THE YESO AQUIFER OF THE MIDDLE PECOS BASIN (*)

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by

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(*) Based on research performed by A. Simcox in partial fulfillment of the requirements for the degree of M.S. in Geoscience with specialization in Hydrology.

ABSTRACT

The area studied includes most of the upper Rio Penasco drainage basin. A geologic map of this section of the eastern dipslope of the Sacramento Mountains was produced on 7.5-minute topographic quadrangles of the U.S. Geological Survey. Two formations, the Permian San Andres and Yeso, are present; their contact is a zone of water accumulation that produces springs wherever it is exposed at the land surface. A fracture zone that was produced by structural deformation contains a portion of the Rio Penasco drainage at the east end of the area and causes water moving eastward along the San Andres-Yeso contact to spill into the valley from springs in the valley walls and in alluvium.

Hydrometer analyses show that the fine-grained sediments in the Yeso Formation are mainly siltstones and that the yellow sediments are slightly coarser and more permeable than the red.

The evolution of the drainage basin is traced using geomorphic, paleontologic, and climatologic evidence. Original work includes mapping of travertine terraces in the Rio Penasco valley below its confluence with Cox Canyon, and ponded sediments at the mouth of Rawlins Canyon. Mollusk fossils from these sites indicate wetter conditions, with correspondingly higher water tables, earlier in the Holocene.

A two-dimensional, finite-difference model was used to model underflow out of the region and to estimate underflow when precipitation was higher; upward leakage was ignored. Results show that current underflow to the Roswell Basin is at least 3778 acre-feet/year, and that an additional recharge rate of 0.5 inches/year would raise the water table back to the level of the travertine terraces.

Water chemistry from wells indicates enrichment of most major chemical constituents with increasing distance from the mountain crest; water chemistry for springs shows the same trend, but correlations are poorer. Tritium concentrations in wells and springs generally decrease from west to east, but a range of values occurs at all distances; this range is wider for springs than for wells. The assumption was made that the area is experiencing simple exponential decay of tritium, and a decay curve for tritium was fitted to the tritium data for wells. Using this method, the time for water to flow across the area is more than 60 years; mixing with older water probably causes this flow time to be too long. Using the hydrologic properties of the Yeso Formation, this flow time is estimated to be 7.5 years.

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INTRODUCTION

The Sierra Blanca-Sacramento Mountains extend from Carrizozo, N.M. to the southwest corner of Chaves County, N.M. in a north-south direction for 80 miles. On the east are the broad expanses of the Great Plains; on the west is the more irregular topography of the Basin and Range Province. The northern part of the range consists of several separate mountain masses composed mainly of igneous rocks that intruded into Permian to Cretaceous-aged strata. The most prominent of these mountains is Sierra Blanca, which reaches 12,003 feet in altitude. The southern part of the range, south of Tularosa Canyon, is known as the Sacramento Mountains (Pray, 1961).

The Sierra Blanca-Sacramento Mountains were uplifted with the Sangre de Cristo and Guadalupe Mountains during Middle and Upper Miocene time. The Sacramento Mountains are tilted about one degree to the east and are bounded on the west by a gravity-fault zone near the base of the present escarpment (Pray, 1961). The Precambrian to Cretaceous rocks in the western escarpment comprise the most complete exposure of Paleozoic rocks in New Mexico. From the crest, the gentle east slope of the Sacramento Mountains extends 80 miles to the Pecos River.

The area studied, which includes most of the upper Rio Penasco drainage basin, is about 120 square miles and lies between latitudes 32 58' N and 32 50' N and longitudes 105 45 W and 105 28' W (Figure 1), in Otero County.

Climate and vegetation

The distance along Highway 82 from the Tularosa Basin to the crest of the Sacramento Mountains at Cloudcroft is only 16 miles, but the difference in elevation is more than 4900 feet. Vegetation from the bottom to the top of this escarpment varies from Chihuahuan desert scrub to a forest of mixed conifers. The conifers, which begin at about 8200 feet include ponderosa pine (Pinus ponderosa), Douglas fir (Pseudotsuga menziesii), white fir (Abies concolor), quaking aspen (Populus tremuloides), southwestern white pine (Pinus strobiformis), and blue spruce (Picea pungens) (Van Devender and others, 1983). At Cloudcroft, at an elevation of 8575 feet and at the west end of the study area, vegetation is dominated by Douglas and white fir, spruce and aspen. At Mayhill, at an elevation of 6538 feet and at the east end, vegetation is dominated by Ponderosa pine.

Cloudcroft had an average precipitation of 25.66 inches between 1955 and 1975; the average temperature was 46.2 F (National Oceanic and Atmospheric Administration). Mayhill had an average of 18.44 inches of precipitation during the same time period with an average annual temperature was 52.2 F (National Oceanic and Atmospheric Administration).

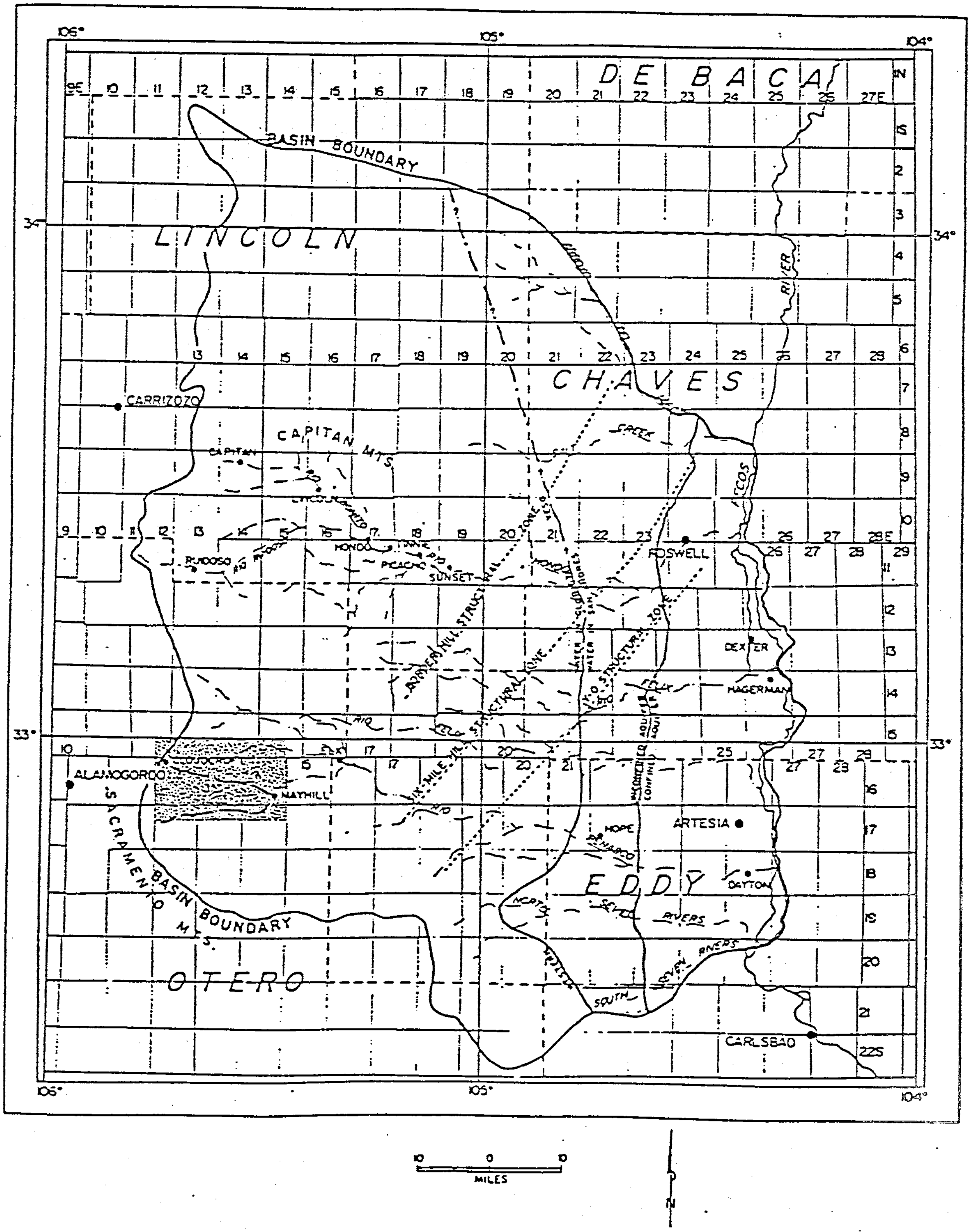


Figure 1. Location of study area.

The main source of moisture is from air in circulation about the Bermuda high pressure area that enters New Mexico from the Gulf of Mexico. Half of the annual precipitation of Otero County falls in the form of sudden thunderstorms from July through September, when this high pressure area is farthest west (Maker and others, 1972). For a discussion of climate and vegetation of the northern Chihuahuan desert since the last major glacial advance see the section on paleoclimate below.

Purpose

One purpose of this study was to produce a geologic map of a section of the eastern dipslope of the Sacramento Mountains (Sheets 1 and 2, in pocket). Perched water conditions, revealed by the presence of springs, were first reported in the upper Rio Penasco drainage basin by Renick (1926); the proximity of springs to the contact between the San Andres and Yeso formations has been noted (Hood, 1960, p. 7,9; Davis and others, 1980; Wasiolek and Gross, 1983). Also some structural controls on groundwater movement were suggested (Wasiolek and Gross, 1983). But previous maps (Kelley, 1971; New Mexico State Highway Department, 1972) were on a scale (1:125,000) that made it difficult to accurately determine the location of springs and wells in relation to the contact. Although not an original purpose, the map of this contact should be useful to drillers for locating good-quality water in interfluve areas.

A second purpose was to trace the evolution of the Upper Rio Penasco drainage basin. During mapping, it became apparent that it was necessary to differentiate Quaternary units to better understand the geomorphic and climatic development of the mountain valleys. Original work includes mapping travertine terraces in the Rio Penasco valley below its confluence with Cox Canyon; these indicate higher water tables and precipitation during the Holocene. Mollusk fossils were collected from two of these terraces and from ponded sediments that formed behind a travertine dam at the mouth of Rawlins Canyon (sec.3, T.16S., R.12E.).

A two-dimensional finite-difference model by Trescott, Pinder and Larson (1976) was used to model the underflow out of the region and to estimate underflow in the past when precipitation was higher.

Another purpose was to add water chemistry and isotope data to those of Wasiolek and Gross (1983). The Statistical Package for the Social Sciences (SPSS), a program available on the NMIMT Dec-20 computer system, was used to correlate major chemical constituents and then to correlate these with tritium data and with distance from the mountain crest. Graphs showing these correlations are called scattergrams and are given in Appendixes E and F. Lithology exerts a strong control on water quality. Therefore, several common rock types of the area were subjected to X-ray diffraction to determine which major chemical constituents are readily available to the groundwater.

Previous investigations

In a 1926 report on the geology and groundwater resources of the upper Rio Penasco drainage basin, Renick noted the difficulty of distinguishing between structures that result from large-scale structural deformation and those that result from more localized solution and subsidence. He noted the occurrence of travertine along the Rio Penasco below Mayhill and around many springs, and gravel deposits that contain fossils high in valley walls. He also recognized the existence of a perched groundwater system. Fiedler and Nye (1933) defined the Sacramento Mountains as a recharge area and western boundary of the Roswell Basin. Their classification of terraces and gravels near the Pecos River is the core of many geomorphic studies. Bean (1949) estimated that 8700 acre-feet of water is contributed each year to the Roswell Basin's artesian aquifer by the Rio Penasco; this is nearly 4% of total annual recharge to that aquifer.

Hantush (1957) did important hydrological research on the artesian and shallow aquifers of the Roswell Basin, but his work did not extend into the higher regions of the Sacramento Mountains. In a study of groundwater resources of the Cloudcroft area that included the first chemical analyses of spring and well water, Hood (1960) concluded that limestones of the Yeso Formation were the main aquifers of the area. He listed two sources for water in these aquifers: the overlying San Andres Formation and direct recharge through canyon bottoms. He proposed that wells be developed at the junctions of canyons. A study of the geology of the western escarpment of the Sacramento Mountains by Pray was published in 1961. Unfortunately, exposures of the Yeso Formation were too poor to permit detailed stratigraphic work. This was somewhat compensated by sections at the northern and southern ends of the escarpment and by subsurface data from the Southern Production Co. No. 1 test well drilled near the crest of the mountains in Sec.5, T.17S., R.12E., although samples from the test well are absent between 320 and 940 feet below the top of the Yeso Formation (Pray, 1961, pp. 107-108). Mourant's 1963 study of the Rio Hondo drainage basin describes a geologic and hydrologic framework similar to that of the Rio Penasco. He included stratigraphic descriptions from well logs, well records, chemical analyses, geologic and water-level maps. A study by Kottlowski (1963) on the Paleozoic and Mesozoic strata of southwestern and south-central New Mexico includes the study area in a discussion of Permian units on the Pedernal landmass. Kelley's (1971) report on the geology of the

Pecos Valley drainage area gives a regional perspective and includes large-scale (1:125,000) geologic maps. His stratigraphic names for members of the San Andres Formation are used in this report. Sloan and Garber (1971) produced geologic and water-level maps at a scale of 1:125,000 that show the location of springs and wells in the Mescalero Apache Indian Reservation, which borders the study area on the north.

Starting with Rabinowitz and Gross (1972), numerous studies for the New Mexico Water Resources Research Institute have used environmental tritium to trace the flow and age of groundwater in the Roswell Basin. Gross and others (1976) increased the number of sampling points for tritium analysis and examined water-level records of observation wells in the Principal Intake Area (Fiedler and Nye, 1933). They proposed the existence of a fast and a slow component of recharge; results showed the slow component to be more important than previously assumed. In other words, upward leakage from the Yeso or deeper formations is at least as important as a source of recharge for the Principal Aquifer of the Roswell Basin as downward percolation of precipitation and runoff. After applying a stochastic model to the western part of the basin, Duffy and others (1978) concluded that western aquifers contribute significantly to recharge of the central basin. In Gross and others (1979), a spring typical of Fiedler and Nye's Principal Intake Area, Paul Spring, was studied in detail. They found that 3% of precipitation on the spring's recharge area actually became recharge to the Paul Spring aquifer. Tritium data indicated two components of flow: one from the upper Yeso Formation and one from the lower San Andres Formation. Davis and others (1980) studied the chemistry and geologic setting of springs in the Sacramento Mountains. Rehfeldt and Gross (1982) used numerical modeling to delineate the spatial distribution and sources of recharge to the carbonate aquifer of the central Roswell Basin. Hoy and Gross (1982) used the stable isotopes of oxygen and hydrogen to supplement earlier tritium and hydrogeologic studies. Results of many of the above studies are summarized in Gross (1982). Wasiolek and Gross (1983) report on the hydrogeology of the upper Rio Penasco drainage basin.

Well and spring numbering system

The numerical designations used in this study for locating wells and springs is that used by the U.S. Geological Survey for New Mexico. The system is illustrated in Figure 2. Each well and spring is assigned a number that is divided into four segments by periods. The first segment denotes the township south of the New Mexico base line; the second is the range east of the New Mexico principal meridian; the third segment is the section; and the fourth segment divides the section into quarters, usually several

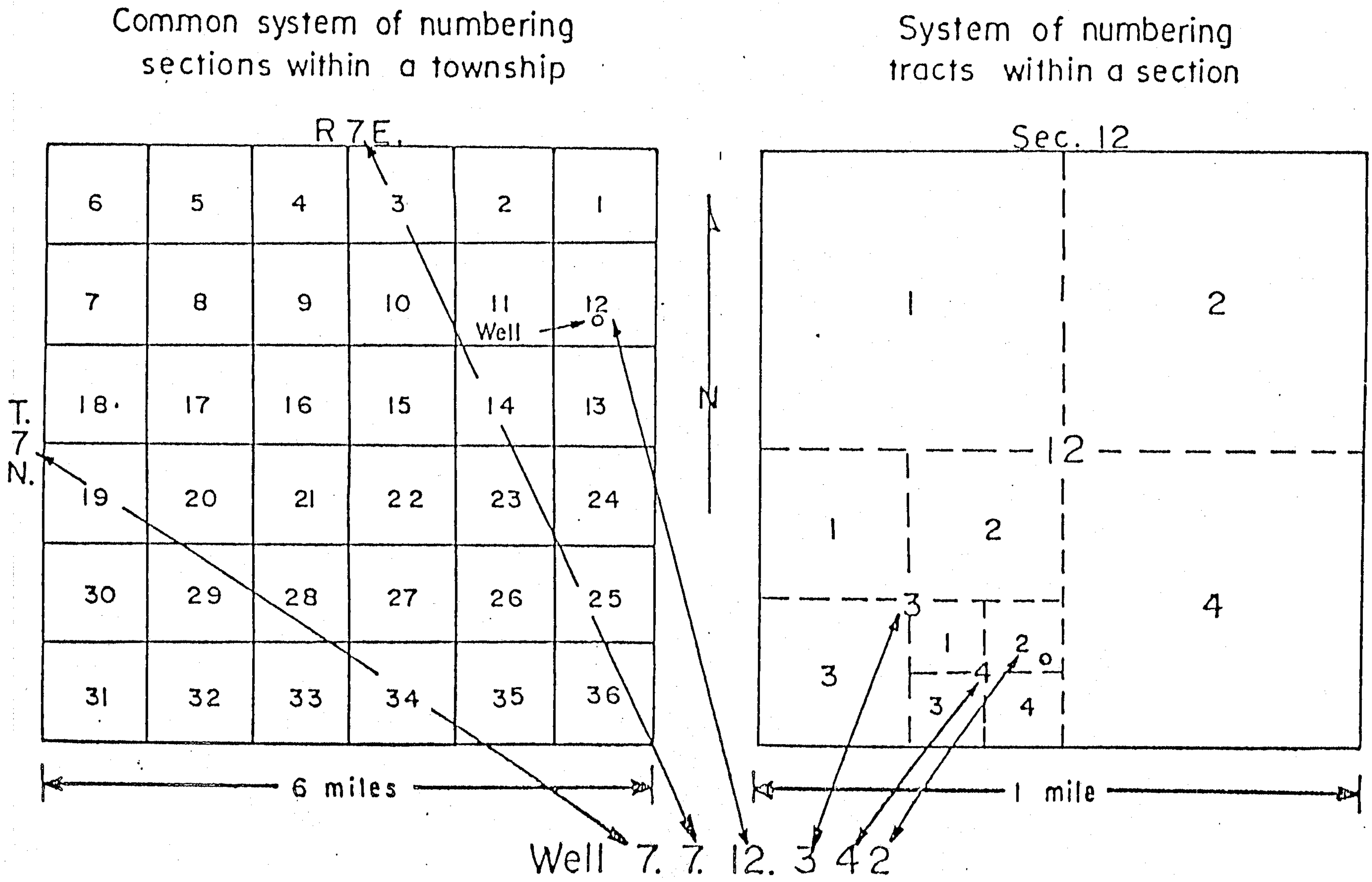


Figure 2. Well location numbering system.

times, to more precisely locate the well or spring.

GEOLOGY

A smaller, general version of the geologic map that accompanies this report is shown in Figure 3, and a stratigraphic column of the rocks that are exposed in the mapped area is shown in Figure 4.

In the study area, the upper Yeso Formation is exposed in the walls and floor of the canyons that dissect the gentle back slope of the Sacramento Mountains. The Rio Bonito member of the San Andres Formation conformably overlies the Yeso Formation and caps the hills between the canyons. Although some structural deformation, in the form of faulting and folding, was expected before mapping began (Wasiolek and Gross, 1983), little of real hydrological significance was found.

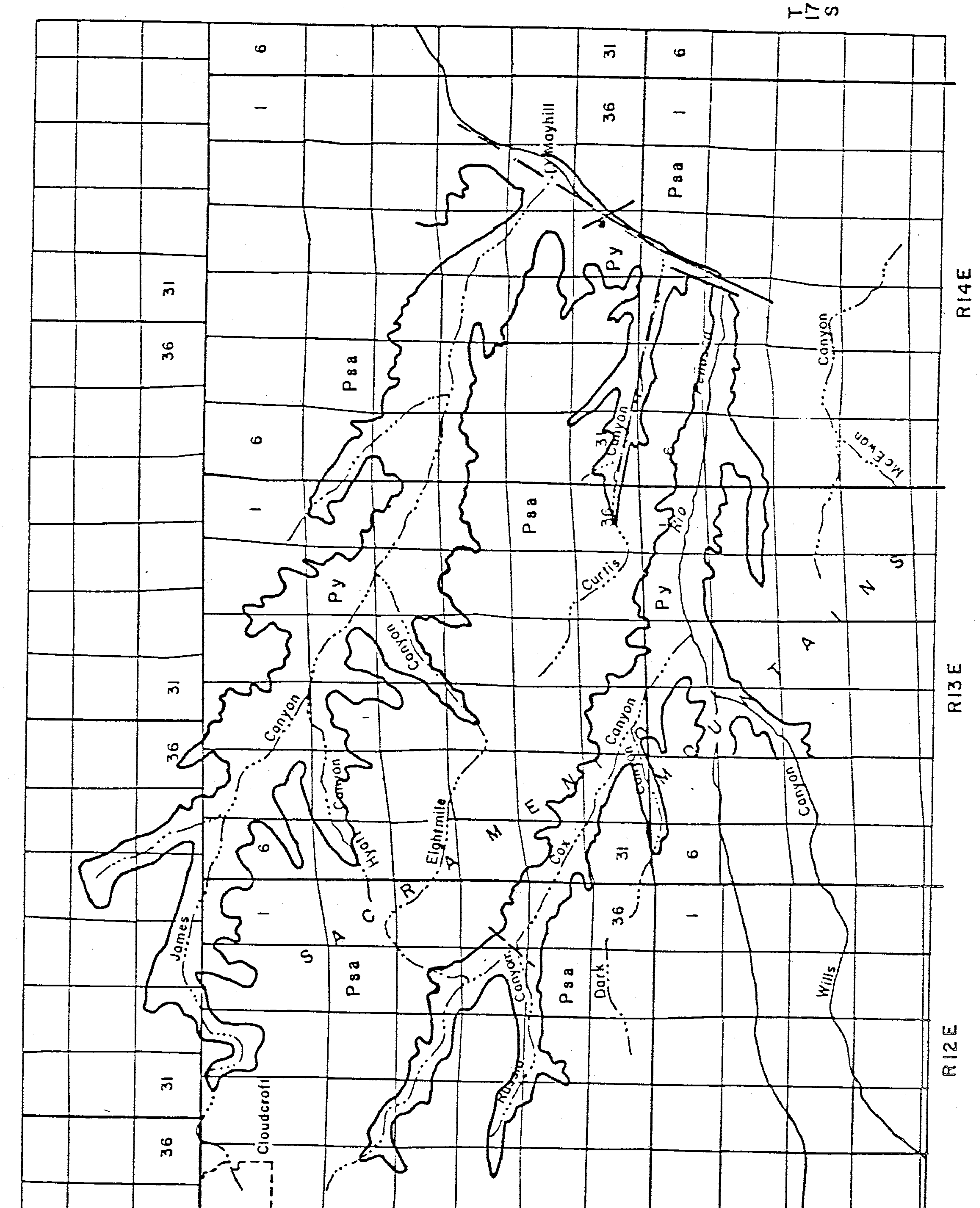
Abo Formation (middle to late Wolfcampian)

In much of northeastern Otero County and parts of southern Lincoln and southwestern Chaves counties Abo red beds were deposited on a surface of relief carved into Precambrian rocks that formed the core of the Pedernal landmass (Figure 5 and Kottlowski, 1963, p. 51). The basal portion of the Abo in the northernmost part of T16S consists of quartz-cobble conglomerates and is evidence of the close proximity of this landmass to the study area (Pray, 1961). Here, on the western escarpment of the Sacramento Mountains, the Abo Formation is largely a sequence of reddish-brown to dark reddish-brown mudstones and arkose, with local basal units of conglomerate (Pray, 1961). The mudstones and shales are darker than the red beds of the overlying Yeso Formation. The Abo Formation ranges from 200 to 500 feet in thickness in the western escarpment; it thickens toward the northwest and south (Pray, 1961). The regional stratigraphic and sedimentologic setting of the Abo Formation in central and south-central New Mexico, including the western escarpment of the Sacramento Mountains, was recently the subject of a guidebook (Roswell Geological Society, 1983). The Abo Formation neither crops out nor is penetrated by wells in the study area.

Yeso Formation (Leonardian)

East of Alamogordo, the Yeso and younger formations were deposited on an even surface left by Abo deposition over the Pedernal landmass (Foster, 1959). The change in lithology from the Abo to the Yeso Formation probably represents a rather sudden invasion of saline to supersaline seas (Pray, 1961).

The Yeso Formation is 1200 to 1800 feet thick in the western escarpment. As described by Pray (1961), rock types consist of carbonate rocks, mostly limestones and some dolomite; red, yellow and gray shales and siltstones;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Cloudcroft
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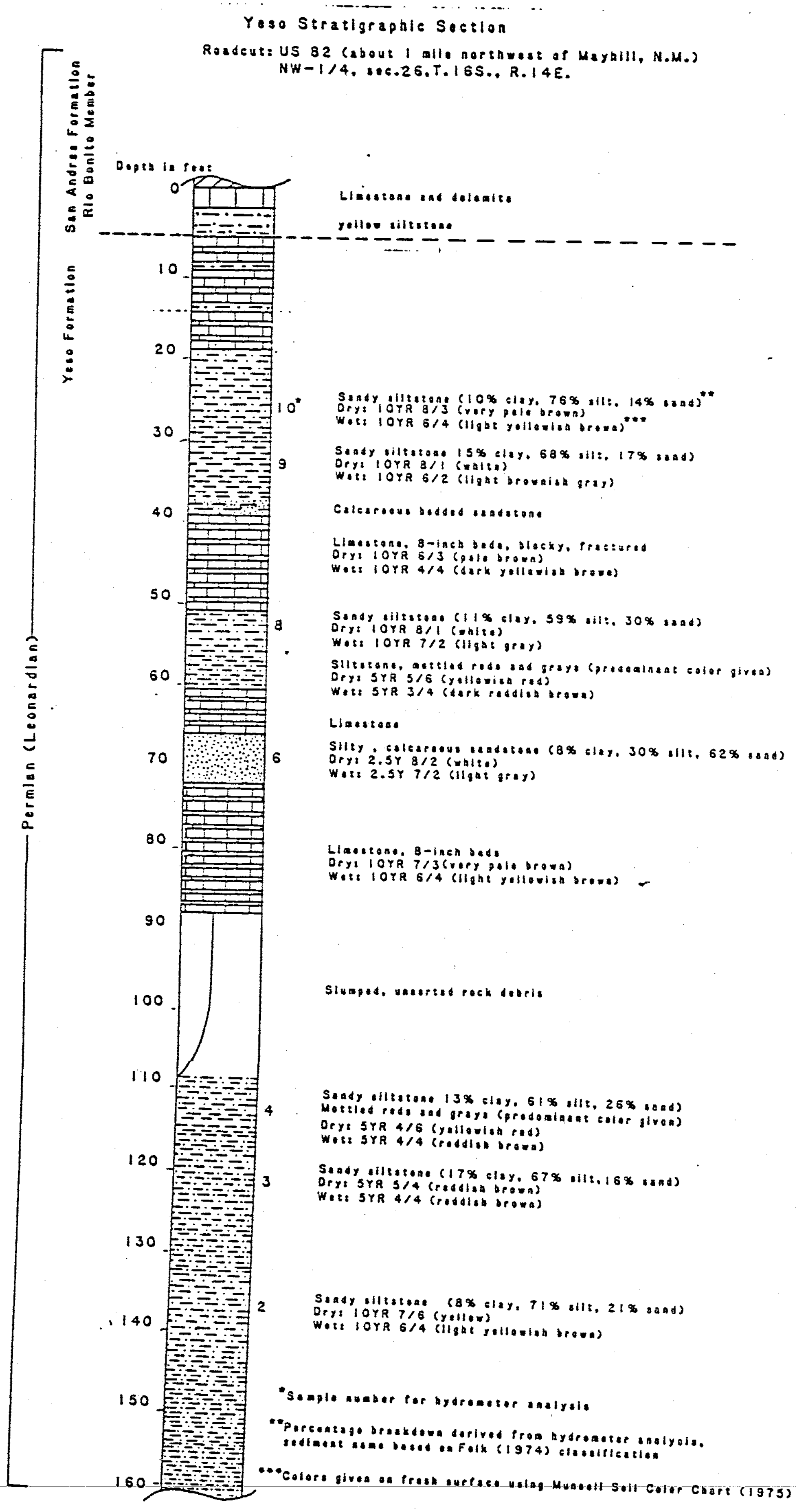

Figure 4. Stratigraphic section from roadcut near Mayhill, N.M. Roadcut is located 1 mile northwest of Mayhill, N.M., on US 82. Results of hydrometer analyses on samples are included.

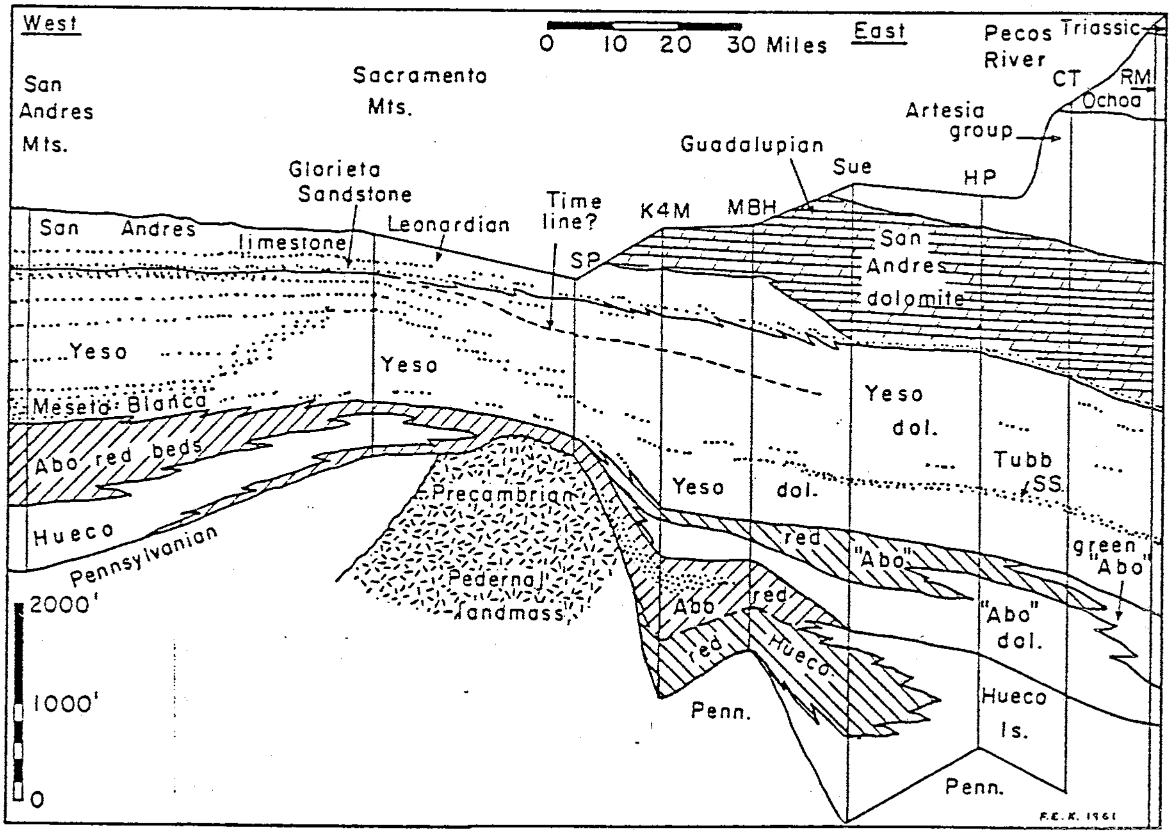

Figure 5. Diagrammatic section of Permian units across the Pedernal landmass. Section from west to east (after Kottlowski, 1963, p. 55).

evaporites, largely anhydrite (gypsum at surface exposures) and minor halite; and yellowish fine-grained sandstones. Pray (1961) found more evaporites in the lower and middle Yeso than in the upper Yeso.

He also found more gypsum, both in pure layers and intermixed with clay and silt, in the northern section than in the southern section of the escarpment. (Pray divided the northern and southern sections at latitude 32 47'30"N; this division is used throughout this report. The study area is entirely located in Pray's northern section.)

	northern section	southern section
Mixed gypsum and shale	28%	2%
Gypsum	19%	7%

Pray 1961 also reports a marked increase in carbonate rocks to the south (25% versus 45%).

Wells and roadcuts of the study area yield information only on the upper Yeso Formation. Some of the best roadcuts, which occur about a mile west of Mayhill, were used to construct a stratigraphic section (Figure 4). Hydrometer analyses of samples from selected intervals revealed that the varicolored, fine-grained sediments characteristic of the Yeso Formation are mostly siltstones, not claystones, and that yellow sediments are slightly coarser-grained than the red. These results are shown on Figures 4 and 6; more detailed data are given in Appendix C. The latter observation is supported by descriptions on driller's logs. Where sandstone or limestone is reported as the water-bearing unit, red shale, red sand or "red Yeso" is reported as the underlying unit twice as often (12 wells) as yellow shale or yellow sand (6 wells). Thus it appears that red sediments form better confining layers than yellow.

Recurring stratigraphic sequences above and below water-bearing zones are also documented on the driller's logs. Throughout the study area, a common sequence is a sandstone or limestone water-bearing zone that is overlain by limestone and underlain by limestone (19 wells) or red shale (9 wells). But water-bearing zones of sandstone overlain by red or yellow shale and underlain by red or yellow shale (8 wells) or limestone (7 wells) occur almost exclusively east of the line that divides R13E from R14E.

X-ray diffraction was done on four samples from major rock units in the Yeso Formation, one sample of surface leachate and one sample from a white layer above solution breccia. Results are given in Table I. Apparently, any evaporites that were present have been leached out of these surface and near-surface exposures. Samples taken at depth may be more representative, since water chemistry suggests the presence of evaporites in minor quantities.

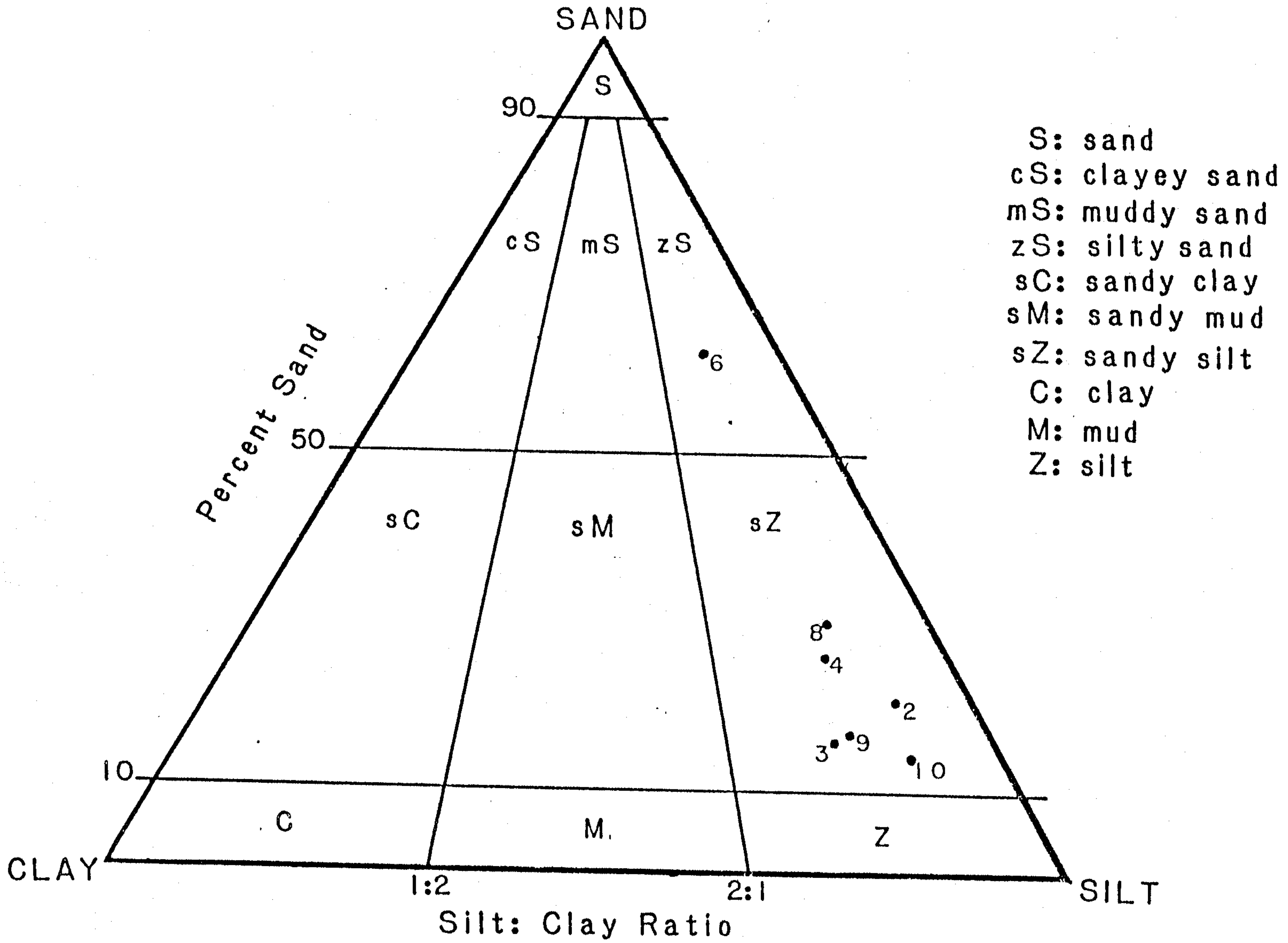

Figure 6. Textural classification of samples from the Yeso Formation based on their proportions of sand, silt, and clay (after Folk, 1954). Location of samples is shown in Figure 4.

TABLE I

RESULTS OF X-RAY DIFFRACTION

SAMPLE NO.	FM*	LOCATION	MAJOR MINERALS (in order of abundance)	DESCRIPTION**
2	Py	16.12.14.41	pure calcite	Layer above solution breccia in gravel pit. Wet: 5YR 7/4 (pink) Dry: 5YR 8/1 (white)
4	Py	16.13.30.41	quartz, calcite, montmorillonite	Siltstone. Wet: 10YR 7/6 (yellow) Dry: 10YR 8/4 (very pale brown)
5	Py	16.13.30.41	quartz, calcite, montmorillonite	Clayey siltstone. Wet: 2.5YR 3/6 (dark red) Dry: 2.5YR 5/6 (red)
7	Py	16.13.29.34	calcite, quartz, sericite	Efflorescence on siltston Wet: 2.5YR 6/4 (light yellowish brown) Dry: 2.5YR 8/4(pale yello
8	Pgs	17.14.08.322	quartz, orthoclase, plagioclase (minor), sericite	Siltstone. Wet: 5YR 8/3 (pale yellow) Dry: 5YR 8/1 (white)
9	Pgs	17.14.08.322	quartz, calcite, montmorillonite, sericite	Sandy siltstone. Wet: 10YR 6/8 (brownish yellow) Dry: 10YR 8/6 (yellow)
10	Psa	17.14.08.322	dolomite, quartz, montmorillonite, (possibly minor plagioclase, kaolinite)	Dolomite layer near base of formation. Wet: 10YR 5/3 (brown) Dry: 10YR 7/2 (light gray)
11	Py	16.14.26.113	calcite, quartz	Bedded (~1 foot) limestone near top of formation. Wet: 10YR 4/2 (dark grayis brown) Dry: 10YR 5/1 (gray)
13	Py	16.14.22.32	calcite, minor illite	Bedded (~1/2 ft) limestone Wet: 10YR 4/3 (dark brown) Dry: 10YR 5/1 (gray)

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* Py= Yeso Fm; Pgs= Glorieta Fm equivalent; Psa= San Andres Fm.

** Colors from Munsell Soil Color Charts (1975).

Glorieta Sandstone (Leonardian)

Glorieta-type sandstones described by Pray (1961) as clean, rounded, frosted, fine to medium-grained orthoquartzites do not separate the Yeso and San Andres Formations in the study area. Instead, 2 to 3-foot layers of friable, poorly cemented, yellowish, silty quartz-sandstone interbedded with carbonates of the lower San Andres Formation grade down into reddish siltstones of the Yeso Formation. X-ray diffraction was done on two samples from this unit (Table I).

San Andres Formation (Leonardian to Guadalupian)

Much of the erosional surface of the crest and back slope of the Sacramento Mountains is formed on the San Andres Formation. While mapping the Pecos slope south of DeBaca County to the Texas border, Kelley (1971) identified three members of the San Andres Formation, which, in ascending order, are the Rio Bonito, Bonney Canyon, and Fourmile Draw. He concluded that the Hondo Sandstone of Lang (1937, p. 850) was a tongue of the Glorieta Sandstone and recommended that the term Hondo be dropped (Kelley, 1971, p. 10). In the northern part of his mapped area, Kelley observed the Rio Bonito Member as tongues in Glorieta Sandstone, but, in the southern part, which includes the upper Rio Penasco area, he observed the Glorieta Sandstone as tongues in the Rio Bonito Member; in other words, they are facies of one another (Kelley, 1971, p. 10).

The San Andres Formation is present in all interfluve areas of the upper Rio Penasco drainage basin; it consists mostly of the Rio Bonito Member and is usually less than 500 feet thick. It appears as a succession of fractured carbonate layers, which are distinquished from Yeso carbonate layers by their distinctive gray to olive-gray color and their greater thicknesses; 1 to 3-foot beds are common. One sample from the base of this formation was analyzed using X-ray diffraction (Table I).

Water-bearing properties of the contact zone

Precipitation infiltrates through the dolostones, limestones and thin silty sand beds of the San Andres Formation until it encounters the sandy silt beds of the Yeso Formation and is forced to move laterally. This zone of water accumulation often occurs within 50 feet of the contact between the San Andres and Yeso formations; springs that occur at this horizon have been termed "contact-zone springs" by Wasiolek and Gross (1983, p. 50). Topography determines where this zone intersects the ground surface and produces springs.

The depth to water-bearing units in wells with respect to the contact between the San Andres and Yeso formations varies across the study area. Near the crest of the mountains, above an elevation of 8500 feet, wells produce water from units above the contact to 200 feet below the contact (Figure 7). In other words, most wells at these elevations produce water from the contact zone rather than from the deeper regional aquifer. At elevations between 8500 feet and 7200 feet, wells produce water from 300 to 800 feet below the contact (Figure 8). But, farther east in the area, wells at elevations of less than 7200 feet again produce water at depths within 400 feet below the contact (Figure 9). Figures 7 to 9 show some interconnection between the contact-zone and regional aquifers, but the transition zone is not distinct enough to be classified separately, as was done by Wasiolek and Gross (1983, p. 47). Therefore, the term "semi-perched zone" is not used in this report.

Geologic mapping

Kelley (1971) produced maps of the Pecos slope that include parts of Lincoln, Otero, Chaves, and Eddy counties. Mapping was done on U.S. Army Map Service (AMS) high-altitude photographs, which have a scale of about 1:54,000, and projected to bases prepared from AMS 2-degree sheets enlarged to a scale of 1:125,000 (Kelley, 1971, p.3). Although Kelley had difficulty mapping the contact between the Rio Bonito and Bonney Canyon members in the high, heavily vegetated areas of Otero County, he concluded that the Rio Bonito Member thickened from about 300 feet in T.15S. to about 650 feet in T.20S at the expense of the Bonney Canyon Member.

Kelley's (1971, Plate 3) map of the upper Rio Penasco drainage basin roughly outlines the contact between the San Andres and Yeso formations; the Glorieta Sandstone tongues are included in the basal San Andres Formation. All of the San Andres Formation is mapped as the Rio Bonito Member, except for three outliers of the Bonney Canyon Member between James and Dollins canyons, 2.8 to 4.6 miles west of Mayhill, and outliers east of the study area, beginning between 0.7 and 1.3 miles southeast of Mayhill. One high-angle fault, trending N 50 E and downthrown to the northwest, is shown in the southeast section of T.16S., R.12E. Although the existence of this fault was not confirmed during this study, some folding and displacement of beds was noted in roadcuts on the north side of the mouth of Russia Canyon. Kelley's map was inadequate for a detailed hydrogeologic study because of its small scale and absence of topographic contours. Also, since no Quaternary units were mapped, springs and wells in alluvium and colluvium could not be distinquished from those in the San Andres and Yeso formations.

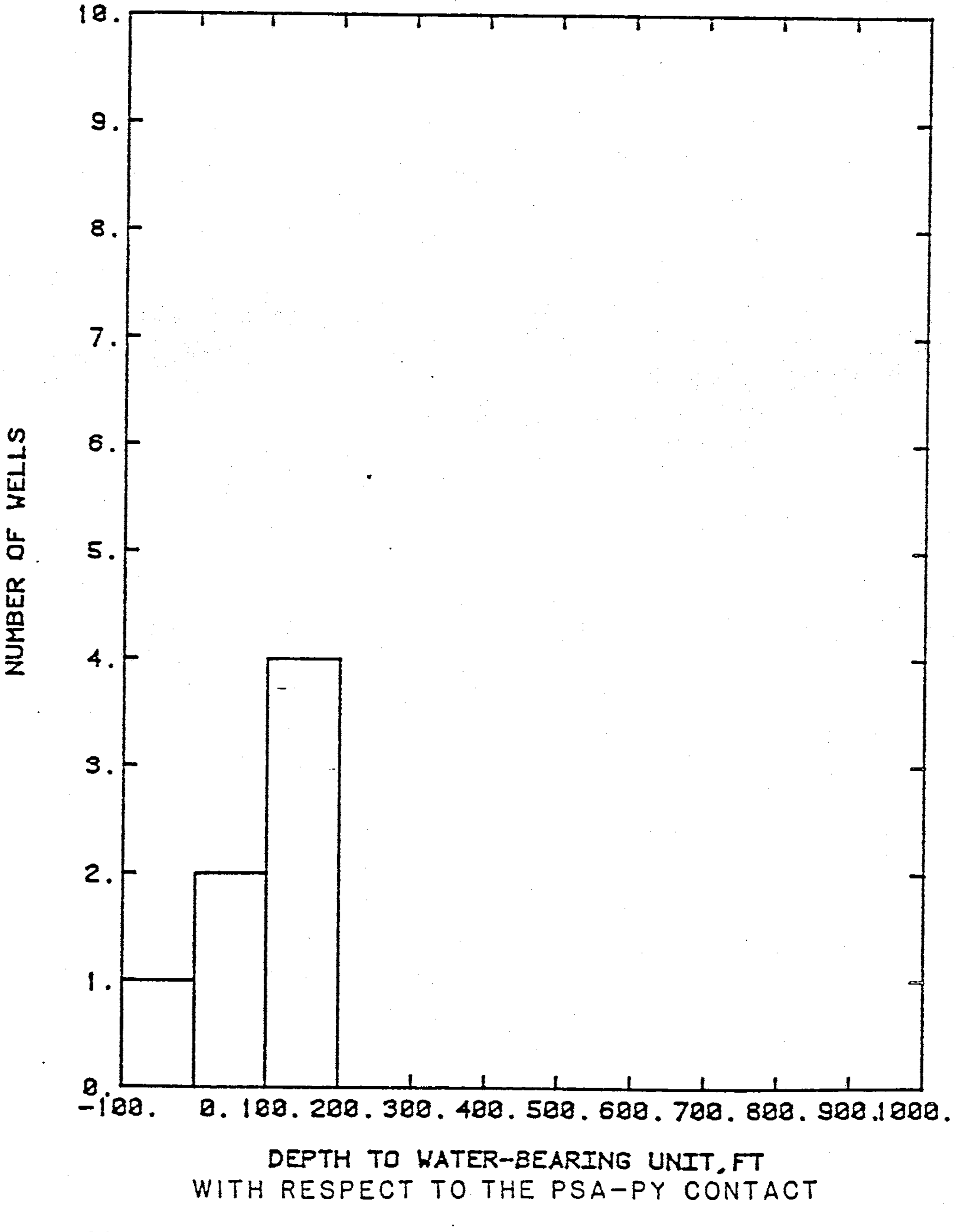


Figure 7. Histogram showing depth to water-bearing units with respect to the San Andres-Yeso contact for wells at elevations above 8500 feet. Negative depths are above the boundary.

