GEOTHERMAL EXPLORATION PROGRAM

HILL AIR FORCE BASE,

DAVIS AND WEBER COUNTIES, UTAH

by

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EXECUTIVE SUMMARY

This report discusses results obtained from a program designed to locate a low- or moderate-temperature geothermal resource that might exist beneath Hill Air Force Base (AFB), Ogden, Utah. These studies were done on behalf of the U. S. Department of Energy by the University of Utah, Department of Geology and Geophysics and the University of Utah Research Institute, Earth Science Laboratory Division, as part of a cooperative agreement between the Departments of Energy and Defense.

A phased exploration program was conducted at Hill AFB. Published geological, geochemical, and geophysical reports on the area were examined, regional exploration was conducted, and two thermal gradient holes were drilled.

Hill AFB is situated on alluvial deposits of the Weber River delta, and is adjacent to the Wasatch Mountains. The alluvial deposits contain extensive near-surface cold-water aquifers that could mask deeper thermal fluids. Bedrock in the area is part of the so-called "overthrust belt" of Utah, Wyoming, Idaho and Montana. The high-angle Wasatch fault separates the valley from the mountains. Faults along which water could circulate to depth, be heated in the normal thermal gradient of the earth, and rise to the near surface, formed the primary exploration target at Hill AFB. Stratigraphic aquifers, that might contain thermal water leaked from faults, formed a secondary exploration target.

Mercury analyses of soils, done at Ogden Hot Springs to test this technique at a geothermal occurence near Hill AFB, indicated a strong but laterally restricted anomaly associated with the hydrothermal activity. The small areal extent of the anomaly and extensive disturbance of soils on Hill AFB indicated that use of the soil mercury technique would be unlikely to contribute to target definition on the Base. Other chemical analyses of thermal and non-thermal waters near and on the Base failed to demonstrate a near-surface thermal component in the fluids.

Detailed gravity profiles, interpreted with constant and variable density models, suggest that the minimum depth to bedrock ranges from 0.46 km (1500 ft) at the east side of the base to 2.29 km (7500 ft) on the west side of the base.

Nearly 15 line miles of reflection seismic surveys indicate the presence of north-south-trending faults on the base and confirm the depths to bedrock interpreted from the gravity data.

Two thermal gradient holes were drilled. Both holes showed the effects of the near-surface, cold-water aquifers. A hole at the east edge of the base was drilled to 390m (1280 ft), and had an observed bottom hole temperature of 13°C (55°F). A hole near the south gate was drilled to 996m (3269 ft), and had an observed bottom hole temperature of 40°C (104°F). These temperatures are cooler than would be expected in a normal Basin and Range province environment in the absence of cold water overflow in aquifers recharged by the Weber river.

This exploration program demonstrates that thermal waters are not present in the shallow subsurface beneath Hill AFB. Options remaining for utilization of the thermal content of the groundwater include ground-water heat pumps or deeper testing of zones with unknown temperature, water quality, and productivity.

INTRODUCTION

This report summarizes the results obtained from a program designed to locate geothermal resources, if such occur, at Hill Air Force Base (Hill AFB), Utah (Figure 1). This work was carried out under modification A002 to Department of Energy Contract DE-AC07-78ET28392, issued to the University of Utah with the Earth Science Laboratory of the University of Utah Research Institute designated as a subcontractor. The assessment of geothermal resources at Hill AFB is part of a cooperative agreement between the Department of Energy and the Department of Defense.

Previous reports on geothermal potential and utilization at Hill AFB include Donovan and others (1978), who discuss an overall resource assessment and utilization program, Austin and Whelan (1978), who discuss geothermal potential at Air Force bases in general, Headquarters AFLC (1979), who discuss a phased development program at Hill AFB, and Glenn and others (1979), who present a preliminary report on this geothermal exploration program at Hill AFB.

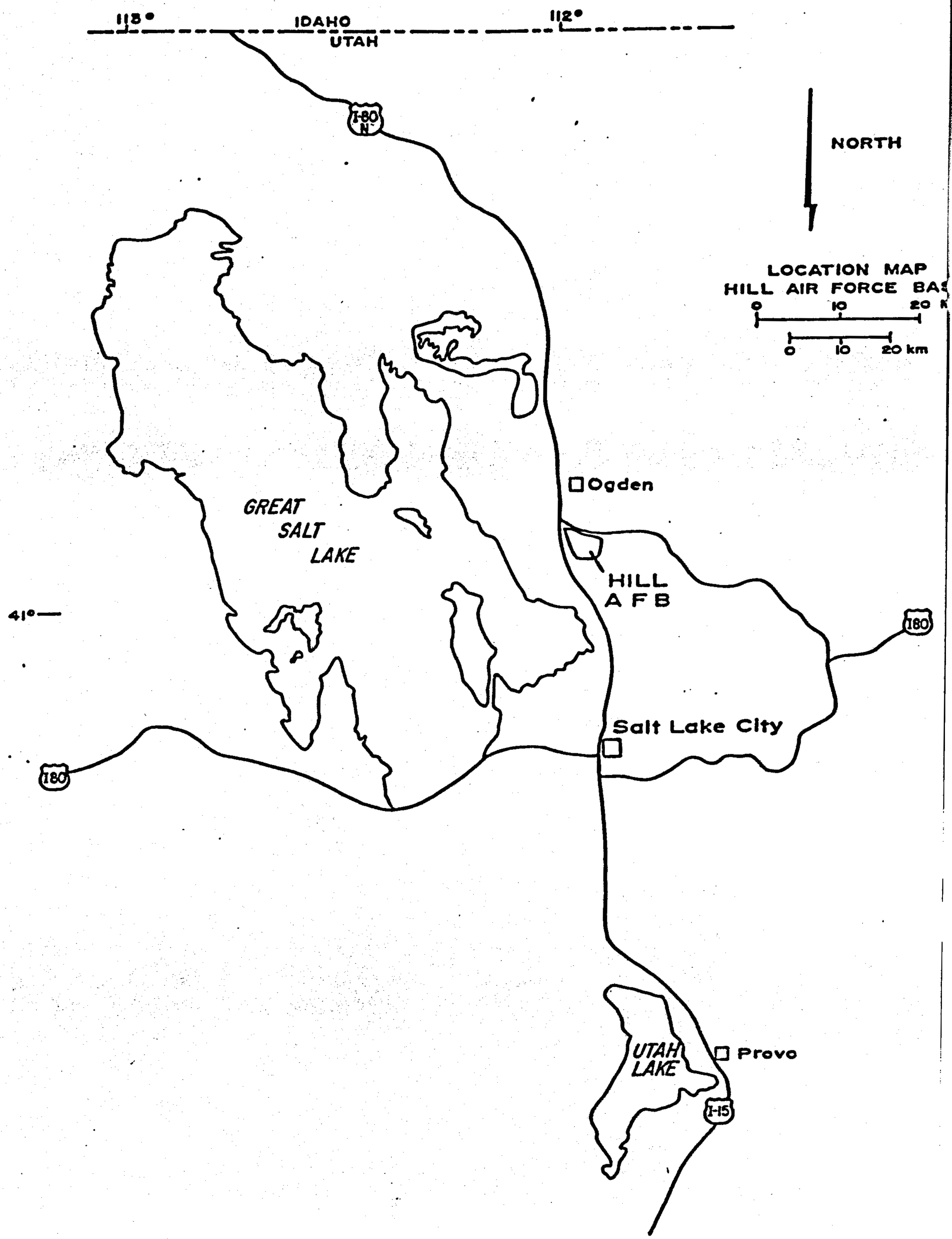
TARGET CONCEPT

Hill AFB lies within an area identified by the U. S. Geological Survey (Muffler, 1979, Map 1) as an "area of significant lateral extent favorable for discovery and development of local sources of low-temperature (<90°C) geothermal water." The description goes on to say, however, that "existing knowledge does not in general permit the inference that thermal water may be found everywhere within the depicted areas."

Geothermal resources suitable for space heating were postulated to occur at Hill AFB by Donovan and others (1978). Geothermal fluids on the base were expected to be similar to the 56° and 57°C (133° and 135°F) temperatures of nearby Ogden, Utah, and Hooper Hot Springs (see Task I-4). These hot spring sites are thought to be "deep-circulation" systems, with meteoric water infiltrating through fractures in the ground, heating in the earth's thermal gradient, and rising to the surface by circulation through faults or fractures. Zones of geologic structure such as faults that could allow upward circulation of heated waters thus formed the primary exploration target at Hill AFB. Alluvial aquifers, which might contain thermal water leaked from faults, formed a secondary target.

EXPLORATION PROGRAM

A phased exploration program was designed to identify favorable geologic structures and then to test these structures for thermal fluids. Phase I included orientation studies, Phase II was composed of detailed geoscientific studies, and Phase III included thermal gradient hole drilling (see Table 1).



113°
IDAHO
UTAH
112°
I-80 N
NORTH
LOCATION MAP
HILL AIR FORCE BAS
0 10 20
0 10 20 km
GREAT SALT LAKE
Ogden
HILL AFB
41°
180
Salt Lake City
180
UTAH LAKE
Provo
I-15

FIGURE 1

TABLE 1

Hill AFB Exploration Program

Phase I	Task I-1	Compilation of available data
	Task I-2	Lineament analyses
	Task I-3	Soil mercury survey
	Task I-4	Aqueous geochemistry
	Task I-5	Gravity survey
Phase II	Task II-1	Appropriate further geochemistry
	Task II-2	Appropriate further gravity
	Task II-3	Seismic survey
Phase III	Task III-1	Gradient hole drilling

These studies were designed to explore beneath the known cold-water aquifers (Feth and others, 1966). This report summarizes the results of the exploration program.

PHASE I

Task I-1 Compilation of Available Geoscience Data

Bedrock under Hill AFB is postulated to be similar to the Precambrian and Paleozoic sedimentary and metamorphic rocks that crop out in the adjacent Wasatch Mountains (Sorensen and Crittenden, 1972). Mesozoic sedimentary rocks may also be present beneath the base. These rocks are part of the geologic area known as the "overthrust belt" where extensive low-angle faulting has taken place (Crittenden, 1972). The Wasatch Mountains are truncated on the west by the Wasatch Fault zone (Morisawa, 1971), which possibly forms conduits for the deep circulation of water.

The bedrock underlying the valley is covered by alluvial materials that were deposited before and during the existence of Lake Bonneville and as part of the delta constructed by the Weber River (Feth and others, 1966). Coarser, porous beds within the alluvial sequence form extensive near-surface cold-water aquifers, which could effectively mask underlying thermal reservoirs.

Task I-2 Lineament Analyses

Aerial photographs and infrared imagery of Hill AFB and the immediately surrounding land were examined to determine the presence of lineaments (Figure 2). Lineaments may be an indication of subsurface geologic structures. In

LINEAMENTS IDENTIFIED IN VICINITY OF HILL AFB

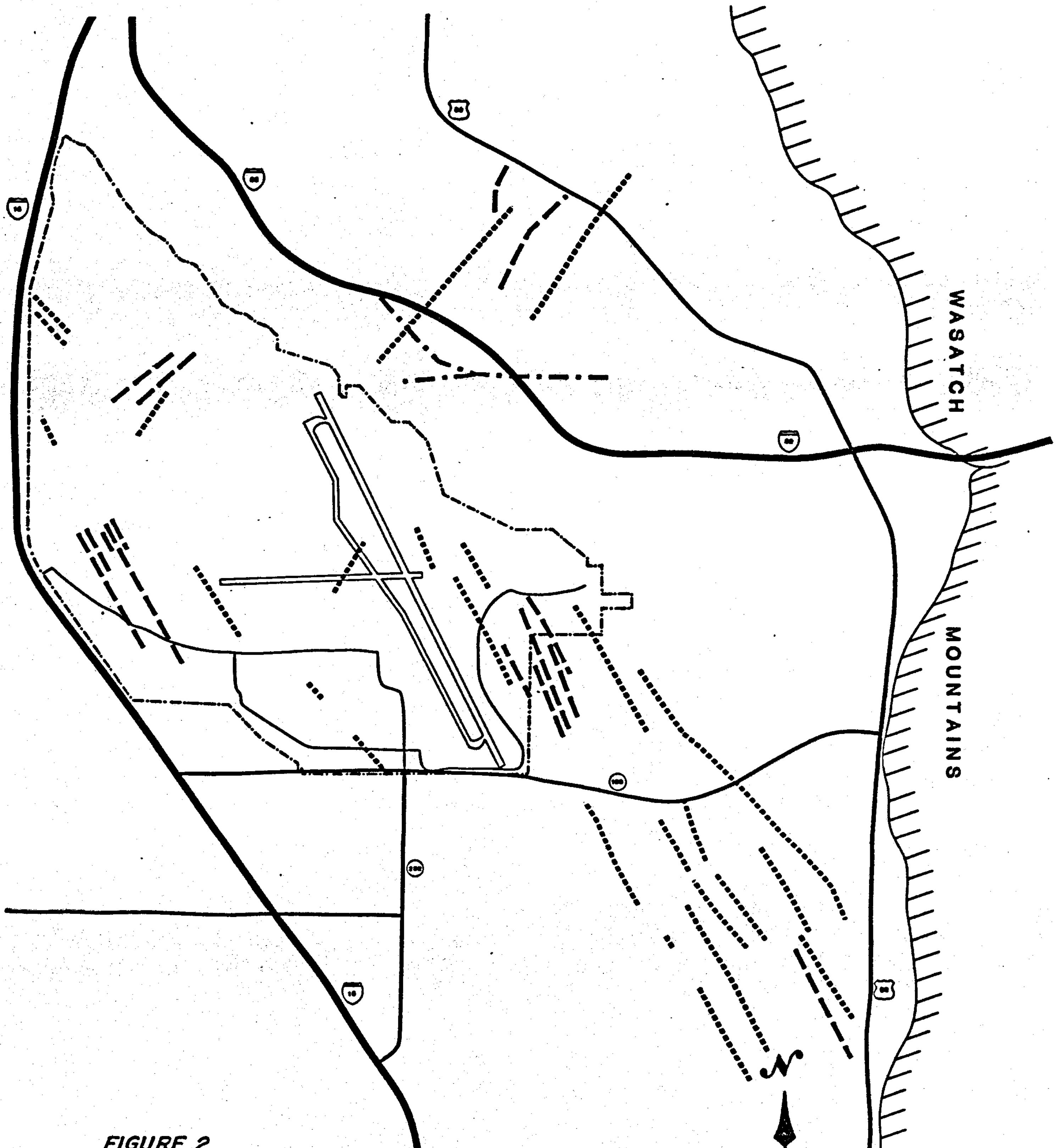


FIGURE 2

LEGEND

I .5 0 I KM.

— · — · — Infrared lineament

— — — — Photo lineament , moderate confidence

·········· — Photo lineament , low confidence this study, lineaments were identified by examination of photographs and verified by field inspection to remove cultural influences.

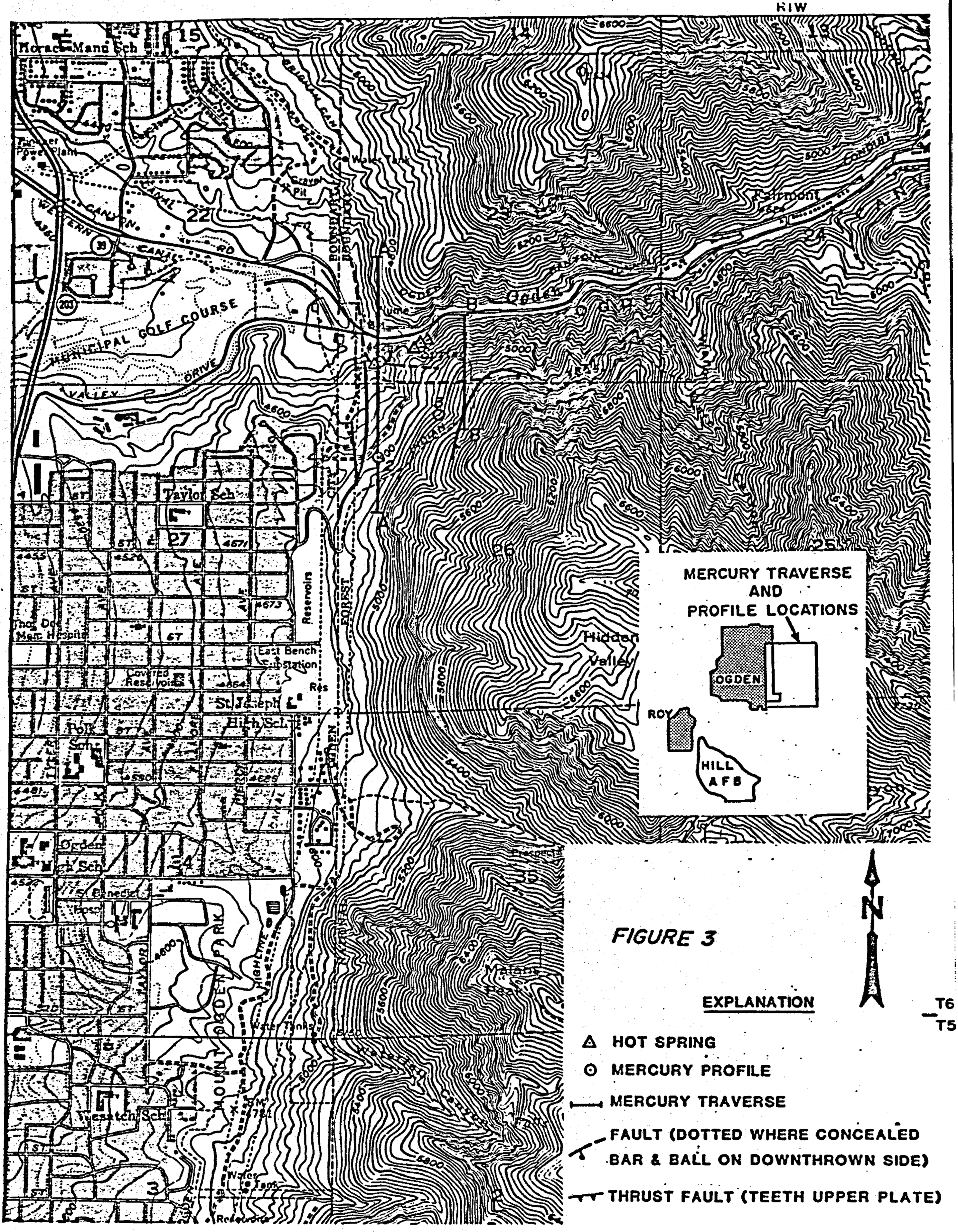
There are two sets of lineaments in the Weber delta area that can be discerned from aerial photographs. The dominant set trends NW, with most strikes about N35°W in a range of N20°W to N43°W. The widest and most continuous zone of these lineaments extends from a northwest curve in the Wasatch fault east of Kaysville, northwest to the Hill AFB golf course. The second linear trend strikes N29°E to N45°E, with N38°E being a typical value. The few linears of this trend are on the north end of the base and on the bench north of the Weber River. These lineaments are subparallel to a major trend of lineaments in the Wasatch range, and may be related to buried shallow geologic structures.

Infrared data for Hill AFB and vicinity were obtained from EG&G's Remote Sensing Group in Las Vegas, Nevada. An infrared lineament separates a warmer zone on the south and a cooler zone on the north within the Weber River floodplain northeast of Hill AFB. This IR linear does not extend onto the base but curves to the northwest within the floodplain. No support for this linear was found on the aerial photos or geologic mapping in the area. Field examination revealed a gravelly soil on the north (cool) side of the linear and a sandy soil on the south (warm) side of the linear. Bryant (1979) does not indicate an east-west fault, which would be an extension of this lineament, in Weber Canyon. Our field study confirmed Bryant's observations.

Task I-3 <u>Orientation Mercury Survey</u>

Anomalous concentrations of mercury are commonly associated with active geothermal systems (White, 1967; Weissberg and others, 1979). Recent studies in fracture-dominated systems at Roosevelt Hot Springs KGRA, Utah (Parry and others, 1976; Capuano and Bamford, 1978; Capuano and Moore, 1980) and Long Valley, California (Klusman and Landress, 1979) demonstrate that the distribution of mercury in soils is controlled by structures that have tapped the geothermal reservoir. These studies indicate that detailed mercury surveys are an effective exploration method for mapping geologic structures in high-temperature geothermal systems even in areas covered by alluvium. However, this technique has not been tested in low temperature systems such as were postulated to exist at Hill Air Force Base. Because of extensive cultural activity and soil disturbance, thick alluvial deposits and cold water aquifers beneath Hill Air Force Base all of which could mask mercury signatures of geothermal activity, an orientation survey was completed at a nearby hot spring.

Three soil profiles and two traverses were sampled in the orientation survey. Their locations are shown on Figure 3, and are referenced to the SW corner of Sec. 23, T6N, R1W. Samples were collected in polyethylene bags and dried at room temperature. The -80 mesh fraction was separated with a stainless steel sieve and stored in airtight glass vials. Mercury concentrations were determined on the -80 mesh material at ESL using a Model 301 Gold Film Mercury Detectory (Jerome Instruments Corp., Jerome, Arizona). Where planned sample locations fell on or near culturally disturbed locations, such as a roadway, the sample site was moved to a nearby location with undisturbed soil to minimize contamination.



MERCURY TRAVERSE AND PROFILE LOCATIONS AT OGDEN HOT SPRINGS, UTAH.

