

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

A POSSIBLE METHOD FOR GEOTHERMAL ENERGY PROSPECTING? *

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* This work was primarily supported by a grant from the Craters of the Moon Natural History Association.

ABSTRACT

The slow, temperature-sensitive, acid-catalyzed hydrolysis of sucrose solutions 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 southwest 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 exploratory study indicate that the method might be useful in geothermal prospecting.

INTRODUCTION

Locating regions for exploratory geothermal prospecting, including deep drilling, would be facilitated by an inexpensive method of accurate shallow 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 measurements, aerial infrared mapping, and satellite surface temperature measurements have also proven unreliable since any measurement of this kind is subject to many short-term temperature fluctuations due to solar heating, vegetation cover, and moisture collection and evaporation resulting from rain or snow.

Shallow areal temperature distributions require measurements integrated over an extended period to average out short-term fluctuations due to surface and sub-surface effects. In this preliminary study, carried out on the Great Rift, we have employed a method of long-term temperature measurement based upon the slow acidic hydrolysis of sucrose samples, developed in Germany by Pallman, et al. (1940) and utilized in this country 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. 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° C.

GENERAL GEOLOGY OF THE SNAKE RIVER PLAIN AND THE IDAHO RIFT SYSTEM

The Snake River Plain, about 560 km long and 80-100 km wide, curves in a great arc across the southern part of Idaho, as shown in Figure 1. It has an altitude near 2,000 meters in the east and 700 meters in the west, and is, for the most part, a lava plateau. Surrounding it are mountains and uplands which include the highest ranges in the region, most with peaks exceeding 3,300 meters in altitude. Geologic and paleobotanic evidence suggest that the Snake River Plain is a relatively young structure which formed during Oligocene time (Axelrod, 1968).

Extending across the eastern part of the Snake River Plain is a 100-kilometer long, north to northwest-trending fissure zone known as the Idaho Rift System (Prinz, 1970). It consists of four rift sets, the northernmost of which is called the Great Rift.

First described and named by Stearns (1928) for the series of fissures in the Craters of the Moon National Monument, Idaho, the Great Rift strikes N35°W and has a total length of 54 kilometers. The northwesternmost portion of the Great Rift penetrated the Paleozoic rocks of the Pioneer Mountains. Recent lava flows fill the valleys between ridges where the range plunges southward into the Snake River Plain.

Stratigraphically, the lava flows associated with the Great Rift comprise a part of the Snake River Group, which occurs principally in the eastern plain and consists of basalts with some interbedded lacustrine and fluvial sediments (Malde, 1965). These rocks range in age from Late Tertiary through Holocene. The youngest flows occur within the Craters of the Moon National Monument and have been dated by tree rings (Stearns, 1963) at about 1650 years before present (B.P.). Others have been dated at 2000 years B.P. (Bullard, 1971).

Recent lavas of the Snake River Group are covered only locally by surficial material. Those within the Monument are almost totally destitute of any cover, and vegetation is very sparse. The older flows within the Snake River Group are more or less concealed, however, and south of the Monument the older flows are covered by a variable thickness of loess. The loess is at least 1.2 meters thick where samples were placed but is almost completely lacking in scattered areas where basalts come to the surface.

SUMMARY OF HYPOTHESES OF ORIGIN OF SNAKE RIVER PLAIN

The Snake River Plain constitutes one of the most poorly understood geologic areas in the United States. Nevertheless, several viable hypotheses on its origin have emerged over the past seventy years.

Russell (1902) suggested that the Snake River Plain is a simple down-faulted graben inundated by flood basalts that now cover the fault traces. Evidence of over 500 meters of vertical displacement on the north side of the western plain was found by Malde (1959), who inferred at least 2,700 meters of total displacement.

Kirkham (1931) proposed that the Snake River Plain is a giant downwarp structure, citing as evidence the inward dip of Tertiary beds on the flanks of the plain. Malde (1965) cited gravity data to emphasize the structural difference between the eastern and western Snake River Plain. He then proposed that the eastern Snake River Plain is a result of downwarping and that the western plain is the result of downfaulting.

