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B. H. Arney
Fraser Goff
Harding Lawson Associates*

*7655 Redwood Boulevard, P. O. Box 578, Novato, CA 94947.

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

EVALUATION OF THE HOT DRY ROCK GEOTHERMAL POTENTIAL OF AN AREA NEAR MOUNTAIN HOME, IDAHO

by

B. H. Arney, Fraser Goff, and Harding Lawson Associates

ABSTRACT

Evaluation of an area near Mountain Home, Idaho, was performed by Harding Lawson Associates of Novato, California, to assess the hot dry rock (HDR) potential of the prospect. The techniques they reported include telluric and gravity profiling, passive seismic, hydrology and water chemistry surveys, and lineament analysis. Gravity and telluric surveys were unsuccessful in locating fractures buried beneath recent volcanics and sediments of the plain because density and conductivity contrasts were insufficient. Gravity modeling indicated areas where granite was not likely to be within drilling depth, and telluric profiling revealed an area in the northwest part of the prospect where higher conductivity suggested the presence of fractures or water or both, thereby making it unsuitable for HDR. Water geochemistry indicated that (hot water) reservoir temperatures do not exceed 100°C.

An area in the east central part of the prospect was delineated as most favorable for HDR development. Temperature is expected to be 200°C at 3-km depth, and granitic rock of the Idaho Batholith should be intersected at 2- to 3-km depth.

I. INTRODUCTION

An area east of Mountain Home, Idaho, on the northern margin of the Snake River Plain (SRP) was chosen for study and evaluation as a potential hot dry rock (HDR) site on the basis of geology, heat flow and temperature gradient measurements, and because of its accessibility and proximity to potential users. Harding Lawson Associates (HLA) were awarded the contract to evaluate the prospect, and to determine the applicability of various exploration techniques to HDR assessment within the western U.S.

The 400-km^2 prospect is located southwest of the Mount Bennett Hills and Camas Prairie (Fig. 1). The western edge of the prospect is approximately 10 km east of Mountain Home and 23 km east of Mountain Home Air Force Base. This part of the SRP margin was selected because it did not appear to be as badly faulted as other sections of the margin. The prospect area contains two deep wells with gradients of 61° and 64°C/km, and it had been reported on the Gulf Energy and Mineral Co. lithology log that one of these, the Bostic 1-A well in the southern part of the prospect, (Fig. 2, in pocket on inside back cover) had bottomed in granite of the Idaho Batholith at 2931 m (9616 ft). Reported bottom-hole temperature of this well is 195°C. In the course of this study, it was discovered that the hole actually bottomed in hydrothermally altered latite, probably part of the Tertiary Idavada volcanic sequence. The potential HDR "reservoir" is that part of the Idaho Batholith that lies beneath sedimentary and volcanic cover at the edge of the SRP.

The HLA study included geological, geophysical, geochemical, and hydrological investigations to assess the HDR potential and to recommend a drill site. The results, conclusions, and recommendations of the HLA study are reported herein.

II. REGIONAL STUDIES

A. Geology

The SRP is an arcuate depression in southern Idaho, filled with Tertiary and Quaternary volcanics that become younger to the east (Armstrong et al. 1975). The western half of the SRP is bounded by faults, with at least 2743 m (9000 ft) vertical displacement along the northern margin (Malde 1959) and somewhat less displacement on faults along the southern margin. The Idaho Batholith, in places overlain by volcanic rocks, lies just north of the SRP, but it is not known how far it extends beneath the plain.

B. Thermal Regime

The Western Snake River Plain (WSRP) is an area of high heat flow, with typical values of about 70 mW/m^2 [1.67 heat flow units (HFU)] in the central area and values of over 100 mW/m^2 (2.39 HFU) along the boundaries (Brott et al. 1978). A partial explanation for the difference may be hydrologic convection, either cold water within aquifers in the plain or deep circulating

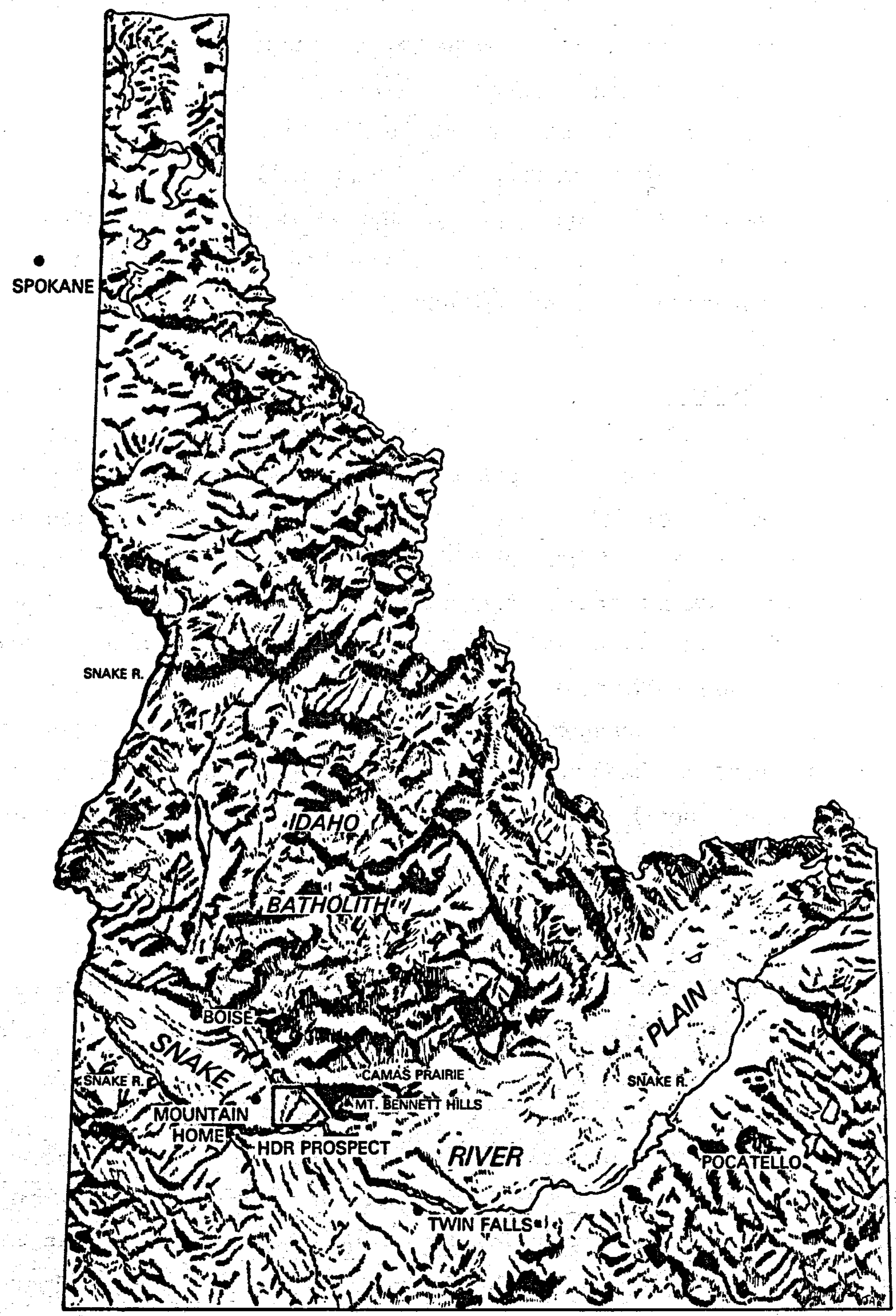
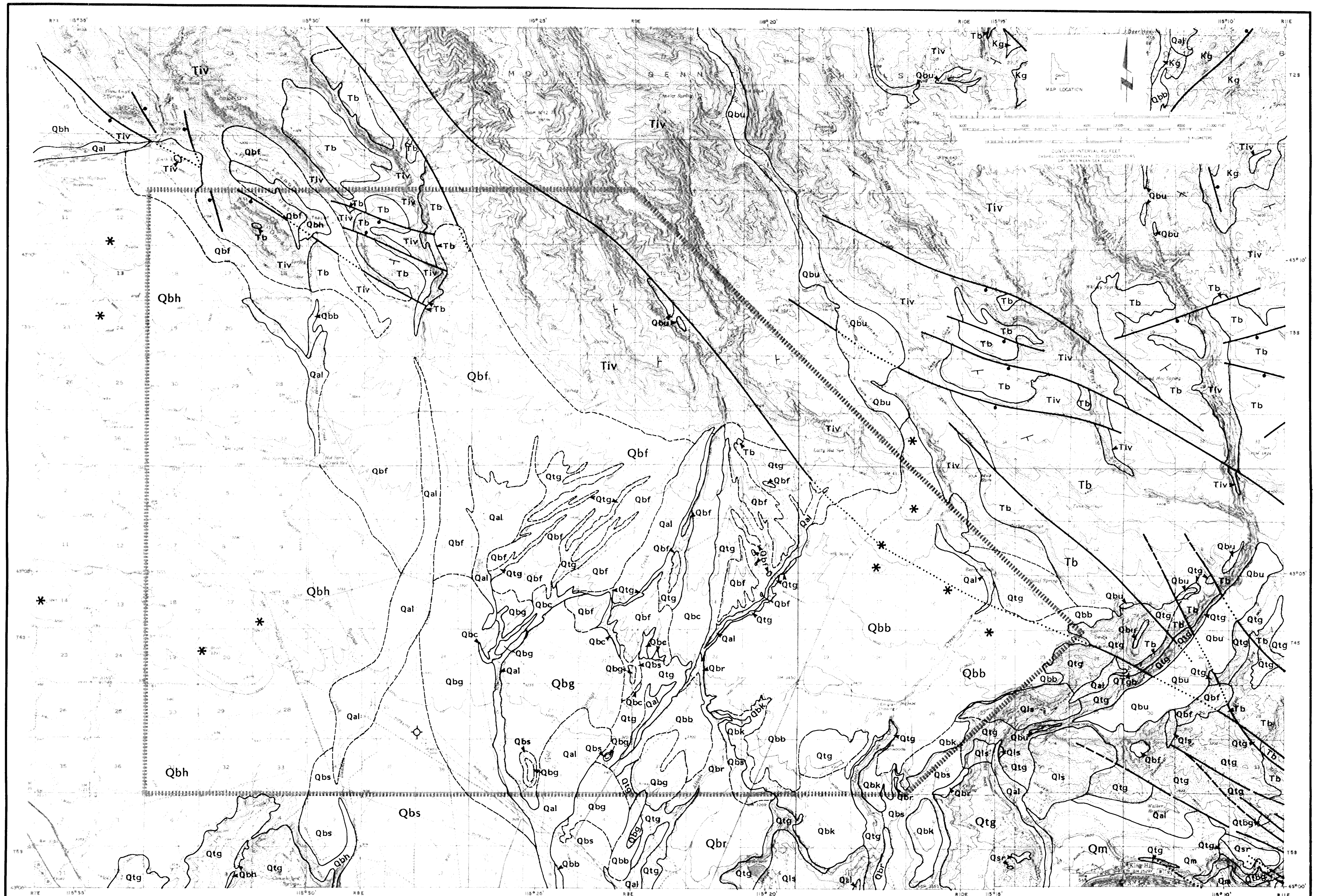


Fig. 1.
Map of Idaho showing HDR prospect area.



EXPLANATION

AGE		SYMBOL	DESCRIPTION
QUATERNARY	HOLOCENE	Qal	Stream alluvium
		Qls	Landslide debris
	PLEISTOCENE	Qm	Melon gravel; boulders and cobbles of basalt in basaltic sand matrix, boulders commonly 1 m in diameter and as large as 3 m, late Pleistocene
		Qsr	Snake River Group, undivided; mainly olivine and/or plagioclase basalt flows and terrace gravels, late Pleistocene
		Qb	Bruneau formation; canyon fill of undeformed, unconsolidated, detrital sediments and interbedded basaltic lava flows with marginal deposits of pebble and fan gravels, middle Pleistocene
		Qbs	Sedimentary material dominated by massive lake beds of white to light brown fine silt, clay and diatomite in layers 15 m or more thick, with subordinate amounts of alluvial silt and sand. Lake beds rise to an elevation of 970 m and merge with alluvial and colluvial deposits of sand, clay and gravel that rise roughly 91 m higher.
		Qbg	Alluvial deposits of sand and pebble gravel from Elevation 970 m to 1000 m. Pebble gravel reworked as beach deposits from contiguous older gravels.
		Qbf	Fan gravel, consisting of cobble and pebble sizes in a coarse sandy matrix derived from decayed granite. Fan deposit gravels extend from front of Bennett Hills to 1000 m elevation.
		Qbu	Undifferentiated basaltic lava flows which erupted episodically from several vents to form a series of lava plateaus and canyon-filling volcanic dams. Differentiated individual flows in ascending stratigraphic order are: Qbb - Berry Ranch lava flow; olivine-plagioclase basalt, coarse texture; Qbk - King Hill lava flows; gray, dense, glassy texture, in three separate flows; Qbr - Morrow Reservoir lava flow; olivine-basalt, moderately coarse texture; Qbc - Cold Springs lava flow; plagioclase-olivine basalt, gray to black, dense, glassy; Qbh - Hammett lava flows; plagioclase-olivine basalt of coarse texture, at least two flows of medium-grained, relatively nonporphyritic basalt.
		Qtg	Glenns Ferry formation - Basin fill of poorly consolidated detrital sediments (Qtg) and minor lava flows of basalt (QTgb), late Pliocene to early Pleistocene
TERTIARY	PLIOCENE	Qtg	Lake and stream deposits characterized by abrupt lateral changes in facies. Facies include (1) massive silt beds; (2) evenly layered thick beds of sand; (3) thinly bedded dark clay, olive silt and carbonaceous shale; (4) ripple-marked sand and silt; (5) granitic sand and fine pebble gravel; and (6) quartzitic cobble gravel. Facies (5) and (6) characterize the Glenns Ferry formation present in the prospect site.
		Qtgb	Lava flows of olivine basalt that form sheetlike bodies within the detrital deposits.
	MID-PLIOCENE	Tb	Banbury Basalt - Lava flows of olivine basalt, interbedded locally with minor amounts of stream and lake deposits, middle Pliocene.
		Tiv	Idavada Volcanics - Silicic latite; chiefly thick layers of devitrified welded tuff, includes some bedded vitric tuff and lava flows, late Miocene to early Pliocene.
CRETACEOUS		Kg	Granitic rocks of Idaho batholith; mainly quartz monzonite and granodiorite in composition.

Geologic contact; dashed where approximately located

Normal fault; dashed where approximately located, dotted where concealed, bar and ball on downthrown side

Strike and dip of beds; Barb indicated direction of dip, estimated. Shown mainly in Idavada volcanics where dips are generally less than 10°.

Volcanic vent

Bostic 1-A exploratory test well (dry).

Geology compiled from and legend modified after: (1) Malde, H.E., and Power, H.A., 1972, Geologic Map of the Glenns Ferry-Hagerman Area, West-Central Snake River Plain, Idaho; (2) Malde, H. E., Powers, H. A., and Marshal, C. H., 1963.

HOT DRY ROCK

GEOTHERMAL PROSPECT EVALUATION
WESTERN SNAKE RIVER PLAIN, IDAHO
Prepared for Los Alamos National Laboratory

Prepared by Harding-Lawson Associates
Engineers Geologists & Geophysicists
Job No. 9798,005.01
February 27, 1981
Approved: SVH

Fig. 2

GEOLOGY MAP OF THE TARGET PROSPECT AND VICINITY

hot water along the boundary faults. Brott et al. (1978) attributed the excess heat on the margin to refraction of heat from basalts in the center of the plain into the higher thermal conductivity granites on the margins of the plain. They suggest that the source of the refracted excess heat is buried basaltic intrusions that were emplaced 10-15 Myr ago.

Numerous thermal wells, mostly less than 50°C, occur within the WSRP. Water over 50°C occurs in several springs and wells in various areas along the margins of the plain. In both Boise and the Bruneau Grand View area, these have been tapped for direct geothermal use.

C. Gravity and Magnetics

Hill (1963) and Mabey (1976, 1978) have interpreted the regional gravity of the WSRP. There is a general positive gravity anomaly coincident with the western plain, which includes three smaller en echelon highs elongated along the axis of the plain. These anomalies are basalt-filled fissures (Hill 1963), or thinning and parting of the upper crust (Mabey 1978). The granitic rock of the Idaho Batholith is not believed to be continuous beneath the plain. Figure 3 shows the regional gravity map for the area surrounding the prospect. The northern boundary of the regional high is expressed as a steep gradient of at least 50 mgals over a distance of about 15 km (9 mi). The gradient trends west northwest about 13 km (8 mi) south of the Mount Bennett Hills.

Aeromagnetic data shown in Fig. 4 indicate that in addition to numerous smaller magnetic highs within the WSRP, there is a high along the southwestern margin and a low along the north edge, consistent with what would be observed with a layer of normally polarized basalt filling the plain (Mabey 1976, 1978).

D. Seismic

Results of seismic refraction profiles from Eureka, Nevada, north to Boise, Idaho, are discussed by Hill and Pakiser (1966). The section of the line across the WSRP, from Elko, Nevada, to Boise, Idaho, indicates that two significant changes occur between the Owyhee uplands in southern Idaho and the SRP: total crustal thickness increases from 32 km beneath the Basin and Range and Owyhee uplands, to 42 km beneath the SRP (based on 7.9 km/s mantle and 6.7 km/s lower crust) and upper crustal thickness (base set at the top of 6.7 km/s layer) decreases from 19 km beneath the Basin and Range and Owyhee uplands to

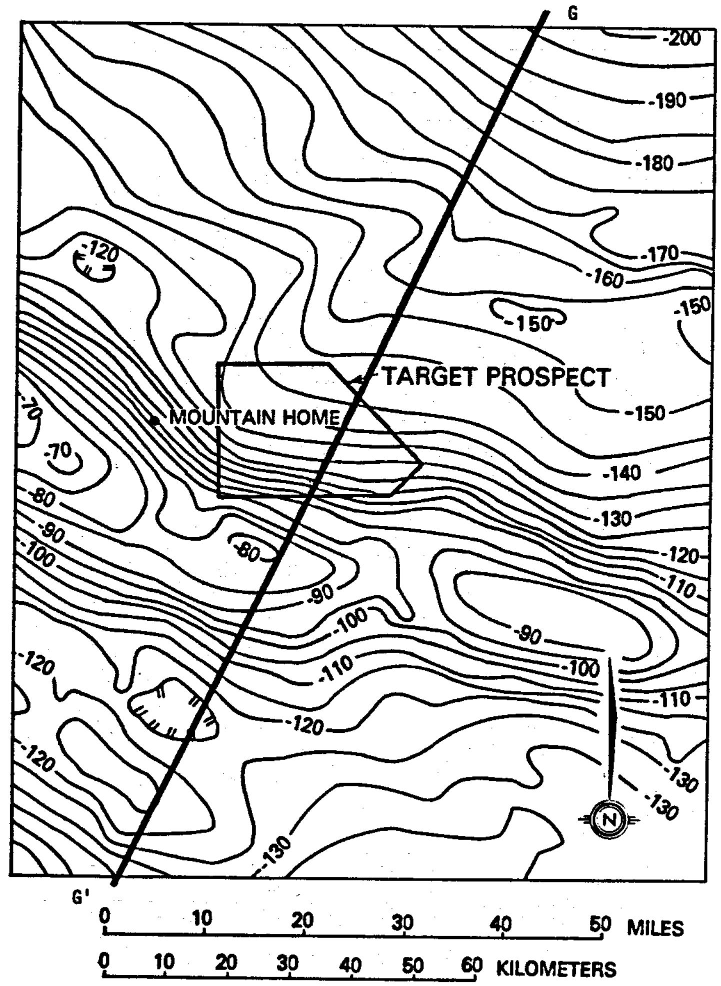


Fig. 3.
Regional gravity map (Mabey et al. 1974) showing prospect area and profile line G-G'.

8-10 km beneath the SRP. A 6.0 km/s layer interpreted as granite is detectable beneath the Basin and Range and Owyhees but appears to end at the WSRP boundary, to be replaced by a 5.2 km/s layer interpreted to be volcanic flows of the SRP. It is not clear from the seismic evidence whether or not the 6.0 km/s ("granitic") layer continues beneath the plain between the 5.2 km/s layer and the lower crustal 6.7 km/s layer, but it is generally thought not to. No information is available on the northern boundary of the plain. Information on crustal thickness derived from seismic refraction was used by Mabey (1976) and Harding Lawson in this report in their interpretation of gravity data.

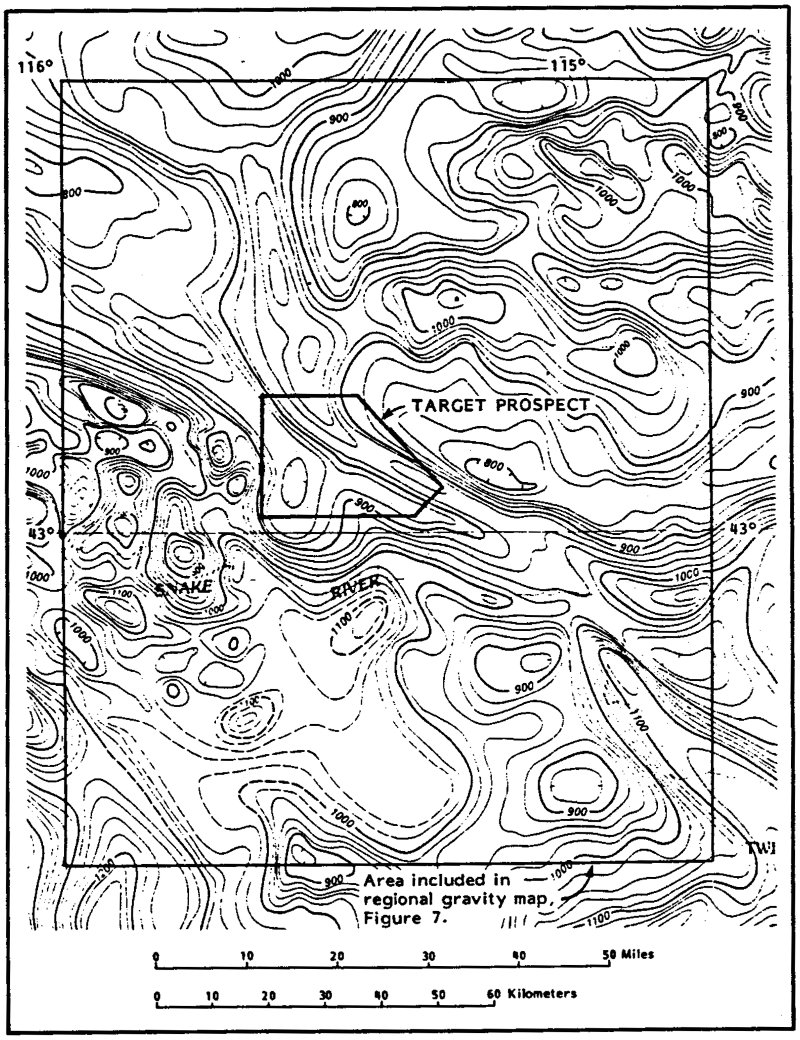


Fig. 4.
Aeromagnetic map of southwestern Idaho in the target prospect vicinity, showing total intensity magnetic field of the earth in gammas, relative to arbitrary datum (after USGS 1978).

III. GEOLOGY OF THE PROSPECT AREA

A reconnaissance geologic map of the west-central SRP (which includes the prospect area) was published by Malde et al. in 1963. A more detailed map (scale 1:48 000) including the southern two-thirds of the prospect area was published by Malde and Powers in 1972. Malde and Powers (1962) described the upper Cenozoic stratigraphy of the area and potassium-argon age dating of the various volcanic rocks has been done by Armstrong et al. (1975, 1980).

A. Stratigraphy

Rocks exposed within the prospect consist of late Miocene to early Pliocene Idavada Volcanics, three formations (Banbury Basalt, Glenns Ferry Formation, and Bruneau Formation) of the Plio-Pleistocene Idaho Group, and Quaternary alluvial deposits (Fig. 5). These formations are separated by unconformities and numerous disconformities occur within individual formations. The composite exposed thickness of Cenozoic formations within the prospect is about 1820 m (5970 ft). The Bostic 1-A well in the southwestern part of the prospect encountered 2950 m (9676 ft) of Cenozoic rocks and bottomed within the Idavada Volcanics.