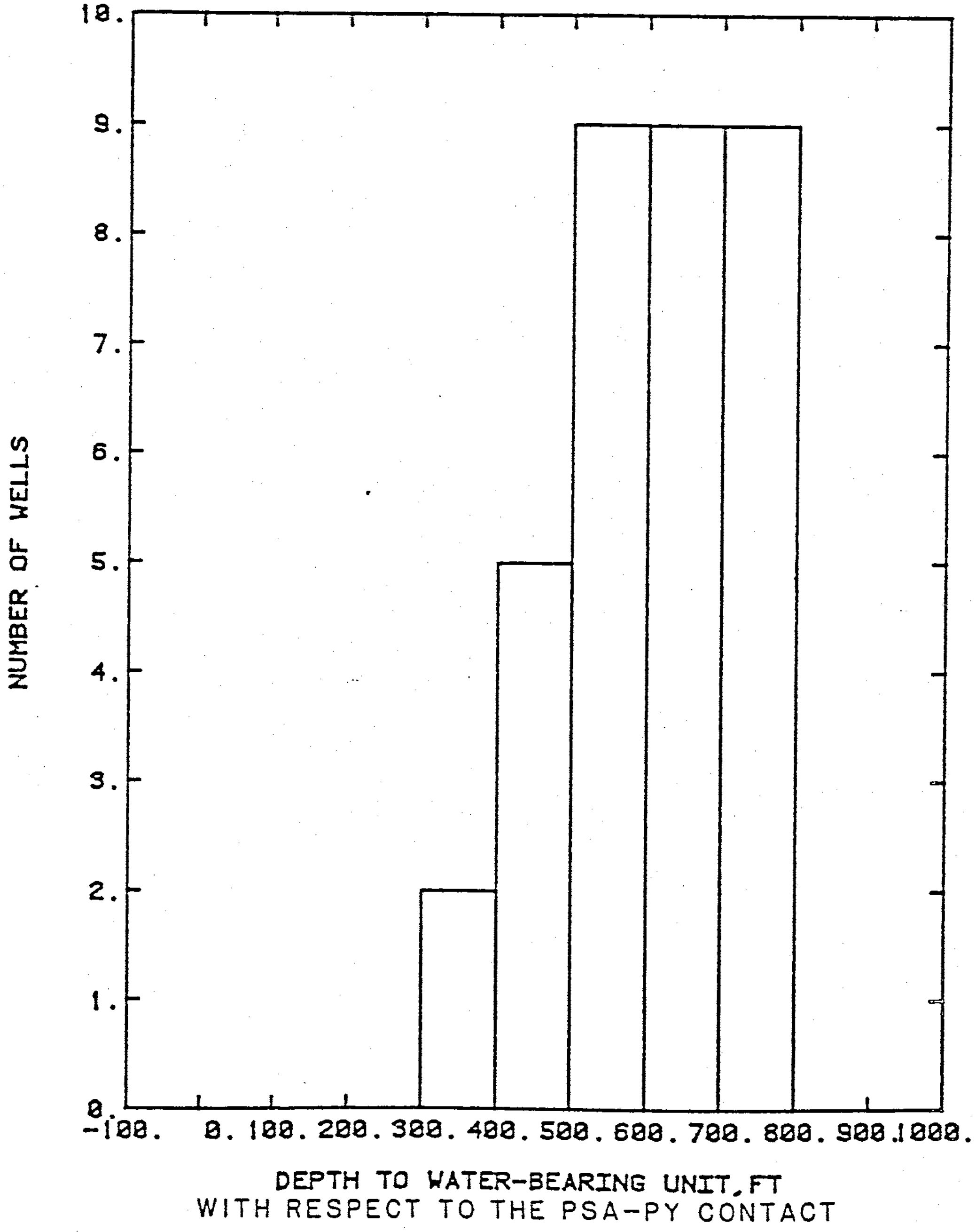


Figure 8. Histogram showing depth to water-bearing units with respect to the San Andres-Yeso contact for wells at elevations between 8500 and 7200 feet in elevation. Negative depths are above the boundary.

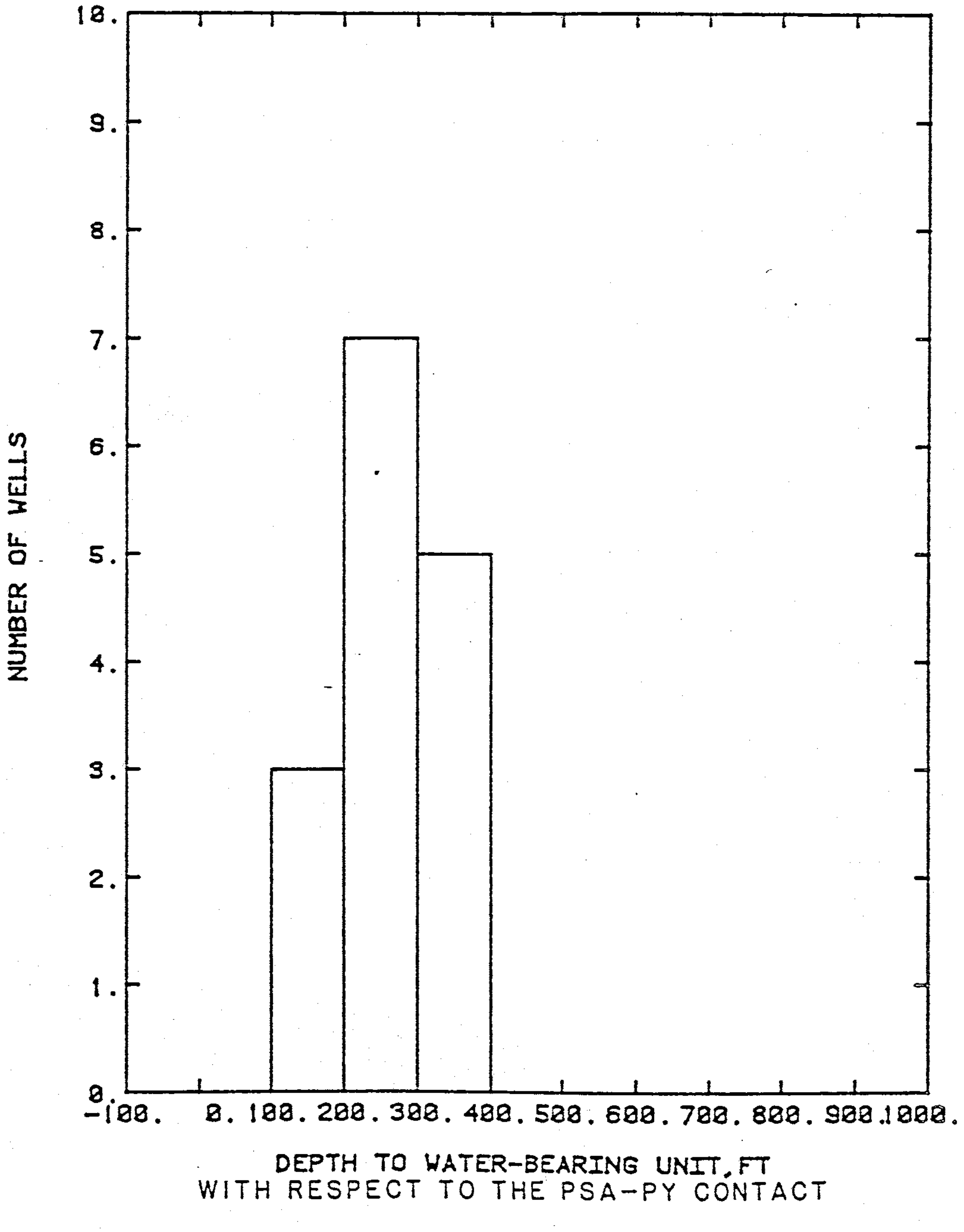


Figure 9. Histogram showing depth to water-bearing units with respect to the San Andres-Yeso contact for wells at elevations below 7200 feet. Negative depths are above the boundary.

The New Mexico State Highway Department (1972) published maps of the southeast quadrant of New Mexico as part of a statewide project to locate road-building aggregate. The maps were produced on N.M.S.H.D. base maps at the same scale (1:125,000) as those of Kelley (1971). Existing pits and quarries were mapped and sometimes sampled, and prospective sites for road materials were located by photographic interpretation. Geologic mapping was done using black and white aerial photographs (oral communication with Arlon Lovelace, November, 1982). As on Kelley's (1971) map, the contact between the San Andres and Yeso formations is roughly outlined in the study area. The present study shows that the contact is less accurately located on the State Highway Department's maps than on Kelley's. Again, the San Andres Formation includes the Glorieta Sandstone equivalent at its base, but, this time, no distinction is made between the Rio Bonito and Bonney Canyon members. Although Quaternary units are mapped, they are generalized into one unit, which includes terrace and stream deposits of gravel, sand, silt, and clay, throughout the area. A fault, trending about N 15 W and downthrown on the southwest side, is shown in T.16S., R.14E., Secs. 27 and 35. The existence of this fault was confirmed during the present study; it appears as a brecciated zone in a valley on the east side of the Rio Penasco valley about one mile southwest of Mayhill. A relative displacement of beds to the southwest is confirmed, but its trend is probably closer to N 28 W. The State Highway Department maps were also inadequate for the present study; like Kelley's (1971) map, the scale is too small and topographic contours are missing.

For this study, a geologic map was produced on 7.5-minute topographic quadrangles of the U.S. Geological Survey. Since one purpose of this study was to test the hypothesis that springs tend to occur near the contact between the San Andres and Yeso formations, their position could not be used as a primary criterion for locating the contact; independent criteria were needed. In accord with Kelley (1971), Glorieta Sandstone tongues were included in the basal portion of the San Andres Formation. But, since lenses of yellowish siltstone and sandy siltstone occur in limestone sequences near the top of the Yeso Formation, this contact was not always clear. Therefore, whenever possible, the contact was chosen at the base of a siltstone layer that was more than one foot thick and overlain by carbonate beds that were distinctly grayer and thicker than Yeso carbonates.

Field mapping was supplemented by aerial photographs; these are available in black and white at the U.S. Forest Service office in Albuquerque and in color at the U.S. Forest Service office in Alamogordo, N.M. The thicker carbonate beds of the Rio Bonito Member show up as distinct lines on photos in the less vegetated areas. The Rio Bonito

Member tends to form steeper slopes than the Yeso Formation; therefore, in the more vegetated areas, the contact often appears as a break-in-slope.

Mapping of the contact confirmed this zone as one of water accumulation; many springs throughout the study area occur within 50 feet of the contact. As a side benefit, drillers can use this map to locate this zone of good-quality water in interfluve areas where springs do not occur.

Less emphasis was placed on mapping of Quaternary units, although this is important for a better understanding of the evolution of the valleys. These units were not systematically traced throughout the area; instead, samples were collected at a few locations (see Quaternary deposits of the study area below).

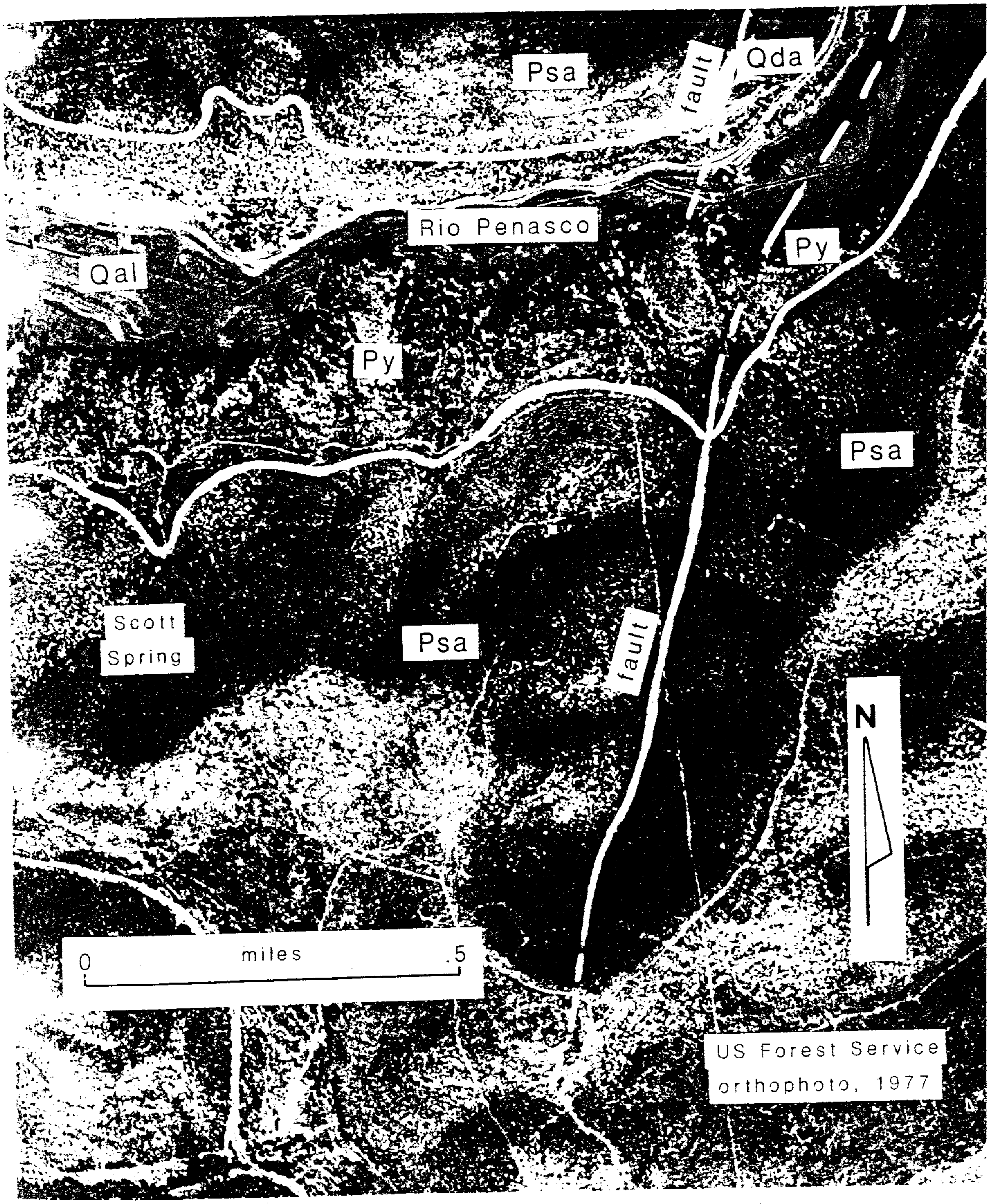
Structure

The major uplift of the Sacramento Mountains occurred after the formation of Fiedler and Nye's (1933) Pliocene-aged Sacramento Plain and appears to be still in progress (Pray, 1961, p.124, 126). As evidence, Pray (1961) cites alluvial or piedmont scarps, up to 80 feet in height, along much of the length of the mountains at the base of the western escarpment. He also cites west-dipping, high-angle, gravity faults with a predominant dip-slip movement, which are especially evident and laterally persistent east of Alamogordo (Pray, 1961, p. 124-125). North and northwest-trending faults within the mountain block, such as the Mescalero fault in T.14 and 15S., R.13E., and the folded and faulted belt along the Sacramento River in T.18 and 19S., R.12 and 13E. (Darton, 1928, p.210-212, Plate 44; Bates, 1961), are compatible with the type and direction of movement (downthrown on the west side) described by Pray (1961). Bates (written communication, May 1983) believes that the Sacramento fault dies out somewhere in the northeastern part of T18S., R.11E.

The San Andres and Yeso formations are tilted about one degree to the east in the study area. Ubiquitous warping of beds and occasional solution breccias were noted during field mapping. In addition to the faults noted by Kelley (1971) and the New Mexico State Highway Department (1972), three large faults, McEwen Canyon, Curtis Canyon, and Mayhill faults, were described by Wasiolek and Gross (1983). The last two of these faults are more accurately called fractures, since little horizontal or vertical displacement is evident. The Mayhill fault, or fracture zone, has caused the Rio Penasco to flow northward for four miles in the eastern part of the study area. Its trend of 30 degrees to the northeast, agrees well with that of the Border Hills structural zone to the northeast. Hydrologically, it is significant that the contact between the San Andres and Yeso formations has been breached by this fracture-controlled section of the Rio Penasco valley. Water, which would otherwise continue moving eastward along the contact and in layers of the upper Yeso Formation, spills into the valley from springs in the valley walls and in alluvium. Erosion continues to expose more of the fracture trace (Figure 10).

Intense folding, which may have resulted from buckling during uplift, occurs at the mouth of Dollins Canyon (Sec.32, T.16S., R.14E.) and probably correlates to the north with a prominent dip in the floor of James Canyon in section 20 of T.16S., R.14E. and with a less conspicuous dip in the floor of Cox Canyon (sec.8, T.17S., R.14E.). This may contribute to a thickening of the valley fill and, subsequently, to the deeper entrenchment of valley fill east of these locations in both canyons.

Figure 10. Orthophoto of fracture zone at east end of study area. Rio Penasco flows in a fracture zone that trends 30 degrees to the northeast. Erosion continues to expose the fracture trace.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fault
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fault
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US Forest Service
orthophoto, 1977

EVOLUTION OF VALLEYS

The present regional dip in most of southeastern New Mexico was caused by epeirogenic uplift of this part of the continent and concurrent basin and range faulting during the late Cenozoic (Chapin, 1979).

During late Miocene to Pliocene time, the Ogallala Formation was deposited by streams that flowed eastward from the irregular belt of mountains between the Rio Grande and Pecos River basins. Although this formation is preserved on the High Plains east of the Pecos and locally west of the Pecos (Fiedler and Nye, 1933; Frye and others, 1982), it is apparently not preserved as far west as the study area.

It is likely that major drainage systems in eastern New Mexico during late Pliocene and early Pleistocene time included the Canadian River, which flowed eastward into the Red River system; a river that flowed eastward through the Portales Valley into the Brazos drainage system; and the Rios Macho, Hondo and Penasco, which carried debris from the Sierra Blanca, Capitan and Sacramento mountains (Hawley and others, 1976, Figure 3).

Workers have tried to correlate erosional and depositional episodes in the Pecos River valley with the four major glacial epochs. The Gatuna Formation was described by Lang (1938) as "an assemblage of rocks of various kinds that were laid down in the Pecos Valley in post-Ogallala time and apparently after the completion of the maximum cycle of erosion in this valley". According to Bachman (1976), these sediments were derived from three sources: the Ogallala Formation, the underlying Permian and Triassic rocks, and uplifts of Permian limestones and of Tertiary igneous porphyries west of the Pecos River valley. Although the time of the start of Gatuna deposition is disputed, it is generally believed to have continued into early to middle Pleistocene time; that is, it was being deposited during the Nebraskan and Kansan glacial epochs.

Terraces and gravels

The Sacramento plain extends westward to the Sacramento Mountains proper, but, since it is the oldest and highest plain, it is thoroughly dissected (Fiedler and Nye, 1933, p.14). Fiedler and Nye (1933, p.97) imply that the Sacramento plain is an erosion surface of Miocene-Pliocene age that served as the source of alluvial deposits of the Llano Estacado (Ogallala Formation). Although remnants of this plain may be present in the study area, they were not observed during this study. The Diamond A plain lies 400 to 1300 feet below the Sacramento Plain and is correlated with gravel-capped mesas along the western edge of the Roswell Basin and with the Mescalero Plain east of the Pecos (Horberg, 1949). Deposits of the Diamond A-Mescalero surfaces are correlative with Bachman's (1976) Gatuna Formation (Hawley and others, 1976, p.256). Leonard and Frye (1975) believe that the development of the Mescalero and Diamond A plains took more than half of Pleistocene time. Deposits underlying the constructional elements of these surfaces comprise at least the younger part of the Gatuna Formation (written communication with John Hawley, June, 1983). Fiedler and Nye put the western edge of the Diamond A plain near the southeastern part of T.16S., R.17E., which is about 18 miles east of the study area. They noted that reentrants of the Diamond A plain are not clearly defined, but may be represented by rock-cut benches and benches veneered with gravel in the canyon of the Rio Penasco west of T.16S., R.17E. (Fiedler and Nye, 1933, pp. 102-104). Therefore, gravel-veneered benches in the Rio Penasco valley east of its confluence with Cox Canyon, and gravels in the valley walls of the study area are correlated with the Gatuna Formation. Metcalf (1973) described Pleistocene-aged mollusks from some of these gravels in sec.21, T.16S., R.14E. (see Quaternary deposits of the study area, below).

After Gatuna time, but still during the middle Pleistocene, the climate became more semiarid and caliche accumulated on the Mescalero Plain (Bachman, 1973). Zones of carbonate accumulation have been traced northward from near Carlsbad to the high mesas flanking the upper Pecos Valley west of Fort Sumner.

Three terraces below the Diamond A-Mescalero surface, the Blackdom, Orchard Park and Lakewood were trenched by the present inner valley of the Pecos and have been traced from Fort Sumner to Carlsbad (Fiedler and Nye, 1933; Jelinek, 1967; Kelley, 1971). The Blackdom and younger Orchard Park terraces were formed on weak Permian rocks and older valley fill by streams from the mountains to the west during a time of increased humidity when solution and collapse were major processes in the Roswell Basin (Bachman, 1974). A stable interval following deposition of the Blackdom allowed soil with prominent caliche zones to form on the surface of the terrace.

The Orchard Park terrace lies as much as 100 feet below the Blackdom in the Rio Felix area (R.23E.) (Kelley, 1971); today, it is the main agricultural plain of the valley. As during Blackdom time, the sediment source was mainly in the Sacramento, Sierra Blanca, and Capitan mountains. According to Bachman (1974), the Orchard Park contains more Tertiary porphyry clasts than the Blackdom, suggesting that headward cutting into the Sierra Blanca and Capitan uplifts reached a maximum during Orchard Park time.

The Lakewood terrace lies 20 to 30 feet above the present valley floor (Horberg, 1949). It occurs as a narrow strip along the Pecos River from near Roswell to about four miles south of Carlsbad and is present in the inner valleys of some western tributaries to the Pecos, including lower reaches of the Rio Penasco (Hawley and others, 1976).

Climate since the late Wisconsinan

The Sacramento Mountains are on the northern periphery of the Chihuahuan desert, between the Southern Rocky Mountains and the Sierra Madre Oriental of northeastern Mexico. They are in a sensitive transitional zone where many plants and animals find their most northern or southern limits (Van Devender, 1983).

The last major glacial advance in the midcontinent of the United States was the last time large permanent lakes existed in the southern High Plains and Basin and Range Provinces. It occurred from about 22,000 to 12,500 years B.P., based on radiocarbon chronology and stratigraphic studies (Reeves, 1976; Hawley and others, 1976). The surplus water budget required to maintain permanent lakes was a result of the interaction of climatic and hydrologic factors, such as evaporation, precipitation, runoff and infiltration rates. Because of this complexity, a debate developed between workers who favor reduced or similar precipitation rates compared to those of today (for example, Galloway, 1970; Brackenridge, 1978) and others who favor higher precipitation rates (for example, Reeves, 1973; Wells, 1979; Van Devender, 1977). Those in the first camp believe that the lakes were maintained by a reduced evaporation rate, which increased runoff; those in the second camp have produced an abundance of fossil evidence, mainly from packrat (Neotoma) middens, which support wetter conditions. Middens, which are shiny, indurated masses preserved in dry rock shelters, contain samples of the flora that existed within 35 feet of the site (Van Devender, 1979). Evidence from these middens points towards a change from woodland to desert or grassland about 8000 years ago in the Chihuahuan, Sonoran and Mohave deserts. Van Devender (1977) has suggested that these vegetational changes can be explained by changes in atmospheric circulation related to melting of continental ice sheets. According to Van Devender, the more southerly position of the Aleutian low and the winter-storm track were the main causes of higher precipitation. But, according to Wells (1979), higher precipitation rates were mostly the result of the more southerly position of the subtropical high-pressure cell, which allowed moister, unstable Gulf air masses to move over the southwest. In his latest paper, Van Devender used evidence from packrat middens to outline climatic conditions on the western escarpment of the Sacramento Mountains from late Wisconsin time to the present (Van Devender and others, 1983). A summary follows.

During the late Wisconsin (22,000 to 11,000 years B.P.), the lower slopes of the western escarpment supported a pinyon, juniper and oak woodland similar to that of the upper part of the Sacramento Mountains today. This elevational lowering of woodland plants suggests that summers were much cooler than today; summer temperatures probably resembled present temperatures for late spring and early fall. The woodland assemblages were more diverse than modern woodlands to the north; this suggests that winters were not much colder than today. Most of the precipitation was in the winter and spring, although some precipitation occurred during the summer. Also winter frontal systems arrived earlier. Van Devender believes that the absence of Chihuahuan desert plants in the late Wisconsin was probably more the result of cool summer temperatures than lower winter temperatures. The climate of the early Holocene (11,000 to 8000 years B.P.) was an extension of that of late Wisconsin: relatively cool summers that allowed the growth of woodland plants at lower elevations than today. However, summer temperatures were somewhat warmer than those of the late Wisconsin as indicated by more xeric understory shrubs in the woodland. Winter temperatures were quite mild, and allowed the addition of Opuntia imbricata and Yucca torreyi to the succulents. Winter continued to contribute more precipitation than other seasons during the early Holocene, but warmer summers began the shift towards development of summer monsoons and increased the importance of orographic precipitation. During the middle Holocene (8000 to 4000 years B.P.), summer precipitation, rather than winter, began to dominate. These warm summers favored the development of the Bermuda High with strong summer monsoons and local orographic rainfall. Also, droughts in early summer became more frequent and had profound effects on vegetation. Van Devender's samples suggest that by the middle Holocene the climate was similar to the late Holocene (4000 years B.P. to the present), but with somewhat warmer temperatures and greater precipitation in the summer. The final development of the modern climatic regime with its hot summers, pre-summer aridity and summer-dominated precipitation pattern which has occurred within the last 5500 years. Removal of soil cover has exposed large areas of carbonate bedrock; this has enhanced the spread of desert shrubs and succulents at the expense of grassland. Van Devender concludes that "the climate of late Holocene is as harsh and stressful as any time since the last interglacial, ending about 65,000 years ago".

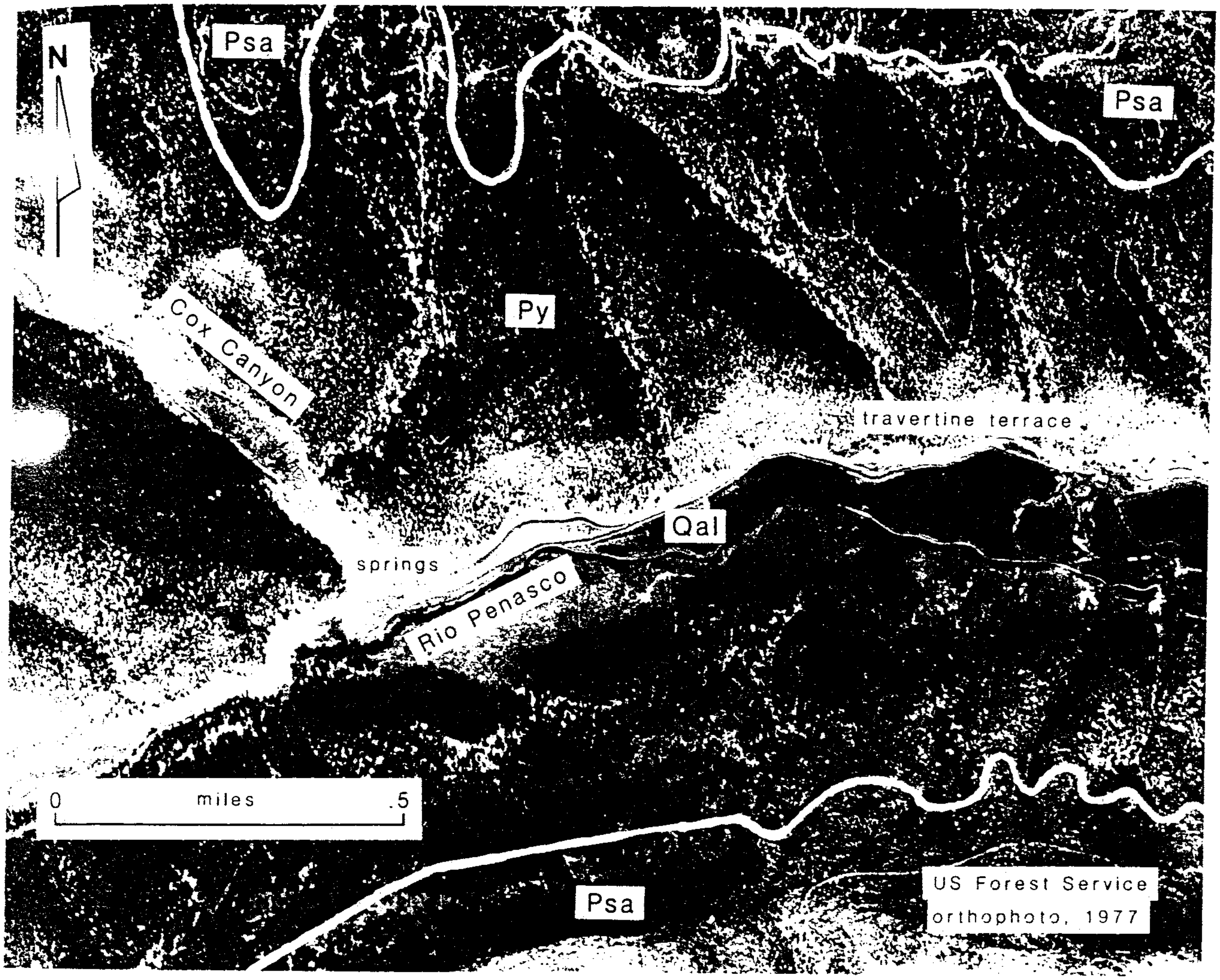
Quaternary deposits of the study area

In the Pleistocene and Holocene, there have been episodes of filling and downcutting in canyons, such as James, Cox and Rio Penasco, that dissect the east slope of the Sacramento Mountains. Streams have cut valleys up to 600 feet through the San Andres and Yeso formations in the study area. The geomorphic evolution of this landscape has probably been affected more by the tectonic disturbances in the Sacramento Mountains discussed in the section on structure than by Pleistocene climatic changes.

Remnants of canyon fill that occur as discontinuous terraces flanking the valleys are probably correlative with Fiedler and Nye's (1933) Diamond A plain and Bachman's (1976) Gatuna Formation. Other canyon-fill deposits occur as colluvium that formed on slopes of the valley walls during cooler, moister times. These large deposits contain angular bedrock fragments that sometimes interfinger with alluvial deposits, suggesting a common origin (Metcalf, 1973). Metcalf (1973) collected mollusks from some of these valley-fill deposits and described a species of the genus Ashmunella (Polygyridae) from a large borrow pit in James Canyon three miles west of Mayhill. The species, which he called Ashmunella jamesensis, resembles Ashmunella mearnsi of the Big Hatchet Mountains of southwestern New Mexico. According to Metcalf, other species of this group have been described from the mountains of south-central New Mexico south of the Sacramento Mountains, from Trans-Pecos Texas and from northwestern Chihuahua, Mexico. A. jamesensis, itself, is described as extremely rare and of Pleistocene age. Metcalf (1982) also reported the occurrence of two subspecies of a land snail of the genus Oreohelix in Pleistocene deposits: Oreohelix oterana oterana and Oreohelix oterana angularis. O.o.oterana occurs in alluvial, reddish silts below valley-flanking terrace surfaces. He described the silts as massive and said they must represent a long period of Pleistocene deposition under rather uniform conditions, but he did not specify these conditions (Metcalf, 1982, p. 262). This subspecies apparently became extinct before the Wisconsin. O.o.angularis usually occurs at higher elevations than O.o.oterana and in some colluvial deposits (Metcalf, 1982, p. 262). Metcalf cites geographically isolating features, such as intercanyon ridges and the high crest of the mountains, but finds the extinction of oreohelicids in the Sacramento Mountains puzzling.

For this study, Metcalf identified land mollusks from three localities (see Appendix D). These include ponded sediments that formed behind a travertine dam at the mouth of Rawlins Canyon (sec. 5, T.16S., R.12E.) and travertine terraces that cross the floodplain of the Rio Penasco east of its confluence with Cox Canyon. One of these terraces is shown in Figure 11. The ponded sediments contain Holocene-aged mollusks (Nesovitrea hammonis) that exist today only in areas farther north in New Mexico; the travertine terraces contain a species, Oxyloma, that probably lived next to water. These, and the occurrence of abundant calcified aquatic-plant debris in the terrace deposits, suggest that the climate has shifted towards dryer conditions, with correspondingly lower water tables, since the end of the last glaciopluvial period. This has

Figure 11. Orthophoto of travertine terrace across floodplain of Rio Penasco east of its confluence with Cox Canyon.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US Forest Service
orthophoto, 1977

undoubtedly resulted in a declining recharge contribution to the Roswell Basin. A two-dimensional, finite-difference model was used to estimate this decline quantitatively; it is discussed in a separate section of this report.

Stream piracy in the study area

The Sacramento Mountains are sharply asymmetrical in east-west profile. As erosion continues to move the mountain crest eastward, headwaters of eastward-flowing streams continue to be pirated by those flowing west. As noted by Bates (1961), headward encroachment by capturing streams is rapid because they erode soft rocks of the Yeso Formation. A good example of stream piracy occurs several miles south of the study area: Aqua Chiquita Canyon was recently beheaded by Scott Able Canyon, a tributary of the Sacramento River. Head-to-head contacts between canyons in and near the study area occur between Toboggan and James canyons in Cloudcroft, between Haynes and Pierce canyons in the western half of section 7, T.16S., R.12E. and between Rio Penasco and Karr canyons in the southeastern quarter of section 26, T.16S., R.11E.

COMPUTER MODELING OF UNDERFLOW

A two-dimensional, finite-difference computer model written by Trescott and others (1976) was used to model underflow out of the area. To apply the model to the back slope of the Sacramento Mountains it was assumed that a model for flow through porous media was valid for the fractured carbonate rocks that occur throughout the Yeso Formation. Since the fractures are closely spaced with respect to the scale of the model and fairly uniformly distributed, this assumption seemed justified. No attempt was made to numerically determine the density and distribution of fractures and solution channels. Secondly, transmissivity was assumed to be uniform throughout the area. Thirdly, the area was assumed to be isotropic. Finally, recharge was assumed to come solely from precipitation; an upward-leakage source was ignored.

Only the eastern half of the area could be used because the configuration of the deeper, more regional flow system is unknown in the western area, where water is obtained from the contact zone.

The governing flow equation used in the model is:

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y} \right) = S\,\frac{\partial h}{\partial t} + W(x,y,t)$$

where,

Txx,Tyy = principal components of the transmissivity tensor (Txx=Tyy in this model).
h = hydraulic head;
S = storage coefficient;
W(x,y,t) = volumetric flux of recharge or withdrawal per unit surface area of the aquifer.

The source term, W(x,y,t), includes well discharge, transient leakage from the aquitard and a recharge flux. The source term is:

$$W_{i,j,k} = \frac{Q_{w[i,j,k]}}{\Delta x_j\ \Delta y_i} - q_{re[i,j,k]} - q'_{i,j,k}$$

where,

Qw = well discharge;
qre = recharge flux per unit area;
q' = leakage flux per unit area from a confining bed;
i,j = y and x coordinate locations, respectively;
k = time step

The leakage term, q', was ignored.

The model uses a block-centered, finite-difference grid. Figure 12 shows the grid used for this study. Each block is approximately one square mile in area.

The boundaries of the model can be either constant head, constant flux or no flux. At a constant-head boundary, the water level is held constant, but the amount of water flowing across the boundary varies in proportion to the changes in water level of the node immediately inside the boundary. At a flux boundary, the amount of water entering or leaving the flow system is specified. At a no-flux boundary, flux is assumed not to occur.

In the model, constant-head boundaries were used on the west and east boundaries. Attempts to measure the water levels in all of the wells in the area were made in 1975 and in January 1979 (New Mexico State Engineer records). Although the weather prevented many wells from being reached during the second attempt, those that were measured usually had water levels that conformed closely to earlier measurements (see Appendix A). Therefore, for the short period for which data are available, the western and eastern boundaries are justifiably treated as constant head.

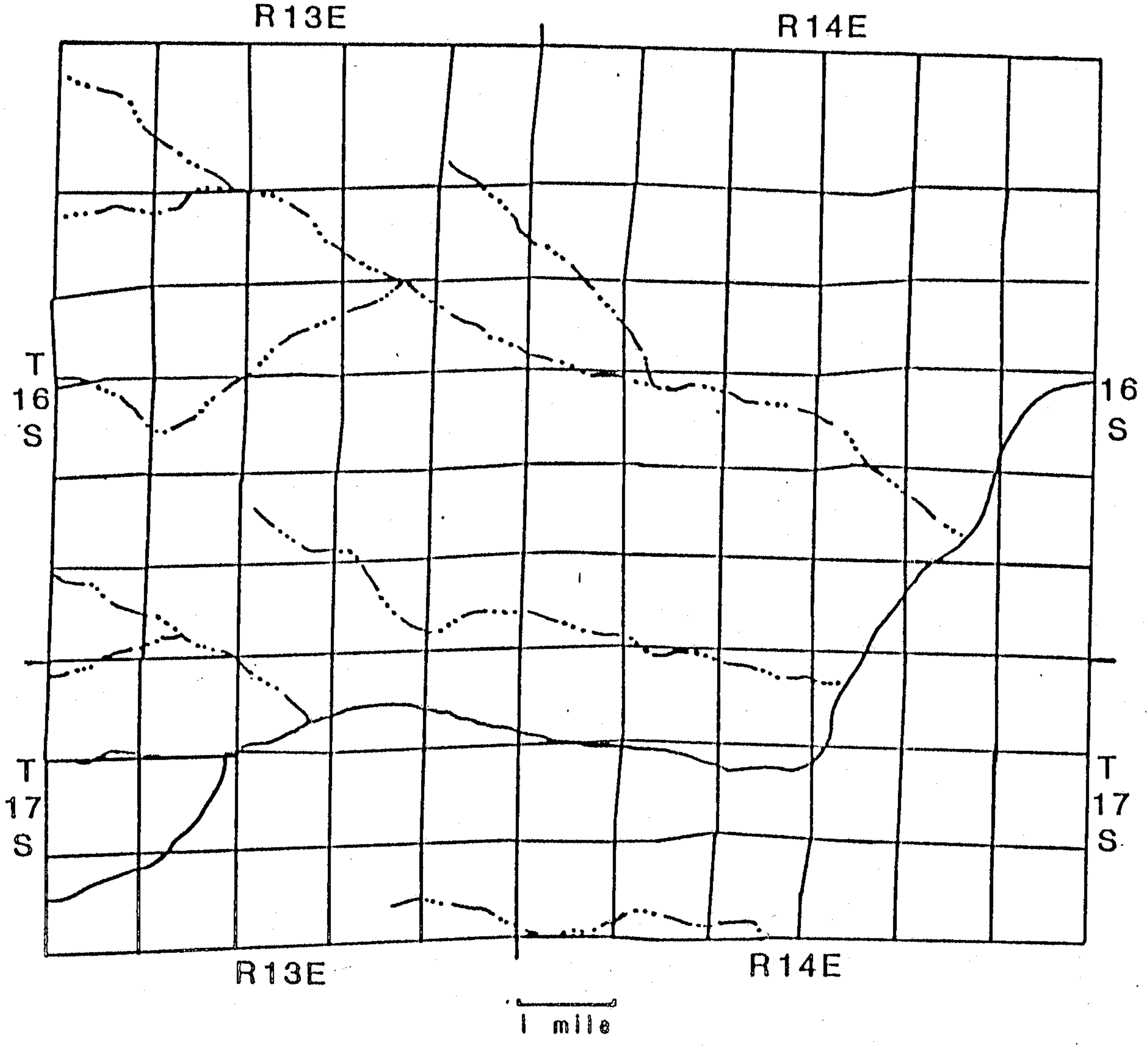
No-flux boundaries were used on the north and south boundaries. This is justified because equipotential lines throughout the modeled area indicate flow along, but not across, these boundaries (Figure 13).

Initial data

The computer simulations required initial values for head, storage coefficient, transmissivity, areal recharge flux and pumping rate at each node in the model.

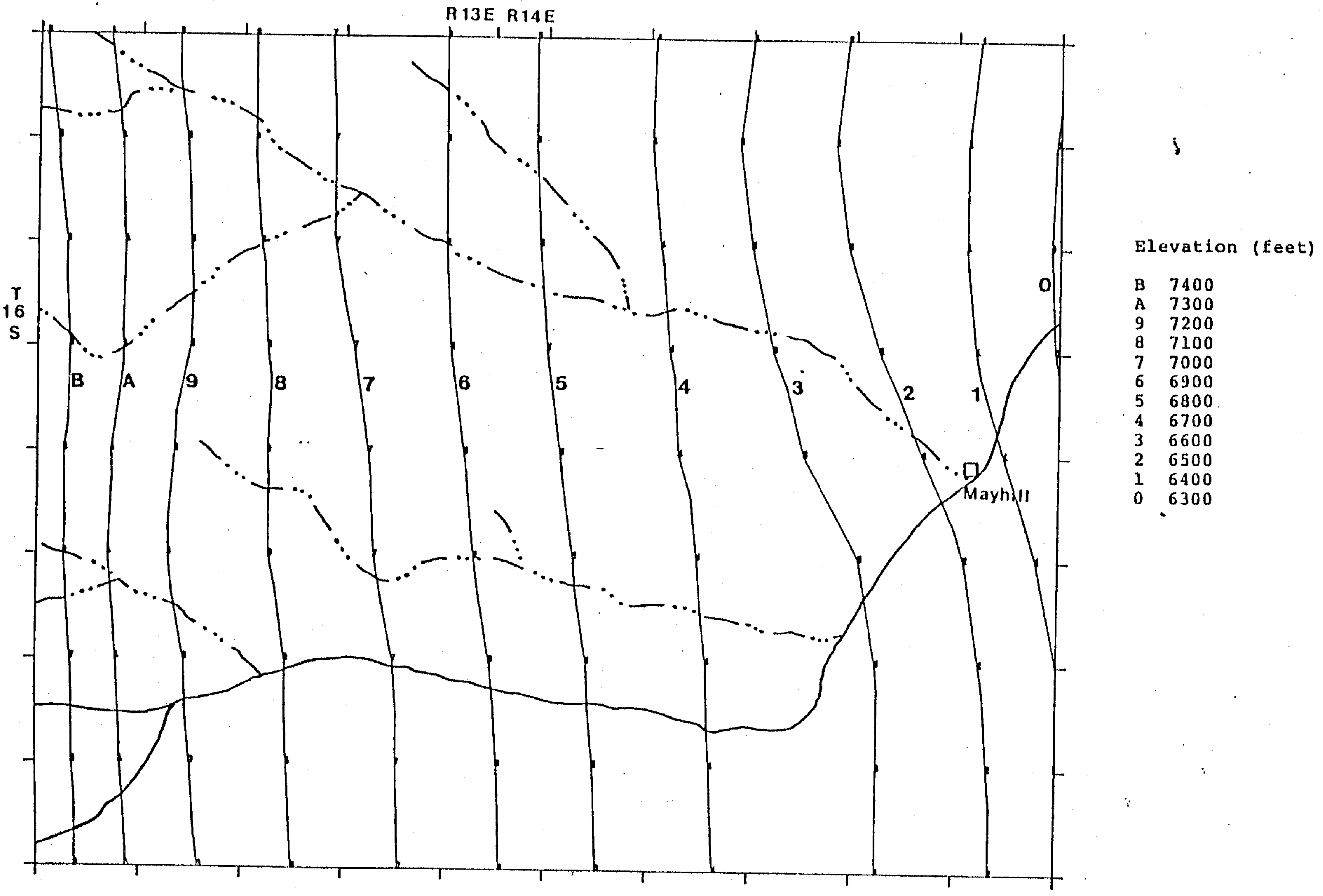
Water levels were obtained from well schedules and well-completion records of the New Mexico State Engineer office, and are given in Appendix A. The initial head distribution used in the model is shown in Figure 13. Although data are mixed from different years (1946 to 1980), pumping rates have remained low and water levels have not changed greatly. Therefore, steady-state groundwater flow exists and the storage coefficient can be eliminated from the governing equation.

Wasiolek and Gross (1983) estimated a transmissivity of 3400 gpd/ft for the study area; this value was applied uniformly across the modeled area. Pumping tests in areas farther east and west suggest that this is a conservative value for the Yeso Formation; therefore, minimum values for underflow were calculated.



Finite-Difference Grid of the Study Area

Figure 12. Finite-difference grid for computer modeling of groundwater flow.



Observed Hydraulic Head

Figure 13. Contour map of the observed head distribution, or water level, in the modeled region. Labels for elevations are arbitrary.

Today, the head distribution is maintained by recharge, mainly in the form of precipitation, from the highest parts of the Sacramento Mountains. But, as previously discussed, the presence of higher terraces in the valley containing Holocene mollusks suggests that water levels have declined since the last glaciopluvial period. To crudely estimate the underflow and head changes during more humid periods, various quantities of recharge were forced into the groundwater system.

