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PHOTOGEOLOGIC INTERPRETATION OF THE
BALTAZOR-McGEE GEOTHERMAL PROSPECTS
HUMBOLDT COUNTY, NEVADA

for
EARTH POWER CORPORATION
TULSA, OKLAHOMA

by
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CONCLUSIONS

1. Geologically, the Baltazor-McGee area consists of Quaternary sediment atop Tertiary volcanic and sedimentary rocks, overlying a pre-Jurassic metamorphosed basement which has been intruded by Mesozoic granitic rocks. Faulting, basin subsidence and erosion have worked to expose these rocks in separate areas, with no complete section exposed anywhere.
2. The principal mountain ranges are bounded by normal faults which act as channels to conduct water to great depths. These trend mainly NNE-SSW (Basin and Range grain) and NW-SE. In addition, McGee Mountain, and the Pueblo and Pine Forest Mountains appear to be cut by intra-range N-S-trending normal faults, along which displacement has occurred.
3. Bounding faults can be projected to intersections at Bog, Baltazor and Gridley Hot Springs, as well as at the McGee Mountain fumarole.
4. Faulting has continued episodically into the Holocene epoch. However, Holocene displacement has not been as great as was Miocene and Pliocene-Pleistocene offset.
5. Metamorphic rocks mapped in the Pueblo Mountains and Pine Forest Mountains are persistent with depth, except where Laramide granitic rocks intrude or surround them. In those areas, metamorphic rocks may occur only as roof pendants, probably no thicker than 3,000 feet.
6. Tertiary rocks of the Pueblo Mountains include units of Oligocene to Pliocene age in Oregon, and may exceed 5,000 feet in total thickness. Most of this is Miocene Steens Basalt flows.
7. The McGee Mountain Tertiary rocks also may exceed 5,000 feet in thickness. However, the base of units younger than the Steens Basalt is not exposed, and it is unknown whether Steens Basalt (or equivalent units) occur in the subsurface. Basalt flows of the Pine Forest Mountains appear to be repeated by displacement along a north-trending fault.
8. The Steens Basalt flows, and their lithologic and stratigraphic equivalents (Pueblo Series basalts, and basalts on

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the west side of the Pine Forest Mountains), are potential fractured reservoirs where preserved from post-Miocene erosion beneath the intermontane valleys, and perhaps at McGee Mountain. The McGee Mountain block may have been positive in middle Miocene time.

9. Tertiary rocks in all parts of the prospect area are in unconformable contact with older rocks on a surface of moderate relief. This surface has been tilted westward; erosion has removed Tertiary rocks from the eastern slopes of the Pueblo and Pine Forest ranges. Later Miocene sedimentary rocks and tuffs were deposited in on-lapping positions onto the older Tertiary and pre-Tertiary, with angular unconformities of as much as 20° between older and younger Tertiary rocks.
10. The Pueblo Valley fault block dips steeply westward below Continental Lake Valley (Bog Hot Valley). Although Continental Lake is not known to be a graben, a series of N-trending fault-block segments, rotated with west-side down, may lead to 2,000 feet of burial of the Steens Basalt beneath later Tertiary sediments and ash-flow tuffs of the Thousand Creek and equivalent formations. The "western boundary" of the Pueblo Mountains block may be a NE-trending fault in the vicinity of Bog Hot Springs.
11. At McGee Mountain, there is no way to determine the attitude of rocks underlying the later Miocene ash-flow tuffs and sediments, nor to be certain of their lithology and age. Sections drawn by some workers show the Steens Basalt (or Pueblo Series) below the younger Tertiary rocks; this is hypothetical. If present, the Steens Basalt will be at least 3,000 feet thick, dipping westerly.
12. A NW-SE grain is imposed on the topography and drainage north of McGee Mountain, and this may be an indication of the proposed Eugene-Denio structural lineament (Lawrence, 1976). Such a lineament may be the result of strike-slip faulting during Tertiary and Quaternary time, adjusting the crust at the northern termination of the Basin and Range extension zone.
13. There was no volcanism north of the Black Rock Mountains from 43 to 34 m.y.b.p.; thereafter there was extensive and intensive

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multi-composition volcanism (34 to 24 m.y.b.p.), but with only a few rhyolitic eruptions. Except for the Ashdown tuff, there is an absence of age-dates in the 24 to 17 m.y. range regionally. There was considerable (mostly basaltic) volcanism from 17 to 6 m.y.b.p. However, there has been only minor basaltic eruptions, resulting in thin flows, from 6 m.y.b.p. to present.

14. No magmatic heat source can be inferred from the volcanic sequence or from structural geology or stratigraphy. Deep circulation of water is favored as heat source.

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PURPOSE AND SCOPE

GeothermEx, Inc. was asked by Earth Power Corporation in October 1977 to perform a photogeologic study of the Baltazor and McGee geothermal prospects, northern Humboldt County, Nevada and southern Harney County, Oregon (figure 1), as a means of evaluating the geothermal reservoir and heat source at these prospects. Work began in October and was completed in December 1977. It included a brief field reconnaissance, to clarify particular points. This report summarizes findings and offers interpretations of structural features, stratigraphy, recent tectonic events, and subsurface conditions.

PROCEDURES

Photogeologic Mapping

GeothermEx was furnished with 330 black-and-white aerial photographs, scale 1:24,000, covering an area of about 900 square miles on 165 stereo-pairs. An additional 40 black-and-white aerial photographs, scale 1:62,500, covered an area of about 800 square miles at the northwestern part of the area. The small-scale photographs duplicated the coverage of the larger-scale photographs for the most part, and extended far north of the prospect area in Oregon. However, they afforded valuable overviews of large parts of the prospect, in the vicinity of the southern Pueblo Mountains and Railroad Point.

