THE GEOTHERMAL POTENTIAL OF THE IBM PLANT SITE AREA, TUCSON, ARIZONA, T15S, T16S, R15E

by

James C. Witcher

Arizona Geological Survey
Open-File Report 79-18

May, 1979

Arizona Geological Survey
416 W. Congress, Suite #100, Tucson, Arizona 85701

Bureau of Geology and Mineral Technology
Geological Survey Branch
Geothermal Group

Prepared under U.S. Department of Energy Contract EG-77-S-02-4362

THE GEOTHERMAL POTENTIAL OF THE IBM PLANT SITE AREA, TUCSON, ARIZONA, T15S, T16S, R15E

by

James C. Witcher

Arizona Geological Survey

Open-File Report 79-18

May, 1979

Arizona Geological Survey
416 W. Congress, Suite #100, Tucson, Arizona 85701

Bureau of Geology and Mineral Technology
Geological Survey Branch
Geothermal Group

Prepared under U.S. Department of Energy Contract EG-77-S-02-4362

NOTICE

PURPOSE

This report is prepared to document work in T15S, T16S, R15E under United States Department of Energy Contract EG-77-S-02-4362 and to provide information to International Business Machine Corporation concerning geothermal energy resource potential of their plant site.

NOTE

Meters and feet are both used in this report. The following conversions may be useful.

Feet x 0.3048 = Meters

Meters x 3.281 = Feet

Celsius and Fahrenheit are both used in this report. The following conversions may be useful.

Celsius x 9/5 + 32 = Fahrenheit

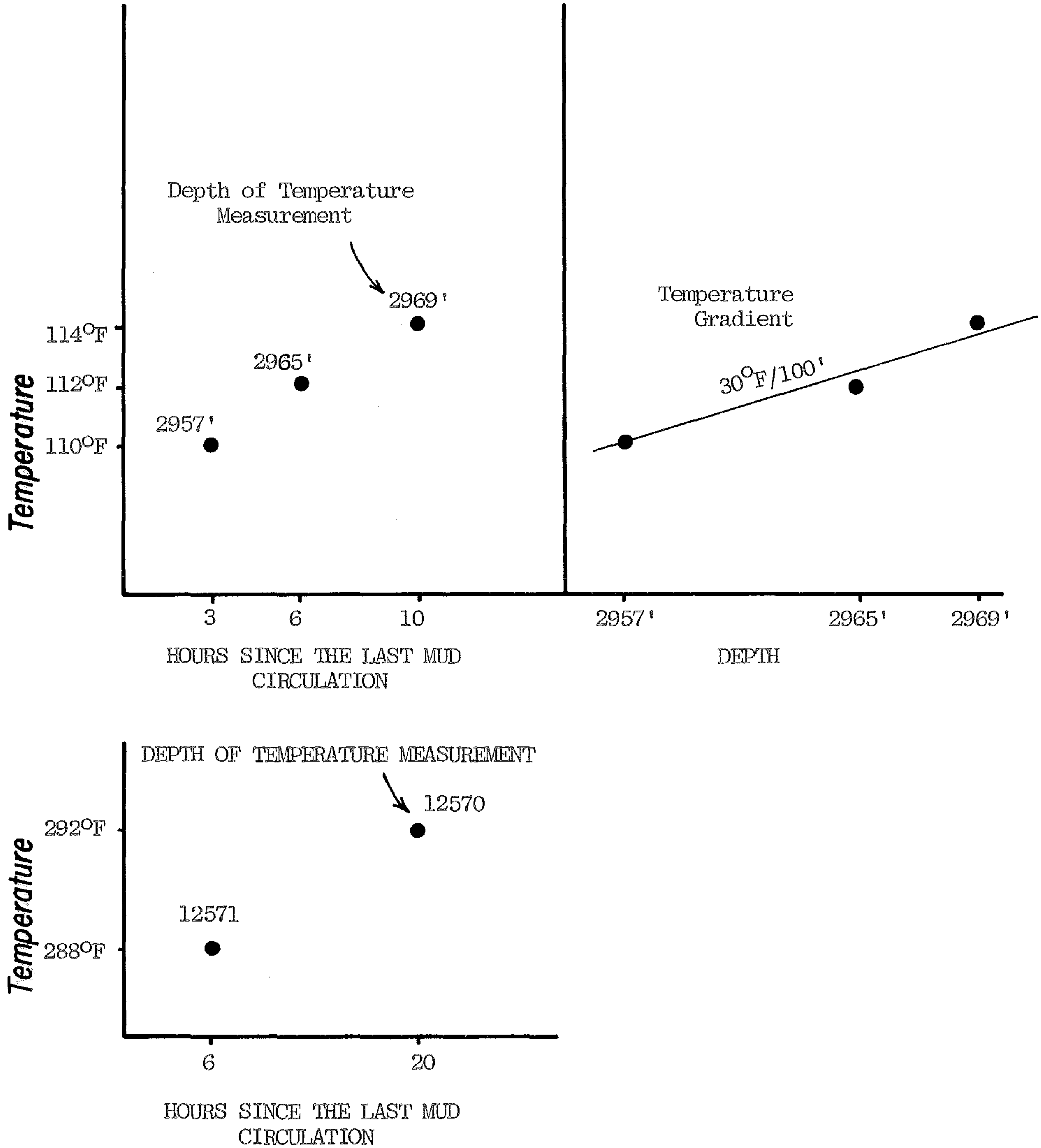
Fahrenheit x 9/5 - 17.78 = Celsius

INTRODUCTION

The IBM plant site south of Tucson, Arizona is favorably located for potential geothermal utilization using natural hot water. High temperatures were measured near the site during geophysical logging of a deep oil test drilled by Humble (Exxon) in 1972. The well, drilled to 12,556 feet 2.5 miles southwest of the IBM site, had measured temperatures of 114°F at 2,969 feet and 296°F at 12,001 feet (Schlumberger Well Services, 1972). These temperatures are minimum temperatures at those depths because they were measured only 10 and 20 hours after mud circulation was stopped. In other words, the well had not reached a stable temperature because rock adjacent to the hole had been cooled by circulating drilling mud introduced from the surface, and the rock was still reheating to its original undisturbed temperature prior to drilling. Figure (1) contains plots of temperature versus time after the last circulation of mud. The plots document the increase in temperature in the Humble (Exxon) well. The shallow temperature measurements from geophysical logging are shown in a temperature versus time plot and a temperature versus depth plot. It is evident that temperature changes with time and not with depth because the inferred temperature gradient, as a change of temperature with depth, is ridiculously high.

FIGURE 1

TEMPERATURE VERSUS TIME AFTER MUD CIRCULATION STOPPED



Data from Schlumberger Well Services, 1972.

MEASUREMENTS MADE DURING GEOPHYSICAL LOGGING
OF THE HUMBLE (EXXON) NO. 1 STATE 32 WELL

REGIONAL HEAT FLOW

The earth's crust beneath the Tucson region conducts an above normal amount of heat from the earth's interior to the surface. Many heat flow values greater than 2.0 H.F.U.[1] have been measured in the Sierrita, Tucson, and Silver Bell Mountains (Sass, et al., 1976). A normal heat flow in the Basin and Range province of southern Arizona is considered to be 2.0 H.F.U. (Keller, et al., 1978). An average United States heat flow is 1.52 H.F.U. (Keller, et al., 1978). An abnormally high heat flow in the Tucson area means that temperatures will tend to be higher at depth beneath Tucson than in areas with normal heat flow. Figure (2) is a generalized map of the Tucson area showing measured heat flows and the location of the study area.