Although pumpage in the modeled region is insignificant, two pumping wells were included in the model:

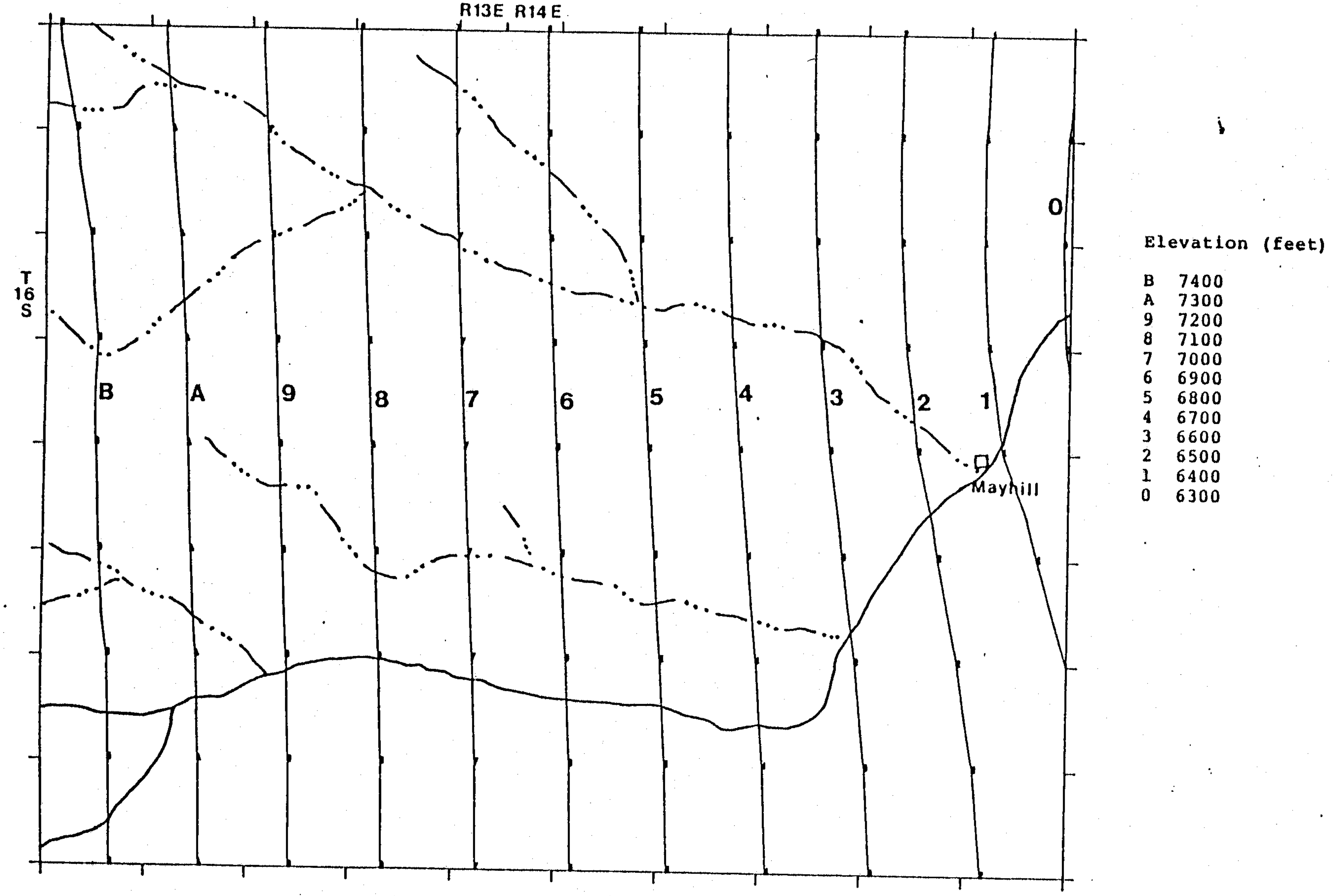
Location	Pumping Rate (acre-ft/yr)
Sec.10, T.16S., R.13E.	10
Sec.26, T.16S., R.14E.	18

Calibration

An exact match between observed (Figure 13) and computed (Figure 14) heads was not warranted because the observed head map is approximated from discrete points that are concentrated in James and Cox canyons. Also, the Yeso is a layered formation that produces water from many limestone and siltstone units. Since the deeper units tend to be under greater artesian pressure, the water level in a well is somewhat dependent on the depth drilled. For this study, agreement within 100 feet was obtained.

Results

Cumulative mass balances for several simulations are shown in Tables II to VI. Some terms on these tables require explanation. The constant-head source is mainly flow across the western boundary and represents the amount of water entering the Yeso Formation from flow along the regional water table. The constant-head discharge is the amount of water flowing eastward, or underflow, from the study area. Recharge was varied to simulate more humid, wetter conditions, such as might have occurred during glaciopluvial periods. Constant-head discharges for additional recharge rates of 0.5 in/yr, 1.0 in/yr, and 10 in/yr are shown in Tables III to V. But if transmissivity is changed, constant-head discharges are changed. For example, underflow for a transmissivity of 3400 gpd/ft with no recharge added to the system amounts to 3778 acre-ft/yr (Table II); for the same conditions, but with transmissivity equal to 10,000 gpd/ft, underflow is 11,139 acre-ft/yr (Table VI). Cross-sections along James and Cox canyons show head changes computed for areal recharge rates of 0.0 in/yr, 0.5 in/yr, and 1.0 in/yr (Figures 15 and 16). Figure 16 shows that an additional recharge rate of 0.5 in/yr should be sufficient to raise the water table back to



Simulated Hydraulic Head

Figure 14. Contour map of the simulated head distribution. Values are within 100 feet

Table II

```
Transmissivity:        3400.00 gpd/ft
Areal Recharge Rate:   0.0 in/yr


                    Mass Balance
               (units are acre-feet)

Sources:                                Discharges:
  Storage         0.00                    Constant head   5.18
  Recharge        0.00                    Pumpage         0.03
  Constant head   5.21                    Leakage         0.00
  Leakage         0.00
  Total           5.21                    Total           5.21


                Rate for a time step
           (units are acre-feet per year)

Recharge           0.00
Pumpage          -24.98
Constant head:
In              3803.07
Out            -3778.02
```

Table III

Transmissivity: 3400.00 gpd/ft
Areal Recharge Rate: 0.5 in/yr

Mass Balance
(units are acre-feet)

Sources:		Discharges:	
Storage	0.00	Constant head	6.65
Recharge	2.96	Pumpage	0.03
Constant head	3.73	Leakage	0.00
Leakage	0.00		
Total	6.69	Total	6.68

Rate for a time step
(units are acre-feet per year)

Recharge	2159.59
Pumpage	-24.98
Constant head:	
In	2723.27
Out	-4857.82

Table IV

Transmissivity: 3400.00 gpd/ft
Areal Recharge Rate: 1.0 in/yr

Mass Balance
(units are acre-feet)

Sources:		Discharges:	
Storage	0.00	Constant head	8.13
Recharge	5.91	Pumpage	0.03
Constant head	2.25	Leakage	0.00
Leakage	0.00		
Total	8.16	Total	8.16

Rate for a time step
(units are acre-feet per year)

Recharge	4315.93
Pumpage	-24.98
Constant head:	
In	1645.14
Out	-5936.02

Table V

Transmissivity: 3400.00 gpd/ft
Areal Recharge Rate: 10.0 in/yr

Mass Balance
(units are acre-feet)

Sources:		Discharges:	
Storage	0.00	Constant head	59.09
Recharge	59.12	Pumpage	0.03
Constant head	0.00	Leakage	0.00
Leakage	0.00		
Total	59.12	Total	59.12

Rate for a time step
(units are acre-feet per year)

Recharge	43,159.43
Pumpage	-24.98
Constant head:	
In	0.00
Out	-43,134.45

Table VI

Transmissivity:	10,000.0 gpd/ft
Areal Recharge Rate:	0.0 in/yr

Mass Balance
(units are acre-feet)

Sources:		Discharges:	
Storage	0.00	Constant head	15.26
Recharge	0.00	Pumpage	0.03
Constant head	15.29	Leakage	0.00
Leakage	0.00		
Total	15.29	Total	15.29

Rate for a time step
(units are acre-feet per year)

Recharge	0.00
Pumpage	-24.98
Constant head:	
In	11,164.51
Out	-11,139.39

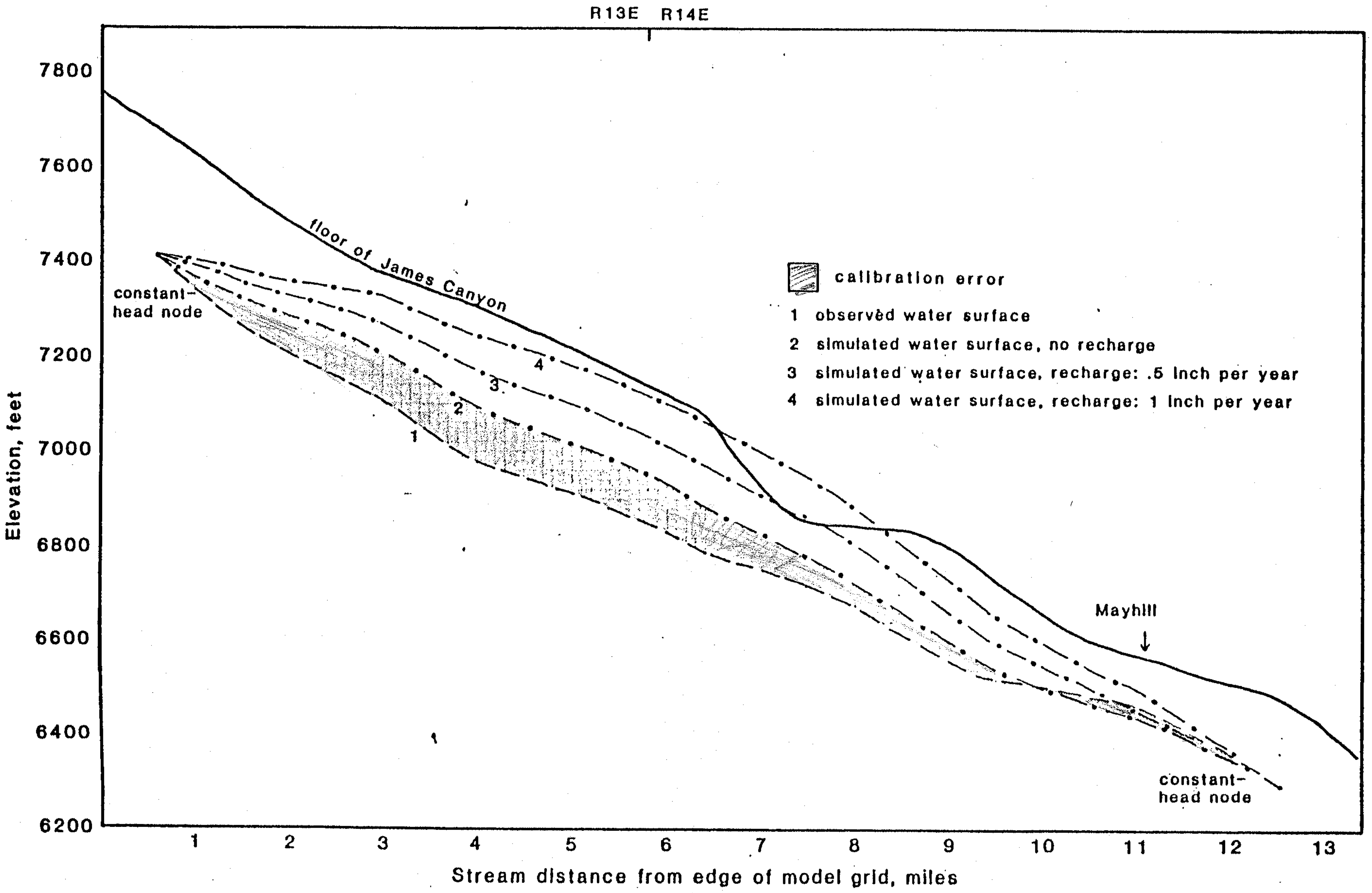


Figure 15. Section along James Canyon showing simulated water surfaces produced by varying the areal recharge flux.

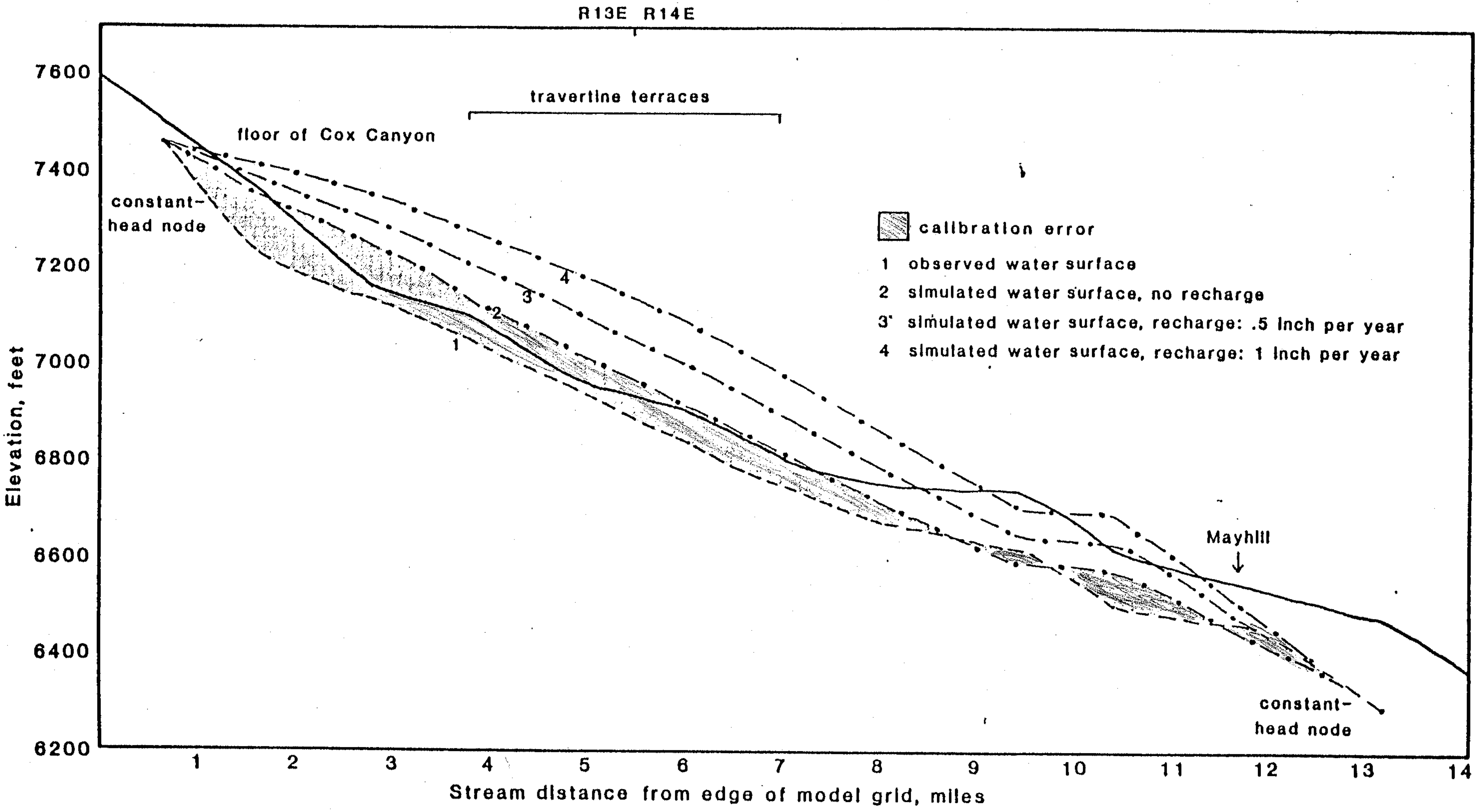


Figure 16. Section along Cox Canyon showing simulated water surfaces produced by varying the areal recharge flux.

the level of the travertine terraces in the Rio Penasco valley below its confluence with Cox Canyon. Additional recharge of 0.5 in/yr to the groundwater system would require several inches of additional annual precipitation.

CHEMISTRY

Wells

Most water analyses from wells in the study area are from the Yeso Formation; therefore, only water from this formation will be considered. Chemistry of water from wells sampled for this study are plotted on a Piper diagram (Piper, 1944) in Figure 17. The following discussion includes these and data from Hood (1960); Summers (1976); Wasiolek and Gross (1983). These data are given in Table VII.

Calcium ranges from 80.0 to 200.0 ppm. It averages 127.9 ppm in 18 wells, and is usually the most abundant cation in the groundwater of the study area. Limestone, which is essentially calcium carbonate with impurities, dolomite, and sulfates, which include gypsum and anhydrite, probably contribute most of this calcium. The ratio of calcium to magnesium, computed from equivalents per million, ranges from 1.55 to 11.56 for 16 wells in the study area. Three wells, 25, 29, and 122, have a ratio greater than 5 to 1, suggesting that the water obtained calcium from relatively pure limestone or other calcium carbonate precipitates, or that gypsum was available for solution. Ratios less than 2 to 1 (wells 54 and 70) may indicate that dolomitic rocks are being dissolved (Hem, 1959, p. 82).

The alkali metals sodium and potassium are often lumped together, yet they behave very differently. Whereas sodium tends to remain in solution, potassium is easily recombined with weathering products, especially clay minerals. Sodium is far more abundant than potassium in natural waters; in the study area, it ranges from 5.4 to 57.0 ppm and averages 16.2 ppm in 20 wells, and potassium ranges from 0.1 to 1.1 ppm and averages 0.7 ppm in 20 wells. Although there is ordinarily very little sodium in carbonate rocks, small amounts of evaporites containing sodium salts may be present in the interbedded sediments of the Yeso Formation.

Sulfate tends to accumulate in water because the most common cations in natural waters do not form insoluble compounds with sulfate. The 50 ppm of sulfate present in groundwater near the mountain crest probably is derived partly from sulfate present in airborne dust that is washed out by rainfall. Sulfate concentration increases with distance from the crest of the mountains (Figure 18). By Mayhill, many wells exceed the desirable maximum limit of 250 ppm set by the Public Health Service in 1962. This steady increase in concentration down the dip of the Yeso Formation suggests that sulfate minerals are distributed rather uniformly instead of being concentrated at scattered localities.

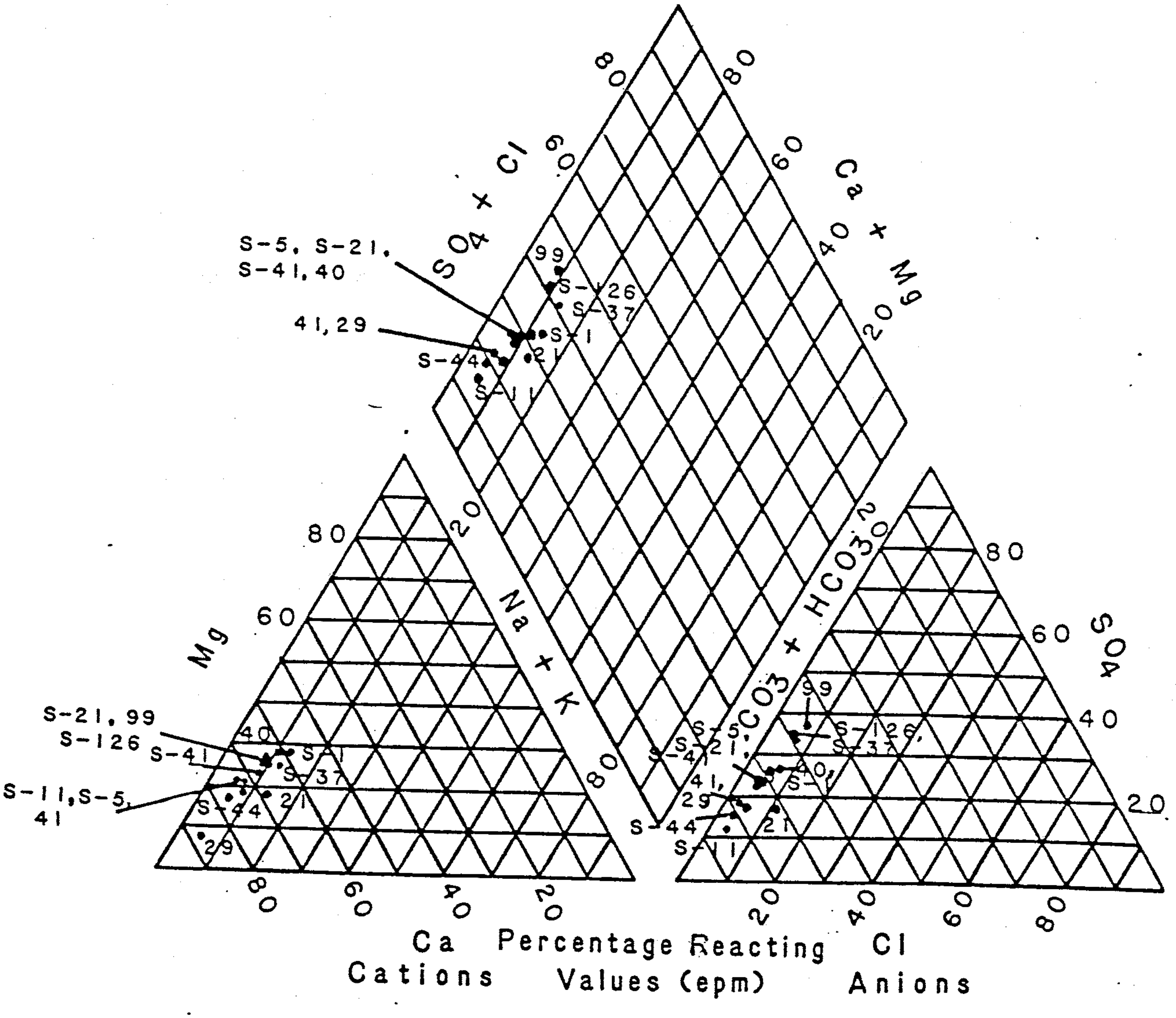


Figure 17. Piper diagram for well and spring chemistry (after Piper, 1944).

TABLE VII.

CHEMISTRY AND TRITIUM DATA FOR WELLS IN STUDY AREA, OTERO COUNTY, N.M.
(chemical constituents in parts per million and equivalents per million (underscored).)

WELL NO.	LOCATION	DATE OF COLLEC-TION	AQ	WELL DEPTH (FT)	TRIT-IUM UNITS	HCO3	CL	SO4	NA	K	MG	CA	TDS	CONDUC-IVITY	PH	SOURCE
18	16.12.03.142	9-52	PY & QAL	100	-	270. 4.43	0.0 0.0	118. 2.46	-	-	10.0 .82	-	712.	-	7.4	SUMMERS (1976)
19	16.12.03.1423	5-56	PY & QAL	195-400?	-	308. 5.05	8.5 .24	61. 1.27	6.7 .29		18. 1.48	98. 4.89	359.	603.	7.6	HOOD (1960)
19	.do	9-61	PY & QAL	195-400?	-	310. 5.08	13. .37	68. 1.42	-	-	7.4 .61	-	-	628.	7.6	SUMMERS (1976)
20	16.12.03.1424	9-61	PY	176	-	316. 5.18	12. .34	54. 1.12	-	-	9.8 .81	-	-	612.	7.2	SUMMERS (1976)
20	.do	9-70	PY	176	-	286. 4.69	31. .87	55. 1.15	11. .48	.4 .01	17. 1.40	-	359.	640.	6.0	SUMMERS (1976)
20	.do	9-73	PY	176	-	329. 5.39	22. .62	51. 1.06	16. .70	.4 .01	12. .99	-	380.	624.	6.2	SUMMERS (1976)
20	.do	5-76	PY	176	-	315. 5.16	30. .85	58. 1.21	17. .74	.7 .02	9.5 .78	-	346.	660.	7.3	SUMMERS (1976)
21	16.12.03.1424	5-76	PY	307	-	315. 5.16	30. .85	58. 1.21	19. .83	.7 .02	12. .99	-	410.	630.	7.5	SUMMERS (1976)
21	.do	7-82	PY	307	23.8	283.0 4.64	23.80 .67	54.65 1.14	16. .70	.39 .01	13. 1.1	80. 4.0	-	335.	7.6	
126	16.12.05.133	3-56	PY	600	-	407. 6.67	12. .34	52. 1.08	13. .57		20. 1.65	119. 5.94	429.	707.	7.5	HOOD (1960)
127	16.12.06.322	3-56	PSA	429	-	401. 6.57	14. .39	57. 1.19	13. .57		21. 1.73	118. 5.89	434.	716.	7.0	HOOD (1960)
25	16.12.06.434422	9-80	PY	300	35.0	378. 6.2	9.8 .27	46. .96	6.3 .27	.48 .012	7.2 .59	127. 6.34	386.	615.	7.9	WASIOLEK AND GROSS (1983)
29	16.12.08.1113	7-82	PY	80	38.9	339.2 5.56	7.26 .20	64.03 1.33	6. .26	.07 .002	5. .41	95. 4.74	-	411.	7.0	
40	16.13.04.31232	10-60	PY	412	2.1	332. 5.4	14. .39	130. 2.71	16. .70	.83 .02	26.0 2.14	114. 5.69	467.	470.	7.7	WASIOLEK AND GROSS (1983)
40	.do	7-82	PY	412	4.1	303.8 4.98	13.72 .39	92.83 1.93	16.25 .71	.38 .01	25. 2.06	85. 4.24	-	470.	7.2	
54	16.13.11.43244	10-60	PY	127	22.3	395. 6.48	81.0 2.29	233. 4.85	57. 2.48	.91 .02	55.0 4.52	140. 7.0	764.	1150.	7.4	WASIOLEK AND GROSS (1983)
57	16.13.13.44410	10-60	PY	400	0.2	342. 5.60	15.8 .45	133. 2.77	12. .52	.70 .02	26.0 2.14	119. 5.94	476.	-	6.1	WASIOLEK AND GROSS (1983)
61	16.13.29.3342	9-80	PY	303	9.7	322. 5.28	11.8 .33	131. 2.73	9.6 .42	.70 .02	22.0 1.81	118. 5.89	454.	700.	7.8	WASIOLEK AND GROSS (1983)

TABLE VII. (continued)

63	16.13.30.32114	9-80	PY	375	9.5	276. 4.52	9.8 .28	156. 3.25	9. .39	.56 .014	22.0 1.81	116. 5.79	451.	645.	7.3	WASIOLEK AND GROSS (1983)
70	16.14.10.14311	10-80	PY	740	0.7	298. 4.88	25.6 .72	446. 9.29	20.0 .87	1.10 .03	58.0 4.77	172. 8.56	873.	1000.	8.3	WASIOLEK AND GROSS (1983)
80	16.14.18.43331	10-80	PY	305	4.2	317. 5.20	16.0 .44	179. 3.73	14.0 .61	.74 .02	29.0 2.39	123. 6.14	520.	650.	8.0	WASIOLEK AND GROSS (1983)
90	16.14.21.21331	10-80	PY	310	1.2	349. 5.72	16.0 .45	186. 3.87	14.0 .61	.63 .02	28.0 2.30	137. 6.84	557.	650.	7.7	WASIOLEK AND GROSS (1983)
99	16.14.26.41222	7-82	PY	268	3.8	514.8 8.44	43.16 1.22	274.06 5.71	30. 1.31	.56 .01	48. 3.95	200. 9.98	-	1000.	7.0	
100	16.14.26.41343	10-80	PY	100	1.4	344. 5.64	19.7 .56	160. 3.33	16.0 .70	.79 .02	30.0 2.43	127. 6.34	526.	540.	8.0	WASIOLEK AND GROSS (1983)
103	16.14.35.12113	7-82	GAL	90	13.0	-	-	-	-	-	-	-	-	-	-	
111	17.13.04.44421	9-80	PY	250	-	276. 4.52	7.9 .22	143. 2.98	7.3 .32	.63 .02	19.5 1.60	109. 5.44	426.	540.	7.9	WASIOLEK AND GROSS (1983)
116	17.14.08.12111	9-80	GAL	105	9.7	354. 5.80	35.5 1.00	268. 5.58	23.0 1.00	1.10 .03	36.0 2.92	165. 9.23	726.	900.	7.5	WASIOLEK AND GROSS (1983)
122	17.14.17.31224	9-80	PY	425	3.9	425. 7.00	7.9 .22	15. .31	5.4 .24	.61 .02	12.0 .99	123. 6.14	589.	435.	7.8	WASIOLEK AND GROSS (1983)
123	17.14.18.34442	9-80	PY	868	0.7	315. 5.16	14.0 .39	125. 2.60	11.0 .48	.91 .02	27.0 2.22	133. 6.64	468.	360.	8.5	WASIOLEK AND GROSS (1983)

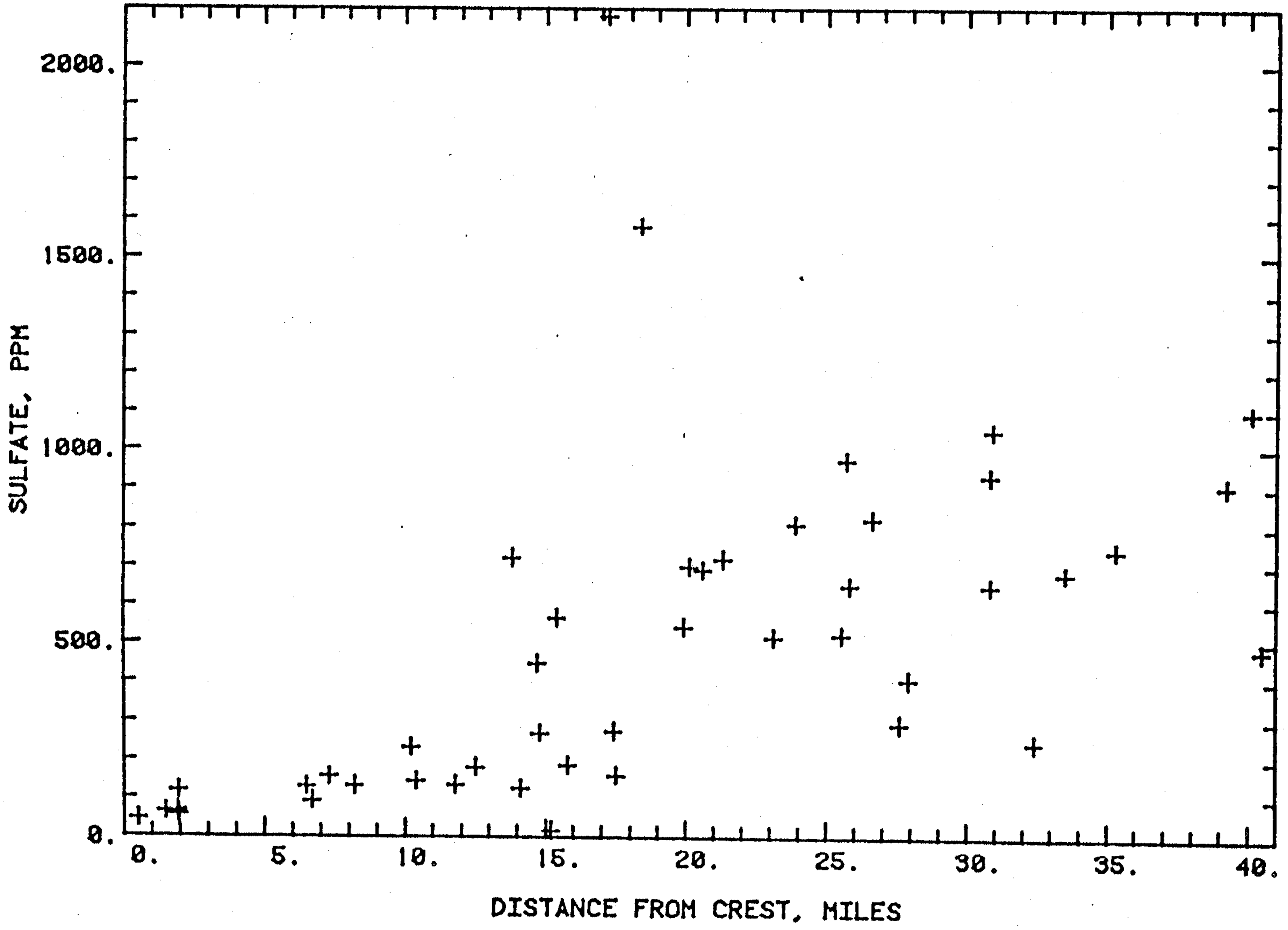


Figure 18. Graph of sulfate in wells vs. distance from the mountain crest. The concentration of sulfate increases with increasing distance from the mountain crest.

Chlorine is the most important member of the halogen group in natural waters and is present as dissociated chloride in dilute solutions. Although chloride concentration is usually less than 30 ppm in wells of the study area, it is elevated to 43 ppm in a well in Mayhill and to 81 ppm in well 54 (sec 11, T.16S., R.13E.). Sodium levels are also significantly elevated in these wells, suggesting that sodium chloride is in solution at these locations.

Additional data from areas north and northeast of the study area in Mourant (1963), Dinwiddie (1963), and Morley (in preparation) are included on scattergrams in Appendix E; these data show that the correlation between increasing concentration of major chemical constituents and distance from the mountain crest can be extended 40 miles eastward at least to the Border Hills structural zone.

Contact springs

Springs that issue from alluvium are subject to mixing of waters from different sources and will not be considered here. Chemistry of water from springs sampled for this study are plotted on a Piper diagram (see Figure 17). The following discussion includes these and data from Dinwiddie (1963); Summers (1976); Davis and others (1980); and Wasiolek and Gross (1983). These data are given on Table VIII.

As in wells, calcium is usually the most abundant cation in the study area, ranging from 36.7 to 123.0 ppm and averaging 86.8 ppm in 22 springs. Springs show a very low correlation (correlation coefficient= 0.294) of calcium concentration with distance from the mountain crest. The ratio of calcium to magnesium in 12 springs ranges from 1.78 to 4.65, and averages 3.18. These numbers suggest little dissolution of gypsum or dolomite by spring waters.

Sodium ranges from 7.8 to 27.0 ppm and averages 12.5 ppm in 27 springs, and potassium ranges from 0.2 to 3.5 ppm and averages 0.6 ppm in 27 springs. Neither element showed a definite pattern of increasing concentration with distance from the mountain crest, but there is some correlation (correlation coefficient= 0.6334) of their combined concentration with that of calcium and magnesium (Figure 19).

Sulfate, which ranges from 43.0 to 242.0 ppm and averages 90.3 ppm in 27 springs, shows the best correlation of all the chemical constituents analyzed with distance from the mountain crest (Figure 20). Despite this, the correlation coefficient, 0.5501, is quite low. As in the wells, this is evidence that a small amount of sulfate minerals probably are still present in the rock formations.

TABLE VIII.

CHEMISTRY AND TRITIUM DATA FOR SPRINGS IN STUDY AREA, OTERO COUNTY, N.M.
(chemical constituents in parts per million and equivalents per million (underscored).)

SPRING NO.	LOCATION	DATE OF COLLECTION	TRITIUM UNITS	HCO3	CL	SO4	NA	K	MG	CA	TDS	CONDUCTIVITY (UMHOS)	pH	TEMP	SOURCE
1	16.11.01.111	7-12-82	10.5 ±0.7	363.6 5.96	23.40 .66	112.34 2.34	20. .87	.41 .01	26. 2.14	90. 4.49	-	600.	7.4	-	
2	16.12.02.142	6-27-82	11.4 ±0.7	-	-	-	-	-	-	-	-	455.	-	12	
4	16.12.03.131222		-	314. 5.15	11. .31	59. 1.23	9.0 .39	.6 .02	57. 4.69	-	410.	650.	7.6	-	SUMMERS (1976)
5	16.12.03.14142a		-	298. 4.88	11. .31	71. 1.48	12. .52	.5 .01	49. 4.03	-	417.	608.	8.2	-	SUMMERS (1976)
6	16.12.03.14142b		-	294. 4.82	12. .34	71. 1.48	12. .52	.5 .01	40. 3.29	-	423.	608.	8.2	-	SUMMERS (1976)
7	16.12.03.142	6-27-82	30.9 ±0.6	-	-	-	-	-	-	-	-	300.	-	13	
8	16.12.03.144222	3-29-56	-	341. 5.59	11. .31	52. 1.08	-	-	-	-	-	622.	7.7	-	DINWIDDIE (1963)
8	.do	6-8-72	-	342. 5.61	8. .23	52. 1.09	7.6 .33	.4 .01	46. 3.78	-	398.	619.	8.3	-	SUMMERS (1976)
8	.do	1973	35.2	311.7 5.12	10.4 .29	63.4 1.32	10. .44	.48 .01	48.1 3.94	38.3 1.90	375.	621.	8.0	-	CHEMISTRY: DAVIS & OTHERS (1980); TRITIUM: WASIOLEK AND GROSS (1983)
8	.do	6-3-77	-	-	-	-	-	-	-	-	-	500.	7.7	3	DAVIS AND OTHERS (1980)
8	.do	6-27-82	40.4 ±0.9	-	-	-	-	-	-	-	-	350.	-	20	
8	.do	7-12-82	-	248.9 4.08	9.28 .26	59.26 1.23	8.5 .37	.125 .003	12. .99	70. 3.49	-	320.	7.65	11	
10	16.12.09.431	9-30-80	13.7	222. 3.64	20.0 .56	150. 3.12	20.0 .87	1.60 .04	16.5 1.36	95. 4.74	414.	495.	8.0		WASIOLEK AND GROSS (1983)
11	16.12.14.41	7-12-82	7.7	411.1 6.74	8.87 .25	42.96 .89	8.25 .36	.19 .01	16. 1.32	95. 4.74	-	443.	7.2	8.9	TRITIUM DATA: WASIOLEK AND GROSS (1983)
13	16.12.19.244	5-26-77	-	-	-	-	-	-	-	-	-	425.	8.0	6	DAVIS AND OTHERS (1980)
21	16.12.23.4324	7-12-82	6.4 ±0.7	323.3 5.30	14.93 .42	81.64 1.70	13.75 .60	.26 .01	21. 1.73	90. 4.49	-	442.	7.4	10	
	16.12.27.12	6-26-77	-	-	-	-	-	-	-	-	-	400.	6.1	6	DAVIS AND OTHERS (1980)
32	16.13.03.411	10-1-80	26.6	349. 5.72	15.8 .45	88. 1.83	13.0 .57	.53 .01	16.0 1.32	123. 6.14	431.	610.	7.3	-	WASIOLEK AND GROSS (1983)

TABLE VIII. (continued)

37	16.13.04.3114	7-12-82	15.2 ±0.7	339.2 5.56	25.01 .71	149.13 3.10	25.25 1.10	.26 .01	27. 2.22	110. 5.49	-	600.	7.0	10.6	
39	16.13.04.442	10-1-80	18.2	268. 4.4	23.6 .67	210. 4.34	25.0 1.39	.88 .02	27.5 2.26	117. 5.84	538.	680.	8.0	-	WASIOLEK AND GROSS (1983)
40	16.13.05.3212	6-26-82	6.1 ±0.6	-	-	-	-	-	-	-	-	350.	-	8	
41	16.13.06.1222	7-12-82	-0.2 ±1.0	353.8 5.80	16.14 .46	69.21 1.86	14. .61	.19 .01	18. 1.46	90. 4.49	-	475.	7.4	10	
42	16.13.06.12434	10-1-80	10.8	307. 5.04	14.0 .39	98. 2.04	10.0 .44	.43 .01	15.0 1.23	108. 5.39	399.	410.	7.8		WASIOLEK AND GROSS (1983)
42	.do	6-27-82	7.4 ±0.6	-	-	-	-	-	-	-	-	390.	-	11.5	
42	.do	7-12-82	10.4 ±0.7	326.2 5.38	12.10 .34	61.56 1.28	10.5 .46	.19 .01	15. 1.23	95. 4.74	-	390.	7.1	7.8	
43	16.13.07.2314	7-12-82	5.8 ±0.7	351.4 5.76	9.92 .28	52.34 1.09	9. .39	.34 .01	14. 1.15	100. 4.99	-	417.	7.1	9.4	
44	16.13.08.42112	10-2-80	4.3	230. 3.76	7.9 .22	137. 2.84	8.9 .39	.61 .02	14.0 1.20	108. 5.39	391.	415.	8.0	-	WASIOLEK AND GROSS (1983)
57	16.13.16.243	10-1-80	4.6	329. 5.40	7.9 .22	50. 1.04	7.8 .34	.56 .01	17.0 1.40	99. 4.94	511.	415.	7.9	-	WASIOLEK AND GROSS (1983)
66	16.13.33.313	9-30-80	11.9	283. 4.64	5.9 .17	74. 1.54	9.0 .39	.65 .02	15.0 1.23	91. 4.54	337.	390.	7.5	-	WASIOLEK AND GROSS (1983)
68	16.13.36.321	6-2-77	-	-	-	-	-	-	-	-	-	560.	7.49	5	DAVIS AND OTHERS (1980)
72	16.14.26.343	6-3-77	-	157. 2.60	30.0 .85	242. 5.03	27.0 1.17	3.50 .09	36.5 3.00	83.9 4.19	501.	760.	7.12	11	DAVIS AND OTHERS (1980)
72	.do	6-28-82	7.2 ±0.5	-	-	-	-	-	-	-	-	675.	-	11.5	
75	16.14.31.111	6-3-77	-	-	-	-	-	-	-	-	-	510.	7.75	12	DAVIS AND OTHERS (1980)
76	16.14.31.1130	6-3-77	21.6 ±0.4	190. 3.12	13.0 .37	83. 1.73	10.5 .46	.50 .01	14.3 1.18	68.5 3.42	285.	470.	7.3	-	DAVIS AND OTHERS (1980)
79	16.14.32.44442	6-3-77	-	-	-	-	-	-	-	-	-	560.	7.2	8	DAVIS AND OTHERS (1980)
81	16.14.34.2243	6-28-82	13.7 ±0.7	-	-	-	-	-	-	-	-	490.	-	13.5	
85	17.11.11.23	5-6-77	-	198. 3.24	5.0 .14	45. .94	8.0 .35	.7 .02	11.3 .93	57.9 2.89	227.	420.	7.9	-	DAVIS AND OTHERS (1980)
85	.do	5-26-77	19.2 ±0.5	-	-	-	-	-	-	-	-	475.	6.0	5	DAVIS AND OTHERS (1980)
85	.do	8-16-77	-	-	-	-	-	-	-	-	-	-	-	11	DAVIS AND OTHERS (1980)

TABLE VIII. (concluded)

86	17.11.13.432	5-25-77	-	-	-	-	-	-	-	-	-	450.	7.8	0	DAVIS AND OTHERS (1980)
87	17.11.24	5-26-77	-	-	-	-	-	-	-	-	-	360.	8.1	4	DAVIS AND OTHERS (1980)
93	17.12.08.443	5-25-77	-	-	-	-	-	-	-	-	-	500.	7.5	1	DAVIS AND OTHERS (1980)
97	17.12.14.3231	5-24-77	-	-	-	-	-	-	-	-	-	460.	7.1	3	DAVIS AND OTHERS (1980)
98	17.12.14.4234	5-24-77	-	-	-	-	-	-	-	-	-	490.	7.15	-	DAVIS AND OTHERS (1980)
99	17.12.16.12212	5-24-77	-	-	-	-	-	-	-	-	-	470.	7.7	1	DAVIS AND OTHERS (1980)
100	17.12.16.43130	5-24-77	15.1 ±0.4	122. 2.0	6.0 .17	51. 1.06	9.4 .41	.5 .01	12.0 .95	36.7 1.83	177.	455.	7.68	1	DAVIS AND OTHERS (1980)
101	17.12.17.1142	5-25-77	-	-	-	-	-	-	-	-	-	500.	7.35	1	DAVIS AND OTHERS (1980)
102	17.12.17.1213	5-25-77	-	-	-	-	-	-	-	-	-	470.	7.3	0	DAVIS AND OTHERS (1980)
103	17.12.17.142 +.23	5-24-77	27.4 ±0.4	168. 2.76	4.0 .11	44. .92	8.3 .36	.5 .01	15.1 1.24	44.4 2.21	200.	490.	7.2	0	DAVIS AND OTHERS (1980)
103	.do	8-16-77	-	-	-	-	-	-	-	-	-	495.	6.6	6.7	DAVIS AND OTHERS (1980)
104	17.12.17.2123	5-25-77	-	-	-	-	-	-	-	-	-	520.	7.3	1	DAVIS AND OTHERS (1980)
106	17.12.20.444	5-24-77	-	-	-	-	-	-	-	-	-	470.	7.12	0	DAVIS AND OTHERS (1980)
108	17.12.21.331	5-24-77	-	-	-	-	-	-	-	-	-	500.	7.61	0	DAVIS AND OTHERS (1980)
111	17.12.29.223	5-24-77	-	-	-	-	-	-	-	-	-	450.	8.0	6	DAVIS AND OTHERS (1980)
111	.do	5-24-77	-	-	-	-	-	-	-	-	-	320.	8.05	9	DAVIS AND OTHERS (1980)
115	17.13.03.423	7-12-82	7.1 ±0.6	-	-	-	-	-	-	-	-	-	-	-	
116	17.13.11.3342 +.4	5-26-77	-	-	-	-	-	-	-	-	-	440.	7.8	10	DAVIS AND OTHERS (1980)
126	17.14.06.34	7-12-82	13.2 ±0.5	361.1 5.92	21.38 .60	165.75 3.45	19.5 .85	.5 .01	27. 2.22	120. 5.99	-	700.	7.4	13.9	
127	17.14.07.24421	5-26-77	-	-	-	-	-	-	-	-	-	525.	7.0	4	DAVIS AND OTHERS (1980)
127	.do	8-16-77	-	-	-	-	-	-	-	-	-	-	-	14.4	DAVIS AND OTHERS (1980)
128	17.14.08.2213	6-28-82	2.3 ±0.6	-	-	-	-	-	-	-	-	480.	-	14	

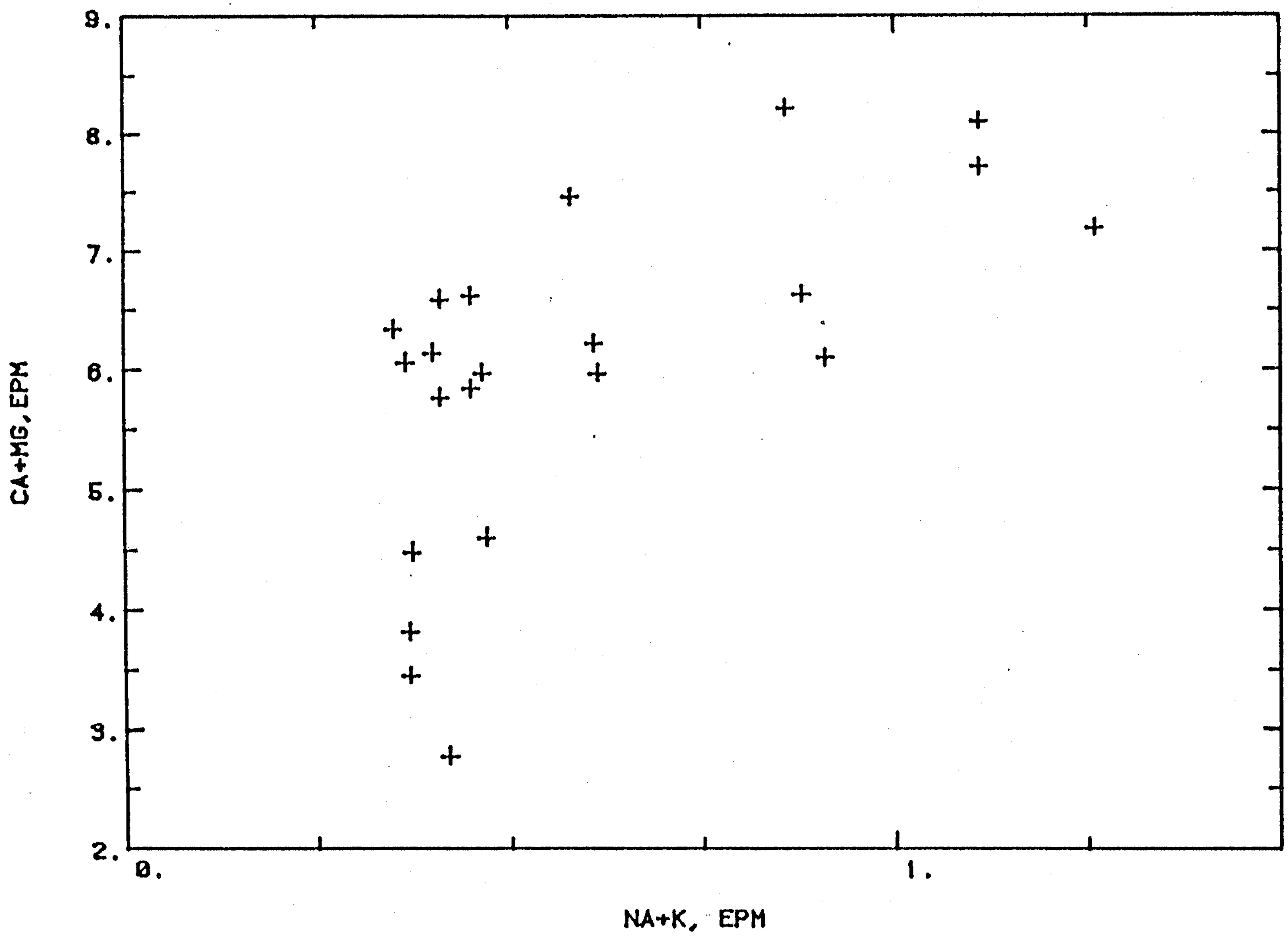


Figure 19. Graph of sodium and potassium vs. calcium and magnesium in springs Some correlation is indicated between the concentrations of these ion pairs.