Samples were collected along three vertical soil profiles to determine the appropriate horizon for sample collection; all were sampled in alluvium covering quartzite. Profile 1 at 190 m (625 ft) E, 91 m (300 ft) N is next to Ogden Hot Springs while profiles 2 at 190 m (625 ft) E, 366 m (1200 ft) S and 3 at 488 m (1600 ft) E, 152 m (500 ft) S are over 305 m (1000 ft) away from the spring. The results of these profiles, shown in Figure 4, are similar to those seen in other hot spring areas. Hg increases at depth near the hot springs while it remains nearly constant or decreases with depth away from the hot springs (Buseck, 1977; Capuano and Bamford, 1978). The higher near-surface mercury concentrations along profiles 2 and 3 might be a result of either atmospheric pollution from the city of Ogden or of near-surface organic-rich soils that could preferentially absorb Hg. Based on these results, a sample depth of 8 to 9 inches (20-23 cm) was chosen, which is below probable surface contamination and still easily sampled.

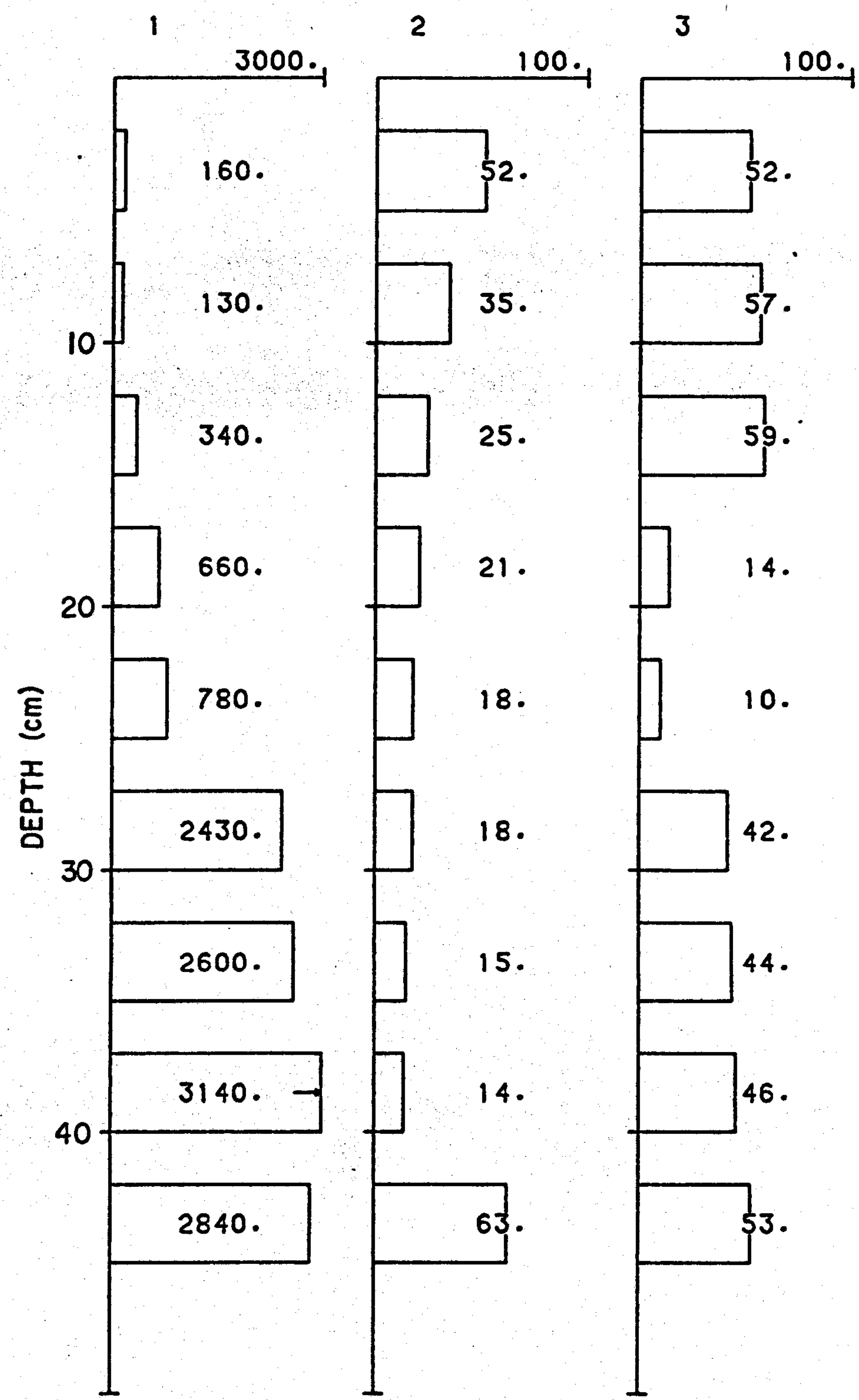
Samples were obtained along the traverses at approximately 100 ft (30.5 m) intervals. This interval choice was based on data from soil mercury anomalies found in high-temperature geothermal systems (Capuano and Bamford, 1978; Klusman and Landress, 1979). Traverse locations were chosen so that A-A' at 190 m (625 ft) E would cross a fault in the vicinity of associated hot spring activity while B-B' at 610 m (2000 ft) E would cross structures away from hot spring activity. Results are shown in Figures 5 and 6. The data are given in Tables 2 and 3. Fault locations and geologic units included in this study were determined from a reconnaissance examination of outcrops and geologic mapping by Bryant (1979). A statistical background of 35 ppb and threshold of 110 ppb Hg were determined for the sampled area using the methods

FIGURE 4

MERCURY PROFILES

SAMPLE TYPE: MERCURY IN SOIL (PPB)

1 2 AND 3
OGDEN HOT SPRINGS, UTAH



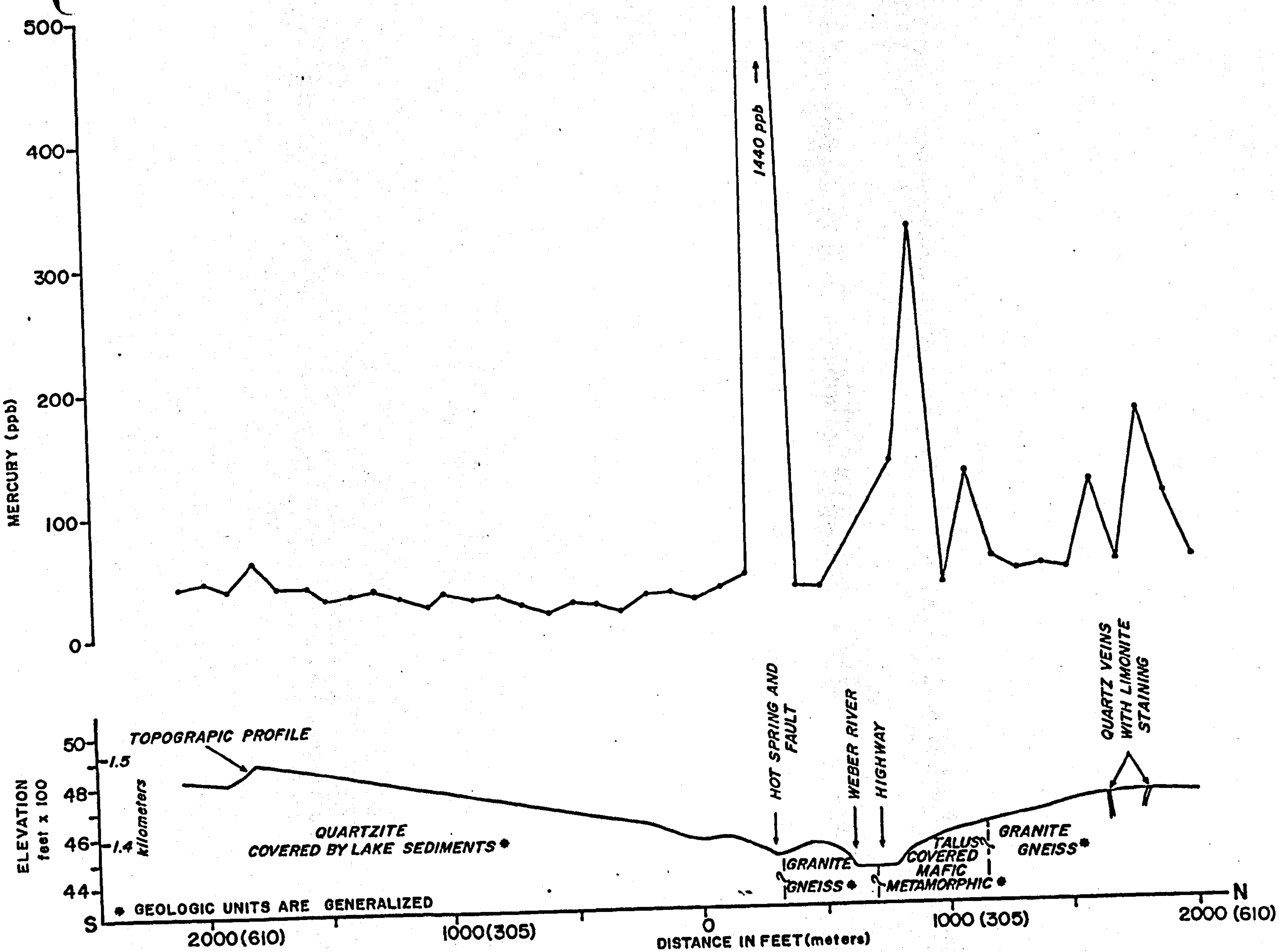


FIGURE 5 MERCURY SOIL TRAVERSE A - A' (625 ft. E, 191m.)

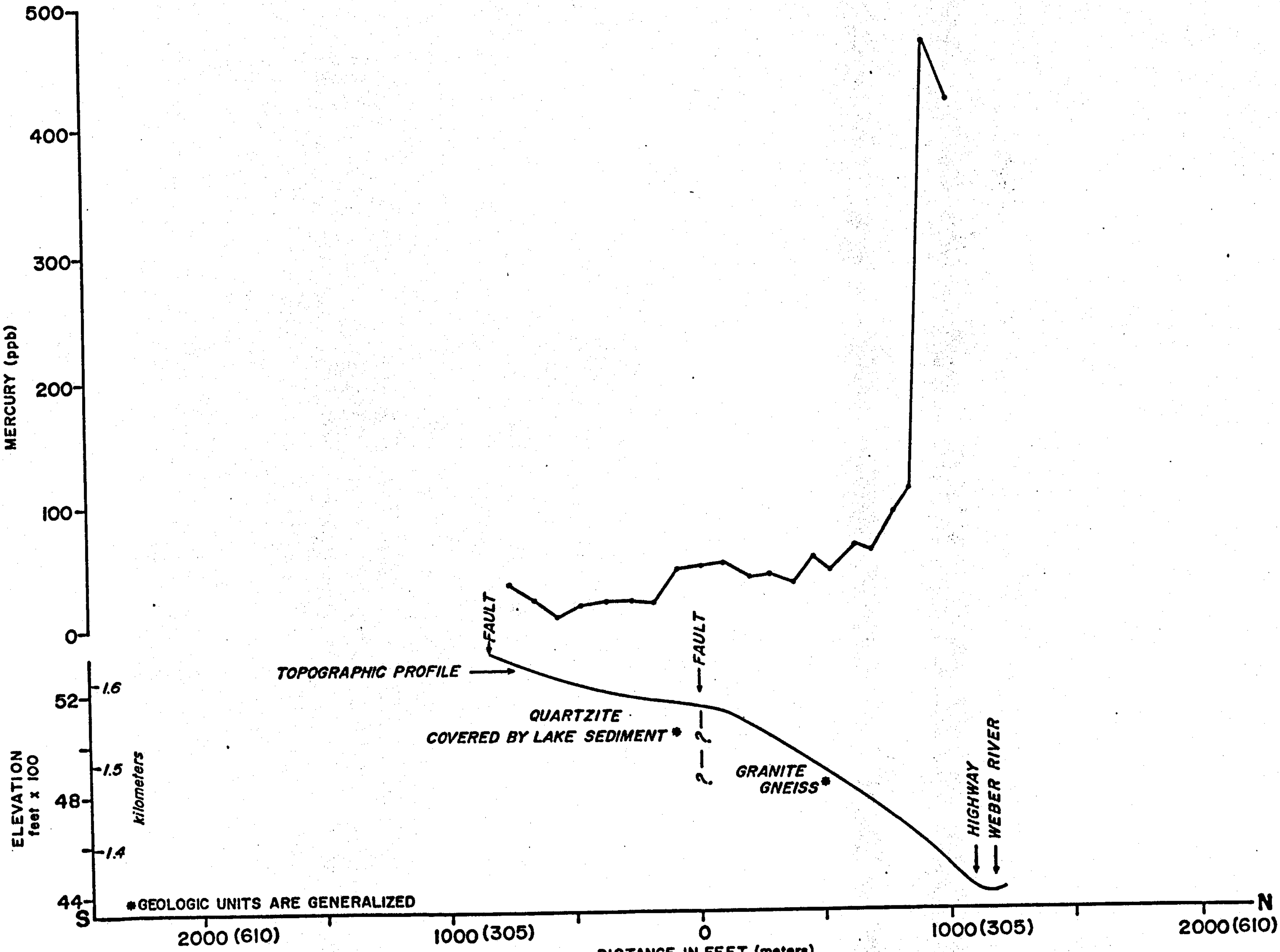


FIGURE 6. MERCURY SOIL TRAVERSE B-B' (2000 ft E, 600m.)

TABLE 2

Mercury Soil Traverse A-A' (625 ft. E), Sample Locations and Mercury Concentrations[1].

LOCATION			MERCURY
Direction	Feet	Meters	ppb
S	2100	640	42
S	2000	610	47
S	1900	579	39
S	1800	549	61
S	1700	518	40
S	1585	483	40
S	1500	457	30
S	1400	427	34
S	1300	396	36
S	1200	366	30
S	1080	329	24
S	1010	308	34
S	900	274	30
S	800	244	30
S	700	213	23
S	600	183	18
S	500	152	25
S	400	122	21
S	300	91	17
S	200	61	29
S	100	30	31

LOCATION			MERCURY
Direction	Feet	Meters	ppb
	0	0	25
N	100	30	35
N	200	61	43
N	300	91	1440
N	400	122	35
N	500	152	33
N	800	244	140
N	900	274	330
N	1000	305	33
N	1100	335	120
N	1200	366	54
N	1300	396	45
N	1400	427	49
N	1500	457	43
N	1600	488	120
N	1700	518	50
N	1800	549	170
N	1900	579	100
N	2000	610	52

[1]All locations reference to SW corner of Sec. 23, T6N, R1W, Utah.

TABLE 3

Mercury Soil Traverse B-B' (2000 ft E)
Sample Locations and Mercury Concentrations[1].

	LOCATION		MERCURY
Direction	Feet	Meters	ppb
S	750	229	36
S	657	200	22
S	564	172	10
S	464	141	20
S	366	112	23
S	268	82	21
S	169	52	20
S	70	21	47
N	28	9	49
N	121	37	52
N	214	65	41
N	300	91	41
N	386	118	34
N	479	146	59
N	547	167	48
N	647	197	67
N	704	215	60
N	782	238	92
N	860	262	110
N	946	288	470
N	1028	313	420

[1]All locations referenced to SW corner of Sec. 23, T6N, R1W, Utah.

of Lepeltier (1969) and Sinclair (1976). This background concentration is comparable to, although higher than, background concentrations measured in high-temperature geothermal areas, which range from 20 to 30 ppb Hg (Matlick and Buseck, 1976; Phelps and Buseck, 1978; Capuano and Bamford, 1978). This higher background, rather than being a result of geothermal activity, could signify the relative absorbing capacity of the soil or cultural contamination.

Anomalous mercury concentrations appear to be associated with Ogden Hot Springs (1440 ppb), the highway (100 to 400 ppb), quartz veins with limonite staining (100 to 200 ppb), and possibly geologic contacts. The relationships between geologic structures and anomalous soil mercury concentrations away from hot spring activity were not clearly determined in this study. The limited lateral extent of anomalous mercury associated with Ogden Hot Springs, less than 30.5 m (100 ft), combined with the thick alluvial cover and cultural disruption in the vicinity of Hill AFB suggested that a mercury soil survey (Task II-1) would not be a useful aid in delineating buried structure with geothermal associations on the base, and no further sampling was done.

Task 1-4 Water Sampling

The evaluation of the chemical composition of thermal springs, wells and cold surface waters has proved at many prospects to be a useful tool in the initial stages of geothermal exploration. Fluid geochemical surveys have provided information on the compositions and homogeneity of the fluids, subsurface temperatures, rock types, the origin of fluids, and fluid pathlines.

Sampling and Preparation:

Water samples were collected in April and May of 1979 from the Weber River, six wells on the base, four wells off the base, five cold springs, and four hot springs in the East Shore area. Figure 7 shows sample site locations.

All samples were filtered with a 0.45 μ membrane filter upon collection and stored in polyethylene containers. These containers were precleaned by soaking them in 20% nitric acid, rinsing in deionized water, and rinsing with the collection water prior to sampling. An untreated sample and a 20% nitric acid dilution sample were collected at each site.

Chemical Analyses:

The pH and bicarbonate concentration were determined at the time of collection on filtered-untreated samples using an Orion Model 407 selective ion meter with Ag/AgCl combination pH electrode and sulfuric acid titration (Presser and Barnes, 1974). Fluoride, chloride and total dissolved solids were determined on filtered-untreated samples by specific ion electrode, silver nitrate titration and gravimetric methods, respectively (Brown and others, 1970). These analyses were performed by Rocky Mountain Geochemical Corporation, Salt Lake City, Utah. Other major and trace elements listed on Table 4 were determined at the Earth Science Laboratory using an ARL Inductively Coupled Plasma Quantometer.

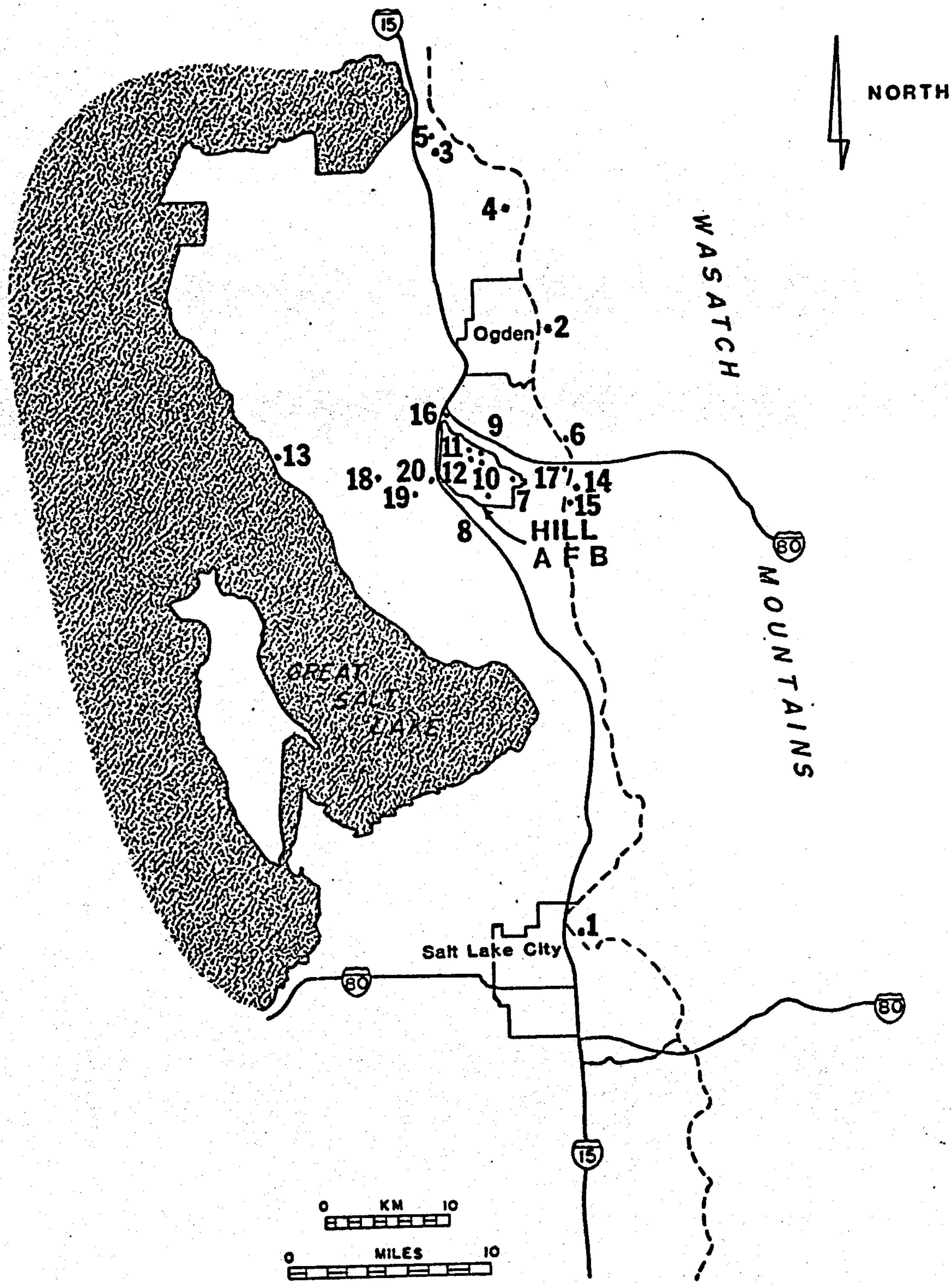


Figure 7 Water sampling sites

Hypothetical sulfate values were derived from the difference in electrical balance between the cations and anions as follows:

$$\frac{\Sigma\text{cations} - \Sigma\text{anions (meq/kg)}}{0.02082} \simeq SO_4^{2-}\text{(ppm)}$$

where 0.02082 is the reciprocal of the combining weight of SO_4^{2-} (Hem, 1970). The values computed from this method come within $\pm$ 25% of the values reported in Goode (1978) for the low-temperature well waters. Sulfate values determined by this method for hot springs were still in poor agreement with the reported sulfate concentrations. Calculated sulfate values were used for description of low-temperature waters; data reported in Goode (1978) were used for the hot springs waters.

