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IGNEOUS-RELATED ACTIVE GEOTHERMAL SYSTEM VERSUS PORPHYRY COPPER HYDROTHERMAL SYSTEM

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ABSTRACT

An active geothermal system developed around a shallow intrusive body has several similarities with a fossil hydrothermal system of porphyry copper deposit, although they differ in hydrothermal alteration, salinity of circulating fluids and metal concentrations. This paper describes hydrothermal systems and related fractures around an intrusive body based on the comparison between porphyry copper and active geothermal systems. Intrusive-related active geothermal systems such as the Geysers in California, Tongonan in Philippines, Kakkonda in Japan, and Larderello in Italy have several common characteristics. That is: (1) They are present above and around an intrusive body. (2) Circulating fluids mostly originate from meteoric water, but some trapped in fluid inclusions in early stages are highly saline, suggesting involvement of magmatic fluids. (3) Contact metamorphism is dominant around an intrusive body with minor potassic alteration. (4) The deep fluid system is controlled by fractures around an intrusive body. However, a fracture system model is difficult to reconstruct geologically. By way of comparison, porphyry copper systems are summarized as follows: (1) The hydrothermal system is developed around a stock-like intrusive body. (2) Highly saline magmatic fluids are involved in an earlier stage, while meteoric fluid is present in later stages. (3) Potassic and phyllic alterations are developed around an intrusion. (4) Two types of fracture systems are recognized. They are radial and concentric structures in the early stage, and diagonal and high-angle ones in the late stage. The hydrothermal activities at the late stage of porphyry copper system are quite similar to those in present geothermal systems. If those activities are controlled by similar physico-chemical conditions, we could apply a fracture model of the late stage porphyry copper system to exploration of present geothermal systems.

1. INTRODUCTION

Porphyry copper hydrothermal systems were studied intensively from the late 1950s to early 70s when exploration and exploitation were vigorous in the southwestern United States and other regions. Porphyry copper deposits are distributed in convergent plate boundaries where calc- alkaline igneous activity is predominant (Gustafson, 1979). The southwestern United States was situated under such a tectonic configuration in the Mesozoic (Heidrick and Titley, 1982). Porphyry copper hydrothermal systems were often compared with active geothermal systems in 1970s and 80s to enhance its exploration model (e.g. Burhnam, 1979; Norton, 1982; Beane, 1983). Likewise, a geologic model for magma-hydrothermal system including intrusive rocks as a heat source also gave some perspective to geothermal exploration. However, it was after the peak of exploration activities for the porphyry copper deposits (in 1980s and 90s) that intrusive bodies were discovered under a number of present geothermal systems (Tamanyu, 1995). Thus, there have been few interactions between mineral and geothermal communities since the excellent review of Beane (1983).

As various erosion levels are observed in the porphyry copper hydrothermal systems, an igneous body for a heat source and a fracture system for a fluid circulation system can be reconstructed geologically. Porphyry copper deposits also record all the history of hydrothermal activities, so that sequential events can be analyzed.

It is much harder to reconstruct the fracture system controlling a present geothermal reservoir, because while some three-dimensional structure can be delineated by geophysical methods, subsurface geologic data can be obtained only by drilling. Nevertheless, one may obtain current parameters such as temperature, permeability, and fluid chemistry, which cannot be determined directly in fossil hydrothermal systems.

2. INTRUSIVE ROCKS

Young intrusive rocks have been found under the developed geothermal systems of the Geysers (Hullen and Nielson, 1993), Tongonan (Lovelock et al., 1982), Kakkonda (Kato and Sato, 1995; Muraoka et al., 1998) and Larderello (Villa et al., 1987; Valori et al., 1992). A hydrothermal convection system is present above and around the intrusion. Plutons seem to be located consistently with the present thermal structure in Tongonan and Kakkonda, while it is still controversial in other areas whether the underlying intrusive body is a heat source for the present geothermal systems. For example, the distribution of intrusive body is not apparently consistent with the present thermal structure in the Geysers geothermal system. A main intrusive body has not been shown by drill hole investigations in Larderello.

Porphyry copper systems have a stock-like intrusive body as the heat and fluid source. The intrusive body consists of several intrusive units, and later intrusive units have more acid composition. The porphyry copper deposits are mostly associated with the latest intrusive unit (Creasey, 1977; Titley and Beane, 1981). Porphyry copper-bearing intrusions might be continuous downward to a deep batholith. Some stratified volcanoes are inferred to overlie the porphyry copper deposits, whose depth is estimated to be 1.5 to 3 km at minimum (Sillitoe, 1973).

3. HYDROTHERMAL EVOLUTION

A major difference of hydrothermal alternation between porphyry copper systems and active geothermal systems is the development of potassic alteration associated with mineralization. The potassium alteration is formed by very saline fluids at high temperatures close to magma in porphyry copper systems (Lowell and Guilbert, 1970). Potassium alteration is less abundant around the intrusive body of the active geothermal system, while contact metamorphism is predominant there (Hullen and Nielson, 1993; Muraoka, 1993).

The effect of the highly saline fluids is presumably much smaller in the present hydrothermal system.

