GEOHYDROLOGY
OF
FISH LAKE VALLEY

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(4733A)

INTRODUCTION

AMAX Exploration, Inc. formed a Federal geothermal Unit in 1981 covering approximately 18,955.6 acres. Of the total acreage AMAX held 13,253.7 and Magma Power Company controls the remainder of the lands within the Fish Lake Geothermal Unit. Magma Energy controls geothermal leases to the east which are adjacent to the Fish Lake Unit. The unit was defined on the basis of fourteen (14) shallow thermal gradient holes from 16 to 70 meters deep. The thermal gradients (increase in temperature with depth) ranged from 40°C/Km to over 1800°C/Km. The thermal anomaly was used to define the boundaries of the geothermal unit. The bulk of the lands within the unit are Federal lands managed by the BLM.

GEOLOGIC SETTING

The gross geological features of the Fish Lake Valley are shown in Figure 1 (after Rush and Katzer (1973)). The generalized geologic features consist of alluvial valley fill of Tertiary and Quaternary age and consolidated bedrock in the areas of the Volcanic Hills, the Silver Peak Mountains and the White Mountains. Approximately 40 square miles in the southern end of the Volcanic Hills (Fig. 2) have been mapped by AMAX in a preliminary way. The regional geology has been described by Albers and Stewart (1972) in a report published by the Nevada Bureau of Mines and Geology. The Fish Lake geothermal prospect is located on the southern flank of the Volcanic Hills approximately 20 Km (12 miles) north of Dyer.

The dominant rock type exposed in the prospect (Fig. 2) is a series of Rhyolitic ash-flow tuffs. The volcanic rocks which cap most of the hills in the area are moderately to strongly welded while the underlying unit is only partly welded. The ash flow tuffs are made up of crystal fragments of quartz, plagioclase feldspars, sanidine feldspar and biotite which comprise 10 to 30 percent of the rock. Lithic fragments of ash-flow tuff, banded rhyolite lava flows, and quartzite which constitute

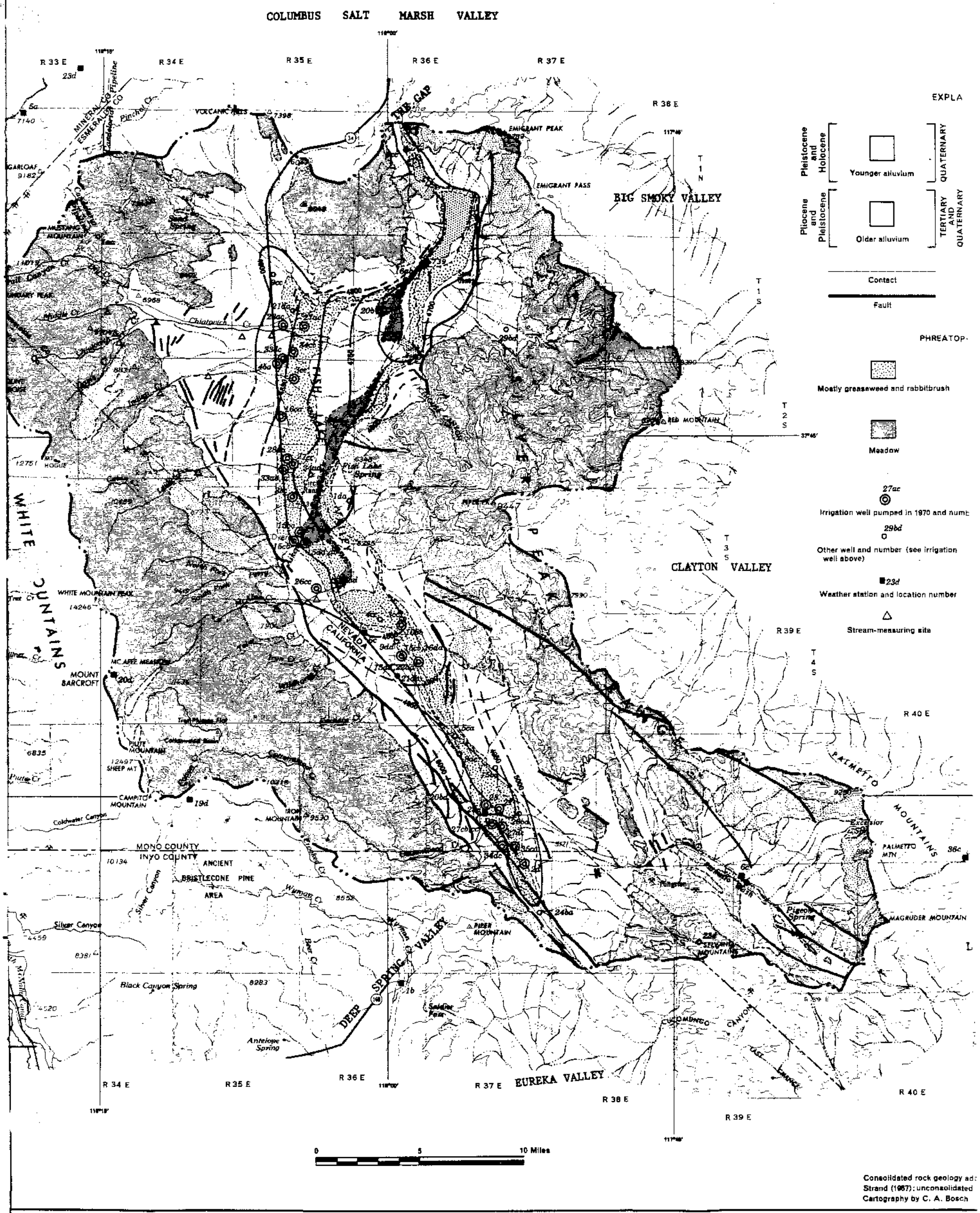


Figure 1. —GENERALIZED HYDROGEOLOGY OF FISH LAKE VALLEY, NEVADA AND CALIFORNIA

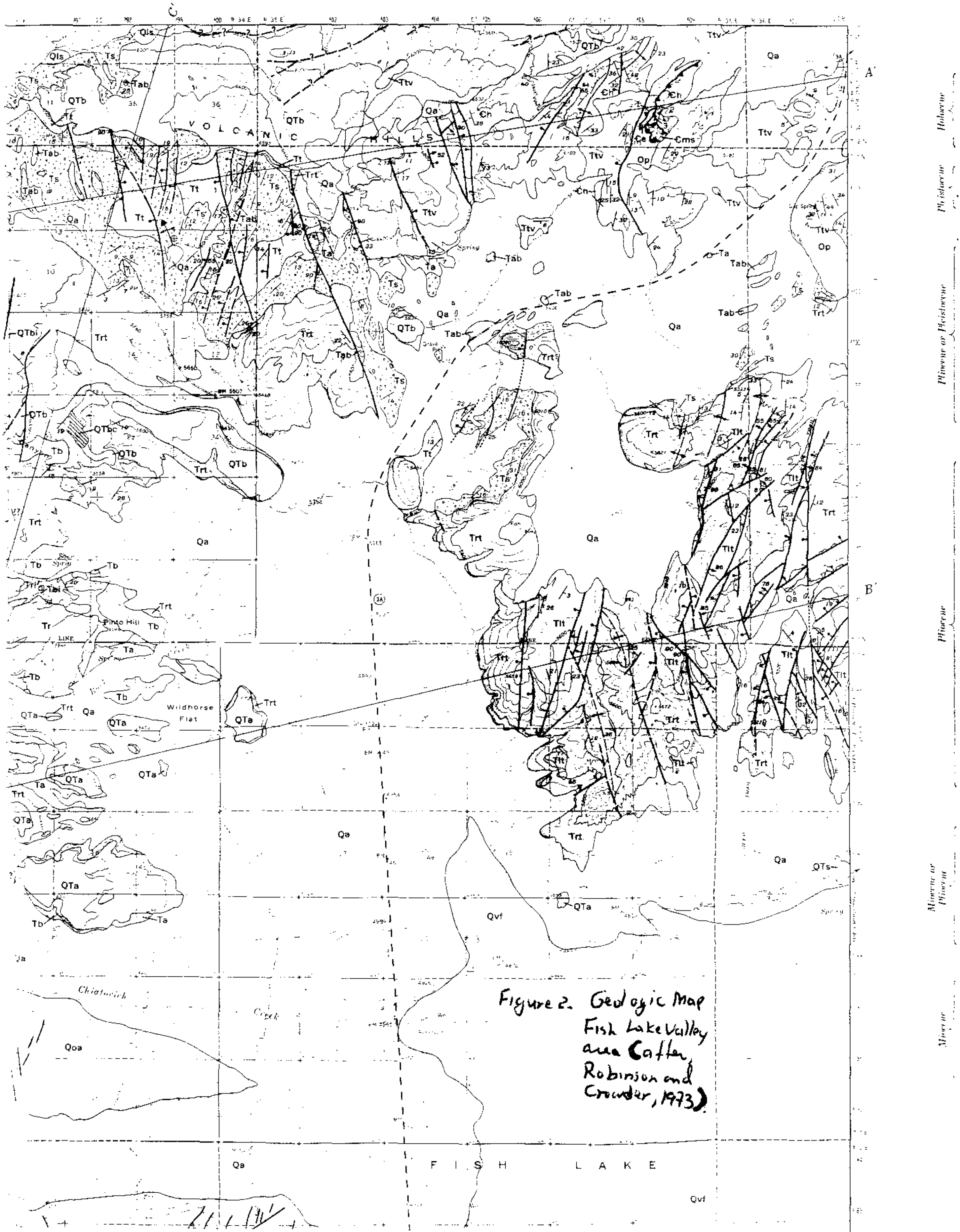


Figure 2. Geologic Map Fish Lake Valley area (after Robinson and Crowder, 1973).

