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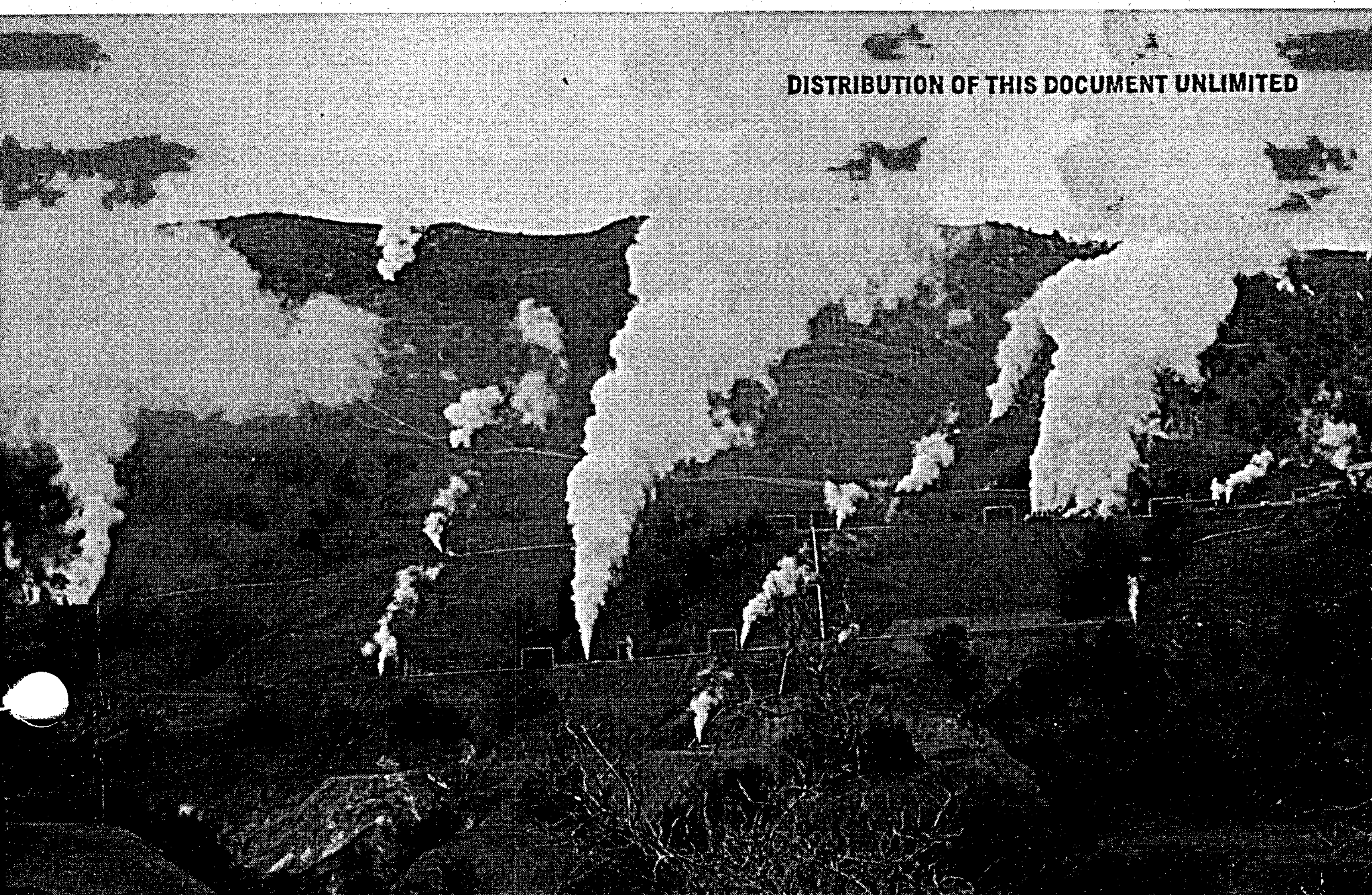

THE COLORADO SCHOOL OF MINES NEVADA GEOTHERMAL STUDY

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Geothermal systems in the Basin and Range Province of the western United States probably differ in many respects from geothermal systems already discovered in other parts of the world because of the unique tectonic setting. To investigate this, a study of the geothermal occurrences at Fly Ranch, approximately 100 miles north of Reno, Nevada, has been undertaken. Ample evidence for a geothermal system exists in this area, including the surface expression of heat flow in the form of hot springs, an extensive area of low electrical resistivity, and a high level of seismicity along faults bounding the thermal area. However, geophysical and geological studies have not yet provided evidence for a local heat source at depth. Additional detailed geophysical and geological studies, as well as drilling, must be completed before the geothermal system can be described fully.

