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EVALUATION OF THE GEOTHERMAL RESOURCES POTENTIAL OF LANDS IN THE WESTERN SNAKE RIVER PLAIN, IDAHO

prepared for

EARTH POWER CORPORATION

by

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PREFACE

Three exploratory wells should be drilled to depths of about 8,500 feet each, in the western Snake River Plain of northern Owyhee County, Idaho, based on data contained in this report. These wells are projected to encounter a commercial geothermal reservoir, with temperatures ranging from 392° F (200° C) to 464° F (240° C) or even higher, in permeable intervals to be found from about 7,000 feet to hole bottom in middle Tertiary volcanic rocks.

This is supported by data from an 11,000-foot-deep hole drilled near Oreana by The Anschutz Corporation, as well as by temperature gradients and chemical data from numerous deep irrigation wells, structural geology and data from gravity and magnetic surveys. Gradients from wells 1,000 to 3,000 feet in depth, if projected in a linear fashion, suggest temperatures of 400° F (205° C) to over 482° F (250° C) at 7,500 to 10,000 feet.

Drilling of deep exploratory tests should be preceded by a program that includes structural photogeology, logging of additional irrigation wells, possibly a series of electromagnetic soundings, and drilling of a supplementary group of 5 gradient holes to about 350 feet.

CONCLUSIONS

1. The potential for finding geothermal resources at temperatures over 400° F is very real within a 30-mile-long zone at the south margin of the Snake River Plain, south of Bruneau, Grand View and Oreana, and near the junction with the Owyhee Upland.

2. The western Snake River Plain formed as a crustal rift or compound graben, beginning in late Oligocene or Miocene time; crustal extension continued at least into Pleistocene epoch. Volcanism has taken place almost continuously during that time within the Plain or at the margin of the Upland.

3. Gravity and magnetic data support the intrusion of a diabasic or gabbroic body (or bodies) along this province boundary, probably in Late Tertiary time, but possibly early in the Quaternary. Its upper surfaces may reach to 3 kilometers (10,000 feet) below the ground surface.

4. The volcanic and volcaniclastic section beneath the Plain consists of Pleistocene and Pliocene rocks of the Idaho Group, underlain by Miocene silicic tuffs. These probably are underlain by middle Miocene basalts and then by a thick and varied volcanic sequence, including basalt, latite, dacite and rhyolite, to a total depth of 3 kilometers.

5. Granitic basement of the Owyhee Upland may be present locally beneath the Plain. However, rifting and continued volcanism may have destroyed the upper crustal zone.

6. Thermal aquifers are recognized in the Banbury Basalt of the Idaho Group and underlying silicic tuffs. However, these are unlikely to be much above 200° F, and are not considered further as the geothermal reservoir.

7. Dozens of irrigation wells produce thermal water from these and shallower aquifers. Chemical indicators (SiO_2 and Na-K-Ca ratio) give discordant temperatures, which can be resolved only by assuming significant mixing of deeper, hotter fluids with cool, meteoric ground water.

8. Mixing models and upper ranges of the Na-K-Ca temperatures suggest equilibrium above 392° F (200° C), and possibly around 465° F (240°C). Depth to these temperatures is unknown, but probably is greater than 7,000 feet, on the basis of results from an 11,000 foot drill hole near Oreana.

9. Temperatures over 392° F (200° C), and reaching 400° F, were encountered episodically at depths between 8,000 and 9,700 feet. This corresponds to a maximum gradient of 5.1° F per 100 feet.

10. Gradients measured in irrigation wells to nearly 3,000 feet in depth, that penetrate the silicic tuffs or overlying Banbury Basalt, average over 3° F per 100 feet across a wide area. Locally, as in Little Valley and south of Oreana, gradients reach 5° F, and in a few cases exceed 6° F per 100 feet. These gradients, if projected to depth, would give temperatures over 500° F at 8,000 feet.

11. Heat flows to 4 heat flow units also have been measured along this northwest-trending zone that extends from south of Bruneau Hot Springs to south of Oreana. The average in this zone is about 3 HFU.

12. D-C resistivity soundings and audio magnetotelluric surveys encountered very low resistivity in the area to the north, between Oreana and Grand View. This appears to be the basis for creation of the Castle Creek K.G.R.A. However, the surveys could not penetrate "electrical basement" at 4,000 to 5,000 feet, probably the middle Miocene basalts.

13. Electrical soundings in the deep hole near Oreana revealed zones of permeability (good conductors) at depths between 7,500 feet and total depth. This agreed with the well history of lost circulation intervals, and apparently correlates with certain of the higher temperature measurements.

14. A zone of favorable exploration targets is recognized in the area of high gradient, high heat flow and high chemical indicators, trending northwest across the southern margin of the Plain. The deep well lies about 2 miles north of this zone as tentatively defined.

15. Eight companies or groups of companies have acquired leases in the region, most of them having some holdings in the favorable zone. Occidental Petroleum and the Earth Power Group have the largest leaseholdings. Fifty percent of the Earth Power leases and applications are within the favorable zone. These leases extend to within 4 miles of the deep hole near Oreana.

16. It is unwise to extend this zone southward into the Owyhee Upland, although high heat flow continues in that direction, because of the likelihood of encountering granitic basement in deep drilling. This would tend to preclude presence of a useful geothermal reservoir.

17. Reservoir in the attractive zone probably will consist of fractured and altered silicic tuffs of the lower volcanic series, perhaps augmented by fractured or rubbly basalts. Well capacity in the postulated deep aquifer is unknown. The shallower aquifers in silicic tuffs and basalts have high porosity and transmissivity.

18. Recharge probably comes from the Owyhee Upland to the south, via fractured silicic tuffs and faults. Rate of recharge to a deep reservoir is unknown. Withdrawal in excess of recharge would have to be expected in a commercial geothermal operation.

19. The leaseholdings of Earth Power Corporation and its associates are positioned quite attractively in the favorable zone, and would warrant further exploration and drilling of deep exploratory holes.

RECOMMENDATIONS

1. Exploration should begin at once in the area. Passive seismic, active seismic, d-c resistivity and gravity and magnetic techniques probably offer little promise.

2. Additional geologic work is warranted, leading to a clearer understanding of the section at depth.

3. A renewed canvass of irrigation and farm wells might yield further data on gradients and chemical thermometers in areas where these data are lacking or incomplete.

4. Electromagnetic (EM) soundings might penetrate the electrical basement, to illuminate deep conductive zones

5. Drilling of temperature gradient holes is warranted in areas lacking adequate gradient data. These should be to depths of about 350 feet. A series of at least 5 holes is recommended.

6. Cost for this entire program would be $100,000. Without the EM soundings, costs would be approximately $65,000. About $50,000 should be budgeted for gradient drilling.

7. No exploration should be done on leases outside of this favorable zone until results are available from deep drilling within the zone.

8. Areas most favorable for continued exploration, perhaps leading to siting deep exploratory holes, are in T. 6 S., R. 1 and 2 E., and T. 7 S., R. 4 and 5 E.

9. After exploration has been completed, a 3-hole drilling program is recommended. Depth per well might be scheduled at 8,500 feet. Cost per well (1976 dollars) might be $500,000, including completion.

INTRODUCTION

Purpose and Scope of Report.

This report evaluates the potential for discovering commercial quantities of geothermal energy on the lands controlled by the Earth Power Group in an area between Bruneau and Grand View in Owyhee County, Idaho. It was prepared in June 1976, and is based upon an analysis of published data, supplemented by personal observations and interpretations made during the period 1973-76 and by data obtained from various private sources.

Location and Description of Prospect.

Owyhee County is in southwestern Idaho (see figure 1). The northern part of the County, with which this report is concerned, is within the western Snake River Plain geomorphic province, and has the Snake River as its northern boundary and principal feature.

The western Snake River Plain is an area of gently rolling to hilly terrain, within which the Snake River has incised a steep-sided but shallow canyon. The river is at elevations of 2,300 to 2,450 feet. The surrounding Plain slopes upward to the south, reaching elevations of 3,500 to 4,000 feet at the junction with the Owyhee Uplands, 15 to 30 miles to the south. These rugged hills and mountains rise to elevations in excess of 8,000 feet. North of the Snake River, the Plain slopes upward toward the front of the Boise Mountains.

The Snake River flows northwesterly across the Plain. A major tributary, the Bruneau River, enters from the southeast and is dammed just south of the junction by the C. J. Strike dam. There are numerous other tributaries to the Snake River; almost all are ephemeral in their lower course and almost all flow in a northeasterly direction.

Population in this area is sparse. The communities of Oreana, Grand View and Bruneau have a combined population of about 300 people. Perhaps twice that number live on scattered farms and ranches, mostly along the principal stream courses. However, Idaho's capital, Boise, and the populous, fertile lowlands of the Boise River lie to the north and northwest at distances averaging 50 miles. That area forms the commercial and agricultural center of the State, with a combined population of over a quarter of a million. South of the Snake River Plain, the mountains and rangelands of the Owyhee Upland are nearly uninhabited.

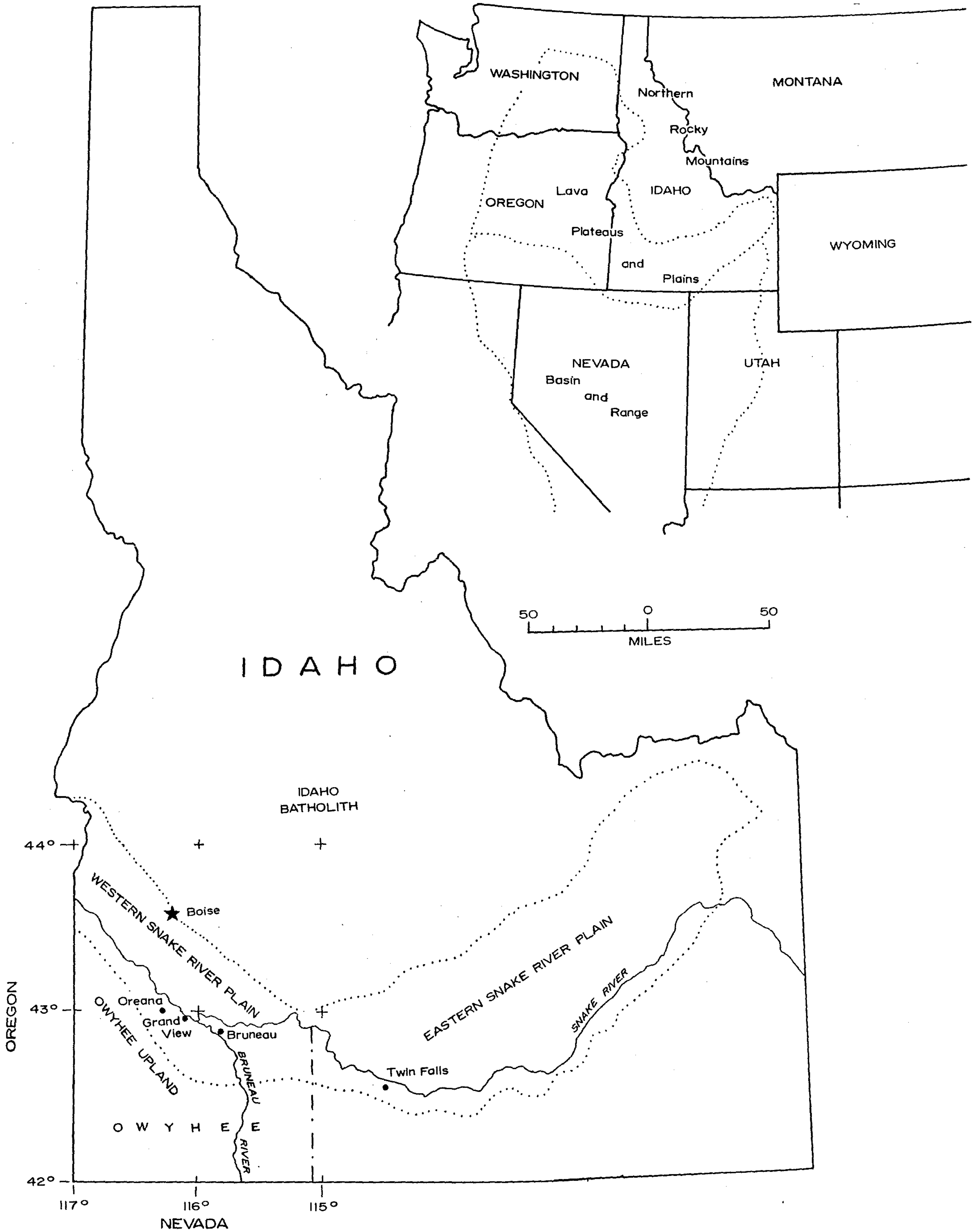


FIGURE 1. LOCATION MAP

Farming and ranching are the economic mainstay of northern Owyhee County. Over one-half million acres of the Snake River Plain and adjacent Owyhee Upland have been let by the U. S. Bureau of Land Management for livestock grazing. The Idaho Department of Water Resources has granted permits for withdrawal of over 1,000 cubic feet per second (cfs) of ground water for irrigation of some 60,000 acres.

Well-maintained State highways and County roads connect the area with the Boise metropolitan area to the northwest. Other principal roads extend south across the Owyhee Upland to Nevada, and east toward Twin Falls. Numerous farm roads criss-cross the settled and farmed areas. Few roads extend into the escarpment between the Plain and the Upland. Therefore, access is limited in the hilly and broken country to the south.

The region is arid, with rainfall averaging less than 10 inches annually. The Upland however receives up to 25 inches on higher summits. Precipitation is greatest in the Spring, and at a minimum during July through September. Winter precipitation often is in the form of snow, especially on the Upland.

The area has the warmest climate of Idaho, with mean annual air temperature of about 52°F. Summer days are hot, with diurnal temperatures in June through September averaging 70°F. Coldest months are December and January, which average 30°F.

The region receives electricity service from Idaho Power Company. A hydroelectric generating station of 83 MW is operated at C. J. Strike reservoir. A smaller plant (10 MW) is located at Swan Falls on the Snake River, near Grand View. Power from these plants is carried into the main transmission system via 138-KVe lines. Pacific Power and Light Company has studied potential routes for a high-capacity line to cross the area east-to-west, connecting to the load center of southwestern Oregon.

GEOLOGY

The western Snake River Plain most recently has been described both as a complex graben and as a true crustal rift (for example, see Bonnichsen et al., 1975 and Mabey et al., 1975). In earlier years, before faulting had been recognized along its northern and southern boundaries, it was conceived of as a regional downwarp: youngest formations are found in the center of the Plain, parallel to its axis; older formations are exposed outward from the center; formation dips usually are toward the center of the Plain (Plate 1). However, these characteristics can be applied equally well to an in-filled graben, and even to a rift. In addition to extensive faulting, evidence from gravimetry and aeromagnetic surveys (discussed below) supports the graben and rift concepts.

The distinction between modes of formation is signficant. In a graben (and in a downwarp), basement would be encountered at increasing depth toward the center of the structure. In a true rift, basement would be absent, replaced by upwelling and intruding youthful igneous material. In a graben or downwarp, older structures would be present at depth, offset, perhaps distorted and altered, but capable of exerting influence through the younger cover to the surface. In a rift, pre-rift structures would be removed, or at least so altered that they would be incapable of exerting influence at the present-day surface. Perhaps only the position of intrusions would mark the former position of pre-rift structures.

Therefore, although north-trending ridges and valleys of the Basin and Range province extend to the southern edge of the Owyhee Upland in northern Nevada, there are no grounds to speculate that Basin and Range structure continues beneath the western Snake River Plain, or that Paleozoic and Mesozoic sedimentary rocks are present at depth.

Basement in the Owyhee Upland and in the mountains north of the Snake River Plain is Cretaceous granitic rock, principally granodiorite, with lesser amounts of quartz monzonite and granite. These are cut by extensive and well-developed dikes and veins of pegmatite. Age-dates for the main part of the Idaho batholith, and for granitic plutons in north-central Nevada and adjacent Oregon, cluster around 100 million years (m.y.), or Cretaceous. However, age-dates of 62 to 66 m.y. were obtained (Pansze, 1972) for a granodiorite pluton in the Owyhee Upland. This corresponds to Paleocene age.

Other igneous bodies of the Idaho batholith have been age-dated as young as 35 to 45 m.y., or Eocene. Mineralized pegmatites are believed to be as young as Oligocene and Miocene, and possibly Pliocene in instances. However, caution must be exercised in estimating age, duration and sequence of igneous intrusive episodes in the region: a powerful thermal shock is believed to have re-set the K-Ar "clock" in Eocene time (D. D. Blackwell, oral communication, 1975) such that many Cretaceous rocks now yield anomalously young age-dates. This thermal shock may have been associated with volcanism and/or deep-seated intrusion. Therefore, the more silicic plutons and dike swarms indeed may be Eocene (or younger) in age. Eocene age-dates for mafic plutons may be suspect.

That granitic rocks extended beneath what is now the western Snake River Plain at the beginning of Tertiary time is unquestioned. A good case for this is presented by Taubeneck (1971). This granitic crust began to founder, beginning possibly as early as Eocene time, and certainly not later than the onset of Basin and Range extension at the start of Miocene time. During the interval, the granitic plutons appear to have been uplifted and unroofed, at least in part. Sedimentation, if any, is unknown.

Volcanism may have begun in the region as early as Eocene or Oligocene time. This time-sequence is derived by analogy with Eocene volcanism in such granitic terrain as the east-central Idaho batholith (Challis Volcanics) and the Boulder batholith (lowland Creek Volcanics), and with Oligocene volcanism of the Idaho and Sierra Nevada batholiths. Pansze (1972) age-dated a series of porphyritic dacite to diorite dikes of the Owyhee Upland at 25 to 28 m.y. (latest Oligocene or early Miocene, according to various chronologies).

At several places along the front of the Owyhee Upland, a thick and varied series of Middle Tertiary volcanic rocks has been observed (McIntyre, 1972; Asher, 1968; Pansze, 1972). Sequence and relationship is not always clear. It appears that basalt and latite flows are most abundant toward the base, inter-fingering with and overlain by arkosic, diatomaceous and silty sediment and vitric tuff, and including at least local andesitic basalt flows. The sequence appears to exceed 3,000 feet in aggregate thickness, although it is unknown how thick a section is present in any one place. These rocks have been age-dated at 12.8 to 16.6 m.y. (Pansze, 1972); an older age has been suggested on geologic relationships. The age-dates correspond to middle Miocene. Middle Miocene was the time of extrusion of vast quantities of basalt lava in western Idaho, Oregon and Washington, the Columbia River Basalts. This series of basalts and latites may in part be synchronous with the Columbia River Basalts, although that name is not used herein. Also, the latites exhibit different textures and may have had a different mode of emplacement. Quite possibly these mafic to intermediate-composition volcanic rocks were associated with regional extension and foundering of crustal blocks, and possibly with true rifting.

The Anschutz Corporation drilled a hole to 11,000 feet in 1974, located 6 miles southeast of Oreana, in Section 13, T. 5 S., R. 1 E. Logs from that hole (Malcolm Mossman, unpublished data) show a 5,000-foot-thick sequence of basalt, basaltic andesite, quartz latite, dacite, dacite porphyry, and porphyritic rhyolite flows, tuffs, breccias, minor intrusions, and miscellaneous associated sediment. An age-date of about 10 m.y. is believed to be too young by several million years. Overlying this is approximately 1,000 feet of basalt and rhyodacite flows and ashes, and volcanically derived silt and sand. This undated material is believed to be correlative to the middle Miocene basalt sequence.

Field relationships suggest that a series of silicic volcanic rocks, locally known as the Owyhee Rhyolite, overlies and intrudes the basalt-latite sequence. However, age-dates for rhyolite welded tuffs and rhyolite and latite porphyry domes are 14.9 to 19.2 m.y., and cluster around 16 m.y. These would be synchronous with or older than the basalt-latite sequence. Contamination of the domes with older rock fragments is possible, giving erroneously great ages. The silicic sequence may be more than 1,000 feet thick.

It is problematical if all of the foregoing rock units extend beneath the Snake River Plain; if present, the distribution and thickness of these units is unknown. Nowhere are they exposed at the surface within the Plain. However, they are present on the margin of the Owyhee Upland. Further, a 2,000-foot-thick section of similar composition, texture (although highly altered) and age was recovered as cuttings from the deep hole 6 miles southeast of Oreana. A generalized stratigraphic section appears as Table 1. Temperature and electrical data are given elsewhere.

Table 1. Generalized stratigraphy from a deep hole near Oreana, Idaho (data from The Anschutz Corporation).

Depth, ft.	Lithology		Comments
0- 750 750- 2,315 2,315- 2,725	Bentonitic sediment Silicic ash, basalt Basalt.	Idaho Group	Glenns Ferry Formation; Poison Creek Formation; 16 m.y. age-date; probably equivalent to basal Poison Creek Fm. despite anomalously great age.
2,725- 4,756	Rhyolite and dacite vitrophyre, porphyry, obsidian.		Probably correlative with Owyhee Rhyolite; 16 ± 1.3 m.y. age-date appears accurate.
4,756- 5,776	Pumiceous and ashy rhyolite and dacite above basalt porphyry and basalt flows, and minor basaltic siltstone and sandstone.		"Sucker Creek Formation"; probable equivalent of Columbia River Group basalts (middle Miocene).
5,776-10,970	Varied sequence of felsite, dacite, rhyolite porphyry, quartz latite, microporphyry, andesite (?), andesitic basalt porphyry (?), and pyroxene basalt: tuffs, flows dikes, small intrusions; argillitized, zeolitized, silicified, hematitized, devitrified in varying degree.		"Cloudburst Gulch Formation"; may be equivalent in part to Miocene (?) basalt-quartz latite sequence of Asher (1968) in Upland; anomalously young age-dates (9.4 ± 0.4 m.y. at 7,600 feet; 10.1 ± 0.4 m.y. at 10,800 feet) may reflect argon loss by reheating; or may accurately date minor younger intrusions.
10,970-11,120	Muscovite-bearing quartz monzonite porphyry; black vitrophyre at 10,090 - 11,110 feet.		Probable Eocene intrusion (41.9 ± 1.7 m.y. age-date), rather than re-heated Cretaceous basement.

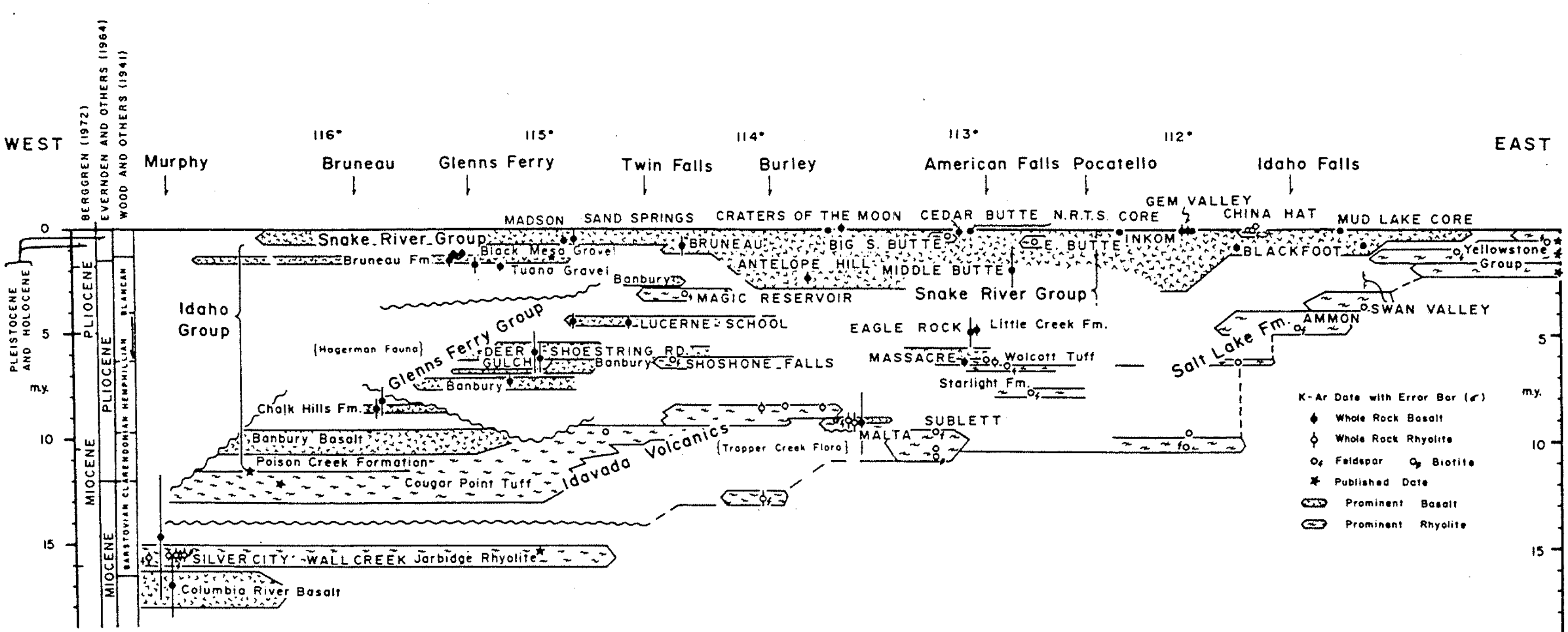
The oldest rock unit exposed on the Plain is a closely jointed, welded, porphyritic tuff, known to most workers as the "Tertiary silicic volcanics," and proposed for formation status by Maldo and Powers (1962) as the Idavada Volcanics. No eruptive center is recognized in the area. Perhaps there had been more than one provenance for these tuffs, and more than one formational name is required to explain apparent complications of thickness, distribution, compositional varieties and relationship to older and younger rocks.

A thickness of at least 3,000 feet has been mapped (Malde and Powers, 1962) at the surface. A water well in Section 27, T. 7 S., R. 4 E., on Jacks Creek at the south end of Little Valley, penetrated nearly 1,250 feet of these silicic volcanic rocks, without reaching an underlying formation (Young and Whitehead, 1975). It is unclear if the deep hole in Section 13, T. 5 S., R. 1 E. encountered the Tertiary silicic volcanics.

The age of these welded tuffs frequently has been stated as Pliocene. Armstrong et al. (1975) considered the Idavada Volcanics to be 9 to 13 m. y. old in the western Plain, on the basis of radiometric age-dates measured elsewhere in southwestern and south-central Idaho. They depicted the unit either as spanning the Miocene-Pliocene time boundary, based upon the mammalian faunal chronology, or as being entirely within Miocene epoch, on the basis of other chronologies (see figure 2). They clearly post-date the mineralized rocks of middle Miocene age. Their emplacement may have been associated with intrusion of a coarse-grained silicic pluton in the Owyhee Upland or the southern margin of the Plain.

Farther to the east and north (near Twin Falls and in the Mt. Bennett Hills) silicic volcanism continued; for the southern part of the western Snake River Plain, however, this marked the end of significant silicic volcanism.

The Idavada Volcanics are in turn overlain by an interbedded series of basalt lavas and diverse sediments known collectively as the Idaho Group (Malde and Powers, 1962), comprising at least 7 locally recognizable formations. The oldest of these, the Poison Creek Formation, consists of clay and silt, some parts bentonitic, minor ash beds and, apparently, basalt lavas. The basalts were at one time considered to be part of the next younger formation, but have been shown by radiometric age-dating (Armstrong, 1975; Armstrong et al., 1975) to be either within the upper part of Poison Creek, or transitional between it and the overlying Banbury Basalt. Poison Creek carries a Clarendonian stage fauna and flora, whereas Banbury spans the Clarendonian-Hemphillian boundary. Depending upon chronology used, this places the formation within either the Miocene or Pliocene epochs. Each formation apparently exceeds 700 feet in thickness, based upon well logs from the western end of the Snake River Plain (Ralston and Chapman, 1969). However, maximum thickness may vary widely across the region.



. Space-time profile along the Snake River Plain, Idaho (from Armstrong and others, 1975a). Local stratigraphy is more complex than this diagram implies, but the essence of the stratigraphic story is presented. Unpatterned areas represent erosion intervals, sedimentary deposits, and other rock units unimportant to the discussion. Many names are not formally defined stratigraphic terms – these informal names and geographic references are given in capital letters only.

FIGURE 2. STRATIGRAPHY AND CHRONOLOGY OF THE SNAKE RIVER PLAIN(FROM ARMSTRONG ET AL, 1975

Overlying the Banbury Basalt is the Chalk Hills Formation, consisting of silt, sand, fine siliceous ash, minor gravel beds, and at least one prominent basalt flow. Its maximum thickness, again from well logs, is 470 feet (Ralston and Chapman, 1969). It is overlain in turn by the Glenns Ferry Formation, which is an accumulation of lacustrine and fluviatile silt, sand and clay, sometimes highly bentonitic, interbedded with numerous basalt flows and hyaloclastites. The apparent similarity in appearance of basalts across the wide region has led many workers to extend the term Banbury Basalt incorrectly to rocks of differing age. Basalts belonging to both the Glenns Ferry and Chalk Hills Formations have been misidentified this way in the past.

Glenns Ferry Formation may be 2,000 feet thick near the town of Glenns Ferry, on the north side of the Snake River. South of the river, a maximum thickness of nearly 1,000 feet has been reported (Ralston and Chapman, 1969). Its age is probably Pliocene.

Still younger are the Tuana Gravel (late Pliocene to early Pleistocene); the Bruneau Formation, consisting of approximately equal volumes of basalt flows and cinders, and fine-grained clastic sediments, of Pleistocene age; and the Black Mesa Gravel, also Pleistocene in age. Whereas the Tuana and Black Mesa Gravels are measured to be perhaps 200 and 50 feet respectively in maximum thickness, the Bruneau consists of an aggregate of nearly 2,000 feet in thickness. However, no single exposure shows a complete section, and the sedimentary units appear to thin from west to east. Maximum thickness of the basalts is in the immediate vicinity of eruptive centers, with thinning occurring outward.

Basalt flows and minor cinders, and remnants of river-terrace gravels comprise the late Pleistocene Snake River Group in this area. Local eruptive centers are recognized, mostly north of the Snake River. However, the unit is discontinuous and thin, and of minor importance south of the river.

Other Late Quaternary deposits are silty and gravelly fan debris, dune sands and wind-blown silts, talus, and alluvial flood-plain deposits. Taken together these may aggregate several hundred feet in thickness. Usually, however, thickness is measured in tens of feet, and the units are discontinuous and patchy.

Structurally, the western Snake River Plain is a low-lying, northwest-trending zone of low relief, marked by linear, principally northwest-trending faults along its northern and southern margins. The faults are discontinuous, subparallel, and probably inactive. Throw probably ranges from a few tens of feet to a few hundred feet (Littleton and Crosthwaite, 1957). Individual faults may reach 8 to 12 miles in length, but many are less than half that length. Most exhibit evidence of downdrop toward the Plain's center, although some intragraben horsts are suspected (see, for example, Geologic Section C'E-E'D of Plate 16, from Young and Whitehead, 1975). No strike-slip offset has been reported in the Idaho portion of the Plain, but Lawrence (1975) has proposed he existence of right-lateral strike slip on the extension of the southern boundary fault near Vale, Oregon. Further, R. W. Greensfelder (oral communication, 1976) has proposed a right-lateral strike slip mechanism to accompany vertical movement of the faults separating the Plain and the Upland.

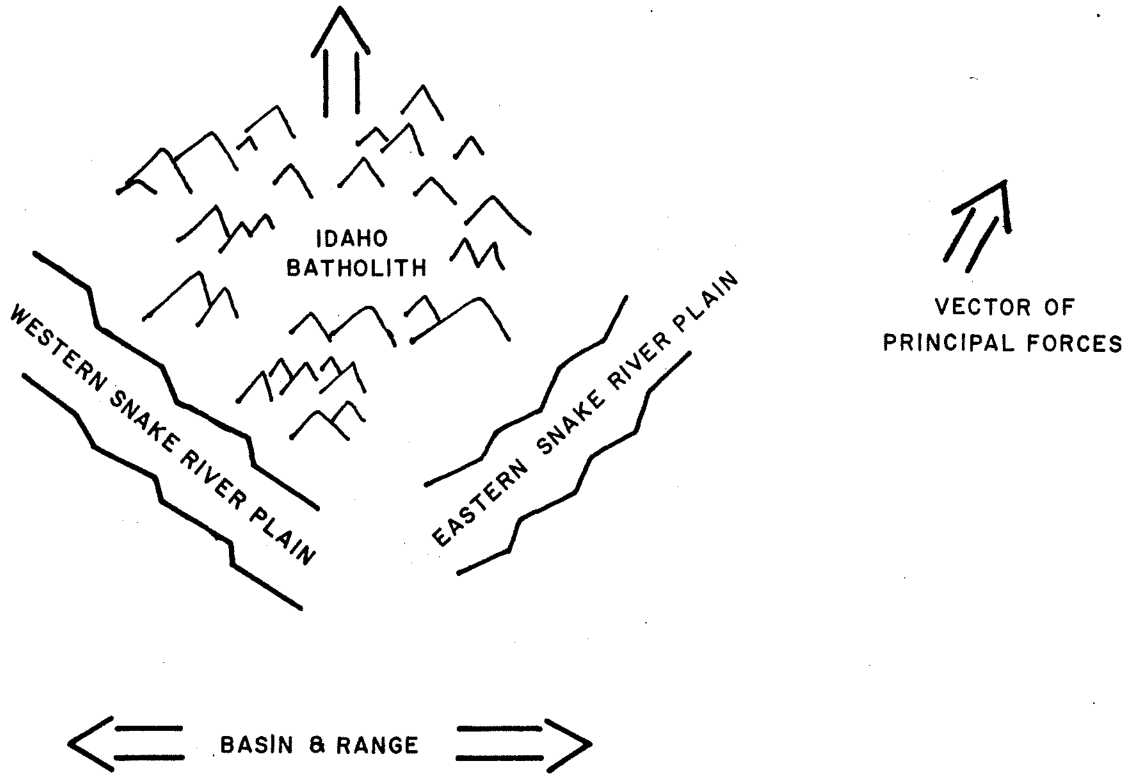
Asher (1968) reported evidences of doming in the Owyhee Upland to the south, generating several sets of fractures and disrupting rocks of Miocene age. Principal fault directions were north-south and northeast-southwest.