The 1:24,000-scale photographs were studied in great detail; and all observed photo-linears were plotted on the photographs. Included as photo-linears are all straight, persistent topographic lines that transect several ridges and/or drainages; persistent tone, shade and texture lines; drainage lines; and lines of geologic frequency such as volcanic-eruptive and outcrop features. Thereupon, the same procedure was repeated with the 1:62,500-scale photographs, and the photo-linear data transferred from both sets of photographs to the 1:62,500-scale base map.

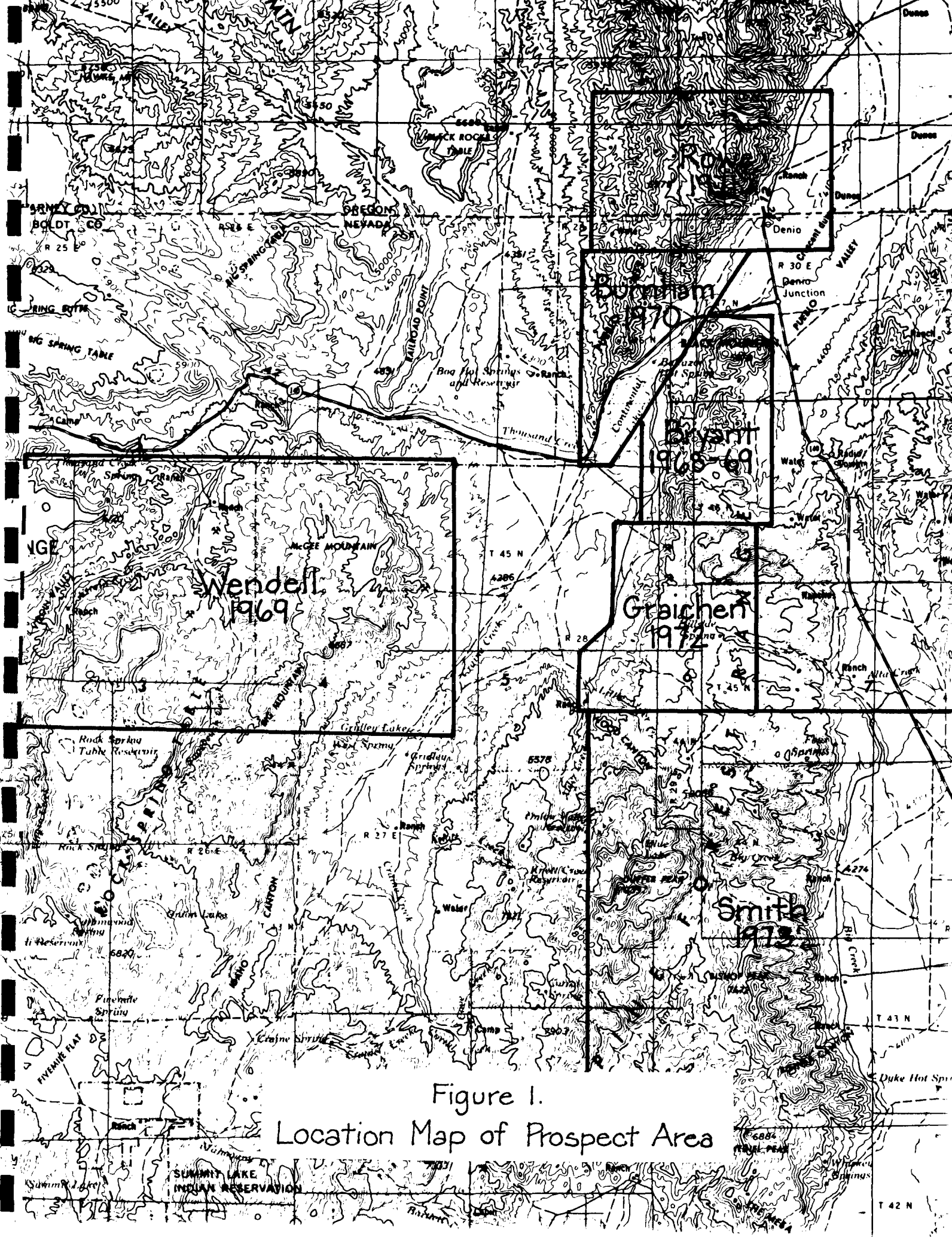


Figure 1.
Location Map of Prospect Area

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Review and Compilation of Existing Geologic Maps

Nine sources of surface geologic mapping were reviewed, interpreted and compiled with the photo-interpreted geology. (Complete references are given at the end of this report.)

Regional (small-scale) maps

1. Walker and Repenning, 1965, Reconnaissance geologic map of the Adel Quadrangle, Lake, Harney and Malheur Counties, Oregon, scale 1:250,000.
2. Willden, 1961, Preliminary geologic map of Humboldt County, Nevada, scale 1:250,000.
3. Stewart and Carlson, 1974, Preliminary geologic map of Nevada, scale 1:500,000.

