

**PRELIMINARY GEOTHERMAL
ASSESSMENT OF THE
YUMA AREA, ARIZONA**

by
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with a section on the hydrology by
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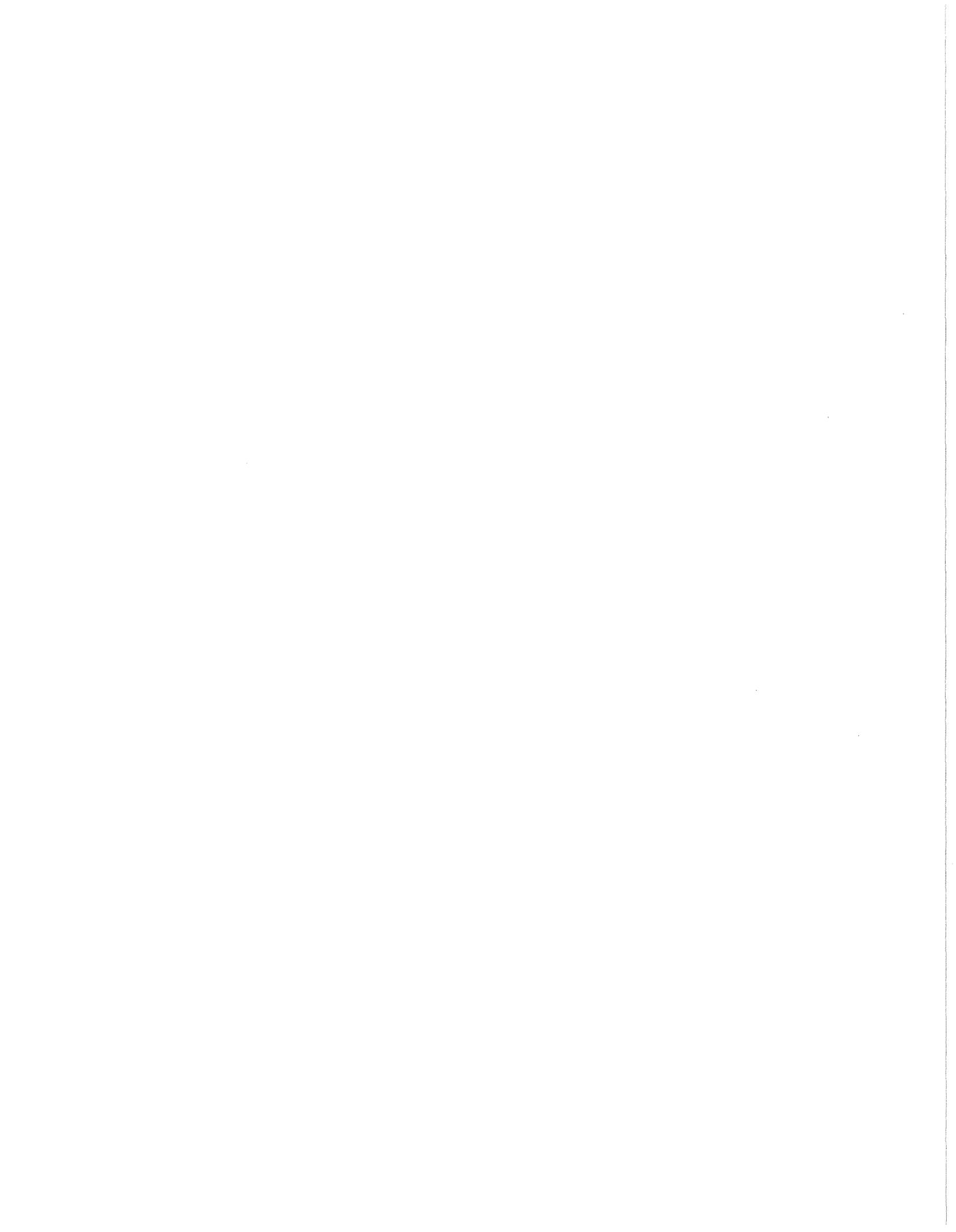
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I. INTRODUCTORY MATERIAL

A. Location and Access

The Yuma study area is located in the extreme southwest corner of Arizona (Figure I-1). The city of Yuma has a long and colorful history because it was a stopping-off point on the southern route to California. Interstate Highway 80 and the Southern Pacific Railroad use the Yuma crossing to connect both traffic and commerce from southern California with that which comes from Phoenix and Tucson.

Yuma is part of a very arid region in the southwest; yet farming is the single most important industry. This is due to the rich soil found in the Gila and Colorado River flood plains and the extensive use of irrigation waters.

B. Local Support

Contacts with local farmers, civic leaders and government representatives were made during the field season. Access to information, both public and private, was obtained. Special thanks should be extended to the U.S. Geological Survey, Yuma, Arizona, and Menlo Park, California; Bureau of Reclamation, Yuma, Arizona, and Boulder City, Nevada; and Woodward-McNeill & Associates, Los Angeles, California.

II. SUMMARY AND RECOMMENDATIONS

A. Development of Potential Resources

The water balance for the Yuma area was determined by estimating the water in storage and the potential for recharge. Annual precipitation is approximately 2.8 inches (7.1 cm) per year.

Yuma has been major agricultural area for over 30 years. As a result of the heavy pumpage of ground water, the upper 300 m of storage has been eliminated from the total storage estimates. Total water in storage below the 300 m horizon is estimated to be 359,700 hm³ (291.6x10⁶ acre-feet); the recoverable water is estimated at 101,500 hm³ (82.3x10⁶ acre-feet).

Irrigation waters generally contain 1,000 to 2,000 mg/l total dissolved solids. Long-term irrigation has caused a uniformity of water chemistry that tends to render the chemical geothermometers of little value.

There are at least 35 wells with recorded discharge temperatures in excess of 30°C, even with extensive infiltration of irrigation waters. Temperature gradient studies are also hampered by the mixing of irrigation water with ground water. Some of the interference can be minimized by restricting the studies to discreet, 50-m thick subsurface horizons. Even then the influence of irrigation water can be seen, but anomalous zones can be more readily recognized.

Gravity highs in the Fortuna Basin, magnetic highs, and fault trends coincide with the above-normal temperature gradients, thus providing specific targets for more definitive exploration.

