REPORT ON THE BROTHERS FAULT ZONE

CROOK, DESCHUTES, LAKE, AND

HARNEY COUNTIES, OREGON

by

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December 1978

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Brothers Fault Zone

Table of Contents

	<u>Page</u>
Introduction.	1
Regional Geothermal Potential	1
Previous Work	3
Regional Geology of the Brothers Fault Zone	6
Hydrology and Geochemistry.	8
Temperature Gradient Data	9
Western Part of the Brothers Fault Zone	10
Glass Buttes Area	13
Eastern Part of the Brothers Fault Zone	13
Conclusions	17
Recommendations	18
Bibliography.	20
Appendix I - Gradient Hole Information	I
Adel, Oregon AMS Sheet	I
Burns, Oregon AMS Sheet	III
Crescent, Oregon AMS Sheet	VII
Calculated Gradients - Crescent, Oregon AMS Sheet	XI
Glass Buttes, Oregon	XIII
Alvord Desert, Oregon	XIV

LIST OF FIGURES

	Page
Figure 1. Location Map.	2
Figure 2. Detailed Map of southeast Oregon showing selected structural features.	4
Figure 3. Photo of the central part of the Brothers Fault Zone and Glass Buttes	11
Figure 4. Photo of Brothers Fault Zone near Iron Mountain	14
Figure 5. Photo of Iron Mountain.	15

LIST OF PLATES

Plate No.

Geologic Map of Crescent AMS Sheet.	1
Geologic Map of Burns AMS Sheet	2
Geologic Map of Adel AMS Sheet	3
Crescent AMS Sheet Temperature Gradient Map	4
Crescent AMS Sheet 100' Isothermal Map.	5
Crescent AMS Sheet 200' Isothermal Map.	6
Burns AMS Sheet Temperature Gradient Map.	7
Burns AMS Sheet 100' Isothermal Map	8
Burns AMS Sheet 200' Isothermal Map	9
Adel AMS Sheet Temperature Gradient Map	10
Adel AMS Sheet 100' Isothermal Map	11
Adel AMS Sheet 200' Isothermal Map	12

Introduction

The Brothers fault zone is a major structural lineament which trends northwesterly across central Oregon (Figure 1). Within the past four years geological and geophysical data have been published which suggest the Brothers fault zone is an attractive regional geothermal prospect. Additional work by Phillips Petroleum Company has confirmed the published work and added much new and encouraging temperature gradient information.

During the summer of 1978 Phillips drilled 43 shallow temperature-gradient holes in and near the eastern half of the Brothers fault zone. This drilling program has completed a reconnaissance temperature-gradient survey of the Brothers fault zone.

This report is being written at this time to consolidate the work done to date, and to begin the process of further evaluating the areas within the Brothers fault zone which require more detailed exploration. Other large-scale tectonic features similar to the Brothers fault zone are identified as possible new regional geothermal exploration targets in southeast Oregon.

Regional Geothermal Potential

Lawrence (1976) has presented convincing evidence that the Brothers fault zone forms part of the northern boundary of the Basin and Range province in Oregon. At the present time the margins of the Basin and Range province are highly attractive regional geothermal prospects. The Roosevelt geothermal field in Utah is located near the eastern boundary of the province, while Coso California, Long Valley California, and Steamboat Nevada are located on, or near, the western boundary. Admittedly these prospects are near a boundary which is expressed by normal faulting, while the Brothers fault zone is primarily a boundary of lateral displacement (Walker, 1969). In spite of this difference the Brothers fault zone is believed to be an excellent regional

FIGURE 1

MAP OF OREGON SHOWING THE LOCATION OF THE AREA OF INTEREST.

ALSO INCLUDED ARE MAJOR STRUCTURAL FEATURES AND RHYOLITIC DOMES IN THE SOUTHEASTERN PART OF THE STATE. (BLACK AREAS) HACHURES ARE SHOWN ON THE DOWNTOWN SIDE OF THE LARGER FAULTS OF THE BASIN AND RANGE PROVINCE.

(FROM MACLEOD ET. AL. 1975)

geothermal prospect.

MacLeod and others (1975) have defined two 250-km-long belts of rhyolitic domes which trend N75°W in southeastern Oregon (Figure 2). The northern belt, consisting of about 100 domes, ranging from 14.7 m.y. to 1200 years in age cuts across the Brothers fault zone at a low angle. This relatively close association between the Brothers fault zone and fairly young siliceous volcanism is a second important regional factor.