Local (large-scale) maps

1. Burnam, 1971, Geology of the southern part of the Pueblo Mountains, Nevada-Oregon, scale 1:24,000.
2. Rowe, 1971, Geology of the south-central Pueblo Mountains, Nevada-Oregon, scale 1:24,000.
3. Wendell, 1969, Structure and stratigraphy of the Virgin Valley-McGee Mountain area, Humboldt County, Nevada, scale 1:24,000.
4. Bryant, 1969, Geology of the northernmost part of the Pine Forest Mountains, Humboldt County, Nevada, scale 1:24,000.
5. Graichen, 1972, Geology of the Pine Forest Mountains, Nevada, scale 1:24,000.
6. Smith, 1973, Geology of the Duffer Peak quadrangle, Humboldt County, Nevada, scale 1:48,000.

All the large-scale maps except Smith are from Master's degree theses carried out under the direction of Professor H. Enlows of Oregon State University, Corvallis, Oregon. Smith's map is a U.S. Geological Survey publication.

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Dr. Enlows rated the works by Burnam and Wendell high in comparison to the others, which may be classified as average by Master's level standards. However, Burnam has serious problems with the stratigraphic succession on the western slopes of the Pueblo Mountains: He misidentifies Quaternary alluvium in areas where Pliocene sediments and tuffs are seen on the photographs peeking through thin gravel and alluvial veneers. Wendell also maps alluvium to conceal problems in stratigraphic succession west of McGee Mountain, as well as in the valley east of McGee Mountain. Otherwise, the two studies appear to be compatible with the present work.

The work by Rowe is simplistic and covers a small area, but appears correct. The stratigraphy and areal distribution of units is in conformance with published work immediately to the north, in Oregon (Walker, 1965).

Graichen's map of the Pine Forest Mountains presents considerable difficulties. His map and cross-sections are based upon a presumption of unusual low-angle faulting and development of angular unconformities in the Tertiary section in the western part of the mountains. This makes his map hard to reconcile with data from the aerial photographs. His units are not compatible with the regional map by Stewart and Carlson (1974) nor directly consistent at the common border with the map by Smith (1973).

Bryant's map of the northern point of the Pine Forest Mountains is compatible with photogeology done for the present study. In the complex geology near the boundary between T. 46 N. and T. 45 N., there may be unresolved problems. Bryant also invokes a very steep angular unconformity between pre-Tertiary and Tertiary rocks, which may not be necessary.

The mapping by Smith is professional and correct. For the present study, photographic coverage existed only along the northern boundary of the Duffer Peak Quadrangle, in a strip one-half-mile wide. Observations in that strip were consistent with those by Smith.

Geology has been taken from these several sources only where there is no disagreement with the present photogeologic mapping.

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A common stratigraphic column was synthesized from the several source maps, and appears at table 1. Time-rock units are adapted from these sources wherever possible.

The photogeologic interpretation is given preference wherever it is in conflict with the previously mapped geology. The principal areas where changes have been made are at the margins of the mountain ranges. Wherever possible, the unit directly underlying the alluvium is shown, if the older unit can be seen in washes and small bluffs.

Where detailed mapping was not available, geology has been interpreted solely from the available air photographs, supplemented by use of regional maps by Walker (1965) and Stewart and Carlson (1974) as guides.

Physiography and general geology have been taken from Klein and Koenig (GeothermEx for Earth Power Corp., 1977), and are modified only where the present investigation produced new information.

GEOLOGY

Physiography and General Geology

The Balthazor and McGee geothermal prospects lie mainly within the Pueblo Valley-Continental Lake watershed, which covers about 1,500 square miles in northern Humboldt County, Nevada. An additional 280 square miles drains southward from southern Oregon toward Continental Lake along the west flank of the Pueblo Mountains (figure 1).

The mapped area includes parts of the Virgin Valley, Pueblo Valley, and valleys containing Gridley Lake and Continental Lake. The latter sometimes is called Bog Hot Valley or Thousand Creek Valley, but is referred to herein as Continental Lake Valley. It contains the hottest thermal manifestations of the area, Balthazor and Bog Hot Springs, and the Painted Hills Mine fumarole. The roughly east-west, arcuate Continental Lake valley is about 95 square miles in extent and receives drainage from Alder and Craine Creeks on the south, Rincon Creek from the north, and from