Fluid Classification and Element Distributions:

The composition of wells and springs listed in Table 4 can be represented conveniently by a trilinear plotting technique described by Hem (1970) (Figure 8). Data plotted in Figure 8 indicate that there are two distinct types of water present in the East Shore area. Waters in the vicinity of Hill AFB (including the Weber River) are relatively enriched in Ca + Mg and HCO_3 + CO_3 relative to the other cations and anions. These fluids are generally low in temperature (10° to 17°C) and ionic strengths (0.003 to 0.01) and are typical of shallow well waters found throughout much of the eastern and central

TABLE 4. WATER ANALYSIS FROM WELLS, SPRINGS AND RIVERS IN THE OGDEN UTAH AREA[a]

		HOT SPRINGS				COLD SPRINGS AND WEBER RIVER					
Name Location[b]		Wasatch (B-1-1)25cd	Ogden (B-6-1)23cc	Utah (B-7-2)14d	Hooper (B-5-3)27	(B-7-1)34	(B-7-2)14	Hamre River (B-5-1)25bb	(B-5-1)36aa	(B-5-1)36a	Weber River (B-5-1)25
ESL #		1	2	3	13	4	5	6	14	15	17
Temp.	°C	41.5	56.0	56.0	57.0	10.0	27.5	12.0	11.0	12.0	10.0
pH		7.2	7.1	6.3	6.5	7.5	7.5	7.2	7.2	8.0	8.1
tds	mg/l	6,650	9,040	21,800	3,830	nd[c]	1780	680	620	630	230
HCO_3	mg/l	274	214	211	233	257	174	134	68	161	122
Na	mg/l	2,281	2,948	7,064	2,326	8.3	389	21	7.9	12	8.9
K	mg/l	91	354	910	222	1.2	63	2.5	0.8	1.3	1.5
Ca	mg/l	503	344	1,023	477	55	28	37	19	43	65
SiO_2	mg/l	15	45	32	28	7.1	18	14	8.3	5.3	6.4
Mg	mg/l	95	6.6	24	76	24	1.5	9.7	3.2	9.2	9.9
Fe	mg/l	0.06	1.9	5.0	1.8	0.5	0.7	0.2	0.6	0.4	0.8
Ti	mg/l	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
Sr	mg/l	9.5	8.5	23	10	0.1	0.6	0.1	0.04	0.2	0.1
Ba	mg/l	<0.5	0.5	0.7	1.6	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Mn	mg/l	<0.2	0.7	2.1	1.4	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Zn	mg/l	0.3	<0.1	<0.1	0.2	<0.1	<0.1	0.1	<0.1	<0.1	0.6
Li	mg/l	1.1	6.9	14	2.4	<0.04	0.7	<0.04	<0.04	<0.04	<0.04
B	mg/l	1.2	3.2	3.7	0.9	<0.1	0.6	<0.1	0.7	<0.1	<0.1
F	mg/l	1.8	3.6	3.4	0.9	<0.1	5.7	<0.1	<0.1	<0.1	<0.1
Cl	ppm	4,820	5,060	11,900	4,720	14	535	19	9	19	15

[a] Ag, Al, As, Au, Be, Bi, Cd, Ce, Co, Cr, Cu, La, Mo, Ni, P, Pb, Sb, Sn, Te, Th, U, V, W, Zr were not detected above the limited of quantitative detection of the ICP.

[b] Locations are based on the Bureau of Land Management system of land subdivision.

[c] Not done.

TABLE 4. WATER ANALYSIS (cont.)[a]

		WELLS - ON HILL AFB						WELLS - OFF HILL AFB			
Name Location[b]		HAFB-4 (B-5-1)33	HAFB-5 (B-5-1)5	HAFB-3 (B-5-1)29	HAFB-2 (B-5-1)29	HAFB-7 (B-5-1)30	HAFB-6 (B-5-1)30	(B-5-2)13ba	(B-5-2)34	(B-4-2)12bb	(B-4-2)1dba
ESL #		7	8	9	10	11	12	16	18	19	20
Temp.	°C	11.5	17.0	13.0	15.0	13.0	14.0	14.0	15.0	13.0	13.0
pH		7.7	7.5	7.5	7.4	7.5	7.9	8.6	7.7	7.7	7.7
tds	mg/l	660	740	770	900	820	760	620	250	320	320
HCO_3	mg/l	297	306	283	305	290	289	126	266	286	311
Na	mg/l	33	42	17	20	19	20	9.1	19	20	24
K	mg/l	6.5	7.4	2.0	2.1	2.0	2.1	1.2	2.7	3.4	4.2
Ca	mg/l	52	58	81	76	74	77	35	69	84	76
SiO_2	mg/l	19	16	9.8	10	10	10	5.8	13	14	13
Mg	mg/l	16	16	18	18	18	18	7.2	17	18	20
Fe	mg/l	0.6	1.6	0.6	0.5	0.5	0.03	0.2	0.6	0.5	0.6
Ti	mg/l	0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1	<0.1
Sr	mg/l	0.2	0.2	0.3	0.3	0.3	0.3	0.1	0.2	0.2	0.2
Ba	mg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Mn	mg/l	0.4	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Zn	mg/l	<0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.2	<0.1
Li	mg/l	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
B	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
F	mg/l	0.1	0.1	<0.1	0.1	<0.1	0.7	<0.1	0.9	<0.1	.13
Cl	mg/l	23	24	21	21	21	24	13	23	25	23

[a] Ag, Al, As, Au, Be, Bi, Cd, Ce, Co, Cr, Cu, La, Mo, Ni, P, Pb, Sb, Sn, Te, Th, U, V, W, Zr were not detected above the limit of quantitative detection of the ICP.

[b] Locations are based on the Bureau of Land Management system of land subdivision.

[c] nd = Not done.

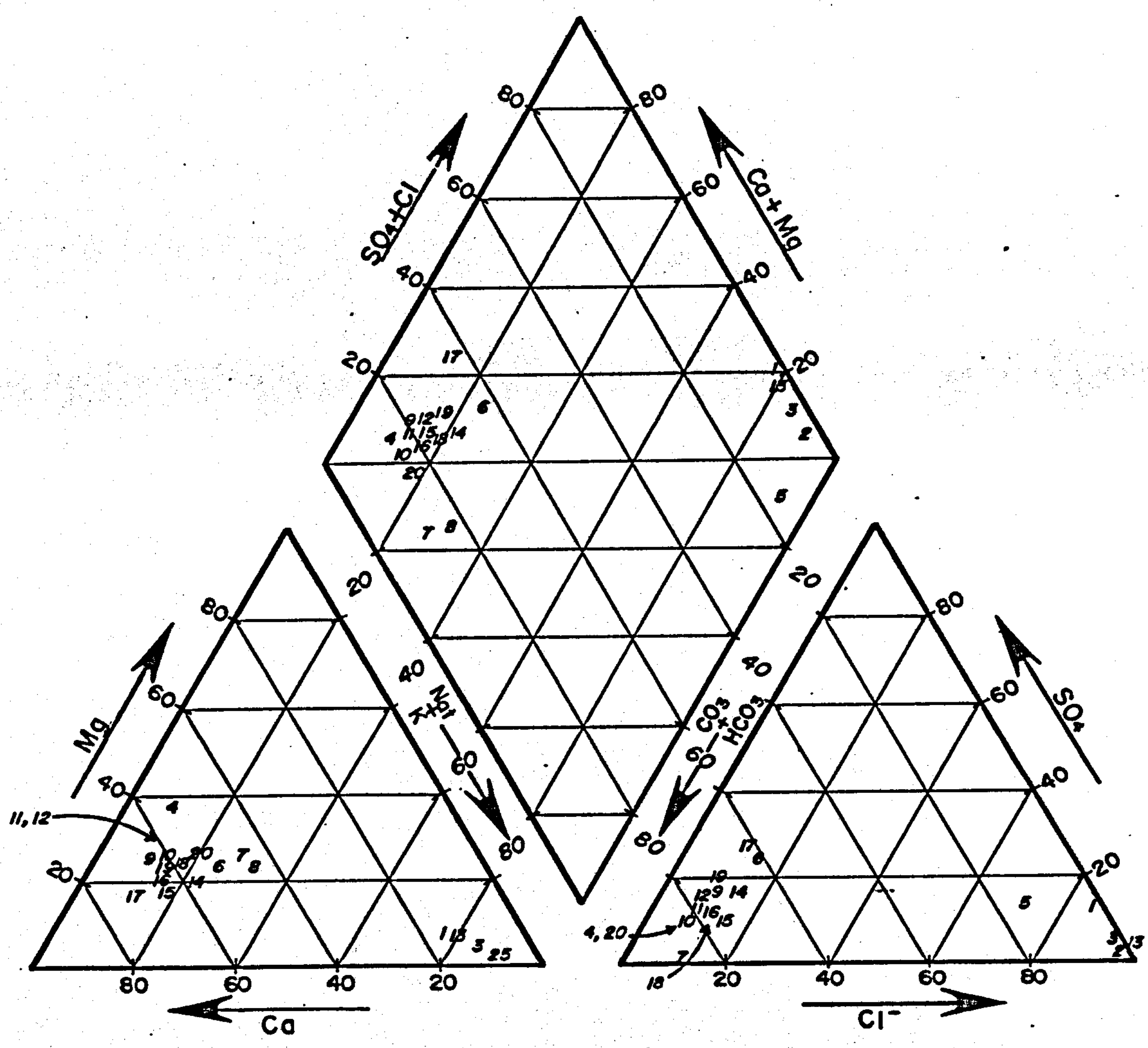
TABLE 4 (cont.)

Limits of Quantitative Determination (LQD)
for Solution Analysis by the ESL ICPQ.

ELEMENT	LQD (mg/l)
Na	3
K	3
Ca	2
Mg	2
Fe	.02
Al	.5
Si	1
Ti	.1
P	.5
Sr	.02
Ba	.5
V	1
Cr	.04
Mn	.2
Co	.02
Ni	.1
Cu	.1
Mo	1
Pb	.2
Zn	.1
Cd	.1
Ag	.04
Au	.08
As	.5
Sb	.6
Bi	2
U	5
Te	1
Sn	.1
W	.2
Li	.04
Be	.004
B	.1
Ar	.1
La	.1
Ce	.2
Th	3

LQD concentrations represent the lowest reliable analytic values for each element. Precision at the LQD is approximately ±100% of the given value with a confidence level of 95%.

FLUID CLASSIFICATION - HAFB



ESL NUMBERS

1 Wasatch H.S.	7 HAFB 4
2 Ogden H.S.	8 HAFB 5
3 Utah H.S.	9 HAFB 3
13 Hooper H.S.	10 HAFB 2
4 Barker Trout Farm	11 HAFB 7
5 Near Utah H.S.	12 HAFB 6
6 Hamre Sp	16 Off Base 16
14 So. of Weber Canyon	18 Off Base 18
15 Private	19 Off Base 19
17 Weber River	20 Off Base 20

FIGURE 8

portions of the East Shore area (Feth and others, 1966). The second group of waters is represented by the hot springs (Ogden, Utah, Hooper, Wasatch) and a warm spring located near Utah Hot Springs. These waters range in temperature from about 28° to 57°C and are enriched in Na + K and Cl. They also have correspondingly higher ionic strengths (0.02 to 0.4).

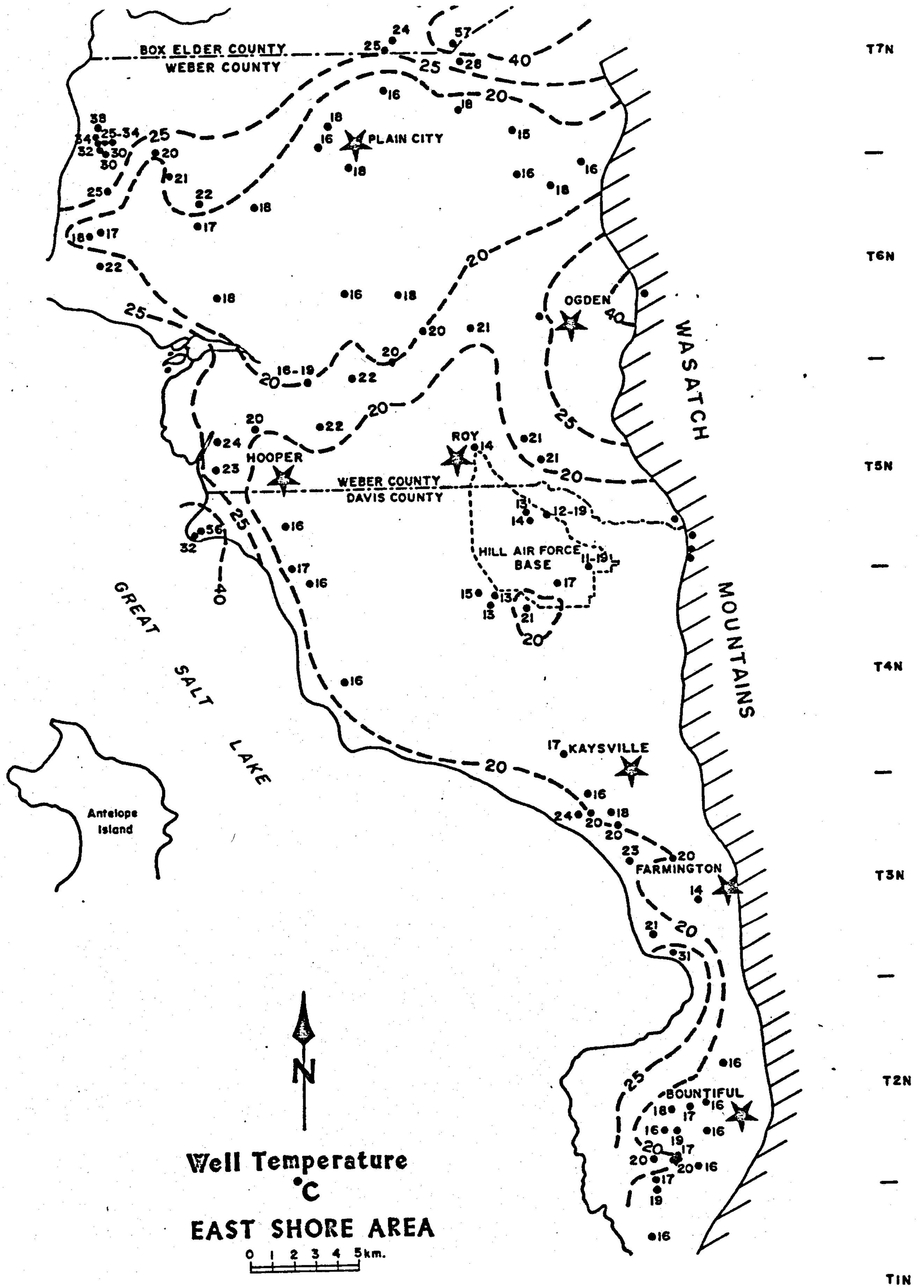
Thermal waters in the Hill AFB area probably represent the surface manifestations of water circulated to depth along faults in a near-normal heat flow regime. Such systems are typically characterized by dilute chloride-bicarbonate-sulfate springs, with total salt concentrations less than 1 gm/l and temperatures commonly below 100°C. The discharge rates of the springs are usually small and storage of water within the systems is not large (Ellis and Mahon, 1977). Many of these features are common to the hot springs and warm springs in the East Shore area.

In addition to the differences observed between these two major water types, local variations in chemistry exist within each group. Three distinctly different fluid chemistries are present within the low-temperature group: the Weber River, wells and springs on and off the base, and two wells located in the south-southeastern portion of the base.

Thermal waters of the East Shore area also exhibit variations. The warm spring located near Utah Hot Springs is lower in temperature and somewhat less enriched in Cl^- + SO_4^{2-} than the hot springs, perhaps as the result of greater groundwater mixing with a thermal fluid.

Evaluation of regional temperature and chemical data (study in progress at the Earth Science Lab) indicates that ground waters from the Hill AFB area differ little from the surrounding ground waters. Consequently the small ranges in element concentrations observed on Hill AFB may not be regionally significant. Figures 9 and 10 show the distribution of temperatures and chloride in wells and springs in the East Shore area. In general, Hill AFB is situated in a region dominated by low-chloride, low-temperature waters. The configuration of the contours in these figures suggests that the majority of the water supplying the Base comes from the east, through Weber Canyon, with flow continuing principally to the southwest, west and northwest beyond the Base. Chloride infiltration from the Great Salt Lake is evident in wells located near the shore line, and anomalous concentrations of chloride are also found near Utah and Ogden Hot Springs.

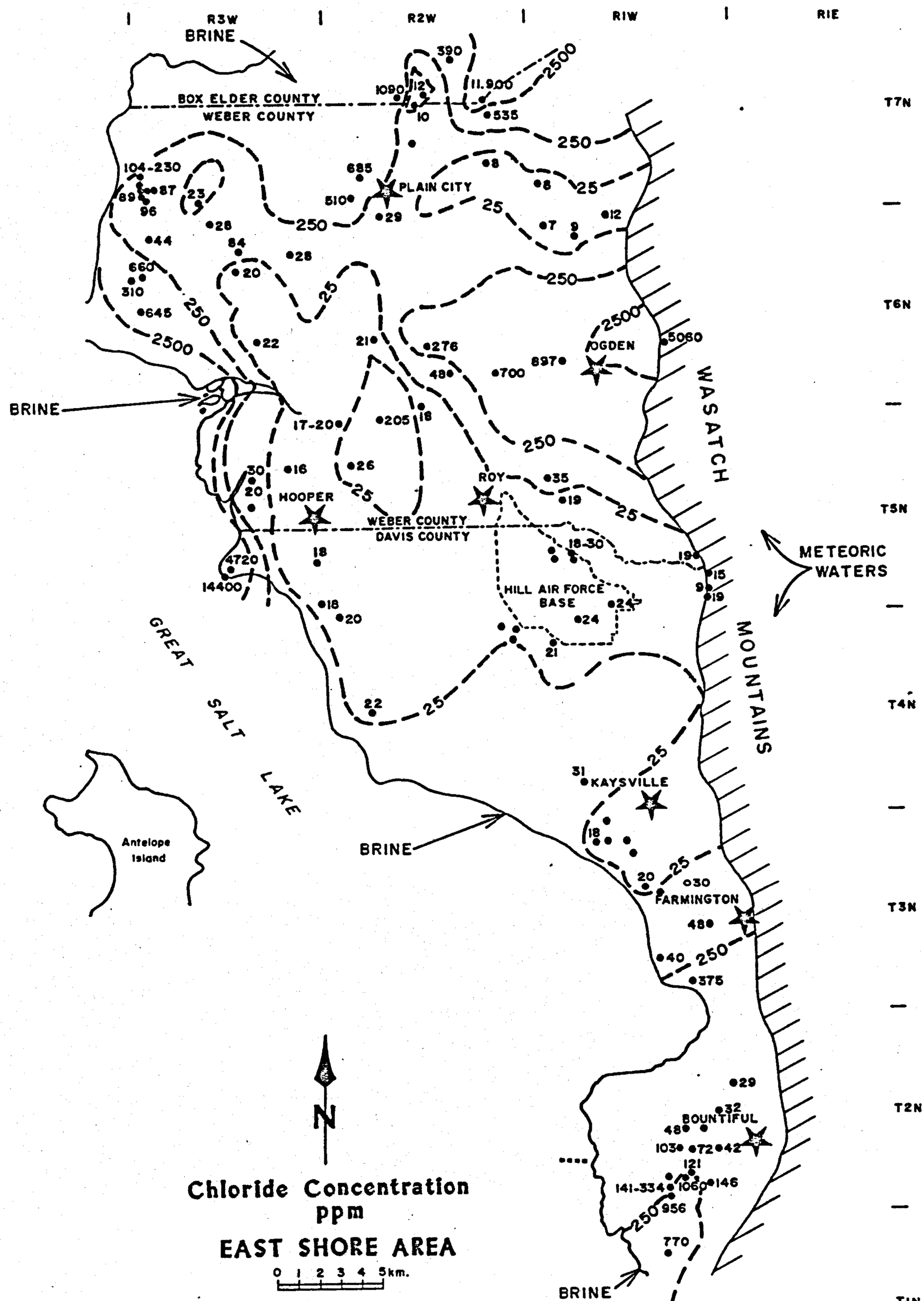
Stable isotope analyses of hot springs in the East Shore area (Cole and Ohmoto, unpublished) indicate that waters in this region are of meteoric origin. δD values for Ogden and Hooper Hot Springs are nearly identical at -135.1°/oo and -133.8°/oo, respectively. The $\delta^{18}O$ values range between -14.9°/oo and -16.6°/oo for Ogden and Hooper Hot Springs, respectively. The enrichment of $\delta_{18}O$ in Ogden Hot Springs relative to Hooper Hot Spring could reflect an isotopic shift accompanying rock-water interaction at a somewhat higher temperature (Ogden 150°C, Hooper 100°C). The deuterium content in these fluids indicates that meteoric water originating at the mountain flank east of Ogden Hot Springs remains essentially unchanged after transport to the site of Hooper Hot Springs, across the valley. Influx of deuterium-enriched Salt Lake brine appears to be negligible at Hooper Hot Springs, even though



Well Temperature °C

EAST SHORE AREA

FIGURE 9



Chloride Concentration
ppm
EAST SHORE AREA
0 1 2 3 4 5km.

