CONF-8606129--1

UCRL- 94566
PREPRINT

DRILLING INVESTIGATIONS OF CRUSTAL RIFTING PROCESSES IN THE SALTON TROUGH, CALIFORNIA

P. W. Kasameyer
L. W. Younker
R. L. Newmark
A. G. Duba

This paper was prepared for submittal to
DOSECC Workshop
"Continental Scientific Drilling Program"
Rapid City, South Dakota
June 12-14, 1986

Lawrence Livermore National Laboratory

UCRL--94566

DE86 010979

DRILLING INVESTIGATIONS OF CRUSTAL RIFTING PROCESSES IN THE SALTON TROUGH, CALIFORNIA

P. W. Kasameyer
L. W. Younker
R. L. Newmark
A. G. Duba

This paper was prepared for submittal to
DOSECC Workshop
"Continental Scientific Drilling Program"
Rapid City, South Dakota
June 12-14, 1986

Lawrence Livermore National Laboratory

DRILLING INVESTIGATIONS OF CRUSTAL RIFTING PROCESSES IN THE SALTON TROUGH, CALIFORNIA

P. W. Kasameyer
L. W. Younker
R. L. Newmark
A. G. Duba

Lawrence Livermore National Laboratory
Livermore, California 94550

Introduction. Drilling provides access to the interior of the continental crust, allowing the direct observation of active processes and the collection of relatively undisturbed samples of the materials resulting from those processes. Unfortunately, the drillhole is myopic, and these observations and samples are valuable only if they can be viewed in context and provide insights into more general applications. In this paper we describe the results of CSDP activities in the Salton Sea Geothermal Field (SSGF), concentrating on a shallow heat-flow survey, but also considering preliminary results from the Salton Sea Scientific Drilling Program (SSSDP). These studies are providing significant insights into the nature of this specific hydrothermal system. By examining the thermal budget for the hydrothermal system, we argue that these studies are also telling a great deal about the nature of the rifting of the continental crust by oblique spreading throughout the Salton Trough.

Salton Trough Models. The Salton Trough is a large sediment-filled rift valley that represents a zone of tectonic transition between the oceanic-style ridge-transform activities of the Gulf of California to the southeast and the San Andreas continental transform fault system to the northwest. Authors with differing interests perceive that this spreading is occurring on different scales, as is indicated by Figure 1 from Lachenbruch, et al, 1985[1]. Here, the thermal zones, perceived by many as the locus of spreading, are shown as less than 10 km in extent (Elders, et al, 1972)[2]. The zones of

1. Lachenbruch, A. H., J. H. Sass and S. P. Galanis, Jr., Heat flow in southern-most California and the origin of the Salton Trough, J. Geophys. Res. 90, 6709-6736, 1985.

2. Elders, W. A., R. W. Rex, T. Meidav, P. T. Robinson and S. Biehler, Crustal spreading in southern California, Science 178, 15-24, 1972.

This work supported by the U.S. Department of Energy at Sandia National Laboratories under contract DE-AC04-76DR00789 and at Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

seismicity suggest that a larger area, perhaps 30 km long, is deforming (Fuis, et al, 1982)[3]. Finally, regional tectonic modeling by Lachenbruch, et al, 1985, requires basalt intrusion into a diffuse zone of deformation 150 km long.

The heat flow data suggest that the localized areas are of limited importance. Figure 2 shows a histogram of the heat-flow values averaged over 5 km x 5 km regions used by Lachenbruch, et al, 1985[1] in a tectonic model for crustal rifting in the Salton Trough. Ten percent of the zones are geothermal fields with anomalously high heat flow, but they contribute only 25% of the total heat flow in the valley. The local systems provide a relatively small portion of the total heat flux of the valley. Does this mean that they contribute only a relatively insignificant amount to the rifting processes? Do we need to require basalt intrusion over a much wider area at this time, or is it possible that all the spreading takes place at hot spots, which must have migrated throughout the wider swath during the last 4 million years? Several lines of evidence could be studied to answer this question: thermal, chemical, mechanical or petrological. In this paper we choose to examine whether the heat input rate to these localized systems is high enough to account for the overall thermal budget of the Salton Trough, and indicate how the CSDP activities are contributing to understanding the thermal budget.

In order to assert that the local zones are indeed the locus of all the spreading at this time, we need to assume that there is no anomalous heat transport into the other areas throughout the Trough, which must be cooling off. To maintain the observed average rate of heat influx, which is required to keep the Salton Trough near sea level (Lachenbruch, et al, 1985)[1], the heat input rate to the hydrothermal systems must be larger than the heat flow out, by a factor of four or more. Thus, by examining the ratio of heat flux out to heat accumulation rate, we can test whether it is possible that all the spreading takes place at these zones.