Table 1. STRATIGRAPHIC CORRELATION CHART

Project Area	REGIONAL				LOCAL			Radiometric Age Dates	Ages	
	Oregon	Nevada	Pueblo Mts (Rowe)	Pueblo Mts (Burnam)	Pine Forest Range (Bryant)	Pine Forest Range (Graichen)	Duffer Peak (Smith)			McGee Mt. (Wendell)
Alluvium, alluvial fans, fluvialite sediments, playa deposits, dune deposits, landslide deposits (QTal)	Alluvium, playa deposits, landslide deposits. Late basalt flows.	Alluvial deposits, playa, landslide, morainal deposits	Alluvium, playa deposits, alluvial fans	Alluvium, playa sediments, alluvial gravels	Alluvium, fluvialite and lacustrine deposits	Alluvium, colluvium (0-250')	Alluvium, alluvial fans, landslide deposits, Lake Lahontan deposits, older alluvium	Alluvium, playa sediments, landslide deposits, older alluvium	by K-Ar, in million years before present (m.y b.p.) (various sources)	Holocene Pleistocene
Basalt flows, includes flow dated at 1.2 m.y.b.p. and Mesa Basalt, which may be as old as Middle-Miocene (QTb)	Basalt and andesite, sedimentary deposits, sinter and tufa	Basalt flows and maar deposits						Mesa Basalt (15-35')		Blancan
Youngest sedimentary rocks, tuffaceous sediments, interbedded tuff, includes Thousand Creek Formation and equivalent rocks (Tstc)	Tuffaceous sedimentary rocks, tuffs and interbedded silicic flows, tuffaceous siltstone, sandstone, conglomerate, tuff, and interbedded basalt and andesite flows	Ash-flow tuffs and tuffaceous sedimentary rocks, rhyolite flows			Table 1			Thousand Creek Formation (360-1120')		Hemphillian Clarendonian
Youngest ash-flow tuffs and interbedded tuffaceous sedimentary rocks; includes Virgin Valley Formation (Tsvv)		Tuffaceous sedimentary rocks, tuff; equivalent of Thousand Creek Formation		Virgin Valley Formation		<Thicknesses estimated by author>		Virgin Valley Formation (370-1230')	14 Welded tuff at McGee Mtn. (Langenkamp) 15 Soldier Meadow 15.5 Summit Lake Tuff, in Black Rock Range	
Rhyolite welded tuffs and flows; includes Canyon Rhyolite, Idaho Canyon Tuff and Craine Creek Tuff and equivalents (Trcr)	Tuffaceous sedimentary rocks, tuffs and silicic flows equivalent to Virgin Valley Fm. and Canyon Rhyolite	Welded and non-welded silicic ash-flow tuffs, air-fall tuffs and sedimentary rock; equivalent of Virgin Valley Formation		Canyon Rhyolite (15.8 m.y.) (probably misassigned)			Idaho Canyon Tuff, Craine Creek Tuff	'Canyon Rhyolite' (probably misassigned) (40-600') Fluvial Sequence (600-1100')	16 Craine Creek Tuff	Barstovian
Ash-flow tuffs, welded and non-welded tuffs, air-fall tuff and sedimentary rock; includes "Middle Miocene Tuff" and "Middle Miocene Fluvialite Sequence" (Tt)	Flows and flow breccias; basalt and andesite flows with interbeds of tuffaceous sedimentary rocks, tuffs and scorias, equivalent to Steens Basalt in part	Basalt flows	Welded tuffs, non-welded tuffs (sillar) * Tuffaceous sedimentary rocks	Welded tuffs and air-fall tuffs* conglomerate, siltstones	Basalt dikes	Ash-flow tuff, volcanic sandstone (1200-1300')		Welded Tuff (180')		
Basalt flows; includes Steens Basalt, Pueblo Series and equivalent flows (Tv)		Steens Basalt	Steens Basalt	Basalt sequence of Steens Mountain	Olivine basalt	Basalt flows (2850-3200') Andesite Basalt	Steens Basalt	<Thicknesses estimated by author>	15-16 Steens Basalt	Hemingfordian
Ash-flow tuffs, air-fall tuffs and sedimentary rocks, and basal andesite flows; includes Ashdown Tuff (Tta)	Pike Creek Formation					Ignimbrite (equivalent to Ashdown Tuff) Rich pebbly volcanic sandstone Olivine andesite	Water-laid and air-fall tuff and Ashdown Tuff. Alkali andesite.		24-25 Ashdown Tuff 31.3 Pike Creek Fm.	Arikarian
Intrusive rocks, granodiorite, quartz diorite, quartz monzonite, diorite (KJgd)	Intrusive rocks; granodiorite and quartz diorite	Granitic rocks, mostly quartz monzonite and granodiorite, diorite	Acidic intrusions, quartz monzonite, biotite granodiorite, quartz diorite	Intrusions, diorite; andesite and aplite dikes	Plutonic rocks; granodiorite, diorite	Plutonic rocks; diorite, quartz monzonite	Intrusive diorite, granodiorite and other granitic rocks		92 at Duffer Creek	Cretaceous Jurassic (?)
Metamorphic rocks, metasedimentary rocks, metavolcanic rocks, greenstones, hornfels (JPU)	Metamorphosed sedimentary and volcanic rocks; silicic grits, greenstones, calc-hornfels.	Metasedimentary rocks, shale, mudstone, siltstone, sandstone, and carbonate (metasedimentary) rock;	Metamorphic sequence, metasediments, include greenstone, phyllites, schists, quartzite, marble	Metamorphic rocks; metasediment, includes greenstone, quartzite, schists	Metamorphic; metasediments; arkosic quartzite, biotite schist, marble, amphibolite	Metamorphic rocks; metasedimentary rocks include arkosic quartzite and biotite schist, marble and amphibolite	Metasedimentary rocks; quartzite, marble, amphibolite, phyllite, chert, hornfels, metavolcanic rocks			Jurassic, Triassic,

Pliocene

Miocene

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Virgin Valley to the west via Thousand Creek. Alder Creek and Thousand Creek flow perennially but disappear into alluvium before reaching the usually dry Continental Lake playa. Gridley Valley is a southward extension of Continental Lake Valley; the two valleys are separated by a few tens of feet of topographic relief. There is similarly low relief across a narrow gap between the Pueblo Mountains to the northwest and the Pine Forest Range to the southeast, which separate Continental Lake and Pueblo Valley. During infrequent periods of high runoff, Continental Lake may spill northeastward through this gap into Pueblo Valley, which is tributary to the Alvord Desert in Oregon.

Continental Lake and Pueblo Valley are structural depressions displaced downwards by faulting relative to surrounding mountain ranges. The valleys may be dip-slope features of the principal range blocks, or grabens. The valley floors generally are flat and roughly 2 to 6 miles wide, surfaced by playa deposits, sand dunes and alluvium in the lowest parts.

The topographic relief is likely the result of persistent structural adjustment, during the Pleistocene and Holocene epochs. Bounding the valleys on the north-northwest is the Pueblo Mountain range, a large fault block that extends northward into Oregon. Southeast is the Pine Forest Range, another westward tilted fault block that extends southward. To the west of the valleys, up-faulted Tertiary landforms of note are the Black Rock Table and Big Springs Table at the north and McGee Mountain-Big Mountain at the south.

