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SPECIAL ASPECTS OF CENOZOIC HISTORY OF SOUTHERN IDAHO AND THEIR GEOTHERMAL IMPLICATIONS, 1976

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By

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ABSTRACT

Regional plate tectonics of the Pacific basin are directly related to these features in southern Idaho: basin development, four major geothermal belts, over 200 hot springs and wells, and a large left lateral rift that coincides generally with the present Snake River course.

The Snake River rift is indicated by 16 different lines of evidence, 12 of which are offset geologic features, each with a displacement of approximately 50 miles. The regional setting, along with local rifting, Cenozoic volcanism, graben development, thermal waters, much faulting, good reservoir conditions, and abundant surface water and ground water supplies makes southern Idaho an ideal region for geothermal exploration. Fish, mollusk and plant fossils, plus stratigraphic and structural correlation, enables reconstruction of eight chronological events in Cenozoic history, including: an early Tertiary basin, the Snake River graben, two major shifts in the Snake River course, a long period of composite volcanism, late Cenozoic rifting, and great Pleistocene uplift. Calcareous oolites appear to be fair indexes to geothermal anomalies in southern Idaho.

INTRODUCTION

The last four years have witnessed considerable petroleum and geothermal exploration effort in southern Idaho. This, plus the fact that Idaho is near enough to the Pacific coast to benefit greatly from the plate tectonic studies of that region, has prompted the author to summarize special aspects pertinent to the current interest. Southern Idaho seems to be strategically situated structurally and stratigraphically for the development of both petroleum basins and geothermal systems. Basin and range conditions, as well as deep downwarped and graben-like, non-marine basins are present. Only a few deep wells have been drilled in the state, and little is known about the resource potential beneath the surface volcanics and lacustrine sediments. Surface evidence, such as thermal waters and petroleum shows, have incited an interest in the area; and the historical events outlined here should be useful to those seeking the resource potential. The work done to date is not too discouraging to deep petroleum prospecting and is very encouraging to geothermal prospecting.

REGIONAL SETTING

In early Tertiary, prior to 60 million years ago, the Pacific plate was moving northwestward from the parallel to the Farallon plate, which was drifting toward the Antarctic (Herron, 1972). During mid-Tertiary, the Pacific plate was still moving northwestward parallel to the southeastwardlymoving American plate, while the Farallon plate was being subducted beneath western North America (Atwater, 1970). The change from southeastward drifting to eastward subduction of the Farllon plate along with southeastward movement of the American plate after mid-Tertiary time implies torque stress with counter-clockwise rotation of the North American plate. During this time in the western U.S.A., there occurred the Basin and Range block faulting, extensive crustal rifting and large-scale downwarping (Atwater, 1970; Hill, 1972; Hamilton and Myers, 1966). The transform faults of the eastern Pacific Ocean were also active at this time and caused differential displacement of the East Pacific Ridge and are possibly closely related to major rifts and downwarps within the continent.

Map 1 shows major structural features in western North America, which are probably the result of this period of regional plate tectonics. Both the regional tectonic features (ridges, transform faults and plate boundaries) and the major continental structures (faults, rifts, grabens and downwarped basins) correspond closely to major belts of geothermal anomalies.

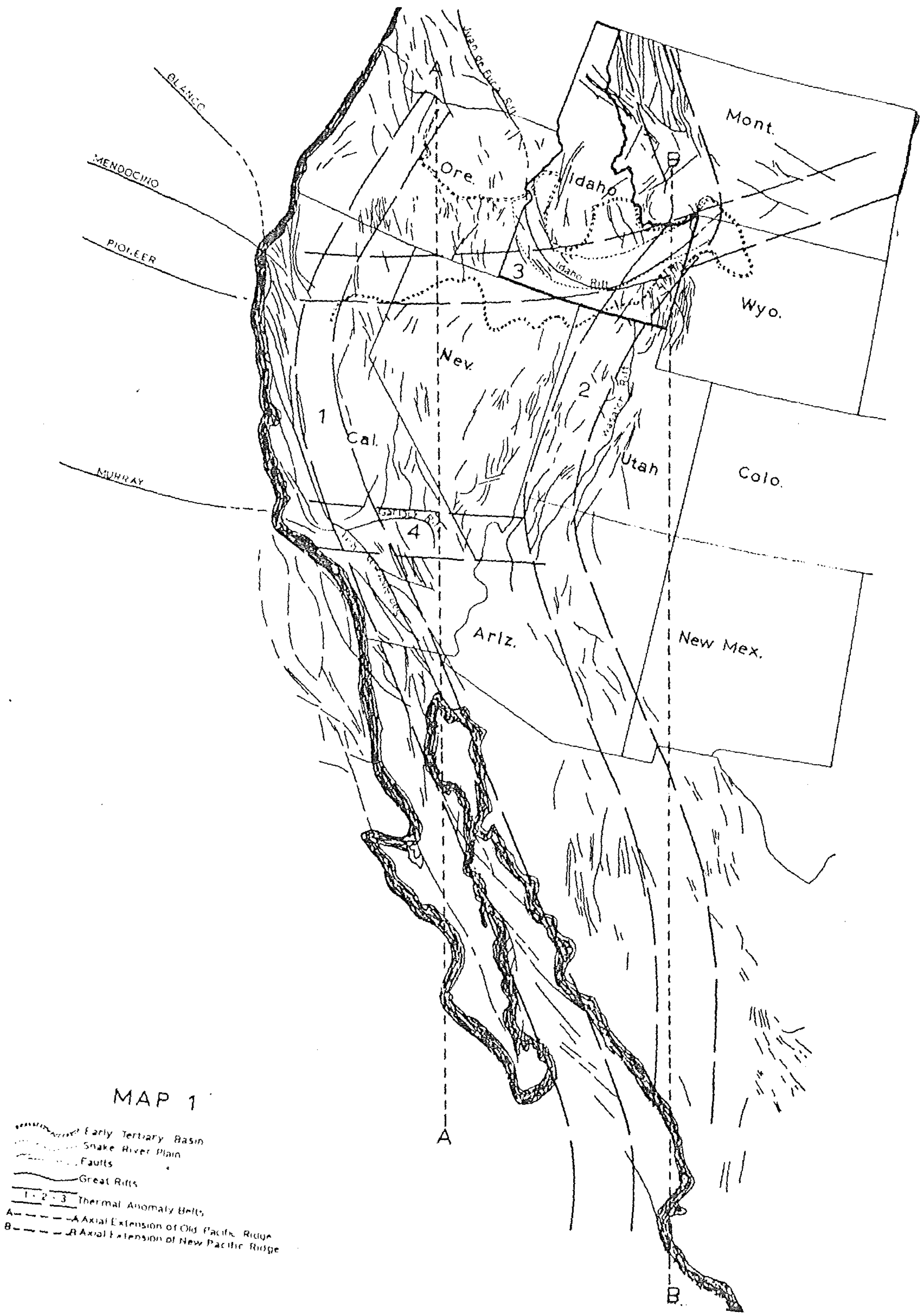
Geothermal belts 1-4 on Map 1 were outlined by plotting anomalous temperatures of hot springs and wells, certain volcanic trends, major fault systems, and known geothermal resource areas (KGRA) taken from Geothermal Overviews and other published accounts. Note on Map 1 that each of these geothermal belts corresponds closely to a major rift. There is evidence that three of the rifts: the Snake River, the Garlock and San Andreas have 40 or more miles of strike-slip displacement. Belts 1 and 2 correspond generally to the projected axes of the old and new East Pacific ridges as depicted by Herron (1972). According to her interpretation, about nine million years ago the axis of the East Pacific rise shifted from a northwestward trend to a northeastern trend and ultimately caused an accelerated strike-slip along the San Andreas fault. Both axes still have relatively high heat flow at the surface. Belts 3 and 4, when projected, intersect major transform fault systems of the East Pacific.

