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Seismic Situation and Necessity of Local Seismic Monitoring in Exploited Mutnovsky Steam-Hydrothermal Field (Southern Kamchatka, Russia)

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ABSTRACT

The seismic conditions of the Mutnovsky geothermal field which is considered a seismoactive zone located in the southeast of Kamchatka was assessed. Two geothermal power plants (12 and 50 MWt) were commissioned in the area 1999 and 2001. The hydrothermal field of the project is close to 2 active volcanoes: Mutnovsky volcano (last eruption was in 2000) and Gorely volcano (last eruption was in 1985-1986). The Kamchatkan earthquakes catalogue recently registered small seismic events immediate to the exploited hydrothermal field. The condition is probably a result of induced seismicity connected with deep drilling and beginning of geothermal field exploitation. At present, the techniques for estimating induced seismicity have not been elaborated yet, whereas damage caused by relatively weak induced earthquakes is becoming more and more significant. So local seismic control is actual.

1. INTRODUCTION

Kamchatka peninsula lies at the north-west part of Pacific Fire Ring. It is the area of tectonic, seismic, volcanic and geothermal activity. Most of earthquakes take place in subduction zone along east coast of peninsula. But some seismic events are associated with crust and active volcanoes.

Kamchatkan seismic stations network is oriented on registration of regional seismicity. The network began to work in 1962, and now it consists of 38 seismic stations.

The Mutnovsky geothermal field is located in the southeast of Kamchatka peninsula at an elevation of 800-900 m above sea level. The Mutnovsky high temperature hydrotherms are located at the intersection of fracture system, in the vicinity of youngest igneous rocks. Mutnovsky is a liquid-dominate reservoir with fluid temperature about 250-270°C. Reservoir fluids contain approximately 1% non-condensable gas, mostly CO2, pressure conditions are close to two-phase, and permeability is fracture-dominant. There are two active volcanoes nearby the hydrothermal field (Mutnovsky vol. and Gorely vol.).

Two geothermal electric power stations (12 MW and 50 MW) work within Mutnovsky hydrothermal field since 1999 and 2002 accordingly. And in the near future deposit exploitation will be intensified (planed power is about 300 MW).

The nearest seismic station is at the distance about 10 km to the north-west of exploited part of the hydrothermal deposit on vol. Gorely. It is intended for observing of this volcano seismicity. The control of the Mutnovsky exploited area is not included to the task of Kamchatkan regional seismic network.

It was considered that the local seismicity is absent in this area. But since 1996 by Kamchatkan regional seismic network data, some subsurface earthquakes have been recorded every year. Probably we observe the appearance of inducted seismicity connected with deep drilling and beginning of geothermal field using. Deposit exploitation can chance reservoir pressure and internal conditions of upper crust and it can be the reason of inducted seismicity. Such investigations were carried out for example in Geysers field (USA) and Kakkonda field (Japan) [2-4, 8-10].

Table 1. Strongest earthquakes of Kamchatka, 1962-2003

	Date	Latitude	Longitude	Depth km	Magnitude
1.	22/11/1969	57.70	163.50	25	7.7
2.	24/11/1971	52.77	159.66	100	7.3
3.	15/12/1971	55.85	163.35	25	7.8
4.	28/02/1973	50.40	156.70	70	7.5
5.	17/08/1983	55.64	161.53	97	6.8
6.	28/12/1984	56.18	163.45	19	7.5
7.	29/02/1988	54.99	167.38	40	7.1
8.	08/03/1991	60.90	167.20	35	7.0
9.	02/03/1992	52.76	160.20	20	7.1
10.	08/06/1993	51.20	157.80	40	7.4
11.	13/11/1993	51.79	158.83	40	7.1
12.	01/01/1996	53.88	159.44	0	7.0
13.	21/06/1996	51.27	159.63	1	7.3
14.	05/12/1997	54.64	162.55	10	7.9
15.	08/03/1999	51.93	159.72	7	7.1

Seismic information in Mutnovsky hydrothermal field is not complete because there are not seismic stations in the local exploited zone and small events are lost. It is necessary to organize local seismic monitoring network for earthquakes registration and seismic situation investigation.