There is no clear evidence of north-south or northeast-trending structures cutting the Snake River Plain, although certain segments of the marginal faults trend nearly north-south. These might be expected either if fractures in the Owyhee Upland extend into the Plain, or if Basin and Range structure extends at depth beneath the Plain. Absence of these suggests that Basin and Range structure is absent at depth, and possibly that the Owyhee Upland moved upward in response to purely local forces, perhaps related to mid-Tertiary intrusion.

Recent speculation on the origin of the Plain has centered around the possibilities of a mantle "hot spot," or of a rifting "triple point" beneath south-central Idaho. In the first case, the continental mass is assumed to have moved southwestward over a quasi-stationary melting plume in the mantle. This may account for the eastern, northeast-trending, Snake River Plain, and the extremely youthful bimodal sequence of rhyolite and basalt of that area, but it does not clarify the origin of the Plain west of the Twin Falls area. A rifting "triple point" would involve northward movement of the Idaho batholith, concurrent with east-west extension across the northern Basin and Range province. The center of this "triple point" is suggested to be near the Idaho-Nevada line south of Twin Falls. It remains unproven, but is attractive as a hypothesis.

In any event, the western Plain appears to have developed separately from the eastern Plain. It can be described mechanically as having been subjected to an extensional couple, as shown diagrammatically in figure 3. This would have resulted in both northwest-trending normal faults, north-northwest-trending shear fractures of possible normal movement, and a possible set of northeast-trending fractures. A further implication is that right-lateral strike-slip displacement may have occurred on certain of the northwest-trending faults.

This northwest and north-northwest pattern (minus the strike-slip movement) is observed on the regional geologic map (see figure 4 a). It also agrees with the pattern observed by Asher (1968) in the Owyhee Upland, and it is in general conformity with the extensional forces reported to have governed the Basin and Range since Miocene time. The possible northeast-trending fracture set is lacking,



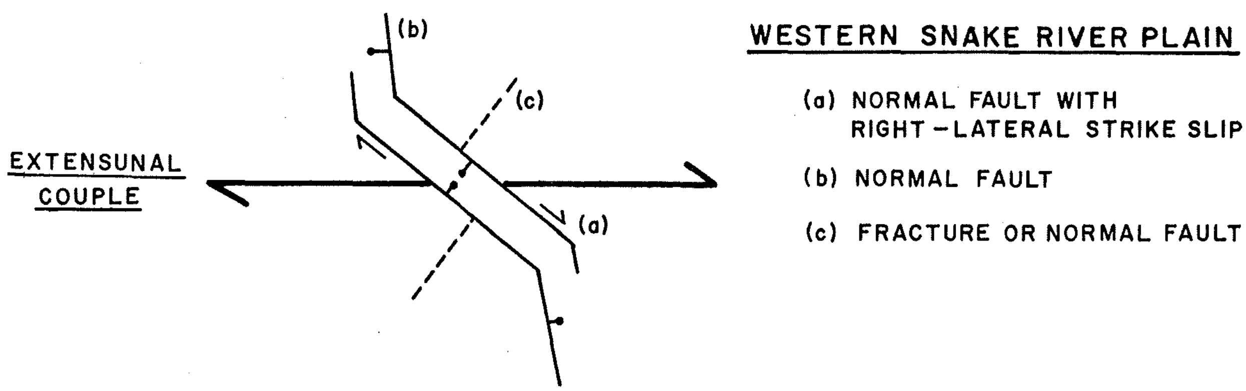


FIGURE 3

SKETCH OF FORCES TO CREATE A NORTHWEST TRENDING RIFE

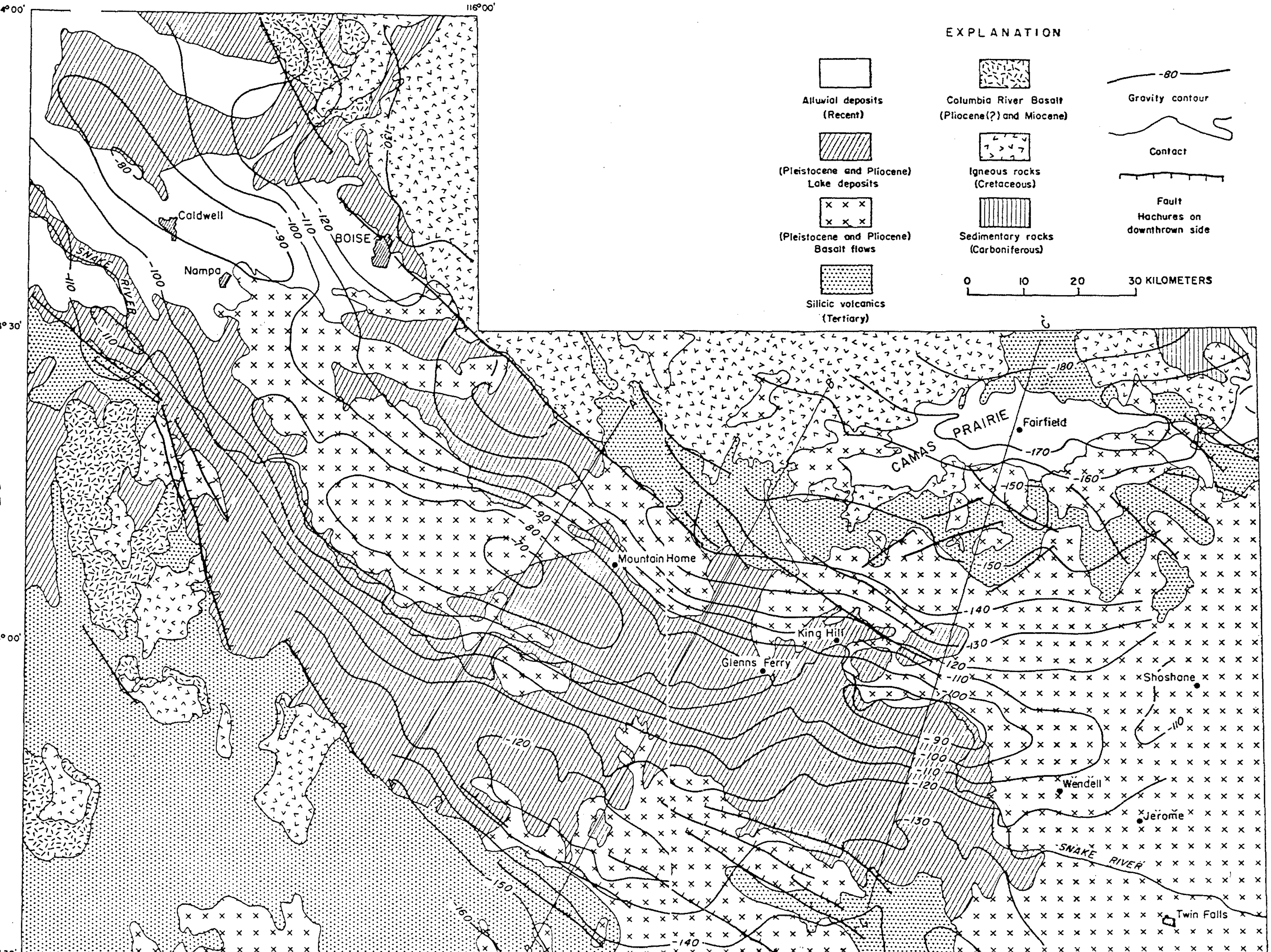
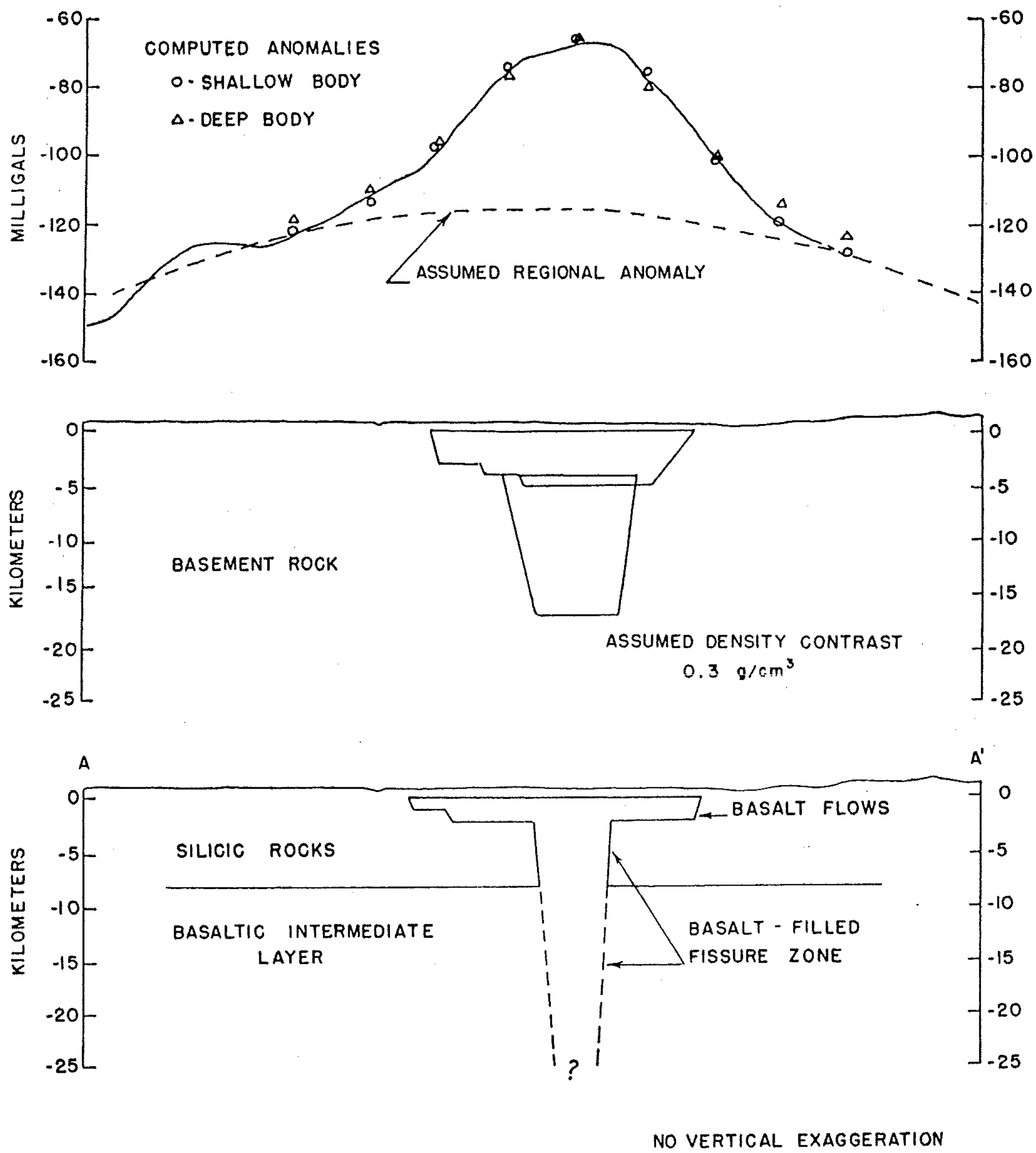


FIGURE 4. (PART A) REGIONAL GEOLOGIC MAP, WESTERN SNAKE RIVER PLAIN (FROM HILL, 1963)



Interpretative section along profile *A-A'*.

FIGURE 4. (PART B) CROSS-SECTION ALONG PROFILE A-A' OF FIGURE 4, PART A

except perhaps as photo-linears recognized on high-altitude photographs (M. Mossman, oral and visual communications, 1975).

The western Snake River Plain may have begun rifting open between late Oligocene (Axelrod, 1968) or middle Miocene (Armstrong et al., 1975) time. Movement continued at least until Pliocene, and probably into Pleistocene epoch, on the basis of offsets recognized in rocks of the Idaho Group and on the morphology of the margin of the Plain. Alignments of Late Quaternary eruptive centers of the Snake River Group suggests at least that the fault set remained as open channelways until the late Pleistocene.

However, the area is almost devoid of historic seismicity (R. W. Greensfelder, oral communication, 1976), and repeated surveys using arrays of portable seismometers and seismographs have failed to detect microseismicity in the area (J. R. Bailey, oral communication, 1976). This suggests that the faults have become inactive, and implies that regional stress field responsible for the rift has come to an equilibrium position, perhaps temporarily. However, the extensional zone of the Basin and Range to the south remains active seismically.

Another implication is that igneous intrusion beneath the western Plain, the Owyhee Upland, and their common margin, assumed to have persisted from Oligocene (and possibly Cretaceous) time to perhaps Plio-Pleistocene time, has ceased, at least temporarily.

THERMAL REGIME

Springs.

Thermal springs, although not of very high temperature, are numerous along the southern side of the western Snake River Plain. Their locations are shown on Plates 1 and 2, and physical and chemical data (compiled from Piper, 1924; Littleton and Crosthwaite, 1957; Ross, 1971; Ralston and Chapman, 1968; and Young and Whitehead, 1975) are given in Table 2.

The hottest of these, Indian Hot Springs (to 158°F), is south of the area under discussion by about 30 miles. However, its chemical characteristics are so similar as to indicate that it has a source mechanism in common with the other thermal springs.

In each case, $HCO_3 + CO_3 > SO_4 > Cl$, and as an approximation $Na \sim Ca \gg K \sim Mg$. SiO_2 ranges from 45 and 46 ppm in the colder springs to 83, 87 and 89 ppm in the Bruneau River valley thermal springs. F is remarkably abundant, equaling or exceeding Cl in 3 cases. TDS is low, averaging about 250 ppm. Flows range from minor trickles to nearly 4 cfs.

Extinct hot springs were reported by Ralston and Chapman (1969) in the drainage of Castle Creek, 12 miles west of Grand View. Rosebriar Spring, at the north end of Little Valley has gone dry, perhaps in response to pumping of nearby wells. Both springs reportedly had deposited $CaCO_3$ and minor amounts of SiO_2.

As a whole this series of thermal springs is not remarkable in temperature, abundance or chemistry, and would receive no more than passing interest if it were not for a series of thermal water wells in the area.

Table 2. CHEMICAL AND PHYSICAL DATA FOR THERMAL SPRINGS

Location	Temp., °F	Flow, gpm	pH	SiO_2	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	F	B	TDS	Comments
			composition, ppm													
1N-3W-21ba	120	35	9.2	75	1	0	126	1.4	150	35	23	31	14.0	-	392	Givens Hot Springs
2S-2W-23	81	5	7.5	46	11	1.3	6	3.8	58	0	1	2	0.3	-	109	
6S-1E-32bba	77	-	7.2	45	37	8.5	22	1.6	126	0	21	35	0.5	0.03	235	flows from granite
-5E-32a	100	5														Rosebriar Spring; may be dry now; deposited $CaCO_3$ and SiO_2
7S-6E-22c	111	35														Bruneau River Valley
-22c	115	1,000	-	78	10	1.0	-48-		85	14	7	18	-	-	243	" " "
-24d	106	1,200														" " "
-34dcb	106	500	9.1	83	6.3	0.2	55	5.5	103	6	8.8	18	8.5	0.01	244	" " "
-34d	98	1,000														may be same as 34dcb
-35bbb		-	8.5	89	13	1.8	43	6.7	126	0	8.8	15	4.5	0.11	247	Bruneau River Valley
8S-6E-3aa	102	55														" " "
-3ba	100	2,000	-	66	5	1.0	-58-		66	24	10	21	-	-	248	" " "
-3bdd	102	500	8.3	87	6.5	0.6	53	6.7	113	5	9.1	15	6.0	0.08	248	same as following entry
-3bd	102	458	8.2	76	5.9	0.4	54	7.3	124	2	8	15	8.8	-	242	Indian Bathtub; $CaCO_3$ deposit
-26cc	111	270														Bruneau River Valley
9S-5E-4	-	-	9.4	-	1.0	-	-92-		-	-	13	26	20	-	303	probably tepid
12S-7E-33c	156	1,730	8.0	75	1.5	0	75	0.6	67	30	8.4	24	14	-	262	Indian Hot Springs; reported SiO_2 deposit, odor H_2S
13S-7E-5a	158	2,700														Indian Hot Springs

(data selected from Piper, 1924; Littleton and Crosthwaite, 1957; Ross, 1971; Ralston and Chapman, 1968; Young and Whitehead, 1975)

Water Wells.

The establishment of irrigated agriculture in the area in the first decades of the 20th Century led to the drilling of numerous deep irrigation wells. Many of these were found to produce thermal ground water; and several reports have discussed them in detail (Piper, 1924; Littleton and Crosthwaite, 1957; Ralston and Chapman, 1969; Young and Whitehead, 1975). The distribution of thermal wells is closely related to the position of tributary valleys of the Snake River. That is, settlement began in the more fertile stream valleys, and drilling of wells largely has been limited to settled areas. In the interfluves, or rolling plain between stream valleys, wells are fewer, and therefore there are fewer wells. Continued agricultural development may lead to penetration of thermal aquifers in these areas.

Principal clusters of thermal wells are in Bruneau Valley, Little Valley (with its principal tributaries, Jacks Creek and Halfway Gulch), Shoofly Creek, Twentymile Gulch, and Castle and Catherine Creeks. A glance at Plate 2 shows that intervening areas are nearly devoid of thermal wells.

Temperatures in these wells increase with depth, as is to be expected. However, whereas the average increase with depth (or thermal gradient) in the western United States is on the order of 1^{o} F per 70 feet, or 1.4^{o} F per 100 feet (25^{o} C per kilometer), in the western Snake River Plain the gradient in many wells averages 4^{o} to over 6^{o} F per 100 feet (74^{o} to over 110^{o} C per kilometer) for wells several hundred feet deep. Gradients in deeper wells (to 3,000 feet) appear to decline to about 3^{o} or 4^{o} F per 100 feet (55^{o} to 74^{o} C per kilometer), although some areas of high gradient lack deeper wells.

The significance of this is complicated by the condition of well completions. That is, individual wells may derive water from several aquifers, whose temperatures are partially a function of depth. Therefore, mixing of waters from several aquifers would cause the calculated gradient to decline. Similarly, wells might not produce from their deepest intervals. Thus, deep wells with non-productive bottom intervals would yield reduced gradients calculated on the basis of total depth.

The highest temperature reported from a water well is 181^{o} F (also given as 184^{o} F) in a hole 2,970 feet deep located in Section 26, T. 5 S., R. 3 E. This yields an uncorrected gradient of 4.4^{o} F per 100 feet (82^{o} C per kilometer), with water entering the hole from 2 separate deep horizons. If projected in a linear fashion to 10,000 feet (3 kilometers), temperature would be 490^{o} F (255^{o} C). The highest temperature (and deepest as a group) wells cluster east and southeast of Oreana (T. 4 and 5 S., R. 1 E.) and south of Grand View (T. 5 and 6 S., R. 3 E.).

However, the highest gradients are to be found elsewhere:

along the Bruneau River Valley principally in T. 6 and 7 S., R. 6 E.;

along the Snake River in T. 6 S., R. 7 E., on the basis of relatively few wells;

in Little Valley, along a northwest line running through T. 7 S., R. 4 and 5 E.; and

at very scattered locations along a continuation of that northwest-trending line, to the southern part of T. 5 S., R. 1 E.

Date on gradients are plotted on Plates 2 and 3 and compiled in Table 3. They come from the following sources: Piper, 1924; Littleton and Crosthwaite, 1957; and Young and Whitehead, 1975. These are raw or uncorrected gradients: no allowances are made for mixing of waters from several aquifers, or for the effects of artesian flow, or the possible difference between depth to aquifer and depth to hole bottom.

In addition to these values, careful measurements of temperature gradient were made in specially selected wells by D. D. Blackwell and C. A. Brott, of Southern Methodist University (Brott et al., 1975). Half a dozen of their values are included on Plate 3. They can be seen to conform closely to the raw gradients described above. Perhaps, therefore, the raw gradients are reasonably accurate.

There is a condition worth noting regarding the high gradients of the Bruneau River Valley: they are intermingled with significantly lower gradients. This suggests that hot water is welling upward (perhaps along faults), being discharged at hot springs, and being intercepted in certain wells. At other wells, however, the convecting hot water is not intercepted, and gradients are lower. The latter, which average about 3^{o} to 3.5^{o} F per 100 feet may reflect true conductive gradient. The higher values may be strongly influenced by convection in the vicinity of hot springs.

In Table 3, gradients for wells entering the Idavada Volcanics have been separated from wells in the Idaho Group, Banbury Basalt, or other formations. These, in turn, are divided by geographic area. It is notable that gradients in the Idavada tuffs exhibit little range in value, compared to those in shallower units. Also it is important to note an apparent increase in gradient southeastward from Oreana, perhaps because well depths decrease in that direction. Finally it should be noted that, if projected, the mean gradients would yield temperatures over 400^{o} F at 10,000 feet (3 kilometers) for each sub-area examined.

Table 3. Temperature gradients from thermal wells in the western Snake River Plain (compiled from Piper, 1924; Littleton and Crosthwaite, 1957; Young and Whitehead, 1975; and C. A. Brott and D. D. Blackwell, unpublished).

(Gradients in volcanic aquifers are underlined)

Location	Well Depth, feet	Tmax, °F	$\frac{dt}{dx}$, °F/100 ft.	Aquifer
3S-1E-35dac	300	68	5.4	Sediments of Idaho Group
4S-1E-26abc	1,700	86	2.1	Sediments of Idaho Group
29ccd	3,040	158	3.5	Idavada Volcanics
30bdb	350	62	2.9	Sediments of Idaho Group
34bad	2,960	170	4.0	Idavada Volcanics; Banbury Basalt(?)
36ba	-	-	2.5	-
-2E-29dbc	>1,000	82	<3.1	Sediments of Idaho Group
-32bcc	2,704	109	2.2	Sediments of Idaho Group; Banbury Basalt(?); Idavada Volcanics(?)
5S-1E- 3aab	1,900	90	2.0	Sediments of Idaho Group
-10bdd	2,960	147	3.3	Idavada Volcanics; Banbury Basalt
-13	11,120	500 at 8,860	5.1	Pre-middle Miocene volcanic rocks
-21cbc	660	149	14.9	Banbury Basalt(?)
-24acd	3,120	151	3.2	Idavada Volcanics
-2S- 1bbc	1,800	121	3.9	Banbury Basalt(?)
- 2aa	1,745	126	4.2	-
- 2cda	2,460	98	1.9	Sediments of Idaho Group; Banbury Basalt(?)
- 5bcd	2,009	109	2.9	Sediments of Idaho Group; Banbury Basalt(?)
-13ada	1,748	(80	1.6)	
		(73	1.3)	Sediments of Idaho Group
-3 -14ccb	2,300	137	3.8	Idavada Volcanics(?); Banbury Basalt(?)
-20ada	2,420	140	3.7	Idavada Volcanics; Banbury Basalt
-22aad	1,300	77	2.0	Sediments of Idaho Group
-25bbb	1,320	64	1.1	Sediments of Idaho Group
-26bcb1	2,970	181	4.4	Idavada Volcanics; Banbury Basalt
-26bcb2	2,970	153	3.4	Idavada Volcanics(?); Banbury Basalt(?)
-27bdd	2,900	140	3.1	Idavada Volcanics(?); Banbury Basalt(?)
-28bcc	2,540	149	3.9	Idavada Volcanics; Banbury Basalt

Location	Well Depth, feet	Tmax, °F	$\frac{dt}{dx}$, °F/100 ft.	Aquifer
-35ccc	2,570	161	4.3	Idavada Volcanics(?); Banbury Basalt(?)
-4E-34ccb	356	81	8.3	Sediments of Idaho Group
-5E-33bbd	250	72	8.2	Sediments and basalt of Idaho Group
-34ddd	885	77	2.9	Sediments of Idaho Group
6S-2E-30cb	-	-	6.9	-
6S-3E- 2cbc	3,050	144	3.0	Banbury Basalt; sediments of Idaho Group
- 2ccc	1,940	(131	4.1	Banbury Basalt; sediments of Idaho Group
		(127	3.9	
- 4ab	1,400	93	3.0	-
- 4bcc	1,680	118	4.0	Banbury Basalt(?); sediments of Idaho Group
- 5cac	3,600	142	2.5	Idavada Volcanics; Banbury Basalt
- 9acc	1,425	102	3.6	Banbury Basalt; sediments of Idaho Group
-10bb	1,400	93	3.0	-
-11ccb	-	-	3.0	-
-11cc	1,423	94	3.0	-
-11dad	1,400	93	3.0	Banbury Basalt(?); sediments of Idaho Group
-13ab	>1,350	100	<3.6	-
-14bcb	-	-	3.1	-
-14bc	1,341	84	2.5	-
-4E-14abc	1,905	129	4.1	Idavada Volcanics; Banbury Basalt
-18bcc	455	64	2.9	Sediments of Idaho Group
-25bcc	1,750	68	0.9	Sediments of Idaho Group
-35cda	955	91	4.1	Sediments of Idaho Group
-5 -10ddd	1,667	101	3.0	Banbury Basalt; sediments of Idaho Group
-18ccb	2,960	81	1.0	Banbury Basalt; sediments of Idaho Group
-24bca	1,095	92	3.8	Banbury Basalt; sediments of Idaho Group
-24ca	1,325	104	4.0	-
-24db	1,170	92	3.5	-
-24ddb	1,938	91	2.1	Banbury Basalt
-24dd	976	94	4.4	-
-29dcc	1,560	91	2.5	Sediments of Idaho Group(?)
-35cca	460	72	4.5	Sediments of Idaho Group
6S-6E-12ccd	990	99	4.8	Sediments of Idaho Group
-18ba	-	-	3.1	-
-19cd	-	-	3.0	-
-19ccd	913	100	5.4	Banbury Basalt; sediments of Idaho Group
-19dbd	1,347	108	4.2	Banbury Basalt; sediments of Idaho Group

Location	Well Depth, feet	Tmax, $^{\circ}$F	$\frac{dt}{dx}$, $^{\circ}$F/100 ft.	Aquifer
-32bdd	1,402	94	3.1	Banbury Basalt; sediments of Idaho Group
-7E- 1acb	>1,000	107	<5.5	Sediments of Idaho Group; Banbury Basalt(?)
- 1dbd	>1,050	91	<3.8	Sediments of Idaho Group; Banbury Basalt(?)
- 2cdd	1,350	94	3.2	Sediments of Idaho Group; Banbury Basalt(?)
7S-1W- 8bba	365	73	6.1	Sediments of Idaho Group
-24b	-	-	1.7	Granite
7S-3E- 4acd	804	93	5.3	Sediments of Idaho Group; Banbury Basalt
-4E- 1acc	1,800(?)	104	2.9(?)	Idavada Volcanics(?); Banbury Basalt(?)
- 3abd	1,142	108	5.0	Banbury Basalt
- 5cca	1,040	86	3.4	Banbury Basalt; sediments of Idaho Group
- 9c	-	-	6.1	-
-10bdb	1,145	100	4.2	Banbury Basalt
-11cbc	1,500	97	3.1	Idavada Volcanics; Banbury Basalt
-12bdd	1,105	109	5.3	Idavada Volcanics; Banbury Basalt
-13bcc	>1,060	102	<4.8	Idavada Volcanics; Banbury Basalt
-13dcd	1,000	104	5.3	Idavada Volcanics; Banbury Basalt
-14abc	1,146	102	4.5	Idavada Volcanics; Banbury Basalt
-15acd	1,065	101	4.7	Idavada Volcanics; Banbury Basalt
-23cbb	810	101	6.2	Idavada Volcanics; Banbury Basalt
-24bd	900	102	5.7	-
-24dc	470	99	10.2	-
-25adc	735	98	6.4	Idavada Volcanics; Banbury Basalt
-26bcb	867	88	4.2	Idavada Volcanics; Banbury Basalt
-27bcc	1,390	81	2.1	Idavada Volcanics
7S-5E- 5dbc	2,405	90	1.6	Banbury Basalt
- 7abb	1,625	102	3.2	Idavada Volcanics; Banbury Basalt
- 8bb	580	73	3.8	-
- 8bc	600	84	5.5	-
- 8ccc	1,500	104	3.5	Idavada Volcanics
- 9dd	1,700	92	2.4	-
- 9ddd	2,065	104	2.6	Idavada Volcanics

Location	Well Depth, feet	Tmax, °F	$\frac{dt}{dx}$, ° F/100 ft.	Aquifer
-13aac	150	77	17.3	Sediments of Idaho Group(?)
-13cbb	1,954	97	2.3	Banbury Basalt; sediments of Idaho Group
-16acd	1,515	103	3.4	Idavada Volcanics; Banbury Basalt
-18bc	517	92	7.9	-
-19ccc	760	98	6.1	Idavada Volcanics; Banbury Basalt
-28acd	1,003	93	4.2	Idavada Volcanics; Banbury Basalt
-6E- 4ac	1,040	81	2.9	-
- 4dc	680	106	8.1	-
- 7aac	1,086	77	2.4	Sediments of Idaho Group; Banbury Basalt(?)
- 9ba	960	122	7.4	-
- 9bad	910	122	7.8	Banbury Basalt(?)
-15ba	1,105	127	6.9	-
-16cd	350	100	14.0	-
-16cdc	513	109	11.2	Banbury Basalt
-18bb	1,480	81	2.0	-
-21dbc	760	109	7.7	Banbury Basalt
-21db	611	104	8.7	-
-22aa	580	117	11.4	-
-22aad	1,410	113	4.4	Idavada Volcanics(?); Banbury Basalt
-23cad	1,300	111	4.6	Idavada Volcanics(?); Banbury Basalt(?)
-26ada	1,000	100	4.9	Idavada Volcanics(?); Banbury Basalt(?)
-26ba	680	102	7.5	-
-27aa	350	117	18.9	-
-27adb	400	109	14.6	Banbury Basalt(?)
8S-1E-10d	-	-	4.2	

GEOGRAPHIC AREA DISTRIBUTION OF GRADIENTS, IDAVADA VOLCANICS

Area	Number of Measurements	Gradient Range, °F/100'	Mean	Depth Range, ft.
Oreana	4	3.2-4.0	3.5	2,960-3,120
Grand View	6	2.5-4.4	3.65	1,905-3,600
Little Valley	17	2.1-6.4	4.3	735-2,065
Bruneau River Valley	3	4.4-4.9	4.6	1,000-1,410

Only one thermal spring was reported for Little Valley, and it has become extinct. It was at the northern or lower gradient end of the valley. The possibility exists that the higher gradients also are convectively influenced; however, the symmetric distribution of values suggests a northwest-trending structure of some importance.

Heat Flow.

Heat flow refers to the conductive transfer of heat through rocks of the crust, as described by the relationship:

$$Q = k \frac{dt}{dx},$$

where Q is heat flow in microcalories per square centimeter per second (HFU); k is thermal conductivity of rocks through which heat flows; and $\frac{dt}{dx}$ is thermal gradient.

Where convecting ground water brings heat close to the surface, Q may be abnormally high. Conversely, where rocks exhibit extremes of thermal conductivity, Q may be abnormal also. Thermal conductivities range from a low of 1.5 to 2 k units for certain, unconsolidated silts and clays to highs of over 12 k units for quartzites and other dense silico-rich rocks. Average granitic rocks have conductivities of about 7; basalts may range between 4 and 7, depending upon texture. Rhyolitic tuffs may average 3 or 4 k units, becoming slightly higher if welded.

Values of heat flow vary not only with thermal conductivity, but are affected by innate differences in radiogenic heat capacity as a function of rock type. Predicted values for heat flow in a "normal" area of mixed sedimentary and volcanic suite, possibly overlying a granitic basement, are about 1.5 to 1.7 HFU. In granitic rocks of the Idaho batholith, and in areas in Nevada having a shallow granitic basement, values greater than 2 HFU commonly are observed. By comparison, areas not underlain by granite, and having a thick accumulation of basalt lavas might be expected to show 1.3 to 1.5 HFU, the difference possibly being due to increased radiogenesis within K-, U- and Th-rich granitic rocks and their detritus. However, for values in excess of 2 or especially 2.5 HFU, radiogenesis is inadequate to explain the high heat flow, and the elevation of gradient above "background" may reflect a contribution of heat from within the deeper crust or mantle.

