

LONG-TERM SUB-SURFACE TEMPERATURE  
MEASUREMENTS ALONG THE IDAHO GREAT RIFT:  
A POSSIBLE METHOD

FOR GEOTHERMAL ENERGY PROSPECTING <sup>1/</sup>

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**ABSTRACT** -- The slow, temperature-sensitive, acid-catalyzed hydrolysis of sucrose solutions (Pallmann method) was employed to measure average sub-surface temperatures over a period of 303 days in the area of the Idaho Great Rift. Temperatures tend to increase to the south-west, away from the Rift and towards the edge of the Snake River Plain where there is considerable manifestation of geothermal activity. The data from this preliminary work indicate that the method should be carefully studied for possible application in geothermal prospecting.

Locating regions for exploratory geothermal prospecting, including deep drilling, would be facilitated by an inexpensive method of accurate shallow

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temperature determinations over large areas. A number of geothermal prospecting methods have been attempted but have met with limited success. Ground water analysis, for example, is seriously limited by uncertainties in water flow rates and consequent varying contact times with different geochemical environments. Heat flow measurements, though showing promise, require drilling of cased wells and will probably prove prohibitively expensive for large-scale exploration. Instantaneous surface temperature measurement, aerial infrared mapping, and satellite surface temperature measurement have also proven unreliable since any measurement of this kind is subject to short-term temperature fluctuations resulting from variations in solar heating, vegetation cover, moisture collection, and evaporation.

Meaningful shallow areal temperature distributions require measurements integrated over an extended period of time in order to average out the short-term fluctuations. We have carried out a preliminary feasibility study of such a method based upon the slow acidic hydrolysis of sucrose samples. This temperature measurement technique was originally developed by Pallmann, et al. (1940) and was later utilized to measure environmental temperatures by O'Brien (1971). The method takes advantage of the fact that the extent of a chemical reaction depends upon the temperature of the reaction mixture. Samples of acidified sucrose solutions placed a few feet underground and left for a period of months can subsequently be analyzed and the extent to which the reaction has proceeded be ascertained. The extent of the reaction is an indication of the temperature of the environment of the sample averaged over the entire time that the sample was left underground. This system is capable of measuring average temperature differences of about  $0.1^{\circ}\text{C}$ .

#### GENERAL GEOLOGY OF THE AREA

The Snake River Plain, about 560 km long and 80-100 km wide, is a basalt plateau, curving in a

great arc across the southern part of the state. Extending northwest across the eastern part of the plain is a 100 km long fissure zone known as the Idaho Rift System (Prinz 1970). At the northwest end of the northernmost rift set lies the Great Rift which is partly within Craters of the Moon National Monument. Volcanic material there, the youngest on the Snake River Plain, has been dated by tree rings at about 1650 years B.P. (Stearns 1963). Other material there has been dated at about 2000 years B.P. (Bullard 1971). In the monument area, the volcanic material is very fresh, without soil or much vegetation. Away from this young material, a variable thickness of loess covers the older flows. This loess is at least 1.2 meters thick where samples were placed, but is almost entirely lacking in scattered areas where basalts are at the surface.

Several different ideas concerning the origin of the Snake River Plain include downwarping, down-faulting, and rifting, perhaps associated with plate motion. Whatever its origin, one can conclude that it is a fairly young geologic feature on the basis of its paleobotany (Axelrod 1968), recency of the volcanics (at least locally), and the presence of hot water at various places on the plain. Because of the probability of at least local high heat flow on the plain, and interest in rapid, inexpensive geothermal prospecting, it seemed appropriate to test the Pallmann method as a geothermal prospecting tool in an area where variation of heat flow could be reasonably expected.

