Numerical modeling of the natural state of the Geysers Valley hydrothermal system (Kronotsky Nature Reserve, Kamchatka) preceding of the Giant Landslide

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Introduction. The Geysers Valley is located in the Kronotsky State Reserve of the Kamchatka Peninsula, Russia. It has the largest natural discharge rate of the twelve high-temperature hydrothermal systems in the Kamchatka. On June 3, 2007, a catastrophic Giant landslide took place in the Geysers Valley, Kamchatka. It occurred synchronously with a steam explosion and was then transformed into a debris mudflow. Within a few minutes, 20 x 10^6 m^3 of rocks were shifted 2 km downstream the Geysernaya river, which created a dam with Podprudnoe lake behind, and buried more than 23 geysers, including 5 famous geysers (Pervenetz, Troinoy, Conus, Maly and Bolshoy). The 20-30 m deep Podprudnoe lake started to inject cold water into the remaining part of the Geysers Valley hydrothermal system.

Landslides with hydrothermal explosions are a challenge to safety conditions for visitors to Geysers Valley, which amounts to 3000 people annually. Hence it is important to understand what hydrothermal system parameters are responsible for landslides/hydrothermal eruptions to set up proper monitoring and recognize precursors of such events. Geysers Valley geothermal reservoir conditions and processes are also may learn as analog for places of potential nuclear waste storage (like Yucca Mountain, Nevada, USA) and heat driven gas pressure buildup (like Fukusima nuclear power plant accident).

The objectives of the present study are to integrate available hydrogeological data (Kiryukhin et al, 2010, 2011) to develop 3D thermal hydrodynamic (chemical) models to deduce a mechanism for the formation hydrothermal system and its response to changing recharge/discharge conditions after the Giant landslide of June 3, 2007, and to understand triggers of such catastrophic events to be able to forecast future ones.

Model set up. TOUGH2-EOS3 software and PetraSim pre- postprocessor were used. EOS3 (equation of state 3) module is capable of describing two-phase (liquid+gas) two-component (water+air) unsaturated zone conditions prevalent in the elevated parts of the Geysers Valley. The model boundary was defined so as include the main thermal features: Lower Geysers Field and Upper Geysers Field, where most of the deep component thermal discharge of 260-300 kg/s occur, and follows the main structural/hydrodynamic boundaries along Uzon-Geysernaya caldera rim, the Geyseranaya and Shumnaya rivers basins. The top of the model coincides with the topographic elevations and the bottom is at -2000 m.a.s.l. The two main geological units (layers) defined in the model are: (1) Pliocene-Quaternary volcanogenic reservoir, (2) Tertiary sedimentary basement. The bottom of the reservoir (top of basement) is defined at -150 m.a.s.l. The polygonal Voronoi mesh generation processing was applied to the model, and the upper layer was divided into 10-mesh sub layers, while the lower layer was divided into 5-mesh sub layers. The total number of grid elements is 10,500. Model zonation includes the following domains with different material properties: caprock units, composed of caldera lake tuffs; host reservoir; fractured reservoir (two permeable fault zones); more permeable lateral contact zone in reservoir (contact between caldera lake tuffs and pre-caldera volcanic units); host basement; fractured basement (two permeable fault zones); reservoir earth surface - top mesh sub layer used to assign atmospheric conditions (pressure of 1 bar and gas saturation of 0.9). This automatically allows discharge at lowlands. Discharge conditions were assigned to 59 hot springs and fumaroles known before the Giant landslide of June 3, 2007. All thermal discharge features were assigned as wells on deliverability. Initial conditions were deduced corresponding to conductive heat flow of 60 mW/m^2 at the bottom of the model and hydrostatic pressure distribution. Heat and mass sources (high temperature upflow recharge) were distributed in the elements at the bottom of the model basement layer along permeable fault zones within the area above of the suggested magma body (a total injected mass flowrate of 250 kg/s, with an enthalpy of 900 kJ/kg).

Modeling results. Modeling runs were completed with outputs at 1000 - 100,000 years, in order to explore the possible timing of the Geysers Valley formation. Inverse modeling capabilities of iTOUGH2-EOS3 were used to calibrate reservoir permeability and productivity indexes of 39 most significant springs based on their flowrates data. Based on modeling different scenarios, it was found that the formation of Geysers Valley hydrothermal system took from 20,000 to 30,000 years in terms of temperature distributions and discharge flowrates. By then most of the modeled springs became boiling with enthalpies of 500-700 kJ/kg and quasi-stable flowrates, while higher thermal features came into two-phase conditions. The shape of the temperature anomaly covers the known thermal features distributions and most of the permeable reservoir maintains a temperature of around 210^{o}C, which corresponds to geothermometry estimates. It was found in the model, that meteoric recharge took place on the outcrops of Mt. Geysernaya rhyolite extrusion $\alpha\xi Q_3^4$ on the right bank of Geysernaya river. Model analysis shows that steam pressure in the wide two-phase zone reaches 7.0-8.5 bars at a depth of 150-250 m between steam vent, backing Giant landslide of June 3, 2007 and geyser Velikan, which are conditions of potential steam explosion, if steam pressure transmits to shallower levels.

Conclusions. The Geysers Valley hydrothermal system is hosted within a system of two permeable faults (confirmed by mapping thermal features), adjacent to suggested partially melted magmatic body and recharged by meteoric water along outcrops of rhyolite-dacite extrusions (ξQ_3^4). Natural state thermal hydrodynamic iTOUGH2-EOS3 modeling shows that 20,000-30,000 years with a high temperature upflow of 250 kg/s and enthalpy of 900 kJ/kg is can build up a hydrothermal system in the Geysers Valley basin with observed output discharge. Modeling also shows that high temperature upflow include two roots (below Lower Geysers and Upper Geysers Fields), meteoric recharge occurs mainly through outcrops of Mt. Geysernaya rhyolite-dacite extrusion (ξQ_3^4) and that steam accumulating below the inclined caprock (southeast from Lower Geysers Field) may have hydrothermal eruption potential. Model parameters are verified by hot springs flowrates, the isotopic composition of thermal fluids (δD, δ^{18}O) and silica geothermometry.

References.

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