FIGURE 10

the spring is located adjacent to the lake shore. This result suggests the presence of a structural condition that allows for flow primarily from the east.

Geothermometry:

One test for the existence of a thermal component in ground water is to estimate subsurface temperatures from compositions of spring and well waters using geothermometry (Table 5). The reliability of the geothermometers depends on the existence of temperature-dependent equilibria at depth, which are quenched during ascent to the surface. Equilibrium in the reservoir may be attained for some reactions and not for others.

Application of geothermometers to water analyses from the Hill AFB area indicates that equilibration temperatures in the hot and warm springs exceeds approximately 50°C, while temperatures in cooler wells and springs fall below 50°C.

The temperature estimates given in Table 5 for springs and wells demonstrate the difficulty in assigning a reliable subsurface temperature to any given fluid. A trend of lower Na-K-Ca temperatures is typical of most of the cooler wells and springs on and near Hill AFB, while hot springs and the warm spring give moderately high Na-K-Ca temperatures (150° to 230°C) but lower quartz (conductive) and chalcedony temperatures (<100°C).

In most cases, measured well and spring temperatures for the non-thermal waters are reasonably close to either chalcedony or Na-K-Ca estimates of

Table 5. Geothermometer Temperatures of Hot Springs, Wells and Cold Springs (oC)

Name	Qtz (Cond)	Chalcedony	Na-K-Ca
Wasatch	53	21	150
Ogden	97	67	219
Utah	82	51	231
Hooper	77	45	197
Barker Farm Spring	29	--	2
Near Utah Spring	60	27	194
Hamre Spring	51	18	30
So. Weber Canyon	33	1	8
Private	20	--	9
Weber R.	25	--	5
HAFB 4	62	28	53
HAFB 5	55	21	57
HAFB 3	39	6	12
HAFB 2	39	7	15
HAFB 7	39	7	14
HAFB 6	39	7	15
Off Hill 16	23	--	9
Off HIll 18	48	15	28
Off Hill 19	51	18	24
Off Hill 20	48	15	32

Table 5. (continued)

Equations for Geothermometers used to compute subsurface temperatures given in Table 2 (SiO_2) in ppm)

Quartz (conductive):

$$T(^{o}C) = \frac{1309}{5.19 - \log SiO_2} - 273.15$$

Chalcedony:

$$T(^{o}C) = \frac{1302}{4.69 - \log SiO_2} - 273.15$$

Na-K-Ca: (unit in molal)

$$T(^{o}C) = \frac{1647}{\log(Na/K) + B \log(\sqrt{Ca/Na}) - 2.24} - 273.15$$

where $B = 1/3$ for $T > 100^{o}C$
$= 4/3$ for $T < 100^{o}C$

Source: Fournier (1977)

equilibration temperature, which indicates the absence of any warm water component in the aquifer below the base.

Discussion of the Ground Water Model

Based on the observations of fluid types, element distributions, subsurface temperatures, mineral-fluid reaction paths and mineral-fluid equilibrium relationships (Earth Science Lab unpublished data), a model of fluid path lines from source region to spring and well locations has been drawn (Figure 11). This model assumes that the source of the thermal energy present in hot spring waters is from the normal geothermal gradient and that certain mineral assemblages were encountered along the pathlines as the water circulated from the source regions (Norton and Panichi, 1978). Figure 11 shows a schematic geologic cross section based in part on geophysical data discussed below, and depicts relationships that may exist between fluid flow, structure and temperatures for the system.

Water emerging at the mouth of Weber Canyon and along the Wasatch Front is a Ca + Mg and HCl_3 + CO_3 enriched fluid. This fluid is diverted in several directions as it moves into the deltaic-alluvial sediments of the basin. Of the fluid that infiltrates to depth in the mountains, part is heated and enriched in Na + K and Cl and then returned to the surface along faults (i.e., Ogden Hot Springs). A portion of this deeply circulating fluid probably continues on to greater depths and migrates along the bottom of or in the bedrock beneath the basin. It may be heated due to the thermal gradient to about 80^{o} to $100^{o}C$, and perhaps equilibrates with feldspar, mica and quartz (Earth Science Lab, unpublished data.)

GROUND WATER MODEL

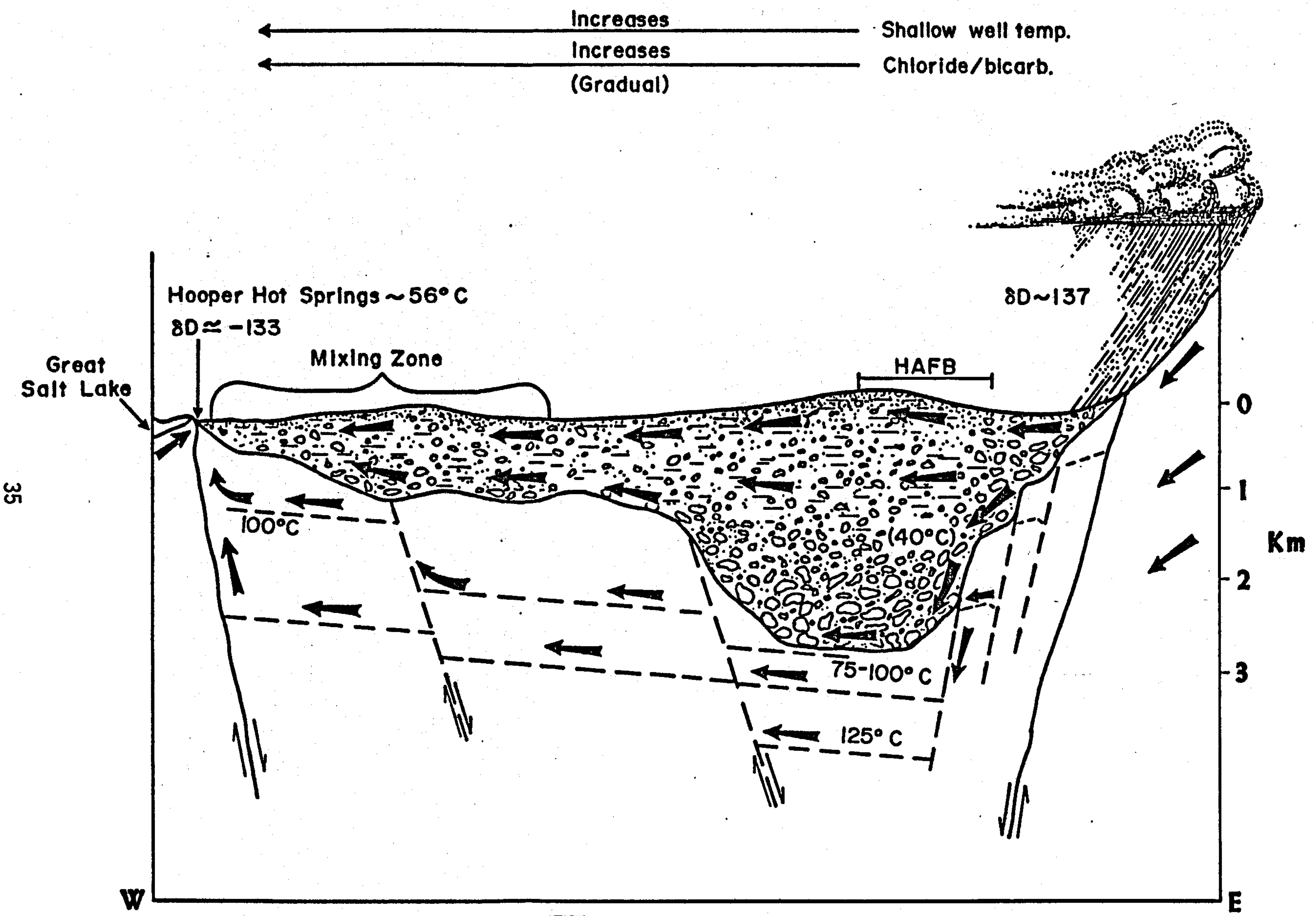


FIGURE 11

alluvium
bedrock
thrust fault or fractures in bedrock
normal faults (arrows indicate movement)
direction of water movement

In the shallow subsurface, a large volume of Ca + Mg, HCO_3 + CO_3 water flows through valley sediments and forms most of the aquifer water found in the valley. This cold fluid appears to be in equilibrium with a mineralogic assemblage thought to be more characteristic of sediments found in the upper and middle horizons of the valley (Earth Science Lab, unpublished data).

The temperatures of the hot springs, prior to mixing with cooler ground water, are estimated to average between 70° and 150°C. These higher temperature fluids have equilibrated with minerals such as K-feldspar, K-mica, quartz, and clay (Earth Science Lab, unpublished data) which are typically found in bedrock or deep alluvial lithologies.

Summary

Chemical modeling of the East Shore area and Hill AFB indicates that no thermal fluid component is present in the shallow subsurface waters beneath the Base. Waters on the Base are typical of ground waters located elsewhere in the central and eastern portions of the East Shore area. The fluids emerging at various hot spring localities represent meteoric waters that have undergone deep circulation along faults, increased in temperature to 80°-150°C and returned to the surface where the warm waters mix with cooler groundwaters.

These analytic results did not indicate that a major component of thermal water has mixed with cold water in the near-surface aquifers, and the task of further water sampling (Task II-1) was not undertaken.

PHASES I and II

Tasks I-5 and II-3 Gravity and Reflection Seismic Surveys

Introduction

VIBROSEIS* seismic and detailed gravity surveys were conducted in the vicinity of Hill AFB. The objective of these surveys was to delineate subsurface structures, particularly faults, that might control migration of deep geothermal fluids to near-surface levels. Thermal gradient drill hole sites were to be selected using the results of the seismic and gravity surveys.

The seismic data were collected and processed by Seismograph Service Corporation (SSC). The survey began on May 15, 1979 and was completed on June 12, 1979. The processing was completed on July 2, 1979.

The gravity data were collected and interpreted by Earth Science Laboratory staff. Surveyed elevations of gravity stations were provided by Hill AFB engineering staff.

The area around Hill AFB contains residential subdivisions, small businesses, schools, water tanks, and major highways. The base is extremely busy and contains numerous buildings, jet ramps, runways, and restricted storage areas. This cultural development precluded the use of many geophysical techniques. Gravity and reflection seismic surveys were therefore believed to be optimum choices from both logistic and information aspects.

*TM Continental Oil Company

The reflection seismic survey needed to be a controlled source technique such as VIBROSEIS. Drilling shot holes and detonating dynamite were not feasible in any part of the survey area.

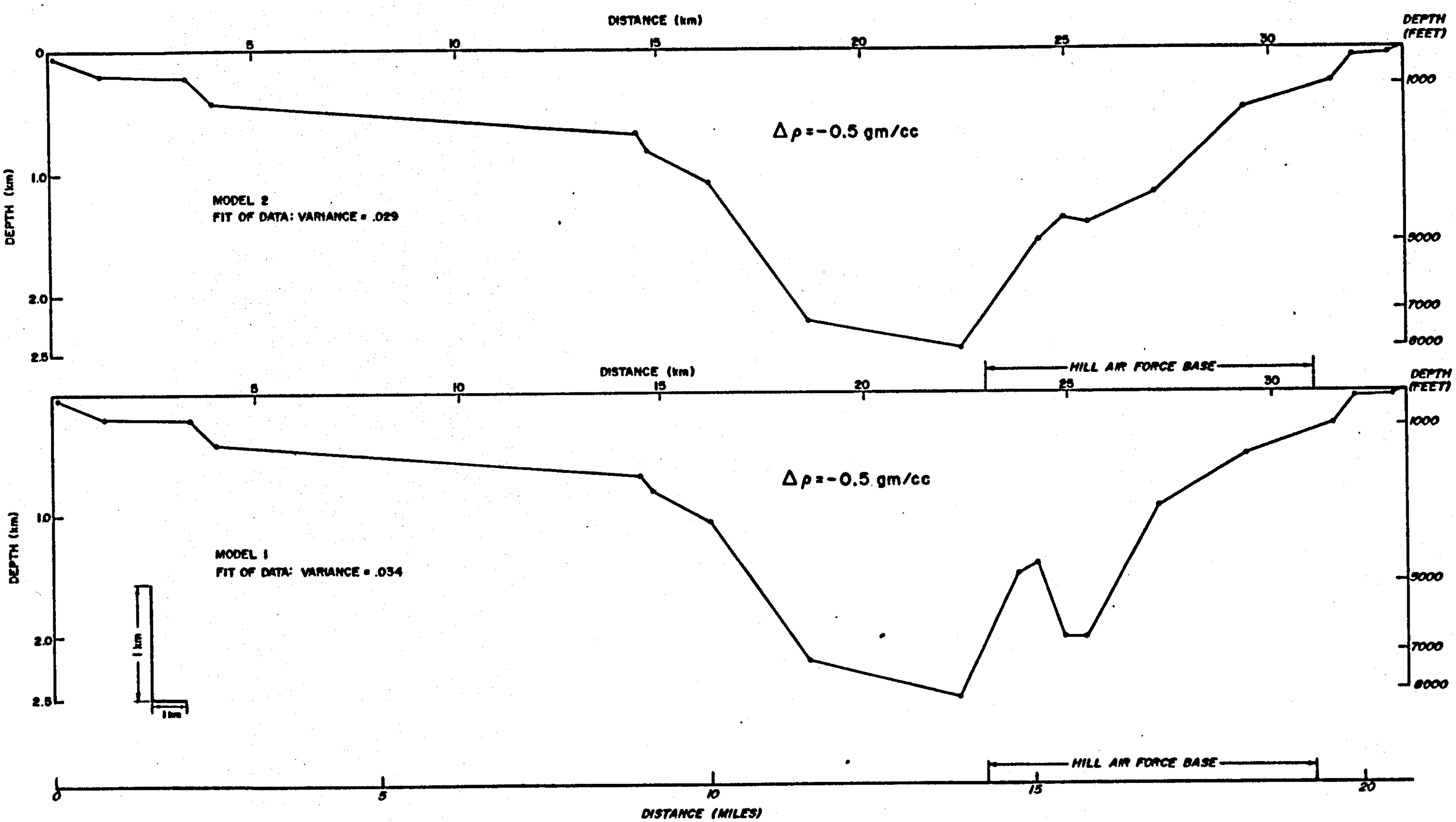
Gravity Survey

Introduction

Available gravity data from work of Lum (1957) was interpreted using a two and one-half dimensional algorithm (Snow, 1978). Two models that fit these data within reasonable error are shown in Figure 12. These data were interpreted in order to provide control on the design of the seismic survey. Both interpreted models indicated that Hill AFB is situated over the eastern side of a graben. The depth to bedrock changes from approximately 0.98 km (3200 ft) at the eastern edge of the Base to approximately 2 km (6600 ft) at the western edge of the Base. A single density contrast of -.5gm/cc was used for these interpretations. Density contrasts typically diminish with depth, and therefore the depth to bedrock could be greater. Hence the depths indicated in Figure 12 should be regarded as minimum depths to the bedrock surface.

The graben is bordered on the east by the Wasatch Fault and the Wasatch mountains. The gravity models suggested that multiple faults, possibly parallel to the Wasatch fault, could underlie the eastern edge or possibly all of the air base.

In an attempt to locate these faults more accurately, both a detailed gravity and a reflection seismic survey were conducted over Hill AFB.



Preliminary Interpretation of Gravity Data
Hill Air Force Base and Vicinity

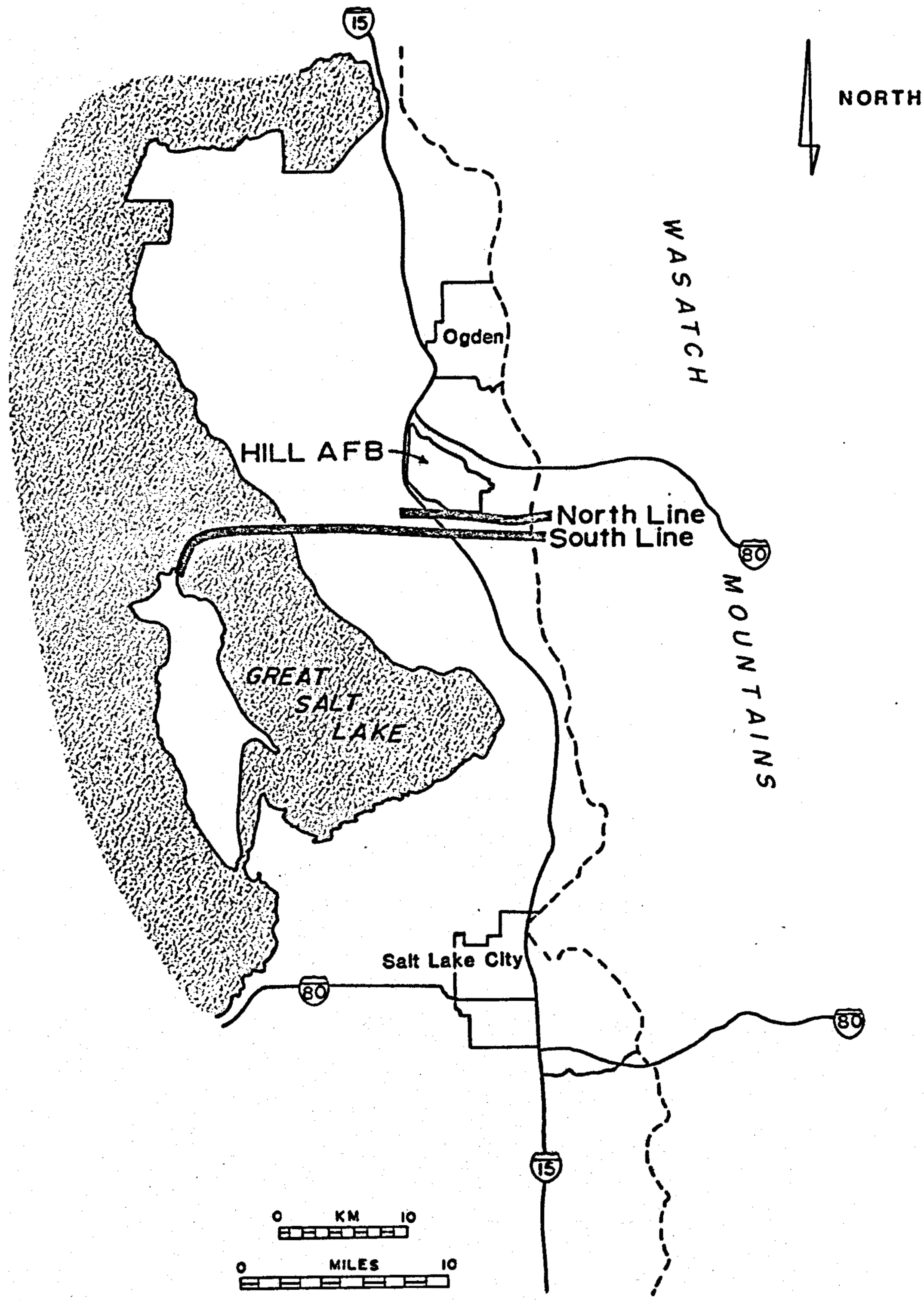
FIGURE 12

Collection of Gravity Data

The two gravity profile locations are shown in Figure 13. The south line was carried westward to Antelope Island in order to define the regional gravity trend to aid in determining a residual gravity anomaly. Except for a few stations at the eastern end of both lines, the station spacing was 152 m (500 ft). Station locations were surveyed to within 0.305 m (1 ft) and elevations to within 0.0305 m (0.1 ft). Personnel from the civil engineering group at Hill AFB did the surveying work. A few station elevations were surveyed with altimeters. Altimeter looping was done every 30 to 45 minutes to minimize drift. Stations with known elevations were included in the loop and indicated the altimeter elevations varied by no more than ± 0.915 m (3 ft) and, in some cases, varied as little as ± 0.305 m (1 ft).

The gravity readings were taken using a La Coste and Romberg gravimeter, and loops were made every 2 to 2.5 hours to minimize effects of tidal variations and instrument drift. A field base station was established at the street intersection 1.61 km (1 mi) south of Clearfield High School. Temporary base stations were established nearer the working areas as needed to reduce travel.

Additional readings were taken at the beginning and the end of each day, both at the field base and at the University of Utah Base Station in Liberty Park (Cook and others, 1971). Two stations were re-occupied to check for operator error. Initial and re-occupied data were within 0.006 mgal.



LOCATION OF GRAVITY PROFILES
HILL AIR FORCE BASE, UTAH

FIGURE 13

Gravity Data Reduction

All computer programs used for data reduction were provided by Dr. K. L. Cook and Laura Serpa at the University of Utah. The data were first corrected for the sensitivity factor of the instrument, tidal variations, and instrument drift. Simple Bouguer anomaly (SBA) gravity values were computed using a density of 2.67 gm/cc. Terrain corrections were calculated for each station out to 0.8 km (one-half mile) or zone F of the Hammer charts (Hammer, 1939). Terrain corrections to 161 km (100 miles) were calculated using a United States Geological Survey program and digitized data (Plouf, 1977). As a check, terrain corrections out to 161 km (100 miles) were obtained by hand for 12 stations using United States Department of Commerce, Coast and Geodetic Survey zone charts. The terrain corrections differed by -.06 to +.87 mgals among stations compared. The discrepancy was commonly less than .25 mgals, and the largest discrepancies occurred at stations in areas of greatest relief. A study of causes for these discrepancies is underway at the University of Utah (Laura Serpa, personal communication). The computer generated terrain corrections are believed, at this time, to be more accurate and were employed to correct the data used in the gravity interpretation. The terrain correction differences would not significantly affect the following gravity data interpretations.