#### SAMPLE DISTRIBUTION

The following assumptions formed a basis for the experimental plans: (1) a heat source beneath the Snake River Plain is suggested by young volcanics on the plain; (2) the center of this heat source underlies the Great Rift, the site with the most recent volcanic eruptions on the plain; (3) Shallow temperature measurements (about 1.2 meters) might reflect this heat source; and (4) temperatures should

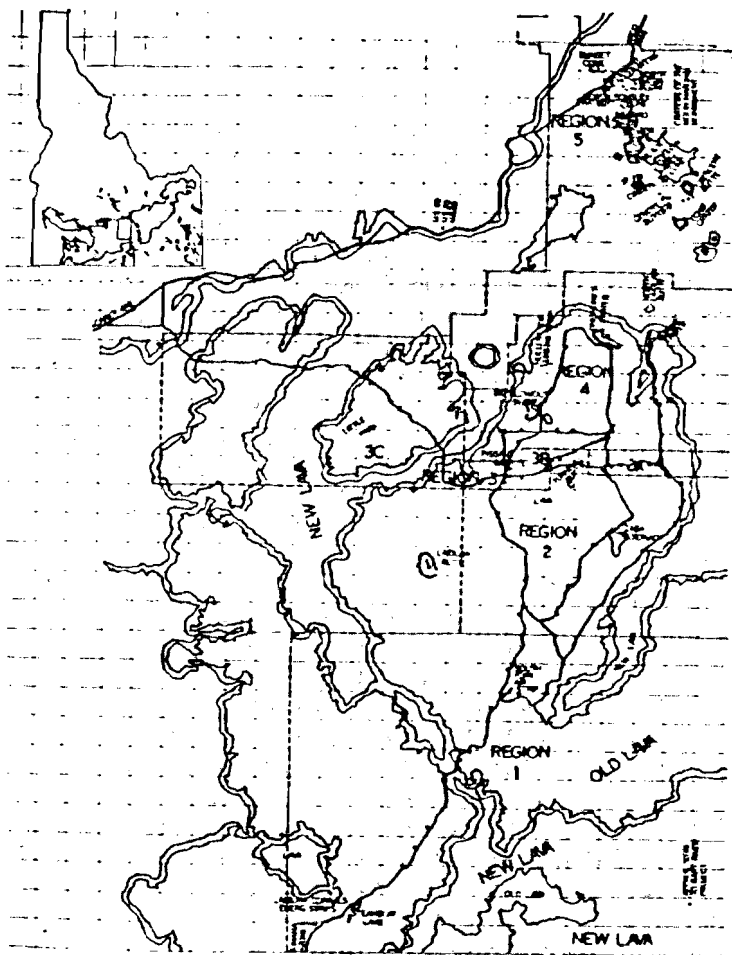


FIG. 1. Sample area in south central Idaho. Solid bold lines indicate region boundaries. Sample locations are shown as small circles. Grid scale: 1 division = 1 mile (1.6 km). Inset shows map of Idaho with Snake River Plain indicated by a continuous outline and faults by irregular lines. Sample area is shown as a rectangle within the inset map.

decrease away from the rift.

Based on these assumptions, thirty samples were placed inside the Craters of the Moon National Monument, spaced over a distance of 4 km along the Great Rift (Fig. 1), and buried to a depth of 1.3 meters in cinders. An additional 150 samples were placed along an irregular 40 km traverse that runs generally SSW from the NW trending Great Rift. These samples were buried at an average depth of  $1.2 \pm .1$  meters in loess.

Sample holes were bored with a two-man gasoline-powered auger. PVC pipes 1.5 m long and 3.8 cm inside diameter were used as sample containers.

