Geothermal Resources Council, TRANSACTIONS, Vol. 3 September 2979

An Update of Tectonics and Geothermal Resource Magnitude of the Salton Sea Geothermal Resource

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Abstract

We have synthesized geological and geophysical data to determine the tectonics of the Salton Sea Geothermal Field region and to re-evaluate its geothermal resource potential, Based upon the existing data, we believe that the Salton Sea high heat flow zone is above a tectonic gap characterized by a depth to the crust-mantle interface of about 14km, by extensive faulting, and by a subsidence *rate* which is much higher at present than the average geological rate. The tectonic gap *is* bounded by the Wister and Westmorland faults on the east and west respectively and by the transverse discontinuity and a set of en echelon faults to the north and south. Two epochs of magmatism have taken place in the region within the upper Pleistocene. The stored heat energy within the hydrothermal reservoir at a depth range of 1 to 3 km is about 1.4 x 10^{20} calories which is larger than previous estimates. A large hot dry rock zone must also underly the hydrothermal resource.

Conceptual Model of the SSGF

It is evident that the region of the Salton Sea Geothermal Field ("SSGF") is an active spreading center based upon data from the active volcanism (Muffler and White, 1969), rate of subsidence (Lofgren, 1978), heat flow pattern (Randall, 1974; Palmer, 1975), staircase seismicity pattern (Schnapp and Fuis, 1977; Johnson and Hadley, 1976), preponderance of active growth faults at sea (Meidav, 1968) and south of the Sea (Meidav et al., 1976), the rise of a magmatic pluton (as evidenced from the magnetic data (Griscom and Muffler. 1971). and general geological data (Elders et al., 1972). We present here an up-*date* of the evolution and structure of the SSGF, which is a refinement of the models proposed by Elders et al. (1972) and Garfunkel (1972), and a revised resource assessment. No doubt, the current model will require futher refinement as additional data are gathered.

The separation of the Pacific Plate from the American Plate (Atwater, 1970) and its extension through the Gulf of California (Lomnitz et al., 1971) has created extensional stresses in the mantle and crust below the Imperial Valley. Slight differences in crustal rock composition in the SSGF region, characterized by lower melting point, higher plasticity or higher hydrous mineral abundance, has caused that area to flow rheologically in response to the stress. In the first stage, block faulting took place. Older granite masses which were adjacent to the Chocolate Mountains subsided and deltaic deposition occured. This process may have started about four million years ago (Elders et al., 1972) and is continuing at present. With a maximum separation rate of bout 8 cm/yr, the average extensional strainrate is about 10^{-7} per year: although, in reality, higher strain rates are calculated for the center of the valley, and lower rates at the margins, based upon Whitten's (1956) and Lofgren's (1974, 1978) data.

Gravity Evidence of Crustal Characteristics

Using Biehler's (1964) Bouguer gravity map, Meidav and Rotstein (1968) calculated a two-dimensional SW-NE model of the Imperial Valley (Figure 1, cross section; see Figure 3 for location of cross section). Evaluating Biehler's density-velocity data, Meidav and Rotstein assigned a mean weighted density of 2.43 gm/cm^3 for the

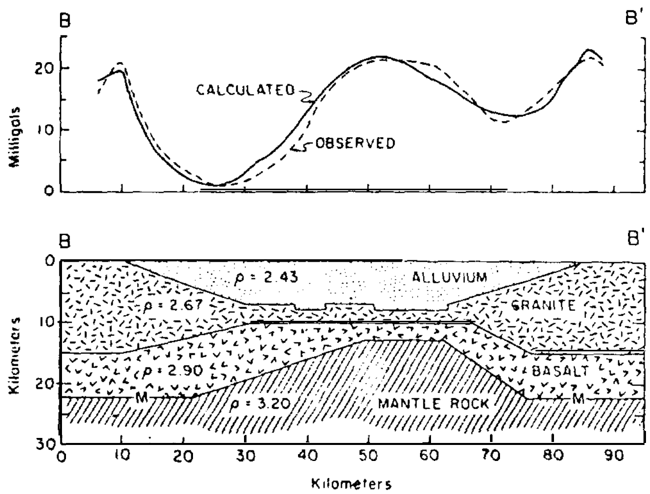

Figure 1: Crustal model of the Imperial Valley based upon gravity data (see Figure 3 for location of section).

