INDIAN WELLS VALLEY

A Water Geochemistry
Study of Indian Wells Valley,
Inyo and Kern Counties, California

by
J. A. Whelan and R. Baskin
University of Utah, Salt Lake City, Utah

For the Eastern Kern
County Resource Conservation District

June 1987

1

Notice... Reference to a company or product name does not imply approval or recommendation of the company or product by the University of Utah or the Eastern Kern County Resource Conservation District to the exclusion of others that may be suitable.

CONVERSION FACTORS

The results of chemical analyses and temperatures in this report are given in metric units rather than the more familiar english units. Concentrations are reported in milligrams per liter (mg/l) or micrograms per liter (Mg/l) and temperatures are reported in degrees Celsius (°C).

Conservation factors reported below are not exact unless noted.

Multiply inch-pound unit	By	To obtain metric unit
foot	0.3048	meter
inch	2.540	centimeter
mile	1.609	kilometer
acre-foot	0.001233	cubic hecto- meter

Milligrams per liter is numerically nearly equal to the unit parts per million (ppm) for concentrations of less than about 7,000 mg/l. Parts per million was formerly used by the U.S. Geological survey to report the results of its chemical analyses.

Micromhos per cm (english system) is now reported as micro siemens per cm (metric system). The quantities are equivalent and the nomenclature is interchangeable.

Water and air temperatures are reported in degrees Celsius (°C), which can be converted to degree Farenheit (°F) by the following equation: $°F = 1.8 (°C + 32)$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) -- a goedetic datum of both the United States and Canada, formerly called "Mean Sea Level of 1929".

The system of numbering wells and springs in California is based on the cadastral land-survey system of the U.S. Government and has been used by the U.S. Geological Survey in California since 1940. Wells and springs are assigned an identification number based on their location in the land net.

By the land-survey system, the area of Indian Wells Valley and all township-range designations found in this report, lie entirely within the southeast quadrant of the Mount Diablo base line and meridian.

Numbers designating the township and range (in that order) are abbreviated in the first part of the location number. A well located in township 27 south and range 40 east would be designated as 27S/40E as shown in figure 1. The township-range designation is followed by a dash which separates the township-range designation from the section number and a 40 acre subdivision. The number which denotes the section within a township follows the dash.

The section is further broken down into forty acre subdivisions which are alphabetically labeled starting with the northeast corner of the section and ending with the southeast corner. The letters "I" and "O" are omitted in order to avoid confusion.

Within this forty acre tract, wells and springs are numbered serially as are designated as such by the final digit in the location number (Figure 1).

Wells are numbered according to their location in the rectangular system for subdivision of public lands in California. For example, in well number 26S/39E-24K1, the number and letter preceding the slash indicate the township (T. 26 S.); the number and letter following the slash indicate the range (R. 39 E.); the number following the hyphen indicates the section (sec. 24); the letter (K) following the section number indicates the 40-acre subdivision. Within the 40-acre subdivision, wells are sequentially numbered in the order they are inventoried (1). The area covered by this report lies entirely in the southeast quadrant of the Mount Diablo base line and meridian.
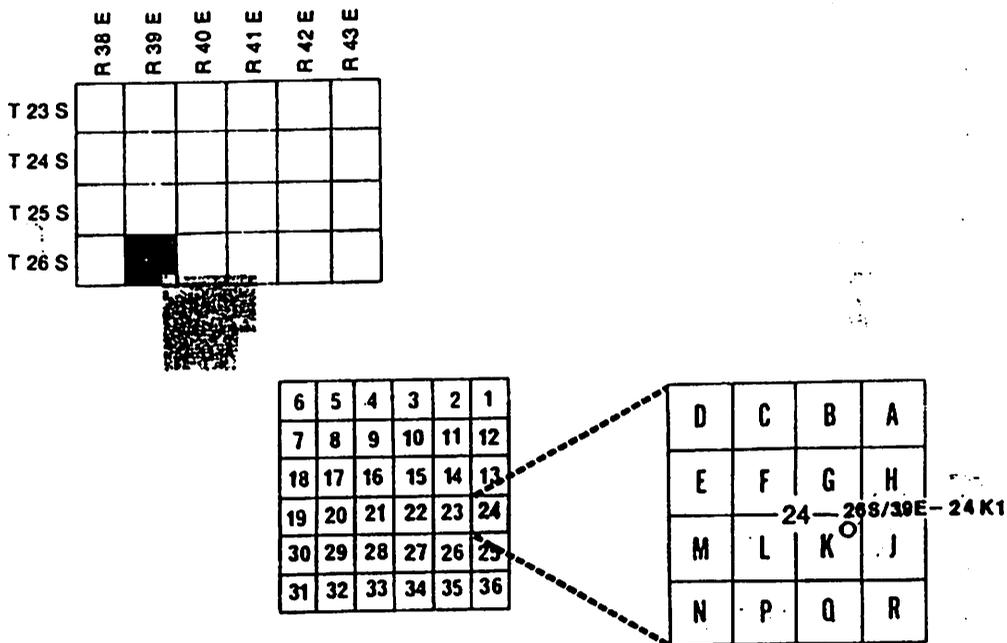
FIGURE 1

ABSTRACT

The geochemistry of ground-water in Indian Wells Valley was studied utilizing water analysis available from the U.S. Geological Survey supplemented by samples taken to increase spatial coverage or from sources which possibly had some different chemistry.

The ground-water system of Indian Wells Valley and vicinity is complex. Using a computer classification of waters by principal cations and anions, of 254 water types possible some 55 occur in the area. By grouping similar types of water together, the following major water types were mapped: (1) Alpine Waters (Calcium-sodium-magnesium/-bicarbonate type) characteristic of the mountainous areas; (2) Sodium-chloride Waters, characteristic of the Coso Geothermal Area, China Lake, and parts of southeastern Ridgecrest; (3) Sodium-Carbonate Waters, one shallow well at Coso Hot Springs and the southwestern portion of Indian Wells Valley; (4) Sodium-bicarbonate Waters, occurring from west of Inyokern, north to the southern boundary of township 25S and south to Michelson Labor-atory; (5) Sodium-bicarbonate-chloride Water, between the eastern edge of the area "R", sodium-bicarbonate water and China Lake Playa, representing mixing of easterly moving sodium-bicarbonate ground-waters with ground waters of China Lake Playa; (6) Sulfate Waters from mineralized area, geothermal areas, and sewerage pond seepage (shallow waters of area "R"); (7) Little Lake-Lumber Mill Waters which are calcium-(sodium-magnesium)-bicarbonate-chloride-(sulfate) Waters which occur from Red Hill in Rose Valley to where Brown Road

turns west in Indian Wells Valley. These waters probably represent a mixture of Alpine and Coso Geothermal Waters, and Deep Rose Valley Waters; (B) The waters of the well fields. Usually sodium-calcium, but sometimes calcium-sodium-bicarbonate-chloride Waters. These waters could represent Alpine Waters concentrated by evapotranspiration mixed with sodium chloride geothermal leakage.

Geothermal leakage into Indian Wells Valley occurs from coso, areas west and just north and south of the main gate of the Naval Weapons Center, the southwestern part of the valley, and Haystack in Spangler Hills.

Thrust faulting in the Sierras, the Coso Range, the Argus Range, and under the valley, provide other avenues for subsurface inflow. Data indicate significant inflow into the valley from Rose Valley. Inflow from the Sierrian Granitics is indicated by the Tungsten Peak Mine which made 170 acre feet of water a year when in operation. Besides evaporation from China Lake Playa and transpiration by plants, other possible losses from the valley are subsurface outflow to Searles Valley through Salt Wells and Poison Canyon and Interbasin flow to Searles Valley beneath the Argus Range.

With the exception of a few wells in the Ridgecrest field, water quality has changed little with time. Water quality may improve, deteriorate, or remain constant with depth.

INTRODUCTION

This report summarizes the results of a study of the geochemistry of groundwater in Indian Wells Valley supported by the Eastern Kern County Resources Conservation District, California. The most important resource of Eastern Kern County, is the human resource. However, the human resource is totally dependent on water - for culinary purposes, for agriculture, for industry and for services. Water supply problems have the potential to become severe in an arid region such as the Mojave Desert. For this reason the Eastern Kern County Resources Conservation district in 1986 commenced a study of ground-water, the principal source of water in Indian Wells Valley. Ground-water studies have been made in Indian Wells Valley since those of Lee (1913) to the present (see the following section). The Conservation District, however realized that all the prior studies were "classical". That is there were more and more well soundings and water analyses, often taken carelessly, without quality control, and with conclusions drawn from the data of the study of that time, perhaps with references to earlier studies. The Conservation District realized that ground-water is but one component of the local geological environment and that to adequately understand ground-water, the total geological environment must be understood. For that reason its program included studies of structural geology (Ward Austin), and shallow heat flow (Geothermal Surveys Inc.), and this study of water geochemistry (classical), and water isotopes. As far as the writers know, this is the first truly integrated study of a ground-water system in a desert basin.

Indian Wells Valley is located in eastern Kern county, southern Inyo county, and northwestern San Bernardino county (Figure 2). The principle settlements in the area are Ridgecrest, China Lake, Inyokern, and Little Lake. The largest employer in the area is the Naval Weapons Center, commissioned in 1943. It employs approximately 4,000+ civilians and about 1,000 military personnel.

CLIMATE

Climatological data was obtained from the Final Environmental Impact Statement, Proposed Leasing within the Coso Known Geothermal Resource Area (BLM, 1980, pp. 2-3 - 2-7). The climate of Indian Wells Valley is typical of the southern California high desert region, is characterized by hot summers, cool to cold winters, large diurnal temperature changes, low humidity, and little cloudiness or visibility restrictions other than occasional blowing dust.

Local topography is an important climatic factor. The Sierra Nevada mountains to the west form a barrier to passing storms and frontal systems, and create a rain shadow effect. The air is warmed as it descends down the lee side of these mountains and the potential for condensation is decreased. As a result precipitation varies from twenty to fifty-five inches on the windward (west) side of the Sierras to less than ten inches annually on the east side. Annual average precipitation in the center of the Indian Wells Valley is about three inches.
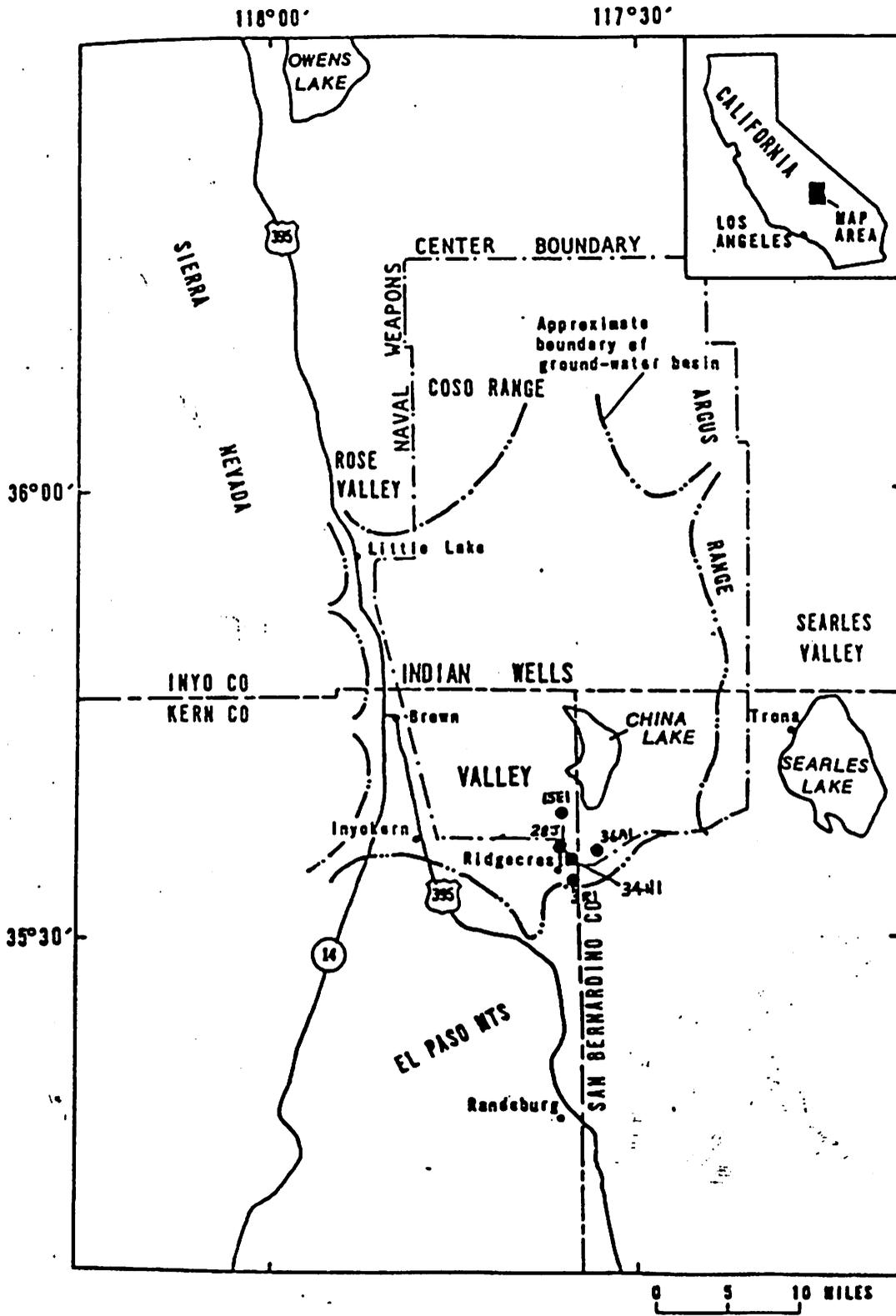
Location of the Indian Wells Valley Ground-Water Basin

Figure 2

8a

The Bureau of Land Management has developed a formula to predict snowfall based on elevation:

$$Y = 0.57 * e^{1.51} * 10^{-3} * X$$

Where:

X = elevation in feet

Y = the average annual snowfall in inches

The correlation coefficient was 0.84. John Hornell (Meteorology Department, University of Utah, personal communication, June 1984) gives an average of the mean annual temperature at the Naval Weapons Center weather station of 64.0 degrees F. Monthly normal temperature range is from 43.11 degree F. in January to 86.2 degrees F. in July. The daily temperature extremes show a normal daily minimum in January of 28.7 degrees ←
F. while the normal high of 102.3 degrees F. occurs in July. The fifty percent probability date of the last spring frost is around April 1.

The mean monthly relative humidity values at China Lake range rom 23% in July to 52% in December. There is an average of seventy-four days (20.3%) per year of total cloud cover, with a maximum number of cloudy days per month during the winter season and a maximum number of clear days per month during the summer and early fall seasons.

Prevailing winds are from the south-southeast or north-northwest at all times of the year. Long term data shows average annual wind speed at China Lake to be 8.2 mph., with the highest monthly average (10.4 mph.) occurring in May. There are occasionally high winds from the north and from the west, the strongest ever recorded in China Lake at 81 mph. in March 1952.

Summer thunderstorms are not uncommon and localized torrential rains and flash-flooding occurs from June through October. Every few years heavy lasting summer rains occur when a hurricane off Baja pumps moisture into the area and traps it against the coastside of the Sierras, temporarily reversing the rain shadow effect.

ACKNOWLEDGMENTS

There have been many studies of Ground-Water in Indian Wells Valley of varying quality and length. None, however, addressed the regional ground-water flow system or ground-water flow system cells (areas of ground-water types) to any extent.

The earliest studies were those of Lee (1913). Another early study of ground-water was that of Whistler (1923). The first U.S. Geological Survey study of the area was that of Thompson (1929). He published some analyses and proposed a water budget for the basin. The first Navy study of ground-water was that of Buwalda (1944). In 1951 Wilcox, Hatcher and Blair published a paper on the quality of water of the Indian Wells Valley.

Kunkel and Chase (1955) in a U.S.G.S. study for the Navy have also calculated a water budget with supporting tables in 1954.

In 1959 Dutcher published data on water wells in the Fremont Valley area. Moyle and Kunkel (1960) published on ground-water conditions in the valley in 1959. In 1963 Moyle published data on Water Wells in Indian Wells Valley area. This publication contains available well data and 220 water analyses (not all complete). Quality control over the analytical work appears to be good.

In 1969 Kunkel and Chase published a U.S.G.S. Open-File Report entitled Geology_and_Ground_Water_in_Indian_Wells_Valley, California. Their geology section will be discussed in the next section of this report.

11

Kunkel and Chase did not have either the number of analyses now available or the present computer capabilities. They (p.51) lumped the waters as sodium carbonate waters based on a scheme involving 50 percent of the milliequivalents they compare in their Group I Waters (low TDS sodium carbonate waters with low fluoride and boron) to the Alpine Waters and places this group in the Inyokern well fields and areas to the north.

For a discussion of what happens north of Inyokern, the reader is referred to the sections on sulfate waters and Little Lake/Lumber Mill Site Waters.

