Goldschmidt 2000
September 3rd–8th, 2000
Oxford, UK.

Journal of Conference Abstracts
Volume 5(2), 839

Fluid-Rock Interaction at the Magmatic-Hydrothermal Interface of the Mt. Cagua and Mt. Mahagnao Geothermal Systems, the Philippines

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During the evolution of a hydrothermal system from immaturity to maturity, the influence of magmatic volatiles diminishes due to increasing interaction with rock and mixing with invading groundwater. In the Philippines, Recent volcanism in Mt. Cagua and Mt. Mahagnao had rejuvenated a waning hydrothermal system, associated with groundwater-dominated cold (<180°C) water discharges and alteration. In each area, one well was drilled through the magmatic-hydrothermal interface at >1500 m while the another, located in the cold outflow zone, was drilled through the groundwater-dominated part of the system.

Even before drilling there are already indications from surface manifestations that high magmatic input is present at depth in an active hydrothermal system such as Cagua, Mahagnao and other magmatic-hydrothermal systems in the Philippines (Reyes and Giggenbach, 1992). These include: (1) the presence of Recent andesite to dacite domes associated with an active solfatara, kaipohan and/or substantial sulfur flows; (2) high Cl and/or F concentrations in fumarole discharges and; (3) the occurrence of highly acid Cl-SO_4 springs at high elevations.

Fluids associated with active magmatic input have a distinct deuterium shift, in addition to the more common $\delta^{18}O$ shift, ascribed to the addition of varying proportions of D-enriched arc-type magmatic waters (Giggenbach, 1992). The proportion of magmatic water in Cagua is 65% and in Mahagnao, 90%. Apart from isotopic compositions, relative N_2, He and Ar contents in gases point to considerable proportions of magmatic fluids (Giggenbach, 1996) in these two areas. Exceptionally high H_2 and CO_2 contents indicate the existence of >330°C, possibly magmatic environments nearby. Furthermore, discharges from wells drilled into the magmatic-hydrothermal interface have $^3He/^4He$ >7 (Giggenbach and Poreda, 1993).

Within the upflow zone of magmatic fluids, the Cagua and Mahagnao wells were drilled through weakly altered microdiorite dikes associated with a sudden increase in measured well temperatures, suggesting that the latest heat source of the hydrothermal systems may be related to these dikes. Measured temperatures within the magmatic-hydrothermal interface is >330°C in both areas, although fluid inclusion homogenisation and mineralogical temperatures indicate temperatures up to 390°C in Mahagnao and >500°C in Cagua.

Low permeability and high temperatures within the magmatic-hydrothermal interface result in the eventual discharge of superheated steam from the wells within a few days of well discharge, before waters representative of the deep reservoir could be sampled. Thus, the only way to characterise the altering waters within the interface is through detailed mineralogical and fluid inclusion studies. Magmatic waters in Cagua and Mahagnao contain 15 000-30 000 mg/kg Cl equivalent, dissolved CO_2 ranging from 0.9 to 4 molal with high concentrations of Ca, Mg, F, B and S in reduced forms. Gold, Ag and Mo are introduced by magmatic fluids. Oxidation of S occurs only where magmatic volatiles dissociate within waterlogged fractures and form acid waters, which produce advanced argillic cation-depleted alteration assemblages.

The magmatic-hydrothermal interface is a narrow zone dominated by a vapour chimney, which connects the deep zones with surface fumaroles. Over the central parts of the vapour chimney, vapours may become superheated, causing evaporation of earlier liquids and the formation of highly saline solutions and halite daughter minerals in fluid inclusions as well as resulting to critical point behaviour in fluid inclusions. Along the edges of this chimney is a narrow zone of acid Cl-SO_4 condensate. As temperatures decrease away from this vapour core, coupled with the mixing of groundwater with residual fluids around the chimney, neutral Cl waters typical of mature hydrothermal systems form. With further cooling and increased dilution with groundwaters, bicarbonate waters form at the periphery of the system. Where faults are present, bicarbonate waters can percolate to deeper levels of the system, causing the formation of low temperature "groundwater-dominated" hydrothermal alteration (see figure 1).

The magmatic-hydrothermal interface in Mt. Cagua and Mt. Mahagnao is an ephemeral phenomenon sustained by intermittent dike intrusion at relatively shallow depths (>1500 m). Low permeabilities allow mineralogical imprints left by the incursion of immature magmatic fluids to be retained. In general the low fluid/rock ratios accompanying alteration within the magmatic-hydrothermal interface leaves a considerable proportion of the wall rock unaltered.