GEOLOGY

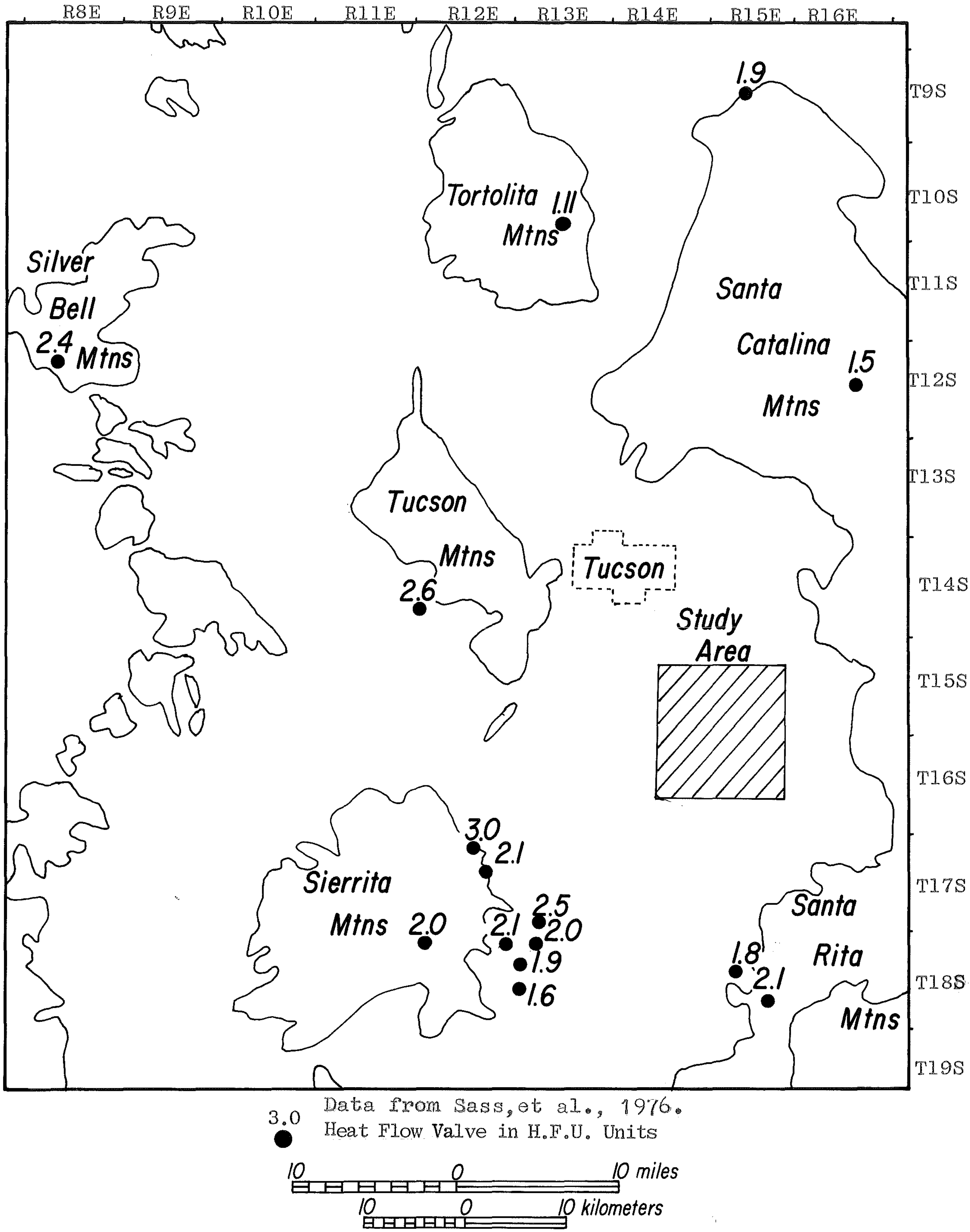
The IBM plant site overlies the northeast periphery of a deep sediment filled structural graben. Available geophysical and well data are interpreted to show a wide and elongated sediment filled basin whose bottom slopes downward from the mountains toward the basin axis. A relatively narrow strip of crust is faulted downward to form a graben along the axis of the basin. The graben structure is filled with sediment derived from the surrounding mountains.

Eberly and Stanley (1978) presented an interpreted seismic reflection profile across the Tucson basin (Figure 3). The

[1] H.F.U. (Heat Flow Units) is equivalent to units x 10^6 Cal/ Cm^2 Sec.

MAP SHOWING MEASURED HEAT FLOWS IN THE TUCSON AREA AND LOCATION OF THE STUDY AREA

FIGURE 2

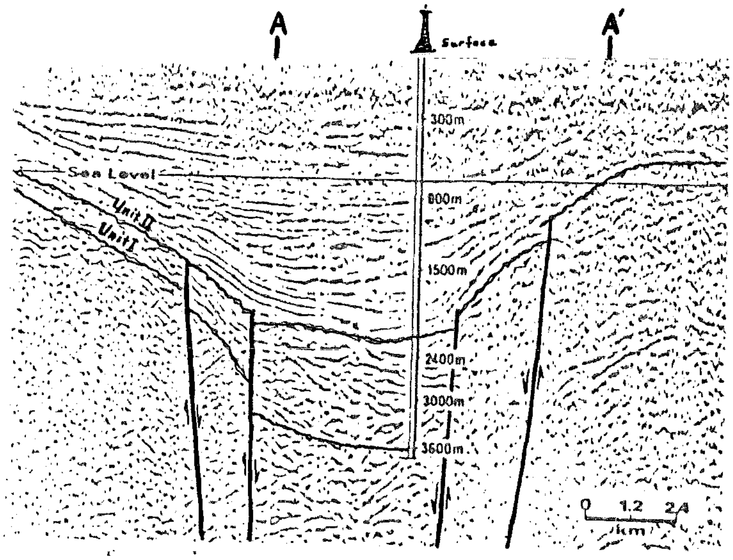


Data from Sass, et al., 1976.

Heat Flow Valve in H.F.U. Units

EAST-WEST
SEISMIC REFLECTION SURVEY
ACROSS THE TUCSON BASIN

Humble (Exxon) No. 1 State 32
to 3,832 m



From Eberly and Stanley (1978)
A and A' are ends of the profile shown
in figure 4.

profile runs east to west across the Humble (Exxon) well 2.5 miles south of the IBM plant site. The seismic data are correlated to the subsurface stratigraphy observed in the well. A wide sloping basement shelf exists on both sides of a graben. The sloped basement shelf may be a pediment which is continually buried beneath clastic sediments. Up to 12,000 feet of clastic sediment and volcanics overlie pre-Tertiary crystalline rock in the central graben. Because thick clastic sediment filling the central graben conducts heat very slowly compared to the granitic material comprising the bulk of the crust underlying the Tucson region, sediment fill in the graben acts as an insulating blanket which traps heat. Also, the graben is sufficiently wide compared to its depth so that the anomalous heat is not refracted laterally to any great extent. Combined with an above normal heat flow, the "sediment heat trap" of the central graben creates a significant geothermal anomaly at depth.

