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REGIONAL AND LOCAL NETWORKS OF HORIZONTAL CONTROL, CERRO PRIETO GEOTHERMAL AREA, MEXICO

Open-File Report 78-~~910~~ 929

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ABSTRACT

The Cerro Prieto geothermal area in the Mexicali Valley 30 km southeast of Mexicali, Baja California, is probably deforming due to (1) the extraction of large volumes of steam and hot water, and (2) active tectonism. Two networks of precise horizontal control were established in Mexicali Valley by the U.S. Geological Survey in 1977-78 to measure both types of movement as they occur. These networks consisted of (1) a regional trilateration net brought into the mountain ranges west of the geothermal area from survey stations on an existing U.S. Geological Survey crustal-strain network north of the international border, and (2) a local net tied to stations in the regional net and encompassing the area of present and planned geothermal production. Survey lines in this net were selected to span areas of probable ground-surface movements in and around the geothermal area.

Electronic distance measuring (EDM) instruments, operating with a modulated laser beam, were used to measure the distances between stations in both networks. The regional net was run using a highly precise long-range EDM instrument, helicopters for transportation of men and equipment to inaccessible stations on mountain peaks, and a fixed wing airplane flying along the line of sight. Precision of measurements with this complex long-range system approached 0.2 parts per million of line length. The local net was measured with medium range EDM instrument requiring minimal ancillary equipment. Precision of measurements with this less complex system approached 3 parts per million for the shorter line lengths.

The detection and analysis of ground-surface movements resulting from tectonic strains or induced by geothermal fluid withdrawal is dependent on subsequent resurveys of these networks.

INTRODUCTION

The Cerro Prieto geothermal area is approximately 30 km southeast of Mexicali, Baja California, in the Mexicali Valley. The geothermal powerplant in the area has been in operation since April 1973 and has a capacity of 75MW of electrical power. This plant is the first commercial facility operating in a liquid-dominated field in the Americas. Thirteen production wells (Garcia D., 1975) clustered in an area of 1.5 km^2 and ranging in depth from 800 m to 1,400 m discharge approximately 2,400 m^3/h of water-steam mixture, or the equivalent of about 14 m of water over the well field each year. Most of this water leaves the area by canal or evaporation as very little is reinjected. Another power plant with an additional 75 MW capacity is now under construction and exploration is continuing to expand the production rate many times.

Crustal deformation frequently occurs in areas where large volumes of fluids are extracted from subsurface reservoirs. Deformation rates are found to be particularly significant where the sequence of reservoir materials is thick and compressible, the withdrawal rates substantially exceed the natural and injection recharge, and the natural and triggered tectonism affects the area. Both horizontal and vertical compression in the system result from the induced hydraulic stresses. These compressive forces are expected to be reflected on the surface as subsidence and ground movement that is radially inward toward the center of the field discharge. As in other areas studied, movements due to hydraulically induced stresses will be superimposed on any regional tectonic deformation that may be occurring.

The volume of reservoir compression is approximately equal to the amount of fluid extracted that is not replaced by injected fluids or natural recharge in single-phase fluid systems. Accordingly, if the discharge from a reservoir and the reinjection into the reservoir are known and the vertical and horizontal compression are measured, regional recharge characteristics can be estimated. This same concept can be applied to geothermal reservoirs with modifications to account for the multiphase fluids involved. In the Cerro Prieto field the volume of reservoir compression should approximate the net volume of fluid extraction (discharge less recharge) and the subsidence bowl is expected to extend horizontally as far as recharge gradients are significant.

In order to measure the natural and induced crustal deformation around the Cerro Prieto geothermal area, three networks of precise geodetic control were established in 1977-78. A first-order leveling loop to measure vertical changes from the international border south through the geothermal field was established by DETENAL (Direccion de Estudios del Territerio Nacional, Mexico). In order to measure horizontal deformation, two networks were established by the U.S. Geological Survey. These are (1) a regional trilateration net by the Geological Survey's Topographic Division, that is a southward extension of the Survey's preestablished crustal-strain net and (2) a network of horizontal control established by the Survey's Water Resources Division, in the vicinity of and through the production area. Surface changes due to induced stresses are expected to be too small to be of environmental concern; however, these movements should assist in gaining a further understanding of the resource potential in the region.