Their Group II waters are also sodium carbonate waters of low total dissolved solids but with higher boron and flouride contents. They place it from the main gate of the Naval Weapons Center to about one mile north of the intermediate well field. They consider their group II waters to be alpine waters modified by base exchange (ions from water going into a mineralized zone releasing different ions into the water). They attribute the mineral with exchange properties to be zeolites. These writers feel that clays in the alluvium and valley sediments are more probably the mineral exhibiting a base exchange potential.

Their Group III waters are sodium chloride waters. These, of course, include waters in and near China Lake playa and waters to the south and east of Ridgecrest. They postulate a clay barrier restricting the movement of the latter waters eastward. They attribute the sodium chloride waters south and east of Ridgecrest to come from a former lake or lakes in the area. An alternate explanation, geothermal leakage, is discussed later in this paper.

12

Kunkel and Chase have presented conclusions on the water budget of the valley. These conclusions are based on both data and extensive assumptions. Conclusions on the water budget will vary depending on the quality of the data and the assumptions made. Calculating a water budget is beyond the scope of this paper. Some data possibly affecting assumptions are contained in the conclusions sections of this paper. Dr. Carl F. Austin at the Indian Wells Valley Water District meeting of June 13, 1988 gave a good critical review of the various water budgets published for the valley which has been published verbatim by the Inyokern News Review (News Review verbatim Transcript).

In 1971 Bloyd and Robson published a paper entitled Mathematical Ground-water model of Indian Wells Valley, California. For a review of this paper the render is referred to Austin.

In recent years there has been a tendency for the U.S.G.S. to publish (usually in cooperation with the Naval Weapons Center) open-file reports to update observations on water levels and to furnish water analyses for a year or a few years. Among these are:

Koehler, J. H. (1971). Ground-Water Conditions During 1970 in Indian Wells Valley, California. U.S.G.S. Open-File Rept. 19p.

Banta, R. L. (1972). Ground-Water Conditions During 1971 in Indian Wells Valley, California. U.S.G.S. Open-File Rept. 9p.

Banta, R. L. (1974) Ground-Water Data, 1973, Indian Wells Valley, California. U.S. Geological Survey, Open-File Report, 9 p.

Lamb, C. E. and Downing, D. J. (1978) Ground-Water Data, 1974-76, Indian Wells Valley, Kern, Inyo, and San Bernardino Counties, California. U.S.G.S. Open-File Rept. 78-335

13

Berenbrock, C. (1987). Ground Water Data for Indian Wells Valley, Kern, Inyo, and San Bernardino Counties, California. 1977-86. U.S.G.S. Open-File Rept. 86-315, 56 p.

In 1973, Dutcher and Moyle published the water-supply paper Geologic_and_Hydrologic_Features_of_Indian_Wells_Valley,_California.

The Coso Geothermal system is an important subsystem which supplies some water to Indian Wells Valley. There is much literature on the system and only a few of the most significant references are mentioned. The Geothermal Project Office, Public Works Department, Naval Weapons Center maintains a Coso Library open to the public. In addition, the California Energy Company Incorporated the geothermal developer at Coso and has much proprietary information on the geothermal reservoir and the hydrology and structural geology of the entire region.

Some of the significant references are Austin and Pringle (1970), Moyle (1977), Soane (1978) and Fournier and Thompson (1980). The principal geothermal brines are of the sodium chloride type. The recharge area is the Sierras (Fournier and Thompson, 1980). The significance of the recharge area will be discussed in a later section of this report.

In 1975 Warner in a study entitled Ground-Water Quality in Indian Wells Valley, California stated (from the abstract) that the dissolved solids content in some areas is increasing slightly, but where this has occurred, it is not yet serious.

In 1978, Dr. P. St. Amand proposed that the Indian Wells Valley ground-water system is a closed basin and he prepared a water budget for the basin on that basis. In 1987 the U.S.G.S. Ground-water Office at San Diego proposed an expanded project for

14

the appraisal of ground-water in Indian Wells Valley on the basis
of the degrendation of the ground-water quality. The apparent
actual change of water quality with time will be discussed in a
later section of this report.

GEOLOGY

The Sierra Nevada Mountains to the west of Indian Wells
Valley consist of granitic rocks with roof pendants of
metamorphic rocks. Some contact metamorphic rocks also occur
(The Tungsten Peak Mine). The Coso Mountains to the north are
complex. Sierrian basement rocks have been penetrated by both
basaltic (dark colored, low silica) and rhyolitic (light
colored, high silica) volcanic rocks of Tertiary to recent age.
An excellent surface map of the Coso Volcanic Field is that of
Duffield and Bacon (1981). The Argus Range locally to the east
and the Spangler Hills to the southeast are also predominantly
Sierrian basement type rocks. The El Paso Mountains to the
southwest are also Sierrian but contain Eocene (Tertiary) basalt
and both continental and marine sediments, and considerable
Paleozoic marine sediments. The U.S.G.S. authors from the
various ground-water offices that have written on the Indian
Wells Valley in the past two decades have all considered the
bedrock to be impermeable and largely non-water bearing. The
permeability of plutonic and volcanic rocks will be discussed in
a later section.

The valley itself consists of alluvium, lacustrine (lake)
deposits, windblown sands, and playa silts and clays and probably
a thick section of Estuorine and marine sediments at depth. The

15

alluvium on the west side of the valley in particular occurs as alluvial fans and glacial outwash debris coming into the valley from mountain canyons and valley fill. Kunkel and Chase (1969) divide the valley alluvium into "older" and "younger" units and give them formation names. The lake deposits are Pleistocene (Ice Age) and are interbedded within the alluvium. Kunkel and Chase proposed a simplistic stratigraphy with the older and younger alluvium deposits separated by the older lake deposits (young lake deposits are represented by the pinnacles in Searles Valley). The Tertiary and Pleistocene was a complex age. Dr. Carl F. Austin (Personal communication 1988) suggests the pluvial periods documented by Norris and Webb have all affected this over. He lists the following glacial events:

YEARS   BEFORE PRESENT

Matthes 0-600

Unnamed 1000

Recess Peak . . . . 2000 - 6000

Unnamed . . . . 6000 - 7000

Hilgard 11,000

Tioga 20,000

Tenaya 26,000

Mono Basin 87,000

Donner Lake 250,000

Casa Diablo 400,000

Sherwin 750,000

McGee 1,500,000

Deadman 3,000,000

Whelan did the geology of a well drilled by the Navy just inside the Naval Weapons Center fence by the Inyokern substation in 1984. Tree rootlets were encountered at 400 feet. At greater depths in this 1000 foot well there were two zones where the alluvium was cemented with caliche. Whelan assumed these to be "splash" zones formed at a shoreline. If his interpretation is correct there were separate lakes present there twice or one lake was transgressing and regressing. In either case, the valley fill is highly complex as well as folded (Carl F. Austin, personal communication, 1988). There may be scattered local confined zones but there is no evidence that the basin as a whole, has any recognizable division into broad horizontal layers of different kinds of waters. The earlier works of the U.S.G.S. considered Indian Wells Valley to be a simple down-faulted block bounded by high angle faults. Zbur (1963) on the basis of seismic refraction, gravity and aeromagnetic studies postulated a maximum of 6200 feet of valley fill. However, he also assumed the valley was bounded by high angle faults. Austin and Moore (1987) have presented convincing evidence that the Coso range was formed by low angle thrust faulting. More and more evidence is surfacing that the Sierra and Argus Ranges are both stacked thrust sheets complicated by major dystual faulting (X. Erskine, personal communication, 1988). Certainly thrusting is important throughout the Basin and Range geologic province and also into the Colorado Plateau.

If as now seems probable, thrust faulting has been important in local geologic history, (O'Brien and Austin, personal

17

communication, 1988; Sierra Bureau Exploration, personal communication, 1988) then the basement under the valley fill in Indian Wells Valley could well be sedimentary rocks. This has significant implications as to both regional ground-water hydrology and the complex pattern of ground-water flow system ← cells in the valley. This will be discussed later.

The basic geologic map of the area is the Trona Sheet, Geologic Map of California (Jenkins, 1962). Nilsen and Chapman (1971) have prepared the Trona sheet, Bouguer Gravity Map of California, Trona Sheet. Neither of these maps preparers had access to the detailed thrust geometry now being shown by the geothermal development in the area.

THEORY BEHIND GEOCHEMICAL INVESTIGATIONS

The quality of natural water is determined by the concentrations and types of dissolved material contained within the water. The dissolved material in the water may have been derived from the atmosphere, biological sources, soils, minerals or through man-induced activities. Bacteria, evaporation, mixing, and chemical reactions may further alter the water as it passes through the hydrologic cycle. In the Indian Wells Valley, widespread geothermal activity is a major contributor to the chemistry of the ground-water present.

In order to determine the chemical quality of water, an analysis must be performed on the sample. This involves the careful measurement of certain parameters of the water sample as it is taken from it's natural environment and proper preparation of the sample for later analysis so the concentrations of the dissolved ions do not change.

On site measurements at the sampling source include temperature, pH, and conductivity. These three parameters can change rapidly with time and must be measured as soon as the sample is taken.

Temperature readings of groundwater are an important source of information. Many factors concerning the measurement and actual ionic composition of water quality are influenced by temperature including pH, conductivity, and the concentration of dissolved ions. Temperature readings must be included in corrections for pH and conductivity since both are based on a certain property of the water at a specific temperature.

Temperature readings are also important in Indian Wells Valley because of the known presence of geothermal features in close proximity and/or within the valley. Geothermal features may contribute heat or heated water to the local groundwater system and cause major changes in the chemistry of the water. If an abnormally high temperature was measured at a sampling location, this would indicate that the ground-water reservoir was connected in some way with a higher than normal heat-flow area. For example, water from a Navy Well at the Inyokern substation is 27° C. Thus a geothermal area may be contributing heat to the local reservoir or may be mixing geothermally altered waters with the more typical ground-waters. An analysis of certain constituents that are found in geothermal waters compared with analyses of neighboring non-geothermal waters is sometimes a fairly reliable method of determining if there is intermixing of waters in the area. This will be discussed under water type.

The measure of acidity or alkalinity (pH) in a water must also be measured immediately after the water is removed from its natural environment. Reported in the base 10 log of the hydrogen ion activity (in moles per liter), pH gives an indication of the type and amount of reactions the water was undergoing at the time of sampling.

pH values change as hydrogen ions are produced or consumed during chemical reactions in the groundwater system. Values of pH are commonly lumped into three major divisions; basic (pH > 7.0), neutral (pH = 7.0) or acidic (pH < 7.0). A water containing equal amounts of hydrogen ion and hydroxide ion (H+ = OH-) at 25 C has a pH of 7.00. If hydrogen ions are added to this water,

the solution becomes more acidic and the pH value decreases. Conversely, if the hydrogen ions are consumed in a reaction, the solution will become more basic and the pH value will increase.

Most natural waters have a pH ranging from about 6.0 to about 8.5 (Hem, p.64, 1985). The range of pH in Indian Wells Valley was from 4.60 (26S/40E-14N1, 06-21-72) to 10.10 (25S/40E-33L1, 03-25-75). Conductivity is a measure of the ability of a substance to conduct electricity. In water resource investigations, specific conductance is measured and is defined as the ability of the solution to conduct electricity at a specified temperature and through a unit length and cross section. The standard temperature at which specific conductance is measured is 25 degrees C and the unit length and cross section are one centimeter and one square centimeter. Specific conductance can be plotted against measured/or calculated total dissolved solids (TDS) and a relationship equating specific conductance to TDS can be established (curves are given in Appendix A).

Analyses can be obtained for all elements and compounds. A complete analysis of all the possible constituents is not necessary for geochemical investigations. Contributions of many of the elements found in natural waters are small and do not effect the overall quality of the water. Analyzing for a large number of ions can become cost prohibitive. The major positive ions (cations) which were chosen for the study of water quality in Indian Wells Valley and that effect the quality of water the most are; Calcium (Ca^{++}), Sodium (Na^+), Magnesium (Mg^{++}), and Potassium (K^+). These were chosen because they are the most

21

common positive ions contributing to the quality of water in the area.

The major negative ions (anions) which were chosen are Chloride (Cl-), Sulfur in the form of sulfate (SO4=), Bicarbonate and Carbonate (HCO3- + CO3=), and Fluoride (F-). They were chosen because they also are major contributors to water quality in the valley. Other elements were included in the analyses because of their effect on humans, livestock, and plants or because they are geothermal indictors. These elements are Silica (SiO$_2$), Boron (B), Iron (Fe), and Arsenic (As).

Calcium - Calcium is the major cation of the alpine waters. Calcium causes water to be "hard". The low total dissolved solids contents keeps the Alpine Waters "soft".It is interesting to note that hard waters tend to prevent heart attacks. In the evolution of desert waters there is a tendency for waters to evolve to more sodium rich waters.

Sodium - Sodium is a very soluble cation. As waters evolve through the desert environment they tend to become enriched in sodium.

Potassium - Potassium is associated with sodium and behaves in a similar manner. Low sodium to potassium ratios may indicate a possible geothermal water.

Magnesium - Although magnesium is generally present in greater amounts than potassium, it is somewhat anomalous to the ground-waters of Indian Wells Valley. The source of magnesium is probably the basalts in the northwest portion of the valley.

Bicarbonate and Carbonate – Bicarbonate and carbonate are the principle anions contributing to the hardness of water. The carbonate bicarbonate system is very complex chemically and variables such as carbon dioxide partial pressure, pH, temperature, type of enclosing rocks, and other ions present effect it greatly.

Chloride – Chloride is the least reactive of the anions. Many geothermal brines are of the sodium chloride type.

Sulfate – Sulfate is the least common of the major anions. There are four sources of sulfates in Indian Wells Valley ground-waters. These are the oxidation of pyrite in Tertiary Lake Clays, the oxidation of sulfides in mineralized areas, sewage pond leakage (sodium sulfate is added to detergents) and leakage from geothermal steam caps. Another source of sulfate could be sedimentary gypsum or anhydrite beds, however, they have not found this in the valley or surrounding mountains.

Fluoride – Although Hem (1985, p.120) places fluoride as a major element it is actually a trace element. It is usually lumped with chloride as a major element. A small amount of fluoride in drinking water prevents dental carries. Larger amounts are considered harmful. The amount of fluoride allowable is temperature dependent because of the amount of water a person consumes is temperature dependent (Hem, 1985, p.211). For the Indian Wells Valley with a mean air temperature of 64° F, fluoride should not exceed 1.8 mg/l.

Silica – Silica (SiO_2) is important chiefly as an indicator of geothermal leakage. A discussion of the silica geothermometer is given by Fournier, in Rybach and Muffler (1981, pp 113-118).

Boron – Boron is of concern because although small amounts of boron is essential to plant nutrition, a small excess over the needed amount is toxic to some types of plants. Hem (1985, pp. 215-216) discusses the effects of boron on plants. Indian Wells Valley ground-waters are generally fairly high in boron, but usually not high enough to be toxic to plants. However, extreme concentrations of boron occur in the surface and shallow ground-waters of China Lake Playa.

Arsenic – Arsenic is of concern because of its toxicity to humans and other animals. Hem (1985, pp. 144-145) gives the EPA standard for drinking water as 50 micrograms per liter. Many analyses of waters from the Indian Wells Valley indicate concentrations of arsenic in excess of 50 mg/l. However, Hem (1985, p. 145 citing McKee and Wolf (1963, p. 140)) notes that waters with 1000 micrograms/l have been used for drinking for short periods of time with no apparent harmful affects but that long term use of concentrations of 210 micrograms/l was reported to be poisonous.

Berenbrock (1987, p. 40) reports a well 25S/40E-33L1 which on two samplings (80-05-21 and 82-06-09) gave arsenic concentrations of 2000 and 2900 micrograms/l respectively.

The mean arsenic content of waters in which arsenic was reported was 152 micrograms/l. The arsenic concentration frequency distribution is skewed towards high valves by a few

very high citations, giving a misleadingly high mean. The median
or mid valve was 15 micrograms/l. The writers feel that the
median is a more meaningful statistic in this case, in that
valley drinking water with contains arsenic far closer to the
median than the mean.

Sampling techniques were set up to insure the quality of the on-site measurements and sample preservation. Although the actual sampling routine varied slightly at each site, U.S. Geological Survey, Water Resources Division procedures were strictly adhered to. The guidelines used were gathered from "Field Guidelines for Collection, Treatment, and Analysis of Water Samples--Arizona District by L. R. Kister and W. B. Garrett. Since the conditions in Indian Wells Valley are similar to those found in Arizona, the sampling and preservation techniques were transferable.

Temperature was measured with an alcohol-based thermometer calibrated against a National Bureau of Standard tested thermometer. The thermometer was rinsed with de-ionized water before and after each use and was dried with lint-free wipes to control contamination.

A Beckman 21 pH meter in conjunction with a Beckman pH electrode and a Corning temperature probe was used to measure pH. The meter was tested immediately before each sample was measured with 4.0, 7.0 and 10.0 pH standards. Two consecutive readings were taken immediately after the sample was removed from the well or spring and if the difference between the two was greater than 0.1 units, then a third reading was taken to resolve the discrepancy. The pH was recorded on field sample sheet.