1. Idavada Volcanics. Idavada Volcanics comprise most of the Mount Bennett Hills, where they unconformably overlie Eocene through Miocene Challis Volcanics and granite of the Idaho Batholith. The Idavada Volcanics are displaced downward to the southwest by northwest-trending boundary faults of the SRP. The Idavada Volcanics consist mainly of silicic latite in the form of devitrified welded ash flow tuffs and interbedded vitric tuffs and lava flows (Malde and Powers 1962). Well-developed columnar jointing is common; platy horizontal jointing is also present. The tuffs contain phenocrysts of plagioclase, clinopyroxene, ± orthopyroxene, and magnetite in a groundmass of devitrified or perlitic undevitrified glass. Petrographic studies at Los Alamos reveal that some flows also contain phenocrysts of fayalitic olivine. These volcanics underwent considerable erosion and deformation before the deposition of Banbury Basalt.

Stratigraphic and fossil relationships (Malde and Powers 1962) and age dating (Armstrong et al. 1975) indicate a late Miocene to early Pliocene age for the Idavada Volcanics. Armstrong's potassium-argon dates on Idavada rocks in the WSRP range from 9-13 Myr.

2. Idaho Group. The Idaho Group has been defined by Malde and Powers (1962) as seven overlapping formations of continental clastic sediments and intercalated basalt flows that range in age from early Pliocene through middle Pleistocene. Although the seven formations are never exposed in continuous sequence at any one locality, their total thickness is nearly 1360 m (4460 ft) (Malde 1965). Of the seven formations, only the Banbury Basalt, Glenns Ferry Formation, and Bruneau Formation appear in the prospect area.

a. Banbury Basalt. Exposures of Banbury Basalt are confined to the northwest portion of the prospect (Fig. 2), where the formation unconformably

AGE			STRATIGRAPHIC UNIT		DESCRIPTION
QUATERNARY	HOLOCENE			YOUNGER ALLUVIUM *	STREAM ALLUVIUM - UNCONSOLIDATED SANDS, GRAVELS, SILTS AND CLAYS.
	PLEISTOCENE	LATE	ROCKS EQUAL TO SNAKE RIVER GROUP	LAVA FLOWS	FRESH BASALT LARGELY UNMODIFIED BY SURFICIAL DEPOSITS.
				OLDER ALLUVIUM	PEBBLE AND COBBLE GRAVEL ON TERRACE 8 - 30 METERS (25 - 90 FEET) ABOVE SNAKE RIVER.
					TERRACE CUTTING
				MELON GRAVEL	ROUNDED BOULDERS AND COBBLES OF LOCAL BASALT IN MATRIX OF BASALTIC SAND. IN SNAKE RIVER CANYON, FORMS HUGE BARS UP TO 90 METERS (270 FEET) HIGH—COMMONLY VENEERED WITH BOULDERS ("MELON PATCHES"). DEPOSITED 30,000 YEARS AGO BY CATASTROPHIC OUTFLOW FROM LAKE BONNEVILLE IN UTAH.
					EROSION OF CANYON - FILLING LAVA FLOWS
				LAVA FLOWS	FRESH BASALT AND PILLOW LAVA FILLING OR CASCADING INTO FORMER CANYON OF SNAKE RIVER. UPLAND SURFACES PARTLY MANTLED WITH EOLIAN MATERIAL.
					CANYON CUT TO PRESENT DEPTH
				CROWSNEST GRAVEL	MAINLY OUTWASH OF COBBLE AND PEBBLE GRAVEL FROM GLACIATED MOUNTAINS OF CENTRAL IDAHO. FORMS TERRACE ABOUT 60 METERS (180 FEET) ABOVE SNAKE RIVER.
				THOUSAND SPRINGS BASALT	SUCCESSION OF LAVA FLOWS THAT FILLED ANCIENT CANYONS AND DEFLECTED SNAKE RIVER TOWARD SOUTHERN MARGIN OF SNAKE RIVER PLAIN. SMOOTH MANTLE OF ALLUVIAL AND EOLIAN DEPOSITS YIELDS COLD-CLIMATE MOLLUSKS.
					CANYON CUTTING
				SUGAR BOWL GRAVEL	OUTWASH OF PEBBLE GRAVEL FROM GLACIATED MOUNTAINS OF CENTRAL IDAHO. DISSECTED REMNANTS DEFINE A TERRACE 120 METERS (360 FEET) ABOVE SNAKE RIVER.
					TERRACE CUTTING
				MADSON BASALT	COLUMNAR LAVA FILLING A FORMER CANYON OF SNAKE RIVER 90 METERS (270 FEET) DEEP.
					PARTIAL ENTRENCHMENT OF SNAKE RIVER
		MIDDLE	IDAHO GROUP (PART)	BLACK MESA GRAVEL	GRAVEL AND SAND ON BROAD REMNANTS OF PEDIMENT WIDELY PRESERVED SOUTH OF SNAKE RIVER AND 170 METERS (510 FEET) HIGHER. HARD CALICHE CAP 2 METERS (6 FEET) THICK.
					BROAD VALLEY EROSION
				BRUNEAU FORMATION *	CANYON FILL OF UNDEFORMED, UNCONSOLIDATED LAKE BEDS (CHIEFLY CLAY, DIATOMITE, AND BEACH GRAVEL) AND INTERBEDDED BASALT. SEQUENCE INTERRUPTED BY SEVERAL LOCAL DISCONFORMITIES CAUSED BY BREACHING OF LAVA DAMS. FILL ABOUT 250 METERS (750 FEET) THICK, BUT ASSOCIATED MARGINAL DEPOSITS OF FAN GRAVEL AND BASALT RISE 90 METERS (270 FEET) HIGHER. YOUNGEST BASALT DATED 1.4 MILLION YEARS BY K-A.
					CANYON CUTTING
		EARLY		TUANA GRAVEL	PEBBLE AND COBBLE GRAVEL INTERBEDDED WITH SAND AND SILT ON DISSECTED EROSION SURFACE SOUTH OF SNAKE RIVER AND 180 TO 250 METERS (540 - 750 FEET) HIGHER. MAINLY DEBRIS FROM HIGHLANDS FARTHER SOUTH. LOCALLY 60 METERS (180 FEET) THICK. HARD CALICHE CAP ABOUT 2 METERS (6 FEET) THICK.
					PLANATION OF BASIN DEPOSITS: MINOR FAULTING
QUATERNARY / TERTIARY	PLEISTOCENE / PLIOCENE	EARLY / LATE		GLENNS FERRY FORMATION *	BASIN FILL OF POORLY CONSOLIDATED DETRITAL MATERIAL AND MINOR LAVA FLOWS OF BASALT. ABRUPT LATERAL CHANGES IN SEDIMENTARY FACIES 100 - 200 METERS (300 - 600 FEET) THICK REPRESENT ADJOINING ENVIRONMENTS OF LAKES (MASSIVE SILT), RIVER CHANNELS (THICK BEDS OF SAND), AND SWAMPY FLOOD PLAINS (THINLY BEDDED DARK CLAY, OLIVE SILT, AND CARBONACEOUS SHALE). BEDDING INTERRUPTED BY NUMEROUS MINOR UNCONFORMITIES RESULTING FROM CONTEMPORANEOUS SUBSIDENCE. ABOUT 600 METERS (1800 FEET) OF BEDS EXPOSED. FOSSILS INCLUDE NUMEROUS VERTEBRATES OF BLANCAN PROVINCIAL AGE, AN EXTRAORDINARILY LARGE MOLLUSCAN FAUNA CONSISTING ALMOST ENTIRELY OF EXTINCT FORMS, AND ABUNDANT REMAINS OF POLLEN, ALGAE, AND DIATOMS. BASALT DATED 3.5 MILLION YEARS BY K-A.
					CONTINUED BLOCK FAULTING AND EROSION
TERTIARY	PLIOCENE	MIDDLE		BANBURY BASALT *	LAVA FLOWS OF OLIVINE BASALT INTERBEDDED LOCALLY WITH MINOR AMOUNTS OF STREAM AND LAKE DEPOSITS. BASALT COMMONLY ALTERED TO GREENISH-BROWN BASALTIC SAPROLITE WITH RESIDUAL SPHEROIDS OF UNDECOMPOSED ROCK. THICKNESS EXCEEDS 300 METERS (1000 FEET) ALONG DRY CREEK NORTHEAST OF KING HILL AND 197 METERS (650 FEET) IN MELON VALLEY SOUTHEAST OF BANBURY SPRINGS. SEQUENCE OF DEPOSITS VARIES BY REASON OF CONTEMPORANEOUS FAULTING AND EROSION.
					INITIAL SUBSIDENCE OF SNAKE RIVER GRABEN
	PLIOCENE	EARLY		IDAVADA VOLCANICS *	SILICIC LATITE; CHIEFLY THICK LAYERS OF DEVITRIFIED WELDED TUFF, BUT INCLUDES SOME BEDDED VITRIC TUFF AND LAVA FLOWS. RHYOLITIC ROCKS OCCUR IN MINOR AMOUNTS, MAINLY AS VITRIC TUFF. PREDOMINANTLY PORPHYRITIC WITH PHENOCRYSTS OF ANDESINE, CLINOPYROXENE, HYPERSTHENE, AND MAGNETITE, BUT WITH NO QUARTZ, SANIDINE, HORNBLENDE, OR BIOTITE. INCLUDES GRANITIC PEBBLE AND COBBLE GRAVEL AT THE BASE ALONG NORTH SIDE OF MOUNT BENNETT HILLS. THICKNESS EXCEEDS 600 METERS (2000 FEET) AT BENNETT MOUNTAIN AND 360 METERS (1200 FEET) ALONG UPPER ROCK CREEK SOUTHEAST OF TWIN FALLS.
	MIOCENE	LATE			
					PROLONGED EROSION AND WEATHERING
	MIOCENE	MIDDLE		CHALLIS VOLCANICS	TUFFS AND FLOWS OF VARIABLE LITHOLOGY, RANGING FROM RHYOLITE TO ANDESITE. RHYOLITE COMMONLY HAS PHENOCRYSTS OF QUARTZ, SANIDINE, AND BIOTITE. ANDESITE HAS PHENOCRYSTS OF PLAGIOCLASE AND HORNBLENDE. COARSE-TEXTURED ROCKS WEATHER TO CRAGGY OUTCROPS. FINE TUFFACEOUS ROCKS WEATHER TO SMOOTH YELLOW SLOPES. FORMS LAYERED SEQUENCES, HIGHLY TILTED AND BROKEN, ALONG NORTH SIDE OF MOUNT BENNETT HILLS AND NORTHEAST OF MAGIC RESERVOIR.
		EARLY			
	OLIGOCENE (?)				
	EOCENE (?)				
					MAJOR UNCONFORMITY
CRETACEOUS				GRANITIC ROCKS OF IDAHO BATHOLITH	INCLUDES SMALL AREAS OF CHALLIS VOLCANICS WEST OF CAMAS PRAIRIE, AND GNEISSIC ROCKS ALONG SOUTH FORK OF BOISE RIVER.

Fig. 5.
Stratigraphy of the WSRP showing depositional and erosional events (based on Malde and Powers 1962, and Malde 1965). *Formations present in target prospects.

overlies the Idavada Volcanics. Within the prospect the Banbury Basalt consists of moderately weathered, vesicular olivine-plagioclase phyric basalt flows with minor interbedded shale and sandstone. The formation is roughly 30 m (98 ft) thick on top of Teapot Dome and approximately 150 m (492 ft) thick in the vicinity of High Springs on Bennett Creek. The formation is broken by northwest-trending normal faults; displacement probably exceeds 300 m (985 ft) across some fault zones (Malde and Powers 1962).

The name Banbury Basalt has been used for basalts of various ages that overlie silicic volcanic rocks but are younger than the Glenns Ferry Formation (Armstrong et al. 1975). This has resulted in a large spread in reported age dates depending on where the formation was sampled. In the Mount Bennett Hills, fossils within the formation are early Hemphillian (late Miocene to earliest Pliocene) (Armstrong et al. 1975). Potassium-argon dates reported by Evernden et al. (1964) and Armstrong et al. (1980) suggest that the Banbury Basalt in the prospect area is 9-10 Myr (mid-Miocene).

b. Glenns Ferry Formation. The Glenns Ferry Formation is a complex intertonguing sequence of nonindurated lake, river, and flood plain deposits of Pliocene to Pleistocene age. The only exposures of the Glenns Ferry Formation in the prospect are fan gravels. These gravels form the lower portion of a dissected alluvial fan that lies along the base of the Mount Bennett Hills in the eastern part of the prospect and consist of coarse sand and angular to subangular pebble- and cobble-size gravel composed of basalt, rhyolite, and granite in a matrix of medium-grained sand. The Glenns Ferry gravels are overlain by younger fan gravels of the Bruneau Formation.

Fossil evidence places the Glenns Ferry Formation in the Blancan Provincial age of Plio-Pleistocene (Malde 1965). Evernden (1964) has recorded dates from 3.2 to 3.5 Myr b.p. but Armstrong et al. (1975) report potassium-argon dates ranging from 4.4 to 6.2 Myr b.p. (late Miocene to early Pliocene).

c. Bruneau Formation. The Bruneau Formation has been divided into lake, stream, and alluvial fan deposits with intercalated basalt flows. Near the town of Bruneau the formation is roughly 400 m (1310 ft) thick (Malde and Powers 1962). About 80% of the prospect is covered by rocks of the Bruneau Formation. At lower elevations, the formation consists of lacustrine sediments. At intermediate elevations these merge with alluvial and colluvial deposits. These deposits grade into fan gravels at the higher elevations along the base of the Mount Bennett Hills. Bruneau sediments are unconsolidated, markedly lenticular, and intertongue with the laterally discontinuous canyon-filling basalt flows of the formation.

Bruneau lake sediments consist of light gray to white beds of silt, clay, and diatomite that crop out along the southern portion of the study area below elevation 980 m (3215 ft).

Bruneau alluvial and colluvial deposits consist of sand, clay, and pebble-size gravels that extend from the top of the lake beds at about 980 m (3215 ft) to an approximate elevation of 1000 m (3280 ft), where they grade into the fan gravels.

Bruneau fan gravel deposits are associated with a dissected alluvial fan located along the front of the Mount Bennett Hills. The deposits are roughly 45 m (148 ft) thick at the apex and overlie older fan gravels of Glenns Ferry Formation. The alluvial fan has been eroded to a relatively flat surface, a portion of which has been covered by Bruneau lava flows. Streams and drainage paths cut as much as 25 m (80 ft) below the surface of the fan. The fan deposits consist of subangular to angular cobble- and pebble-size gravels of basalt, rhyolite, and granite in a medium-grained sandy matrix rich in volcanic glass. The Bruneau lava flows were erupted episodically from several volcanic centers (see Fig. 2). Individual lava flows generally exhibit columnar jointing and are 8-23 m (26-76 ft) thick, consisting of plagioclase and/or olivine-phyric and nonporphyritic basalts. The basalt varies from dense and glassy to coarse-textured and vesicular. Cumulative thicknesses of 150-900 m (492-2952 ft) have been reported for these canyon-filling basalts (Malde 1965; Ralston and Chapman 1968). Both Evernden et al. (1964) and Armstrong et al. (1975) report potassium-argon ages of 1.4 Myr from basalts of the Bruneau Formation.

3. Quaternary Sediments. Surface sediments of Holocene age are accumulating within the lower reaches of the drainage ravines. These deposits consist of unconsolidated gravel, silt, and clay.

B. Bostic 1-A Petrology.

The Bostic 1-A well is located in the southwest portion of the prospect area (Fig. 2). This 2949 m (9676 ft) deep well was drilled as a petroleum wildcat in 1974.

Bostic well cuttings from selected intervals of volcanic rock were examined with binocular and petrographic microscopes. The results are summarized in Fig. 6.

The Middle Pleistocene Bruneau Formation has been mapped at the surface in the area of the well (Malde et al. 1963). Basalts at depths of 427-536 m (1400-1760 ft) are thought to comprise the lowermost part of the formation. Underlying these are shale and sandstone of the Plio-Pleistocene Glenns Ferry Formation to a depth of 1247 m (4090 ft).

Two sequences of basalt separated by 320 m (1050 ft) of sedimentary rock underlie the Glenns Ferry Formation; these are collectively correlated with the middle Pliocene Banbury Basalt.

The well bottoms in silicic flow and pyroclastic rocks interpreted to be Idavada Volcanics. Some basalt also occurs in this portion of the well and may represent feeder dikes for younger basalt flows and/or intertonguing of the Idavada latite with basalt of another formation. Detailed discussion of the petrography and stratigraphy of the Bostic 1-A well will be presented in a separate report (Arney, Belluomini, Gardner, and Wood, in preparation).

Two older rock units underlie the Idavada Volcanics about 16 km northeast of the prospect area (Malde et al. 1963): flows and tuffs of Eocene to Miocene Challis Volcanics and Cretaceous granitic rock of the Idaho Batholith. In some places Challis is shown underlying Idavada, in others Idavada directly overlies the Batholith. The three formations apparently do not occur in a continuous unfaulted sequence anywhere in the Mount Bennett Hills. Neither Challis nor Idaho Batholith was encountered in the Bostic well, nor are they exposed at the surface in the prospect area. Idaho Batholith is believed to exist at depth beneath the northern part of the prospect, though its southern

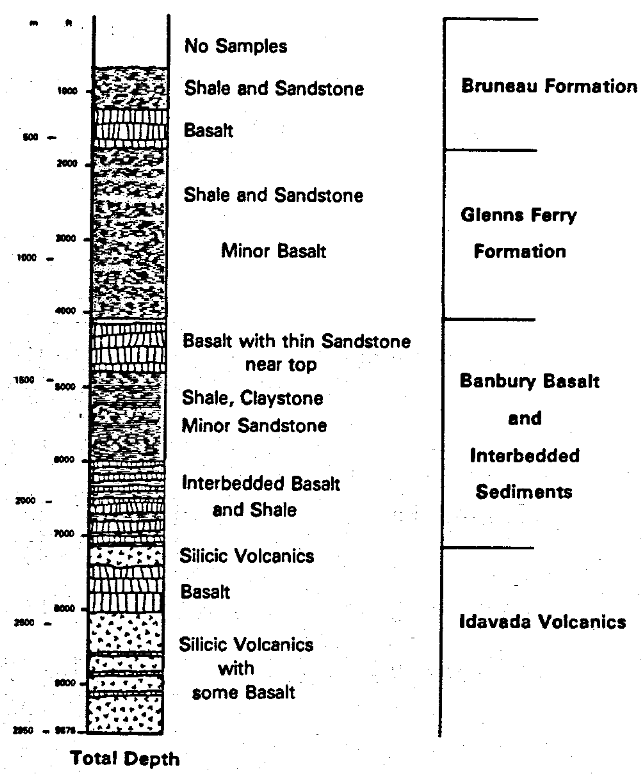


Fig. 6.
Bostic 1-A lithology log.

extent beneath the WSRP is not known. Challis Volcanics may or may not occur between the batholith and Idavada sequence.

C. Structure.

The predominant structural feature within the prospect is a zone of northwest-trending normal faults that traverses the northern portion of the area. This zone defines the northern boundary of the WSRP. Along it, Pliocene through Quarternary deposits occupying the plain have been juxtaposed against Mio-Pliocene silicic volcanic rocks (within the prospect) and Cretaceous granite (farther to the northwest). Faults in the zone trend 40° to 50° west of north and dip 70° to 90°, with the downthrown block usually on the southwest side. A generalized north-south cross-section through the prospect is shown in Fig. 7. Interpretation of gravity data from this study (Section IV-D) has resulted in modifying the depth and type of basement beneath the Bostic well from the granitic rock previously assumed.

Most of the mappable faults displace Idavada Volcanics and Banbury basalt along the front of the Mount Bennett Hills (Fig. 2). Small grabens are present in the northwest corner of the prospect.

Malde (1959), and correlation between the surface exposures of Idavada Volcanics at Bennett Mountain (elevation 2270 m (7490 ft) and the Bostic 1-A well, suggest the following displacements across the fault zone.

		Aggregate Minimum Displacement	
Formation	Age	Meters	Feet
Post-Bruneau*	Post-Middle Pleistocene	Deposits are fractured but not measurably offset	
Bruneau*	Middle Pleistocene	185	607
Glenns Ferry*	Late Pliocene to Early Pleistocene	360	1181
Banbury Basalt	Middle Pliocene	2300	7544
Idavada Volcanics	Late Miocene to Early Pliocene	3490	11447

*Displacement for these formations were reported by Malde (1959), who examined exposures north of the town of King Hill, located about 16 km (10 mi) southeast of the prospect.

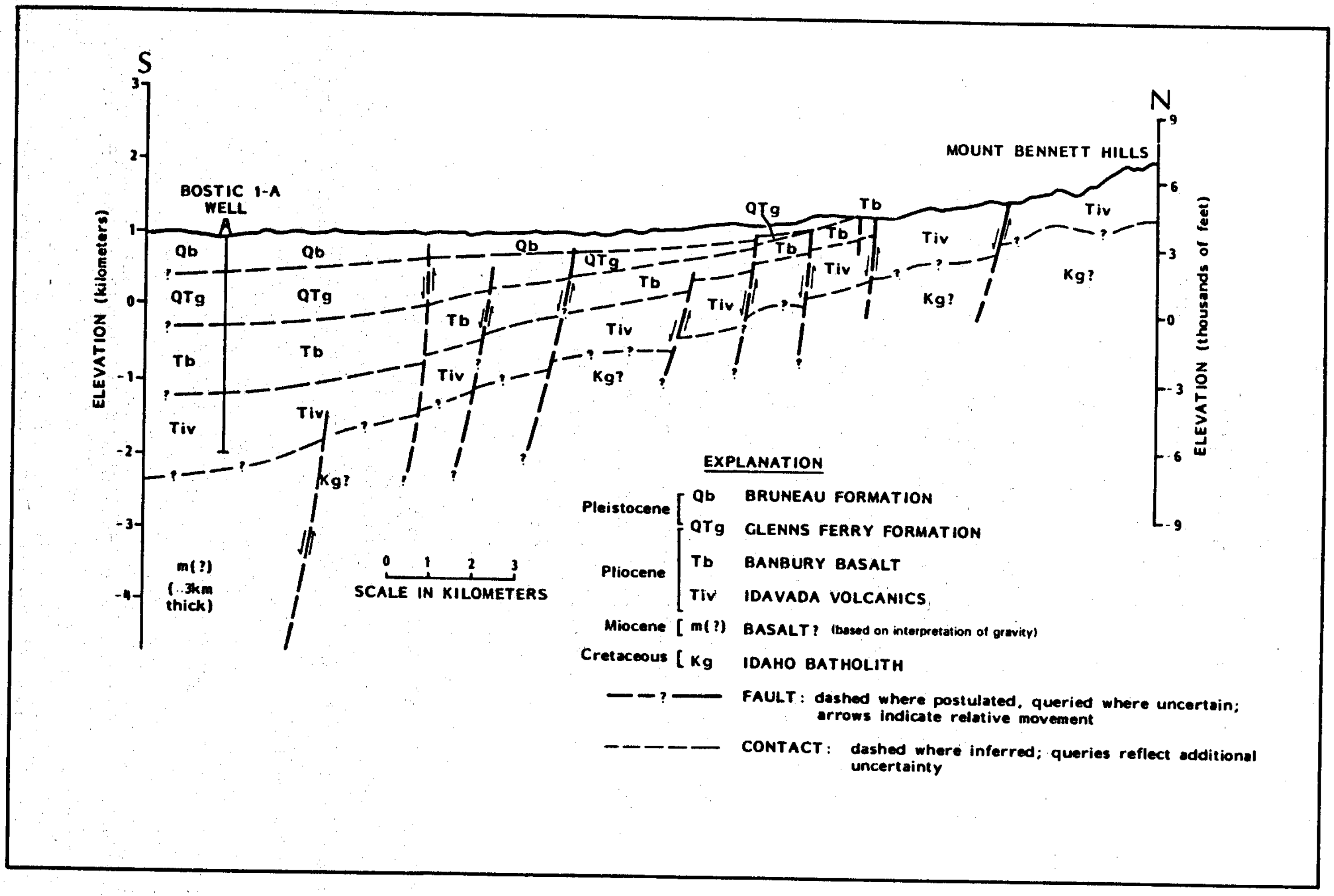


Fig. 7.
Generalized cross-section through the target prospect, WSRP, Idaho.

EXPLANATION

TOPOGRAPHIC LINEAMENT; INCLUDES VEGETATION ALIGNMENTS, VEGETATION CONTRASTS, TONAL CONTRASTS, ALIGNED SPRINGS, AND LINEAR DRAINAGES, VALLEYS AND RIDGES

LINEAMENT CORRESPONDING WITH A MAPPED FAULT

4 LINEAMENT CORRESPONDING WITH GRAVITY AND/OR TELLURIC ANOMALY, NUMBER KEYED TO GEOPHYSICS DISCUSSION IN TEXT

HOT DRY ROCK

GEOTHERMAL PROSPECT EVALUATION
WESTERN SNAKE RIVER PLAIN, IDAHO
Prepared for Los Alamos National Laboratory

Prepared by Harding-Lawson Associates
Engineers Geologists & Geophysicists
Job No. 9798,005.01
February 27, 1981
Approved:

Fig. 8.