Heat flows reported by D. D. Blackwell and C. A. Brott (oral communication, 1976) and Urban and Diment (1975) are shown on Plate 3, and are compiled in Table 4.

Table 4. Heat flow data for the western Snake River Plain.

Location	Q, HFU	Gradient, °F/100 ft.	Gradient, °C/km
2S- 3W	3.1	3.55	47
2S- 2W-16d	2.0	3.77	51
2S- 1E-14dd	3.3	4.43	63
4S- 1E-36ba	1.7	3.50	46
4S-10E-30bba	3.1	6.02	92
6S- 2E-30cb	4.1	7.83	125
6S- 3E-11ccb	1.6	3.94	54
6S- 3E-14bcb	1.7	4.10	57
6S- 6E-18ba	1.8	4.10	57
6S-12E-19cd	3.3	7.17	113
7S- 1W-24b	2.2	2.67	31
7S- 4E- 9cc	3.3	7.06	111
8S- 1E-10dd	3.3	5.20	77

The heat flow values fall into two broad groups: 6 with "average" values (1.6 to 2.2), and all associated with gradients no higher than 3° F per 100 feet; 7 with high values (3.1 to 4.1), and having gradients that range from 2.6° to 6.9° F per 100 feet (4 are above 5° F per 100 feet). Of these 13 values, 2 of the high suite are located along what may be called the northern margin of the Snake River Plain, near Flenns Ferry, and 2 are located along the northwest-trending line, described earlier, from Little Valley toward Oreana, near the southern margin of the Snake River Plain. Two values (one of each group) are within the granitic terrain of the Owyhee Upland. The 5 unquestionably lowest values are close to the center of the Plain, on the south side of the river. The equivocal values (high heat flow, low gradient) either are within the Plain or in granitic terrain at its margin.

From these sparse data it is suggested that the strongest thermal conditions (high gradient and high heat flow) are encountered along the margins of the Snake River Plain; that toward the center of the Plain heat flow is normal, possibly because of low conductivity in Idaho Group sediments; and that heat flow in the granitic Owyhee Upland is slightly above normal, similar to the Idaho batholith. This is taken to mean that there has been a large-scale disturbance in the lower crust, probably associated with continued volcanism and intrusion. Therefore, regional heat flow is abnormal and the crust possibly is thinner than expected. Finally, the join between the Upland and the Plain remains the most attractive target for further exploration.

Deep Drilling.

Temperatures to 500° F were reported from a hole drilled by The Anschutz Corporation in Section 13, T. 5 S., R. 1 E. This is equated to an uncorrected gradient of 5° F per 100 feet. The hole is nearly midway between the heat flow hole yielding a gradient of 2.6° F per 100 feet, and another reporting 6.9° F per 100 feet. The latter it will be recalled is on the northwest-trending line of higher temperature gradients.

A summary of temperature data appears as Figure 5. From this it can be seen that 4 values of 392° F (200° C) or higher were reported, none between 302° and 392° F (150° and 200° C), and over 20 deep values were under 302° F (150° C). The bottom-hole temperature on the continuous temperature log was only 300° F. This would yield a gradient of only 2.3° F per 100 feet. The maximum temperature zone is between about 7,500 and 9,700 feet in depth. Within this zone, there are indications from resistivity soundings (see below) and from the drilling history of numerous permeable horizons. It is interpreted that some of these permeable zones may carry very hot water. This hot water does not move in a direct vertical line from depth (temperatures decline toward hole bottom). Possibly these aquifers flow from the zone of recharge, that is from the south toward the north. This is consistent with the picture of highest heat flow and gradient, and recharge to aquifers, in an area along the join between the Upland and Plain.

The absence of very high temperatures in the continuous temperature log is explained convincingly by the liberal use of lost-circulation material to seal off the deep permeable horizons. Point-temperatures measured on bottom during breaks in the drilling reflect a relatively undisturbed thermal regime.

A gradient of over 5° F per 100 feet can be constructed by using the maximum temperature of 500° F and the depth 8,860 feet. This is not unreasonable for the area, especially for the southern part. Convection of very hot water from depths of 2 or 3 miles is inferred.

A alternate approach involves arbitrary assignement of heat flow and thermal conductivity values, and calculation of a theoretical temperature gradient. For example, heat flows of 2.2 and 3.2 are assumed, based upon nearby heat flow values. Conductivity is assumed to increase regularly with depth, such that k equals 3 to 4 above 4,750 feet, equals 5 in the zone 4,750 to 5,800 feet, and is between 5 and 7 for the remainder of the hole. This yields the synthetic temperature gradients shown in Table 5.

FIGURE 5

TEMPERATURE DATA FROM THE ANSCHUTZ CORP. DEEP WELL NEAR OREANA

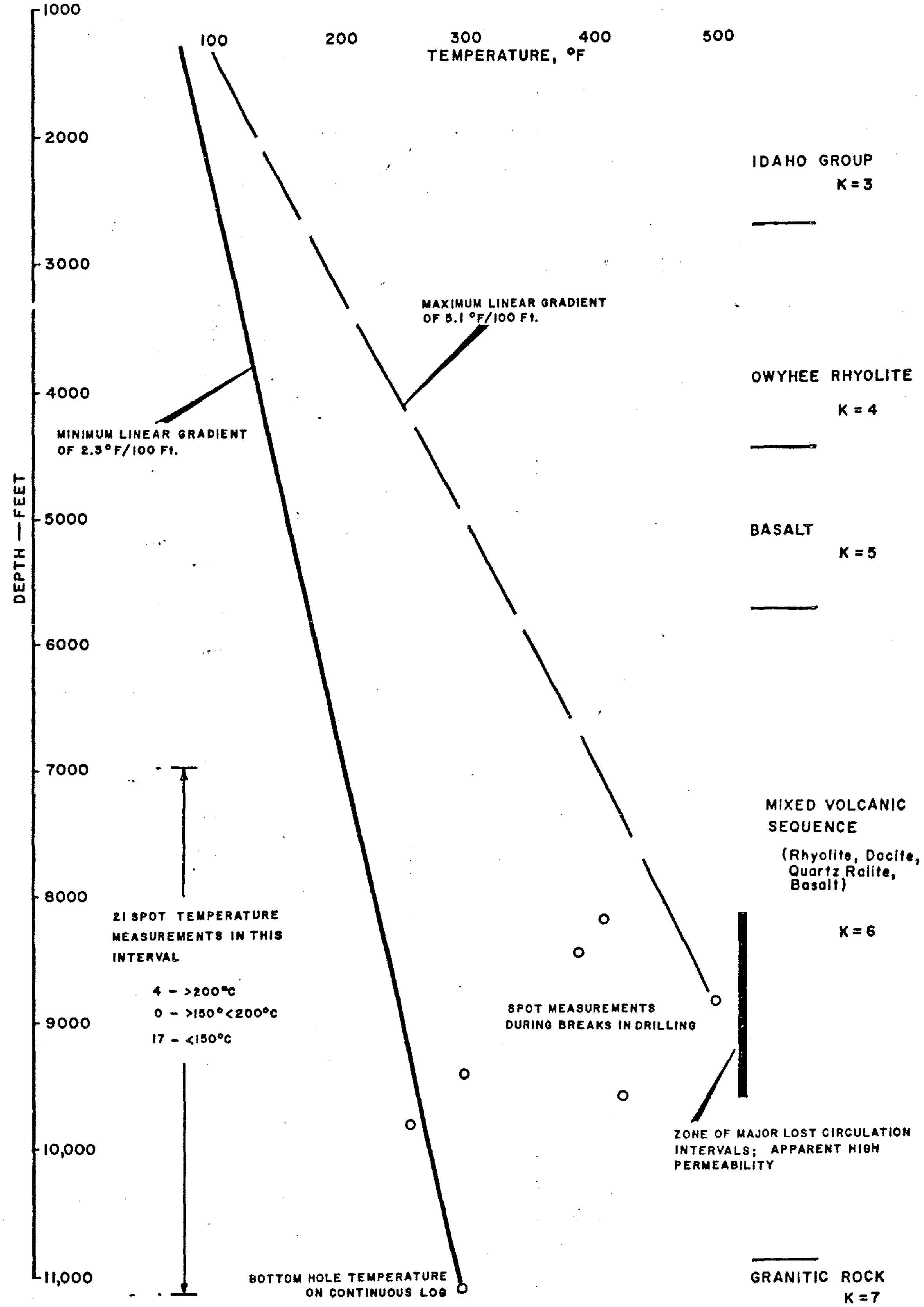


Table 5. Synthetic temperature gradients, Anschutz deep well.

Depth interval, ft.	Assumed thermal conductivity, k	Gradient calculated (°F per 100 ft.) at assumed heat flows 2.2	3.2		Cumulative temperatures (°F) at assumed heat flows 2.2	3.2
0- 4,750	3.5	3.5	5.1		166	242
4,750- 5,800	5	2.4	3.6		25	38
5,800-11,000	6	2.0	3.0	(8800 ft.)	61	90
					252	370
				Surface T	52	52
					304°	422°
Averaged gradient °F per 100 feet, 0-8800 feet					2.9°	4.2°

The synthetic temperature of 422° F, based upon heat flow of 3.2 HFU, matches 3 of the 4 higher values from the Anschutz well (393°, 410°, 425° F), but is significantly lower than the maximum (500° F). Two possibilities exist: an inaccurate reading of 500° F, or convective influx of higher temperature water. There is no mechanical evidence of a faulty temperature measurement. However, convection is known to operate throughout the section. Convection could make the conductive heat flow equation inaccurate, and easily could lead to the discrepancy in values.

From all of this I conclude that convection may take place from depths of 3 miles or even greater, bringing water at temperatures to 500° F, or even higher, to within 9,000 feet of the surface; and that a composite gradient of 4° to over 5° F per 100 feet is likely to 9,000 feet in areas of deep convective upwelling.

There is no other deep hole to confirm or clarify the Anschutz report. Near Mountain Home, close to the northern margin of the Plain some 30 miles to the northeast, a hole to 9,600 feet reported 375° F. This equals an uncorrected gradient of nearly 3.5° F per 100 feet. Unpublished heat flow values in that area are 1.5 to 1.9 HFU, with shallow gradients of 2° to 3° F per 100 feet.

Young and Whitehead accepted 3.6° F per 100 feet (2° C per 100 feet) as the weighted average gradient. This yields a temperature of 410° F by linear extrapolation to 10,000 feet. Although this ignores the effects of changes in gradient as a hole penetrates from rocks of one thermal conductivity to another, the value is not greatly less than that calculated by use of weighted thermal conductivities (4° to 5° F per 100 feet), as discussed above.

HYDROLOGY AND HYDROCHEMISTRY

Hydrology.

Surface hydrology is dominated by the Snake River. However, ground-water hydrology is more concerned with the intricate relationship between infiltration of rainwater along the front of the Owyhee Upland and the discharge of thermal waters to wells on the Plain. In that connection, the only function served by the Snake River is as regional base-level, toward which all vectors of ground-water flow are pointed.

Recharge takes place principally within the fractured, welded tuffs of the Miocene silicic volcanics. Littleton and Crosthwaite (1957) and Ralston and Chapman (1969) described truly prodigious rates of infiltration of rainwater and snow-melt runoff along creeks at the front of the Owyhee Upland, into fractures in the welded tuffs.

It was noted that all formations appear to dip toward the center of the Snake River Plain, at angles of 2^{O} to perhaps 8^{O}. This simple layering is complicated by relief on the original topographic surface, and is offset by numerous normal faults, most downthrown toward the valley. Additionally, certain units are recognized as being more permeable than others. For example, water wells drilled on the southern side of the Plain commonly produce water from the Miocene silicic volcanics, the Banbury Basalt, and parts of the Glenns Ferry Formation, and less commonly from the Bruneau Formation and Poison Creek Formation. The Chalk Hills Formation typically serves as an aquiclude, as do parts of the Glenns Ferry and Poison Creek Formations. The overlying Black Mesa and Tuana Gravels usually are above regional water level, as is the Snake River Group of basalts. Therefore, these units, although permeable, serve only as discontinuous channelways for infiltration of rainwater; and this is not significant, because so little rain falls directly onto their outcrop areas in the Plain, as compared to precipitation in the Owyhee Upland. This has led Rightmire et al. (1975) to conclude that recharge on the southern Snake River Plain is less than that of the northern Plain.

Thus, a relatively simple picture may be drawn, of recharge into a permeable upland front, with circulation down dip beneath the Plain. Faults cutting the dipping beds serve as vertical channels for downward movement of cold recharge water and for upward movement of thermal discharge. Discharge takes place into a stacked series of aquifers, each separated from the other by relatively impermeable beds. This is shown diagrammatically in Figure 6. The data on individual formations is summarized in Table 6, from Young and Whitehead, 1975. It should be noted that most of their data pertain to the near-surface geologic section, and that they have little or no information concerning anything older than the Owyhee Rhyolite. Therefore, they add nearly nothing to the concepts of a deep geothermal reservoir.

Idealized hydrogeologic section showing general relation of geologic units, recharge, and ground-water movement.

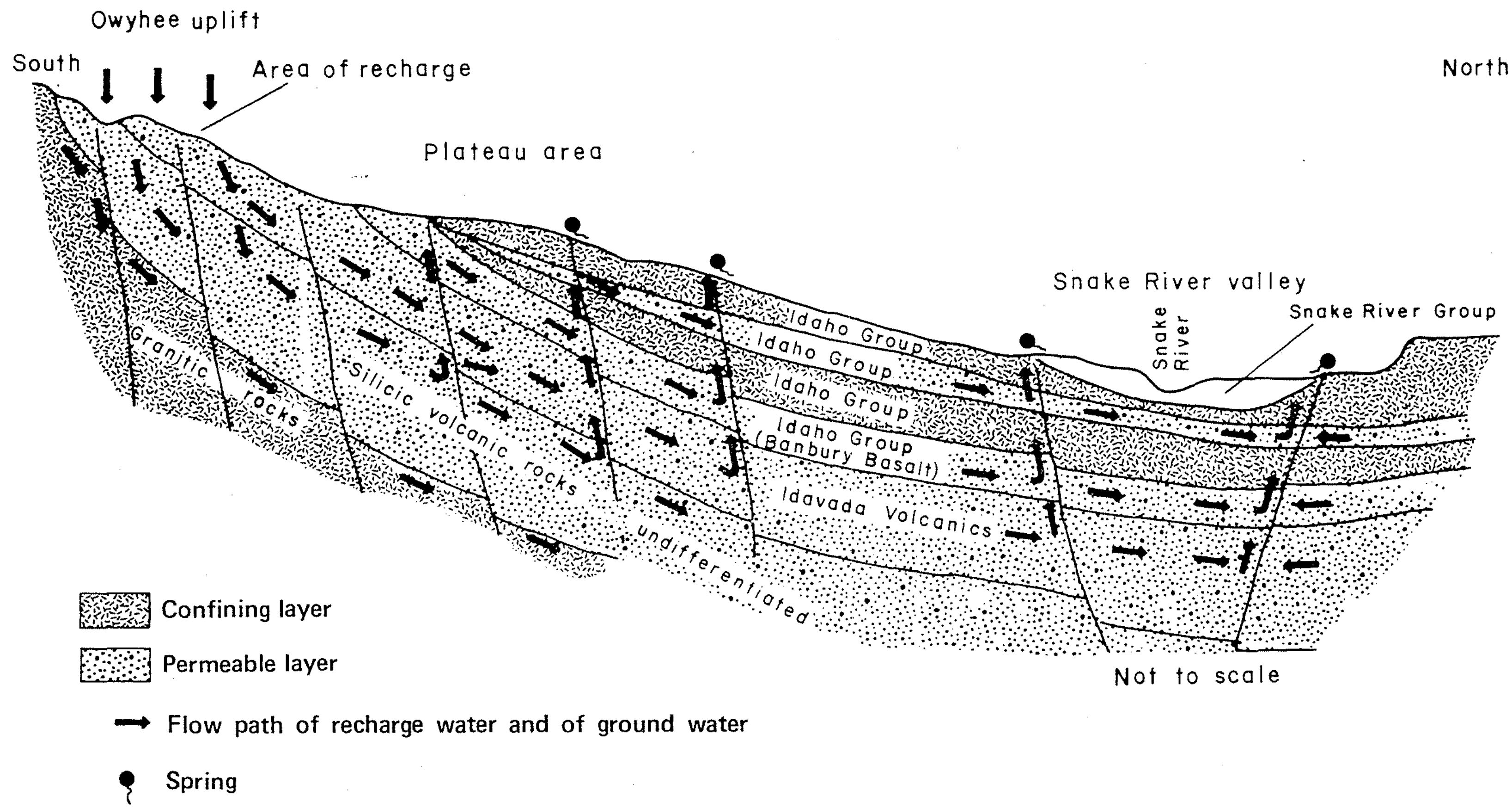


FIGURE 6.

TABLE 6.

DESCRIPTION AND WATER-BEARING CHARACTERISTICS OF GEOLOGIC UNITS

Era	Period	Epoch	Rock unit	Description[1]	Water-bearing characteristics[2]
Cenozoic	Quaternary	Holocene	Alluvium and dune sand (Qal, Qd)	Qal, alluvium; Qd, dune sand. Includes clay, silt, sand, and gravel. Chiefly fluvial and eolian deposits of Holocene age. The deposits form hills, mounds, and crescent-shaped dunes.	Surficial deposits that are not permanently saturated. Too limited in extent to be important as aquifers.
Cenozoic	Quaternary	Pleistocene	Melon Gravel of the Snake River Group (Qm)	Consists of boulders, cobbles, and pebbles in a matrix of basaltic sand. Boulders commonly 3 feet in diameter.	Surficial deposits that are not permanently saturated. Not important as aquifers.
Cenozoic	Quaternary	Pleistocene	Crowsnest Gravel of the Snake River Group (Qc)	Chiefly silicic volcanic pebbles but with abundant quartz and porphyry cobbles in places. Gravels occupy terraces about 50 feet above the Snake River.	Surficial deposits that are not permanently saturated. Not Important as aquifers.
Cenozoic	Quaternary	Pleistocene	Unnamed gravel of the Snake River Group (Qg)	Consists of pebble and cobble gravels that occupy terraces along the Bruneau River.	Surficial deposits that are not permanently saturated. Not important as aquifers.
Cenozoic	Quaternary to Tertiary	Pleistocene to Pliocene	Idaho Group, undifferentiated (QTiu)	Poorly to well-stratified fluvial and lacustrine deposits of unconsolidated to consolidated gravel, sand, silt, and clay with layers of ash and intercalated basaltic lava flows. In places exceeds 3,000 feet in thickness.	Yields to wells vary from very poor to good depending upon unit penetrated. Important as an aquifer. See descriptions for individual units below.
Cenozoic	Quaternary	Pleistocene	Black Mesa Gravel of the Idaho Group (Qp)	Consists of gravel and sand as much as 25 feet thick. Remnants of a widely preserved pediment surface. Gravel is largely reworked from older gravels and is capped by a caliche layer several feet thick.	Not important as an aquifer. In most places the unit occurs above the water table.
Cenozoic	Quaternary	Pleistocene	Bruneau Formation of the Idaho Group (Qbs, Qbb)	Canyon fill of undeformed, unconsolidated detrital material and interbedded basaltic lava flows associated with marginal deposits of gravel and basalt. Qbs, detrital material, dominated by massive lakebeds of white-weathering fine silt, clay, diatomite, and minor amounts of silt and sand. Includes beds of ironstained pebble and cobble gravel; Qbb, basaltic lava flows, locally stained brown and yellow. Exceeds 1,000 feet in thickness. Exposed in places along the Bruneau and Snake Rivers.	Yields water to wells slowly. Important as an aquifer only to stock and domestic wells owing to the fine-grained nature of the sedimentary deposits. The basalt unit generally lies above the water table in this area.
Cenozoic	Quaternary	Pleistocene	Tuana Gravel of the Idaho Group (Qt)	Consists of pebble and cobble gravel interbedded with layers of massive brown to gray sand and silt. Includes both silicic volcanic and bouldery quartzitic debris. Capped by a caliche layer several feet thick. Total thickness of the unit is about 200 feet.	Not important as an aquifer. In most places the unit occurs above the water table.
Cenozoic	Quaternary and Tertiary	Pleistocene and Pliocene	Glenns Ferry Formation of the Idaho Group (QTg)	Basin fill of poorly consolidated detrital material and minor lava flows of olivine basalt. Includes fluvial and lacustrine deposits characterized by abrupt lateral facies change. Facies include: Massive silt layers, evenly layered, thick, cemented sand beds; thin beds of dark clay, olive silt, and carbonaceous shale; ripple-marked sand and silt; granitic sand and fine pebble gravel; quartzitic cobble gravel; thin beds of silicic volcanic ash; and thicker beds of	Yields water to wells. Generally the yield is low but some wells produce as much as 3,600 gal./min. from sand zones. Important as an aquifer.

TABLE 6. Description and water-bearing characteristics of geologic units. (continued)

Era	Period	Epoch	Rock unit	Description[1]	Water-bearing characteristics[2]
				fragmental basaltic material. Maximum exposed thickness is about 2,000 feet, with the lacustrine facies composing the greatest volume.	
Cenozoic	Tertiary	Pliocene	Chalk Hills Formation of the Idaho Group (Tc, Tcb)	Basin fill of consolidated, locally indurated, clastic deposits, and minor basaltic lava flows. Tc, lake and stream deposits and volcanic ash in variegated sequences of white, pink, brown, and gray beds; Tcb, lava flows of olivine basalt about 25 feet thick. Maximum exposed thickness is about 300 feet.	Yields water slowly to wells. Important as an aquifer only to domestic and stock wells.
Cenozoic	Tertiary	Pliocene	Banbury Basalt of the Idaho Group (Tb)	Lava flows of olivine basalt interbedded locally with minor amounts of stream and lake deposits. Flows mostly vesicular and less than 15 feet thick. Includes some basaltic pyroclastic material in vent areas. Maximum thickness is about 1,000 feet.	Yields to wells range from very poor to excellent depending upon degree of alteration present in area penetrated by the well. A highly altered zone of this basaltic unit tends to be a poor aquifer, whereas the unaltered unit is a good aquifer.
Cenozoic	Tertiary	Pliocene to Miocene	Silicic volcanic rocks (Tsv)	Silicic volcanic rocks, undifferentiated. Includes Idavada Volcanics and rhyolitic rocks.	Remarks for Idavada Volcanics and rhyolitic rocks apply to this unit.
Cenozoic	Tertiary	Pliocene	Idavada Volcanics (Tiv)	Silicic latite; chiefly thick layers of devitrified welded tuff, but includes some vitric tuff and lava flows. Rhyolitic rocks occur in minor amounts. Predominantly porphyritic with phenocrysts of andesine, clinopyroxene, hyperstene, and magnetite, but with no quartz, sanidine, hornblende, or biotite. Overlies older rhyolitic and related rocks, locally exceeds 3,000 feet in thickness.	The highly jointed and fractured character of these rocks make them a good aquifer in the study area and large well yields are obtained. It is believed that these rocks serve to transmit recharge-water to the area and thence upward to overlying units.
Cenozoic	Tertiary	Miocene(?)	Rhyolitic rocks (Tv)	Fine- to coarse-grained extrusive rocks rich in quartz and biotite. Locally cut by mineralized fault zones. Several thousand feet are exposed in the Owyhee uplift.	Unknown; may be an important aquifer.
Mesozoic	Cretaceous	—	Intrusive rocks (Ki)	Intrusive granitic rocks of comparable age and composition to the Idaho batholith. Exposed in the southwestern part of the study area. Believed to form the basement complex.	Unknown; may be an aquifer.

[1] Modified chiefly from Malde, Powers, and Marshall (1963); and in part from Littleton and Crosthwaite (1957).

[2] Modified from Littleton and Crosthwaite (1957) and Ralston and Chapman (1969).

The depth to which circulation goes, and the potential for permeable units beneath the silicic volcanics has been a moot point. The highest temperature reported in a water well is 181° F at about 3,000 feet. Such temperatures could be attained by circulation to only 4,000 feet. However, deeper circulation is likely. Even if we assume that temperatures reach or locally exceed 200° F, the Idavada tuffs cannot be the reservoir we seek. Data from the Anschutz well suggest that permeable zones exist to at least 9,000 feet, 4,000 feet below the base of the Owyhee Rhyolite in that area. Also moot is the question which faults allow deepest circulation, and where is heated ground water brought most rapidly upward from depth. In view of the heat flow and gradient data, as well as the Anschutz logs, it is suggested that there is a regional thermal anomaly beneath the southern margin of the Plain, and that in this marginal zone deepest and highest-temperature convection is occurring.

Rightmire et al. (1975) evaluated data on stable isotopes of oxygen and hydrogen for the Bruneau - Grand View region, as part of their geothermal study of the region. They concluded that recharge probably came from some distance to the south or southeast, rather than from local rainfall on the Plain. They concluded also that at least some of this water had been in storage for a very long period. This is compatible with concepts of deep circulation after recharge from the Owyhee Upland. Concerning the shallow aquifers, they predicted rapid drawdown, on the basis of limited data. They were unable to conclude anything about the deeper circulation system especially regarding temperature or storage capacity.

It is postulated that a deep reservoir would consist of fractured and altered silicic tuffs and small intrusions, perhaps augmented by fractured and rubbly basalt flows. Shallow aquifers of this type (Banbury Basalt and Idavada tuffs) have high porosity and transmissivities. The effects of hydrothermal alteration on porosity and permeability may be adverse, especially if a widespread clay-mineral suite is developed. However, the most silicic rocks may maintain permeability.

Despite our lack of knowledge of storage capacity or rate of recharge at 3 kilometers in depth, it is a safe assumption that production through commercial geothermal wells would exceed recharge. Thus, there would be a net consumptive demand on the deep reservoir.

Hydrochemistry.

Chemical data for springs and wells are given in Table 2, taken from Young and Whitehead and older sources. There is good agreement between all the sources. The thermal wells are less homogeneous in chemical character than the thermal springs. Within certain clusters of wells, regardless of depth, higher-temperature wells contain less HCO_3 than lower-temperature wells; for other clusters this is not true. SO_4 is not always more abundant than Cl. For some wells, $SO_4 + Cl \gtrsim HCO_3 + CO_3$, which is never observed in the springs. Young and Whitehead (1975) also made several interesting observations on chemistry, which are reproduced verbatim as follows:

Chemistry of Thermal Waters

The chemical composition of the sampled thermal waters in the Bruneau-Grand View area shows that they are generally of a sodium bicarbonate type and are characterized by low chloride and high bicarbonate concentrations and a nearly neutral pH (White, 1957, p. 1649). Although most of the thermal waters in the area are classified as a sodium bicarbonate type, certain marked differences in their chemical constituents serve to distinguish water in the sedimentary-rock aquifers of the Idaho Group (the Bruneau, Glenns Ferry, and Chalk Hills Formations) from water in the volcanic-rock aquifers (the Banbury Basalt of the Idaho Group and the Idavada Volcanics).

Thermal water from wells penetrating only the sedimentary-rock aquifers is high in dissolved-solids concentration (greater than 600 mg/l), is nearly neutral in pH, and usually contains fluoride concentrations of less than 2 mg/l. In striking contrast, water from wells penetrating the volcanic-rock aquifers is low in dissolved-solids concentration (less than 500 mg/l), high in fluoride concentration (usually greater than 8 mg/l), and is alkaline (pH greater than 8.5).

Chloride concentrations range from 2.7 to 79 mg/l in the thermal waters sampled. Chloride concentrations for water from the volcanic-rock aquifers were less than 20 mg/l and only slightly higher for most water issuing from the sedimentary-rock aquifers. Generally, sulfate concentrations were much higher in water from the volcanic-rock aquifers than in water from the sedimentary-rock aquifers. However, marked exceptions to this were noted in a few samples from shallow wells that were near the Snake River.

The reason for the low chloride, high fluoride, and high sulfate concentrations in the thermal water from the volcanic-rock aquifers is not understood. However, even though this water has distinct characteristics, it is not unlike other thermal water found in Idaho. As shown below, the chemical similarities of water from the volcanic-rock aquifers and thermal water from the Idaho batholith (which also contains low chloride and high fluoride and sulfate concentrations) is noteworthy

(Young and Mitchell, 1973). This similarity indicates that rocks similar in mineralogy to the granite of the Idaho batholith may lie at depth below the Bruneau-Grand View area as proposed by Schoen (1972).

	Volcanic-rock aquifers		Idaho batholith	
	well 4S-1E-34bad1	well 5S-3E-26bcb1	Sunbeam Hot Springs 11N-15E-19c1S	Vulcan Hot Springs 14N-6E-11bda1S
Temperature (°C)	75.5	83.0	76.0	87.0
Silica (mg/l)	91	110	91	120
Calcium (mg/l)	1.0	2.1	1.5	1.8
Magnesium (mg/l)	0	0	0	.1
Sodium (mg/l)	99	110	85	94
Potassium (mg/l)	.8	1.7	2.4	3
Sulfate (mg/l)	40	62	54	43
Chloride (mg/l)	13	15	12	17
Fluoride (mg/l)	13	15	15	24

(end verbatim passage).

To this should be added the observation that water from thermal springs of the Idaho batholith more closely resembles water from the Tertiary silicic volcanics than it does waters either from thermal springs of the Bruneau area or from the Banbury Basalt. This is based upon a comparison of the chemistry of waters coming only from the Banbury Basalt with waters coming only from the underlying Idavada silicic tuffs. The implication of this is that the deeper waters may be more comparable to water issuing from granite; and that these deeper waters may be in communication with granitic rocks beneath the southern part of the Plain. Recharge at the margin of the Owyhee Uplift would accomplish this. Also, the deep well in 5 S., 1 E., intercepted altered granitic rocks at about 11,000 feet in depth. This rock was age-dated at 42 m.y. (Malcolm Mossman, oral communication, 1975). Possibly it is not part of the Cretaceous batholith, but belongs to a younger intrusion. As such it might not be contiguous at depth with the batholith; however, circulation of heated water through this pluton could cause the chemical evolution noted above, because of its mineralogical similarity to rocks of the batholith.

It is again concluded tentatively that ground water circulates to depths of over 10,000 feet and comes into contact (and thermochemical equilibrium) with granitic rocks. Significant quantities of water might also be stored in the upper portions of a fractured granite. This suggestion was made by Young and Whitehead (1975); experience at the geothermal field of Roosevelt Hot Springs, Utah, offers the same conclusion.

Young and Whitehead's chemical ratios and aquifer temperatures, derived from the chemical analyses, is reproduced as Table 7, and in part plotted on Plate 3. The ranges in values are wide, as might be expected across so large an area with wells of such varying depth, and with such varied aquifer lithology.

Silica-based temperatures range from 198° to 315° F (92° to 157° C), with several of the higher values derived from the generally shallow sedimentary aquifers. This was analyzed by Young and Whitehead as reflecting equilibrium between warm water and the more-soluble amorphous form of SiO_2 in the SiO_2-rich sediments. The values derived from the deeper, volcanic units appear to be governed by quartz solubility, and therefore are more reliable. These values range from 253° to 315° F (123° to 157° C), with a definite trend toward higher values in the north, or closer to the Snake River.

There are no analyses within 6 miles of Blackwell's highest heat flow point (6S-2E-30cb). Those closest to his second highest value (7S-4E-9c) yield 273° to 279° F (134° to 137° C) consistently. Those wells bracketing the deep Anschutz well (5S-1E-13) at distances of one to 3 miles vary widely in silica geotemperature (260°, 268° and 291° F; or 127°, 131° and 143° C).

This suggests to me that waters have ascended from deeper zones into the silicic tuffs and Banbury Basalt, and either have in part re-equilibrated after long-term storage, or have been mixed with other, cooler waters.

Values obtained from the Na-K-Ca geothermometer range even more extremely than do the SiO_2 values, from 70° to 403° F (21° to 206° C). Young and Whitehead (1975) discounted values from the sedimentary rock aquifers as being unreliable due to selective solution of alkali-bearing minerals. For volcanic aquifers they stated that:

> The estimated temperatures by the Na-K-Ca method... are probably much more reliable than those for water from the sedimentary-rock aquifer, especially where these temperatures have the support of the silica geochemical thermometer.

Values in volcanic aquifers range widely and interestingly. In the Bruneau River Valley these are low (174° to 200° F, or 79° to 93° C) and very discordant with SiO_2 temperatures. Near Grand View, the discrepancy is greater, with the maximum Na-K-Ca value being 223° F (106° C), versus 291° F (143° C) for SiO_2. East of Oreana, 4 wells are discordant, and 2 are in good agreement. The latter, 3 and 4 miles northeast of the deep Anschutz well, yield 291° F (143° C) by SiO_2, and 300° and 320° F (149° and 160° C) by Na-K-Ca.

TABLE 7.