In the middle 1970's the Oregon Department of Geology and Mineral Industries (DOGAMI) published several open-file reports containing temperature and heat-flow data from shallow temperature-gradient holes in and near the Brothers fault zone. Hull and others (1977) showed that over much of its length the Brothers fault zone has anomalously high heat flow.

It is primarily due to the DOGAMI temperature-gradient work that Phillips became actively interested in the Brothers fault zone.

Previous Work

Recognition of the Brothers fault zone as a regional geothermal target has been rather slow in evolving. No areas within or near the Brothers fault zone were declared KGRA's by the U. S. Geological Survey prior to January 1974. This is due in large part to the fact that only one hot spring and several warm springs occur in, or near, the Brothers fault zone.

In the early 1970's Gulf Oil obtained geothermal leases on much of the fee land in central Oregon. However, no exploration work was performed and at the present time Gulf is allowing their leases to expire.

During the initial Federal lease filing period in January 1974, only two areas in the Brothers fault zone received applications. The unnamed hot springs south and west of Harney Lake were at the center of one area and Glass Buttes was the other area.

FIGURE 2

**MAP OF SOUTHEASTERN OREGON
SHOWING OUTCROPS OF SILICEOUS
DOMES (in black) AND OTHER
STRUCTURAL FEATURES NAMED
IN THIS REPORT.**

(FROM MACLEOD ET. AL. 1975)

In 1975 MacLeod and others suggested that Newberry Volcano has the highest potential for geothermal power production in southeast Oregon. In this significant paper they did not mention the potential of the Brothers fault zone. Also in 1975 DOGAMI published a temperature profile from a 721-foot-deep well at Glass Buttes which has a temperature gradient of $12.6^{\circ}\text{F}/100'$ (Bowen, 1975, Benoit, 1977). It was this profile which initially interested Phillips in the Brothers fault zone in general, and in the Glass Buttes area in particular.

In 1976 Bowen and others (1975) published the temperature gradients from 26 heat-flow holes drilled during 1975 in the Brothers fault zone. This data, along with the 1976 Phillips temperature-gradient data at Glass Buttes (Benoit, 1977) proved that a large thermal anomaly existed at Glass Buttes and suggested that the Brothers fault zone was a regionally high-heat-flow area.

In 1977 Hull and others published the final results of the DOGAMI heat flow study of the Brothers fault zone. This report suggested the eastern half of the Brothers fault zone clearly had anomalously high heat flow, while the western half had only slightly above normal heat flow. Additional shallow temperature-gradient data collected from pre-existing stock wells by Phillips personnel in 1977 generally agreed with this interpretation.

Late in 1977 Phillips drilled Glass Buttes Strat. Test #1 to a depth of 2007 feet. This strat. test was the first hole deeper than 1000' to be drilled in the Brothers fault zone. It has proven that the anomalous near-surface temperature gradients can extend to depths of at least 2000 feet. This strat. test has a bottom-hole temperature of 202°F , which is the hottest temperature measured to date in the Brothers fault zone.

The Strat. Test #1 results along with the few temperature profiles available east of Glass Buttes (Benoit, 1978) suggested that it would be worthwhile to drill shallow temperature-gradient holes at regular intervals in the eastern half of the Brothers fault zone. During the summer of 1978, 40 temperature-

gradient holes were drilled in the Brothers fault zone between Glass Buttes and Frenchglen. This drilling partially outlined a thermal anomaly covering between 150 and 300 square miles.

Regional Geology of the Brothers Fault Zone

The Brothers fault zone is a 20-30 kilometer wide zone of generally "parallel, partly en-echelon, high angle, normal faults". (Bowen and others, 1976). The Brothers fault zone trends N60°W while individual fractures trend N40°W. To the south of the Brothers fault zone northwesterly-southeasterly crustal (basin and range) extension has taken place while to the north no crustal extension has been recognized. Based on this information Lawrence (1976) has interpreted the Brothers fault zone to be a zone of right-lateral tear faulting which forms part of the north boundary of the Basin and Range Province.