The Pueblo and Pine Forest Ranges are composed of pre-Tertiary igneous and metamorphic rocks, overlain unconformably by Tertiary lava flows and pyroclastic rocks.

In the Pueblo Mountains, the lower part of the Tertiary section consists of the Steens Basalt or Pueblo Series basalts, which in other locations exceed 5,000 feet in thickness. These are overlain by up to 500 feet of tuffaceous sediments, tuff and ignimbrite. Above the basalt, the total thickness of tuffs, volcanic sediments and rhyolite is 2,000 to 2,300 feet, and possibly more.

In the western part of the region, at McGee Mountain, topography is formed by a few relatively recent fault scarps, displacing a thick section of generally flat-lying Tertiary flow

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rocks and their sedimentary derivatives. Virgin Valley is deeply incised in a thick section of volcanic tuff and lake beds, and cuts a narrow steep-walled canyon through rhyolite in Thousand Creek Gorge.

The thickness of sedimentary fill in Continental Lake Valley is uncertain and variable. The oldest Quaternary alluvium probably grades downward into interbedded and interfingering Tertiary volcanic and sedimentary rocks. The total thickness of rocks above the pre-Tertiary crystalline basement may vary from 4,000 to 7,000 feet, but may be much less. In addition, the volcanic sequences and crystalline rocks beneath the valleys undoubtedly are broken into uneven relief by normal faults which strike NNE-SSW and NW-SE. Farther north, in Alvord Valley, Oregon, the northern extension of Pueblo Valley, the probable maximum thickness of fill indicated by gravity studies is about 3,300 to 5,000 feet. However, Alvord Valley is a graben bounded on both the east and west by normal faults, whereas for the valleys in the prospect area it cannot be shown clearly that there are faults on both sides.

On its west side, Continental Lake Valley clearly is bounded by the fault escarpments of the Pueblo Mountains and McGee Mountain. Basalt flows exposed at the western base of the Pine Forest Range dip 25° to 27° westward beneath the valley fill; if a fault exists, it is not apparent. Fill in Continental Lake Valley may be wedge shaped, thickening westward. Buried structures also may be present. As the valley is about 1.5 miles wide just south of Baltazor Hot Spring, the basalts project to a depth of 3,700 feet below valley surface at the Pueblo range front. The basalts also could be overlain by rhyolite flows, tuff and tuffaceous sediments at least 800 feet thick; and the maximum thickness of fill may easily be one to two thousand feet less than 3,700 feet.

The Quaternary valley fill along the McGee Mountain escarpment appears to be very thin. McGee Mountain is composed of 2,000 to 3,200 feet of tuff, tuffaceous sediments and rhyolites of Miocene and Pliocene age, which may overlie several thousand feet of basalt flows. Vertical displacement on the McGee Mountain fault has been estimated to total only about 500 feet, placing the top of the pre-middle Miocene welded tuffs and sedimentary rocks 2,000 feet below the valley surface, with the 2,000± feet of post-middle Miocene tuffs and volcanic sediments above. This leaves only a very thin veneer of Quaternary alluvium on top.

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No useful information was obtained from the only deep well in the region, at Knott Creek Ranch (T.D. 1,150 feet; 43N-27E-4A), south of Gridley Lake in Gridley Valley. Its log lists clay, sand and gravel overlying granite at 1,148 feet.

Stratigraphy

Stratigraphy of the McGee Mountain-Baltazor area is synthesized mainly from six sources: five Master's degree theses (Bryant, 1969; Wendell, 1969; Burnam, 1971; Rowe, 1971; Graichen, 1972) and one published map (Smith, 1973). Regional sources (Walker, 1965; Stewart and Carlson, 1974) were useful for regional correlations. There was reasonable stratigraphic consistency amongst the six authors.

Rocks exposed in the Pueblo Mountains, Pine Forest Range and McGee Mountain areas range from Permian(?) - Triassic to Holocene in age (table 1, Stratigraphic Correlation Chart).

Pre-Tertiary Rocks

Two main groups of pre-Tertiary rocks are found in the area. The oldest is a belt of Permian(?) to Triassic sedimentary and metavolcanic rocks. These metamorphosed rocks are intruded by granitic rocks of Jurassic and Cretaceous age.

For the purpose of this report, the metasedimentary and metavolcanic rocks are all considered as one unit, even though Bryant (1969), Smith (1973) and Graichen (1972) divided them on the basis of composition and metamorphic grade. The rocks are phyllitic to schistose in texture, and dip steeply and in some places are highly contorted. The rocks are of greenschist metamorphic facies and are thought to have been altered during Jurassic-Cretaceous time. They generally trend north to northeast and dip steeply to either east or west.

Plutonic rocks with granitic textures are present in the central and eastern parts of the Pine Forest and Pueblo Mountains, and form the younger pre-Tertiary unit. Here, also, they are shown as a single unit, although field mapping by previous workers has

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distinguished at least 5 major plutonic bodies. These are quartz diorite, quartz monzonite, granodiorite, alaskite and spilite. Minor gabbro occurs also. Such features as sharp contacts between individual plutons, xenoliths of one rock type within another, discordance of foliation, and assimilation indicate several episodes of intrusion.

Radiometric age-dates indicate that intrusion and crystallization occurred during the Cretaceous Period. Age-dates range from 80 to 101 m.y.b.p. (Carlson and others, 1975).