LINEAMENT MAP OF THE TARGET PROSPECT AND VICINITY

Idavada Volcanics are observed at 2270 m (7445 ft) on top of Bennett Mountain, and 1150 m (3772 ft) at the base of the Mount Bennett Hills. Depth of the top of the Idavada is at 2176 m (7140 ft), 1208 m (3965 ft) below sea level in the Bostic 1-A well. Of the total displacement of 3478 m (11 410 ft) that occurred during and after the Idavada period, 1120 m (3673 ft) can be traced on faults in the Mount Bennett Hills. It is likely that the remaining 2358 m (7737 ft) can be accounted for by faults that lie beneath the SRP, but the exact position of the buried faults has not been determined. The dip of the Idavada Volcanics beneath the SRP is unknown so actual displacements cannot be estimated.

Regional gravity data and the presence of hot wells and springs indicate a major west-northwest-trending subsurface fault, downthrown to the south, roughly 13 km (8 mi) south of the base of the Mount Bennett Hills. Although movement on this fault may have displaced Idavada and younger formations, as have those in Mount Bennett Hills, Malde (1959) suggests that a minimum of 3000 m (9840 ft) of offset had occurred on the northern margin of the plain before late Miocene (pre-Idavada) time. This is consistent with paleobotanical evidence that the SRP first developed in Oligocene time (Axelrod 1968). Both Malde and Axelrod suggest that the fault zone moved recurrently from Oligocene (pre-Idavada) to Middle Pleistocene (about 0.54 Myr).

On published maps (Malde et al. 1963; 1972), no faults are shown offsetting Quaternary rocks in the prospect area. Northeast of Mountain Home and about 1.7 km (1 mi) west of the prospect, fault scarps are well preserved in lava flows of the Bruneau Formation. These scarps range in height from about 1 m (3 ft) to over 30 m (100 ft), and have been modified by erosion and incised by stream valleys. Late Pleistocene and Holocene surface deposits lie across these scarps without apparent offset. The southeastern extent of these faults is not currently known.

IV. STUDIES PERFORMED BY HARDING LAWSON ASSOCIATES

To evaluate the area as a HDR prospect, several criteria needed to be applied.

(1) Is the temperature within 3-5 km of the surface sufficient (200-300°C)?

(2) Does crystalline "reservoir rock" exist within reasonable drilling depths (3-5 km)?

(3) Is the "reservoir rock" tight or sealed over a large enough area to respond to established HDR methods?

To assess the area, information was needed on the nature and extent of faulting, seismicity of the area, effects of hydrology on temperature gradients, temperature information from water chemistry, depth to basement, and permeability of basement.

Several methods were used to obtain this information: lineament analysis, passive seismic survey, telluric survey, gravity survey, and spring and well water geochemistry. In addition, a petrographic study was made of the Bostic well cuttings. Those results were summarized in the previous section.

A. Lineament Analysis

A lineament analysis was carried out to locate buried faults and to determine the orientation and density of faulting within the target prospect. Photo imagery was analyzed by several individuals making independent interpretations to provide a more complete and objective evaluation. Only those lineaments that could be recognized on both small- and large-scale imagery were used in the analysis (Table I).

Images were examined for topographic linears such as stream paths, valleys, ridges, slope changes, aligned springs, and other linear land forms. The data were then analyzed by comparing them with geologic, seismic, aeromagnetic, and gravity maps.

The lineaments were field checked to determine what geologic feature(s), if any, caused them. Those which appeared to be unrelated to any structure were eliminated from the analysis. The field checking was facilitated by a low sun angle aerial reconnaissance survey. Oblique color and black and white photographs of the more prominent features were taken during the survey. These photographs were compiled into an annotated photo log that is kept in a permanent reference file at Los Alamos.

Depending on the particular scale of the imagery, shorter topographic features tend to define lineaments that distort the continuity and trends of the longer lineaments. Therefore, only those lineaments with minimum length

TABLE I

PHOTOGRAPHY USED IN LINEAMENT ANALYSIS OF MOUNTAIN HOME HDR PROSPECT

Type	Scale	Date	Source
Standard high sun angle Ektachrome	1:31 680	7/76	U. S. Bureau of Land Management
NASA/Aircraft (U-2 color infrared conventional imagery	1:120 000 to 1:124 000	10/25/72	U. S. Geological Survey EROS Data Center
NASA/Landsat digitally enhanced multi-spectral scanner (MSS) panchromatic images in Band 5 and Band 7	1:3 369 000	9/28/78 and 1/06/79	U. S. Geological Survey EROS Data Center
NASA/Landsat digitally enhanced MSS false color composite band imagery spectral Bands 4, 5, and 7	1:3 369 000	9/28/79 and 1/06/79	U. S. Geological Survey EROS Data Center

of 2 km (1.25 mi) were taken from the U-2 imagery and 10 km (6 mi) from the Landsat imagery.

Lineaments identified from the imagery analysis were transferred to a base map (Fig. 8, in pocket on inside back cover) and studied for location, length, azimuth (or strike), and overall pattern. Rose diagrams that show length vs azimuth relationships and histograms that show frequency vs azimuth relationships identify the predominant structural trends (Figs. 9 and 10).

Figure 8 shows the lineaments identified during this study. They vary in sharpness and continuity but are generally characterized by subdued topographic expression. Not all the lineaments are faults, but the strong northwest and northeast preferred orientations suggest that these trends are controlled by a through-going structural fabric. A small number of north-trending lineaments were observed.

On both the Landsat (Fig. 9) and U-2 (Fig. 10) imagery, the northwest-trending lineaments are the most numerous. They are better defined and more continuous than the northeast-trending lineaments. Many of them correlate

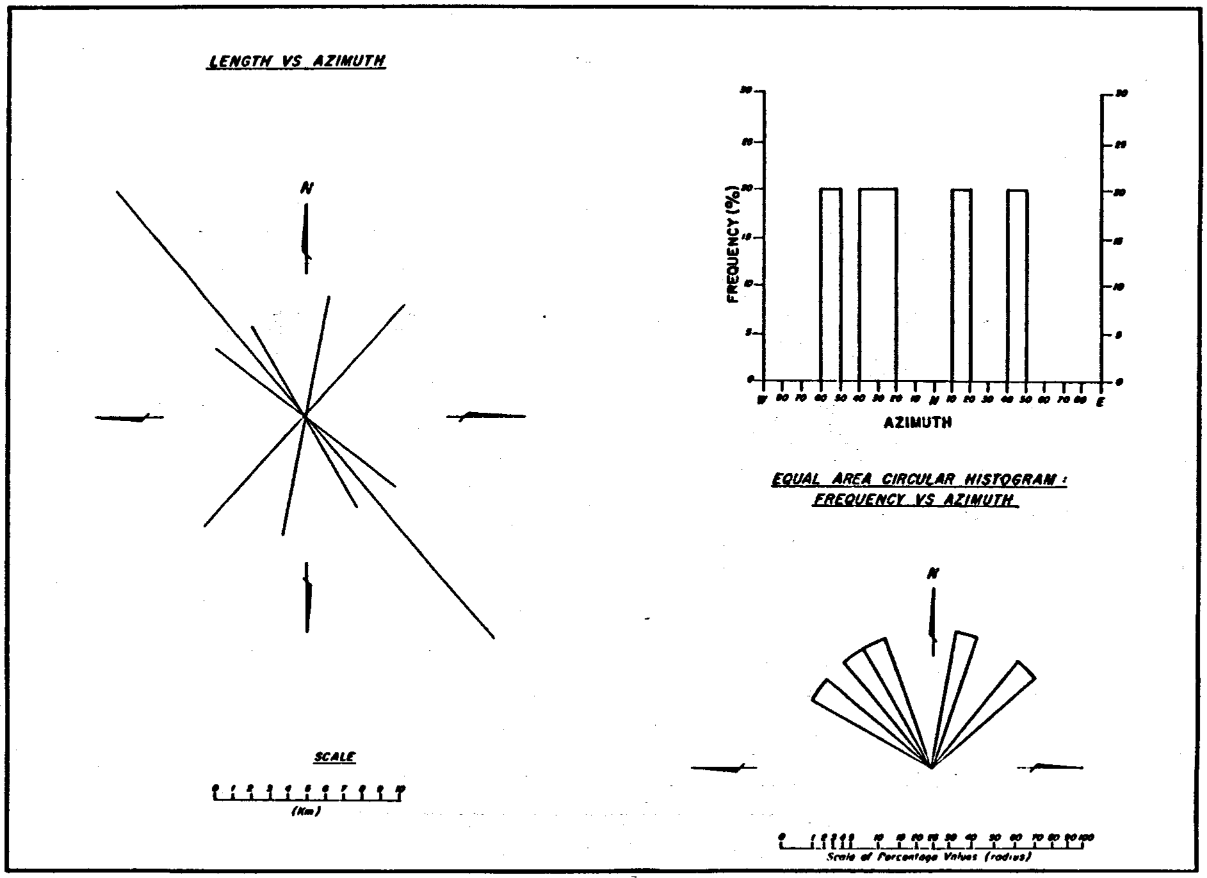


Fig. 9.
Lineament Data ≥10 km from Landsat imagery.

with segments of major faults that have been mapped in the granitic and silicic volcanic basement rocks of the region. Their parallelism with the principal boundary faults of the WSRP suggests a genetic relationship.

B. Passive Seismic

1. Historic Seismicity. A compilation of earthquake epicenters in southern Idaho for events of magnitude (M) greater than 3.0 through 1978 by the National Oceanic and Atmospheric Administration (NOAA) (1978) indicates no activity within the prospect. The earthquake nearest the prospect occurred 25 km (15.6 mi) to the north; all other events were at a distance of at least 50 km (31 mi).

Applegate and Donaldson (1977) report that microseismic monitoring for 18 months near Boise, 80 km (50 mi) from the prospect, failed to detect local

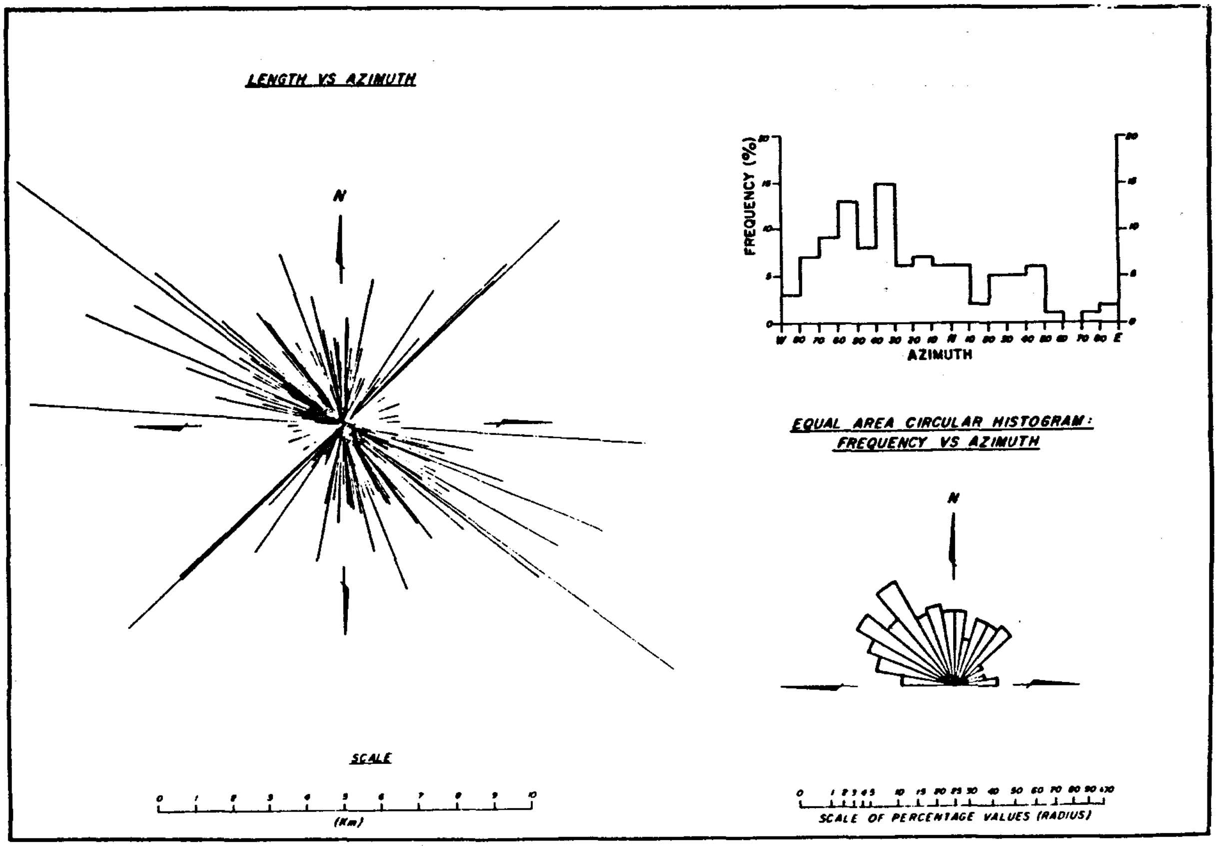


Fig. 10.
Lineament data ≥ 2 km from U-2 imagery.

detected from eastern Oregon and from within the Idaho Batholith, but not along the SRP-Batholith boundary.

A study of historical and recently recorded seismicity in southwestern Idaho by Vincent and Applegate (1978) produced the maps shown in Fig. 11. Felt Reports are events before 1963 for which no instrumental determination of location are available. Several small earthquakes ($M \leq 2.5$) were recorded at a distance of about 50 km (31 mi) north and west of the prospect, with one such event located about 30 km (19 mi) away.

2. Passive Seismic Monitoring. Between mid-October and mid-December 1979, seismic events were monitored continually for 48 days using a Sprengnether MEQ-800 seismograph and a 1-Hz geophone. The seismograph was located sequentially at four locations in the Mount Bennett Hills near the northern boundary of the prospect (Fig. 12).

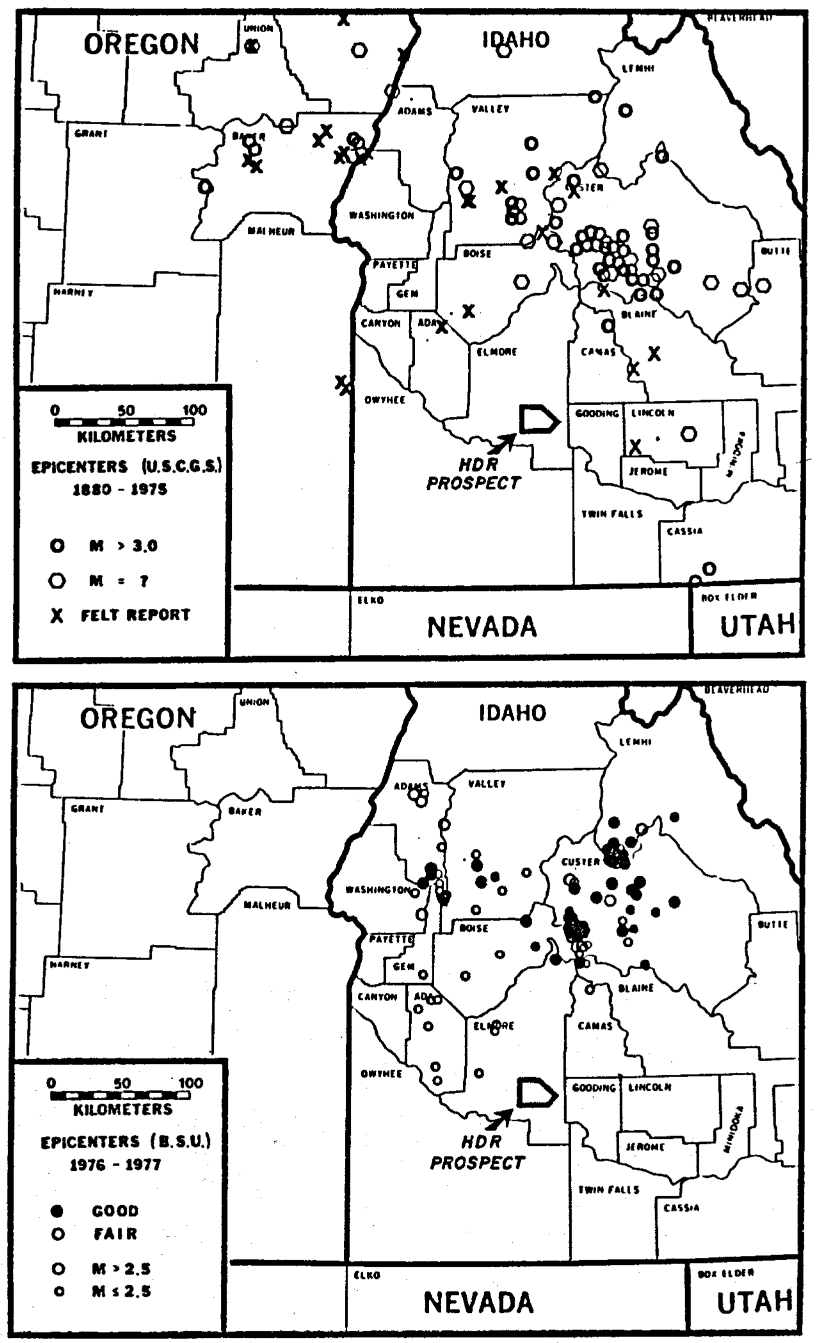


Fig. 11.
Earthquake epicenters in southwestern Idaho (modified after Vincent and Applegate 1978).

2

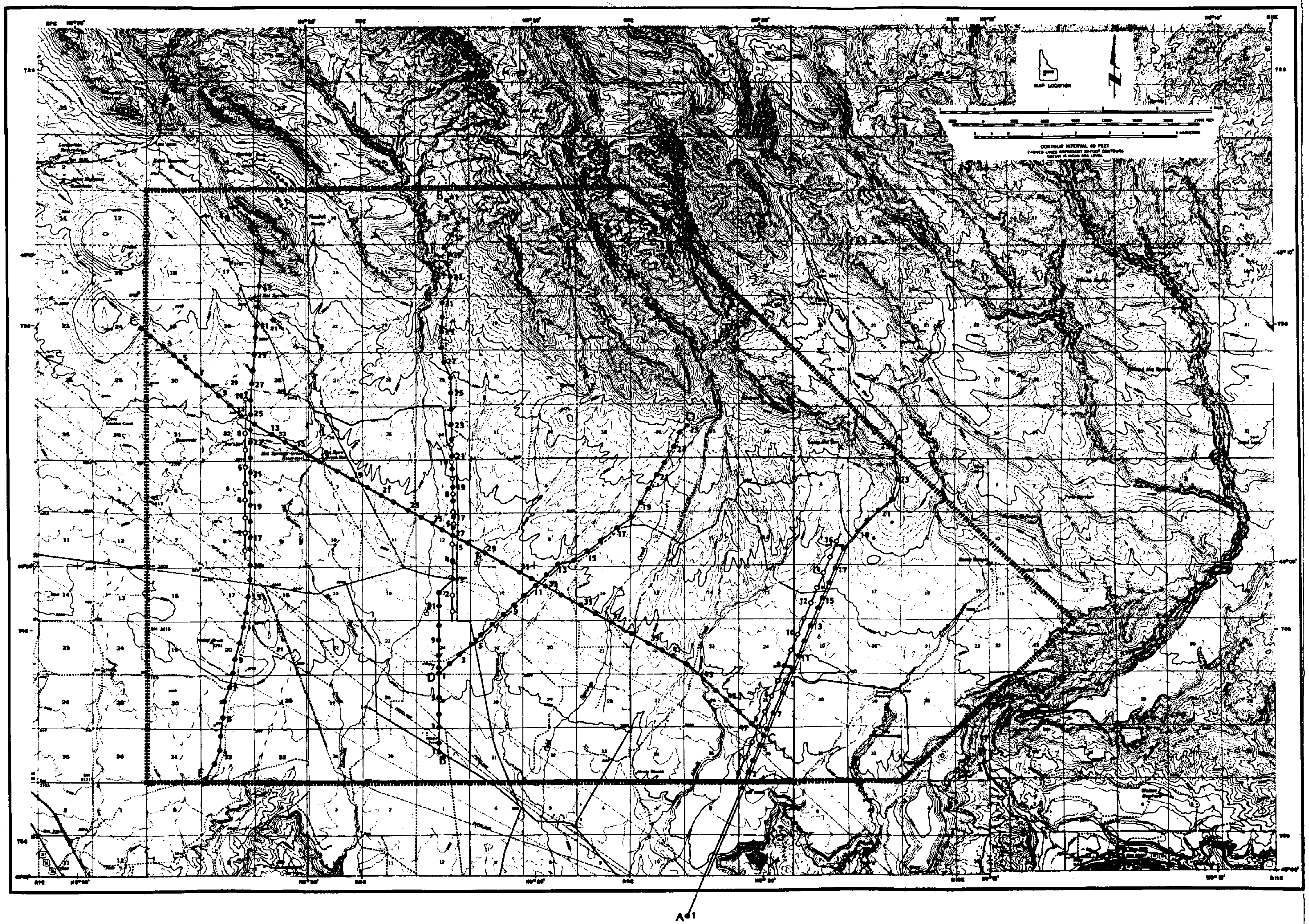


Fig. 12.
Location map of geophysical surveys.

EXPLANATION

- 17 ● GRAVITY STATION LOCATION AND NUMBER
- ○ 2 TELLURIC PROFILING STATION LOCATION (CENTER OF 500 METER DIPOLE) AND NUMBER
- X SEISMOGRAPH LOCATION
- A SURVEY LINE DESIGNATION

Table II shows the frequency of seismic events recorded during this period. The very local microearthquake activity (about one event per week) is quite low and occurs outside the prospect. The expense of deploying a three-seismometer array to locate the sources of microearthquakes was judged unwarranted at this stage in the prospect evaluation.

A pattern of persistent earthquake activity (about 10 a week) at a distance of about 140 km (88 mi) shows a marked similarity for each event. This suggests a localized source. The U.S. Coast and Geodedic Survey (now National Earthquake Information Service) (USCGS) map of epicenters from 1880-1975 (Fig. 11) shows an indistinct zone of seismic activity trending west-northwest across central Idaho. This zone has been called the Idaho Seismic Belt by Smith and Sbar (1974) and lies approximately 140 km (88 mi) north of the prospect. Vincent and Applegate (1978) at Boise State University (BSU) recorded over 800 seismic events during 1976 and 1977, ranging from 10 to 130 events per month. Most lie within the Idaho Seismic Belt. It is likely that the clusters of regional events recorded in this survey also have their source in the Idaho Seismic Belt.

TABLE II

FREQUENCY OF SEISMIC EVENTS RECORDED BETWEEN MID-OCTOBER THROUGH MID-DECEMBER 1979

Recorded Earthquakes	Events per Week	Magnitude
Regionals, >300 km distance	about 3-4	3.25 to 3.5
Regionals, ≤300 km distance	about 3-4	2.25 to 2.5
Clusters of regionals (~140 km)	about 10	2 to 3.5
Locals, 30-100 km distance	possibly 1	0.5 to 2.25
Very local, ≤25 km distance	possibly 1	0 to 1.0
Very local high frequency unidentified events	about 3	

C. Electrical Resistivity.

A telluric profiling survey was performed in an attempt to locate faults that might juxtapose conductive aquifers against resistive aquitards and to help identify deep fracture zones that should be more conductive than surrounding unfractured areas. Telluric data were acquired at frequencies of 8.0 and 0.05 Hz using a dipole length of 500 m (1650 ft). Dipoles were oriented parallel to the survey lines. Different penetration depths are achieved by the use of two frequencies.

Data were obtained at 34 locations over a total length of 17 km (10 mi) along portions of three survey lines (Fig. 12). Data for survey lines A, B, and F are plotted on Figs. 13(a), (b), and (e), respectively. Station locations indicated are at the center of each 500-m dipole.

The 8-Hz data for each of these survey lines indicate highly variable resistivity in the near-surface material. Presumably, this is the result of complex intermixing of upper Pliocene and Pleistocene sediments and basalt flows along with complex hydrology. The correlation of these data with surface features is only moderately good. A resistivity increase at the northernmost station on line A correlates well with extensions of fault 2 and lineament 3 (Fig. 8), where more resistive silicic volcanic rocks have been juxtaposed against more conductive SRP sediments and basalts.

There is little correlation between the anomalies on the 8-Hz and 0.05-Hz telluric profiles. This suggests that if the geologic features producing the anomalies extend to great depths, then the resistivity contrasts associated with these features are not high and not resolvable beyond relatively shallow depths of about 1 km (3300 ft).

Along line A the deep resistivity seen from the 0.05-Hz data is relatively uniform, with a slight resistivity increase to the north toward the Idaho Batholith. Along line B the data are also quite uniform, but with a slight resistivity decrease toward the Batholith. Line F reveals an abrupt resistivity drop to the north. Because absolute resistivities are not obtained with this method, the telluric data could be interpreted to indicate either a resistive anomaly to the south or a conductive anomaly to the north.