These particular historical events and tectonic conditions of shifting plates and ridges, colliding plate boundaries, transform faulting and strike-slip rifting, along with volcanism, subcrustal flowage of magma, crustal thickening, and downwarping in Cenozoic time have given western North America a high potential for geothermal resources.

The State of Idaho occupies a very strategic place within this geothermal region because of a peculiar culmination of numerous favorable conditions to the production of geothermal resources. These include:

(A) Regional Geothermal Belts - Two of the four major regional geothermal belts cross the southern part of the state and intersect one another in the southeastern portion of the state.

(B) Early Tertiary Basin - Southern Idaho contains nearly one-half of a very large, early Tertiary downwarped basin, called the


BLANCO
MENDOCINO
PIONEER
MURRAY
Ore.
Idaho
Mont.
Wyo.
Nev.
Cal.
Utah
Colo.
Ariz.
New Mex.
1
2
3
4
A
B
Early Tertiary Basin
Snake River Plain
Faults
Great Rifts
1 · 2 · 3 Thermal Anomaly Belts
A— — — —A Axial Extension of Old Pacific Ridge
B— — — —B Axial Extension of New Pacific Ridge

MAP 1

"Volcanic Rift Province" by Hamilton and Meyers (see Map 1). The crust was thin in Mesozoic time, and Cenozoic tension ruptured it and allowed large volumes of Magma and lava to flow into the area and rebuild the crust (Hamilton and Meyers, 1966). Stone thinks the Snake River basalts probably came from such deep primary magma because of their chemical uniformity and high iron and low silica and alkali content (1971). Deep-seated ruptures such as these involcanic areas are probable conduits for heat transfer in one way or another.

That this area was a basin during early Tertiary time, is indicated by early Tertiary lava flow (Challis volcanics), lower Miocene Paludal deposits, pre-miocene lacustrine deposits (?), and correlation with basin conditions in Oregon, Nevada and California. There is also evidence that the Snake River once ran northward to the Challis area through the Lost River country. Fossil flora studies by Axelrod (1968) also depict an early Tertiary basin development.

(C) Snake River Graben - Superimposed on the earlier basin is the Snake River downwarp, which is probably of late Tertiary-Quaternary age. This basin is smaller than the early Tertiary basin, and the western half, at least, is a fault graben. The basin contains up to 20,000 ft. of interbedded volcanic (flows, ash, tuff) and lacustrine and fluvial sediments. Stone (1971) mentions estimates from gravity surveys of 13,000 to 38,000 feet of rocks, with the density of basalt dropped down against the Idaho Batholith. Hill estimated from his gravity interpretation that the floor of the plain near Mountain Home is 9,600 feet below the surface and 1,400 feet below the top of the Idavada volcanics (Stone, 1971). A well drilled in this area (Sec. 25, T4S, R8E) was in highly altered rhyolite at total depth, 9,676 feet. Kirkham estimated from stratigraphic measurements a maximum thickness of 18,000 feet of section above the Idavada volcanics at the northwest end of the plain (Stone, 1971). The author has measured approximately 12,000 feet of lacustrine sediments from the lower Miocene, Sucker Creek Fm to the Pleistocene, Glenns Ferry Fm in the western end of the plain. A well drilled by the Standard Oil Company of California near Parma, Idaho, reached a depth of approximately 12,000 feet. If this well did not reach the basement, the Snake River graben is over 12,000 feet deep at that site. A deep well in Section 13, T5S, R1E in Owyhee County penetrated 11,000 feet of lacustrine and volcanic sediments without reaching basement. These facts indicate deep downwarping and/or faulting, probably since early Tertiary time.

A graben of this depth, filled with very porous and permeable rocks interbedded with lava and lake clays and associated with many deep-seated faults, is an ideal setting for the development of geothermal cells. Another favorable aspect is the abundant ground water supply to the basin, in addition to the Snake River and other surface streams.

(D) Thermal Waters: Over 200 known hot springs and many hot water wells are found in Idaho and range in temperature from warm to 93^{0}C at the surface. Subsurface temperature estimates from geochemical indicators range from less than 100^{0}C to 250^{0}C. These estimates are from preliminary surveys and will be modified and corrected as more data is accumulated. Some geological and geophysical data indicate that much higher temperatures can be expected at depth. (See Nichols, et al, 1972, and Anderson, 1972). Temperatures encountered in deep wells (4,000-11,000 ft.) are as high as 400^{0}F.

(E) Volcanism: Volcanism is a well-known associate of the better geothermal areas of the world, particularly the type that produces siliceous volcanics of Recent age. Idaho has had an abundance of volcanism of all kinds, but most of it was Pleistocene or older. The Recent volcanics of Idaho are basic basalts. There is evidence that much greater hot spring activity and possibly geyser action has occurred in the past at the sites of certain faults which transect the siliceous volcanic areas. This evidence is in the form of silicified oolites and fossil beds, highly-altered tuffs and lavas, chert deposits which might be fossil geyserite, gypsum and limestone deposits associated with warm-water algae, very thick lacustrine oolite banks, and hydrothermally-altered materials in deep wells.

It is very possible that rapid and great increase of surface water and ground water during the ice age, resulting from the change of climate from relatively dry Pliocene to the pluvial Pleistocene of this area could have flooded the geothermal reservoirs and inhibited thermal activity. On the other hand, the greater water supply of Pleistocene time might have produced the hot spring activity by covering the more strategic areas. As the supply subsided to the narrower regions and lakes dried up, the activity decreased or stopped. This latter possibility seems most plausible, since most of the evidence of past activity is associated with ancient lake deposits and other waterways.

(F) General Geology: The large Idaho Batholith covering half of the state, the orogenic area of southeastern Idaho with thick sections of Paleozoic and Mesozoic sedimentary rocks, the Snake River graben and downwarp with possibly 20,000 feet of interbedded permeable and non-permeable sediments, the Idaho rift and numerous faults, and good ground water reservoirs, early Tertiary and Cretaceous lacustrine beds, many volcanics, many hot springs, all associated with the two great regional geothermal zones, make very favorable conditions for geothermal prospects.

(G) Snake River Rift: Sixteen different types of evidence investigated by the author and discussed on the following pages indicate that a deep-seated left lateral rift with a displacement of 40-50 miles coincides generally with the Snake River course across the State of Idaho. When projected, the rift is in line with a fault zone in Oregon, which in turn runs into the great fault of the Juan de Fuca Strait (See Map 1). On the western end of the rift, in addition to the 50 miles of eastward movement, there was approximately 15 miles of southward shift, as the southern block was pulled away from the Idaho Batholith. The rift displaces rocks of Miocene to Pleistocene in age. The exact age of the rifting is not known, but it is presumed to have started approximately five million years ago, when the strike-slip of the San Andreas was accelerated (Atwater, 1970). Most of the slippage on the Snake River rift has occurred since early Pleistocene. Late Pleistocene rocks and structures show considerable displacement.

The left lateral movement on this rift and the right lateral movement of the San Andreas implies that the block of crust consisting of the State of Nevada, Idaho (south of the Snake River), western Utah, eastern California and the State of Oregon moved southeastward in a slightly counter-clockwise motion in Pliocene-Pleistocene time. The eastward thrusting along the Wasatch Front and the Sevier orogenic belt are results that might be expected from such rotational movement of this area and may imply an even older rift history. The left lateral displacement along the Garlock Fault in California is evidently the result of different rates of eastward movement, rather than from different directions of movement. The Garlock, therefore, is a transform fault and could be an extension of the Murray fracture zone in the Pacific Ocean.