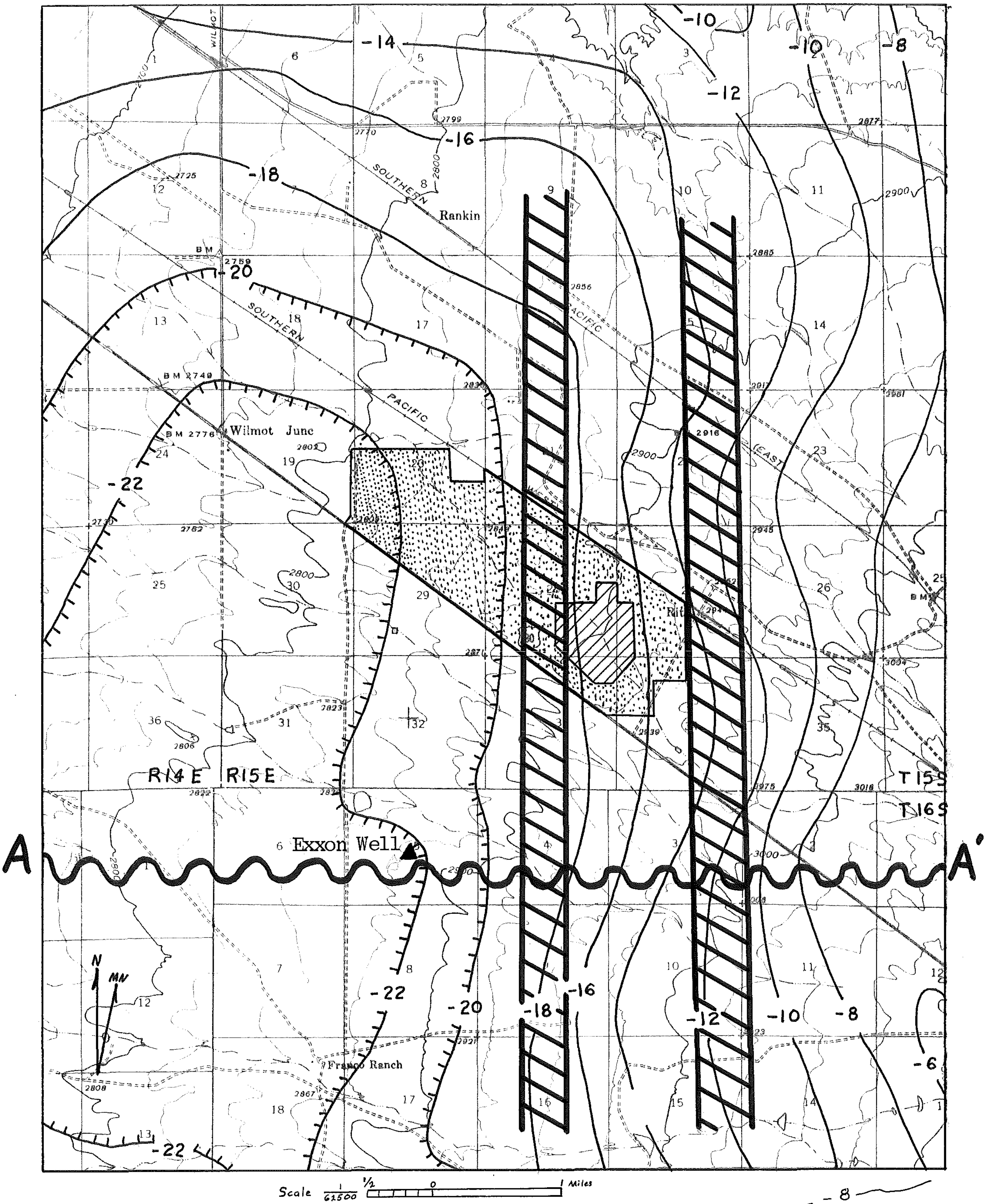
A major problem in evaluating the geothermal potential of the IBM site deals with how much heat may be extracted per unit of time. The temperatures exist, but can the rock store and produce enough water to bring the heat to the surface where it may be used?

Water is stored in the pore spaces and fractures in rock. The percent of void spaces or porosity of the rock will partially control the availability of usable hot water. Permeability or the amount of water that may be withdrawn from rock over a period of time is a result of the degree of interconnections between the void spaces. Permeability is the most important factor for hot water production.

Good permeability may be found in areas of extensively fractured rock in many fault zones. Also, good permeability is observed in many kinds of sandy and gravelly sediment. A gravity map of the IBM site area (Figure 4) shows a linear zone of steep gravity gradients trending north to south across the IBM site (Davis, 1971). The steep gravity gradients probably indicate major Late Tertiary subsurface faults buried beneath basin fill sediment. Seismic reflection data substantiate that conclusion. The fault zone may provide good fracture permeability and may act as a conduit so that hot water at depth may rise to shallow depths.

Temperature data obtained from temperature logs on file in the Tucson City Hydrologist's Office and from temperature logs taken by the Geothermal Group, Arizona Bureau of Geology and Mineral Technology is plotted on maps to delineate the temperature distribution beneath the IBM site area. The temperature logs obtained by the city of Tucson are used by the city hydrologist to evaluate hydrologic conditions in the Tucson basin. The temperature logs obtained by the Geothermal Group are for geothermal studies. Figure (5) is a map showing temperature distribution at 400 feet below the surface. A warm temperature anomaly is observed in the northwest quarter of Section 9, T16S, R15E. The measured 29°C temperature in the anomaly areally correlates to an inferred fault zone postulated

