SAN EMIDIO GEOTHERMAL SYSTEM

EMPIRE, NEVADA

GRC Field Trip – October 1995

by

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Introduction

The San Emidio (aka Empire) geothermal system is located on the eastern side of the San Emidio Desert, a valley sited approximately 55 miles north-northeast of Reno, Nevada (Figures 1 and 2). The Lake Range bounds the valley to the east and the Fox Range forms the western boundary. Empire Farms Partnership supplies geothermal water to the Integrated Ingredients' vegetable dehydration plant in the valley. OESI Power Corporation and Constellation Energy, Inc. generate electricity at the 3.5 MW (net) geothermal binary power plant located approximately one mile south of the dehydration plant. The Wind Mountain gold mine, three miles north of the dehydration plant, utilizes geothermal water for heap leaching.

Geology

The geology of the San Emidio Desert (Figure 3) is dominated by a thick sequence of Tertiary volcanic and sedimentary rocks that accumulated on an irregular topographic surface cut into a Mesozoic metamorphic basement. Geologists have assigned the metasedimentary and metavolcanic basement rocks to the Nightingale (TrJn) formation of Triassic and Jurassic Age (Moore, 1979). This formation consists predominantly of a thick sequence of metamorphosed and folded argillaceous rocks interbedded with carbonates, sandstones, and volcanics. Low-grade, greenschist regional metamorphism has converted the argillaceous rocks to slate containing chlorite, muscovite, biotite, quartz and plagioclase.

Overlying the Nightingale formation are Miocene Age volcanic rocks composed mostly of a volcaniclastic assemblage of tuffaceous sandstones, mud flows and ash-flow tuffs (Tsv). These fine to medium-grained volcaniclastic rocks include at least three lenses of dark grey, intermediate composition lava flows. Above this is a stratigraphic unit (Tvu) consisting of andesite and dacite volcanic flows. These lavas have been radiogenic aged as Miocene, and are sparsely porphyritic, containing a few plagioclase and hypersthene phenocrysts.

Late Tertiary clastic rocks and Recent alluvium are the youngest geologic units at San Emidio. These units are poorly-sorted sediments that constitute the valley fill and range in size from clay to gravel. In the geothermal resource area, these Tertiary clastics have been highly silicified and fractured.

Structurally, the San Emidio region exhibits a pattern of north and east trending faults related to Basin and Range tectonism. Major north-trending faults have rotated the Tertiary rocks eastward and appear to have localized the geothermal system and its alteration products along the range-front faults of the Lake Range. Mapping by Mesquite and others (Figure 4) shows that there are four north-south striking faults and one southwest-northeast trending fault in the SER leasehold area. The unnamed southwest trending fault has been mapped in the Wind Mountain gold mine and strikes into the valley. The easternmost fault is the main range-front fault that separates the valley from the Lake Range and dips westward. The South Range-Front fault is exposed in the southern portion of the Lake Range and is projected onto the Empire Farms Partnership (EFP) leases. This normal fault also dips westward and has at least 1000 ft of throw. The Three Mile Canyon fault has been mapped in the Lake Range and is projected onto the leasehold to coincide with the fault scarp and mineralization observed on the EFP lands. The Valley fault is hidden beneath alluvium, but seismic reflection data and geologic correlations using well logs clearly indicate the fault has displaced the Tertiary volcanics over 1800 ft.

Hydrothermal Alteration

Although today there are only minor naturally-occurring steam seeps in the San Emidio Desert, there is a long, linear zone of acid-sulfate (steam) alteration which parallels the Lake Range. Active hydrogen sulfide seeps from the geothermal system have produced native sulphur deposits and zones of intense acid leaching aligned along this zone. Shallow prospect pits in the alteration have also exposed gypsum and mercury sulfide minerals. This alteration zone coincides with the Three Mile Canyon fault north of the vegetable dehydration plant.

Dark grey, massive silica sinter outcrops parallel the South Range-Front fault north of the dehydration plant. Drilling histories and lithologic logs from San Emidio wells also report a silica caprock overlies the shallow geothermal system in Tertiary sands. This very hard silica caprock is composed of secondary quartz and silicified sands.

Exploration & Drilling

In the 1970's, several geothermal companies, but primarily Chevron, conducted exploration in the San Emidio Desert to evaluate the area's potential. Exploration techniques utilized included aerial mapping, self-potential, reflective seismic, dipole-dipole resistivity, gravity, seismic ground noise, and temperature gradient surveys. Chevron's shallow temperature gradient survey work began in 1976 and continued through 1979. At least 63 holes, ranging in depth from 40 to 2000 ft were drilled and logged for temperature and lithology. Two of the holes, 50-78 and 3, reported temperatures greater than 240°F, with hole 3 having the highest temperature, 274°F at a depth of 78 ft (Figure 5). This work suggested that there was a shallow, narrow geothermal outflow zone parallelling the range-front in this area. Temperatures were too low, however, to be of any interest at the time.

In 1976, Phillips Geothermal Company drilled a temperature observation well, ST-1, to a depth of 1935 ft (Figure 5) about 500 ft east of the dehydration plant location. Phillips' geologists reported fractures were first intersected at 1910 ft with the well "kicking", followed by lost circulation. Phillips regained circulation and drilled ahead to 1935 ft where they encountered a "large fracture" and total lost circulation. After injecting mud to cool the hole, Phillips ran tubing and moved the rig off. The subsequent temperature profile measured in ST-1 shows a conductive gradient to a depth of 1800 ft where a temperature of 298°F was recorded. Below this depth, temperatures reverse slightly, possibly due to residual lost circulation cooling at the time of the survey.