Such rifts as the Snake River Rift are common to geothermal areas around the world, and they produce several conditions which are very conducive to the development of active geothermal cells. The rift itself is a large, deep-seated fault zone which makes deep hot areas available to surface and subsurface percolating waters. The rift zone consists of numerous fractures and brecciated rock, which makes good reservoir conditions for circulating cells. Volcanism is often associated with the rifts and can produce conduction and convection vehicles for heat transfer to shallow reservoirs. Subsidiary faults radiating outward from the rift can act as separate geothermal reservoirs by capturing energy from the main rift. Continued movement along such rifts keeps the reservoirs open and prevents loss of permeability by continually fracturing and rotating the reservoir rock particles.

The 16 lines of evidence for the rift found in Idaho are these:

(1) Lithologies on opposite sides of the Snake River (rift) do not match. Even where they are of the same age and type, their primary structures and textures indicate that each side represents a different part of the stratigraphic section. This is true of

both the basalts and lake sediments. It should be remembered, however, that the rift is not one single fault, but a fault zone. Slivers of rock sections lag behind in places and make correlation difficult.

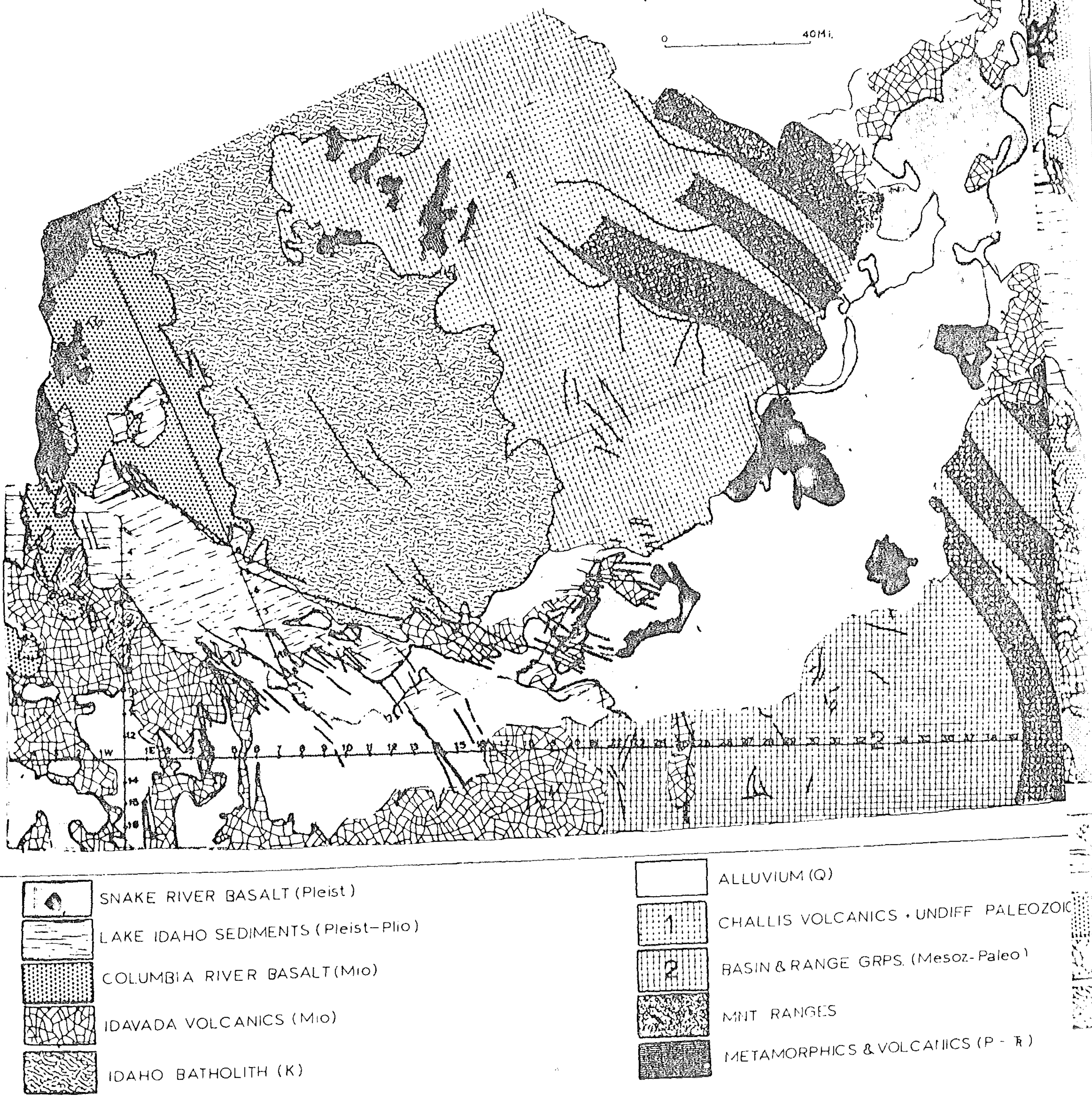
(2) The mountain ranges and associated longitudinal faults of the Basin and Range area of southeastern Idaho are displaced eastward from the ranges north of the Snake River Plain. The ranges both to the north and south of the plain plunge beneath the plain structurally. Most of the ranges are flanks of complexly folded and twisted synclines, indicating torque stress, and most of the valleys are breached anticlines filled in the Tertiary volcanics and lake sediments. The structural elements, as well as the topographic ranges, plunge toward the Snake River downwarp and appear to extend beneath it. Mesozoic eastward thrusting in the Lemhi Range and others, plus associated gravity slides and normal block faulting of late Basin and Range uplift age (Beutner, 1972), are probably reflections of this regional plate tectonism.