A Lab-Line Lectro-MHO-Meter Model MC-1 Mark V conductivity meter in conjunction with Lab-Line Instruments, Inc. conductivity cups was used to measure specific conductance. The meter was

standardized each morning before use with three standards bracketing a range from less than 100 microseimens per cm to 2500 microseimens per cm. The cells were rinsed with de-ionized water a minimum of three times before each use and then rinsed twice with the sample water before being filled for the reading. This assured that contamination from the previous sample and dilution from the de-ionized water was kept at a minimum.

Three one liter polyethylene bottles were filled at each sampling location with either filtered or unfiltered water. (one bottle was acidified to preserve certain ions.) The bottles were rinsed twice with the corresponding water before filling. Acidified bottles were rinsed with HNO3 at the lab and the water filtered through a 0.45 micron nitro-cellulose filter with a Geofilter Peristalic Pump. The unfiltered water was taken directly from the spring or well head. Each bottle was labeled sealed and cooled for shipment to the lab.

The laboratory chosen to analyze the samples collected during this study is the ACZ laboratories of Colorado Springs, CO. It was chosen because of a very good reputation for quality water analyses.

The best measurement of quality of an analysis is to take the difference of the positive charges on cation and the negative charges on anions and divide this by the sum and multiply by 100, giving a percent error. A satisfactory analysis should have a percentage error of plus or minus 5 percent. The positive and the negative charges are given on the reporting sheets.

Also when a report of an analysis is received, the investigator should look for obvious or probable errors and if any results appear erroneous contact the laboratory and have it checked for typographical errors on the reporting sheet, dilution errors, etc.

Table 1. -- Detection limits (Mg/l) and analysis techniques for the elements and compounds used in this report.

Arsenic.........USGS, (1-2-62-78), AA Automated-Hydride   0.001

Bicarbonate*.....EPA 310.1 Titrimetric****   1

Calcium.........EPA 200.7 ICP*****   1

Carbonate*.......EPA 310.1 Titrimetric   1

Chloride........EPA 32.2 Automated - Ferricyanide   1

Fluoride........EPA 340.3 Automated - Complexone   0.02

Iron............EPA 200.7 ICP   0.02

Magnesium.......EPA 200.7 ICP   1

pH..............EPA 150.1 Meter (units)   1

Potassium.......EPA 200.7 ICP   1

Silica..........EPA 200.7 ICP   0.1

Boron...........EPA 200.7 ICP   0.02

Sodium..........EPA 200.7 ICP   1

Solids**........EPA 160.1 Gravimetric 108 C******   2

Sulfate.........EPA 375-3 Gravemetric   4

* as CaCO3

**dissolved

***Atomic Absorption

****Chemical

*****Induced Coupled Plasma (Atomic Absorption)

******Precipitation and Weighing

USGS - U. S. Geological Survey, EPA - Environmental Protection Agnecy, AA - Atomic Absorption, ICP - Inductivity Coupled Plasma

The methods of interpretation for water quality data are many and, as with other types of data, contain many pitfalls. Care must be taken in the collection, preservation, analysis of the water sample along with the interpretation of the analyses.

The analytical methods used to determine the concentration of the major constituents (solute) in each water sample are reported by the laboratory as the weight (in milligrams) of a given solute per unit volume (liter) of solvent. Minor constituents such as arsenic, and boron are reported by the U. S. Geological Survey in micrograms per liter and by the laboratory in milligrams per liter.

Water analyses from other sources may be reported in various other units. Conversion factors for these units can be found in Hem, 1987.

In order to compare different ionic species, a conversion involving the weight and electrical charge of each ion is used. When the formula weight of an ion is divided by the charge of that ion, the result is termed the equivalent weight. If this equivalent weight is then divided into a concentration value reported in milligrams per liter, the result becomes milligram-equivalents per liter. For convenience, milligram-equivalents per liter has been shortened to milliequivalents per liter (meq/L). The following table contains the necessary equivalent weights for mg/L to meq/L conversion.

Table 2.   --   Conversion factors for Milliequivalent conversions.

(From Hem, 1985)

Element and reported species   multiplication factor

Bicarbonate (HCO3)...................... .01639

Calcium (Ca2+)......................... .04990

Carbonate (CO2-)....................... .03333

Chloride (Cl-)......................... .02821

Fluoride (F-).......................... .05264

Magnesium (Mg2+)....................... .08229

Potassium (K+)......................... .02558

Sodium (Na+)........................... .04350

Sulfate (SO42-)........................ .02082

EXAMPLE:

Analysis of Water from 27S/39E-2161   mg/l

Bicarbonate   122

Calcium   41

Carbonate   0

Chloride   17

Flouride   40

Magnesium   11

Potassium   8

Sodium   41

Sulfate   49

Calculations:

Cations   mg/l

Calcium   41 X 0.0499 =   2.05

Magnesium   11 X 0.08299 =   0.91

Potassium   8 X 0.02558 =   0.20

33

```
Sodium        41 X 0.04350 =                    1.78
                                              ----------
         Total Cations                           4.91

Anions                                           mg/l

    Bicarbonate 122 X 0.01639 =                  2.00

    Carbonate     0 X 0.03333 =                  0.00

    Chloride     17 X 0.02821 =                  0.48

    Flouride    0.4 X 0.05264 =                  0.02

    Sulfate      49 X 0.02082 =                  1.02
                                              ----------
         Total Anions                            3.52
```

PERCENT ERROR = ((4.91 - 3.52)(4.91 + 3.52)) X 100 = 16.29%

The use of milliequivalents per liter denotes that the unit concentration of all ions are chemically equivalent (i.e. that for each unit of positive ion (cation) there is one unit of negative ion (anion). In a stable environment, the balance of cations and anions should equal zero.

This chemical equivalence between cations and anions provides a quick yet reliable method of evaluating the quality of both the sampling technique and the lab analysis. If one assumes that the environment the sample was taken from was in equilibrium,
than a comparison of the computed milliequivalents per liter for the major cations (Na, K, Ca, and Mg) versus the major anions (Cl, SO4, F, CO3, and HCO3) will enable a balance to be made and if no balance exists to show the degree of error present.

Hem (1985) states that "Under optimum conditions, the

accuracy of plus or minus 2 to plus or minus 10%". Balances have been computed for all of the analyses used in this report.

Graphical representation of milliequivalents per liter allows the user a visual means of comparing gross water composition without the need for tables of data. Hem (1985) explains many of the graphing methods used in water quality analysis in use today.

A modified "pattern" diagram, similar to the one described by Stiff, 1951, has been chosen to aid in the classification and analysis of water types in Indian Wells Valley. This pattern, commonly called a modified Stiff diagram reduces the effects of dilution or concentration on the shape of the pattern and facilitates the interpretation of sample analyses.

The modified Stiff diagrams are based on a milliequivalent per liter comparison of the major cations and anions of a given sample. The cation and anion equivalents are plotted to the left and to the right of a vertical axis, respectively. The horizontal scale is in milliequivalents per liter and similar species such as sodium and potassium are grouped and labeled as such (Na+K, Cl+F, HCO3 +CO3).

After the points have been plotted on the graph, they are then joined together by straight lines forming a closed diagram. This closed pattern is called a modified Stiff diagram. Modified Stiff diagrams can be calculated by hand or computer derived. Those given in this report were computer derived. One of the main values of stiff and modified stiff diagrams is they are visually recognizable "fingerprints" for major water types.

33

As the composition of the dissolved constituents contained in a water sample change over time, the shape of the modified Stiff diagram will change. Plotting the diagrams on a map in their respective sampling positions will show spacial variability in the gross water composition while a temporal comparison will show changes in composition over time.

Graphically displayed comparisons of the chemical constituents dissolved in natural waters is an easy way to compare the gross chemical composition of waters.

Another method of classifying water is by gross composition. This method also uses the milliequivalent per liter values but compares the percentage of the major cations and anions and classifies the water based on the percentages of each constituent. If a certain cation or anion makes up over 20 percent of the total cations or anions, it is included in the naming of a water. The cation with the largest percentage of the total cations is named first in the water type, the second largest cation percentage is next and this continues until the percentage of the remaining largest cation drops below 20 percent. The anions are next, with the largest percentage leading. The anions also continue to be named in lesser percentages until the percentage of the remaining largest anion also drops below 20 percent. This list of lessening cation percentages followed by lessening anion percentages make up the water type name. Thus a water could be of a sodium-chloride (Na-Cl) type, a sodium-calcium chloride (Na-Ca-Cl) type, a sodium-calcium-magnesium-chloride-bicarbonate-sulfate (Na-Ca-Mg-Cl-HCO3-SO4) type, etc. Of a possible 254 types of ground-waters, 55 are found in the Indian Wells Valley.

CONDUCTIVITY VS. TOTAL DISSOLVED SOLIDS

Estimates of Total Dissolved Solids (mg/l) in a water sample can be obtained without sending the sample to a laboratory by using specific conductance. Specific conductance measures the ability of the sample to conduct electricity at a specific

temperature and through a unit distance. Plotting calculated total dissolved solids against specific conductance allows the establishment of a curve relating one variable to the other. If specific conductance for a particular water type is measured and compared against an established relational graph of specific conductance vs. total dissolved solids then the total dissolved solids content for the sample can be estimated.

An attempt was made to correlate specific conductance with total dissolved solids using water analyses from the U.S. Geological Survey records and those samples collected specifically for this study. Many of the U.S. Geological Survey analyses did not include both total dissolved solids and specific conductance. Both of these parameters are necessary to construct the relational curve mentioned above. Since so few analyses were complete, graphs for all water types and areas were not reliable. However, relationships for TDS vs. conductivity for specific water types were calculated.

Using a computed total dissolved solids (sum of major components measured in mg/l) and conductivity a linear regression line was fitted to the data. A correlation coefficient "R" was computed for the line. If R= -1.00 or +1.00 there is a perfect correlation between the independent and dependent variables. If R=0, there is no correlation. In this case R was 0.30 which is unsatisfactory. It was decided to attempt correlation again using the computer derived water types. Curve fitting was attempted only if there were three or more samples of a water type (two samples always give a straight line with perfect correlation). In general linear regression lines fit well. The

resulting curves of computed TDS vs. conductivity are shown in appendix A. One can determine the water type of a given well from the computer printout furnished to the ECRCD and Plate 1, take the conductivity of a sample and determine its TDS using the appropriate curve.

GEOTHERMOMETRY

The Naval Weapons Center has a program to evaluate navy lands including those in the Indian Wells Valley for geothermal resources. Under this program available groundwater temperatures were contoured. Where depths were available, Pseudo-temperature-gradients were calculated and contoured. A pseudo gradient is an assumed temperature rise per increment of well depth. The term pseudo-gradient is used because true temperature gradients are calculated from actual measurements of temperature at various depths. Since in the Navy study the available temperatures were from bulk water samples and the depth(s) of water entry in the well(s) was (were) not known, a pseudo-gradient was made which is only a gross approximation of actual geothermal gradients. However, Dr. David Chapman (Personnel Communication, October 1987) has shown them to be useful in exploring for geothermal energy.

Where there is a leakage of geothermal fluids into a ground water system, chemical analysis of waters can sometimes be useful in predicting the temperatures of the geothermal reservoir. A discussion of chemical geothermometers is given in Fournier (1981, pp. 112-122). Navy personnel have computed all of the usual chemical geothermometers for the waters of the Indian Wells Valley (there are several thermometer systems: the silica geothermometers, as well as sodium-potassium, sodium-potassium-calcium (with magnesium correction if appropriate) and sodium-lithium thermometers). The Navy has contoured the quartz conductive cooling and sodium-potassium-calcium derived reservoir temperatures for Indian Wells Valley. All of the above data were

concordant and indicated possible geothermal leakage into the ground water in two areas, one just north and slightly west of the main gate to NWC and one just slightly south and west of the main gate.

Chemical composition of ground waters indicates other areas of geothermal leakage into the local ground-waters. These will be discussed in the section on water types.

DETERMINATION OF GROUND-WATER FLOW SYSTEM CELLS

Plate I is a plot of areas where various types of ground-water are found (ground water flow system cells). It was ← prepared using three sets of data.

In a first map, waters which gave similar modified Stiff diagrams were plotted and areas where a given water type dominated were outlined on a map of the Indian Wells Valley (Naval Weapons Center, China Lake, California N3530-W11715/45X45, 1972).

In a second map, computer generated water types were plotted using color codes for each ion in the classification. In general, the two maps were in good agreement.

A Utah State computer agency contoured the analyses for sulfate, boron, pH, and total dissolved solids. In general these maps confirmed the assignment of areas made on the basis of the above methods. When using the contour maps, the northern portion (two-thirds) of the maps should be ignored as the number of data points was too low for computer contouring.

It was considered desirable to determine what kind of rocks the various types of water had been in contact with . This was desirable so that "bed rock" inflows could be identified. Dr. T. Cerling, Assistant Professor of Geology, University of Utah, noted that one of his students (Pederson, 1985) had considerable success relating the rocks of a drainage basin to water chemistry using a trilinear plot of silica, alkalinity and sulfate plus chloride. The scheme was developed by Stallard and Edmund (1983). To use it, one computes the milliequivalent of the

All + Indian Wells Valley

ALK

46 4492

Figure 3

40a

plus sulfate and sums them. The individual milliequivalents and the sum are used to compute percentages for their plotting. The study was of the Amazon Basin. The writers were doubtful that the scheme would work in the Mojave Desert because of the great difference in climatic conditions which affects rock weathering. Also the scheme was developed for surface waters not ground-water. Pederson's study was in the bighorn basin of Wyoming. All analyses with the appropriate components analyzed were calculated and plotted (Figure 3). As one would expect most sample sites positioned in plutonic and volcanic area because of the proximity of the Sierras and Coso Volcanics. There were some which plotted in the limestone area, shale area, evaporate (playa) area, and in geothermal area. The geothermal area was added to the plot by Whelan (Figure 3). Trends of water types as determined by the scheme were plotted on another copy of the referenced map. The trends were in general agreement with the trends of water types as determined by the other methods.

Unfortunately the fact that some waters appear to have a limestone affinity and other a shale affinity does not prove or disprove the presence of Paleozoic metasediments in the basement. The Indian Wells Valley has been occupied by Holocene and Pleistocene lakes which affects the results significantly.

Stallard and Edmond (1983) also proposed a trilinear plot of milliequivalent of alkalinity, calcium plus magnesium and sulfate recalculated to 100 percent to relate water compositions to the sedimentary rock environment. All applicable water analyses were plotted on this diagram (Figure 4). It appears
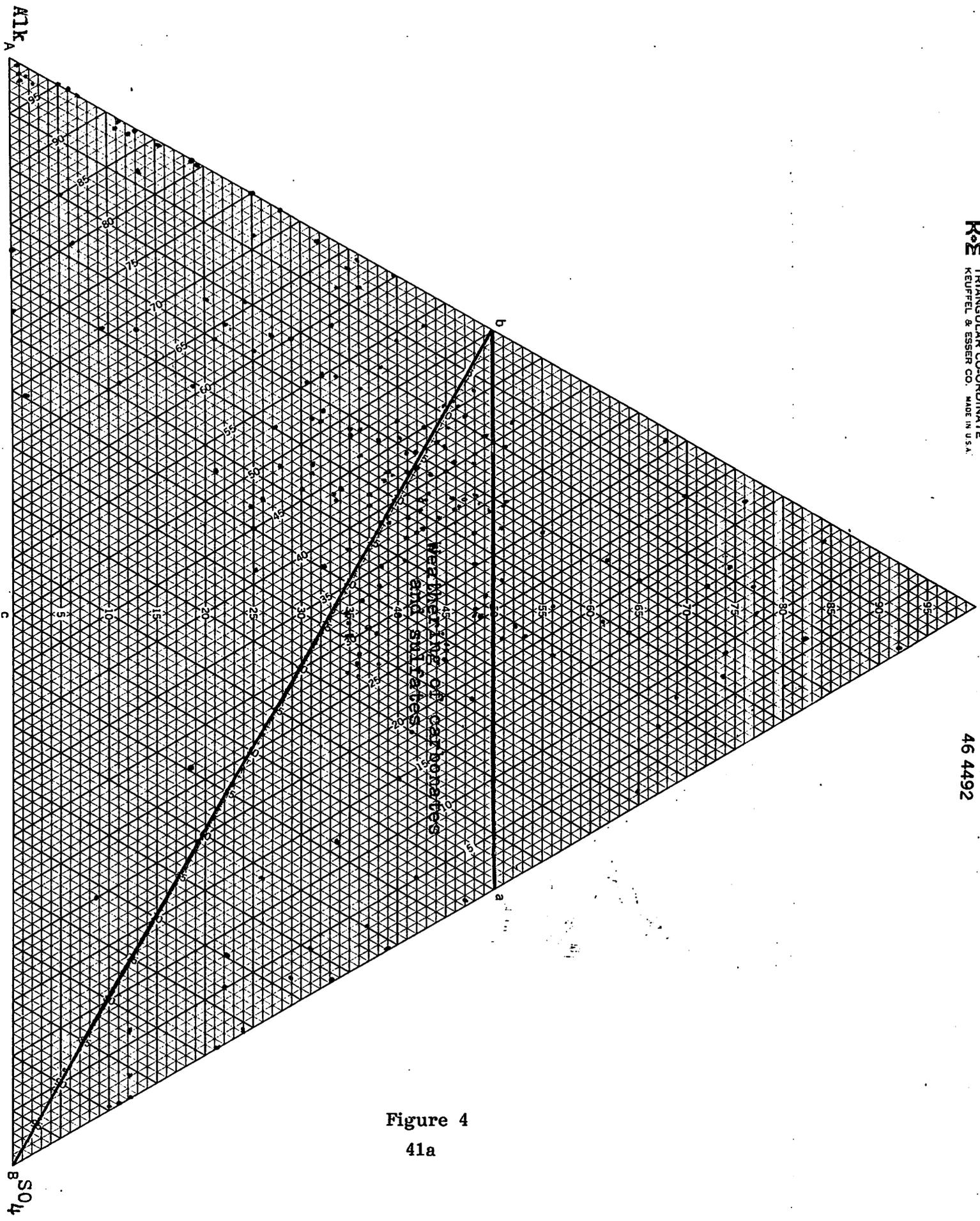
41

Figure 4

41a

that this diagram, developed for surface waters in the tropics, is not applicable to the ground-water environment of the desert in Indian Wells Valley as the majority of the points show a sedimentary relationship (Figure 5). Since much of the alluvium is composed of Sierrian Rocks, which are granitic with lessor metamorphic rocks, one would expect the waters to have exhibited an igneous association. This suggests that roofpendant sedement of the Sierrian may be major aquifers feeding the valley.