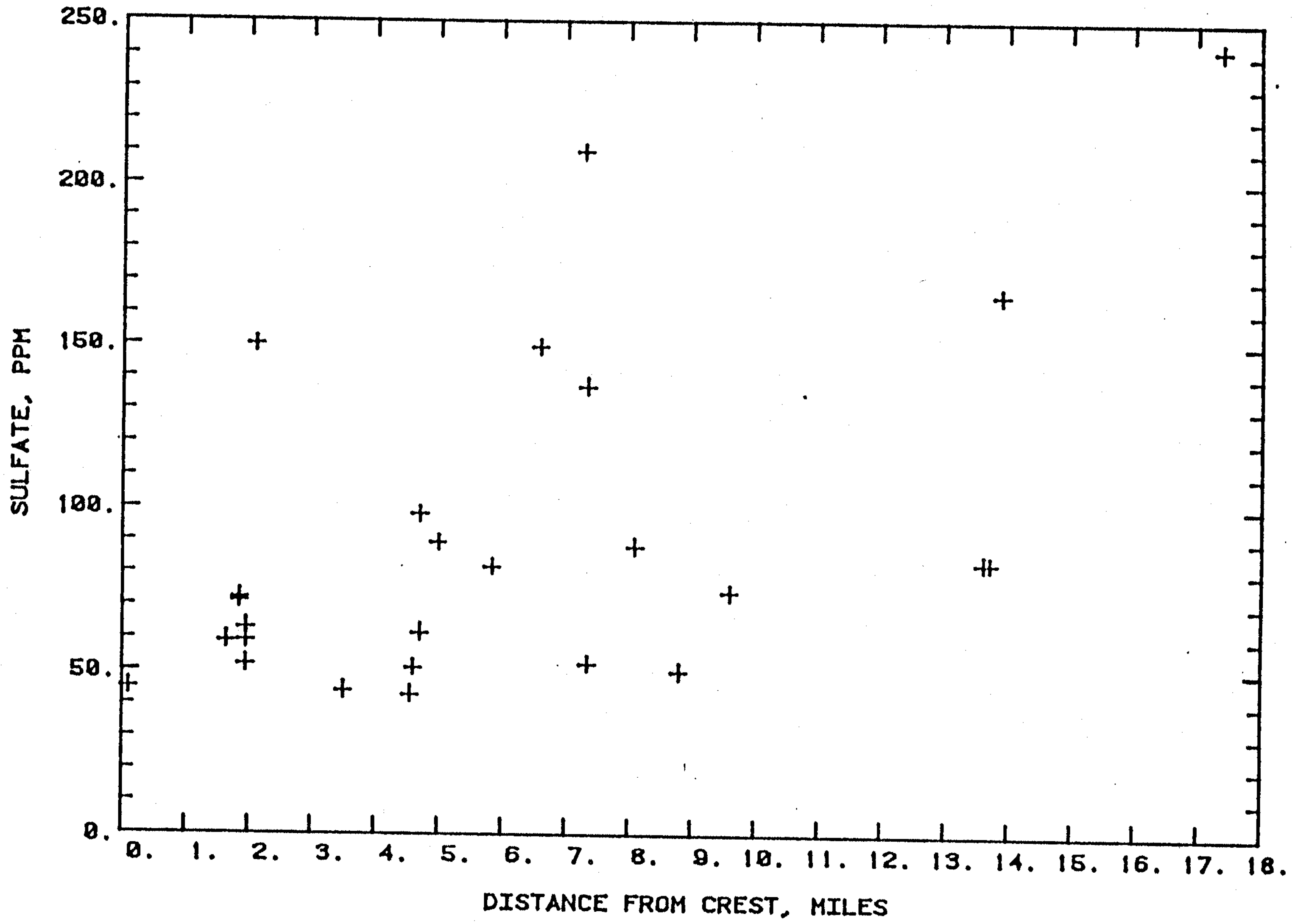


Figure 20. Graph of sulfate in springs vs. distance from the mountain crest. The concentration of sulfate increases with distance from the mountain crest.

Chloride ranges from 4.0 to 30.0 ppm and averages 12.8 ppm in 27 springs of the study area. It also shows some, albeit low, correlation (correlation coefficient= .4931) with distance from the mountain crest (Figure 21).

Appendix F contains more scattergrams and correlation coefficients for chemical constituents and distance from the mountain crest.

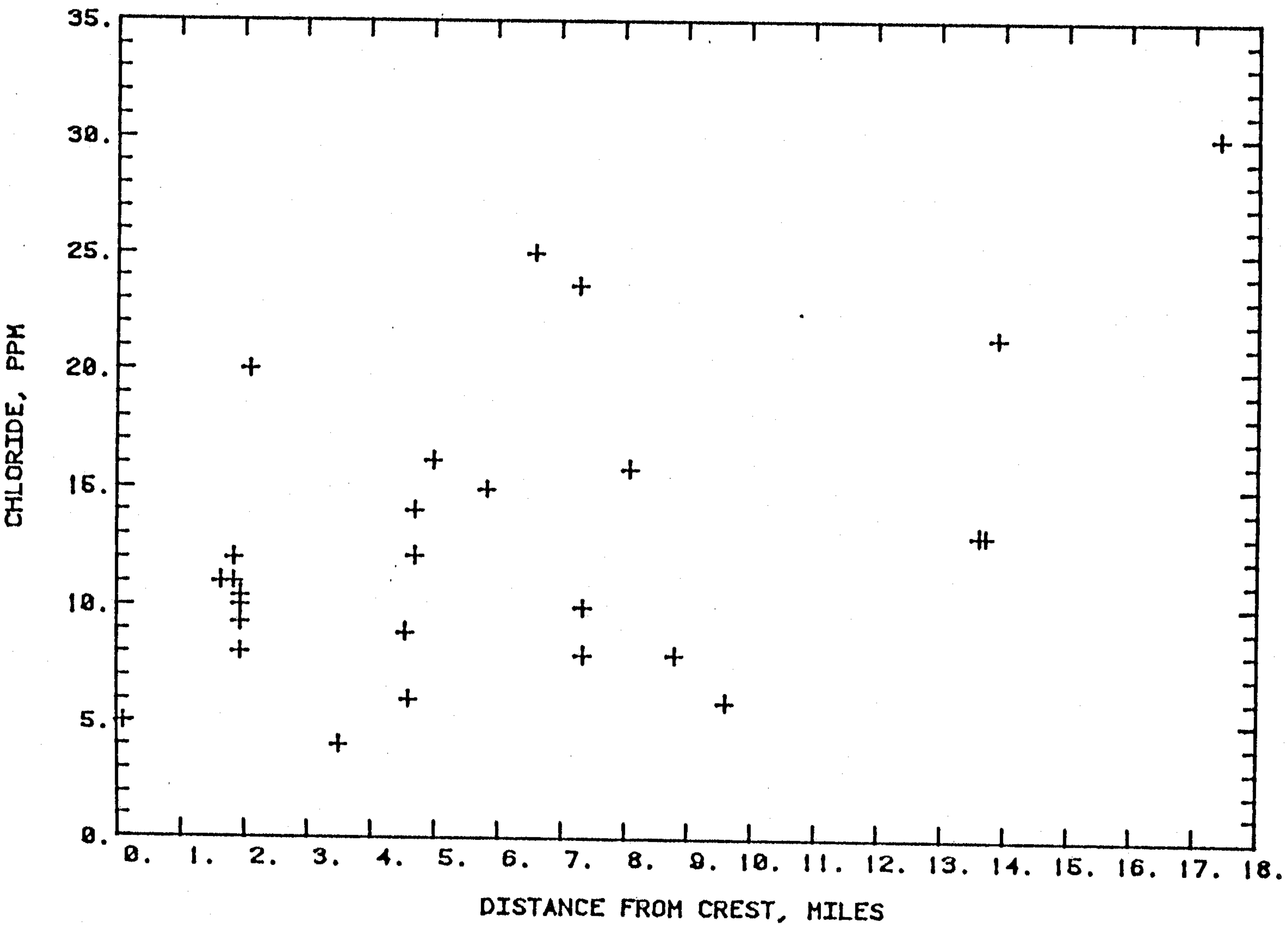


Figure 21. Graph of chloride in springs vs. distance from the mountain crest. This graph suggests an increase in the concentration of chloride with distance from the mountain crest.

TRITIUM

Theory

Tritium (H3,T) is a radioactive isotope of hydrogen, which becomes incorporated into the water molecule as HTO. Environmental tritium is added to atmospheric and surface water by cosmic radiation and by nuclear tests. Its concentration is reported in tritium units (TU), where one TU equals one tritium atom for every 1018

hydrogen atoms. No information exists on levels of tritium in precipitation in New Mexico before atmospheric nuclear testing began in 1954, but it probably averaged 10 TU (Rabinowitz and Gross, 1977). Measurements began in central New Mexico in October 1956, with some gaps after that date (Rabinowitz and others, 1977, p.9).

In 1963, the year of the Nuclear Test Ban Treaty, the tritium count in precipitation reached a peak of several thousand TU; it has since declined over the North American continent to about 100 TU (Gross, 1982) or less. Records of the NMIMT Tritium Laboratory show the average tritium activity of precipitation in the study area to be about 35 TU.

Tritium and groundwater

The activity peaks produced by nuclear tests can be used to trace horizontal and vertical flow through groundwater systems. Because the half-life of tritium is 12.26 years, dating is limited to about 50 years (Rabinowitz and Gross, 1977). Tritium content of groundwater decreases by radioactive decay as the water moves downgradient from its point of entry into the groundwater system. Theoretically, precipitation with a tritium activity of 10 TU will show up as groundwater with a tritium activity of 5 TU after 12.26 years. Hydrodynamic dispersion causes mixing and dilution between incoming and older water of the aquifer; this often decreases theoretical values.

It should be emphasized that "young" water, which is high in tritium, mixed with "old water", which is low in tritium, will have a tritium activity similar to water that entered the groundwater system with an elevated tritium activity and has remained there for years without mixing.

Tritium procedures

A reliable hydrologic interpretation depends on precise and accurate measurements of tritium activity in water. The method used in this and other cited studies has a counting standard deviation of less than plus or minus 3% and an overall accuracy of about plus or minus 10% because of the many stages involved. Tritium procedures are detailed in

Rabinowitz and Gross (1972).

Results

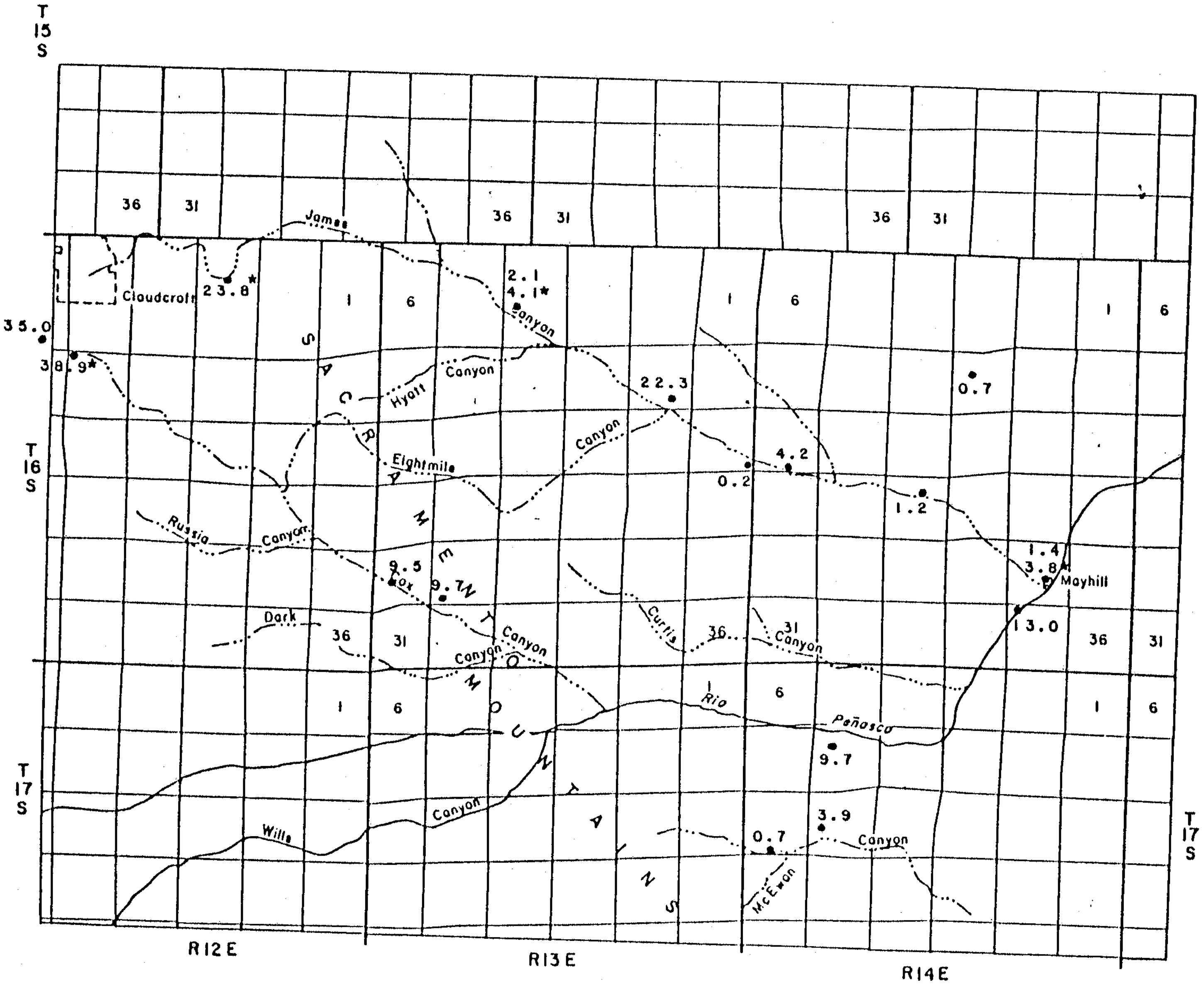
Data discussed include those collected for this study and those from Davis and others (1980) and Wasiolek and Gross (1983), and are given on Tables VII and VIII. Since most wells and springs have only a single tritium determination, profiles of tritium activity over time at a point in the region could not be constructed. Therefore, interpretation of observations has to rely on other geologic and hydrologic information.

Wells

This discussion is based on one tritium determination for each of 14 wells and 2 tritium determinations for one well in the Yeso Formation; well 103 (T.16S., R.14E., sec.35) and well 116 (T.17S., R.14E., sec.8) were excluded because they produce water from alluvium. Figure 22 shows the location and tritium activity of the sampled wells. Figure 23 shows the distribution of tritium activity in wells with distance from the crest of the Sacramento Mountains. Well depth varies from 868 feet (well 123 in T.17S., R.14E., sec.18) to 80 feet (well 29 in T.16S., R.12E., sec.8). Tritium activities vary from 38.9 to 0.2 TU. A range of activities is found at all distances from the crest. This indicates movement and mixing of recharging waters down gradient from the crest of the Sacramento Mountains and induced recharge to the Yeso Formation along James, Cox and McEwan canyons, which contain all wells sampled for tritium. Since sampling was not restricted to a single horizon in the aquifer, tritium content also indicates vertical stratification; for example, four of the five deepest wells in the study area, wells 40, 57, 70 and 123 have tritium activities as low as 2.1, 0.2, 0.7, 0.7 TU, respectively.

It is noteworthy that no tritium value higher than present atmospheric activity has been discerned within the study area. The data may indicate that all peaks have moved east of Mayhill. To test this theory, the best-fitting exponential curve was fitted to the data. The highest value on this curve, at the west end of the area, is 30.9 TU; the lowest value, at the east end of the area, is .91 TU. This curve was overlain by a tritium decay curve with the same highest and lowest values (Figure 24). Although the fit was good, travel time from the crest to Mayhill exceeded 60 years. Mixing with older water probably causes this flow time to be too long (see the section on flow velocity and the hydrologic properties of the Yeso Formation, below).

Appendix E shows scattergrams and correlation coefficients for tritium plotted against the concentration of major chemical constituents; these generally indicate



*sampled in 1982
(others sampled in 1980)

Figure 22. Tritium activity in wells

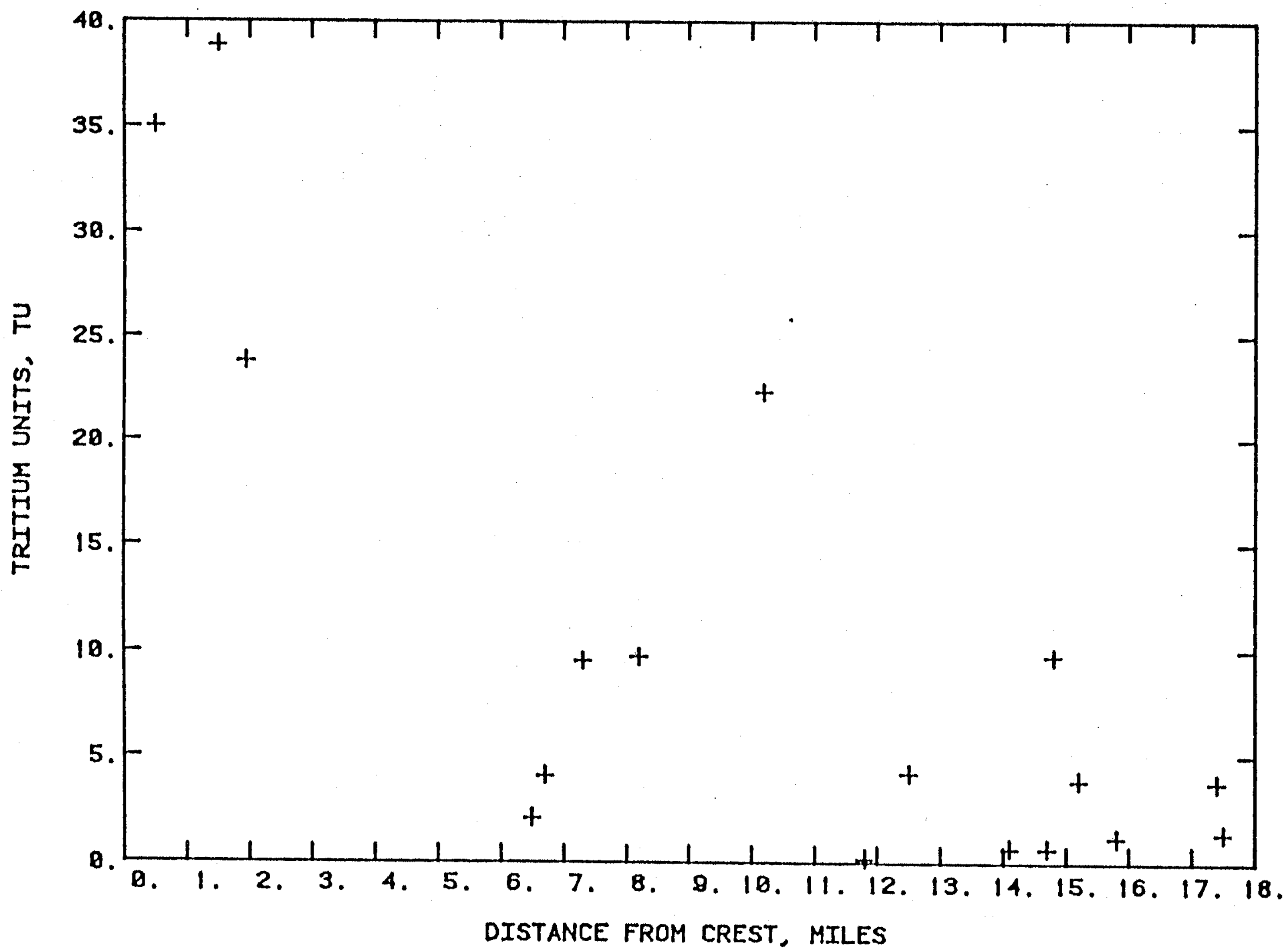


Figure 23. Graph of tritium in wells vs. distance from the mountain crest.

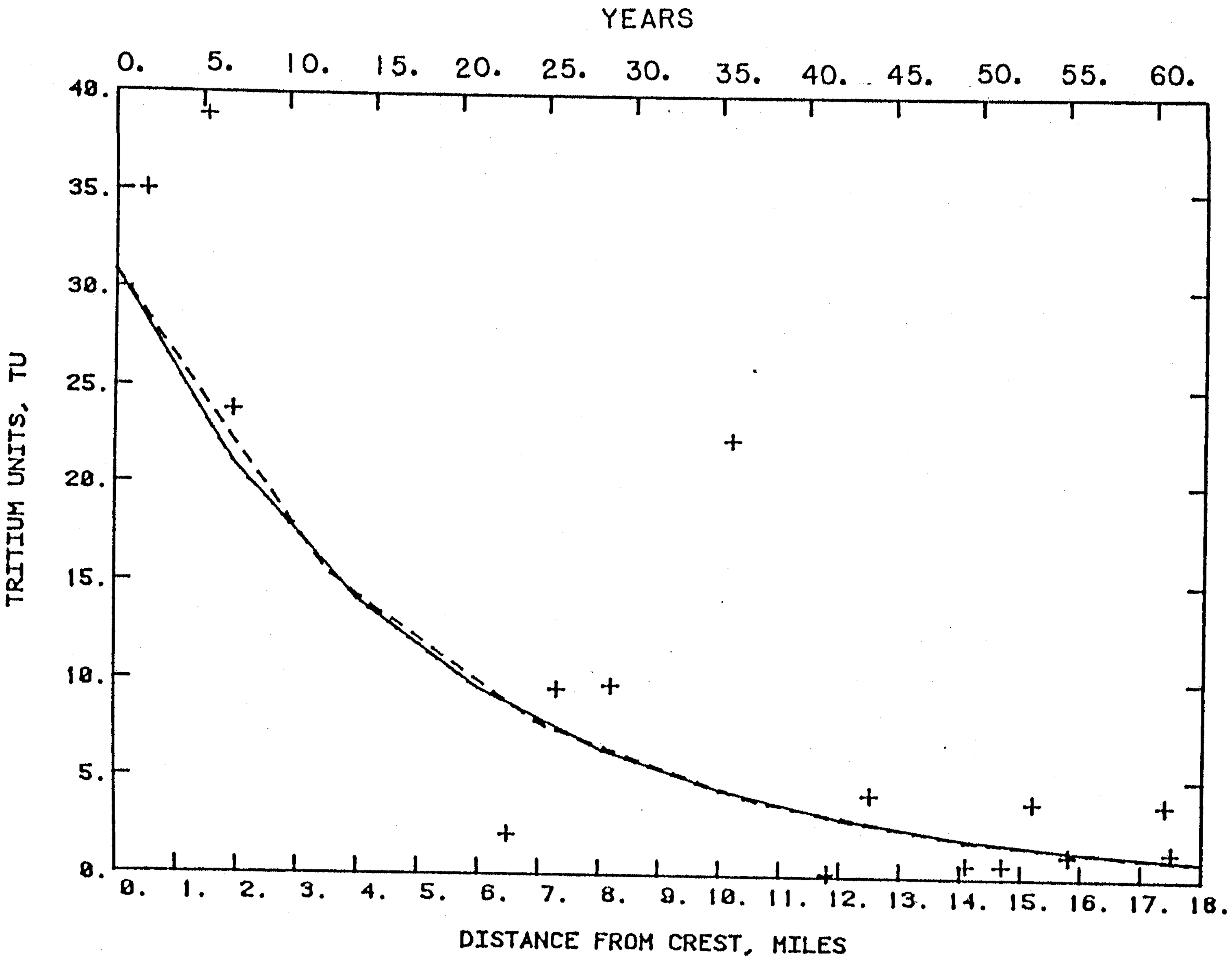


Figure 24. Decay of tritium activity in well water as a function of distance from the mountain crest and of time. The solid line is the best-fitting logarithmic curve for tritium activity in well water (distance axis on bottom); the dashed line is an exponential decay curve for tritium with an initial activity of 30.9 TU (time-axis on top).

increasing mineralization of water with decreasing tritium activity.

Contact springs

Springs that issue from alluvium are subject to mixing of waters from different sources and will not be considered here.

The location of springs sampled for tritium is shown in Figure 25. An apparent trend discerned from these observations is a decrease in tritium concentration with increasing distance from the mountain crest (Figure 26). But, in detail, a wide range of tritium concentration occurs at all distances from the crest to Mayhill.

Recharge to springs comes from direct precipitation over the entire area and infiltration through the San Andres as well as from movement of water down gradient along the contact zone between the San Andres and Yeso formations. Since this is a perched zone, upward leakage from the Yeso Formation is unlikely.

Appendix F shows scattergrams and correlation coefficients for tritium plotted against magnesium concentration and conductivity; the latter indicates increasing mineralization of water with decreasing tritium activity.

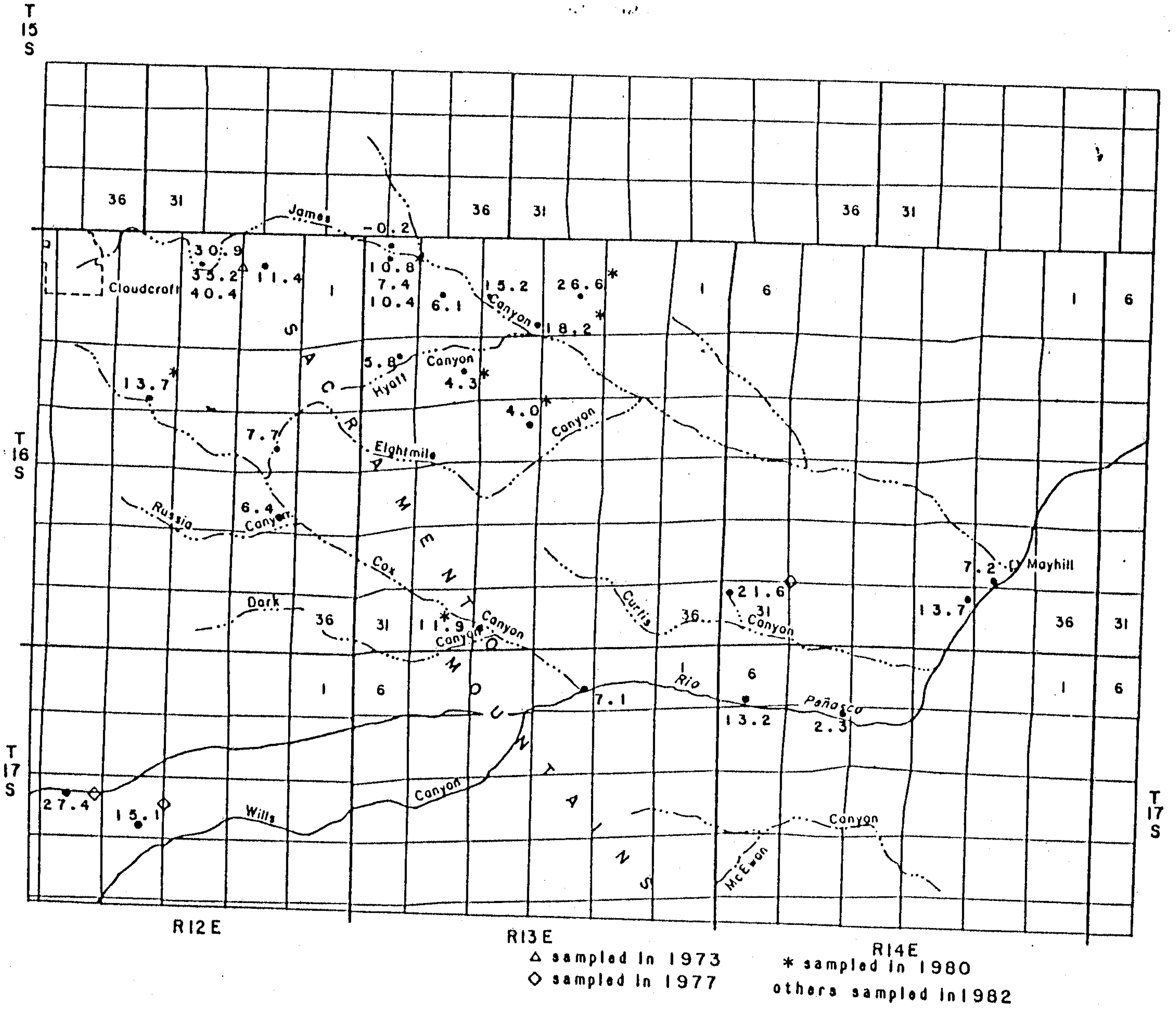


Figure 25. Tritium activity in springs

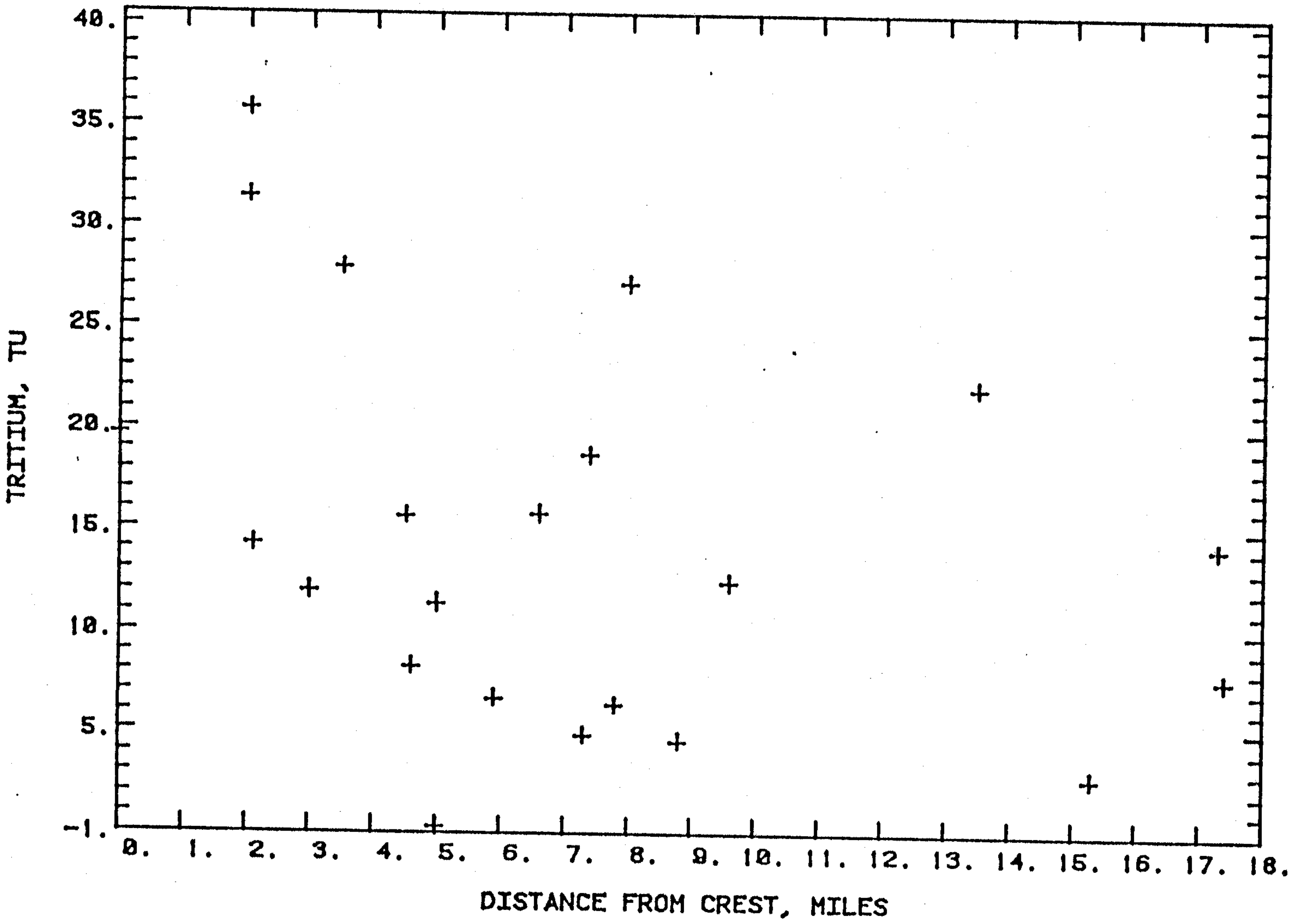


Figure 26. Graph of tritium in springs vs. distance from the mountain crest.

FLOW VELOCITY AND HYDROLOGIC PROPERTIES OF THE YESO FORMATION

Hydraulic conductivity is not easily derived from transmissivity estimates for the study area because of layering in the Yeso Formation. Much of the Yeso Formation consists of silt, silty sand and fractured limestone. According to Freeze and Cherry (1979, p.29), hydraulic conductivity ranges from 10-9m/s (3.5 x 10-7ft/s) in silt and limestone to 10-2m/s (3.5 ft/s) in silty sand. Average hydraulic conductivity for this formation is substantially lowered by beds of low hydraulic conductivity. This problem can be overcome somewhat by choosing some ratio of horizontal to vertical hydraulic conductivity that is greater than one. Summers (1974) chose a ratio of 100 to 1 for the Yeso Formation in the Tularosa basin, which is 14 miles north of the study area. Using this ratio and pumping-test results he gives the average horizontal component of hydraulic conductivity as 130 gpd/ft2 (2.01 x 10-4ft/s) and the vertical component as 1.3 gpd/ft2 (2.01 x 10-6ft/s). His horizontal component was consistent with values obtained near Mountainair, New Mexico, where solution of gypsum was also evident. For beds of the Yeso Formation that do not contain gypsum or in which gypsum has not been dissolved, Summers believes the horizontal component of hydraulic conductivity approaches that of the Abo Formation (7 to 15 gpd/ft2 or 1.08 x 10-5 to 2.32 x 10-5 ft/s). Summers (1974) estimated the effective porosity of the Yeso Formation in the Tularosa basin to be 0.5 to 1.0%, based on his experience in other areas. According to Darcy's law, average linear-flow velocity can be described by

$$v= K/n \; dh/ds$$

where,

K= hydraulic conductivity of the medium (L/T)
n= porosity of the medium
h= piezometric head (L)
dh/ds= hydraulic gradient along direction of flow

Average linear-flow velocity can be calculated by using Summers' estimates of the horizontal component of hydraulic conductivity and porosity, and a hydraulic gradient of .02, which is derived from the contoured water-level map of the region (see Figure 13). Using these values,

$$v= (2.01 \times 10^{-4}\ \text{ft/s} /.01) * .02 = 4.03 \times 10^{-4}\ \text{ft/s}$$
$$\text{or } 34.79\ \text{ft/day}$$

Therefore, it would take 7.5 years for water entering the ground at the crest of the Sacramento Mountains to reach Mayhill, 18 miles to the east.

CONCLUSIONS

(1) Hydrometer analysis shows that the fine-grained sedi- ments of the Yeso Formation are mainly siltstones and that yellow sediments are slightly coarser and more permeable than the red.

(2) The Rio Penasco valley is aligned with a fracture zone at the eastern end of the study area; this causes water moving eastward near the contact between the San Andres and Yeso Forma- tions and in layers of the upper Yeso Formation to spill into the valley from springs and to issue into alluvium. This frac- ture zone appears to be an extension of the Border Hills struc- tural zone.

(3) Gravels preserved in the walls above the floodplain of James and Cox canyons contain Quaternary-aged mollusks and are probably Gatuna Formation and are correlative with deposits of the Mescalero-Diamond A surfaces (Hawley and others, 1976, p. 256).

(4) Ponded sediments that formed behind a travertine dam at the mouth of Rawlins Canyon (sec.5, T.16S., R.12E.) contain mol- lusks that now exist farther north in New Mexico. Travertine terraces that cross the Rio Penasco floodplain east of its con- fluence with Cox Canyon contain mollusks that lived next to water. These suggest that wetter conditions existed during the last glaciopluvial period, with correspondingly higher water tables.

(5) Numerical modeling, given all its assumptions, shows that an additional recharge rate of 0.5 in/yr would be suf- ficient to raise the water table back to the level of the tra- vertine terraces. Additional recharge of 0.5 in/yr to the groundwater system would require several inches of additional annual precipitation.

(6) Recharge to the Roswell Basin from the study area is at least 3778 acre-ft/yr; it has declined since the last glacio- pluvial period due to increasing aridity in the Upper Holocene.

(7) A distribution of transmissivity for the Yeso Formation is needed to better estimate underflow out of the study area.

(8) X-ray diffraction of selected samples did not show the presence of evaporites; they may have been leached out of these near-surface exposures. Water chemistry suggests that they occur in minor quantities at depth.

(9) The steady increase in concentration of sulfate in well water from west to east in the study area suggests that small amounts of sulfate minerals are distributed rather uniformly in the Yeso Formation.

(10) All major chemical constituents in well water show increasing concentration with distance. This holds true when data are added from areas farther north and northeast on the Pecos Slope at least to the Border Hills structural zone.

(11) Tritium activity in wells generally decreases from west to east, from 38.9 TU to 0.2 TU, in the study area. The range of values at all distances east of the mountain crest probably indicates movement and mixing of recharging waters down gradient, induced recharge along canyons and vertical stratification of water. A decay curve for tritium was fitted to the tritium data for wells in the area. Using this method, the time for local recharge water to flow downgradient across the entire area is more than 60 years; mixing with older water probably causes this flow time to be too long.

(12) Calculations based on geologic and hydrologic data from Summers (1974) indicate that it takes about 7.5 years for water in the most permeable layers of the Yeso Formation to flow 18 miles from the mountain crest to the east end of the study area.

RECOMMENDATIONS FOR FUTURE STUDY

The upper Rio Penasco should be gauged to establish baseflow. More than one gauge would give estimates of channel losses. These data would improve the water budget given in Wasiolek and Gross (1983).

The Sacramento Mountains apparently contributed more recharge to the Roswell Basin in the past than they do today, but its quantity remains elusive. It may be possible to find a modern-day analog of the environment that prevailed during the last glaciopluvial. This would give an estimate of precipitation and evapotranspiration rates that could be put into a water budget for the past.

Slug and pumping tests, preferably with observation wells, would give the transmissivity distribution necessary to refine the computer model described herein.

Hydraulic conductivity can not be derived from transmissivity because of layering in the Yeso Formation. Permeameter tests on samples from various layers in the Yeso would give a better ratio of horizontal to vertical hydraulic conductivity. This should yield better estimates of the time it takes for water to flow across the area. A study of fracture density and spacing between bedding planes could be done to estimate hydraulic conductivity within carbonate layers.

An inventory of wells and springs and their geologic situation, and tritium and chemistry analyses should be done for the western escarpment of the Sacramento Mountains. Water levels in wells will allow us to extend contours for the regional water table.

A study of the water chemistry of the Pecos Slope may reveal regional patterns of groundwater movement and zones of mixing.

Water samples could be analyzed for the stable isotopes of hydrogen and oxygen as well as for tritium. Fractionation of these isotopes in precipitation and groundwater can indicate the geographic origin of precipitation; in this area, precipitation comes from either the Pacific Ocean or from the Gulf of Mexico.

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APPENDIX A: Record of wells in study area

RECORDS OF WELLS IN STUDY AREA, OTERO COUNTY, N.M.

WELL LOCATION NUMBER: Explanation in section on well-numbering system.

AQUIFER: PY, Permian Yeso Formation; PSA, Permian San Andres Formation; QAL, quaternary alluvium.

WATER LEVEL: R, reported; C, from well-completion report; all others are measured.

COMMENTS: DOM, domestic; IRR, irrigation; MUN, municipal; REC, recreation; STK, stock; PERF, perforated interval; SPEC.CAP, specific capacity; T, transmissivity; GPM, gallons per minute; GPM/FT, gallons per minute per foot; GPD/FT, gallons per day per foot; CHEM, chemistry in table VII; TU, tritium count in table VII.