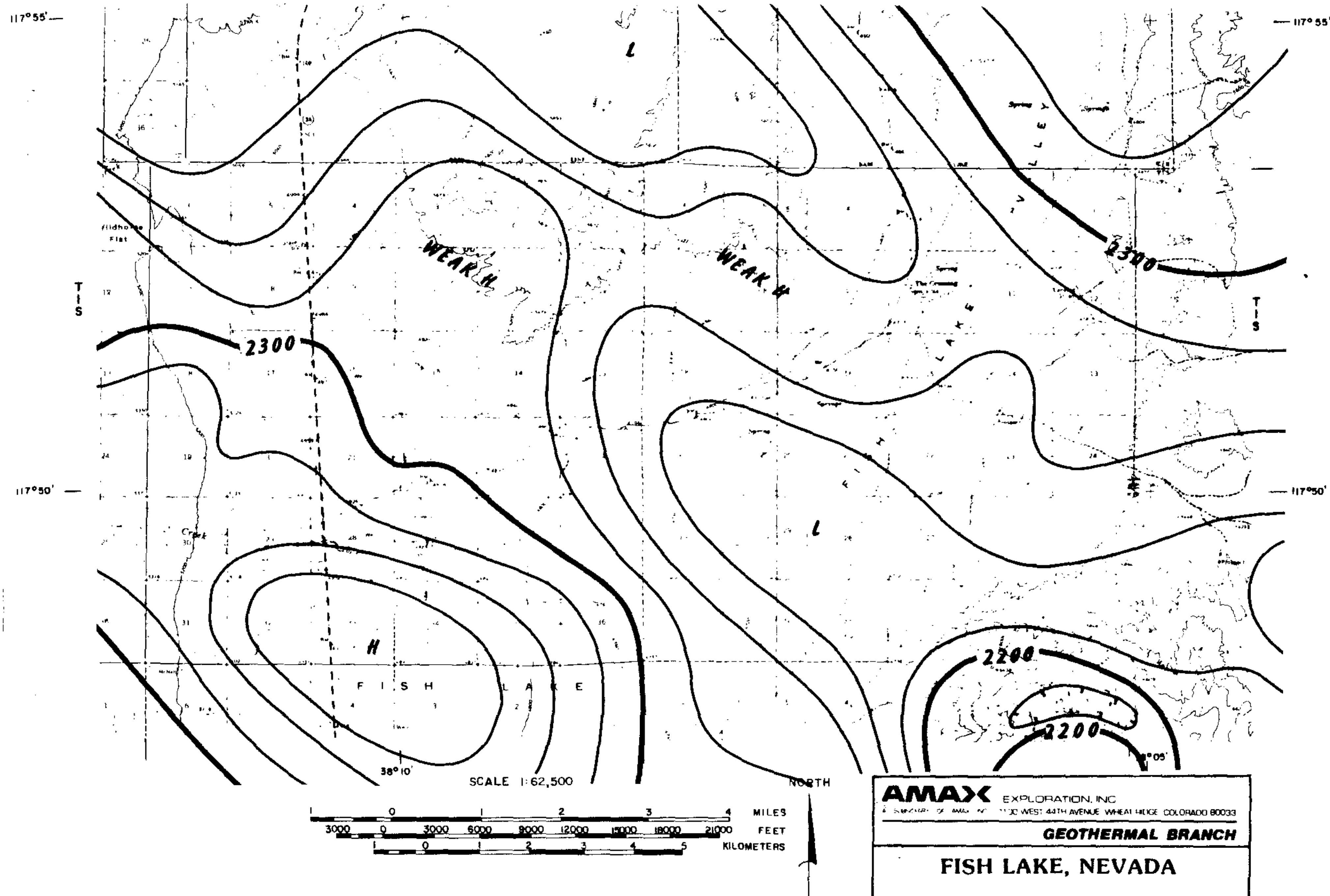
10 to 40 percent of the rock. The remainder of the rock is made up of a matrix of volcanic ash. The volcanic rocks are hydrothermally (hot water) bleached, altered and silicified over a large area. In the bleached rocks, the glass of the matrix is partially altered to clays, probably mixed kaolinite and montmorillonite. In areas of sulfur and mercury mineralization, Secs. 11 and 14, T1S, R35E, the alteration is more intense and includes argillic (clay) minerals, alunite, opalite, chalcedony and crystalline quartz. The alteration and mineralization could be either of sulfataric, fumerolic or hydrothermal in origin

GEOPHYSICAL STUDIES

As a part of AMAX's geothermal exploration in the Fish Lake area a series of geophysical studies were undertaken. The published aeromagnetic map of the area GP-753(1971) shows a strong northwest trend extending from the Silver Peak Mountains northwest into the Fish Lake area (Fig. 3). The west-northwest trend probably reflects the structural grain of the Lower Paleozoic rocks in this part of Nevada (Albers and Stewart, 1972).

Figure 4 is a simple Bouguer gravity map of the Fish Lake area. The map is based upon approximately 60 data points from the literature (Healey et al 1980) and about 60 more date points collected by AMAX. The map shows the same west-northwest trending structural grain seen on the aeromagnetic map. The thermal anomaly coincides with the east-northeast trending gravity high in the center of the map area.

In March of 1982 AMAX contracted a magnetotelluric survey at the Fish Lake prospect. The resistivity values obtained by the MT survey for the rocks at depths of 500 and 1000 meters agree well with the values from the electrical logs for well 81-44, 42-7 and VRS#1. The low resistivities are related to the altered clay rich volcanics and do not represent geothermal fluids.