Local Seismic monitoring must be included in all projects of the geothermal electric power stations building, especially in the areas of high tectonic and seismic activity.

2. REGIONAL SEISMICITY

The unique industrial constructions (Mutnovsky and Verhne-Mytnovsky PPlants) are in high seismic risk zone. Seismic activity of Kamchatka is nearly highest in the world. Strong earthquakes that can cause strong ground motions with intensity 7 or more in power stations area take place in seismic focal zone that crops out along east coast of Kamchatkan peninsula in 1962-2003 (Tab.1, Fig.1), but strong crust seismic events were observed within peninsula too.

Focal zone of earthquakes fall under peninsula (Fig.2). According to the seismic risk zoning map (1997) Mutnovsky hydrothermal field belongs to an area having seismic intensity 9 (Fig.3) [11].

Strongest crust earthquake of this time is Karymskoe earthquake (N 12, H=0 km). It was in 1996 in Karymsky volcanic center. Two nearest volcanoes (Karymsky and Akademia Nauk) began to erupt after this seismic event. Large surface ruptures were found in the earthquake region. So ground motions had intensity more than 9 there. Fortunately, this region is uninhabited so there were no victims. Such earthquakes may happen on other parts of Kamchatka too.

By long-term seismic prediction strong earthquake may happen near southern part of Kamchatka (in seismic focal zone) in nearest years.

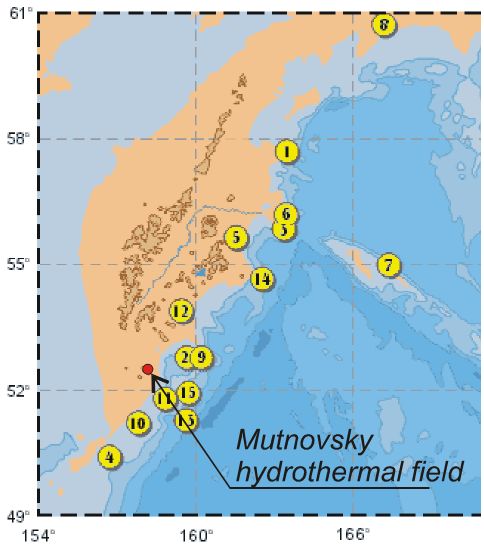

Figure.1 Map of strongest earthquakes of Kamchatka, 1962-2003 (Tab.1)

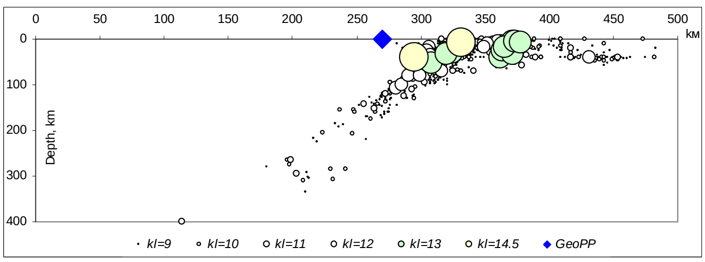

Figure.2 Vertical cross section of earthquakes focal zone across area of Mutnovsky hydrothermal field

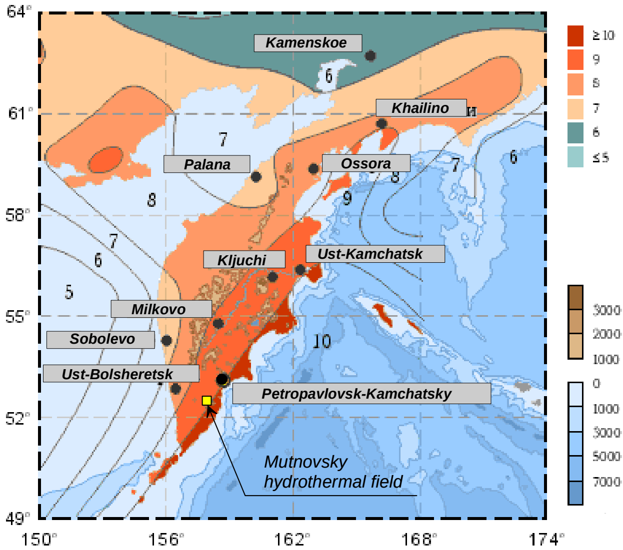

Figure 3. Map of the seismic risk zoning (1997).