WELL NO.	LOCATION	OWNER	AQ	WELL ELEV. (FT)	WELL DEPTH (FT)	WATER LEVEL DEPTH TO H2O (FT)	WATER LEVEL DATE	ELEV OF H2O-BEARING UNIT (FT)	ELEV. PSA-PY CONTACT (FT)	WATER LEVEL ELEVATION (FT)	COMMENTS
1	15.13.28.12421	I.RUPP,JR	PY	8231.2		58.12	1-79	-	8400	8173.1	IRR;
2	15.13.33.11333	C.B. MITCHELL	QAL	8240	27	17R	1946	-	8120	8223	DRILLED TO 100' & PLUGGED; NOT IN USE
3	15.13.34.34201	CLOUD-9 LTD	PY	8050	580	541R	12-77	7480?	8240	7509	MUN,REC; PERF: 516-556
4	15.14.23.33211	PHILIP R. DURHAM	PY	7410	300	70C	9-76	7180	-	7340	DOM,STK; PERF: 222-300
5	15.14.23.43141	MARTIN S. COOLIP	PY	7380	400	330C	2-77	7030	-	7050	DOM,STK; PERF: 340-380
6	15.14.23.4413	CARL M. SCHMITT	PY	7360	400	345C	1-80	7005	-	7015	DOM; 12 GPM; PERF: 340-400
7	15.14.23.44134	CARL M. SCHMITT	PY	7340	315	DRY	2-78	<7025	-	<7025	
8	15.14.26.32333	O.F. OLIVO	PY	7420	200	160C	3-77	7300	-	7260	DOM; PERF: 140-200
9	15.14.34.11144	E.L. RITCHIE	QAL	7690	-	30C 19.75	8-76 2-79	-	-	7670.2	IRR; HAND-DUG
10	15.14.34.122222	E.L. RITCHIE	PY	7580	483	108.6R	6-76	-	-	7471.4	IRR
11	15.14.34.122224	E.L. RITCHIE	PY	7580	325	-		-	-		CAVED IN; NOT IN USE
12	15.14.34.21233	E.L. RITCHIE	QAL	7500	90	40R	6-76	-	-	7460	IRR
13	15.14.34.212331	E.L. RITCHIE	QAL	7500	103	65R	6-76	-	-	7435	IRR
14	15.14.34.2123344	E.L. RITCHIE	QAL	7500	120	65R	6-76	-	-	7435	IRR
15	15.14.34.22233	E.L.	QAL	7460	80	30R	6-76	-	-	7430	IRR

		RITCHIE									
16	15.14.34.22311	E.L. RITCHIE	PY	7460	192	52R	9-75	7408	-	7408	DOM,STK; PERF: 48-160
17	15.14.35.11214	E.L. RITCHIE	GAL	7540	-	-13R	6-76	-	-	7553	IRR; HAND DUG; DISCHARGES ABOVE LAND SURFACE
	(16.12.05.133 - SEE #126)										
18	16.12.03.142	CITY OF CLOUDCROFT	PY & GAL	8310	100	-		-	8500		DESTROYED BETWEEN 1954 & 1956; CHEM
19*	16.12.03.1423	CITY OF CLOUDCROFT WELL #2 (#3 IN WELL SCHEDULE)	PY &GAL	8312.3	195- 400?	60 144.3 149.3 148	8-54 2-62 10-75 5-76	8312	8500	8164.3	MUN; SPEC.CAP= 1.4 GPM/FT (SMITH MACHINERY, ROSWELL IN SUMMERS,1976,P.19); YIELD(1956): 135 GPM; DRILL STEM DROPPED IN HOLE IN 1970; WATER CASCADES FROM 50'; CHEM
20*	16.12.03.1424	CITY OF CLOUDCROFT WELL #1 (#2 IN WELL SCHEDULE)	PY	8310	176	76	3-56	-	8500	8234	MUN; SPEC.CAP.= 3 GPM/FT (SMITH MACHINERY, ROSWELL IN SUMMERS,1976,P.18); YIELD: 90-150 GPM; WATER CASCADES FROM 48'; CHEM
21*	16.12.03.1424	CITY OF CLOUDCROFT WELL #3 (#1 IN WELL SCHEDULE)	PY	8310	307	84 136	11-72 5-76	-	8500	8174	MUN; PERF: 177-307' SPEC.CAP.= .9 GPM/FT (SMITH MACHINERY, ROSWELL IN SUMMERS,1976,P.20) YIELD: 108-120 GPM; WATER CASCADES FROM 105'; CHEM,TU
22	16.12.05.32223	CLOUD COUNTRY	PY	8640	-	-		-	8620		REC
23	16.12.05.333343	SILVER CLOUD ESTATES 2	PY	8729.5	-	41.09 17.26	11-75 1-79	-	8620	8712.2	NOT IN USE
24	16.12.05.43131	CLOUD COUNTRY	PY	9020	840	460R	1-74	8540	8620	8560	REC; PERF: 460-560, 750-840
	(16.12.06.322 - SEE #127)										
25	16.12.06.434422	SILVER CLOUD ESTATES	PY	8796.1	300	259R	1975	8531	8640	8537.1	PERF: 250-300; CHEM,TU
26	16.12.06.441313	SILVER CLOUD ESTATES 3	PY	8765.1	336	229.36	11-75	8513	8640	8535.7	NOT IN USE

27	16.12.06.44133	SILVER CLOUD ESTATES	PY	8758	335	227C	9-75	8506	8640	8531	DOM; PERF: 231-319
28	16.12.07.21222	JOHN K. MIKELS	PY	8880	320	283C	9-78	8575	8640	8597	DOM; 10 GPM; PERF: 300-320
29	16.12.08.1113	JACKSON	PY			-		-	8620		CHEM, 10
30	16.12.08.114121a	SILVER CLOUD ESTATES 1	PY	8738.1	246	43.07	11-75	8703	8600	8695.0	DOM; 1 GPM; NO PUMP; PERF: 40-164
31	16.12.19.31123	S&J JOINT VENTURE	CAL		-	-		-	-		OLD HAND DUG; NOT IN USE
32	16.12.19.3132	S&J JOINT VENTURE	PY		-	-		-	-		NOT IN USE
33	16.12.24.33112	A. DAVID SWOPE	PY	7805.6	328	295C 330R >325	3-62 3-74 1-79	7511	8200	7475.6	IRR; 175-200 GPM
34	16.12.25.24142	GISELA E. MELKUS	PY	7793.2	348	238.6	3-74	7513	8050	7554.6	DOM; PERF: 312-348
35	16.12.25.24212	JAMES MANATT	PY	7734.2	250	181.98	3-74	-	8040	7552.2	DOM
36	16.12.25.24411	IRENE PRICE	PY	7835.7	330	270C	7-73	-	8040	7565.7	DOM
37	16.13.03.42122	PRESBYTERY OF THE SW	PY	7940	715	675C	3-65	7245	7800	7265	DOM; PERF: 685-715
38	16.13.04.13122	CHARLES GROVER	PY	7727.1	350	342.95 339.82	3-74 1-79	-	8000	7387.3	NOT IN USE
39	16.13.04.13233	C.R.& M.L. GROVER	PY	7860	500	215C	1-78	7512	8000	7645	DOM,IRR; RED SAND: 2 GPM, YELLOW SAND: 4 GPM; PERF: THROUGHOUT
40	16.13.04.31232	J.SHYRE (J.TUFT)	PY	7622.6	412	300C 250.6?	5-64 3-74	7283	8000	7372?	DOM; ROBINHOOD PARK ALSO GIVEN AS OWNER; NO PERF; CHEM, 10
41	16.13.04.41322	HARLEY ESTATE	PY	7646.2	525	-		-	7930		DOM
42**	16.13.04.44141	SKI HI DEV.CO. 4	PY	7548.1	415	310C 343.70 322.82	1-73 3-74 1-79	7218	7920	7225.3	DOM; NOT IN USE; PERF: 330-385
	(16.13.05.110 - SEE #128)										
43	16.13.05.24343	TWIN FORKS RANCH	PY	7717.9	-	316.79 315.01?	3-74 1-79	-	8000	7402.9?	STK
44**	16.13.06.24430	SKI HI	PY	7841.5	398	322.35	3-74	7549.5	8080	7545.2?	NOT IN USE; IN 1-79 WELL

		DEV.CO. 3				296.25?	1-79				REPORTED TO BE "BLOWING AIR OR CASCADING WATER"
45**	16.13.09.424434	SKI HI DEV.CO. 1	PY	7641.2	652	514.94	3-74	7036	7800	7126.3	NOT IN USE; PERF: 596-652
46	16.13.10.12242	F.P. ROSTUHAR	PY	7510	400	360C	8-74	7125	7800	7150	DOM,STK; 6 GPM; PERF: 360-400
47	16.13.10.42342	BURGETT FLORAL 2	PY	7440	435	-		-	7745		GREENHOUSE; TAKEN OUT OF USE IN 1982
48	16.13.10.4241	BURGETT FLORAL	PY	7390	400	-		-	7745		NOT IN USE
49	16.13.10.431	BURGETT FLORAL	PY	7860	-	-		-	7800		NOT IN USE
	(16.13.11.110 - SEE #129)										
50**	16.13.11.11122	SKI HI DEV.CO. 2	PY	7521.5	596	454.21 436.31	3-74 1-79	7046.5	7760	7085.2	DOM; NOT IN USE; PERF: 551-596
51	16.13.11.3113	BURGETT FLORAL	PY	7360	450	-		-	7745		NOT IN USE
52	16.13.11.31131	BURGETT FLORAL	PY	7420	430	-		-	7745		DOM; TAKEN OUT OF USE IN 1982
53	16.13.11.31313	BURGETT FLORAL 6	PY	7362.5	340	-		-	7745		DOM; TAKEN OUT OF USE IN 1982
54	16.13.11.43244	VELMER LANE	PY	7353.1	127	106.90 104.28	3-74 1-79	7263	7640	7248.8	DOM; PERF: 90-127; CHEM, TU
55	16.13.13.234213	JOHN C. BRANNAN	PY	7271.4	467	417C	10-67	-	7520	6854.4	DOM FOR LAZY DAY CABINS
56	16.13.13.41343	VELMER LANE	PY	7260.7	445	398.95	3-74	6831	7540	6861.7	DOM
57	16.13.13.44410	BOB RODOLPH	PY	7190.2	400	370C 366.57?	1968? 1-79	6820	7520	6823.6?	DOM,STK; PERF: 370-400; CHEM, TU
58	16.13.18.32310	HARVEY INVEST. CO.RANCH	PY	8280	200	133.40	3-74	-	8080	8146.6	STK
59	16.13.19.42320	HARVEY INVEST. CO.RANCH	PY	8200	-	126.84	3-74	-	8050	8073.2	STK
60	16.13.23.44134	CARL E. SCHMITT	PY	8140	315	DRY	2-78	<7825	7560	<7825	
61	16.13.29.3342	CARROL WOOD 4	PY	7625.5	303	245C	8-62	7340.5	7920	7360.5	DOM; CHEM, TU

62	16.13.30.13311	EL DORADO LAND CORP.	PY	7741.7	200	125C 193.43	6-73 3-74	7562	8000	7548.3	DOM; 30 GPM; PERF: 155-200
63	16.13.30.32114	J.MANATT (T.HAVINS)	PY	7737.5	375	194.79 183.50	3-74 1-79	7437.5	8040	7554	IRR; CHEM, 10
64	16.13.30.4320	JAMES MANATT 3	PY	7640.9	260	99.00 66.81	3-74 1-79	7421	7960	7554.1	DOM
65	16.13.30.44130	R.C. WOOD 2	OAL	7627.6	175	49.5R 91.42	9-54 3-74	-	7980	7536.2	IRR; 3-74 WATER LEVEL TAKEN WHILE WELL AT 16.13.30.44230 PUMPING
66	16.13.30.44230	R.C. WOOD 1	PY	7646.6	260	176C 162.0?	2-60 1-79	7510	7960	7484.6?	IRR,DOM; IN GAL; YESO AT 18'
67	16.13.30.442332	R.C. WOOD 6	OAL	7648	210	49.5R	9-54	-	7960	7598.5	IRR
68	16.14.01.23433	US FOREST SERVICE	PY	6845	459	440C	4-54	6648	-	6405	STK; OBSTRUCTION NEAR 185'
69	16.14.05.12233	HAZEL KOCK	PY	7540	800	DRY	1-78	<6740	-	<6740	
70	16.14.10.14311	JOHN L. PARKER	PY	7210	740	716C	11-60	6483	7200?	6494	DOM; PERF: 715-740; CHEM, 10
71	16.14.13.4430	ROBERT DOCKRAY	PY	6501.9	295	255C 246.18	7-58 3-74	6222	<6760	6255.7	DOM; PERF: 275-295
72	16.14.17.30000	J.C.L.D. SAINTS CHURCH CAMP	PY	7100	-	356.28?	3-74	-	7360	6743.7?	DOM
73	16.14.17.31242	F&M JONES	PY	7140	505	450C	5-78	6690	7360	6690	DOM,STK; 12 GPM; PERF: 445-505
74	16.14.17.33141	PIONEERS CHRIST. CHAPEL	PY	7100	321	275.17	1-79	6720	7390	6824.8	DOM; 20 GPM; PERF: 281-321
75	16.14.17.333313	H.H.RAGAN	PY	7019.1	300	245C	6-73	6894	7390	6774.1	DOM; PERF: 245-285
76	16.14.17.44341	GORDON WIMSATT	PY	7020	390	273R	3-56	-	7240	6747	DOM
77	16.14.18.33330	EVERETT HADLEY	PY	7175.1	305	362R 353R	1951 1951	-	7510	6822	DOM,STK
78	16.14.18.41443	L.E. PARKER	PY	7370	604	540C	8-67	6795	7400	6830	DOM FOR PINE VIEW SUBDIV.; PERF: 575-600
79	16.14.18.42132	W.H.SKEEN	PY	7210	453	405C	7-75	6810	7400	6605	DOM; 30 GPM
80	16.14.18.43331	FOYE VARBEL	PY	7100	305	277C	9-56	-	7410	6823	DOM; IN GAL; YESO AT 60'; PERF: 290-305;

											CHEM, TD
81	16.14.20.11144	BONNIE ALLEN	PY	7060	288	240C	10-78	-	7390	6820	DOM; 15 GPM; PERF: 231-266
82	16.14.20.113313	H.H.KAGAN	PY	7150	-	-		-	7390		DOM
83	16.14.20.12122	CODY M. BELL	PY	7050	354	311.33	3-74	6726	7320	6738.7	DOM PERF: 320-355
84	16.14.20.123324	H.H.KAGAN	PY	7050	330	315R	3-74		7320	6735	DOM
85	16.14.20.12433	E.J.BOAKS (RUBEN ELEC)	PY	7008.9	322	280C	5-65	6708	7280	6728.9	DOM; PERF: 300-322
86	16.14.20.24211	E.A.HADLEY	PY	6950	338	258C	1951	-	7200	6692	STK
87	16.14.21.11422	EVERETT HADLEY	PY	6920	340	300R 295R	1946 1946	-	7200	6625	DOM,STK
68	16.14.21.11424	EVERETT HADLEY	PY	6910	362	342C	7-81	6450	7200	6568	DOM; 20 GPM; PERF: 240-262
89	16.14.21.11424	EVERETT HADLEY 9	PY	6910	326	300R	3-74	-	7200	6610	DOM,STK
90	16.14.21.21331	KENNETH POTTER JR	PY	6858.6	310	275C	9-56	6574	7200	6583.6	DOM; PERF: 285-305; CHEM
91	16.14.21.21333	NM STATE HIGHWY DEPT.	PY	6846.9	-	256.53 253.32	3-74 1-79	-	7200	6595.6	DOM
92	16.14.23.24221	NM STATE HIGHWY DEPT.	PY	6648.4	319	280C DRY	10-55 3-74	6363	6760	<6329.4	DOM; NOT IN USE; PERF: 260-310
93	16.14.24.11324	US.FOREST SERVICE	PY	6615.7	349	295C >295	7-61 3-74	6321	<6760	<6320.7	DOM; PERF: 310-349
94	16.14.24.11342	US FOREST SERVICE	PY	6616.5	-	-		-	<6760		NOT IN USE
95	16.14.24.12413	NORTHCUT (FORMERLY A. BAIN)	PY	6520	-	-		-	<6760		DOM
96	16.14.24.13213	JOHN L. PARKER	PY	6553.4	138	120C 240R 164.19	10-55 3-74? 2-79	6433	<6760	6389.2	DOM; WELL WAS DEEPENED TO ?
97	16.14.26.23434	MAYHILL (STIRMAN)	PY	6610	275	253R	3-74	-	6730	6357	MUN
96	16.14.26.32121	MAHILL RUNYAN	QAL	6568	-	22.40 18.96	3-74 1-79	-	6840	6549.0	MUN; 1-79 WATER LEVEL TAKEN WHEN PUMP OFF 25 MIN.
99	16.14.26.41222	B.A.SAVOIE (RUNYAN)	PY	6559.4	268	246C	1968?	6455	6720	6313.4	DOM; 2.5 GPM; CHEM, TD

100	16.14.26.41343	OLEN R. HINSHAW	PY	6523.4	100	25C 76.56	1-74 3-74	6443	6560	6446.8	DOM; 10 GPM; NOT IN USE; IN GAL; YESO AT 42'; PERF: 75-100; CHEM, TD
101	16.14.34.22440	R.T. LEWIS 2	PY	6625.2	110	29.93 31.60	3-74 1-79	6524	6840?	6593.6	IRR; IN GAL; YESO AT 40'; PERF: 93-110
102	16.14.34.24333	R.T. LEWIS 1	PY	6642.7	110	52C	6-56	6591	6800?	6590.7	DOM,IRR; IN GAL; YESO AT 5'; PERF: 70-110
103	16.14.35.12113	J.J.&LLOYD POSEY 1	GAL	6586.7	90	31C	7-62	6552	6700?	6555.7	IRR; IN GAL; YESO AT 68'; PERF: THROUGHOUT; TD
104	17.12.10.14343		GAL?	7880	-	24.49	1-79	-	-	7855.5	
105	17.12.11.14433	ALLEN B. LEEPER	GAL	7780	215	70R >67 >87	4-54 3-75 1-79	-	-	<7693	NOT IN USE
106	17.12.12.22133	R.C. SHERMAN	PY	7740	240	220C	6-75	7570	-	7520	DOM,STK; 5 GPM; PERF: 200-240
107	17.13.01.34112	WILLIAM BREEDLOVE	PY	7020	110	78C	1-78	6920	7400	6942	DOM; 20 GPM; IN GAL; YESO AT 10'; PERF: 90-110
108	17.13.01.44211	ARNOLD GREEN	GAL	6977.5	-	54.65 56.69	3-74 1-79	-	7300	6920.8	DOM; NO PUMP
109	17.13.03.1110	WHITLOCK	PY	7286.1	-	133.32 126.60	3-74 1-79	-	7700	7159.5	IRR,DOM
110	17.13.03.42400	BERNIE BOUNDS	PY	7186.3	250	73.76 69.96	3-74 1-79	-	7550	7116.3	IRR; NO DRILLER'S LOG
111	17.13.04.44421	BERNIE BOUNDS	PY	7250	250	89.62 74.85?	3-74 1-79	-	7700	7175.1?	IRR; NO DRILLER'S LOG; CHEM
112	17.14.03.12144	PERRY POSEY	GAL & PY	6694.4	114	91C 54.90 52.49	11-55 3-74 1-79	6594	6850	6641.9	DOM; IN GAL; YESO AT 100'; PERF: 64-114
113	17.14.03.1341	CECIL BARKLEY	GAL	6740.4	105	122C 84.36	10-55 3-74	6597	6920?	6656.0	DOM; PERF: 143-160
114	17.14.06.3300	KENNETH JESSUP	PY	6922.0	115	15C	8-59	6897	7280	6907	IRR; IN GAL; YESO AT 2'; PERF: 60-115
115	17.14.06.43331	I.W. DOCKRAY	GAL	6895.8	105	7.41 10.71	3-74 1-79	6876	7200	6885.1	IRR; PERF: 20-32
116	17.14.08.12111	HERBERT DOCKRAY 1	GAL	6850.9	105	36.87 36.49	3-56 1-57	6806	7100	6821.1	IRR; 45' "HONEYCOMB LIME"

						29.78 29.38 29.81	3-74 1-75 1-79				(=TRAVERTINE) REPORTED AT SURFACE; CHEM, TU
117	17.14.08.12223	HERBERT DOCKRAY 3	GAL	6825.5	61	140	12-69	6797.5	7050	6811.5	DOM,STK; PERF: 35-60
118	17.14.08.22133	ROBERT E. BOYD	GAL & PY	6788.6	127	1.48 1.42	3-74 1-79	6781	7020	6787.2	IRR; IN GAL; YESO AT 48'; PERF: 0-117
119	17.14.09.12333	LEE PAYNE	PY?	6777.4	202	1670 27.80	5-56 1-79	6592	6920	6749.6	DOM
120	17.14.10.11133	CECIL BARKLEY	PY	6699.2	131	1050 19.73 16.62	11-55 3-74 1-79	6584	6875	6682.6	DOM,IRR; IN GAL; YESO AT 76'; PERF: 96-131
121	17.14.12.21331	PAUL MILLER	PY	6776	515	-		-	<6800		DOM
122	17.14.17.31224	TALL PINES GIRL SCOUT CAMP	PY	7400	425	4000	3-54	7000	7150?	7000	DOM; PERF: 365-425; CHEM, TU
123	17.14.18.34442	PHILLIP J. HOWARD	PY	7455	868	7980	12-70	6620	7200?	6657	DOM; PERF: 826-856; CHEM, TU
124	17.14.18.4340	CHARLES HAROLD	PY	7420	-	-		-	7180?		DOM
125	15.13.34.340	CLOUD COUNTRY WEST #2	PY	7980	575	479.2 480.0 454 460	5-74 11-74 12-77 1-78	7472?	8240	7520	PERF: 516-557'; SPEC.CAP.= 6 GPM/FT, T= 22,000 GPD/FT, YIELD: 235 GPM (SUMMERS, 1978, p.26,51); T= 12,500 GPD/FT (W.F.GUYTON & ASS., IN SUMMERS, 1978, p.18)
126	16.12.05.133	CLOUDCROFT LODGE	PY	8680	600	500R	1954?				DOM; YIELD: 40 GPM (HOOD,1960, p.24); CHEM
127	16.12.06.322	JAMES & BUD	PSA	6725	429	392.1	3-56				DOM; CHEM
128	16.13.05.110		PY	7860	398	301	12-77	7480	8100	7559	"SULLIVAN CANYON WELL"; PERF: 291-325; 359-391 (FROM TV LOG- WELL SURVEYS COMPANY)
129	16.13.11.110		PY	7640	576	435	12-77	-	7760	7205	"100-ACRE WELL"; PERF: 493-576? (FROM TV LOG- WELL SURVEYS COMPANY)

* TRANSMISSIVITY(T) IS ABOUT 3000 GPD/FT AND SPECIFIC YIELD IS ABOUT .13 (PROBABLY ALLUVIUM AND WEATHERED YESO FM) (SUMMERS, 1976, p.53)

** TRANSMISSIVITY IS ABOUT 4300 GPD/FT (W.F. GUYTON & ASS., IN SUMMERS, 1976, p.53)

APPENDIX B: Record of springs in study area

RECORD OF SPRINGS IN STUDY AREA, OTERO COUNTY, N.M.

SPRING LOCATION NUMBER: Explanation in section on well- and spring-numbering system.

FORMATION: PY, Permian Yeso Formation; PSA, Permian San Andres Formation; PY-PSA, contact zone between San Andres and Yeso formations; QAL, Quaternary alluvium; QCL, Quaternary colluvium

YIELD: GPM, gallons per minute; (D), from Davis and others (1980), (DI), from Dinwiddie (1963); (S), estimated by Simcox for this report; (SE), from State Engineer's Records; (SU), from Summers (1976); (W), from Wasiolek and Gross (1983)

COMMENTS: Spring name in parenthesis; DOM, domestic; IRR, irrigation MUN, municipal; STK, stock; CHEM, chemistry in table VIII; TU, tritium count in table VIII.

SPRING NO.	LOCATION	OWNER	FORMATION	ELEV (FT)	YIELD (GPM)	COMMENTS
1	16.11.01.111		PY	-	20(S)	"TWIN SPRINGS"; ON WESTERN ESCARPMENT (OUTSIDE OF STUDY AREA); ISSUE AT CONTACT LS/ YELLOW SILT(MUD)STONE; CHEM, TU
2	16.12.02.142 (or.11)	BOB MOSER	PY-QAL	8280	2.0(W) 2(S)	ISSUE AT CONTACT LS/ RED CLAY(?); IRR(9-75); GIVEN AS 16.12.02.32200 ON WELL SCHEDULE; CHEM, TU
	16.12.03.1		QAL	-	27(W)	PUMPHOUSE CANYON (SPRING-FED)
3	16.12.03.11144	VILLAGE OF CLOUDCROFT NO. 4	QAL	8380	-	MUN(9-75); 10" (DIAM.) STEEL PIPE & 4" LINE TO STORAGE BOX; GIVEN AS 16.12.03.11343 ON WELL SCHEDULE
4	16.12.03.142		QAL	8300	-	PERENNIAL SEEP DEPOSITING TUFA NEAR RT 82; CHEM, TU
5	16.12.03.144222	VILLAGE OF CLOUDCROFT	QAL	8320	60(DI) 67(SU)	TWO SPRINGS; CHEM, TU; THIS IS SUMMERS'(1976) AREA NO.4
6	16.12.03.14142a	VILLAGE OF CLOUDCROFT NO. 2	QAL	8300	5.7(SU)	MUN(9-75); FLOW THROUGH 4" LINE TO STORAGE TANK
7	16.12.03.14142b	VILLAGE OF CLOUDCROFT NO. 3	QAL	8300	2(SU)	MUN(9-75); FLOW THROUGH 4" LINE TO RESERVOIR; GIVEN AS 16.12.03..32123 ON WELL SCHEDULE; CHEM
8	16.12.03.131222	VILLAGE OF CLOUDCROFT NO. 1	QAL	8380	3.9(SU)	MUN(9-75); FLOW THROUGH 4" CLAY PIPE TO STEEL RESERVOIR; GIVEN AS 16.12.03.342431 ON WELL SCHEDULE
9	16.12.09.3142		PY-PSA	8600		
10	16.12.09.431		PY-PSA	8500	-	CHEM, TU
11	16.12.14.41		PY-PSA	8275	201(W)	"CULBERSON SPRING";

						FLOWING OVER LARGEST TUFA DEPOSIT FOUND IN STUDY AREA; CHEM, TU
12	16.12.16.42 a.13		PSA	8640	-	"EXPERIMENTAL FOREST SPRINGS"; 5 SPRINGS
13	16.12.19.244		GAL	8640	7(D)	HEADWATER SPRING OF RUSSIA CANYON; CHEM
14	16.12.19.31324	S&J JOINT VENTURE	-	-	-	1.5" STEEL PIPE AND 6" ALUMINUM TUBE
15	16.12.20.412		PY-PSA	8400	-	HEADWATER SPRING OF RUSSIA CANYON
16	16.12.20.423		PY-PSA	8400	-	2 HEADWATER SPRINGS OF RUSSIA CANYON
17	16.12.21.1343		PY-PSA	8380	-	
18	16.12.21.3210		PY-PSA	8380	-	
19	16.12.21.32322		PY	8330	-	
20	16.12.23.1312		PY-PSA	8250	2.0(W)	"FITE SPRING"
21	16.12.23.4324		GAL-PY	7880	-	CHEM, TU
22	16.12.23.4414	DAVID SWOPE	GAL	7840	-	IRR(9-75); FLOW INTO SMALL EARTHEN DITCH
23	16.12.23.44311		GAL	7840	-	
24	16.12.23.4443	DAVID SWOPE	PY	7950	-	IRR(9-75); FLOW INTO SMALL EARTHEN DITCH
25	16.12.24.3244		PY	8000	-	
26	16.12.25.12112	DAVID SWOPE	PY	7910	-	IRR-DOM(10-75); 4 SEEPS; FLOW INTO DITCH AND 1.5" LINE
27	16.12.26.121		PY	7950	15.0(W)	"SPLIT SPRING"
	16.12.27.12		GAL	8200	52.5(D)	STREAM FLOW OF LUCAS CANYON; CHEM AT RUSSIA CANYON
28	16.12.27.141		PY	8250	2.0(W)	"IRIS SPRING"; 3 SPRINGS 1/4 MI UPSTREAM; 2 SPRINGS 1 MI UPSTREAM
29	16.12.36.112		PSA	8300	-	"BIRD SPRING"
30	16.13.03.112		GAL	8080	.1(W)	"HOG SPRING"
31	16.13.03.324	U.S.FOREST SERVICE	PSA	8000	5.0(W)	
32	16.13.03.411		PY-PSA	7800	-	CHEM, TU
33	16.13.03.41434	PRESBYTER-	PY	7720	5.0(W)	"ROBERTSON SPRING";

	(or.24)	IAN CHURCH				DOM-STK(3-74)
34	16.13.03.44422 (or.24)	PRESBYTER-IAN CHURCH (A.WHARTON)	PY	7650	3.0(W)	"BRICK CHIMNEY SPRING"; STK-DOM(3-74)
35	16.13.04.13		PY	7840	-	6 SPRINGS
36	16.13.04.2421	U.S.FOREST SERVICE	PY-PSA	7950	-	"JURGINS SPRING"; STK(3-74)
37	16.13.04.3114	GROVER	PY-PSA	7920	-	CHEM, TU
38	16.13.04.333434	CHUCK GROVER	PY	7850	-	IRR(9-75); FLOWS INTO EARTHEN DITCH; ALSO SPRING 1/4 MI NNE
39	16.13.04.442		PY	7600	-	CHEM, TU
40	16.13.05.3212	J.O.& E.O BAIRD	PY	7820	44.7(W) 5.3(S)	NOT IN USE(9-75; 7-82); FLOWS FROM LS-YELLOW SILTST. CONTACT ABOVE SULLIVAN CANYON; GIVEN AS 16.13.05.34143 ON WELL SCHEDULE; CHEM, TU
	16.13.06	LOT 3	QAL	7925	40.4(W)	
	16.13.06	LOT 9	-	-	81(W)	
	16.13.06	LOT 12	-	-	36(W)	
41	16.13.06.1222		PY	7950	-	ISSUE FROM TUFA; CHEM, TU
42	16.13.06.12434 (ON LOT 3)	KIRSAIT & BAIRD	QAL	7925	18(W)	IRR-DOM(9-75); FLOW INTO 500-BARREL STEEL TANK; ALSO TO BAIRD HOUSE; 2 1.25" PVC LINES; GIVEN AS 16.13.06.12241 ON WELL SCHEDULE; CHEM, TU
43	16.13.07.2314	U.S.FOREST SERVICE	QAL	8070	-	"JOHNSON SPRING"; STK(3-74); GIVEN AS "HYATT SPRING" ON USFS MAP; CHEM, TU
44	16.13.08.42112		PY-PSA	7900	3.0(W)	"LITTLE HAY SPRING"; STK(3-74) CHEM, TU
45	16.13.09.24444	CLOUD COUNTRY	PY	7740	-	"HEADQUARTERS(H.Q.) SPRING"; MTU(3-74)
46	16.13.09.31233	JOSEPH SHYRE	PY-PSA	7960	29.8(W) 13(S)	"HYATT SPRING"; SERIES OF SPRINGS; MTU(10-75); 3 SUNKEN STEEL DRUMS; WATER SUPPLY FOR ROBINHOOD SUBDIV. 3(?) 2" LINES; GIVEN AS "JOHNSON SPRING" ON USFS MAP AND IN STATE ENGINEER'S FILES; CHEM, TU
47	16.13.09.42222 (or.24)	CLOUD COUNTRY	PY-PSA	7800	-	"BEAR SPRING" MTU(3-74); 250' UPHILL FROM "H.Q. SPRING"
48	16.13.10.2122	HUGH KIRKPATRICK	PY	7610	-	"PEW SPRING"; STK(3-74); GIVEN AS 16.13.03.32324 ON WELL SCHEDULE
49	16.13.10.3422		PY-PSA	7800	>50(W)	
50	16.13.10.413		PY	7720	-	"GOLDFISH SPRING"

51	16.13.10.43220	BURGETT FLORAL (H. KIRKPATRICK)	PY	7720	>5.0(W)	"LAWSUIT SPRING"; 2 SPRINGS; GREENHOUSE (NOT IN USE, 5-63); FLOW TO LARGE STORAGE TANK
52	16.13.12.2324	U.S.FOREST SERVICE	PY-PSA	7550	-	"MCNATT SPRING"; STK(3-74); GIVEN AS 16.13.12.24313 IN WELL SCHEDULE
53	16.13.14.11424		QAL	7370		
54	16.13.15.314		QAL	7600	20(W)	EIGHTMILE CANYON (OLD HARVEY RANCH)
55	16.13.15.233		QAL	7520		
56	16.13.16.2132		PY-PSA	7860	15.0(W)	"COTTON SPRING"
57	16.13.16.243		PSA	7975	-	CHEM, TU
58	16.13.20.244		QAL	7880	-	2 SPRINGS
59	16.13.22.22440	H.H.HUGHES JR.	PY	7620	-	"LOWER 3 L CANYON SPRING"; 1.25" LINE; GIVEN IN SEC. 23 ON USGS 15' QUAD (1952)
60	16.13.22.23424	H.H.HUGHES JR.	PSA	7780	-	IRR(9-75); 3 SMALL SPRINGS ABOUT 35' APART; ONE 1.25" PVC PIPE
61	16.13.22.24		PY-PSA	7700	-	"UPPER 3 L CANYON SPRING"
62	16.13.32.23324	HAROLD WOOD	QAL	7500	1(SE)	DOM(3-74); 2.5' DIAM. STEEL TROUGH INTO 4" PVC PIPE INTO 2" PVC PIPE INTO 1" PVC PIPE INTO CONCRETE BOX
63	16.13.32.4414		PY	7520	-	
64	16.13.33.3111		PY	7520	>50(W)	2 SPRINGS
65	16.13.33.31144	GARNER	PY	7560	80(SE)	IRR-DOM(9-75); 2" BURIED PIPE TO 4 LARGE DIRT RESERVOIRS 350' DOWNHILL; 1" LINE TO HOUSE
66	16.13.33.313		PY	7620	-	CHEM, TU
67	16.13.33.34223	BEGBY ESTATE	QAL	7380	-	STK(12-75); 1.25" PVC PIPE
68	16.13.36.321		QAL	7450	15(D) 50.1(W)	"GOAT SPRING"; CHEM
69	16.14.18.23242	HOPTON (FORMERLY PARKER)	PY	7390	-	DOM(3-74); 2" LINE
70	16.14.21.4		PY	6950	1.0(W)	"MARS SPRING"
71	16.14.26.32		PY	6670	-	"BELL SPRING"
72	16.14.26.343	POSEY	QAL	6520	1000(D) 2035(W) 7000(S)	"POSEY SPRING"; UNDERLAIN BY YESO FM. GIVEN AS 16.14.26.431 IN STATE ENGINEER'S FILES; CHEM, TU

73	16.14.27.3434		PY	6800	2.0(W)	"DEER SPRING"
74	16.14.30.4324	U.S.FOREST SERVICE	PY-PSA	7300	15.0(W)	"DOLLINS SPRING"; STK(3-74); GIVEN AS 16.14.30.44342 ON WELL SCHEDULE
75	16.14.31.111		PY-PSA	7400	4(D)	"MICKISON SPRING #2"; CHEM
76	16.14.31.1130	U.S.FOREST SERVICE	PY-PSA	7400	9(D)	"MICKISON SPRING"; CONCRETE BOX; CHEM, TU
					35.1(W)	COMBINED YIELD FOR MICKISON SPRINGS
77	16.14.31.43233 (or.34)	U.S.FOREST SERVICE	PY	7200	3.5(W)	"ROBINSON SPRING"; STK(3-74)
78	16.14.32.342		PY	7120	5.0(W)	"CANYON SPRING"
79	16.14.32.44442	U.S.FOREST SERVICE	PY-PSA	7100	4(D)	"LIGHTNING SPRING #1"; STK(3-74); CONCRETE BOX; CHEM
80	16.14.33.34231		PY-PSA	7010	30.1(W)	"LAKE SPRING"; GIVEN AS 16.14.33.4 IN STATE ENGINEER'S FILES
81	16.14.34.2243	T.E.LEWIS(?)	PY	6640	1(S)	FAULT-CONTACT SPRING; CHEM, TU
82	16.14.36.32122	U.S.FOREST SERVICE	PSA	7100	-	"GOAT SPRING"; STK(3-74)
	17.11.02 + .11		-	-	100(W)	
83	17.11.02.44344	DAVIS NO. 1	-	-	-	STK(10-75)
84	17.11.11.22231	DAVIS NO. 2	-	-	-	STK(10-75); 1.5" LINE
85	17.11.11.23		QAL	7950	147.5(D) 167.1(D)	HEADWATER SPRING FOR RIO PENASCO; CHEM, TU
86	17.11.13.432		-	-	15.0(D)	DIRECTLY UNDERLAIN BY GRAY YESO CLAY; COLLAPSED YESO (SOLUTION BRECCIA(?)) OCCUR ABOUT .2 MILE NORTH; CHEM
87	17.11.24		PY	-	83.4(D)	CHEM
88	17.12.01.3432		-	8300	-	
89	17.12.02.44		-	8400- 8150	-	3 SPRINGS
90	17.12.03.3314		-	8300	-	
91	17.12.07.2422		-	8720	-	"DELWORTH SPRING"
92	17.12.08.3341		-	6500	-	
93	17.12.08.443		QCL,PY	8360	63.2(D)	ISSUES FROM COLLUVIUM (PROB BASE OF LS UNIT); UNDERLAIN BY YESO CLAY; CHEM
94	17.12.09.12144		-	8300	-	"BENSON SPRING"
95	17.12.10.131		-	8060	-	

96	17.12.11.3124		-	7620	-	
97	17.12.14.3231		PY	8070	10.0(D)	ISSUES FROM BASE OF BEDDED(5-15 CM) LS NEAR TOP OF YESO; GIVEN AS 17.12.14.314 IN DAVIS AND OTHERS (1979); CHEM
98	17.12.14.4234		PSA	7970	.5(D)	ISSUES FROM GLORIETA-YESO CONTACT; GIVEN AS 17.12.14.422 IN DAVIS AND OTHERS (1979); CHEM
99	17.12.16.12212		QCL	8175	5.0(D)	DEPOSITING TUFA; CHEM
100	17.12.16.43130		PSA	8600	2.0(D)	SMALL SPRING ISSUING ABOUT 30 FT ABOVE BASE OF SAN ANDRES FM.; TUFA PRESENT; CHEM, TU
101	17.12.17.1142		PY	8240	10.0(D)	ISSUES FROM TOP OF TUFA-COVERED CLIFF; CHEM
102	17.12.17.1213		QCL	8240	25.0(D)	UPWARD FLOW INDICATED FROM LOWER 2 SPRINGS IN COLLUVIUM; OTHER SPRINGS & TUFA PRESENT; CHEM
103	17.12.17.142 +.231		PY	8225	175.0(D) 167.6(D)	"BLUFF SPRINGS"; 4 SPRINGS; YESO LOCALLY EXPOSED; LARGE SPRING DEPOSITING TUFA; CHEM, TU
104	17.12.17.2123		PY	8225	12.0(D)	ISSUES FROM COLLUVIUM; UNDERLAIN BY CLAY; CHEM
105	17.12.17.3232		-	8640	-	"CHARLES SPRING"
106	17.12.20.444		QAL	8475	93.6(D)	ISSUES FROM LS-SILTST. CONTACT; CHEM
107	17.12.21.2222		-	8260	-	
108	17.12.21.331		PY	8525	12.0(D)	ISSUES THROUGH JOINT IN BEDDED LS; UNDERLAIN BY SILTY CLAY; CHEM
109	17.12.22.2234		-	8500	-	
110	17.12.24.141		-	8260	-	
111	17.12.29.223		-	-	147.5(D)	STREAM FLOW IN WILLS CANYON ABOVE JCN WITH HUBBELL CANYON; CHEM
112	17.13.01.241	U.S.FOREST SERVICE	PY	7224	1.0(W)	"FAST (OR LONG OR LOST) SPRING"; STK(3-74); GIVEN AS 17.13.01.22311 ON WELL SCHEDULE
113	17.13.01.443		PY	7000	5-15(W)	
114	17.13.03.4140		-	7120	-	
115	17.13.03.423		QAL	7120	>50(W)	2 SPRINGS; GIVEN AS 17.13.03.4214 IN STATE ENGINEER'S FILES, TU
116	17.13.04.44113	U.S.FOREST SERVICE	PY	7400	-	"BIG HILL SPRING"; STK(3-74)
117	17.13.07.212		QAL	7160	-	
118	17.13.11.3342		QAL	7600	164.7(D)	2 SPRINGS ISSUE FROM ALLUVIUM IN FLOOR AND ON SLOPES OF BEAR CANYON; UNDERLAIN BY YESO FM.; CHEM
119	17.13.11.4142		QAL	7400		2 SPRINGS

120	17.13.12.343		PSA	7470		"SLOUGH SPRING"
121	17.13.14.211		PSA	7590	45.1(W)	"TURKEY SPRING"
122	17.13.18.1433		-	7940	-	"BEAR SPRING"
123	17.14.04.1113		QAL	6940	3.0(W)	"LIGHTNING SPRING"
124	17.14.04.4411		PY-PSA	6860	1.0(W)	"BIG HILL SPRING"
125	17.14.05.22		QAL	6900	-	"LOWER LIGHTNING SPRING"; 3 SPRINGS
126	17.14.06.34		QAL	6890	-	IN COX CANYON ALLUVIUM; UNDERLAIN BY YESO FM.; CHEM, TU
127	17.14.07.24421	U.S.FOREST SERVICE	PY	6925	1(D) 2.4(D)	"WEEMS SPRING"; 2(?) SPRINGS ISSUE INTO TANK THROUGH LS; STK(3-74); CHEM
128	17.14.08.2213		PY	6840	-	EPHEMERAL SEEP; CHEM, TU
129	17.14.08.4123		PY-PSA	7040	.5(W)	"DENNY SPRING"; GIVEN AS 17.14.08.414 IN STATE ENGINEER'S FILES
130	17.14.08.4244		PSA	7150	2.9(W)	"SCOTT SPRING"; GIVEN AS 17.14.08.441 IN STATE ENGINEER'S FILES

APPENDIX C: Hydrometer analysis of samples from the Yeso Formation

Hydrometer procedures (after Day, 1965)

1. Prepare a dispersing agent from 40 grams sodium pyrophosphate per liter distilled water. Add 100 ml of dispersing agent to a 1000 ml hydrometer jar, and add distilled water to make 100 ml. Mix thoroughly. Record the temperature of the solution. Lower the hydrometer into the jar and read the top of the miniscus surrounding the stem, R_L. Record R_L and temperature periodically during the following steps.

2. With a mortar and pestle carefully disaggregate an oven-dry sample. Be careful not to crush individual grains.

3. Pass the sample through the no. 4 sieve. Weigh and save the retained fraction.

4. Split the fraction passing through the no. 4 sieve into subsamples using the sample splitter and place a subsample into a metal milk-shake mixing cup. (Weigh 25 to 50 gram subsamples if the soil is mostly clay and 75 to 100 gram subsamples if it is sandy.)

5. If it appears that the sample does not have an appreciable amount of organic matter, it is not necessary to oxidize the sample with hydrogen peroxide.

6. Add 100 ml of dispersing agent and enough distilled water to cover the soil sample. Let stand for 5 minutes (due to the importance of dispersion, samples are often left standing for more than 18 hours). Fill the cup with distilled water to within 2 inches of the top. Then stir with mixer for 5 minutes if sandy, 10 minutes if clayey.

7. Transfer the suspension to the 1000 ml hydrometer jar. Remov any sediment from the mixing cup by rinsing with distilled water. Fill with distilled water to the 1000 ml mark.

8. Remove the hydrometer. Place a rubber stopper or your hand over the end of the hydrometer jar and turn end-over-end for about 1 min. Return jar to table and mark the time immediately with a stop watch.

9. Carefully lower the hydrometer into the jar and read the top of the miniscus on the scale after 30 seconds. Remove the hydrometer. Record temperature of the suspension.

10. Place the hydrometer in the jar about 10 seconds before subsequent readings at 1, 4, 20, and 120 minutes. Record temperature. Rinse the hydrometer with distilled water and dry between readings.

11. After the final hydrometer reading empty the hydrometer jar on a fine (270) mesh wet washing sieve (one with high sides). Wash with tap water until wash water is clear. Transfer this material to a container and dry overnight in the oven at 105°C.

12. Prepare a nest of six sieves fining downward (e.g. no. 8, 16, 30, 50, 100, 200) with a lid on top and a pan on the bottom. Place dried sample on top sieve and agitate in mechanical shaker for 15 minutes. Weigh the amount retained on each sieve. Be certain to remove as much of the granular material stuck on the screen as possible using a brush.

Data Sheet for Hydrometer Analysis

Date: 6/22/82 Location: NW 1/4, Sec.26, T.16S., R.14E.
Sample No.: 2 Description: yellow sandy siltstone
Mass of sample(g): 44.84
Hydrometer correction data:

Water temp. (^{o}C): 23 RL: 1.5

Hydrometer analysis:

Time (min)	Temp. (^{o}C)	R	C=R-RL (g/l)	Theta (from table)	Viscosity (poises)
0.5	23.0	36.0	34.5	39.2	.009380
1.0	23.0	28.0	26.5	41.6	.009380
4.0	23.0	16.5	15.0	44.9	.009380
20.0	23.0	9.5	8.0	46.9	.009380
60.0	23.5	7.0	5.5	47.4	.009271
120.0	24.5	5.5	4.0	47.8	.009055

Calculations (continued)

	Correction factor	Corrected theta	Percentage* suspended (P)	Particle** diameter (X) (mm)
0.5	1.0825	42.4	76.9	.060
1.0	1.0825	45.0	59.1	.045
4.0	1.0825	48.6	33.5	.024
20.0	1.0825	50.8	17.8	.011
60.0	1.0762	51.0	12.3	.0066
120.0	1.0636	50.8	8.9	.0046

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* P= 100 x (C/C*), where C* is the dry weight of sample

** X= Corrected theta/sqrt(time) x 10^{-3}

Data Sheet for Hydrometer Analysis

Date: 6/24/82
Sample No.: 3
Mass of sample(g): 56.02

Location: NW 1/4, Sec.26, T.16S., R.14E.
Description: reddish-brown sandy siltstone

Hydrometer correction data:

Water temp. (^{o}C): 24.0 RL: 1.5

Hydrometer analysis:

Time (min)	Temp. (^{o}C)	R	C=R-RL (g/l)	Theta (from table)	Viscosity (poises)
0.5	24.0	47.0	45.5	35.9	.009161
1.0	24.0	43.0	41.5	37.1	.009161
4.0	24.0	32.0	30.5	40.4	.009161
20.0	23.5	20.5	19.0	43.8	.009271
60.0	23.0	14.5	13.0	45.5	.009380
120.0	22.0	12.0	10.5	46.2	.009608

Calculations (continued)

	Correction factor	Corrected theta	Percentage* suspended (P)	Particle** diameter (X) (mm)
0.5	1.0698	38.4	81.2	.054
1.0	1.0698	39.7	74.1	.040
4.0	1.0698	43.2	54.4	.022
20.0	1.0762	47.1	33.9	.011
60.0	1.0825	49.3	23.2	.0064
120.0	1.0956	50.6	18.7	.0046

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* P= 100 x (C/C^{*}), where C^{*} is the dry weight of sample

** X= Corrected theta/sqrt(time) x 10^{-3}

Data Sheet for Hydrometer Analysis

Date: 6/23/82	Location: NW 1/4, Sec.26, T.16S., R.14E.
Sample No.: 4	
Mass of sample(g): 47.55	Description: yellowish-red, sandy siltstone

Hydrometer correction data:

Water temp. (°C): 23.0 RL: 1.5

Hydrometer analysis:

Time (min)	Temp. (°C)	R	C=R-RL (g/l)	Theta (from table)	Viscosity (poises)
0.5	23.0	36.0	34.5	39.2	.009380
1.0	23.0	30.5	29.0	40.9	.009380
4.0	23.0	18.5	17.0	44.4	.009380
20.0	23.0	10.5	9.0	46.6	.009380
60.0	22.0	9.0	7.5	47.0	.009608
120.0	23.0	8.0	6.5	47.2	.009380

Calculations (continued)

	Correction factor	Corrected theta	Percentage* suspended (P)	Particle** diameter (X) (mm)
0.5	1.0825	42.4	72.6	.060
1.0	1.0825	44.3	61.0	.044
4.0	1.0825	48.1	35.8	.024
20.0	1.0825	50.4	18.9	.011
60.0	1.0956	51.5	15.8	.0066
120.0	1.0825	51.1	13.7	.0047

---

* P= 100 x (C/C*), where C* is the dry weight of sample

** X= Corrected theta/sqrt(time) x 10^{-3}

Data Sheet for Hydrometer Analysis

Date: 6/22/82
Sample No.: 6
Mass of sample(g): 40.19

Location: NW 1/4, Sec.26, T.16S., R.14E.
Description: white, silty, calcareous sandstone

Hydrometer correction data:

Water temp. (°C): 23.0   RL: 1.5

Hydrometer analysis:

Time (min)	Temp. (°C)	R	C=R-RL (g/l)	Theta (from table)	Viscosity (poises)
0.5	23.0	18.0	16.5	44.5	.009380
1.0	23.0	12.5	11.0	46.1	.009380
4.0	23.0	9.0	7.5	47.0	.009380
20.0	23.0	6.0	4.5	47.7	.009380
60.0	24.0	6.0	4.5	47.7	.009161
120.0	25.0	5.0	3.5	47.9	.008949

Calculations (continued)

	Correction factor	Corrected theta	Percentage* suspended (P)	Particle** diameter (X) (mm)
0.5	1.0825	48.2	41.1	.068
1.0	1.0825	49.9	27.4	.050
4.0	1.0825	50.9	18.7	.025
20.0	1.0825	51.6	11.2	.012
60.0	1.0698	51.0	11.2	.0066
120.0	1.0574	50.6	8.7	.0046

---

* P= 100 x (C/C*), where C* is the dry weight of sample

** X= Corrected theta/sqrt(time) x 10^{-3}

Data Sheet for Hydrometer Analysis

Date: 6/23/82	Location: NW 1/4, Sec.26, T.16S., R.14E.
Sample No.: 8	
Mass of sample(g): 65.05	Description: white, sandy siltstone

Hydrometer correction data:

Water temp. (°C): 23.0 RL: 1.5

Hydrometer analysis:

Time (min)	Temp. (°C)	R	C=R-RL (g/l)	Theta (from table)	Viscosity (poises)
0.5	23.0	45.0	43.5	36.5	.009380
1.0	23.0	35.0	33.5	39.5	.009380
4.0	23.0	18.5	17.0	44.4	.009380
20.0	22.5	12.0	10.5	46.2	.009494
60.0	22.5	10.0	8.5	46.7	.009494
120.0	23.0	9.0	7.5	47.0	.009380

Calculations (continued)

	Correction factor	Corrected theta	Percentage* suspended (P)	Particle** diameter (X) (mm)
0.5	1.0825	39.5	66.9	.056
1.0	1.0825	42.8	51.5	.043
4.0	1.0825	48.1	26.1	.024
20.0	1.0891	50.3	16.1	.011
60.0	1.0891	50.9	13.1	.0066
120.0	1.0825	50.9	11.5	.0046

---

* P= 100 x (C/C*), where C* is the dry weight of sample

** X= Corrected theta/sqrt(time) x 10^{-3}

Data Sheet for Hydrometer Analysis

Date: 6/24/82
Sample No.: 9
Mass of sample(g): 63.62

Location: NW 1/4, Sec.26, T.16S., R.14E.
Description: white, sandy siltstone

Hydrometer correction data:

Water temp. (°C): 23.5 RL: 1.5

Hydrometer analysis:

Time (min)	Temp. (°C)	R	C=R-RL (g/l)	Theta (from table)	Viscosity (poises)
0.5	23.5	50.0	48.5	35.0	.009271
1.0	23.5	40.0	38.5	38.0	.009271
4.0	23.5	20.5	19.0	43.8	.009271
20.0	23.0	14.0	12.5	45.6	.009380
60.0	22.5	12.0	10.5	46.2	.009494
120.0	22.0	11.5	10.0	46.3	.009608

Calculations (continued)

	Correction factor	Corrected theta	Percentage* suspended (P)	Particle** diameter (X) (mm)
0.5	1.0762	37.7	76.2	.053
1.0	1.0762	40.9	60.5	.041
4.0	1.0762	47.1	29.9	.024
20.0	1.0825	49.4	19.6	.011
60.0	1.0891	50.3	16.5	.0065
120.0	1.0956	50.7	15.7	.0046

---

* P= 100 x (C/C*), where C* is the dry weight of sample

** X= Corrected theta/sqrt(time) x 10^{-3}

Data Sheet for Hydrometer Analysis

Date: 6/23/82
Sample No.: 10
Mass of sample(g): 54.60

Location: NW 1/4, Sec.26, T.16S., R.14E.
Description: very pale brown, sandy siltstone

Hydrometer correction data:

Water temp. (^oC): 22.5 RL: 1.5

Hydrometer analysis:

Time (min)	Temp. (^oC)	R	C=R-RL (g/l)	Theta (from table)	Viscosity (poises)
0.5	22.5	46.0	44.5	36.2	.009494
1.0	22.5	36.0	34.5	39.2	.009494
4.0	22.5	20.0	18.5	43.9	.009494
20.0	22.5	12.5	11.0	46.1	.009494
60.0	23.0	10.0	8.5	46.7	.009380
120.0	23.5	8.0	6.5	47.2	.009271

Calculations (continued)

	Correction factor	Corrected theta	Percentage* suspended (P)	Particle** diameter (X) (mm)
0.5	1.0891	39.4	81.5	.056
1.0	1.0891	42.7	63.2	.043
4.0	1.0891	47.8	33.9	.024
20.0	1.0891	50.2	20.1	.011
60.0	1.0825	50.6	15.6	.0065
120.0	1.0762	50.8	11.9	.0046