Plate I is considered the most important product of this investigation. However, one must be cautioned on its use because of certain limitations. Dashed lines are used to separate water types. They are dashed because in general the boundaries are very approximate, this because of the lack of sufficient data points in large areas. When wells of moderate depth produce reasonable amounts of water, of good quality, many wells are drilled. Where the aquifier is very deep, the yield poor, or the quality poor, few wells are drilled and control on plotting deteriorates.

Another factor is depth control. Of 375 wells sampled through the years by the U.S.G.S. depths are available for only 150 or 42 percent. Of the sites sampled specifically for this study, depths were available for 7 of 12 wells or only 58 percent. There are very few deep wells in this valley. In the China Lake Playa, for instance, only very shallow wells were available for sampling.

Plate I contains some personal interpretation. For instance, sodium-calcium-chloride and calcium-sodium-chloride

waters were lumped together in areas of mixing. If one well had a different water type than most others in an area or was much different in depth compared to the others, it was not used.

The writers acknowledge that this is a preliminary map but believe that it will be useful in subsequent investigations and it is expected that future workers will improve upon it.

WATER TYPES

ALPINE WATERS

The least modified water in the region would be meteoric water derived from the granitic terrain of the Sierras. These waters are of the calcium-magnesium-sodium-bicarbonate-sulfate-chloride type. A modified stiff diagram is shown as Figure 5. These waters are normally of low total dissolved solids. As these waters work their way to the valley they are modified by evapotranspiration, reactions with soils and rocks, and mixing with other waters.

SODIUM-CHLORIDE WATERS

There are two sources of sodium-chloride brines in the Indian Wells Valley region. One source is geothermal brines and the second, playa brines.

The analyses of a typical geothermal brine (CGEH-1, Coso geothermal field) given by Fournier and Thompson together with an analysis of a sodium chloride playa brine are given in Table 3. Salt Wells and Searles Lake waters are also of this type. A modified Stiff diagram is shown on Figure 6.

CGEH-1		CHINA LAKE
Coso Geothermal Field		253140E 25M1
Sampled at ~360 ft.		(USGS Data)

	CGEH-1	CHINA LAKE
Temperature	195 C	
pH	5.40	7.3
SIO2	119	
ca	55	26
Mg	1	71
Na	1510	26000
K	132	320
Li	13	
HCO3	119	570
SO4	53	130
Cl	2330	40000
F	3.3	
B	49	912

Calc TDS   4384.43

TDS measured   66400
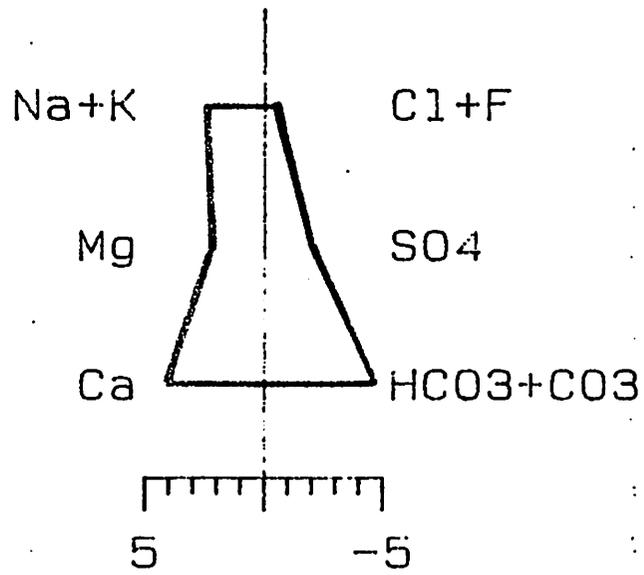
IWV1 GRUMPY BEAR WELL   09-16-86

Figure 5

45a

Na+K — Cl+F

Mg   SO4

Ca   HCO3+CO3

480   −480
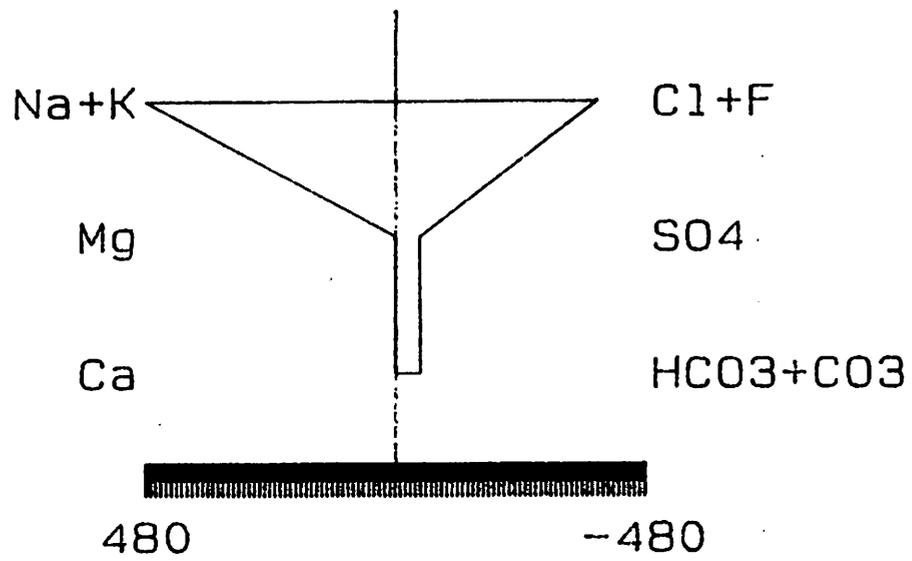
Figure 6
45b

SODIUM CARBONATE AND SODIUM BICARBONATE WATERS

The location of these waters is shown on Plate 1. Most are sodium bicarbonate waters. Of special interest are waters from 27S/37E-31B and 26S/35E-35L. These are sodium carbonate waters with low total dissolved solids. A similar water is present in the 103 foot well by the old house at the south end of the Coso Hot Springs area. This is not to imply that there is any communication between these areas, but to note that there may be an inflow of geothermal waters into the southwest corner of the Indian Wells Valley. It is the writers experience that sodium carbonate and sodium bicarbonate geothermal waters generally indicate low temperature systems. Modified Stiff diagrams of these waters are shown on Figure 7.
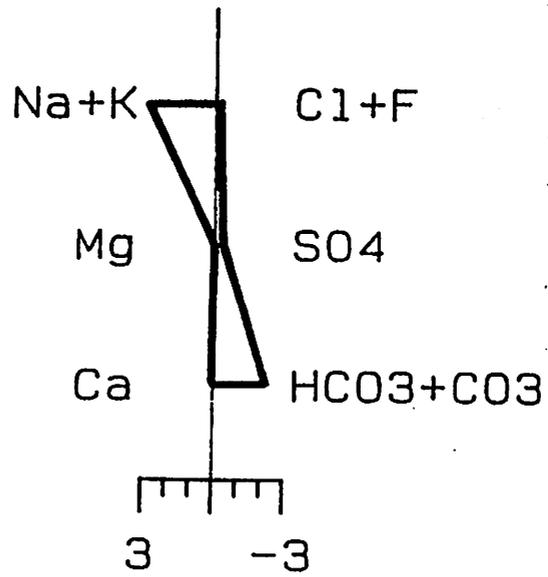
WELL   275/39E-21G   9/17/86

Figure 7

46a

There are several occurrences of sulfate waters in the area. One is Walker Well a calcium-sulfate-bicarbonate type water There is a sulfide type mineralization near Walker Well.

Waters from the Tungsten Peak Mine (Figure 8) and a shallow well at 38E/26S-15Q are of the calcium-sodium-sulfate type. It is believed that the sulfate is from sulfides found in contact metamorphic mineralization (minerals formed where an igneous rock has intruded a sedimentary rock). When the mine was in operation, it made 110 gallons a minute or about 180 acre feet a year.

A shallow seepage from the sewage ponds is a very peculiar sodium-magnesium-sulfate water (sodium sulfate has replaced phosphates in detergents (Figure 9).
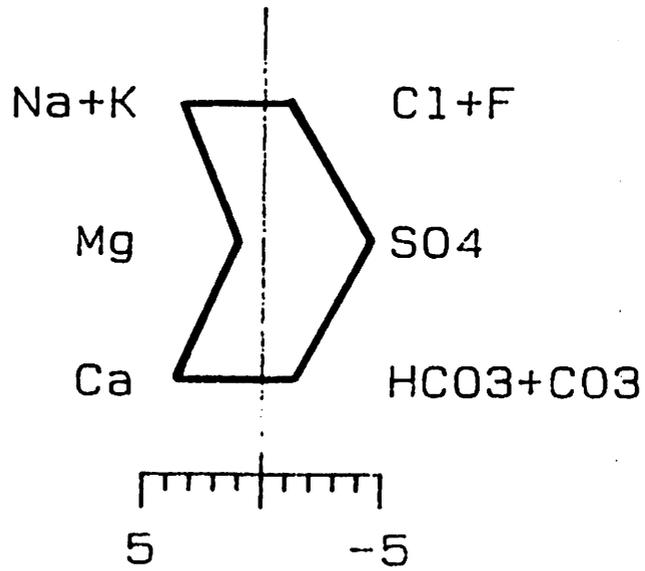
IWV=4 TUNGSTEN PEAK MINE   09-16-86

265/38E-10H

Figure 8

47a

77Ft
Ph 7.3
"Sewage wtr"

Na+K   Cl+F

Mg   SO4

Ca   HCO3+C

188   -188
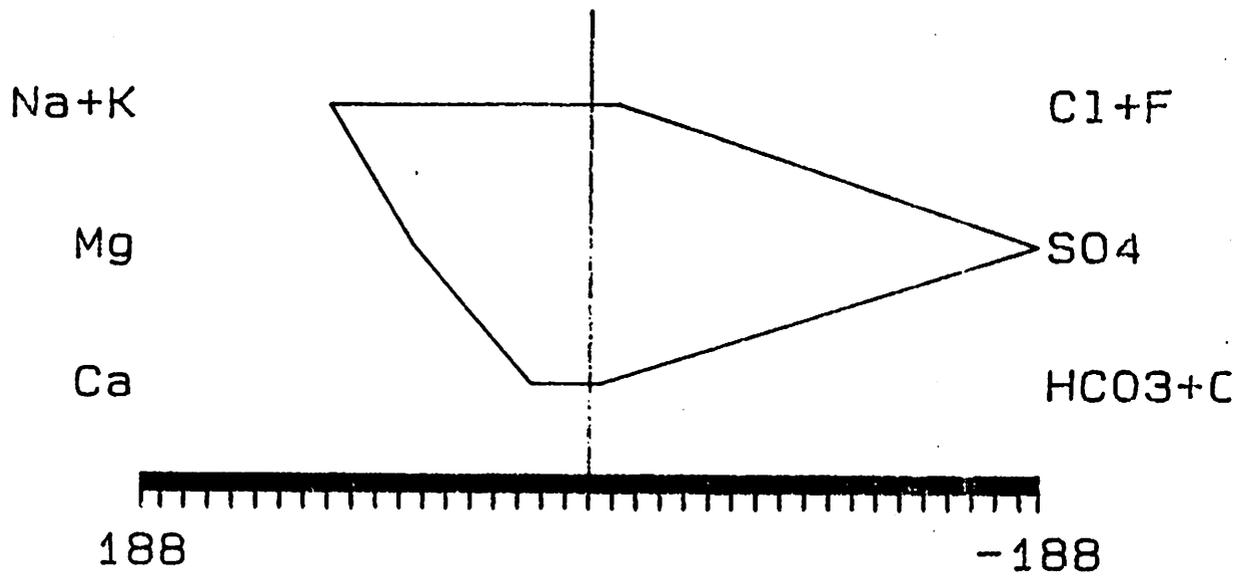
26S/40E-22H2   82-06-08

Figure 9
47b

LITTLE LAKE/LUMBER MILL WATERS

A complex but interesting set of waters is called Little Lake/Lumber Mill Waters. These are found in sampling sites from east of Red Hill in Rose Valley to the area where Brown Road turns from North to west at the site of the former village of Brown in Indian Wells Valley. The waters are of somewhat varying types. The exploration hole at Red Hill was of the Sodium-calcium-bicarbonate type. A well 22S/38E-8C, is of the sodium-calcium-~~potassium~~ _magnesium_-bicarbonate type, Little Lake Spring, is a calcium-bicarbonate-chloride type. The Lumber Mill site is of the sodium-bicarbonate-chloride-sulfate type, and a well in 39E/25S-11P a sodium-bicarbonate-chloride-sulfate water. However, the modified stiff diagrams indicate that the waters are of all of one family. The various cation and anions (except bicarbonate which dominates the anions) must hover around 20 percent of the milliequivalents so they drop in and out of the computer classification. A modified stiff diagram of the Little Lake Spring is shown as Figure 10.

Mixing models did not work well on Little Lake/Lumber Mill site waters. The senior author feels that the calcium and bicarbonate ions are a contribution from alpine waters. The sodium is probably geothermal, and that the magnesium is probably leached from the basalts. The writers feel very strongly that the chloride represents a coso geothermal component. The sulfate is more difficult to evaluate. Its source could be Geothermal (Coso) or deep Rose Valley waters. Isotope data confirm the presence of a geothermal component in the northwestern Indian Wells Valley.

Na+K   Cl+F

Mg   SO4

Ca   HCO3+CO3

13   −13
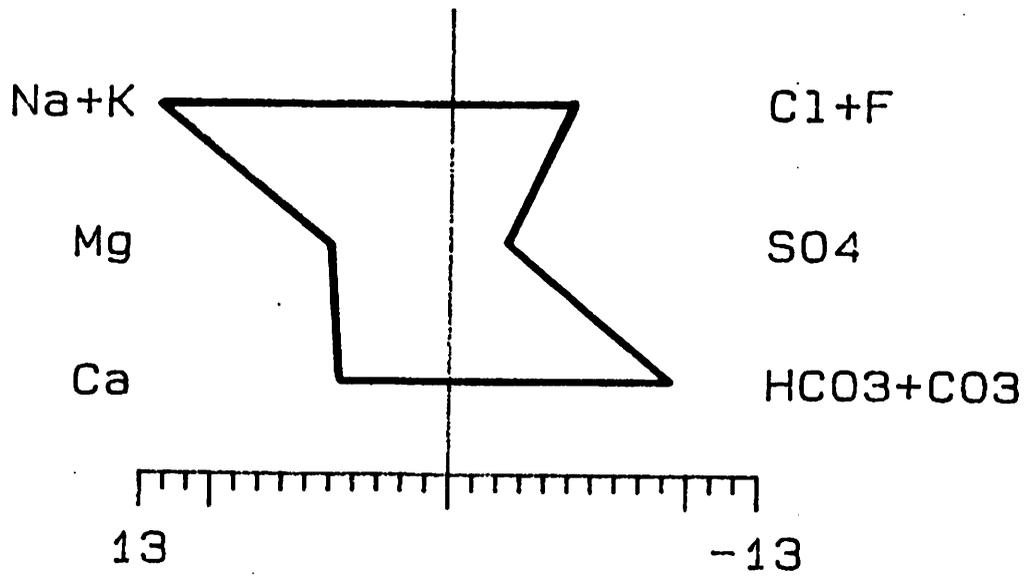
IWV−12   09−18−86 1330   235/28E−17

Figure 10

48a

GROUND-WATERS OF THE INYOKERN INTERMEDIATE

AND RIDGECREST WELL FIELDS

These are complex waters. Sodium is usually, electrically, the dominant cation, although calcium occasionally is. Magnesium contents are low. Bicarbonate is almost always the dominant anion. Chloride is usually the next dominant anion. Sulfate may or may not be present in amounts large enough to appear in the computer classification.