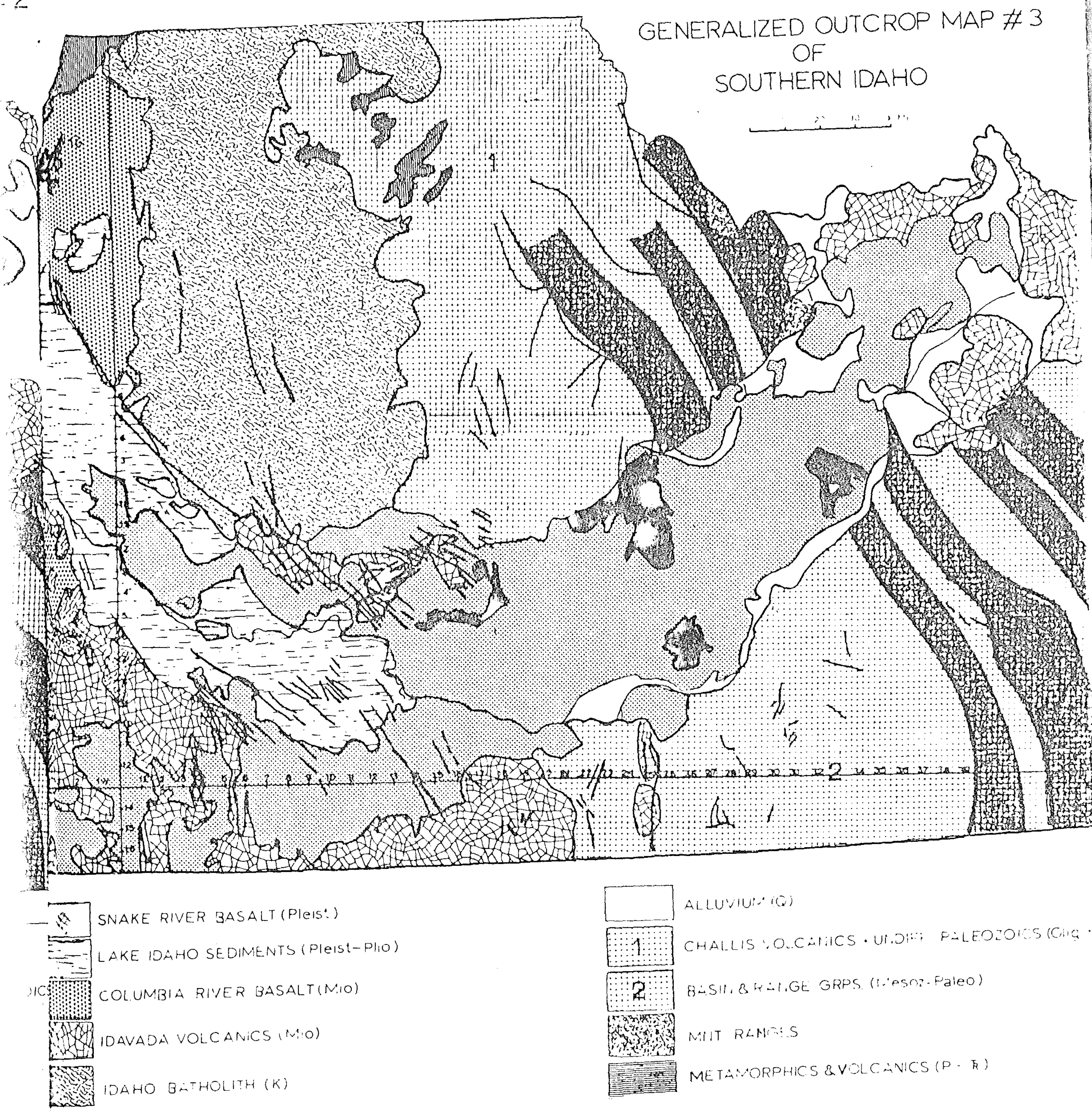
To extend the ranges and structures across the plain without the left lateral rift concept, it would be necessary to form a large "s" shaped fold in the whole mountain system. The rift interpretation is much simpler.

(3) A look at the geologic map of Idaho reveals the Snake River basalts of the eastern portion of the plain as a deposit of uniform breadth, and it is all north of the river. In the western half of the plain, this same deposit is spread out to twice the width of its eastern portion, with the central part missing, as though it had been split and pulled apart. Half the basalts are on one side of the river and half on the other side. By shifting the southern portion to the west and northwest about 45 miles, the deposits fit together with the same breadth as the eastern half. (See Maps 2 and 3). The faults that produced Craters of the Moon lava beds and those on the Wood River during the Recent epoch are large cross faults resulting from the rifting in the area of greatest curvature. They are evidence of the youthfulness of the Snake River Rift of this report. Prinz indicates a very young date for these north-northwest striking faults of 2130±130 years, and that an older rift system striking northeast is also prominent (Prinz, 1970).

(4) The swarm of faults located near the center of the western half of the plain (see Map 7) are grouped together for no apparent reason. Why most of the faulting should be concentrated in one compact area like this, is a difficult problem. However, when the southern portion is shifted westward to its pre-rift posi-

GENERALIZED OUTCROP MAP #2
OF
SOUTHERN IDAHO
(PRE-RIFT)



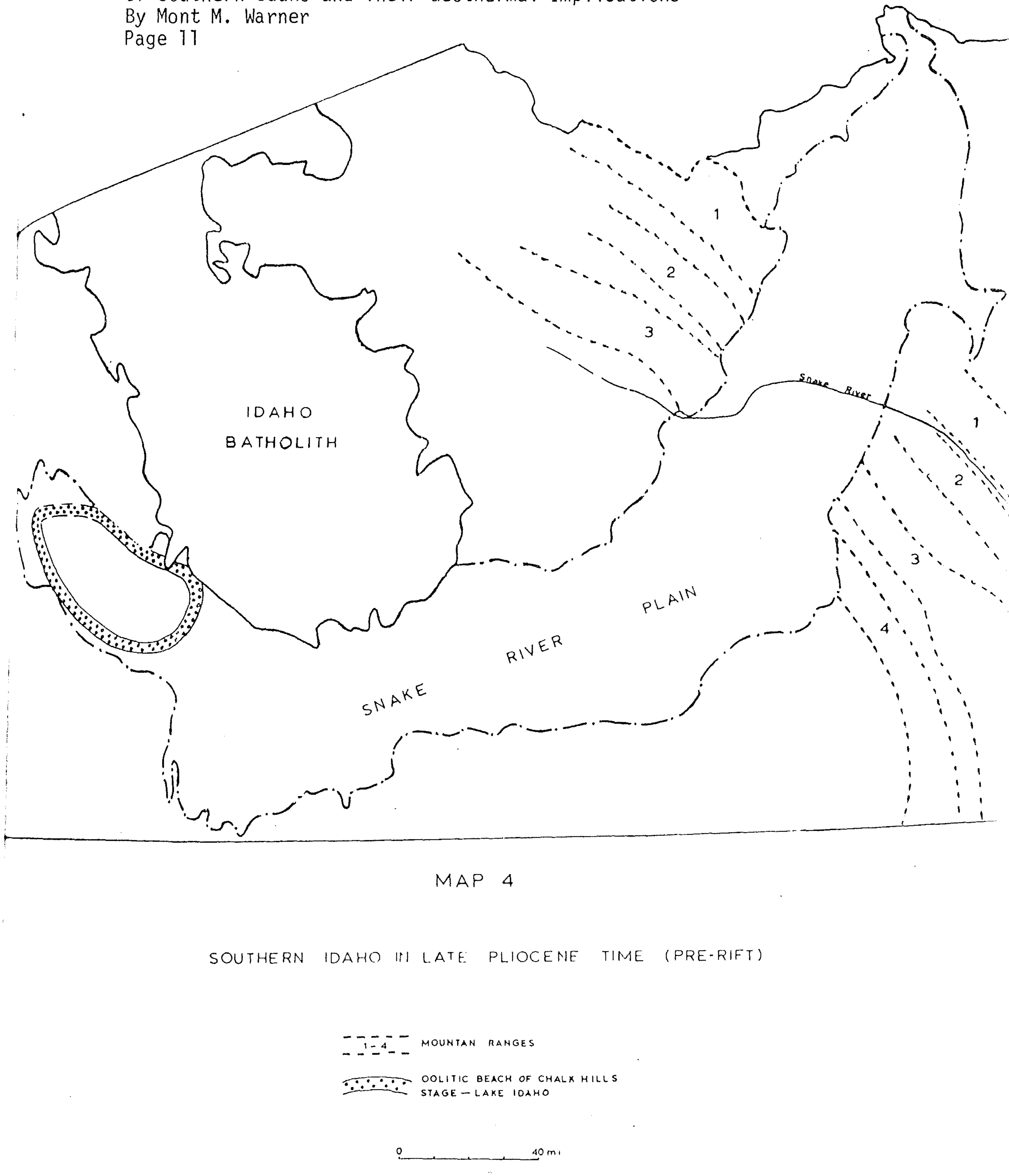

GENERALIZED OUTCROP MAP # 3
OF
SOUTHERN IDAHO
SNAKE RIVER BASALT (Pleist)
LAKE IDAHO SEDIMENTS (Pleist-Plio)
COLUMBIA RIVER BASALT (Mio)
IDAVADA VOLCANICS
IDAHO BATHOLITH (K)
ALLUVIUM (Q)
1
CHALLIS VOLCANICS + PALEOZOICS
2
BASIN & RANGE GRPS. Paleo)
MNT RANGES
METAMORPHICS & VOLCANICS

tion, the fault pattern becomes more reasonable. The faults are more uniformly distributed along the plain in a linear fashion as might be expected in a structural graben and are oriented more logically in regard to structural mechanics (see Map 6).