In addition, a short-duration micro-earthquake survey in the Yuma area recorded a few local events (Woodward-McNeill & Associates, 1974). The authors concluded that the greater number of events may be associated with the Algodones fault, the trace of which contains the more important anomalies of this survey. Micro-earthquake activity is also prominent over the Mesa anomaly, Imperial Valley, California.

The Yuma study area falls within the Mojave-Sonora Megashear (Anderson and Silver, 1979). The youngest rocks presently known to be displaced along the megashear are Jurassic in age. Formation of basin and ranges in this portion of the southwest was probably started after mid-Tertiary time. These basins and ranges are superimposed over the 150+ km wide megashear with California and Arizona basins and ranges paralleling the trend of the earlier structure.

B. Recommendations for future work

The following work is recommended because it will substantially aid in confirming the proposed Algodones geothermal anomaly. (1) Reinterpret the available electrical studies. (2) Establish a microseismic array in the area of the established temperature gradient anomaly. (3) Drill heat-flow holes over the same area. (All production holes in the East Mesa anomaly fall within the 5-HFU heat-flow contour. A similar situation may exist over the proposed Algodones anomaly).

III. LAND STATUS

The Yuma area is situated along the Arizona side of the Colorado River in the southwestern corner of the state. As a result of its geographic location and history, much of the land near the river is in private ownership (Map III-1). The U.S. Army holds a large tract of land to the east and away from the river.

Table III-1 shows the general land status of the area by major controlling group.

Table III-1 Land Status of the Yuma,
Arizona Study Area.

| <u>Owner or Trust Group</u> | <u>Area (mi²)</u> | <u>Area (km²)</u> |
|-----------------------------|------------------------------|------------------------------|
| Private Ownership | 283.75 | 734.9 |
| State of Arizona Trust | 44.0 | 114.0 |
| BLM Resource Lands | 25.5 | 65.3 |
| Military Reservation | 370.5 | 959.6 |
| Indian Reservations | <u>1.75</u> | <u>4.5</u> |
| TOTAL | 725.5 | 1878.3 |

Approximately 51 percent of the land is held by the military, 39 percent is privately owned and the State of Arizona holds 6 percent in Trust. The Bureau of Land Management has jurisdiction over 3.5 percent of the land. Indian Reservations constitute well less than 1 percent of the total land under consideration.

IV. RESOURCE EVALUATION

A. Introduction

The principal objective of this report is to assess the geothermal resource potential of the Yuma area, southern Yuma County, Arizona, and to recommend a plan for more definitive work, if it seems warranted. The initial evaluation comprises a literature search and an evaluation of the available data as they pertain to geothermal exploration, followed by first-hand data acquisition.

Yuma was selected for preliminary assessment because of the favorable geologic setting. The Salton Trough, a large sediment-filled structural depression, extends northwest from the Gulf of California in Mexico, through the southwest corner of Arizona, and into California. Proven high-temperature geothermal reservoirs exist in Mexico and California along the trace of the Salton Trough. The extension of the trough through Arizona suggests the possibility of a geothermal target in the Yuma area.

B. Previous Work

Early reports on the Yuma area are limited to a soil survey by Holmes (1903) and brief geologic descriptions by Wilson (1931, 1933). Ground water conditions were described by Johnson (1954) and by Brown, Harshbarger and Thomas (1956). During the 1960's the U.S. Geological Survey conducted extensive geologic, geohydrologic and geophysical investigations in the Yuma area and published the results in a series of Professional Papers. The most useful of the Professional Papers to this geothermal

assessment are those by Mattick, Olmsted and Zohdy (1973), and Olmsted, Loeltz and Ireelan (1973). Recent work includes ground water maps by Wilkins (1978), a ground water status report by the Bureau of Reclamation (1978) and an aeromagnetic interpretation of the Yuma area by Aiken, Wettereuer and de la Fuente (in press). Keith (1978) indexed mining properties in Yuma County. Arizona maps depicting Landsat and Skylab lineaments (Lepley, 1978, 1979), residual Bouguer gravity (Aiken, 1975), and residual aeromagnetism (Sauck and Sumner, 1970) provide regional geophysics for the study area. Unpublished work was found in Ph.D. dissertations and M.S. thesis from the University of Arizona, Tucson; a power plant siting report by Woodward-McNeill & Associates (1974); and field notes from Swanberg (c.a. 1973).

C. Geology

The area of investigation lies within the Sonoran Desert and Salton Trough subprovinces of the Basin and Range physiographic province. The region is bounded on the northeast by the northwest-trending Tinajas Atlas, Gila and Laguna Mountains. The west and southwest sides of the study area are defined by the Colorado River and the international boundary with Mexico (Figure I-1).

The Yuma area is geologically diverse. It is made up of low, rugged, northwest-trending mountains separated by sediment-filled basins. The extreme topographic relief between the nearly-buried bedrock and the basin bottom is the result of the continual deepening of the Salton trough. Thus the Salton trough tectonics play a more important role in the Yuma area than do the Basin and Range tectonics (Eberley and Stanley, 1978).

Map IV-1 has the salient geologic features of the area.

1. Surrounding Mountain Blocks. The principal mountains in and around the study area are the Tinajas Atlas, Gila, Butler and Laguna Mountains in Arizona and the Cargo Muchaco and Chocolate Mountains in California. All but the Laguna range in Arizona are composed of granite, gneiss and schist (Wilson, Moore and Cooper, 1969). The Laguna Mountains are principally non-marine sedimentary rocks of Tertiary age (Olmsted and others, 1973). In California, the Cargo Muchacho Mountains are composed of pre-Tertiary crystalline rock; the Chocolate Mountains, of Tertiary volcanics: basaltic andesite to basalt in the southwest and more silicic pyroclastic rocks further east (Olmsted and others, 1973).

2. Basin Sediments. A geomorphic land form classification for the Yuma area was devised by Olmsted and others (1973). Table IV-1 is a summary, in decreasing age, of the subareas present in the study area. The sedimentary units started filling the Fortuna and San Luis basins in early Tertiary time. Figure IV-1 is a generalized stratigraphic column for these basins.

The first four units have been labeled the "poorly water-bearing rocks of Tertiary age" by Olmsted and others (1973). They considered these units to be the lower part of the groundwater reservoir since they contain either scant quantities of water or water that is highly mineralized. There are two exceptions, both in the northern part of the area, where good quality water is found in quantity.