AMAX EXPLORATION, INC

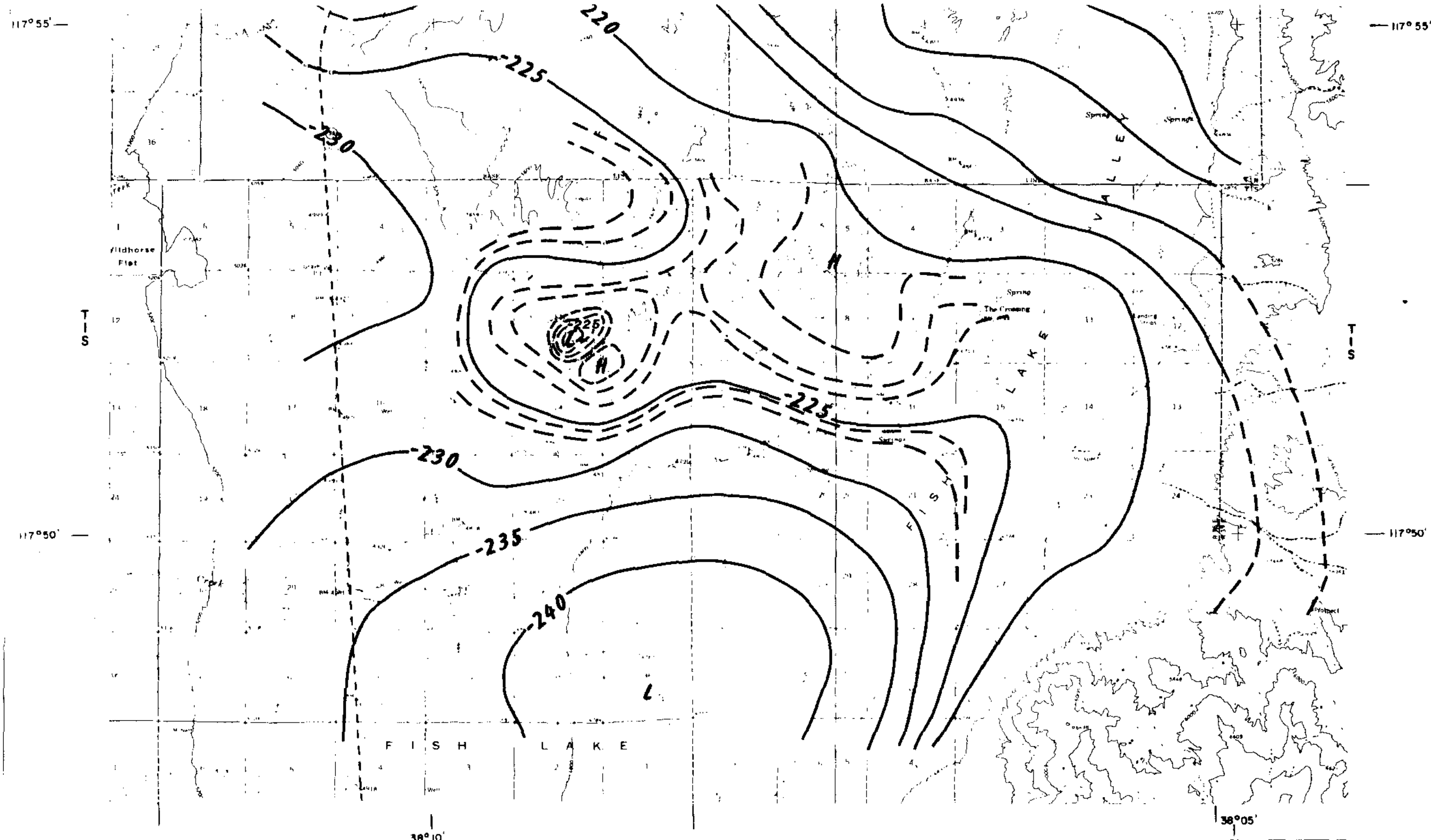
GEOTHERMAL BRANCH

FISH LAKE, NEVADA

AEROMAGNETICS

FIGURE 3

SOURCE:	DRWN. BY:	DATE:



SCALE 1:62,500

1 0 1 2 3 4 MILES

3000 0 3000 6000 9000 12000 15000 18000 21000 FEET

1 0 1 2 3 4 5 KILOMETERS

NORTH

AMAX EXPLORATION, INC.

A SUBSIDIARY OF AMAX INC. 7100 WEST 44TH AVENUE, WHEAT RIDGE, COLORADO 80033

GEOTHERMAL BRANCH

FISH LAKE, NEVADA

SIMPLE BOUGUER MAP

FIGURE 4

SOURCE: DRWN. BY: DATE:

EXPLORATION DRILLING

A total of nine (9) intermediate depth thermal gradient holes have been drilled in the Fish Lake area since the formation of the geothermal unit. AMAX drilled four (4) holes which ranged from approximately 300 to 700 meters deep and Magma Energy drilled five (5) holes ranging from 183 to 308 meters deep.

The intermediate depth thermal gradient holes have provided important data on the litholigic characteristics of the Tertiary rocks and established the presence of at least two (2) shallow low temperature reservoirs. A large area to the east and northeast and a small area to the south of the termal anomaly are underlain by a reservoir of warm waters with temperatures of 40-50°C. Within the main part of the thermal anomaly a shallow geothermal reservoir at about 160°C has been encountered.

The thermal gradients in the intermediate depth holes substantiate the presence of the shallow geothermal reservoirs. The depth-temperature curves may go isothermal (Fig. 5) through the reservoir then continue as a normal conductive gradient. Another common feature seen on the depth-temperature curves (Fig. 5) is a roll-over indicative of outflow of thermal waters over rocks of lower temperatures, or may they represent an inflow of cold water.

This thermal gradient data and the lithologic data from the intermediate depth thermal gradient holes provide some understanding of the geothermal hydrology of the area. The widespread shallow warm water reservoir (40-50°C) appears to be confined to rocks of the Lower Esmeralda Formation (Fig. 2) where two or more layers appear to have good lateral porosity and permeability. The heat flow map (Fig. 6) of Fish Lake Valley shows how the warm waters (40-50°C) have spread northward, eastward and to a much smaller extent southward from the center of the thermal anomaly. The lateral flow is confined to the one or two layers