I. INTRODUCTION

Large estimates of the potential capacity for producing geothermal power in the conterminous United States are based on the assumption that the Basin and Range Province has many unrecognized geothermal systems. These systems must differ in many respects from geothermal systems already discovered in other parts of the world because of the rather unique tectonic setting of the Basin and Range Province. In other areas, geothermal systems are usually closely associated with modern, easily recognized stages of volcanism, and the geothermal reservoirs are formed directly in the porous, pyroclastic rocks around these centers of volcanism. In the Basin and Range Province, the amount of modern volcanism is minor, raising a question as to whether or not enough heat is being supplied for the development of good geothermal systems. Also, if geothermal reservoirs are present, they may exist in porous alluvial sedimentary rocks or in fractured crystalline rocks rather than pyroclastics. At present, we cannot describe a Basin and Range Province geothermal system physically, so that geological and geophysical exploration programs can be designed specifically to find them.

The Colorado School of Mines has received support from the National Science Foundation under Grant GI 43866 to do a definitive geological and geophysical study of a Basin and Range type geothermal system.

The study is to be carried out on a geothermal prospect which might be considered to be typical of geothermal systems expected to be present in the Basin and Range Province. Fortunately, Sun Oil Company agreed to share with us the results of an exploration program that they have carried out for geothermal energy in the Basin and Range Province for the past decade. On the basis of their regional exploration results, we selected the Black Rock Desert, and more specifically, the Fly Ranch — Gerlach hot springs complex, as a prospect with a high probability of developing into an economically viable geothermal reservoir. The area lies approximately 100 miles north of Reno, Nevada, as shown in Figure 1. Many thermal springs lie within the prospect area, as indicated on Figure 1.

The plan for the study is to make use of the best available geological and geophysical techniques for evaluating the temperature, volume, and other pertinent characteristics of any geothermal reservoir within the survey area. The effectiveness of the exploration is to be evaluated by drilling a test hole to verify the predictions made on the basis of exploration results.

II. GENERAL GEOLOGY

The study is to be centered about the Fly Ranch hot spring complex, which lies in and around Hualapai Flat, about fifteen miles north of Gerlach, Nevada. A geologic map of the area is shown in Figure 2. Hualapai Flat is a topographic (and probably structural) embayment of recent sediments into the Granite Range. It is separated by a low saddle from the extensive Black Rock Desert to the east. It is bounded on the south and west by a granite massif (the Granite Range), and by thick volcanic piles on the northwest, which are in part continuous to the west with the volcanic rocks of the Modoc Plateau.

The sequence of events recorded by the rocks of the area are:

(1) Deposition and subsequent thermal metamorphism of late Paleozoic (?) volcanic and sedimentary rocks.

(2) Intrusion of Cretaceous granodiorite into the late Paleozoic (?) volcanic and sedimentary rocks, with profound erosion of the land surface.

(3) Extrusion and intrusion of Tertiary volcanic rocks.

(4) Quaternary lake cycles.

(5) Recent faulting.

The late Paleozoic rocks are, as a group, the oldest rocks exposed in northwestern Nevada. They have not been studied and can only be described as a sequence of metamorphosed flows, tuffs, breccias, and sedimentary rocks. They crop out as several small hills roughly circling Hualapai Flat.

The Granite Range massif is, on the basis of normative and modal quartz-orthoclase-plagioclase abundances, a granodiorite (K/Ar age of 91.6 million years; Ref. 1). It resembles other intrusive rocks of northwestern Nevada with no major petrographic differences. It comprises a horst block that rises 5000 feet above the valley floor at Gerlach. It is in intrusive contact with late Paleozoic (?) rocks in places.

The volcanic rocks bordering Hualapai Flat are of the Oligocene South Willow Formation (Ref. 2). The South Willow Formation is predominately intermediate to mafic volcanic flows and breccias. The formation unconformably overlies pre-Tertiary rocks near Cottonwood Creek and is overlain just to the west by Miocene-Pliocene volcanic rocks which represent the eastern border of the Modoc Plateau volcanic rocks. The Calico Mountain Range is predominantly intermediate flows, tuffs, and sedimentary rocks. The base of the sequence is not exposed and the top is an erosional surface. The youngest rocks of the area are several intrusive rhyolite plugs in the northwestern corner of Hualapai Flat which intrude the South Willow Formation. They can only be said to be post-South-Willow formation and probably late Miocene to Pliocene.

Quaternary deposits consist of Pleistocene Lake Lahontan deposits and Recent playa, dune, and alluvial sediments. Sizeable buildups of sinter are present around several hot springs and warm water wells.

