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STREAMING POTENTIALS RESULTING FROM THE DESCENT OF METEORIC WATER--A POSSIBLE SOURCE MECHANISM FOR KILAUEAN SELF-POTENTIAL ANOMALIES

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From extensive self-potential (SP) surveys made on Kilauea Volcano, Hawaii, Zablocki (1976) concluded that all of the mapped positive SP anomalies, upwards to 1.5 volts in magnitude, could be related unambiguously and exclusively to subsurface localizations of heat. This conclusion was the basis for recommending the siting of a geothermal test hole for the Hawaii Institute of Geophysics in the vicinity of a prominent SP anomaly in Puna, Hawaii (Zablocki, 1977). The subsequently drilled hole (HGP-A) encountered high-temperature fluids at depth. Various reservoir tests are currently underway to assess its potential as a viable source for electric power generation.

The apparent success of the Puna SP survey has further increased the desire to understand the principal source mechanism responsible for these distinct and large-magnitude anomalies. If the mechanism were clearly understood, then the SP data might ultimately be helpful in quantifying the configuration of the heat sources and the mode of distribution of the associated hydrothermal fluids.

No definitive mechanism has as yet been established. Various types of evidence, however, appeared to favor an electrokinetic phenomenon as the primary source. The potentials were thought to result from the differential displacement of certain ion species in the waters that overlie deeper-seated hot zones. Other potential-generating sources such as isothermal diffusion-adsorption or oxidation/reduction were discounted as probable primary sources on the basis of their limited electric potential capacity or the many restrictive conditions required to produce them. Thermoelectric processes, involving the direct interaction between liquid and subsolidus lava, also were discounted because of the unrealistically shallow depths to magma inferred from analysing some of the SP anomalies.

A thermoelectric process that was considered a possibility is thermal diffusion, a process that gives rise to a potential gradient whenever a temperature gradient exists in an electrolyte. This potential gradient arises from the tendency of the ions to diffuse at different speeds, the polarity and magnitude being such as to equalize their diffusion rates. Reported values of thermal potential coefficients of common electrolytes are of the order of 0.2 to 0.5 millivolt/C° (Tyrrell and Colledge, 1954). However, a major inconsistency of this process with some mapped dipolar anomalies is the impractically shallow depths and short lateral distances at which a reversal in a large temperature gradient would be required to explain large magnitude negative potentials on the immediate flanks of similarly large magnitude positive potential anomalies.

It is reasonable to expect that all of the large SP anomalies on Kilauea result from a common principal mechanism. A phenomenological model that would hold up to explain one type of anomaly should also be expected to hold up for another. To this end, a mechanism that seemed to be generally compatible with the observed anomalies and which required a thermally-induced, ion-displacement process was electrofiltration. Electrofiltration (streaming) potentials can arise when a differential fluid pressure exists in the pore-water system of a rock (Dakhnov, 1959). Ions of the same polarity in the pore water are absorbed preferentially along the pore walls, leaving an excess of opposite-charged ions in the pore water. Charge separation occurs when the water flows. Most rocks absorb cations, so that the mobile anions will effect a potential gradient that is positive in the direction of the fluid flow. The magnitude of the potentials is directly proportional to the differential pressure, the ion-adsorption efficiency of the rock (zeta potential), and the dielectric constant and resistivity of the pore water; it is inversely proportional to the fluid viscosity.

The possibility of large streaming potentials arising in a hydrothermal convection cell that might be formed above a magma body or high temperature lavas would depend largely on the dynamic pressures developed and the nature of the convecting interstitial fluids. It seemed reasonable that the high rock permeabilities, abundant ground water, and the shallow heat sources in Kilauea would be adequate to support fluid convection. Further, if the pore fluid at some depth existed partially in a vapor phase, then the electrical conductivity and viscosity of the fluid might be markedly reduced. Accordingly, these factors would tend to produce larger electro-filtration coefficients than those commonly reported for moderately conductive electrolytes (a few to tens of millivolts per atmosphere).

Notwithstanding the qualitative merits that this model has for explaining the source for Kilauean anomalies, a recent critical evaluation of a few anomalies has brought out some inconsistencies. The wavelength of some anomalies suggest top-of-source depths to be as shallow as 30 meters. Resistivity sounding measurements made in these areas indicated that the flanking lavas are undersaturated in water to depths of about 600 meters (Zablocki, 1976; 1978). Below these depths, lower resistivities were ascribed to the local water table. It is difficult to envision, therefore, how a well-developed convection cell could occur at such shallow depths in the undersaturated medium. Another inconsistency, or enigma, that is confronted when applying this, or any other model in which the potentials are assumed to be derived from a buried localized source, is the virtual absence of perturbations of the surface potentials due to some nearby large-scale topographic features. For example, a large magnitude (1.5 volts) and broad (1.5 x 1.0 km) anomaly is associated with a correspondingly broad fumarolic area located on the north rim of Kilauea Caldera (Zablocki, 1976). Surprisingly, however, the large potentials remain essentially constant right up to the edge of the caldera rim where the near-vertical scarp is about 100 meters above the caldera floor. Similarly, large and steep potential gradients that are developed on the flanks of some anomalies indiscriminately transect several large, deep pit craters with no apparent deviations that one might expect if there was a lateral component to the potential-derived currents. The lack of such deviations has probably contributed more to the exceptional smoothness of the mapped potential distributions in Kilauea than any other single factor.

The foregoing observations have prompted me to seek yet another mechanism that would be compatible with all observations as well as be hydrogeologically reasonable. In the Puna SP survey mentioned earlier, it was observed that a large, smooth, potential gradient tended to confom with the topography. The potentials were more negative upslope than toward the shoreline (water table). The linear gradient in this area was about -2 mv/m. In a research hole drilled near Kilauea's summit, the potential difference measured between the surface and the local water table (488 m deep) was -655 mv (-1.35 mv/m). An SP borehole log, made in conjunction with electrical logs, showed that the gradient was fairly constant in the zone above the water table.

These observations strongly indicate that the vertical descent of abundant meteoric water through the vadose zone can give rise to significantly large streaming potentials. Resistivity soundings made in non-thermal areas around Kilauea's summit (elevation $\sim$ 1 km above sea level) indicate great depths to the water table. Even the anomalously shallow water table encountered in the summit drill hole (610 m above sea level) represents a substantially thick vadose zone.

The proposed mechanism, then, involves the assumption that the surface potential intensities are directly proportional to the thickness of the vadose zone. Accordingly, the apparent positive anomalies developed over thermal areas may simply reflect the shallow depths to which cool meteoric water may descend before encountering higher temperature fluids rising above a deeper heat source. The flanking cool lavas would allow the water to descend to greater depths (i.e., to water table). The thicker vadose zone (200-700 m) would result in large negative potentials at the surface whereas the thinner zone directly over the thermal area would be significantly less negative. A resulting potential profile across the thermal feature would therefore appear as a positive polarity anomaly.

This model would explain the shallow depths noted for some of the anomalies, and because the potentials are generated essentially in a vertical direction, the model would explain the virtual absence of perturbations in the vicinity of local topographic features. Also, this model does not require an unusually large potential-generation scheme to account for some of the largest magnitude anomalies that have ever been reported. Enhancement of the anomalies may result from the ascending water vapor over the thermal area and from a large flux of liquid-phase water diverted laterally and downward along the immediate flanks of the thermal zone.

Unlike some of the other proposed mechanisms, this new scheme should be amenable to testing by some theoretical and experimental studies. If such studies should support this concept, then we can begin to assess the quantitative utility of SP measurements in Hawaii.

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