Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Geysers Valley Hydrothermal System (Kamchatka): Recent Changes Related to Landslide of June 3, 2007

A.V. Kiryukhin, T.V. Rychkova, V.A. Droznin, E.V. Chernykh, M.Y. Puzankov, L.P. Vergasova

Institute of Volcanology and Seismology FEB RAS, Piip-9, P-Kamchatsky, Russia 683006

avk2@kscnet.ru

Keywords: Geysers, landslide, Kamchatka.

ABSTRACT

On June 3, 2007 catastrophic landslide took place in Geysers Valley, Kamchatka. It started with steam explosion and was then was transformed into debris mudflow. Within 2 minutes (D. Shpilenok, pers.com. 2007), 20 mln m^3 of mud, debris, and blocks of rock were shifted away. As a result of this, eight major geysers located at lower elevations were sealed under 20-40 m of thick mud debris flow, and eleven geysers sank beneath the 20 m deep Podprudnoe Lake created by rock dam across the Geysernaya river. Analysis of the hydrogeological conditions of the landslide, which took place in the Geysers Valley shows that a possible cause of this was a long term steam upflow occurred along inclined bottom of the Geyzernaya pumice tuffs unit, which finally resulted in deep hydrothermal alteration of the pumice to highly silicified zeolites and montmorillonite and the corresponding loss of their stability. Landslide triggers may include plumbing magma system pressure increase, seasonal flooding, and steam explosions.

Two years of monitoring the two key geysers' cycling parameters (Velikan and Bolshoy), Podprudnoe Lake level and thermal discharge from the lake, yield to the following results:

1. Velikan maintained stable geyser activity cycling with an average time period slowly decreasing from 382 min (July 2007 – March 2008) to 372 min (April 2008 – July 2008), 347 min (August 2008 – October 2008), 345 min (November 2008 – March 2009), and almost returning to the time period recorded before the landslide - 339 min (2003). Some cycling period increase after landslide off-load may characterize geyser stress sensitivity. Velikan cycling is also very sensitive to the heavy rains and winter snowfalls, which may increase the idle period up to 32 hours.

2. Bolshoy showed cycling with average time period declining from 84 to 64 min between Sept 2007 and May 2008 when Podprudnoe Lake was at a low level, while the high level in the summer of 2008 pushed cold water inflows from Lake into the geyser channel and terminated its activity.

3. Thermal discharge of the Geysers Hydrothermal System catch at the exit from Podprudnoe Lake is sensitive to the Lake level, increasing to 300 kg/s in the winter time, and sharply declining to 30-100 kg/s during flood period in June.

1. INTRODUCTION

The landslide on 3-06-2007 was not surprising for Kamchatka, where 2 to 3 of 28 active volcanoes are erupting per year and earthquakes with magnitudes greater than 6.0 happen annually. What is surprising was the location of this landslide – the Vodopadny Creek Basin, which does not have the steep slopes and hydrothermal activity exhibited by the rest of the Geysers Valley. This raises a key question – why did this landslide, which shifted 20 mln m^3 of rocks 2 km downstream of the Geysernaya river, bury eight major geysers at lower elevations under 20 - 40 m of mud debris and flood eleven geysers located 20 m beneath Podprudnoe Lake?

The caprock of the hydrothermal reservoir is composed of Geysernya Unit (Q_3^4 grn) lake caldera deposits (pumice tuffs, tuff gravels, tuff sandstones and lenses of breccias), dipping at an angle of 8 - 25° to North-West (Fig. 1). When thermal fluid upflow reaches this inclined caprock layer, it separates into steam phase and liquid phase, with steam going South-East and liquid going West to the geysers and hot springs discharge area along the Geysernaya River Valley. The low heat conductivity of the caprock unit (0.25 W/m^{o}C) favors temperature rise and a corresponding increase in steam explosion potential. This circulation pattern confirmed by a new fumarole field and hot springs emerging after the landslide cut off caprock composed of the Geysernya Unit (Q_3^4 grn) in the Vodopadny Creek Basin. Total discharge of those springs with temperatures 12-26°C was estimated as 30 kg/s. Chemical composition corresponds to steam mixed with meteoric waters. Blocks of crushed rocks in the upper part of landslide were found to be completely hydrothermally altered to highly silicified montmorillonite with zeolites (mordenite, clinoptylolite) (L.P. Vergasova, pers. com., 2008). That shows significant steam contribution into caprock destruction and loss of rock stability before the 3-06-07 catastrophe.