Pre-Tertiary structure is obscured by the extensive volcanic cover and lack of Mesozoic and older rocks. The area marks the transition from a physiographic province where general Basin and Range faulting is obvious to the Modoc Plateau Province to the west, where continuous flows of basalt obscure the faulting to some extent. The area is seismically active and several faults have been mapped across Recent playa deposits with vertical offsets of up to ten feet.

III. INFRARED SURVEY

Airborne infrared scanning or mapping is potentially a powerful tool in prospecting for geothermal systems (Refs. 3, 4, and 5). The most impressive results have been obtained in neovolcanic areas where extreme variations in temperature exist at the earth's surface. Infrared imaging may also be of use in exploration in a basin and range setting in two ways; by providing an inventory of both thermal and normal spring activity, and by serving as an indicator of the location of fault traces at the earth's surface. In an arid region such as northwestern Nevada, many springs are intermittent, or discharge below the earth's surface. Such springs can alter the soil moisture sufficiently to affect the temperature or emissivity and cause a detectable change in thermodynamic temperature. Infrared imagery can then be used to locate hidden springs and water discharges to be sampled for geochemical studies.

An infrared survey was flown in early October, 1974, with the area being covered extending from the vicinity of Gerlach on the south to Soldiers Meadows on the north. The survey was flown by Earth Satellite Corporation, using a Daedalus scanner operating in the 8 to 14 micrometer wave-length band, and flown at an altitude of 7500 feet above the land surface. The imagery obtained from the area immediately around the Fly Ranch hot springs is shown in Figure 3.

IV. MICROSEISMICITY STUDY

The author of Ref. 6 has reviewed evidence that there is a close association between locally intense microseismic activity and the occurrence of geothermal systems. The microseismicity of northwestern Nevada has been described in several papers (Refs. 7, 8, 9 and 10). However, coverage of the Gerlach - Fly Ranch area in these earlier studies was poor, and so, Microgeophysics, Inc., of Golden, Colorado, was engaged to carry out a microseismicity survey of the Black Rock Desert area. For this purpose, five high-gain (3 to 6 m), high-frequency (1 to 30 Hz) seismic arrays with a detection threshold below magnitude -1.0 were operated for a total of 30 days in May and June, 1974.

Each array operated with seven Sprengnether model MEQ-800-B portable seismic systems sited at separations of approximately 3 miles. Only vertical geophones were used; these were connected to a recording system which recorded on smoked paper at a chart speed of 120 mm/min. Each recording system had an integral timing system based on a precision clock synchronized daily with a WWVB signal. Arrival times for compressional waves were determined within ±0.05 seconds. Almost all seismometer locations were on outcrops of crystalline or igneous rock. Station sites were moved during the course of the survey, so that the same seven recording systems were used to form the five arrays.

A total of approximately 420 local events and 111 teleseisms were identified during the 30 days of operation. All but 100 of the local events were observed on a single day, Julian day 169, 1974, in a concentrated swarm that occurred along the boundary between the Black Rock Desert on the east and the Granite Range block on the west. Prior to this day of swarm activity, the rate of occurrence of local earthquakes was approximately 2 per day. These events outlined activity along a line separating the Granite Range block from the Black Rock Desert, and along an east-west line passing through Hualapai Flat. This may be seen in Figure 4, a map showing contours of the cumulative amount of strain energy released during the 25 days preceding the swarm. The swarm occurred immediately to the southeast of the alkali flat in the southern end of Hualapai Flat, at the site of maximum strain rate prior to the swarm.

V. ELECTRICAL SURVEYS

Electrical resistivity surveys are accepted as being the most direct approach to locating reservoirs containing geothermal fluids (Ref. 11). An increase in rock temperature from a normal value of 20° to 60°C to an anomalous value of 200° to 300°C will evoke a five- to six-fold reduction in resistivity. A reservoir with sufficient volume to be of economic interest will provide a very large target for electrical prospecting techniques, unless the effect of temperature is cancelled by compensating changes in water salinity or porosity. Such changes are unlikely.

Because of the size and large contrast in resistivity for a geothermal reservoir, any electrical surveying technique with the capacity to reach to depths of 5000 to 10,000 feet will be capable of detecting the reservoir. We have used the dipole mapping technique for reconnaisance, and this is to be followed by more definitive electromagnetic sounding surveys (Ref. 11) once the probable location of a geothermal reservoir has been determined.