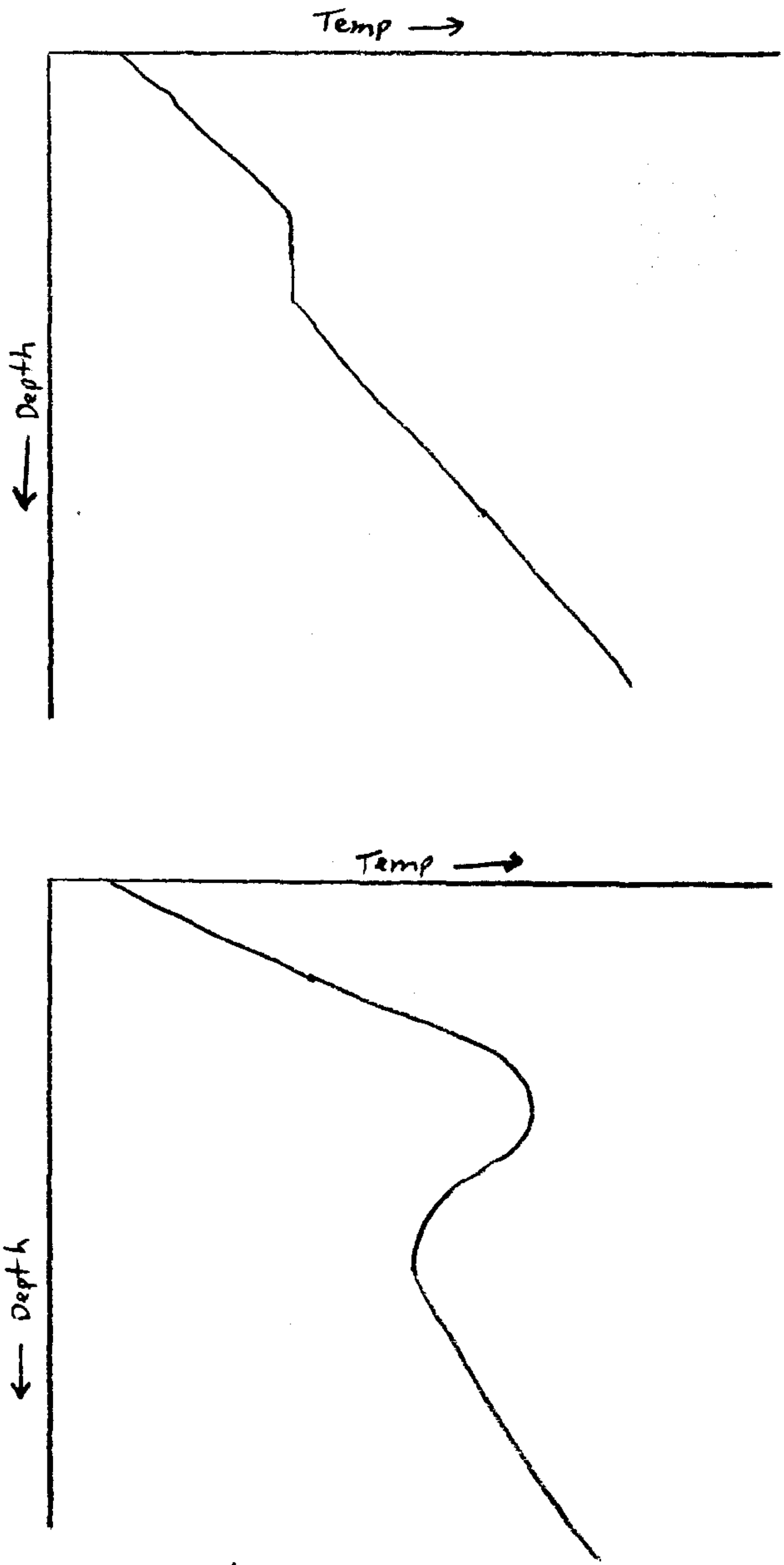


Figure 5. Typical depth-temp curves

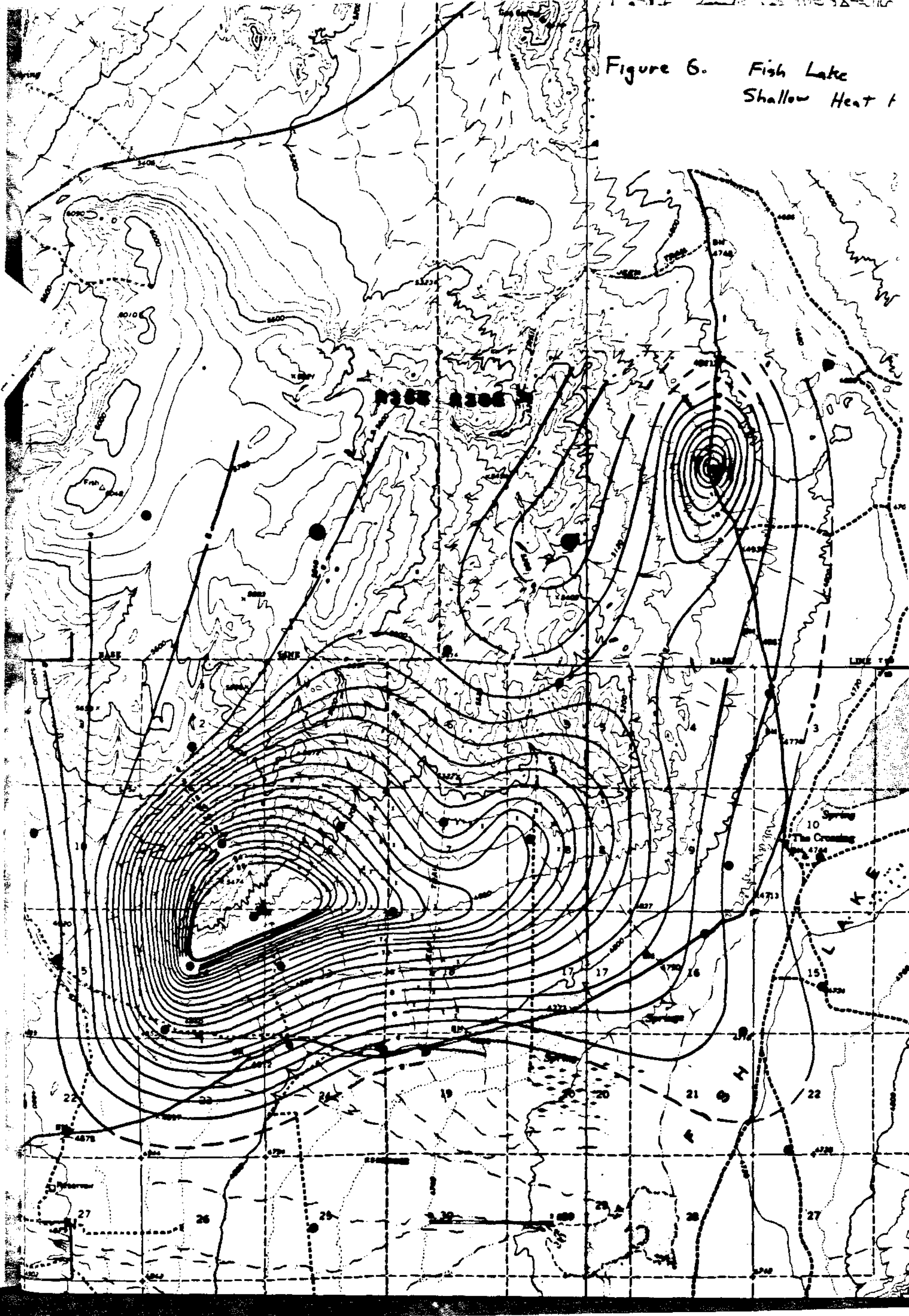


Figure 6. Fish Lake
Shallow Heat F

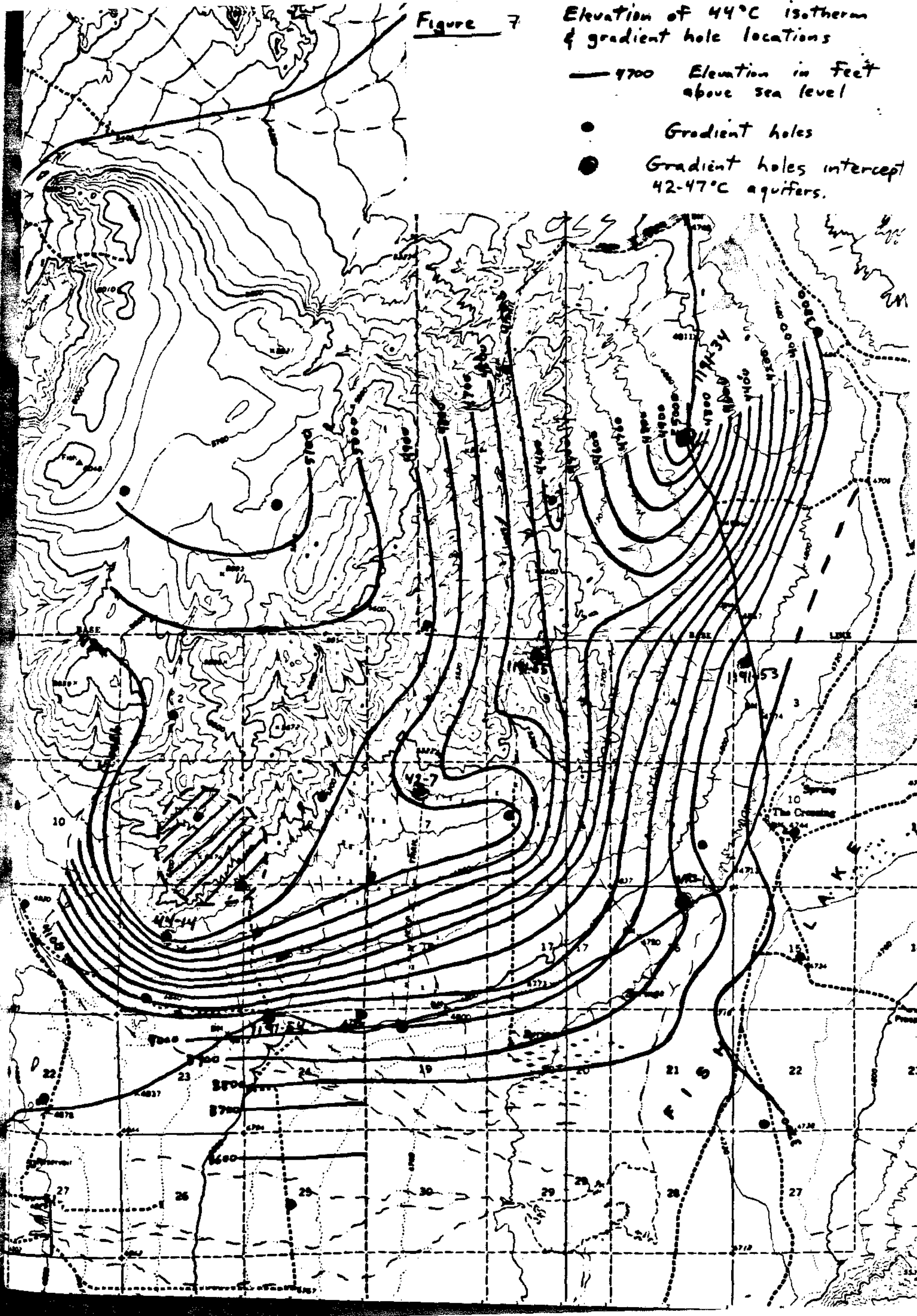


Figure 7 Elevation of 44°C isotherm & gradient hole locations

of the necessary porosity and permeability. The rocks have little or no vertical permeability due to the abundance of clays. As the warm waters move through the rocks they react with the rocks to form more clay minerals and will precipitate minerals in open fractures and thus tend to become self-sealing systems.

The gentle eastward dip of the Tertiary volcanic and volcaniclastic rocks (Fig. 2) is confirmed by a plot of the depth to the 44°C isotherm (Fig. 7). The plumbing system (fractures) are shown by approach of the isotherm to the surface in the northeast part of the area and an area of recharge is indicated by northeast trending depression in the center of the map. If one compares the depth to the 44°C isotherm with the depth to the ground water surface (Fig. 1) we see that is is approximately 1000 below the groundwater surface in the area of the valley south of the Volcanic Hills.

GEOCHEMICAL STUDIES

AMAX has collected and analyzed approximately 110 water samples from the Fish Lake Valley area. Rush and Katzer (1973) published analyses on 32 stream, spring and water well samples. Most wells producing from the basin fill in Fish Lake Valley have water chemistry similar (Table I) to the streams and springs flowing from the White Mountains (Fig. 8). The thermal waters all have a chemical signature which is different than the normal ground waters of the streams, springs or water wells in the Valley fill (Fig. 9).

The chemical differences between groundwaters and thermal waters can be seen a plot of sodium versus boron (Fig. 10). The groundwaters all plot near the ordinate and the thermal waters fall along a line of uniform slope. The chemical characteristics of the Fish Lake waters can also be shown on a chlorine versus boron diagram (Fig. 11).

Table I. Chemical analyses of representative waters in Fish Lake Valley Area

	Rush & Katzen Chiatovich Creek SWNW Sec.28,T1S,R35E	W11150 Water Well SWNW Sec.28,T1S,R35E	W11638 Buster Creek Sp NESW Sec. T3S, R35E
Temp°C	13	18	16
Flow(gpm)		---	---
pH	7.4	6.92	7.7
Cl	0.0	2.0	12.0
F	---	0.3	1.3
SO_4	2.0	0.0	180.0
HCO_3	32.0	42.0	255.0
CO_3	0.0	0.0	0.0
SiO_2	---	26.0	28.0
Na	4.0*	5.3	42.0
K	---	1.2	7.7
Ca	7.0	10.0	100.0
Mg	1.0	1.0	36.0
Li	---	0.0	0.1
B	---	0.0	0.0
TDS	---	87.8	662.1
Ec(K)	55.0	---	---

*Reported as combined Na and K.

