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GEOTHERMAL POTENTIAL OF PERU AND MODERN EXPLORATION METHODS

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PERUVIAN GEOTHERMAL POTENTIAL

Perhaps no other country in the world shares with Peru such a strong electricity-grade geothermal resource potential in combination with a limited amount of past exploration and development. No geothermal drilling has yet been conducted for the purposes of electrical energy production. However, new Peruvian laws and regulations should foster the birthing of a local geothermal exploration and development industry, which will significantly benefit some parts of Peru that lack conventional fossil fuel and hydroelectric energy alternatives.

The strong geothermal potential of Peru is evidenced by more than 500 areas of hot springs and fumaroles, as well as by 16 active volcanic complexes (mostly stratovolcanos) and widespread active faulting. The Instituto Geológico Minero y Metalúrgico (INGEMMET) has divided Peru's geothermal manifestations into six geographic regions extending from near the southern border with Chile to near the Ecuadorian border on the north (Fig. 1, Verastegui, 1988). Most of these regions follow the western margin of the Peruvian cordillera, and are characterized by active faulting, anomalous heat flux, and in several cases, active or young volcanism.

Figure 1. INGEMMET has divided Peru into six geothermal regions: 1) Cajamarca, 2) Huaraz, 3) Churin, 4) Central, 5) Cadena de Conos Volcanicos, and 6) Puno-Cuzco. Figure from Peruvian Ministry of Energy and Mines.

Of these six geothermal regions or provinces, the one with the greatest potential for widespread electrical energy production is Region V (Fig. 1), named "Cordillera Volcanica del Sur" by Verastegui (1988), which stretches for a distance of approximately 300 km from Volcán Paugarani to the southeast to Volcán Sabancaya on the northwest. At least seven volcanic centers in this region are associated with active geothermal manifestations including boiling springs, fumaroles, and siliceous sinter. Fault scarps cut the young volcanic topography in a number of places.

EXPLORATION METHODS

The development of Peru's geothermal resources will be facilitated by new and modern exploration techniques. These exploration activities can be grouped into 1) reconnaissance, 2) surface mapping and sampling, 3) geophysical surveys, and 4) drilling.

Reconnaissance geothermal surveys are important in Peru because the remoteness and difficult accessibility have limited the ability to conduct detailed investigations in many areas. Reconnaissance activities include the identification of hot springs, fumaroles, hot ground, surface deposits of silica, carbonates, and evaporite minerals, hydrothermal alteration, vegetation anomalies, fault scarps, and hydrothermal eruption craters. During initial-stage reconnaissance, evidence of young volcanic activity is searched for, and thermal water and gas samples are taken to estimate the composition and temperatures of possible subsurface geothermal reservoirs.

Although some aspects of reconnaissance exploration are obvious or intuitive, such as the documentation and sampling of thermal springs, modern tools can significantly improve the ability to rapidly identify and more accurately delineate surface geothermal features. For example, many areas of hot ground are not associated with visible steam discharges, and can be easily overlooked without the use of portable digital temperature devices for measuring soil temperatures at shallow depths ranging from 10 centimeters to 2 meters. In remote terrain, multispectral and hyperspectral remote sensing surveys can provide invaluable data for identifying thermal anomalies and possible areas of young hydrothermal alteration. Low sun-angle photography and 3-D depictions of aerial photography on digital elevation models (e.g. Google Earth) can be used to identify young faults and young volcanic land forms. Young silica sinters (comprised principally of amorphous opal) can be distinguished from their older counterparts with X-ray diffraction (XRD) analyses. XRD analyses can also be used to discriminate young solfataric alteration (often composed of kaolinite and alunite) from surface exposures of older hydrothermal alteration, and identify borate and sulfate evaporite minerals associated with diffuse surface discharges of gases and thermal waters.

Once regions of geothermal interest have been identified with reconnaissance investigations, more detailed surface mapping is used to provide crucial data for building models and concepts of the possible locations of subsurface geothermal reservoirs. Surface mapping activities include geological mapping, geochemical surveys, and shallow temperature surveys. Geological mapping is used to identify the distribution and composition of potential host rocks, including possible young volcanic rocks, and to define the areas of hydrothermal alteration and surface geothermal manifestations in more detail. Radiometric dating and whole rock chemical analyses are used to determine the age of volcanic rocks and identify potential silica-rich compositions that are more likely to be associated with anomalous upper crustal temperature gradients. Geological surveys are also crucial for the recognition and mapping of young faults, their kinematic histories, and to estimate fault displacements. This structural information can be assembled into a 3-D structural model and combined with stress/strain data to predict locations of fault-induced permeability depth.

In some circumstances, shallow temperature surveys (30 cm to 2 m depth) using modern portable, digital equipment (Fig. 2) can provide additional valuable information to more accurately map near-surface convective outflow plumes and gas discharges. This is especially true in dry desert climates where deep water tables can prevent surface manifestations from forming. A number of recent geothermal discoveries in the desert environment of the Great Basin, USA (Coolbaugh et al., 2007; Kratt et al., 2010) attest to the value of this technique, and suggest their potential value in similarly dry terrain of Peru. In wetter jungle climates, high-sensitivity trace element analyses of chloride and other dissolved constituents of rivers and streams can be used to identify thermal spring contributions and trace them to their source(s).