In the dipole mapping survey, the concept is that a current field will be distorted by the presence of conductive masses of rock such as are associated with geothermal reservoirs. This distortion is mapped by measuring electric field intensity at many points around a single bipole current source. Areas of unusually low electric field intensity are normally assumed to be areas of unusually low resistivity. However, problems arise in this straightforward evaluation of dipole mapping surveys because in some cases, an area of anomalously low electric field intensity may appear without there actually being any subsurface region of low resistivity present. This occurs commonly at a fault-like boundary between a region with moderate resistivity values and another region with high resistivity values. In order to avoid being misled by such "false" anomalies, it is necessary to provide multiple coverage of an area in which an anomaly has been found, using several differently situated bipole sources. The rotating dipole method offers an approach to multiple coverage which is superior to the use of multiple but randomly located sources.

In the rotating dipole method, measurements of electric field intensity are made at a receiver location as a function of the orientation of the source wire as the source wire is swung through a 360° rotation. As the source rotates, the direction of current flow at the receiver site will rotate through all possible directions, and apparent resistivity values which are maximally and minimally affected by boundaries in actual resistivity will be measured. The field procedure consists of making only two sets of electric field measurements at a receiver site, one for each of two orientations of the source wire. Then, the two electric field vectors can be added in the proper proportions to determine the apparent resistivity for any orientation of the source bipole.

Rotating dipole surveys were carried out in the Fly Ranch - Gerlach area using five sets of bipole sources. Each bipole source was one mile in length, and powered with current steps with amplitudes ranging from 40 to 120 amperes. The current waveform was that of an asymmetrical square wave, with a repetition rate of 3 per minute. Measurements of electric field strength were made at 320 receiver sites, at distances from the bipole source ranging up to 5 miles.

Many different resistivity values can be computed from the data obtained in a rotating dipole survey, but computations made for various theoretical models suggest that the best value is an average of the maximum and minimum apparent resistivities obtained on rotation. A contour map of averaged maximum and minimum resistivities measured from one pair of bipole sources is shown in Figure 5. The sources are located in the Black Rock Desert, immediately south of the Hualapai Flat area, and over the epicenters of the majority of the earthquakes detected during the microseismicity survey. An area of extremely low resistivity is present at the contact between the bedrock saddle and the Black Rock Desert sediments, with values of less than 1 ohm-meter being observed. Within the bedrock to the north, extending into Hualapai Flat, apparent resistivities remain moderately low, being about 20 ohm-meters along the trend of the hot spring activity.

VI. SUMMARY

Ample evidence exists for a geothermal system at Fly Ranch. Some of the most persuasive evidence is the surface expression of heat flow, represented by hot springs at or near the boiling point, and widespread areas of warm water seepage, seen on the infrared imagery. That this is not some random surface manifestation of structurally controlled ground water flow along a fault system is the evidence for an extensive reservoir at depth provided by the electrical resistivity surveys. The sesimic activity along faults bounding the area of low resistivity suggests that high temperatures at depth have raised the pressure of pore fluids above normal. On the other hand, the geophysical and geological studies have not yet provided evidence for a local heat source at depth.

Additional detailed geophysical and geological studies must be carried out to evaluate the potential of the geothermal system properly. However, it will be necessary to drill at least one test well to determine the effectiveness of the exploration procedures.