This report is concerned only with the establishment of the two networks to monitor horizontal crustal changes that are expected to occur. Included are five illustrations (from Lofgren and Massey, 1978) describing the network layouts. Station descriptions and measured distance data are not included and for the local net are reported in the open-file report, "Monitoring crustal strain, Cerro Prieto geothermal field, Baja California, Mexico," by Lofgren and Massey, 1978). Station descriptions and distance data on the regional net are also not included and will be shown in subsequent reports. No determination of strain rates can be made from the initial data. Resurveys of the nets are scheduled for 1978-79 and 1979-80 at which time(s) measured changes can be analyzed for causal relationships. Both nets will be expanded as required to keep pace with additional developments in the area.

The cooperation and technical assistance very generously given by our Mexican colleagues in completing this portion of the research project is greatly appreciated.

NETWORK LAYOUT

Figure 1 shows the local network around and through the geothermal field. Also shown is the general location of the present geothermal production area (shown schematically as a circle) and the location of inferred faults that subdivide the geothermal field into blocks. Repeated measurements of the lines in this network will show changes in length that represent components of horizontal ground surface movement during the intervening time interval.

Three types of control stations are shown in figure 1: (1) A solid triangle that represents stations from where medium range (described below) electronic distance measuring (EDM) instruments were set, (2) reflector sites shown by solid circles where retroreflectors were set to reflect the laser beam back to the instrument, and (3) an open triangle on Cerro Prieto volcano representing a station on the regional trilateration net from where a set of measurements were made to reflector stations on the valley floor (see figure 2).

Figure 2 shows the regional trilateration net extended southward from the existing crustal-strain net north of the international border. Also schematically shown is the present geothermal production area. The two types of stations shown are (1) regional trilateration stations (open triangles) established on bedrock on mountain peaks (except for one station on the border and one station north of the border west of El Centro), and (2) reflector stations on the local net (solid triangles) that were tied by distance measurements to stations on the regional net.

Figure 3 shows a typical local net EDM instrument setup (station M-3 with well M-3 in the background). This station is a centerpunched brass cap set in a concrete monument, slightly above the ground surface and adjacent to the well.

Figure 4 shows a typical reflector setup on a local net station. Concrete canal structures were used as station sites when possible due to their rigidity and elevation above the surrounding terrain.

Figure 3.--Typical EDM instrument setup.

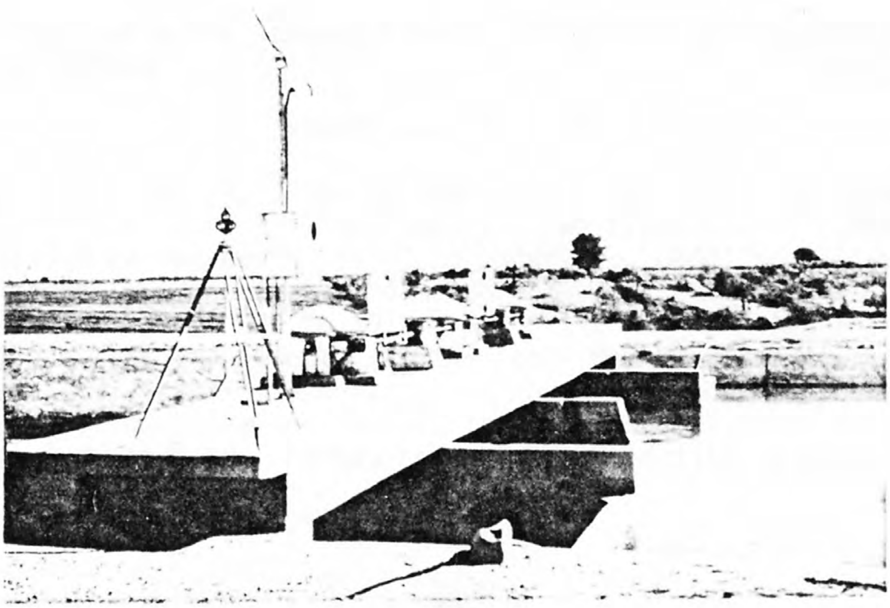

Figure 4.--Typical reflector setup.