The hydrothermal system and young volcanoes at the SSGF have been studied by a variety of techniques but temperature profiles in deep and shallow wells have, to date, provided the most useful information about the circulation patterns in system. Our previous studies of the SSGF led to the development of a simple conceptual model of the

3. Fuis, G. S., W. D. Mooney, J. H. Healy, G. A. McMeehan, and W. J. Lutter, Crustal structure of the Imperial Valley region, U. S. Geol. Surv. Prof. Pap. 1254, 25–49, 1982.

flow in the sampled portions of this field (Kasameyer, et al, 1984)[4]. A recent re-examination of this model shows that, to fit the observations from the SSGF, the rate of heat input into the system by advection to the rate of heat flux from the top of the system by conduction is somewhere between 2.8 and 10. If this model is valid, and if the same ratio applies to all the other fields, then the heat influx rate for these fields is large enough to account for the steady-state heat flux from the Salton Trough.

Several factors were unknown when we published the model for the SSGF. Thermal gradients were measured only in part of the anomaly, and none of the high heat-flow contours were closed. All drillholes encountered monotonically increasing temperatures, so the thickness of the zone of outward migration was unknown. The details of the thermal structure near the edge of the high gradient zone were unknown. Finally, the applicability of this approach to other fields in the Salton Trough remains untested. All of these factors affect the thermal budget and therefore bear on the question of the application of studies of the SSGF to the problem of regional tectonics. Recent CSDP experiments have answered some of these questions.

Continental Scientific Drilling Activities at the Salton Sea Geothermal Field. The LLNL-Sandia thermal gradient survey[5], supported by DOE-OBES, completes the coverage of the top of the hydrothermal system at the SSGF, defining its shape and lateral extent. In November and December, 1985, nineteen holes were drilled 80 m below lake level offshore in the region north of the volcanic domes along the southern shore of the Salton Sea (Figure 3). The holes were drilled using a truck-mounted rig set on a floating barge, cased with one inch diameter PVC pipe, sealed against infiltration of formation fluids and filled with water. Temperatures were logged periodically in each hole until three months after drilling to ensure that temperatures had reached equilibrium. Short (1 m) cores were obtained from the bottom of four holes, and cuttings were collected every three meters when possible. Thermal conductivities are being measured on a number of core and cutting samples that represent the range of formation lithologies encountered. With

4. Kasameyer, P. W., L. W. Younker, and J. M. Hanson, Development and application of a hydrothermal model for the Salton Sea geothermal field, Geol. Soc. Am. Bull, 95, 1242-1252, 1984.

5. Newmark, R. L., P. W. Kasameyer, L. W. Younker, and P. C. Lysne, Research drilling at the Salton Sea Geothermal Field, California: The Shallow Thermal Gradient Project, EOS, in press, 1986.

one exception, all holes show uniformly increasing temperatures with depth, indicating that, as expected, conduction dominates in the cap of the field. Bottom-hole temperatures range from about 27°C to above 90°C. Thermal gradients over the lower 46m range from about .09°C/m to over .92°C/m. Thermal conductivities measured on samples within hours after drilling range from about .4 W/mK to over 1.3 W/mK.

Although the data are still being collected, the shape of the system, as reflected in the 0.3 °C/m contour, can be seen on the preliminary thermal gradient map (Figure 3). There is a pronounced asymmetry of the high gradient zone relative to the chain of volcanic buttes. The thermal anomaly extends only a short distance offshore, primarily in the northern and southern edges of the field. The northwestern boundary of the field follows an arcuate pattern roughly coincident with the pattern of the buttes and markedly contrasting with the shape of the southeastern boundary of the field. Finally, the northeastern part of the field is broader than the field to the southwest, and the high temperature region in the south extends significantly beyond the onshore magnetic anomaly, in contrast to the northern region where the magnetic anomaly and thermal anomaly appear to be closely correlated.

The SSSDP deep hole is contributing important information to the definition of the thermal budget for the circulating hydrothermal system, in addition to providing the opportunity for extensive sampling and other studies. Temperature results reported to date[6] are not surprising. The gradient in the upper part of the hole is slightly lower than the center of the field, comparable to that seen at River Ranch No. 1, indicating that we are getting significant information about the outside edge of the central anomaly. There is no published indication that the bottom of the convecting system has been detected as of yet. Equilibrium thermal information from this drillhole currently being collected will provide valuable constraints on the temperature structure within the circulating system, as well as extending its known depth. Both parameters will be used to relate the heat input rate to the surface heat flux.