A conductive anomaly to the north is more plausible because the lateral extent of the telluric anomaly corresponds with that of a broad gravity low observed along the northern third of line F and the western third of line C. The concurrence of these two anomalies could indicate fluid-filled fractures

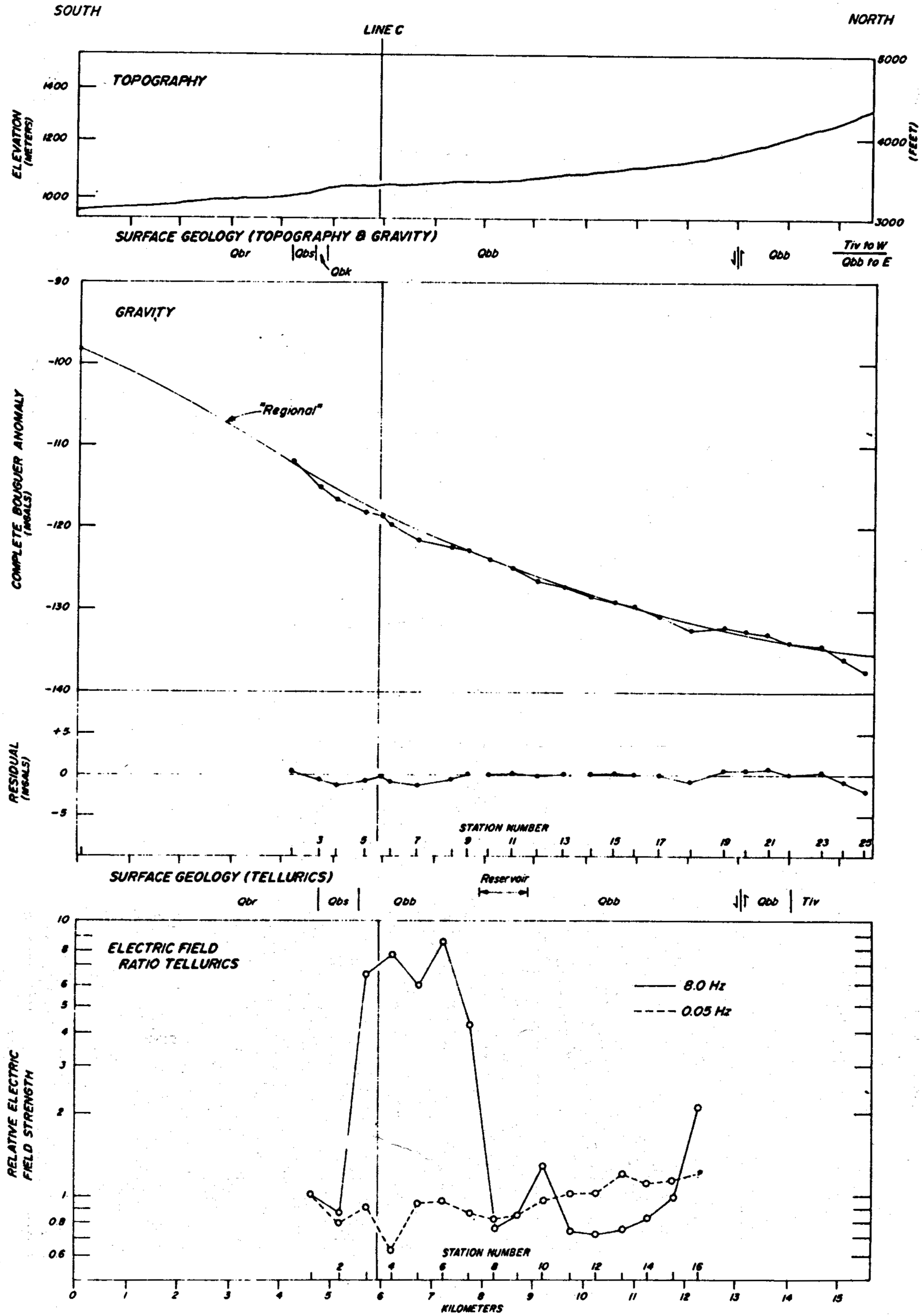


Fig. 13(a).
Topography, gravity, and telluric profiles along survey line A.

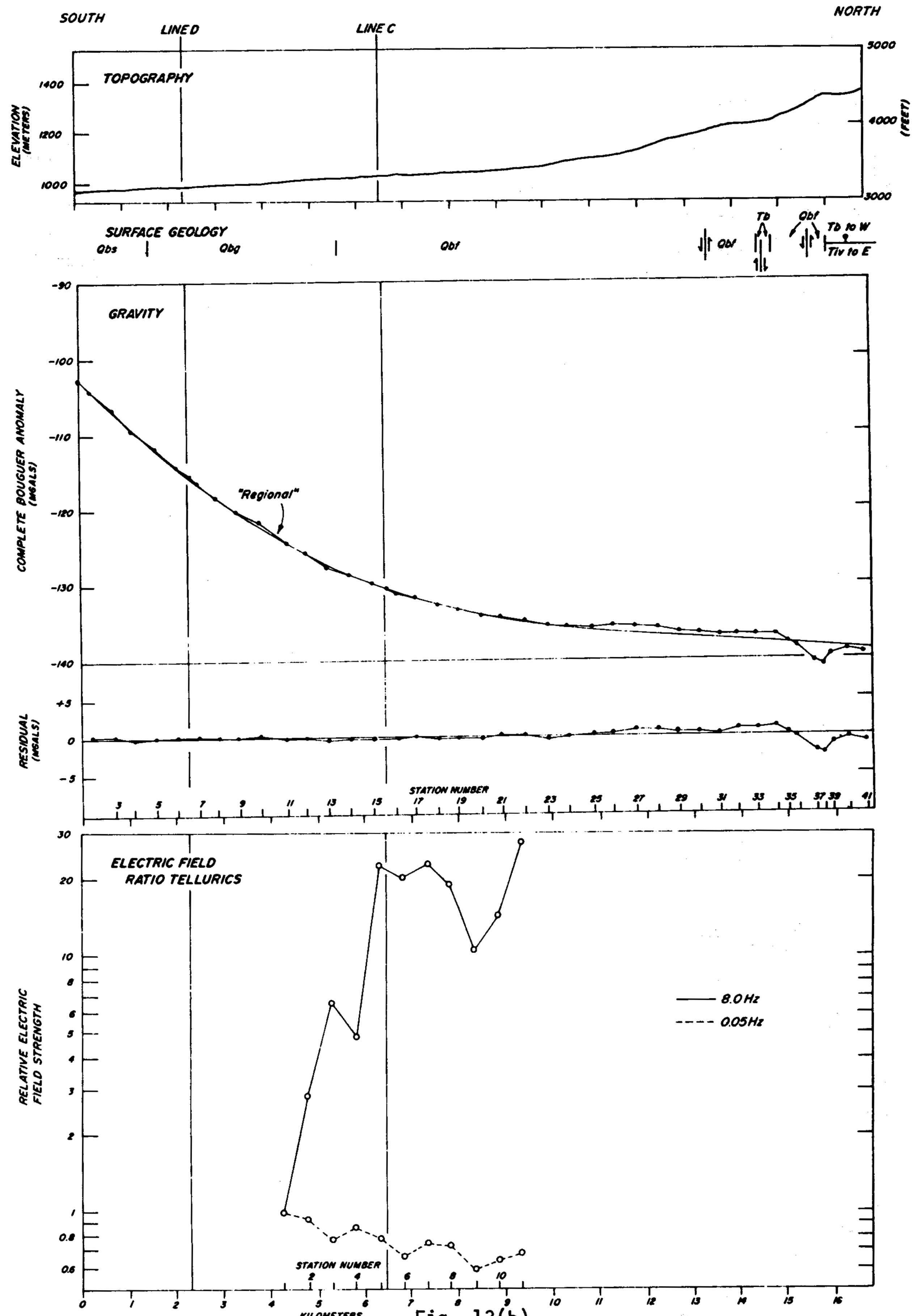


Fig. 13(b).
Topography, gravity, and telluric profiles along survey line B.

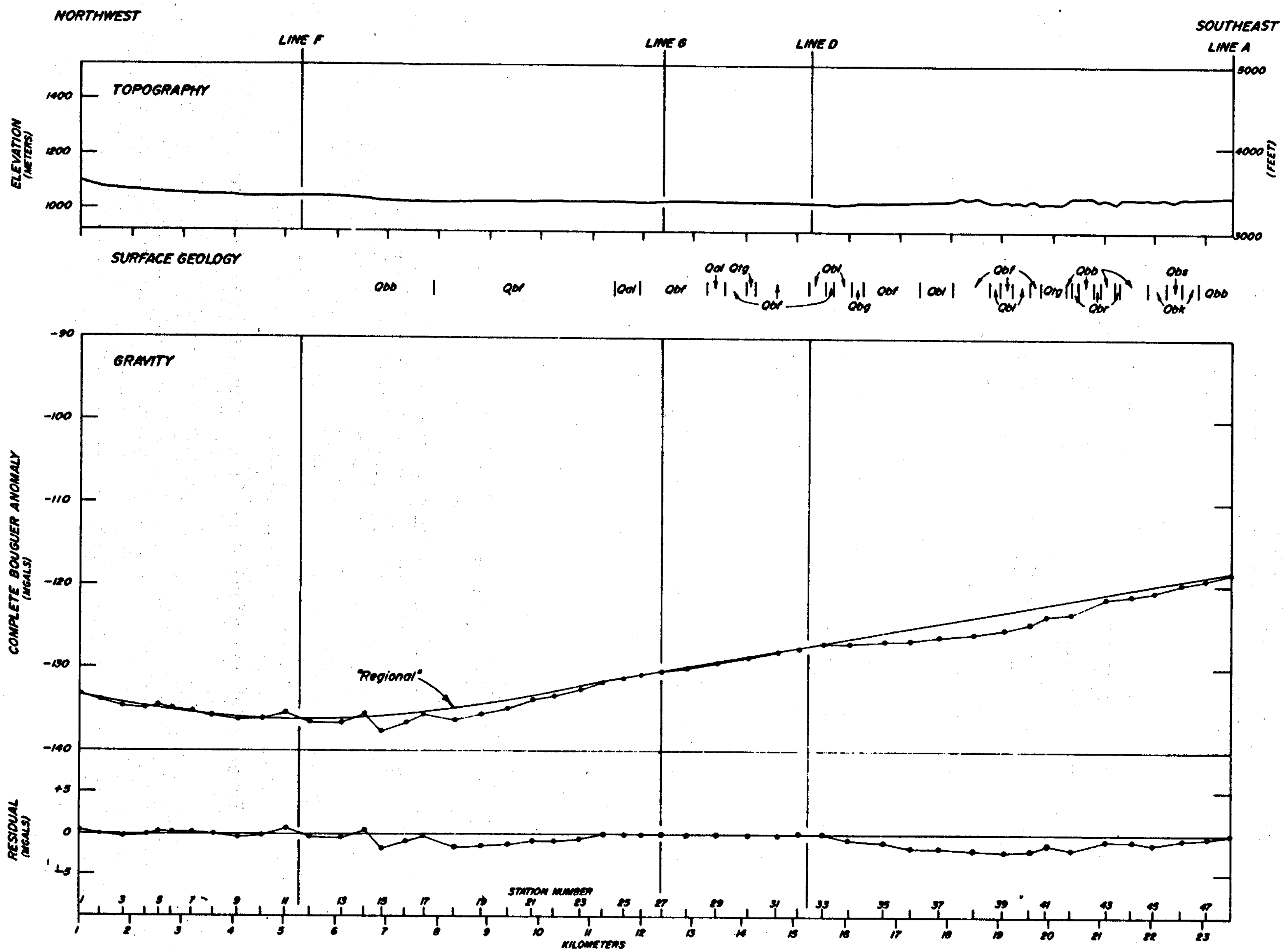


Fig. 13(c).
Topography and gravity profiles along survey line C.

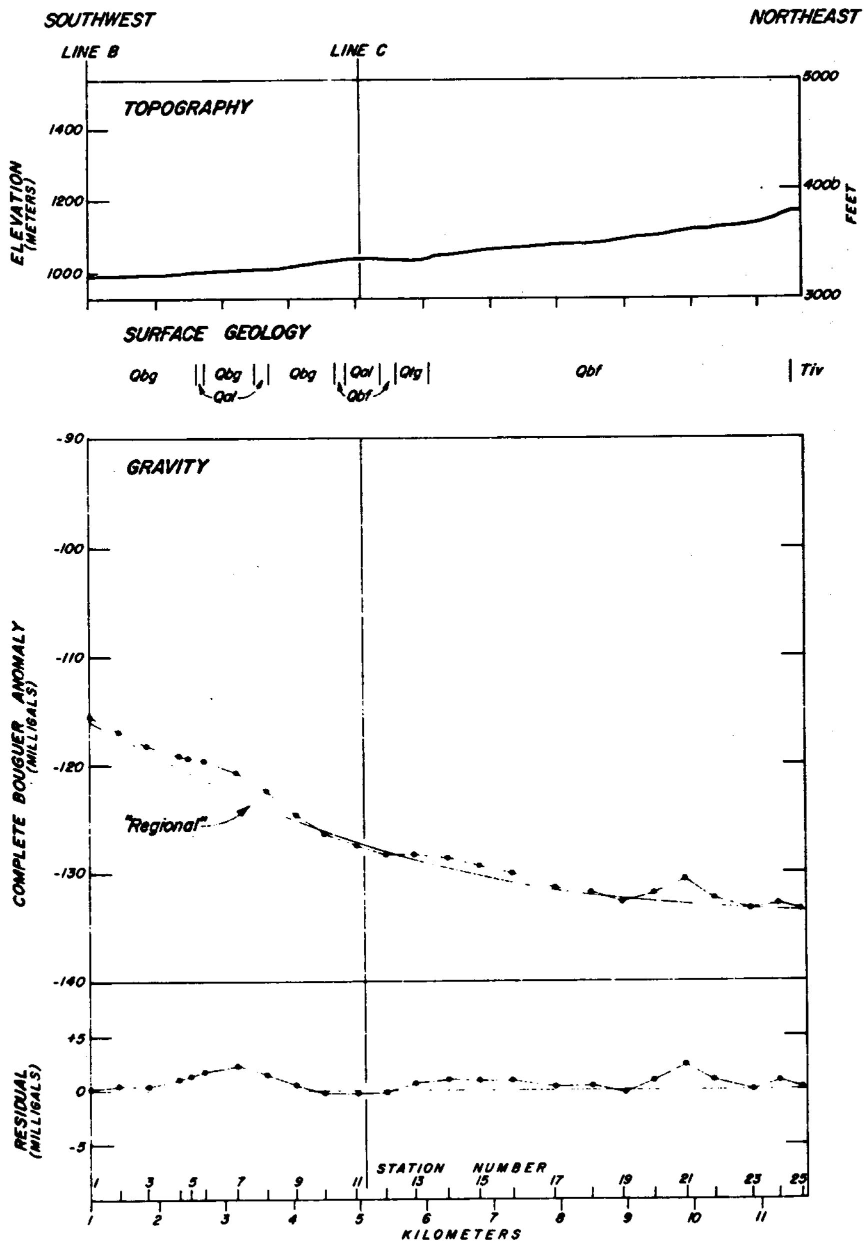


Fig. 13(d).

Topography and gravity profiles along survey line D.

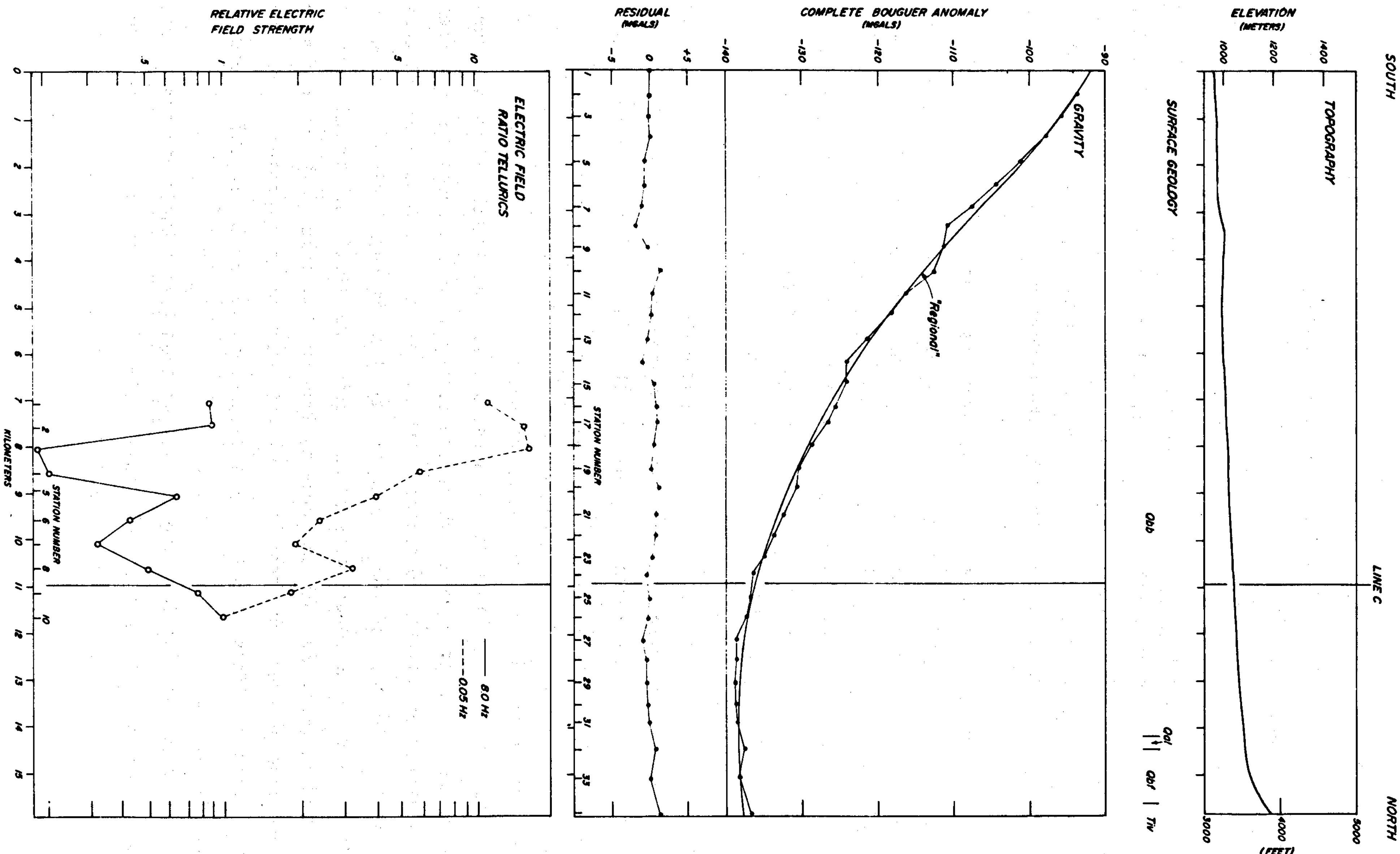


Fig. 13(e).

Topography, gravity, and telluric profiles along survey line F.

at depth or a fault-controlled basin with a greater thickness of sediments. The latter is more probable.

D. Gravity.

1. Local Gravity Survey. The primary purpose of the gravity survey was to locate faults where basalts might abut silicic volcanics or sediments. Another objective of the gravity survey was to use these data in conjunction with other geophysical data to help locate low-density anomalies that might be associated with fracturing, and therefore more permeable zones that should be avoided.

The gravity survey consisted of 173 stations spaced at 500-m (1650 ft) intervals along two north-south lines, two northeast-southwest lines, and one northwest-southeast survey line (Fig. 12). The data are plotted on Figs. 13a-e and contoured on Fig. 14. The gravity data were reduced according to standard procedures (Dobrin 1976) to obtain the Complete Bouguer anomaly. A density of 2.67 g/cm^3 was used for the Bouguer and terrain corections. The Hammer (1939) terrain correction method was employed, with corrections calculated for zones D through J.

Gravity survey lines A, B, D, and F are roughly perpendicular to the axis of the WSRP and traverse a portion of a steep gravity gradient that runs west-northwest along the northern margin of the plain and through the southwestern portion of the prospect (Fig. 3). If this steep gravity gradient is considered to be a regional gradient and is subtracted from the Bouguer anomaly, then residual gradients occur as shown on Figs. 13(a-e). In general, these residuals do not exhibit striking anomalies. The largest anomaly occurs at the northern end of line B, where the survey line traverses three mapped faults that offset Idavada Volcanics, Banbury Basalt, and Middle Pleistocene fan gravels. The rest of the line B gravity data is remarkably smooth, with the possibility of a minor offset at Station 25 that may correlate with lineament 4 on Fig. 8. On the gravity contour map (Fig. 14) the northern third of line B does not drop off at the same gradient observed on the northern parts of lines A and D so a slight gravity high may exist between Stations 25 and 35.

The gravity residual for line F displays anomalies between Stations 6 and 15 that correlate with a dissected basaltic vent. North of this are minor anomalies, generally less than 1 mgal in amplitude, which occur as simple

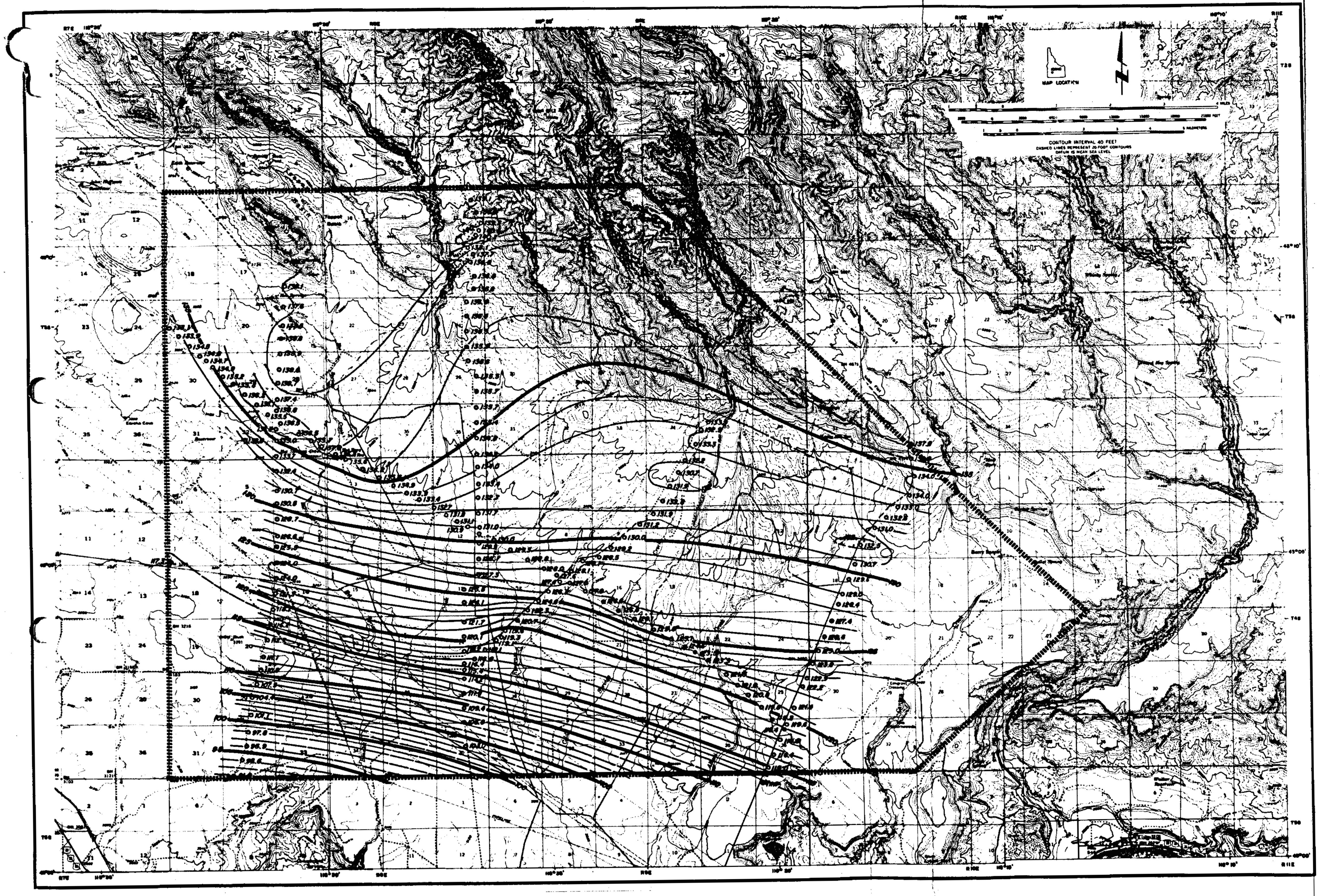


Fig. 14.
Bouguer gravity.

