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PHOTOGEOLOGIC INTERPRETATION OF THE

BALTAZOR–McGEE GEOTHERMAL PROSPECTS

HUMBOLDT COUNTY, NEVADA

for

EARTH POWER CORPORATION

TULSA, OKLAHOMA

by

GeothermEx, Inc.

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CONCLUSIONS

1. Geologically, the Baltazor-McGee area consists of Quaternary sediment atop Tertiary volcanic and sedimentary rocks, over-lying a pre-Jurassic metamorphosed basement which has been intruded by Mesozoic granitic rocks. Faulting, basin sub-sidence 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 Moun-tains 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 persistant 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 Oligo-cene 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 strati-graphic 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 ero-
sion 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 sedi-
mentary rocks and tuffs were deposited in on-lapping positions
onto the older Tertiary and pre-Tertiary, with angular uncon-
formities 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 Contin-
ental 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 hypo-
thetical. 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 pro-
posed 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 goethermal 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 par-
ticular points. This report summarizes findings and offers inter-
pretations 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 over-
views 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 photo-
graphs. Included as photo-linears are all straight, persistant
topographic lines that transect several ridges and/or drainages;
persistant 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 trans-
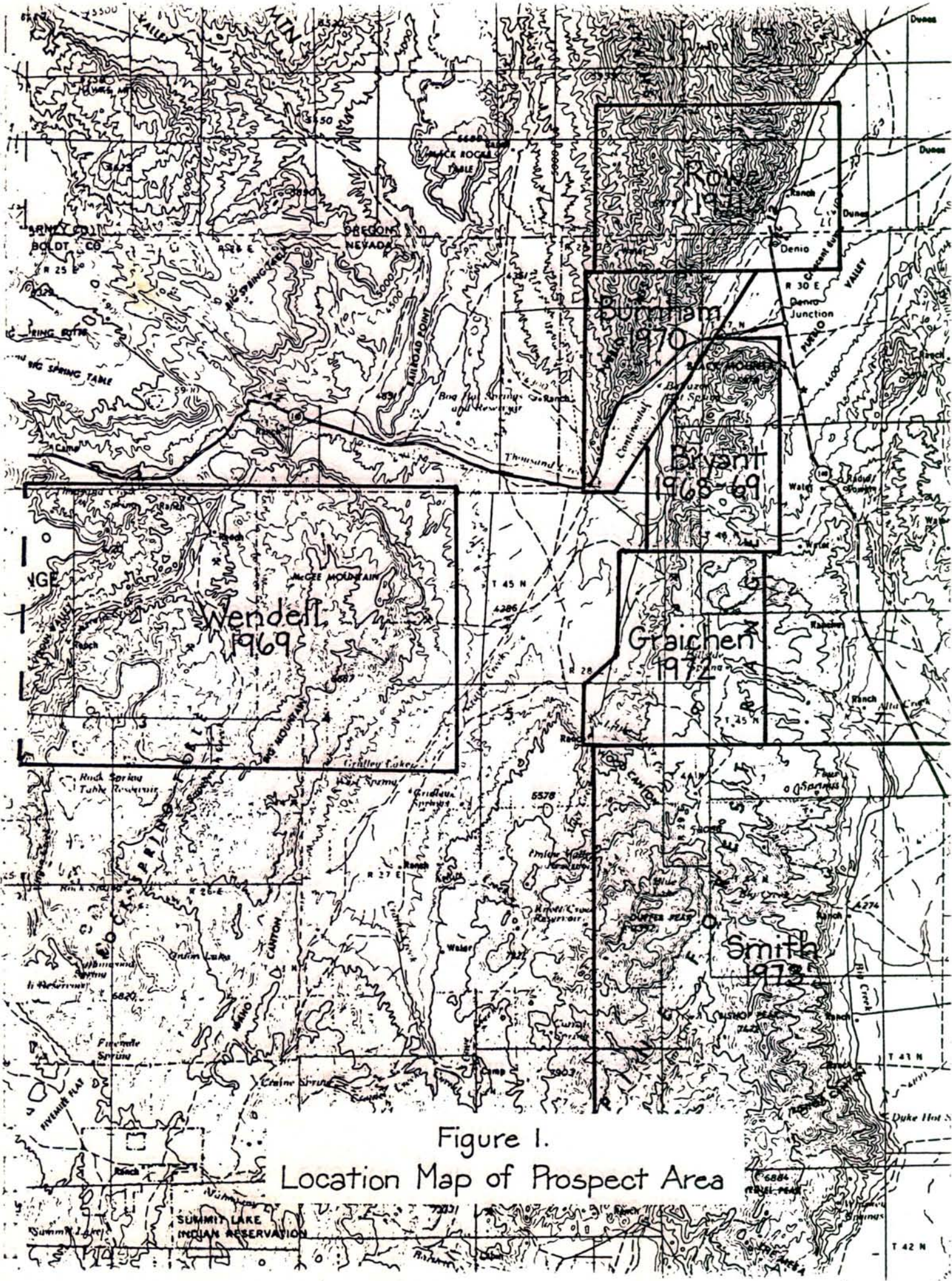ferred from both sets of photographs to the 1:62,500-scale base
map.