Gravity Data Interpretation

The Complete Bouguer Anomaly (CBA) gravity data and the assumed regional and residual gravity data anomaly are shown in Figure 14. The data were interpreted using computer programs and procedures described by Snow (1978).

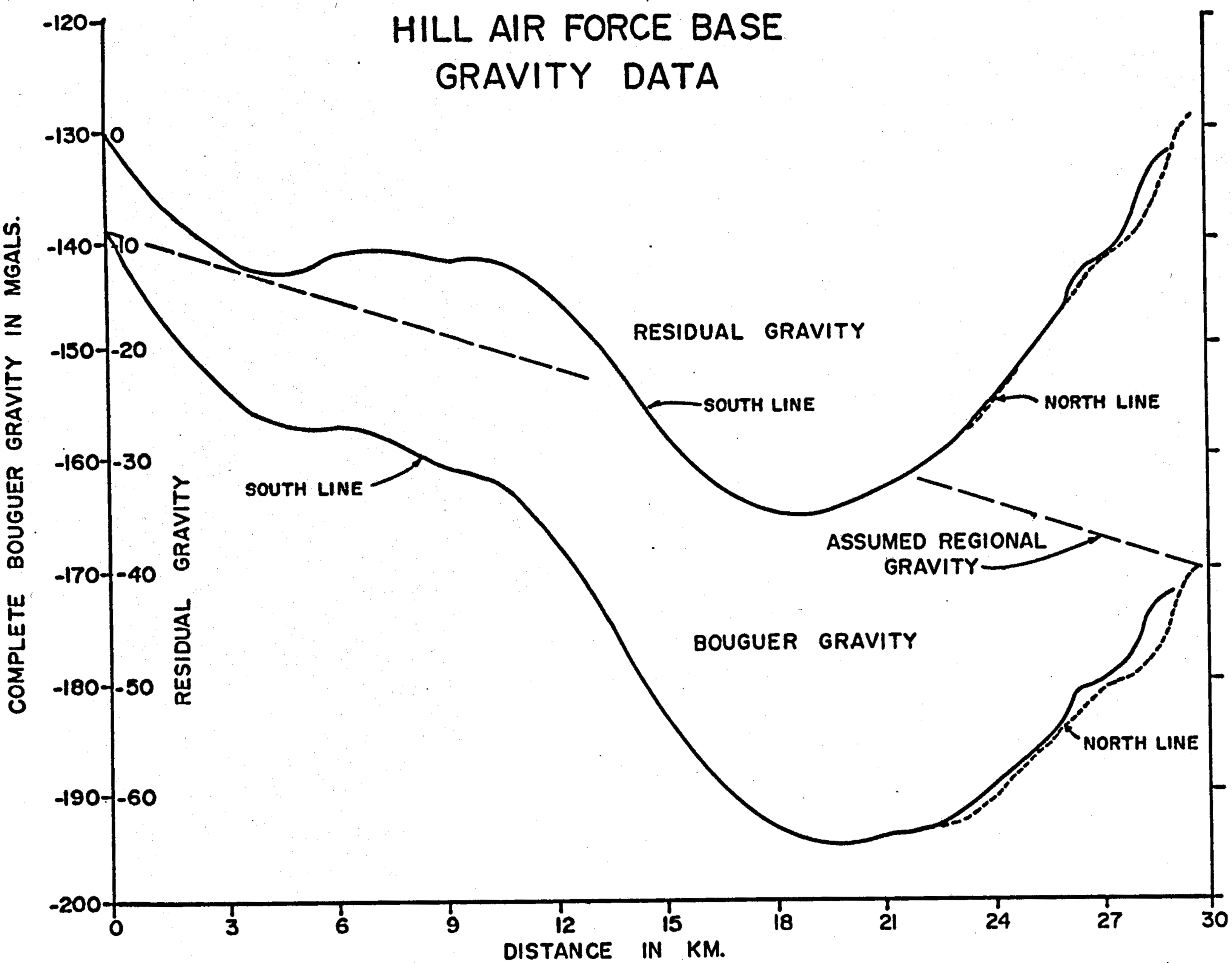

HILL AIR FORCE BASE
GRAVITY DATA
COMPLETE BOUGUER GRAVITY IN MGALS.
RESIDUAL GRAVITY
-120
-130
-140
-150
-160
-170
-180
-190
-200
0
-10
-20
-30
-40
-50
-60
RESIDUAL GRAVITY
SOUTH LINE
NORTH LINE
SOUTH LINE
ASSUMED REGIONAL GRAVITY
BOUGUER GRAVITY
NORTH LINE
0
3
6
9
12
15
18
21
24
27
30
DISTANCE IN KM.

FIGURE 14

The interpretation was made using a forward solution algorithm rather than direct search or inversion algorithms. The data were interpreted using both constant and variable density models. The interpreted models for the south and north lines are shown in Figures 15, 16, and 17. The models should not be regarded as unique as both single (Figure 15) and variable (Figure 16) density models are found to fit the south line data equally well.

Fault locations may be postulated in the gravity model where the model has steps in the polygon sides. Gravity models, although reasonable, are arbitrary without subsurface control, which is lacking at depth in the Hill AFB area.

Discussion

Although a variety of models might equally match the observed gravity data, the models could be expected to reflect similar properties. The graben structure is firmly established. The east side of the graben is steeper than the west side and both sides probably contain more than one normal fault. One or more faults on the east side probably lie beneath the area of Hill AFB. The gravity interpretations indicate that the depth to bedrock (to rock having a density of 2.67 gm/cc) beneath Hill AFB ranges between 0.458 km (1500 ft) on the east to 2.29 km (7500 ft) on the west. These depths are probably minimum estimates since true subsurface densities are not known and may be higher, resulting in lower density contrasts, and the factors for regional gravity correction, although reasonable, are not exact.

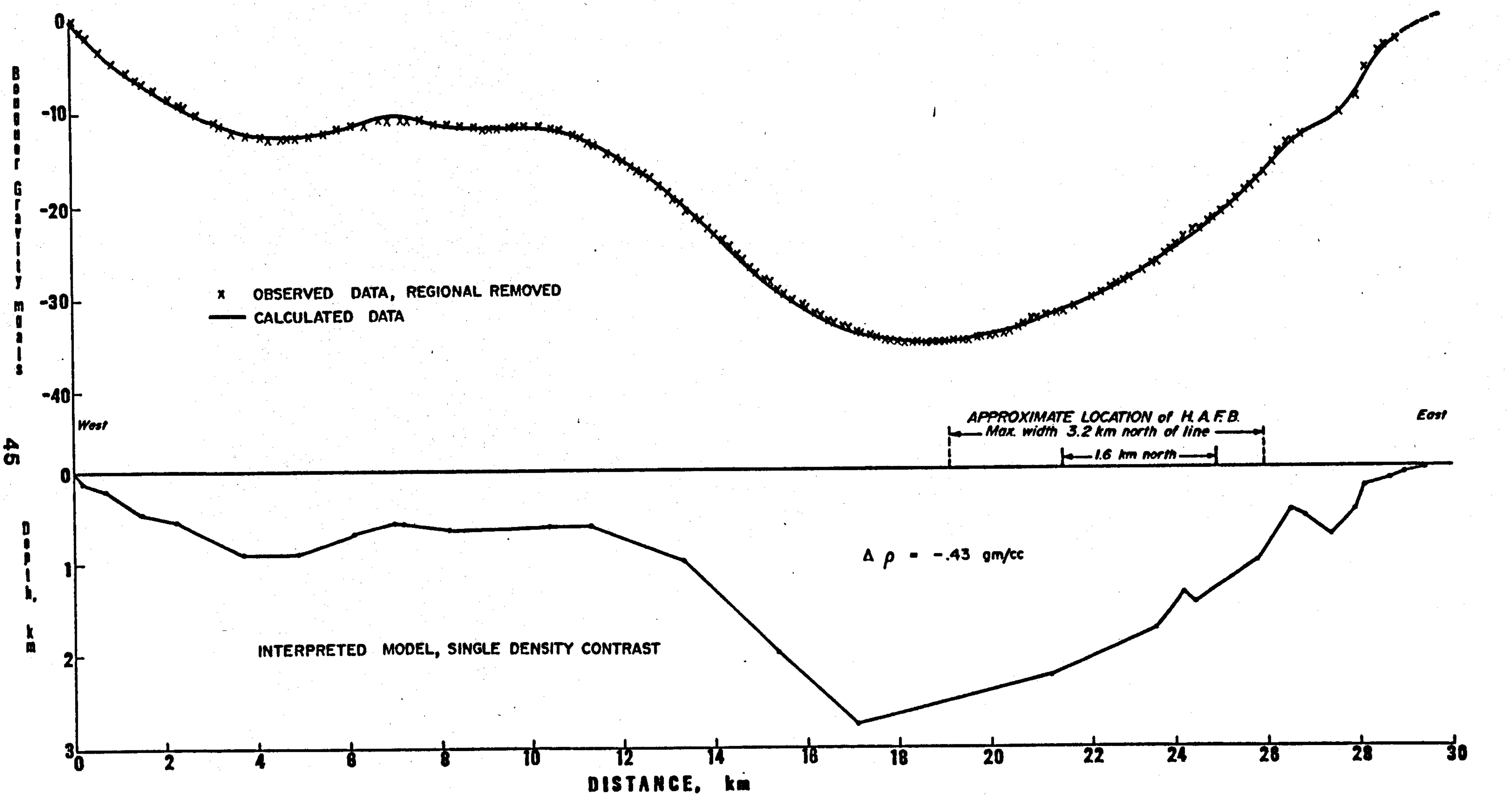


Figure 15 Bouguer Gravity and Interpreted 2-D Model for South Line Gravity Profile
Hill Air Force Base, Utah

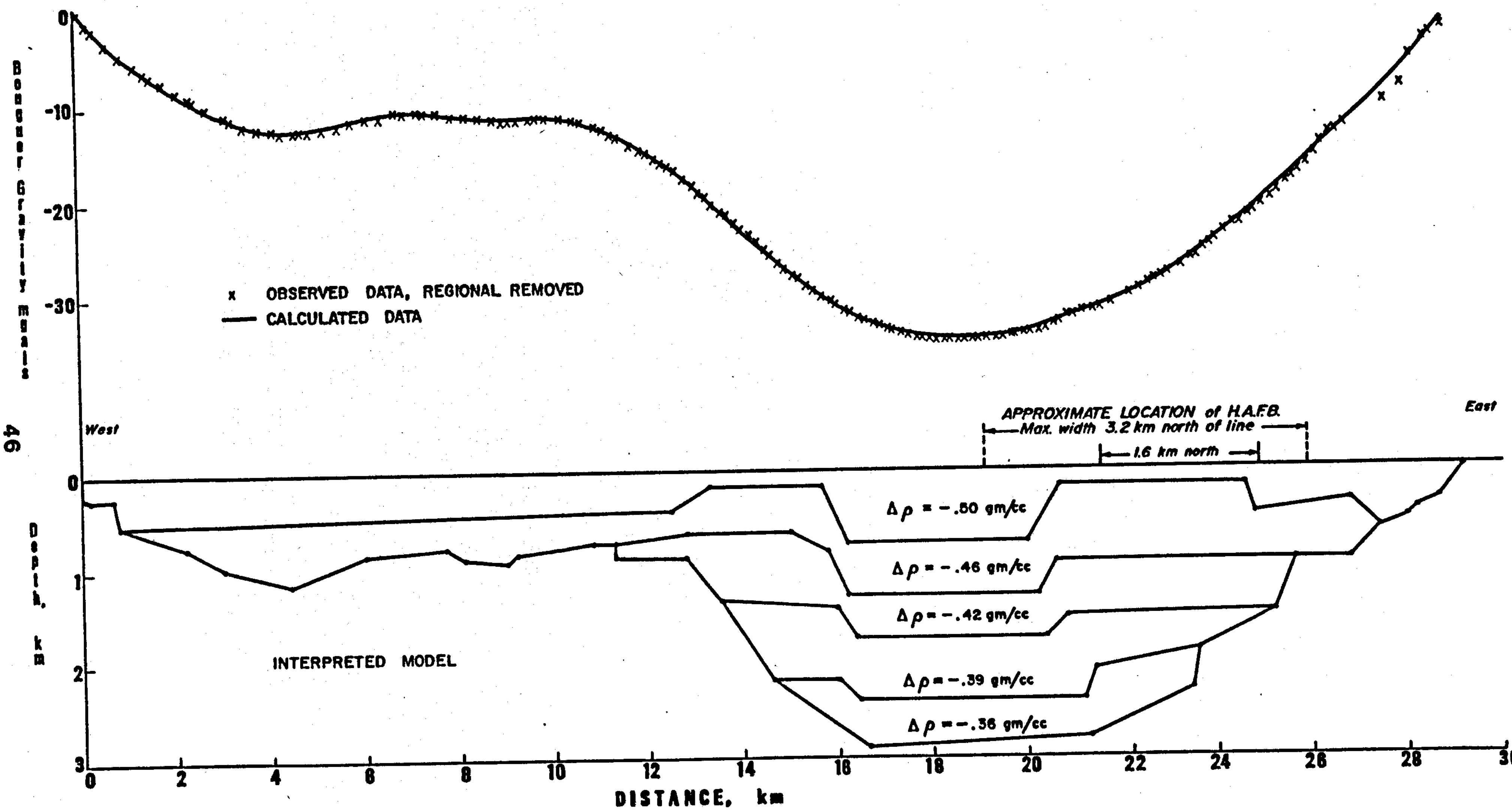


Figure 16 Bouguer Gravity Data Interpretation of South Line, Variable Density Model Hill Air Force Base, Utah

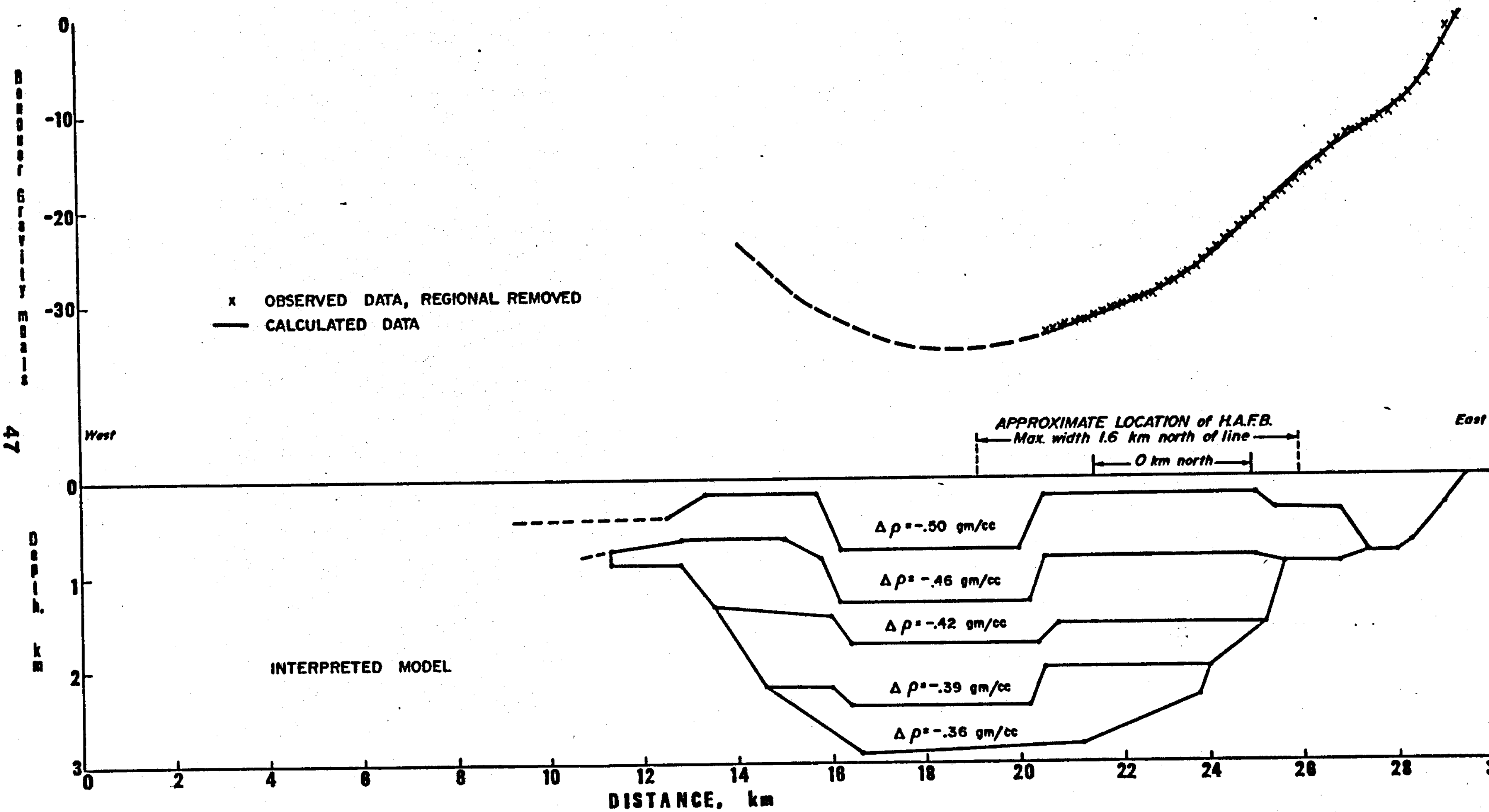
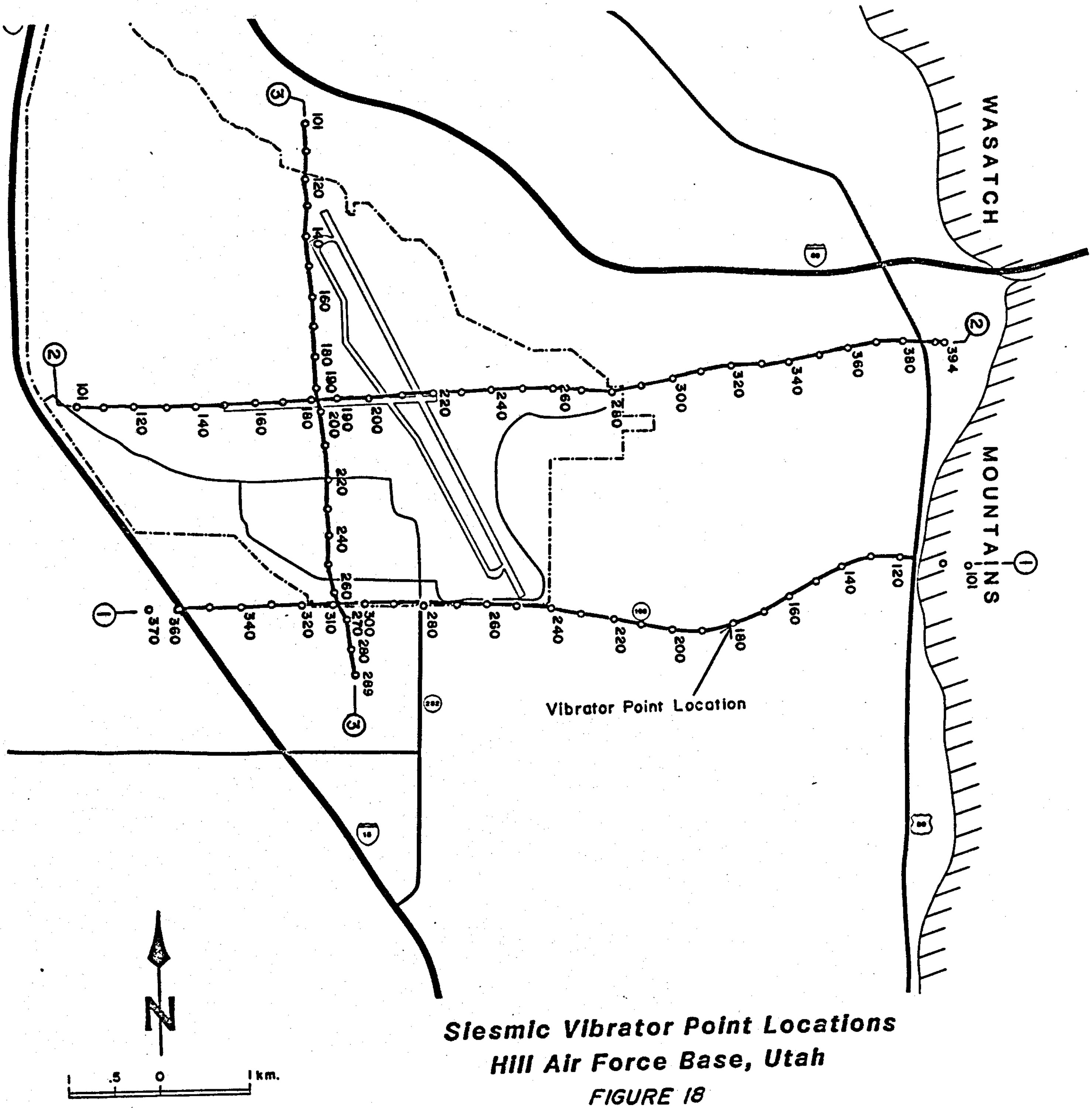


Figure 17 Bouguer Gravity Data Interpretation of North Line, Variable Density Model Hill Air Force Base, Utah

Reflection Seismic Survey

Introduction

A VIBROSEIS reflection seismic survey was conducted in the vicinity of Hill AFB by Seismograph Service Corporation under contract to the University of Utah Research Institute. Two east-west lines and one north-south tie-line were surveyed (Figure 18). Line 1 begins east of US Highway 89, approximately 457 m (1500 ft) east of the mapped position of the Wasatch Fault (Bryant, 1979). The line follows Utah State Highway 193 (Hill Field Road) west to Interstate I-15. The line passes the southern boundary of the air base. The line passed many private houses, paralleled buried sewers and water mains and, at vibrator point 230, the line passed several water storage tanks. Line 2 began east of US Highway 89, possibly just west of the Wasatch Fault (Bryant, 1979). The line crossed private land and continued through Hill AFB to its western edge. On the base, line 2 crossed the main runway and jet ramps, which necessitated vibrator point gaps. Line 3 began at the north end of Hill AFB and ended on private land south of the base. The line crossed a jet parking area and Utah State Highway 193, which again created vibrator point gaps. The south end of line 3 was curved slightly east to avoid the water tanks and a major power line. Also, the south end of line 3 was terminated by hay fields. The result was less common-depth point stacking of line 3 than was intended where it crossed line 1. Where the vibrators came close to homes or water tanks, their power was reduced. High traffic noise levels and less energy into the ground generated poorest signal-to-noise records on line 1.