GEOPHYSICS AND MAJOR GEOLOGIC STRUCTURES FIGURE 4



IBM Property

Proposed facilities site

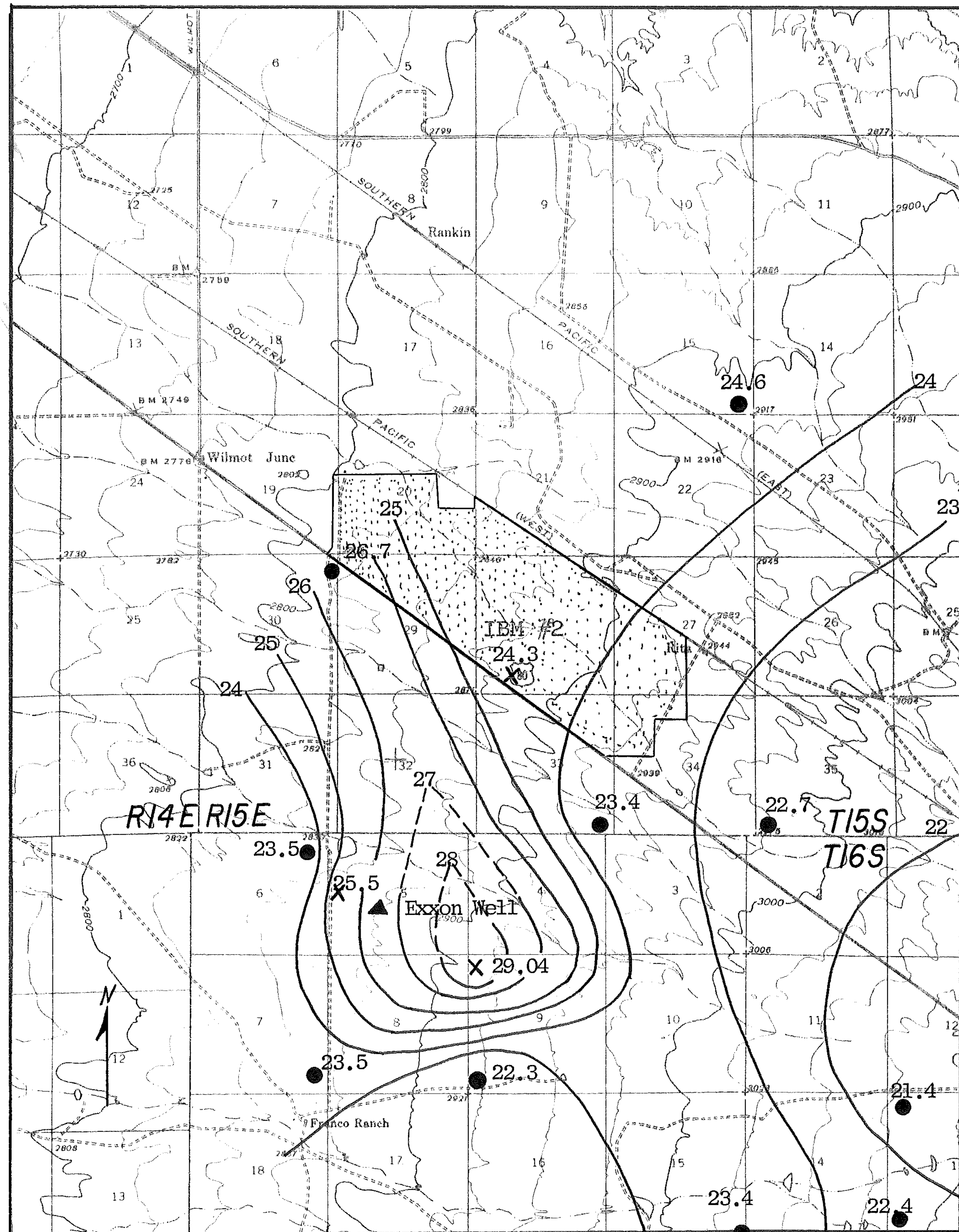
Inferred fault zones

-8 Gravity contours in milligals

Seismic survey

TEMPERATURE DISTRIBUTION - 400 FEET

FIGURE 5



Contour equals one degree centigrade

● Location

23.5 °C

Scale 1/62500

● City of Tucson Temperature Log

▲ Exxon Well

X Bureau of Geology Temperature Logs

IBM PROPERTY

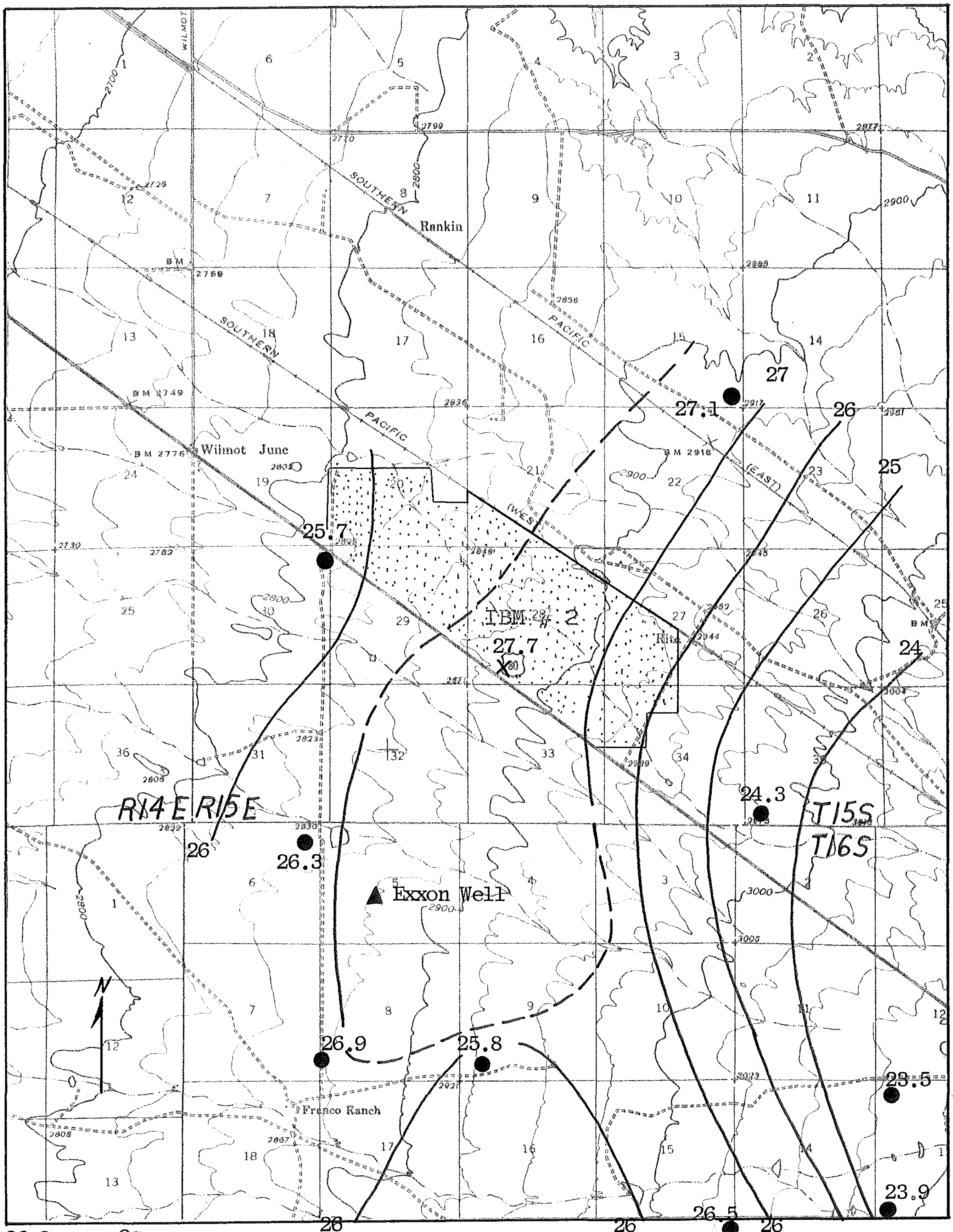
from seismic and gravity data. Figure (6) is a map of temperatures at 800 feet beneath the IBM site area. A north trending zone of higher temperature is evident. While the data are sparse, it is interesting to note that the 800 foot anomaly also correlates areally to the postulated fault zone by being displaced slightly to the west. An average temperature gradient map derived from bottom hole temperature and well depths has higher gradients in a zone roughly paralleling that seen in the 800 foot zone (Fig. 7).

The zone of higher temperatures and gradients is believed to be the result of hot water moving along the fault zone inferred from gravity and seismic data. The inactive fault probably does not displace or extend into the youngest and uppermost sediment, but is older and has been buried by the sediment. However, at depth, rock displaced by the fault may be highly fractured, thereby providing conduits for hot water circulation. Hot water may rise along the fault zone and heat or leak into the overlying sediment. The relatively low magnitude of the temperature anomaly may result from near surface (less 1,200 feet) flows of cold water which would tend to subdue or mask any geothermal phenomenon associated with a buried fault zone.

A temperature log of the IBM well exhibits two zones of very low temperature gradients overlain by intervals of high temperature gradients. The low temperature gradient zones may indicate lateral flow of water in very permeable aquifers (Fig. 8).