A radically different hypothesis is that of Hamilton and Myers (1966) who proposed that the Snake River Plain formed by tensional rifting caused by slow northwestward drift of a crustal plate containing the Idaho batholith.

Prinz (1970) cited evidence of conjugate northeast-and northwest-trending rift sets on the plain and suggested that the Idaho Rift System is the result of extension with a large east-west or northeast-southwest component. He concluded that the Rift System may be related to crustal plate movements. Furthermore, he noted that the Rift System arcs across the plain in such a way as to join directions with the northwest-trending fault block ranges to the north and the south-trending ranges to the south and went on to suggest a possible relationship between the extension recorded by the Idaho Rift System and that which produced normal faulting outside the Snake River Plain.

Until more geological and geophysical data become available the origin of the Snake River Plain will remain somewhat of a mystery. Whichever hypothesis is correct, localized heat sources would be expected, and the area is currently of interest for geothermal energy development. Unexpectedly, the results of this study, as described below, indicate that the region near the Monument appears to have lower sub-surface temperatures than that of the rest of the Plain.

SAMPLE DISTRIBUTION

Four geological assumptions formed the basis of the Great Rift geothermal experiment. These are:

1. a large heat source exists beneath the Snake River Plain as suggested by the vast amount of young volcanics that fill the plain.
2. the center of this heat source underlies the Great Rift, the site of the most recent volcanic eruptions on the plain.
3. sub-surface heat emanating from this source might decrease rapidly away from the Great Rift.
4. temperature measurements at a shallow depth (about 1.2 meters) would reflect heat coming from greater depth.

In accordance with these four assumptions samples were distributed in two locations. Thirty samples were placed inside the Craters of the Moon National Monument along the Great Rift. They were spaced along the Rift over a distance of 4 kilometers and buried to a depth of 1.3 meters in cinders.

About 150 samples were placed along an irregular 40-kilometer traverse that ran generally SSW from the northwest-trending Great Rift. Sample density decreased away from the Great Rift. These samples were buried at an average depth of 1.2 meters ($\pm .1$ meter) in loess. In most areas the loess was found to contain a caliche hardpan at a depth generally between .3 meter and 1.0 meter.

Sample holes were bored with a two-man gasoline-powered auger. One and one-half meter long PVC pipes of 3.8 cm inside diameter were used as stakes to contain the samples. Each pipe was partially closed and sharpened to a point at one end, as shown in Figure 2, leaving openings near the sample to permit free passage of moisture. After all holes were dug and pipes implanted, sediment was packed into the space around the pipes until the pipes rested firmly in place. The samples were then placed in the stakes.

No problems were encountered in burying the samples in cinders along the Great Rift. Samples and equipment were carried into the Monument on foot. However, certain restrictions on sample locations along the traverse were encountered. The first difficulty was that of poor roads and limited access. Desert heat, heavy equipment, and the necessity for placing all samples nearly simultaneously prevented straying too far on foot from accessible roads. The presence of impregnable hardpan or lava flows less than 1.2 meters below the surface presented another problem. This situation was encountered in many areas and forced movement to other locations. These restrictions prevented

establishing a straight traverse at an angle directly perpendicular to the Rift and also prevented spacing successive samples at exponentially greater distances away from the Rift. The thick hardpan made it impossible to drill to precisely the same depth at all of the sample locations, resulting in a variation of sample depth up to 20 cm.

PROCEDURE

Temperature measurements were made using a modification of the method given by Schmitz and Volkert (1959). Optical rotations, good to $\pm 0.01^\circ$, were taken at $25.0 \pm 0.1^\circ$ 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: 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.

