Fracture Development Within the Karaha-Telaga Bodas Geothermal Field, Indonesia

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ABSTRACT

Karaha-Telaga Bodas is a partially vapor-dominated geothermal system located in an active volcano in western Java. More than 2 dozen geothermal wells have been drilled to depths of 3 km. Detailed paragenetic and fluid-inclusion studies have defined liquid-dominated, transitional and vapor-dominated stages in the evolution of this system.

The liquid-dominated stage was initiated by shallow magma intrusion into the base of the volcanic cone. Lava and pyroclastic flows capped a geothermal system. The uppermost andesite flows were only weakly fractured due to the insulating effect of the intervening altered pyroclastics, which absorbed the deformation. Shear and tensile fractures were filled with carbonates at shallow depths and by quartz, epidote and actinolite at depths and temperatures over 1km and 300°C. The system underwent numerous local cycles of overpressuring, which are marked by subhorizontal tensile fractures, anastomosing tensile fractures and implosion breccias.

The development of the liquid system was interrupted by a catastrophic drop in fluid pressures. As the fluids boiled in response to this pressure drop, chalcedony and quartz were deposited in fractures having the largest apertures and steep dips. The orientations of these fractures indicate that the escaping overpressured fluids used the shortest possible paths to the surface.

Vapor-dominated conditions were initiated within a vertical chimney over the still hot intrusion. As pressures declined these conditions spread outward. Downward migration of the chimney occurred as the intrusion cooled and the brittle-ductile transition migrated to greater depths. Condensate that formed at the top of the vapor-dominated zone percolated downward and low-salinity meteoric water entered the marginal parts of the system. Calcite, anhydrite, and fluorite precipitated in fractures upon heating. A progressive sealing of the fractures occurred, resulting in the downward migration of the cap rock. In response to decreasing pore pressures in the expanding vapor zone, the fracture system within the vapor-dominated reservoir progressively collapsed, leaving only residual permeability, with apertures supported by asperities or propping breccia. In places, the fractures have completely collapsed where normal stresses acting on the fracture walls exceeded the compressive strength of the wall rock.

Introduction

This paper introduces a study of the fracture development of an andesite-hosted geothermal system at Karaha – Telaga Bodas. It is based on the fracture logging from core, interpretation of Electrical Micro Imaging (EMI) and Formation Micro Scanner (FMS) images from deep geothermal production wells, and mineralogic and petrologic investigations. Individual goals include:

1) determination of fracture orientations and kinematics,
2) determination of fracture seal/conduit properties, and
3) determination of the relative succession of fractures.

Geological setting of the Karaha – Telaga Bodas geothermal field

Karaha-Telaga Bodas is one of several geothermal systems occurring in west Java (Figure 1). This geothermal field is situated within N-S trending andesitic ridge, which is perpendicular to the modern-day minimum principal stress (Nemčok, *et. al.*, 2001). Galunggung volcano, most recently active between 1822 and 1984, is located at the southern end of the ridge. Its ESE-facing horseshoe crater is believed to have formed 4200 years ago (Katili and Sudrajat, 1984) in response to a large debris avalanche. Deep drilling in the field has defined a partially vapor-dominated system consisting of a cap rock characterized by steep temperature gradients and low permeabilities, an underlying vapor-dominated region that extends to depths below sea level and a deep liquid-dominated region with measured temperatures up to 350°C (Allis *et al.*, 2000). The vapor-dominated regime extially complete dry-out of the fractures within the vapor-dominated portion of the system occurred prior to drilling (Figure 5). These fractures contain frequent voids. Their apertures are supported by cement bridges, host rock asperities and propping breccias. In places, where resolved normal stresses overcome the strength of these supporting materials, resultant crushing caused total closure of fracture apertures.

Conclusions

Fault and fracture development in the Karaha – Telaga Bodas system can be related to its three main development stages: liquid-dominated, transitional and vapor-dominated stage (Table 1).

The liquid-dominated stage is characterized by penetrative alteration that enhanced the cap rock properties. Fracturing was

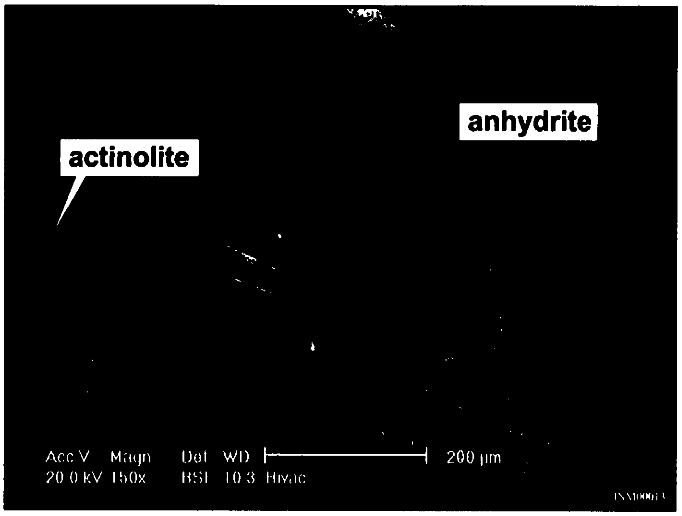

Figure 5. SEM backscattered electron image of the vein (1044.9 m, T-8) (Moore, *et. al.*, 2000). Image shows the anhydrite crystals postdating actinolite crystals. Subhorizontally oriented anhydrite crystal is coated with peeling-off titanium-rich scale, which indicates extremely dry conditions.

controlled by tectonic stress interacting with the overburden load and modified by fluid pressure. Pore fluid pressure frequently exceeded hydrostatic value. These increases were driven by fault/fracture compaction, fault/fracture cementation, continuing input of fluids, heating and pressure decrease.

The transition to a vapor-dominated regime followed a catastrophic drop in pore fluid pressure. Related precipitation took part only in fractures representing the shortest possible path to the surface. Fracturing driven by tectonic stress interacting with overburden stresses, modified by fluid pressure, is characteristic of this stage.

The vapor – dominated regime replaced the earlier liquid – dominated regime. Fracturing was driven by the tectonic stress interacting with the overburden load. Precipitation from condensed vapor progressively sealed the fracture system downwards, resulting in expansion of the cap rock. Because pore fluid pressure values are below hydrostatic, the fracture system within the vapor-dominated reservoir has minimal apertures, supported by rock asperities, cement bridges and propping breccia. Normal stresses acting upon the fracture walls control the base of the productive reservoir. The fracture apertures close where normal stresses exceed the compressive strength of the supporting asperities, bridges and breccias.

Table 1. Relative timing of mineralization.

	Time →				
		Early liquid-dominated	High-T liquid-dominated	Transitional	Vapor-dominated
	penetrative	*veins*	*veins*	*veins*	*veins*
Near surface	argillic alt. silicification	sericite/chlorite			advanced argillic
Shallow	argillic alt.	sericite/chlorite	chlorite pyrite calcite/hematite	chalcedony quartz	calcite anhydrite
Deep	argillic alt. silicification	quartz sericite/chlorite	epidote + albite + pyrite ± actinolite ± biotite ± clinopyroxene	chalcedony quartz	chlorite anhydrite pyrite ± wairakite calcite fluorite

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