Chevron also drilled two full-size wells looking for a higher temperature source of the shallow geothermal outflow zone. In 1975, Kosmos 1-8 was completed at a total depth of 4013 ft, finding neither permeability or useful temperature (maximum ~230°F). In 1978, Chevron drilled Kosmos 1-9, located approximately 3300 ft east of Kosmos 1-8. This well was directionally drilled westward to a true vertical depth of 5303 ft. The Kosmos 1-9 temperature profile indicates it penetrated a 260°F, shallow geothermal outflow zone. The temperature then reversed to 225°F until near the bottom of the well, where the temperature again increased slightly to 250°F.

At least seventeen production, injection and exploration wells or gradient holes were drilled somewhat later in association with the Empire power plant development (Figure 5). Most of these were drilled in the mid-80's to test and develop the near-surface shallow geothermal outflow zone sands where a highly productive ±275°F resource was located. In 1988 an attempt to locate a better injection zone was made by drilling three slim holes to ±2000 ft. These three holes were injection tested, but exhibited only minor permeability. Static temperature profiles were not measured. However, unequilibrated measurements suggest that at least one of these holes nearly reached a ±300°F resource.

AMAX, the operator of the Wind Mountain gold mine, has drilled two wells into the shallow geothermal outflow zone about three miles north of the dehydration plant. These wells yield hot water that is flashed before being pumped to the leaching piles. Very limited information exists on these wells, but visual observation suggests that their temperature exceeds 250°F.

EFP has drilled nine wells at San Emidio (Figure 5). In 1991, Well 28-9 was drilled to 1204 ft. The rig was then moved to the 51-16 site where the well was completed at a total depth of 992 ft. EFP's third well was a slim hole, 65B-16, at a location now beneath the dehydration plant. Hole stability problems prevented drilling through a caving formation at 1160 ft. The drilling equipment was skidded east to the 75-16 location, and a slim hole was drilled to 1085 ft, where hole stability problems again caused suspension of drilling. Other early EFP exploration wells include 32-21 (430 ft TD), 61-16 (±640 ft TD), and 68-16 (±680 ft TD). EFP completed Well 65C-16, the initial production well for the dehydration plant, in 1993 in the shallow outflow zone. This well reached a total depth of 523 ft, but was plugged back to ±350 ft in order to eliminate deeper, colder inflow. Well 65C-16 can produce ±900 gpm (pump limited) with a wellhead temperature of 267°F and only minor pressure drawdown.

In June 1994, EFP deepened existing slim hole 75-16 from 1085 to 1821 ft. It was believed this hole would encounter the thermal upwelling feeding the shallow outflow zone from the South Range-Front fault. At 1792 ft, permeable fractures associated with the fault were first intersected. Between 1800 and 1820 ft, major open fractures allowed the bit to free-fall two to three feet twice. Short term flow testing indicated that the well was capable of flowing 306°F water and that it had very little pressure drawdown. The casing size only allowed a small submergible pump to be run into 75-16, and it pumps 306°F water at a 475 gpm rate with no measurable pressure drawdown

The drilling of a nearby full-size production well followed the success of the 75-16 deepening. This well, 75B-16, was completed in August at a total depth of 1970 ft. A six hour flow test with the rig on the hole stabilized almost immediately at 920 gpm, producing 308°F water with minor pressure drawdown. Unlike 75-16, most of the production in 75B-16 seems to be coming from a highly permeable volcanic clastics interval at about 1500 ft, rather than from the nearby fault zone itself. Presently, 75B-16 is pumping up to 1250 gpm (pump limited) of 308°F water with less than one psi of pressure drawdown.

Geochemistry

The San Emidio geothermal water produced by 75B-16 is a sodium chloride type water with a total dissolved solids concentration of 4150 mg/l. The ion ratios are similar to other northern Nevada geothermal waters. This water is environmentally and operationally benign, and should not present any problems except for calcite precipitation if allowed to flash. The quartz geothermometer predicts a reservoir temperature of 309°F, which is essentially identical to the produced water temperature of 308°F. The cation geothermometer suggests a higher resource temperature of 379°F. Such disagreement is not uncommon with chemical geothermometers. Thus, the possibility of higher temperature resource at much greater depth exists. However, the coincidence of the quartz thermometer and the measured production temperature suggest that about 310°F is probably the correct resource maximum temperature.

Geologic/Hydrothermal Model

Subsurface temperature data and results of two geophysical surveys have been combined with the above well drilling information to yield a conceptual geologic/hydrothermal model of the San Emidio geothermal system, as described below.

Utilizing the available temperature logs from the wells and temperature gradient holes, a temperature contour map has been constructed (Figure 6). The temperatures at 3850 ft above sea level (approximately 200 ft below ground) range from 75°F to 276°F. The thermal anomaly trends north-northwest north of the dehydration plant, but it bends southwest south of the plant. The temperatures at 3650 ft above sea level (approximately 400 ft below ground) also show the same thermal anomaly trends. However, most wells within the thermal anomaly report lower temperatures at this depth (3650 ft), confirming that most San Emidio wells have penetrated a shallow geothermal outflow zone coincident with silicified valley fill sands.