Only order of magnitude results can be determined by mixing models because of reactions of ground-waters with enclosing rocks (solution of mineral, deposition of minerals, ion exchange), transpiration (loss of water from plant leaves), evaporation, and mixing of two or more waters with or without chemical reactions. In using mixing models chloride is often weighted heavily because it is the ion least reactive to surrounding rocks. Also, what waters do you mix? However, it appears that the waters of the Inyokern Field could result from the concentration of Alpine Waters by evaporation and transpiration and mixing with a few percent geothermal brines. The intermediate field would have less geothermal leakage or other sodium chloride leakage. To make the waters of the Ridgecrest field would require a larger geothermal component than to make the usual waters of the intermediate field, but less than that of the Inyokern field.

Chemical analyses of groundwater samples from wells and springs in Township 22 South, Range 37 East (22S/37E) along the Sierra front and at Coso Junction, are similar to groundwater typically found on the crest of the Sierra-Nevada range, located west of Indian Wells Valley. Township 27 South, Range 37 East, includes the south part of Rose Valley and a portion of the east slope of the Sierra range. All of the analyses used from this section came from within Rose Valley itself. This area was included in the study because of its close proximity to Indian Wells Valley and previous studies which suggest water movement from Rose Valley into Indian Wells Valley through the Little Lake area. The shallow waters found in Rose Valley are typically a calcium-sodium-magnesium-bicarbonate type based on the 20% water classi-fication scheme and are a result of direct recharge from the Sierra Range to the west.

Waters from the Rose Valley Ranch house well and irrigation well to the North are of the calcium-sodium-sulfate-bicarbonate-chloride type. The house well is 675 feet deep and the irrigation well 724 feet deep. The irrigation well is capable of producing 2000 gpm without measurable draw down (Phil Hennis, Personnel Communication 1979).

Only one water sample was obtained from Township 22 South, Range 38 East (22S/38E). This sample was taken from and exploration drill hole just east of Red Hill (22S/38E-30K1) and is very similar to water from the Little Lake Sampling sites. The total dissolved solids content of the water from this well

The water taken from the Red Hill site had a high silica content (82 mg/l) implying some connection with geothermal activity.

Township 22 South, Range 39 East (22S/39E), included the Coso Geothermal field in the northwest, part of the Coso Range to the southeast and contains a wide range of water types. The array of differences between the waters can be attributed to geothermal activity, various drilling depths and structural differences throughout the area. The principal geothermal brine is of the sodium-chloride type with about 5000 mg/l total dissolved solids. This area is located to the immediate north of Indian Wells Valley and may be affecting the quality of water in Indian Wells Valley itself via both Coso Valley and Coso Basin. There is some evidence that geothermal waters are entering Indian Wells Valley in the area around Little Lake and the basalt flows. Two observation holes have been drilled in Section 10 (22S/39E-10 D1 and 10C1). The waters encountered in these holes are mixtures of sodium-chloride type geothermal brines and valley underflow which is similar to the alpine waters of Haiwee spring at the head of the valley to the north (21S/39E-10P). The western most well water is about 90 percent geothermal leakage and 10 percent valley underflow, the one to the east is 60 percent geothermal water and 40 percent underflow. The holes are a quarter of a mile apart. The figures which were calculated by a chloride mixing model and checked with mixing models of the other major ions.

The water samples which were collected from T23S/38E-8C, Little Lake Spring, and the well at the site of the lumber mill

51

(now removed) include the well in BC which is 150 feet deep. All are complex multi-cation and anion waters that we have designated the Little Lake multi-cation type.

The northwest corner of Indian Wells Valley lies in Township 23 South, Range 38 East (23S/38E) and includes the areas both north and south of the Little Lake surface water divide. Groundwaters north and south of the divide are very similar in composition with only a slight increase in total dissolved solids to the south. Pumping records from the lumber mill at the bottom of Nine Mile Canyon show virtually no drawdown over the past years even though over 1000 acre feet of water have been removed from the area annually. The recharge rate to the area effected by the pumping must logically be equal to the amount of water being removed from the aquifier by that pumping. Water from the area of the lumber mill is high in dissolved solids and appears to be effected by contributions from geothermal waters. Water to the west of the lumber mill site, towards the Sierra Range water quality can be expected to improve as one leaves the lower valley fill and moves upgradient towards the mountains.

Township 23 South, Range 39 East (23S/39E), lies towards the center of the Naval Weapons Center and includes Airport Lake and, in its southwest corner, part of the basalt flows. No water samples have been analyzed from this area. However, since this township lies directly south of the Coso geothermal field there is a strong possibility that any groundwater found in this area will contain a significant geothermal component.

Township 23 South, Range 40 East (23S/40E), lies east-

northeast of Airport Lake and downgradient from Mountain Springs Canyon and Renegade Canyon. This township is also located within the Naval Weapons Center. No water analyses from the township have been found.

The Mountain Springs Canyon area in the Argus Range lies within Township 23, Range 41 East (T23/R41) and is located to the northeast of Indian Wells Valley. This Township includes Mountain Springs Canyon water analyses. The water of the spring itself is of the calcium-sodium-magnesium bicarbonate-chloride type. Water from the Wild Rose Mine is of the calcium-sodium-magnesium-bicarbonate type.

Township 24 South, Range 38 East (T24/R38) lies directly south of the township containing the Little Lake divide and rests along the Sierras on the western side of Indian Wells Valley. In the northeast and eastern sections of the township, the waters are of the Little Lake/Lumber Mill area type. In the southwest corner of the township the water quality is similar to an "alpine" type water.

Township 24 South, Range 39 East (T24/R39) is located northwest of China Lake Playa and south of the Coso Geothermal Field and includes the southeast section of the basalt flow and a portion of the White Hills. The chemical composition of the waters in this area are mainly sodium-bicarbonate. Waters from this area have a high dissolved solids content. Drilling has been limited in this area due to the quality of water encountered and the location of the township within the confines of the Naval Weapons Center. It is possible that the water from this township has been affected by inflow from the geothermal area, however,

53

there is insufficient data to support this idea.

Township 24 South, Range 40 East (T24/R40), includes the southeast portion of the White Hills and Paxton Ranch to the southeast. The township lies entirely within the confines of the Naval Weapons Center and contains only a few scattered wells. The township seems to be an area of water mixing with many complex types - sodium-chloride-bicarbonate (6A1, White Hills), sodium-magnesium-calcium-chloride (20J1), calcium-sodium-chloride (24EV) and sodium-calcium-magnesium-chloride (36 M1, Paxton Ranch).

Township 24 South, Range 41 East (T24/R41), includes part of the Argus Range on the east side of Indian Wells Valley. Fournier (1979) sampled a spring in Wilson Canyon (Section 13F). The water is of the calcium-magnesium-bicarbonate type.

Township 25 South, Range 38 East, (T25/R38) is located along the western edge of Indian Wells Valley and includes the area northwest of Leliter. Water types vary both with depth and location within this township. Water from wells in sections 13, 14, 23, and 24 are similar to waters from the Los Angeles aqueduct. The waters differ slightly from alpine waters by an increase in magnesium and a decrease in calcium. However, the changes are minor and positive differentiation of water type between alpine and aqueduct waters is very difficult, if not impossible. These alpine waters are probably a direct result of recharge from the Sierra range.

Sand Canyon surface water was sampled from a short stretch of stream in section 7 on August 21, 1986. This water was an

54

alpine type water. since the chemical composition of water may change drastically upon removal from the ground, this sample was not used in the overall investigation of water quality in Indian Wells Valley. However, the stream was reabsorbed into the ground shortly below the sampling site thus providing recharge to the ground-water system in the valley.

A water sample from a deep well in the northeast corner of the township (section 11) has the characteristics of Little Lake type water. Although this lies in the middle of the aforementioned alpine water plume, the deep well probably samples from a lower aquifer influenced by the higher density little lake type water. This sampling site was the furthest southern extent of the pure little lake type water signature.

In Section 36 of this township, a sample was able to be collected from one well at different depths. There was an overall increase in TDS and a great increase in Sulfate with depth. There is no data from the SW corner of this section.

Township 25 South, Range 39 East, is located towards the center of Indian Wells Valley and lies northeast of Leliter. This township lies almost entirely within the confines of the Naval Weapons Center and contains a few scattered wells. Many of the wells were sampled in 1946 with no recent samples taken. There seems to be both Little Lake type waters and alpine waters in this township. Because of limited depth data, it is not possible to interpret the groundwater system in this township.

Township 25 South, Range 40 East (T25/R40), lies to the north of Armitage Field, included much of China Lake Playa, and

Center. Depth control for this section is also very poor yet there appears to be a specific pattern in the quality of the water within this township. The south and southeast edges of the township contain water of a distinctly higher total dissolved solids and are of a sodium-chloride or sodium-bicarbonate type. The western part of the section appears to be influenced by alpine type waters. Yearly samples from a well in section 20, from 1974-1976, (depth 174 feet) show an alpine type water. Water from section 18 also is strongly influenced by alpine water. Perhaps water is coming from the west and forming a plume into this section.

Township 25 South, Range 41 East (T25/R41), includes portions of the Argus Range and the southeast section of China Lake Playa. There are few samples from this township and all of them are from the China Lake Playa area. This water is a sodium chloride type with high total dissolved solids and is probably directly related to evaporation near and in the playa area.

Township 26 south, Range 38 East (T26/R38), lies to the southwest of Leliter and contains water samples form a well located in 15Q, the Tungsten Peak Mine (formerly the Hi-Peak Mine), Indian Wells Canyon, and sites further east in the valley alluvium.

Water from the northern half of the township is primarily a sodium-calcium-sulfate water. This water type extends all the way across the township and in the next township to the east. The water sample collection from the Tungsten Peak Mine came from the third level from a pipe driven into the bedrock in that area.

The wells to the south and east of this area are probably getting water from the bedrock, the bedrock is supplying water the alluvium.

A deep well in section 27 (723 feet) which was sampled in 1974, had a total dissolved solids content of approx. 300 mg/l, a field pH of 6.3 and a sample temperature of 29.5 degrees C. The high temperature and abnormally low pH indicate that this water may have been effected by geothermal activity.

Another indication of geothermal activity in the area comes from a well in the southeast corner of the township. This well had a TDS of less than 200 mg/l, a field temperature of 27.5 degrees C. and a pH of 9.36. The water is of the sodium-carbonate type. Alpine water lies to the west in section 33.

Township 26 South, Range 39 East, (T26/R39) includes the town of Inyokern and the western half of Inyokern Road. Sections 23 and 24 display 2 distinct water bodies above and below an indicated break line around 300-350 feet. Perhaps this is a separating clay layer. In sections 29 and 30 the water bodies are basically all the same.

Township 26 South, Range 40 East (T26/R40) encompasses the towns of China Lake and Ridgecrest, the east half of the Inyokern road and Armitage Field. Samples from this township indicate the presence of two qualifiers. The shallow aquifier, generally less than 50 feet, has been sampled extensively throughout the area and contains over 40 years of records. In the last 10 years or so, there has been an overall increase in total dissolved solids.

This increase seems to be related both spacially and chemically to sewage effluent from the sewage treatment ponds located in sections 13, 14 and 14 a and the golf course, watered by the effluent in sections 23 and 24. There is a limited amount of data available on the deep, generally greater than 500 feet, aquifer but the water quality seems to be relatively constant over time except in the case of one deep well. The two aquifers are probably separated by a structural control such as a clay layer which prohibits or inhibits movement of water between the aquifers.

the water quality of the shallow aquifer varies greatly and spacially. This variation is due mainly to an influx of sodium sulfate water. The spacial relationship between the sewage ponds and the contaminant plume and the fact that the sewage effluent is a sodium sulfate water, points to the sewage lagoons and the watering of the golf course as the principle contributors to the increase in total dissolved solids in the very shallow aquifer. This plume of contaminated water runs NE to SW and can be seen most dramatically on the sulfate contour map generated by computer.

There is a limited amount of data available for the deep aquifer in this area, however, it appears that the quality of water has not changed significantly over time.

Water samples obtained from the north and northeast sections of the township, in the vicinity of China Lake Playa, show an increase in sodium chloride content probably due to the proximity of China Lake.

Township 26 South, Range 41 East, (T2/R41) lies to the east of China Lake and includes Lone Butte and Salt Wells Valley. Water samples from this township are of a high total dissolved solids, sodium chloride type and are not suitable for domestic or irrigation use. These waters are very similar to those found just to the northwest of the township in the China Lake playa area and to waters pumped from the Leslie Salt Company wells located in 26S/43E-17D.

Township 27 south, Range 38 East (T27/R38) lies in the southwest corner of Indian Wells Valley and includes Armistead and Freeman Junction. There are few wells located in this township but those with water quality analysis in the western sierrian portion indicate that the water is of the alpine type. Water from section 31 D is of the sodium-carbonate type with a total dissolved solids of 196 mg/l and a flouride content of 4.6 mg/l.

Township 27 South, Range 39 East (T27/R39) is located just north of the El Paso Mountains. Many of the wells in 27S/40E have waters of the sodium-chloride type although there are wells with other types of water (sodium-chloride-bicarbonate, with 452 mg/l TDS, 27S/40E-1D). Both of these types of water could represent geothermal leakage. The second type cwould be a mixture of a sodium-chloride and a sodium-sulfate geothermal brine. Haystack peak, to the east, exhibits snow melt. That is, after a light to moderate snow, Haystack peak will be snow free while the surrounding areas are snow covered. this in an indication of

geothermal leakage. Well defined snow melt areas occur at Coso

and Roosevelt Geothermal Fields. Roosevelt is near Milford,

Utah. The waters of 27S/41E may be leakage from the Haystack

system entering the township over clay layers in the alluvium.

CHANGES OF WATER QUALITY WITH DEPTH

Water quality is a relative term. What is good quality depends upon the use. What would be excellent culinary (drinking, domestic use) water would indeed be poor quality water for the producer of salt. High quality water in a hot water-type geothermal reservoir would have a high temperature and low total dissolved solids. Feed water for the boilers should have low total dissolved solids. However, most people consider water quality in terms of culinary waters, irrigation water, and water for livestock where the gross measure of quality is total dissolved solids but certain trace elements, for instance arsenic in culinary water, boron in the case of irrigation water are also important. Hem (1985, pp. 210-215) cites EPA standards for culinary waters and gives a good discussion of water quality in relation to use including industrial uses. In this section water quality is referred to in the gross sense—increase of total dissolved solids.

Water quality may increase, decrease or remain constant with depth. Some examples of water quality decreasing slightly with depth include the Little Lake Lumber Mill waters. The spring at Little Lake has a dissolved solids content of 1064 mg/L while the Lumber Mill site well with a depth of 611 feet has water of 1220 Mg/L. A deep well just inside the base (26S/39E-21R) near the Inyokern substation had a dissolved solids content of only 215 Mg/L (residue at 180 c) and calculated total dissolved solids of 221 Mg/L. Figure 10 shows the dissolved solids content

of this deep but very pure water and the shallower wells around it (Figure 10). Figures 11 and 12 show variations of water quality in some wells of varying depth within specific sections.

CHANGES OF WATER QUALITY WITH TIME

There are two schools of thought on the ground-water system of the Indian Wells Valley. One school, whose strongest proponent is Dr. Pierre St. Amand (1986), is that the ground-water system is a closed basin and that losses from it are limited to consumptive use, evapo-transpiration, and evaporation from China Lake Playa. By making the assumption that the values of the losses at the playa equals the recharge, one can then present strong arguments, that the users of water in Indian Wells Valley are "mining" water and that the future of the valley is indeed quite bleak.

The second school, whose most vocal proponent is Dr. C.F. Austin, acknowledges the surficial losses given above but makes considerably different assumptions on subsurface recharge and losses and believes that the ground-water system is open, that recharge exceeds the surface losses, and that Indian Wells Valley is actually contributing water to both Searles Valley to the east through the underflow beneath the Argus Range and to the Koehu Lake-Cantil area to the south through underflow beneath the El Paso and Black Range areas.