Figure I.
Location Map of Prospect Area

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.

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 consistant 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.

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

	REGIONAL		
Project Area	Oregon	Nevada	Pueblo Mt
Alluvium, alluvial fans, fluviatile sediments, playa deposits, dune deposits, landslide deposits (QTal)	Alluvium, playa deposits, landslide deposits. Late basalt flows.	Alluvial deposits; playa, landslide, morainal deposits	Alluvium; play alluvial fans.
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	
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 ↑ Tuffaceous sedimentary rocks, tuff; equivalent of Thousand Creek Formation	
Youngest ash-flow tuffs and interbedded tuffaceous sedimentary rocks; includes Virgin Valley Formation (Tsvv)		Welded and non-welded silicic ash-flow tuffs, air-fall tuffs and sedimentary rock; equivalent of Virgin-Valley Formation	
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	↓	
Ash-flow tuffs, welded and non-welded tuffs, air-fall tuff and sedimentary rock; includes "Middle Miocene Tuff" and "Middle Miocene Fluviatile 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 (sillar) * Tuffaceous =
Basalt flows; includes Steens Basalt, Pueblo Series and equivalent flows (Tv)		Steens B.	St
Ash-flow tuffs, air-fall tuffs and sedimentary rocks and basal andesite flows; includes Ashdown Tuff (Tta)	↓ Pike Creek Formation	↓	
Intrusive rocks, granodiorite, quartz diorite, quartz monzonite, diorite (KJgd)	Intrusive rocks; granodiorite and quartz diorite	Granitic rocks, mostly quartz monzonite and granodiorite, diorite	Acidic intrus monzonite, b quartz diori
Metamorphic rocks; metasedimentary rocks, metavolcanic rocks; greenstones, hornfels (JPu)	Metamorphosed sedimentary and volcanic rocks; silicic grits, greenstones, calc-hornfels, schists	Shale, mudstone, siltstone, sandstone, and carbonate (metasedimentary) rock; volcanic flows, and flow breccias (metavolcanic rock)	Metamorphic metasediment stone, phyli quartzite, m

(*c

Table 1. STRATIGRAPHIC CORRELATION CHART

s. (Rowe)	Pueblo Mts (Burnam)	Pine Forest Range (Bryant)	Pine Forest Range (Graichen)
deposits;	Alluvium, playa sediments, alluvial gravels	Alluvium; fluviatile and lacustrine deposits	Alluvium, colluvium (0-250)
			⟨Thicknesses estimated⟩ by author
	Virgin Valley Formation		
	Canyon Rhyolite (15.8 m.y.) (probably misassigned)		
non-welded tuffs limentary rocks	Welded tuffs and air-fall tuffs* conglomerate, siltstones	Basalt dikes	Ash-flow tuff, volcanic sandstone (1200-1300')
ns Basalt	Basalt sequence of Steens Mountain	Olivine basalt	Basalt flows (2850-3200') Andesite Basalt
		Ignimbrite (equivalent to Ashdown Tuff) Rich pebbly volcanic sandstone Olivine andesite	Volcanic sandstone, ash-flow tuff (equivalent to Ashdown), andesite (K-Ar = 25.3 ± 5 m.y.)
ns. quartz tite granodiorite,	Intrusions, diorite; andesite and aplite dikes	Plutonic rocks; granodiorite, diorite	Plutonic rocks; diorite, quart monzonite
sequence, ; include green- s schists, le	Metamorphic rocks; metasediment; includes greenstone, quartzite, schists	Metamorphic; metasediments; arkosic quartzite; biotite schist, marble, amphibolite	Metamorphic rocks; metased mentary rocks include arkosi quartzite and biotite schist marble and amphibotite (>1800')

ine Creek Tuff reported by Noble, 1970)