The most important of the lowest four units is the Bouse Formation. There is only one surface exposure of the Bouse Formation in the Yuma area, about 3.2 km (2 miles) southeast

Table IV-1 Geomorphic Subareas of the Yuma Area.
Arizona (from Olmsted and others, 1973).

1. Mountains and hills
 - a. Tinajas Atlas Mountains
 - b. Gila Mountains
 - c. Laguna Mountains
 - d. Butler Mountains
 - e. Vopoki Ridge
 - f. Yuma Hills
 - g. Boundary Hills
2. Dissected old river deposits - "Upper Mesa",
3. Dissected piedomont slopes - Gila Mesa
4. Undissected piedomont slopes
 - a. Davis Plair
 - b. Fortuna Plain
5. River terraces and mesas - Yuma Mesa
6. Sand dunes - Fortuna Dunes
7. River valleys
 - a. South Gila Valley
 - b. North Gila Valley
 - c. Bard Valley
 - d. Yuma Valley

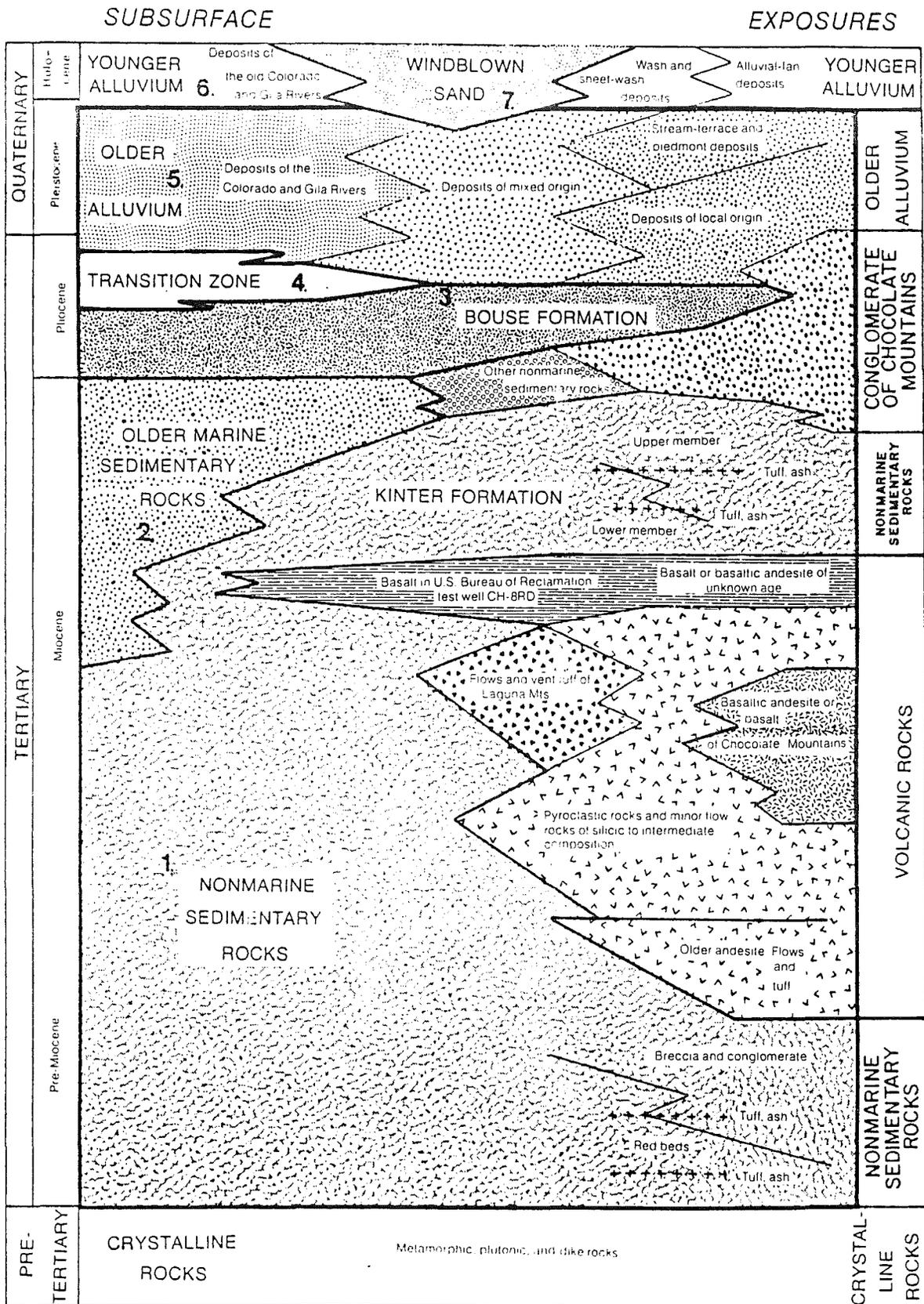


FIGURE IV-1. Stratigraphic column for the Yuma Study Area, Arizona (After Olmsted and others, 1973).

of Imperial Dam. The Bouse is important because it appears to be the shallowest, reliable wide-spread stratigraphic marker in the subsurface and it was deposited prior to the major strike-slip movement along the San Andreas fault system. With the exception of an area around and immediately south of the town of Yuma, the Bouse Formation has been found everywhere in the subsurface of the basins. The one exception is due to a pinch out against a buried basement high (Figure IV-2).

The principal units containing agricultural and domestic ground waters are the older alluvium, younger alluvium and wind-blown sand. They range in age from Pliocene to Holocene and all were deposited after initiation of fault movement along the San Andreas system.

D. Geochemistry

Yuma is a long-standing agricultural community. A large volume of water from the Colorado River, along with water from the subsurface aquifers, is used annually to irrigate crops. The localized ground-water recharge from these continuous irrigation practices has created a large ground-water mound. Numerous drainage wells have been installed to reduce the size of this artificial ground-water high.

The long-term mixing of river water with ground water has created an artificial water chemistry. The homogeneity of values in the irrigated areas can be illustrated by looking at silica values, the Ca/Mg ratios and the total dissolved solids (TDS).