(5) Deposits of Columbia River basalts and Cretaceous granitic plutons in western Owyhee County appear to be displaced from the Columbia River basalts and batholitic material in Washington County, some 50 miles to the north. Pre-rift reconstruction positions these deposits in a more logical site, next to similar deposits around the Idaho Batholith. Taubeneck (1971) has shown that structural trends, gneissic border trends, and similar mineral compositions indicate that the granitic plutons in the South Mountain area of Owyhee County are probably extensions of the Idaho Batholith. He also states that an east-west change of about 50 miles in structural direction in southwest Idaho has occurred since Oligocene time. This directional change was from southwest to southeast. Such directional shift and also the amount of shift (50 miles) fit perfectly the Snake River Rift concept.

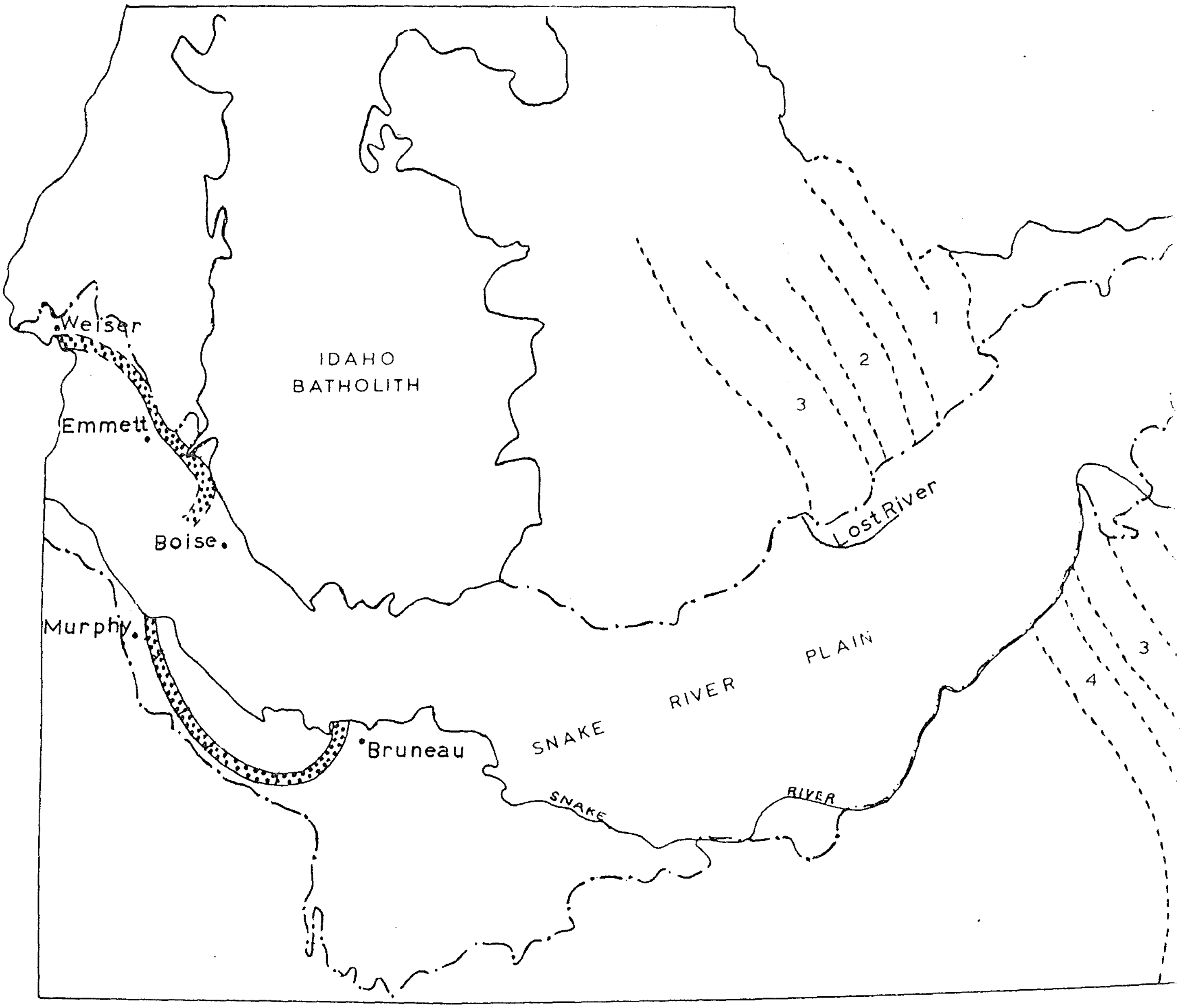
(6) A field study of ancient Lake Idaho (Rush and Smith, 1967) stratigraphy enabled this author to correlate deposits and outline an ancient beach of Pleiocene age. This beach is of the Chalk Hills stage of Lake Idaho and is represented by calcareous oolite deposits and fossil beds of mollusks, ostracods, diatoms, wood fragments and fish debris. The oolites are listed as basal Glenns Ferry by others, but since they represent the last stage of an evaporating and dying lake stage, it seems more appropriate to place them at the top of the Chalk Hills Formation. The abundance of fossil debris associated with the oolites is further evidence of the terminal nature of that particular lake environment. This Chalk Hills shoreline was traced from the Bruneau area along the northern edge of Owyhee County to the town of Murphy and also along the southern end of the Idaho Batholith from the vicinity of Emmett to north of Boise. This particular section of oolites is not found west of the Murphy site in Owyhee County nor east of Boise on the north side of the plain.

The shoreline facies pinch out in each case. The southern shore in Owyhee does not match with the shore to the north across the rift, but is offset by about 45 miles (see Map 5). Pre-rift reconstruction brings the two shorelines into perfect fit and outlines the original lake shore as it was before rifting occurred. (see Map 4). Very good marker beds (colored ashes, oolites, fossil beds and clay beds) were used in correlation, so there is no doubt about its accuracy. A bright red ash, called the Cherokee ash, is found at the top of the Poison Creek formation and is very persistent throughout the western half of the Snake



MAP 4

SOUTHERN IDAHO IN LATE PLIOCENE TIME (PRE-RIFT)