Duffer Peak (Smith)	McGee Mt. (Wendell)	Radiometric Age Dates	Ages	
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	
	↑ Mesa Basalt (15-35') ↑ Thousand Creek Formation (360-1120')		Blancan Hemphillian Clarendonian	Pliocene
	Virgin Valley Formation (570-1230')	14 Welded tuff at McGee Mtn. (Langenkamp) RTI 15 Soldier Meadow 15.5 Summit Lake Tuff, in Black Rock Range		Miocene
Idaho Canyon Tuff, Craine Creek Tuff	"Canyon Rhyolite" (probably misassigned) (40-600') Fluvial Sequence (600-1100') Welded Tuff (180')	16 Craine Creek Tuff	Barstovian	
	⟨Thicknesses estimated by author⟩		Hemingfordian	
Steens Basalt		15-16 Steens Basalt		
Water-laid and air-fall tuff and Ashdown Tuff. Alkali andesite.		24-25 Ashdown Tuff 31.3 Pike Creek Fm.	Arikarian	
Intrusive diorite, granodiorite and other granitic rocks		92 at Duffer Creek	Cretaceous, Jurassic (?)	
Metasedimentary rocks; quartzite, marble, amphibolite, phyllite, chert, hornfels, metavolcanic rocks			Jurassic, Triassic, Permian (?)	

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Virgin Valley to the west via Thousand Creek. Alder Creek and
Thousand Creek flow perenially 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 depres-
sions 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 persistant
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, vol-
canic 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

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 allu-
vium 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 val-
leys 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 escarp-
ment appears to be very thin. McGee Mountain is composed of 2,000
to 3,200 feet of tuff, tuffaceous sediments and rhyolites of Mio-
cene 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 rock 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

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 epi-
sodes of intrusion.

Radiometric age-dates indicate that intrusion and crystal-
lization 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 Fluviatile 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 fluviatile 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 equiva-
lent 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, sand-
stone, 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
opalitization.

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 Forma-
tion appears to represent concurrent and younger fluviatile depo-
sits 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 radio-
metrically 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

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 identifical 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 moun-
tains 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 strati-
graphic 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 Moun-
tain. Principal negative features are Pueblo Valley and the Con-
tinental 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; how-
ever, 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 north-
west 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

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 erup-
tion 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 Pleisto-
cene-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

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° to 40° E and dip S 35° 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 persistance 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.