Selected attitudes of lineation have been taken from prior mapping and are plotted on the geologic map (plate 1).

Tertiary and Quaternary Rocks

Tertiary rocks of the area span the Oligocene to Pliocene epochs, and are all volcanic or derived from volcanic rocks. Radiometric age-dates range from a maximum of 30 m.y.b.p. for an olivine andesite at the base of the Tertiary section in the area mapped by Graichen (1972), to 1.2 m.y.b.p. for the Mesa basalt north of Railroad Point.

The Stratigraphic Correlation Chart (table 1) presents Miocene-age basalt flows generally at the base of the Tertiary section in the Pueblo Mountains. In the Pine Forest Mountains, a series of andesite flows, Miocene ash-flow tuffs and volcanic sandstones appear to underlie the basalts. In the McGee Mountain area, Miocene rocks younger than the Steens Basalt flows are the oldest rocks exposed.

In the Pine Forest Mountains, the oldest Tertiary rocks are andesite flows, volcanic sandstone and air-fall and ash-flow tuffs, including a prominent ash-flow named the Ashdown Tuff (Smith, 1973). The Ashdown Tuff has been age-dated at about 24 m.y. This may be correlative with the Pike Creek Formation of the northern Pueblos, as described by Walker (1965).

Overlying the tuff and sandstone sequence is a thick olivine basalt unit, that generally is correlated with the Steens Basalt of middle and late Miocene age. The basalt flows have been measured from 2,000 to more than 3,000 feet in aggregate thickness

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in the Pueblo and Pine Forest Mountains. Individual flows range from 5 to 100 feet in thickness. Minor interbeds of ash-flow and air-fall tuff occur, mostly in the upper part of the basalt unit.

These thick basalts generally strike north-south and dip gently to moderately to the west.

The Steens Basalt was not observed at McGee Mountain (Wendell, 1969). However, a thick sequence of basalt flows and flow breccias has been assumed by Wendell (1969) to be present in the subsurface (his "Pueblo Mountain Basalt Series").

Welded and non-welded tuffs and tuffaceous sedimentary rocks (volcanic sandstone), overlie the Steens Basalt both in the Pueblo Mountains and the southern parts of the Pine Forest Mountains, whereas only silicic tuffs and clastic sediments are exposed in the middle and late Miocene section at McGee Mountain. There, the "Middle Miocene Welded Tuff" (200 feet thick), and "Middle Miocene Fluvial Sequence" (600 to 1,000 feet thick) (Wendell, 1969) apparently are younger than the Ashdown Tuff and volcanic sandstones of the Pine Forest Mountains and probably are stratigraphically above the Steens Basalt.

Rhyolite is exposed in the McGee Mountain area and Pueblo Mountains. It consists of both flows and welded tuffs, resting unconformably upon the middle Miocene fluvial sequence. The unit was named the Canyon Rhyolite by Merriam (1910), and the name is retained by Wendell (1969) and Burnham (1971). The unit is not identified by name in the Pine Forest Mountains, but there the welded Idaho Canyon Tuff (Smith, 1973) is at about an equivalent stratigraphic position. However, it originated from a separate source.

Some flows of the McGee Mountain area still retain initial surface flow ridges and lobes. Vent areas for the flows also are easily identified.

The average thickness of the lower rhyolite flows, measured by Wendell (1969) along the McGee Mountain escarpment, is 380 feet. This represents overtopping and coalescing of several flows from closely spaced vents. The welded tuffs of the upper part of the Canyon Rhyolite are from 40 to more than 100 feet thick. At McGee Mountain summit, a thickness of 197 feet suggests that the source vents were nearby.

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A thick sequence of tuffaceous sedimentary rocks, tuffs and interbedded silicic flows unconformably overlies the Canyon Rhyolite. The sequence also includes tuffaceous siltstone, sandstone, diatomite, lignite, conglomerate, air-fall vitric tuff, and basalt and andesite flows. In type localities, the sequence has been named the Virgin Valley Formation and the Thousand Creek Formation on the basis of distinctive fauna of different ages in the two formations. Cumulatively, the strata are 600 to 2,400 feet in thickness. Wendell (1969) suggest that an erosional and minor angular unconformity separates the Virgin Valley Formation from the Thousand Creek Formation. Strata below the unconformity have gentle folds, whereas strata above it are undeformed and flat lying. Such minor structural detail was not evident on the aerial photographs.

Much fracturing and alteration occurs in the Virgin Valley Formation, particularly the deposition of opal and gypsum, and iron straining. This alteration is probably hydrothermal. The presence of diatomite provides a source of free silica for the opalitzation.

The Virgin Valley and Thousand Creek Formations reflect a nearly continuous lacustrine and fluvial environment from middle Miocene to early Pliocene. Similar lake basins existed in many parts of the region during this time; for example, the upper Cedarville Series of Surprise Valley, California was deposited during the late Miocene and early Pliocene epochs.

The Virgin Valley Formation probably represents a single lake basin, isolated at times, whereas the Thousand Creek Formation appears to represent concurrent and younger fluvial deposits in a broad adjacent area to the north and east.

A rhyolitic welded tuff present in two areas along the eastern scarp of McGee Mountain was mapped (Wendell, 1969) as post-Thousand Creek-Virgin Valley, and probably Pleistocene in age. Samples collected by Langenkamp (1977) were age-dated radiometrically at 14 m.y.b.p. Apparently, the material is an upthrown fault slice, having no relationship to Pleistocene volcanism.