Geophysical surveys play a key role in the extrapolation of the geological and geochemical environment from the surface down to depths where geothermal reservoirs may exist. Key methods include resistivity and magnetotelluric (MT) surveys. Resistivity surveys have proven their value in many areas of the world for mapping the more conductive upper to middle portions of geothermal reservoirs characterized by argillic alteration and solute-rich thermal fluids. At greater depths in higher temperature reservoirs, MT surveys have the ability to see beneath clay caps to identify resistive zones associated with propylitic alteration at temperatures exceeding 200°C and at depths of up to several kilometers (Fig. 3). Subsurface models of conductivity can be combined with geological and structural mapping data, fluid geochemistry, and thermal surveys, to develop models of 3-D fluid flow, heat convection, and identify possible locations of geothermal reservoirs.

Figure 2. Insertion of 2-meter-long hollow steel pipe into the ground using an electric hammer and portable generator mounted on an all-terrain vehicle (ATV). Temperatures at a 2-meter depth can be measured by inserting a digital resistance temperature device down the middle of the pipe.

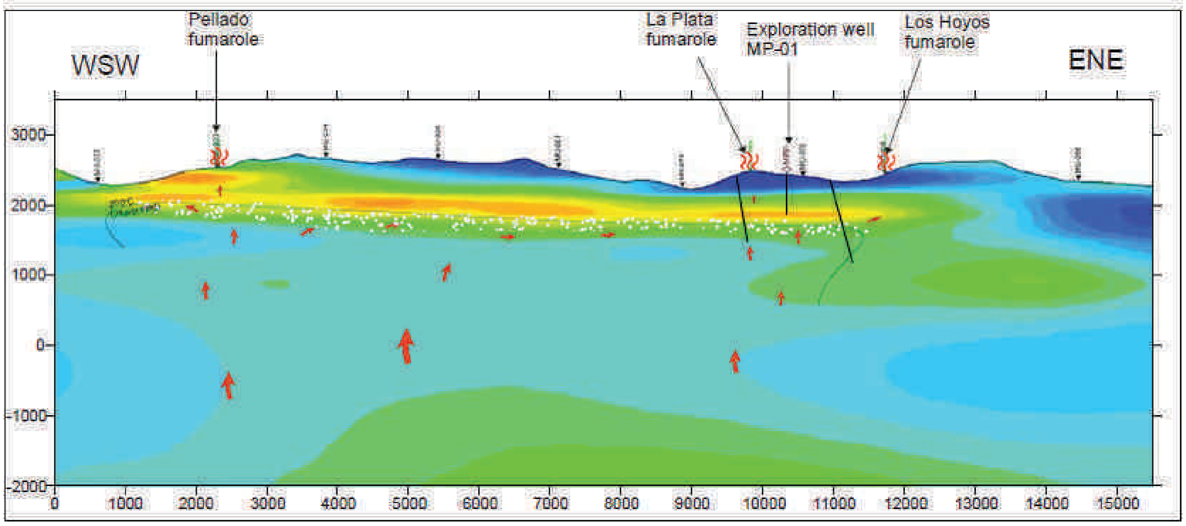

Figure 3. 2D resistivity model of Magma's Mariposa reservoir, central Chile, from an MT survey. Dashed line represents the 200°C isotherm inferred from the data and the likely top of the reservoir below a clay cap.

Drilling is the final and most cost-intensive phase of geothermal exploration. In some areas, especially where blind geothermal systems with minimal surface expressions are present, relatively shallow temperature gradient wells (with maximum depths determined by the temperature gradient so that they can be drilled without a blow-out preventer (BOP) and at a very low cost) can be used to verify the presence of thermal groundwater and to acquire fluid samples whose geochemistry can be used to estimate reservoir temperatures.

Where deeper wells are needed, another exploration technique is the use of coring slimholes (Fig. 4). The coring of slimholes provides a number of advantages over directly moving to the production drilling phase following surface geology and geophysics, with or without TG holes. These holes, with upper casing diameters of 12 inches or less and "production" casing from 4 – 5 inches are less expensive than production holes, they require shorter overall preparation time, and greater geological detail can be obtained from continuously cored holes. These holes offer the advantage of better defining well targets and improving the chances of success of deep production drilling. If sized appropriately, they can be flow tested, providing valuable reservoir information upon which to base development and feasibility plans. An additional advantage in Peru is that the rigs used for slimhole drilling are available from the mineral industry and there are an increasing number of companies that are gaining experience in geothermal slimhole drilling.

Figure 4. Coring rig drilling an inclined hole during winter conditions on Magma's Laguna del Maule exploitation concession in Chile (photo by Frank Baumann).

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