3. NEAREST VOLCANOES

Hydrothermal field is close to two active volcanoes: Mutnovsky volcano (2322m) and Gorely volcano (1829m).. Local volcanic earthquakes from ones are registered by Kamchatkan seismic network. Seismic station GRL (Fig.6) is working here, it was built on Gorely volcano in 1982.

Gorley caldera is elliptical and is about 10 x 13 km with a shield cone at its center. Gorely is a very active caldera volcano with some of its latest eruptions in1980-81 and 1984-86. Usually Gorely eruptions were explosive (Fig.4). Most of these eruptions have been observed in Petropavlovsk, Kamchatka which is 75 km away. Ash falls were on the distance 30-100 km from volcano.

During last 200 years (in historical time) the time between eruptions was 4-60 years. Gorely volcano is quiet during last 18 years.

Figure.4 Explosive eruption of Gorely volcano in 1980.

Mutnovsky volcano is a compound volcanic massif (Fig5). There is not seismic station on this volcano. Volcano has crater lakes and very active fumaroles. There is not periodicity in eruptions. During last 200 years 16 eruptions were observed. They had explosive character in the main. Last weak ones were in 1960 and 2000.

Last, 2000 eruption was characterized as a phreatic explosion that has caused substantial changes in the topography of the volcano. Hot mud flow had length about 600 m. This event probably was triggered by hydrogeological situation change by glacier removing into crater bottom in 1996-1999.

Figure.5 Mutnovsky volcano. Steam-gas flow.

Volcanic hazard in the area of Power Plants is
- ash falls,
- hot mud flows
- electro-magnetic phenomenon in ashes clouds triggering death of electric equipment.

Eruptions of Mutnovsky and Gorely volcanoes are attended with seismic activity: local earthquakes and volcanic tremor. Seismic monitoring allows to estimate the volcano state and the volcano danger before eruption beginning.

4. REGIONAL NETWORK OF SEISMIC STATIONS

Kamchatkan regional network of seismic stations began to work in 1962. It consisted of 8 stations. But first seismic station was built in Petropavlovsk-Kamchatsky in 1915, it worked till 1927. It was one of the first stations in the world.

Nowadays seismic network on Kamchatka consist of 38 stations. 8 of them still use photo paper and galvanometers. Other stations are radio telemetric with digital registration. Seismic data are transmitted by radio channels to Petropavlovsk-Kamchatsky. Data are collected and estimations of earthquakes parameters are made during one day after happening. Now Kamchatkan region catalogue has about 87000 notes of EQ parameters.

Kamchatkan seismic stations network is oriented on registration of regional seismicity. It does not intent for local seismic control of Mutnovsky hydrothermal field.

5. LOCAL SEISMICITY ON MUTNOVSKY HYDROTHERMAL FIELD

By analysis of Kamchatkan earthquakes catalogue it was show that from 1996 small surface earthquakes are registered from the area of exploited hydrothermal field (Fig.6).

Description of periods of time:

A – time from beginning of seismic observations on Kamchatka (1962) till second nearest station RUS building (December of 1987). It is important moment because of this station improved EQ registration and increased accuracy of hypocentres determination. In 1980-th this area was enough active: we can see seismic swarm under Viliuchinsky (1981) volcano and (in left down corner) part of swarm under Asatcha volcano that is nearest neighbour of Mutnovsky volcano from south-west. Last activity of Gorely volcano associated with this period of time too.

B-time from 1988 till 1995. In 1996 first small earthquake were registered in the region of Mytnovsky hydrothermal field. Region is very quite.