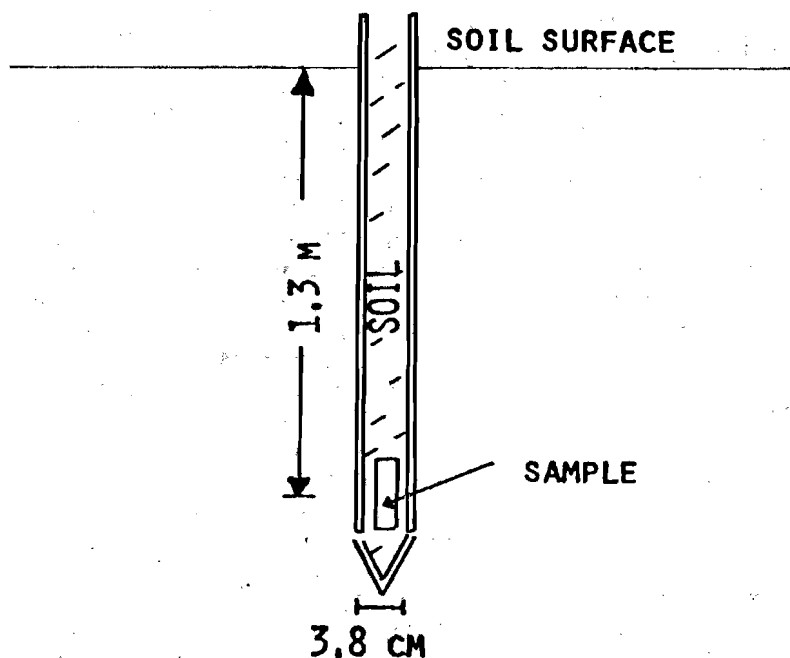


FIG. 2. Polyvinyl chloride (PVC) pipe sample stake

Each pipe was partially closed and sharpened to a point at one end, with openings near the sample to permit free passage of moisture (Fig. 2). After all holes were dug and pipes implanted, sediment was packed into the space around the pipes until they rested firmly in place. The samples were then placed in the pipes and the pipes filled with soil.

Sampling problems along the traverse normal to the rift included those of access, necessitating the irregular plan of sample locations (see Fig. 1), and impregnable hardpan or lava flows less than 1.2 meters below the surface, accounting for a variation in sample depth up to 0.2 meters.

#### PROCEDURE

Temperature measurements were made using a modification of the method given by Schmitz and Volkert (1959) as described by O'Brien (1971). Optical rotation angles measured with precision of  $\pm 0.01^\circ$ , were taken at  $25.0 \pm 0.1^\circ\text{C}$  with a Carl Zeiss 77677 polarimeter using a 1 dm thermostated cell at a wavelength of 546.1 nm. In order to prevent bacterial decomposition of the sucrose solutions, all equipment and capsules were autoclaved prior to being used in preparing the original solution. In addition, the sugar, salt, and sodium citrate were exposed to ultraviolet light for fifteen minutes, and the water was double distilled, boiled, sealed, and allowed to cool.

All samples were prepared from a single solution. The 0.750 g/ml buffered sucrose solution was obtained by mixing 4500 g of sucrose, 62.6 g of sodium citrate, 29.9 ml of 12 F hydrochloric acid, and 900 g of sodium chloride (to prevent freezing) in a six-liter volumetric flask. Sterilized water was poured into the flask until the flask was half filled. Sufficient formaldehyde was added to bring its concentration to 0.13% as an additional precaution against bacterial decomposition. The solution was stirred constantly and small portions of water were added

periodically for four days until all of the solid material was dissolved. The resulting clear solution had a pH of 3.7 and a specific rotation of  $+73.23^{\circ}$ .

Individual samples were prepared by filling 20 ml Beckman Poly QII vials and freezing the solution immediately. To ensure that the capsules would not leak, Teflon tape was wrapped around the threads of each vial. In order to allow the samples to be placed in the ground in the shortest possible time, the holes were drilled and all of the sample stakes were put in place before the samples were taken into the field. The samples, stored in dry ice, were then emplaced. A total of three days was required to distribute the samples, while their recovery required two days; all samples, therefore, were left underground for  $303 \pm 2$  days.

As each sample was recovered, it was immediately refrozen in dry ice until analysis could be carried out. It was found that a few samples had obviously deteriorated despite our precautions, and these were discarded. Some samples were also lost during road edge maintenance and through other causes.

In the laboratory, the capsules were removed from the freezer three at a time and left at room temperature for approximately thirty minutes to warm. After each sample had thawed, a small portion was used to rinse the thermostated polarimeter tube, while the remainder was used to determine the optical rotation. Only a few minutes were required for each solution to equilibrate after being poured into the tube. Five readings were taken and the average was recorded as the observed rotation of the sample.