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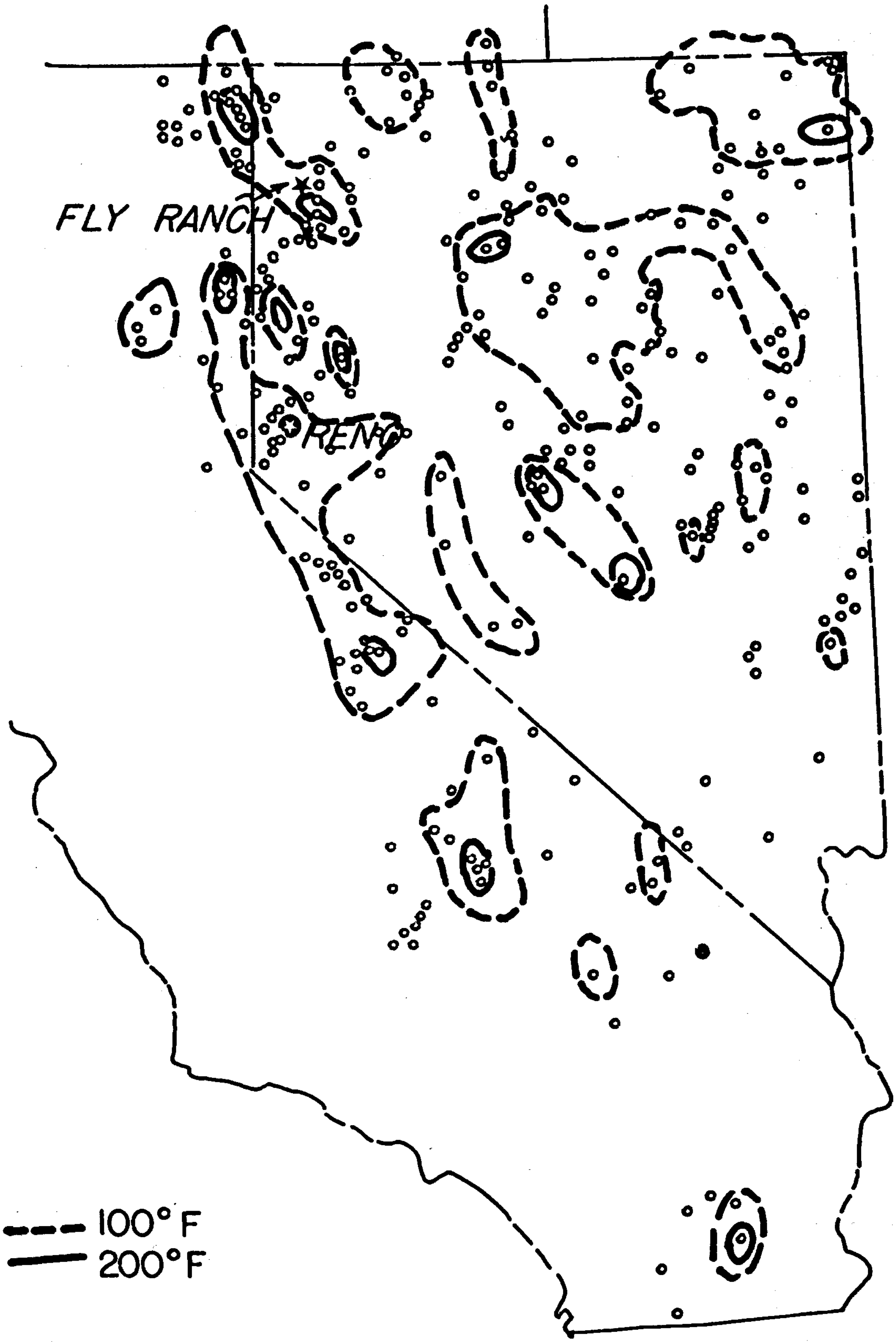

Fig. 1. Contours of thermal spring temperatures in the Basin and Range Province in Nevada and California