Silica concentrations in 153 samples have a mean value of 27.9 mg/l (milligrams per liter). Standard deviation for the sample suite is only ± 0.59 . The total dissolved solids are

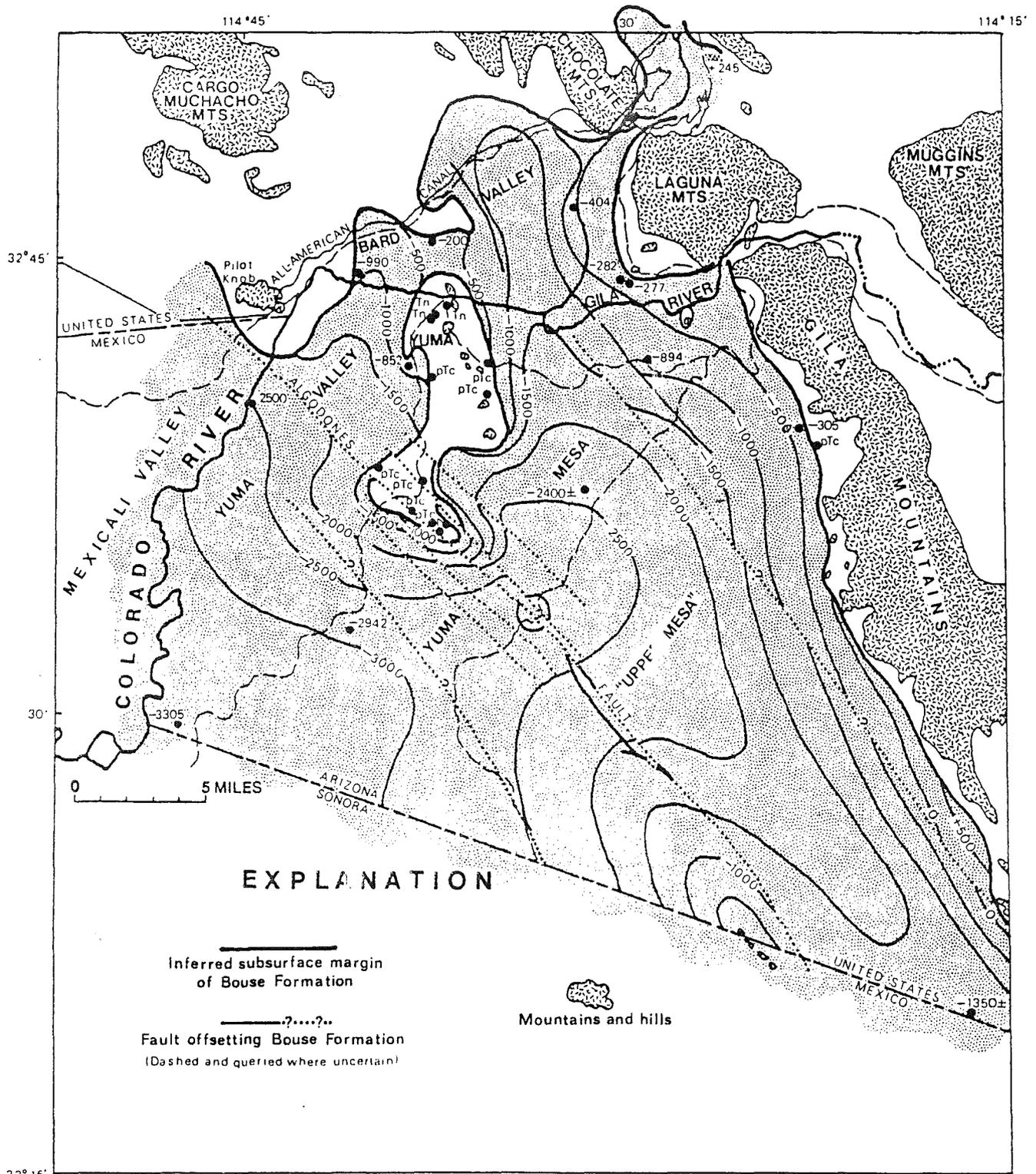


FIGURE IV-2
Location of the Bouse Formation in subsurface

moderately high and again, relatively uniform. They generally vary between 600 and 2,500 mg/l with about 65 percent in the 1,000-2,000 mg/l range. A few samples were reported to contain as much as 8,000 mg/l TDS.

The obvious problems created by irrigation water and ground water in the Yuma area preclude the carte blanche use of the standard chemical geothermometers.

E. Geophysics

Regional Bouguer gravity (Aiken, 1975), aeromagnetic (Sauck and Sumner, 1970), and Landsat and Skylab lineament (Lepley, 1978, 1979) maps have been published for the state of Arizona. Geophysical studies of the area were also conducted by Mattick and other (1973), Sumner (1972), de la Fuente (1973), Aiken, Wetteruer and de la Fuente (in press) and Woodward-McNeill & Associates (1974).

Residual aeromagnetics (Map IV-2) and Bouguer gravity (Map IV-3) reveal the presence of deep, sediment-filled, fault-bounded basins; sediment-buried mountain blocks; and structurally high bedrock ridges. Mattick and others (1973) estimated the maximum thickness of basin material as 5000 m, while Woodward-McNeill & Associates (1974) suggested a similar thickness of more than 4,500 m.

1. Magnetics. The Residual Aeromagnetic Map (Figure IV-2) clearly shows a basement high just south of the town of Yuma and an extension of that high southeastward into Mexico. This high generally follows the trace of the Algodones fault.

2. Gravity. A prominent northwest trend in the isogal contours can be seen on the Bouguer Gravity Map (Map IV-3).

The northwest trends of the Gila Mountains, San Luis and Fortuna basins, and the Algodones Fault parallel the gravity trend. In general, the bedrock outcrops and mountains are associated with the gravity highs, while the gravity minimums are found over the deepest portions of the basins. Maximum depth to basement in the Fortuna Basin is in excess of 4,500 m while in the San Luis Basin it is over 3,600 m.

The two basins are separated by a basement high, as illustrated by the positive anomalies that extend southward from the city of Yuma to the Algodones Fault, then southeastward to the Boundary hills that crop out along the international border.

Basement modeling of gravity data by Woodward-McNeill & Associates (1974) indicates that the Fortuna Basin is bounded by faults. The Algodones Fault passes to the east of the Boundary hills, but there are parallel fault segments also to the west of the hills. Subparallel faults are found in the San Luis Basin, but their delineation was developed from other geophysical methods.