The change in the shallow thermal anomaly trend south of the dehydration plant indicates that the San Emidio geothermal system is structurally controlled. In the Basin and Range province, the structures that control geothermal systems are usually normal range-front faults. The bend in the thermal anomaly suggests that two different faults (i.e., the South Range-Front and Three Mile Canyon) are conduits for the thermal fluids at San Emidio. At the near surface, both faults feed the silicified outflow zone. The highest temperatures in Figure 6 also occur near the intersection of these faults, suggesting increased fracturing and upwelling at the faults' intersection.

The two early wells in the EFP area that showed a continuing temperature increase with depth were Phillips' ST-1 and EFP's 65B-16. The temperature profiles from these wells are conductive until maximum temperatures of almost 300°F are encountered. This suggests that these two wells are sited near the upwelling thermal zone which feeds the outflow zone.

The deepening of Well 75-16 and the completion of Well 75B-16 both encountered a ±308°F resource (Figure 7). The temperature profiles indicate a shallow ±230°F out-flow zone was also penetrated from ±100 to ±400 ft. Below this zone, the temperature are conductive until the higher temperature reservoir is intersected. This deeper reservoir appears to be isothermal, indicating active fluid migration up the South Range-Front fault zone.

Cross section A-A' (Figures 3 and 8) through the EFP well field illustrates the geologic structures that Mesquite believes control the geothermal system. The section trends northwest through the dehydration plant and includes EFP Wells 65B-16, 65C-16, 75-16, Phillips Well ST-1, and Chevron holes 54-79 and 44-78. Three wells, Kosmos 1-8, Kosmos 1-9, and 28-9 have been projected approximately 2300 ft southward into the section. This cross section shows that Kosmos 1-8 did not penetrate basement rock at a total depth of 4013 ft. Kosmos 1-9 encountered basement at ±3700 ft true vertical depth. Phillips' ST-1 is reported to have drilled into basement at 1590 ft. Chevron temperature gradient hole 54-79 encountered basement approximately 500 ft higher than ST-1. Thus, significant offset has occurred in the Triassic/Jurassic basement rock, with geologic units being down-dropped toward the valley in separate blocks along normal faults.

Thermal contours on the cross section (Figure 8) summarize Mesquite's interpretation of the hydrothermal system at San Emidio. The thermal contours indicate 300°F+ fluid rises along the South Range-Front fault until it encounters the impermeable volcanic lavas (Tvu). Lack of permeability in these lavas forces the hot water to flow laterally and up-dip in the underlying permeable volcanic clastics (Tsv) until it encounters permeable Tertiary sands at the Three Mile Canyon fault contact. In these highly permeable sands, the thermal water flows west as well as continuing to rise upwards, mixing with cold groundwater until it encounters the silica caprock. This impermeable horizon forces the thermal waters outward in a thermal outflow zone of silicified sands in the Tertiary valley fill.

Until Well 75-16 was deepened, the only significant permeability found by any of the wells at San Emidio was in the shallow outflow zone. All of the Empire power plant wells, both injectors and producers, are completed in this zone. Similarly, the original dehydration plant supply well, 65C-16, and the single injector, 68-16, are completed in this zone. Wells 75-16 and 75B-16 which both yield 308°F water were designed and completed to intersect the geothermal resource before it reached the shallow outflow zone. Well 75-16 intersected and penetrated the upwelling zone associated with the South Range-Front fault. Well 75B-16 encountered a highly productive aquifer in the cross-flow horizon contained in the volcanic clastics and did not quite penetrate as deep as the fault.

References

Moore, Joseph N., 1979. Geology Map of the San Emidio Geothermal Area: DOE/ET/28392-33, 8 pp.