---

* P= 100 x (C/C^*), where C^* is the dry weight of sample

** X= Corrected theta/sqrt(time) x 10^{-3}

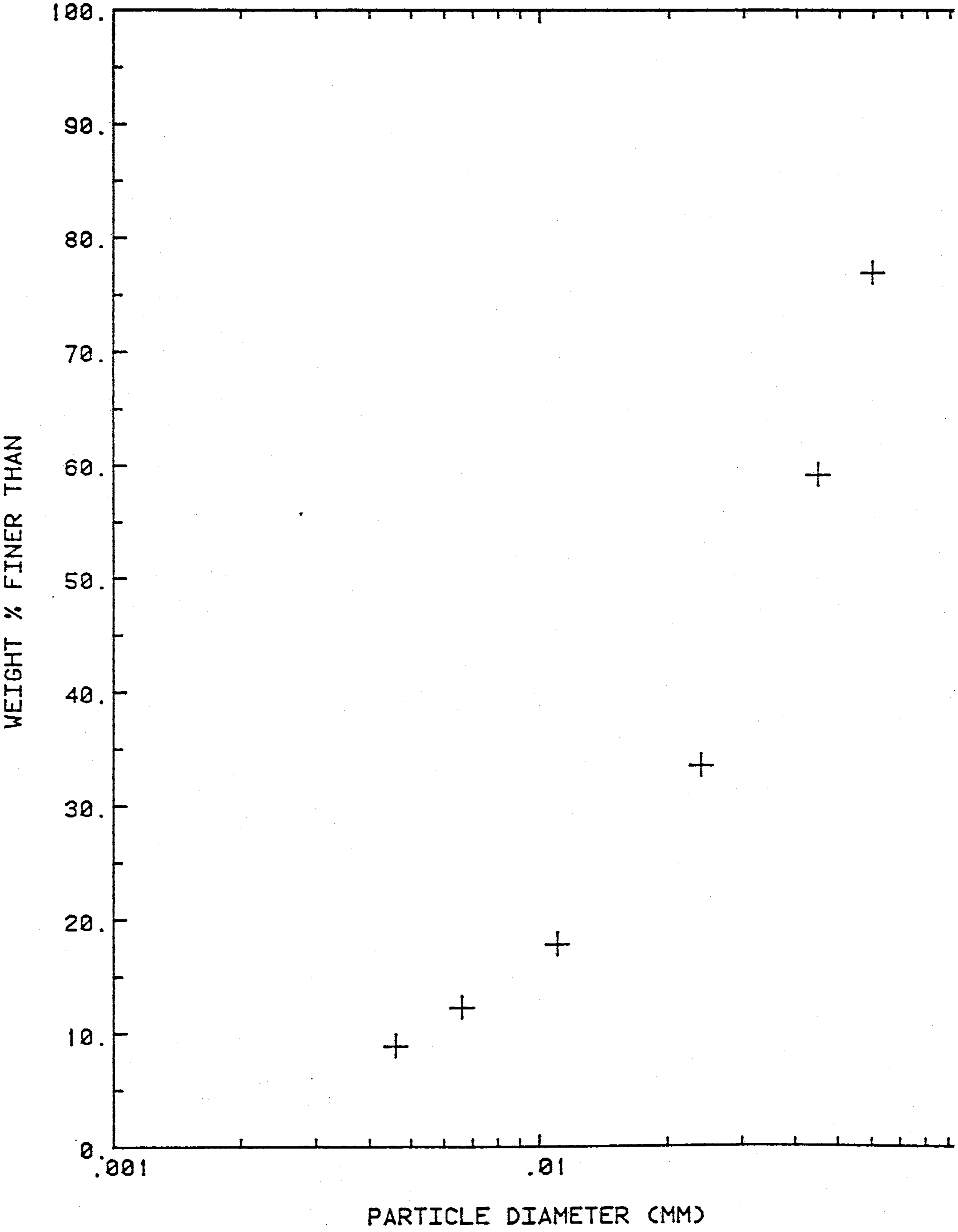

Figure 27. YESO SAMPLE 2

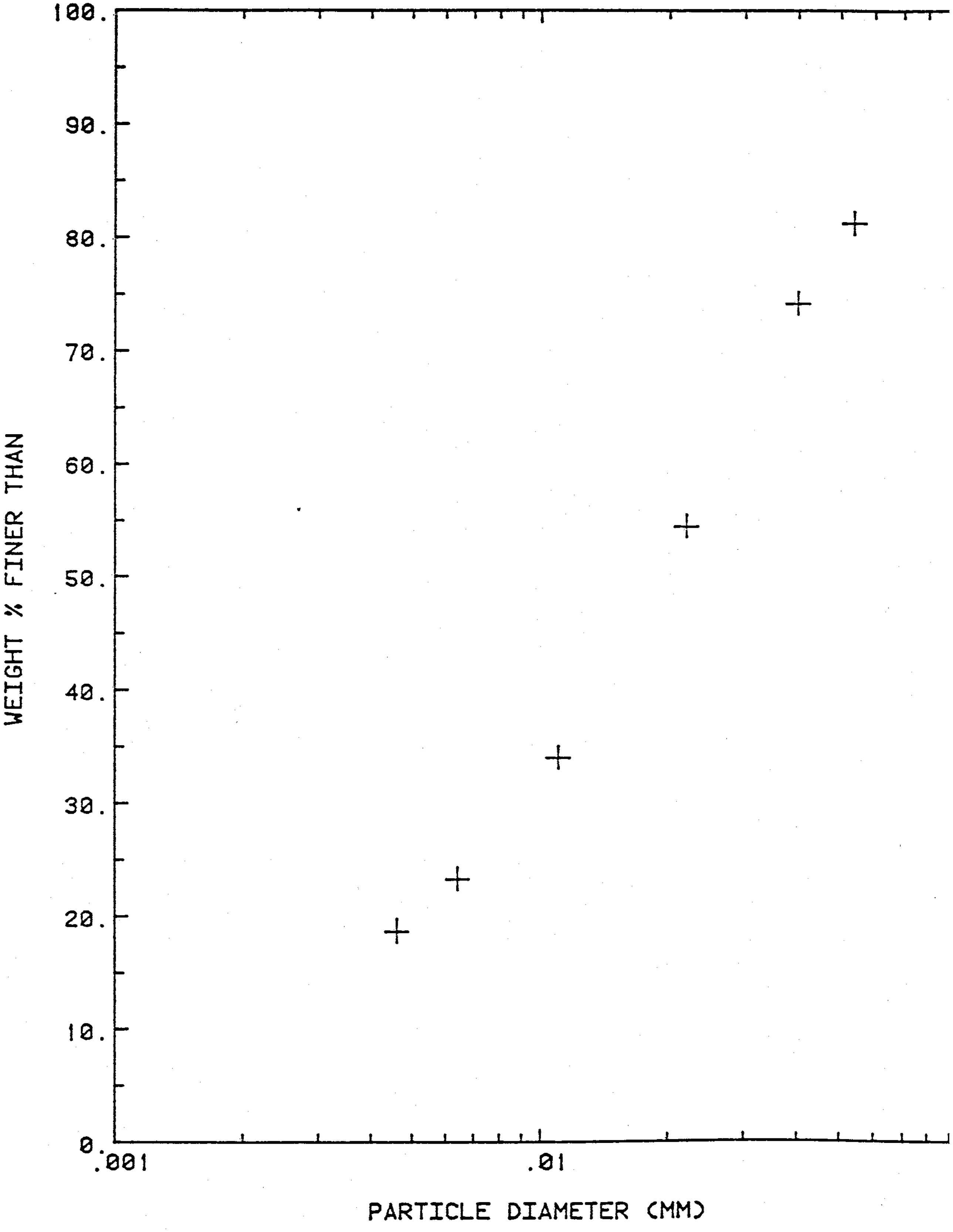

Figure 28. YESO SAMPLE 3

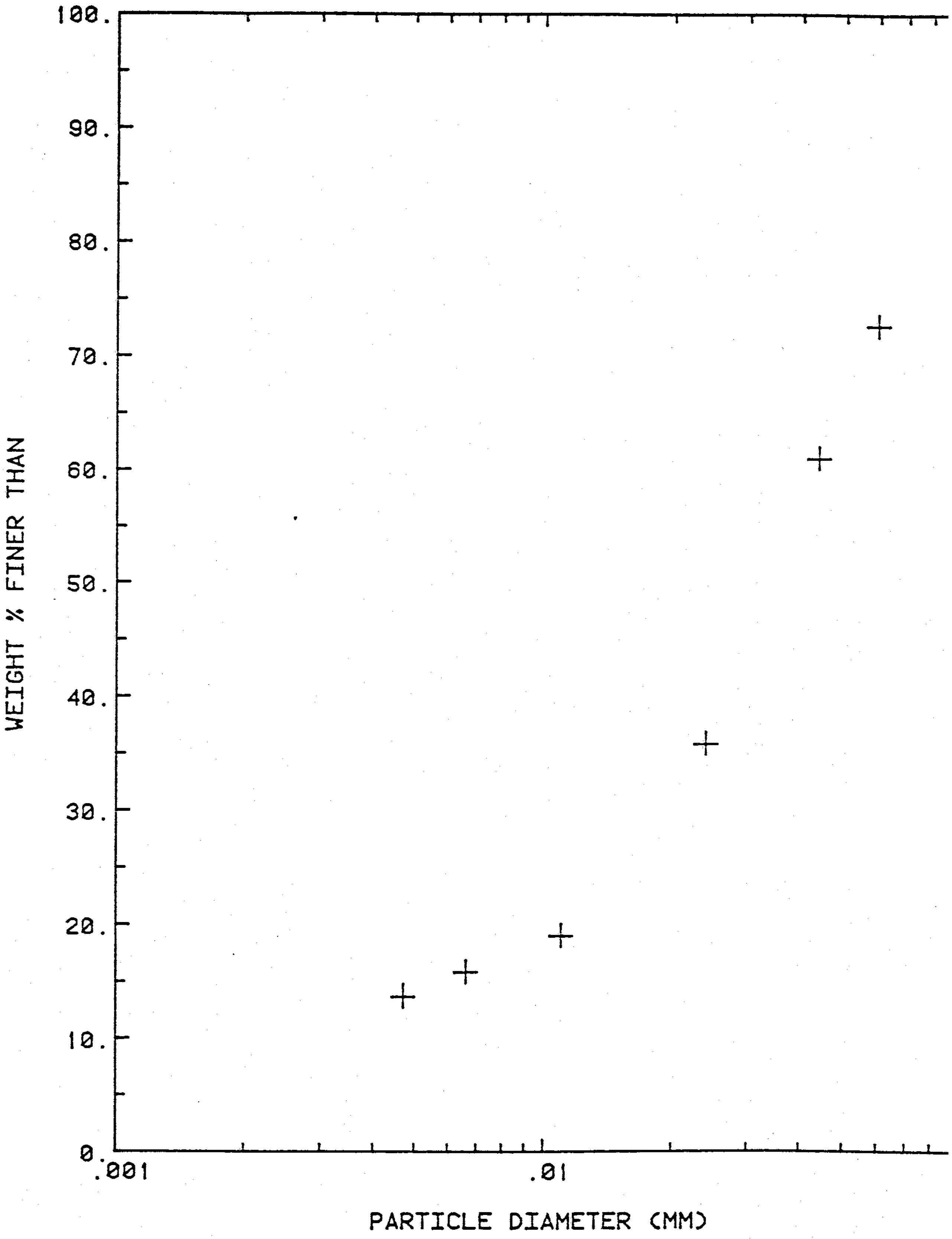

Figure 29. YESO SAMPLE 4

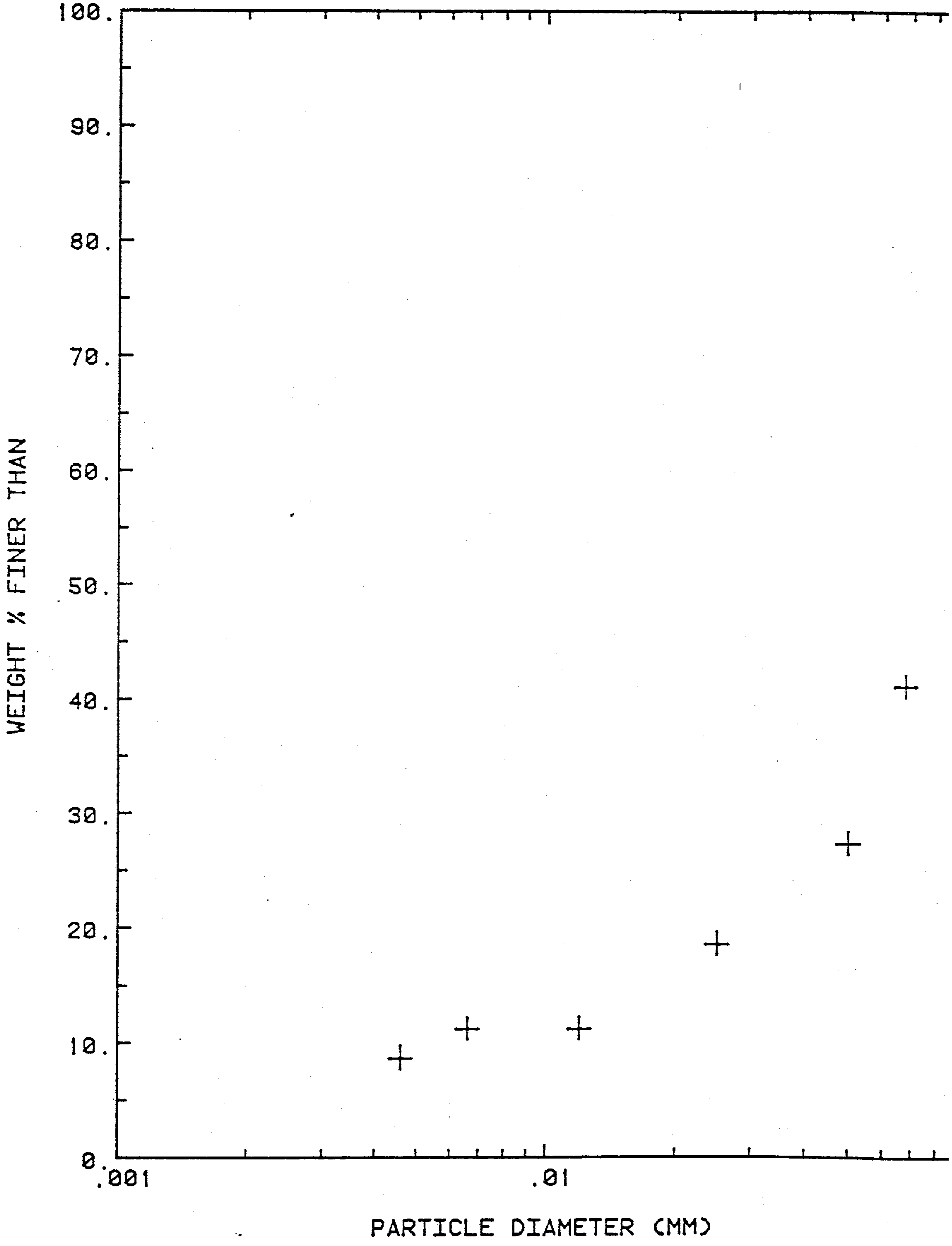

Figure 30. YESO SAMPLE 6

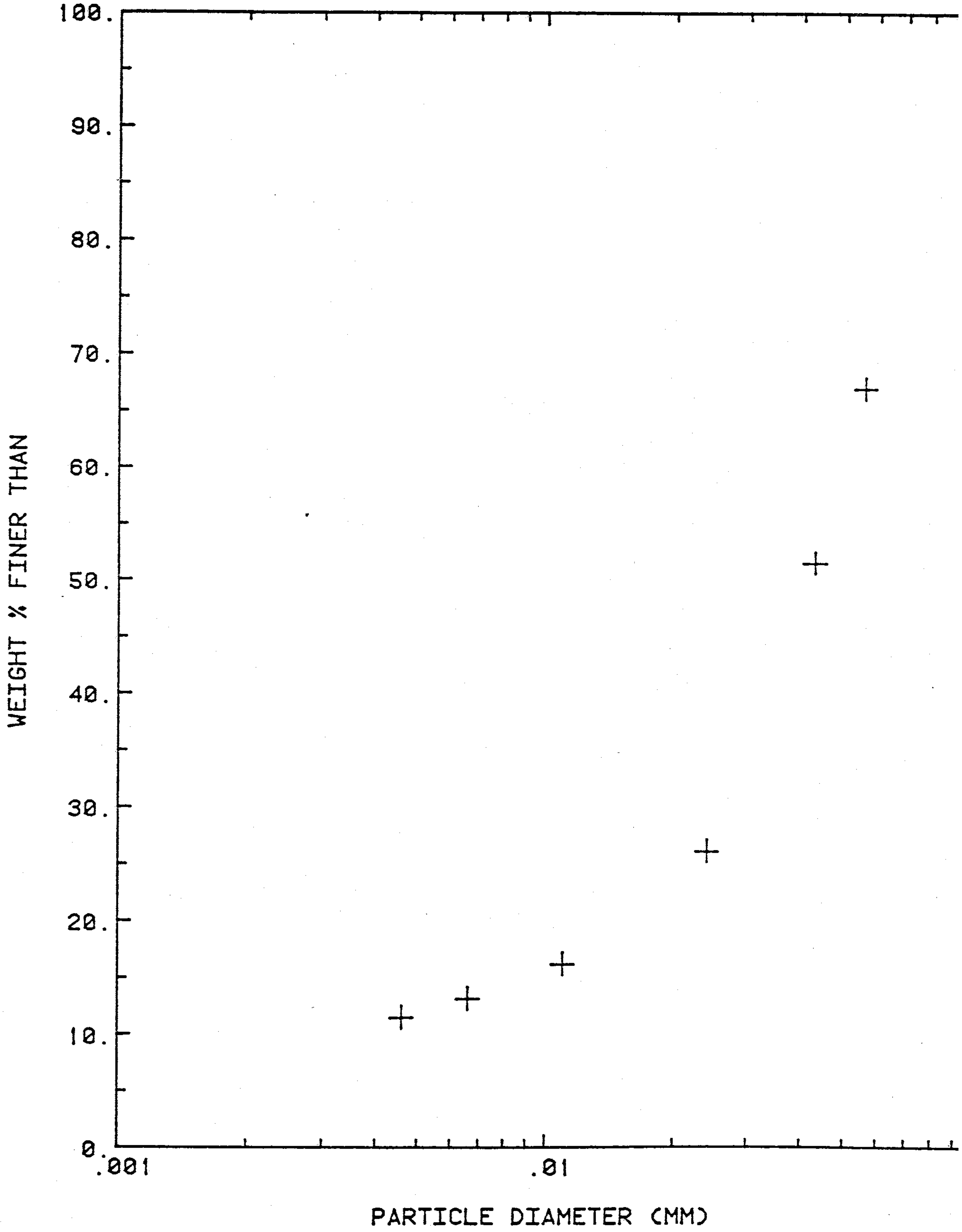

Figure 31. YESO SAMPLE 8

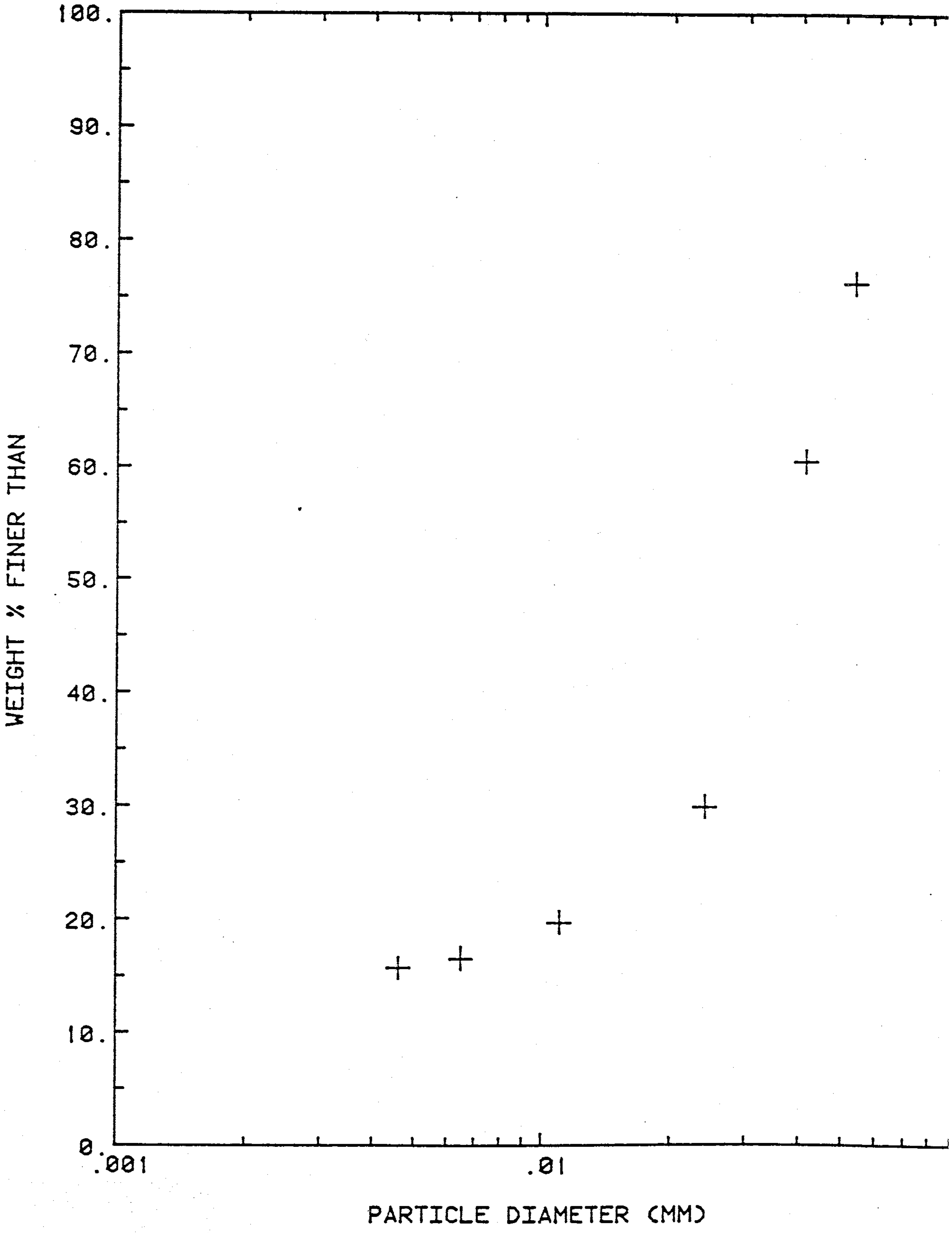

Figure 32. YESO SAMPLE 9

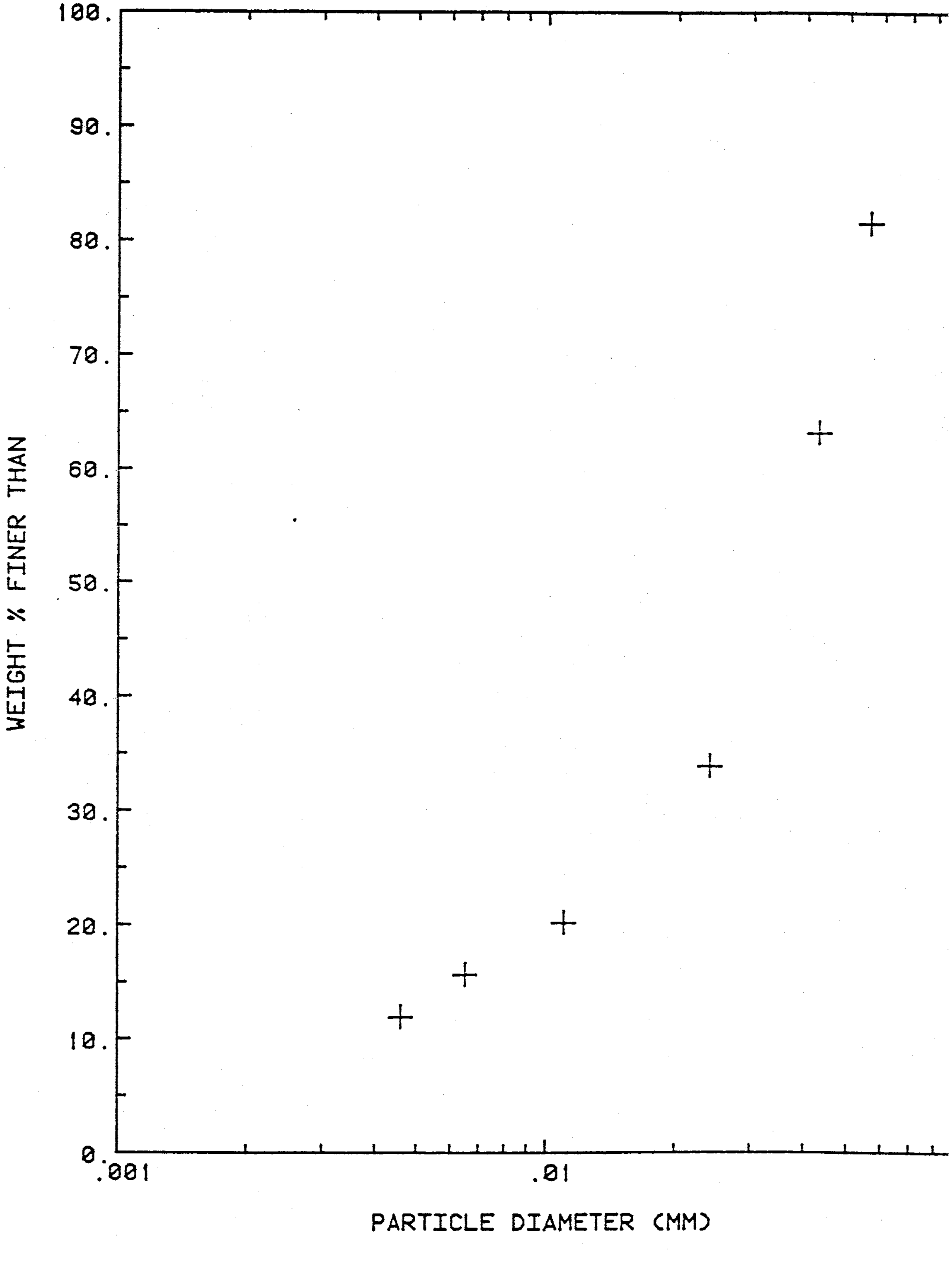

Figure 33. YESO SAMPLE 10

APPENDIX D: Mollusk locations and identifications

The University of Texas at El Paso
EL PASO, TEXAS 79968 – (915) 747-5164

Department of
Biological Sciences

15 January 1983

Ms. Alison Simcox
Box 2865, C.S.
Socorro, New Mexico 87801

Dear Ms. Simcox:

I have gone through the collections of fossil mollusks that you sent. The list of species of land snails is on the accompanying page. My own knowledge of the fauna of the Sacramento Mountains is based mainly on collections that I made several years ago at 300 ft. intervals along the Tularosa (5,400-8,400 ft.) and Peñasco (5,280-9, ft.) river valleys (collections from both floodplains and valley walls). I indicate whether your species are present in the Tularosa or Peñasco collections. I also indicate the species that were reported from probable Pleistocene deposits at the Keen Spring site (near Oscura, Tularosa Basin) by Karen Ashbaugh. She did a thes on several faunas from spring-related deposits and I noticed that quite a few of your species were also taken by her at Keen Spri

I was rather surprised that two species showed up, which I had seen rarely or not at all in the Sacramentos. So far as I know, <u>Nesovitrea hammonis</u> doesn't occur in the Sacramentos at this time, although I have it from probable Holocene deposits along the Penasco and Tularosa river valleys. I have taken <u>Vertigo elatior</u> only once, at the 8,100 ft. level along Peñasco Canyon (valley wall). This was a single specimen but did seem to be fresh. Thus, the abundance of this <u>Vertigo</u> at your site # 3 was quite a surprise. I enclose the pertinent pages concerning these two species from Ms. Ashbaugh's thesis. They summarize the situation. The Sacramento-Sierra Blanca Mt. complex is so extensive and I have collected in relatively few places, all things considered; thus I hate to make too much of a case concerning the absence or rarity of these two species. (It would be good to collect near you Loc. # 3 when the snow melts). However, there is certainly a suggestion that things were a bit different faunally at the time when your assemblage was living, east of Cloudcroft. In addition to Nesovitrea hammonis being present in the Holocene and absent in modern assemblages in the Sacramentos, there is another land snail, Oreohelix socorroensis, that seems to have disappeared from the Sacramentos at some time in the Holocene. (Both occur farther north in New Mexico at present). Thus, there seem to have been some subtle shifts, possibly related to minor climatic changes (cf. also the aquatics, mentioned below).

The aquatic species found at all localities (see below) indicat that water was present but I'm sure you knew that already. The Oxyloma probably lived very near water--probably within a few inches I've seen Oxyloma only in a restricted area along the Tularosa River in the Sacramento Mts.. The taxonomy of it and of the succineids (in the same family) are uncertain. The Vertigo, Carychium and Deroceras probably lived in a damp, possibly marshy, habitat. The other species might occur in habitats grading from damp to somewhat driver. However, all are species that commonly occur along montane canyons in the higher elevations of the Sacramentos today.

I am returning the aquatic species herewith. I thought it better for Dr. Dwight Taylor to identify them, as he has much more expertise in the aquatics than I; is especially interested in the Mew Mexico fauna; and is, I understand, working as a consultant for the Bureau. However, I suspect that there may be a couple of specie among the aquatics from Loc. 2 that no longer occur in the Sacramen a physid and a fragment, possibly of a lymnaeid.

You didn't indicate whether you wanted these speciments back or not. I am retaining them, pending word from you. We would, of course, be happy to add them to our collection.

Although I'd like to come up that way and look at the assemble waterfowl at Bosque del Apache some time soon, I may not make it so think it best to send this on. I hope I have been of some small hel to you and will try to elaborate on any points that leave you confuse

Sincerely,

Art M.

Art Metcalf

Fossil Localities

1 N.M., Otero Co., 17.13.02.42; valley of Rio Penasco; Holocene deposits; 10 to 40 ft of aphanitic, vugular, crumbly travertine, containing disseminated charcoal, aquatic-plant stems and molds, and mullusks.

2 N.M., Otero Co., 17.14.06.433; valley of Rio Penasco; Holocene deposits; similar to locality 1.

3 N.M., Otero Co., 16.12.03.14; 2.5 mi ESE of center of Cloudcroft; Holocene deposits on W side of Rawlins Cn. Rd.; 0.1 mi S of its jct. with U.S. Highway 82; about 10 ft of ponded sediments, containing charcoal and abundant mollusks; sediments apparently accumulated behind a travertine dam; ponded sediments grade into marly, gravelly alluvium.

SHELLS OF FOSSIL MOLLUSKS SUBMITTED BY ALISON SIMCOX, JAN, 1983

*Numbers of specimens indicated.

Identification to species	Simcox Localities*			Tularosa Valley (modern)	Penasco Valley (modern)	Ke Spr (fo
	1	2	3			
Carychium exiguum (Say)			2	X		X
Vertigo elatior Sterki			38		X	X
Pupilla blandii Morse			1	X	X	X
Vallonia cyclophorella Sterki			138	X	X	X
Vallonia perspectiva Sterki			5	X	X	X
Punctum conspectum (Bland)			7		X	
Oxyloma sp.	2			X		
Succineidae (sp. indet.)		4	52	X	X	X
Euconulus fulvus (Müller)		1	5	X	X	
Nesovitrea hammonis (Ström)			30			X
Zonitoides arboreus (Say)			10	X	X	
Deroceras laeve (Müller)			1	X	X	X
Ashmunella rhyssa rhyssa (Dall)			39	X	X	X

Plate 1

Figures

1,2 Vallonia cyclophorella Sterki (11.7X, 2.56 mm*); Loc. 3

3,4 Punctum conspectum (Bland) (29X, 1.48 mm); Loc. 3

5 Vallonia perspectiva Sterki (15.9X, 2.02 mm); Loc. 3

6 Vallonia perspectiva Sterki (15.7X, 1.90 mm); Loc. 3

7 Carychium exiguum (Say) (29X, 1.62 mm); Loc. 3

8 Vertigo elatior Sterki (7.5X, 2.00 mm); Loc. 3

* Diameter

1

2

3

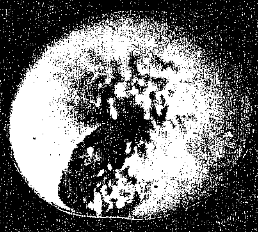

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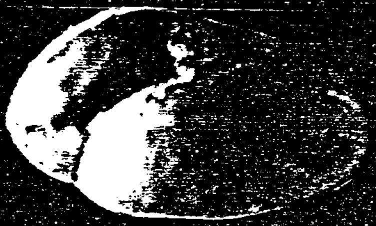
Plate 2

Figures	
9	Euconulus fulvus (Muller) (16.0X, 1.81 mm); Loc. 2,3
10	Euconulus fulvus (Muller) (26.2X, 1.82 mm); Loc. 2,3
11	Deroceras laeve (Muller) (23.3X, 1.76 mm); Loc. 3
12	Pupilla blandii Morse (15.7X, 3.00 mm); Loc. 3
13	Oxyloma sp. (9.3X, 8.59 mm); Loc. 1
14	Nesovitrea hammonis (Strom) (7.4X, 3.63 mm); Loc. 3
15	Succineidae (sp. indet.) (11.8X, 4.13 mm); Loc. 3

9



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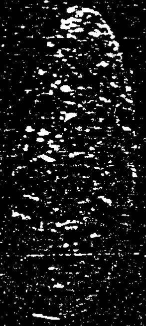

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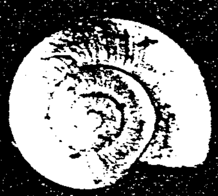
12

13



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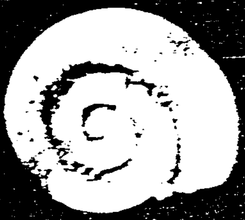
15

Plate 3

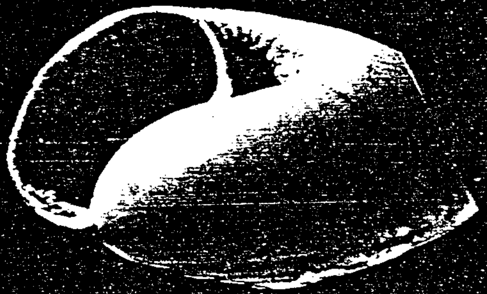
Figures	
16,17	Helicodiscus singleyanus (23X, 1.39 mm); Loc. 3
18,19	Ashmunella rhyssa rhyssa (Dall) (4.9X, 9.30 mm); Loc. 3
20	Fossaria parva (7.7X, 3.26 mm); Loc. 3
21	Zonitoides arboreus (Say) (7.7X, 4.29 mm); Loc. 3
22	Zonitoides arboreus (Say) (4.85X, 4.54 mm); Loc. 3



16

17

18



19

20

21

22

Family Hydrobiidae

Cf. Fontelicella (Nafricola) hendersoni (Pilsbry, 1933)

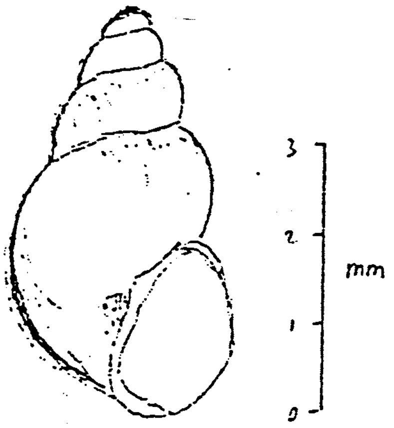


Plate 4

See description on following page.

From: Jiri Zidek
Subject: aquatic mollusks from the Sacramento Mountains

Family Physidae

Physella utahensis (Clench, 1925)

Three specimens from loc. 2; Six specimens from loc. 3 - 5 of these are only partially exposed in travertine. All of the specimens are incomplete; nevertheless, they are clearly smaller (about 25%) than the representative specimen of *P. utahensis* illustrated by Burch (1982, Figure 645). The difference in size notwithstanding, the morphology of the shell is definitely that of *P. utahensis*. Clench (1925) described Recent *utahensis* as a new subspecies of *Physa* (today *Physella*) *lordi* from New Mexico, but neglected to provide locality data. More recently, *utahensis* has been recognized as a separate species. Thus, although Burch (1982, p.55) lists *P. utahensis* as occurring only in Wyoming, Colorado, and Utah, it actually occurs in New Mexico as well, but it may not extend as far southward as in the past - I don't know how old your samples are. Also, there are two immature specimens, about 3 mm long, of *Physa* (sensu lato) from loc. 3. They, of course, can not be identified any closer than Physidae Indet.

Family Sphaeriidae (Pelecypoda)

Both *Sphaerium* and *Pisidium* are represented from loc. 3, although I am not able to identify the species.

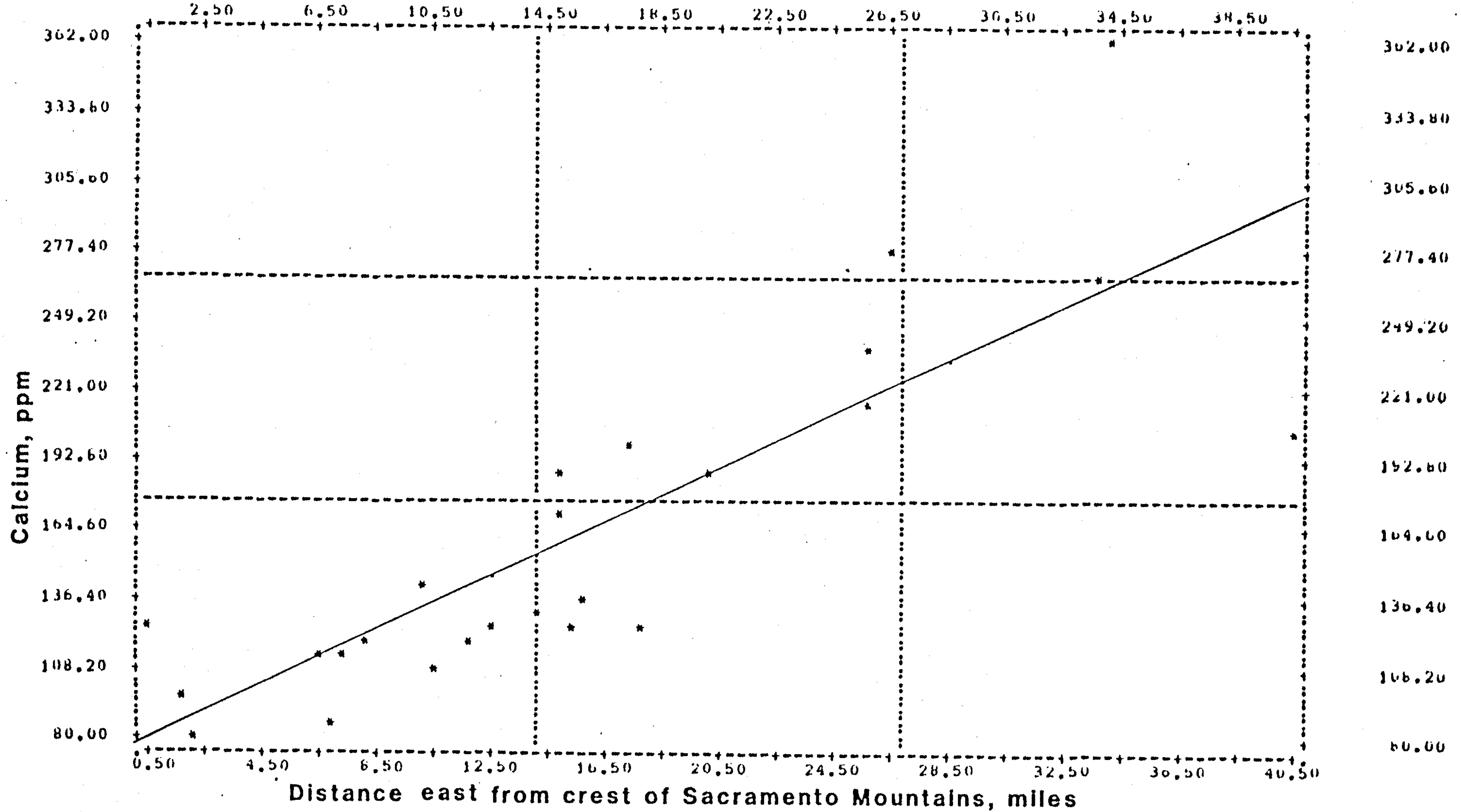
Family Hydrobiidae

Cf. *Fontelicella* (*Nafricola*) *hendersoni* (Pilsbry, 1933).

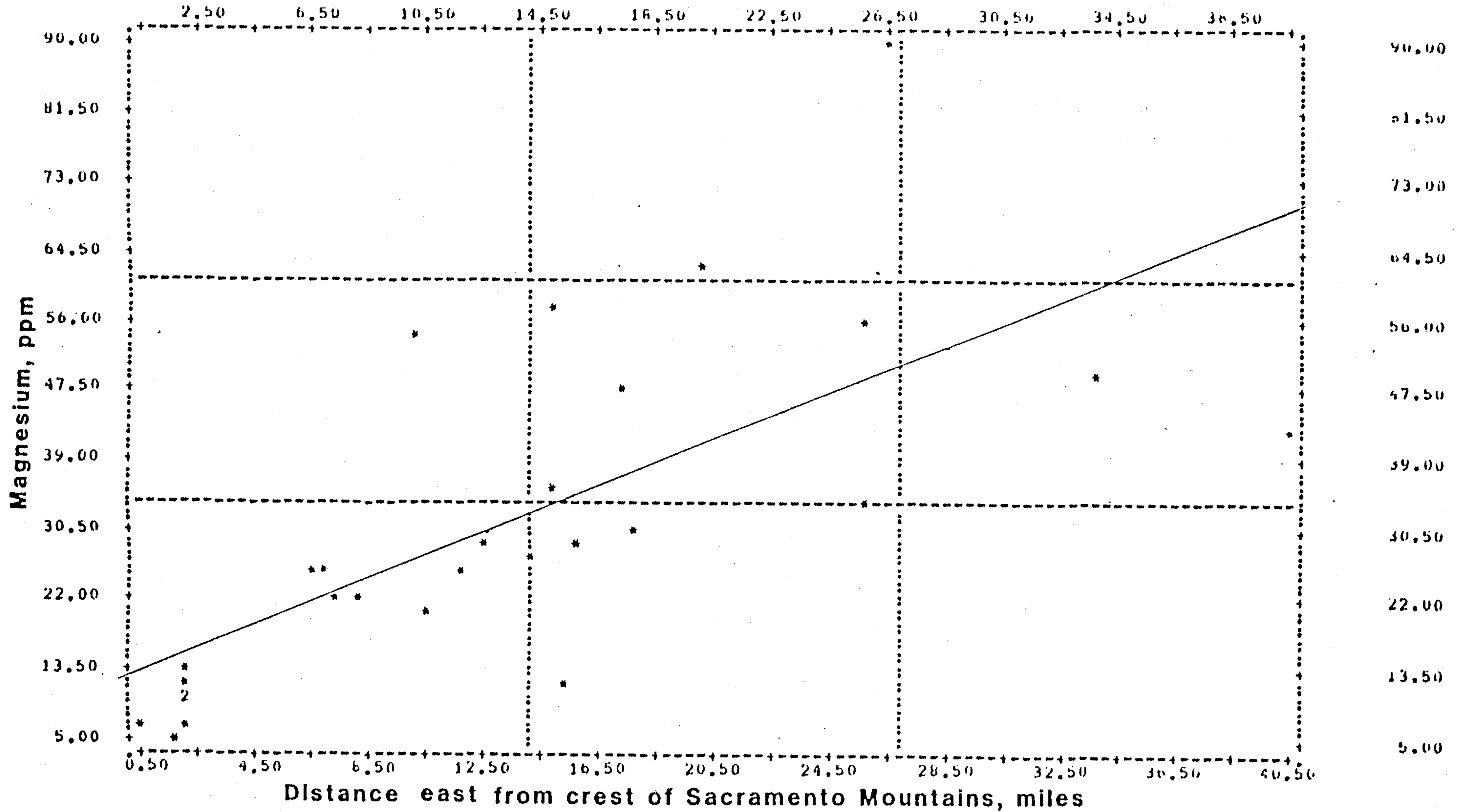
Five specimens from loc. 3. They correspond most closely to *F.*(*N.*) *hendersoni* in shell morphology (cf. Burch, 1982, Figure 240), but since hydrobiid snails can be reliably identified only on the basis of soft anatomy (sex organs), the above identificati must be regarded as tentative. Burch (1982, p.110) lists only *Fontelicella* sensu stricto for New Mexico, and restricts the subgenus *Nafricola* to Idaho, Oregon, and Wyoming.

The gastropods require still water, however, this is not necessarily the case with the clams. I would refrain from making any definitive conclusions on the environment; the sample is clearly inadequate for that.