3. Electrical Geophysics. Electric log data and electrical soundings indicate that the Bouse Formation has an average resistivity of 3 ohm-m (ohm-meters) and the older marine sedimentary rocks have an average resistivity of 8 ohm-m. In general, Mattick and others (1973) interpreted the electrical data in terms of formation coarseness, degree of cementation, and water salinity. Only brief reference was made to the effects of warm water on formation conductivity. Reinterpretation of electrical data in light of its usefulness as a geothermal exploration tool might enhance the possibility of locating a hydrothermal reservoir in the Yuma area.

4. Seismic Refraction and Reflection. Refractive seismic surveys were conducted by Woodward-McNeill & Associates (1974) as part of the siting process for a nuclear power plant. They ran over 22 km (14 miles) of refraction profiles across the San Luis and Fortuna basins. The profiles were generally east-west and all work was south of the town of Yuma. Depth of penetration was approximately 90 m (300 ft.). It was hoped that such an array would accurately measure the water-table interface 25 to 30 m below the surface, but the lack of velocity contrast prevented this. The profiles picked up velocity variation at depths of 75 m (250 ft,) when the geophone receivers were widely separated. Shallow velocity variations were picked up with close spacing of the receivers. All anomalies were interpreted as being the result of erosion, deposition, or faulting.

Woodward-McNeill & Associates (1974) suggested that Mattick and others (1973) either saw a less-complex situation or oversimplified their interpretation. They base their suggestion on the observations of, "Highly varied materials with seismic velocities ranging from very low (820 to 1250 ft. per sec.) near surface to localized high-velocity zones (7500 to 9530 ft. per sec.) at greater depths".

Six seismic reflection profiles across the area were constructed by the U.S. Geological Survey and the Exxon Corporation. Woodward-McNeill & Associates (1974) reinterpreted the data, and found that they clearly picked up the upper Bouse Formation contact at 900 to 1,200 m (3,000 to 4,000 ft.) depth. Quality of the shallow data was poor to fair. Very little data could be used for marking the basement contact so no verification of the gravity-derived basement was attempted.

A number of faults were postulated through offsets of the Bouse Formation 900 to 1,200 m below the surface. A few of these offsets correlate with fault traces interpreted from the shallower refraction surveys. Map IV-1 shows the traces and apparent motions of the major subsurface faults.

5. Micro-earthquakes. As part of the nuclear power plant siting process, micro-earthquakes were recorded for 30 days at two locations south of the town of Yuma (Woodward-McNeill & Associates, 1974). One of the locations was near the Yuma Bombing Range and, as a result of aircraft noise, exploding bombs, and road traffic, the quality of records was poor. At the other site, 86 events were recorded, including a 2.5 magnitude event whose origin was just east of Riverside, California.

Even though the readings near the Yuma Bombing Range were poor, there were nine events that could not be attributed to an outside source. The site nearest the Algodones Fault had the greatest number of recorded events. The obvious conclusion is that if minor motion originates along the Algodones Fault, micro-earthquakes would more likely be observed at this site than at a site away from the fault.

Additional stations would have to be set up to verify motion along the fault systems. It should be noted that swarms of micro-earthquake epicenters fall within the 5 HFU heat-flow contour that outlines the East Mesa, California geothermal anomaly (Swanberg, 1975).

6. Water Temperatures and Gradients. Most of the wells in the study area are used for irrigation or ground-water mound drainage. As a result, most of the water temperatures come from the principal water-bearing unit, the "coarse-gravel zone" of

Olmsted and others (1973), unit 5 in Figure IV-1. These authors inventoried over 450 wells in the area, most less than 100 m depth. Table IV-2 lists 35 of these wells with recorded discharge temperatures of 30°C or greater. No measured wells have a discharge temperature in excess of 40°C. Figure IV-3 is the isothermal map of Olmsted and others (1973) for waters developed in the coarse-gravel zone. They suggested that most of the "warm anomalies" are related to faults or fault zones. Such an interpretation is reasonable because warm water can rise along planar fault zones due to (1) the difference in piezometric head between recharge and discharge zones and (2) the difference in density between warm and cool waters. Olmsted and others (1973) also suggested that some anomalies may reflect hot zones in pre-Tertiary crystalline rocks and some may be due to discreet alluvium zones or horizons that are less transmissive than the alluvium in surrounding areas.

Table IV-2 Location, temperature, depth, and gradient of wells in the Yuma area with discharge temperatures of 30°C or greater.

| <u>Location</u> | <u>Temperature (°C)</u> | <u>Depth (m)</u> | <u>Gradient (°C/km)*</u> |
|------------------|-------------------------|------------------|--------------------------|
| (C-6-20) 32adb | 31.1 | 152.4 (a) | 61.7 |
| (C-6-21) 31dad | 31.1 | 39.6 (b) | 237.2 |
| (C-6-21) 34dba | 33.3 | 82.6 (b) | 140.4 |
| (C-8-23) 32cbc | 34.4 | 7.0 (a) | >1000. |
| (C-9-21) 2bca | 36.4 | 90.8 (b) | 161.8 |
| (C-9-21) 12dbc | 31.9 | 103.5 (b) | 98.6 |
| (C-9-21) 13ccb | 34.5 | 101.6 (b) | 125.9 |
| (C-9-21) 14acc | 31.4 | 92.9 (b) | 104.4 |
| (C-9-21) 14bac | 33.9 | 82.6 (b) | 147.7 |
| (C-9-21) 16add | 30.0 | 91.1 (b) | 91.1 |
| (C-9-21) 21dcc | 30.3 | 92.4 (a) | 93.1 |
| (C-9-21) 23abd | 32.5 | 83.5 (b) | 129.4 |
| (C-9-23) 5aab | 30.6 | 70.1 (a) | 127.0 |
| (C-10-22) 18cdc | 30.6 | 31.7 (a) | 280.8 |
| (C-10-23) 12aba1 | 32.8 | 209.1 (a,b) | 53.1 |
| (C-10-23) 13dcc1 | 30.6 | 62.1 (b) | 143.3 |
| (C-10-23) 14aaa | 32.3 | 166.4 (a,b) | 63.7 |
| (C-10-23) 28cad | 30.6 | 48.2 (b) | 184.8 |
| (C-10-23) 28ccd | 34.2 | 70.1 (b) | 178.3 |
| (C-10-23) 28cdd | 31.0 | 59.9 (b) | 160.6 |
| (C-10-23) 29ddc | 30.3 | 75.6 (b) | 113.8 |
| (C-10-23) 36ddd | 33.9 | 64.3 (b) | 189.7 |
| (C-11-21) 4ddc | 33.3 | 100.1 (b) | 115.9 |
| (C-11-22) 13acb | 30.0 | 72.5 (a,b) | 114.4 |