It is also worth noting that interferometric (InSAR) images of surface deformations of the Uzon caldera shows that from 2000 to 2003, approximately 0.15 m of inflation occurred in the Uzon caldera, extending beneath the adjacent Kihpinych volcano (P. Lundgren, 2006). This inflation was probably related to magma flooding at shallow levels. The area of inflation with a deformation amplitude of 12 - 15 cm is located in upper stream of the Geyzernaya river. Twelve hot and boiling springs unknown before landslide (with flowrates up to 1 kg/s) were found inside or close to the contour of the inflation zone during field observations 2007 - 2008. In addition to this, a new group of boiling hot springs emerged at the south-east end of the upflow axes zone at the right bank of the Shumnaya River, near the junction with the Geyzernaya. This upflow axes zone acts as a dyke or junction fault to the abovementioned magma reservoir (Fig. 1).

Based on this, we can conclude that the landslide was a regular event of the Geysernaya Unit (Q_3^4 grn) destruction scenario, resulting from rising steam work at the bottom of the inclined hydrothermal reservoir caprock, including gradual steam condensate saturation increase and rock hydrothermal alteration with loss of rock stability. Pressure

increase in the magma-fed heat source of the hydrothermal system and seasonal flooding with meteoric waters may trigger such catastrophic events. Remaining spots of Geysernya Unit (Q_3^4 grn) outcrops on the east slope of the Uzon caldera rim are pointers to similar processes that occurred in past times (Fig. 1).