A 0.750 g/ml buffered solution was obtained by mixing 4500 g of sucrose, 62.6 g of sodium citrate, and 900 g of sodium chloride (to prevent freezing) in a six-liter volumetric flask. To this mixture was added a 29.9 ml portion of 12F HCl. Sterilized water was poured into the flask until the flask was half filled. Sufficient formaldehyde was added to bring its concentration to 13% as an additional precaution against bacterial decomposition. The solution was stirred constantly and small portions of water were added periodically. Approximately four days of mixing was required to dissolve all of the solid material. 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 Q II 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 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 ± 2 days.

As each sample was recovered, it was immediately re-frozen in dry ice until analysis could be carried out. It was found that some samples had obviously deteriorated despite our precautions, and these were discarded. A few samples were also lost due to road-edge maintenance and 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 of it was used to rinse the thermostated polarimeter tube, while the remainder was used to determine the optical rotation. Only a few minutes was required for each solution to

equilibrate after being poured into the tube. Five readings were taken of the rotation and the average was recorded as the observed rotation. The observed rotations were then converted to specific rotations and then to normalized temperatures for further analysis.

The observed optical rotations were converted to specific rotation by use of the equation

$$[\alpha]_{\substack{25 \\ 256 \\ 546}}^{25} = - \frac{\alpha}{c \cdot l} \quad (1)$$

where $[\alpha]_{\substack{25 \\ 256 \\ 546}}^{25}$ is the specific rotation at 25°C and 546 nm, α the observed rotation, c the sucrose concentration in g/ml, and l the sample path length in dm. Conversion of the specific rotations to mean temperatures was accomplished by use of the relationship given by Schmitz and Volkert (1959).

$$T(^{\circ}\text{K}) = \frac{-a}{\text{pH} - b - \log t + \log [\log(R_0 - R_{\infty}) - \log(R_t - R_{\infty})]} \quad (2)$$

where $T(^{\circ}\text{K})$ is the temperature in degrees Kelvin, t is the time in days, R_0 is the initial specific rotation, R_t is the specific rotation at time t , and R_{∞} 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, since only relative temperatures were of interest. Equation 2 was therefore used to convert our specific rotation data to relative temperatures as follows. Specific rotations of 30 samples randomly chosen throughout the area were averaged and their mean value, 69.12° , was substituted into equation 2 as R_t . The temperature representative of this set of samples was arbitrarily chosen as 285.16°K (12°C) and this value was used as T . Other values used were: pH, 3.70; time, 303 days; and R_0 , 73.23° . The value of R_{∞} of -19.36° was obtained using the equation given by Zerban (1925), and the value of a , 5857, was that given by Schmitz and Volkert (1959). Solution of the equation for b yielded a value of 20.1. In this manner, b was used as an arbitrary constant to normalize our data to 12°C . The resulting equation used in converting our specific rotation data to relative normalized temperatures is

$$T(^{\circ}\text{K}) = \frac{5857}{18.98 - \log[1.993 - \log(R_t - 19.36)]} \quad (3)$$

RESULTS

To facilitate treatment of the normalized temperature data the sample area was divided arbitrarily into five regions, arranged in the general direction SSW to NNE, Region 1 being the southernmost. A map of the area is shown in Figure 3. The Craters of the Moon National Monument comprised Region 5. Region 3 was further divided into three subregions, arranged in an east-west orientation, Region 3A being the easternmost. The average normalized temperatures for each of the regions is given in Table 1.

TABLE 1
AVERAGE NORMALIZED TEMPERATURES

REGION	AVERAGE NORMALIZED TEMPERATURE, °C	STANDARD DEVIATION	NUMBER OF SAMPLES
1	14.0	0.499	10
2	12.2	1.28	14
3	11.8	0.751	25
4	11.0	1.10	42
5	9.33	1.76	26
3A	11.3	0.584	13
3B	12.3	0.445	8
3C	12.8	0.624	4

From these data there appears to be an increase in sub-surface temperatures in the direction away from the Great Rift and to the south, the Craters of the Moon National Monument being the coolest. A similar but less well-defined trend appears in the east-west direction from the Monument, as seen from the Regions 3A through 3C.