Table IV-2 Cont.

| <u>Location</u> | <u>Temperature (°C)</u> | <u>Depth (m)</u> | <u>Gradient (°C/km)*</u> |
|-----------------|-------------------------|------------------|--------------------------|
| (C-11-22) 23dab | 30.6 | 100.0 (a,b) | 89.0 |
| (C-11-22) 24bab | 30.0 | 82.3 (a,b) | 100.9 |
| (C-11-23) 9bbb | 33.6 | 36.6 (a) | 325.4 |
| (C-11-23) 16ccc | 30.6 | 36.6 (a) | 243.3 |
| (C-11-23) 24ddd | 31.2 | 42.4 (a,b) | 224.2 |
| (C-11-23) 34bbc | 31.6 | 63.6 (b) | 155.8 |
| (C-12-21) 14dab | 31.5 | 112.5 (a,b) | 87.1 |
| (C-12-21) 17cbc | 35.4 | 97.5 (a,b) | 140.5 |
| (C-12-21) 25add | 32.5 | 125.0 (a,b) | 86.4 |
| (C-12-22) 9bab | 35.6 | 105.5 (b) | 131.8 |
| (C-13-20) 2abd1 | 37.6 | 366.0 (a) | 43.5 |

a. Depth of completed well.

b. Maximum depth of well perforation or depth of actual temperature measurement.

* Gradient calculated using mean annual temperature of 21.7°C.

GEOHYDROLOGY OF THE YUMA AREA, ARIZONA AND CALIFORNIA

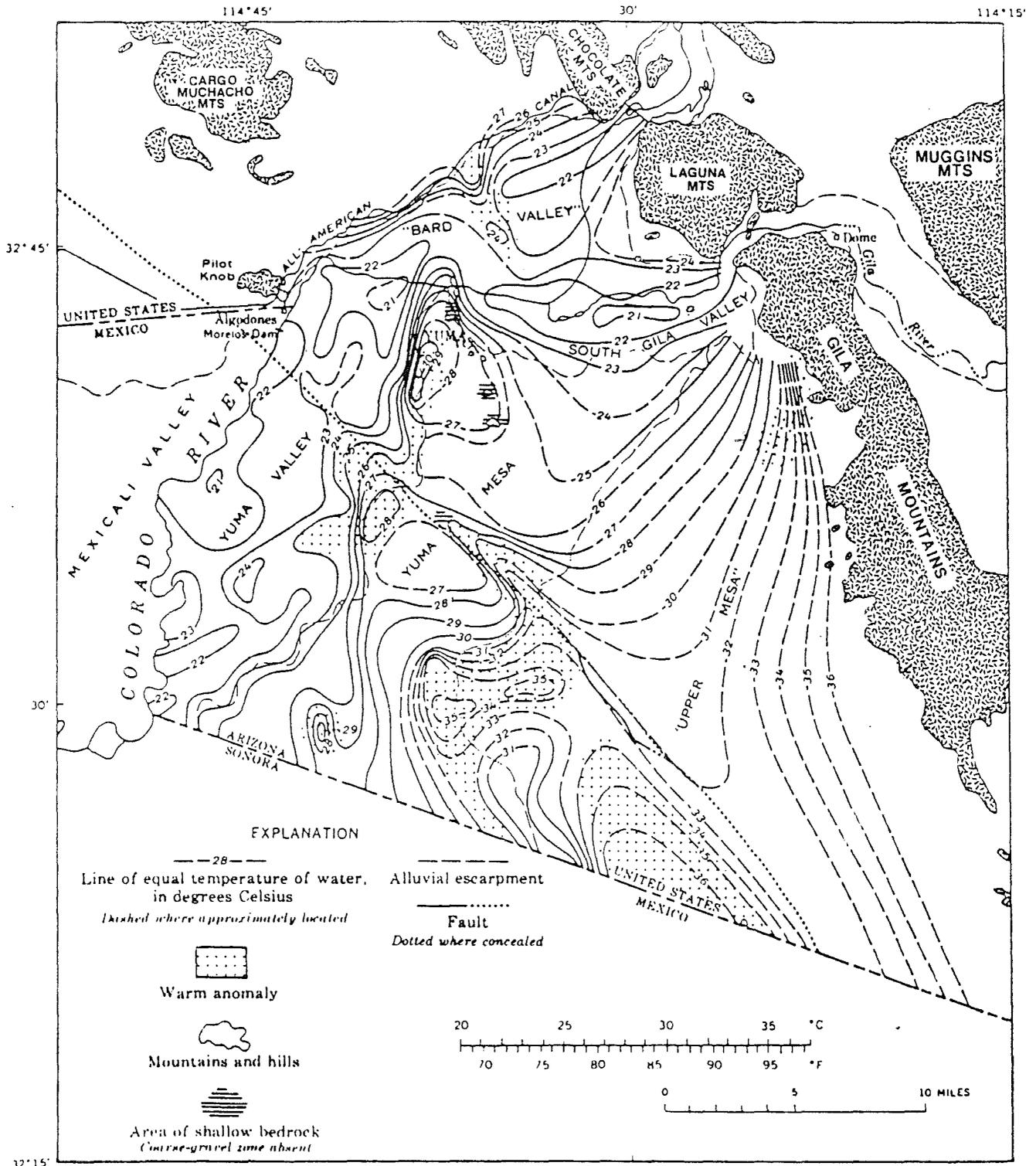


FIGURE IV-3: Temperature of ground water in coarse-gravel zone below the water table, 1965-68.

from Olvestead and others 1973

Temperature gradients were calculated by subtracting the mean annual air temperature from the discharge temperature, dividing by the reported well depth, and extrapolating the result to one km depth. The metric system was used throughout and the results are reported in °C/km. Although the mean annual air temperature varies by as much as 2°C across the study area, this correction was neglected. However, individual recording data for each well is listed in Olmsted and others (1973) should further refinement of the data be required.