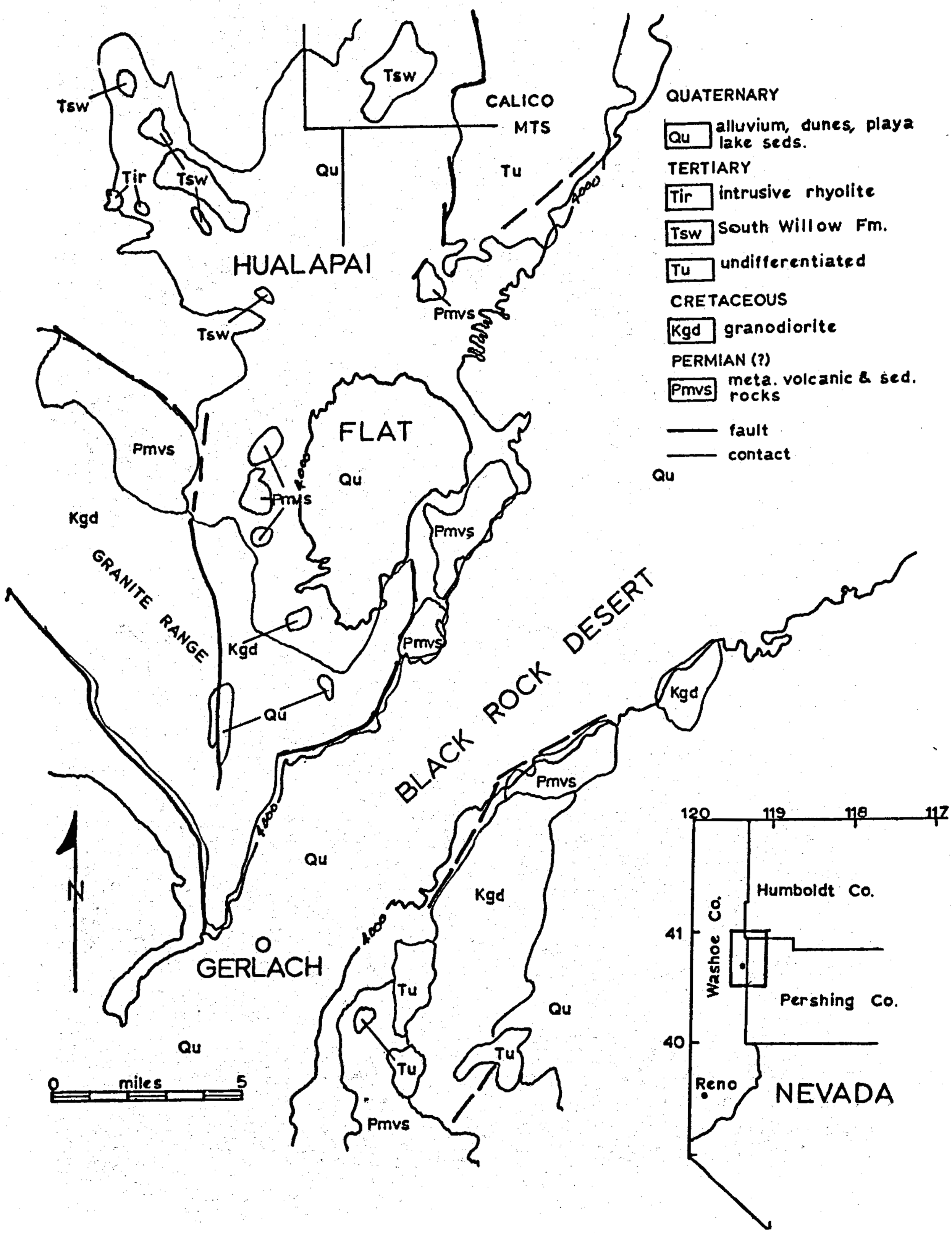

Fig. 2. Reconnaissance geological map of the Black Rock Desert area of northwestern Nevada