Imperial sedimentary section, and an initialdepth to basement of 6 km, based upon Biehler's (1964) seismic refraction data. The density for the granite was taken as 2.67, basalt as 2.9, and mantle rock as 3.20. The resultant model (Figure 1) suggests that in order to account for the gravity data, a depth to the Moho of 22 km must be assumed at the margins of the Valley, shallowing to 14 km at the center of the Valley. The density contrast between the alluvium and the granite which it displaces is -.24 (=2.43-2.67). The density contrast between the isostatically rising mantle in the middle of the Valley is about t.3, or about the same order of magnitude (but of opposite sign). Hence, subsidence of the Valley floor must be matched by an approximately equivalent rise in the crust-mantle surface, if isdstasy is to be maintained. For periods of time which are large compared with the Newtonian viscosity coefficient of any material, it behaved as though it were a liquid, as far as hydrostatic pressures redistribution goes. Thus, at some depth within the mantle, say 30 km, lithostatic pressures have been everywhere the same, if plastic deformation is equal to or faster than the operating tectonic movement at shallower depths.

In response to the strain associated with separation of the American and Pacific plates, and due to slight heterogeneity in petrology, a gap has been formed in the upper crust. The gap has been filled with low density sediments, reducing the lithostatic pressure within the mantle, causing it to rise and restore isostatic equilibrium. This change caused a rise in the isothermal surfaces within the crust. The rise in turn acted as a feedback causing further reduction in crustal rigidity, and, therefore, accelerating the rheological flow rate of the crust in responseto the plate separation forces. This flow, in turn, increased the rate of subsidence of the Valley surface and the Valley floor, eventually leading to volcanism. Review of the subsidence data suggests that the process is faster at present than it has been over the geological past by one order of magnitude. In places it reaches 3.4 cm/yr e.g. at the Salton Sea; Lofgren 1978, as compared with about 3 mm/yr calculated for the average subsidence overabout two million years. The accelerated spreading and subsidence in the Salton Sea area has been responsible for at least two epochs of volcanism and suggests that an increased rate of volcanic activity may be anticipated in the future.

The fact that sedimentary in-filling of the Imperial Valley was stopped by man, starting at the turn of the twentieth century, coupled with the ongoing subsidence of about 3.4 cm/yr at the Salton Sea, is creating an upward isostatic stress at the Moho which would require a rise of the Moho of about 22-23 cm/yr, if the stress is instantaneously transmitted. In the long run, this stress may increase the seismicity of the region and decrease the time interval between volcanic episodes beyond the recent rate.

Volcanic Activity

Five small volcanic cones are aligned along the southern end of the Salton Sea. Robinson and Elders (1971) have described the origin of the volcanoes as a response of the basalt to the pull-apart. Muffler and White (1969) have provided a single age dating of the volcanics at some time between 16,000 and 55,000 years ago.

Both the ground magnetic map of Kelley and Soske (1936) and the aeromagnetic data (Griscom and Muffler, 1971) show that the size of the pluton which underlies the volcanic alignment is much greater than that which would have been caused by five small volcanoes.

Combining the surface geodetic data and the ground magnetometer data, it is possible to show that the large magnetized stock is about four times older than the volcanic eruptions, with the latter having extended out of it a few tens of thousand of years ago. This age determination is calculated from the amount of displacement of the magnetic contours along the Red Hill Fault (Figure 2). There are two offsets of these contours

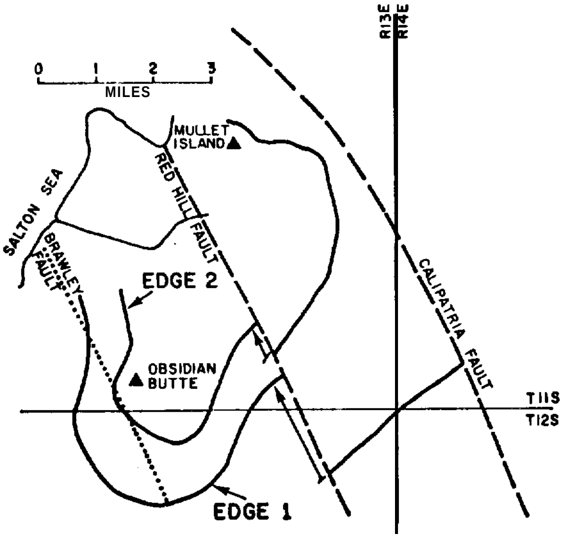

Figure 2: Structural features of the southeastern part of the SSGF, showing the displacement of the edges of two magmatic intusions along the Red Hill Fault. The interpretation is based upon Kelley and Soske's (1936) ground magnetic data.