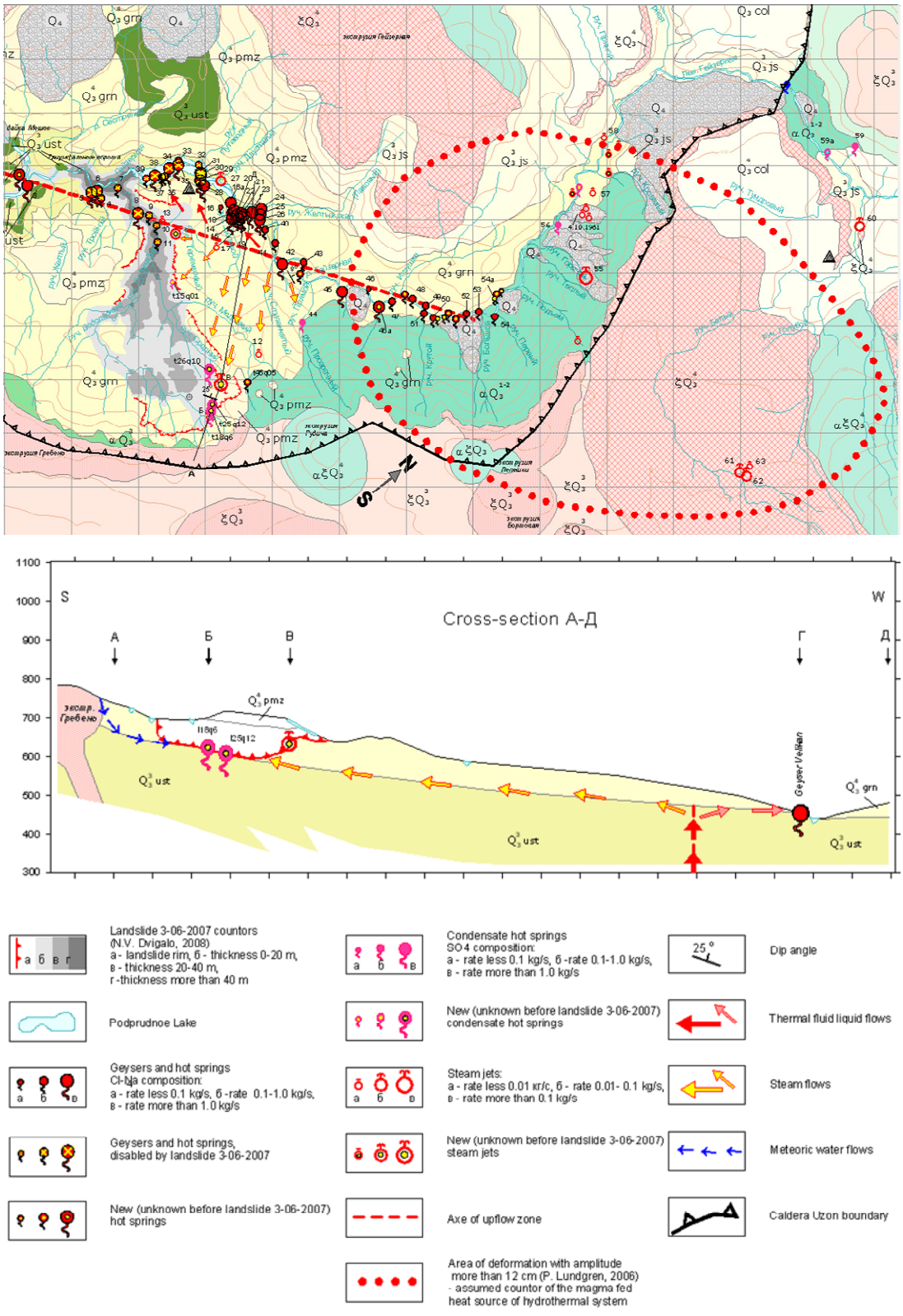

Figure 1: Circulation conditions in hydrothermal reservoir of the Geyzers Valley, Kamchatka. Geology from V.L. Leonov (pers. com., 2008). Hot springs and steam jets after O.P. Bataeva (pers. com., 2003), new hot and boiling springs (unknown before landslide) marked with yellow circle. #23 - Geyser Velikan, #28 – Geyser Bolshoy. Map grid – 500 m.

2. PERIODICITY OF CYCLING OF VELIKAN AND BOLSHOY GEYSERS AND HYDROTHERMAL SYSTEM DISCHARGE AFTER LANDSLIDE ON 3-06-2007.

2.1 Methods of Measurements

Since July 2007, temperature loggers HOBO U12-015 have monitored the periodicity of the geysers Velikan and Bolshoy cycling (Fig. 2). Temperatures are recorded at intervals of 2-5 min by loggers installed at hot water discharge channels of the geysers. The absolute maximum temperature record before the absolute minimum temperature record marks the time of the geysers eruption. To monitor Podprudnoe Lake level, HOBO WATER LEVEL LOGGERs U20-001-04 were used. One logger recorded barometric pressure, while another one sank into the lake to record water pressure. The relative lake level was estimated from the pressure difference. Since Podprudnoe Lake is fed by the Geyzernaya River, it is possible to calibrate transient level data versus river flowrate (Fig. 3). Hydrometric measurements were conducted at the entry (Schell point) and exit (Dam point) of the Geysernaya River to Podprudnoe Lake (Fig. 2).

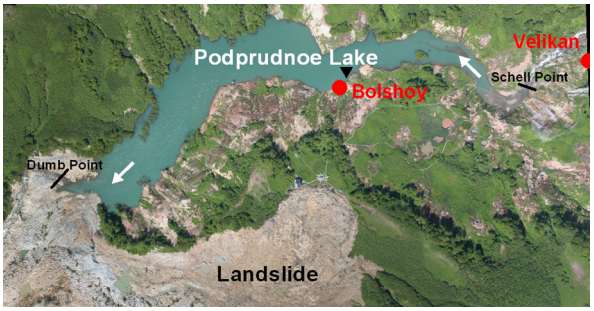

Figure 2: Podprudnoe Lake aerial view. Circles show geysers Bolshoy and Velikan locations, Dam Point and Schell Point – are flowrate measurements positions at the entry and exit of the Geysernaya river to Podprudnoe Lake, correspondingly, triangle point of Podprudnoe lake level measurements.

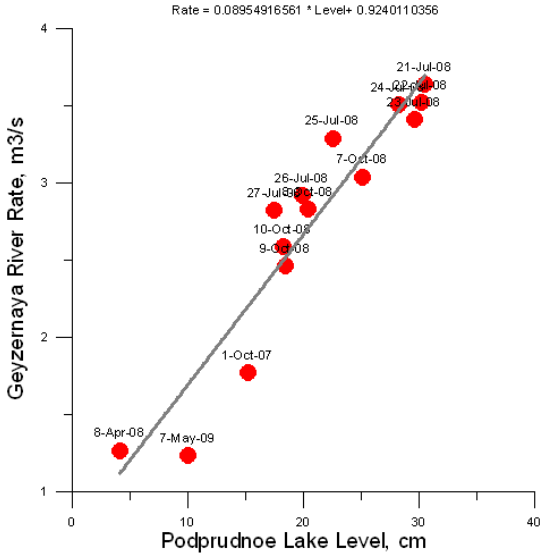

Figure 3: Geysernaya river flowrate (at Dam point) vs level of Podprudnoe Lake.