Siesmic Vibrator Point Locations
Hill Air Force Base, Utah
FIGURE 18

Noise Study and Choice of Seismic Survey Parameters

A noise spread utilizing three sweeps, two sweep lengths, and several geophone and vibrator patterns was completed before the actual survey began. The noise study was designed by Seismograph Service Corporation; its parameters are sketched in Figure 19.

Three parallel spreads of 16 stations were utilized, each with 33.5 m (110 ft) station intervals. Three geophone patterns were used: (1) 24 geophones, 33.5 m (110 ft) inline; (2) 24 geophones, 67 m (220 ft) inline; and (3) 12 geophones in a 2 ft (0.61m) circle. A 56-14 Hertz downsweep and a 15-80 Hertz upsweep were used. Data were collected for both a 9- and 14-second sweep time and 16 sweeps per vibrator were used in each case. The 15-80 Hertz sweep was sampled at 2 ms intervals and the 56-15 Hertz sweep was sampled at 4 ms intervals. These sweeps were vibrated from distances of 134, 671, and 1208 m (440, 220, and 3960 ft) into the various geophone patterns using 33.5 m (110 ft), 67 m (220 ft) and stacked vibrator patterns. The noise study was done at vibrator points 210, 226, and 242 on line 1.

The data from the various tests suggested the 56-14 Hertz downsweep gave the best results and sampling at 4 ms intervals was sufficient. All patterns that included a 67 m (220 ft) geophone spread or 67 m (220 ft) vibrator spread looked better than 33.5 m (110 ft) spreads. The results for a 67 m (220 ft) spread for both the geophones and the vibrators were not markedly better than any of the 67-33.5 m (220-110 ft) combinations. For logistic reasons we decided to use 67 m (220 ft) for both the vibrators and the geophones. A 14-second sweep was preferred to improve the signal-to-noise ratio.

NOISE STUDY PATTERNS

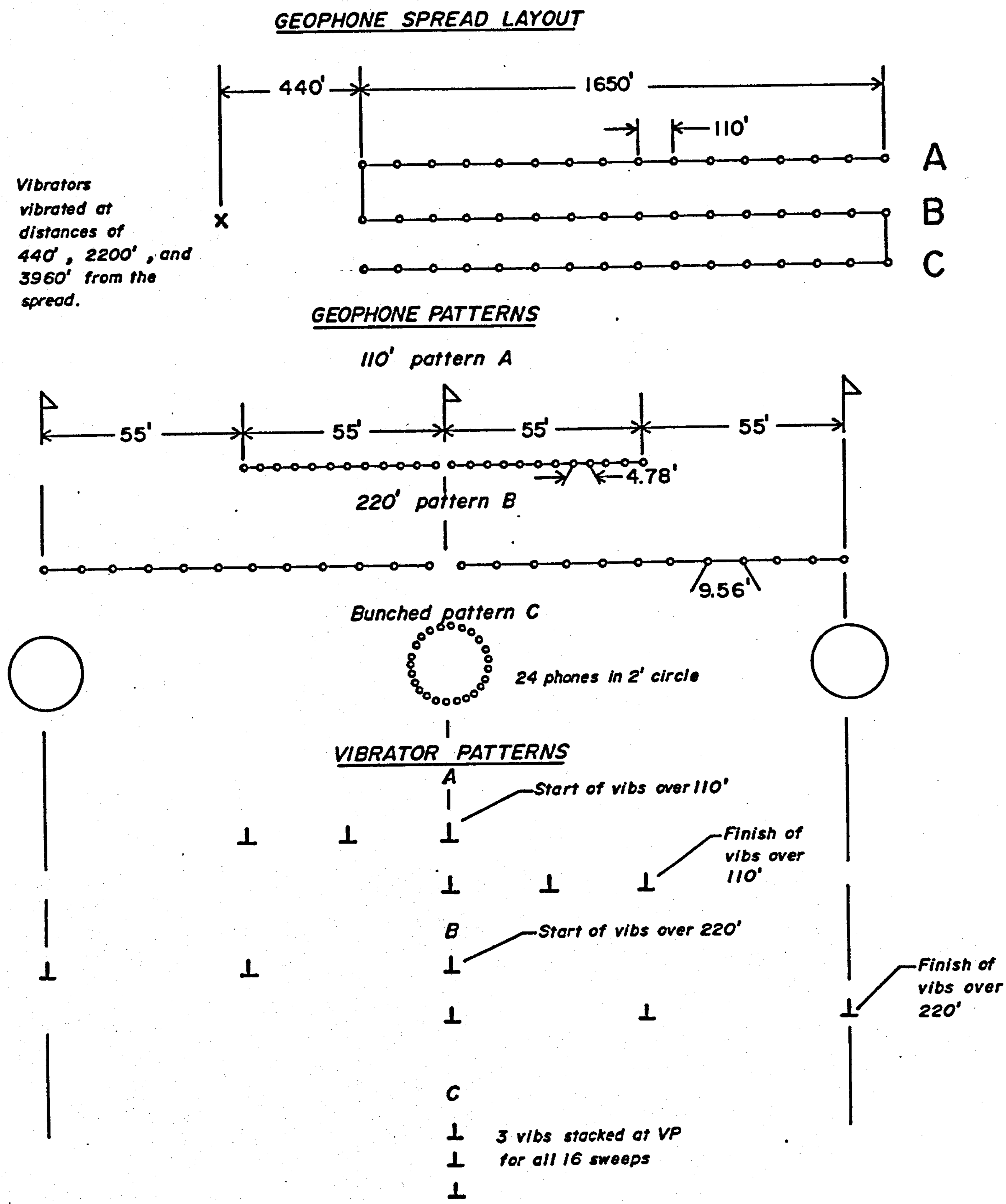


FIGURE 19

Seismic Data Acquisition and Processing

The VIBROSEIS survey parameters used in the Hill AFB project are shown in Table 6. The geophone and vibrator patterns used are shown in Figure 20. High traffic volume along line 1 caused several breaks in the geophone cables and many survey delays. Heavy road construction machinery created noise problems on the west end of line 1, in the same area where the vibrators were turned down beside houses and buried water tanks. Three vibrators were operating at all times. Four vibrators were in operation along most of line 2.

Raw field data were summed and correlated in the field on a Phoenix 704 mini-computer. Brute stacks of the data were generated as the survey progressed. These stacks permitted early evaluation of data quality and survey parameters, and a preliminary interpretation of the subsurface structure and stratigraphy. The location of the north-south tie line (line 3) was determined after reviewing the brute stack of line 1.

The summed and correlated data tapes were shipped to SSC's Denver office for final processing. The processing parameters and sequence are given in Table 7. The processed data are displayed in Figures 21, 22 and 23. The figures include an overlay showing inferred fault locations and stratigraphic reflections. An interpretation is discussed below.

The seismic data look very good down to 1.0 second, fair to poor between 1.0 and 1.5 seconds, and poor below 1.5 to 2.0 seconds. True reflections below 2.0 seconds may be present in data on lines 2 and 3. The data quality do not justify any interpretation below 2.0 seconds, and little confidence should be placed on interpretations below 1.2 seconds.

TABLE 6
VIBROSEIS* Survey Parameters

OPERATION METHODS	
Method used:	24-fold common depth point
Recording spread used:	Inline asymmetrical (36 traces west, 12 traces east)
Offset distance: (source center to nest center)	440 feet - near traces (36,37) 4920 feet - far trace
Station spacing:	110 feet
Geophone interval:	9.56 feet between phones - centered on the recording station with first phone 4.78 feet from station flag. Total pattern length of 220 feet by 0 feet wide. 2 strings of 12 phones connected in series-parallel giving 24 phones per nest.
Geophone type:	EV-22, 8 Hz phones
VP Interval:	220 feet
Vibrator pattern:	3 or 4 vibrators inline for total pattern length of 220 feet. 55 feet spacing when using 3 vibrators, approximately 37 feet spacing when using 4 vibrators
Number of sweeps per vibrator per trace:	16 over 220 feet
Sweep:	56-14 Hz 14 sec duration
Equipment: Type vibrators:	Center mounted, SSC-VIBK Tractor mounted.

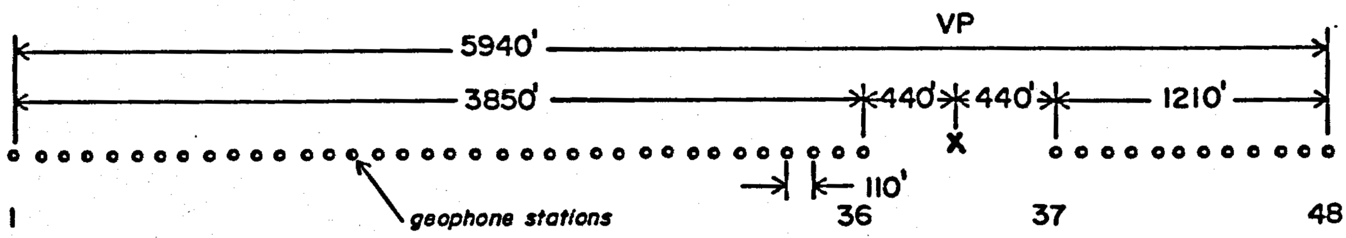
*TM Continental Oil Company

TABLE 6 (cont.)

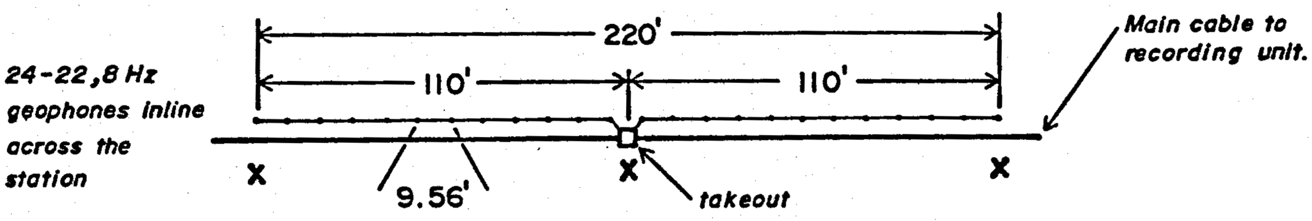
OPERATIONS METHODS (cont.)

Instrumentation: Amplifier recorder system	DFS IV
Number of channels used	48
Field filter:	12 Hz lowcut, 62 Hz hicut, 60 cycle notch filter in
Tape:	0.5 inch, 9 track
Format:	SEG-B, 800 BPI
Summing and correlation:	In trailer-mounted PHOENIX 704 mini-computer system
Sample rate:	Recorded/processed at 4 ms

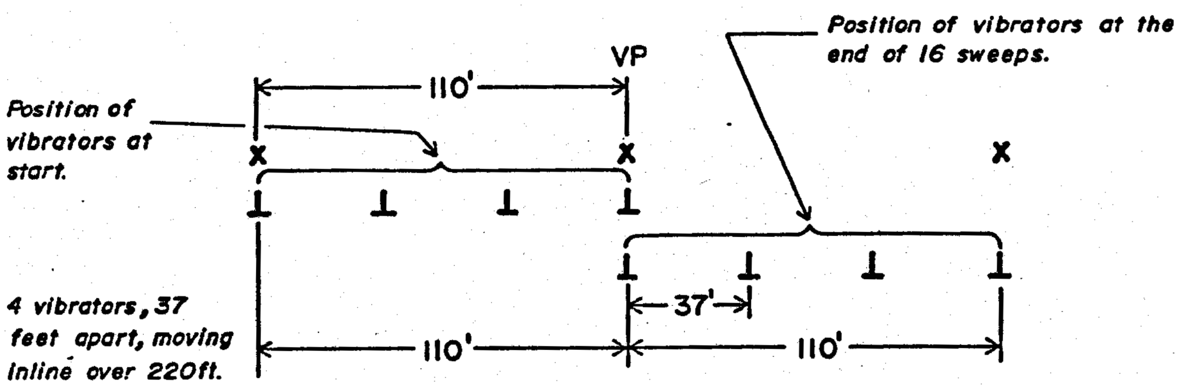
GENERALIZED FIELD LAYOUT



DETAIL OF GEOPHONE ARRANGEMENT



DETAIL OF VIBRATOR PATTERN



3 vibrators, 55 feet apart, moving, inline over 220ft.

16 sweeps per vibrator

Sweep frequency: 56-14 Hz

HILL AIR FORCE BASE PROSPECT
DAVIS COUNTY, UTAH

FIELD SURVEY PATTERNS

FIGURE 20

TABLE 7

Seismic Data Processing Parameters

Demultiplex/Sum + Correlation

CDP sort

Datum Stations 4800 feet @ V(E) 5000 ft/sec

Velocity Analyses
Normal Moveout

Mute

Automatic Statics - Trace Generated

CDP Stack 1/Root (N)

Filter 15-18, 55-60 Hertz, 0.0-1.5 sec
13-15, 40-50 Hertz, 1.5-5.0 sec

Trace Equalization - Time Variant 0.5 sec window

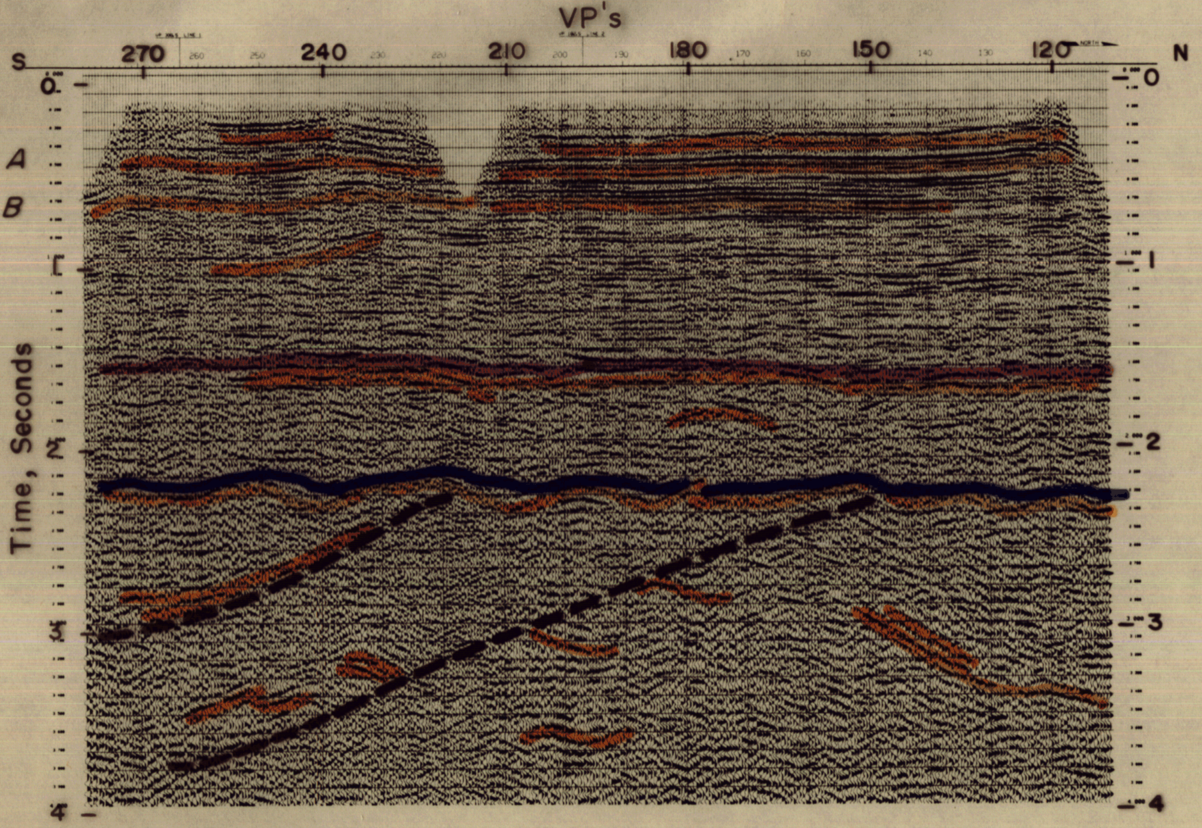
Coherency

Deconvolution 28 ms. GAP 100 ms Operator

Final Filter 15-18, 55-60 Hertz, 0.0-1.5 sec
13-15, 40-50 Hertz, 1.5-5.0 sec

Trace Equalization - Time Variant 0.5 sec window.

SEISMIC SECTION, LINE 3



VIBROSEIS DATA
HILL AIR FORCE BASE, UTAH
LINE 3

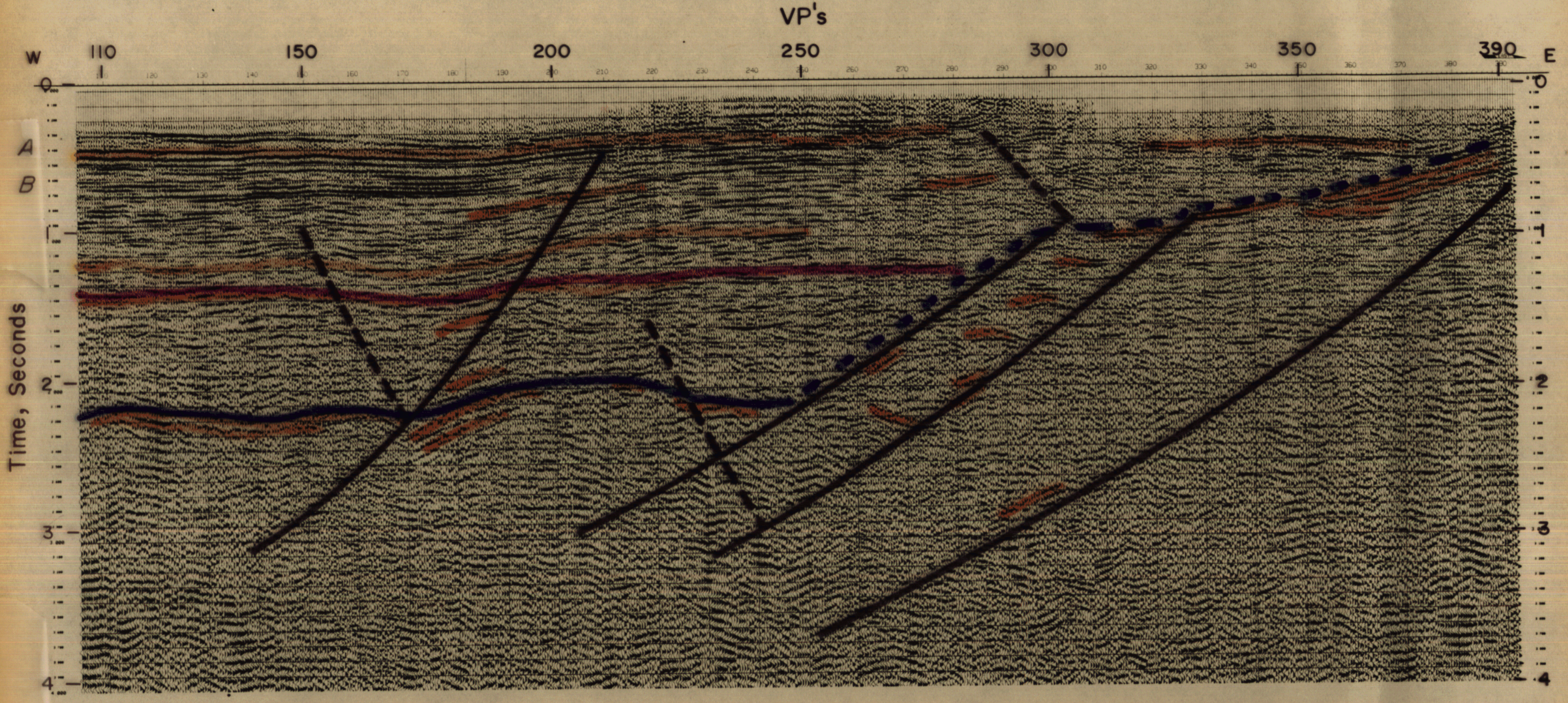
*TM CONT. OIL CO.

Reflectors
Faults
Base of Quaternary?
Base of Tertiary?