The observed optical rotation is related to the specific rotation by the relationship

$$[\alpha]_{546}^{25} = \frac{a}{c \cdot l} \quad (1)$$

where  $[\alpha]_{546}^{25}$  is the specific rotation at  $25^{\circ}\text{C}$  and

546 nm,  $a$  is the observed rotation,  $c$  is the sucrose concentration in g/ml, and  $l$  is the sample path length in dm. Conversion of the specific rotation to mean temperature can be accomplished by use of the relationship given by Schmitz and Volkert (1959):

$$T = \frac{-a}{\rho l - b - \log t [\log(R_1 - R_c) - \log(R_t - R_c)]} \quad (2)$$

where  $T$  is the temperature in degrees Kelvin,  $t$  is the time in days,  $R_1$  is the initial specific rotation,  $R_t$  is the specific rotation at time  $t$ , and  $R_c$  is the specific rotation upon completion of the reaction. The constant  $a$  is the Arrhenius activation energy of the reaction divided by  $2.303 R$  where  $R$  is the gas law constant. The constant  $b$  is related to the Arrhenius preexponential term and is concentration dependent.

Actual temperatures were not needed in this study, and indeed an average temperature value integrated over many months would have no apparent scientific worth. We therefore report our results simply as observed rotation values which are a function of the long-term time-averaged subsurface temperature environments of the samples.

## RESULTS

To facilitate treatment of the data, the sample area was divided into five geographic regions, arranged in the general direction SSW to NNE, Region 1 being the southernmost. A map of the area showing the boundaries of the regions is shown in Fig. 1. The Craters of the Moon National Monument comprised Region 5. Region 3 was further subdivided into three subregions, arranged in an east-west orientation, Region 3A being the easternmost. The means of the rotation values of the samples within each of the regions are given in Table 1. Since some sample spoilage had occurred, samples with obvious contamination were discarded and the data from each region were tested according to Chauvenet's criterion in order to statistically isolate particularly

TABLE 1. Average observed optical rotation values of 112 sucrose samples after 303 days underground. The lower the rotation angle, the higher the average temperature. Region locations are shown in Fig. 1.

| Region | Avg rotation angle | standard deviation | number of samples |
|--------|--------------------|--------------------|-------------------|
| 1      | 51.51              | 0.52               | 9                 |
| 2      | 52.62              | 0.62               | 18                |
| 3      | 52.77              | 0.69               | 26                |
| 4      | 53.47              | 0.39               | 40                |
| 5      | 53.79              | 0.51               | 19                |
| 3A     | 53.26              | 0.25               | 13                |
| 3B     | 52.87              | 0.31               | 8                 |
| 3C     | 51.83              | 0.72               | 6                 |

deviant samples. The latter test resulted in the elimination of only six samples from the entire set of data before final means and standard deviations were computed.

The data in Table 1 can be related to temperature differences by noting that a larger rotation angle indicates a lower average temperature. The difference between the largest and the smallest values is equivalent to approximately  $4.7^{\circ}$  C.

From these data there appears to be an increase in subsurface temperatures in the direction away from the Great Rift and to the south, the Craters of the Moon National Monument (Region 5) being the coolest. The distance-temperature correlation coefficient was 0.92 with confidence limits greater than 95%. A similar but less well defined trend appears in the east-west direction from the Monument as seen from the Regions 3A through 3B (correlation coefficient of 0.94, confidence limits slightly less than 90%).