The actual survey station as shown in figure 5 is a round-headed

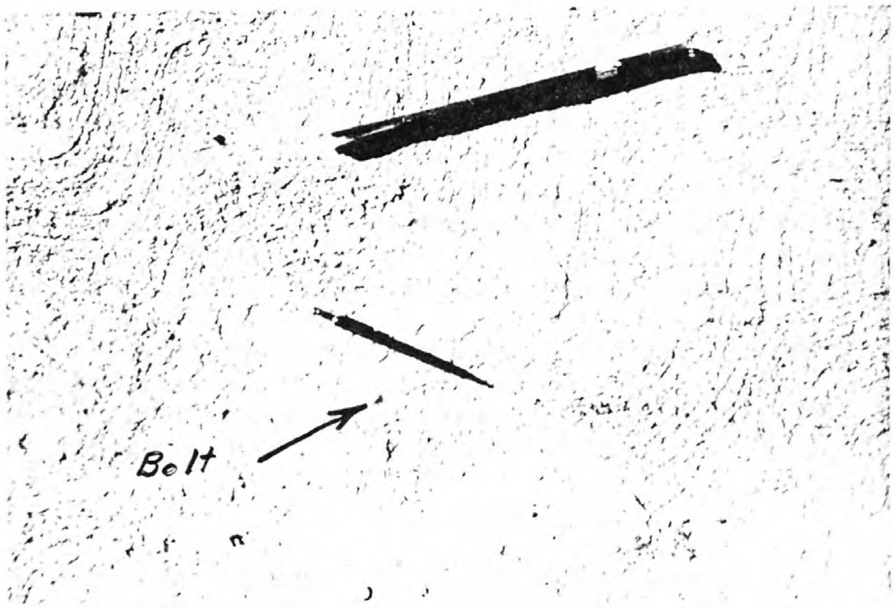

Figure 5.--Round-headed bolt, 16 mm diameter, set flush in concrete bridge deck. Bolt head is centerpunched and stamped with station number.

bolt stamped with the station identification and set flush with the concrete surface.

SURVEY EQUIPMENT USED.

Both nets were surveyed by the U.S. Geological Survey using highly precise line-of-sight EDM instruments. Two types of instruments were used: (1) A medium-range (to 12 km under good conditions) Keuffel and Esser Ranger III[1] instrument to measure the distance in the local net, and (2) a long-range (up to 40 km) Geodolite for the long shots found in the regional net and also to tie the local net stations to stations in the regional net. Both instruments use a modulated red laser beam in the visible spectrum. The accuracy of the measurements using the Ranger III is about 3 mm in 1 km, whereas that of the Geodolite is about 2 mm in 10 km.

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[1] The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

The distance measurement by either instrument is affected by atmospheric conditions. Therefore, corrections for temperature, barometric pressure, and for the Geodolite, humidity, are applied to the data obtained. On the local net using the Ranger III, temperature and pressure are determined at each end of the line being measured and the correction is entered into the instrument. The extremely high precision furnished by the Geodolite is obtained by a continuous determination of the temperature and humidity along the full length of the line. These data are gathered by probes mounted on an airplane that is flown along the line of sight while a measurement is in progress. The retroreflectors used for measuring both nets are commercially available units of conventional design. The design is such that a light ray or beam projected from an instrument is returned to the instrument along the path of propagation.

Helicopters were used to transport men and equipment to the many inaccessible stations on the regional net. All stations on the local net can be easily reached by auto which allows a high frequency of repeat measurements at a relatively low cost.

SUMMARY

As shown in figures 1 and 2 the networks of horizontal control have been established and the first year's surveys completed. Repeated measurements will be necessary to secure the data required for an interpretive analysis. Resurveys are scheduled for 1979 and 1980 by the U.S. Geological Survey.

REFERENCES

Garcia D., Salvador, 1975, Geoelectric study of the Cerro Prieto geothermal area, Baja California, Mexico: United Nations Symposium on the Development and Use of Geothermal Resources, 2d, San Francisco, 1975, Proceedings, v. 2, p. 1010.