Other workers (Stewart and others, 1975, Allen and Beaulieu, 1976) have suggested that the Brothers fault zone is part of a much longer feature known as the Oregon-Nevada lineament, which extends from central Nevada to the Pacific Ocean. It is interesting to note that the Beowawe thermal area is located only five miles east of the Oregon-Nevada lineament in northern Eureka County, Nevada. A maximum temperature of 420°F has been measured at Beowawe. Possibly the Nevada section of this lineament needs future study. However, this report concerns only the portion of the lineament between Bend, Oregon and Steens Mountain. This section has classically been considered to be the Brothers fault zone.

The Nevada segment of the Oregon-Nevada lineament coincides with one of the most striking aeromagnetic anomalies in the state of Nevada (Sweeney and others, 1978). In contrast the Oregon segment has no convincing aeromagnetic expression (U.S. Geological Survey, 1973).

Geologic maps at a scale of 1:250,000 covering this area have been published. They are included as Plates 1, 2, and 3 (Walker and others, 1967, Greene and others, 1972, Walker and Repenning, 1965).

The geologic maps show the Brothers fault zone cuts across an inter-layered series of Miocene to Holocene sedimentary and volcanic rocks. The volcanic rocks are primarily Miocene to Pleistocene basalt flows and Pliocene rhyolitic ash-flow sheets. These extensive sheets of relatively young rock completely conceal the older structures and stratigraphy.

The Brothers fault zone cuts at a low angle across a previously mentioned belt of about 100 rhyolitic domes which extends from Duck Butte at the east to Newberry Crater at the west (Figure 2). The axis of the belt of domes and the Brothers fault zone intersect near the western edge of Glass Buttes. The factors localizing the belt of domes are not understood.

The belt of domes shows a well defined and regular westward decrease in age for domes less than 10 m.y. old (MacLeod, 1975). Iron Mountain, located 11 miles west of Harney Lake gives a K-Ar date of 2.7 m.y. (Parker, 1974, Hull, 1977). This is the only dome known to be younger than 10 m.y. which does not closely fit the age progression. Numerous small mafic vents are associated with the central and western part of the Brothers fault zone, but none are present in the eastern third of the fault zone.

It is not accurately known when the Brothers fault zone became active. It appears that the fault zone is presently active, as Quaternary playas and alluvium in the Glass Buttes area show evidence of northwesterly trending fault scarps (Benoit, 1977). The Brothers fault zone is seismically quiet at the present time with only a single intensity III earthquake near Bend occurring between 1841 and 1970 (Couch and Lowell, 1971, Lawrence, 1976).

Hydrology and Geochemistry

The Brothers fault zone receives an average of 12 inches of rain per year. Precipitation is either rapidly evaporated or percolates rapidly into the earth to depths of several hundred feet. With the exception of the Wagontire Mountain area there are no year round streams in the area and very few springs. Numerous springs and seeps are present on and around Wagontire Mountain. In the Wagontire Mountain area Boneyard, Old Dobkins, Harry Arnold, Bradley, and South Creek Springs were visited. The spring temperatures ranged from 50.4°F to 59.4°F, the total dissolved solids ranged from 56 to 90 ppm, and the discharges ranged from 2 gpm to 30 gpm.

Very little is known about the subsurface hydrology of the area. The depth to the water table is rarely less than 200 feet, and in much of the area it is greater than 400 feet. To the west of Glass Buttes there are numerous abandoned homesteads with dry wells which suggests small perched water tables were fairly common. There are presently numerous stock wells ranging in depth from 200 feet to 900 feet which produce several gallons per minute. To the east of Glass Buttes very few stock wells are present. Only rarely did Phillips' and DOGAMI's shallow temperature-gradient holes hit water. Only when holes were drilled near Harney or Weed Lakes and in the Blitzen River Valley was water encountered near the surface.

Much of the water which falls on the Brothers fault zone south and west of Harney Lake probably reappears at the surface in the large-volume, slightly warm, springs near the Double O Ranch.

The only hot spring associated with the Brothers fault zone is located south of Harney Lake in T27S-R29½E Section 36. A chemical analysis of this spring is shown below (Mariner, 1974). This spring has a predicted silica temperature of 132°C and a Na-K-1/3 Ca predicted temperature of 130°C.