NOTES:

1. CONTOURS ARE SHOWN AT 1 MILLIGAL INTERVALS AND ARE DASHED WHERE APPROXIMATELY LOCATED.
2. ALL STATION VALUES AND CONTOURS ARE NEGATIVE.
3. BOUGUER AND TERRAIN CORRECTION DENSITY USED WAS 2.67 g/cm^3.
4. TERRAIN CORRECTIONS APPLIED THROUGH HAMMER ZONE J.
5. GRAVITY STATIONS ARE SHOWN BY OPEN CIRCLES (o).

offsets from one station to the next. The sources of these anomalies must be shallow [less than 250 m (820 ft)] based on the half-width of the anomaly and may be caused by near-surface features such as the edge of a basalt flow. Some of these anomalies correlate with northwest trending lineaments 5 through 13 on Fig. 8. Similar anomalies appear on line C between Stations 15 and 18 and may be associated with north-south trending lineaments 14, 15, and 16.

The Bouguer anomaly for the northern third of line F and the western third of line C (Fig. 13c and e, Fig. 14) shows a broad gravity low, which correlates with the 0.05-Hz resistivity low discussed in the preceding section.

The gravity data between Stations 3 and 17 on the southwestern end of line D display smooth undulations. Based on the spacing of the inflection points, the sources of the undulations could be up to 1 km (0.6 mi) deep. The 2 mgal anomaly that peaks at Station 7 on line D is not observed on line B less than 2 km (1.2 mi) to the west. The lack of continuity suggests that the sources of the anomalies are shallow and local.

The anomalous high at Station 21 has very high gradients, which dictates that the source is shallow, probably less than 500 m (1650 ft) deep. This and the other anomalies on line D could be caused by the remnants of buried volcanic vents. The anomalies at the southern end of line A between Stations 2 and 9 have a short wavelength that indicates a shallow (less than 500 m (1650 ft) depth to source. The anomaly at Station 18 correlates with telluric anomalies and with lineament 17 (Fig. 8); this may be associated with range-front faulting at the base of the Mount Bennett Hills. The two northernmost gravity stations on line A suggest the edge of an anomaly that may be associated with lineaments 18 and/or 19.

Predominantly normal faulting is observed along the northern boundary of the Plain at the base of the Mount Bennett Hills. H. E. Malde (U.S. Geology Survey, Denver, personal communication, 1980) feels that this is a major fault or fault system. Still, with the exception of the steep gravity gradient in the southern part of the prospect, the gravity data do not show any major anomalies. The observed fault at the base of the Mount Bennett Hills (Fault 2, Fig. 8) produces a negligible anomaly. Apparently there are enough sediments intercalated with the basalts to balance out any density differences between fault blocks, so the method was not successful in locating buried faults, which must exist between the Bostic 1-A well and the base of the Mount Bennett Hills.

2. Regional Gravity Modeling. Figure 15 shows a northeast-southwest gravity profile across the WSRP along line G-G'. Two-dimensional numerical modeling (Talwani et al. 1959) was employed to obtain the density model shown in the bottom half of Fig. 15. The lithologic log for the Bostic 1-A well was used to estimate the thicknesses and densities of the three near-surface units shown in the model. The well encountered about 1200 m (3900 ft) of Glenn's Ferry and younger formations, represented by the density 2.30 g/cm^3 in the model. This is underlain by 960 m (3200 ft) of the Banbury formation, for which an aggregate density of 2.62 g/cm^3 was used. From a depth of about 2180 m (7200 ft) to bottom at 2949 m (9676 ft), the well encountered silicic volcanics of the Idavada formation, for which a density of 2.46 g/cm^3 was assumed. Geologic data suggest that the base of the Idavada Volcanics may lie a few hundred meters below the bottom of the Bostic well. To the northeast of the WSRP on the north side of the Mount Bennett Hills the 2.46 g/cm^3 material could be replaced by a lesser thickness of lower density material forming

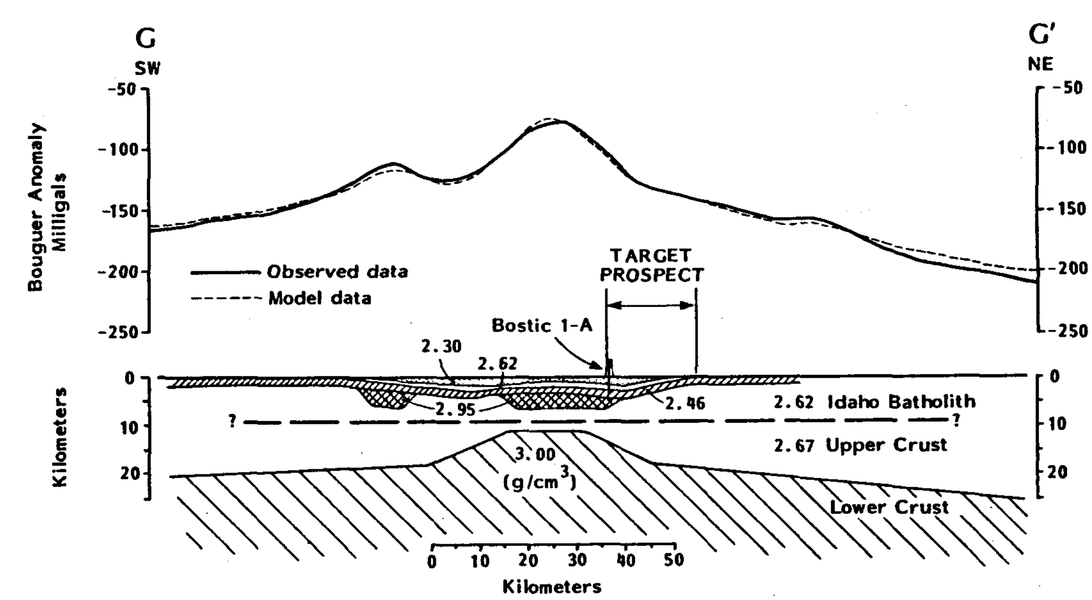


Fig. 15.
Gravity Profile G-G' across the WSRP. Location of profile shown on Fig. 2.

alluvial fill in the Camas Prairie. To the southwest of the southern margin of the WSRP the 2.46 g/cm^3 material represents silicic volcanics overlying Basin and Range structures and rock types. The two rock masses with densities of 2.95 g/cm^3 are basalt, probably of Miocene or early Pliocene age. These features are necessary to model the two gravity highs near the center of the profile line.

The Idaho Batholith is represented by relatively low-density (2.62 g/cm^3) granitic rocks. The model shows a transition to somewhat higher density (2.67 g/cm3) upper crustal material, but this is hypothetical and does not provide lateral density contrasts, which would affect the calculated gravity response. Lower crustal material with a density of 3.00 g/cm^3 lies at depth.

The regional trend in the gravity data is a broad high centered on the WSRP, decreasing toward the center of the Idaho Batholith to the northeast and toward the Basin and Range Province to the southwest. Seismic refraction data suggest this is the result of an abnormally thin upper crust beneath the WSRP (Hill and Pakiser 1966). According to this model, the top of denser lower crustal material may extend upward to a depth of about 10 km (6 mi) beneath the center of the WSRP, then plunges to the north and south. As shown in Fig. 15, this provides an adequate explanation for the broad regional gradient observed in the gravity data. Superimposed upon the regional gradient are two major gravity highs. The northernmost of these, as has been discussed above, lies along the axis of the WSRP. The wavelength of these anomalies indicates that the maximum depth to source could be approximately 8 km (5 mi). However, efforts at modeling the data with various possible sources indicate that bodies near this maximum depth would have unreasonably high-density contrasts. Alternatively, if the density contrast is kept below 0.4 g/cm^3, the causative bodies must be so large that the anomalies for the two bodies merge together. It becomes necessary, then, to consider these bodies relatively shallow.

Wood and others (1980) describe reflection seismic and well log data in the WSRP west of Boise. Massive basalt (believed to be Miocene or early Pliocene) more than 2000 m (6600 ft) thick is encountered in the center of the Plain starting at a depth of about 950 m (3100 ft). The seismic data indicate that the basalt has been normally faulted to produce a horst with 800 m (2600 ft) of relief in this part of the Plain. This structure can account for much of the gravity high observed along the axis of the Plain in this area.

However, a horst with this amount of relief cannot by itself explain the 50 mgal high observed in the WSRP just south of the prospect. The Bostic well did not penetrate enough basalt in its total 2949 m (9676 ft) to produce an anomaly of this amplitude.

One may thus conclude that the top of the body responsible for this anomaly must lie at a depth slightly below the bottom of the Bostic well. Using a density contrast of 0.33 g/cm^3 the body must be about 3000 m (9900 ft) thick to produce the observed anomaly. In the model the two anomalous highs are somewhat enhanced by a horst in the middle of the Plain and variations in the thickness of alluvial fill.

After many attempts to fit other models to the observed data, the final fit was obtained with a model identical in concept to that proposed by Mabey (1976). The massive bodies modeled with a 2.95 g/cm^3 material are interpreted to be Miocene or early Pliocene basalt that filled graben structures early in the development of the WSRP. Interpretation is made more difficult by the fact that the dense bodies required by the gravity model are not reflected in the regional aeromagnetics. Basalts at a depth of 3.6 km in this area would be above the curie point and should produce aeromagnetic as well as gravity anomalies. The lack of close agreement between the two may mean that near-surface basalt flows are the major contributors to the observed aeromagnetic anomalies.

Based upon gravity modeling it appears that at the Bostic well location massive basalt approximately 3 km (1.8 mi) thick would be encountered with continued drilling. However 2-5 km (1.2-3 mi) to the north, or at an equivalent location along the strike of the steep gravity gradient shown in Fig. 14, Idaho Batholith granite probably underlies the Idavada Volcanics.

E. Prospect Area Geohydrology.

The prospect lies in the Central Snake River Drainage Basin (1868 hydrologic boundary 17050101), with divides comprising the Mount Bennett Hills to the north, King Hill Creek drainage divide to the east, Snake River to the south, and the drainage divide between Rattlesnake and Canyon Creeks to the west. The basin area is somewhat over 1500 km^2 (579 mi^2) (see Fig. 16).

The area is semi-arid, with estimated mean annual precipitations of 244 mm (9.6 in.) per year near the prospect site at Mountain Home and 510 mm (20.1 in.) per year in the Mount Bennett Hills to the north (Young 1977). Much of

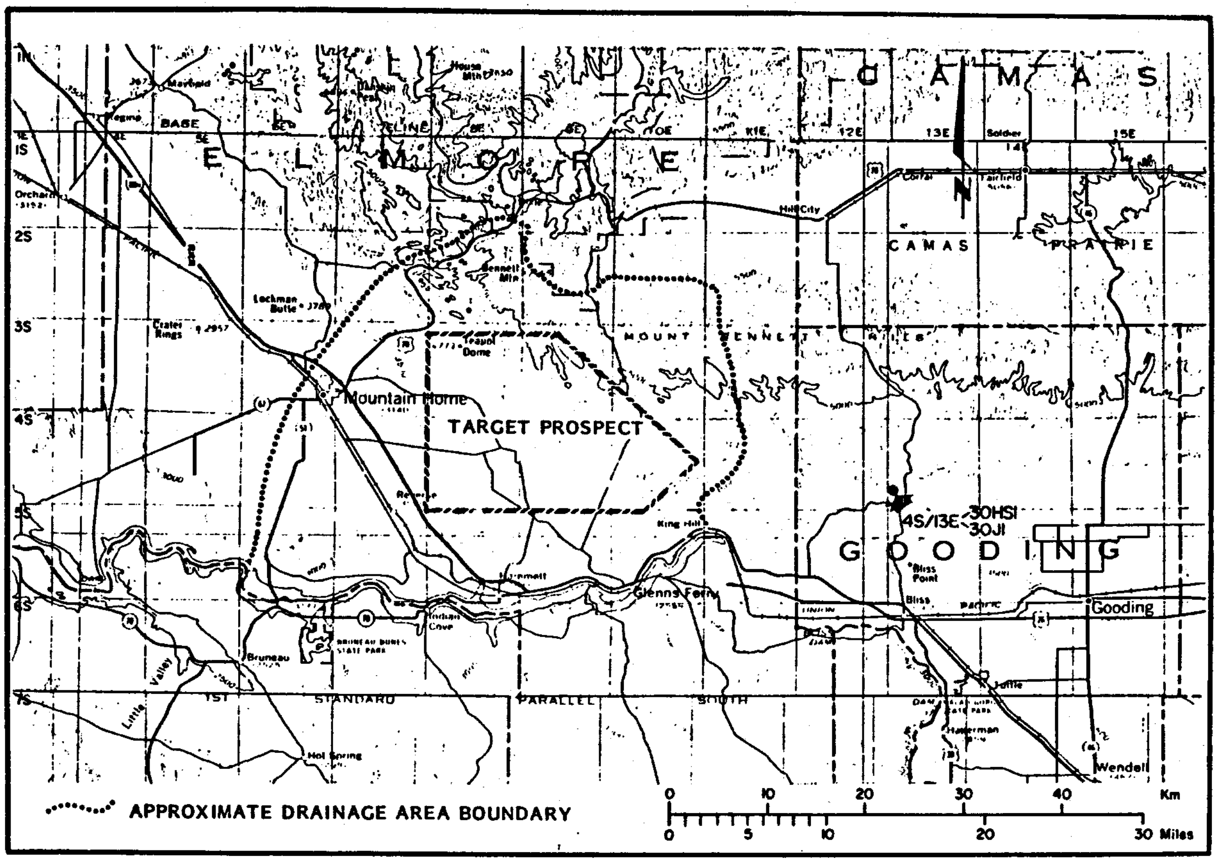


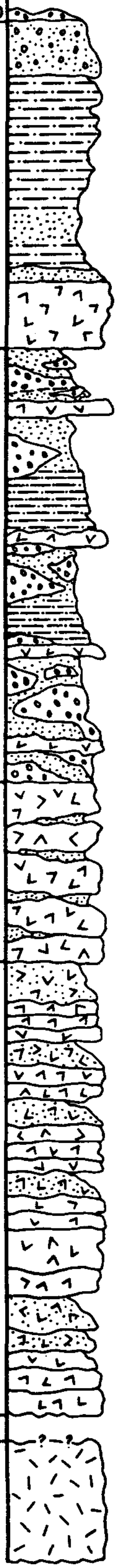
Fig. 16.
Surface drainage patterns in the target prospect vicinity.

the precipitation falls as snow. The Mount Bennett Hills snow pack extends surface flow and ground-water recharge well into spring.

1. Surface Drainage. The three principal streams in the prospect area are Bennett, Cold Springs, and Little Canyon Creeks. The major tributaries are Hot Springs, Rye Grass, and Alkali Creeks. These flow generally southeast in the Mount Bennett Hills, then turn to follow the slope of the plateau southwest across the prospect site. There are no natural lakes in the area.

2. Ground Water. Ground water may occur in virtually every rock unit. The basalt flows are often highly fractured and the sedimentary units are discontinuous and lenticular. Moreland (1976) describes many discontinuous perched water zones and aquicludes.

Figure 17 summarizes data compiled by Young (1977) on the geohydrology of the region. Contours shown on Fig. 18 indicate the regional ground-water flow from the Mount Bennett Hills to the Snake River. The gradient changes



AGE		THICKNESS (meters)	LITHOLOGY	GEOLOGIC UNIT	DESCRIPTION	WATER BEARING CHARACTERISTICS
QUATERNARY	PLEISTOCENE	0-20		ALLUVIUM	Unconsolidated clay, silt, sand, and gravel occurring beneath flood plains of Boise and Snake Rivers. Crops out in narrow belts along major tributaries and in a broad belt near Mountain Home.	Hydraulic conductivity generally high; however, because of thinning and irregularity of beds, yields to wells are generally small to moderate. Most important along Boise River flood plain where well yields of 0.158 m^3/sec. metric are reported.
					UNCONFORMITY	
QUATERNARY	PLEISTOCENE	~530		BRUNEAU FORMATION	Includes fan deposits consisting largely of coarse sands derived from decayed granitic rocks. Thickness of fan deposits does not exceed 90m. Also includes vesicular olivine basalt, dark gray to black, weathers to reddish-gray-brown. Thickness of basaltic flows is about 240 m. in study area. Unit also includes detrital material, dominated by massive lake beds of white-weathering fine silt, clay, diatomite, and minor amounts of sand.	Fan deposits are generally above water table. Basalt composes principal aquifer in Mountain Home area. Reported well yields from basalt range from .00063 to .221 m^3/sec. Detrital material generally has low hydraulic conductivity.
					UNCONFORMITY	
TERTIARY	PLIOCENE	>600		GLENNS FERRY FORMATION	Poorly consolidated detrital material and minor flows of olivine basalt. Includes lake and stream deposits consisting of massive silt layers, cemented sand beds, thin beds of dark clay, olive silt, and granitic sand and fine pebble gravel.	Hydraulic conductivity generally low. Reported well yields range from 0.00019 to 0.00221 m^3/sec.
					UNCONFORMITY	
TERTIARY	PLIOCENE	>300		BANBURY BASALT	Olivine basalt flows interbedded locally with minor stream and lake deposits.	High permeability due to vesicles and jointing but generally much less permeable than overlying Quaternary basalts. Not an important aquifer in area.
					UNCONFORMITY	
TERTIARY	LOWER PLIOCENE	~600		IDAVADA VOLCANICS	Silicic latite; chiefly thick layers of devitrified welded tuff, but includes some vitric tuff and lava flows.	Hydraulic conductivity variable.
		?			UNCONFORMITY	
CRETACEOUS				IDAHO BATHOLITH	Quartz monzonite and granodiorite, light to medium gray.	Hydraulic conductivity low. Yields to wells small.

200 M

Fig. 17. Stratigraphy and water bearing characteristics of formations in the Mountain Home Area, Idaho (modified from Young 1977).

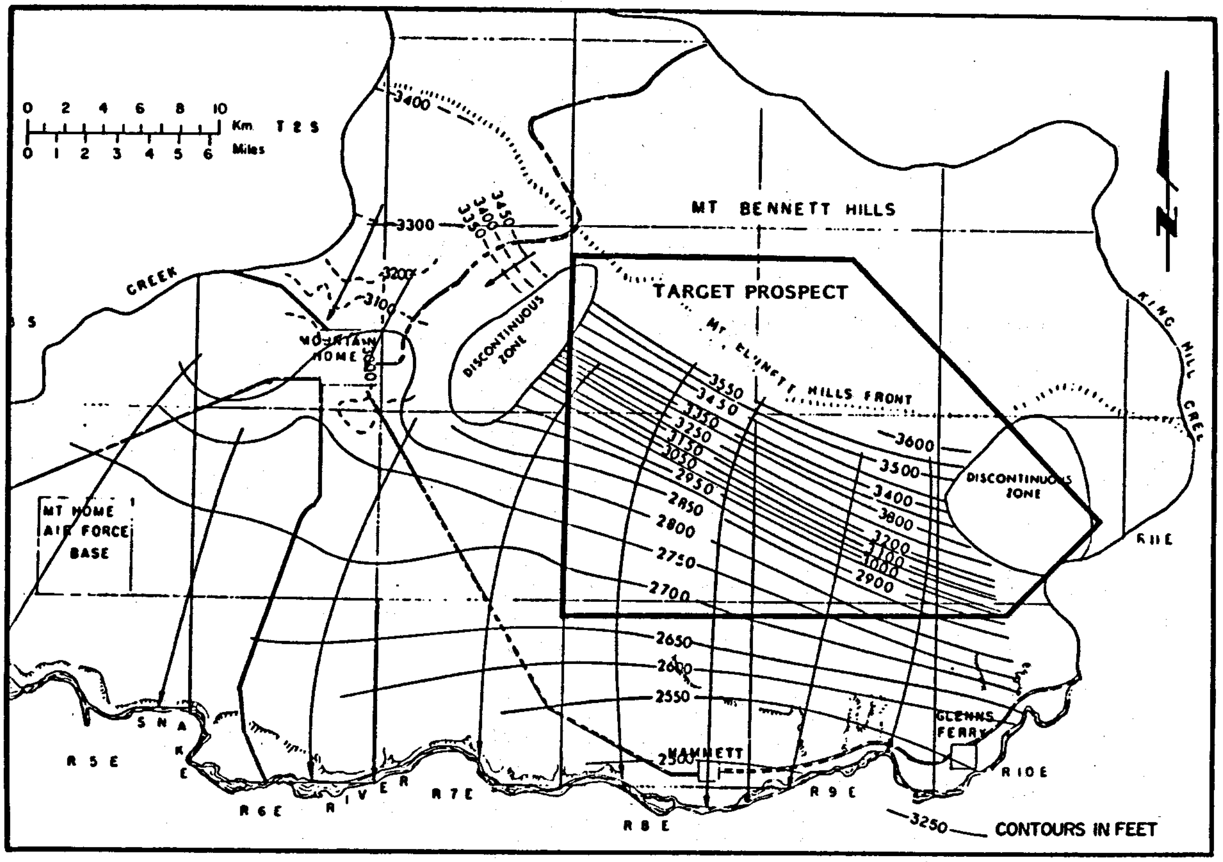


Fig. 18.
Generalized ground-water level contours in feet (from Ralston and Chapman 1968).

abruptly from about 9.5 m/km (50.2 ft/mi) to about 3.8 m/km (20.1 ft/mi) at about the 860-m (2850-ft) contour. Because the topography does not change, this must indicate a change in permeability due to an aquifer discontinuity or to a ground-water barrier. The change may be due to faulting. Ground-water elevations as determined from the hydrology survey are listed in Table III and shown in Fig. 19.

Water producing strata can be divided into four groups:

(1) shallow gravel aquifers, 1- to 20-m depth (3 to 66 ft);

(2) intermediate zone 10 to 100 m (33 to 328 ft) not often producible;

(3) a deep cold aquifer, 142 to 146 m (466 to 479 ft); and

(4) a zone below 183 m (600 ft) that produces hot water; this zone is discontinous and may include or consist of connected faults. Pumping in one of the warm wells of this lower zone produced drawdown in the others.