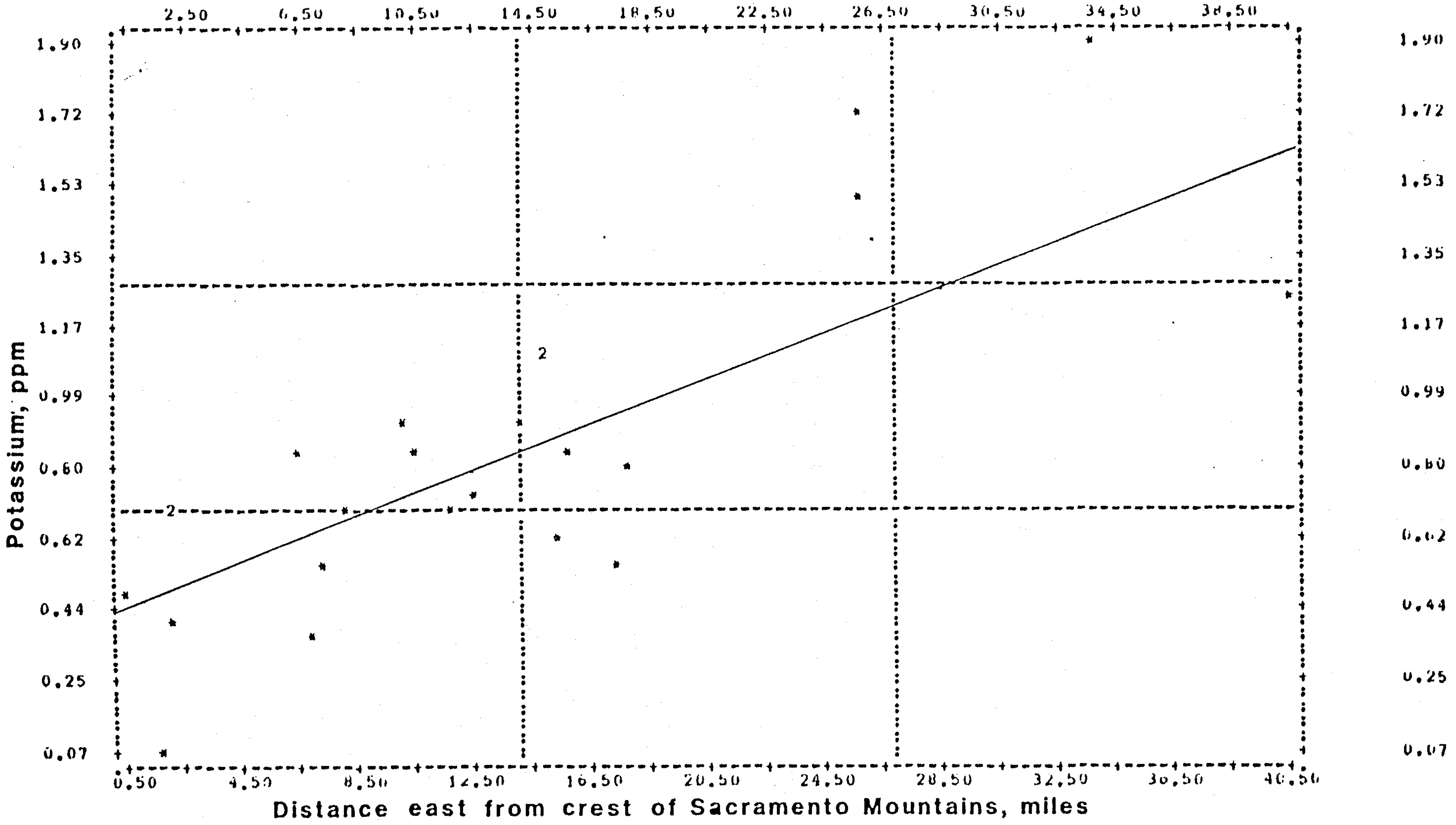
APPENDIX E: Scattergrams of chemical constituents and tritium activity in wells



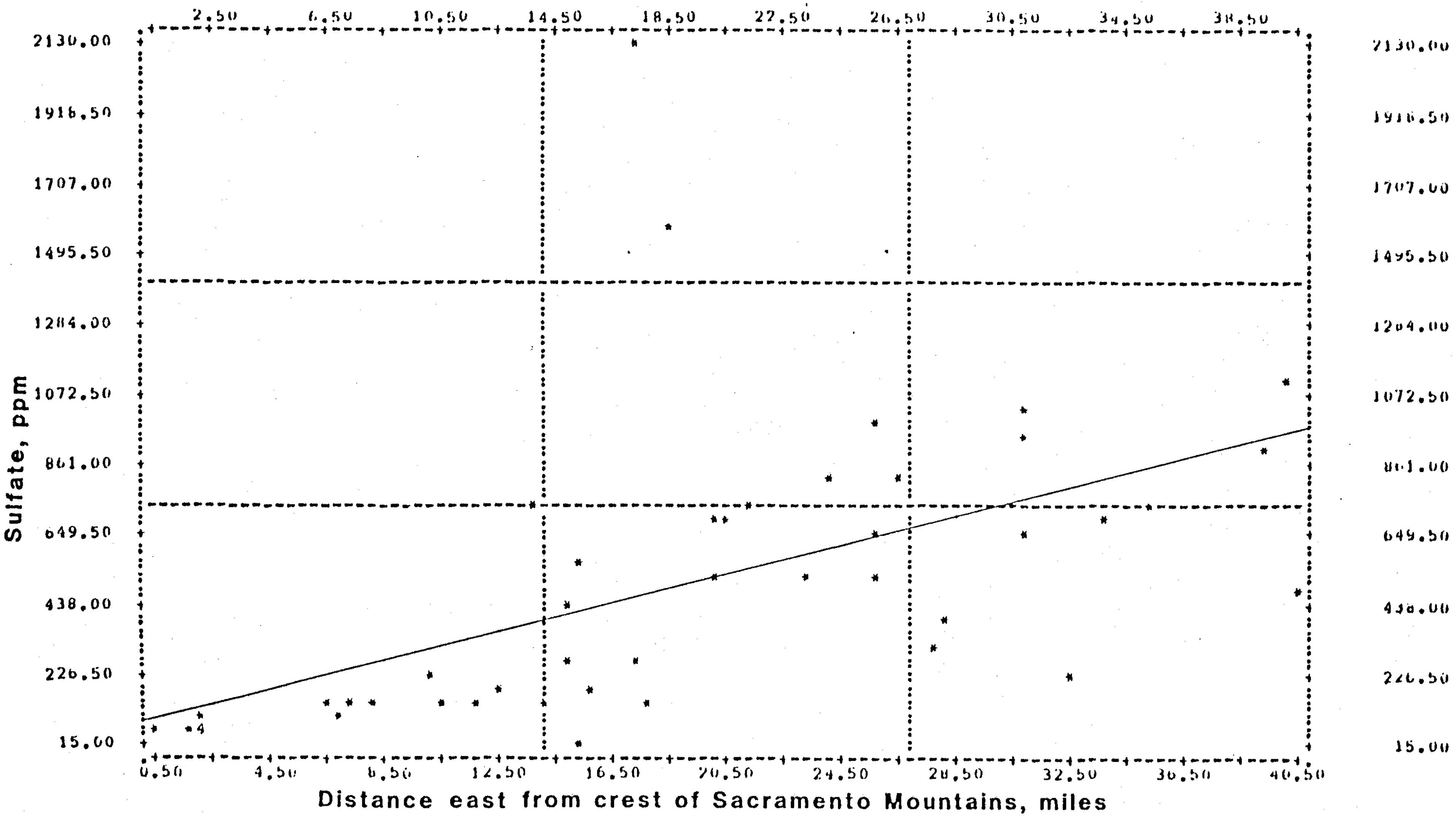
```
Statistics:
  Correlation (R)-      0.83986     R squared       -       0.70537      Significance   -      0.00000
  Std err of est -     38.21125     Intercept (a)   -      75.18376      Slope (b)      -      5.54627
  Plotted values -     25           Excluded values-        0            Missing values -     23
```



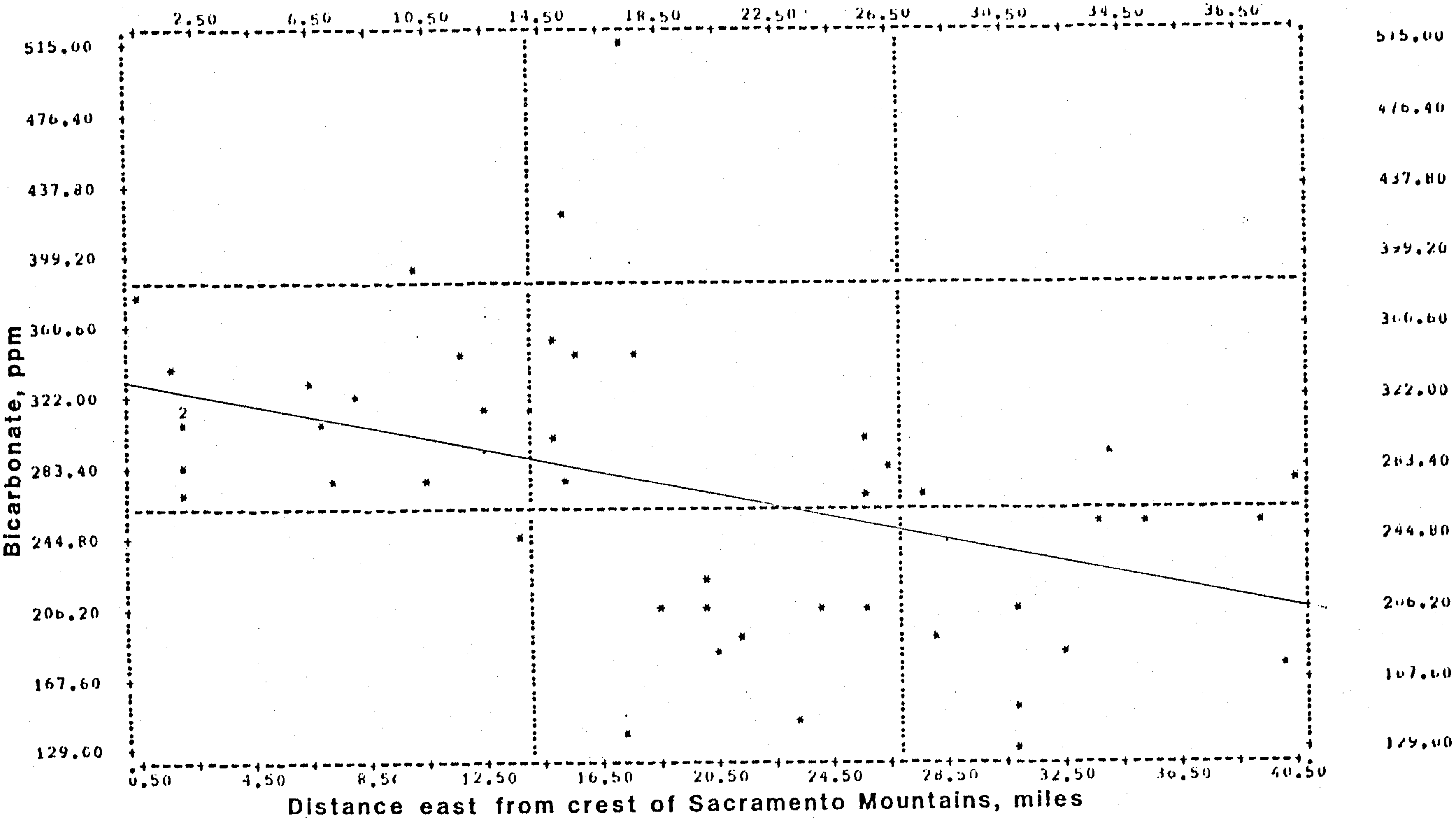
```
Statistics:
  Correlation (R)-       0.71126     R squared        -      0.50588     Significance    -      0.00001
  Std err of est -      14.69404     Intercept (a)    -     12.20466     Slope (b)       -      1.42216
  Plotted values -        26         Excluded values-          0         Missing values  -     20
```



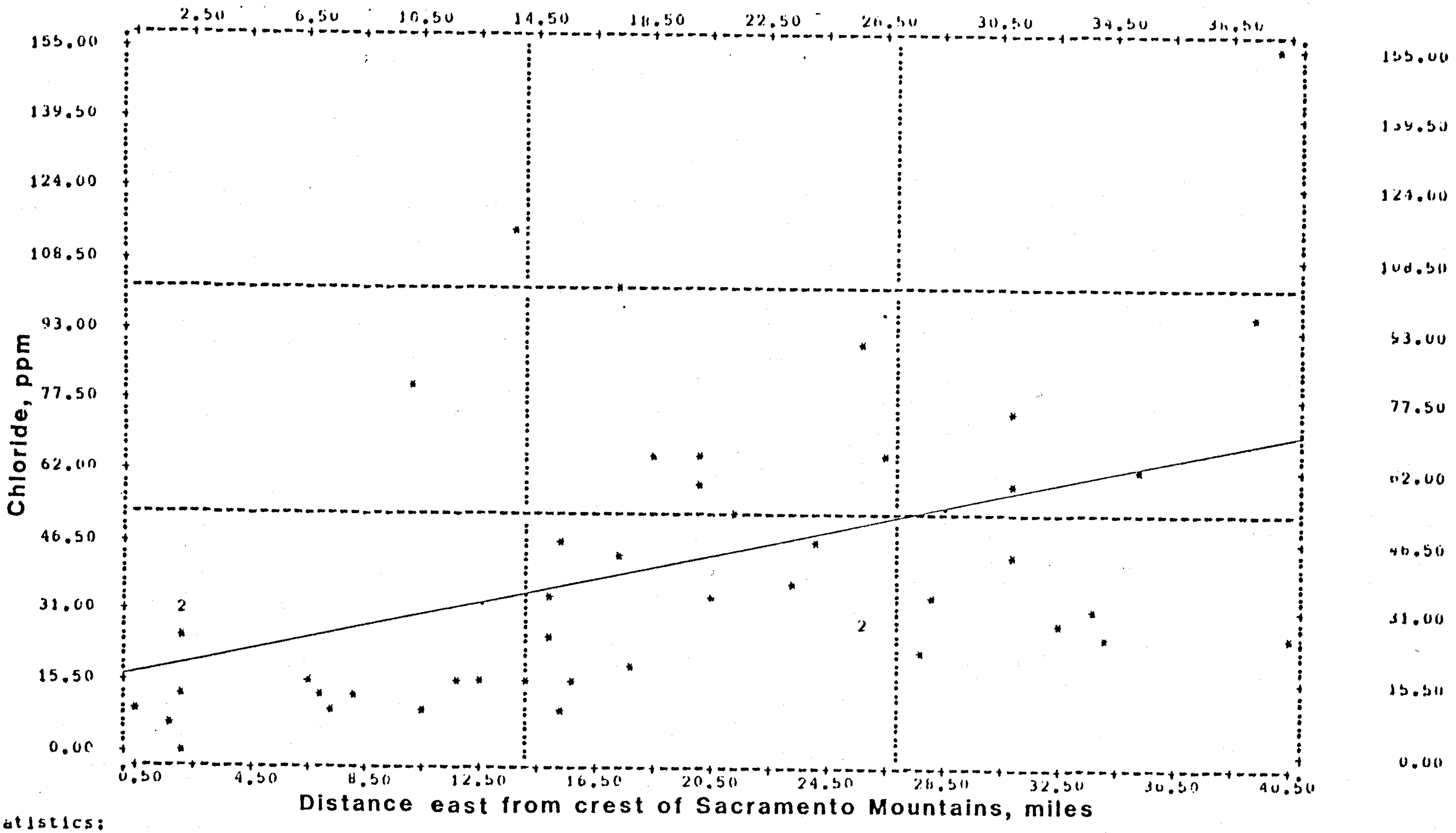
```
Statistics:
  Correlation (R)-        0.79668     R squared      -        0.63469     Significance   -         0.00000
  Std err of est - .      0.25930     Intercept (a)  -        0.40887     Slope (b)      -         0.03297
```



```
Statistics:
  Correlation (R)-        0.55771      R squared      -       0.31104      Significance   -        0.00002
  Std err of est -      364.58269      Intercept (a)  -      84.71861      Slope (b)      -       21.56381
  Plotted values -         47          Excluded values-        0           Missing values -        .
```

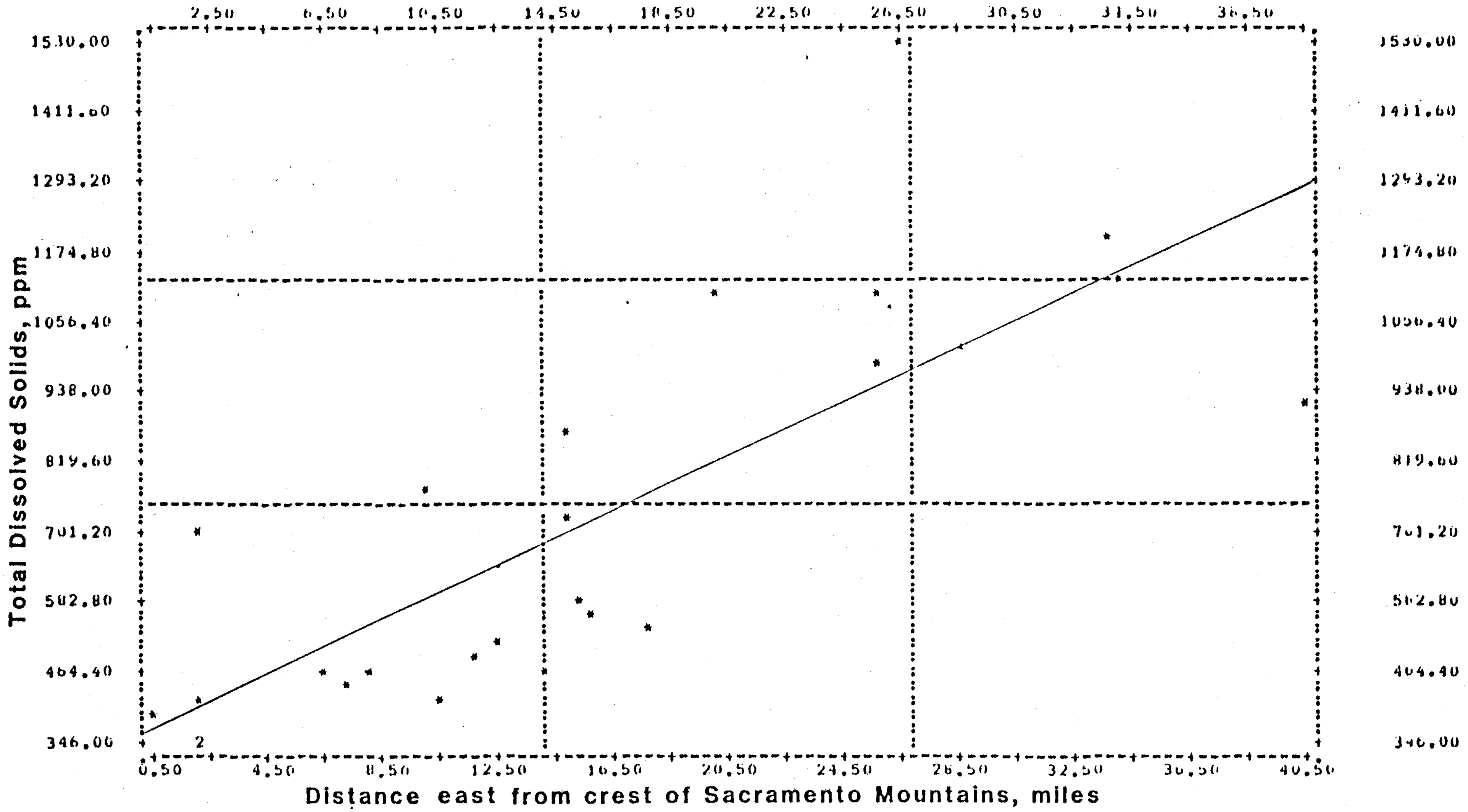


```
Statistics:
  Correlation (R)-     -0.49038     R squared     -       0.24047     Significance   -       0.00020
  Std err of est -     68.97361     Intercept (a) -     335.61769     Slope (b)      -      -3.38360
  Plotted values -     48           Excluded values-     0            Missing values -       0
```



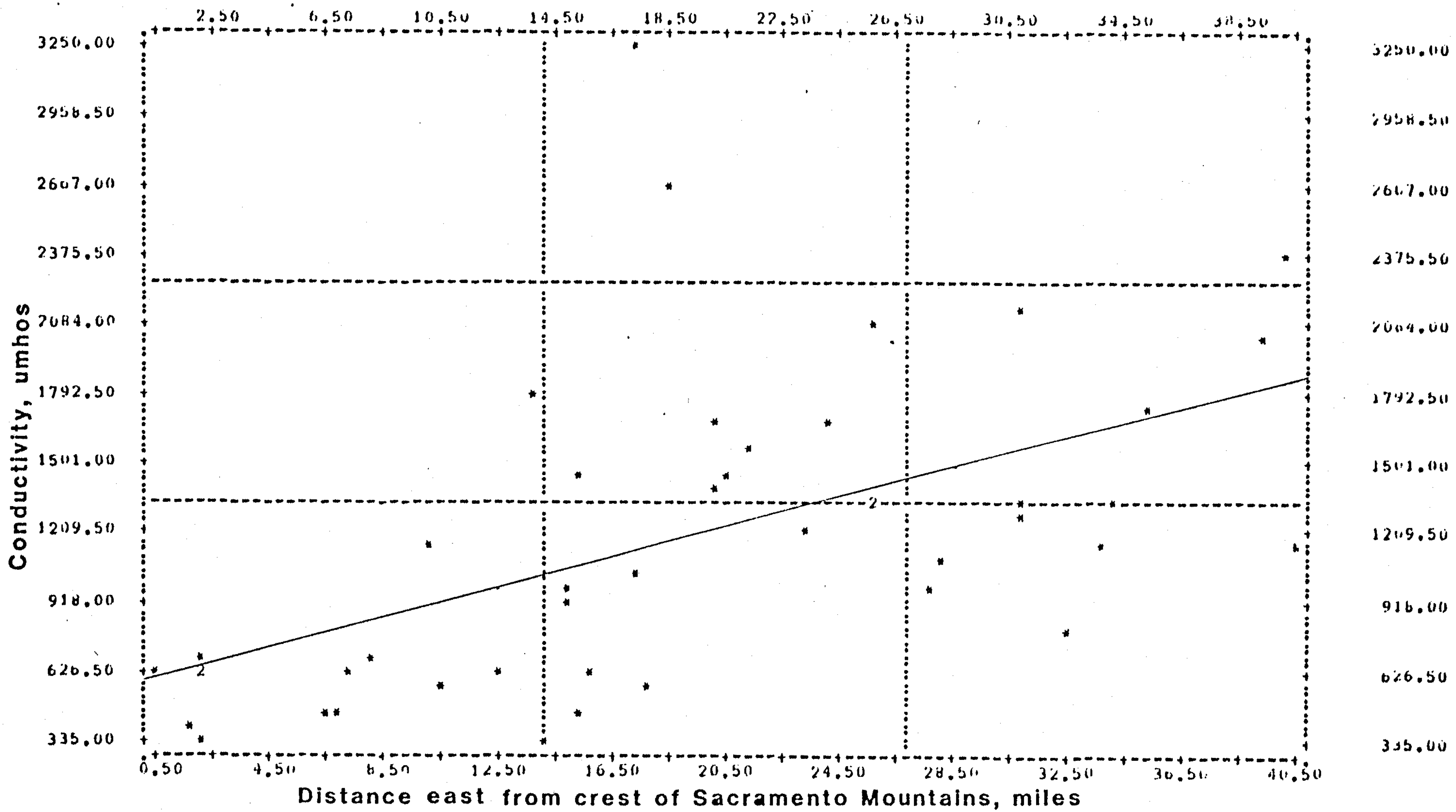
```
Statistics:
  Correlation (R)-        0.46590     R squared       -      0.23610     Significance   -      0.00023
  Std err of est -       28.55604     Intercept (a)   -     14.58025     Slope (b)      -      1.38416
  Plotted values -       46           Excluded values-       0           Missing values -      0
```

Figure 39



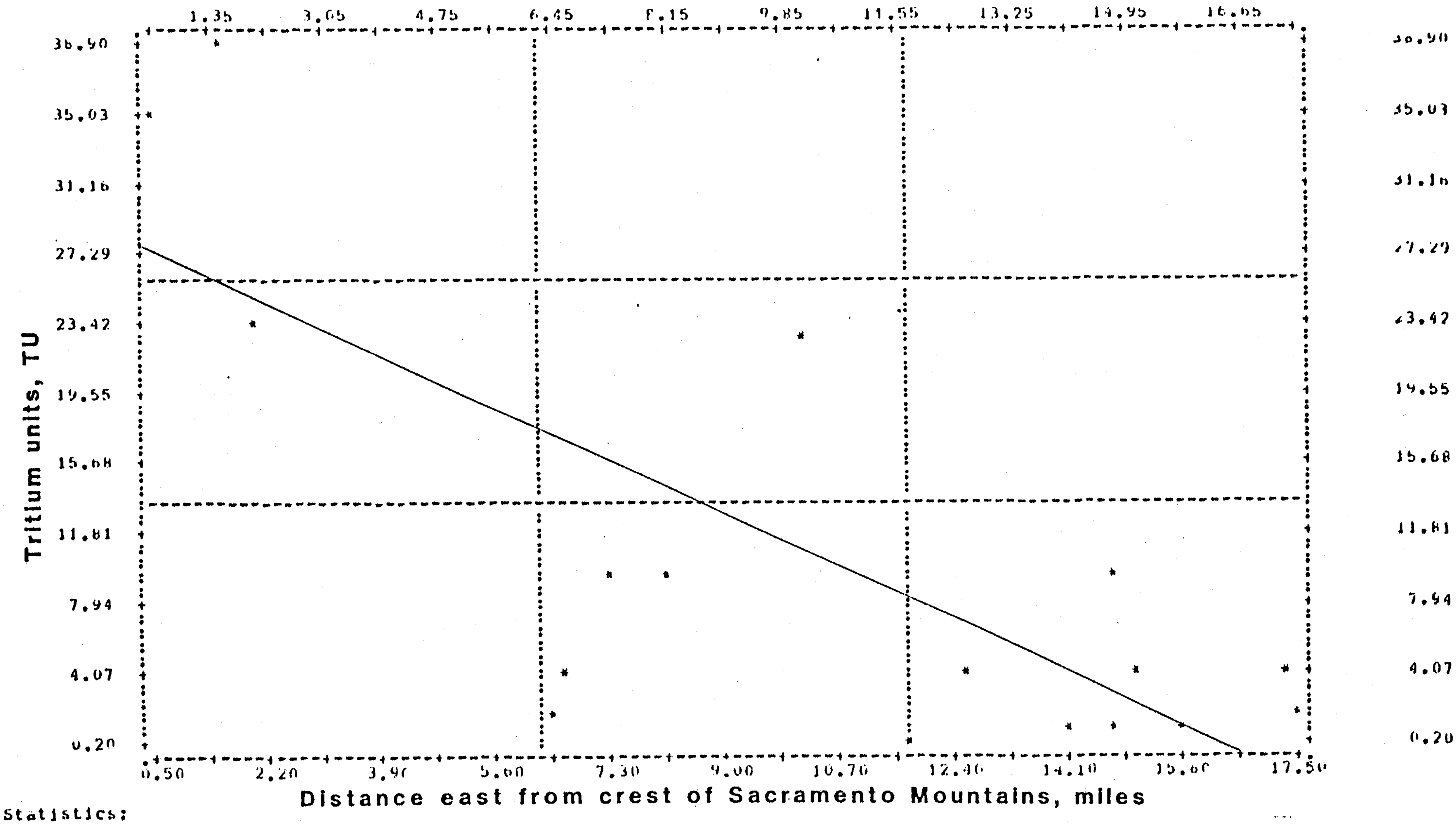
```
Statistics:
  Correlation (F)-      0.78587     R squared      -     0.61759     Significance   -      0.00000
  Std err of est -    203.25692     Intercept (a)  -   353.71396     Slope (b)      -     23.07836
  Plotted values -     25           Excluded values-     0           Missing values -     23
```

Figure 40



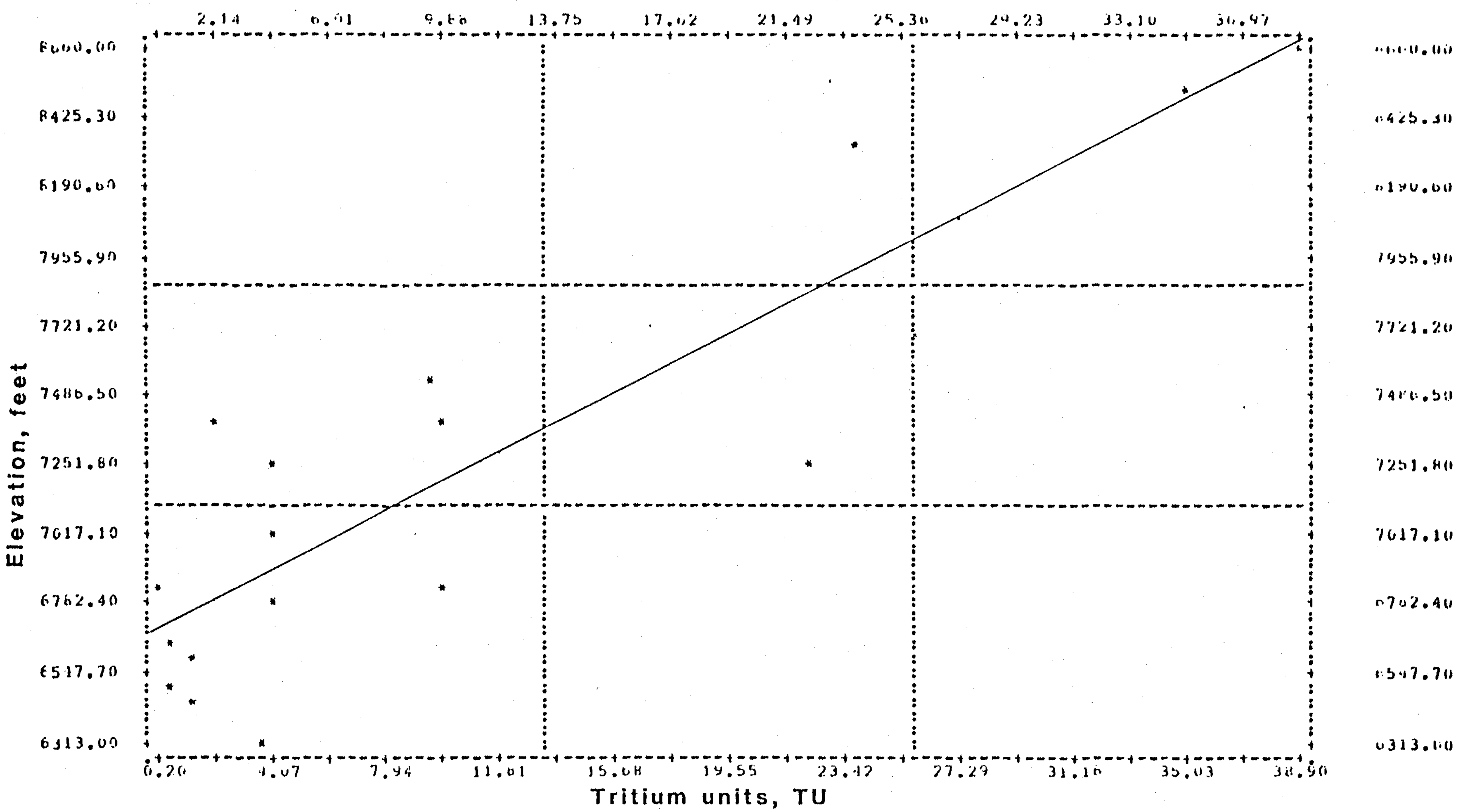
```
Statistics:
  Correlation (R)-      0.54469      R squared       -      0.29669      Significance    -      0.00005
  Std err of est -    554.97816      Intercept (a)   -    578.07726      Slope (b)       -     31.42761
  Plotted values -       45          Excluded values-         0          Missing values  -        3
```

Figure 41



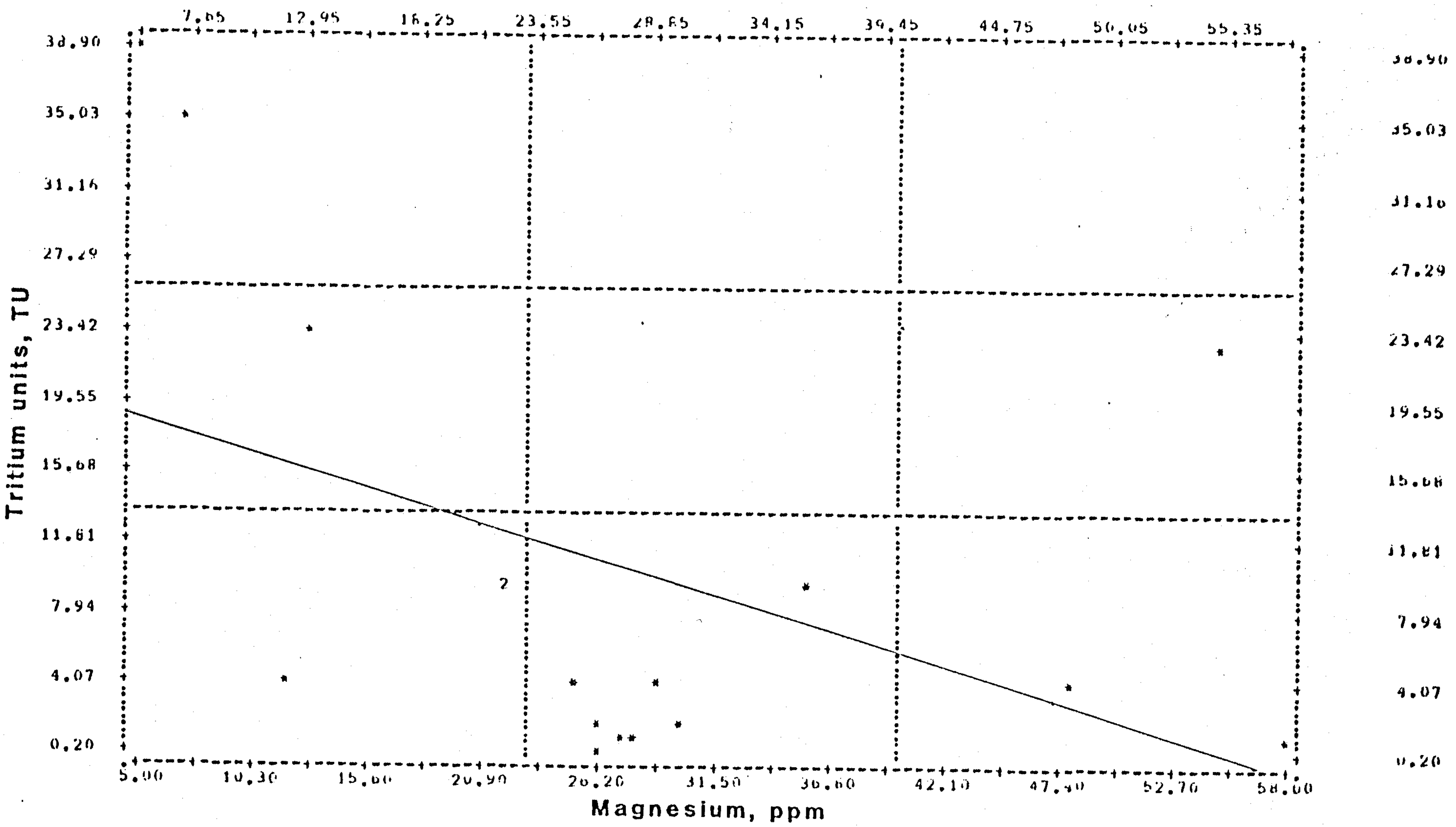
```
Statistics:
  Correlation (R)-      -0.77171     R squared      -        0.59554     Significance    -      0.0001
  Std err of est -       6.04329     Intercept (a)  -       27.71894     Slope (b)       -     -1.64840
  Plotted values -      17           Excluded values-        0           Missing values  -      1
```

Figure 42



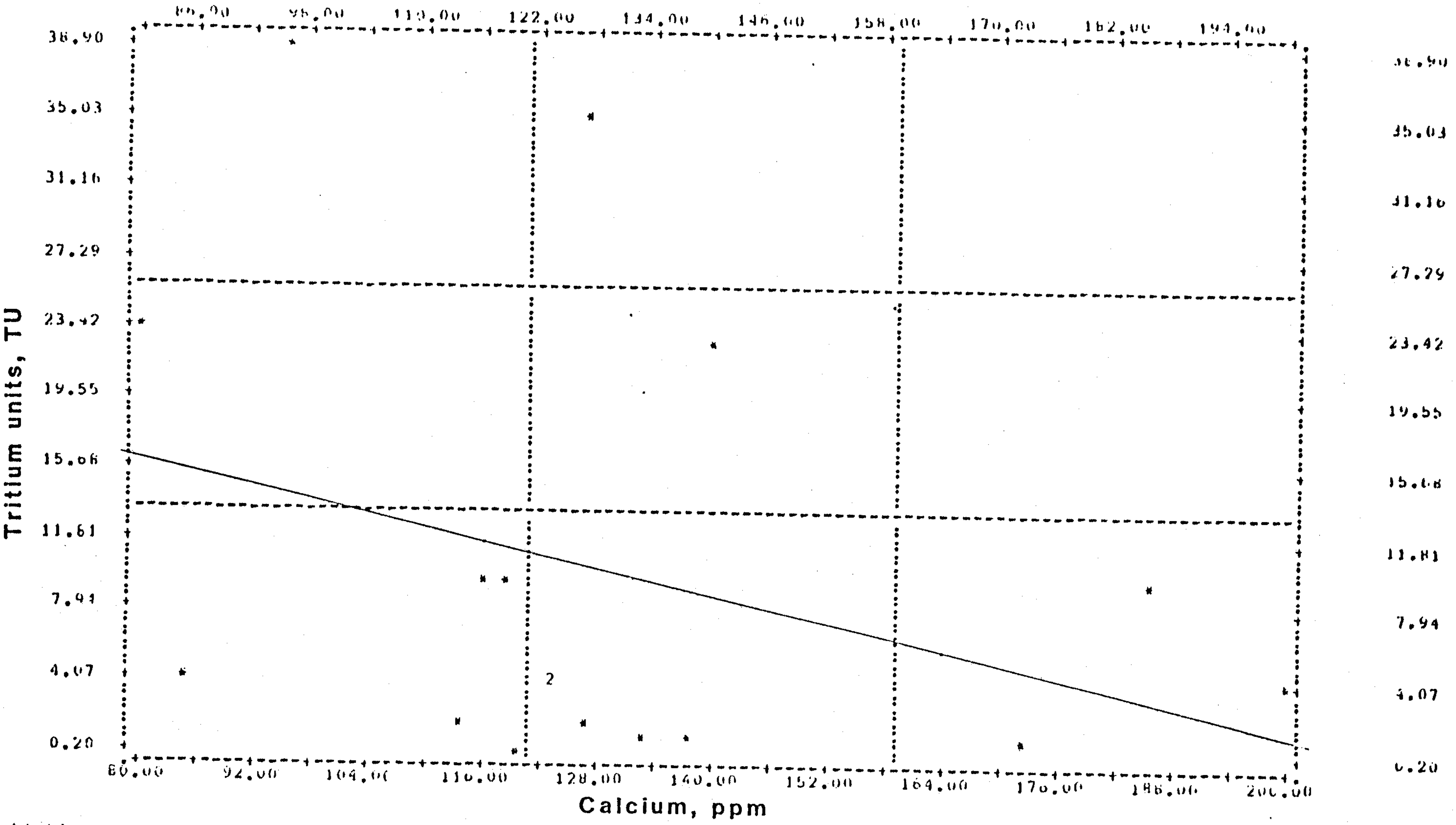
```
Statistics:
  Correlation (R)-      0.88364     R squared      -      0.78082     Significance    -      0.00000
  Std err of est -    350.70410     Intercept (a)  -   6668.12516     Slope (b)       -     52.01444
  Plotted values -     17           Excluded values-      0           Missing values  -      1
```

Figure 43



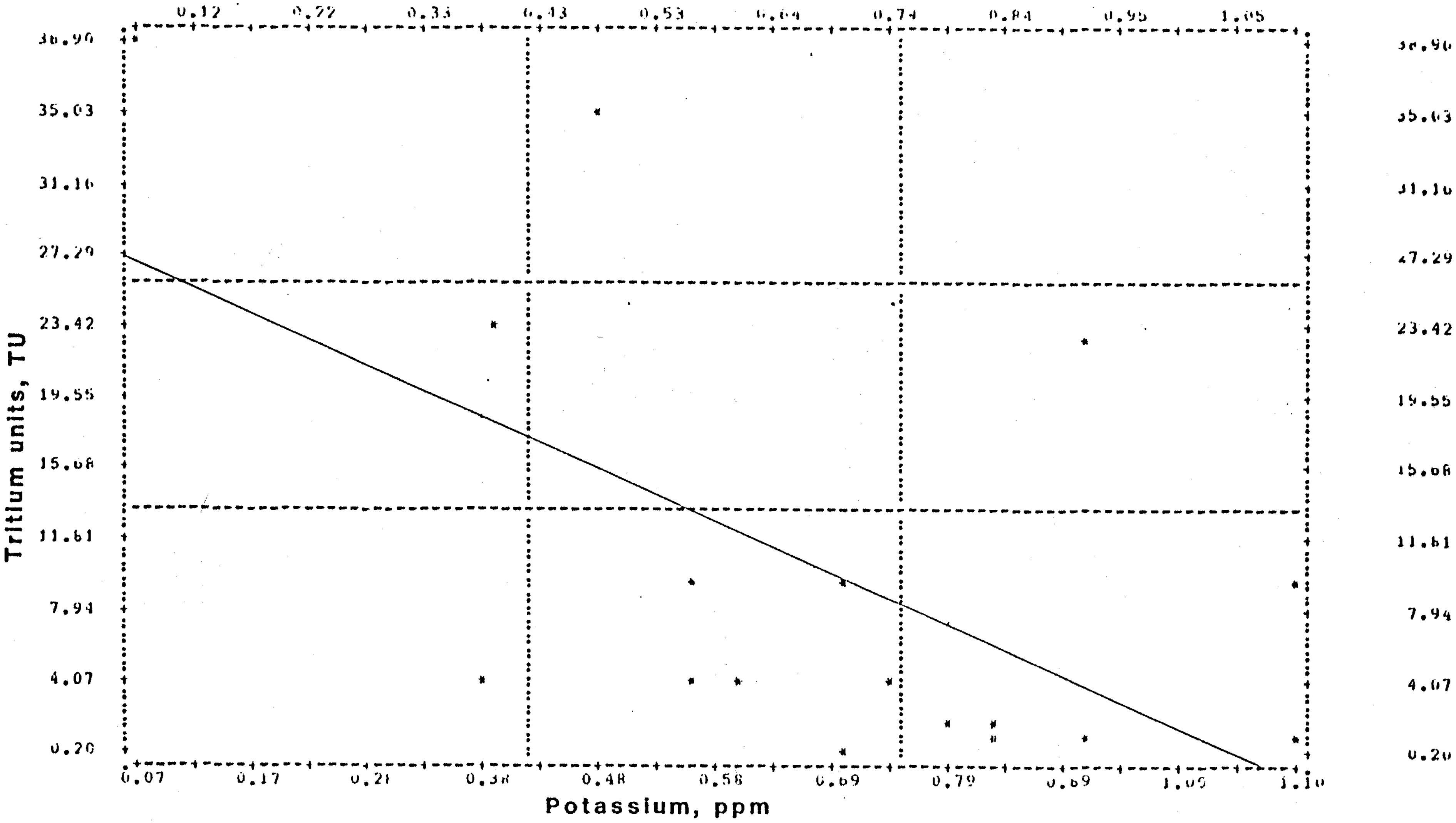
```
Statistics:
  Correlation (R)-        -0.44556     R squared       -        0.19852     Significance    -        0.03653
  Std err of est  -       11.39286     Intercept (a)   -       26.13340     Slope (B)       -       -0.36459
  Plotted values  -       17           Excluded values-         0           Missing values  -        1
```

Figure 44



```
Statistics:
  Correlation (R)-        -0.31095      R squared       -        0.09669      Significance   -        0.11221
  Std err of est -        12.09499      Intercept (a)   -       25.50673      Slope (b)      -       -0.11962
  Plotted values -        17            Excluded values-         0            Missing values -         1
```

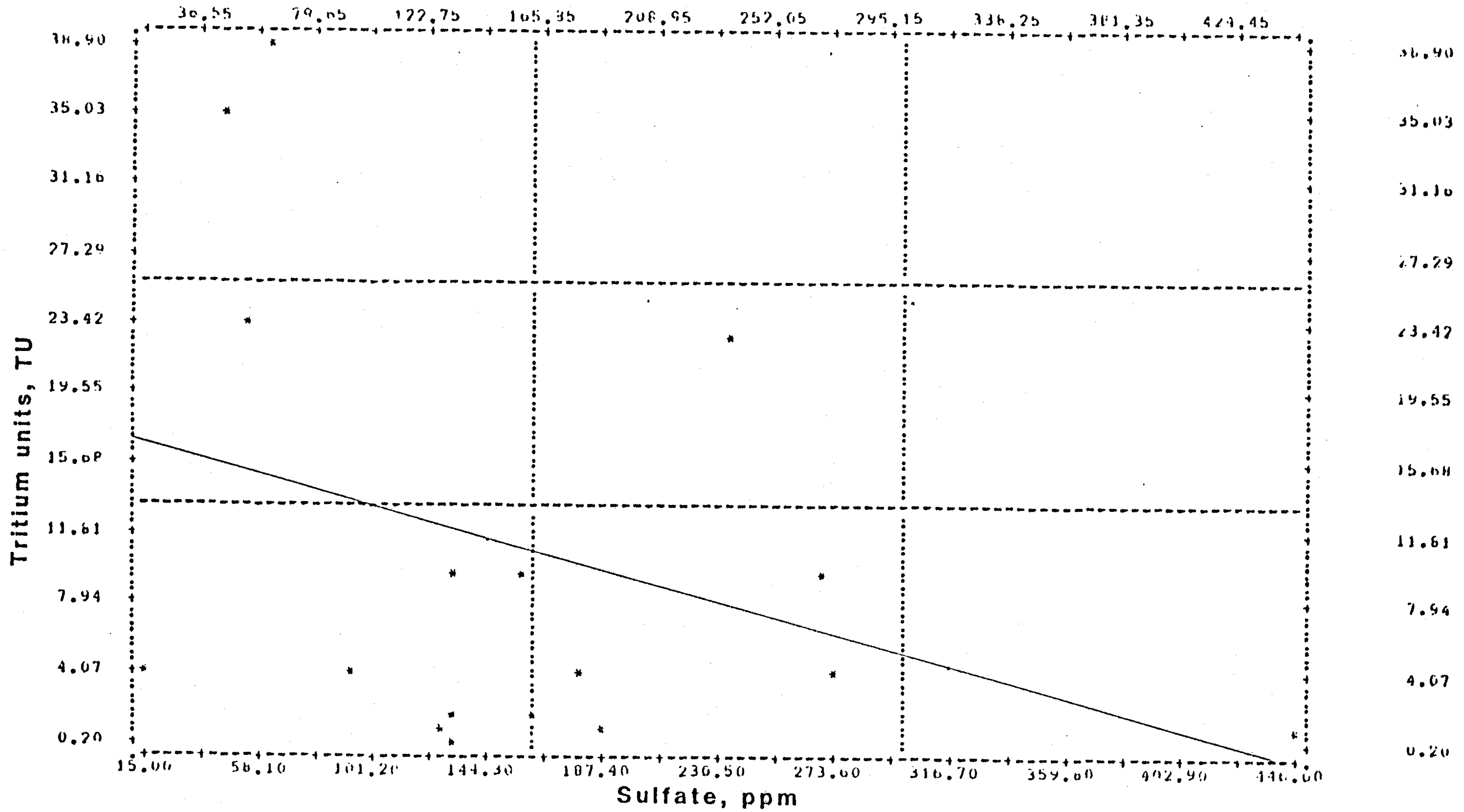
Figure 45



Statistics:

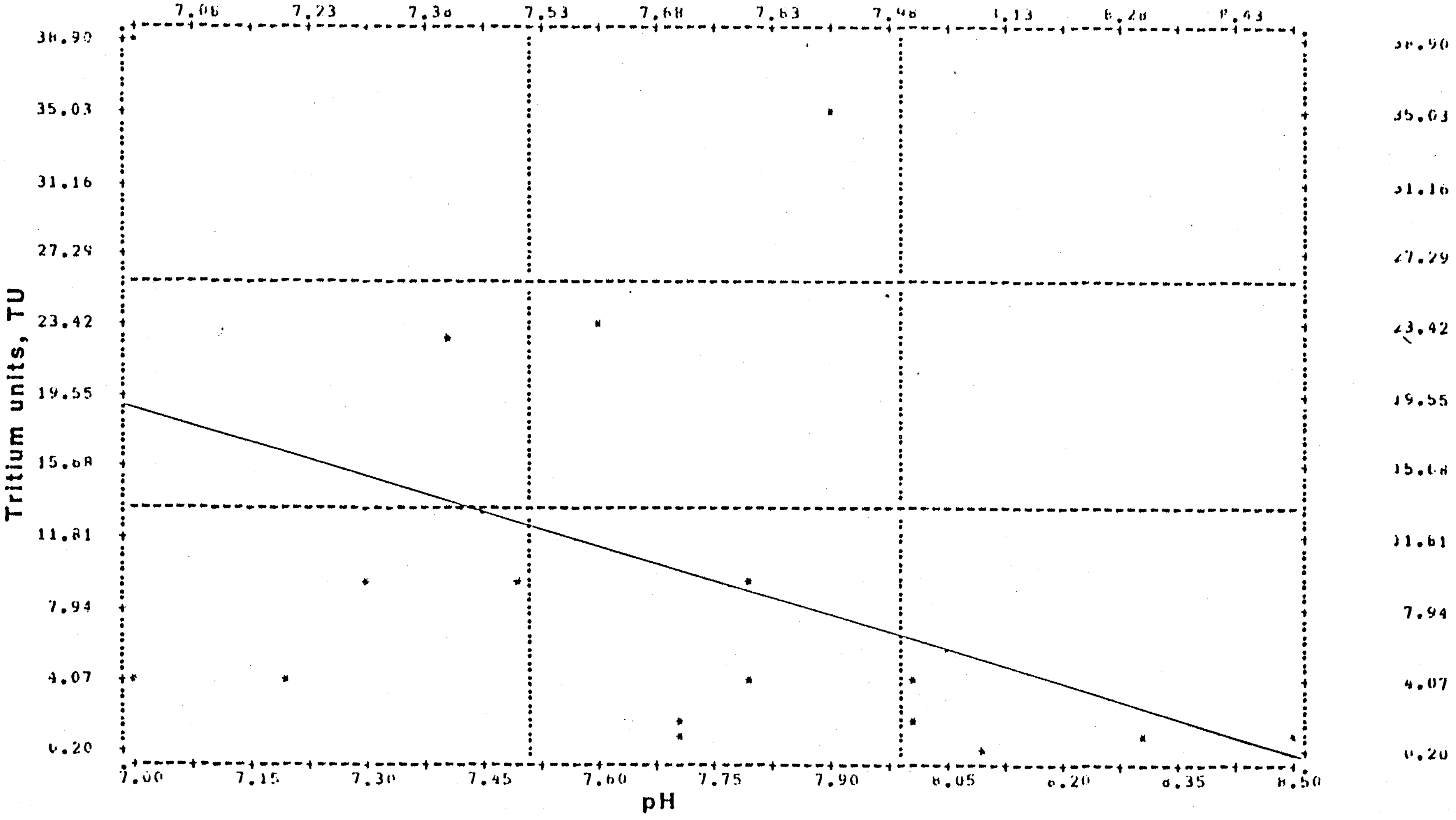
Correlation (R)-	-0.58886	R squared -	0.34675	Significance -	0.00044
Std err of est -	16.28553	Intercept (a) -	28.71940	Slope (b) -	-27.18957
Plotted values -	17	Excluded values-	0	Missing values -	1

Figure 46

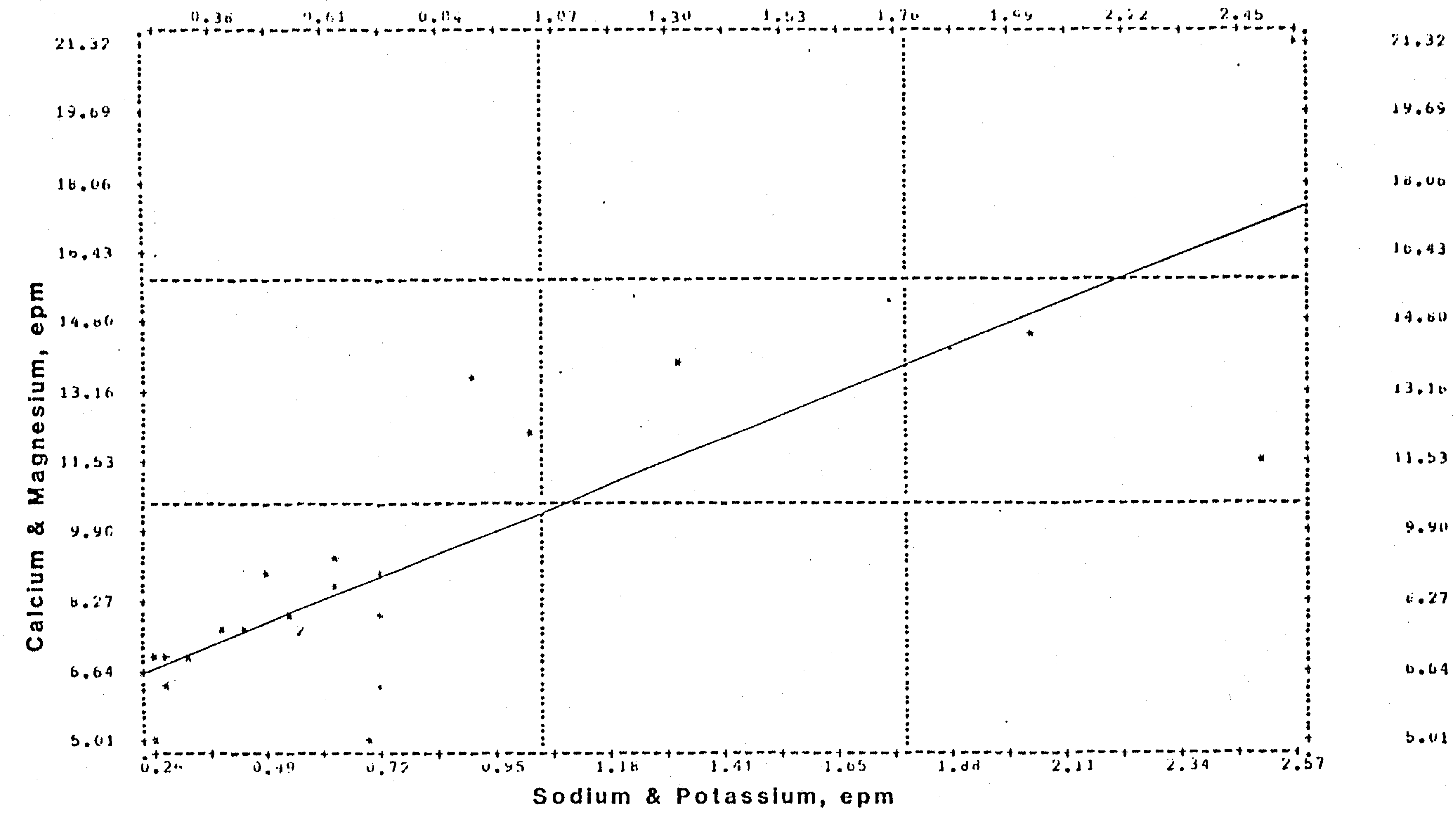


```
Statistics:
  Correlation (R)-       -0.37767     R squared       -        0.14263     Significance   -      0.06752
  Std err of est -       11.78370     Intercept (a)   -       17.11598     Slope (B)      -     -0.04446
  Plotted values -       17           Excluded values-         0           Missing values -      1
```

Figure 47

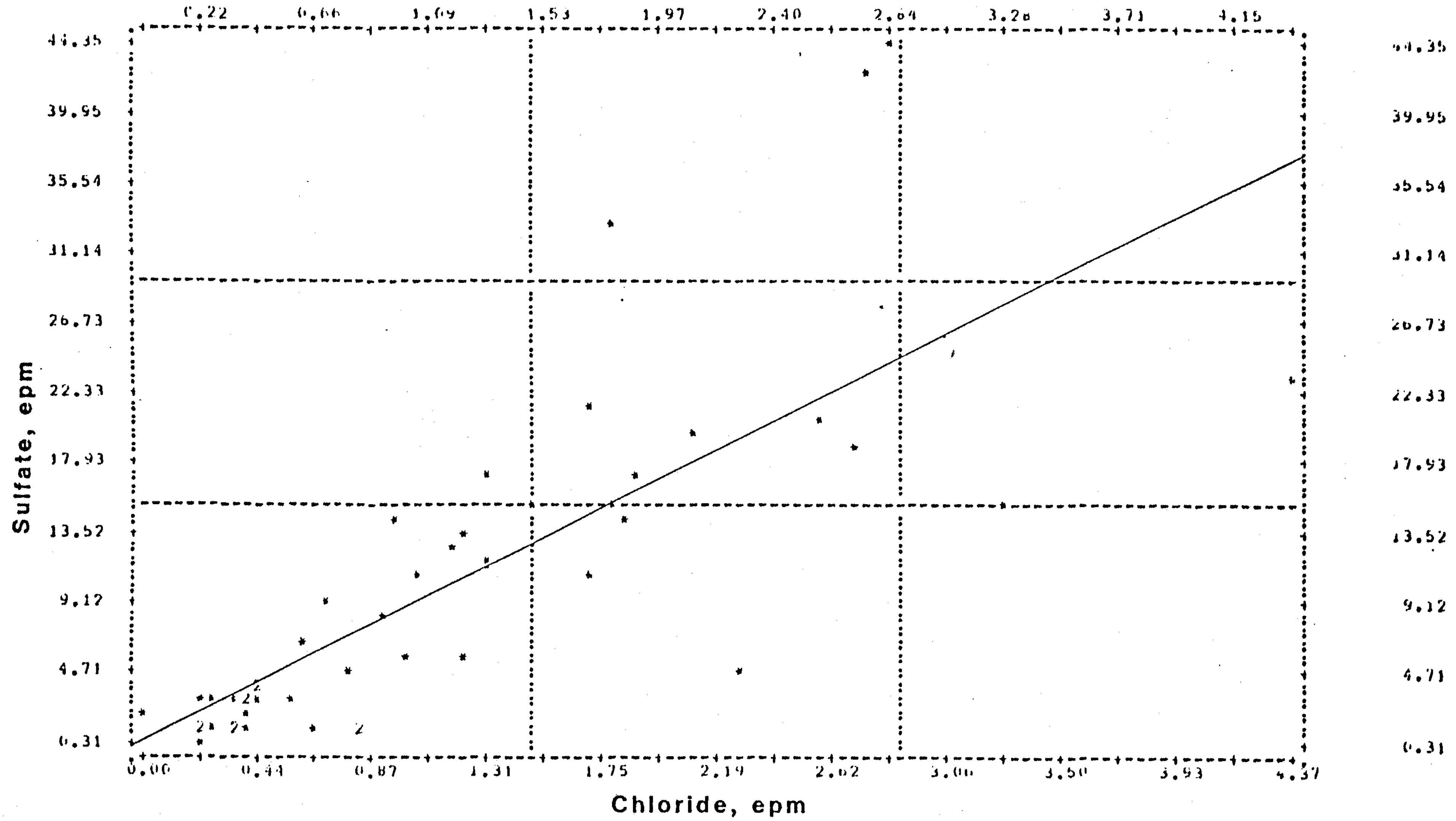


```
Statistics:
  Correlation (R)-      -0.41067     R squared      -      0.16865     Significance   -      0.05077
  Std err of est -      11.60325     Intercept (a)  -    101.66048     Slope (b)      -    -11.62590
  Plotted values -      17           Excluded values-      0           Missing values -      1
```



Statistics:

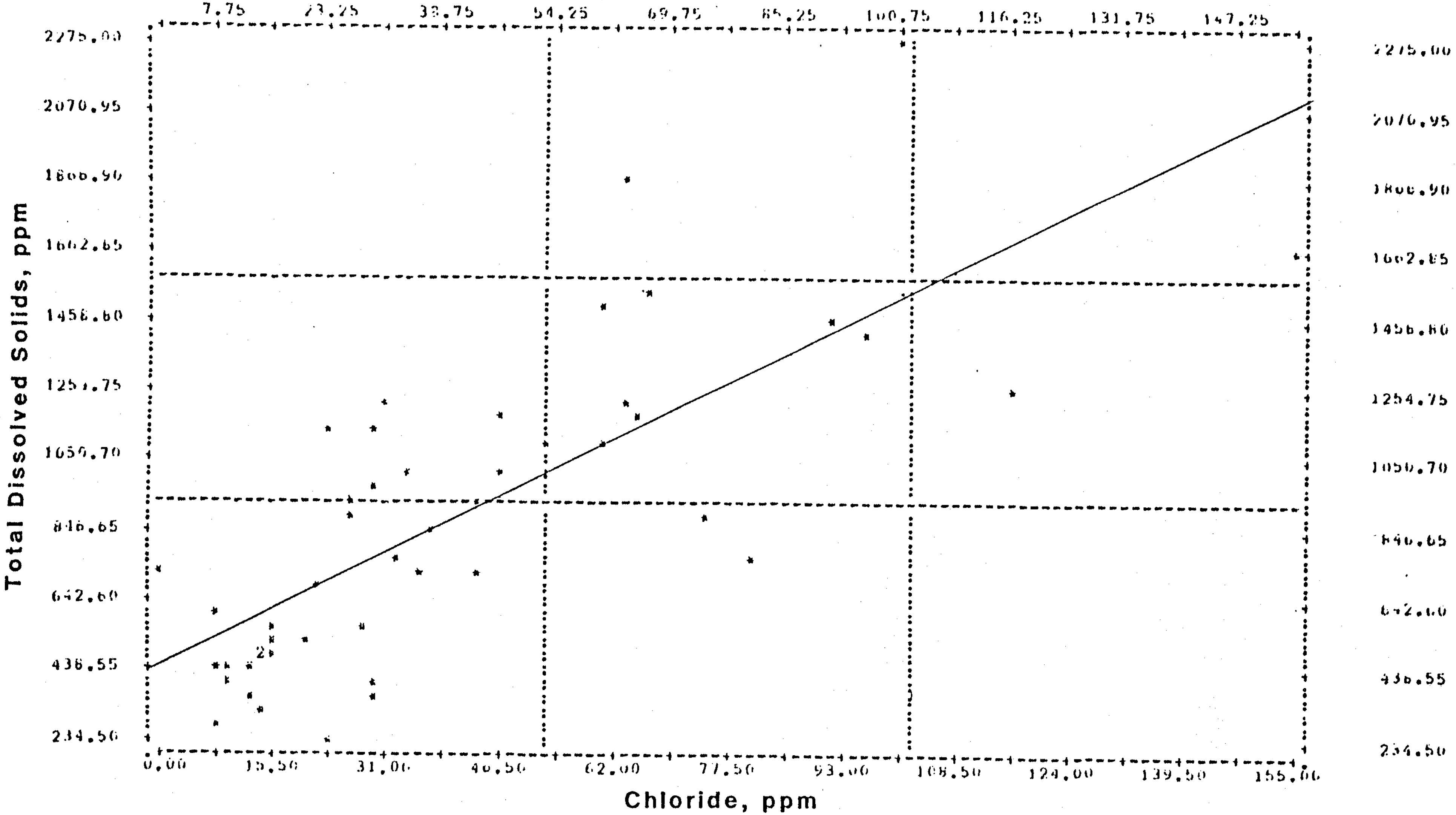
Correlation (R)-	0.82917	R squared -	0.68753	Significance -	0.00000
Std err of est -	2.13440	Intercept (a) -	5.42165	Slope (b) -	4.02593
Plotted values -	23	Excluded values-	0	Missing values -	27



Statistics:

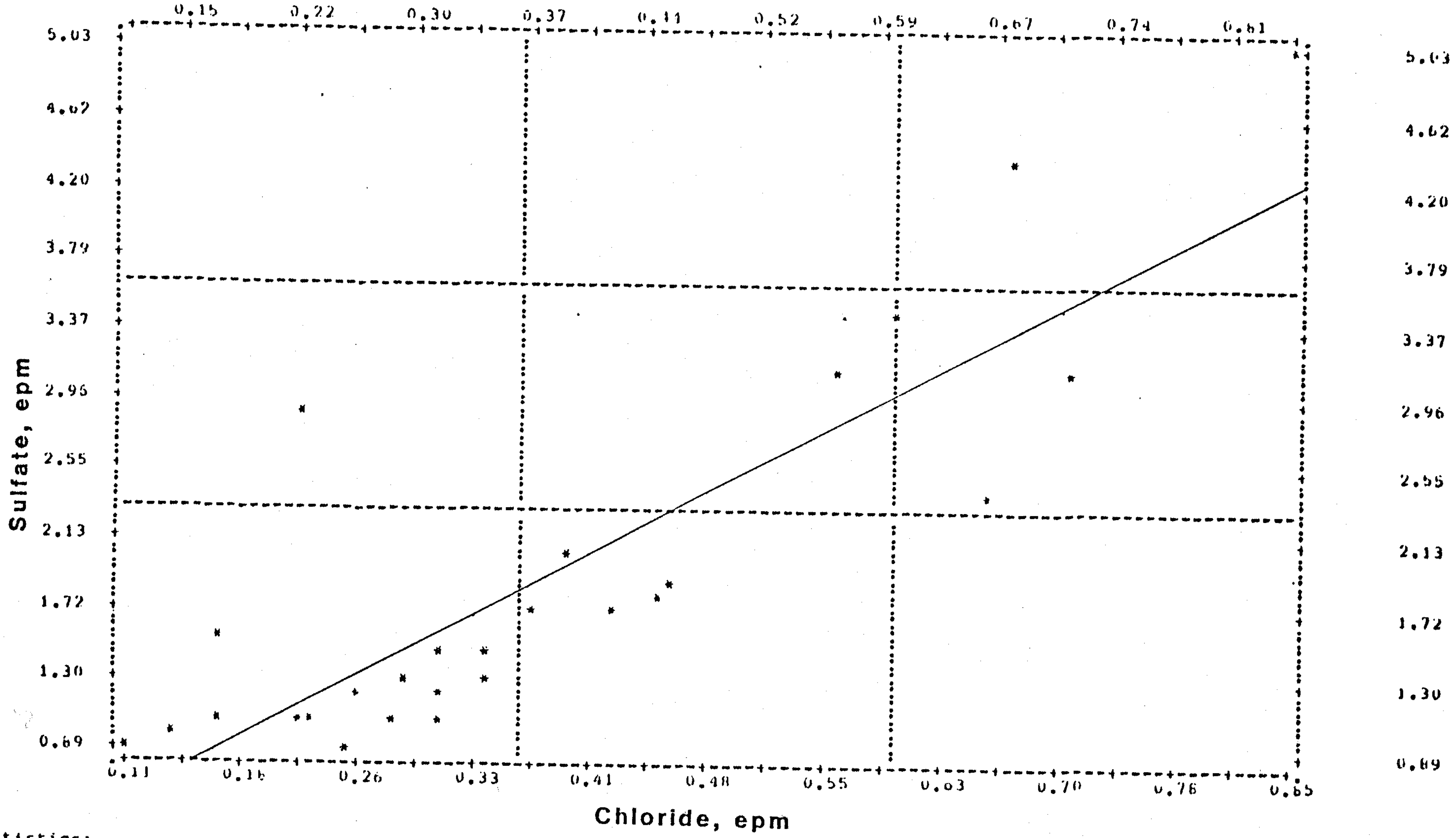
Correlation (R)-	0.77302	R squared -	0.59755	Significance -	0.00010
Std err of est -	6.65004	Intercept (a) -	0.29141	Slope (b) -	8.38203
Plotted values -	48	Excluded values-	0	Missing values -	2

Figure 50



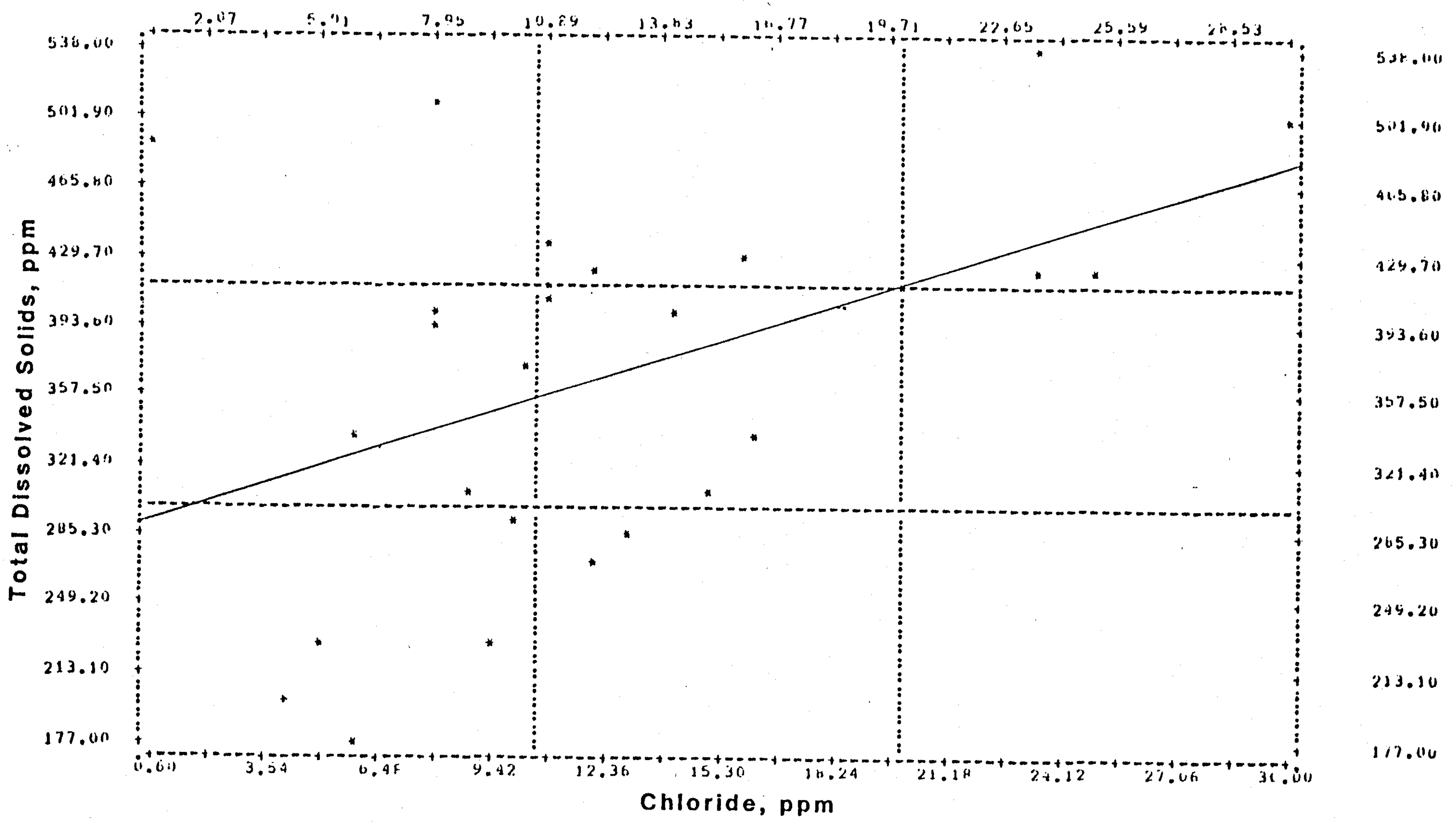
```
Statistics:
  Correlation (r)-        0.76846       R squared      -        0.59053     Significance   -        0.00000
  Std err of est -      291.75942       Intercept (a)  -      436.44314     Slope (b)      -       10.72389
  Plotted values -       46             Excluded values-        0         Missing values -        0
```

APPENDIX F: Scattergrams of chemical constituents and tritium activity in springs



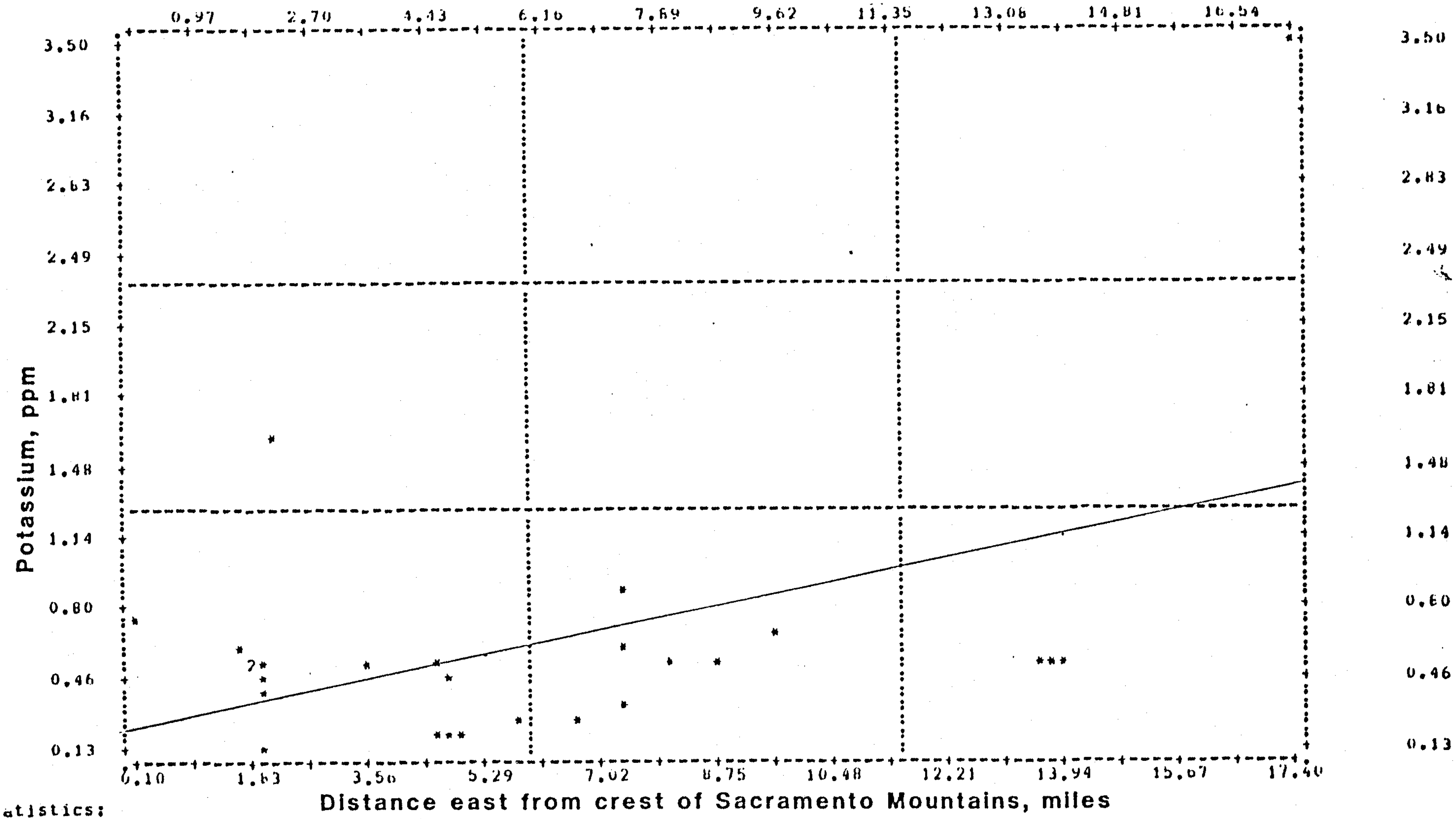
```
Statistics:
  Correlation (R)-        0.85805     R squared      -      0.73625     Significance    -     0.00000
  Std err of est -        0.56911     Intercept (a)  -      0.06255     Slope (b)       -     4.69111
  Plotted values -     27             Excluded values-      0           Missing values  -     0
```

Figure 59

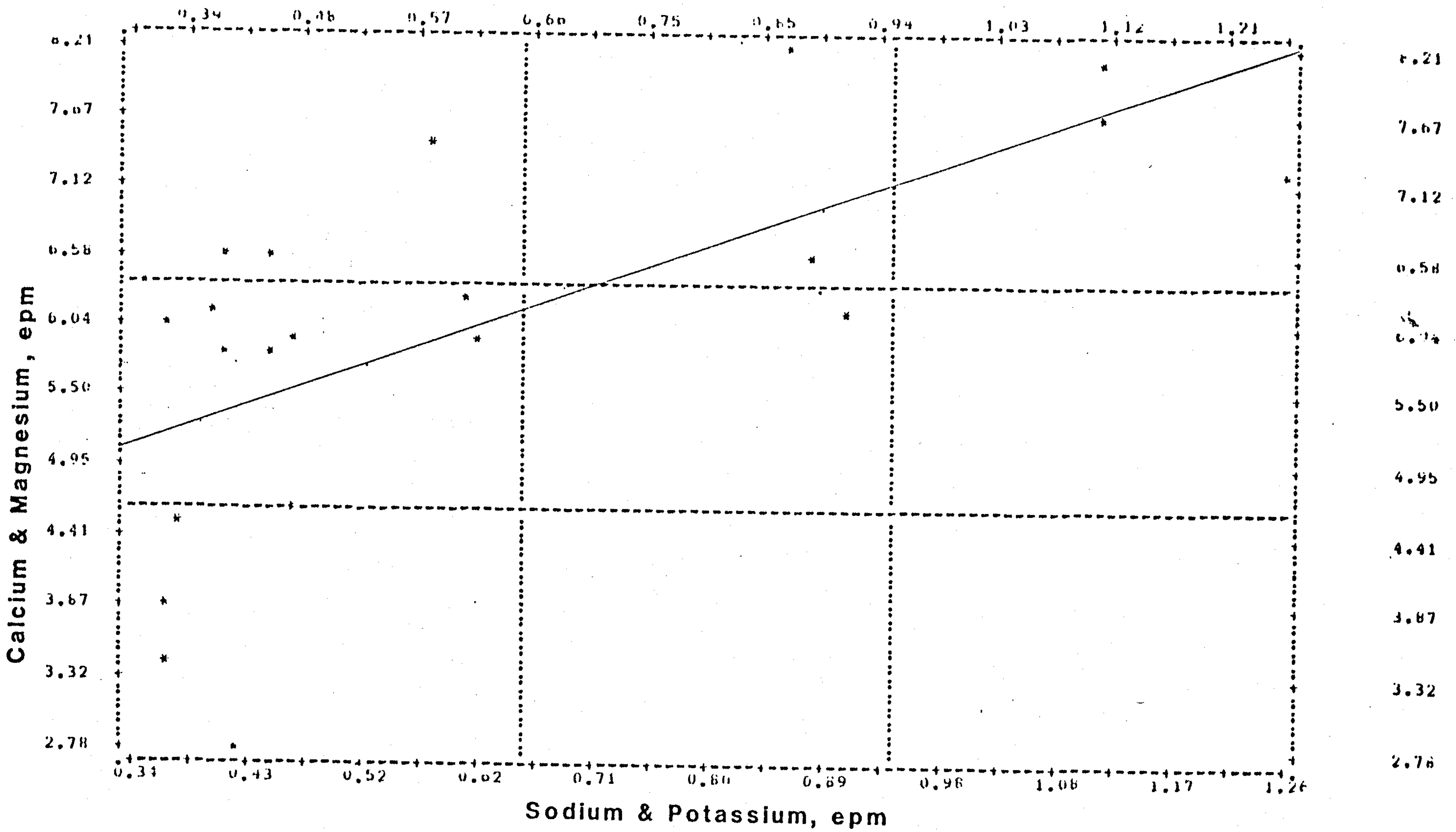


```
Statistics:
  Correlation (r)-        0.45361     R squared        -        0.20576     Significance   -        0.00674
  Std err of est -       67.97575     Intercept (a)  -      289.29735     Slope (b)      -        0.32360
  Plotted values -       27           Excluded values-        0           Missing values -        0
```

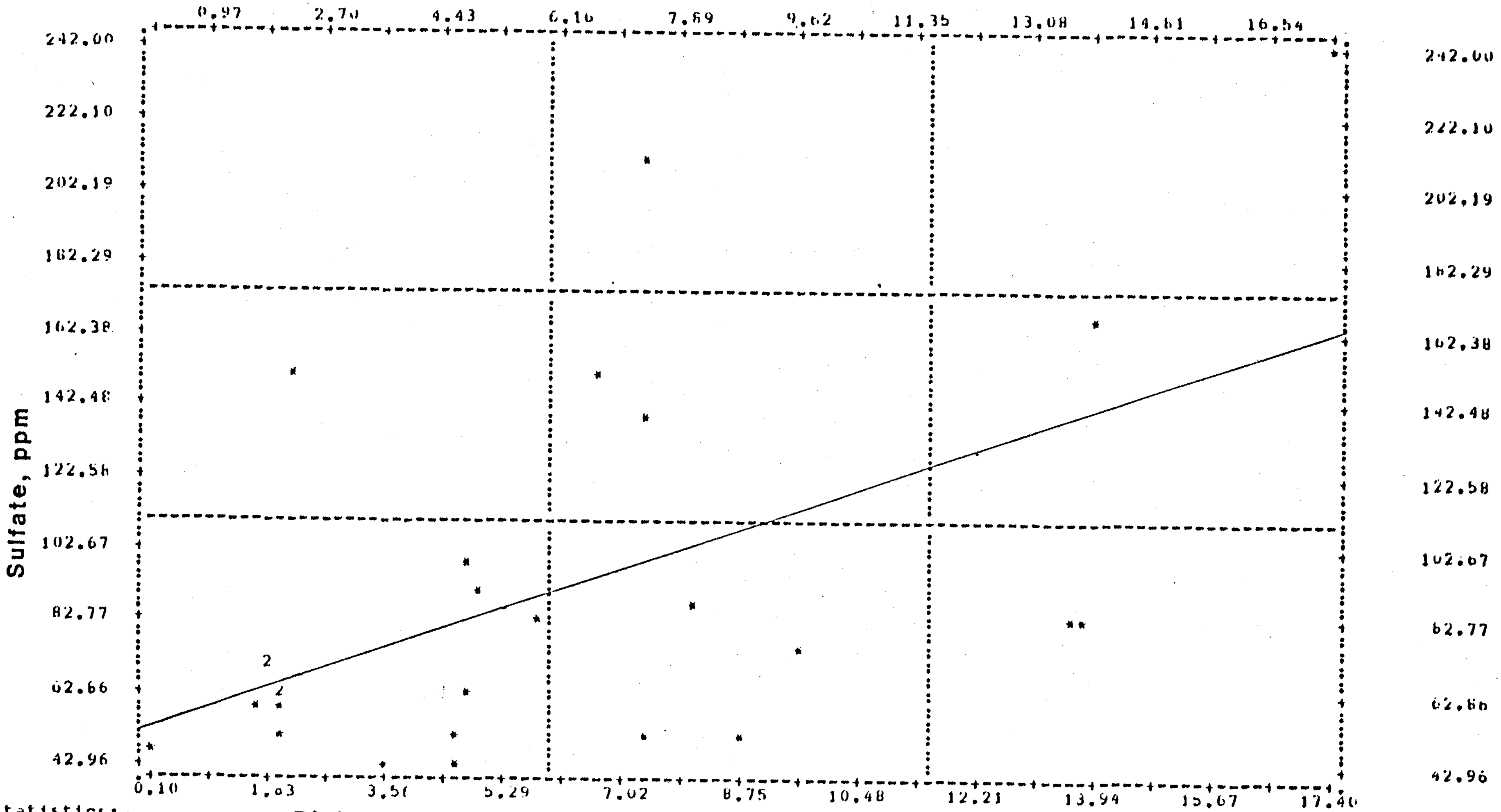
Figure 52



```
Statistics:
  Correlation (R)-        0.43608     R squared       -        0.19016      Significance    -        0.01149
  Std err of est -        0.58863     Intercept (a)   -        0.23723      Slope (b)       -        0.06230
  Plotted values -        27          Excluded values-         0            Missing values -         0
```

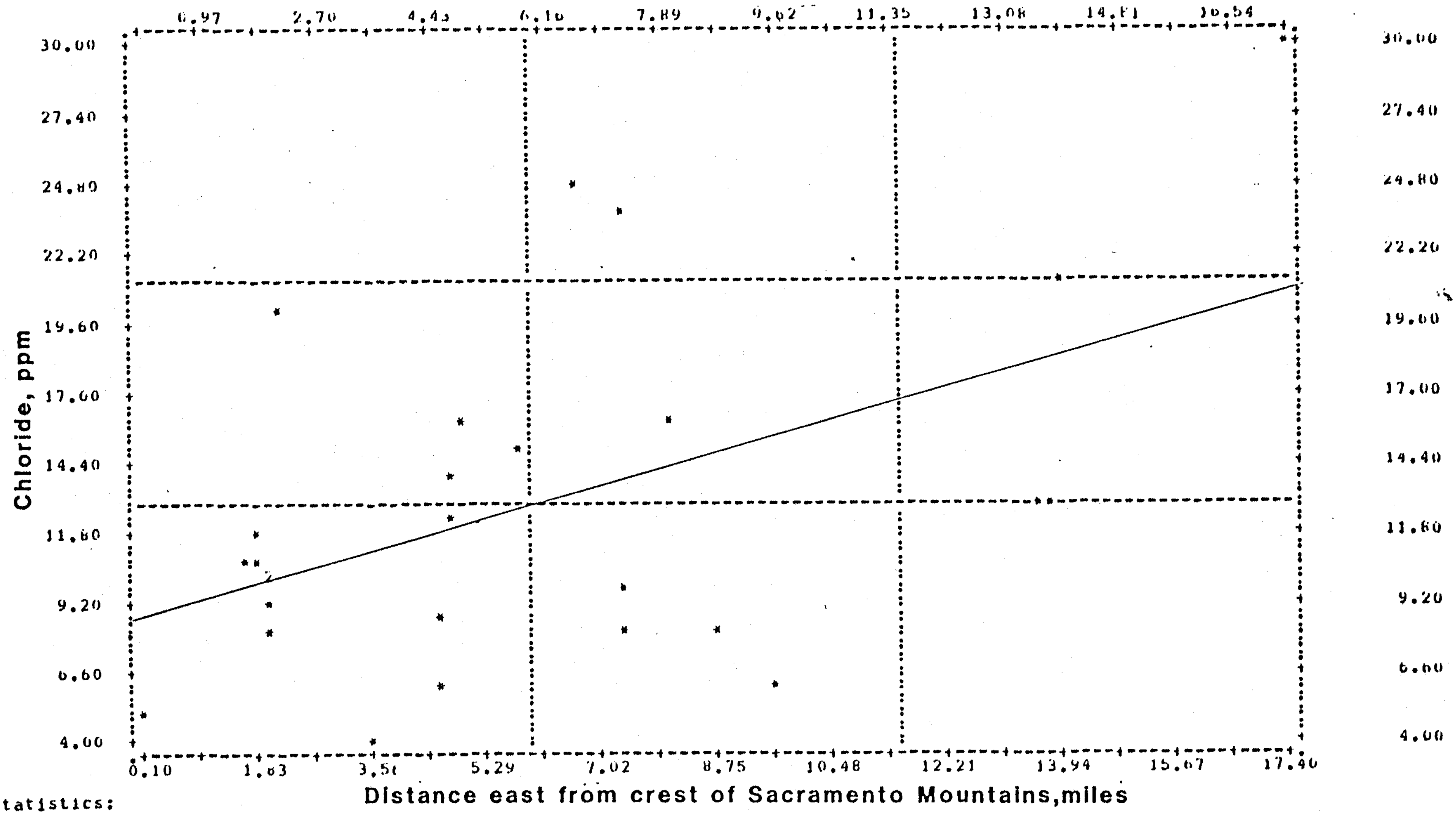


```
Statistics:
  Correlation (R)-        0.63341     R squared       -       0.40120     Significance   -       0.00076
  Std err of est  -       1.13552     Intercept (a)   -       4.08299     Slope (b)      -       3.18912
  Plotted values  -       22          Excluded values-        0           Missing values -       5
```

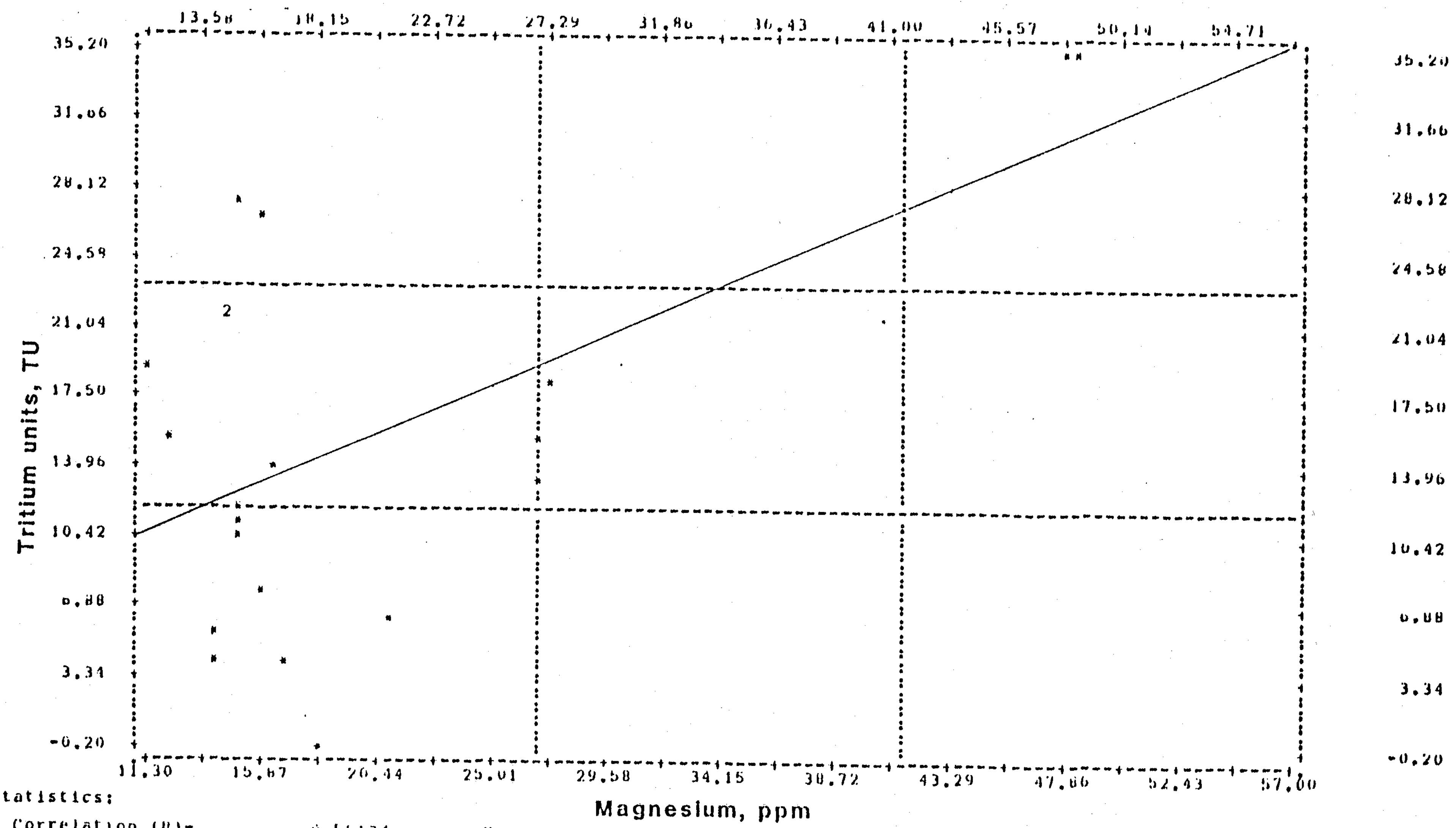


```
Statistics:
  Correlation (R)-      0.55014     R squared        -      0.30265     Significance    -      0.00147
  Std err of est -     44.26009     Intercept (a)    -     52.65043     Slope (b)       -      6.30662
  Plotted values -      27          Excluded values-        0           Missing values  -      0
```

Figure 56

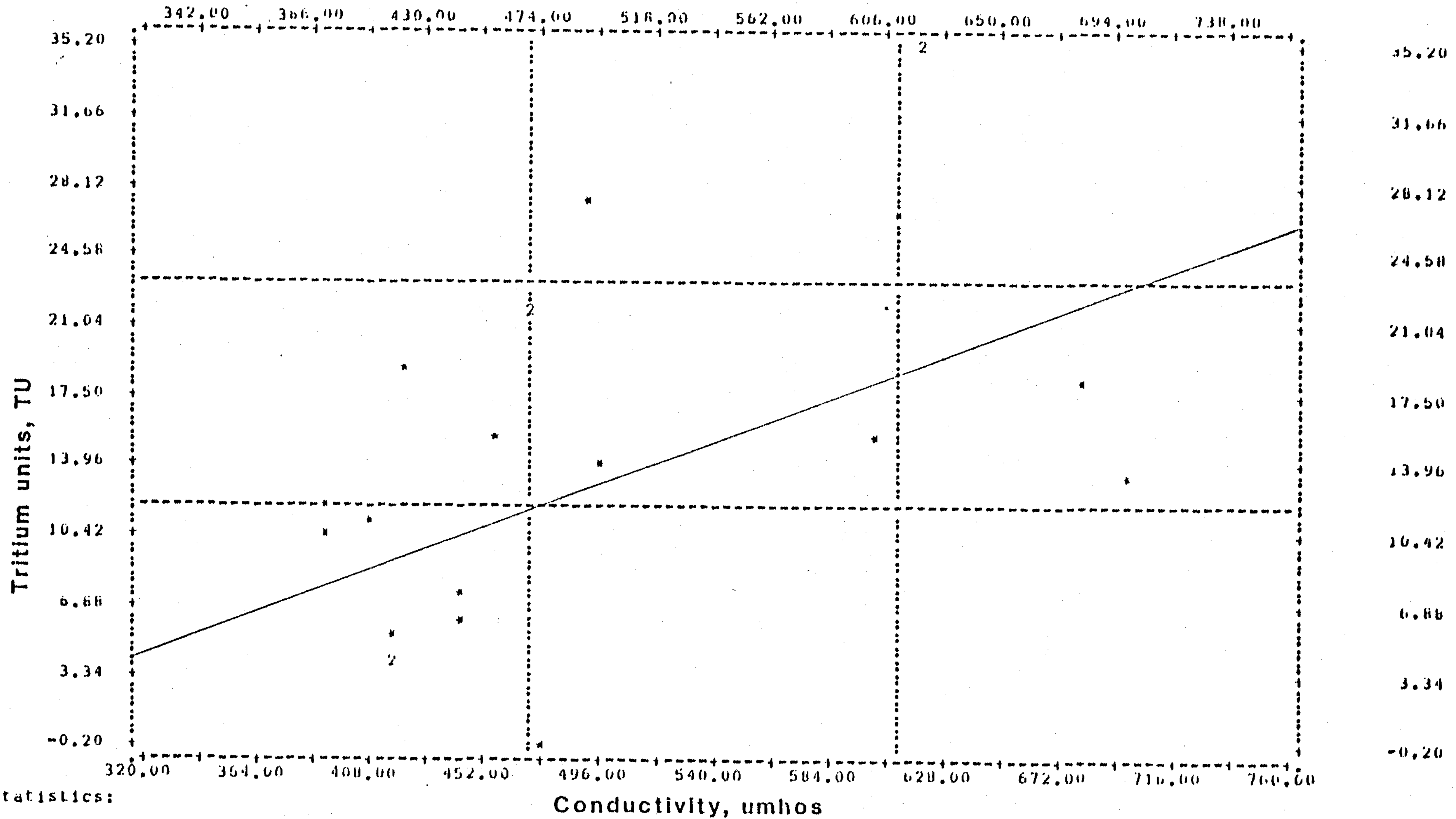


```
Statistics:
  Correlation (R)-       0.49305    R squared       -     0.24310    Significance   -     0.00449
  Std err of est -       5.70257    Intercept (a)   -     8.58638    Slope (b)      -     0.70586
  Plotted values -       27         Excluded values-      0          Missing values -     0
```



```
Statistics:
  Correlation (R)-        0.56134     R squared       -        0.33796      Significance    -        0.00265
  Std err of est -        8.23658     Intercept (a)   -        4.30275      Slope (b)       -        0.55186
  Plotted values -        21          Excluded values-         0            Missing values  -        6
```

Figure 58



```
Statistics:
  Correlation (R)-       0.54916     R squared        -       0.30191     Significance    -       0.00494
  Std err of est -       8.45992     Intercept (a)    -     -11.09374     Slope (B)       -       0.05495
  Plotted values -      21           Excluded values-         0           Missing values  -       0
```

Figure 59