INTERPRETATIONS AND CONCLUSIONS

Before proceeding with an evaluation of our rather tenuous data, it is necessary first to examine the assumption that our shallow temperature measurements actually indicate the presence of a deep heat source. Other explanations for the trend in temperature were considered. First, since the mean elevation gradually decreases from 1745 meters in Region 5 to 1380 meters in Region 1, it is possible that the warming trend in that direction is a function of elevation. Topographic maps in sufficient detail to make possible a study of this suggested correlation are not available for the entire area. Detailed maps are, however, available for Region 5, and the altitude range for the samples in this region is 70 meters (about 1/5 of the range for the entire sample area). In Region 5, no correlation was found between altitude and sample temperature. 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 meters above the surrounding plane with those on the floor of the plane nearby.

A second effect considered was the possibility that the sample temperatures were a reflection of the relative amount of sunlight to which the soil above the sample was subjected. In Region 5 samples were placed both on the northern and the southern sides of buttes, and thus were shaded for differing portions of the day. Again, however, no significant difference was noted in this region between samples located in sunny sites and those in shady sites.

A third variable which we assumed might influence the measured temperatures was the percolation of ground water around the samples, since at the time of their removal, some of the samples were very wet while others were completely dry. This information was noted in the field log, but when the wet samples were compared with the dry ones, there appeared to be no temperature difference between the two groups.

A fourth consideration was that the permeability of the soil to the movement of air might affect the temperature of the environment of the sample. The samples in Region 5 were nearly all placed in highly permeable volcanic cinders, and the data in this region show temperatures much below the other regions. In addition, the standard deviation is very large in this region. It seems that both effects are due at least in part to air permeating the soil.

Due to the limited nature of the study, the lack of observed correlation with the variables discussed above is not conclusive. However, with this reservation in mind, we will make the tentative statement that the samples have indicated differences in sub-surface temperatures and that the observed trends are real. Based on this conclusion, it is noted, that, contrary to expectation, sub-surface temperature appears to increase towards the southern and perhaps the western edge of the Snake River Plain, away from the area of the Monument.

Higher temperatures along the edge of the Plain may mean that faults are present along its borders and that these faults act as conduits to bring heat coming from the lower crust or upper mantle to the surface. Heat from beneath the Great Rift, on the other hand, might be effectively shut off from the surface by unfaulted, thicker, and more recent flows and intercalated sediments.

Although geological and geophysical data indicate extensive faulting parallel to the borders of the Snake River Plain west of Twin Falls, there is little direct evidence for bounding faults on the southern edge of the eastern Snake River Plain. Carr and Trimble (1963) did find a northeast-trending set of small faults near American Falls (75 kilometers southeast of the Monument) which they believe relates to a $N45^{\circ}E$ fault zone along which the Plain subsided. This, however, constitutes about the only direct evidence for the presence of such faults.

While evidence for the presence of bounding faults along the southeastern edge of the Snake River Plain is not conclusive, there are numerous north-trending Basin-and-Range type faults that 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. Significantly, there are several hot springs along the southern edge of the Plain associated with these faults and near the southernmost end of the traverse.

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 in their vicinity either through heat transfer by percolating groundwaters 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.

The efficacy of this technique for determining 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