<div align="center">SUMMARY</div>

All of the major thermal manifestations, including Balta-zor, 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 photo-lineaments 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 consid-
erably 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 dis-
placement. 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 litera-
ture 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 tempera-
ture 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 mag-
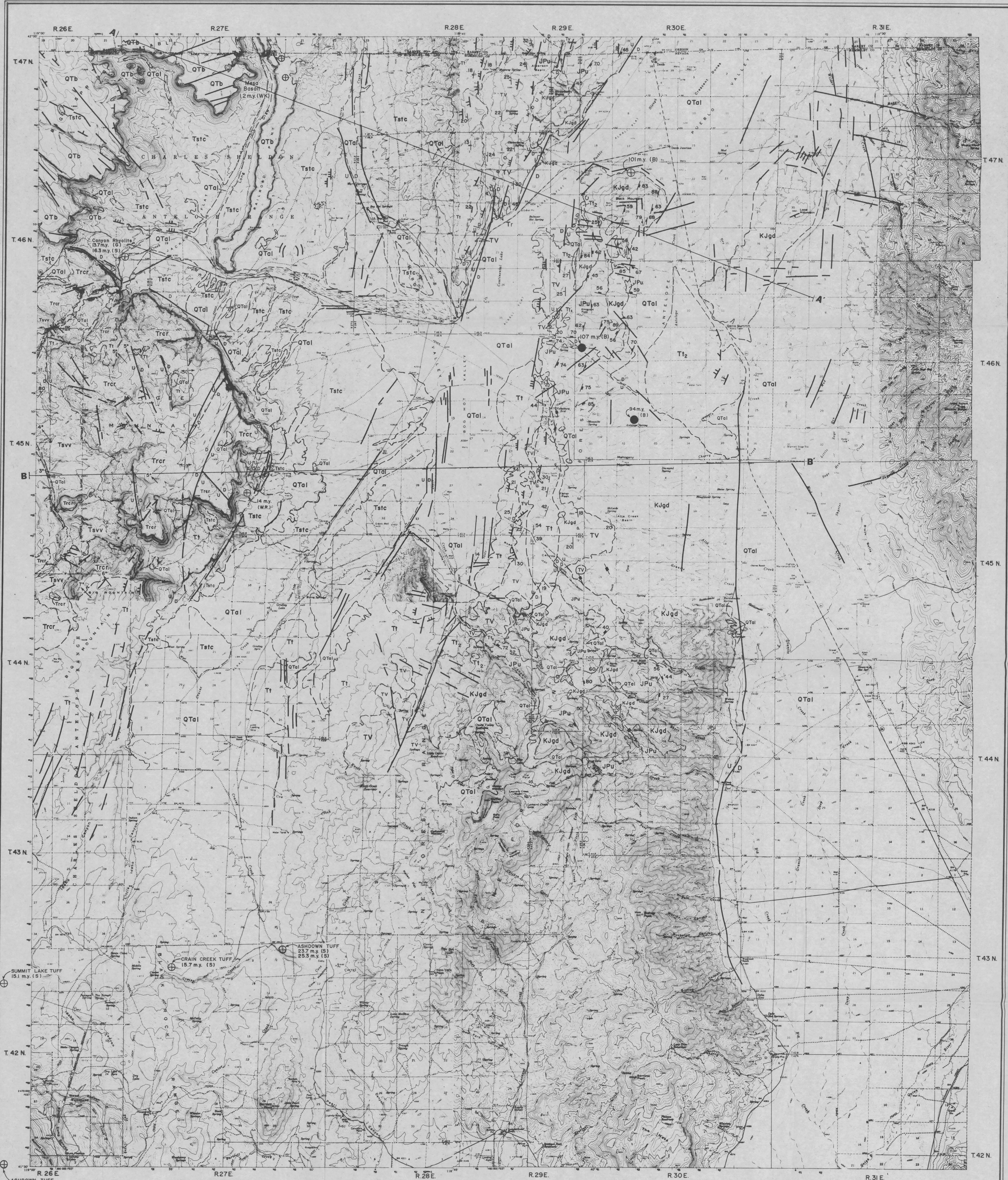matic heat source, is indicated for the Baltazor-McGee prospect.

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EARTH POWER PRODUCTION COMPANY
TULSA, OKLAHOMA

GEOLOGIC MAP

BALTAZOR-McGEE GEOTHERMAL PROSPECTS
HUMBOLDT COUNTY, NEVADA

DATE: OCTOBER 3, 1978	DRAWN BY : J.R.T.
SCALE : 1:62,500	SURVEY

PHOTO-GEOLOGY BY: GEOTHERMEX, FEB. 1978
MURRAY GARDNER
JAMES KOENIG

SCALE 1:62500

CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

GEOLOGIC LEGEND

QTal	Alluvium, etc.	Tt	Ash-flow tuffs, fluviatile sediments	
QTb	Basalt flows	Tr	Rhyolite of south end of Pueblo Range	
Tstc	Youngest sediments	TV	Steens Basalt	
Tsvv	Youngest ash-flow tuffs	Tt₂	Older ash-flow tuffs	
Trcr	Rhyolite flows	KJgd	Granitic rocks	
		JPu	Metasediments and metavolcanics	

Contacts, dashed where approximate
Lineaments interpreted from photographs- Unupthrown side
D= downthrown side
Faults, location from referenced sources, dashed where approximate   U= upthrown side   D= downthrown side
Measured altitude, dip and strike from referenced sources
Measured altitude, trend and dip of foliation from referenced sources
Location of radiometric age dates
Approximate location of radiometric age dates

< 5°
5 -10°
10 -25°
25 -45°
< 45°

REVISIONS

RHYOLITE of BLACK ROCK RANGE 25 m.y. (S)
CRAIN CREEK TUFF 15.7 m.y. (S)
ASHDOWN TUFF 23.7 m.y. (S) 25.3 m.y. (S)
SUMMIT LAKE TUFF 15.1 m.y. (S)
ASHDOWN TUFF 23.9 m.y. (S)
Canyon Rhyolite 16.3 m.y. (G)
Mesa Basalt 1.2 m.y.(WK)
14 m.y. (W.R.)
101 m.y. (B)
107 m.y. (B)
94 m.y. (B)

CHARLES SHELDON ANTELOPE RANGE

R.26 E. R.27 E. R.28 E. R.29 E. R.30 E. R.31 E.

T.47 N. T.46 N. T.45 N. T.44 N. T.43 N. T.42 N.