ESTIMATED AQUIFER TEMPERATURES AND CHEMICAL RATIOS FOR SELECTED SAMPLED WATERS

Well or spring identification number	Discharge (cubic feet per second)	Water temperature at surface (°C)	Aquifer temperature from geochemical thermometers (°C): a) Silica	b) Mixed water method: Temp. hot water	b) Mixed water method: Percent cold water	c) Sodium-potassium-calcium	Atomic Ratios: Sodium/Potassium Na/K	Magnesium/Calcium Mg/Ca	Sodium/Calcium Na/Ca	Chloride/Fluoride Cl/F	Chloride/Boron Cl/B	Chloride/Lithium Cl/Li	Sodium/Lithium Na/Li	Sodium/Boron Na/B	$\sqrt{\text{Calcium}}$/Sodium $\sqrt{Ca}/Na$	Molar Ratios: Calcium/Bicarbonate Ca/HCO_3	Chloride/Bicarbonate plus carbonate $Cl/(HCO_3 + CO_3)$	Chloride/Bicarbonate Cl/HCO_3	Chloride/Sulfate Cl/SO_4
3S-1E-35dac1	–	20.0	106	–	–	56	9.92	0.379	1.74	1.96	39.2	50.2	352	275	0.680	0.266	.054	0.054	0.695
4S-1E-25ccd1	0.01	30.0	148	–	–	186	18.2	.191	21.6	22.3	7.63	6.04	116	146	.059	.040	.045	.045	10.3
26abc1	.01	27.0	135	–	–	200	14.7	.355	33.5	11.6	5.09	3.44	102	151	.052	.026	.029	.029	8.15
29ccd1	3.3	70.0	127	173	64	78	213	–	145	.536	24.4	235	3,020	314	.040	.026	.171	.299	.695
30bdb1	–	16.5	108	–	–	30	4.33	.160	.417	4.82	41.2	52.8	238	186	2.64	.389	.036	.036	.610
34bad1	–	75.5	132	176	61	81	210	–	173	.536	26.4	254	2,990	311	.037	.021	.188	.311	.734
4S-2E-29dbc1	.02	28.0	137	–	–	175	23.4	.541	27.4	55.4	15.3	9.63	158	250	.050	.032	[illegible]	.053	1.56
32bcc1	.05	43.0	143	–	–	160	30.0	.199	45.1	1.05	5.19	12.8	174	70.6	.058	.023	.076	.076	7.38
5S-1E- 3aab1	–	32.0	148	–	–	192	15.2	.079	16.8	19.3	6.87	5.03	112	153	.073	.052	.039	.039	5.65
10bdd1	2.7	64.0	127	182	69	61	243	–	79.2	.464	24.8	254	3,020	294	.054	.053	.198	.355	.699
21cbc1	.81	65.0	123	169	66	72	243	–	134	.464	23.3	254	3,020	277	.041	.035	.207	.392	.699
24acd1	4.5	64.5	131	189	70	96	131	–	158	.500	28.5	137	1,510	314	.038	.020	.198	.294	.771
5S-2E- 1bbc1	.06	49.5	123	213	82	60	244	–	88.2	.572	4.44	313	2,600	36.8	.055	.056	.260	.599	5.09
2cda1	.02	36.5	131	–	–	187	19.3	.332	44.0	2.09	6.36	6.60	102	98.0	.046	.022	.064	.064	16.6
5bcd1	.17	42.5	143	–	–	149	38.1	.349	50.3	1.25	6.16	15.7	181	71.3	.055	.036	.115	.154	5.58
13ada1	.01	23.0	143	–	–	197	15.8	.330	34.9	10.7	7.63	7.07	94.6	102	.050	.026	.067	.067	21.2
5S-3E-14cbb1	.14	58.5	126	196	74	62	193	–	66.1	.419	4.99	352	2,750	38.9	.062	.055	.285	.469	4.06
15cba1	.01	15.0	153	–	–	171	23.8	.427	22.2	14.8	9.99	6.41	76.8	120	.061	.038	.070	.070	15.1
20ada1	–	60.0	143	242	79	73	206	.150	135	.423	5.87	–	–	51.3	.045	.062	.290	.956	5.29
20bbb1	.01	27.0	143	–	–	169	20.6	.153	9.55	32.3	11.6	8.04	95.1	137	.102	.091	.073	.073	10.1
22aad1	.01	25.0	157	–	–	170	23.6	.295	22.9	29.1	2.28	7.83	79.4	98.0	.063	.042	.096	.096	21.5
25bbb1	.01	18.0	122	–	–	168	21.3	.478	11.6	75.0	10.7	5.83	64.2	118	.099	.087	.091	.091	11.5
26bcb1	–	83.0	143	196	61	91	110	–	91.3	.536	8.03	73.4	830	90.8	.048	.145	.296	1.17	.546
26bcb2	–	67.0	137	208	72	95	125	.110	128	.536	8.32	97.9	1,110	94.1	.040	.065	.284	.738	.529
27bdd1	–	60.0	118	170	69	76	157	.110	96.5	.429	6.25	–	–	47.1	.054	.059	.285	.464	3.20
28bcc1	–	65.0	136	208	73	106	127	–	211	.383	7.38	147	1,460	73.6	.033	.045	.271	.956	3.46
35ccc1	–	71.5	137	202	68	75	170	–	79.2	.572	8.72	78.3	830	92.4	.033	.028	.265	.510	.502
5S-4E-34ccb1	–	27.0	134	–	–	71	11.8	.151	1.70	5.67	42.3	25.2	179	300	.403	.570	.136	.136	.169
5S-5E-33bbd1	–	22.0	92	–	–	62	41.9	1.26	3.45	44.7	50.9	42.6	223	267	.198	.308	.202	.202	.251
34ddd1	–	25.0	130	–	–	197	12.4	.682	11.4	21.4	10.5	10.7	130	128	.103	.071	.066	.066	4.52
6S-2W-14cba1S	.06	11.0	–	–	–	–	6.97	.412	2.55	33.6	64.1	–	–	129	1.05	.304	.387	.387	1.67
6S-1E-32bba1S	–	25.0	97	–	–	21	23.4	.379	1.04	22.5	214	–	–	345	1.00	.447	.287	.287	1.35
6S-3E- 2cbc1	–	62.0	137	217	75	128	72.9	–	174	.599	6.82	93.0	906	66.4	.033	.021	.235	.380	.953
2ccc1	1.6	53.0	137	244	82	146	46.8	.137	160	.567	7.23	88.1	830	68.1	.036	.015	.197	.258	1.51
4bcc1	–	48.0	143	–	–	167	29.2	–	120	.491	7.63	108	1,660	118	.042	.042	.142	.326	.591
5cac1	–	61.u	134	212	75	90	29.5	–	22.4	.473	19.7	190	1,780	185	.132	.090	.185	.214	1.10
9acc1	3.7	39.0	153	–	–	176	20.4	.046	47.0	.648	7.99	26.9	366	109	.071	.035	.104	.121	.591
11dad1	–	34.0	148	–	–	162	24.0	.088	26.8	.536	8.39	43.1	519	101	.100	.055	.122	.122	.753
6S-4E-14abc1	3.3	54.0	157	–	–	143	39.8	.033	38.4	.424	10.7	–	–	95.9	.074	.381	.343	1.63	.660
18bcc1	2.3	18.0	96	–	–	44	13.8	.131	1.14	7.04	35.1	60.0	382	224	.728	.401	.072	.072	.358
25bcc1	.20	20.0	120	–	–	92	12.4	.092	4.04	1.92	32.9	30.4	319	344	.245	.484	.187	.187	.166
35cda1	–	32.5	135	–	–	206	8.98	.036	17.8	.603	27.5	88.1	709	221	.166	.073	.161	.161	.847
6S-5E-10ddd1	.01	39.0	124	220	87	141	47.5	.190	80.5	.277	6.63	294	3,620	81.8	.049	.025	.145	.162	1.41
18ccb1	–	27.0	148	–	–	169	23.3	.042	44.7	.824	11.3	97.9	755	87.2	.072	.064	.291	.370	.869
20aab1	.01	43.5	110	150	76	151	33.4	.035	40.8	.380	5.46	66.5	664	54.5	.072	.036	.135	.148	10.4
24bca1	.01	33.5	131	–	–	141	44.4	–	58.1	.258	6.96	254	3,620	99.1	.057	.037	.131	.150	1.05
24ddb1	–	32.5	125	254	92	94	73.2	–	61.6	.236	8.83	215	2,990	123	.061	.034	.138	.149	.710
29dcc1	.01	32.5	148	–	–	161	23.5	.070	21.4	.423	11.4	41.9	375	102	.111	.092	.213	.221	.806
35cca1	–	22.0	120	–	–	73	10.7	.143	2.48	1.05	33.6	53.8	408	254	.415	.349	.114	.114	.376
6S-6E-12ccd1	–	37.0	148	–	–	178	20.4	.099	31.4	1.73	5.27	16.9	247	77.0	.064	.031	.066	.066	11.9
19ccd1	.01	38.0	130	253	90	133	51.0	–	54.0	.206	8.98	–	–	129	.068	.049	.152	.183	.594
19dbd1	–	42.0	128	223	86	91	84.1	–	71.2	.206	8.98	196	2,840	130	.059	.040	.154	.198	.806
32bdd1	.06	34.5	130	275	92	132	51.6	.053	52.9	.218	9.59	215	2,840	126	.068	.036	.135	.143	.887
6S-7E- 1acb1	.01	41.0	120	196	84	138	55.3	.141	64.8	7.55	12.6	57.8	341	81.6	.037	.017	.174	.174	41.2
1dbd1	.02	33.0	120	225	90	139	51.8	.244	53.8	13.2	12.7	70.3	343	61.9	.041	.021	.232	.232	49.6
2cdd1	.01	34.5	122	228	90	144	47.0	.142	63.1	3.95	10.1	548	3,170	58.1	.042	.017	.184	.184	45.2
8bba1	–	23.0	130	–	–	199	13.2	1.08	16.1	13.0	18.5	13.9	302	403	.077	.075	.055	.055	.154

a) Using curve A (equilibrium with quartz) Fournier and Truesdell, 1970
b) Model 1, Fournier and Truesdell, 1974
c) Fournier and Truesdell, 1973

TABLE 7. Estimated aquifer temperatures and chemical ratios for selected sampled waters. (continued)

Well or spring identification number	Discharge (cubic feet per second)	Water temperature at surface (°C)	Aquifer temperature from geochemical thermometers (°C): a) Silica	b) Mixed water method: Temp. hot water	b) Mixed water method: Percent cold water	c) Sodium-potassium-calcium	Atomic Ratios: Sodium / Potassium Na/K	Magnesium / Calcium Mg/Ca	Sodium / Calcium Na/Ca	Chloride / Fluoride Cl/F	Chloride / Boron Cl/B	Chloride / Lithium Cl/Li	Chloride / Lithium Na/Li	Sodium / Boron Na/B	$\sqrt{Calcium}$ / Sodium $\sqrt{Ca}/Na$	Molar Ratios: Calcium / Bicarbonate Ca/HCO_3	Chloride / Bicarbonate plus carbonate $Cl/(HCO_3+CO_3)$	Chloride / Bicarbonate Cl/HCO_3	Chloride / Sulfate Cl/SO_4
7S-3E- 4acd1	1.6	34.0	134	–	–	78	3.51	0.090	1.06	2.27	27.5	28.2	187	182	0.837	0.363	0.058	0.058	0.452
7S-4E- 1acc1	1.7	40.0	127	226	87	182	13.5	.048	13.4	.475	26.2	–	–	249	.180	.133	.166	.187	1.14
3abd1	3.7	42.0	134	250	88	194	10.6	.028	13.8	.524	22.1	170	1,390	180	.190	.100	.161	.170	.982
5cca1	4.1	30.0	135	–	–	85	6.12	.046	1.88	2.33	22.1	28.4	272	212	.476	.494	.097	.097	.151
10bdb1	1.1	37.5	137	–	–	198	9.63	.023	11.4	.490	23.9	168	1,420	201	.207	.106	.140	.140	.809
11cbc1	4.4	36.0	137	–	–	92	8.50	.031	4.90	.608	28.4	91.0	679	212	.323	.216	.142	.142	.700
12bdd1	–	43.0	135	250	87	185	12.4	.023	12.7	.517	25.6	–	–	240	.188	.110	.149	.149	1.12
13bcc1	3.3	39.0	134	267	90	193	10.7	.045	11.7	.476	24.4	157	1,480	231	.200	.125	.145	.155	.903
13dcd1	2.8	40.0	136	270	90	186	12.0	.019	10.6	.438	30.5	176	1,600	277	.202	.166	.170	.194	1.07
7S-4E-14abc1	3.7	39.0	135	275	90	196	9.81	.023	10.9	.723	22.5	159	1,360	193	.217	.105	.134	.134	1.02
15acd1	5.9	33.0	137	–	–	88	8.25	.057	3.64	.379	27.5	64.6	483	205	.363	.272	.139	.139	.414
23cbb1	7.3	38.5	135	275	90	188	11.3	.027	8.43	.589					.217	.169	.166	.175	.690
25adc1	6.1	36.5	137	–	–	93	6.64	.024	6.41	.393	28.0	215	755	98.0	.379	.101	.175	.175	.857
26bcb1	2.9	31.0	132	–	–	94	9.22	.051	6.03	.784	33.3	235	1,360	193	.291	.192	.200	.200	1.23
27bcc1	3.1	27.0	123	–	–	87	10.2	.134	5.01	1.14	38.8	274	1,390	197	.316	.223	.221	.221	1.13
7S-5E- 5dbc1	.05	32.0	122	248	92	175	17.6	.037	25.0	.621	17.1	186	1,900	174	.121	.077	.180	.188	.447
7abb1	7.8	39.0	132	256	89	187	11.7	.039	10.5	.541	33.2	192	1,540	267	.208	.135	.176	.176	1.30
8ccc1	1.8	40.0	132	244	88	183	13.6	.028	16.3	.453	25.8	–	–	235	.160	.111	.174	.198	1.11
9ddd1	2.0	40.0	131	246	88	90	12.5	.069	7.26	.438	45.8	176	1,510	392	.252	.215	.165	.182	1.13
13aac1	.78	25.0	133	–	–	91	9.43	.211	4.94	.536	25.4	97.9	770	200	.302	.274	.172	.172	.452
13cbb1	–	36.0	127	247	90	187	12.0	–	13.0	.438	21.1	176	1,510	181	.188	.119	.170	.180	1.07
16acd1	–	39.5	132	250	89	180	14.7	.025	13.8	.328	33.2	192	1,600	293	.177	.124	.179	.179	1.11
19ccc1	2.6	36.5	134	–	–	186	12.3	.021	12.5	.491	30.5	215	1,660	235	.183	.114	.184	.184	1.03
28acd1	2.5	34.0	134	–	–	199	9.61	.060	10.9	.463	26.4	–	–	222	.201	.130	.169	.169	.894

However, the most curious values are obtained in Little Valley and vicinity. Na-K-Ca values here are bimodal, one group of 6 being 189° to 201° F (87° to 94° C), and the other group of 11 being 356° to 390° F (180° to 199° C). This compares to SiO_2 temperatures of 253° to 279° F (123° to 137° C). There is no concordance. Yet, the high Na-K-Ca values are attractive, and are in areas of high gradient in volcanic aquifers (9 of 17 are greater than 4.0° F per 100 feet, and only 5 of 17 are below the regional "average" of about 3.5° F per 100 feet). Blackwell's station of 3.3 HFU (6.1° F per 100 feet) is located just to the west.

Young and Whitehead (1975) also prepared temperature estimates based upon mixing models of cool and thermal waters. Correctly, they disregarded those from sedimentary aquifers where amorphous SiO_2 had contaminated the SiO_2 temperature. Therefore, they arbitrarily eliminated almost all values above 428° F (220° C) on the assumption of presence of amorphous silica; this was done even from volcanic aquifers, despite the fact that the mixing models for:

> "Water flowing from the volcanic-rock aquifers are probably more sound, as the silica content of this water is probably in equilibrium with quartz."

For wells intercepting the Tertiary silicic volcanics, mixed-water models yield temperatures of 338° to 527° F (170° to 275° C), with assumptions of 61 to 92% cold water. Some of these values may be too high. But it is interesting to note that 4 of the highest values are located in the Little Valley high-gradient zone; and that values near the Anschutz deep well are 356° and 372° F (182° and 189° C).

From the above data, Young and Whitehead (1975) concluded that:

> "Aquifer temperatures in the Bruneau-Grand View area were estimated at and probably do not exceed 150° C (302°F), except where the sampled water at the surface is of mixed origin; here, maximum temperatures at depth probably do not exceed 220° C (428° F)."

The following range of temperatures is obtained from the geochemical indicators in the volcanic aquifers, and especially from the deeper silicic volcanics:

Mixed waters (80 - 92%)	343° - 527° F (173° - 275° C)
High range Na-K-Ca	289° - 390° F (143° - 199° C)
SiO_2	244° - 314° F (118° - 157° C)
Low range Na-K-Ca	142° - 223° F (61° - 106° C)

The observed hydrologic patterns supports the idea of mixing in shallow aquifers. Mixing would lower the SiO_2 temperature more sharply than the Na-K-Ca temperature, because the diluting water would likely be poor in SiO_2, but might have appreciable alkali in solution. Assumptions of up to 90 percent dilution seem excessive, although significant dilution may have occurred. The low range of Na-K-Ca temperatures are of two types: increased Ca relative to Na, and depleted K relative to Na (see Table 8). Those in the northern area are with only one possible exception of the latter type, depleted in K relative to Na. However, the Na: K ratio (also a geothermometer, in certain environments) does not vary significantly amongst the high and low series of Na-K-Ca temperatures in Little Valley and near Bruneau Hot Springs. That is, Ca is overabundant. Na: K temperatures all are in the 392°F (200° C) range in this area. The overabundance of Ca probably reflects dilution by cool calcium bicarbonate waters. Elsewhere, the picture is more complex; but along the northwest-trending line from Bruneau Hot Springs through Little Valley, towards Oreana, mixing with cool bicarbonate waters appears definite. From this we can conclude that the upper range of Na-K-Ca values is more correct than the lower range.

Dilution would lower the SiO_2 temperatures significantly. Qualitatively, it is likely that an equilibrium point for the SiO_2 and Na-K-Ca temperatures would be in the range 375° to 464° F (190° to 240° C); that is, beginning at the upper end of the Na-K-Ca values and extending into the lower range of mixed water temperatures derived by Young and Whitehead (1975) for this sub-area. Such temperatures would not be found within the silicic volcanics, but in underlying aquifers at depths of perhaps 7,000 to 11,000 feet.

This agrees closely (for qualitative assumptions) with conclusions derived from other lines of approach, and offers support for exploration targets near the southern hinge line between the Plain and Upland. Elsewhere, the ambiguous data do not clearly support temperatures over 392° F (200° C). North of the Anschutz well, temperatures of 302° - 320° F (150° - 160° C) are suggested. Near Grand View, slightly lower equilibrium temperatures are inferred. Of course, calculation of mixing models might raise these greatly, but this step is not clearly supported by the alkali ratios.

Table 8. Sodium-potassium-calcium ratios for volcanic aquifers (from Young and Whitehead, 1975)

Well location	Na: K	Na-K-Ca Temperature, °F	Na-K-Ca Temperature, °C	Na: Ca
4-1-29	213	172.4	78	145
-34	210	177.8	81	173
-2-32	30	320.0	160	45.1
5-1-10	243	141.8	61	79.2
-24	131	204.8	96	158
-2- 5	38	300.2	149	50.3
-3-14	193	143.6	62	66.1
-20	206	163.4	73	135
-26	110	195.8	91	91.3
-26	125	203.0	95	128
-27	157	168.8	76	96.5
-28	127	222.8	106	211
-35	170	167.0	75	79.2
6-3- 5	29.5	194.0*	90*	22.4
-4-14	39.8	289.4	143	38.4
7-4- 1	13.5	359.6	182	13.4
-11	8.5	197.6*	92*	4.9
-12	12.4	365.0	185	12.7
-13	10.7	379.4	193	11.7
-13	12.0	366.8	186	10.6
-14	9.8	384.8	196	10.9
-15	8.3	190.4*	88*	3.6
-23	11.3	370.4	188	8.4
-25	6.3	200.0*	93*	6.4
-26	9.2	201.2*	94*	6.0
-27	10.2	188.6*	87*	5.0
-5- 7	11.7	368.6	187	10.5
- 8	13.6	361.4	183	16.3
- 9	12.5	194.0*	90*	7.3
-13	12.0	368.6	187	13.0
-16	14.7	356.0	180	13.8
-19	12.2	366.8	186	12.5
-28	9.6	390.2	199	10.9
-6-22	10.8	174.2*	79*	4.4
-23	12.5	200.0*	93*	7.7
-26	8.9	176.0*	80*	3.9

* Wells for which lowered T°C Na-K-Ca appears to be caused by an excess of Ca in solution.

GRAVITY, AEROMAGNETIC AND SEISMIC SURVEYS

Regional gravity and aeromagnetic surveys have been made across large parts of southern Idaho. Gravity maps have been published by Mabey and Peterson, 1975; Mabey, Peterson and Wilson, 1974; Hill, 1963; and Bonini, 1963. Aeromagnetic maps have been issued in open-file form by the U. S. Geological Survey. Mabey et al. (1975) interpreted gravity and magnetic data for the Plain.

The gravity data all have been prepared as simple Bouguer maps. That is, no terrain-corrected data are available. For the relatively flat center of the Plain this is less important. For the hilly margins of the Plain, terrain-corrected values may be a few milligals different than simple Bouguer values.

Magnetic maps show total magnetic intensity, in gammas. One map (U. S. Geological Survey, 1971) appeared in Young and Whitehead (1975). Another map (U. S. Geological Survey, 1974) has been processed to residual magnetic intensity by removal of a regional magnetic gradient (Plate 4).

Considerable work remains to be done with each type of survey. Gravity data not only could be terrain-corrected, but could then be modeled to fit various geometric shapes conceived of as the cause of complete Bouguer anomalies. Such residual maps might show deep crustal structure more clearly. Similarly, residual intensity maps might be adjusted for assumed thicknesses of crustal rocks of various magnetic susceptibilities and intensities. Also, studies of remanent magnetism and polarity effects could help separate deep-seated structural features from near-surface ones.

At this stage, it is recognized that the Snake River Plain is characterized by a series of at least 3 linear, northwest-trending, en echelon Bouguer gravity highs; and that the granitic highlands to the north and south are characterized by regional, nearly circular Bouguer gravity lows. One impressive high, at least 30 miles long and with closure of 6 milligals, extends from southeast of Bruneau River Valley to northwest of Little Valley (see Plate 5). On its north there is a series of small amplitude lows. Elsewhere, the regional gradient dominates, from low on the south to high in the north. There is at least 60 milligals of relief in an 18-mile-wide zone from south to north.

Packing of the isogals is intense in several places, suggesting sharp and abrupt discontinuities in rock density. These probably are faults, separating the granitic Owyhee Upland from the Plain, and within the Plain representing successive fault-bounded blocks.

The only indications of divergence from the northwest pattern are at several small northerly flexures in the isogals. These may reflect north-northwest-trending fractures inferred from the regional stress field described earlier. The only north-south or northeast flexures are at Bruneau Hot Springs (7 S., 6 E.) and at the west end of Little Valley (7 S., 4 E).

The dense, elongate, northwest-trending masses are believed to be mafic igneous bodies. These may be thick sections of Miocene basalt lava buried beneath younger cover (mabey et al., 1975); or they may be diabase-gabbro intrusions, possibly as young as Pliocene or Pleistocene in age. The geometry of fault-bounded blocks of basalt lava is not easy to construct and keep in conformity with data from geology and deep drill holes. For example, the Anschutz well penetrated a thousand feet of middle Miocene basalts atop 5,000 feet of rhyolite, dacite, latite and basalt, beneath the Idavada tuffs. This apparently has no expression in the gravity data. An assumed basalt section near Little Valley must be very thick, to be expressed so clearly in the gravity values.

The magnetic maps show a series of linear to circular highs and lows, with a very prominent magnetic high trending N. 45^{o} to 60^{o} W. across an area some 6 or 8 miles south of the gravity high. The residual magnetic map differs in many particulars from the magnetic intensity map, except for the linear high. Its length (35 miles of closure), amplitude (260 gammas) and continuity make it the most impressive feature of the map.

Values within the granitic Upland are lower than anything in the Plain, suggesting that the bulk of material underlying the Plain is magnetically more intense than granodiorite or quartz monzonite. Of course, basalt and gabbro would be more magnetic. Therefore, these mafic volcanic rocks are nominated as the cause of the magnetic highs, and of the generally higher intensity over the Plain relative to the Upland.

Lacking data on inclination and polarity, it is difficult to speculate effectively on structure from the magnetic intensities. Some near-circular highs north of Snake River may be Quaternary basaltic eruptive centers. The general texture of lows and highs may reflect the relative thickness of the non-magnetic sedimentary section in the Plain. The intense gradients bordering the major high, including one trending northeast-southwest through 8 S., 2 E., may be fault controlled.

Finally, the separation between the gravity and magnetic highs may be more apparent than real, and may partly be due to polarity effects on a tilted magnetic body. That is, the body giving rise to the magnetic anomaly may be essentially coincident with the body giving rise to the gravity anomaly. If this is so, a dense, magnetic, linear intrusion, such as gabbro or diabase, is suggested. Its depth is unknown, although Hill (1963) suggested an optimum 3.5-mile-depth to bodies of excess mass, and Bonini proposed that a body denser than granite by 0.1 to 0.3 gm/cm^2 would need to be 3 to 7 miles thick, beneath the Plain. This could take the form of upwelled mantle tholeiite, injected into rifts within and at the margins of the Snake River Plain.

Mabey et al. (1975) pointed out the difference in gravity and magnetic signatures between the eastern and western Plain. The former shows evidence of deep structure, whereas no older structures are visible beneath the volcanic cover of the western Plain. This led to speculation of a thinned upper crust, underlain at 2 kilometers by a "thick layer of dense magnetic rock." Probably it is not the Columbia River Group of basalts, as Mabey et al. suggested, and instead may be an intrusion of large size. The presence of boundary faults also was noted.

Chemical and nuclear explosions in the early 1960s, mostly at the Nevada Test Site, provided data on crustal structure of southwestern Idaho. One of the recording stations (Strike) was at the C. J. Strike dam, at the junction of the Bruneau and Snake Rivers. The seismic records were interpreted by Pakiser (1963), Hill and Pakiser (1967), and more thoughtfully by Prodehl (1970).

When compared to the thin-crusted Basin and Range province, the Snake River Plain exhibits a thicker total crust (see Figure 7). However, the upper or granitic layer appears to be absent beneath the Plain. The crust consists therefore of a thin, low-velocity, intermediate layer, on top of a much thicker lower crust whose velocity is approximately equal to that of the lower crust beneath the Basin and Range. It can be inferred that the granitic layer has been altered or remelted, or is absent because of rifting, and has been replaced by upward-moving mantle differentiate (the intermediate velocity layer). This is typical of flood basalt and crustal rift areas.

In the vicinity of station Strike, this intermediate-velocity material extends to within a few kilometers of the surface. The granitic upper crustal layer ends somewhere at the edge of the Plain. This is consonent with exploration results, in which altered granite of Eocene age was encountered at just over 3 kilometers in depth in the Anschutz well, and with gravity and magnetic data suggesting excess-mass bodies (mafic igneous rock) at depths of a few miles.

The great unknown in the interpretation of seismic refraction data is the vertical distribution of temperature beneath a given site, and its effect upon rock densities and wave velocities. If the lower

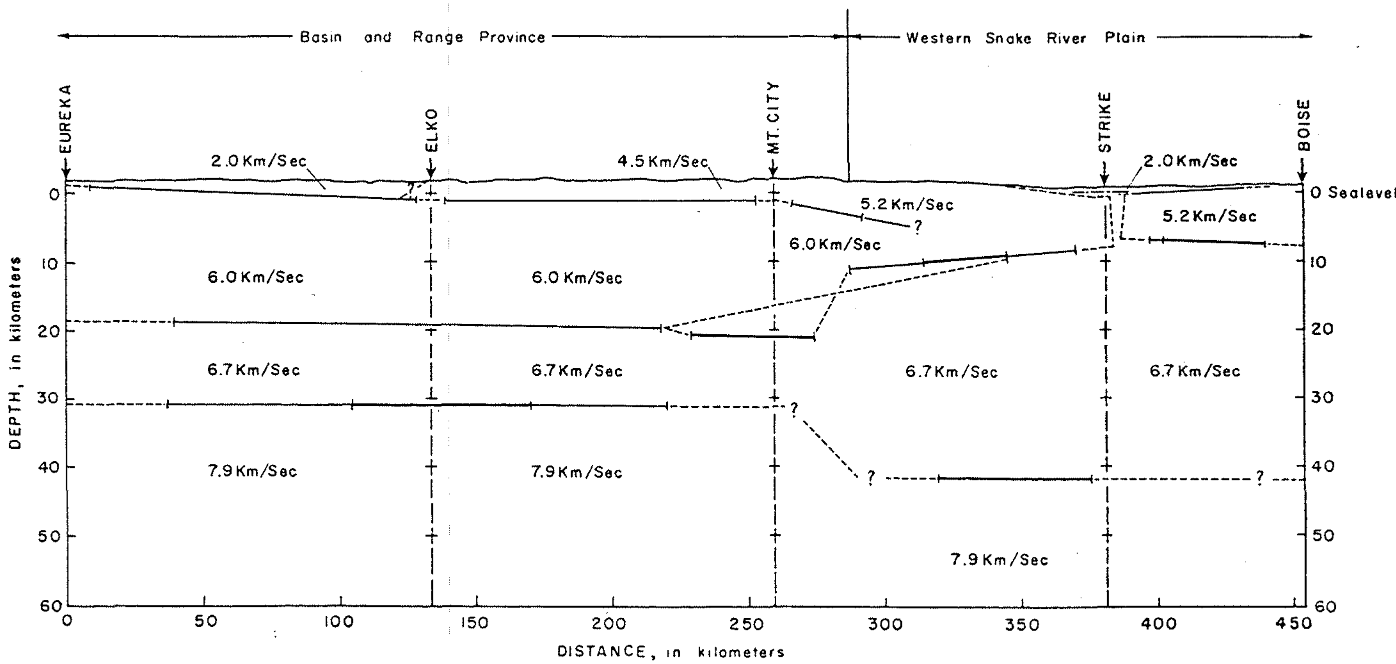


Figure 7, Crustal structure of the Snake River Plain and Basin and Range provinces, from seismic refraction profiles (From Hill and Pakiser, 1967)

crust of either (or both) the Plain and the Basin and Range has unusually high temperature (and evidence does exist to support this), the crustal structures based upon travel times of seismic waves may need to be reinterpreted. Specifically, crustal thickness may be less than assumed previously.

At present, crust beneath the Plain is calculated to be 24 miles thick, which is 3 miles less thick than in the adjacent mountains. Assumptions of higher-than-normal temperature beneath the Plain might reduce this to about 21 miles, which is closer to calculations for much of the Basin and Range.

Seismically, the Plain is quiet. This can be interpreted in two ways. First, the faults within and bounding the Plain are inactive, perhaps in response to an equilibrium reached in the regional stress field. Second, rock masses at depth may deform plastically rather than brittly. That would occur if temperatures are sufficiently high at depth to eliminate brittle inertia and cause plastic or molten flow. Even if this is true at depths of, say, 6 kilometers or deeper, it does not explain the lack of very shallow seismicity, commonly observed elsewhere.

GEOELECTRICAL SURVEYS

Data from three sets of geoelectrical surveys are available in varying degree: a reconnaissance-grade audio-magnetotelluric survey (Hoover and Tippens, 1975); a series of Schlumberger de-resistivity soundings (Jackson, 1974); and a set of potential difference measurements made on the surface and down-hole in the Anschutz deep well, along with Schlumberger down-hole induction logs (Malcolm Mossman, oral communication, 1975). There is a sharp difference in the point of forces of each survey, and therefore it is not surprising that each illuminates a different geologic section.

The AMT emphasizes illumination of shallow conductive bodies, and de-emphasizes the resistors or deep resistor-conductor sequences. Therefore, its results are most applicable to the hot-water-bearing Banbury Basalt and Tertiary silicic volcanics. Anything resistive underlying these rocks appeared as electrical basement. There was no differentiation of possible conductors within this basement.

Interestingly, at 8 Hz, which is the frequency of maximum penetration, the AMT survey outlined a closed low of 10 ohm-meters covering some 60 square miles and centered between Oreana and Grand View (Plate 6). Within this, a 4.5 ohm-meter closed low extended across 5 square miles. The Anschutz well was located within the 10 ohm-meter closure, and 3 miles south of the 4.5 ohm-meter low. At 8 Hz, resistivities were found to exceed 220 ohm-meters in one area, in Bruneau Canyon, south of the hot springs.

The low resistivity anomaly corresponds closely to a structural high in the silicic volcanics. The anomaly clearly represents hot water circulating in the fractured tuffs. These waters issue to the surface at temperatures to 181° F, and derive from greater depth, apparently via faults or via interfingered zones of lower and higher permeability. The silicic volcanics are not the geothermal reservoir sought for; therefore, this AMT survey has little practical use in exploration.