Lofgren, B. E., and Massey, B. L., 1978, Monitoring crustal strain, Cerro Prieto geothermal field: Symposium on the Cerro Prieto Geothermal Field, 1st, San Diego, Calif., 1978, Proceedings.

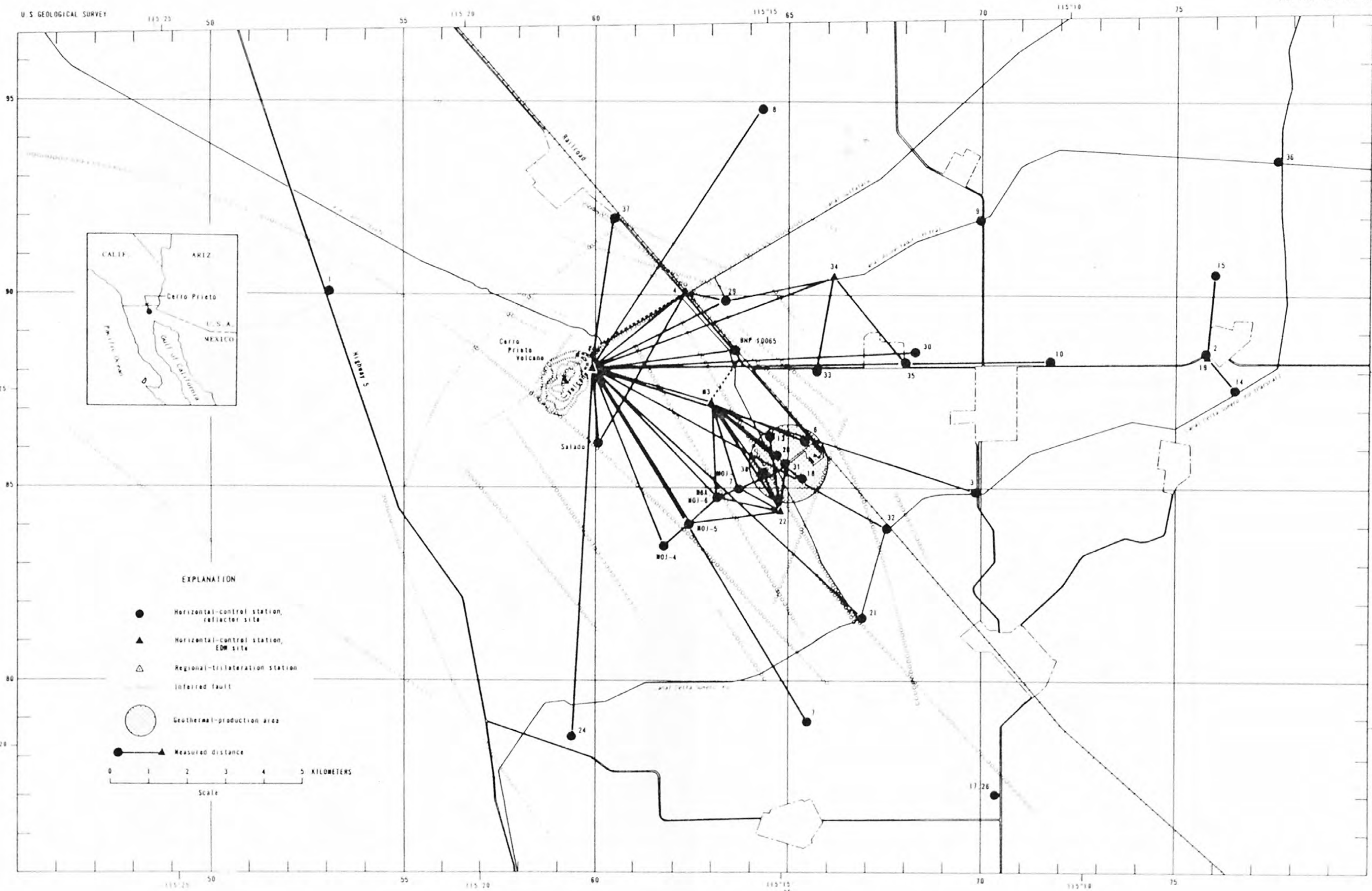

FIGURE 1.—Local network of horizontal-control and inferred faults, Cerro Prieto geothermal area, Mexico.