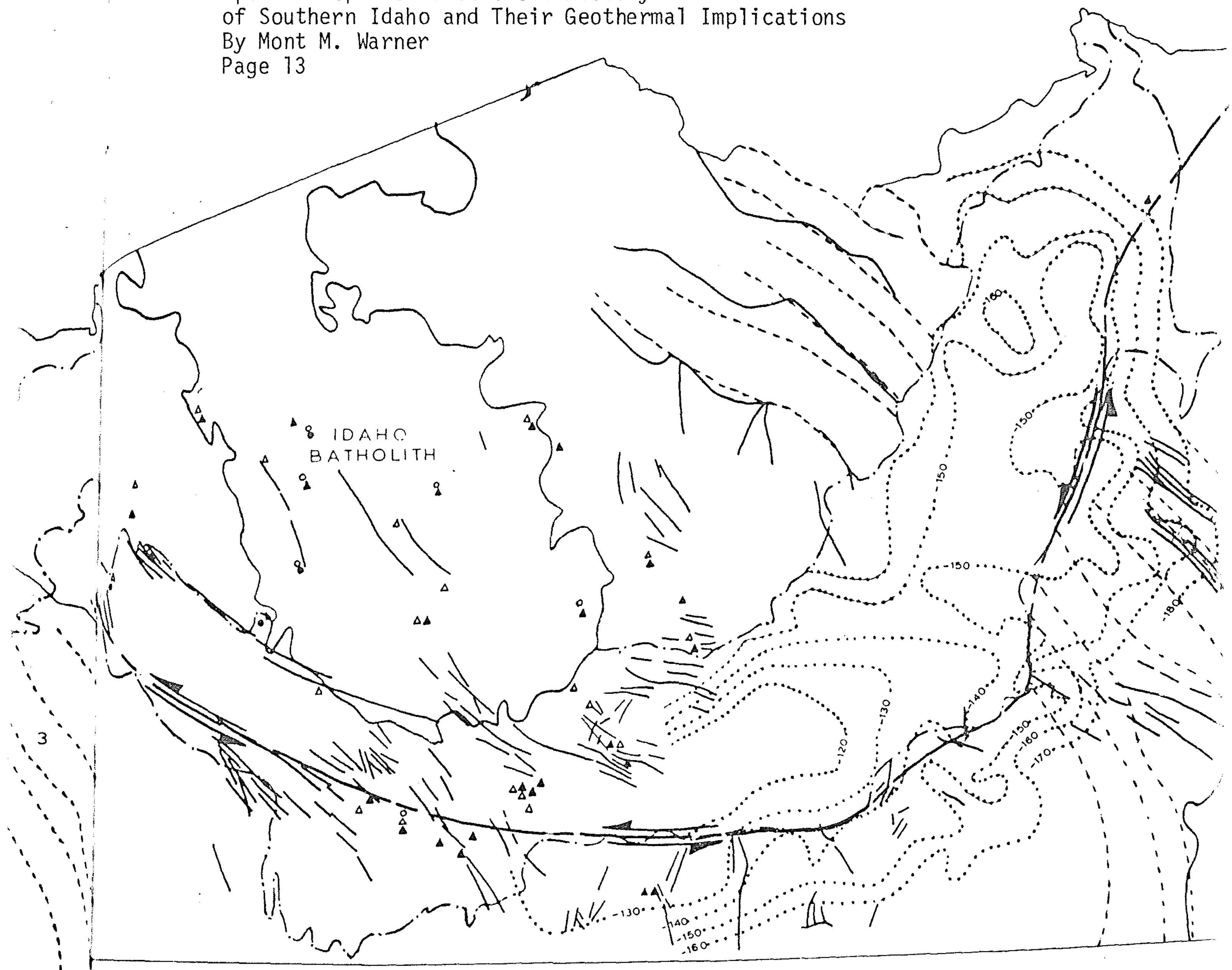
MAP 5

SOUTHERN IDAHO AT PRESENT (POST-RIFT)

1–4 MOUNTAIN RANGES

OOLITIC BEACH
CHALK HILLS STAGE — LK. IDAHO

0 40 mi



MAP 6

SOUTHERN IDAHO (PRE-RIFT)

IDAHO RIFT ZONE

GRAVITY CONTOURS (after HILL)

FAULTS

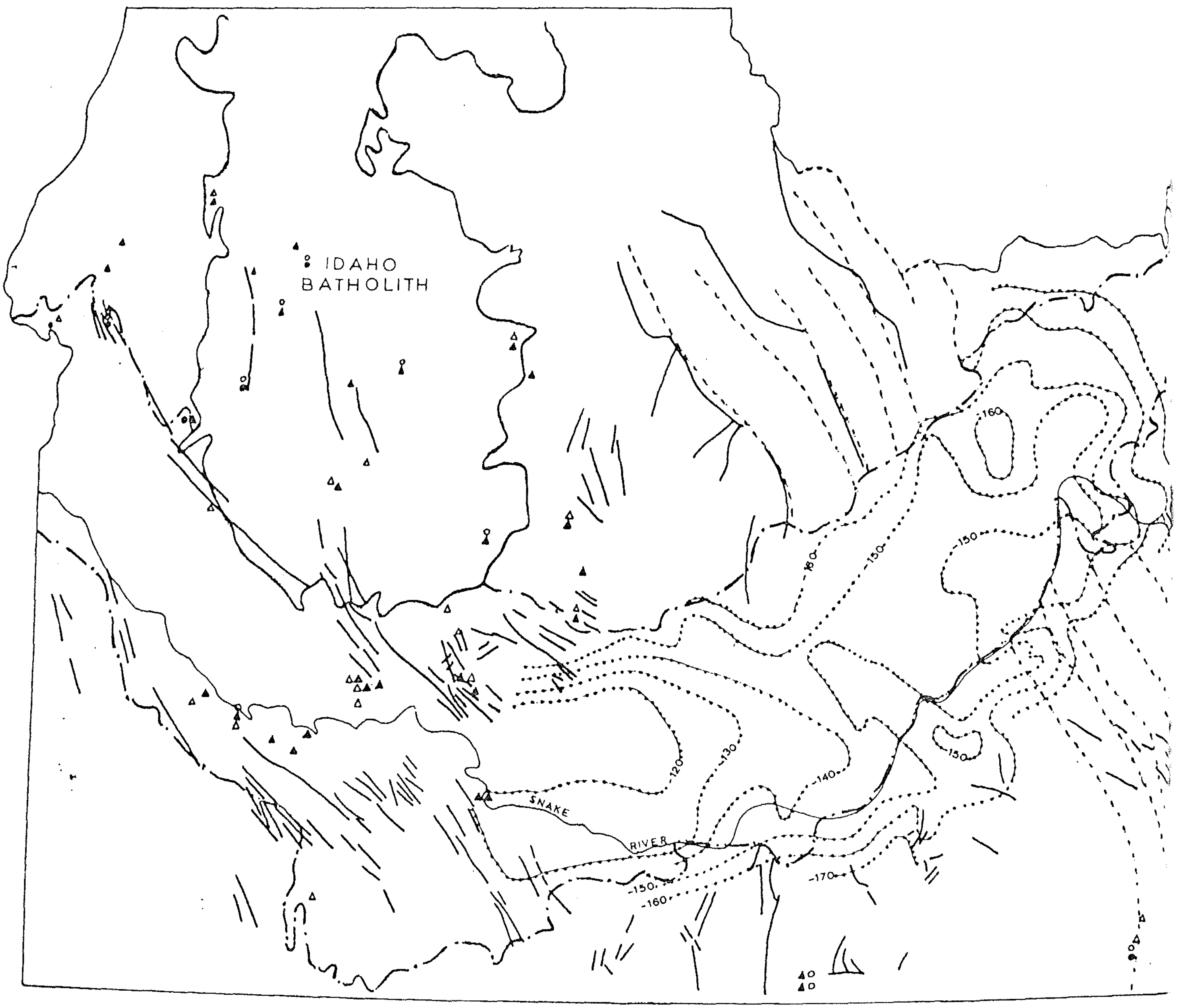
● 150° or more (C) from Si estimates

▲ 130° 149° " " "

○ > 80°C Surface Temp

△ 60°-70°C " "

0 40 mi.



MAP 7

SOUTHERN IDAHO (POST-RIFT)

SEE MAP 6 FOR SYMBOLS

0 40 mi.

River Plain. It is very uniform in color and thickness, being about 10 feet thick. This ash was very useful in correlating the stratigraphy. Maps 4 and 5 show the pre-rift and post-rift lake shores and the maximum offset caused by rifting. The following is a generalized description of the stratigraphic section in the vicinity of Murphy, Idaho.