Figure 1

GEOTHERMAL LEASEHOLDS
SAN EMIDIO DESERT
WASHOE COUNTY, NV

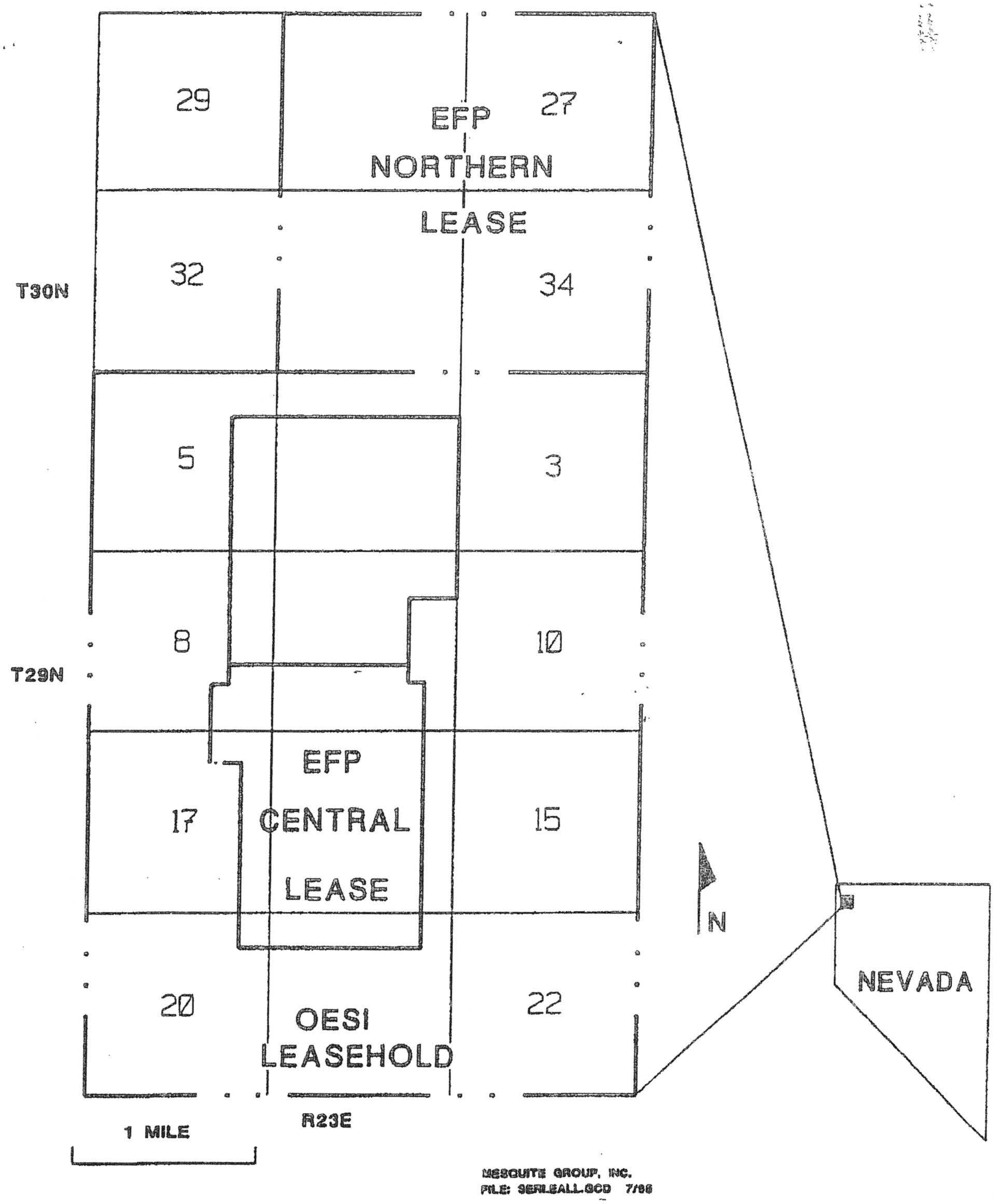
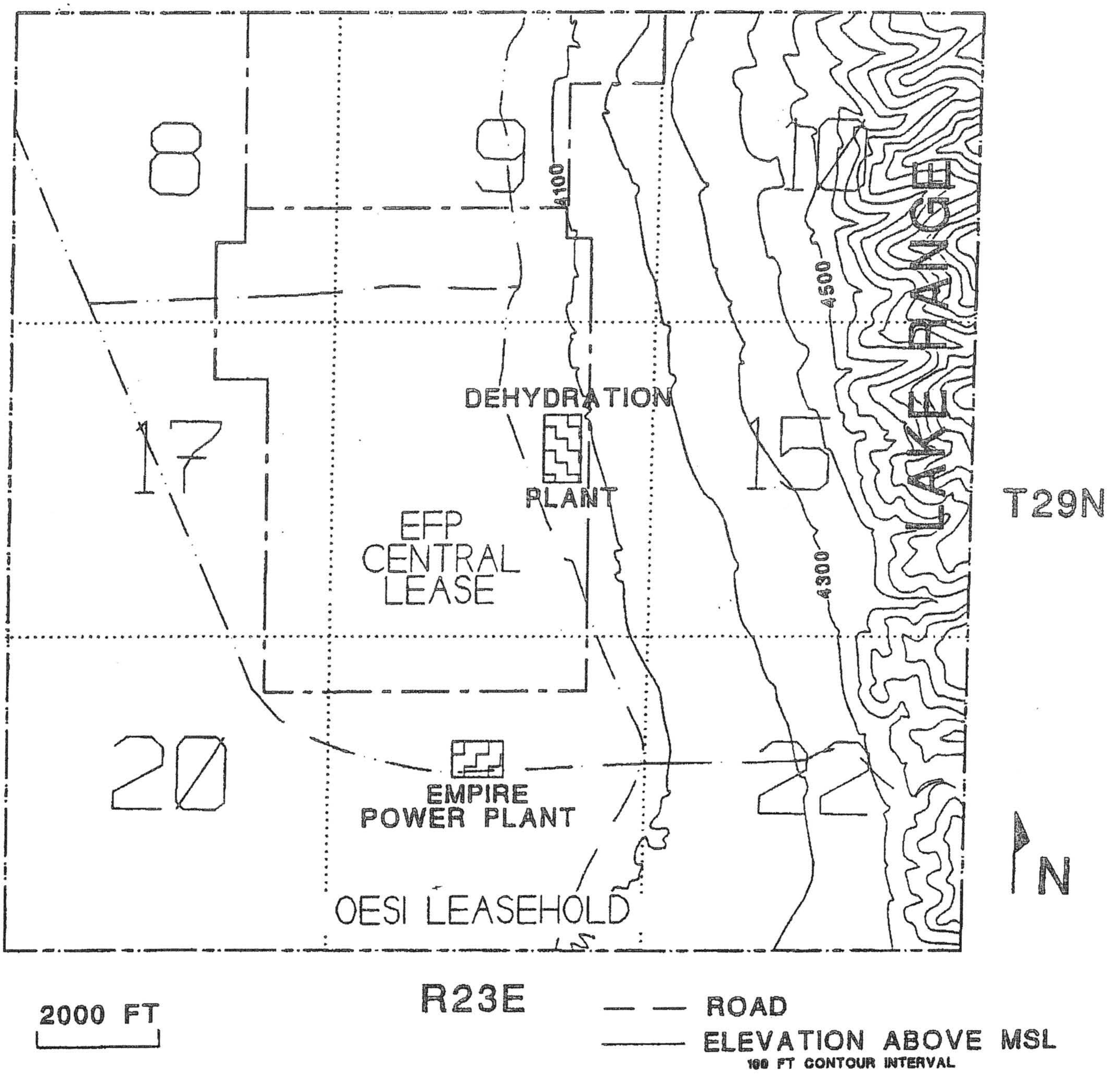