The Mesa Basalt caps the Pliocene sediment, and crops out on prominent high mesas of Rock Spring Table, Gooch Table and other similar features. The unit is from 15 to 35 feet thick, quite extensive, and probably originally covered about 500 square

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miles immediately west of the leasehold area. The Mesa Basalt has been dated as middle Pliocene by stratigraphic relationships.

The youngest volcanic rock unit of the area is a basalt flow in the north-central part of the Railroad Point quadrangle. The basalt is flat-lying and caps and protects the underlying Thousand Creek Formation from erosion on the long, narrow mesa called Railroad Point. Its composition is identical to the Mesa Basalt and it occupies the same stratigraphic position. It may have originated from vents near the Oregon-Nevada boundary. A radiometric age-date of 1.2 m.y.b.p. was obtained from a sample.

Regional Structure

This part of the Basin and Range structural province is characterized by northeast- and north-trending fault-block mountains and valleys. Most of these are tilted blocks, but some simple horst and graben structures occur. The northwest-trending faults generally have less offset and have not produced major fault block mountains.

The fault sets may indicate a simple stress system in the crust and resultant wrench faults from a relative north-south compression, east-west extension. According to Lawrence (1976), the result of this extension has been development of several zones of right-lateral strike-slip faults, as well as normal, dip-slip faults. The function of the strike-slip faults is to absorb strains at the Basin and Range province boundaries in Oregon.

One strike-slip fault zone postulated by Lawrence (1976) trends S 55° E to S 60° E, and runs from Eugene, Oregon to Denio, Nevada. The southeasternmost part of the zone is marked by the low pass between the Pueblo and Pine Forest Mountains.

Deformation may have begun as early as Oligocene time, and certainly by the early Miocene epoch, as demonstrated by the stratigraphic record. Several episodes of deformation, with intervening quiet episodes, have occurred in Oregon and northern Nevada. The two episodes of greatest faulting in the area were during the middle Miocene and late Pliocene-early Pleistocene epochs. The presence of fresh-appearing small fault scarps at the base of major ranges and fault offsets of the Quaternary mesa-forming basalt indicate that the Basin and Range deformation has persisted

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to the present time, although probably diminished in intensity. Additional evidence suggesting very young strike-slip faulting is presented by Richens and Ryall (1973) in their discussion of the 1973 earthquake swarm near Denio. They concluded that fault-plane solution of the seismic events indicate right-lateral oblique-slip motion on a plane striking N 11° W and dipping 60° E. This direction is about 40° northward of the trend of the projected Eugene-Denio zone of strike-slip motion, as well as northwestward of the predominant trend of the Basin and Range faults.

Local Structural Features

The principal positive features in the area are Big Mountain-McGee Mountain, Pine Forest Mountain and Pueblo Mountain. Principal negative features are Pueblo Valley and the Continental Lake Valley basins. The Virgin Valley syncline is a broad, shallow trough at the western margin of the area.

Big Mountain-McGee Mountain

The Big Mountain-McGee Mountain fault block is marked by an eastward-facing arcuate boundary fault, convex eastward, at the eastern margin of the mountain. A change of fault direction from northeast to northwest may represent intersection of Basin and Range grain with the Eugene-Denio lineament. Within the mountain block, principal fault and photo-lineations trend N 15-35° E and N 15-45° W. All faults appear to be steeply dipping and normal. Some lineations have no discernable movement; however, the principal range-bounding fault, which Wendell (1969) called the Major Fault, probably has from 500 to several thousand feet of displacement. Wendell measured a maximum of 700 feet. Wendell also mapped three sub-parallel faults at the easternmost salient of McGee Mountain. These probably are minor, and were not conspicuous on the aerial photographs. These faults appear to be associated with a change of trend from northeast to northwest along the major fault. A surface thermal anomaly (hot ground near the Painted Hills Mine) may be controlled by this change of principal grain (Klein and Koenig, 1977).

Throughout northern McGee Mountain, faults and photo-linears are approximately parallel to the northwest-trending

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main range-front fault. In the southern part of the McGee Mountain block, the interior faults and linears trend north-eastward, again parallel to the principal fault.

Wendell (1969) mapped a northward-trending anticline with gently dipping limbs in the eastern part of the McGee Mountain block. This could not be verified by photogeology. Some beds west of the axis of the proposed fold do dip westward, from 5 to 15°. Wendell proposed, from the record of deformation and erosion of selected strata, that doming of the anticline occurred in middle Miocene and again in early Pliocene epoch. There is no evidence to support doming by a new intrusive magma.

Late Pleistocene to Holocene movement along the major arcuate fault has resulted in dissection of older alluvial fans and development of fresh low scarps in the alluvial deposits. Significant landsliding is present throughout the area, and the major landslides show little or no dissection, indicating their recency. If doming or uplift has been active as suggested, it is not known to be associated with magma emplacement or with eruption of volcanic materials.

Pine Forest Mountains

The Pine Forest Mountains consist of a main north-south eastern ridge, with a secondary western ridge centering on Duffer Peak. Wood Canyon and Leonard Creek separate the two parts of the range.

The mountains are a dissected westward-tilted fault block, with a principal normal fault along its east side.

Dips measured by Bryant (1969) and Graichen (1972) in olivine basalt on the western part of the range are persistently 20 to 30° westward. There are no Tertiary rocks exposed on the eastern side of the range for a comparison of attitudes.

The offset of volcanic rocks and the projection of dipping units from west to east suggest at least 3,000 feet of normal displacement on the principal fault. Movement on the fault was probably episodic, principally during Miocene, Pliocene and Pleistocene-Holocene epochs.