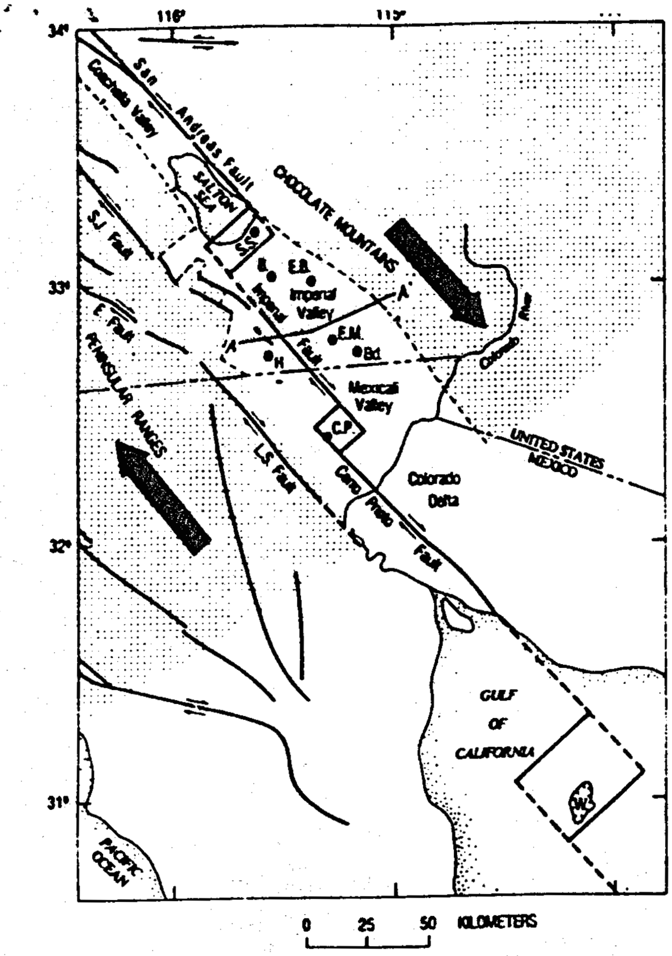
The total area and heat flux coming from the field, the thickness of the circulating zone, and the abruptness of the transition from high to low gradients are the principal data constraining the rate of heat influx into the SSGF. The results from these

6. Salton Sea Scientific Drilling Progress Monitor, Issue No. 3, U.S. DOE, 1986.

experiments will feed back into thermal models and lead to conclusions about the thermal budget for this field, and about the importance of the local hot-spots in crustal rifting. If we become convinced that all the spreading takes place at hot-spots, then the chemical and petrologic studies at the SSGF provide insight, not only into hydrothermal alteration in geothermal systems, but also to the manufacture of new continental crust by the interaction of energy and materials from the mantle with continental sediments.

<u>Future Drilling Investigations in the Salton Trough</u>. There are many possibilities in the Salton Trough for future CSDP activities designed to understand the regional thermal and tectonic processes. The highest priority in this regard is to obtain deep temperature data which bear on the relationship between the thermal structure of the localized geothermal anomalies and the regional thermal regime. The present SSSDP hole reached approximately 10,500 feet, and a proposal has been sent to DOE to deepen it to 14,000 feet. A simple argument indicates that the proposed deepening is likely to reach the bottom of the well-studied hydrothermal circulation zone, providing a solid constraint on the thermal budget. The central temperature of the hydrothermal system is approximately 350 °C. A drill hole to the depth where that temperature would be produced by the normal conductive gradient would reach the bottom of the thermal anomaly. For the regional Salton Trough gradient of .075 °C/m, we expect 350 °C at about 14,000 feet. For the slightly elevated gradient observed surrounding the SSGF, .11 °C/m, 350 °C is encountered at about 10,000 feet. We anticipate a high probability of the thermal regime changing from nearly isothermal as one or the other of these depths is approached, and the nature of that change will indicate the total thickness of the hydrothermal system, or its connection to a deeper and perhaps more widespread one.

In addition to the already proposed deepening of the SSSDP hole, there are many other ideas that, if analyzed and justified, might make attractive CSDP projects in the Salton Trough. An intermediate depth (3000 foot?) hole could be drilled at the northwest boundary of the SSGF, to understand the cause of the asymmetry in the geothermal anomaly, and to test the validity of the lateral flow model. This hole could be complemented by a reflection profiling study focused on the nature of the localized spreading center at depth (Henyey, personal communication). A drill hole into the seismically active zone, but between the geothermal fields, could be targeted to identify the rock properties and state of stress in order to develop a seismo-tectonic model of deformation. Additional constraints on the regional heat budget could be provided by filling in the gaps in the heat flow coverage with measurements in the western part of the valley and to the south and east of the Salton Sea (Lachenbruch, Sass, and Galanis, personal communication). Heat input rates from other geothermal fields throughout the Salton Trough need to be evaluated in order to more effectively assess whether the heat input to the localized geothermal systems is sufficient to drive the rifting process.