As an intrusive body cools down, mixtures of saline fluids and meteoric water react with wall rocks, producing phyllic, propylitic and argillic alterations in the porphyry copper system. In contrast, salinity of present geothermal fluids is generally quite low. Propylitic and argillic alterations are common and advanced argillic alteration is observed near the surface where acid fluids are circulating. Active systems have ongoing processes of water-rock interactions, and there are such immature zones that high temperature fluids are circulating in unaltered rocks. For example, the Quaternary granite in the Kakkonda geothermal system holds its igneous mineral assemblage (Kato and Sato, 1995).

4. FRACTURE SYSTEMS

Geothermal fluids are circulating in the marginal zone of the intrusive body in the Geysers, Tongonan and Kakkonda. Such permeable zones around the intrusions are considered to be highly fractured, but fractures have not been well characterized because of difficulties in observing subsurface geologic structures. That is a bottleneck in constructing an exploration model for igneous-related deep geothermal system.

Geologic structure is, however, readily observed at the surface outcrops of porphyry copper system. The radial and concentric fracture systems, and high-angle conjugate fracture systems are developed in porphyry copper systems. The fracture system consists of joint, fault, vein and dike, which are closely related to hydrothermal activities (Heidrick and Titley, 1982).

Extensive fractures are formed perpendicular to minimum principal stress. Concentric (cone-sheet) and radial fractures are created around an intrusive body, when the magma pressure is higher than the surrounding lithostatic pressure in the shallow crust (Hubbert & Willis, 1957; Koide and Bhattacharji, 1975). The concentric and radial fractures are developed within 1.5 km from the intrusive body in Safford in Arizona (Heidrick and Titley, 1982). A similar fracture system is distributed around the Henderson intrusive body in Colorado (Carten, et al., 1988).

Since both magmatic dikes and hydrothermal veins are observed around an intrusion, they were presumably formed at magmatic and successive stages after aqueous fluids were separated from the magma. The driving force of the mineral veins could be high-pressure fluids separated from magma (Whitney, 1975; Burnham, 1979). As the minimum principal stress is in the horizontal plane at the top of the fluid-bearing intrusion, fractures should be developed vertically. Thus, numerous fractures are developed upward, resulting in stock-work fracture system above the intrusion (Burnham, 1979).

As the pluton cools down, another type of fracture system begins to develop. Two types of fracture systems were studied in Safford (Heidrick and Titley, 1982). The first is magma-related fractures of concentric and radial types. The other type is high-angled conjugate fracture systems formed during the late stage. The latter is made up of faults, mineral veins and mineralized joints. Those fractures and veins are regionally distributed over individual intrusive bodies. The directions of those fractures are ENE and WSW, which presumably reflect a paleo stress field controlling Laramide orogeny 50 Ma ago. Those were formed at the late stage when the meteoric water was regionally circulated.

5. ACTIVE GEOTHERMAL SYSTEM VS PORPHYRY COPPER SYSTEM

Intrusive-related active geothermal systems such as the Geysers in California, Tongonan in Philippines, Kakkonda in Japan, and Larderello in Italy have several common characteristics. That is: (1) They are present above and around an intrusive body. (2) Circulating fluids mostly originate from meteoric water, but some trapped in fluid inclusions in early stages are highly saline, suggesting involvement of magmatic fluids. (3) Contact metamorphism is dominant around an intrusive body with minor potassic alteration. (4) The deep fluid system is controlled by fractures around an intrusive body. However, the fracture system is difficult to reconstruct geologically.

In contrast, porphyry copper systems can be summarized as: (1) The hydrothermal system is developed around a stock-like intrusive body. (2) Highly saline magmatic fluids are involved in an earlier stage, while meteoric fluid is present in later stages. (3) Potassic and phyllic alterations are developed around an intrusion. (4) Two types of fracture systems are recognized. They are radial and concentric structures in the early stage, and diagonal and high-angle ones in the late stage.

6. IMPLICATIONS

The hydrothermal alteration of porphyry copper system is studied areally around an intrusive body, while that of an active geothermal system is usually investigated downward from the surface. Mineral assemblages in both systems are quite similar at moderate temperatures, corresponding to propylitic and argillic alterations where meteoric water is predominantly circulating, and hydrothermal minerals of sericite, quartz, chlorite, epidote, albite, pyrite, kaolinite, and motmorillonite are observed. At higher temperatures potassic alteration is predominant in porphyry copper, whereas the contact metamorphism is dominant and partly greisen and potassic alteration are associated with the active geothermal systems.

The fluid above 350° C is more magmatic while that below 350° C more meteoric based on studies of isotope and fluid inclusions (Henley and McNabb, 1978). This temperature of 350° C is also corresponding to the ductile-brittle transition. Meteoric water can invade to the intrusive and its surrounding rocks when the temperature decreases to 350° C.

The concentric and radial fractures around the intrusive body are presumably not expected in the active geothermal system because the high-temperature and highly saline fluids which produced potassic alteration are not considerably involved. On the contrary, high-angle conjugate fractures where the low-salinity fluid is involved could be expected above an intrusion in active geothermal systems. Those are formed below the temperature of ductile-brittle transition of 350° C. Shear rupture and joints are expected under the pore pressure of meteoric water.

The hydrothermal activities at the late stage of porphyry copper system are quite similar to those in the present geothermal systems. If those activities are controlled by similar physico-chemical conditions, we could apply a fracture model of the late stage porphyry copper system to exploration of present geothermal systems.

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