CHEMICAL ANALYSIS OF UNNAMED HOT SPRING
SOUTH OF HARNEY LAKE

Temp	68°C	
pH	7.26	
Specific Conductance	2970	umhos
SiO ₂	92	ppm
Ca	12	ppm
Mg	1.8	ppm
Na	630	ppm
K	13	ppm
Li	.45	ppm
HCO ₃	566	ppm
CO ₃	1	ppm
SO ₄	140	ppm
Cl	590	ppm
F	3.3	ppm
B	11.3	ppm

During the summer of 1977 fourteen water samples were collected from pumping wells and springs, principally in the western half and to the south of the Brothers fault zone. Because these samples are not located within significant thermal anomalies, and with one exception appear to be normal dilute meteoric waters, they will not be further discussed. The analyses are available at the Reno office. The one exception is from the Cook Well (Cc-12) and is not located within the Brothers fault zone.

Temperature Gradient Data

It is convenient to divide the Brothers fault zone into eastern and western halves when discussing the temperature data. The western data is located on the Crescent AMS sheet (Plates 4, 5, and 6) and the eastern data is located on the Burns and Adel AMS sheets (Plates 7, 8, 9, 10, 11, and 12). These sheets also

contain much data outside the Brothers fault zone. Additional data for the temperature-gradient holes is presented in Appendix I.

Holes prefixed by NC, GB, BFZ, AND AD were drilled by Phillips. Holes prefixed by C, BU and A are from previously published reports or were measured in pre-existing wells by Phillips personnel. The holes labeled Cc on the Crescent AMS sheet are pumping water wells where the gradient has been calculated from the depth of the well water temperature measured. These gradients may be subject to errors of 25 or 30 percent.

The temperature gradients shown on the maps is the last linear gradient at the bottom of the holes. Therefore, when the gradient changes with depth, the depth of the hole becomes a critical factor in controlling the gradients shown on the maps.

It is felt that nearly all accessible pre-existing drill holes and water wells in the Brothers fault zone have been probed. Any additional temperature data required will have to be generated by Phillips.

Western Part of the Brothers Fault Zone

The western part of the Brothers fault zone cuts across the northwest quarter of the Crescent AMS maps (Plates 1, 4, 5, and 6). Geologically and topographically this part of the Brothers fault zone is characterized by flat-lying late Pliocene and Pleistocene basalt flows with relatively widely spaced normal faults. The relief on these fault scarps seldom exceeds 100 feet. These basalts partially bury rounded widely spaced siliceous domes and flows which can stand up to 2000 feet above the plains (Figure 3). This segment of the Brothers fault zone is not easily recognized from the ground. The available temperature data shows above normal temperatures and temperature gradients to coincide with the Brothers fault zone. There is no progressive westward increase in temperatures or gradients as might have been expected from the westward decrease in

Figure 3. Photograph of the central part of the Brothers fault zone showing basalts cut by small parallel fault scarps. Rhyolite domes and flows in the background make up Glass Buttes.

ages of the siliceous domes.

To the west of R20E the highest measured gradient is $5.1^{\circ}\text{F}/100'$ in Hole C-39 and the highest calculated gradients are $5.1^{\circ}\text{F}/100'$ in Cc-1 and $5.4^{\circ}\text{F}/100'$ in Cc-6. With a gradient of $5^{\circ}\text{F}/100'$ a temperature of 400°F will be reached at about 7000 feet. It is felt that the temperature anomalies west of R20E in the Brothers fault zone lack the intensity to justify additional work in the near future.

Just to the north of the Brothers fault zone in T18S-R17E Brooks (1963) reports seven mercury occurrences. This small district has produced about 50 flasks of mercury from the Clarno formation, or dikes intruding the Clarno formation. No temperature data has yet been collected in this area.

In ranges 20, 21, and 22 east there are several moderately intense thermal anomalies and the temperature-gradient contour pattern becomes quite complicated (Plate 4). This complex contouring is due in large part to the

variable depths of the holes. Holes C-45, C-49, and C-50 (Appendix I) show large decreases in the thermal gradient between depths of 200 and 240 feet. It is felt that the gradients shown for C-48, GB-19, GB-5, GB-6, and C-16 would decrease significantly if the holes were deeper than 250 feet. Therefore, the anomaly centered on holes C-48 and GB-19 is not considered to be worth further exploration in the near future.

Hole C-41, located in T24S-R21E, has a gradient of $6.6^{\circ}\text{F}/100'$ with the gradient appearing to increase with depth. The significance of this one-point anomaly is unknown. Additional data in this area would only be useful if the data came from depths greater than 400 feet. Drilling holes to 500 feet in the basalts in this area would be expensive and time consuming. However, it would be useful to drill at least one hole to 500 feet in this anomaly.