The writers evaluation of what geochemical data contributes to the solution of the above dilemma, both factual and hypothetical, will be given in the section on discussion, conclusions and recommendations.
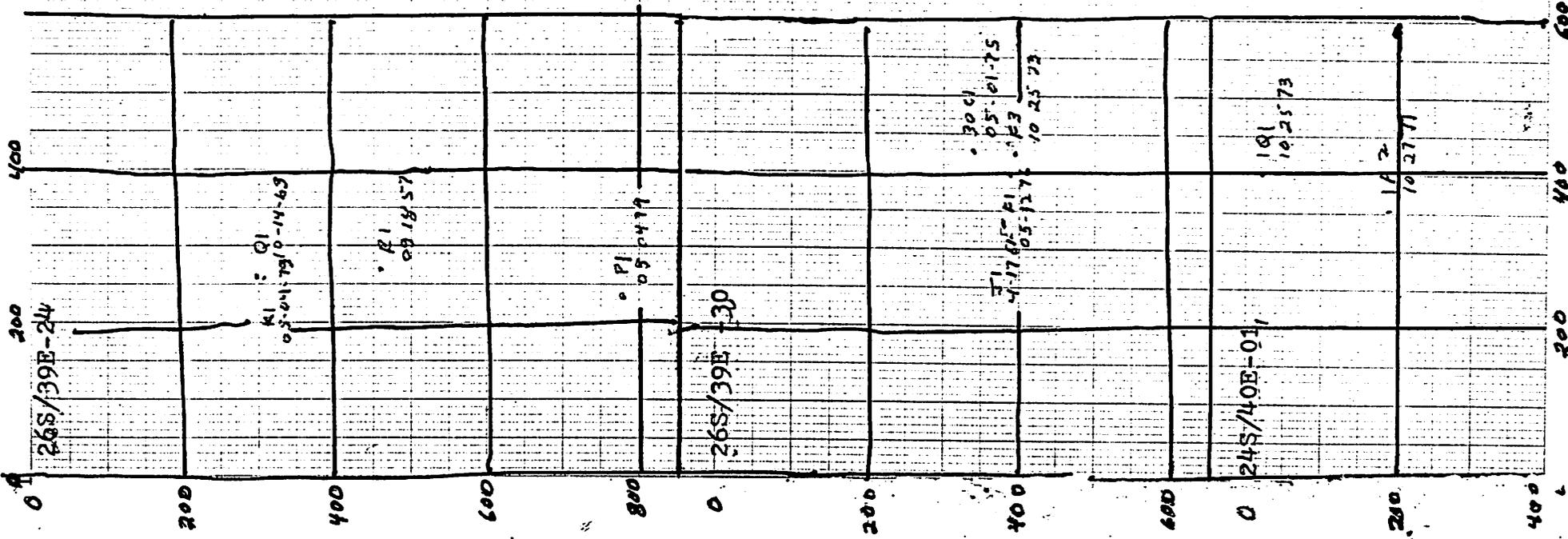
Figure 12 Total Dissolved Solids vs Depth in wells in the sections noted.

Total Dissolved Solids - mg/1
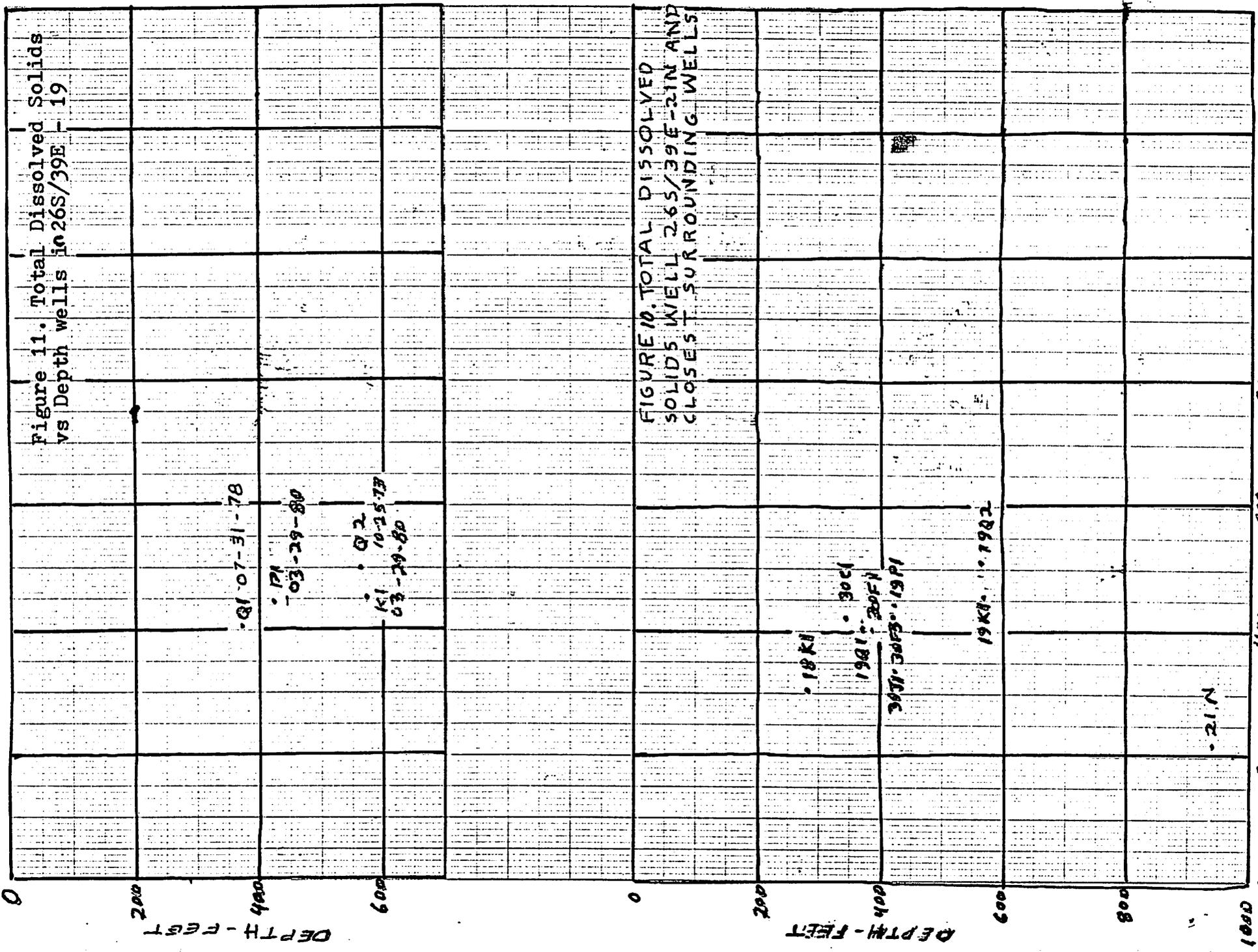
Figure 11. Total Dissolved Solids
vs Depth wells in 26S/39E – 19

FIGURE 10. TOTAL DISSOLVED
SOLIDS WELL 26S/39E-21N AND
CLOSEST SURROUNDING WELLS

TOTAL DISSOLVED SOLIDS - mg/l

DEPTH - FEET

DEPTH - FEET

Q1 - 07-31-78

P1
03-29-80

Q2
10-25-73
K1
03-29-80

18K1

1981 · 30L

1981 · 20FN

36TJ · 30J 1146

19K1 · 1981 · 1922

21N

The closed basin school is very concerned that high usage will cause significant lateral migration of water from areas of possibly poor water quality, hence degrading waters of where deep pumping depressions occur. Of special concern is the possible migration of sodium chloride waters into the Ridgecrest well field from the southern and southeastern parts of the city.

In 1975 Warner stated (ABS) "That in 1972 the dissolved solids concentration in the ground water in some areas is increasing slightly, but where this has occurred, it is not yet serious."

In 1987, the U.S. Geological Survey made a proposal to the Indian Wells Valley Cooperator Meeting, for funding, on the basis of water level decline and water quality degradation. They documented this with five graphs.

The writers of this report had computer print outs of the various ion concentrations of all sample sites used by the U.S.G.S. with serial print outs and they tried to estimate changes of quality with time visually. This did not prove satisfactory.

The approach finally taken was to convert the time intervals to days and to calculate total dissolved solids by summing the major components — those with concentrations reported in mg/l not micrograms/l. There is considerable scatter, probably due to normal variance of analyses, slight variation in the components, mistakes in analyses or reporting, etc. Regression lines (best fitting lines mathematically) were then calculated for the data. If the fit was good (goodness-of-fit can be calculated) and if

the slope is positive the quality of water was decreasing, if
negative, increasing (doubtful), or if zero remaining constant.
This approach was partially successful. It was often not
however, because of poor curve fits because of the scatter noted
above.

Except for a few wells in the Ridgecrest are, and the
shallow waters of "area R" on NWC being contaminated by seepage
from the sewage ponds, the writers opinion is that the quality of
water in the Indian Wells Valley is changing little if any at
most wells.

SUMMARY, DISCUSSION, CONCLUSIONS,
AND RECOMMENDATIONS

The obvious conclusion one can draw from this study is that
the geochemistry of ground-waters in Indian Wells Valley is very
complex. Using a computer classification of waters by principal
cations and anions, of 254 water types possible under the
classification scheme, some 55 occur in the Indian Wells Valley,
Rose Valley, the Sierras, the Coso and Argus Mountains, the Coso
Geothermal area, Salt Wells and Poison Canyon.

By lumping similar waters together, the following major
ground-water flow cells can be delineated:

Sodium-chloride waters - Coso Geothermal Field, China
Lake Playa, Southeastern Ridgecrest, Salt Wells, and
Poison Canyon.

Sodium-carbonate waters - Coso Geothermal (one site).
SW-IWV two sites are noted. This very possibly indi-
cates geothermal inflow into the northwest part of
the valley.

Sodium bicarbonate waters occur in a horse shoe shaped

64.

area from Inyokern up to the dividing line between T24S and T25S and back down to Michelson Laboratory. On the east side of the horse shoe an area of mixed waters - sodium-bicarbonate-chloride occurs between the sodium chloride brines of China Lake Playa and the sodium-bicarbonate-waters, indicating mixing around the Playa.

Sulfate waters of various types - Walker Well in the Sierras, the Tungsten Peak Mine, a well in 26S/38E-15, some wells about 2 miles north of Inyokern, and Deep Rose Valley waters. The source of the sulfate may be oxidation of sulfides formed by mineralization (the Walker Well and Tungsten Peak Mine), or geothermal. *occurring in Lake sediments*
The very shallow waters in "area R", Naval Weapons Center are contaminated with sodium sulfate rich waters from the sewage ponds.

Alpine waters - waters characteristic of the mountainous regions. Calcium-sodium-magnesium-bicarbonate waters with low total dissolved solids.

Red Hill/Little Lake/Lumber Mill Site waters of somewhat variable classification by computer, but which generally give similar modified stiff diagrams. Calcium-(sodium-magnesium)-bicarbonate-chloride-(sulfate) waters. Probably a mixture of Alpine, Deep Rose Valley and Geothermal waters.

Ground-waters of the Inyokern intermediate, and Ridgecrest well fields. Sodium is usually the dominant cation although sometimes calcium. The magnesium content is usually low. Bicarbonate and chloride are the important anions. These waters could be formed by concentrating Alpine waters by transpiration and evaporation and mixing with small amounts of geothermal waters. The waters of the Argus Range are sodium-calcium-magnesium-bicarbonate waters.

Water quality may degrade, improve, or remain constant with depth. In most cases water quality has changed too little with time to be identifiable. Exception are a few wells in the Ridgecrest area. Degradation may represent vertical leakage from low temperature geothermal reservoirs in bedrock. Other possible areas of geothermal inflow are the southwest corner of the valley and the Haystack Peak area of the Spangler Hills.

The growing realization of probable thrusting with

65

associated lystical faulting in the Sierras, the Coso Range and the Argus Range has many implications on interpretation of the ground-water geochemistry. The hanging wall of a thrust sheet would probably be an aquatard - a barrier to ground water flow. The footwall is probably badly sheared. The crushed foot wall of a thrust in the Oquirrh Mountains of Utah is know to the operating geologists of the Bingham Canyon Copper Mine (formerly Kennecott ~~Copper~~ Copper Company now British Petroleum Minerals) as the "chaotic area". Thus the footwall of a thrust could well be a major aquifier while lystical faults and dish shaped thrusts (Silver, 1986) could serve as major water collectors in the hangwall system. Fracture permeability can be very high. As examples, in driving the San Jacinto tunnel in granites flows of up to ~~16000~~ 16200 gpm occurred when major faults were crossed (Procter, White, and Terzaghi, 1946, pp 27-28) ~~(Gibbons)~~ a geothermal well (54-3) in the Roosevelt field near Milford, Utah, producing from the dome fault zone with a diameter of just over nine inches had an initial mass flow of 1,500,000 pounds of steam and water an hour (approximately 3000 gpm). (R. Lenzin, personal communication, 1976). Thus water could be entering the Indian Wells Valley from beneath thrust plates of the Sierras.

Another aspect of possible thrusting in this region is that the lower plates are believed to be sediments (Erskine, personal communication, 1980). Also the basement under Indian Wells Valley could be sediments. Mifflin (1968) in a paper entitled Declination of Ground Water Flow Systems In Nevada shows there are large interbasin flows of ground-water between basins, under

mountain ranges in Nevada. The NWC Rocketeer, noted that springs

at the Death Valley Onyx Mine in the Panamint Valley make 60,000

gallons a day or 70 acre-feet a year. This may be an example of

such underflow beneath the ranges. It is highly probable that

there is interbasin leakage from Indian Wells Valley through the

Poison Canyon area and under the Argus Range as a whole into

Searles Valley. It is also highly probable that waters are

entering Indian Wells Valley from the bedrock basement. There

are good indications - measured temperatures, pseudo-temperature

gradients, and chemical geothermometers - that there is

geothermal leakage into the valley west and just north and south

of the main gate of the Naval Weapons Center. The Haystack Peak

which exhibits a very anomalous pattern snow melt pattern may

represent another source of geothermal leakage into the valley.

These geothermal plumes may be a partial cause of some loss of

water quality. Water chemistry indicates probable geothermal

leakage into the south-western portion of the valley recognizing

that the Little Dixie area is a deep circular sub-basin,

seaparate from the Indian Wells Valley. The fact that a complex

water occurs all the way from Red Hill in Rose Valley to the

Brown Road turn in Indian Wells Valley indicates a major flow of

ground-water from Rose Valley into Indian Wells Valley. The

lumber mill used about 1,000 acre-feet of water a year (C. F.

Austin, personal communication to Whelan, June 1988). When

collecting a sample there millworkers told Baskin that there was

very little draw down. Lower Little Lake Spring flows about one

cubic foot a second or over 700 acre feet per year. Most of this

infiltrates. These facts indicate that the estimate of 45 acre-

feet a year entering Indian Wells Valley from Rose Valley by Bloyd and Robson (1971) is absurd. The 10,000 acre-feet estimate of Thompson (1929) seems more reasonable (and could be conservative). Another source of recharge that has been neglected is leakage from the old aqueduct, which Dr. C. F. Austin estimates to be about 4,000 acre-feet in Indian and Rose Valleys' (personal communica-tion to Whelan, June 1988). Another source of recharge usually not considered is water from the Sierrian granites and metamorphics. Faults, joints, and even micro-fractures all contribute to permeability. The Tungsten Peak Mine, when last in operation, (and never completely dewatered) made 110 gpm of water (Dr. C. F. Austin, personal communication to Whelan, June 1958) or 170 acre-feet a year. There is another source of this type of calcium-sodium-sulfate water, a shallow well in 26S/38E-22D. $\P$ At the present time the writers feel that enough usable chemical data are now available to enable interation of flow data with structure data. After the geochemical data have been integrated with the structural and other data there may they be additional critical sites that should be sampled and it might be desirable to obtain Tritium ages on some of the fundamental water types.

REFERENCES CITED

Autsin, C. F. and Moore, J. L. (1987). Structural Integration of the Coso Geothermal Field. NWC TP 6841, 24 p.

Austin, C. F. and Pringle, J. K. (1970). Geologic Investigations at the Coso Thermal area. NWC TP 4878, 40 p.

Bailey, P. (1946. Report on water supply of Indian Wells Valley, Kern Count, California to the Lands Division, Department of Justice. United States. V. 529, 532, Acres of land in the Counties of Inyo, Kern, San Bernardino, etc. et al, no. 2472-H civil.

Banta, R. L. (1972). Ground-Water Conditions During 1971 in Indian Wells Valley, California. U.S.G.S. Open-File, 9 p.

Barenbrock, C. (1987). Ground-Water Data for Indian Wells Valley, Kern, Inyo, and San Bernardino Counties, California, 1977-84. U.S.G.S. Open-File Report 86-315, 56 p.

Bureau of Land Mangement (1980) Proposed Leasing Within the Coso Known Geothermal Resource Area, Final Environmental Impact Statement, pp. 2-1 through 2-7.

Bloyd, R. M., Jr. and Robson, S. G. (1971). Mathematical Ground-Water Model of Indian Wells Valley. U.S.G.S. Open-File 36 p.

Buwalda, J. P. (1944). Underground Water Supply in Indian Wells Valley, Kern County California, to the Lands Division, Department of Justice. United States v. 529, 532 Acres of Land in the Counties of Inyo, Kern, San Bernardino, etc., et al., no 2472-H Civil.

Duffield, W. A. and Bacon, C. R. (1981). Geologic Map of the Coso Volcanic Field and Adjacent Areas, Inyo County, California.

Dutcher, L. C. (1969). Data on Water Wells in the Fremont Valley area, Kern County, California. U.S.G.S. Open-File Report, 125 p.

Dutcher, L. C. and Moyle, W. R., Jr. (1973). Geologic and Hydrologic Features of Indian Wells Valley, California. U.S.G.S. Water Supply Paper, 2007, 30 p.

Fournier, R. O. (1981). Application of Water Geochemistry to Geothermal Exploration and Reservoir Engineering. In Geothermal Systems E.D. by L. Rybach and L.J.P. Muffler, Wiley, pp. 113-118.

Fournier, R. O. and Thompson (1980). The Recharge Area for the Coso, California, Geothermal System Deduced From 2O and 2180 in Thermal and Non-Thermal Waters in the Region. U.S.G.S. Open-File Report, 80-454, 24 p.