along the Red Hill Fault; 0.5 kmatshallow depths near the young volcanic pile, and about 2 km at greater depth of about 5 km. We assume that the Red Hill fault has been active prior to the older cycle and that it started displacing the deeper stock immediately upon the latter's intrusion into the upper crust. Likewise, immediately after the eruption of the five volcanic cones, perhaps along a northeast-trending dike, their root became subject to the same right lateral movement. Hence, if we assign an age of, say, 50,000 years to the volcanic event, we may deduce that the parent stock is about 200,000 years old assuming a constant rate of displacement.

The data from electrical resistivity, seismology, magnetics, geodetics shows that northwest trending faults and conjugate northeast-trending faults (Figure 3) lace the area. We believe that the Wister Fault forms the northeastern boundary of the developing Salton Sea gap (or rhombochasm), and that the Westmorland Fault forms its southwestern boundary. The northernconjugate boundary

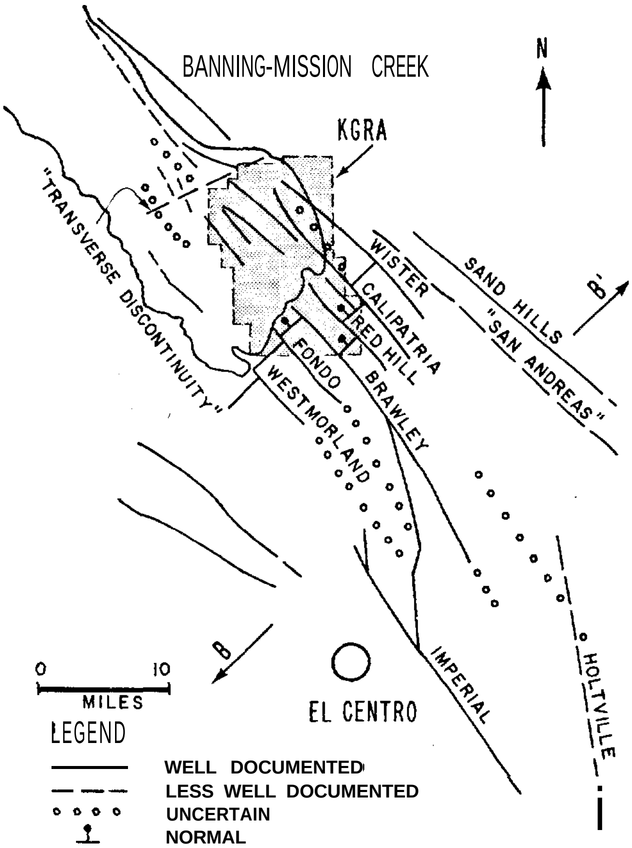

Figure 3: Structural map of the SSGF, based upon combined geophysical data.