To the south of the Brothers fault zone two anomalies are shown on the Crescent temperature-gradient map. The anomaly in Range 16E is basically a one-point anomaly centered on C-43. This data is suspect as the gradient increases from nothing above 300 feet to $7.9^{\circ}\text{F}/100'$ between 300 feet and 396 feet. This increase may be due to cooling of the hole above depths of 300 feet by downward-moving groundwater in highly permeable basalts. Little faith can be placed in the calculated gradient from Cc-10. It is felt that this anomaly is more apparent than real. No future work is recommended within this anomaly.

The second anomaly, located in T27S-R22E, may also be more apparent than real. The deepest hole, WT-3, shows a 50% decrease in the thermal gradient at a depth of 300 feet (Appendix I). It is likely that the shallower holes in this anomaly will show similar decreases with depth. However, the area between this anomaly and Glass Buttes should be evaluated more thoroughly in the future. Hole C-23, which is located about five miles from any other measured

hole, gives a good linear gradient of $5.8^{\circ}\text{F}/100'$. This area lies within a fault zone which splays southward from the Brothers fault zone at the western edge of Glass Buttes (Plates 1 and 2). This area also contains the only significant cluster of domes found between the two belts described by MacLeod and others (1975). Several of these domes give K-Ar dates of 6 to 7 m.y.

The shallow temperature data from the Newberry Crater area (holes prefixed by NC) are not very useful and has been previously discussed by Benoit (1977).

Glass Buttes Area

The Glass Buttes area is the best known thermal anomaly in the Brothers fault zone. The western part of the thermal anomaly is located on the Crescent AMS sheets and the eastern part is on the Burns AMS sheets. The shallow temperature gradients and geology have been discussed by Benoit (1977). The Glass Buttes thermal anomaly covers about 111 square miles with gradients above $6^{\circ}\text{F}/100'$. Although the gradients are high, the highest temperature measured in a shallow temperature-gradient hole in the area is 83°F . This is very low when compared to other promising thermal anomalies in Nevada. Glass Buttes Strat. Test #1 (Benoit, 1978) was the first geothermal hole in the Brothers fault zone to prove that the anomalous temperature gradients can extend to moderate depths and that it may be possible to find 400°F temperatures at depths of less than one mile. A temperature of 202°F was measured at a depth of 2007 feet.

At the present time Glass Buttes is regarded as the best geothermal prospect in the Brothers fault zone. Additional strat. tests are planned for this area when an agreement is reached with Trend Exploration.

Eastern Part of the Brothers Fault Zone

This part of the Brothers fault zone is located on the Burns AMS sheets

(Plates 2, 7, 8, and 9) and the Adel AMS sheets (Plates 3, 10, 11, and 12).

It is in this area that the Brothers fault zone has its maximum topographic expression. To the south and west of Harney Lake the fault scarps are commonly several hundred feet high and produce a fairly rugged horst and graben topography (Figure 4).

Figure 4. Photograph of the Brothers fault zone west of Harney Lake. In this area the Brothers fault zone has its maximum surface expression.

Iron Mountain, located 11 miles west of Harney Lake, is probably the most spectacular rhyolitic dome in the area. It is a central Oregon landmark, steeply rising over 1000 feet above the surrounding plains (Figure 5).

Figure 5. Photograph of Iron Mountain, a large 2.7 million year old rhyolite dome.

This dome has been dated at 2.7 m.y. (Parker, 1974, Hull, 1977) and prior to obtaining temperature-gradient data in the area was thought to be a possible exploration target.

The rocks exposed at the surface are basalts, ranging in age from Miocene to Holocene, and an extremely widespread rhyolitic ash flow tuff of Pliocene age. The Pliocene ash-flow tuffs were probably erupted from large calderas now buried in Harney Basin. The youngest igneous rocks in the area are the Holocene basalts of the Diamond Craters which are located several miles northeast of the Brothers fault zone.

To the southeast of Glass Buttes a very large thermal anomaly has been partially outlined. This anomaly is located on the Burns AMS sheet (Plate 7) and extends a distance of 30 miles from BFZ-5 to BFZ-15. This anomaly is from 5 to 10 miles wide. As shown on Plate 7 the anomaly appears to have three centers. These are located at holes BFZ-5, BU-38 and BFZ-7, and BFZ-15. BFZ-15 is located three or four miles southwest of the Brothers fault zone.