2.2 Periodicity of the Geyser Velikan Cycling

Velikan (Giant) is the most powerful in Geysers Valley. It is estimated that Velikan has a bath volume of 13.5 m^3 (6 m deep x 4.5 m^2) and an erupting water volume of 40-60 m^3, e.g. average recharge rate is more than 2.4 kg/s (Fig. 4). Fig. 5 shows integrated results of the Geyser Velikan cycling observations, Podprudnoe Lake level and barometric pressure from Aug. 2007 to March 2009.



Figure 4: Geyser Velikan eruption on July 22, 2008. Upper figure - idle phase, lower figure – eruption phase. Two people standing left for scaling.

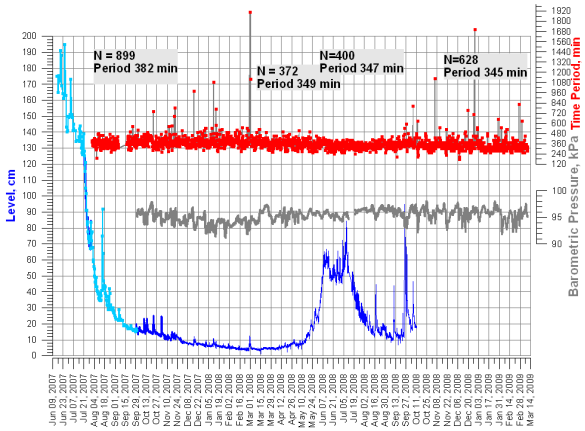

Figure 5: Time period of the Geyser Velikan cycling (upper graph), relative level of Podprudnoe Lake (lower graph), and barometric pressure (middle graph) – vs. time after landslide 3-06-2007.

Velikan's cycling is sensitive to direct recharge of the atmospheric precipitations into the bath (bath area is 4.5 m^2),

so heavy snowfalls and typhoons may delay eruptions and correspondingly increase the time period of cycling. The maximum time period of cycling observed was 32 hours during heavy snowfall on Feb. 29, 2008. Velikan maintains cycling with average time periods of 382 min (July 2007 – March 2008), 372 min (April 2008 – July 2008), 347 min (August 2008 – October 2008), 345 min (November 2008 – March 2009), almost returning to the time period recorded before the landslide - 339 min (August 2003 – October 2003, V.A. Droznin (http://www.ch0103.emsd.iks.ru).

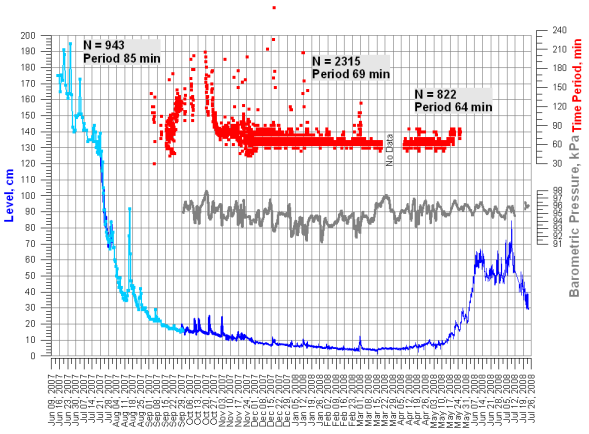

Figure 6: Time period of the Geyser Bolshoy cycling (upper graph), relative level of Podprudnoe Lake (lower graph) and barometric pressure (middle graph) – vs. time after landslide 3-06-2007.

2.3 Periodicity of the Geyser Bolshoy Cycling

Bolshoy's cycling activity depends heavily on the Podprudnoe Lake level (Fig. 6, 7). Bolshoy was disabled when the relative level rose above 25 cm (July 2007, May – September 2008), since cold water recharge from lake into geysers channel took place. Bolshoy started to cycle on Sept. 1, 2007, when lake level dropped below 25 cm. The average time periods of cycling were 85 min. (September – November, 2007), 69 min. (December 2007 – March 2008), and 64 min. (April – May 2008). Since June 2008, Bolshoy has been disabled again, due to lake level rise and cold water inflow into the geysers channel. There was no indication of Bolshoy geyser cycling during winter-spring 2009. Bolshoy's time period of cycling was 108 min. (August – October 2003) before the landslide on 3-06-2007 (V.A. Droznin, (http://www.ch0103.emsd.iks.ru).



Figure 7: Geyser Bolshoy bath flooded by Podprudnoe Lake (May 7, 2009).