Table I. (continued)

	W14169 Hartman Well S NWSW Sec.3,T2S,R35E	W14164 VRS #1 NWNE Sec.16,T1S,R36E	W14960 81-14 @ 465' after 4 hrs. flow
Temp°C	23	42	95*
Flow(gpm)	3000	35	100/air lift
pH	7.0	8.1	9.0
Cl	21.0	300.0	1200.0
F	1.0	2.6	9.2
SO_4	42.0	69.0	210.0
HCO_3	165.0	92.7	244.0
CO_3	0.0	77.4	120.0
SiO_2	42.0	86.0	280.0
Na	69.0	250.3	1200.0
K	6.0	21.0	130.0
Ca	15.0	7.2	3.2
Mg	6.0	1.4	<0.5
Li	0.2	0.7	4.3
B	0.5	5.3	28.0
TDS	367.7	913.3	3429.2
Ec(K)	---	1496.0	5400.0

*Blouie line temperature in separated H_2O phase.

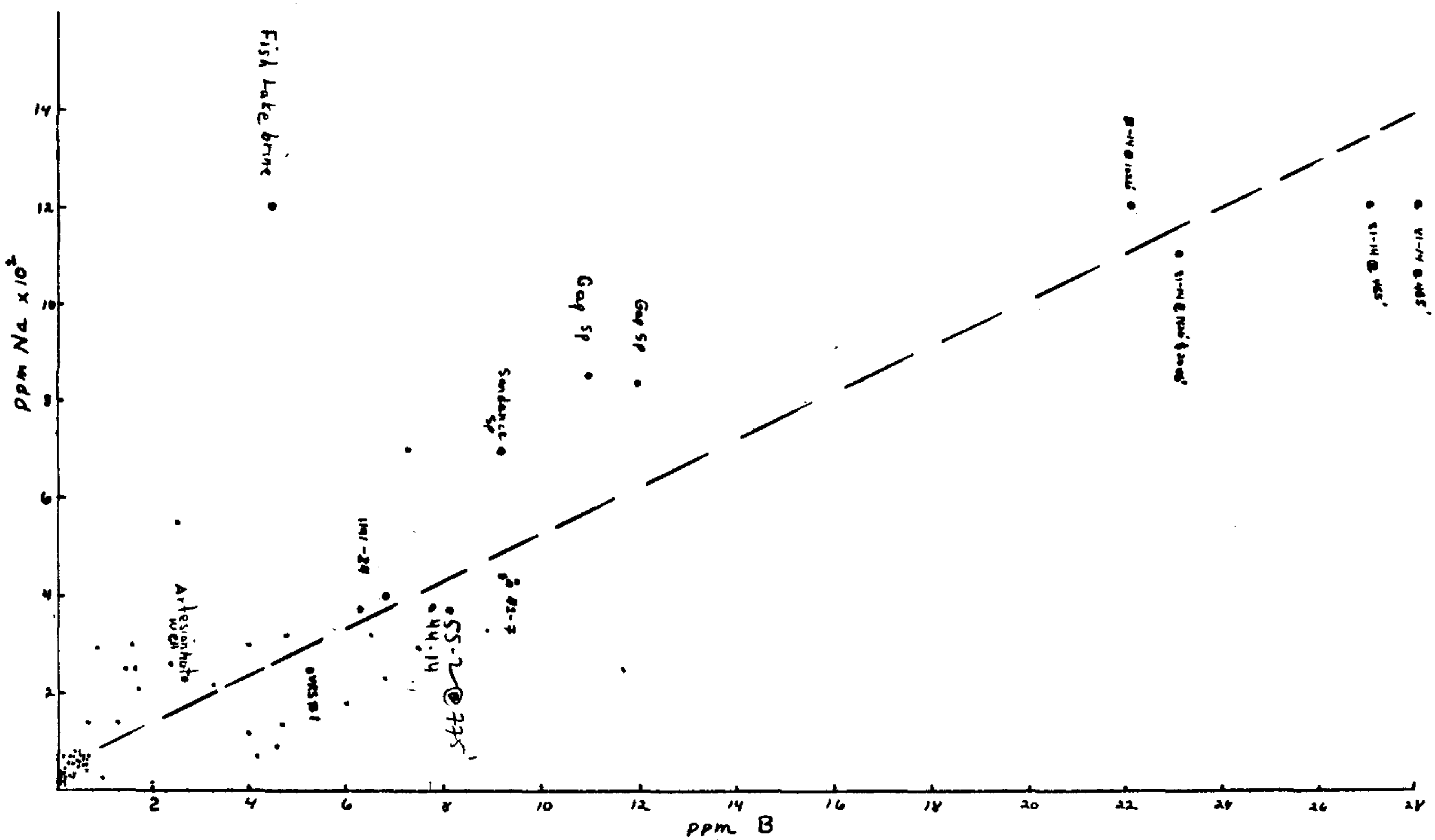


Figure 10 Sodium vs boron diagram for Fish Lake area waters.

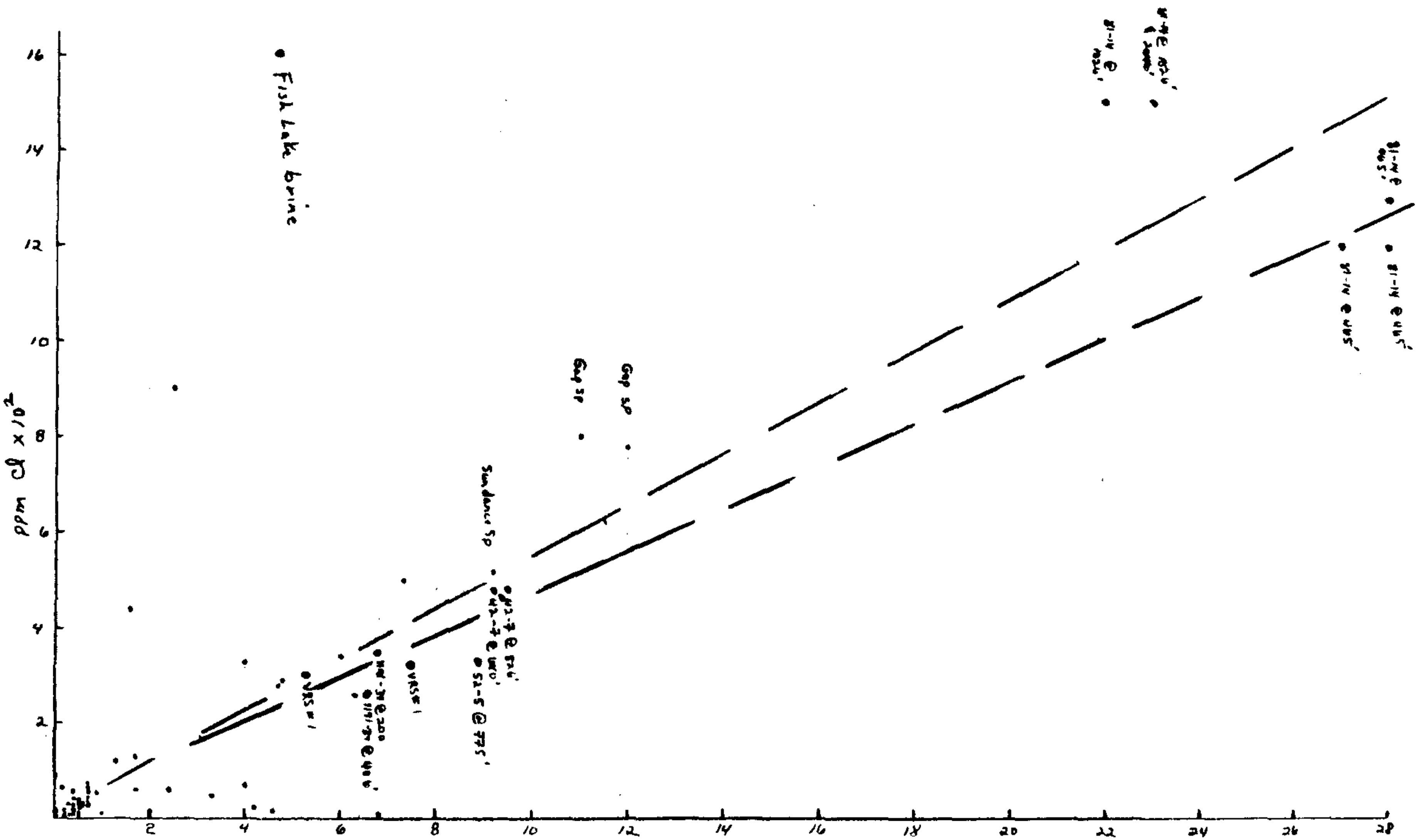


Figure 11 Chlorine vs Boron diagram for Fish Lake waters

GROUNDWATER HYDROLOGY

The shallow groundwater system utilized by the farmers and ranchers in the Fish Lake Valley is a typical valley-fill reservoir according to Rush and Katzer (1973). The thickness of the alluvium varies from zero at the valley boundaries to as much as 960 feet at the Cord well, NESW Sec.33,T2S,R35E. The oil well drilled in NWNE Sec.16,T1S,R36E was reported by Rush and Katzer to have alluvium to a depth of 5000; however, the well was probably spudded into Tertiary volcanic rocks as they outcrop within a few feet of the drill pad.