Figure 2

SAN EMIDIO CENTRAL AREA

SAN EMIDIO DESERT

WASHOE COUNTY, NV



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FILE: SERTOP1.GCD

FIGURE 3

GEOLOGIC MAP

SAN EMIDIO DESERT
WASHOE COUNTY, NV

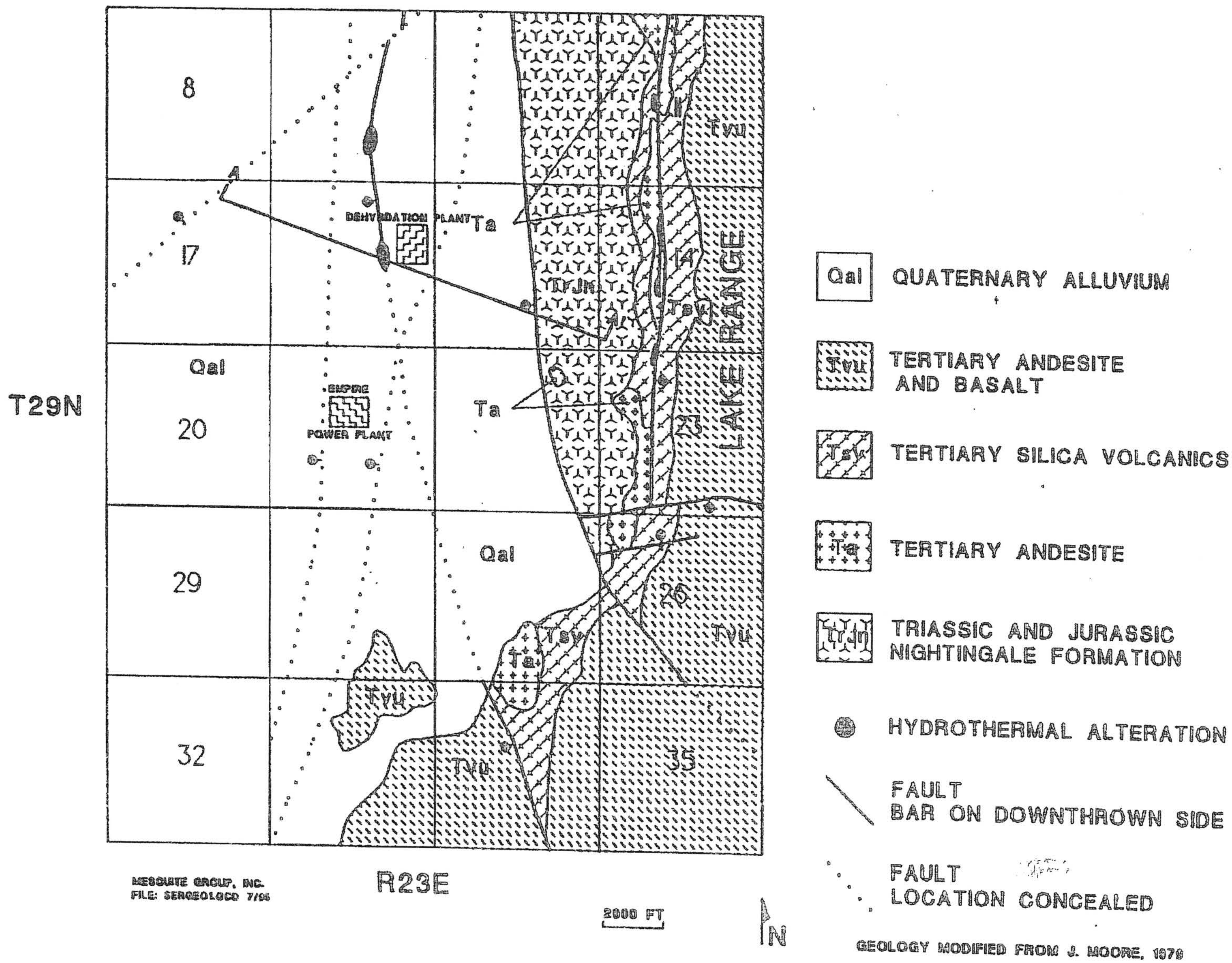
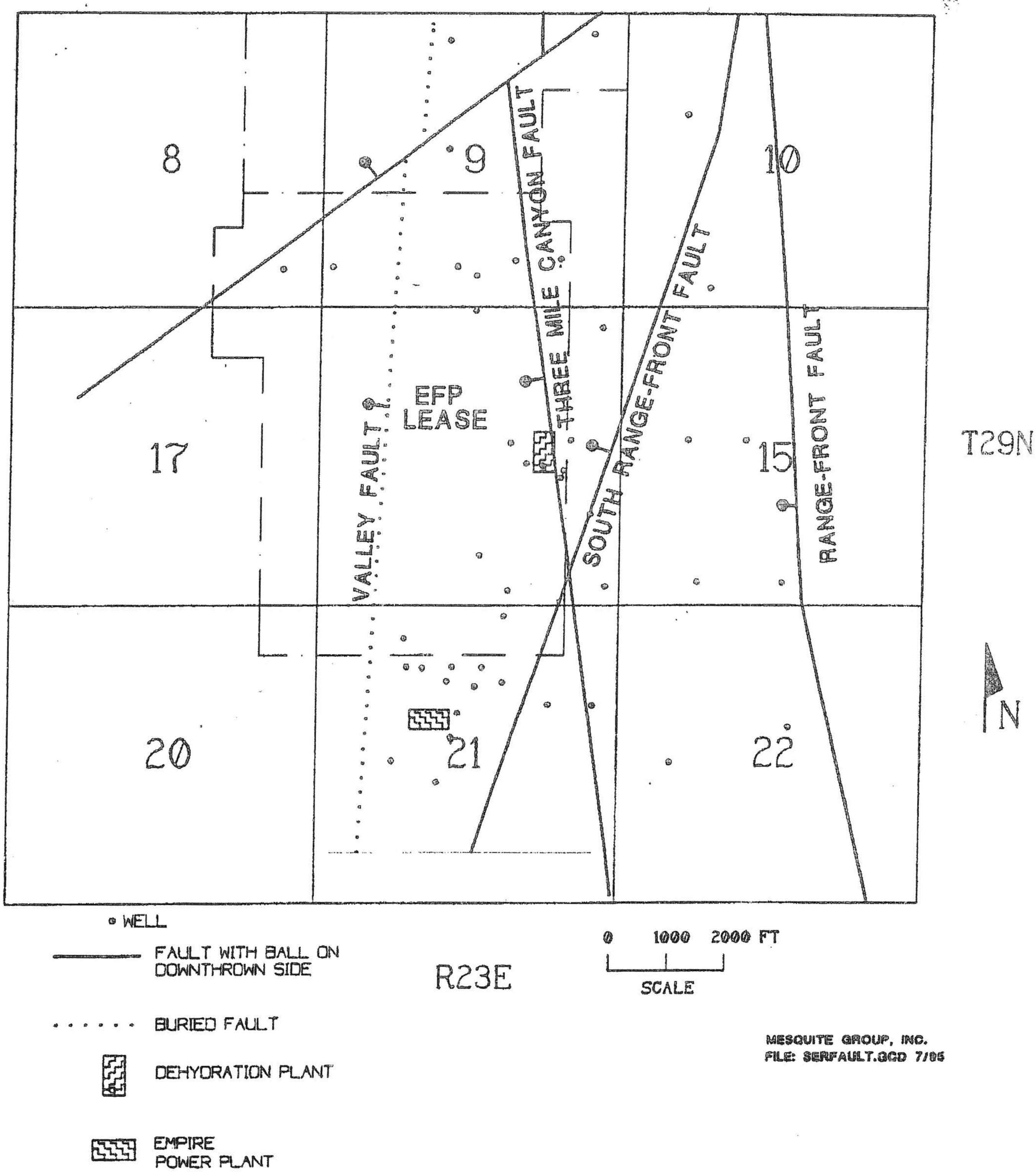