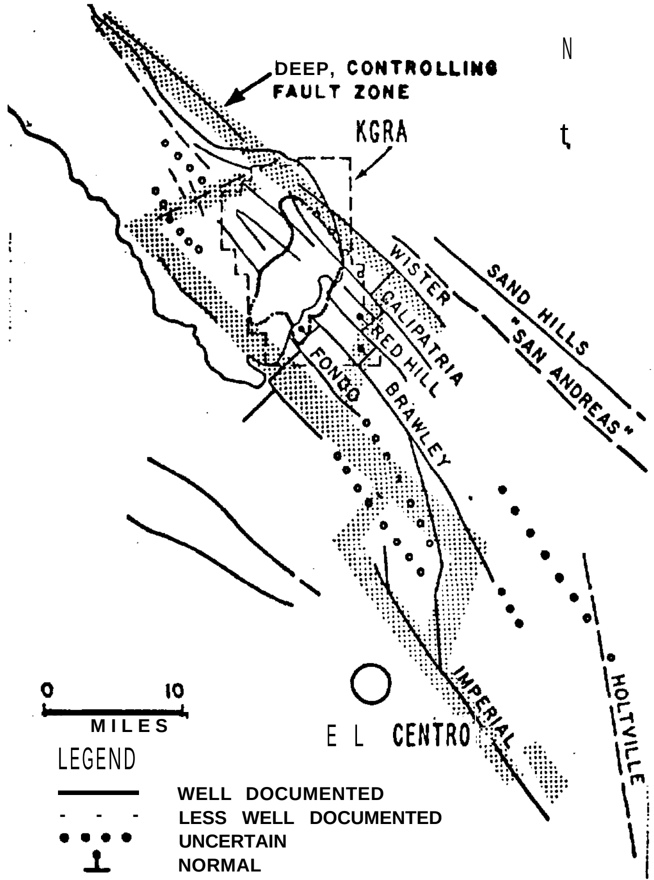

Figure 4: Approximate boundaries of the gap in the region of the SSGF showing the 800 mW/m^2 heat flow contours (area enclosed with dots in southeast part of Salton Sea).

of the gap is the Transverse Discontinuity, which is located approximately where the Sea narrows down, marked by an abrupt change in shallow faulting in the Sea (Meidav, 1968) and by a change in the gravity field from a normal synclinal low to the north, to a gravity high to the south. The southern boundary of the gap is not clearly defined, but may be marked by a set of en echelon conjugate tension faults which occur between the more prominent northwest-trending faults. The approximate southern boundary is shown in Figure 4.

Thermal Regime and Geothermal Resources

Palmer (1975) has constructed an isothermal block diagram of part of the Salton Seageothermalfield, which shows evidence of hydrothermal convection below the cap layer. Palmer's maps show that the isothermal surfaces behave as though the center of heat is located along a northeasterly-trending axis coinciding more-or-less with the axis of the young volcanoes. The i&thermal surfaces are oblivious to the verticalorhorizontal boundaries, as though the entire system were to consist of a single convective cell. Helgeson (1968) has demonstrated that the salinity-enthalpy-depth relationship in the geothermal system is such that the salinity increase offsets the reductionin density which would normally have taken place with an increase in temperature. This vertical self-equilibration of salinities again suggests that over long time periods (thousands of years), the Salton Sea geothermal system may be considered vertically permeable. We hypothesize that northwest trending faulting, and gap opening (i.e. by transverse faulting) continuosly creates new fluid pathways. We deduce from seismological data that brittle fracturing of this type does not extend below basement depth at the Salton Sea geothermal field area namely around 6 km. Hence, the base temperature of the circulating geothermal fluid does not exceed the highest measured temperature (about 340^oC) by more than about 160^oC assuming a constant gradient from 2 km to 6 km.

Lee and Cohen's (1979) shallow heat flow data indicates that the high heat flow area (more than 200 mw/m^2 or 4.8 HFU) may cover more than 560 km^2. Previously, Lee (1977) demonstrated the validity of shallow heat flow data in the area, by correlating his results with the deeper thermal data at a number of sites. If we take the reservoir thickness as 2 km and the mean reservoir temperature as 265°C, the reservoir energy is about 1.4 x 1020 calories, or about 5.86 x 10^{20} Joules. This estimate is about six times greater than that made by Brook et al., in USGS Circular 790 (USGS, 1978).

The USGS team has estimated the electrical energy potential for the Salton Sea Geothermal Field at 3400 MWe for 30 years. The difference between our estimate and that of the USGS results from re-evaluation of the resource area due to the new shallow heat flow data. Deeper temperature surveys will be needed to ascertain if our proposed larger resource estimate is justified.

It is impossible at this time to prognosticatethe percentage of the accessible resource which will be ultimately harnessed. A host of technological, environmental and institutional barriers is yet to be overcome before the Salton Sea Geothermal resource is fully developed. No consideration of the hot dry rock energy resource was made. However, it is evident that the hot dry rock energy at a depth range of 3-6 km is considerablygreater than that of the overlying hydrothermal resource.

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