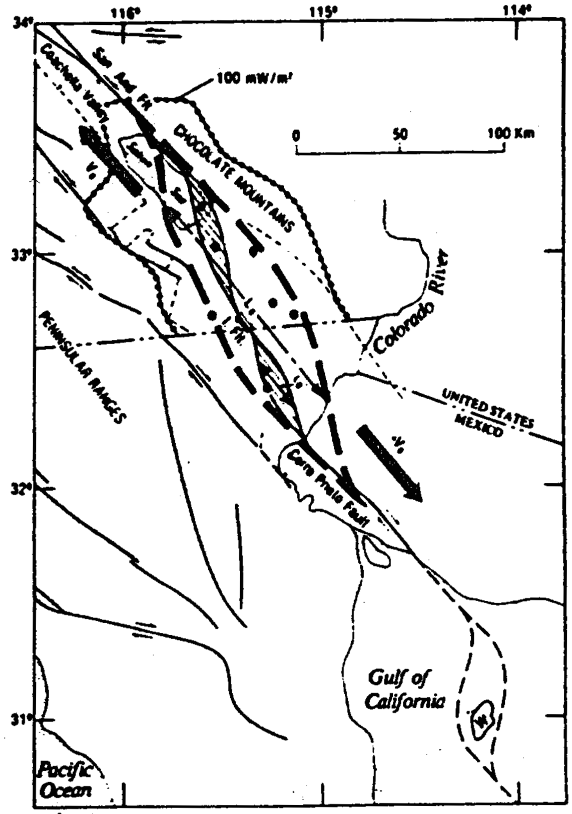


Fig. 1a and Fig. 1b Three Scales of deformation in the Salton Trough (Lachenbruch[1]). What is the relationship between the local hot spots (i.e., S.S., C.P.), the intermediate scale seismic zones (Shaded and marked Lo') and the large scale (Lo) of the zone where strain takes place?

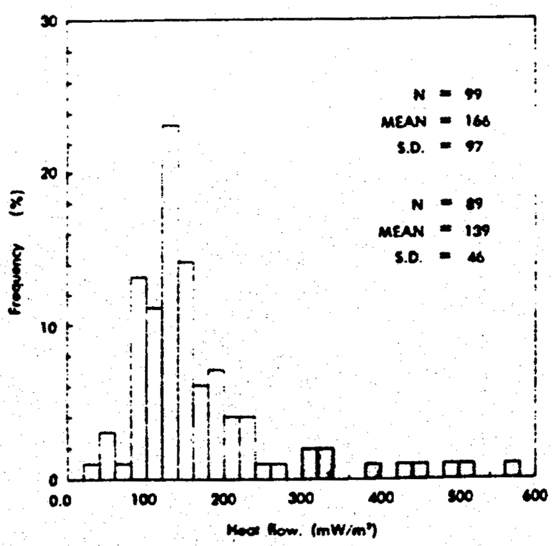


Fig. 2 Distribution of average heat flows from 3 arc min x 3 arc min regions in Imperial Valley . Statistics for N = 99 include all values; statistics for N = 89 exclude regions with mean heat flows ≥ 300 mW M^{-2} (crosshatched). (figure from Lachenbruch[1])

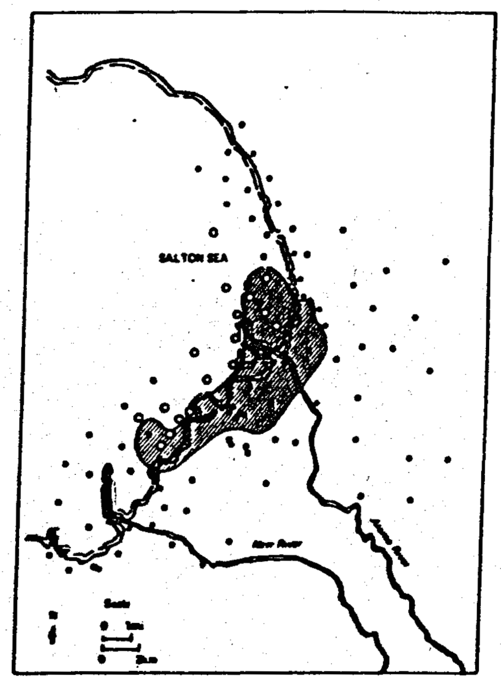


Fig. 3 Locations of thermal gradient data at the SSGF (from 5). Open circles indicate data collected in November – December 1985, closed circles indicate earlier data. The shaded area contains all values with gradients above 0.3 °C/m.

Technical Information Department · Lawrence Livermore National Laboratory
University of California · Livermore, California 94550