Two points are noteworthy, however. First, the apparent resistivities are significantly lower across the entire region at 8 Hz than they are at 26 Hz or shallow frequencies. A corollary is that apparent resistivities generally are lower when viewed along a north-south line than when viewed east-west. This structural anisotropy is not explained by Hoover and Tippens (1975). Second, the reconnaissance nature of the survey does not provide adequate data for points of interest south of the principal hot-water wells. Either despite or because of this lack of data, there is a dense packing of iso-resistivity lines near the southern margin of the Plain, along a northwest-trending line passing from 5 S., 1 E. to the southeast corner of 7 S., 5 E. This may be a major structural boundary (see Figure 4 a).

The Schlumberger soundings (Jackson, 1974) were able to define electrical basement along 2 profiles: one east-west, parallel to and south of the Snake River; the other north-south, through the heart of the AMT anomaly. Neither profile explored the northwest-trending line of high heat flows, thermal gradients, and chemical anomalies, although the north-south line did intersect it at its southern end (Plate 7). Therefore, the Schlumberger survey is of limited value. The Schlumberger sounding closest to the Anschutz well (#20) encountered electrical basement at about 1,500 meters (4,900 feet). This agrees very well with the lithologic log, where basalt (possibly correlative with the Columbia River Group) was entered at 4,756 feet. However, nothing was learned of conditions within electrical basement.

At one or two places at the eastern end of the east-west Schlumberger traverse, electrical basement was not encountered. Electrical basement became progressively shallower to the south along the north-south traverse, suggesting simple step faulting, down to the north.

Jackson (1974) concluded that the hot water ascended from deep but unknown sources, probably along these faults.

Potential difference measurements were made in the Anschutz deep well using the drill rods as one electrode. Measurements were taken at approximately 5,000, 8,000 and 11,000 feet, and integrated with data from the down-hole Schlumberger induction logs. A low resistivity section was observed from about 2,500 to nearly 5,000 feet. This, of course, was the rhyolite section. From there to nearly 6,000 feet was a strong resistor, the basalt flows. Underlying this to hole bottom was a section of variable resistivity including numerous zones of low resistivity. Between 7,500 and 9,700 feet these often corresponded to lost circulation intervals, including those yielding the 4 temperature measurements above 392^{o}F (200^{o}C). One permeable zone about 350 feet thick was recognized.

It is very doubtful that these deeper low resistivity zones were penetrated by any of the surface geoelectrical techniques. Jackson (1974) and Hoover and Tippens (1975) stressed the need for down-hole logs to evaluate their work, especially the nature of electrical basement. Lacking this, it is concluded that there may be several intervals of low resistivity elsewhere within the electrical basement, similar to or even better than those observed in the Anschutz well.

ANALYSIS AND EVALUATION

Regional Analysis.

Regionally, the western Snake River Plain has been shown to exhibit youthful basaltic volcanism, high heat flow, high temperature gradients in shallow wells, widespread distribution of thermal water, and chemical indicators suggestive of high temperatures at depths of 2 kilometers or so.

Additionally, it has been shown that granitic crust may be absent, or present only in small discontinuous patches, beneath the Plain; and that a Tertiary and Quaternary volcanic and sedimentary section may extend to 3 kilometers or more in depth. Within this young section, shallow thermal aquifers are recognized in the Idaho Group, and another thermal aquifer is present in the underlying Miocene silicic tuffs. It is thought likely that high-capacity aquifers are present in the middle Miocene basalt lavas and possibly in Miocene rhyolite, latite and basalt flows, tuffs and stocks beneath the Miocene silicic Volcanics.

Further, it is thought that Miocene to Pleistocene mafic intrusions underlie parts of the Plain, especially in areas of major-positive gravity and magnetic anomalies. These are distributed widely across the western Plain, but in the Bruneau-Oreana region are most extensive and intense along the supposed margin between the Plain and the Owyhee Upland.

The most impressive heat flow, gradient and chemical anomalies lie along a northwest-trending line that corresponds broadly to the axis of the gravity and magnetic anomalies. Therefore, it is considered reasonable that ground water recharging into the subsurface in this area circulates through a cover of at least 3 kilometers of volcanic and volcaniclastic rock before entering the heated mafic intrusions.

In its simplest form, the geothermal system would consist of circulation of cool ground water to several kilometers, followed by heating of the water, ascension along faults, and storage in permeable horizons. The base depth of such circulation is unknown. The existance of faults as two-way channels is inferred, as is the presence of permeable aquifers of significant lateral extent and thickness beneath the middle Miocene basalts, on the basis of chemical parameters and from results of the Anschutz drill hole.

It is also noted that less-favorable gradients, heat flows and chemical indicators are observed to the north, closer to the Snake River. Similarly, on the basis of limited data, the Owyhee Upland appears less attractive. (The Upland is underlain by granite, which offers less potential for a reservoir.)

The Anschutz deep well lies midway between the high gradient northwest-trending belt and the numerous thermal wells near the Snake River. It has been shown to exhibit high temperature and possibly significant permeability at depth, in an area where chemical indicators do not project temperatures beyond 302°F (150° C) and where gradients are transitional between "background" (2.8° to 3.5° F per 100 feet) and very high (over 5° F per 100 feet). Further, the zones of high temperature and potential permeability are within the so-called electrical basement of Hoover and Tippens (1975) and Jackson (1974).

South of the zone of highest gradient and heat flow, granitic basement appears to shallow rapidly, such that within a horizontal distance of no more than 10 miles the granite has risen from a depth of over 2 miles to crop out at the surface. Gradients vary from strong to poor in this zone. The likelihood of encountering granite at shallow depth makes this a less-attractive area for prospecting.

Within the Plain as a whole, gradients of perhaps 3° F per 100 feet may be sustained to depths of 3 kilometers or more. This would equate to 350° F temperatures at 10,000 feet. Along the most favorable axis, this gradient is expected to increase to 4° F and perhaps locally to in excess of 5° F per 100 feet, such that temperatures of 450° F to over 550° F might be encountered at 10,000 feet. Deep circulation along hinge-line faults into a region of still-hot mafic intrusions is proposed as the cause of the temperature anomaly. Reservoir is postulated to be present in either the middle Miocene basalt sequence or in the underlying suite of Oligocene(?)-Miocene volcanic rocks. As such, it is invisible in the existing surface resistivity work, because of the presence of strong resistors within the basalt sequence. A commercial geothermal reservoir is unlikely in the silicic volcanic rocks overlying the basalts.

Chemical indicators favor mixing of deep-seated geothermal water and meteoric recharge, probably in the silicic volcanic and overlying aquifers. Mixing models favor a temperature of over 392° F (200° C), and probably as high as 464° F (240° C) at depths of 2 to 3 kilometers. North of the favorable axis, it is difficult to arrive at an accurate temperature estimate; however, the 302° to 320° F (150° to 160° C) mentioned by Young and Whitehead agrees reasonably with an estimate based on a 3° F per 100 feet gradient.

It is extremely difficult to estimate the electric power potential of the area. Renner _et al_. (1975) estimated 3,375 cubic kilometers (805 cubic miles) of reservoir, with a stored heat content of 263 x 10^{18} calories. This figure is approximately twice the heat stored in the rocks of the Yellowstone Caldera, although based on a subsurface temperature of only 293° F (145° C). Nathanson and Muffler (1975) derived a recovery factor, e_r, for use in estimating the electric power potential of systems over 302° F (150° C) at depth, as forecast by Renner _et al_. (1975). If the recovery factor for the

Bruneau-Grand View-Oreana region is set at only one-quarter of that set for a system at temperatures of 311° - 383° F (155° - 195° C), the potential is for 1,745 MW for a century of use! The calculation is conservative, and the estimate is vast (3 times the present-day installed generating capacity at The Geysers, California). If extensive permeability is found at temperatures to 464° F (240° C) or higher, the calculation might be exceeded in actuality. Obviously, extensive exploration, including drilling of deep wells, is needed to test this concept.

Leasehold Evaluation.

From the foregoing I have drawn a zone within which geothermal targets may be more favorably located (Plate 8). Not surprisingly, this corresponds closely to the axis of high heat flow and temperature gradient in the deeper aquifers, as well as to the positive Bouguer anomaly and magnetic anomaly. It also corresponds to my estimate of the zone of highest geochemical temperatures. The Anschutz deep well is about 2 miles north of its northern boundary.

This is compared to the leasehold of Earth Power Corporation and its associates (Plate 8). In the Grand View-Oreana- region, the Earth Power Group has approximately 65 percent of its acreage within the most favorable zone, and the remaining 35 percent along its northern and, to a lesser extent, its southern margins. This acreage extends to within 4 miles to the south and southeast of the Anschutz deep well. No acreage of the Earth Power Group is within the granitic terrain of the Owyhee Upland (no reservoir), or along the Snake River.

The acreage position near Bruneau is more extensive, and as a result is more widespread. About 40 percent either is within the favorable zone, along an indefinite extension of it to the southeast, or along its margins. The remaining acreage is farther north, along the flanks of Bruneau River valley, extending to C. J. Strike dam and reservoir, and even beyond, reaching to within 2 miles of Snake River.

Much of this acreage, although placed along attractive trends, largely is devoid of confirming well data. This is so principally because irrigation wells are most abundant along the numerous river and creek valleys, where land has been acquired in fee by ranchers and farmers; the Earth Power Group largely has acquired non-competitive leases to federal acreage in the intervening rolling plains. However, a well with shallow gradient of 6.9° F per 100 feet lies a mile to the west of the acreage south of Oreana, and another with a 5.4° F gradient is just at the lease boundary. The high-gradient wells of Little Valley are on fee acreage interspersed with the federal acreage leased by Earth Power Corporation and its associates.

Taken overall, therefore, at least half of the acreage is placed strategically along what Brott and Blackwell have called the area of "best geothermal implications" (Brott et al., 1975), and with which I concur. Within this large block of acreage, carefully selected locations may be expected to yield a section of volcanic and volcaniclastic rocks as much as 3 kilometers (10,000 feet) thick. Within this section, permeability may be sought in middle Miocene basalts or, more probably, in underlying fractured and altered volcanic rocks of varying provenance. Temperature gradients of a minimum of 4° F per 100 feet may be expected. These gradients would yield temperatures of 450° F at 3 kilometers. Brott et al. (1975) showed that gradients up to 5.5° F could be expected at depth along the boundary between the Plain and Upland. Therefore, a 4° F gradient may be conservative.

Continuing southward beyond the favorable zone, granitic basement can be expected to be found at shallower depths. Reservoir remains questionable in such rocks. Therefore, although the zone of highest gradients extends southward, no additional leasing is recommended.

The block of acreage along the Bruneau River may have lower prospective value. Most shallow gradients and geochemical temperatures were determined in the sedimentary aquifers of the Idaho Group, and thus are suspect as being non-representative of deeper conditions. This does not preclude high temperatures and adequate permeability at depth beneath the Idavada silicic tuffs. However, conditions to the south seem more favorable on various grounds. The northern acreage should be held in abeyance until the southern block has been explored. If a discovery is made on the southern block in Little Valley or near Bruneau, exploration might then proceed northward.

Exploration should begin in the southern block of acreage, along the favorable zone, at once.

Competitive Position.

It is of strong interest that the Castle Creek K.G.R.A., as established by the Department of the Interior, lies almost entirely north of the more favorable zone: of some 80,000 acres, only 6,000 (8 percent) is within the zone. This probably arises from selection of the 10 ohm-meter contour in the shallow AMT survey as the basis for creation of the K.G.R.A. I consider this to have been unrealistic.

The most attractive lease units within the K.G.R.A. were acquired by Dow Chemical Company and Phillips Petroleum Company by competitive bids. Not surprisingly, the lease unit immediately to the north was acquired by The Anschutz Corporation, as their deep well was located on public land within that unit. The prices paid by these 3 companies (Table 9) may be considered when attempting to evaluate the more favorably viewed area to the south.

The smaller Bruneau K.G.R.A. lies half within the projected extension of the favorable zone. It is essentially surrounded by lands leased by the Earth Power Group (Table 10).

A birds-of-prey sanctuary may be established along the Snake River in this region. Fortunately, nearly all of the study zone for this sanctuary is well to the north of the area of interest for geothermal resources. However, the zone impinges upon approximately 1,000 acres of leases of the Earth Power Group south of Grand View and upon perhaps 3,000 acres in the northern end of the Bruneau River valley. Other companies holding federal applications were less fortunate, having larger fractions of their applications within the sanctuary study zone.

Competitive interest has quickened significantly since late 1973. At the time of the January 1974 open filing for non-competitive federal leases, only the Earth Power Group, Union Oil Company and Phillips Petroleum Company submitted applications. The Anschutz Corporation previously had acquired much of the fee acreage in lease. Since January 1974, applications for federal leases have been submitted by ARCO, Dow and Geothermal Resources International (GRI), as well as by Phillips, the Earth Power Group, and Anschutz. Gulf Oil Company has acquired fee leases in the area, also. Distribution of lease position, K.G.R.A.s, and the sanctuary study area is shown on Plate 8.

ARCO has a solid lease block located within and south of an extension of the most favorable zone in the Bruneau Canyon area. The Earth Power Group has acreage abutting ARCO. Gulf's acreage is scattered and small, and is mostly north of the favorable zone. However, they hold one small block in Little Valley that is in the zone, and another at the southern margin of the zone, south of Grand View. Dow's acreage is in 2 areas; one is coherent, sizeable, and attractively placed within the zone south of Oreana; the other is composed of small fragments, within and north of the zone near Bruneau. Phillips has acreage within the K.G.R.A., part of which seems well placed and attractive. Union's holdings are small and scattered in the Grand View area. GRI bought leases within the K.G.R.A., at and north of what might be described as the northwest extension of the attractive zone.

The Anschutz Corporation sold its geothermal holdings to Occidental Petroleum Corporation in spring of 1976. The Occidental leases are mostly fee land, but include federal lands within the K.G.R.A. and adjacent to it on the west, south and southeast. Much of the leasehold lies within the sanctuary study area; these federal applications have not been acted upon. Occidental now holds the lease to the site of the deep well, as well as acreage scattered from the

Table 9. Results of the Castle Creek and Bruneau K.G.R.A. Lease Sales.

Bruneau K.G.R.A. 6/19/75 Total 2,500 acres in 2 Tracts

Tract #	Size, acres	Bids Received	Amount, $	Amount/acre, $
1	1,160.00	The Anschutz Corporation	2,470.80	2.13*
2	1,440.00	The Anschutz Corporation	3,067.20	2.13*
		Total	$5,538.00	$2.13 average

Castle Creek K.G.R.A. 11/03/75 Total 20,923.68 acres in 9 Tracts

Tract #	Size, acres	Bids Received	Amount, $	Amount/acre, $
1	2,492.00	Nancy P. Anschutz	2,815.96	2.13*
2	2,353.15	Geothermal Resources Int.	7,060.00	3.00*
		Nancy P. Anschutz	2,659.06	1.13
3	2,475.29	Nancy P. Anschutz	20,025.10	8.09*
		Geothermal Resources Int.	7,500.00	3.03
		Phillips Petroleum Co.	6,757.54	2.73
4	1,720.00	The Anschutz Corporation	61,232.00	35.60*
		Geothermal Resources Int.	5,160.00	3.00
5	2,080.00	Dow Chemical Company	9,360.00	4.50*
		Phillips Petroleum Co.	8,112.00	3.90
		Geothermal Resources Int.	6,240.00	3.00
		Nancy P. Anschutz	2,350.40	1.13
6	2,480.00	Phillips Petroleum Co.	30,925.60	12.47*
		Nancy P. Anschutz	20,063.20	8.09
		Dow Chemical Company	11,160.00	4.50
		Geothermal Resources Int.	7,440.00	3.00
7	2,217.98	Nancy P. Anschutz	17,943.46	8.09*
		Geothermal Resources Int.	6,660.00	3.00
		Phillips Petroleum Co.	5,655.84	2.55
8	2,545.26	Phillips Petroleum Co.	9,570.17	3.76*
		Geothermal Resources Int.	7,650.00	3.01
		Nancy P. Anschutz	2,876.14	1.13
9	2,560.00	Anschutz Designee **	3,148.80	1.23
	18,363.68	Total High Bids	162,081.09	8.82 average

* = winning bids
** Not bid 6/19/75, reoffered as Tract 1 11/3/75.

northern Bruneau River valley to west of Oreana. In size it rivals the Earth Power Group. Several of the parcels are intermingled with Earth Power acreage.

It is not an accident that leasing began first in the area of the thermal wells near Oreana and Grand View, and the thermal springs of the Bruneau River valley, and then migrated southward. The attractive factors of high gradient and heat flow, high geochemical thermometers, and structural position have been commented on in many conferences (see, for example, Brott et al., 1975) and private meetings.

Those companies that have taken sizeable positions within this southern zone are most favorably set. This includes Earth Power Corporation and its associates, as well as Dow, Phillips and Occidental, and possibly ARCO. GRI's leases may be too far north and west; Gulf's acreage is fragmented, although they do have leases to 2 interesting tracts. Union's position is weak and fragmented.

The two largest positions are those held by Earth Power and Occidental, followed at a distance by ARCO, Dow and Phillips. A large lease position is to be preferred at this time, until exploratory drilling can provide greater detail.

EXPLORATION PROGRAM

Other than the drilling of holes, very little can be done to provide information at depth. However, until deep holes can be sited, several exploratory techniques will provide useful information.

To begin with, the status of geologic mapping is poor (see Plate 1a). Careful photogeology may be able to resolve some of the confusion. Traverses should be made on the ground, to determine some of the properties (fracturing, induration, thickness, sequence) of rocks likely to be encountered at depth beneath the Idavada silicic tuffs. As these rocks are not exposed in the Plain, it will be necessary to revisit areas in the Owyhee Upland studied by Asher (1968), McIntyre (1972) and Anderson (1965). Further, these data can be integrated with lithologic data from the Anschutz deep well to permit the construction of more reliable geologic cross-sections to 3 kilometers, or possibly deeper. The work begun by Young and Whitehead (Plate 1b, cross-sections) will be valuable.

The photogeology, field geologic reconnaissance, and preparation of maps and cross-sections probably can be accomplished in 30 man-days of effort, for a total cost, including travel and report preparation, of about $9,000.

Secondly, it is likely that additional water wells remain to be sampled and inventoried in the area of optimum interest. This would involve a cancass of ranchers and farmers in the district to secure information on additional wells and permission to use them. If a well has not been pumped for several weeks, it would be possible to measure temperature gradient to depth. If a well is flowing or being pumped, or if it can be started to pump, a sample can be taken for additional chemical analysis.

The goal of this program would be to obtain data in areas now devoid of data or with only sparse information, as well as for areas with contradictory or ambiguous well data. There is no certainty, however, that this can be accomplished.

If undertaken, costs might run $7,500 for a man-month in the field, in which time perhaps 20 additional wells could be surveyed, including costs for map and report preparation.

Electrical surveys probably will be less effective in searching for a deep conductor beneath or within the resistive electric basement. This is, of course, the problem that faced Hoover and Tippens (1975) and Jackson (1974). D-C resistivity techniques probably would not be effective. AMT has limited ability to discern depth. Therefore, electromagnetic soundings (EM) appears to be the only realistic method left. EM soundings might be able to locate deep conductive layers, and certainly would be of use in exploring the base of the conductor in the Idavada tuffs. However, there is no assurance that the technique would work effectively across the entire region.

Even if it worked as planned, it would be expensive. Daily costs of more than $1,000 can be anticipated, with one or two days required per each deep sounding. A series of 20 soundings spread across the 30-mile-long zone of interest would offer fair detail, and would cost some $35,000, including mobilization, field work, interpretation and report preparation.

It has been remarked several times that gradient data are lacking for several parts of the favorable zone. This can be remedied in part by the drilling of a series of temperature gradient holes. Holes should not be located adjacent to water wells that have been or can be measured, and should be within the zone of maximum interest, on or just adjacent to leases of the Earth Power Group.

Holes should be deeper than 200 feet in this terrain, preferably reaching the Idavada tuffs or Banbury Basalt, because much of the discussion of deep gradients was based upon data from these formations (Young and Whitehead, 1975, and Plate 3 and Table 3, herein). Across the region, the depth to these units probably will be greater than 500 feet, and often greater than 1,000 feet (Plate 1b). It is unreasonable to drill gradient wells to such depth, because of cost. Therefore, estimates of cost should be based upon holes to 350 feet.

Cost per foot probably will be $20 on the average. Completion and logging might add $1,000 per hole. Therefore, $8,000 should be budgeted per hole. Five holes seems a minimum program, considering the effort that will be needed for obtaining permits to drill on public land. A minimum budget of $40,000 is recommended, with the possibility of increasing to $50,000 if needed. Prospective gradient sites are shown on Plate 8.

A total of $100 thousand has been recommended, as follows:

Geology	$ 9,000
Well survey	7,500
EM soundings	35,000
Gradient drilling	50,000
	$101,500

Not all of this is necessary. In the strictest sense, it is possible to choose a drill site on the basis of data available today. Even with additional data there will remain some uncertainties as to drill site and anticipated conditions at depth. Probably the additional gradient drilling is most useful, with the EM soundings least necessary.

It is not recommended that passive seismic surveys (ground noise, microearthquake survey) be attempted. Similarly, it is questionable where significant new data would result from additional reduction of gravity and aeromagnetic data now on hand. To my knowledge, no one has attempted active seismic refraction or reflection surveys for geothermal exploration in the Snake River Plain. Given the anticipated cost and uncertainty of result in an area of intense basalt "reflectors," it is recommended that seismic profiling not be considered at this time.

It may prove possible to trade data with other companies active in geothermal exploration in the area. Trades for additional temperature gradients in areas lacking water wells would be especially useful.

Excluding time for arranging permits or for contracting with drilling or geophysical companies, this work could be accomplished within 3 calendar months.

If it is necessary to pick the site of a deep exploratory hole without further ado, the preferred area would be in T. 6 S., R. 1 or 2 E. This region is bounded by several gradient wells of over 5^{o} F per 100 feet, and is within the zone of optimum interest structurally and on the basis of gravity and magnetic data. The Anschutz deep well is only a handful of miles to the north or northwest. An alternate area would be in Little Valley, in T. 7 S., R. 4 or 5 E. This area also exhibits high gradients and is structurally well placed. Additionally, geochemical indicators are quite attractive.

The Earth Power Group leasehold is undeniably attractive. At such time as deep drilling is planned, a series of 3 holes should be budgeted for, in order to test the extensive structure adequately.

Drilling in the Idaho Group, with the possible exception of the Banbury Basalt, should be simple and relatively inexpensive. The underlying Idavada silicic tuffs should not offer problems, despite the abundant hot water, unless there has been extensive silicification. Middle Miocene basalts would offer more difficult and slower drilling, because of both the massiveness of flow interiors and the likelihood of encountering caving rubbly zones. The underlying thick sequence of mixed lithology and provenance would offer varied drilling conditions and problems.

Probably, however, the total cost (1976 dollars) for a hole to a hypothetical depth of 8,500 feet would be about $500,000 completed, or $60 per foot, including casing and well-head apparatus. This is cheaper per foot than drilling costs in The Geysers or in parts of the Basin and Range province, but comparable to or even more expensive than drilling in the Imperial Valley.

SELECTED REFERENCES

Anderson, N. R., 1965, Upper Cenozoic Stratigraphy of the Oreana, Idaho, 15' quadrangle: unpublished Ph.D. dissertation, University of Utah.

Armstrong, R. L., 1975, The Geochronometry of Idaho: Isochron/West, no. 14, p. 1-50.

Armstrong, R. L., Leeman, W. P. and Malde, H. E., 1975, K-Ar dating, Quaternary and Neogene rocks of the Snake River Plain, Idaho: Am. Jour. Sci., v. 275, no. 3, p. 225-251.

Asher, R.R., 1968, Geology and mineral resources of a portion of the Silver City region, Owyhee County, Idaho: Idaho Bur. Mines & Geol. Pamphlet 138, 106 p.

Bonini, W. E., 1963, Gravity anomalies in Idaho: Idaho Bur. Mines & Geol. Pamphlet 132, 10 p.

Bonnichsen, B., Travers, W. B., and Citron, G., 1975, Rhyolitic volcanism and structural evolution of the Snake River Plain (abs.): Geol. Soc. Amer. Abs. Programs, v. 7, no. 5, p. 589-590.

Brott, C. A., Blackwell, D. D. and Mitchell, J. C., 1975, Heat flow studies of the Snake River Plain (abs.): Geol. Soc. Amer. Abs. Programs, v. 7, no. 5, p. 590-591.

Hill, D. P., 1963, Gravity and crustal structure in the western Snake River Plain, Idaho: Jour. Geophys. Res., v. 68, no. 20, p. 5807-5820.

Hill, D. P. and Pakiser, L. C., 1967, Seismic-refraction study of crustal structure between the Nevada Test Site and Boise, Idaho: Geol. Soc. Amer. Bull., v. 78, no. 6, p. 685-704.

Hoover, D. B. and Tippens, C. L., 1975, A reconnaissance audio-magnetotelluric survey, Bruneau-Grand View area, Idaho; <u>in</u> Part 2, Geothermal investigations in Idaho: Idaho Dept. Water Resources Bull. 30, p. 53-79.

Jackson, D. B., 1974, Report on direct current soundings over a geothermal prospect in the Bruneau-Grand View area, Idaho: U. S. Geol. Survey Open File Report 74-240, 43 p.

Lawrence, R. D., 1976, Strike-slip faulting terminates the Basin and Range province in Oregon: Geol. Soc. Amer. Bull., v. 87, no. 6, p. 846-850.

Littleton, R. T. and Crosthwaite, E. G., 1957, Ground-water geology of the Bruneau-Grand View area, Owyhee County, Idaho: U. S. Geol. Survey Water-Supply Paper 1460-D, p. 147-198.

Mabey, D. R. and Peterson, D. L., 1975, Gravity anomalies in (a) a part of the western Snake River Plain and in (b) the Bruneau-Grand View area, southwest Idaho; Figure 7 of Part 2, Geothermal investigations in Idaho: Idaho Dept. Water Resources Bull. 30.

Mabey, D. R., Peterson, D. L. and Wilson, C. W., 1974, Preliminary gravity map of southern Idaho: U. S. Geol. Survey Open File Report 74-78, scale 1:500,000.

Mabey, D. R., Peterson, D. L. and Wilson, C. W., 1975, Regional gravity and magnetic studies of the Snake River Plain (abs.): Geol. Soc. Amer. Abs. Programs, v. 7, no. 5, p. 624-625.

Malde, H. E. and Powers, H. A., 1962, Upper Cenozoic stratigraphy of western Snake River Plain, Idaho: Geol. Soc. Amer. Bull., v. 73, no. 10, p. 1197-1220.

Malde, H. E., Powers, H. A. and Marshall, C. H., 1963, Reconnaissance geologic map of west-central Snake River Plain, Idaho: U. S. Geol. Survey Misc. Geol. Inv. Map I-373.

McIntyre, D. H., 1972, Cenozoic geologic of the Reynolds Creek Experimental Watershed, Owyhee County, Idaho: Idaho Bur. Mines & Geol. Pamphlet 151, 115 p.

Nathanson, M. and Muffler, L.J.P., 1975, Geothermal resources in hydrothermal convection systems and conduction-dominated areas, <u>in</u> Assessment of geothermal resources of the United States-1975: U. S. Geol. Survey Circular 726, p. 104-121.

Pakiser, L. C., 1963, Structure of the crust and upper mantle in the western United States: Jour. Geophys. Res., v. 68, no. 20, p. 5747-5756.

Pansze, A. J., 1972, K-Ar ages of plutonism, volcanism and mineralization, Silver City region, Owyhee County, Idaho: Isochron/West, no. 4, p. 1-4.

Piper, A. M., 1924, Geology and water resources of the Bruneau River basin, Owyhee County, Idaho: Idaho Bur. Mines & Geol. Pamphlet 11, 56 p.

Prodehl, Claus, 1970, Seismic refraction study of crustal structure in the western United States: Geol. Soc. Amer. Bull., v. 81, no. 9, p. 2629-2646.

Ralston, D. R. and Chapman, S. L., 1969, Ground-water resource of northern Owyhee County, Idaho: Idaho Dept. Reclamation Water Info Bull. 14, 85 p.

Renner, J. L., White, D. E. and Williams, D. L., 1975, Hydrothermal convection systems, in Assessment of geothermal resources of the United States-1975: U. S. Geol. Survey Circular 726, p. 5-57.

Rightmire, C. T., Young, H. W. and Whitehead, R. L., 1975, Isotopic and geochemical analyses of water from the Bruneau-Grand View and Weiser areas, southwest Idaho; Part 4, Geothermal investigations in Idaho: U. S. Geol. Survey Open File Report 76-166, 53 p.

Ross, S. H., 1971, Geothermal potential of Idaho: Idaho Bur. Mines & Geol. Pamphlet 150, 72 p.

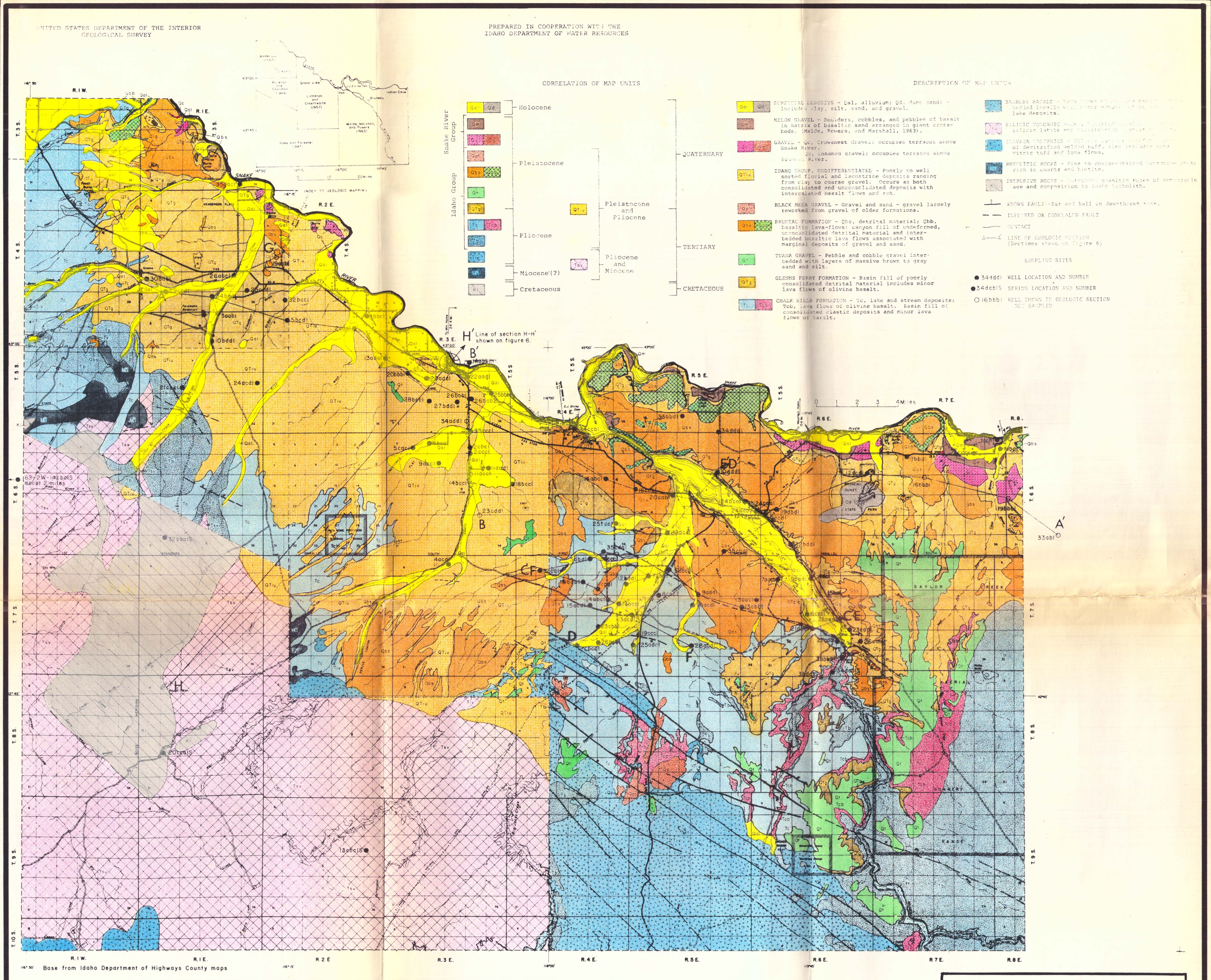
Taubeneck, W. H., 1971, Idaho batholith and its southern extension: Geol. Soc. Amer. Bull., v. 82, no. 7, p. 1899-1928.

Urban, T. C. and Diment, W. H., 1975, Heat flow on the south flank of the Snake River rift (abs.): Geol. Soc. Amer. Abs. Programs, v. 7, no. 5, p. 648.

U. S. Geological Survey, 1971, Aeromagnetic map of southwestern Idaho: Open File map, scale 1:500,000.

U. S. Geological Survey, 1974, Residual magnetic intensity map, Bruneau, Idaho: Open File Report 74-149, scale 1:62,500.

Young, H. W. and Whitehead, R. L., 1975, An evaluation of thermal water in the Bruneau-Grand View area southwest Idaho; in Part 2, Geothermal investigations in Idaho: Idaho Dept. Water Resources Bull. 30, p. 1-49.