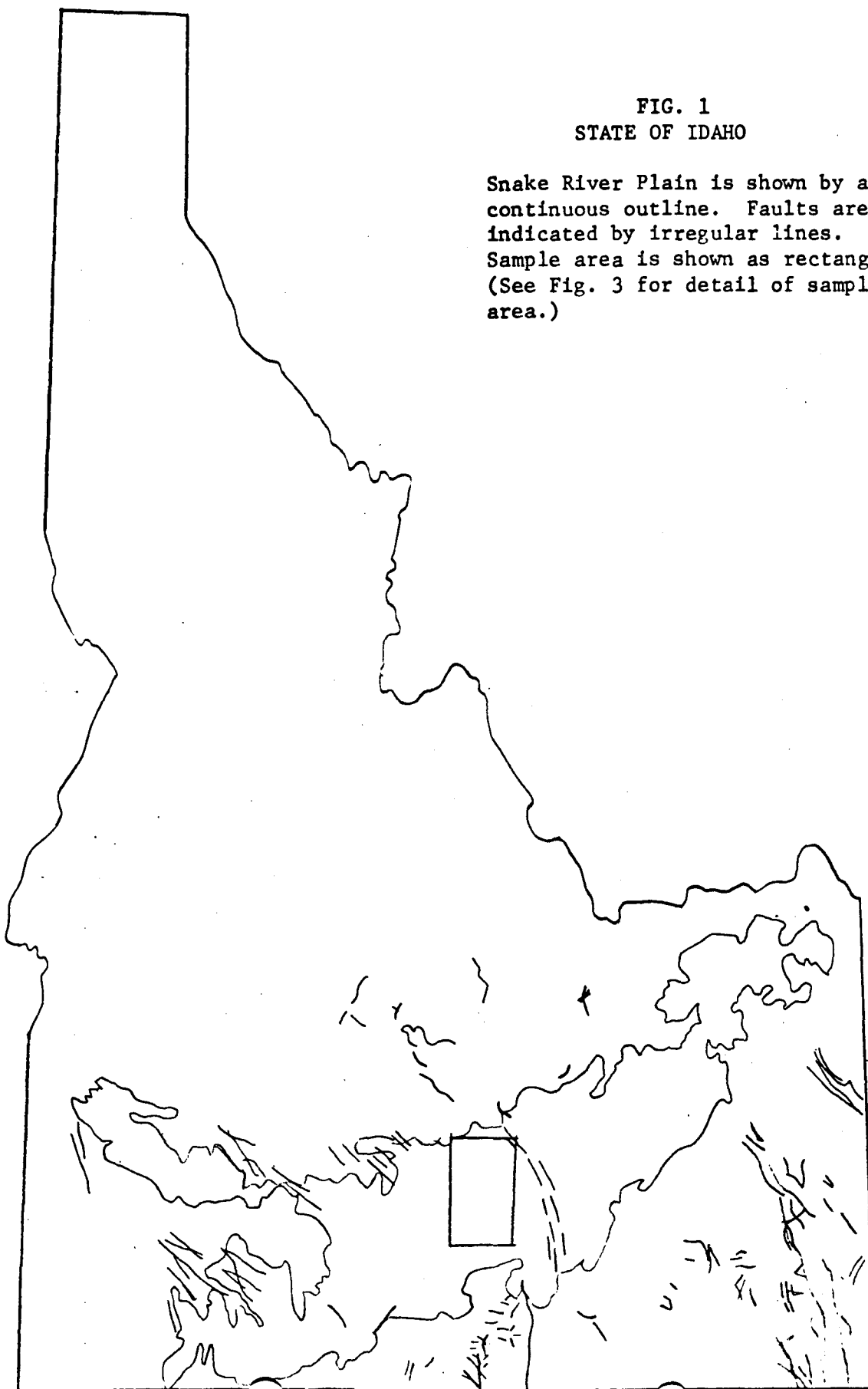
traverses across a known "hot spot" with temperature measurements at several hundred points would provide a clearer understanding of the factors controlling the distribution of heat at shallow depth.