2.4 Hydrothermal System Discharge

Total thermal discharge of the Geysers hydrothermal system was estimated by V.M. Sugrobov in September 1989 by the chloride rate method, assuming chloride rate in downstream of Geyzernaya river is derived from hot springs discharge with an average chloride concentration of 0.9 g/kg. According to V.M. Sugrobov, Geyzernaya river flowrate was 3340 kg/s with chloride concentration 85 mg/kg. Hence, total chloride rate was 283.9 g/s. Assuming a maximum chloride concentration in hot springs of 0.9 g/kg, total thermal discharge of hydrothermal system was estimated to be 315 kg/s (Sugrobov V.M., et al, 2004).

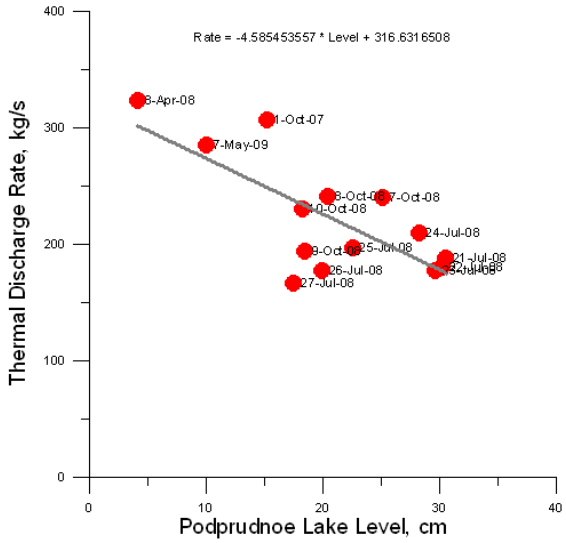

Figure 8: Thermal discharge rate (estimated by chloride method) of the Geyzernaya river vs. level of Podprudnoe Lake.

Geyzernaya river flowrate measurements with water sampling for chemistry analysis were performed to obtain input data for thermal discharge rate estimation, similar to the method V.M. Sugrobov (2004) used. Figs. 3 and 8 show the relationships between Podprudnoe Lake level and both Geyzernaya River flowrate and thermal discharge rate (estimated by chloride method). Based on the relationship between thermal discharge rate and Podprudnoe Lake level obtained (Fig. 8), lake level was converted into time dependent thermal discharge rate at the exit from Podprudnoe Lake (Dam point) as shown in Fig. 9. Similar estimate was performed for thermal discharge upstream to Podprudnoe Lake (Schell point).

Chloride estimated thermal discharge at the exit from Podprudnoe Lake (Dam point) gradually increased from 243 kg/s (October 2007) to maximum value 300 kg/s (March 2008), then sharply dropped to 30 - 100 kg/s (June 2008, summer flooding), and rebounded to 245 - 260 kg/s (August - September 2008). Chloride estimated thermal discharge at the entrance to Podprudnoe Lake (point Schell) gradually increased from 140 kg/s (October 2007) to 160 kg/s (March 2008), then sharply declined to 20-80 kg/s (June 2008, summer flooding), and rebounded to 130 - 150 kg/s (August - September 2008). The difference between the Dam and Schell points characterizes thermal discharge in Podprudnoe Lake: the average value of 115 - 140 kg/s (August – April) drops to 10 - 20 kg/s (summer flooding time) (Fig. 9).

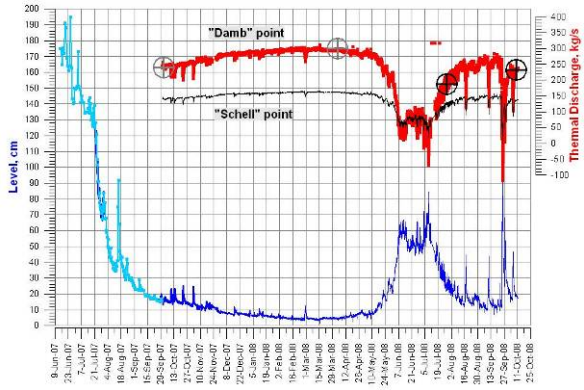

Figure 9: Chloride estimated thermal discharge at the exit from Podprudnoe Lake (Dam point) – upper graph, Chloride estimated thermal discharge at the entrance to Podprudnoe Lake (point Schell) – middle graph, and relative level of Podprudnoe Lake (lower graph). Ring crosses correspond to flowrate measurements and sampling times, used for rate vs. level model calibration.