Generalized geology, locations of sampled wells and springs, and lines of geologic sections in the Bruneau-Grand View area, southwest Idaho.

REPRODUCED DIRECTLY FROM "GEOTHERMAL INVESTIGATIONS IN IDAHO – PART 2."

EARTH POWER GROUP

TULSA, OKLAHOMA

PLATE I-A

GEOLOGIC MAP

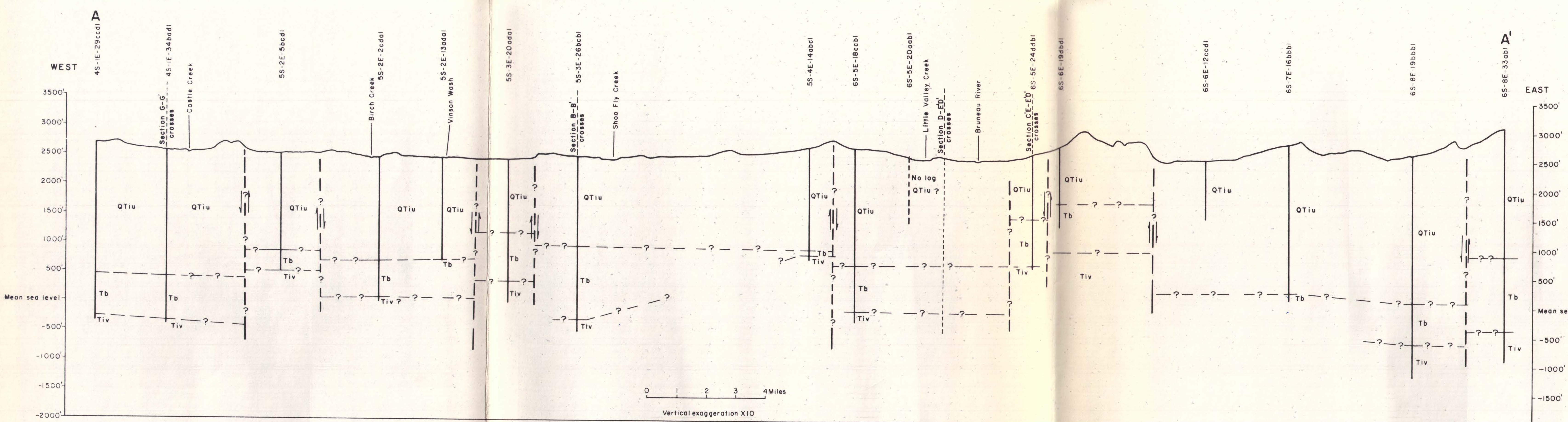
SCALE

0 1 2 3 4 5 6 Miles

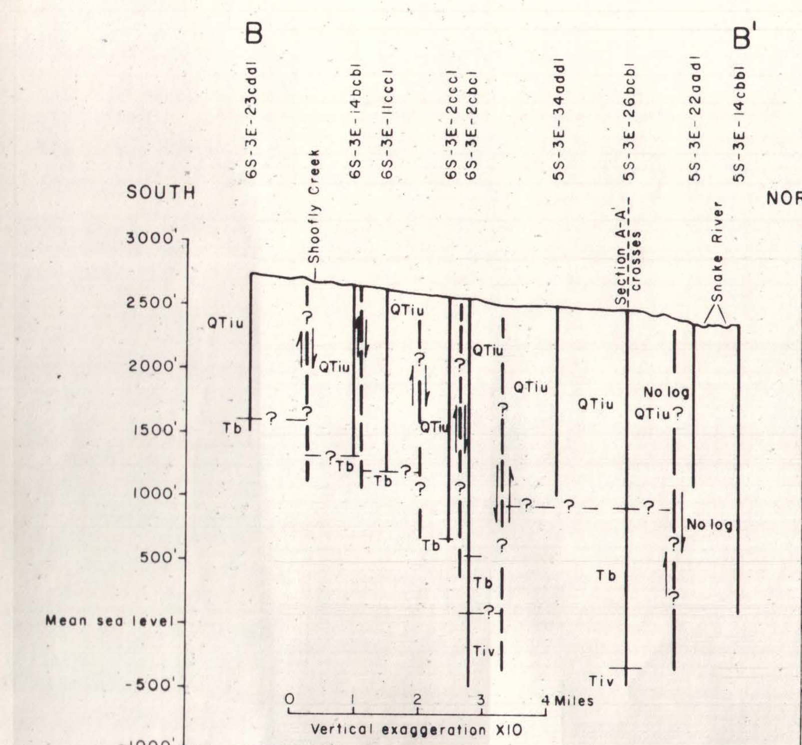
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
IDAHO DEPARTMENT OF WATER RESOURCES

PLATE 1-B



GEOLOGIC SECTION A—A'



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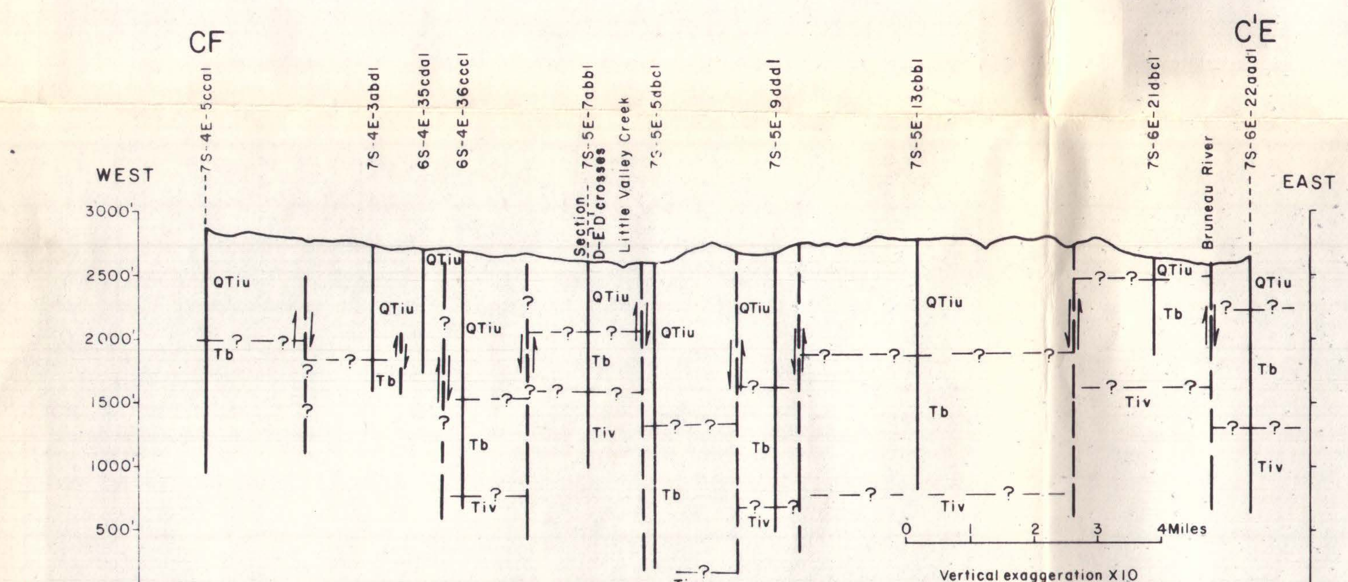
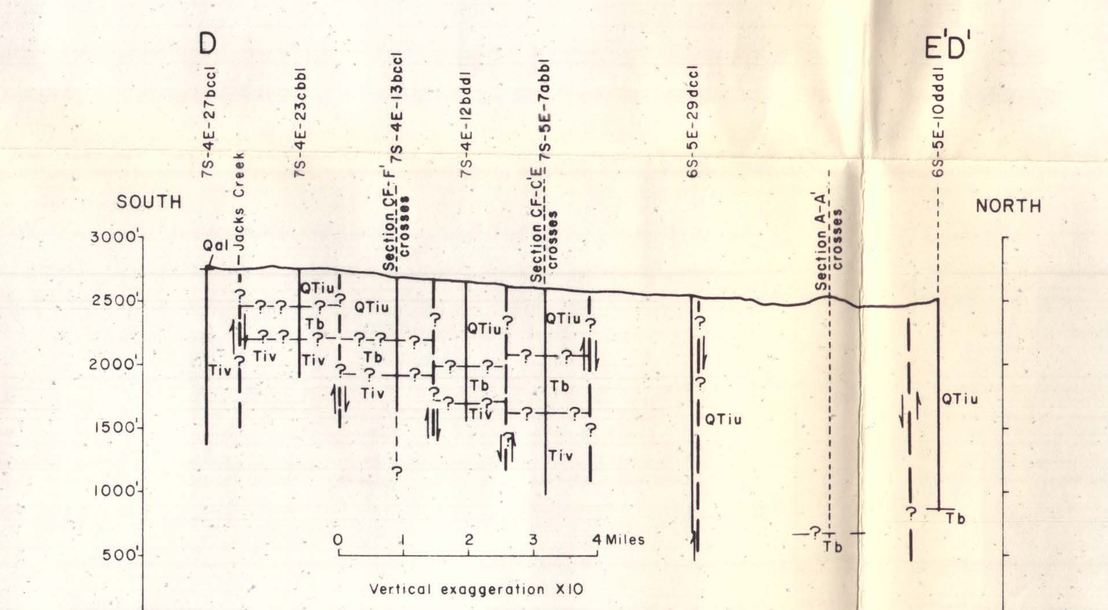
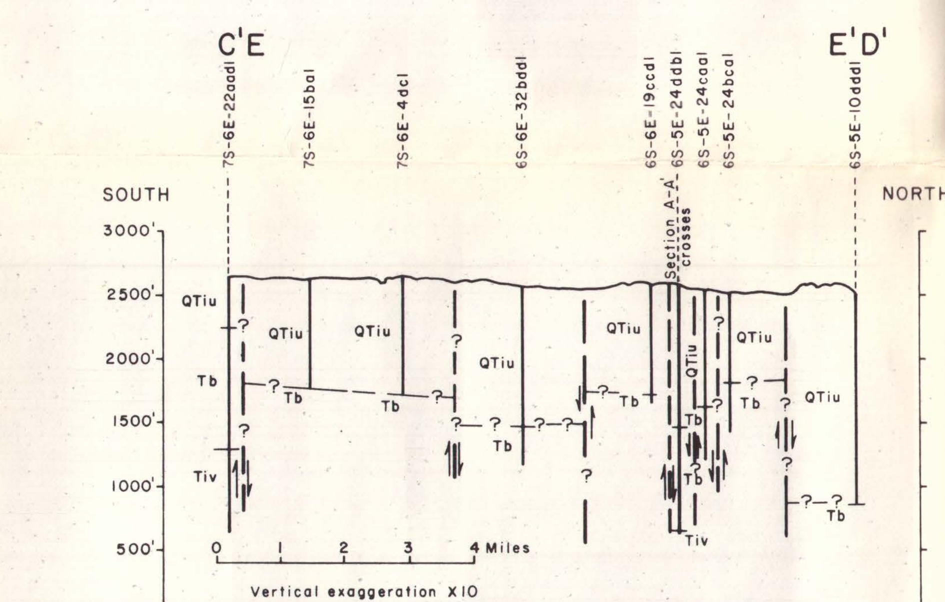


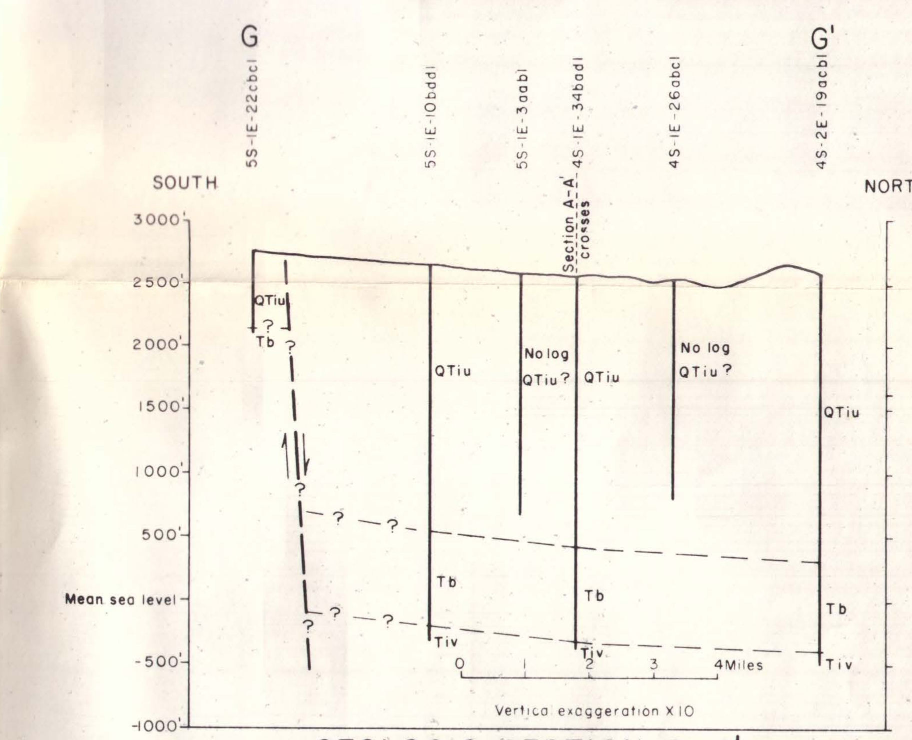
GEOLOGIC SECTION CF—C'E



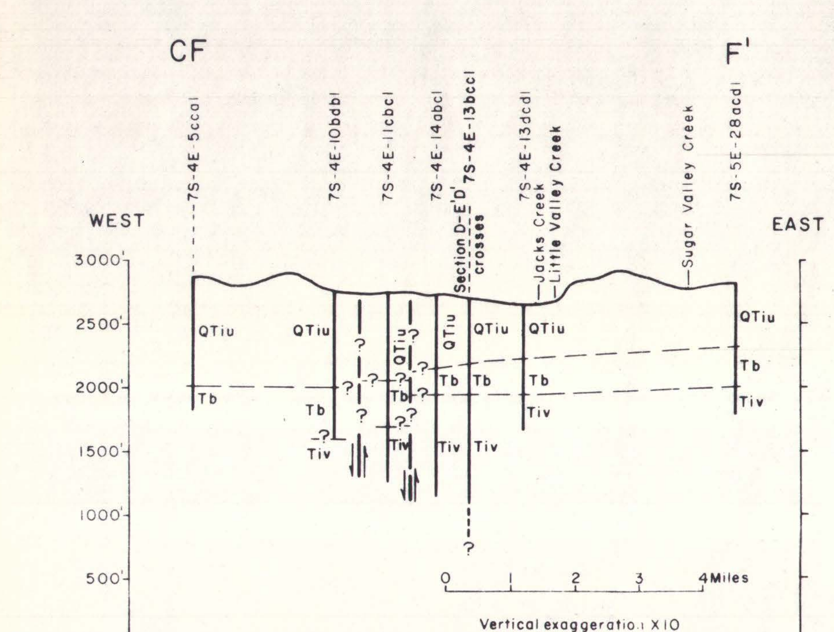
GEOLOGIC SECTION D—E'D'



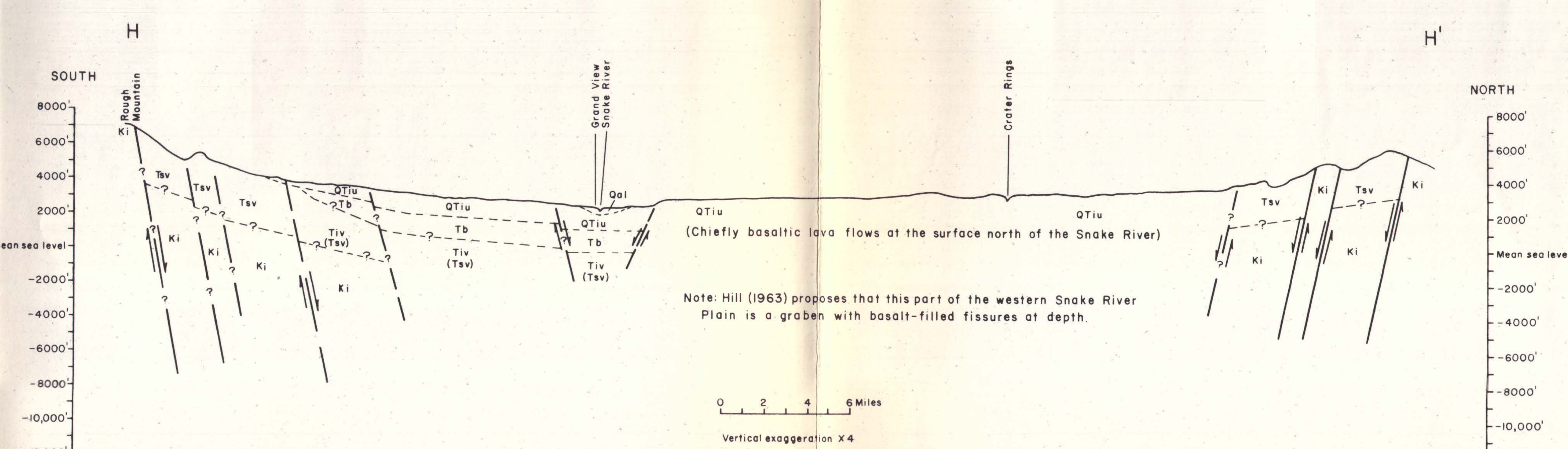
GEOLOGIC SECTION C'E—E'D'



GEOLOGIC SECTION G—G'



GEOLOGIC SECTION CF—F'



GEOLOGIC SECTION H—H'

EXPLANATION

Qal ALLUVIUM

QTiu IDAHO GROUP, UNDIFFERENTIATED

Tb BANBURY BASALT

Tsv SILICIC VOLCANIC ROCKS, UNDIFFERENTIATED

Tiv IDAVADA VOLCANICS

Ki INTRUSIVE ROCKS

FAULT, OR FAULT ZONE
Dashed where approximately located, queried where inferred. Arrow indicates direction of movement. Angle of faults, as shown, do not represent true dip.

NOTES:
Refer to figure 4 and table 1 for description of geologic units.

Thickness of units shown may exceed those given in table 1, as a result of generalizing and consolidating units. Refer to appendix B for drillers' logs.

Location of sections A-A', B-B', CF-C'E, D-E'D', C'E-E'D', CF-F', and G-G' are shown in figure 4. Location of section H-H' is shown in part in figure 4 and in whole in figure 7a (regional gravity map).

--Selected generalized geologic sections in the Bruneau-Grand View area and in part of the western Snake River Plain, Idaho.

UNITED STATES DEPARTMENT OF THE INTERIOR
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PLATE 1-A

CORRELATION OF MAP UNITS

Qal, Qd	Holocene		QUATERNARY
Qm, Qc, Qg, Qp, Qbs, Qbb (Snake River Group)	Pleistocene		QUATERNARY
Qt, QTg (Idaho Group)		QTiu: Pleistocene and Pliocene	
Tc, Tcb, Tiv (Idaho Group)	Pliocene	Tsv: Pliocene and Miocene	TERTIARY
Tv	Miocene(?)		TERTIARY
Ki	Cretaceous		CRETACEOUS

DESCRIPTION OF MAP UNITS

Qal, Qd — SURFICIAL DEPOSITS - Qal, alluvium; Qd, dune sand; - Includes clay, silt, sand, and gravel.

Qm — MELON GRAVEL - Boulders, cobbles, and pebbles of basalt in matrix of basaltic sand arranged in giant cross-beds. (Malde, Powers, and Marshall, 1963).

Qc, Qg — GRAVEL - Qc, Crowsnest Gravel; occupies terraces above Snake River.
Qg, Unnamed gravel; occupies terraces above Bruneau River.

QTiu — IDAHO GROUP, UNDIFFERENTIATED - Poorly to well sorted fluvial and lacustrine deposits ranging from clay to coarse gravel. Occurs as both consolidated and unconsolidated deposits with intercalated basalt flows and ash.

Qp — BLACK MESA GRAVEL - Gravel and sand - gravel largely reworked from gravel of older formations.

Qbs, Qbb — BRUNEAU FORMATION - Qbs, detrital material; Qbb, basaltic lava-flows; canyon fill of undeformed, unconsolidated detrital material and inter-bedded basaltic lava flows associated with marginal deposits of gravel and sand.

Qt — TUANA GRAVEL - Pebble and cobble gravel inter-bedded with layers of massive brown to gray sand and silt.

QTg — GLENNS FERRY FORMATION - Basin fill of poorly consolidated detrital material includes minor lava flows of olivine basalt.

Tc, Tcb — CHALK HILLS FORMATION - Tc, lake and stream deposits; Tcb, lava flows of olivine basalt. Basin fill of consolidated clastic deposits and minor lava flows of basalt.

Tb — BANBURY BASALT - Lava flows of olivine basalt inter-bedded locally with minor amounts of stream and lake deposits.

Tsv — SILICIC VOLCANIC ROCKS, UNDIFFERENTIATED - Consists of silicic latite and biotite-rich rhyolitic rocks.

Tiv — IDAVADA VOLCANICS - Silicic latite; chiefly layers of devitrified welded tuff, also includes some vitric tuff and lava flows.

Tv — RHYOLITIC ROCKS - Fine to coarse-grained extrusive rocks rich in quartz and biotite.

Ki — INTRUSIVE ROCKS - Intrusive granitic rocks of comparable age and composition to Idaho batholith.

KNOWN FAULT--Bar and ball on downthrown side.

INFERRED OR CONCEALED FAULT

CONTACT

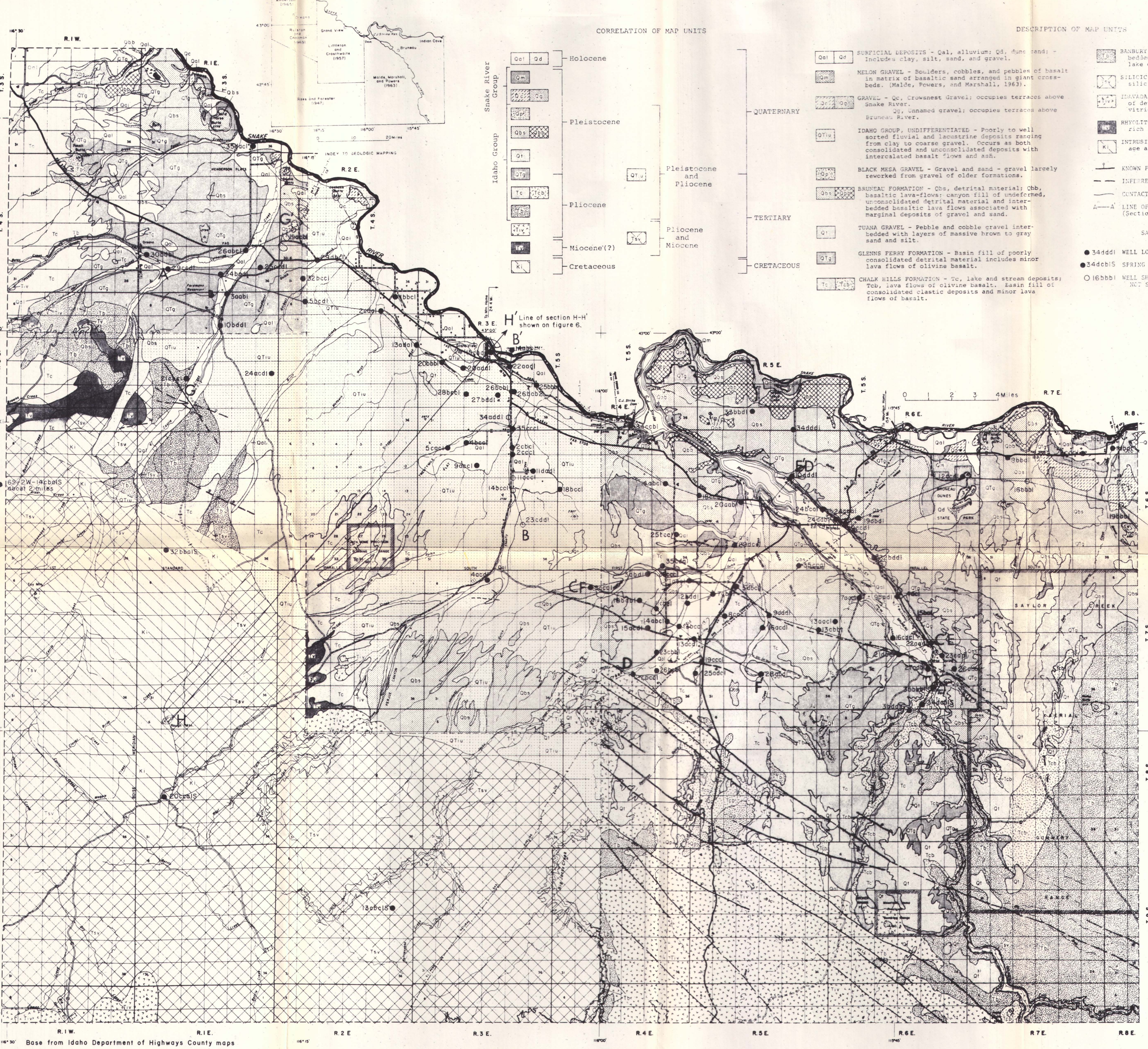
A——A' LINE OF GEOLOGIC SECTION (Sections shown on figure 6)

SAMPLING SITES

● 34dddl WELL LOCATION AND NUMBER

● 34dcblS SPRING LOCATION AND NUMBER

○ 16bbbl WELL SHOWN IN GEOLOGIC SECTION NOT SAMPLED



Generalized geology, locations of sampled wells and springs, and lines of geologic sections in the Bruneau-Grand View area, southwest Idaho.

UNITED STATES DEPARTMENT OF THE INTERIOR
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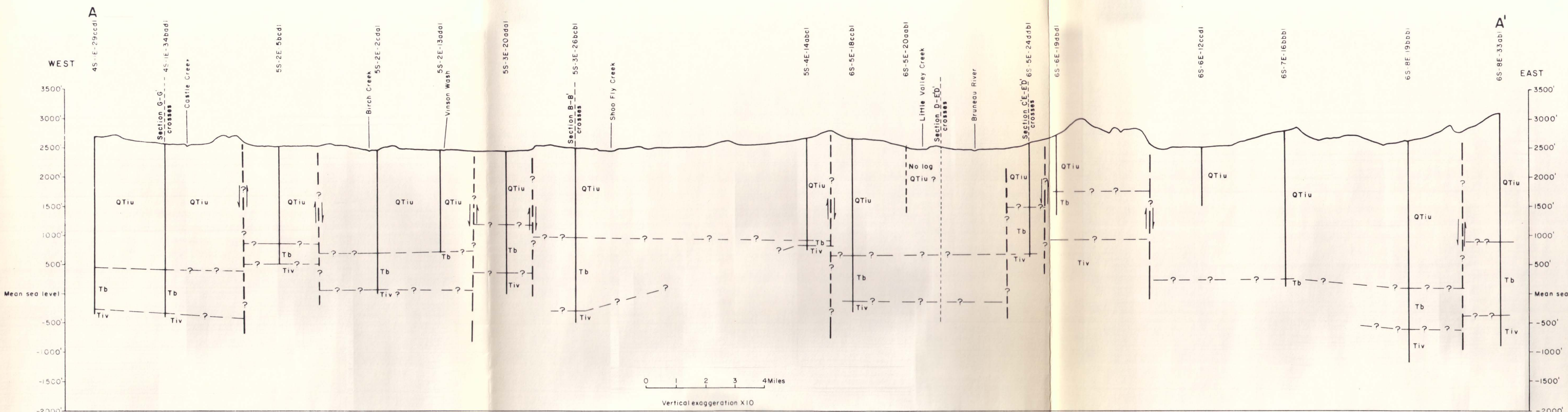
IDAHO DEPARTMENT OF WATER RESOURCES

EARTH POWER GROUP

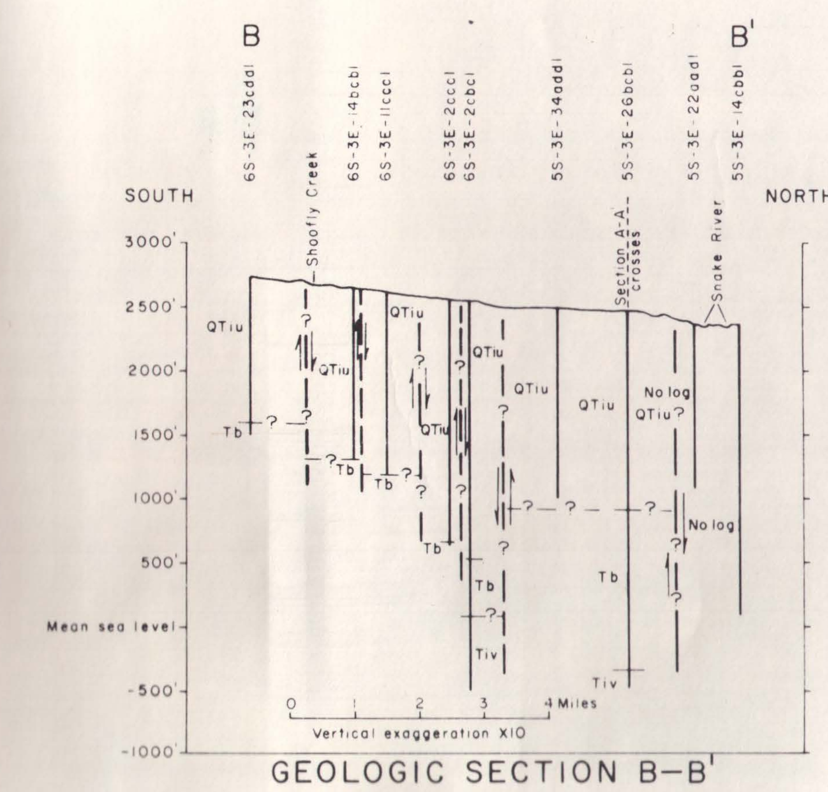
TULSA, OKLAHOMA

PLATE I-B

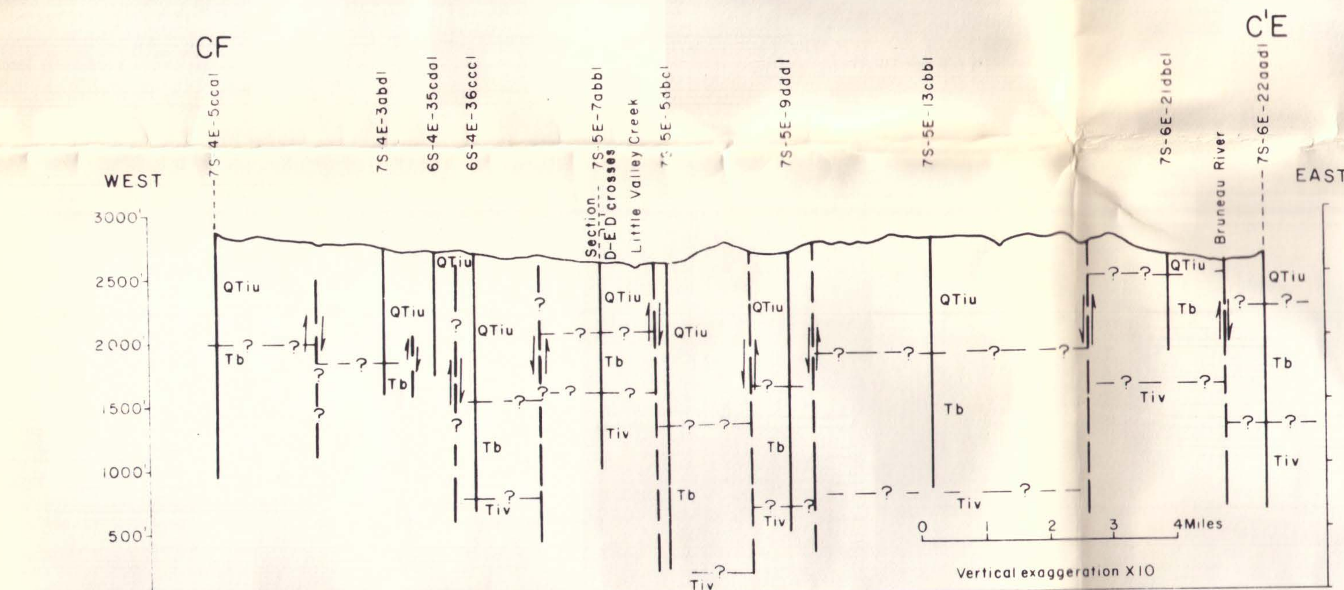
REPRODUCED DIRECTLY FROM "GEOTHERMAL INVESTIGATIONS IN IDAHO – PART 2."