Within the valley-fill reservoir the groundwater occurs in the enter-granular pores and flows from areas of recharge to areas of discharge (Fig. 12 and 13). In the Fish Lake Valley the groundwater is confined to the alluvial valley-fill with consolidated impermeable rocks forming the hydrologic boundaries (Fig. 12). The groundwater reservoir is recharged in the following ways: (1) surface run-off from the mountains, (2) minor lateral flow from consolidated rocks such as with Fish Spring, (3) precipitation on the alluvial areas, (4) minor leakage along faults in the consolidated rocks into the valley-fill and (5) some of the irrigation waters seep back into the groundwater reservoir. The dominant source of recharge is from surface run-off. The groundwater flow is from the alluvial aprons along the mountain fronts toward the axis of the valley (Fig. 1) and then northward along the valley to the playa. The water level contours on the hydrogeologic map of Rush and Katzen (1973) illustrate the extent of the valley-fill reservoir.

GEOTHERMAL HYDROLOGY

The geothermal gradient drilling program, as previously mentioned, has outlined the presence of two (2) shallow geothermal reservoirs: (a) a widespread low temperature (40-50°C) reservoir and (2) a 160°C reservoir in the vicinity of well 81-44 (Fig. 14). In order to illustrate a

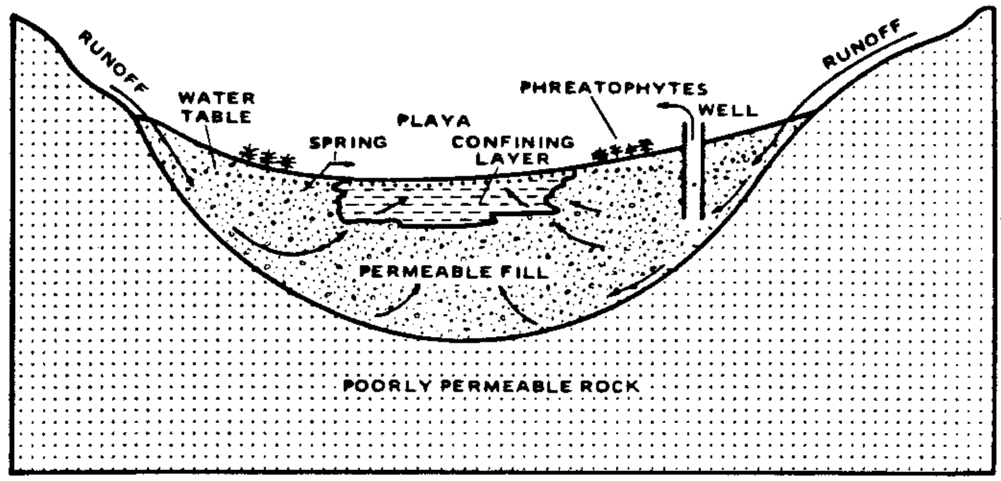


Figure 12. Schematic diagram of valley-fill reservoir with ground water flow confined to the alluvial fill.

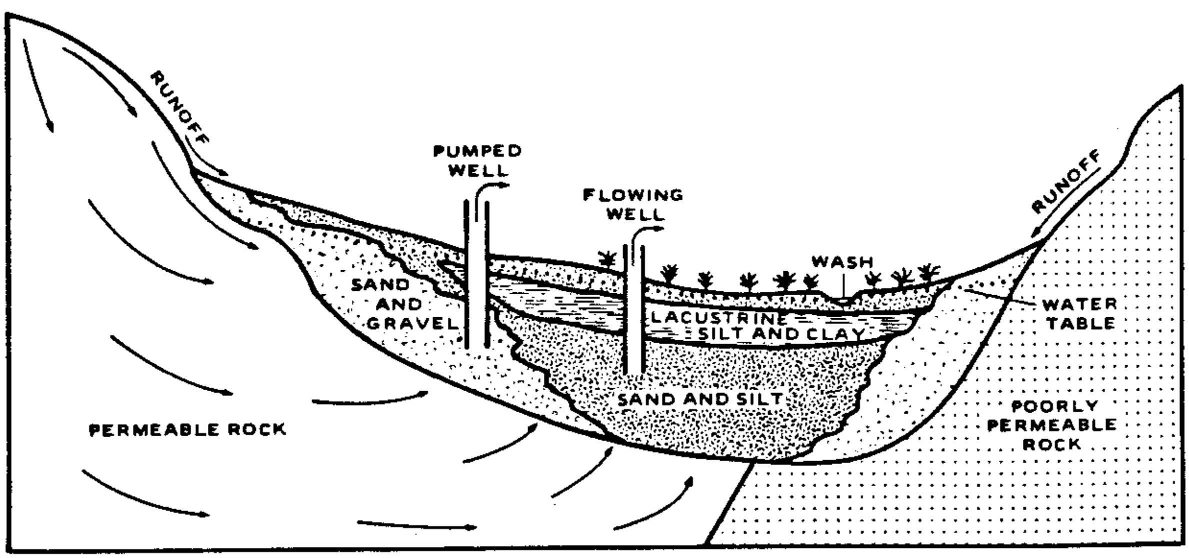


Figure 13. Schematic diagram with ground water flow from permeable bedrock into basin fill.

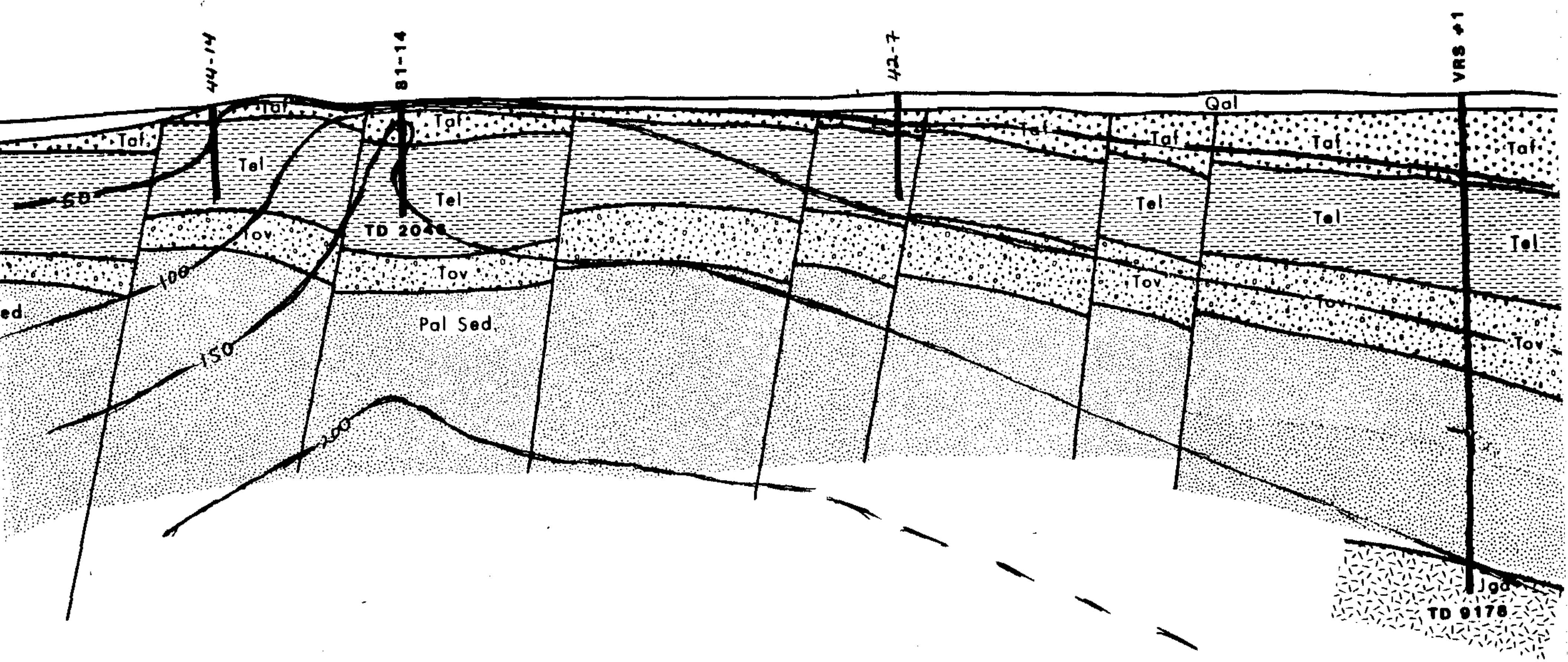


Figure 14. East-west geologic section through thermal gradient wells and the Oil test VRS #1.