TABLE III

WATER SAMPLING DATA

Spring or Well Location No.	Altitude (feet)	Depth to Water* meters	Depth to Water* (feet)	Ground-Water Level Elevation meters	Ground-Water Level Elevation (feet)	Date Measured (Data Source)** Second Measurement if available	Depth of Well meters	Depth of Well (feet)	Remarks
2S/7E-24ES1	4560	S		1396	(4560)	11/09/79 (HLA)			
2S/7E-36FS1	3950	S		1204	(3950)	11/10/79 (HLA)			
3S/7E-1G1	3747	45	(149.5)	1097	(3598)	10/01/76 (Y)	53	(175)	Domestic well
3S/8E-3NS1	4160	S		1268	(4160)	11/10/79 (HLA)			Water level 1' below surface
3S/8E-5HS1	4080	S		1243	(4080)	11/10/79 (HLA)			Dry
3S/8E-10JS1	4080	S		1243	(4080)	11/11/79 (HLA)			Small seepage, damp ground
3S/8E-13GS1	4050	S		1234	(4050)	11/11/79 (HLA)			Dry
3S/8E-16HS1	3835	S		1169	(3835)	11/11/79 (HLA)			Seepage, damp ground
3S/8E-16NS1	3555	S		1083	(3555)	11/11/79 (HLA)			Dry (mapped as hot spring)
3S/8E-16N1	3600	10	(34)	1084	(3556)	1/1962 (IDWR)	274	(900)	First water at 50'
3S/8E-20AS1	3555	S		1083	(3555)	11/11/79 (HLA)			Dry (mapped as hot spring)
3S/9E-20JS1	4170	S		1271	(4170)	11/11/79 (HLA)			Dry
3S/8E-22DS1	3600	S		1097	(3600)	11/11/79 (HLA)			
3S/8E-22PS1	3460	S		1055	(3460)	11/16/79 (HLA)			
3S/8E-36P1	3395	A		1035	(3395)	11/14/79 (HLA)	183	(600)	Artesian hot well (32°C)
3S/8E-36P2	3395	A		1035	(3395)	9/08/66 (IDWR)	183	(600)	Well flowed at 535'
3S/8E-36P2	3395	A		1035	(3395)	11/14/79 (HLA)	183	(600)	Artesian hot well (68°C)
3S/8E-36P3	3395	9		1032	(3386)	11/14/79 (HLA)	12	(39)	
3S/9E-25NS1	4115	S		1254	(4115)	11/13/79 (HLA)			Hot spring (57°C)
3S/9E-26FS1	3910	S		1192	(3910)	11/18/79 (HLA)			
3S/10E-31DS1	4360	S		1329	(4360)	11/13/79 (HLA)			
3S/10E-31DS2	4360	S		1329	(4360)	11/13/79 (HLA)			
3S/10E-31HS1	4040	S		1231	(4040)	11/14/79 (HLA)			
3S/10E-31HS2	4010	S		1222	(4010)	11/14/79 (HLA)			Wet ground
4S/10E-6F1	3710	1.2	(4)	1129	(3706)	11/12/79 (HLA)			Dry in summer
4S/10E-6F1	3710	1	(3)	1130	(3707)	8/27/66 (IDWR)	142	(465)	Same as 6F1
4S/10E-6F2	3715	surface ?		1132	(3715)	11/12/79 (HLA)	85	(280)	Fed from reservoir
4S/10E-6C1	3750					11/12/79 (HLA)			
4S/10E-6M1	3680	27	(90)	1094	(3590)	11/12/79 (HLA)	177	(580)	Water level measured 5/1977
3S/10E-31RS1	3880	S		1183	(3880)	11/12/79 (HLA)			Hot spring (62°C)
4S/8E-1K1	3690	A		1125	(3690)	12/15/79 (HLA)	439	(1440)	Artesian hot well (60°C)
4S/8E-11R1	3310	1.2	(4)	1008	(3306)	11/15/79 (HLA)	3	(10)	Dug well
4S/8E-11R3	3310	dry		826	(2710)	11/15/79 (HLA)	183	(600)	Dry well
4S/8E-11R4	3310	dry		866	(2840)	11/15/79 (HLA)	143	(470)	Dry well
4S/8E-11RS2	3320	S		1012	(3320)	11/15/79 (HLA)	2	(6)	Developed spring
4S/8E-11RS5	3325	S		1013	(3325)	11/15/79 (HLA)			Does not dry up
4S/8E-14A1	3300	127	(416)	879	(2884)	10/1964 (IDWR)	178	(583)	
4S/8E-12NS1	3310	S		1009	(3310)	11/15/79 (HLA)			Perennial spring
4S/8E-23N1	3200	2	(6)	973	(3194)	11/16/79 (HLA)	2.4	(8)	
4S/8E-26M1	3170	3	(9)	963	(3161)	11/16/79 (HLA)	5	(17)	
4S/9E-3J1	3610					11/17/79 (HLA)			No data
4S/9E-3Q1	3570	24	(80)	1064	(3490)	11/17/79 (HLA)	46	(150)	
4S/9E-8B1	3440					7/02/56 (IDWR)	137	(449)	Major water at 434'-449'
4S/9E-8B2	3440	A				3/1961 (IDWR)	358	(1175)	Artesian hot well (62°C)
4S/9E-9R1	3480	A		1061	(3480)	11/17/79 (HLA)	427	(1400)	Artesian hot well (56°C)
4S/9E-10A1	3540					11/17/79 (HLA)			No data
4S/9E-10D1	3530					11/17/79 (HLA)			No data
4S/9E-10G1	3520	1.5	(5)	1071	(3515)	8/15/66 (IDWR)	183	(600)	Major water at 522'-545'
4S/9E-18F1	3300	74	(244)	931	(3056)	11/15/79 (HLA)	427	(244)	
4S/9E-18F2	3300					11/15/79 (HLA)			Well went dry in 1977
4S/9E-18F3	3300					11/15/79 (HLA)			
4S/9E-18F4	3300	dry		934	(3063)	8/20/76 (IDWR)	72	(237)	Abandoned well
3S/8E-32N1	3350	157	(515)	864	(2835)	6/29/78 (IDWR)	187	(615)	Major water 515'-595'
4S/9E-28J1	3220	61	(200)	920	(3020)	11/15/79 (HLA)	61	(200)	Goes dry in fall
4S/9E-33DS1	3180	S		969	(3180)	11/15/79 (HLA)			Perennial spring
4S/9E-33ES1	3175	S		968	(3175)	11/15/79 (HLA)			Perennial spring
4S/10E-10AS1	3940	S		1201	(3940)	11/17/79 (HLA)			Dry
4S/10E-10P1	3660					11/17/79 (HLA)	4	(13)	Dug well
4S/10E-10P2	3660	2	(7)	1106	(3653)	11/17/79 (HLA)	3.6	(12)	Dug well
4S/10E-10P3	3670	2	(7)	1116	(3663)	11/17/79 (HLA)	3	(10)	Dug well
4S/10E-30D1	3450	111	(363)(?)	941	(3087)(?)	no date (IDWR)	691	(2268)	Next to reservoir
4S/10E-30D2	3450					3/19/68 (IDWR)	384	(1260)	Next to reservoir
4S/10E-27GS1	2840	3		865	(2837)	11/18/79 (HLA)	2	(6)	Developed spring
4S/10E-34PS1	2670			814	(2670)	11/17/79 (HLA)			Trickle of water
5S/9E-5KS1	3090	S		942	(3090)	11/16/79 (HLA)			Developed spring
5S/9E-5KS2	3100	S		945	(3100)	11/16/79 (HLA)			Developed perennial spring
5S/9E/5Q1	3080	7		937	(3073)	11/16/79 (HLA)	5	(16)	Dug well
5S/10E-3AS1	2570	S		783	(2570)	11/18/79 (HLA)			Perennial spring
5S/10E-3H1	2570					11/18/79 (HLA)			
5S/10E-12M1	2580	61		768	(2519)	7/26/73 (IDWR)	27	(88)	
5S/10E-12N1	2560	30		771	(2530)	3/17/66 (IDWR)	21	(70)	Major water at 65'
5S/10E-12K1	2560	34		770	(2526)	9/17/70 (IDWR)	37	(120)	

* S = spring, surface discharge
A = artesian well
** HLA = Harding-Lawson Associates; BLM = Bureau of Land Management; IDWR = Idaho Department of Water Resources Records; Y = Young, 1977

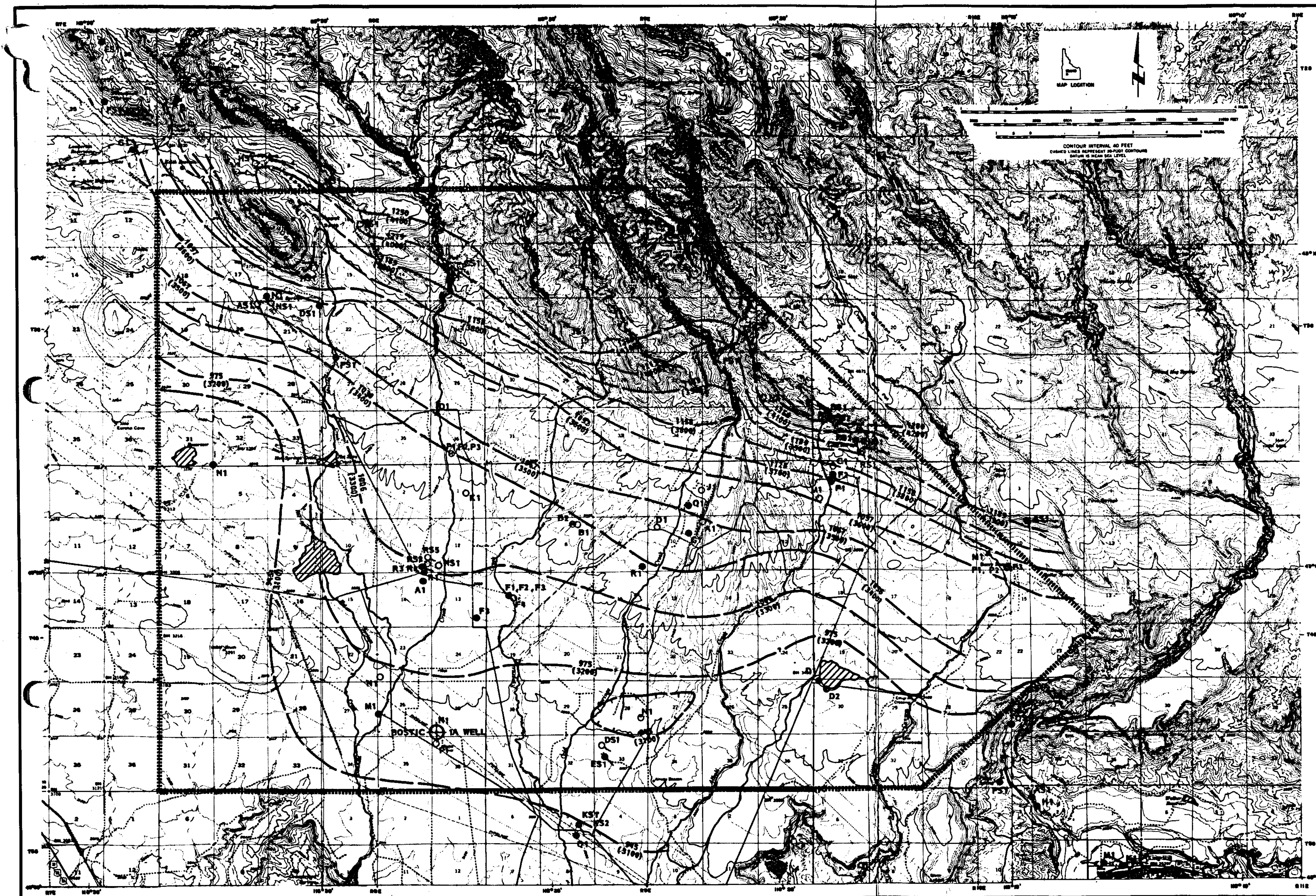


Fig. 19.
Ground-water elevation.

EXPLANATION

B1 ● WATER WELL & SECTION LOCATION I.D.

⊖ HOT WATER WELL & SECTION LOCATION I.D.

FS1 SPRING & SECTION LOCATION I.D.

WS1 DRY SPRING (11/79) & SECTION LOCATION I.D.

D1 ▲ SURFACE WATER SAMPLE LOCALITY, AND LOCATION I.D.

RESERVOIR

STREAMS (BOTH PERENNIAL & INTERMITTENT)

1097 (3600) GROUND WATER ELEVATION IN METERS (FEET)

TABULATED WATER LEVEL DATA:

EXAMPLE: 2S/7E - 24ES1 (TOWNSHIP / RANGE - SECTION, LOCATION I.D.)

The colinearity of the hot artesian wells, Lee Hot Springs, and other hot springs in the area along a N55W trend parallel to major geologic structures suggests the presence of a hydraulically conductive fracture zone or a fault acting as a ground-water barrier. There is no surface indication of faulting.

There are three types of springs in the area:

(1) contact, caused by water moving laterally along the top of an impermeable layer until it intersects the ground surface, seasonal;

(2) depression, where the water table intercepts the ground surface, seasonal, and

(3) thermal, which are artesian and fault-controlled, perennial.

F. Geochemistry of Spring and Well Waters

A field survey of the prospect area in November 1979 consisted of a canvass of local water wells, interviews with residents regarding well and spring use, measurements of well water levels, and chemical/isotopic analysis of selected springs, wells, and surface waters.

Field procedures of Presser and Barnes (1974), were used for sampling of natural waters. Thermal waters are herein considered to be those fluids having temperatures above 30°C. Temperature, pH (by meter), and alkalinity of all samples were determined in the field. The SiO_2 and H_2S contents of thermal fluids were also analyzed in the field. One plastic bottle of filtered water from each source was collected for major cation and anion analysis while a second plastic bottle of filtered, acidified water (HNO_3 to pH ≤ 2) was collected for trace metal analysis. A third bottle (glass) of raw water was collected for isotopes.

All water samples were analyzed for major cations and anions using standard methods (Table IV). Roughly 30% of the samples were analyzed independently by laboratories at LFE Corporation and New Mexico State University. In addition, selected samples of thermal waters were analyzed for As, Fe, Hg, Mn, Mo, Pb, Sb, and Zn (Table V). The D and ^{18}O contents of a variety of waters were also determined by standard methods (Table VI). This new data was supplemented with existing published data (Young and Mitchell 1973) and unpublished water well records obtained from the Idaho Department of Water Resources.

TABLE IV

NAME, LOCATION, FIELD DATA, AND CHEMICAL DATA OF 39 THERMAL AND NONTHERMAL WATERS OF THE MOUNTAIN HOME AREA, IDAHO (CHEMICAL VALUES IN mg/ℓ)

No.	Name	Location	Temp °C	Sp. Cond.[a] μmhos	pH[a]	SiO_2	Ca	Mg	Na	K	Li	HCO_3[a]	CO_3	SO_4	Cl	F	B
01	Unnamed Cold Spring	NW-1/4 s.24 2S 7E	11	78	7.35	29.4	14	1.13	4.6	1.83	0	28.6	0	3	7	.3	.09
02	Frenchman Spring	NW-1/4 s.36 2S 7E	13	70	7.12	26.9	8	1.0	3.2	1.57	0	27.4	0	2.1	6	.25	.08
04	Teapot Basin Spring	SW-1/4 s.3 3S 8E	15	119	7.05	28.1	15	2.45	7.3	1.69	0	58.5	0	4.5	7.2	.2	.09
05	Unnamed Cold Spring	NW-1/4 s.22 3S 8E	10	220	7.50	25.6	21	4.73	10.3	1.51	0	43.9	0	10.5	26.0	.25	.08
06	Unnamed Cold Spring	SW-1/4 s.22 3S 8E	15	240	7.77	12.3	18	2.3	28.2	4.82	.01	126	0	7.5	10	2.5	.10
07	Bennett Creek (flowing)	NW-1/4 s.36 3S 8E	8	125	8.01	27.2	14	1.9	13.1	2.77	0	71.3	0	6	9	1.1	.09
08	Hot Well L. Beam	SW-1/4 s.36 3S 8E	32	340	9.5	105[a]	6	.25	73	.71	0	87	33[a]	7.5	8	16.4	.06
09	Hot Well L. Beam	SW-1/4 s.36 3S 8E	68	385	9.42	130[a]	4	.18	80.6	.60	0	71	46[a]	9	11	16.4	.06
10	WHM Well L. Beam	SW-1/4 s.36 3S 8E	26	345	7.84	58[a]1	26	3.6	56.0	3.14	.01	167	3[a]84	9	10	13.8	.16
11	Unnamed Hot Springs	SW-1/4 s.25 3S 9E	57	230	8.95	145[a]	4	.22	52	1.91	.01	58	30[a]	7.5	9	8.2	.09
12	Cold Springs Creek	NW-1/4 s.26 3S 9E	6	70	7.86	26.2	6	.5	12.4	1.68	0	40	0	3	5	1.75	.07
13	Unnamed Cold Spring	NW-1/4 s.31 3S 10E	9	48	6.74	80.5	7	.7	7.7	1.38	0	22	0	4.5	6	.4	.07
14	Unnamed Cold Spring	NE-1/4 s.31 3S 10E	16	86	7.13	43[a]0	10	.92	11.2	2.33	0	46	0[a]	4.5	7	.55	.07
15	Latty Hot Springs	SE-1/4 s.31 3S 10E	62	240	9.38	135[a]	2	.15	55.4	1.27	.01	50	33[a]	7.5	8	4.9	.07
16	Hot Well T. Gill	SE-1/4 s.1 4S 8E	60	360	9.57	125[a]	2	.10	84	.9	0	66	49[a]	9	9.6	16.4	.09
17	Well T. Gill	SE-1/4 s.11 4S 8E	12	370	6.97	29.1	26	4.3	58.5	12.84	0	224	0	12	9	4.6	.10
18	Cold Spring T. Gill	SE-1/4 s.11 4S 8E	14	305	6.76	29.1	23	4	44.4	4.52	0	174	0	9	7	1.6	.09
19	Well Galey Ranch	SW-1/4 s.26 4S 8E	13	263	7.25	26.5	27	6.8	25.3	4.52	0	143	0	9	9	1.6	.08
20[b]	Hot Well (ref.)	NW-1/4 s.36 4S 8E	38	703	7.8	86	3.2	.2	160	3.7	-	447	0	5.4	10	3	-
21	Well B. McGrew	SE-1/4 s.3 4S 9E	15	190	8.28	46.1	22	2.9	14.4	3.56	.01	111	0	4	5.6	1.4	.06
22[b]	Hot Well WalkerL	NE-1/4 s.8 4S 9E	62	387	9.2	85	.9	0	82	.8	-	81	41	14	3.2	16	-
23	Hot Well B. McGrew	SE-1/4 s.9 4S 9E	57	400	9.6	121[a]	3	.2	85.4	.75	.01	66	47	9	9	17.8	.16
24	Warm Well Walker	NW-1/4 s.18 4S 9E	21	375	8.22	37.9	54	8.4	27.1	5.93	.02	205	0	13.5	14	2.5	.12
25	Warm Well Walker	NW-1/4 s.18 4S 9E	13	180	7.22	20.9	23	3.7	10.8	5.58	0	99	0	7.5	7	1.1	.16
26	Well Walker	NW-1/4 s.18 4S 9E	19	370	8.21	54.3	49	7.9	25.4	5.62	.01	193	0	15	16.8	1.75	.08
27	Lynn Riggs Cold Spg.	NW-1/4 s.33 4S 9E	12	180	6.73	32.9	16	1.9	25	5.29	0	96	0	9	10.8	1.6	.08
28	Little Canyon Creek	SW-1/4 s.10 4S 10E	7	65	7.64	21.5	9	1.3	7	1.71	0	39.6	0	4.5	6	.3	.06
29	Heaton Windmill	SE-1/4 s.10 4S 10E	12	110	6.71	27.8	15	1.8	9.0	5.2	0	67	0	5	6	.45	.06
30	Spring Presley Home	SE-1/4 s.27 4S 10E	19	474	8.02	33.5	55	5.1	40	8.48	.12	219	0	35	12.6	1.2	.10
31	Cedar Springs	SW 1/4 s.34 4S 10E	9	710	8.33	37[a]9	86	24.8	53	18.80	.13	324	0[a]	101	26	.8	.12
32	White Arrow Hot Spgs.	NE 1/4 s.30 4S 13E	63	422	9.09	143[a]	6	.24	87	1.43	.03	129	26[a]	14	2	14.2	.19
33	Erkins Well (hot)	SE 1/4 s.30 4S 13E	30[c]	510	8.4	51.8	16	.2	98.5	4.64	.01	235	1.2	16.5	16	3.2	.23
34	Henley Spring	SE 1/4 s.5 5S 9E	12	275	7.33	26.5	29	5.3	31	9.17	0	163	0	9	10	2.7	.07
35	Well Pruitt	SE 1/4 s.5 5S 9E	13	311	7.35	29.1	30	5.5	34	26.12	0	173	0	12	11	2.0	.07
36	Presley Ranch Spg.	NE 1/4 s.3 5S 10E	6	920	8.12	26.5	105	36	69.4	12.32	.06	323	0	240	32.8	1.3	.15
37	Well Presley Ranchhouse	NE 1/4 s.3 5S 10E	14[d]	340	8.29	30.3	41	6.1	24.8	5.84	.04	173	0	18	8	.55	.03
38[b]	Hot Well (ref)	NE 1/4 s.7 5S 10E	32	367	8.5	42	2.5	0	79	.9	-	115	16	12	6.1	20	-
39[e]	Well (ref)	NE 1/4 s.1 3S 7E	20	273	7.5	59	26	5.6	18	5.8	-	108	-	15	14	.7	-

[a]Field determined.

[b]As reported in Young and Mitchell 1973.

[c]Hose line.

[d]Spigot.

[e]Young 1977.

TABLE V

TRACE METAL AND HYDROGEN SULFIDE ANALYSES

Sample No.	Location T R Section	As	Hg	Sb	Zn	Mn	Mo	Pb	Fe	H_2S
		mg/ℓ								
08	3S/8E-36	.028	.0003	<.1	<.02	<.05	<.01	<.005	<.10	1.5
09	3S/8E-36	.055	.0003	<.1	<.02	<.05	<.01	<.005	<.10	.0
11	3S/9E-25	.018	.0004	<.1	<.02	<.05	<.01	<.005	<.10	0.1
15	3S/10E-31	.026	.0004	<.1	.02	<.05	<.01	<.005	<.10	0.1
16	4S/8E-1K	.038	.0003	<.1	<.02	<.05	<.01	<.005	<.10	0.1
23	4S/9E-10	.049	.0003	<.1	<.02	<.05	<.01	<.005	<.10	0.1
33	4S/13E-30	.050	.0003	<.1	<.02	<.05	<.01	<.005	<.10	0.1

TABLE VI

ISOTOPE ANALYSES OF SELECTED WATERS

No.	Name	Temp °C	δD,°/₀₀	$\delta^{18}O$,°/₀₀	^{13}C°/₀₀
1	Unnamed Cold Spr.	11	-126.00	-15.94	
4	Teapot Basin Spr.	15	-125.67	-16.01	
5	Unnamed Cold Spr.	10	-120.70	-14.72	
9	Hot Well L. Beam	68	-138.73	-17.76	-8.88
12	Cold Spr. Creek	5.5	-125.69	-16.28	
14	Unnamed Spr.	16	-126.49	-16.27	
15	Latty Hot Spr.(piped)	62	-141.33	-18.10	
23	Hot Well B. McGrew	56.5	-139.29	-17.74	-10.21
32	White Arrow Hot Spr.	63	-140.71	-17.85	-8.83
					-8.28
10	Warm Well L. Beam	26		-17.60	
25	Well Walker	13		-15.38	
27	Spring L. Riggs	12		-15.31	
29	Heaton Windmill	12		-15.12	
30	Spring Presley Home	19		-16.78	
36	Spring Presley Ranch	6.0		-15.29	

Analyses done at Scripps Oceanographic Institute by H. Craig and J. Welhan.

1. Water Regimes (Hydrogeology) and Water Quality. The location and chemical characteristics of thermal and nonthermal waters of the prospect are displayed in Fig. 20 (in pocket on inside back cover). Nonthermal waters occur mainly at the base of the Mount Bennett Hills and in intercalated sediments and basalts to the south. They are composed primarily of sodium-calcium bicarbonate water. The Na/Ca ratio and total dissolved solids (TDS) of these fluids increases to the southwest as the water flows toward the Snake River drainage. Nonthermal waters sampled outside the prospect to the south and southeast have slightly higher concentrations of sulfate, chloride, and magnesium than those within the prospect.

Thermal waters apparently circulate along northwest-trending faults or buried faults as indicated by the lineation of their points of occurrence. Thermal waters are composed of sodium bicarbonate water. Fluoride concentrations are relatively high whereas concentrations of chloride and sulfate are quite low.

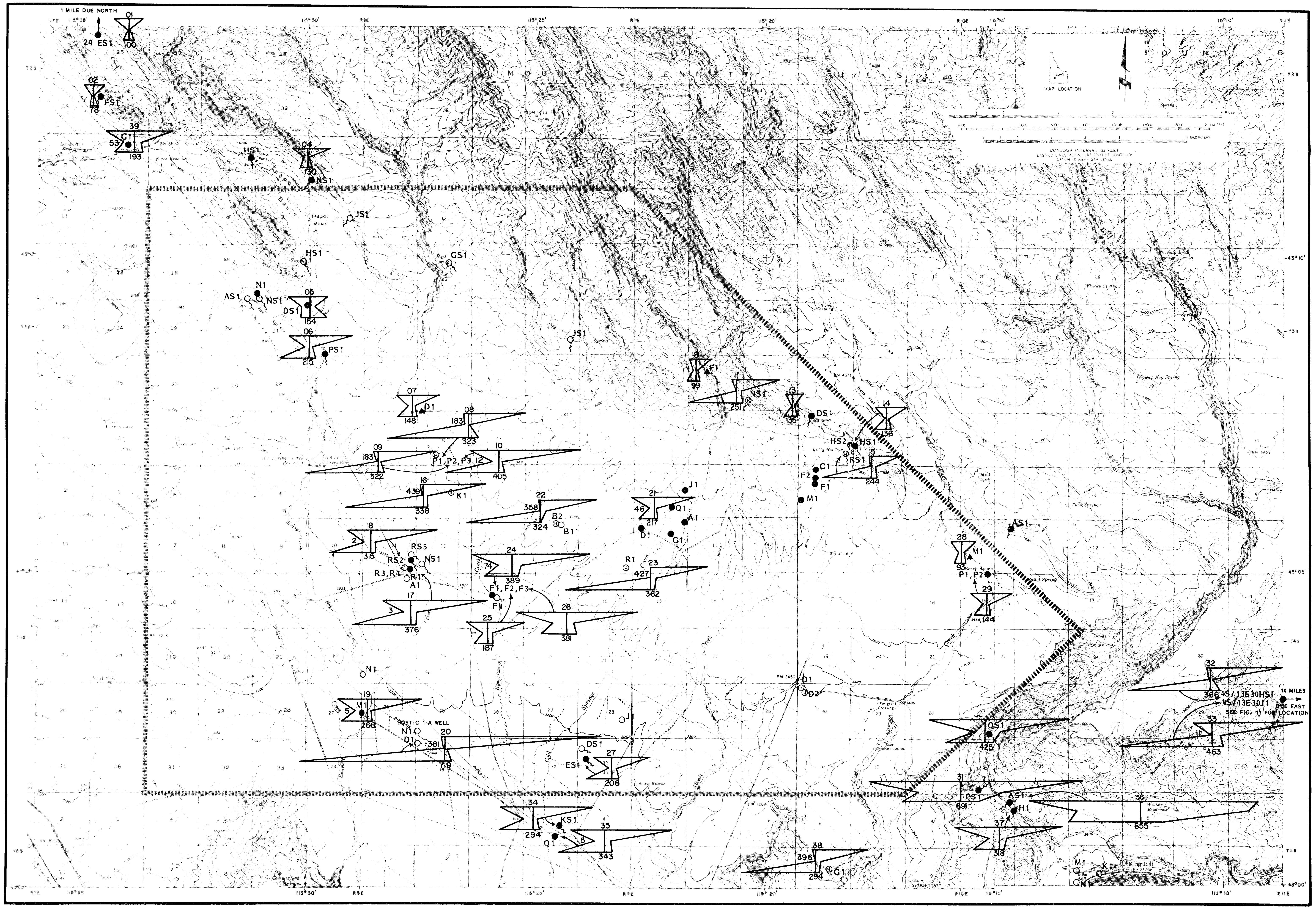
2. Isotopes. Figure 21 plots results of D and ^{18}O isotope analyses of waters from the prospect area. Although all waters show a slight shift to the right of the Craig Meteoric Line, they plot along a line parallel to it (Craig 1961). This indicates that all waters are composed of meteoric water and that their ^{18}O shift is due to a systematic, but unknown cause. Perhaps this shift is due to either evaporative (Craig et al. 1963) or to high-altitude (Wollenberg et al. 1980) effects. The somewhat greater ^{18}O shift displayed by cold spring No. 5 is not understood. There is no evidence from this data that the thermal waters have undergone high-temperature (>150°C) rock-water interaction in a deep geothermal environment. The isotopes indicate equilibrium temperatures <100°C.