Hem, J. D. (1985). Study and interpretation of the Chemical Characteristics of Natural Water. U.S.G.S. Water-Supply Paper, 2254, 263 p.

Kunkel, F. C., Chase, G. H., and Hiltgen, W.J. (1954). Tables of selected Data to Accompany U. S. Geological Survey Report on Geology and Ground Water of the Inyokern Naval Ordnance Test Station and Vicinity. U.S.G.S., Open-File Report, 115. p.

Jenkins, O. P. (1962). Geology Map of California, Trona Sheet. California Division of Mines and Geology.

Koehler, J. H. (1971). Ground-Water Conditions During 1970 in Indian Wells Valley, California. U.S.G.S. Open-File, 19 p.

Kunkel and Chase, (1955). Geology and Ground Water of the Inyokern Naval Ordnance Test Station and Vicinity, China Lake, California. U.S.G.S. Report for the Navy, 166 p.

Kunkel, F. and Chase, G. H. (1969). Geology and Ground-Water In Indian Wells Valley, California. U.S.G.S. Open-File Report, 84 p.

Kunkel, F. and Worts, G. F., Jr. (1953). Progress Memorandum on the Ground Water Investigation and Suggested Test-well Drilling Program for the Inyokern Naval Ordnance Test Station, U.S.G.S. typewritten report for release to the Navy only.

Lamb, C. E. and Downing, D. J. (1978). Ground-Water Data, 1974-76, Indian Wells Valley, Kern, Inyo, and San Bernardino Counties, California. U.S.G.S. Open-File, 78-335.

Lee, C. H. (1913). Ground-Water Resources of Indian Wells Valley, California. Calif. State Conservation Commission Report, pp. 401-429

McKee, J. E. and Wolfe, H. W. (1963). Water Quality Criteria. California State Water Quality Board Publication 3-A, 548 p.

Mifflin, M. D. (1968). Dilineation of Ground Water Systems in Nevada. Center for Water Resources Research, Desert Research Institute, University of Nevada, Reno. Technical Report Series H-W, Hydrology and Water Resources Publication No. 4, 53 p. plus appendices.

Moyle, W. R., Jr. (1975). Summary of Basic Hydrologic Data Collected at Coso hot Springs, Inyo County, California. U.S.G.S. Open-File Report, 77-485, 93 p.

Naval Weapons Center (1972). Map of Naval Weapons Center, N3530-W11751/45X45.

Nilsen, T. H. and Chapman, R. H. (1971). Bougher Gravity map of California, Trona Sheets. California Division of Mines and Geology.

Norris, Robert M., and Webb, Robert W. (1976) Geology of Calif-
ornia. New York, N.Y., John Wiley and Sons, 365 pp.

Pederson, R. L. (1985). Geochemical Studies in the Bighorn
Basin, Wyoming. Unpublished M. S. Thesis, University of Utah,
pp. 37-45.

Silver, Leon T. (1986). Evidence for Paleogene Low-Angle
Detachment of the Southern Sierra Nevada. Pasadena, Calif.,
Division of Geological and Planetary Sciences, California
Insitute of Technology.

Spane, F. A. Jr. (1978). Hydrogeologic Investigation of Coso Hot
Springs, Inyo County, California. Naval Weapons Center Technical
Report 6025, 56 p.

St.-Amand, P. (1986). Water Supply of Indian Wells Valley,
California. NWC TP 6404, 71 p.

Thompson, D. G. (1929). The Mojave Desert Region, California.
U.S.G.S. Water Supply Paper, 578, pp. 144-185.

U.S. Geological Survey (1987). Project Proposal for Evaluation
of Ground Water Quality in Indian Wells Valley, California.
U.S.G.S. 11 p.

Warner, J. W. (1975). Ground-Water Quality in Indian Wells
Valley, California. U.S.G.S. Water Resources Investigations 8-
75, 59 p.

Whistler, J. T. (1923). Report on Indian Wells Valley an
Freemont Valley, California. California State Division of Water
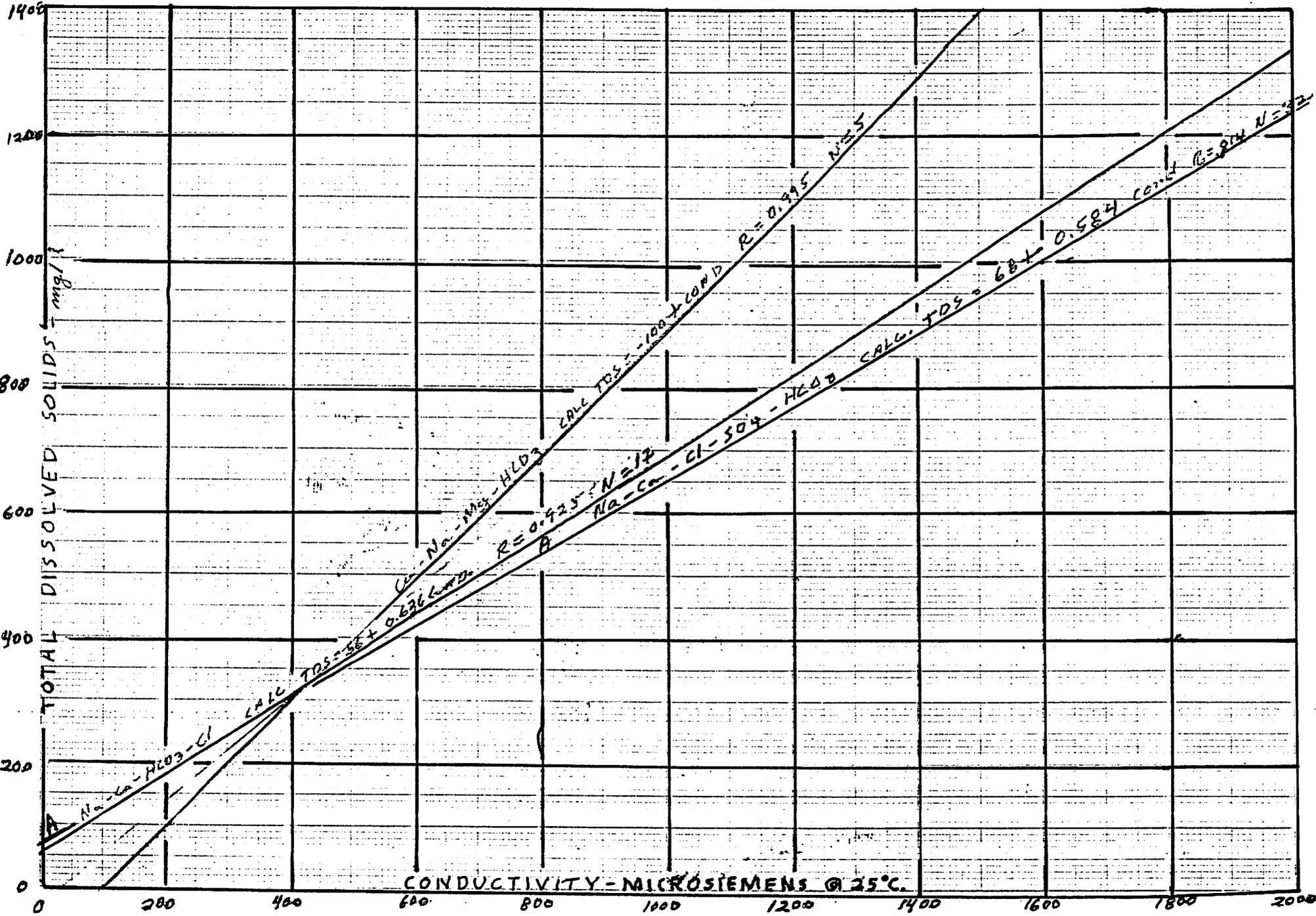Rights. Mimeographed report 83 p.

Wilcox, L. V., Hatcher, J. T. and Blair, G. Y., (1951). Quality
of Water of the Indian Wells Valley. U. s. Salinity Lab Report,
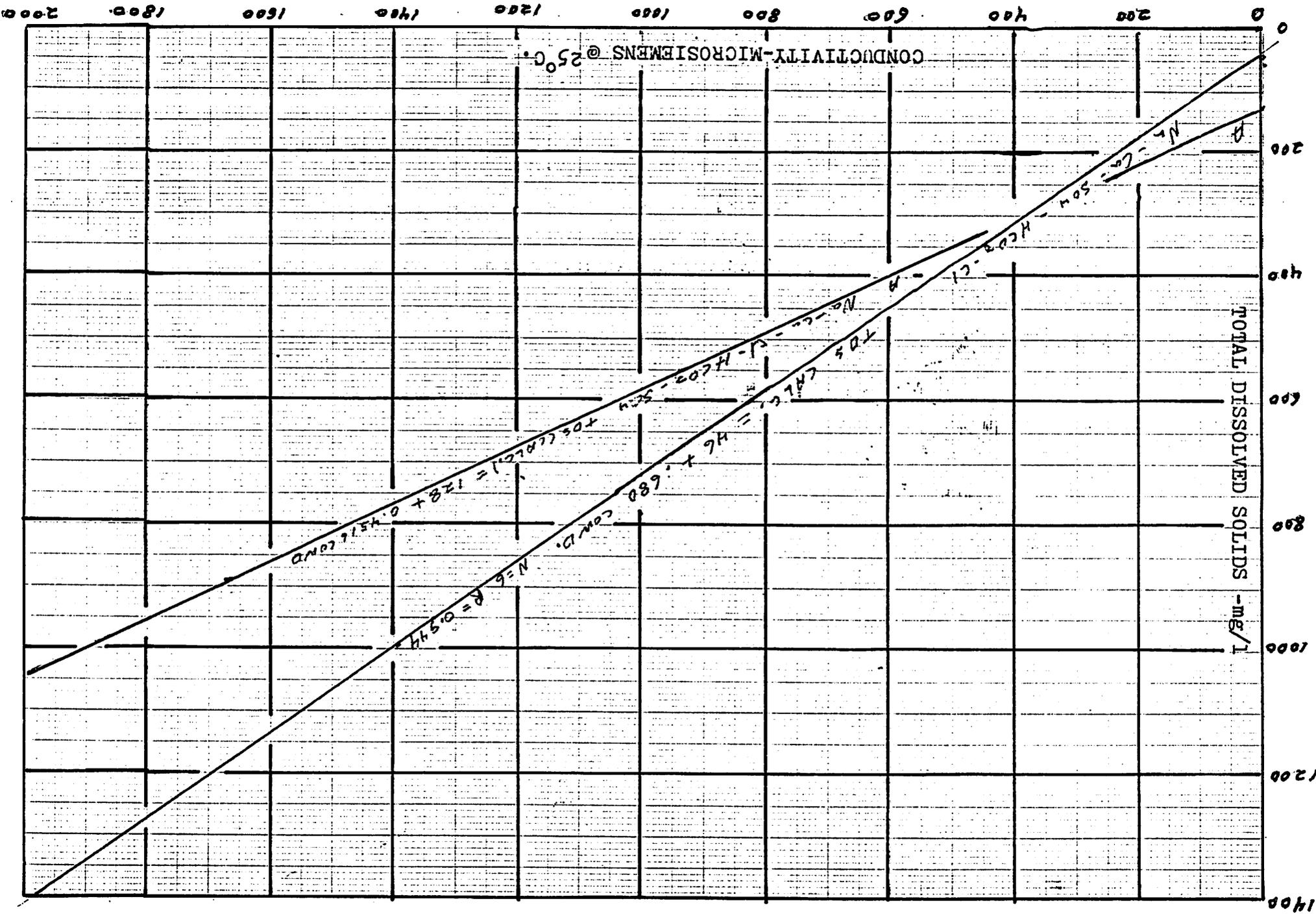No. 45, 33 p., 11 tables.

Zbur, R. T. (1963). Geophysical Investigation of Indian Wells
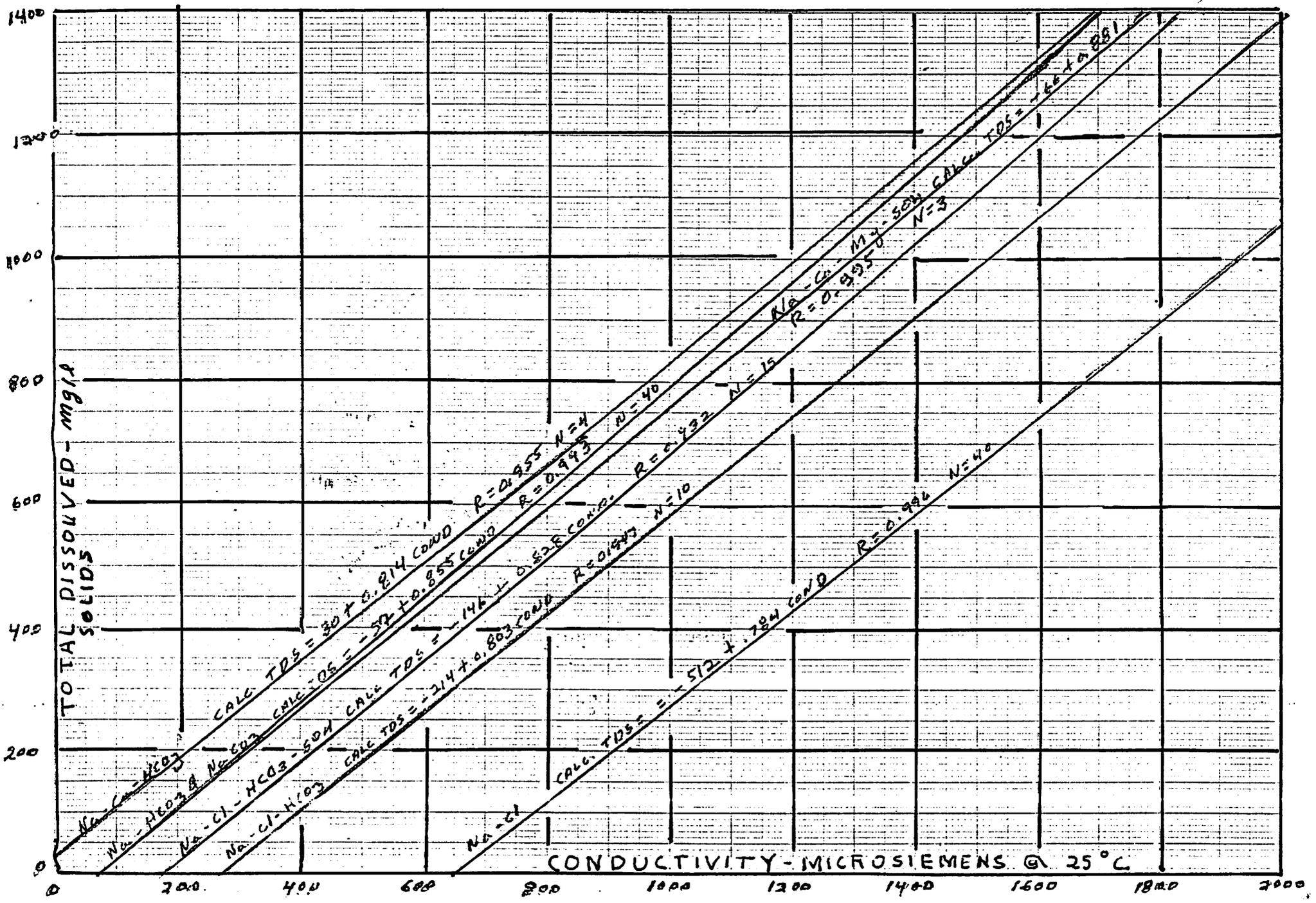Valley, California. NOTS TP 2795, 98 p.

Procter, R.V., White, T.L. and Terzaghi (1946), Rock Tunneling with Steel Supports, Commercial Shearing and Stamping Co., Youngston, Ohio, pp 27-28.