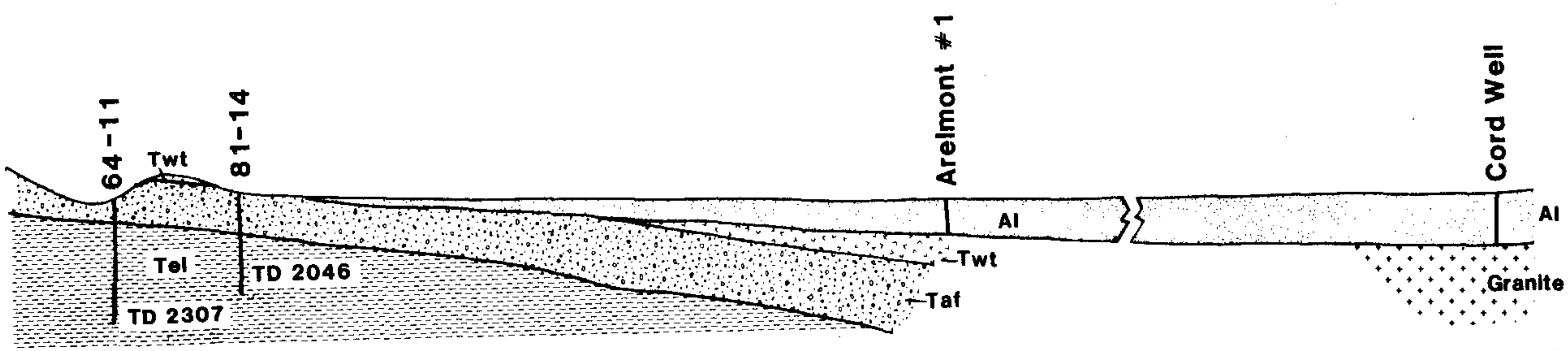


Figure 15. North-South geologic section Volcanic Hills to Cord well

possible geothermal model for the Fish Lake area let us examine Figure 16. The blue arrows indicate, in a general way, the groundwater flow in the basin-fill reservoir. The purple arrows show the path of waters in the recharge area of the geothermal system. These waters move through fractures and along faults in the generally impermeable bedrocks of the mountain ranges. The flow rate of the deep recharge water is very slow compared to the recharge in the valley-fill. For example, various workers have postulated values of from 10cm/yr. to as much as 30m/yr. If we assume a flow rate of ten meters per year, then water which enters the recharge system at or above the 10,000 foot elevation in the White Mountains would require 2600 years to reach the geothermal reservoir at a depth of 2Km beneath Volcanic Hills. In actual fact the rate is probably closer to 0.5 meter/year and thus would require 39,000 years (Cathles 1981). The rate of movement of the geothermal waters (red arrows) may be increased by hydrofracturing within the reservoir.

Water movement within the system is largely controlled by gravity. The cold recharge waters are heavy and sink as they become heated they become lighter and begin to rise. As the warm waters rise along the faults and fractures they react with the rocks to form clay minerals and seal the system. The water is then forced to move away from the faults and fractures and in doing so may create an extensive zone of alteration along the hanging wall. Cold recharge water moving down such fractures mix with the rising hot geothermal waters and give rise to the mixed-water reservoirs previously discussed, ie the 40-50°C reservoir shown near the top of Figure 16. The low temperature geothermal reservoir appears to be contained within two or more units of the Tertiary rocks. The water remains confined to sedimentary or volcaniclastic layers for two reasons: (1) the rocks have a sufficient lateral permeability to allow flow and (2) has a very restricted vertical permeability due to clay layers formed by water-rock reactions. There are no hot springs formed even where the 40-50°C reservoir is close to the surface (Fig. 7). The reservoir at well 42-7 (Fig. 14 & 15) occurs within a tuffaceous sandstone layer in the Lower Esmeralda Fm. From the

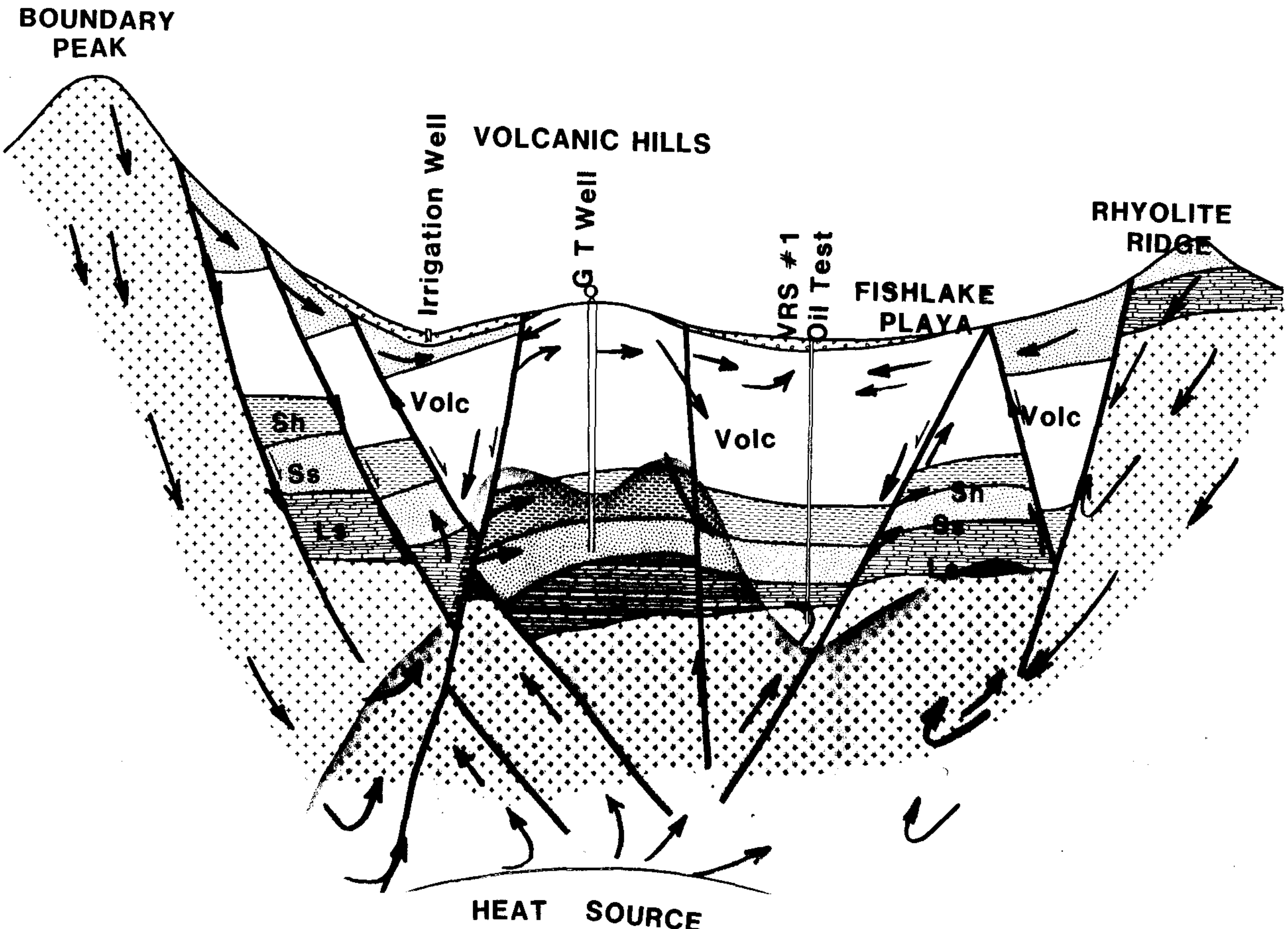


Figure 16. East-west hydrogeologic section Boundary Peak to Rhyolite Ridge.

published description of the formation aquifer in VRS #1 is appears to also be in a tuffaceous sandstone of the Lower Esmeralda Formation. The shallow moderate temperature reservoir encountered in well 81-14 appears to be fault or fracture controlled and is completely self-sealed as there are no hot springs at the surface. The postulated geothermal reservoir 200°C is within the Paleozoic rocks and probably extending downward into the Juraissic granites as seen in VRS #1 (Fig 14). There are 1.6Km of impermeable Tertiary volcanic and volcaniclastic rocks which seal the reservoir and prevent significant upward/or downward migration of waters (Fig. 16).