Figure 4

STRUCTURE MAP
SAN EMIDIO GEOTHERMAL SYSTEM
WASHOE COUNTY, NV



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FILE: SERFAULT.GCD 7/95

Figure 5

GEOTHERMAL WELL LOCATIONS
SAN EMIDIO GEOTHERMAL SYSTEM
WASHOE COUNTY, NV

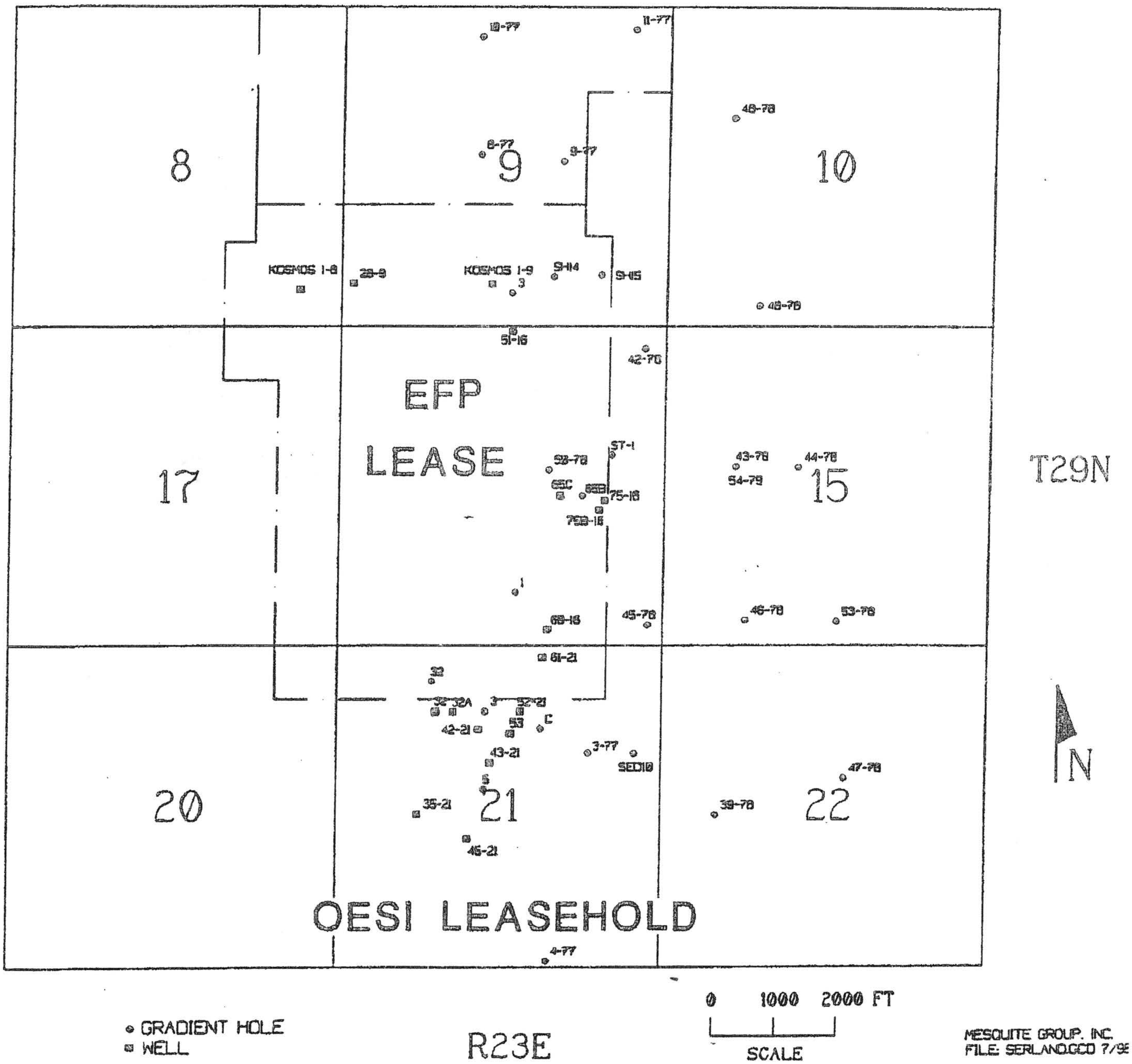
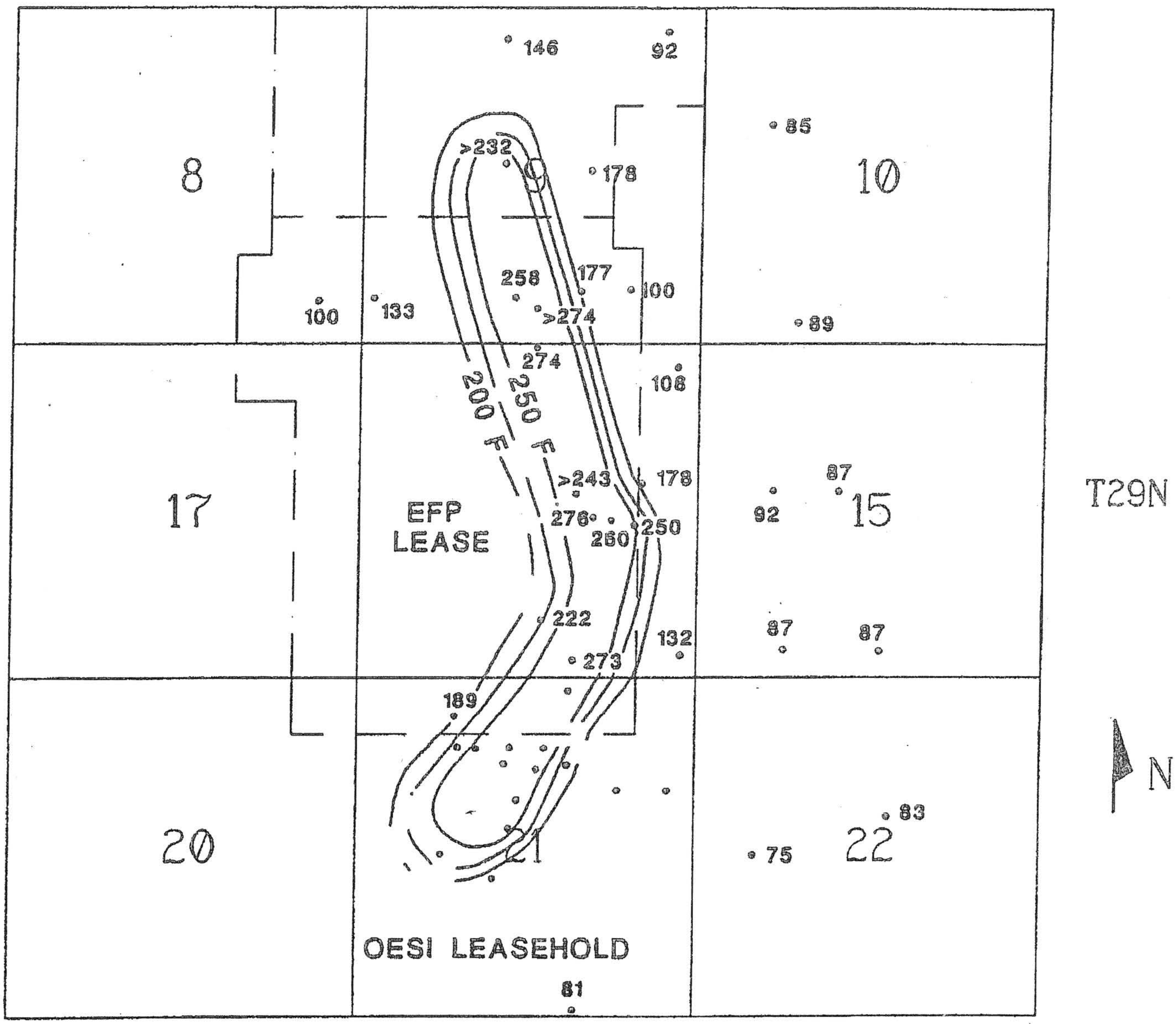