CONDUCTIVITY VS. TOTAL DISSOLVED SOLIDS CURVES

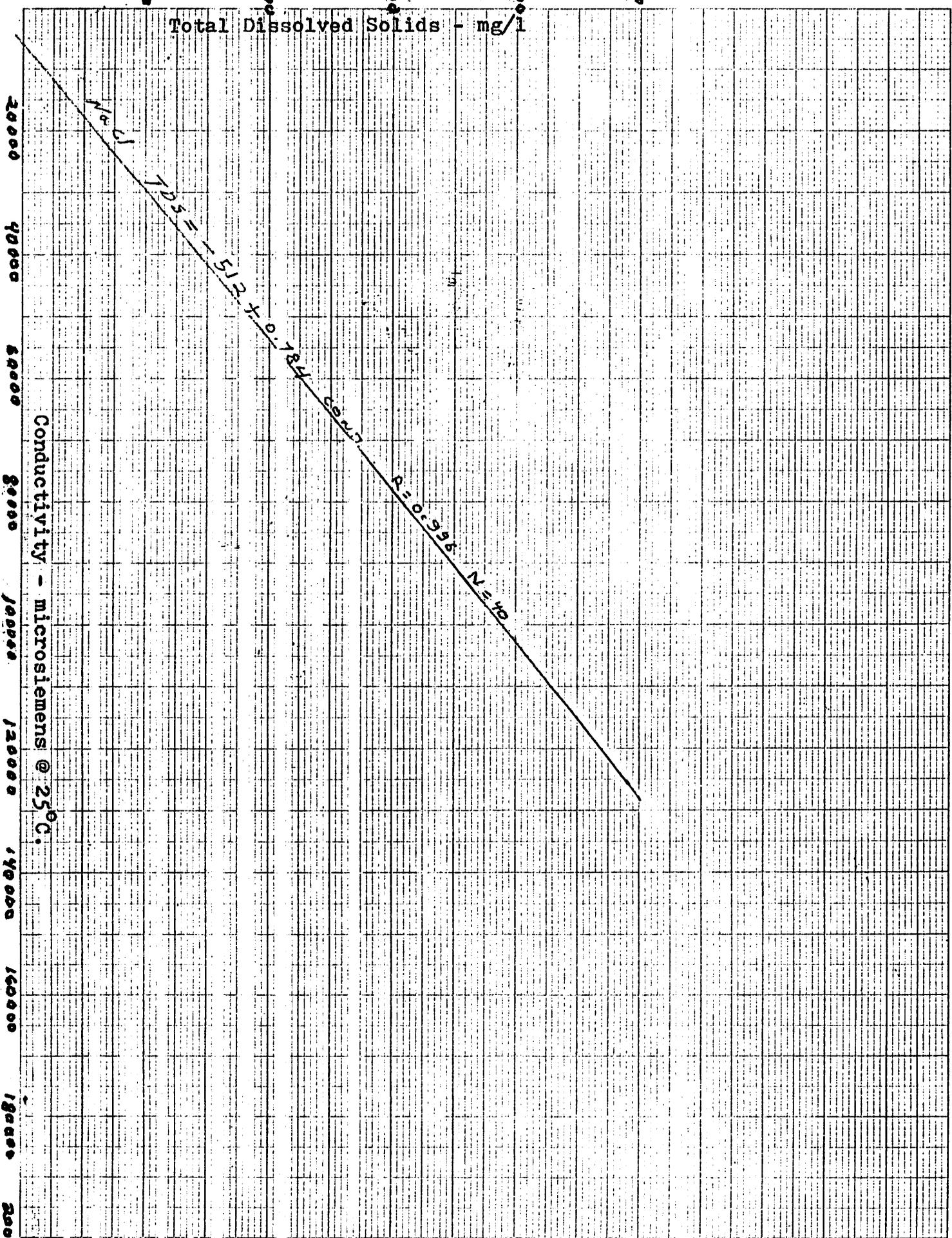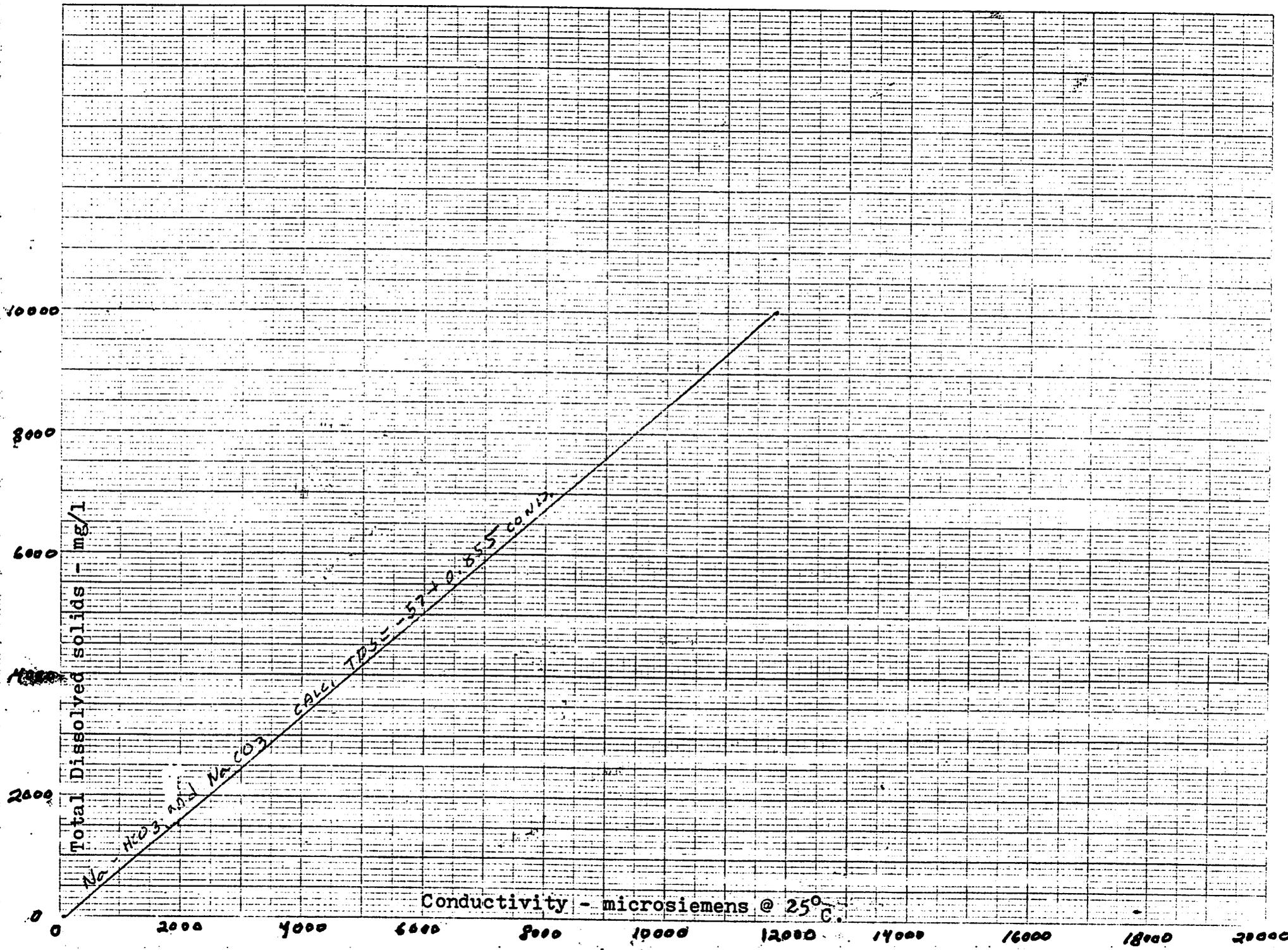TOTAL DISSOLVED SOLIDS —mg/l

CONDUCTIVITY-MICROSIEMENS @ 25°C.

$Na - HCO_3$ Calc. TDS = 0.583 N = 26

Na_2SO_4 Calc. TDS = 0.702 N = 26 R = 0.973

$Ca(HCO_3)_2$ Calc. TDS = $-33.4 + 0.618$ cond. R = 0.830 N = 26

Calc. TDS = $-81 + 0.705$ cond. R = 0.973 N = 26

$Na - Na_2SO_4$ Calc. TDS = $-21.9 + 0.834$ cond.

$Ca - Na_2SO_4$ Calc. TDS = $-21.9 + 0.834$ cond.

CONDUCTIVITY — MICROSIEMENS @ 25°C.

CONDUCTIVITY-MICROSIEMENS @ 25°C

0   200   400   600   800   1000   1200   1400   1600   1800   2000

TOTAL DISSOLVED SOLIDS -mg/l

0   200   400   600   800   1000   1200   1400

$Na - Ca - SO_4 - HCO_3 - Cl$ $-A$

$Na - Ca - Cl - HCO_3 - SO_4$ $-B$

TDS CALC.= (COND)(0.680) + 128 $R = 0.9454$

$Na - Ca - SO_4 - HCO_3 - Cl$ $-A$

TDS CALC.= 0.680 x 74 + COND.   N=6   R= 0.44

TOTAL DISSOLVED SOLIDS mg/l

CONDUCTIVITY · MICROSIEMENS @ 25°C

$N = HCO_3 · Cl · SO_4$

TDS CALC. = 60 + 0.64 CCOND

$R = 0.999$ $N = 10$

Total Dissolved Solids - mg/l

$TDS = -512 + 0.784 \text{ (cond)}$

NaCl

$R = 0.996 \quad N = 40$

Conductivity - microsiemens @ 25°C.

K•E 10 X 10 TO ½ INCH • 7½ X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1472

Total Dissolved solids – mg/1

Conductivity – microsiemens @ 25° C.

Na HCO3 and NaCO3 CALC' TDS = -57 + 0.855 COND

10000

8000

6000

4000

2000

0

0   2000   4000   6000   8000   10000   12000   14000   16000   18000   20000

Eastern Kern County Resource, Conservation District Samples
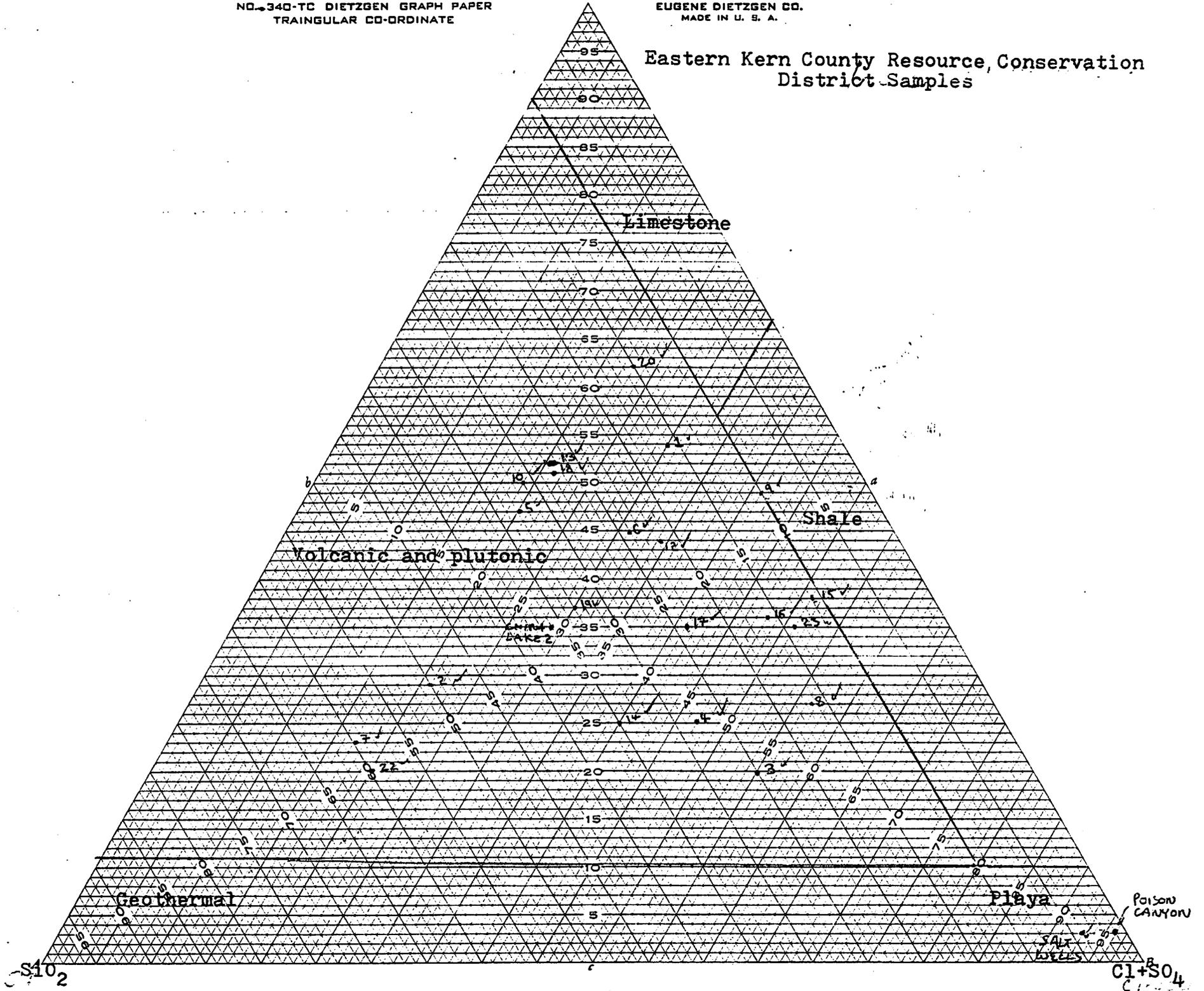
NO. 340-TC DIETZGEN GRAPH PAPER
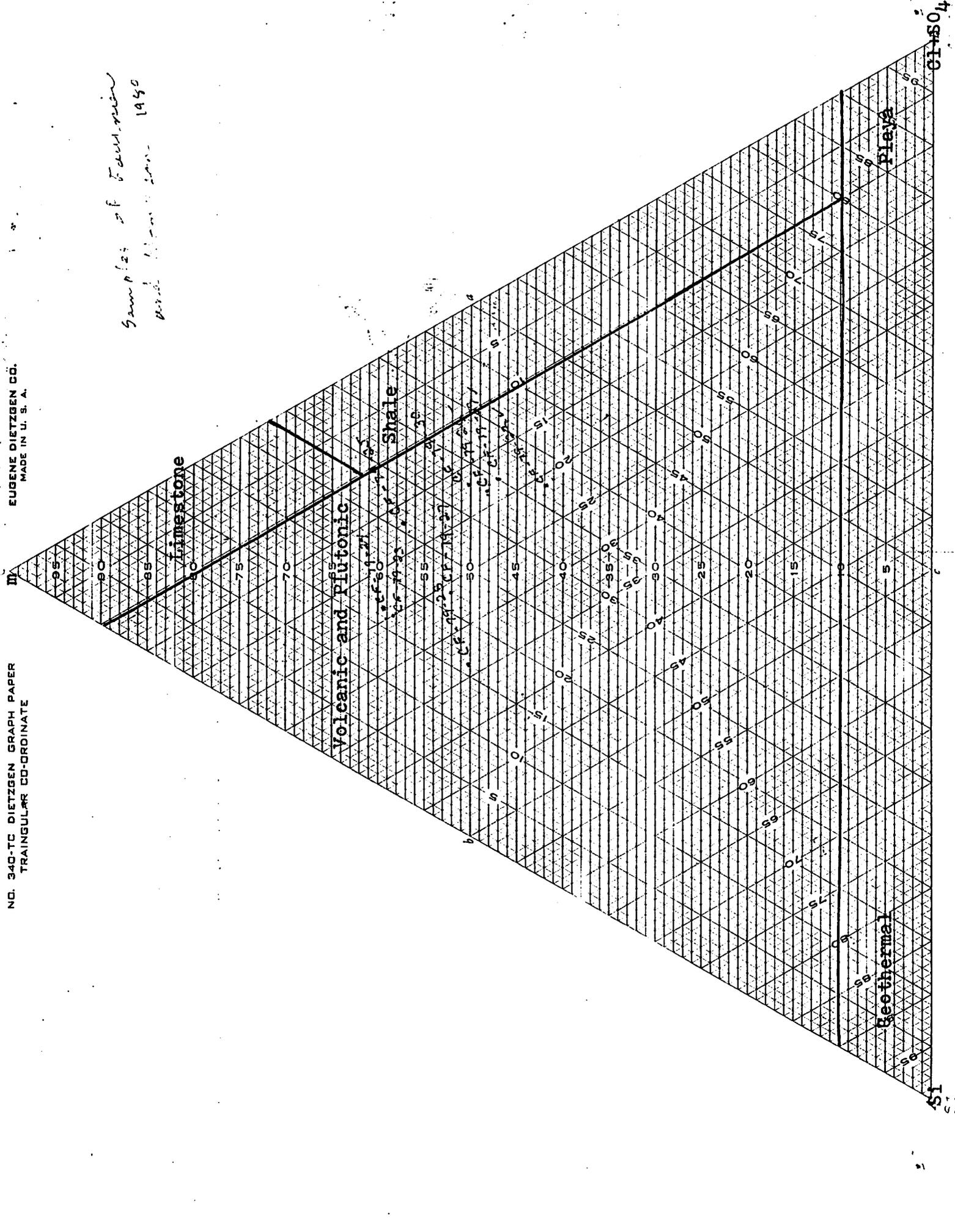TRAINGULAR CO-ORDINATE

EUGENE DIETZGEN CO.
MADE IN U. S. A.

Alk

Cl+SO₄

SiO₂

Limestone

Shale

Volcanic and Plutonic

Playa

Geothermal

95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5

Alk

Cl+SO$_4$

Si

Samples of formation
water ... 1450

Limestone

Shale

Volcanic and Plutonic

Playa

Geothermal

CF-11-24
CF-19-22
CF-24-25 CF-19-27
CF-17-??

Alk

U.S.G.S. Samples

Limestone

Volcanic and Plutonic

Shale

Geothermal

Playa

Si

95 90 85 75 70 65 55 50

5 10 15 20 25 30 35

5

IWV

Eastern Kern County Resource
Conservation District Samples

Alk

Chlor

SO4

Carbonates and Sulfates

Poison Canyon

Salt Well