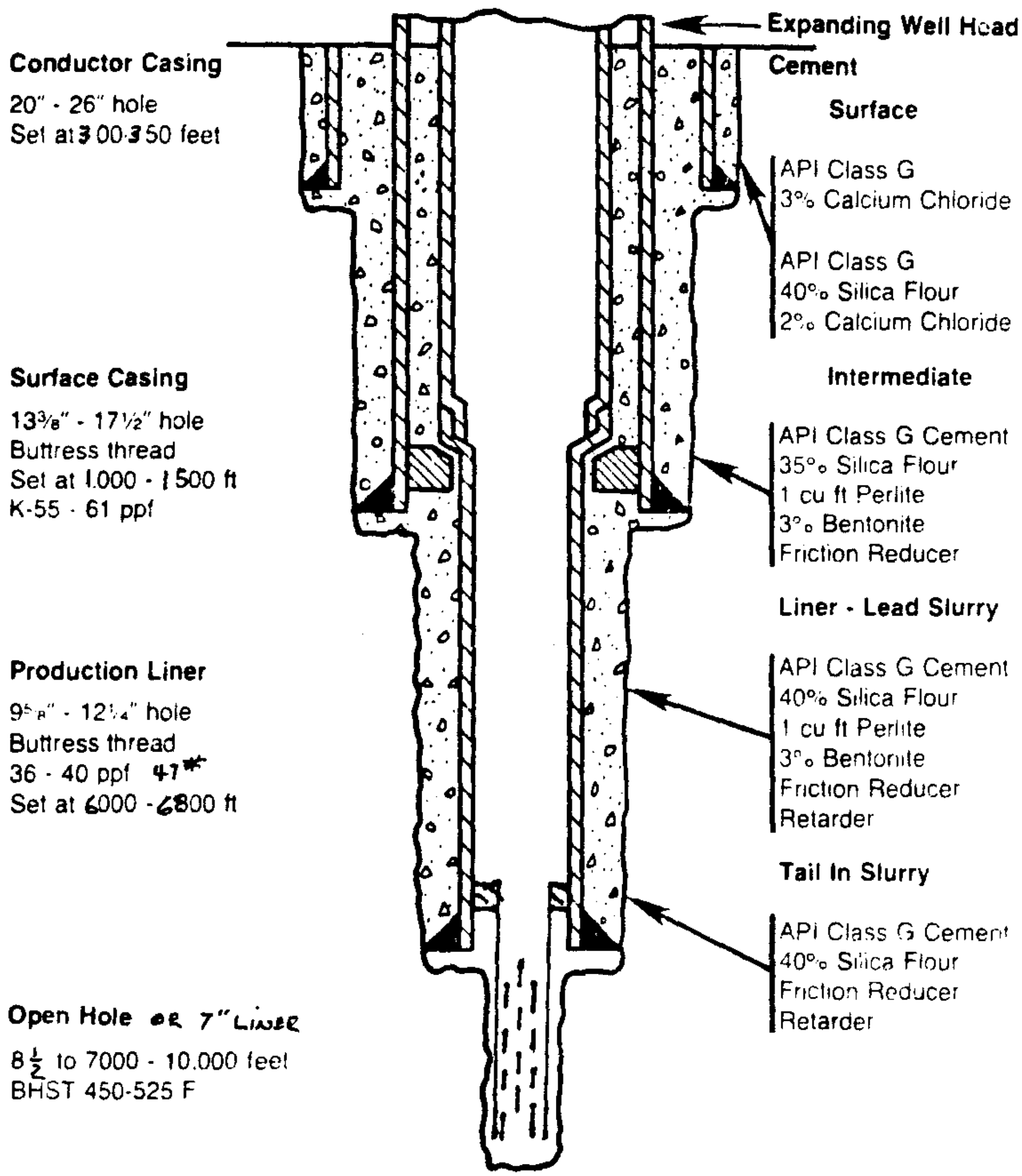
GEOTHERMAL DRILLING

The drilling of geothermal wells within the State of Nevada is regulated by several different agencies. The drilling on the Federal geothermal unit at Fish Lake must be done under an approved Plan of Exploration or Plan of Operation which includes a detailed drilling program of how the well will be drilled, the casing and cementing plans, the blowout prevention equipment which will be used, the specifics of the drilling fluids which will be used, the details of the electrical logs which will be run and how the well will be completed. The Plan of Exploration was approved as a part of the Unit by the U. S. Geological Survey, Menlo Park, California and has been administered by the Bureau of Land Management Reno office for the past year (+). In addition to the Plan of Exploration we must also adhere to the regulation in GRO 1 through 5 and any special stipulations which were made a part of our Plan of Exploration or the Geothermal Drilling Permits which the BLM approves before we begin to drill.

Also, within the State of Nevada all geothermal wells drilled within designated water basin must either be permitted through the State Engineers office or we must receive a waiver from his office, and at the present time we must also permit our activities through the new

Department of Minerals and Energy. Each layer of bureaucracy will allow drilling only when the plan has adequate protection of the near surface groundwaters used for domestic, stock and irrigation purposes (Fig. 16). As previously discussed (Figs. 14 & 15), the geothermal reservoirs are self-sealing (thin section studies show 30 to 80 clay content in the rock which basically renders the rock impermeable. When a fracture in the cap rock forms it is immediately filled with minerals peripitated from the fluids and exposed rock surfaces alter to clays.

Figures 17 and 18 show a typical geothermal well and the casing required by the regulations. The depth, size and weight of casing is given on Figure 17. The nature and composition of the cement and additives is also given. Figure 18 is a section drawn to scale for a proposed geothermal well on the south flank of the Volcanic Hills to show the casing program in relation to the expected geologic formations.



Note - Liner top sometimes squeezed tie back string usually 10¾".
All slurries mixed with 0% free water.
Preflushes used on all strings.

Figure 17. Schematic diagram of a geothermal well, casing size and weight as well as the nature of cement used for each

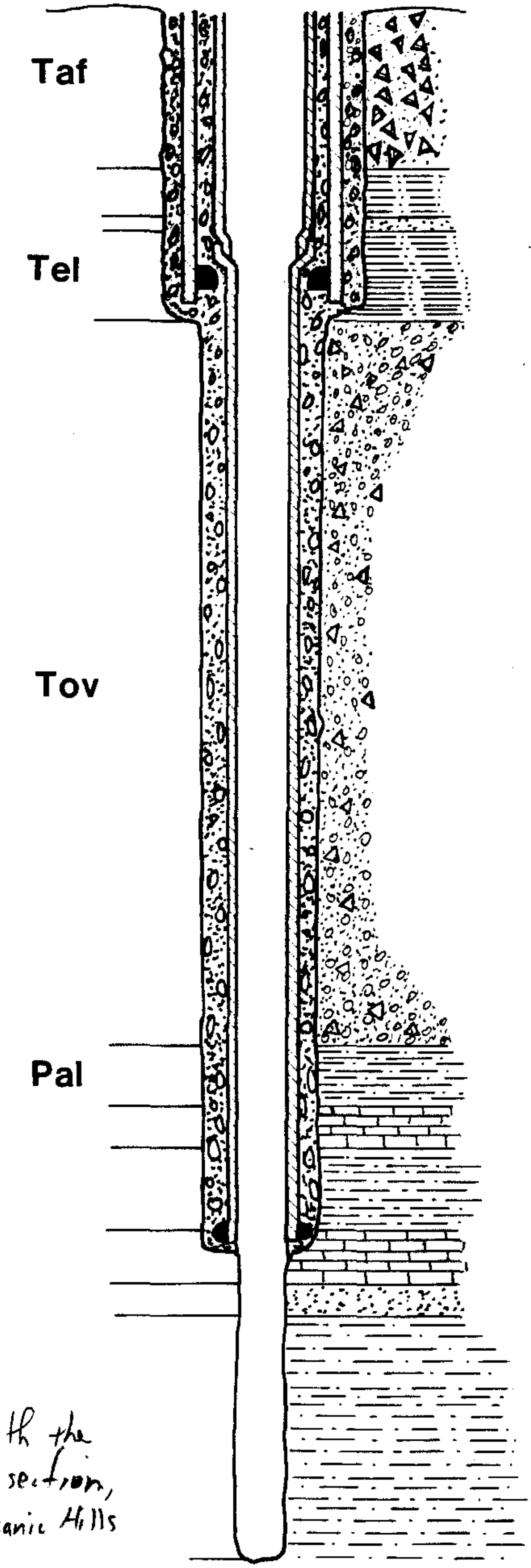


Figure 1B. well diagram with the expected geologic section, south flank of Volcanic Hills

REFERENCES

Albers, J. P. and Stewart, J. H., 1972, Geology and Mineral Deposits of Esmeralda County, Nevada; Nevada Bureau of Mines and Geology, Poull 78.

Cathles, L. M., 1981; Fluid Flow and Genesis of Hydrothermal Ore Deposits; Econ. Geol. 75 Anniversary Volume p. 424-457.

Healey, D. L., Wahl, R. R. and Cursey, F. E., 1980, Bouguer Gravity Map of Nevada, Goldfield and Mariposa Sheets; Nevada Bureau of Mines and Geology Map 68.

Robinson, P. T. and Crowder, D. F., 1973, Geologic map of the Davis Mountain Quadrangle, Esmeralda and Mineral Counties, Nevada and Mono County, California; U. S. Geological Survey map GQ-1078.

Rush, F. E. and Katzer, T. L., 1973, Water Resources Appraisal of Fish Lake Valley, Nevada and California; State of Nevada Dept. of Conservation and Natural Resources, Division of Water Resources Recon. Ser. Rept. 58