C – time from 1996 to May, 2004. We can see epicentres of small surface earthquakes in the central part of the map. Such seismic events were not registered here yet.

So we can propose that seismic processes in this region may be connected with intensive man-caused influence on the environment. This activity may destruct natural balance of hydrothermal system and initiate seismicity.

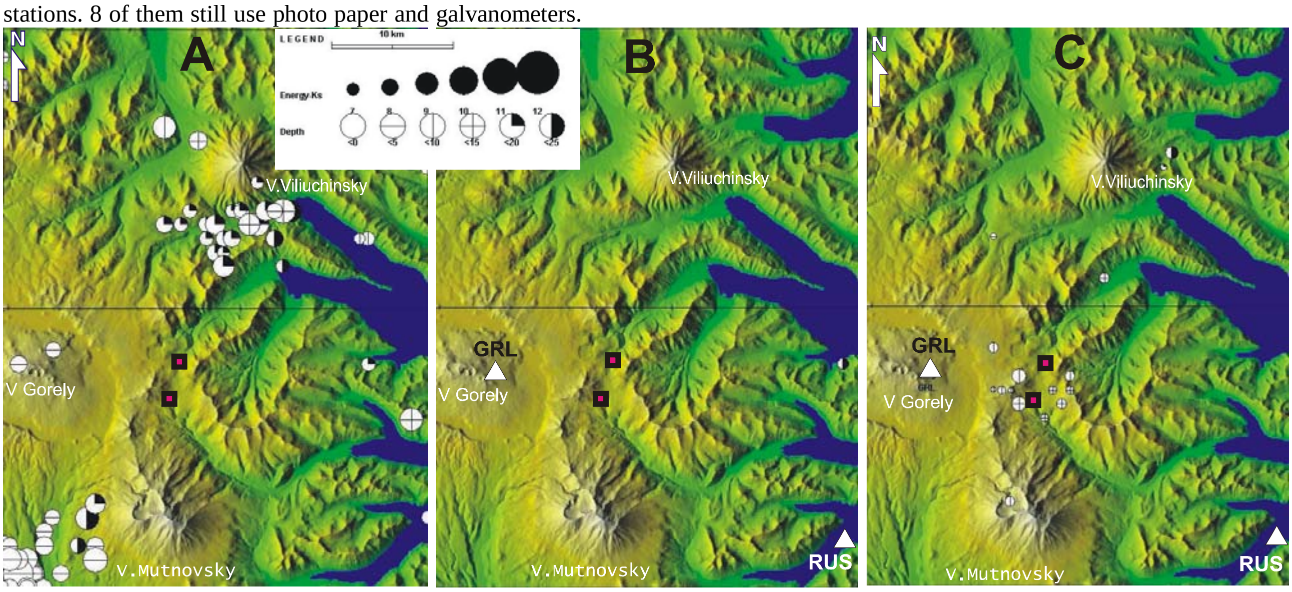

Figure.6 Map of shallow EQ epicenters for different periods of time: A- 1962-87, B – 1988-95, C – 1996-2004. Area: 52.4-52.8 N, 158.0-158.5 E. Depth of EQ: H<25 km. Triangles – seismic stations. Squares – PPlants.

6. INDUCED SEISMICITY

As far as we know industry activity may trigger earthquakes. Earthquakes can be induced by reservoir impoundment, fluid injection, mining, or oil, gas and thermal water extraction [1]. Induced quakes create a risk of personal injury or damage to property.

In many exploited hydrothermal field of the word induced seismicity was found. It is ordinary phenomenon. For example:

Geysers , USA
Coso, USA
East Mesa, USA
Salton Sea, USA
Louisiana Gulf Coast, USA
Kakkonda, Japan
Matsushiro, Japan
Larderello, Italy
Cesano, Italy
Latera, Italy
Vulcano Island, Italy
Val d'Illiez, Wallis, Switzerland
Southern Negros, Philippines
Tonganan, Philippines
Puhagan, Philippines
Mexicali Valley, Mexico
Cerro Prieto, Mexico
Los Humeros, Mexico
Sao Paulo State, Brazile
Beowawe, USA
Svartsengi, Iceland
Hengill-Grensdalur, Iceland
Wairakei, New Zealand
Ahaaki, New Zealand
Olkaria, Kenia
Lahendong, Indonesia
Darajat, Indonesia
Kizilcahamam, Turkey

Triggered earthquakes can appear later than exploitation of deposit begin. Below there are examples of seismic activization on oil and gas fields connected with material extraction from the crust [12] (Such earthquakes some times cause damage).