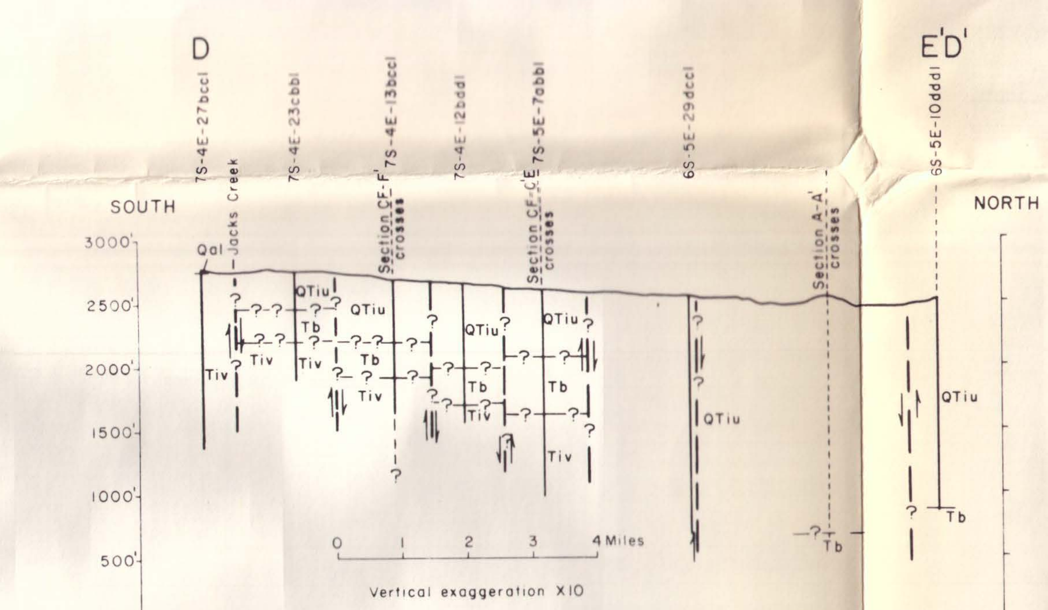
GEOLOGIC SECTION A—A'



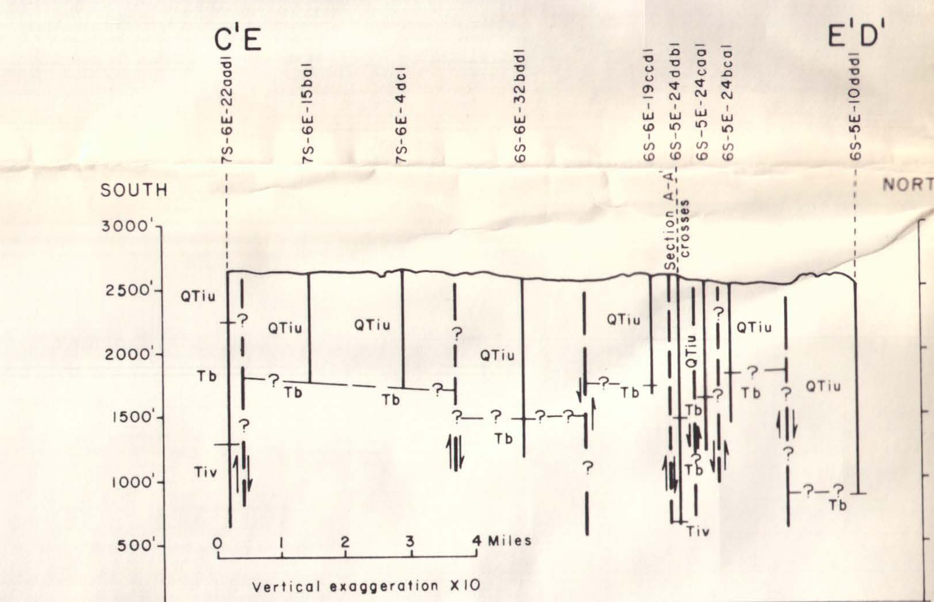
GEOLOGIC SECTION B—B'



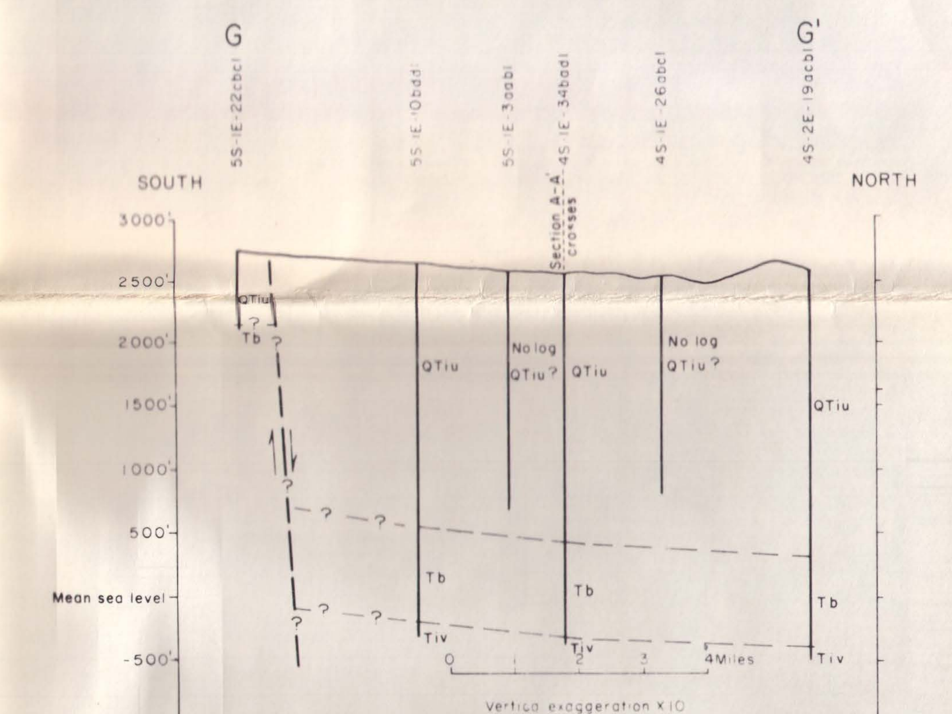
GEOLOGIC SECTION CF—C'E



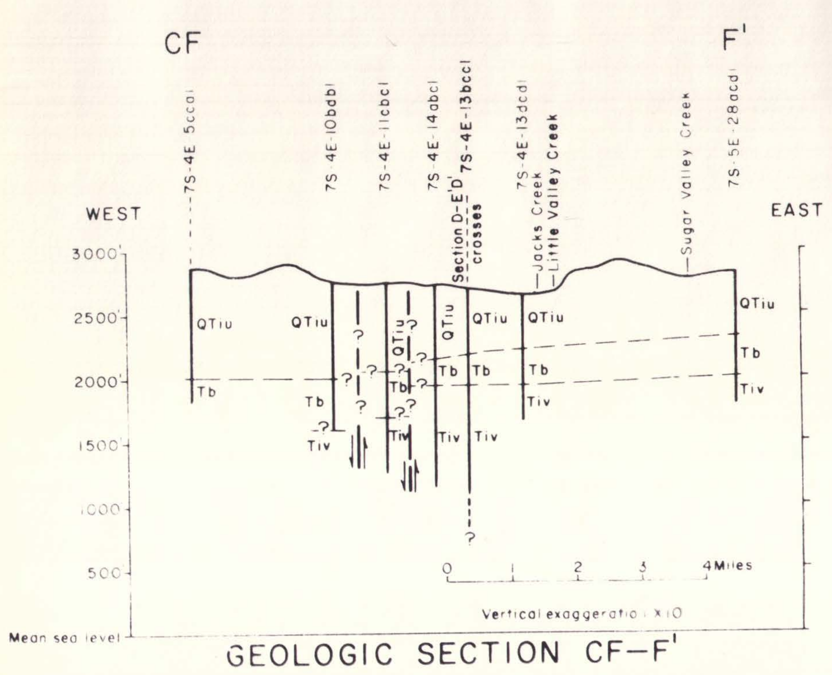
GEOLOGIC SECTION D—E'D'



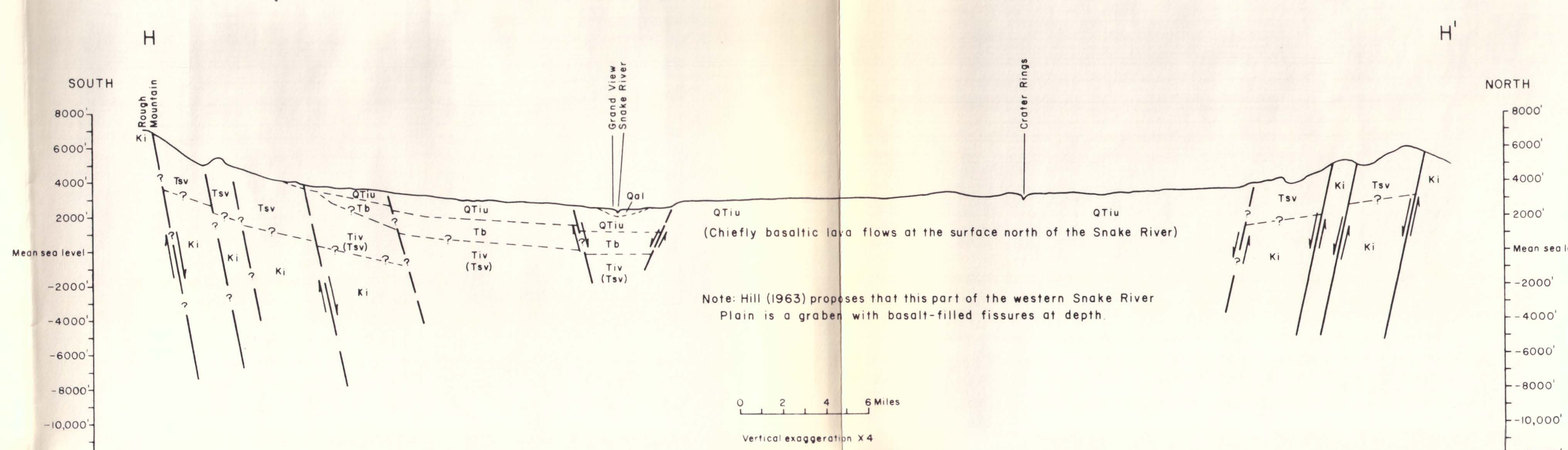
GEOLOGIC SECTION C'E—E'D'



GEOLOGIC SECTION G—G'



GEOLOGIC SECTION CF—F'



GEOLOGIC SECTION H—H'

EXPLANATION

Qal ALLUVIUM

QTiu IDAHO GROUP, UNDIFFERENTIATED

Tb BANBURY BASALT

Tsv SILICIC VOLCANIC ROCKS, UNDIFFERENTIATED

Tiv IDAVADA VOLCANICS

Ki INTRUSIVE ROCKS

?— FAULT, OR FAULT ZONE
Dashed where approximately located, queried where inferred. Arrow indicates direction of movement. Angle of faults, as shown, do not represent true dip.

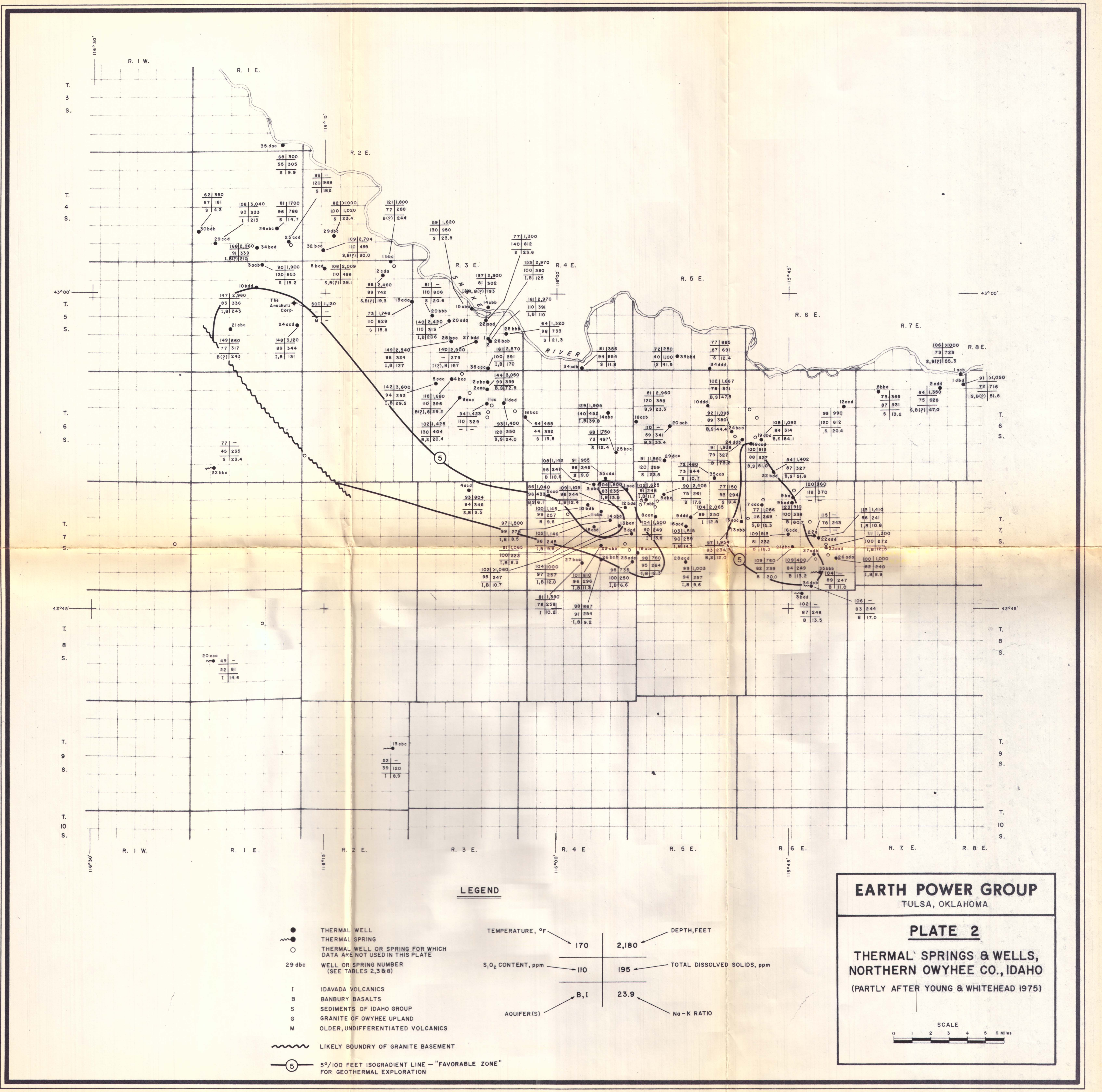
NOTES:

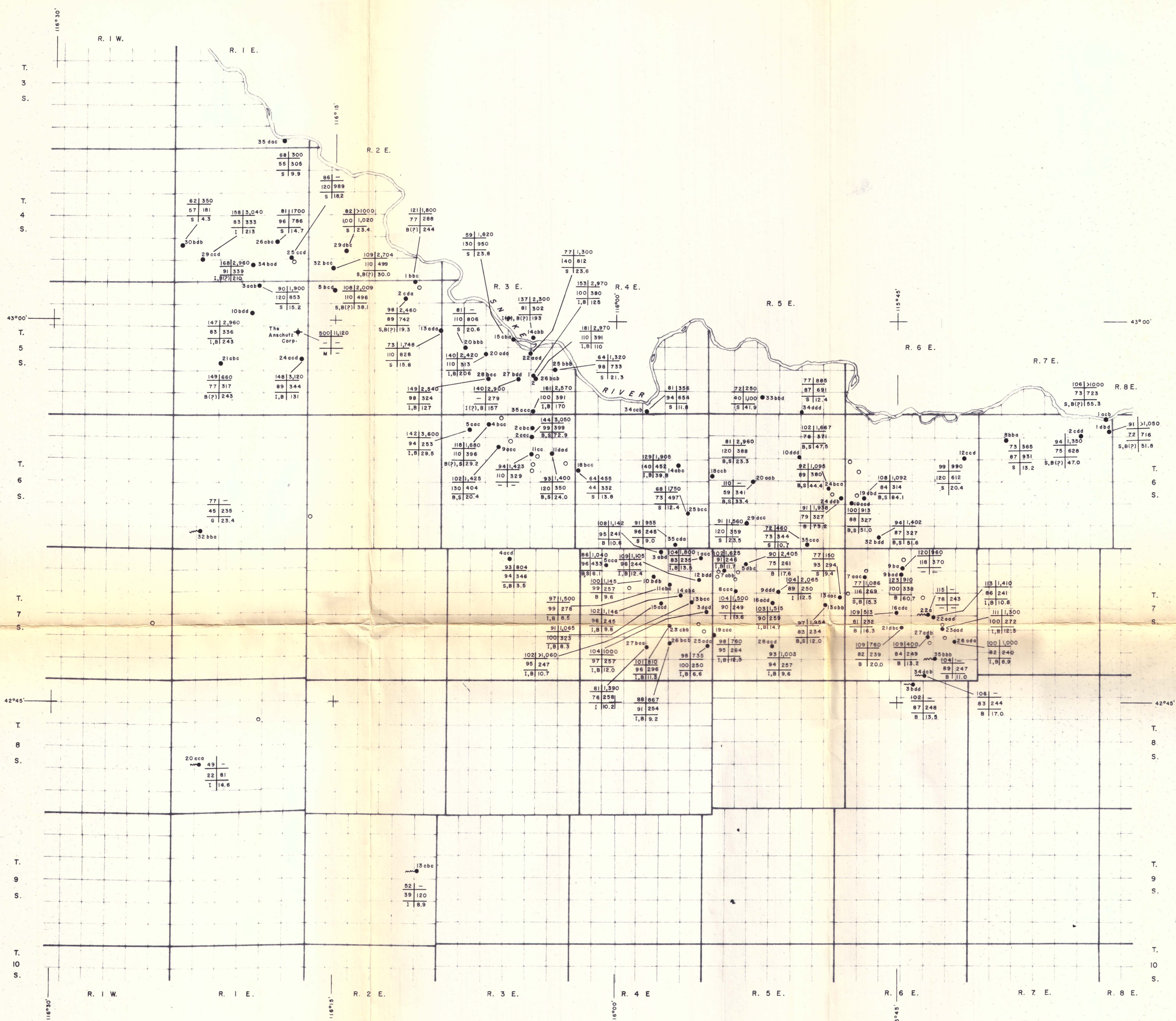
Refer to figure 4 and table 1 for description of geologic units.

Thickness of units shown may exceed those given in table 1, as a result of generalizing and consolidating units. Refer to appendix B for drillers' logs.

Location of sections A-A', B-B', CF-C'E, D-E'D', C'E-E'D', CF-F', and G-G' are shown in figure 4. Location of section H-H' is shown in part in figure 4 and in whole in figure 7a (regional gravity map).

--Selected generalized geologic sections in the Bruneau-Grand View area and in part of the western Snake River Plain, Idaho.


EARTH POWER GROUP
TULSA, OKLAHOMA
PLATE 2
THERMAL SPRINGS & WELLS, NORTHERN OWYHEE CO., IDAHO
(PARTLY AFTER YOUNG & WHITEHEAD 1975)
SCALE
0 1 2 3 4 5 6 Miles
LEGEND
THERMAL WELL
THERMAL SPRING
THERMAL WELL OR SPRING FOR WHICH DATA ARE NOT USED IN THIS PLATE
29 dbc WELL OR SPRING NUMBER (SEE TABLES 2,3 & 8)
I IDAVADA VOLCANICS
B BANBURY BASALTS
S SEDIMENTS OF IDAHO GROUP
G GRANITE OF OWYHEE UPLAND
M OLDER, UNDIFFERENTIATED VOLCANICS
LIKELY BOUNDRY OF GRANITE BASEMENT
5°/100 FEET ISOGRADIENT LINE — "FAVORABLE ZONE" FOR GEOTHERMAL EXPLORATION
TEMPERATURE, °F 170
DEPTH, FEET 2,180
SiO2 CONTENT, ppm 110
TOTAL DISSOLVED SOLIDS, ppm 195
AQUIFER(S) B, I
Na-K RATIO 23.9
SNAKE RIVER
The Anschutz Corp.
R. I W.
R. I E.
R. 2 E.
R. 3 E.
R. 4 E.
R. 5 E.
R. 6 E.
R. 7 E.
R. 8 E.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
T. 9 S.
T. 10 S.
116°30'
116°15'
116°00'
115°45'
43°00'
42°45'



LEGEND

- ● THERMAL WELL
- ● THERMAL SPRING
- ○ THERMAL WELL OR SPRING FOR WHICH DATA ARE NOT USED IN THIS PLATE
- 29 dbc — WELL OR SPRING NUMBER (SEE TABLES 2, 3 & 8)
- I — IDAVADA VOLCANICS
- B — BANBURY BASALTS
- S — SEDIMENTS OF IDAHO GROUP
- G — GRANITE OF OWYHEE UPLAND
- M — OLDER, UNDIFFERENTIATED VOLCANICS

TEMPERATURE, °F → 170	2,180 ← DEPTH, FEET
S_iO_2 CONTENT, ppm → 110	195 ← TOTAL DISSOLVED SOLIDS, ppm
AQUIFER(S) → B, I	23.9 ← Na-K RATIO

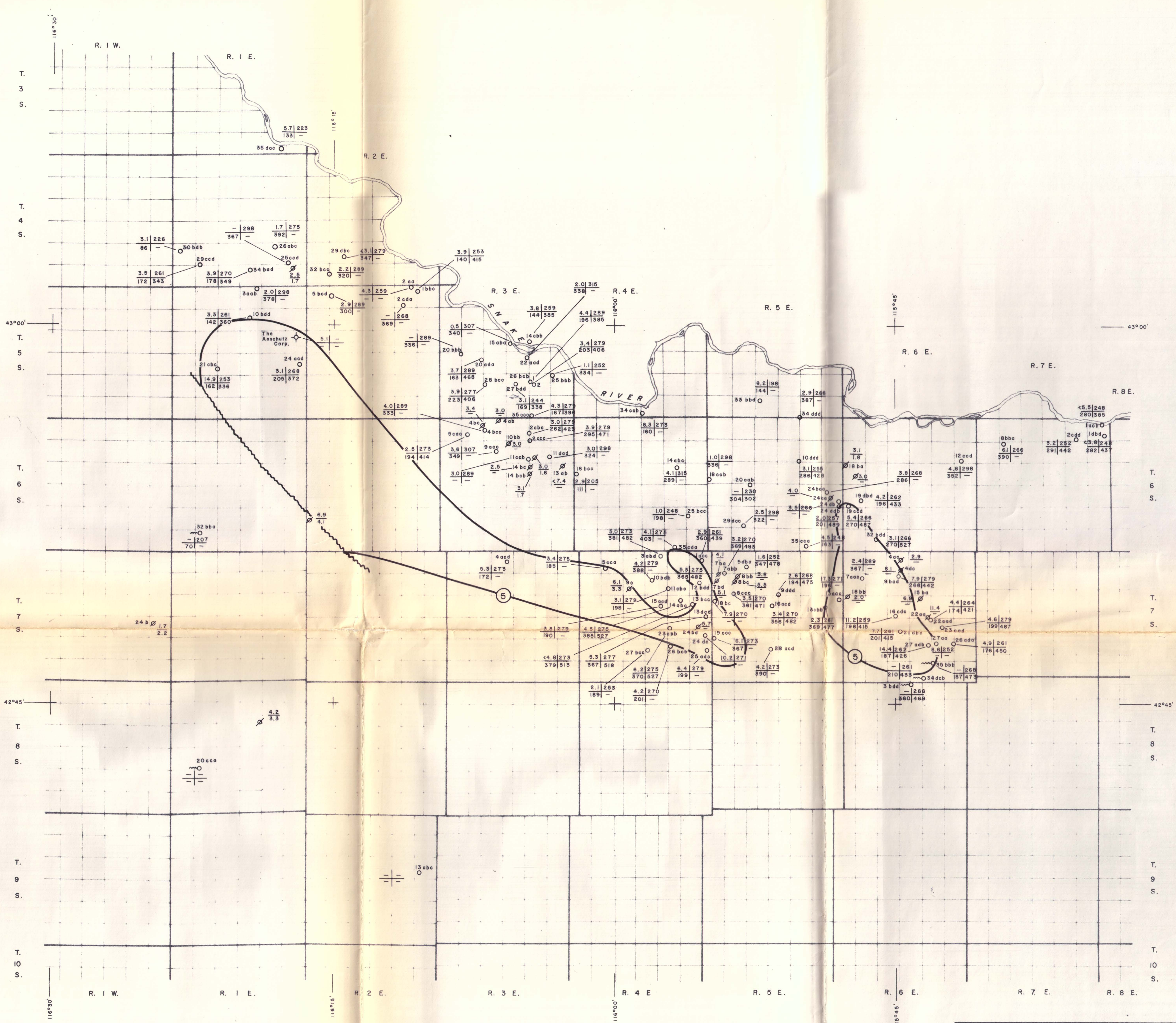
EARTH POWER GROUP
TULSA, OKLAHOMA

PLATE 2

THERMAL SPRINGS & WELLS, NORTHERN OWYHEE CO., IDAHO

(PARTLY AFTER YOUNG & WHITEHEAD 1975)