TEMPERATURE DISTRIBUTION - 800 FEET

FIGURE 6



26.9 °C
● Location

▲ Exxon Well

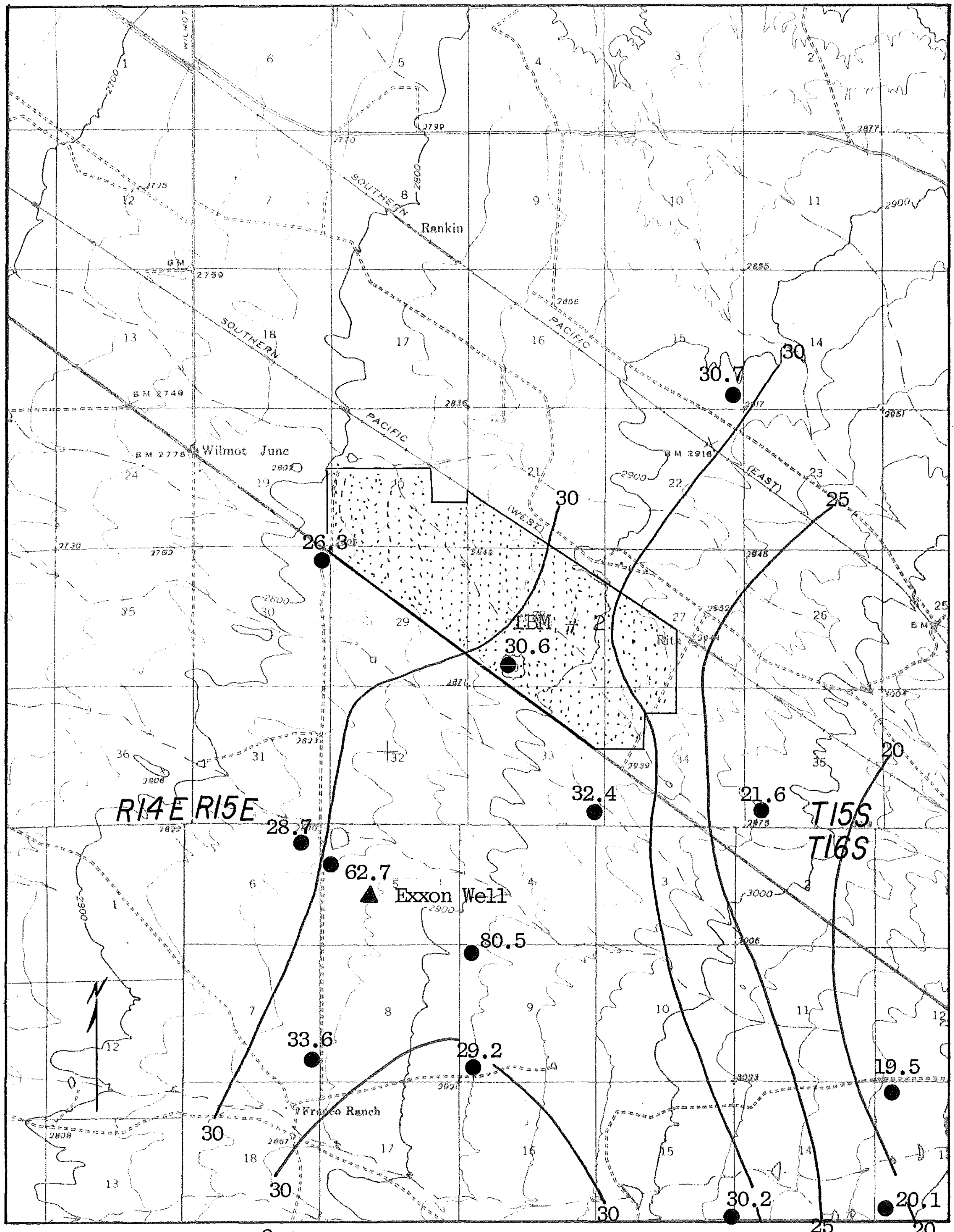
● City of Tucson Temperature Log

X Bureau of Geology Temperature Log

Contours equal one °C

Scale 1/62500

IBM PROPERTY



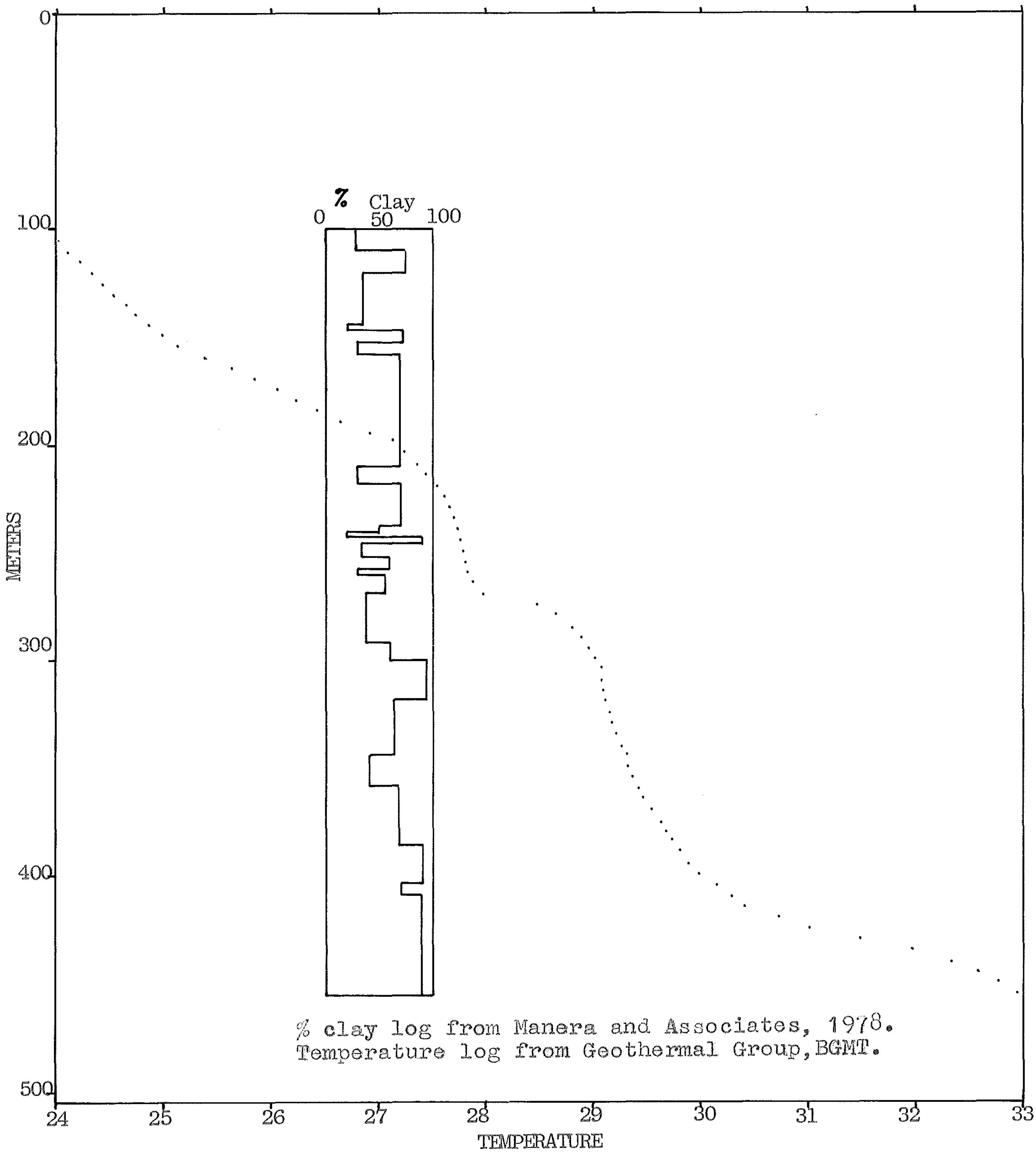
°C/km
29.2
Location ● Calculated Average Gradient Using Bottom Hole Temperature, Depth and 19°C Mean Annual Temperature