In Russia first GeoPP was build on the south extremity of Kamchatka on Pauzhetsky geothermal field in 1967. One of the first Kamchatkan seismic stations work in this area from 1961.

By data of this station region of Pauzhetsky geothermal field from 1961 till 1972 was characterized as very seismic quite. But from 1973 seismic activization begin in the vicinity of hydrothermal system. A lot of EQ were registered. Some of them were perceptible. Ground motions in seismic station building had intensity about 6. It is first example of induced seismicity appearance in hydrothermal field in Russia. Activization began 6 years after exploitation start. Such seismic events are registering in resent years too.

At present, the techniques for estimating induced seismicity have not been elaborated yet, whereas damage caused by relatively weak induced earthquakes is becoming more and more significant.

Table 2. Examples of time delay between start of field exploitation and induced seismic activization.

Deposite	Time between exploitation beginning and seismic activization	Mmax
Strachan (Canada)	2	M=3.4
Gazli (Uzbekistan)	12	M=7.1-7.3
Fashing (USA)	16	M=4.3
Snipe Lake (Canada)	7	M=5.1
Starogroznenskoe (Russia)	8	M=4.7
Burun (Turkmenistan)	13	M=6
Sleepy Hollow (USA)	19	M=3.5
Rangely (USA)	19	M=3.9
Cocdell (USA)	25	M=4.7
Imogene (USA)	29	M=3.3
Kum-Dag (Turkmenistan)	34	M=5.7
Romashkinskoe (Russia)	39	M=3, I=3-6
Coalinga (USA)	87	M=6.7

Induced seismicity can be used for seismic monitoring of hydrothermal fields. Small earthquakes and induced seismic emission associated with stress in and around reservoir, also can be used to image the reservoir dynamics. Microseismicity can be used to monitor rock mass deformation that can cause well failure. Some else applications on induced microseismicity: tracking of injection water front, fault mapping, mapping of the orientation, height, length, complexity and temporal growth of the induced fractures [5,6,7, 13].

7. ECOLOGICAL ASPECT

Main ecological problems connected with geothermal energy production are:

1. discharge of steam-water mix into the atmosphere
2. pollution of native reservoirs (rivers, streams)
3. decreasing and disappearance of native hydrothermal manifestations
4. change of surface level
5. induced (triggered) seismicity

We can say that Mutnovsky and Verhne-Mutnovsky GeoPP are really ecological clean for atmosphere and hydrosphere due to used technology excepted thermal liquid contact with environment. Reinjection is carried out for hydrothermal reserve reconstruction.

Induced seismicity and change of surface level are significant ecological problems of geothermal energy production. It is necessary to organize seismic and geophysical monitoring of these phenomenon. Complex control is the most effective.

8. CONCLUSIONS

Estimation of seismic risk in area of Mutnovsky GeoPP is smaller than really one. It was made in the beginning of 80-

th by paleoseismic data and analysis of 1962-1982 region seismicity. But during next years new data and facts were collected. Summarizing of all available data allows us to evaluate seismic hazards and its negative consequences.

In the Mutnovsky hydrothermal area small shallow earthquakes probably connected with field exploitation were detected. Induced seismicity is one of the main problems of man-made influence on the environment.

It is necessary to set up additional seismic stations for reliable registration of seismicity from deposit area directly for monitoring changes of hydrothermal system and GeoPP safety. It is important for monitoring of nearest volcanoes activity too. Most actual and effective is complex monitoring of different geophysical fields.

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