Basal basalt	10-20 ft.	Glenns Ferry Formation (Pleistocene)
Silty clay, light gray to tan	250 ft.	
Calcareous oolites	15 ft.	Chalk Hills Formation (Pliocene)
Sandstone, fine-very coarse, gray	60 ft.	
Ash, glassy, gray-white	10 ft.	
Ashy silt, light tan	50 ft.	
Basalt, black	0-100 ft.	
Ash, bright red, crystalline	20 ft.	Poison Creek Formation (Pliocene)
Ash, yellowish brown, crystalline	20 ft.	
Ash, brownish pink, crystalline	5 ft.	
Tuff, greenish gray, clastic	30 ft.	
Ignimbrite, greenish gray-pink-yellowish gray	35 ft.	
Volcanic breccia, pebble size	5 ft.	
Tuff, yellowish gray, clastic	25 ft.	
Sandstone, medium-coarse, quartzose	20 ft.	
Tuff, yellowish brown, clastic	20 ft.	
Basalt, black	50-100 ft.	

(7) A series of anticlinal folds are situated south of the rift zone in Owyhee County. The folds plunge northward toward the Snake River Plain, but are not represented directly north of the rift zone from their present position. There are structural noses north of the rift some 50 miles west of these anticlines, which could be the original northern extensions of the anticlines.

(8) Water wells which had shows of gas are located on the northern end of some of the anticlines in Owyhee County. With pre-rift reconstruction, these wells are found to be directly opposite oil test wells north of the rift, which also had good gas shows, and were probably drilled on the northern extension of the Owyhee anticlines.

(9) Temperatures of hot springs and wells at the surface and those of ground water, estimated by geochemical means, are represented by symbols plotted on Maps 6 and 7. It is obvious that the hot water sites north of the rift (Snake River) coincide rather well with major fault zones. (See Map 7). South of the rift on the post-rift map, this relationship does not hold. On the pre-rift map, however, the hot water sites, both north and south of the rift, coincide well with major fault zones. (See Map 6). If the northern side had been the one that shifted rather than the southern side, none of the thermal sites would match the fault patterns. These relationships, therefore, indicate that there has been rifting; and that it was the block south of the rift that moved, and the northern block remained stationary. The deep-seated, stable batholith on the northern side and the Bannock overthrust zone of southeastern Idaho substantiate this interpretation. This interpretation also fits the concept of a counter-clockwise rotating block between the Snake River Plain and the Garlock Fault and between the San Andreas and Wasatch Front.

The original deep faults are apparently responsible for most of the hot spring activity and should be the best prospect sites. The present-day fault lines on the southern block will terminate at shallower depths and are not likely to connect with deep heat sources.

(10) The gravity interpretation of the Snake River Plain presented by Hill (1963) is favorable to the rift concept. Most of the anomaly in the western end of the plain is north of the rift. In the eastern end, the anomaly is more irregular in pattern and crosses the postulated rift zone. By shifting westward the anomalies south of the rift, a better fit with those north of the rift results; and the pattern becomes more uniform and less ambiguous. (See Maps 6 and 7).

(11) A well drilled three miles west of Meridian is located very near the preshift fault line of the rift zone. Considerable fault gouge was encountered in the well at a depth of 3,000 ft., as was expected.

(12) The Snake River enters Idaho from the southeast and upon entering the Snake River downwarp, makes an abrupt right angle turn and runs southwest to follow the downwarped graben around the southern end of the Idaho Batholith. Most of the tributaries show a similar pattern, flowing into the Snake River at right angles to its course. Such a stream pattern is typical of fault-controlled drainage. It has been postulated that the Snake River at one time ran northward. This theory fits the rift concept very well. Reconstruction of pre-rift conditions would place the Snake River entrance into the downwarp, 50 miles west of its present site. The course, projected northward, runs into the Lost River area and along the western side of the Lemhi Range into the Salmon River country. (See Map 4). The present Lost River could be losing its flow into the old Snake River channel.

(13) Hill and Pakiser (1966) have shown from a series of reversed seismic refraction profiles that the earth's crust thickens abruptly at the boundary between the northern Basin and Range Province and the western Snake River Plain. The crust under the plain is approximately 12 km. thicker, and the thickening is in the lower layer of crust, which has a seismic velocity of 6.7 km/sec.

This condition would be expected in a rift zone where volcanism could lift large masses of magma toward the surface along deep-seated faults (Hamilton and Myer, 1966). A natural zone of structural weakness might be expected at the junction of the differential thickening. The left lateral rift of this paper coincides generally with that junction.

(14) Deep wells and geophysical data from the central graben of the western Snake River downwarp indicate that there is between three and ten thousand feet of basalt beneath the central plain. A deep well of 11,000 ft. depth in the Castle Creek area of Owyhee County south of the rift zone encountered only a few hundred feet of basalt and only 2,000 ft. of siliceous and intermediate lava. The rift along the Snake River course, therefore, is a definite boundary between two different stratigraphic sections.

(15) The silicic volcanics shown on the geologic map of Idaho are also offset on opposite sides of the river. Those in the vicinity of the Raft River area about 50 miles east of those between

Fairfield and Magic. Armstrong and Leeman (1971) found these lavas in the western Snake River Plain to be 9-13 million years old, those in the central part, 8-10 m.y., and those in the eastern end, 4-5 m.y. old. In the Island Park and Yellowstone areas, they are two m.y. or less in age. This age relationship indicates the rifting began in the west and progressed eastward over the past 10 million years and fits nicely with the plate tectonics mentioned previously. They also found a general facies relationship from east to west, as follows: A) silicic volcanics with minor basalt and sediments, B) basalt flows with minor sediment and silicic domes, C) lacustrine and fluviatile sediments interbedded with basalt flows. During the 10 million years, these facies have shifted eastward across Idaho in a systematic manner at the rate of about four centimeters per year (Armstrong and Leeman, 1971). It is possible that this apparent shift in facies is the result of structural shifting and thrusting along the rift zone.

(16) All these listed features (structural, stratigraphic and geomorphic) which show left lateral displacement along the rift are displaced the same amount, between 45 and 50 miles.

Armstrong (1968) suggests that the material overlying gneiss domes in the Albion Range of southern Idaho is allochthonous and may represent rocks that originally lay far to the west of their present position. Thrusting such as this and the Bannock overthrust of southeastern Idaho might be expected along a major rift zone.

Schmidt and Mackin (1968) show that first order physiographic features in west-central Idaho are ranges and valleys formed by block faulting during late Tertiary and Quaternary. Also, middle Pleistocene lacustrine beds are tilted as much as 20^{0} off the edges of the Idaho Batholith. This late tectonism also reflects the young age of the Snake River rift, which probably caused the cross faulting and tilting.

SPECIAL EVENTS

In addition to the geothermal phenomena, other interesting conditions and events resulted from the tectonics over the past 10 million years.

PALEOHYDROLOGY

Miller suggests that, "Fossil fish may contribute important evidence for the existence of former lakes and streams and of their interrelationships with now-separated drainage systems." (Miller, 1965). There is evidence that old Lake Bruneau (Miller and Smith, 1967) was produced in late Pliocene by an early Snake River and persisted until early Pleistocene. It was then drained through capture by the Salmon River, which ran on to produce the Hells Canyon gorge and on to the Columbia River basin. Fish and mollusk fauna also indicate that the Snake River later ran southwesterly from Idaho via the Owyhee River into the Klamath basin of Oregon and northern California (Taylor, 1960).

A smaller lake, known as Lake Idaho, was later formed in the western end of the Snake River Plain (Miller and Smith, 1967).