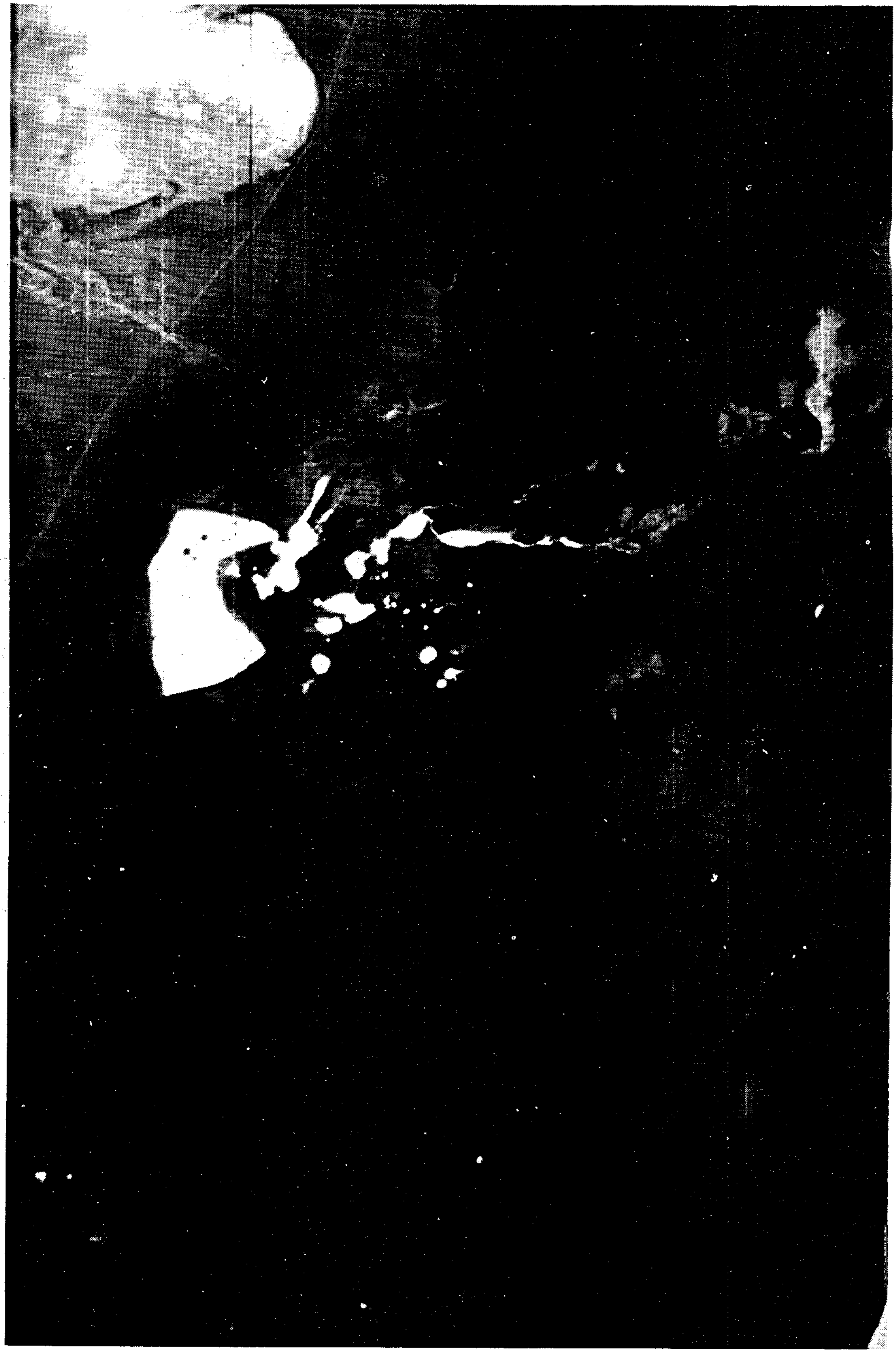

Fig. 3. Infrared imagery of the vicinity around the Fly Ranch hot springs, northern Nevada