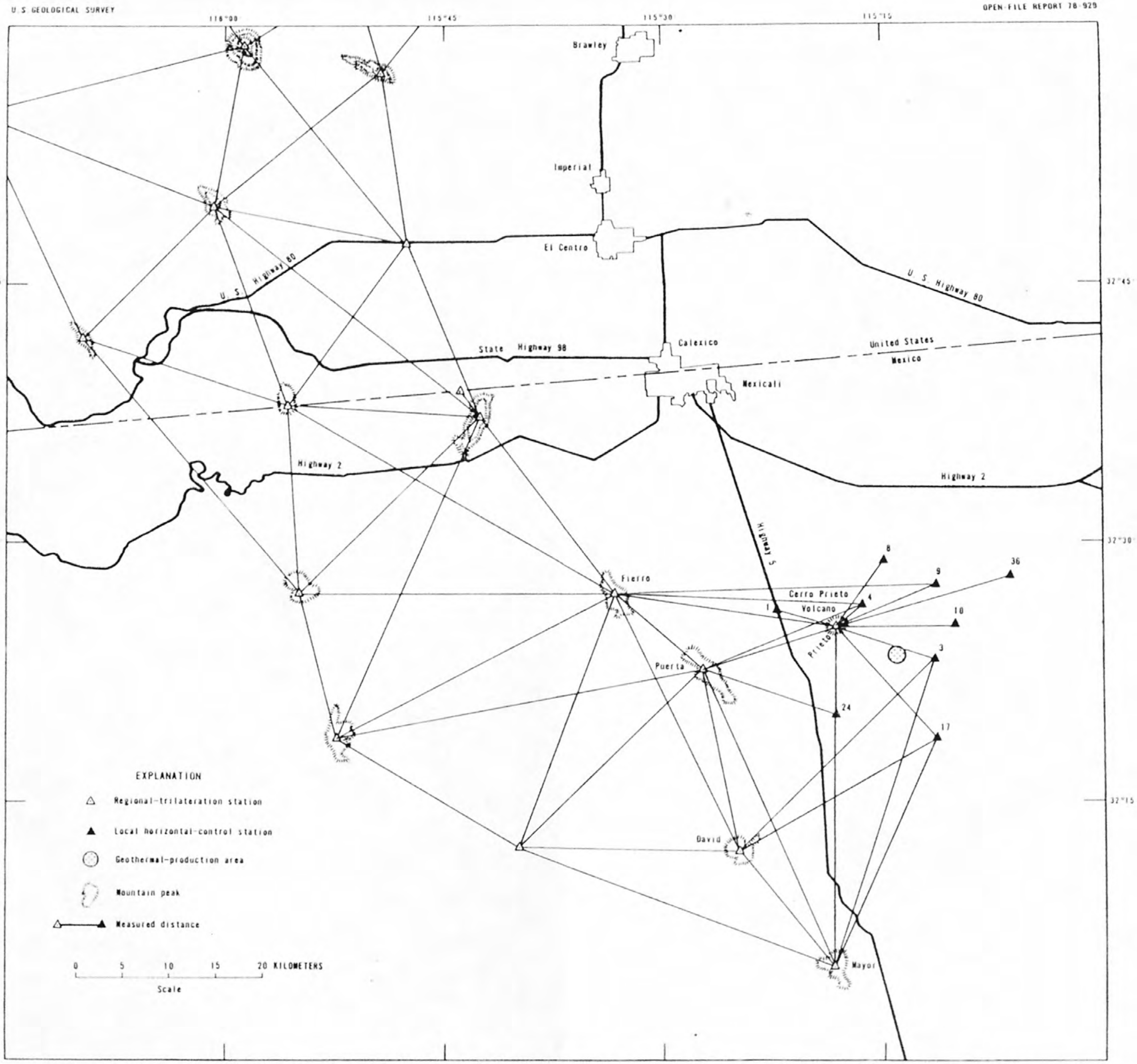

FIGURE 2.—Regional-trilateration network of horizontal-control and bedrock ties, Cerro Prieto geothermal area, Mexico