in 2 minutes.

CONCLUSIONS

As a result of the analysis of the time series continuous (1 record / 5 minutes) observations in the conditions of not broken operations, (January - December 1996) for the variations of pressure in geothermal reservoir of Verhne-Mutnovsky area of Mutnovsky geothermal deposit (the point of observation of well 30, the depth of measurements is 950 m) the limits of the influence of seismic events at the hydrothermal system were revealed: influence intensity and radius of the hydrodynamical echo.
Firstly, the earthquakes with $K_s<7$ do not greatly influence pressure time series of geothermal reservoir.
Secondly, the earthquakes with $K_s<11$ significantly influence pressure variations only when the epicenter is within the distance of 105 km.
The results obtained may be useful for the further analysis of time series of pressure and shed additional light for the nature of the correlation of pressure variations of hydrothermal systems and seismic events.

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Table 1. Earthquakes with Ks > 7 in radius of 105 km from the well 30 (52.33˚N, 158.14˚E) for the period since June 25 till July 23, 1996

N	Date (on Greenwich)	Time	Latitude (˚N)	Longt (˚E)	Depth (km)	Ks	Distance (km)
1.	6/25/96	23:00:29	51.63	158.93	5	7.3	100
2.	6/27/96	0:55:28	51.71	158.97	5	7.2	94
3.	6/27/96	9:33:23	51.59	158.9	17	7.4	102
4.	7/9/96	2:02:11	51.55	157.52	118	8	102
5.	7/15/96	12:27:00	51.73	158.97	43	7.2	92
6.	7/17/96	2:50:51	53.07	158.92	106	8	102
7.	7/22/96	5:21:20	51.55	158.53	22	7.4	96
8.	7/23/96	1:58:46	51.57	158.53	25	7.2	94

Table 2. Earthquakes with Ks > 7 in radius of 105 km from the well 30 (52.33˚N, 158.14˚E) for the period since September, 1996

N	Date (on Greenwich)	Time	Latitude (˚N)	Longt (˚E)	Depth (km)	Ks	Distance (km)
1.	9/14/96	0:56:17	52.49	159.32	17	7.1	87
2.	9/21/96	4:18:29	52.54	158.33	144	9.5	32
3.	9/23/96	15:56:37	52.51	159.55	24	8.4	102
4.	9/23/96	15:58:07	52.49	159.55	24	7.4	102
5.	9/27/96	10:02:45	51.61	158.55	5	7.6	90
6.	9/28/96	14:23:52	51.6	158.43	5	7.5	89