Contours equal °C/km

IBM PROPERTY

Scale 1/62500

TEMPERATURE AND PER CENT CLAY LOG OF THE IBM #2 WELL



High transmissivity of other IBM wells attests to the presence of very permeable aquifers (Taylor and Foster, 1978). A shallow northwest oriented geochemical trend crossing the IBM site area and roughly parallel to Interstate 10 has been postulated to be evidence of a former course of the Pantano Wash or flow of water from the southeast where the high calcium contents are derived by dissolution of limestone and then transported via groundwater (Laney, 1972). In either case, very good shallow aquifers with lateral water movement are implied. Lateral water movement could effectively mask or subdue deeper geothermal anomalies.

The lowest interval observed in the temperature log of the IBM #2 well has high temperature gradients. Very clayey sediment occur at the same depths as the high temperature gradients. Clayey sediment, in general, does not allow for water flows because it is impermeable; therefore, any heat transfer would be by conduction and not convection. Also, convective heat flows would exhibit very small temperature gradients as opposed to temperature gradients in conductive intervals which would be high or normal. The high temperature gradients observed in the bottom of the IBM #2 well probably continue for 1,000 feet to 1,500 feet since the clayey sediment in the bottom of the well is correlated with a 1,500 foot thick clayey sequence observed in the Exxon well at similiar depths.

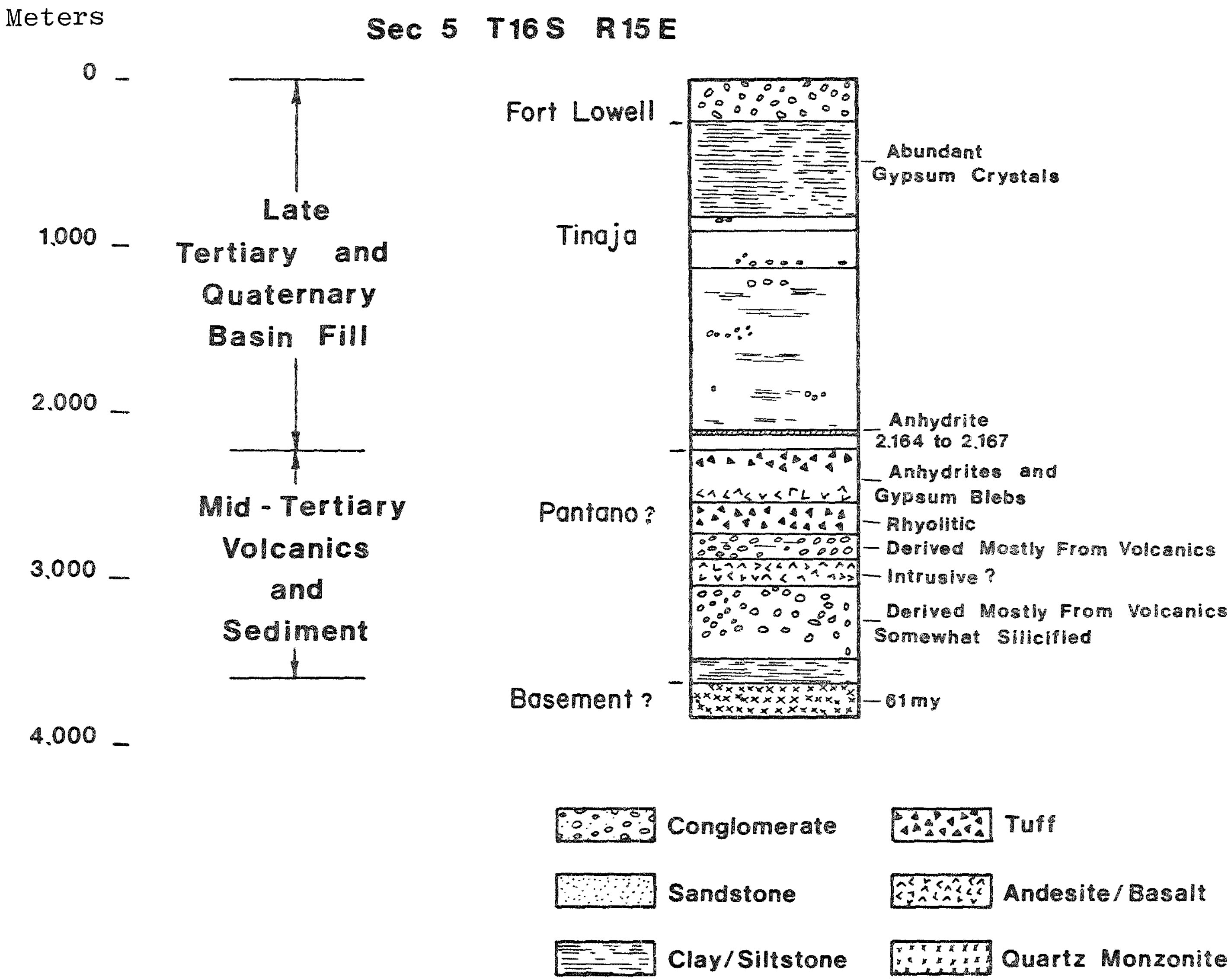
The only well known to penetrate the complete sequence of rocks in the IBM site area is the Humble (Exxon) well in Section

5, T16S, R15E. Figure (9) is a log of that well interpreted from data reported by Eberly and Stanley, (1978). The upper sands and gravels are the source of most groundwater supplies in the Tucson basin and are called the Fort Lowell Formation (Davidson, E.S., 1973). Fine grained sediment and clays beneath the Fort Lowell Formation contain abundant gypsum crystals between 564 and 686 meters. Sand and conglomerate occur from 914 meters to 1,170 meters. Interbedded sand, silt and clay occur down to 2,218 meters along with a 3 meter anhydrite bed at 2,164 meters. The sediment overlain by the Fort Lowell Formation is probably the equivalent of the Tinaja Formation of Davidson (1973). The volcanics and sediments beneath the Tinaja Formation may be highly disturbed by faulting and may be laterally discontinuous. The volcanics and sediments are not considered to be basin fill and may be equivalent to the Pantano Formation which is pre-Basin and Range "disturbance" (Eberly and Stanley, 1978) (Scarborough and Peirce, 1978).

An inspection of the stratigraphy logs of the Humble (Exxon) well shows several zones of coarse grained sediments that might be suitable for geothermal purpose in the IBM site area.