Group Interval 220′
2400% CDP Stack
14 Second Sweep
16 Sweeps/VP
56-14 Hz Sweep

FIGURE 23

SEISMIC SECTION, LINE 2



*VIBROSEIS DATA
HILL AIR FORCE BASE, UTAH
LINE 2

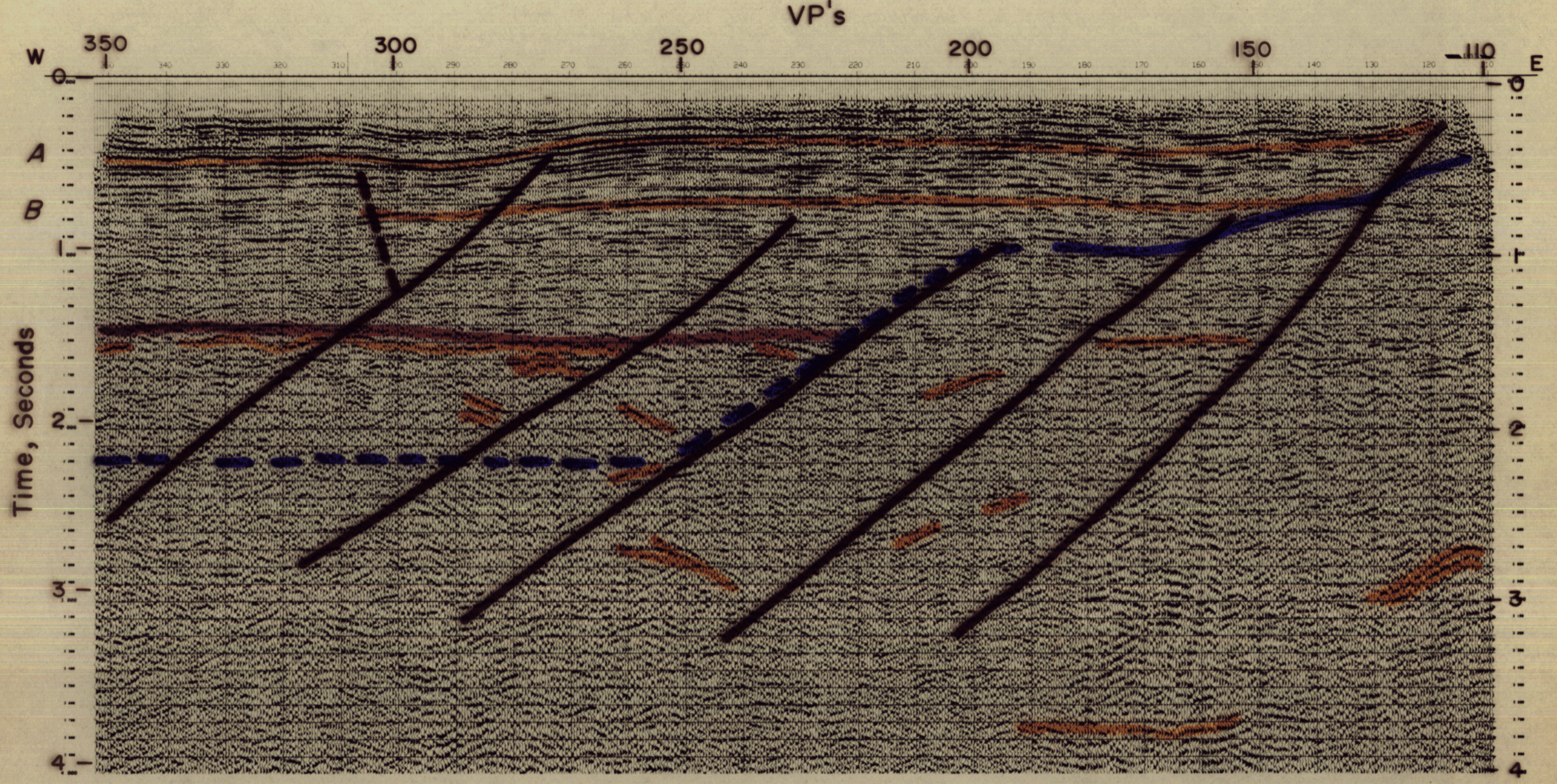
*TM CONT. OIL CO.

Reflectors
Faults
Base of Quaternary?
Base of Tertiary?

Group Interval 220′
2400% CDP Stack
14 Second Sweep
16 Sweeps/VP
56–14 Hz Sweep

FIGURE 22

SEISMIC SECTION, LINE 1



*VIBROSEIS DATA
HILL AIR FORCE BASE, UTAH
LINE 1

*TM CONT. OIL CO.

Reflectors
Faults
Base of Quaternary?
Base of Tertiary?

Group Interval 220'
2400% CDP Stack
14 Second Sweep
16 Sweeps/VP
56-14 Hz Sweep

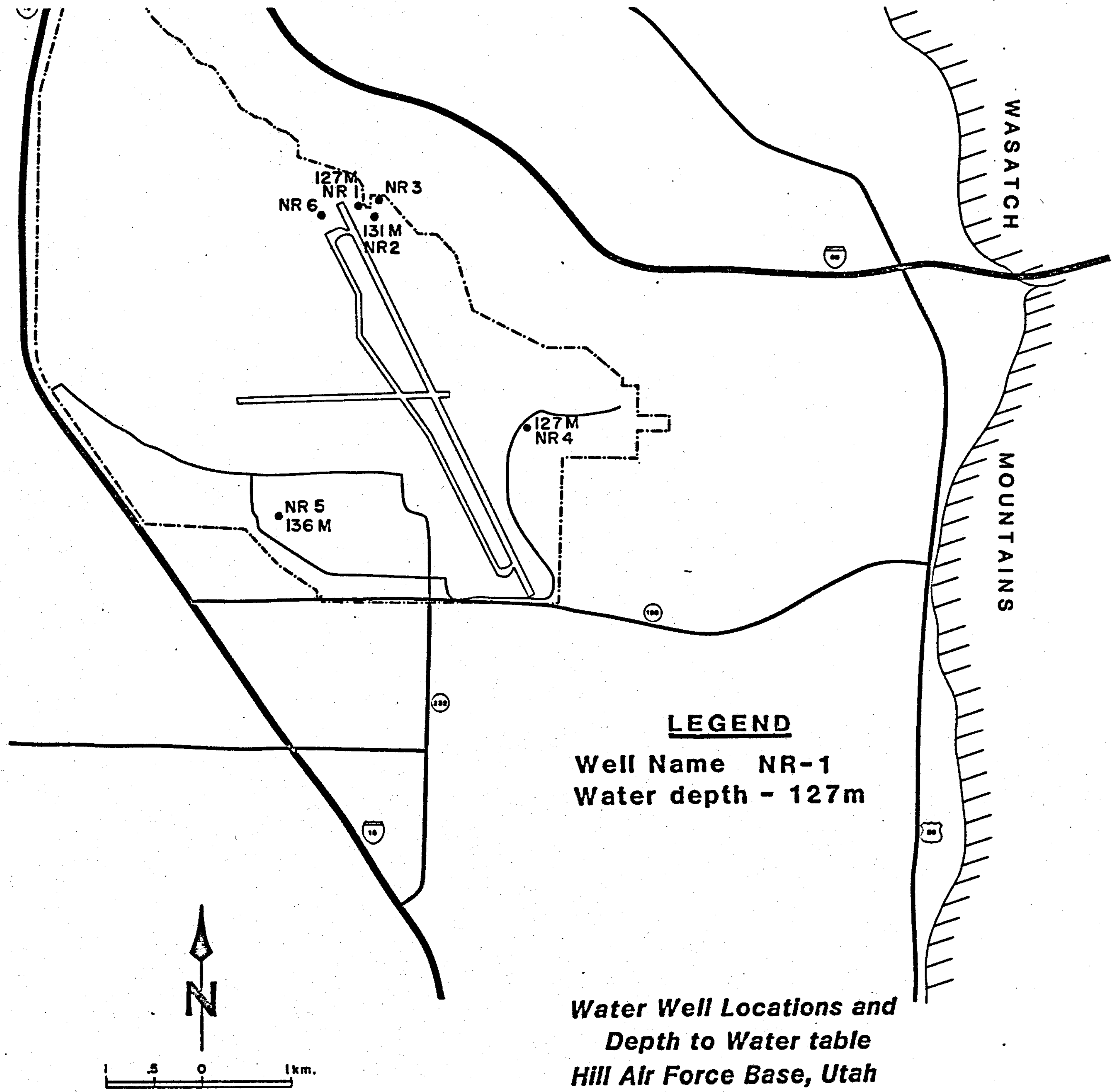
FIGURE 21

Wave equation migration was used to migrate data on lines 1 and 2, but velocity control below 1.0 second was too poor for a very good result and the data are not shown.

Seismic Data Interpretation

Very little subsurface control data exist for the Hill AFB area. Several water wells have been drilled on the base to depths of 244 m (800 ft). The well locations and the approximate depth to aquifers are marked in Figure 24. The lithology in each well is primarily layered silts and clays above the aquifers, and sands, silts and gravels within the aquifers. Several 0.61 to 0.92 km (2000 to 3000 ft) deep drill holes away from Hill AFB indicate this lithology can be expected to continue to some depth beneath the base (Feth and others, 1966). The deep wells suggest that the sediments closer to the mountains contain more sands and gravels, while sediments further from the mountains are primarily silts and clays. In the absence of good subsurface control, the seismic data have been interpreted qualitatively with the main objective being a determination of fault locations.

The three lines were compared where they intersected. Strong reflections common to all three lines were identified across each section. Other events on each line were also noted. Faults were interpreted where reflections on the section showed definite vertical shifts. These interpretations were made on transparent overlays and an interpreted section for each line was adjusted to be consistent with the brute stack, final processed stack, and the migrated sections.



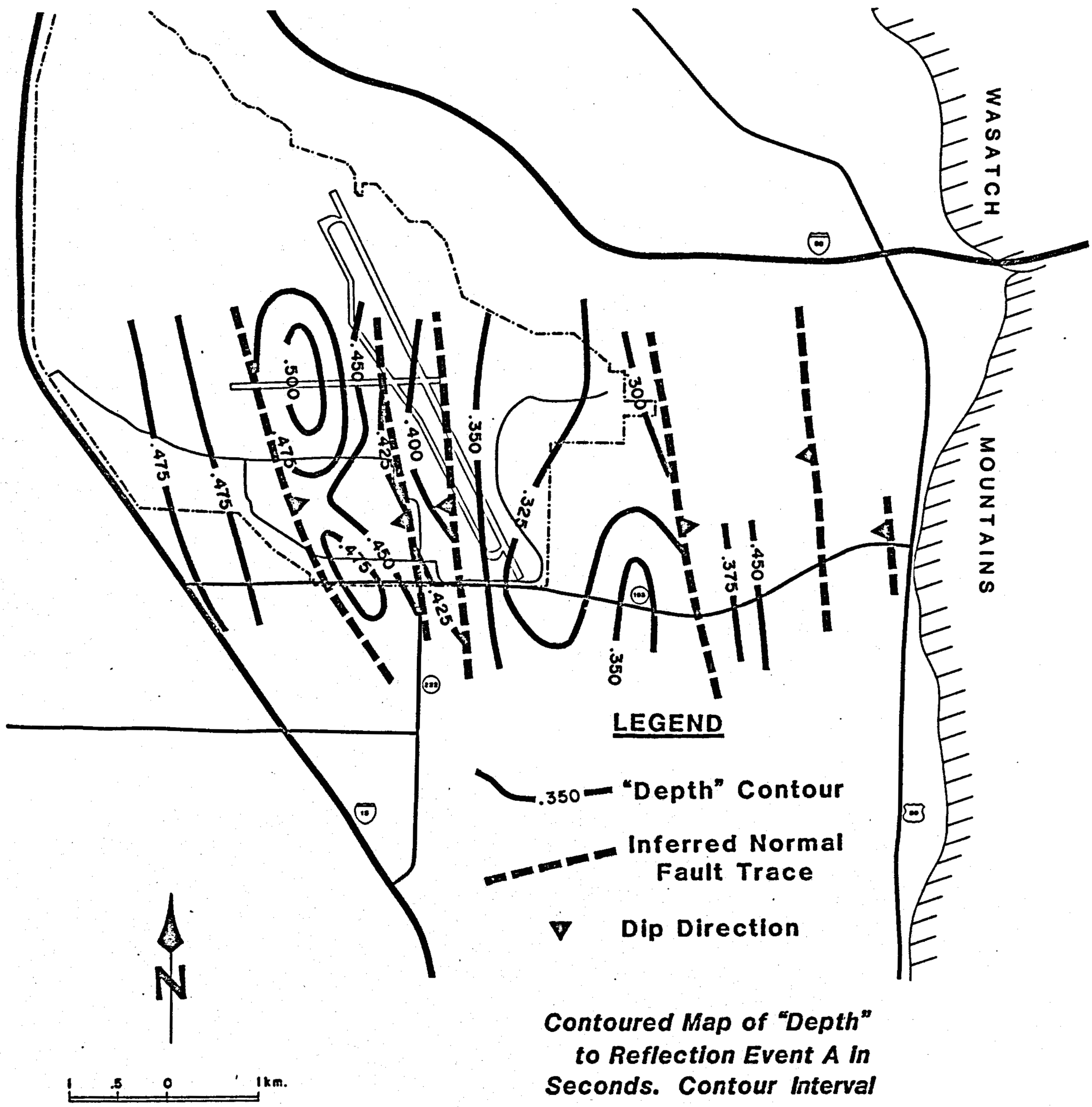
Water Well Locations and Depth to Water table Hill Air Force Base, Utah

FIGURE 24

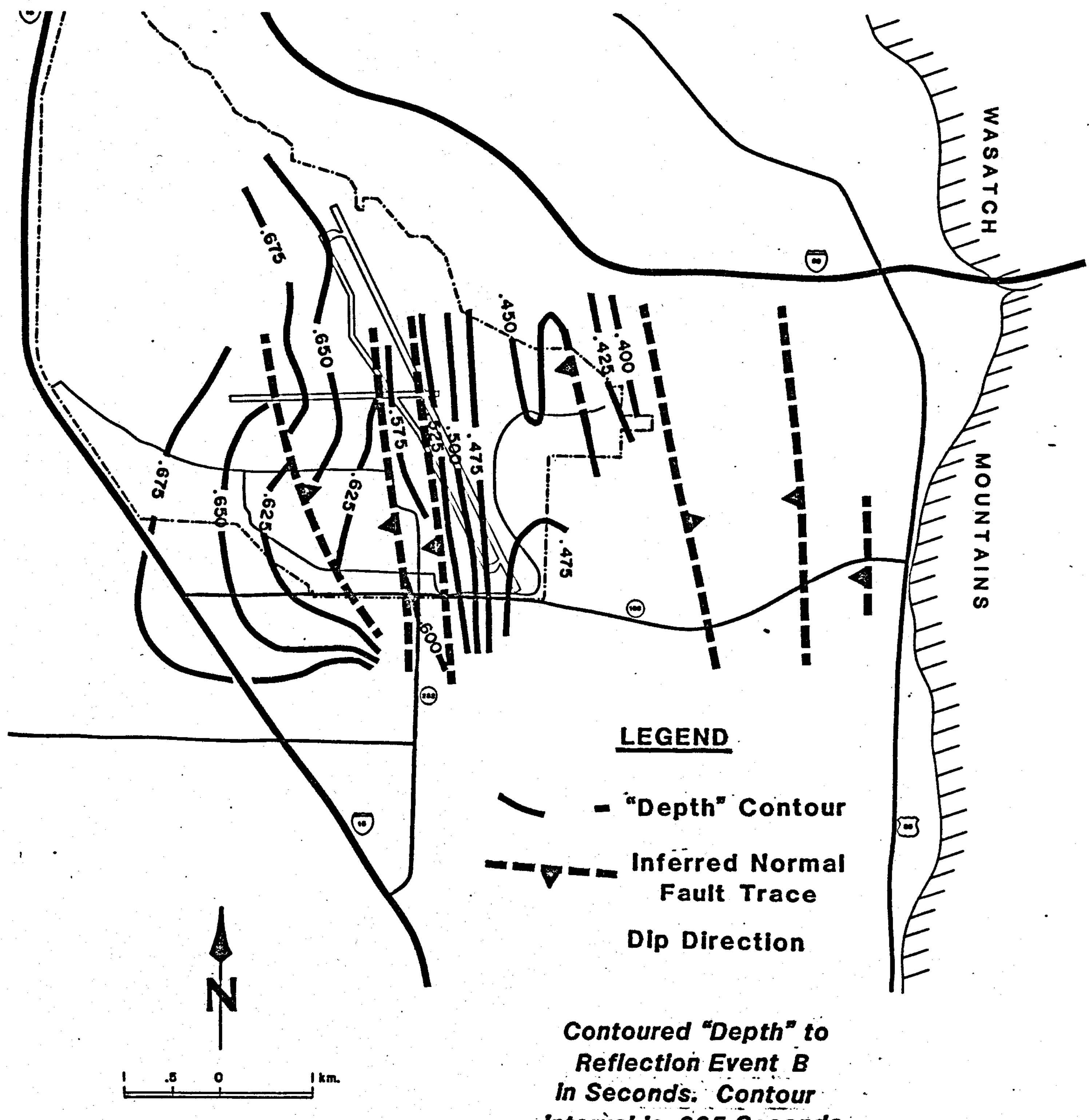
Two events, which appeared to be traceable on all lines and over the greatest lateral distance, were chosen to construct contoured plan maps of depths to reflectors. These events are labelled A and B on each seismic section. The contoured maps for events A and B are shown in Figures 25 and 26. The contour maps are given in time units rather than depth. Depth conversion is difficult due to a lack of good velocity control. Interpreted faults are also shown on the maps. Neither event A nor event B can be traced with any certainty entirely across the length of the east-west lines. Hence, the plan maps show a few speculative contours at the east end of the lines.

All interpreted faults are normal faults with the majority having the west side downthrown. The fault trends are primarily north-south. This interpretation agrees with the trace of the Wasatch Fault in this area (Bryant, 1979). Bryant also shows the Wasatch Fault in several places as two or three faults, with some splays having the east side downthrown. The seismic data indicate that the range front is bounded by several curvilinear, en echelon faults, a few of which have an east dip. This idea is consistent with work of Bell (1952). Near Hill AFB this series of faults continues at least to the center of the base. The data also suggest the presence of a small north-south horst structure along the east side of the base. The horst resulted from both east- and west-dipping normal faults and is clearly defined by both east-west seismic lines.

The depth to the first good reflection in the seismic data appears to coincide with the known depths to the aquifer. The first reflection, which correlates among the lines, varies from approximately 0.180 seconds to 0.350



Contoured Map of "Depth" to Reflection Event A in Seconds. Contour Interval Is .025 Seconds
FIGURE 25



Contoured "Depth" to Reflection Event B in Seconds. Contour Interval Is .025 Seconds

FIGURE 26

seconds. Assuming an average velocity of 1.52 km/sec (5000 ft), these two-way travel times imply depths of 137-267 m (450-875 ft). This first reflector is believed to be the gravel aquifer. For example, Well #4 is situated near VP 260 on line 2. The depth to the aquifer is approximately 173 m (567 ft) and depth to the first reflector near VP 260 on line 2 is approximately 183 m (600 ft). Well #5 is about 1400 ft west of VP 230 on line 3. The well shows about 178 m (585 ft) and the seismic data about 171 m (560 ft) depth to the gravel aquifer.

The seismic data stacking, which is based on an assumption of near-horizontal stratigraphy, was undoubtedly hampered by a complex subsurface lithology. Lateral facies variations probably occur frequently and abruptly. Hill AFB is located on Weber River delta and Lake Bonneville deposits, with both shoreline and bottom sediments. The seismic data apparently show a typical delta off-lap characteristic toward the west on lines 1 and 2. Also, faults are high angle and when they occur, they are closely spaced. The stacking problem is clearly demonstrated by the "choppy" data and by the variability of the stacking velocities.

Comparison of seismic and gravity models

The seismic data interpretation of line 2, using stacking velocities to estimate subsurface velocity with depth, is shown on the variable density gravity model in Figure 27. The seismic boundaries used in the section correspond to the estimate for the base of Quaternary(?) and Tertiary(?) formations and the near-surface reflector A. Several interpreted fault locations are shown in Figure 27. On the basis of this interpretation, two drill holes were planned to intersect the faults located beneath the central and eastern parts of the base.