Interestingly the cold and hot waters plot in different regions of Fig. 21. This suggests a different recharge (or source) area for the thermal waters, possibly several km northeast and/or at higher elevation than recharge areas for cold surficial waters (Wollenberg et al. 1980).

3. Major Cation and Anion Chemistry. Natural waters of the prospect area consist of two general chemical types (Table IV):

(1) sodium-calcium-carbonate water, which usually occurs as cold water having relatively low TDS and

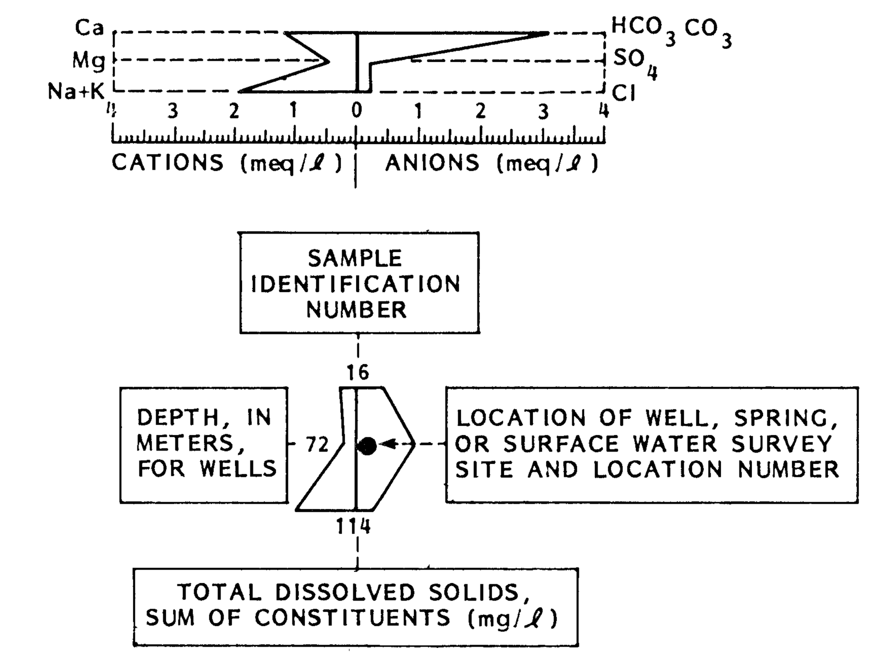
(2) sodium-bicarbonate water, which is generally thermal water containing higher concentrations of TDS.



EXPLANATION

MODIFIED STIFF DIAGRAMS

HORIZONTAL AXES SHOW MILLIEQUIVALENT OF RESPECTIVE IONIC SPECIES



LOCATION NUMBERS ASSOCIATED WITH THE FOLLOWING SYMBOLS ARE EXPLAINED IN TEXT.

- SPRING
- SPRING, DRY AT TIME OF INVENTORY
- HOT SPRING
- WATER WELL
- WATER WELL (NOT CANVASSED)
- HOT WATER WELL
- SURFACE WATER SAMPLE SITE

HOT DRY ROCK

GEOTHERMAL PROSPECT EVALUATION
WESTERN SNAKE RIVER PLAIN, IDAHO
Prepared for Los Alamos National Laboratory

Prepared by Harding-Lawson Associates
Engineers Geologists & Geophysicists
Job No. 9798,005.01
February 27, 1981
Approved [signature]

Fig. 20.

CHEMICAL CHARACTERISTICS OF WATER

IN AND NEAR THE TARGET PROSPECT SHOWING WELLS, SPRINGS AND SURFACE WATER SAMPLING LOCATIONS

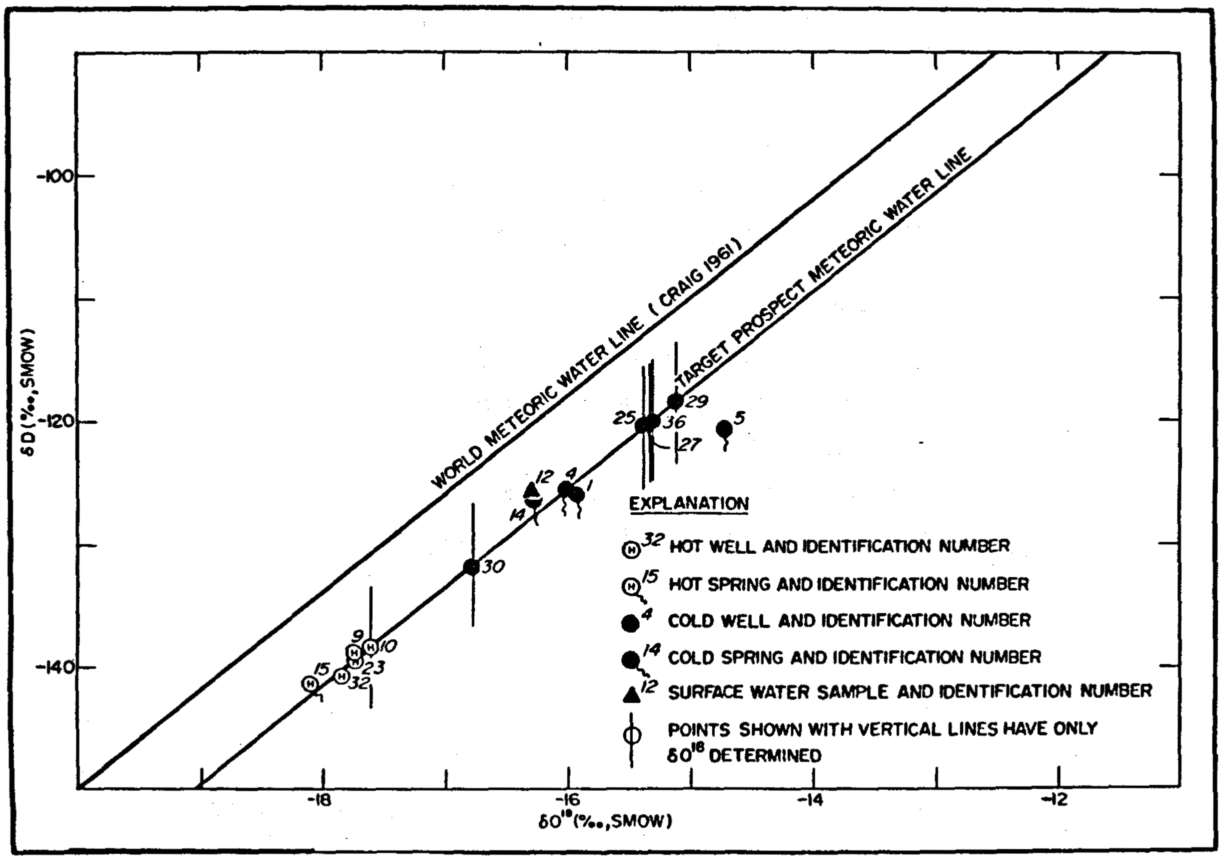


Fig. 21.
Water isotope data for the prospect area.

These differences in chemistry between thermal and nonthermal fluids are best observed in the Langelier-Ludwig diagram of Fig. 22 (Langelier and Ludwig 1942) and in the (Na + K) vs (Ca + Mg) plot of Fig. 23. Thermal waters tend to contain relatively high Na + K compared to nonthermal waters. All waters contain relatively little Cl (<40 mg/ℓ). Although the two water types fall into distinct fields in Figs. 22 and 23, three thermal waters (numbers 10, 11, and 15, Fig. 23) apparently consist of mixtures of colder fluids and hotter water from a deeper source. Some interflow between aquifers probably occurs locally.

4. <u>Trace Metal Chemistry</u>. Thermal waters of the prospect area contain relatively low concentrations of As, B, Hg, Li, and H_2S (Tables IV and V). In general, thermal waters that have equilibrated at high temperatures ($\geq$ 100°C)

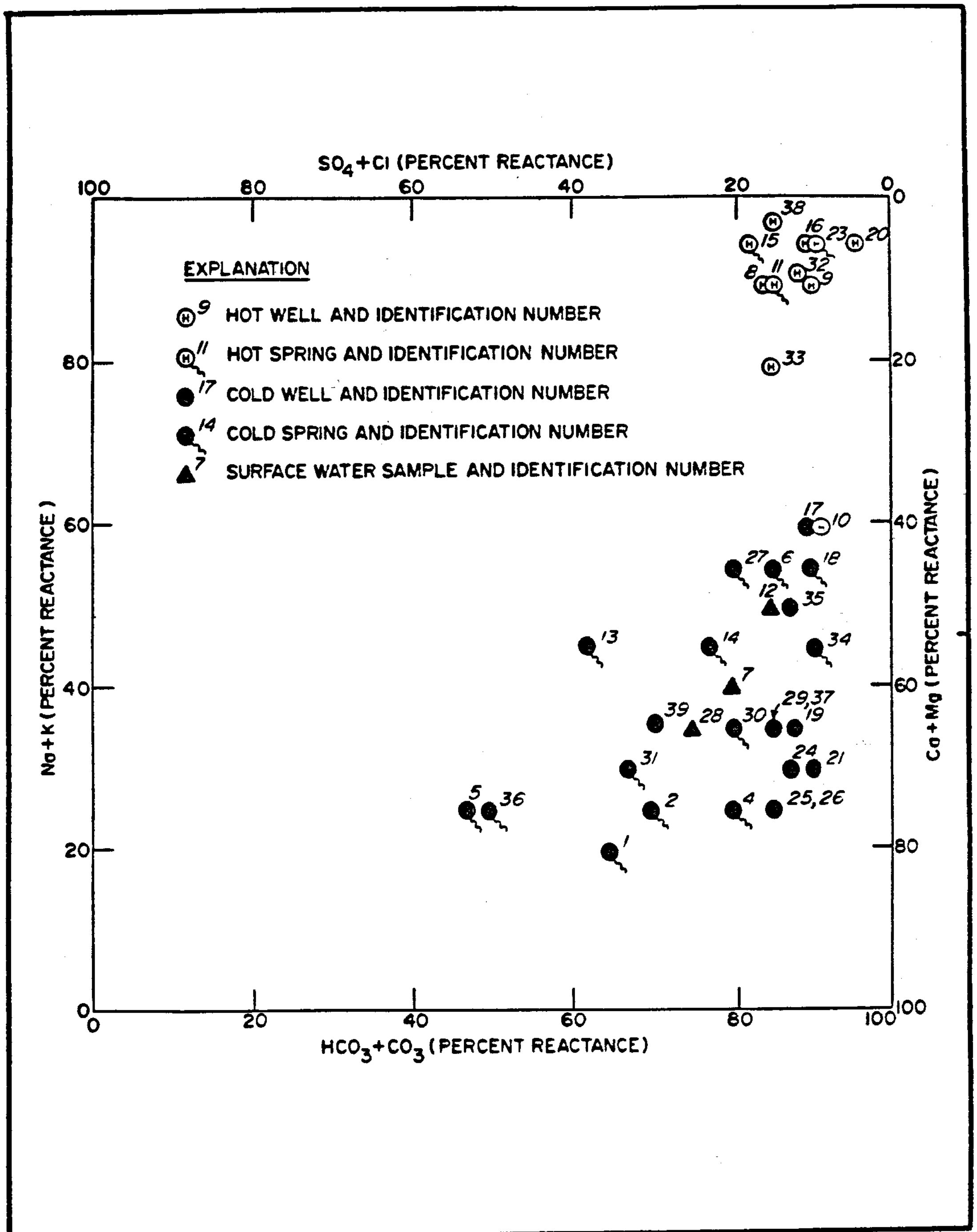


Fig. 22.
Langelier-Ludwig diagram for prospect water chemistry data.

will contain substantially higher concentrations of trace metals, in particular Li >1 mg/l and B >1 mg/l (see also White 1957). Thus, thermal waters of the prospect are apparently equilibrated below temperatures of 100°C.

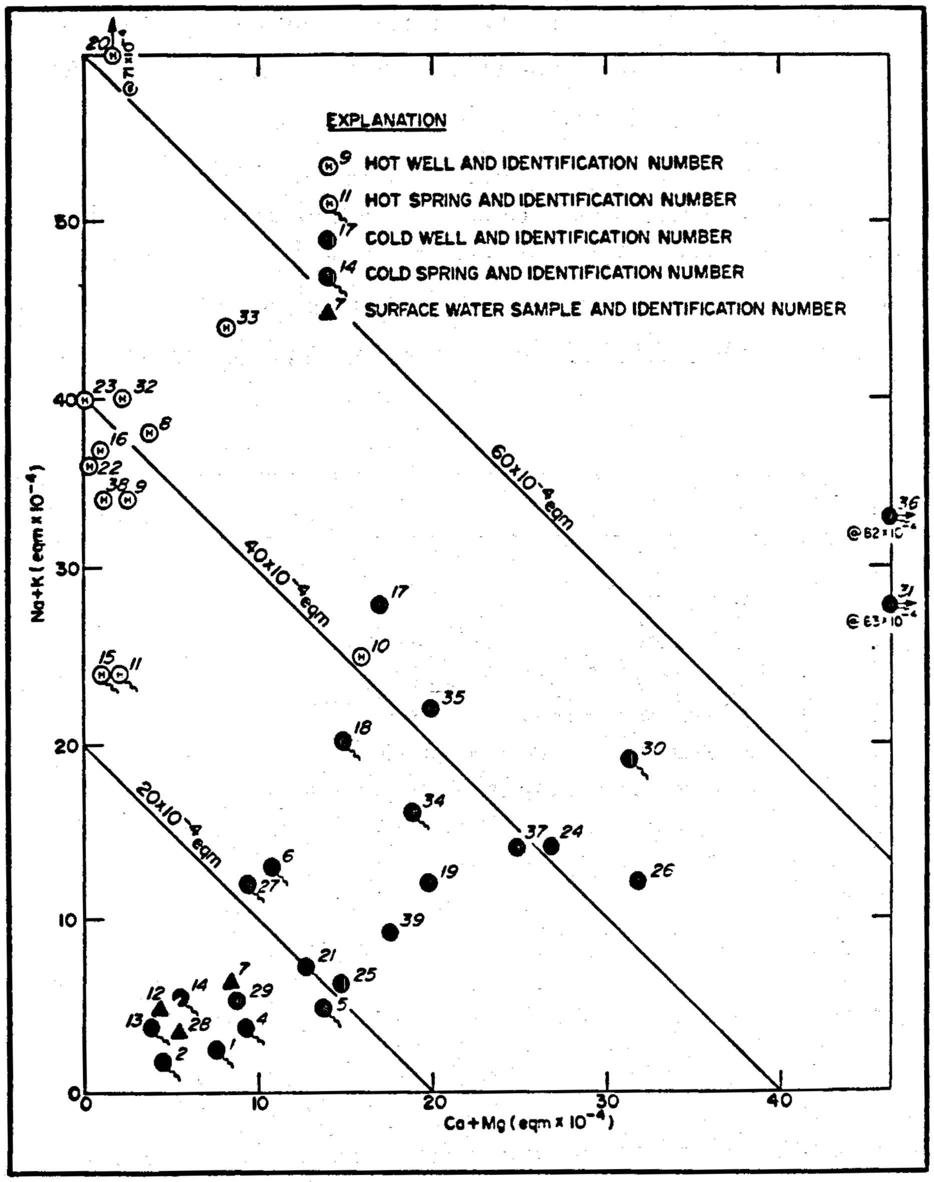


Fig. 23.
Calcium and magnesium vs sodium and potassium plotted in equivalents per million x 10^{-4} for prospect water chemistry data.

5. <u>Chemical Geothermometry and Chemical Equilibration</u>. Chemical geothermometers rely on several assumptions that can usually be verified in the field only in thermal areas containing many hot springs and wells. Major assumptions include (1) temperature-dependent solubility of chemical species, (2) constant rock-water equilibrium of the fluid, and (3) no mixing of surface and deep fluids. Judicious interpretation of chemical geothermometers has many pitfalls (Fournier and Truesdell 1973; Fournier et al. 1974; Fournier and Potter 1979; Goff and Donnelly 1978).

Silica concentration as a function of quartz solubility is a useful geothermometer if reservoir temperatures are greater than 150°C (Fournier and Rowe 1963). Fluids equilibrating at these temperatures generally deposit silica sinter, especially at spring orifices. Such deposits are lacking in the target prospect. However, fluids in reservoirs of lower temperature are generally in equilibrium with other silica phases, chalcedony, cristobalite, and amorphous silica. The overall distribution of silica vs temperature data (Fig. 24) suggests that silica concentration is controlled by dissolution of

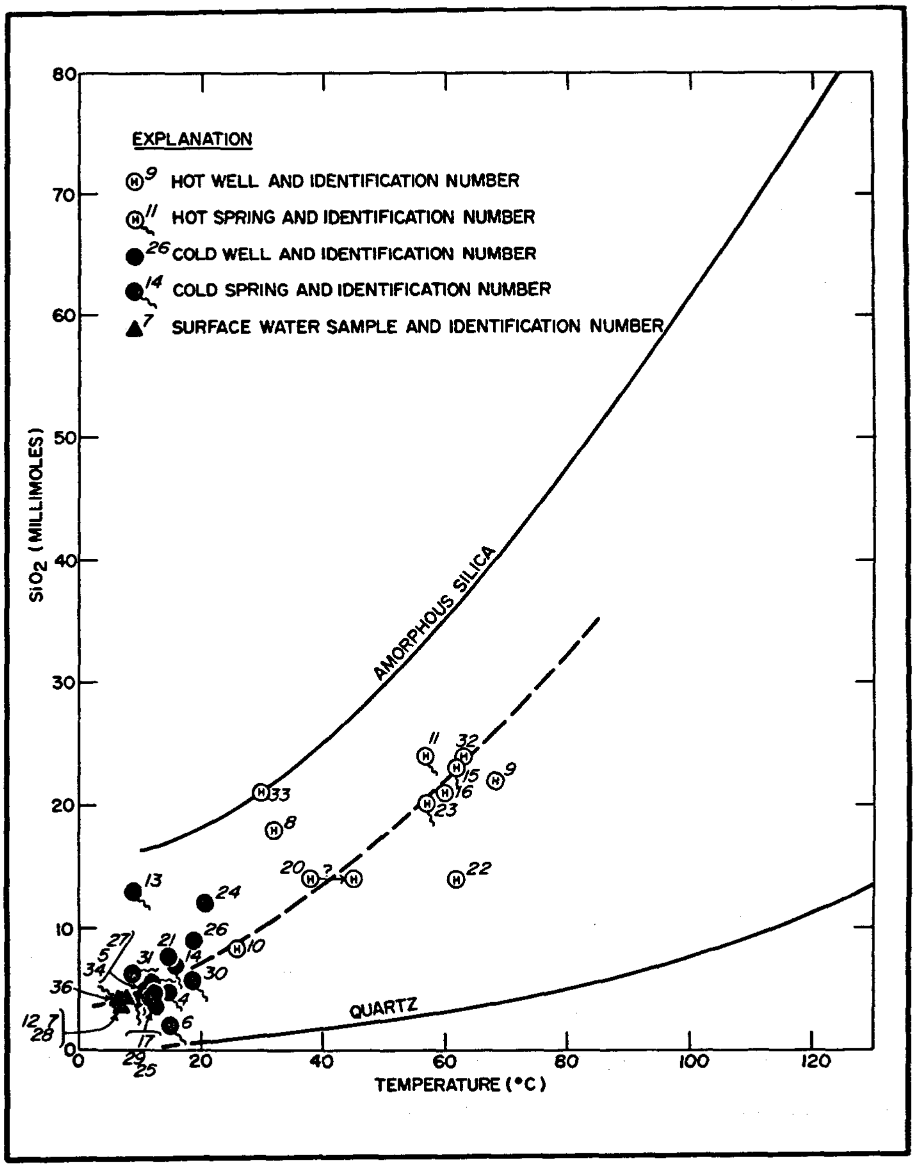


Fig. 24.
Silica vs measured temperature.

cristobalite or complex dissolution of two silica phases. The dashed line shown in Fig. 24 suggests some type of temperature dependent dissolution but this line is hypothetical. Thus, it appears unlikely that reservoir temperatures calculated from quartz solubility (Table VII) are meaningful.

The Na-K-Ca geothermometer of Fournier and Truesdell (1973) is useful for waters that have equilibrated in rocks having abundant feldspars. Calculation of hypothetical reservoir temperatures using the Na-K-Ca (β = 4/3) case yields estimates less than 100°C for all but one of the thermal waters of the prospect area. Therefore, estimates based on the β = 1/3 case are not justified (Fournier and Truesdell 1973). Calculated temperatures are in most cases within ± 30°C of discharge temperatures, even for waters that appear mixed on Fig. 23, suggesting little or no mixing of hot and cold fluids (Fournier and Truesdell 1973). The low magnesium concentrations of the fluids does not warrent correction of these estimates according to Fournier and Potter (1979). Thus, chemical geothermometry does not indicate the waters have equilibrated above 100°C.

In summary, major- and trace-element chemistry, isotopic data, and chemical geothermometry all indicate that thermal waters of the target prospect have equilibrated at temperatures less than 100°C.

TABLE VII

RESERVOIR TEMPERATURES CALCULATED FROM WATER CHEMISTRY OF THERMAL WATERS (>25°C)

				T°C SiO_2		T°C Na-K-Ca	
No.	Name	T°C	SiO_2 mg/ℓ	amorph	quartz	β=4/3	β=1/3
08	Hot well L. Beam	32	105[a]	19.3	139.7	40	
09	Hot well L. Beam	68	130[a]	30.2	151.7	43	
10	Warm well L. Beam	26	58.1	-8.3	108.6	51	
11	Unnamed hot spring	57	145[a]	36.6	158.7	73	
15	Latty Hot Spring	62	135[a]	32.7	154.5	75	
16	Hot well T. Gill	60	125[a]	28.9	150.4	69	
20	Hot well	38	86	9.1	128.4		125
22	Hot well	62	85	9.1	128.4	82	
23	Hot well McGrew	57	121[a]	26.4	147.7	55	
32	White Arrow Hot Spring	63	143[a]	36.6	158.7	61	
33	Hot well Erkins	30	51.8	-13.0	103.1	78	
38	Hot well	32	42	-21.1	93.7	63	

[a]Measured in field.

G. Temperature Gradients and Water Chemistry.

Heat-flow values measured near the prospect reported by Sass and Lachenbruch (1979) and Brott et al. (1978) are plotted on Fig. 25. The mean heat flow for the 11 points within a 30 km (19 mi) radius of the prospect is 87.5 ± 22.2 mW/m^2 (2.09 ± 0.53 HFU). Temperature and depth data for wells in the prospect are summarized in Table VIII and plotted on Fig. 26.