## INTERPRETATIONS AND CONCLUSIONS

In this study, the lowest shallow temperatures were measured in the areas where the highest deep temperatures had been expected. Before rejecting the assumption that shallow temperature measurements result from a deep heat source, other explanations for the observed trend in temperature were considered. First, since mean elevation gradually decreases from 1745 meters at the Rift to 1380 meters at the SW end, it is possible that the warming trend in that direction is a function of elevation. Topographic maps in sufficient detail to test this suggested correlation are available only for Region 5. A correlation was found between altitude and sample temperature over the 70-meter elevation range in Region 5 ( $r = .46$  with confidence limits greater than 99%). However, temperatures were found to increase, rather than decrease, with increasing elevation. Also, throughout the sample area, no correlation between temperature and elevation was observed on comparing the temperatures of samples placed on buttes up to 100 m above the surrounding plain with those on the floor of the plain nearby.

A second possibility is that the sample temperatures reflect insolation differences. In Region 5, samples were placed both on northern and southern sides of buttes, and thus were shaded for differing portions of the day. However, measured temperatures of the samples located in sunnier areas did not appear significantly higher than those of the samples which were in shadier sites.

A third variable which might influence the measured temperatures is percolation of ground water around the samples. In fact, at the time of their removal, some samples were very wet and others were completely dry. Despite this wide moisture variation, however, there appeared to be no difference in temperature between the two groups.

A fourth consideration is that permeability of the soil to movement of air might affect shallow

subsurface temperatures. The samples in Region 5 were nearly all in highly permeable volcanic cinders; among the five regions, measured temperatures there are lowest and standard deviation is the highest. Both effects may be due in part to air permeation. On the other hand, in the loess regions outside the Monument, there is no evidence of a correlation between temperature and soil permeability. The smooth trend in temperature rise to the southwest and the small standard deviation values both suggest that permeability effects are negligible.

On the basis of the above considerations, it appears that, contrary to expectation, shallow subsurface temperature increases toward the southern edge of the Snake River Plain, away from the area of the Monument. Three explanations may account for this effect.

First, higher deep subsurface temperatures may actually be present along the Plain border and a uniform conduction/convection system from one end of the traverse to the other may account for the observed difference in shallow temperatures. Second, uniform deep subsurface temperatures may be reflected as higher shallow temperatures near the edge of the Plain due to increased heat flow resulting from plain-margin faulting. Third, uniform, deep subsurface temperatures may be more effectively insulated in the Rift area toward the center of the Plain due to the presence of less faulted, thicker, and more recent lava flows and to intercalated sediments.

The information bearing on these possible explanations is very sparse, consisting mostly of the following observations. Carr and Trimble (1963) noted a northeast-trending set of small faults near American Falls (75 km southeast of the Monument) which they believe relates to a N45°E fault zone along which the Plain subsided. Numerous north-trending Basin and Range type

faults terminate along the southern border of the Plain. As Prinz (1970) noted, these north-trending faults parallel the southern part of the Idaho Rift System. There are several hot springs associated with these faults along the southern edge of the Plain, near the southernmost end of the traverse. Known geothermal highs, such as those at Raft River and at Boise, are along the margin of the Plain. Higher elevations along the Rift suggest a thicker section of basalt and intercalated sediments there. If volcanic activity along the Rift were more explosive than to the southwest, resultant permeable structures such as those studied by Niccum<sup>2/</sup> might also account for decreased heat flow to the surface.

In summary, the presence of faults along the southern edge of the eastern Snake River Plain may explain the apparent temperature increase in that direction. These faults might be responsible for increased heat transfer by percolating ground waters or through simple dry conduction. Heat flow would be relatively inhibited near the center of the Plain by the thicker sequences of flows and sediments there. Regardless of the reason for the temperature relationship, it cannot be explained by known characteristics of the Snake River Plain.

The efficacy of the Pallmann technique for ascertaining geothermal heat distribution is still open to question. More extensive testing is required before a definite determination of its workability can be established. Perhaps numerous traverses across a known "hot spot" with temperature measurements at several hundred points would provide a clearer understanding of the factors controlling the distribution of heat at shallow depth.

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<sup>2/</sup> Niccum, M. R. 1969. Geology and permeable structure in basalts of the east central Snake River Plain near Atomic City, Idaho. Unpublished M. S. thesis, Idaho State University, Pocatello, Idaho.

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