This interpretation fits well with the present writers' theory of rifting and graben faulting of southern Idaho. The following sequence of events and conditions seems to be a reasonable summary of the paleohydrology: 1) In early Tertiary, a large structural and topographic basin was centered in southern Idaho and extended into parts of Oregon, California, Nevada and Wyoming, 2) Extensive volcanism of both basic and silicic nature began, and by the end of Pleistocene had filled the down-faulted basin with more than 12,000 feet of pyroclastics, lavas, and lacustrine sediments, 3) An early Snake River entered the present vicinity of Blackfoot and eventually filled the basin to produce old Lake Bruneau by mid-Pliocene time, 4) The Salmon River captured the lake and drained it through the Snake River gorge and the Columbia River basin, 5) The Snake River now ran northward across the drained basin into the Salmon River, 6) In mid-Pliocene, the Snake River Plain was produced by downwarping and graben faulting, and the new basin was filled with Lake Idaho, 7) The Idaho rifting began, and by mid-Pleistocene, caused Lake Idaho to drain to the west. This drainage took a fish hook pattern, following the Owyhee River southwesterly through southern Oregon, northwestern Nevada to northern California (See Fig. 1), 8) The Snake River now followed this drainage pattern along the rift until late Pleistocene uplift in southwestern Idaho caused the drainage to shift northward. Since that time, the river has followed the rift to Idaho's western border and then to the old Salmon River course through Hells Canyon. Southwestern Idaho is still structurally higher than the rest of the plain.

OOLITES

The top of the Chalk Hills formation in the western Snake River Plain is marked by oolite deposits from 20 to over 100 feet thick. At the base of the oolites, and at places associated with them is a bed rich in fish and mollusk fossils. The fish fossils consist of broken and scattered fragment, as though they were deposited by high energy deposition. The lithology varies from very fine silt to conglomerate. The sands and oolites are cross bedded and rippled with cross beds from a few inches in height and length to large ones 10 to 20 feet in size. The individual oolites range in diameter from 1/4 mm to 2 mm. The oolites in most cases have sand or silt grains as nuclei; and in composition they are over 97% carbonate, except where they have been silicified by thermal waters near fault zones.

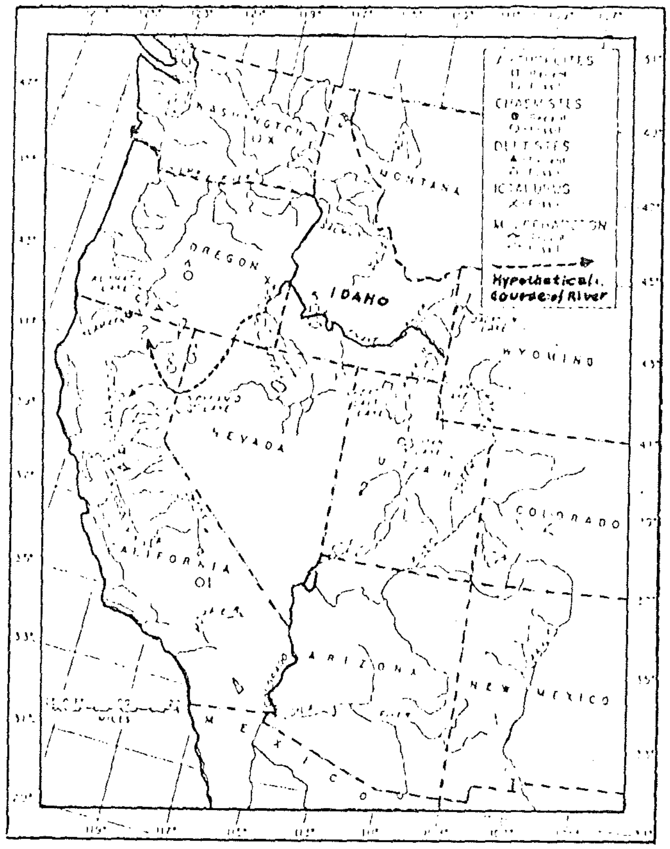


FIGURE 1

Hypothetical Course of an Early Pleistocene Snake River (after Taylor, 1960)

The sequence undoubtedly represents an ancient beach facies and has been dated as 3.5 million years in age (Taylor, 1966).

In the vicinity of the Indian Bathtubs south of Bruneau, there exists an algal reef of the same age as the oolites. The reef is stratigraphically equivalent to the oolite section and contains the same fossil fauna. It is approximately 20 feet thick and, before eroded, covered an area of about 30 square miles. It is highly porous and permeable limestone resting on lacustraine clay. It also is in a faulted area that contains hot springs.

An interpretation of the environment that produced the reef and oolites could be as follows:

Lake Idaho formed in the fault graben and supplied ground water to deep-seated faults along its edges. Hot springs developed along these faults and supplied hot water to the lake, keeping the water temperature relatively high. (These springs are still active in the vicinity of the algal reef.) The hot waters brought with them much mineral matter, including lime, silica and gypsum. Warm water algae grew and flourished in the lime-rich warm lake and precipitated the calcium carbonate as a limestone reef. Mullusks and fishes also flourished in the warm lake, and their fossil remains are found in and amont the reef deposits. Volcanic ash was showered into the lake from time to time and supplied it with additional mineral matter and an abundance of silica. Diatoms flourished in the silica-rich water and from place to place produced beds of nearly pure diatomite. At one stage (Chalk Hills) in late Pliocene, the lake began to subside, either by drainage or evaporation, and concentrated the salts. Calcium carbonate precipitated along the beaches, forming wide strips of oolitic sand. As the lake shores receded, the early oolite beaches washed back into the lake over the newly forming oolites to produce overlapping oolite and sand layers containing large sweeping crossbeds and reaching thicknesses up to 100 ft. in places.

BASIN DEVELOPMENT

Stratigraphic relationships between the Mountain Home area and Owyhee County indicate the following events:

1. An early Tertiary basin with a central axis south of the Snake River for the most part existed until mid-Pliocene time. This is evidenced by a relatively thick section of Miocene and early Pliocene volcanics and sediments in the southern sector.

2. In mid-Pliocene, a vertical displacement of approximately 2,000 feet occurred along the Idaho Rift, dropping the area north of the Snake River and forming a new structural basin (graben). This new basin was filled with a relatively thick upper Pliocene to Recent stratigraphic section. This section of basalts, ashes and tuffs is very different in lithology as well as thickness from its equivalent above the Owyhee rhyolite in Owyhee County.

3. There is probably more than 12,000 feet of volcanics and sediments in both basins, but the southern basin is filled mainly with Miocene or older rocks, while the northern basin is filled mainly with Pliocene or younger rocks.

CONCLUSIONS

The underlying extensions of the East Pacific ridges of high heat flow and the Snake River Rift, transverse to them, appear to be the prime controls on geothermal conditions in southern Idaho. Early subsidiary faulting to the rift helps to localize geothermal resources by directing percolating ground water to the rift and heat source. Thrusting associated with the active block south of the rift accentuated folding south of the

Snake River, displaced surface fault lines, and camouflaged subsurface conditions to a considerable degree. Mapping of size and thickness of oolite deposits, silicified zones and faults, along with resistivity surveys should be very helpful to geothermal prospecting in this area. The fact that some subsurface formational temperatures in deep wells do not match well with surface temperature implications nor with temperature estimates from geochemical indicators means that extreme care in the use of geochemical prospecting of this area is imperative. That portion of the Snake River Plain north of the rift has better correlation between structural elements and thermal anomalies than does the southern portion. Therefore, the northern side should be the easiest to prospect for geothermal resources, but will not necessarily have the best reservoirs. The above conditions, along with the great lava accumulations, imply that detailed geologic mapping and moderate depth resistivity surveys are probably the best means for geothermal exploration in southern Idaho.

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