Although the gradient for the Bostic well is around 70°C/km (4.8°F/100 ft) and fairly linear, the shallow hot wells in the region have much higher gradients, up to 280°C/km (16.3°F/100 ft). Both available hydrology and water chemistry suggest that heat flow calculated from shallow temperature-gradient

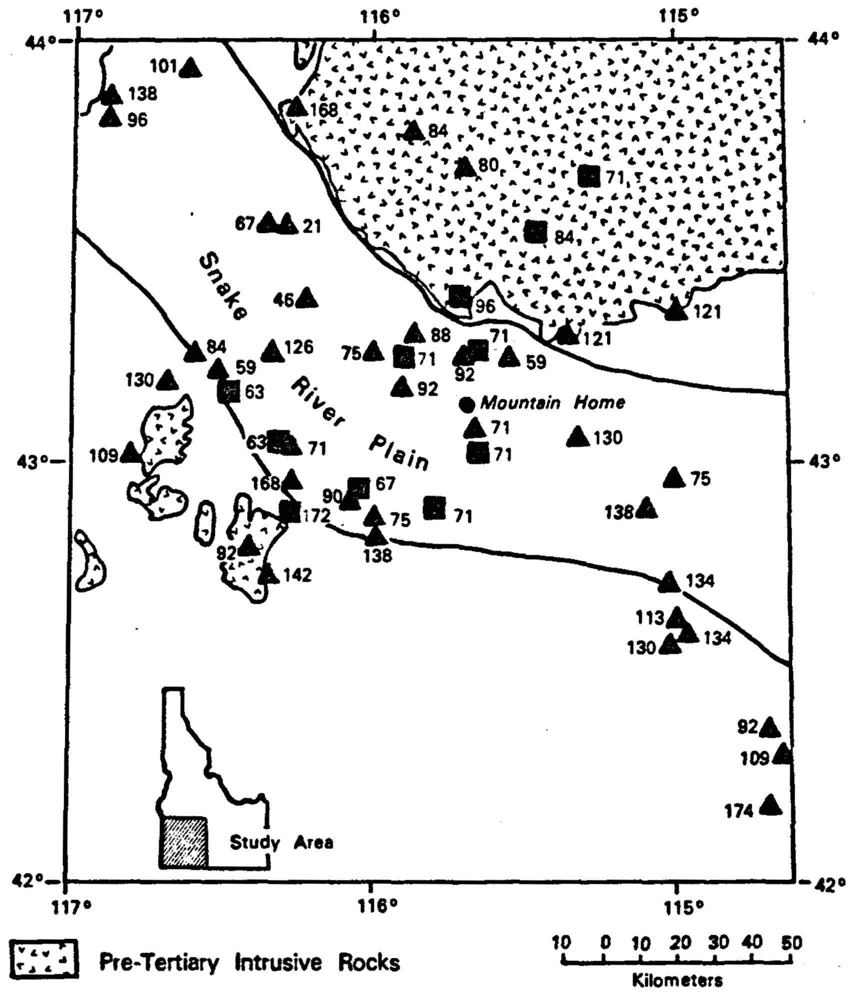


Fig. 25.
Regional heat flow in mW/m^2 from Sass and Lachenbruch 1979 - ▲ and Brott et al. 1978 - ■.

TABLE VIII

TEMPERATURE AND DEPTH DATA FOR WELLS AND SPRINGS

Water Chemistry ID No.	Temperature °C[a]	Depth meters	(feet)	Location No.	Remarks[b]
	20W	53	(175)	3S/7E-1G1	(Young, 1977)
	66W	0	(0)	3S/8E-16NS1	Lee Hot Springs (Ralston and Chapman, 1968)
	22W	188	(615)	3S/8E-32N1	Brown sandstone and gravel aquifer at 157-181 m (515-595 ft)
8	32W	183	(600)	3S/8E-36P1	Artesian; low flow = 45 gpm
9	68W	183	(600)	3S/8E-36P2	Artesian; blue sandy gravel with clay aquifer - high flow = 400 gpm
10	26B	12	(40)	3S/8E-36P3	Hydraulic communication with 36P2
11	57W	0	(0)	3S/9E-25NS1	Approximately 3 km northwest of Latty Hot Springs
15	62W	0	(0)	3S/10E-31RS1	Latty Hot Springs
16	60W	439	(1440)	4S/8E-1K1	Artesian, 4500-5500 gpm - sand and broken rock aquifer
17	12B	3	(10)	4S/8E-11R1	
	-	183	(600)	4S/8E-11R3	Dry (possibly use for temperature gradient measurement)
	10W	178	(583)	4S/8E-14A1	Aquifer - black lava 108-142 m (355-465 ft), clay and boulders 142-146 m (465-480 ft) (perf.), large crevice with sand 169-174 m (556-570 ft)
19	17B	5	(16)	4S/8E-26M1	(Approximate temperature)
20	38W/45W	581	(1906)	4S/8E-36D1	Artesian; 38°C reported by Young and Mitchell (1973); 45°C reported by Ralston and Chapman (1968)
21	11W	49	(160)	4S/9E-3Q1	
		137	(449)	4S/9E-8B1	Aquifer - blue quartz sand 132-137 m (434-449 ft)
22	62W	306/358	(1005/1175)	4S/9E-8B2	Artesian
	21W	183	(600)	4S/9E-10G1	Aquifer at 159-166 m (522-545 ft), lava, sand and gravel
23	56.5W	427?	(1400?)	4S-9E-9R1	Artesian, encountered red volcanic rock 274-427 m (900-1400 ft); some hot water 335-366 m (1100-1200 ft); hotter water and more flow at 396 m (1300 ft)
24	21W			4S/9E-18F1	
25	13W			4S/9E-18F2	
26	19W			4S/9E-18F3	
	15W	9?/27?	(30?/90?)	4S/10E-6F1	2 aquifers - gravel 3-9 m (9-30 ft); sandy clay 14-28 m (45-93 ft) (just southwest of Latty Hot Springs)
29	12B	3	(10)	4S/10E-10P3	
	Cold 77W	341-469 469-692	(1120-1538) (1538-2268)	4S/10E-30Q2	Altered, probably columnar, jointed, Banbury Basalt at 640 m (2100 ft) (Ralston and Chapman, 1969)
35	13B	5	(16)	5S/9E-5Q1	
	20W	27	(88)	5S/10E-12M1	
38	32W	396	(1300)	5S/10E-7G1	(Young and Mitchell, 1973)

a W = wellhead temperature; the temperatures of wells with water chemistry ID numbers were measured by HLA, other temperatures from drillers logs
B = bottom hole temperature
b Subsurface data from drillers logs unless noted otherwise

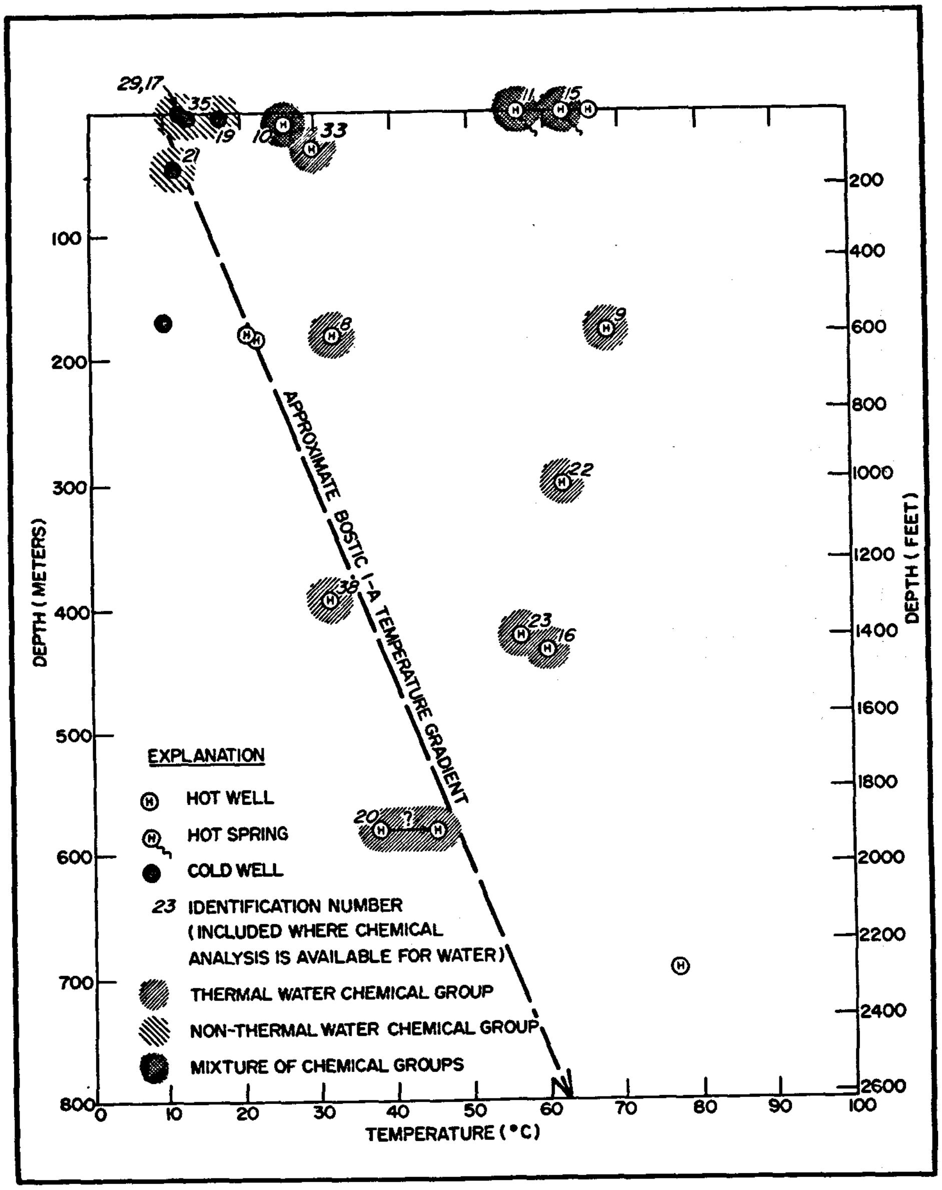


Fig. 26.
Temperature vs depth and chemical classification.

holes in the prospect may not represent heat flow at depth because of convection due to ground-water flow. Highly permeable hot artesian aquifers occur at depths of 180-600 m (590-1968 ft), upwelling hot water occurs at several locations, and cold aquifers exist above the hot aquifers.

H. Silica Heat Flow.

The silica heat-flow interpretation technique (Swanberg and Morgan 1979) uses regional heat-flow estimates and silica trends to indicate heat sources or hydrologic conditions. Using the empirical equation

$$T_{SiO_2} = mq + b \quad ,$$

where T_{SiO2} is the calculated (quartz) silica temperature in degrees Celsius, q is heat flow in mW/m^2, m is the empirical constant = 0.67°C x m^2/mW and b is the regional mean air temperature, 11.4°C, heat-flow values are from each water analysis. Taken on a regional basis where several hundred analyses can be used to obtain an average value for the region, anomalies and trends can be delineated (Swanberg and Alexander 1979). Using the data from this water survey, the mean silica geotemperature calculated by Swanberg is 88.2 ± 24.1°C, resulting in a regional heat flow of 114.6 mW/m^2. Using only nonthermal waters an average silica geotemperature of 81.2 ± 15.7°C is calculated, giving a regional heat flow of 104.1 mW/m^2. This data is closer to the modal silica heat flow of 90-100 mW/m^2 but is somewhat higher than the average of the eleven closest heat flow points from Fig. 26, which is 87.5 ± 22.2 mW/m^2.

Regional profiling of silica heat flow calculated from water analyses in WATSTORE results in the pattern shown in Fig. 27. The Bruneau-Grandview hydrothermal area shows up south of the Snake River and west of Glenns Ferry on both conventional heat flow and silica heat-flow images. An additional area of high-silica heat flow in the southern half of the Mountain Home prospect is substantiated by the one conventional heat-flow value published for that area. Whether this indicates the presence of a hot reservoir as in the Bruneau-Grandview area, or increased potential for an HDR resource cannot be determined without exploratory drilling.

V. EVALUATION OF HDR POTENTIAL OF THE PROSPECT

A. Basement

Petrographic analysis of cuttings from the Bostic 1-A well in the southwest part of the prospect indicates that granitic rock was not penetrated.

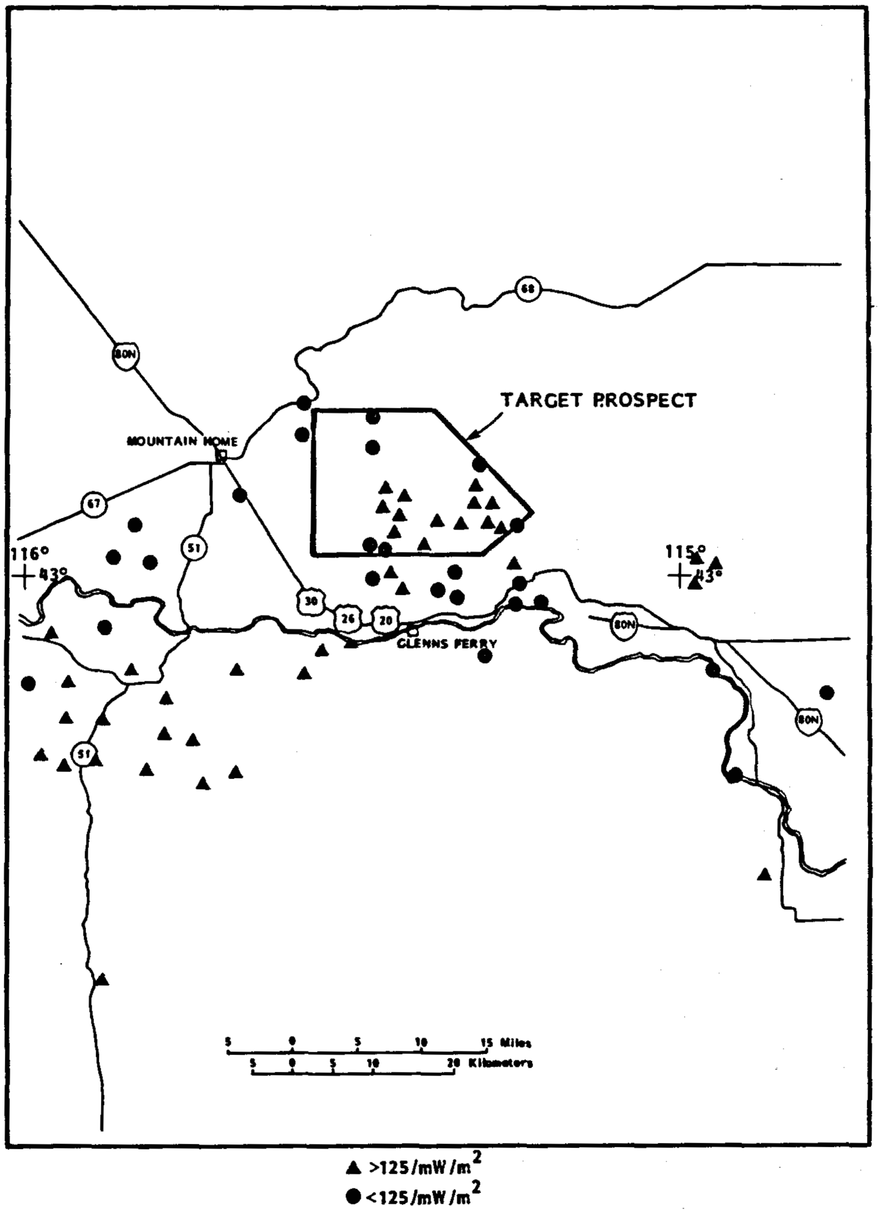


Fig. 27.
Silica heat flow (from Swanberg 1980).

The gravity survey (and other published studies) suggest that granitic basement in the area of the Bostic 1-A is either absent or present at depths greater than 8 km (5 mi).

In the central portion of the prospect, gravity modeling, based on the stratigraphy of the Bostic well, indicates that granite may underlie Idavada volcanics at a depth of approximately 4 km (2.5 mi) a few kilometers north of the Bostic well, and may occur at depths of approximately 2 km (1.3 mi) at the base of the Mount Bennett Hills.

In the northern part of the prospect in the Mount Bennett Hills, more than 0.6 km (0.4 mi) of Idavada Volcanics overlie the Idaho Batholith (Malde et al. 1963). This suggests that granite may lie 0.6 to 1.0 km (0.4 to 0.6 mi) beneath the surface of exposed Idavada Volcanics.

B. Fractures/Permeability

Faults with surface expression and photo lineaments attributed to fractures are found primarily in the north and northwest parts of the prospect along the Mount Bennett Hills. The steep gravity gradient indicates major fault displacement in the southwest corner of the prospect, although there is no surface expression. The faulting may extend to basement rocks at depth, indicating unsuitably permeable conditions for an HDR reservoir in both north and southwest parts of the prospect. With the exception of the southwest gravity anomaly, complete Bouguer data show only minor anomalies from shallow sources within the prospect. Because faulting is observed in the Mount Bennett Hills and there is a minimum vertical displacement of 2.4 km (1.6 mi) between the base of the hills and the Bostic well, faulting must exist, but density contrasts are insufficient to locate it using gravity surveys.

The coincidence of a broad gravity low with apparent low resistivity in the northwest corner of the prospect indicates that area may be unsuitable for HDR development. These anomalies probably indicate an abnormally thick fault-controlled section of sediments. Resistivity anomalies were not observed at depth in the central and eastern parts of the prospect. Thus the central and southeast sections of the prospect appear more likely to be underlain by unfractured impermeable basement.

C. Heat Source.

The prospect is in an area of regionally high heat flow. Although insufficient data exist to contour the prospect, higher silica heat-flow measurements were found concentrated in the southern half. Higher cation temperatures occur in the northern half near the Mount Bennett Hills. Anomalously high-temperature gradients in shallow hot wells in the region are probably affected by upwelling hot water from greater depths. The fairly consistent gradient (65-70°C/km) of the Bostic well is judged a reliable indicator of temperature at depth for most of the prospect.

D. Seismicity.

The prospect region exhibits a very low level of seismicity, both for major (>3.5) earthquakes through 1978 and microseismic activity monitored for 48 days during this study.

E. Accessibility and Potential Users.

Except for the rugged Mount Bennett Hills along the northern part of the prospect, all the prospect is topographically accessible to drilling equipment and later shipment of equipment for an HDR facility. Many gravel roads already service the scattered ranches and utility easements on the prospect. Most of the prospect is within jurisdiction of the U. S. Bureau of Land Management and permits for this initial study have been obtained with little difficulty. Continued cooperation for access and permits would be anticipated for future studies and HDR development.

Temperatures ultimately obtained from an HDR well would dictate the type of applications for which it is to be used. Potential users are the nearby ranches, municipalities, the Mountain Home Air Force Base, and agricultural processing.

The results of this study suggest that the central eastern part of the prospect (shown in Fig. 28) has the greatest potential as an HDR site. However, more detailed information about the depth to and degree of fracturing or permeability of granite, the location and displacement of subsurface faults, and temperature gradients is needed. Further studies are recommended below.

VI. RECOMMENDATIONS

The following studies are recommended before an actual drill site is chosen.

A. Seismic Reflection Survey.

This survey (if successful) could determine deep subsurface stratigraphy and structure beneath the prospect. Two seismic lines are recommended: an eastern line approximately 8 km (5 mi) in length oriented north-south to help

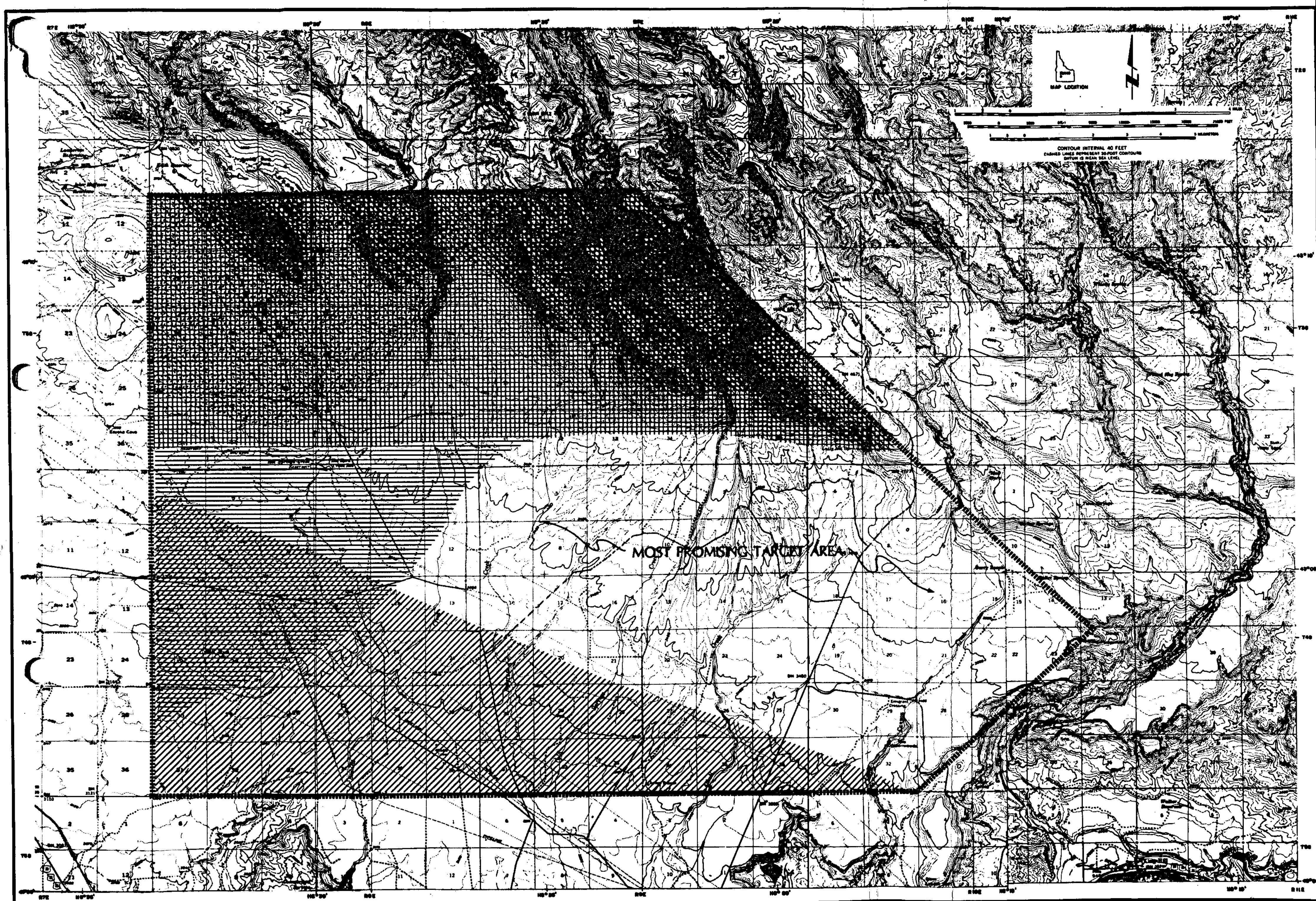


Fig. 28.
Map with best part of prospect indicated.

EXPLANATION

SYMBOL	CONSTRAINT DESCRIPTION
	LOWER SILICA HEAT FLOW (<125mW/m^2)
	DEEP OR NO GRANITE BASEMENT
	HIGHLY PERMEABLE BASIN FILL AT DEPTH
	HIGH CONCENTRATION OF FAULTS AND LINEAMENTS
	DIFFICULT ACCESS IN STEEP TERRAIN

determine the depth of granitic rock beneath the proposed target area, and a western line approximately 20 km (12.5 mi) in length oriented northeast near the Bostic well to tie in with known stratigraphy of the well. Problems are often encountered in doing seismic surveys in basalts and it is possible that a shallow unfractured basalt might act as an impenetrable reflector. However, seismic surveys have been shown to be effective in structural interpretation at other Snake River Plain locations (McIntyre et al. 1980).

B. Electromagnetic Survey.

The main purpose of a controlled-source electromagnetic survey would be to locate and determine the resistivity of the granitic basement. Portions of the granite basement found to have low conductivity would be favorable for HDR development.

C. Temperature Gradient Holes.

Two or three holes 1000 m or more in depth should be drilled in the target area for temperature gradient and geologic data specific to the prospective drill site. The depth is required to measure the temperature gradients below the deep aquifers.

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The principal HLA participants and consultants were:

<u>HLA Staff</u>

Frank C. Kresse	Project Director
Gary E. Van Houten	Project Manager
J. Harry Beyer	Senior Geophysicist
Richard B. Weiss	Senior Geologist/Hydrologist
David B. Simon	Project Geologist
Stephen G. Belluomini	Project Geologist
David H. Peterson	Project Geologist
Douglas Bullis	Editor

<u>Consultants</u>

Franco Tonani	Geochemistry
Chandler Swanberg	Heat Flow
Giancarlo Facca	Geology
Thomas V. McEvilly	Geophysics
Walter Vennum	Petrography

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