3. FUTURE STUDY

This fascinating story of how a hydrothermal system destroyed itself and put itself into large-scale cold water injection conditions requires further detailed investigation. In terms of reservoir engineering, it is important to fully understand this case in order to mitigate hazards inherent to the nature of hydrothermal systems, learn efficient ways of geothermal energy use and try to retain the attractive value of the Geysers Valley for visitors. Hence, the following questions should be addressed for future study:

1. Is this cold injection useful or dreadful for remaining geysers field?

2. Is it possible to the estimate aquifer system's hydraulic parameters (such as permeability-thickness, etc) based on recorded transient data of Lake level, thermal discharge and geyser activity?

3. Can we reproduce in the model rising steam destructive work on caprock hydrothermal alteration with the subsequent loss of stability?

4. Is this model predictive enough to forecast such catastrophic events in future?

4. CONCLUSIONS

1. The catastrophic landslide on 03-06-07 was an event of the Geysernaya Unit (Q_3^4 grn) destruction scenario, resulting from steam rise along inclined hydrothermal reservoir caprock with corresponding hydrothermal alteration and loss of rock stability. Magma flooding into shallow levels of the hydrothermal system (detected by surface deformations with amplitude of 12 - 15 cm in upper Geyzernaya river and new hot springs emerging there) accomplished by seasonal flooding may trigger such catastrophic events. As a result of this, eight main geysers located at lower elevations were buried under 20 - 40 m thick mud debris flow, and eleven geysers sank beneath Podprudnoe Lake. Podprudnoe Lake is 20 m deep and was created by landslide rock damming of the Geysernaya River. It acts as a large scale cold water injection site for the rest of the hydrothermal system.

2. The largest geyser, Velikan, maintains stable cycling with an average time period gradually down from 382 min. to 345 min., which is comparable to the 339 min. time period recorded before landslide. Velikan cycling is sensitive to the heavy rains and winter snowfalls, which may increase its idle period up to 32 hours.

3. Bolshoy exhibits cycling with an average time period gradually decreasing from 84 to 64 min during winter time 2007/2008 at low Podprudnoe Lake level, while high water level in the summer time 2008 pushed cold water inflows from Lake into the geyser channel and terminated its activity. Before the landslide, Bolshoy cycling was bi-modal and time period was 108 min. There was no evidence Bolshoy cycling during winter time 2008/2009.

4. Thermal discharge of the Geysers Hydrothermal System catch at the exit from Podprudnoe Lake is sensitive to the Lake level, increasing to 300 kg/s in the winter time, and sharply declining to 30 - 100 kg/s during flood period in June.

ACKNOWLEDGEMENTS

Authors express their gratitude to V.A. Zlotnikov, V.L. Leonov, Y.A. Norvatov, I.F. Delemen. Significant help to arrange field work in Geysers Valley came from Kronotsky State Reserve Administration – O.A. Dahno, T.I. Shpilenok, V.I. Mosolov and from KB GS RAS director V.N. Chebrov. This work was also supported by RFBR project 09-05-00605-a.

REFERENCES

Goleva G.A. Geysers and Hot Lakes of Kronotsky Reserve (Kamchatka) // Guidebook. Moscow, Progress-Academia, 1993, 64 p. (in Russian).

Dvigalo V.N., Delemen I.F., Droznin V.A. Short-term forecast of landslide processes in Geysers Valley // Report on State contract # 5 of 14.12.2007, P-Kamchatsky, 2008, 155 p. (in Russian).

Kiryukhin A.V., Leonov V.L., Delemen I.F., Rychkova T.V. Project of long-term monitoring of landslide processes in Geysers Valley // Report on State Contract # 14 of 20.12.2007, P-Kamchatsky, 2008, 55 p. (in Russian)

Sugrobov V.M., Sugrobova N.G., Karpov G.A., Leonov V.L. «Geysers Valley – Pearl of Kamchatka» // Scientific guidebook. Moscow, 2004, 212 p. (in Russian).

Droznin V.A., Kiryukhin A.V., Muraviev J.D. Geysers Characteristics Before and After Landslide June 3-rd 2007 (Geysers Valley, Kamchatka) // Abstract AGU Meeting 10-14 Dec. 2007, San-Francisco, USA.

Lundgren P., Lu Z. Inflation model of Uzon caldera, Kamchatka, constrained by satellite radar interferometry observations // Geophysical Research Letters, Vol. 33, L06301, 2006, 4 p.

Rinehart J.S. Geysers and Geothermal Energy. // Springer-Verlag, New York, 1980, 223 p.