FIGURE 9

Lithologic Log
Exxon State (32-1) Well
Sec 5 T16S R15E



RECOMMENDATIONS

The indicators of geothermal potential are very promising for the IBM site area and additional investigation is certainly warranted. Geophysical logs, stratigraphic logs and cuttings of the Humble (Exxon) well are available for study through the Arizona Oil and Gas Conservation Commission and the Arizona Bureau of Geology. These logs and samples should be studied thoroughly in order to obtain estimates of porosity and permeability of subsurface rock in the IBM site area.

The feasibility of re-entering the Humble well should be seriously considered. According to the well reports on file at the Arizona Oil and Gas Conservation Commission, the well is abandoned and plugged with cement at four 100 feet intervals. Depending upon the condition of the hole, these plugs could be drilled out at a very reasonable cost.

A detailed temperature log of the hole should be made if it is re-entered. Additional geophysical logs should be run in order to compute the intergranular permeability of the formations. The Saraband process developed by Schlumberger Well Services may be used to calculate permeability from geophysical logs. The most permeable formation could then be tested for production and chemical quality. Making use of the Humble well would be very cost effective since the well could be used as a production or reinjection well.

The seismic reflection data and seismic interpretation of the IBM site area may be available for purchase from Exxon at a reasonable cost. These data may be highly useful in delineating further subsurface structure or evaluating the usefulness of additional seismic profiling in the area.

Surface geophysics to include a detailed gravity survey should be done before a deep well is drilled if the Humble (Exxon) well is not re-entered. A gravity survey is relatively inexpensive and subsurface density information may be obtained from well cuttings which would facilitate detailed modeling of the subsurface structure. Electrical surveys may be desirable; however, the many high voltage power lines in the area may render electrical geophysics useless.

Heat flow studies would be very useful, but they might not be cost effective exploration as 10 to 15 heat flow holes may be necessary. The heat flow holes would have to be drilled 1,200 feet in order to get below temperature variations caused by near surface water flows and recharge. The cost for a heat flow hole to 1,500 feet would be approximately $30,000 if the drilling costs are $20 per foot.

Temperature logs of all available wells in the IBM site area should be obtained. Water samples from all pumping wells in the area surrounding the site should be obtained and analyzed. These samples will provide "bench mark" data of the ground water quality prior to geothermal development and the data are useful in identifying geothermal anomalies for siting wells. Boron, chloride, silica, fluoride, lithium, sodium, potassium, calcium, magnesium, bicarbonate, sulfate, temperature and pH should be analyzed in the water samples. Trace elements such as mercury, selenium, copper, iron and phosphate may be of interest too.

DRILLING COSTS

Re-entry into the Humble (Exxon) well would probably cost around 700,000 dollars. This cost would include geophysical logs, casing, drilling, drill bits, cement, coring and testing of the well. Leaving the original hole at 6,000 feet with directional drilling to 11,000 feet would insure that good aquifer tests and geophysical logs are obtained, and it might provide additional water production.

The cost of drilling and testing a new production well to 10,000 to 12,000 feet will probably be around 2 to 2.5 million dollars. The drilling and testing time for these depths would be 2 to 3 months. The largest drilling expense is mobilization and demobilization of the drill rig. However, with the deep oil and gas drilling that may commence soon in southern Arizona, a rig may be available in Arizona at considerably less mobilization rates.

A new production well drilled to 7,000 feet may cost under 1 million dollars. Again, the greatest expense is mobilization of the drill rig because it would have to be acquired from Farmington, New Mexico, Midland, Texas, or California.

LEASES

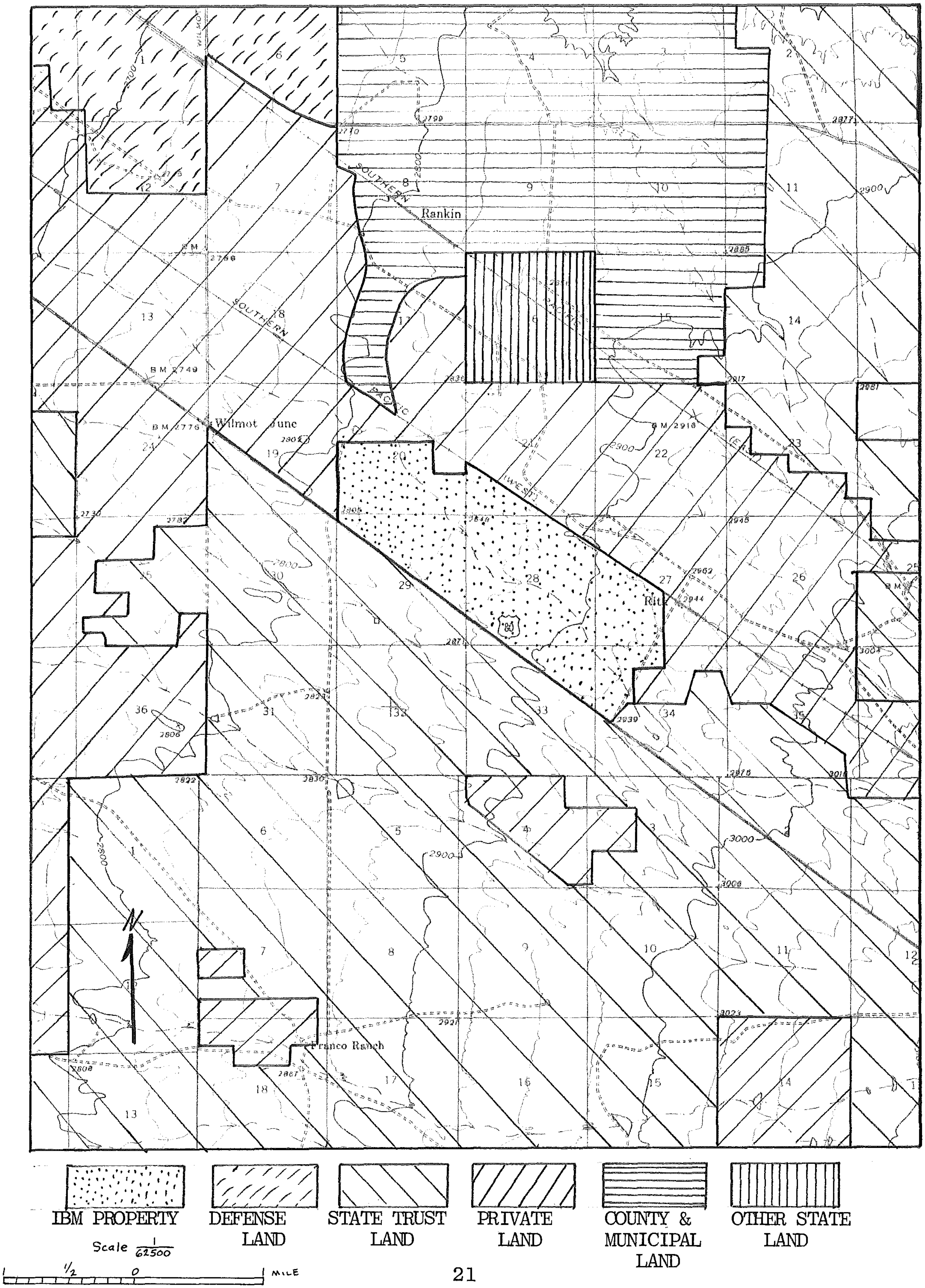
The most important step in a geothermal program at the IBM site will be to make a thorough land status survey of a large area around the plant site. Applications for geothermal leases should be made on all state and federal land adjacent to the IBM site. The geothermal rights for the private land immediate to the plant should be secured. These actions would insure IBM's rights to the geothermal resource beneath the plant site area. Figure (10) is a generalized land status map of the plant site area. Most land adjacent to the site on the south is state land with some interspersed private holdings.