SCALE
0 1 2 3 4 5 6 Miles



LEGEND

- ○ THERMAL WELL
- ○ THERMAL SPRING
- 29 dbc — WELL OR SPRING NUMBER (SEE TABLES 2, 3 & 8)
- ⌀ — TEMPERATURE GRADIENT CALCULATION OR HEAT FLOW HOLE
- ~~~ — LIKELY BOUNDRY OF GRANITE BASEMENT
- —(5)— — 5°/100 FEET ISOGRADIENT LINE - "FAVORABLE ZONE" FOR GEOTHERMAL EXPLORATION

GRADIENT, °F/100 FEET	S_iC_2 DERIVED TEMPERATURE
3.7	275
190	410
Na-K-Ca DERIVED TEMPERATURE	MIXING MODEL TEMPERATURE

GRADIENT, °F/100 FEET — 2.1

HEATFLOW, MCAL/CM²/SEC. — 3.2

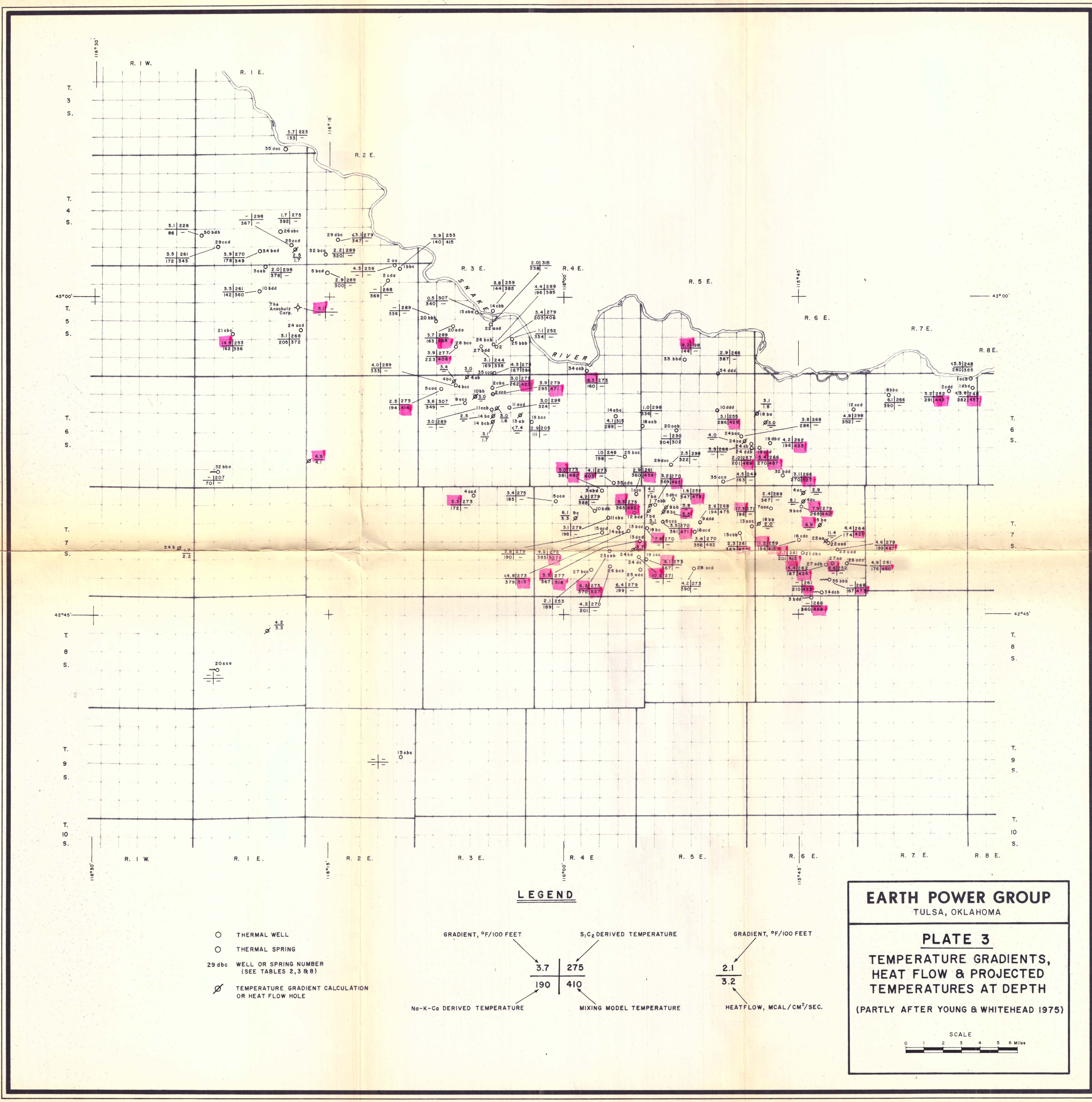
EARTH POWER GROUP
TULSA, OKLAHOMA

PLATE 3
TEMPERATURE GRADIENTS, HEAT FLOW & PROJECTED TEMPERATURES AT DEPTH

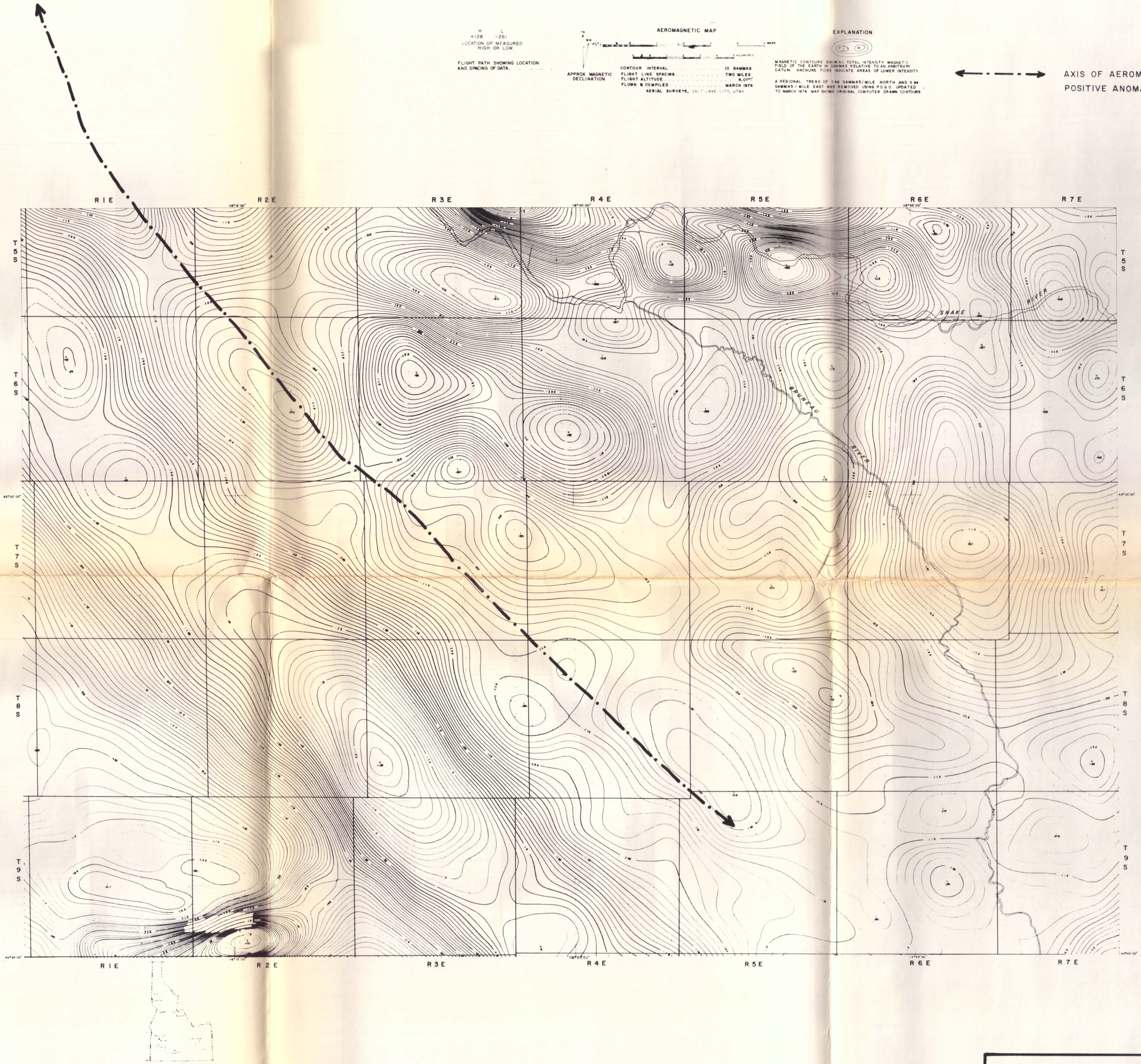
(PARTLY AFTER YOUNG & WHITEHEAD 1975)

SCALE

0 1 2 3 4 5 6 Miles



EARTH POWER GROUP
TULSA, OKLAHOMA
PLATE 3
TEMPERATURE GRADIENTS, HEAT FLOW & PROJECTED TEMPERATURES AT DEPTH
(PARTLY AFTER YOUNG & WHITEHEAD 1975)
SCALE
0 1 2 3 4 5 6 Miles
LEGEND
THERMAL WELL
THERMAL SPRING
29 dbc WELL OR SPRING NUMBER (SEE TABLES 2,3 & 8)
TEMPERATURE GRADIENT CALCULATION OR HEAT FLOW HOLE
GRADIENT, °F/100 FEET
SiO2 DERIVED TEMPERATURE
3.7 | 275
190 | 410
Na-K-Ca DERIVED TEMPERATURE
MIXING MODEL TEMPERATURE
GRADIENT, °F/100 FEET
2.1
3.2
HEATFLOW, MCAL/CM²/SEC.
SNAKE RIVER
R. 1 W.
R. 1 E.
R. 2 E.
R. 3 E.
R. 4 E.
R. 5 E.
R. 6 E.
R. 7 E.
R. 8 E.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
T. 9 S.
T. 10 S.
116°30'
116°15'
116°00'
115°45'
43°00'
42°45'
The Anschutz Corp.



REPRODUCED DIRECTLY FROM U.S. GEOLOGIC SURVEY MAP 1974
— AXIS OF POSITIVE ANOMALY ADDED.

EARTH POWER GROUP
TULSA, OKLAHOMA

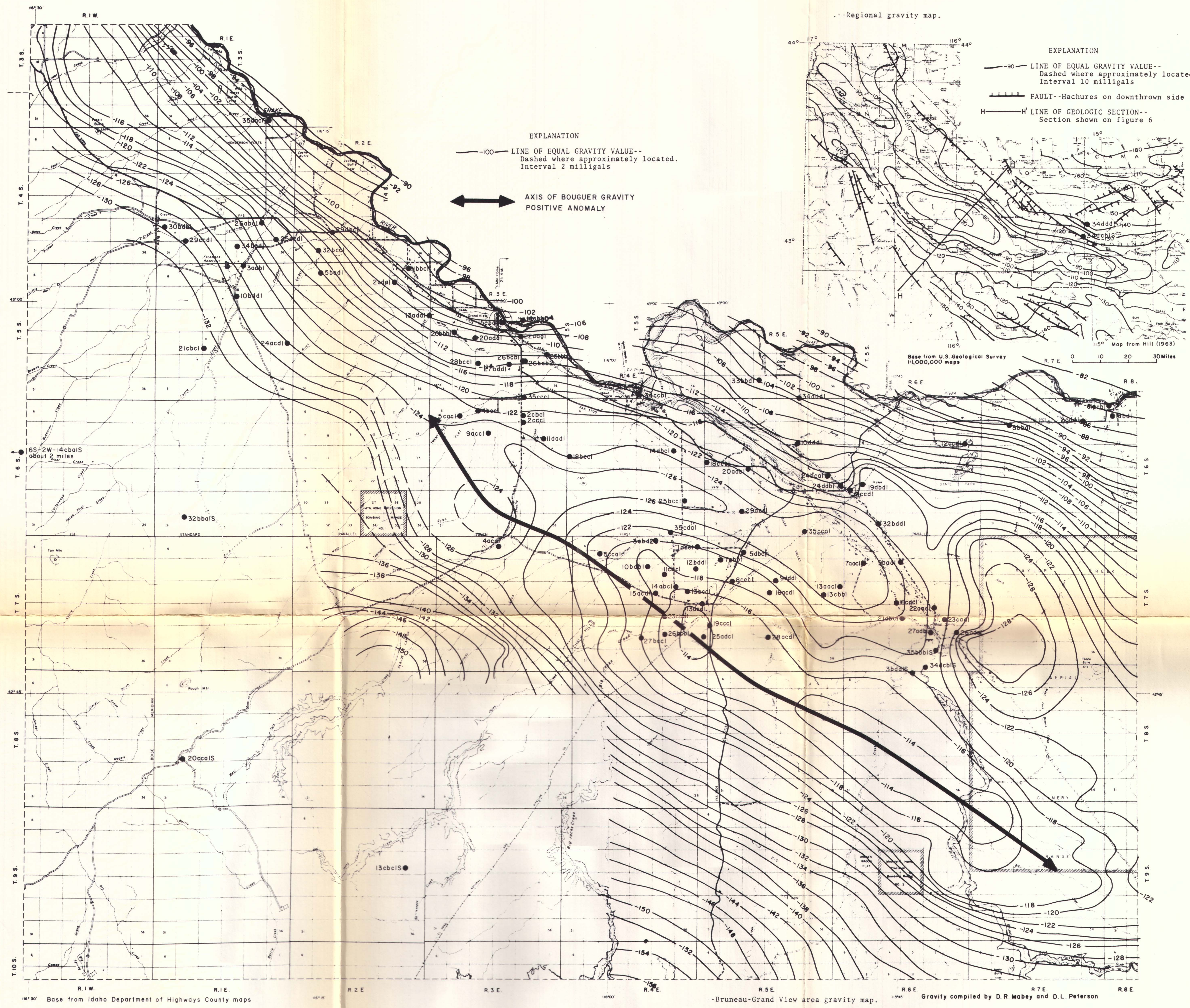
PLATE 4
RESIDUAL MAGNETIC INTENSITY MAP
BRUNEAU, IDAHO

U.S. GEOLOGICAL SURVEY 1974

SCALE
0 1 2 3 4 5 6 Miles

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
IDAHO DEPARTMENT OF WATER RESOURCES



--Gravity anomalies in (a) a part of the western Snake River Plain and in (b) the Bruneau-Grand View area, southwest Idaho.

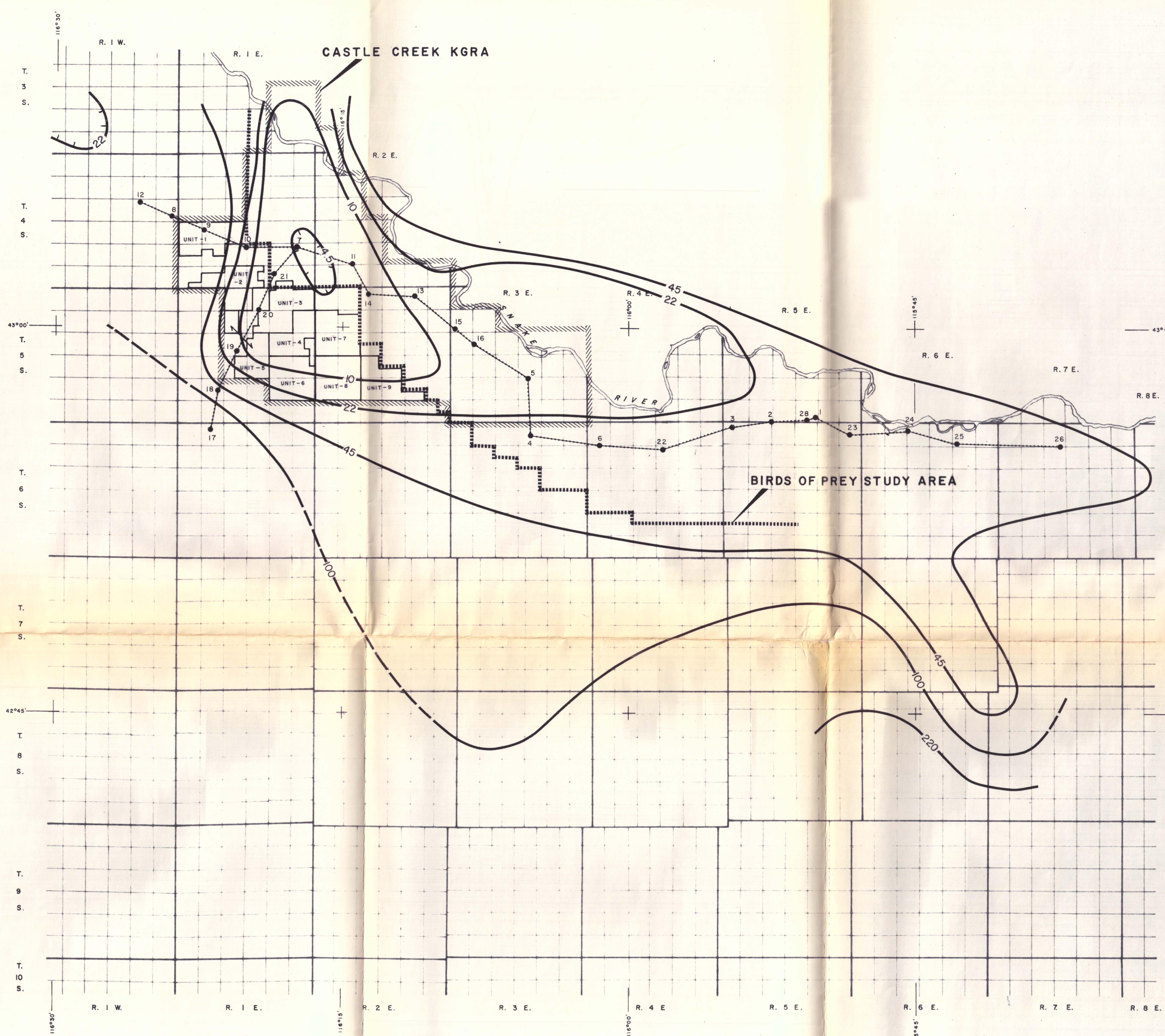
REPRODUCED DIRECTLY FROM "GEOTHERMAL INVESTIGATIONS IN IDAHO – PART 2"
AXIS OF POSITIVE ANOMALY ADDED.

EARTH POWER GROUP
TULSA, OKLAHOMA

PLATE 5

GRAVITY MAP

SCALE
0 1 2 3 4 5 6 Miles



UNITS AND TOP DOLLAR PER ACRE BID

UNIT	$/ACRE
1	2.13
2	3.00
3	8.09
4	35.60
5	4.50
6	12.47
7	8.09
8	3.76
9	1.23

STATION LOCATIONS FROM D.B. JACKSON, 1974, USGS OPEN FILE REPORT 74-240.

SCHLUMBERGER E-R STATIONS USED FOR CROSS SECTION (PLATE 7)

EXPLANATION

100

LINE OF EQUAL APPARENT RESISTIVITY

Dashed where data are incomplete. Hachured to indicate closed area of lower apparent resistivity. Interval, in ohm-metres, is variable.

EARTH POWER GROUP

TULSA, OKLAHOMA

PLATE 6

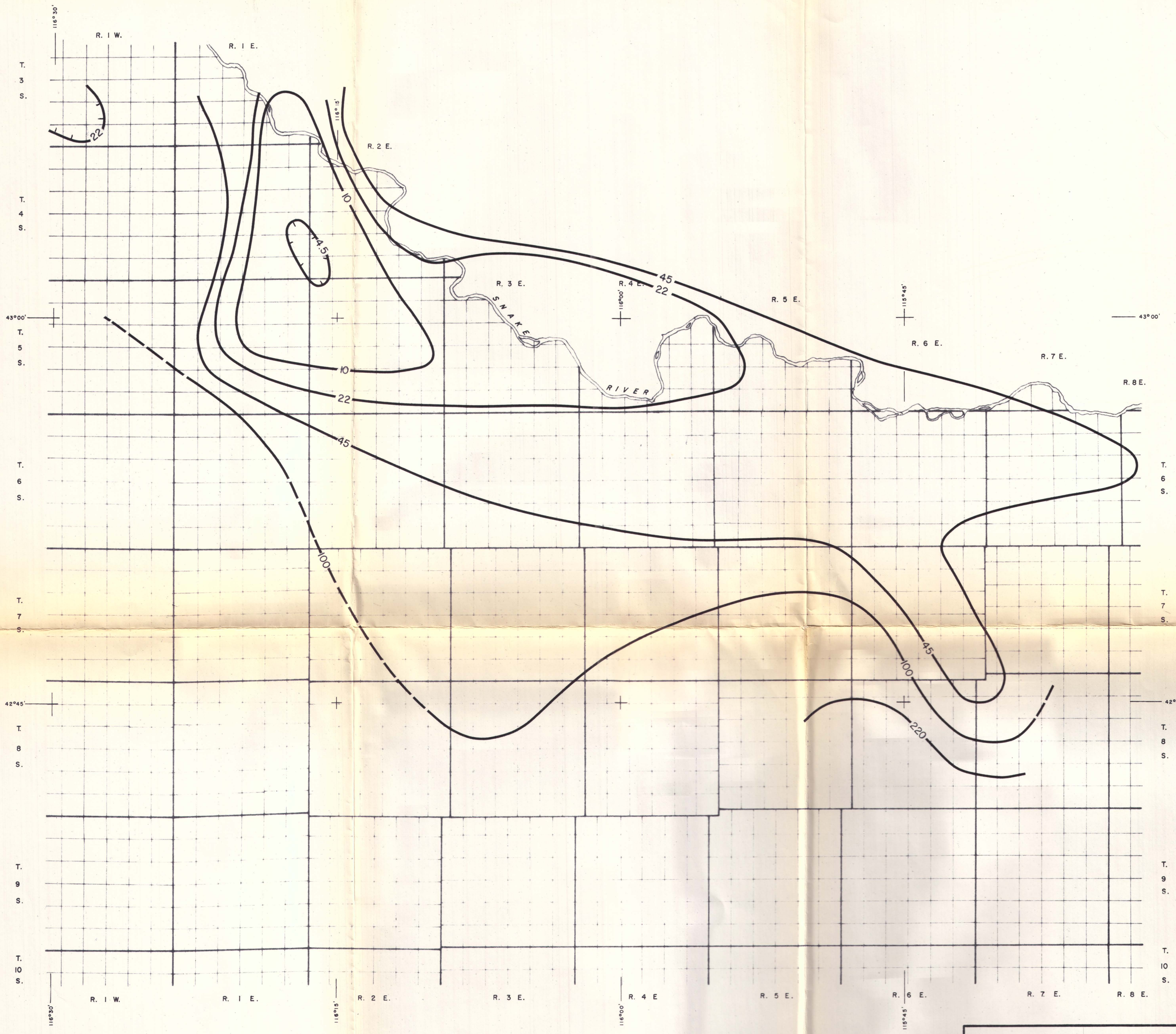
APPARENT RESISTIVITY MAP AT 8 HERTZ

KGRA UNITS & HIGH BIDS FROM BLM-IDAHO

FROM FIGURE 14, PAGE 63 "GEOTHERMAL INVESTIGATIONS IN IDAHO—PART 2."

SCALE

0 1 2 3 4 5 6 Miles



EXPLANTION

100

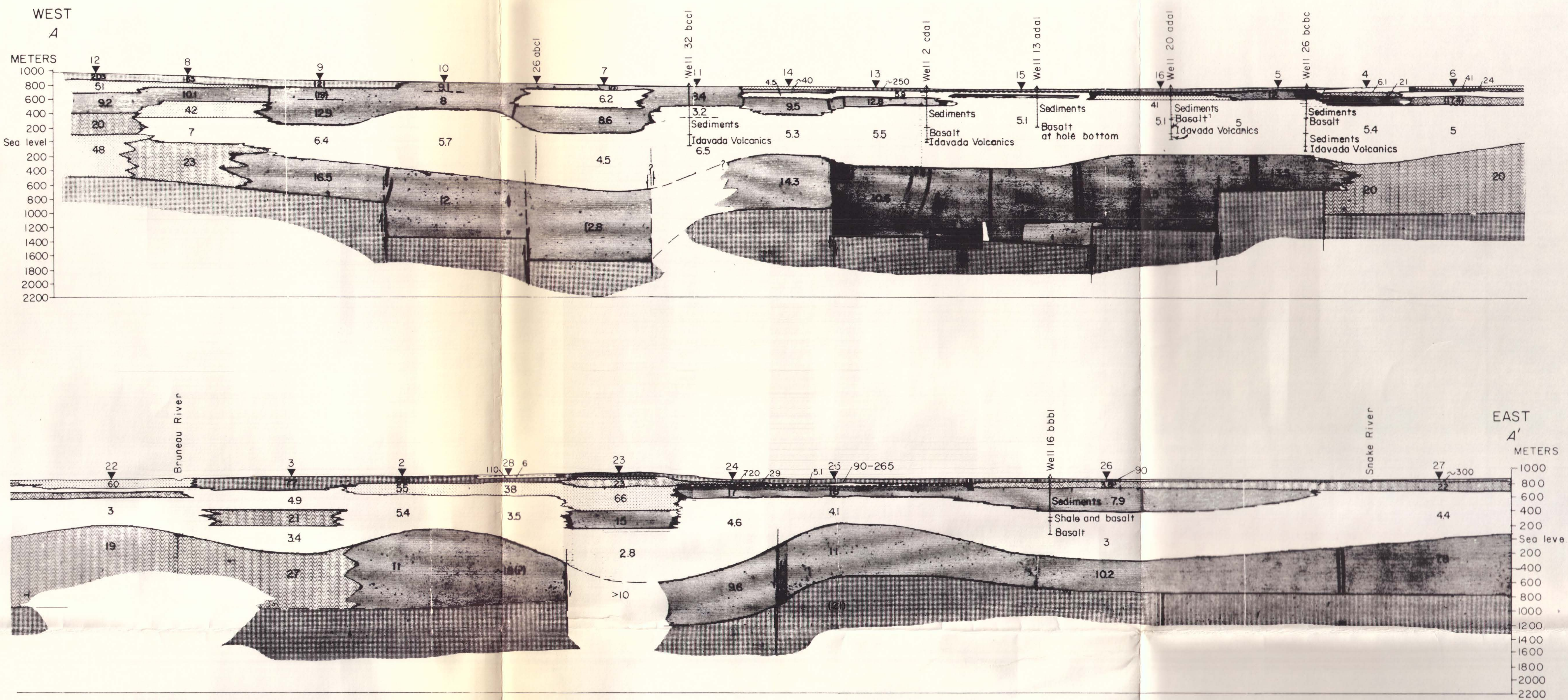
LINE OF EQUAL APPARENT RESISTIVITY

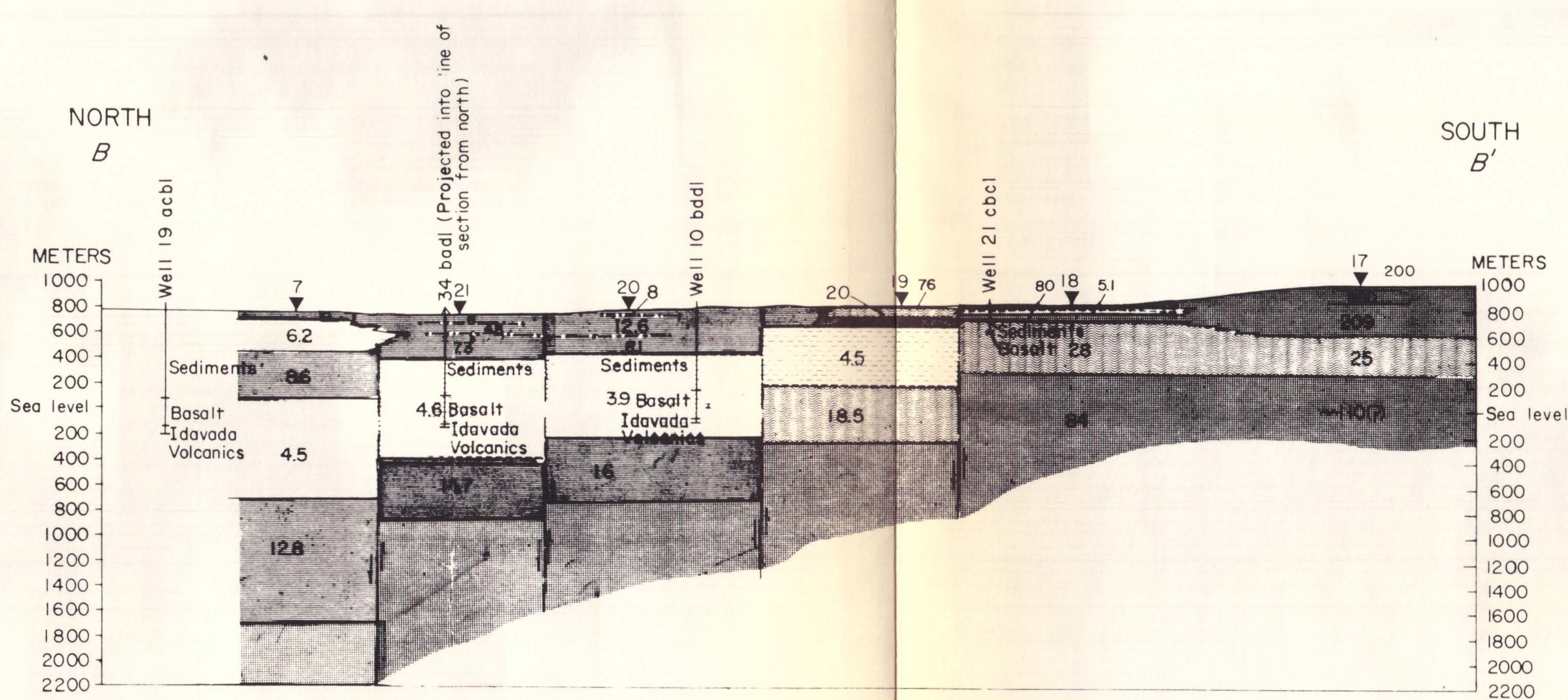
Dashed where data are incomplete Hachured to indicate closed area of lower apparent resistivity Interval, in ohm-metres, is variable.

EARTH POWER GROUP
TULSA, OKLAHOMA

APPARENT RESISIVITY MAP AT 8 HERTZ

Plate 6.





0 1 2 3 4 5 6 7 8 9 10 KILOMETERS

(VERTICAL EXAGGERATION X 2)

EXPLANATION

96
Layer resistivity, in ohm-m

(174)
Layer resistivity that has been included in either a higher or lower resistivity range (zip pattern) to improve layer correlation between 2 soundings

3.2 / 6.5
Separation of clearly definable layers that fall within the same resistivity range

26 ▼
Schlumberger sounding

Approximate layer boundary

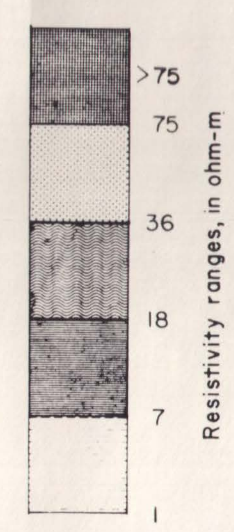


Plate 2. VES profiles *A A'* and *B B'*, Bruneau-Grand View area, Idaho.

SCHLUMBERGER DIRECT CURRENT LAYER RESISTIVITY FROM D. B. JACKSON, 1974. U.S.G.S. OPEN FILE REPORT 74-240

(STATION LOCATIONS ON PLATE 6.)

EARTH POWER GROUP

TULSA, OKLAHOMA

PLATE 7

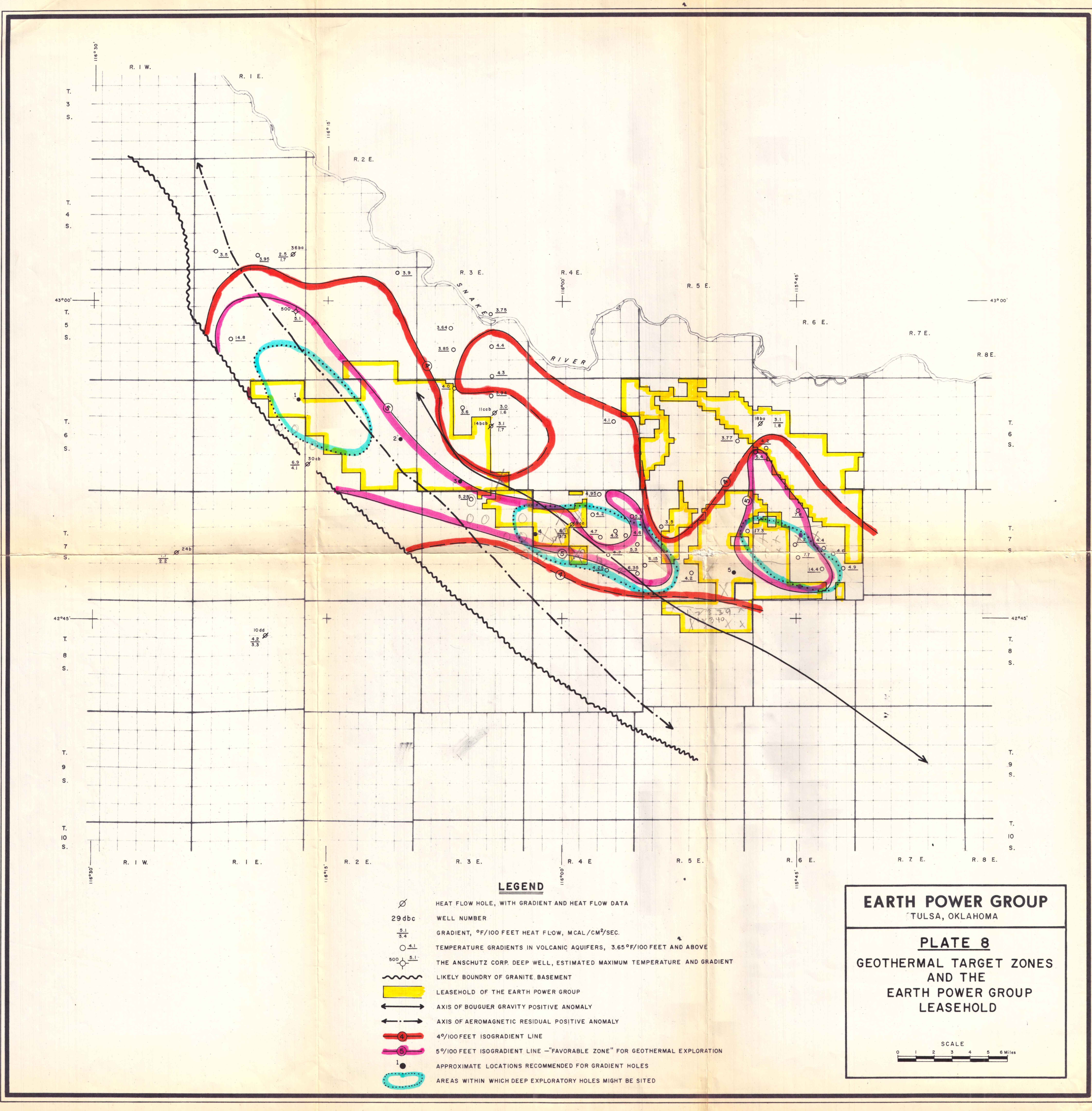
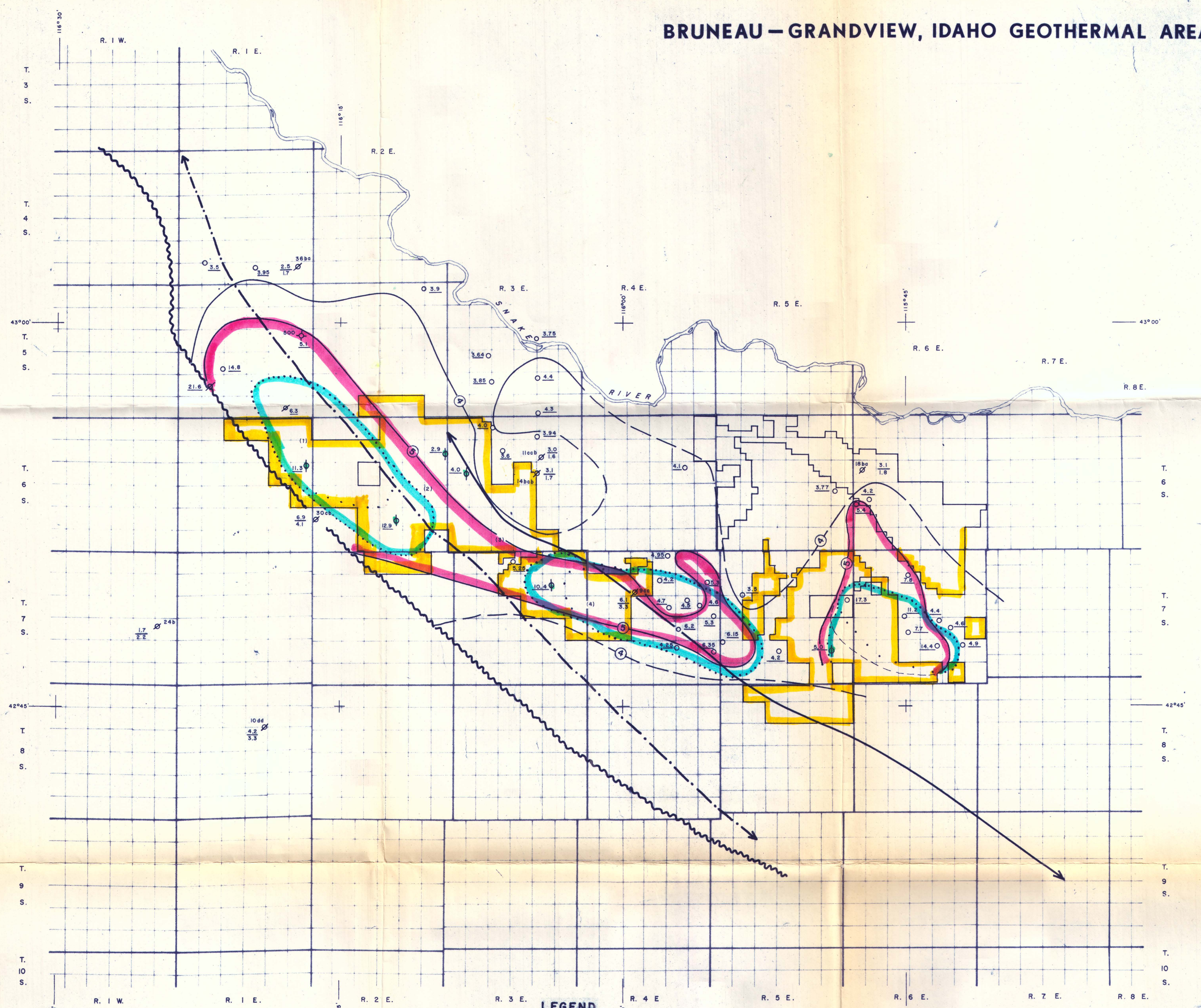


PLATE 8

GEOTHERMAL TARGET ZONES AND THE EARTH POWER GROUP LEASEHOLD

BRUNEAU — GRANDVIEW, IDAHO GEOTHERMAL AREA



LEGEND

HEAT FLOW HOLE BY EARTH POWER CORP

HEAT FLOW HOLE, WITH GRADIENT AND HEAT FLOW DATA

29dbc WELL NUMBER

5.1 / 3.4 GRADIENT, °F/100 FEET HEAT FLOW, MCAL/CM²/SEC.

4.1 TEMPERATURE GRADIENTS IN VOLCANIC AQUIFERS, 3.65°F/100 FEET AND ABOVE

500 5.1 THE ANSCHUTZ CORP. DEEP WELL, ESTIMATED MAXIMUM TEMPERATURE AND GRADIENT

LIKELY BOUNDRY OF GRANITE BASEMENT

LEASEHOLD OF THE EARTH POWER GROUP

AXIS OF BOUGUER GRAVITY POSITIVE ANOMALY

AXIS OF AEROMAGNETIC RESIDUAL POSITIVE ANOMALY

4 4°/100 FEET ISOGRADIENT LINE

5 5°/100 FEET ISOGRADIENT LINE —"FAVORABLE ZONE" FOR GEOTHERMAL EXPLORATION

(1) APPROXIMATE LOCATIONS RECOMMENDED FOR GRADIENT HOLES

AREAS WITHIN WHICH DEEP EXPLORATORY HOLES MIGHT BE SITED

EARTH POWER GROUP
TULSA, OKLAHOMA

PLATE 8

GEOTHERMAL TARGET ZONES AND THE EARTH POWER GROUP LEASEHOLD

SCALE
0 1 2 3 4 5 6 Miles

Revised: January 1977/ May 1977