The gradients were plotted and contoured on three separate maps: wells less than 50 m deep (Map IV-4), wells between 50 and 100 m deep (Map IV-5), and wells greater than 100 m deep (Map IV-6). Dividing the gradients into discreet horizons (0-50 m, 50-100 m, >100 m) is important because it allows easy comparison of gradients with similar depths and it emphasizes the effects of depth on temperature gradients. Table IV-3 lists the arithmetic mean and weighted mean temperature gradients used in the construction of Maps IV-4, IV-5 and IV-6. Both the arithmetic mean gradient and the weighted mean gradient values decrease with depth. This reduction is in response to the normal thermal behavior of deep sediments, namely compaction and cementation increase with depth, thereby increasing thermal conductivity. Temperature gradient and thermal conductivity are inversely related. Figure IV-4 is a frequency histogram showing the gradient variations for the three selected intervals.

Wells in the 0-50-m class (Figure IV-4-A) are trimodal, with a tendency for positive skewness past the 150-170°C/km mode. Wells in the 50-100-m class (Figure IV-4-B) are dis-

Table IV-3 Temperature gradients for wells in the Yuma area, Arizona.

| <u>Interval (meters)</u> | <u>Number of Wells</u> | <u>Average Depth (meters)</u> | <u>Arithmetic Mean* Gradient (°C/km)</u> | <u>Weighted Mean** Gradient (°C/km)</u> |
|--------------------------|------------------------|-------------------------------|--|---|
| 0-50 | 262 | 37.2 | 95.2 | 82.8 |
| 50-100 | 178 | 65.0 | 77.0 | 68.6 |
| >100 | 32 | 179.2 | 44.1 | 35.7 |

* Arithmetic Mean Gradient =
$$\frac{\sum_i (\text{Temperature Gradient})}{(\text{Number of Wells})}$$

** Weighted Mean Gradient =
$$\frac{\sum_i (\text{Temperature Gradient} \times \text{Depth of well})}{\sum_i (\text{Depth of well})}$$

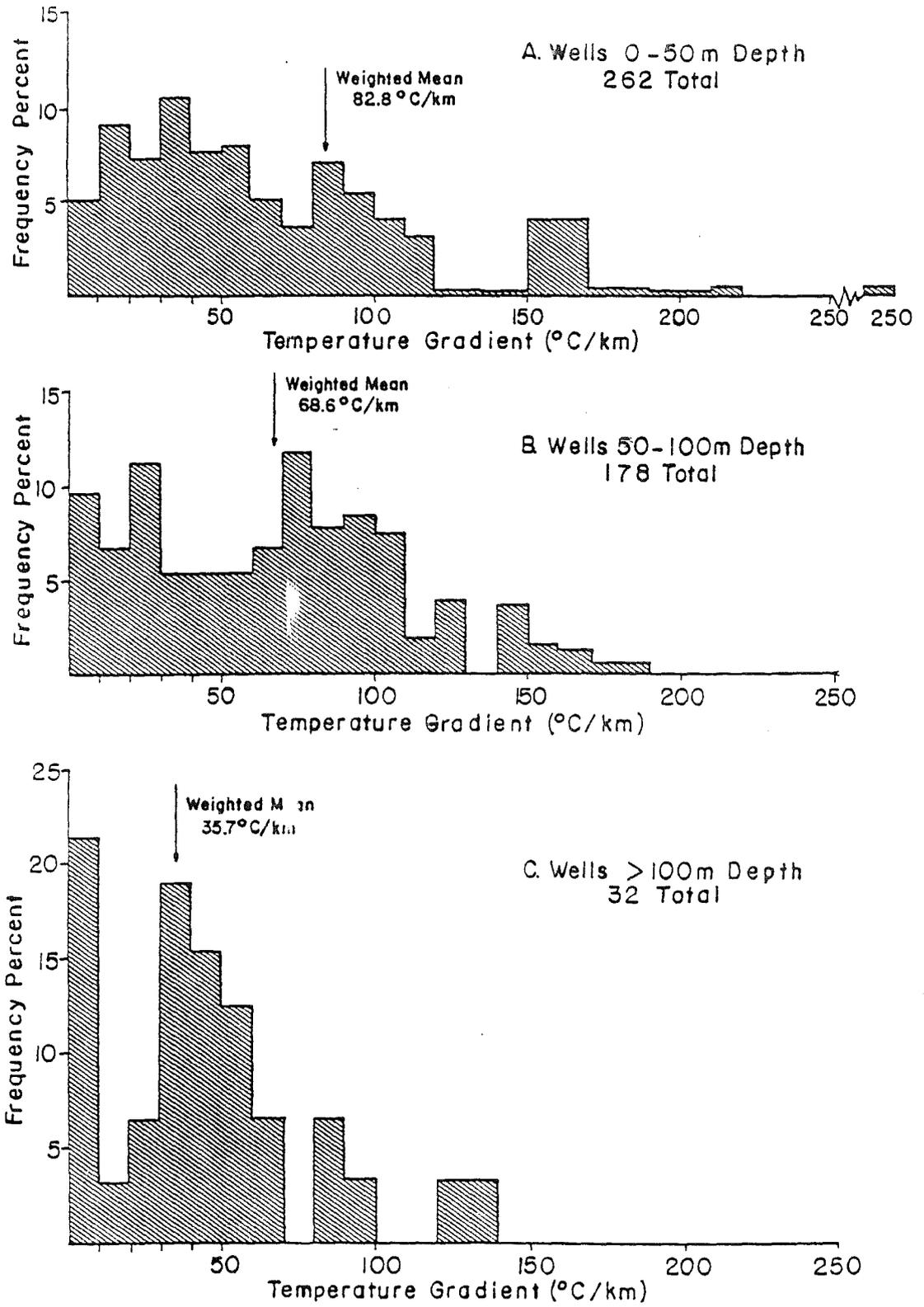


FIGURE IV-4.
Frequency distribution of temperature gradients from selected well depth intervals.

tinctly bimodal, possibly trimodal, but definitely skewed positive. Those wells deeper than 100 m (Figure IV-4-C), exhibit a definite bimodal habit that could conceivably develop into a quadramodal system with a larger sample population. There is a positive skewness in the present form.