A thorough study of state and federal requirements and regulations concerning geothermal development is required in order to expediate exploration and development.

The Arizona State Land Department awards geothermal leases on state owned land. Legislative Act (HB 2257) in 1977 allows for leasing of geothermally prospective land. The leasing of state land is done through competitive bids. After the State Land Department reviews the lease proposal, the location of the proposedlease is published for ten weeks. Bids are awarded to the highest bonus bid of a qualified application. Bonus bids are an excess bid above the standard bid of one dollar per acre for the first year. Subsequent annual rental is one dollar per acre and the maximum allowed size of a single lease tract is 2,560 acres or 4 square miles.

LAND STATUS

FIGURE 10



DRILLING

The Arizona Oil and Gas Conservation Commission supervises drilling, operation, maintenance, and abandonment of geothermal wells.

Before drilling a geothermal well, an application to drill or re-enter a well is filed with the Arizona Oil and Gas Conservation Commission. A $25 application fee and a surveyed land plat are required with the drilling application. A $5,000 surety bond is also required for each well drilled. Blow-out preventers and casing are required in order to protect and seal shallow aquifers. The Oil and Gas Conservation Commission also requires that well logs and monthly production rates be filed in their office.

CONCLUSION

Hot water between 90°C and 140°C may be possible between 7,000 feet and 11,000 feet. Production from this interval may range up to 500 to 1,200 gallons per minute if sufficiently permeable sediment and volcanics are encountered in a deep well. The conclusions drawn in this report should be considered preliminary. Further geologic and geophysical studies are advised to further delineate the geothermal potential of the IBM plant site area.

REFERENCES

Davidson, E.S., 1973, Geohydrology and water resources of the Tucson basin, Arizona: U.S. Geological Survey Water-Supply Paper 1939-E, 81 p.

Davis, R.W., 1971, An analysis of gravity data from the Tucson basin, Arizona, in Arizona Geological Society Digest, Vol. IX, pp. 103-121.

Eberly, L.D., and Stanley, T.B., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geological Society of America Bulletin, Vol. 89, pp. 921-940.

Ganus, W.J., 1965, Lithologic and structural influence on the hydrodynamics of the Tucson basin: M.S. Thesis, University of Arizona, 37 p.

Johnson Division, 1966, Ground Water and Wells, Universal Oil Products Company, St. Paul, Minnesota, U.S.A.

Keller, G.V., Grose, L.T., and Drewdson, R.A., 1978, Speculations on the nature of geothermal energy in basin and range province of Western United States, Colorado School of Mines Quarterly, Vol. 73, No. 4, Pt. 2, 6 p.

Laney, R.L., 1972, Chemical quality of the water in the Tucson basin, Arizona, U.S. Geological Survey Water Supply Paper 1939-D.

Mburu, Samuel, G., 1975, Vertical temperature and chemical gradients in ground water in the Tucson basin, Arizona: Unpub. M.S. Thesis, University of Arizona, 93 p.

Sass, J.H., Diment, W.H., Lachenbruch, A.H., Marshall, B.V., Monroe, R.J., Moses, Jr., T.H., and Urbanu, T.C., 1976, A new heat flow contour map of the conterminous United States, U.S. Geological Survey Open File Report 76-756, 24 p.

Scarborough, R.B., and Peirce, H.W., 1978, Late Cenozoic basins of Arizona, in land of Cochise - southeastern Arizona, 29th New Mexico Geological Society Guidebook: New Mexico Geological Society and Arizona Geological Society, pp. 231-241.

Schlumberger Well Services, 1972, Geophysical logs of Humble (Exxon) No. 1 State 32, Arizona Oil and Gas Conservation Commission Well #597.

Supkow, D.J., 1971, Subsurface heat flow as a means for determining aquifer characteristics in the Tucson basin, Pima County, Arizona, Ph.D. Dissertation, University of Arizona, 182 p.

Swanberg, C.A., et al., 1977, An appraisal study of the geothermal resources of Arizona and adjacent areas in New Mexico and Utah and their value for desalination and other uses: New Mexico Energy Institute Report No. 6, 76 p.

Taylor, J.G., and Foster, K.E., April 1978, Final environmental inventory International Business Machines (IBM) development site, Tucson, Arizona, Office of Arid Land Studies, University of Arizona.

Witcher, J.C., 1979, A preliminary study of the geothermal potential of the Tucson metropolitan area in Geothermal Reservoir Site Evaluation Semiannual Progress Report for Period July 1978 - January 1979, DOE Contract EG-77-S-02-4362, Arizona Bureau of Geology and Mineral Technology, Geothermal Group.

TUCSON BASIN

The Tucson metropolitan area, containing 30 shallow (<1000 feet) wells having temperatures greater than 30^{O}C, overlies a deep sediment-filled basin with a heat flow of 2.0 H.F.U. In a region of 2.0 H.F.U. the temperature gradients in the basin fill sediment are predictably high. Exxon drilled a deep stratigraphic test in Section 5, Township 16 South, Range 15 East and recorded temperatures of 147^{O}C at 12,000 feet 20 hours after mud circulation ceased. The temperature gradient calculated using 18^{O}C mean annual temperature is 36^{O}C/km. This gradient is a minimum because the temperature measurements taken during geophysical logging indicate the temperature in the well had not reached equilibrium after drilling disturbance.

The Exxon well shows basin sediments extending to depths exceeding 7,000 feet. The upper 1,000 feet of basin sediments contain the aquifers used by the city of Tucson. Below 1,000 feet, fine-grained sediment, siltstones and gypsiferous clays, occur to depths of 3,000 to 4,000 feet. Coarse-grained sediment occurs beneath the confining siltstones and clays. Tucson Gas and Electric Company drilled two wells into the fine grained-sediment and discovered 52^{O}C water at 2500 feet. This water is under confined conditions and rose in the well to near the surface. The sands and gravels beneath the confining clays are potentially significant geothermal reservoirs at 1 and 2 km depths. These potential aquifers are likely to provide water under artesian conditions.

Preliminary studies indicate convective systems occur in these lower sediments beneath the confining clays. Basin structure may provide a locus for such activity. In order to identify potential systems, a very large comprehensive compilation of published and unpublished water chemistry, well logs, temperatures, geologic and geophysical data is being gathered. These data are being compiled onto maps for interpretation. While the well data, water chemistry and temperature logs are from the upper 1,000 feet and significant lateral water flow exists, these data hopefully will identify areas of potential systems beneath the fine-grained sediment. All available hot wells will be sampled for water chemistry. Temperature logs of open wells in the Tucson basin will continue to be collected. Complete and detailed subsurface temperature and water chemistry maps will result from these studies. These maps will provide targets for deep potential resources and also characterize recharge and chemistry source areas. In addition, published gravity data will be modeled to map basin structure and the thickness of basin fill.

At the present time, IBM Corporation is actively pursuing the feasibility of geothermal applications in their new two million square foot plant southeast of Tucson. The Arizona Bureau of Geology and Mineral Technology provided IBM with a preliminary assessment of geothermal potential in Township 15 and 16 South, Range 15 East, where the IBM plant site is located. A whole gamut of potential users for direct use geothermal applications exists in Tucson.