Figure 6

TEMPERATURE AT 3850 FT ABOVE SEA LEVEL
SAN EMIDIO GEOTHERMAL SYSTEM
WASHOE COUNTY, NV



• TEMPERATURE (F) AT 3850 FT ABOVE SEA LEVEL

R23E

0 1000 2000 FT

SCALE

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Figure 7
EFP Well Temperature Profiles

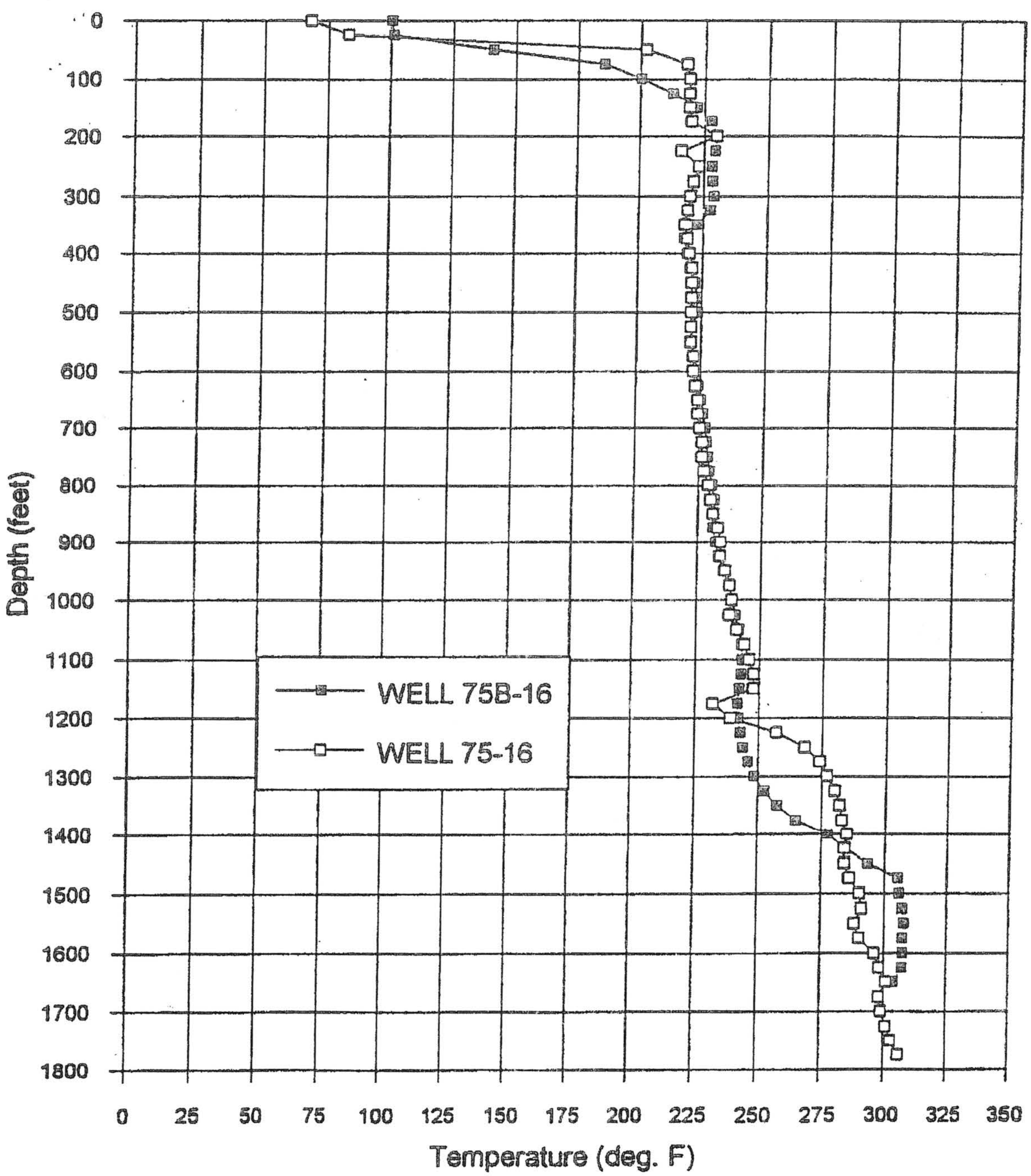

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Figure 8

THERMAL CROSS SECTION
SAN EMIDIO GEOTHERMAL SYSTEM
WASHOE COUNTY, NV