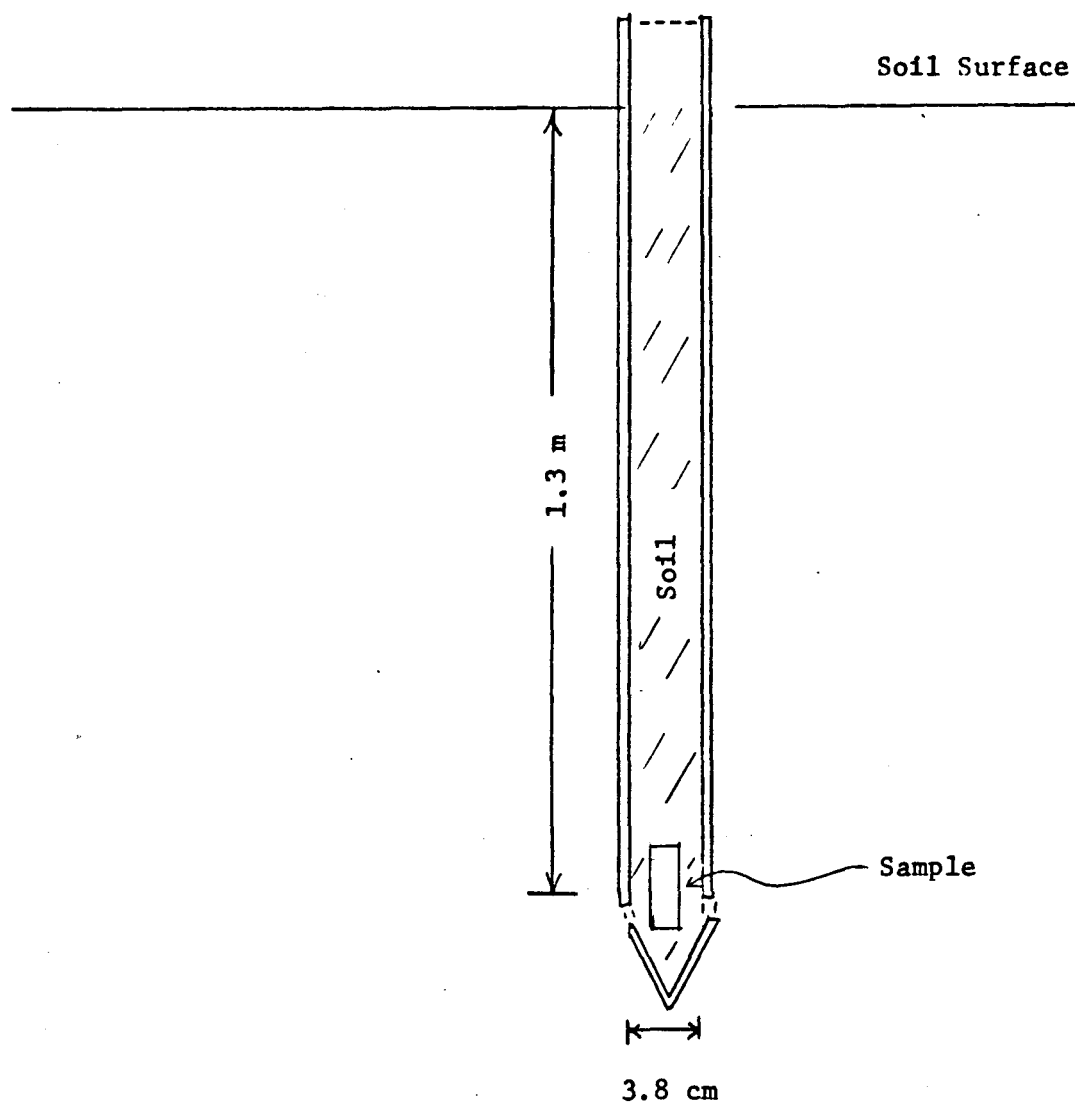
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FIG. 1
STATE OF IDAHO

Snake River Plain is shown by a continuous outline. Faults are indicated by irregular lines. Sample area is shown as rectangle. (See Fig. 3 for detail of sample area.)



**FIG. 2**

Polyvinyl Chloride Pipe Sample Stake

FIG. 3
SAMPLE AREA

Solid bold lines indicate boundaries of old and new lava. Broken bold lines indicate region boundaries. Sample locations are shown as small circles. Grid scale: 1 division = 1.6 km. (1 mile)