In all three cases, the lowest temperature-gradient mode is considered the result of ground-water recharge. The next highest mode represents normal basin conditions, while subsequent modes, or positive skewness, is the result of abnormal temperature conditions. Temperature gradient maps IV-4 through IV-6 clearly support this interpretation. The recharge influence is represented by the low-value contours along the Gila and Colorado River, and in areas of heavy farming activity. Anomalous zones depicted on maps IV-4 through IV-6 generally agree with anomalous zones in Figure IV-3 and are on fault traces shown in map IV-1.

F. Summary Resource Evaluation

1. The Fortuna and San Luis basins are bounded by and contain faults related to the San Andreas fault system. Some of these faults have had recent movement.

2. A buried ridge lies along the Algodones high. The Bouse Formation (Pliocene) pinches out in subsurface in an area roughly from Yuma south to the Algodones Fault.

3. Both gravity and magnetic highs occur in the region of the Bouse Formation pinch out.

4. Isothermal maps of well-discharge temperatures show that anomalous temperatures correlate with the basin gravity highs.

5. Temperature-gradient maps constructed from well data of

similar depth have anomalous solutions that also correlate with areas having gravity highs.

6. Deep layers of low electrical resistivity suggest that hot saline water may exist below the Bouse Formation. These data should be reinterpreted.

7. Micro-earthquake studies conducted to the south and east of the Algodones anomaly suggest an increase in activity in the direction of the Algodones Fault. Additional stations should be set up at sites near the Algodones anomaly.

8. Numerous test wells have been drilled over the years by the U.S. Geological Survey and the Bureau of Reclamation. Cores and/or cuttings of these holes should be retrieved and the holes relogged for heat-flow studies.

9. If heat-flow studies can not be done from existing wells and cuttings, new heat-flow holes should be drilled.

V. ENVIRONMENTAL ASPECTS

A. General

The Yuma area has been an agricultural center for many years. Artificial fluxuations in the water table by ground-water pumpage and river-water irrigation have caused a loss of chemical identity in the ground water. To the east of Yuma and its agricultural activities is the Air Force Bombing Range where surface disturbance is more random.

The exploration for and development of a geothermal resource in the Yuma area would result in the construction of additional surface structures over the reservoir, and the drilling of wells to tap the resource. Neither of these activities is in excess of past and present practices.

Should an economic resource be developed in the Yuma area, appropriate care and concern will have to be taken. Withdrawal of the geothermal resource water may cause local subsidence and, should the waters be salty, there may be a brine disposal problem. But both can be handled, to some extent, through injection of the brine into the production horizon.

VI. YUMA BASIN RESERVOIR ESTIMATE

The Yuma area contains three separate ground-water reservoirs, the Fortuna Basin, the San Luis Basin, and the Yuma Trough. The total alluvial surface of the Yuma area covers about 1400 km². Because of intensive ground-water studies and nuclear power plant siting studies in the area, data on subsurface conditions for this area are much more extensive than for most basins in Arizona. The water in the upper part of the ground-water basin is extensively used for municipal and agricultural supply, so the upper 300 m of the basin has been excluded from the reservoir computations.

Based on gravity and oil well data (Mattick and others, 1973; Olmsted and others, 1973) the Fortuna Basin is 4600 m deep; the San Luis Basin is 365 m deep; and the Yuma Trough, 1000 m. The basins are floored by pre-Tertiary plutonic, metamorphic, and dike rocks, and contain thick sequences of marine, continental, and volcanic rocks. Major changes in sediment type are undoubtedly marked by unconformities. Porosity and specific yield have been estimated by inspection of the lithologic log for the Exxon Yuma-Federal no. 1 well. The weighted porosity and specific yield for each major sedimentary unit was computed, and the corresponding volume of water was derived. The total volume of water in storage in the basin below 300 m amounts to 359,700 hm³. Total recoverable water amounts to 101,500 hm³. Table VI-1 shows water storage and recovery by unit and by basin.

Table VI-1 Yuma Basin

| <u>Sediment Type</u> | <u>Thickness</u> | <u>Area</u> | <u>Porosity</u> | <u>Specific Yield</u> |
|-----------------------|------------------|---------------------|-----------------|-----------------------|
| <u>Fortuna Basin</u> | | | | |
| Continental | 460 m | 546 km ² | 20% | 10 |
| Marine | 1980 | 364 | 15% | 3.5 |
| Continental | 2130 | 202 | 15% | 4.5 |
| <u>San Luis Basin</u> | | | | |
| Continental | 1000 m | 409 km ² | 20% | 10 |
| Marine | 1190 | 326 | 23% | 3.5 |
| Volcanics | 670 | 160 | 12% | 3.6 |
| Continental | 790 | 76 | 16% | 4.5 |
| <u>Yuma Trough</u> | | | | |
| Continental | 300 m | 55 km ² | 20% | 10 |
| Marine | 761 | 34 | 15% | 3.5 |

| | <u>Water in Storage</u> | <u>Recoverable Water</u> |
|--|--|--|
| Upper continental unit (excluding upper 300 m) | 71,500 hm ³ (58.0x10 ⁶ acre-feet) | 35,700 hm ³ (28.9x10 ⁶ acre-feet) |
| Marine | 201,000 hm ³ (162.9x10 ⁶ acre-feet) | 39,800 hm ³ (32.3x10 ⁶ acre-feet) |
| Volcanic | 12,800 hm ³ (10.4x10 ⁶ acre-feet) | 3,800 hm ³ (3.1x10 ⁶ acre-feet) |
| Lower continental unit | 74,400 hm ³ (60.3x10 ⁶ acre-feet) | 22,200 hm ³ (18.0x10 ⁶ acre-feet) |

The water stored in the portions of the ground-water basin beneath the Bouse Formation is undoubtedly under confined (artesian) conditions. Mining of large volume of water from some portions of the aquifer beneath the Bouse Formation could pose geotechnical problems similar to those caused by agricultural water withdrawal from confined ground-water systems. Subsidence resulting from ground-water pumping has been well documented in many parts of the southwest and has been linked to withdrawal of water from or beneath fine-grained, nonindurated sediments. However, volcanic rocks and well-indurated sediments generally are considered to experience much smaller problems with subsidence than nonindurated sediments. Another geotechnical problem involves protection of potable water supplies in the shallow part of the aquifer from any saline geothermal waters. Potable water supplies can be adequately protected using reasonable care and currently available technology. The extent and magnitude of any subsidence problem resulting from geothermal development cannot be ascertained from the data available.

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