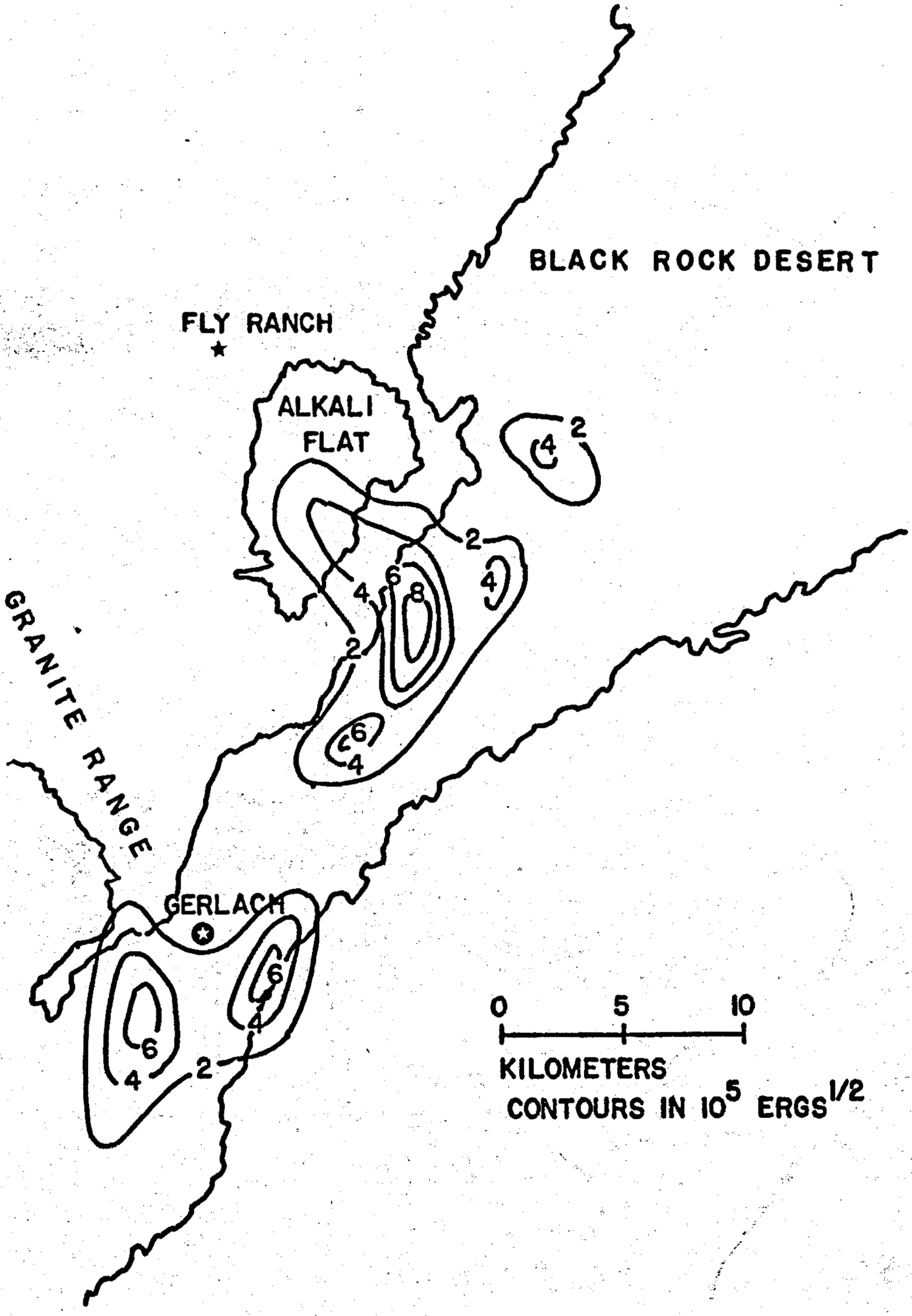

Fig. 4. Strain release for a twenty-five day period in the Black Rock Desert

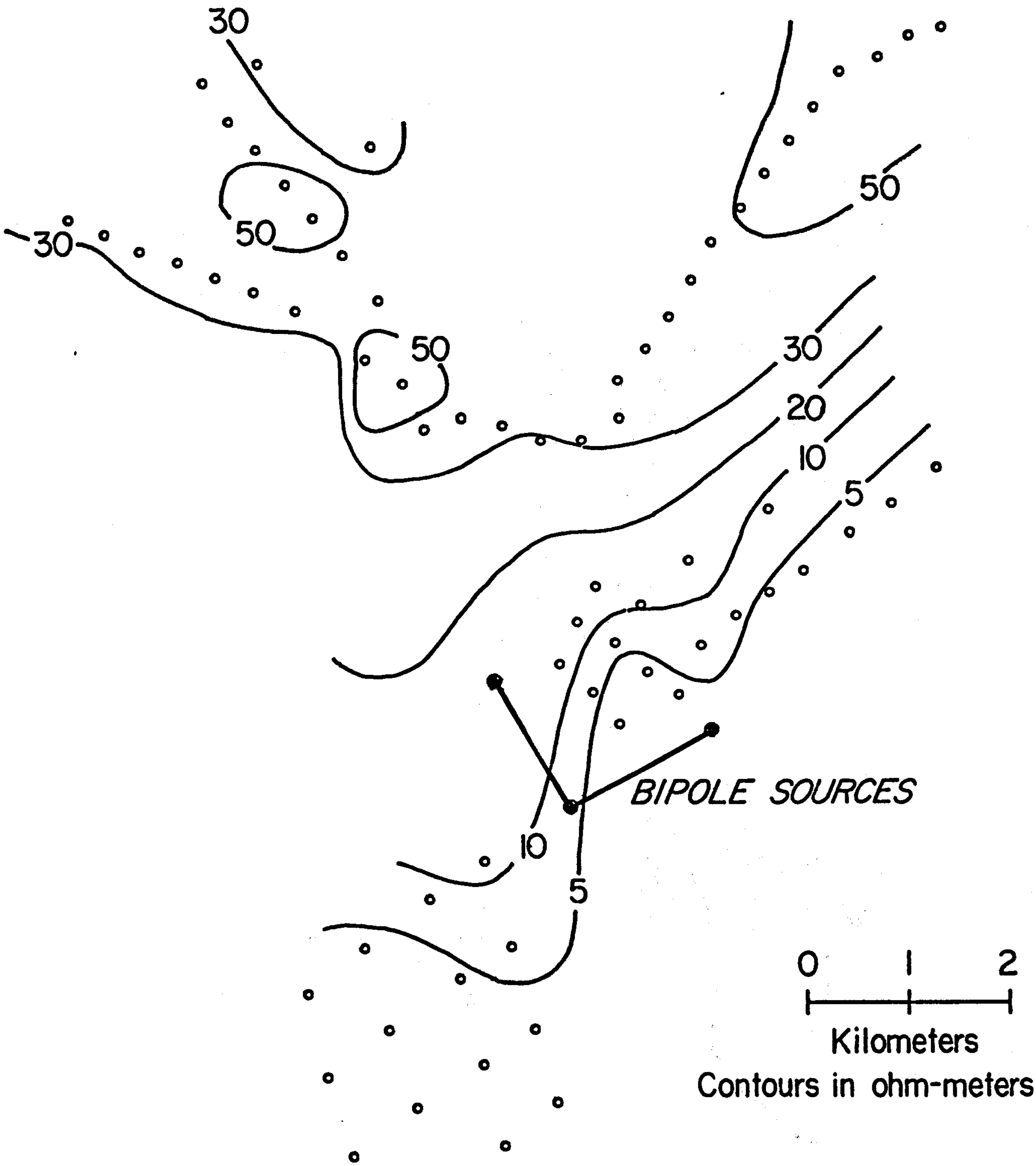

Fig. 5. Example of a rotating dipole resistivity survey at the western edge of the Black Rock Desert