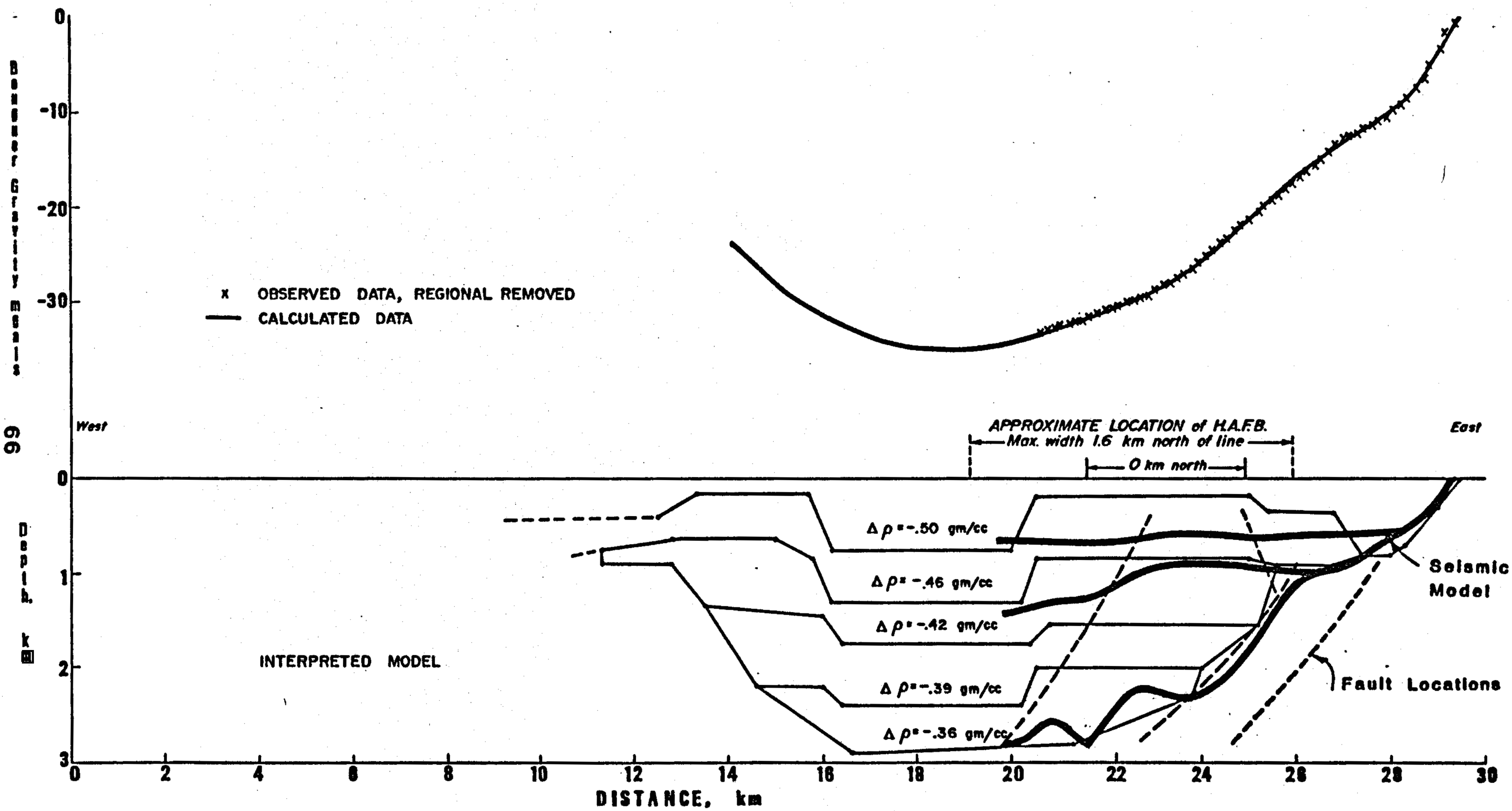


Figure 27 Bouguer Gravity Data Interpretation, Variable Density Model, Compared to Interpreted Seimic Section, North Line, Hill Air Force Base, Utah

Summary

The gravity data were interpreted using single and variable density models. Both models fit the observed data equally well. The gravity models were typical Basin and Range graben structures. The variable density model suggests that the central graben area has either a greater thickness of less dense material or smaller faults than the margins. Major faults are located at the boundaries of the graben. Two or more faults are indicated on each side of the graben.

The seismic data were good between 0.2 and 1.2 seconds on all three lines. These data clearly indicate several north-south faults in the subsurface between the range front and the center of Hill AFB. The faults are all normal faults with most dips and downward movements to the west. Some east-dipping faults were also evident. The east- and west-dipping normal faults created a small north-south horst structure along the east side of the base. The major faults underneath the base almost bisect the base. The faults are interpreted to be normal faults, mostly dipping to the west.

Both the gravity and seismic models agree resonably well, and major north-south faults are interpreted to lie below the central and eastern parts of the base.

PHASE III

Tasks III-1, -2, -3 Thermal Gradient Drilling, Lithologic Logging and Well Logging

Introduction

Two thermal gradient holes were drilled under this exploration program. The sites are indicated on Figure 28. Both holes were sited away from potential cultural interferences.

HAFB No. 1 was sited near the east edge of the base and VP 282 on Line 2 to intersect the westward-dipping structures at minimum depth and cost (see Figures 22 and 28). HAFB No. 2 was located near the south gate and VP 278 on Line 1 and was targeted to intersect a fault and stratigraphic horizons inferred from the seismic profiles (see Figures 21 and 28).

Drilling began on August 21, and was completed on October 17, 1979. Boyles Brothers Drilling Co. was the prime contractor for drilling. The HAFB No. 1 was drilled to a total depth of 390 m (1280 ft), and HAFB No. 2 was drilled to a total depth of 994 m (3260 ft). The holes were drilled with mud and were completed by the insertion of 2 inch (5 cm) cast iron pipe. Aquifer tests were not obtained under this drilling program, since mud damage to the formations was expected.

Drilling proceeded slowly, due to difficult conditions. An average rate of 30-60 ft per 12 hour shift was achieved on HAFB-2.

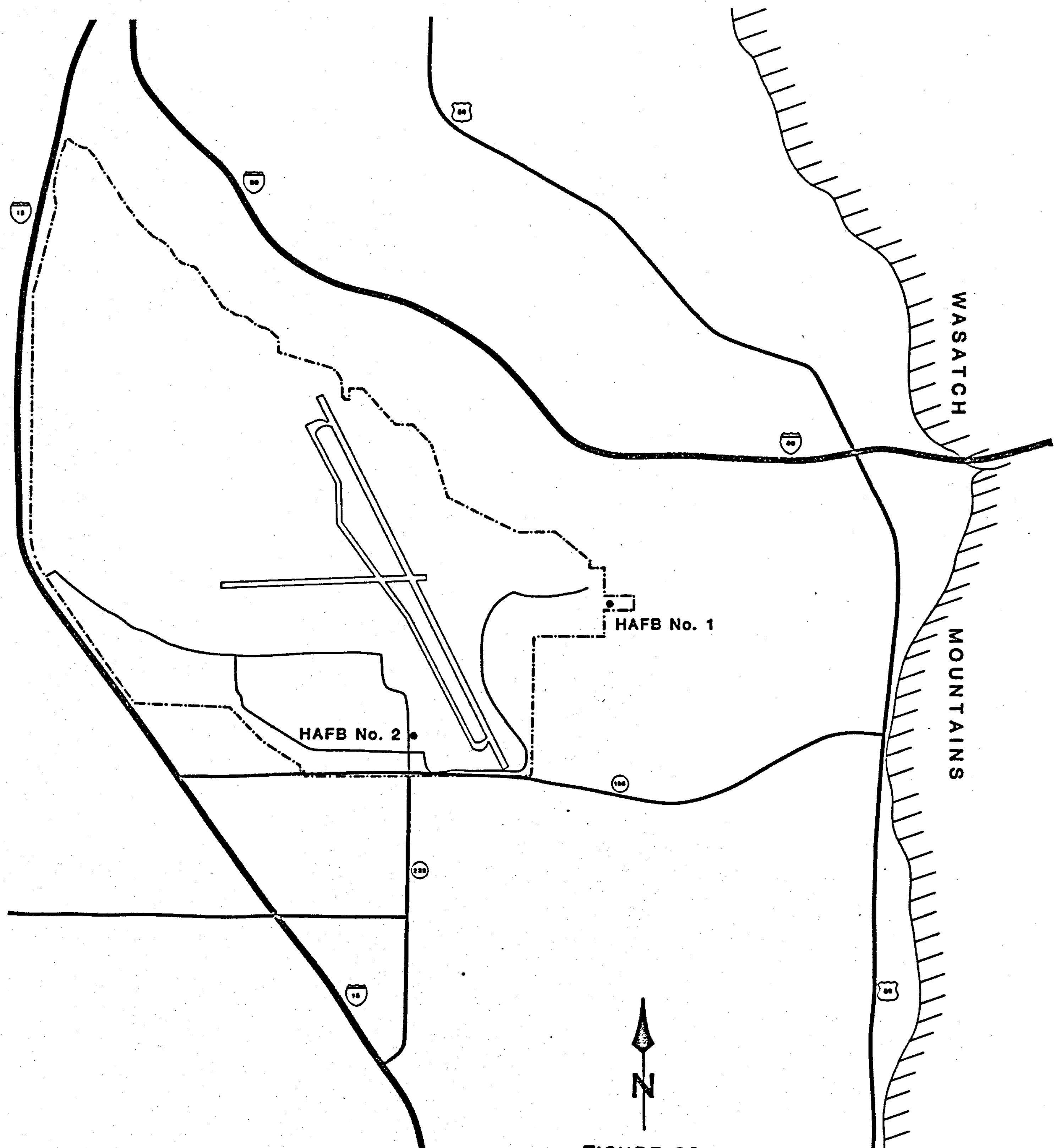


FIGURE 28
Thermal Gradient Hole Locations
Hill Air Force Base, Utah

1 .5 0 1 km.

Caliper, temperature, long and short normal resistivity, and natural gamma logs were obtained in both holes drilled on Hill AFB under this contract. The logging was designed to obtain subsurface temperature and lithologic data. Concern over losing more expensive tools in the holes precluded obtaining porosity, density, and acoustic velocity data. The holes were drilled in poorly consolidated alluvium and the drillers had difficulty keeping the holes open during drilling. Lithologic logs were prepared from an examination of chip samples.

Well Log Data Interpretation

The well log data have been digitized and are plotted on Plates I and II, (HAFB-1 and HAFB-2 respectively). A summary of lithology, as determined from a study of ten-foot composite chip samples, is also shown on the plates. With only minor differences, lithology in both holes correlates quite closely to 290 m (950 ft).

The caliper log depicts several zones of caving in each hole and both holes exhibit some degree of hole rugosity throughout their lengths. Several lost circulation zones were noted in HAFB-2 at depths between 268-292 m (880-957 ft), 335-368 m (1100-1208 ft), and possibly two other intervals deeper in the hole. The caliper log indicates these lost circulation zones are accompanied by fractures or hole enlargement. Lost circulation occurred throughout the length of HAFB-1, particularly below 226 m (740 ft).

Detailed lithologic interpretations of the well logs were not made, but general interpretations are possible. The natural gamma log should reflect the presence of varying amounts of potassium, uranium and thorium, or uranium and thorium daughter products. Clays typically exhibit a higher natural gamma count than sands; this characteristic is evident in the Hill AFB drill holes. Also, the natural gamma logs show evidence of gradational bedding. For example, between 46-64 m (150-210 ft) in both holes the natural gamma counts increase with depth indicating probable increasing clay with depth in the surface sand unit. Other examples can be seen throughout both drill holes. The high natural gamma counts observed between 332-337 m (1088-1105 ft) in HAFB-1 may reflect an anomalously high uranium content. The chip samples in this interval are being analyzed by spectral gamma techniques to determine the cause of the high gamma counts.

The resistivity logs show fairly uniform highest resistivity opposite the clean quartzose sand beds at 396-701 m (1300-2300 ft) in HAFB-2 and lowest resistivity opposite the mudstone unit at 128-162 m (420-530 ft) in HAFB-2.

Temperature logs were obtained in HAFB No. 1 on 9/21/79 (a continuous log) and 10/7/79 to total depth for every 5 m (16 ft); both are plotted in Plate 1. The first log decreases from ambient air temperature at the surface to the borehole fluid temperature at 79 m (260 ft) and remains nearly constant with depth. The log was obtained only a few hours after circulation stopped. The second log was obtained approximately two weeks later and shows zones of slight cooling in the borehole which indicates recovery to the normal temperature regime. The bottom hole temperature is 13°C (55°F).

Temperature logs were obtained in HAFB No. 2 on 9/21/79 (a continuous log) to a depth of 495 m (1624 ft) and on 11/15/79 to a depth of 500 m (1640 ft) measured every 5 m (16 ft). Continuous logs were obtained to total depth on 10/15/79, 10/22/79 and 12/18/79. The sequence of logs depicts the thermal recovery in the drill hole. The upper portion of the hole, within the aquifer and above 366 m (1200 ft) was warmed during drilling and subsequently became cooler. Below 366 m (1700 ft), the hole was cooled during drilling and subsequently became warmer. This reverse temperature change is common and produces temperature log cross-over points such as observed at 604 m (1980 ft). HAFB No. 2 penetrates through an aquifer, as is seen by the significant increase in temperature below a depth of 366 m (1700 ft). The bottom hole temperature at 994 m (3260 ft) is 40°C (104°F).

The variability of the temperature logs at the surface in both holes reflect the different air temperatures at the times the logs were obtained. The mean annual surface temperatures is about 13°C (55°F) which is close to the average of the surface temperature values observed on the several logs. The aquifer temperature also appears to be close to the mean annual temperature.

A temperature gradient profile in HAFB-2 has been computed from the 12/18/79 temperature log. The various temperature logs obtained subsequent to hole completion indicate this final temperature log reflects near-thermal equilibrium conditions in HAFB-2. The lower temperatures, and the near-zero and negative gradients in the upper part of the drill hole reflect the influence of cooler ground-water flow in the known aquifer at these depths.

Below approximately 732 m (2400 ft) the temperature gradient increases to an average of 64°C/km. This increased gradient can be attributed to the lower thermal conductivity of the predominantly silty and clayey sediments below this depth and the highly suppressed temperatures in the aquifer above this depth. An increase in temperature at depth is observed between the 10/22/79 and 12/18/79 logs but the gradient remains unchanged. The temperature log cross-overs (e.g., at 610 m, 2000 ft) indicate the upper part of the drill hole was warmed while the lower part was cooled during drilling.

CONCLUSION

No thermal anomaly has been identified beneath Hill AFB as a result of these studies. The cold water near-surface aquifers of the Weber delta effectively mask any deeper warm fluids. Although geophysical studies identified favorable structural and stratigraphic targets, deep testing of these targets by drilling failed to identify anomalously warm zones associated with them.

The absence of shallow warm waters beneath the base suggests that options available for the exploitation of the heat content of the ground water are restricted to either application of heat pump technology or deeper drilling to test geologic settings that presently have unknown water temperature, quality, and productivity characteristics.

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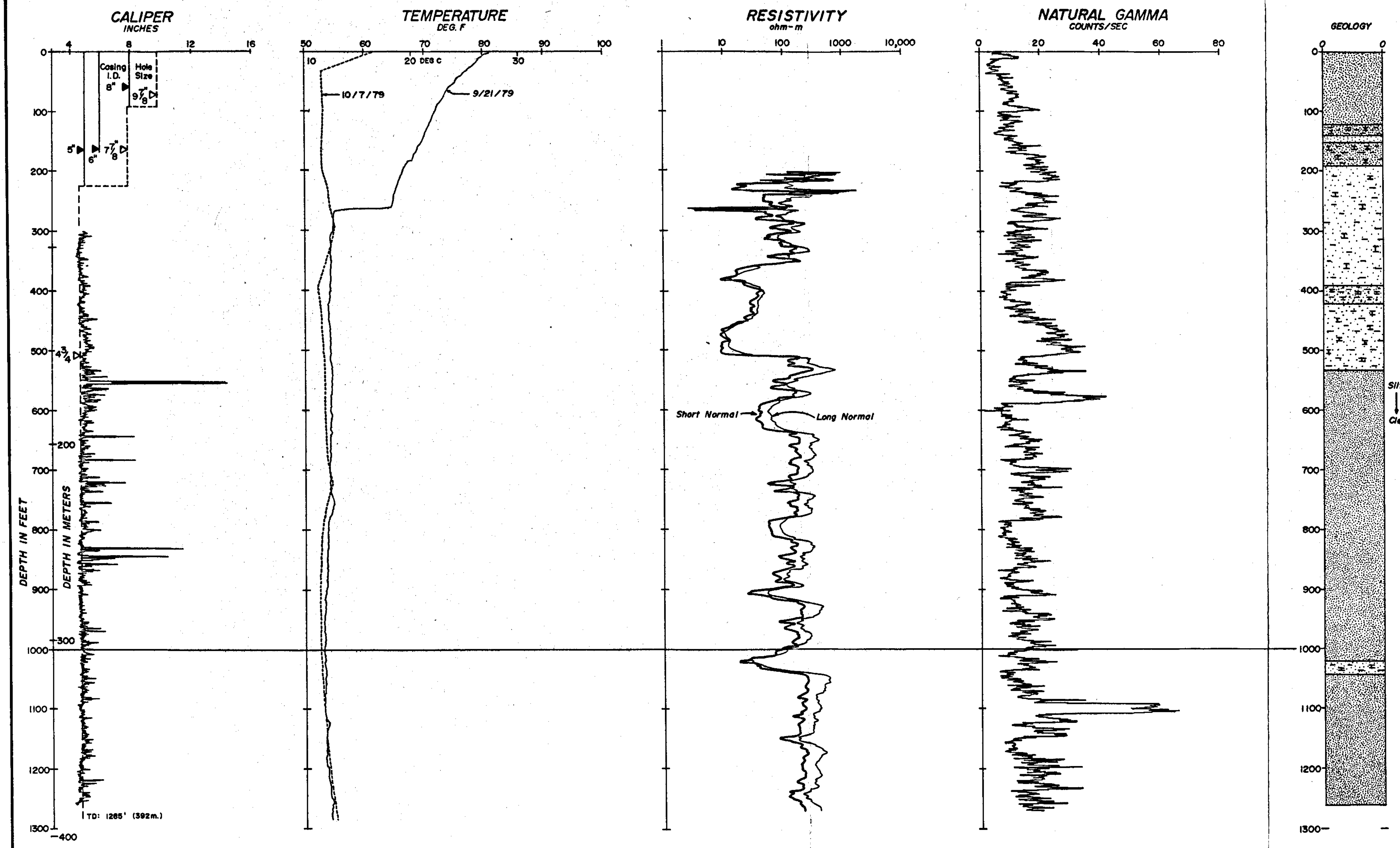

GRAPHIC LITHOLOGY EXPLANATION
Equigranular Quartzose Sand
Silt, Clay and Carbonate Quartzose Sand
Silt, Clay and Carbonate Mixture
Silt, Clay and Carbonate Mixture with Quartzose Sand

PLATE I
WELL LOGS
HILL AFB

HOLE 1

EARTH SCIENCE LABORATORY

UNIVERSITY of UTAH RESEARCH INSTITUTE

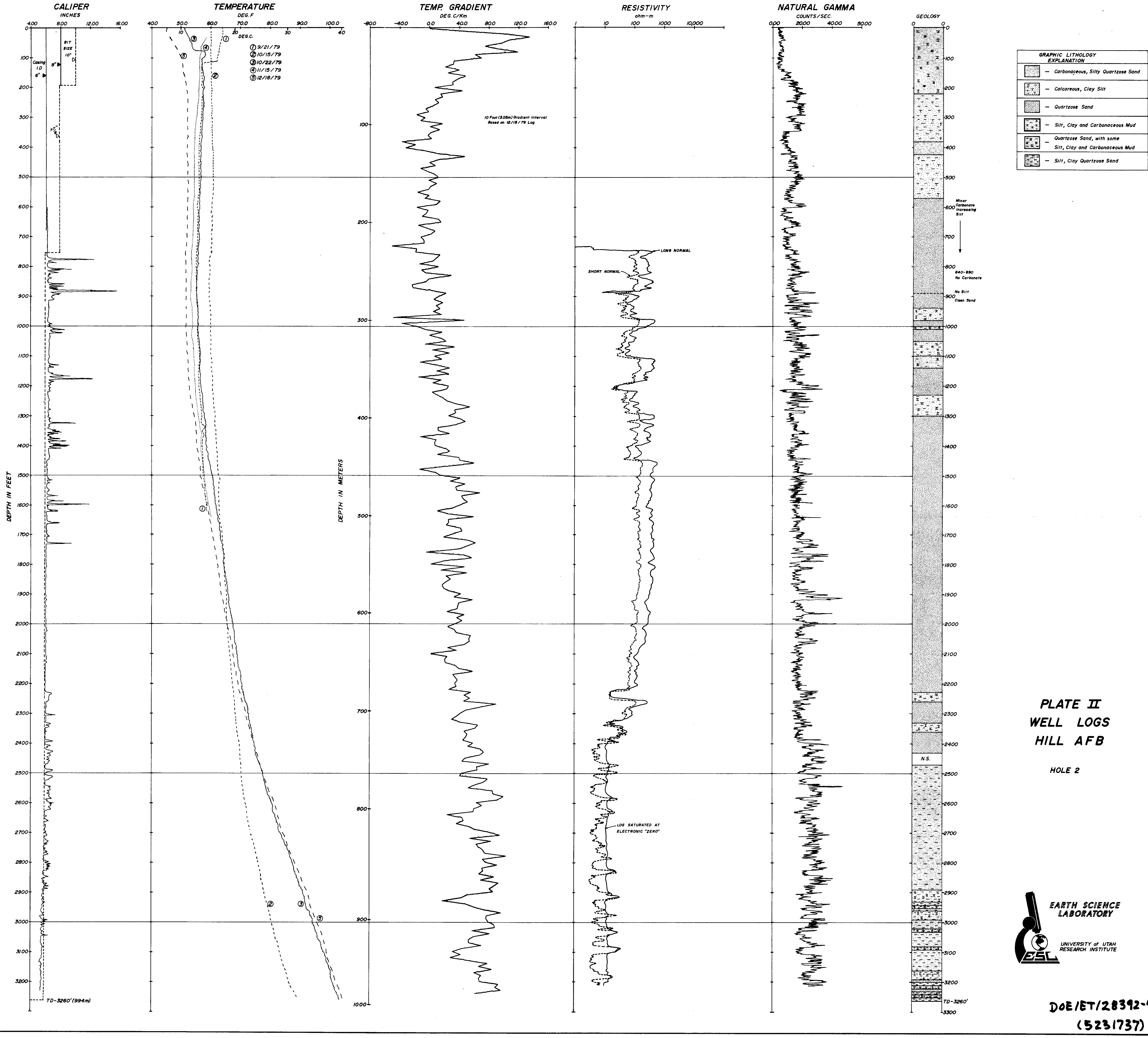

PLATE II
WELL LOGS
HILL AFB

HOLE 2

EARTH SCIENCE LABORATORY

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