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Thus, it appears that the range is a single tilted block, west side down, east side up. It has been suggested that the structure is more complex, and that a west-side bounding fault is present, making the range a horst block.

A photo-linear trends northeastward from the vicinity of Vicksburg (section 12, T. 46 N., R. 28 E.), where Bryant mapped a fault with southeast side up. No linear feature was observed on the aerial photographs where Bryant proposed and mapped a northwest-trending fault extending across the range from near Vicksburg. According to Bryant, the southwestern block was raised about 500 feet relative to the northeastern block along this fault.

Northeast, west-northwest- and northwest-trending joints appear as linear features in the northern part of the range. Northerly linear features occur in eastern Alkali Flat adjacent to the range. Quartz veins with east-northeast and north-northwest trends fill joints near the Ashdown Mine. Bryant described several episodes of deformation recorded by foliation and folding of metamorphic rocks. These features are restricted to the schists, and are not easily seen on the aerial photographs. The metamorphism is related to events and igneous intrusions of pre-Tertiary age; consequently, only the effects upon permeability of reservoir rock resulting from the deformation is pertinent to geothermal exploration.

In T 44 and 45 N, R 28 E, doming has affected rocks as young as the Miocene(?) Ashdown Tuff. Folds, faults and dike-filled joints are present in these townships and the structure is quite complex. Relationship to deep-seated igneous bodies is hypothetical, however, and not clearly supported by fact.

Pueblo Mountains

The southern Pueblo Mountains are a tilted fault block which appear to be a northward continuation of the structure of Pine Forest Range. The range-front faults are normal, trend northeast, and diagonally truncate the internal structure of the Mountain range, resulting in its narrowing and eventual disappearance to the south. These faults also are responsible for the rather narrow gap between the Pueblo and Pine Forest Mountains, now occupied by Continental Lake Valley. As Burnam (1971) suggested, the

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local and regional structure show that the two ranges originally were joined as a single north-trending fault block that later was separated by northeast-striking normal faults with the down-thrown side to the southeast. This appears to be more logical than invoking strike-slip faulting to explain the configuration.

Volcanic and sedimentary rocks in the Pueblo Mountains form a generally north-striking and west-dipping homoclinal structure. Dips are about 20° in the Tertiary strata. Older northeast-trending structures characterize the pre-Tertiary terrain. Schistosity and original bedding strike $N 20^\circ$ to 40° E and dip $S 35^\circ$ to 80° E. Many small, tight folds occur in the schistose rocks. Granitic intrusions have followed the northeast trends.

Burnam (1971) and Rowe (1971) discussed displacements of individual, parallel range-bounding faults, and estimated a total of 6,000 to 8,000 feet of relative movement in the faults bounding the Pueblo Mountains.

Stratigraphy indicates that faulting has persisted at least through part of the Pliocene Epoch. Erosion of older basin deposits (probably Pliocene) and geomorphology support persistence of faulting to the Pleistocene Epoch.

Steep scarps with only minor dissection, fault scarps cutting alluvium near the mouth of Denio Creek (off map), and lack of elevation adjustments in segments of Pueblo Valley again indicate persistence of faulting into Holocene time.

SUMMARY

All of the major thermal manifestations, including Baltazor, Bog and Gridley hot springs, and the hot area at McGee Mountain, can be associated with principal faults. The geologic map (plate 1) shows the presence of north-northeast-trending photolineaments close to each of the thermal features.

Furthermore, Hose and Taylor (1974) have described a northeast-trending fault system, which they term a lineament, apparently based upon unpublished mapping by Noble (1969) to which they were privy:

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A small-scale (AMS 1:250,000) map of western Humboldt County, Nevada, discloses a prominent lineament beginning in the vicinity of a large cluster of hot springs close to Soldier Meadow, and trending N. 30° to 35° E. through Baltazor Hot Spring into Pueblo Valley, Oregon and Nevada, a distance of more than 65 miles (fig. 6). Attempts to understand the relationship of this lineament to the hot springs are based on unpublished reconnaissance geologic mapping by D. C. Noble (1969).

Noble's geologic map shows the lineament to be considerably more complex than the topographic map indicates. Just north of Summit Lake the lineament splits and both branches appear to be controlled partly, although not wholly, by faults. Perhaps less prominent structures, such as joints in the Tertiary lavas, contribute to the lineament. In any case, the faults are of only modest displacement. The eastern branch at the northern end is a concealed fault of very large displacement that truncated the Pueblo Mountains at an angle of about 50° from their trend. Baltazor Hot Spring rises from this part of the lineament. The western branch of the lineament extends along faults as far north as McGee Mountains [sic] and is inferred to extend farther north beneath what Noble mapped as late Miocene tuffs to terminate at Bog Hot Springs.

The tremendous contrast in magnitude of faulting along the lineament suggests, to us at least, that the lineament existed as a large fault in the Early Tertiary terrain and that tectonism that occurred after the Oligocene and Miocene volcanic rocks were deposited resulted in modest renewed displacement that manifested itself in the volcanic cover.

The geologic map produced from photographs available for this study, other existing maps, and the general geologic literature for the region all point toward fault-controlled flow of meteoric water to great depth, and subsequent lateral flow and rise along other faults. Temperature-gradient data are not entirely supportive of this conclusion. The anomalous areas on the temperature gradient map (Langenkamp, 1977) are not strongly linear, and tend to cross basins and ranges equally. However, the density of holes is not great. Fault-controlled deep flow rather than a magmatic heat source, is indicated for the Baltazor-McGee prospect.

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