This anomaly is not strongly reflected on the isothermal maps.

The deepest hole in the northern part of this anomaly is BU-38, a privately owned stock well at 260 feet deep. In the southern part BFZ-38 and BFZ-39 at 426 feet and 460 feet are the deepest holes. Over much of this anomaly the temperature gradients are moderately irregular and half the holes are less than 150 feet deep. Also the holes are spaced from three to six miles apart. Therefore, the data gathered to date is regarded as encouraging but not overly trustworthy.

In the northern part of this anomaly 75% of the temperature-gradient holes did not reach planned depth due to severe lost-circulation problems encountered in drilling obsidian flows and basaltic cinders present beneath the basalt flows in the area. In the southern part the drilling problems are much less common. This very large anomaly needs to be more completely evaluated in the near future.

To the southwest of this anomaly the Horse Head Mountain mercury prospect is present in T27S-R25E (Brooks, 1963). This prospect has produced a very small amount of mercury. Hole BFZ-10 was drilled in the center of this prospect and produced a $2.9^{\circ}\text{F}/100$ thermal gradient. No additional work is necessary in the vicinity of the Horse Head Mountain mercury prospect.

Further southeast within the Brothers fault zone no well-defined large thermal anomalies were detected. Holes BFZ-29, 31, 35 and BU-41 have temperature gradients between 5.0 and $6.4^{\circ}\text{F}/100'$, but these holes are usually separated by colder holes.

In the Blitzen River Valley hole BFZ-33 encountered relatively high temperatures but had a gradient reversal. Warm holes in this valley are not thought to be significant as there are three known slightly warm springs in the southern part of the valley. With the possible exception of the area around BFZ-29 and BFZ-35 it is felt that the far eastern part of the

Brothers fault zone does not need further work in the near future.

Immediately southeast of Harney Lake the relatively large Coyote Butte thermal anomaly is present. This anomaly is outside the Brothers fault zone and appears to be related to the unimpressive nearby unnamed hot spring which gives a predicted reservoir temperature of 130°C. Phillips has not done any work in this area and only reconnaissance work is planned in this area in the near future.

Conclusions

The Brothers fault zone of central Oregon has been evaluated on a reconnaissance basis as a regional geothermal exploration target. Within the Brothers fault zone the Glass Buttes area is the most exciting prospect based on geological and thermal data. To the southeast of Glass Buttes it is possible that a very large thermal anomaly has been discovered. Additional temperature-gradient work is necessary to accurately outline this anomaly.

At the present time it has not been proven that geothermal reservoirs exist within the Brothers fault zone. Only deep drilling will prove or disprove the presence of geothermal resources. With current knowledge it is not possible to predict the type of reservoir which may be present. Hot dry rock, hot water, and/or steam could be present.

If exploration within the Brothers fault zone can be regarded as successful to date, then several other similar large scale features in southeastern Oregon may be worthy exploration targets.

The feature most similar to the Brothers fault zone is the Eugene-Denio lineament. This zone is parallel to, and 60 miles south of, the Brothers fault zone. The fault pattern associated with the Eugene-Denio zone is not as clear as the Brothers fault zone, but it has the same implication of right lateral motion. At least 20 earthquake epicenters are located in two distinct clusters

along this fault zone (Couch and Lowell, 1971, Lawrence, 1976). Several thermal springs are found along this lineament, but this may be coincidental. This zone, like the Brothers fault zone, cuts at low angle across a belt of rhyolitic domes (Figure 2). This belt of domes is broader and more diffuse than the belt cut by the Brothers fault zone. Phillips' Lakeview Prospect is located in this belt of domes. Mineral exploration holes up to 1000 feet deep have temperature gradients up to $9^{\circ}\text{F}/100'$ over an area of unknown size in this prospect. There are virtually no other temperature-gradient data available in this large area.

Within Oregon there are two other similar, yet much shorter, fault zones. The Vale fault zone runs northwest through the Cow Hollow (Vale) thermal anomaly. The Bully Creek area where Chevron and Amax are active lies about six miles southwest of the Vale fault zone. The Mount McLoughlin fault zone lies about 50 miles southwest of the Eugene-Denio fault zone and is relatively short. The Klamath Falls thermal area lies along or near this zone. The Vale and Mount McLoughlin fault zones do not appear to be as significant as the Eugene-Denio fault zone or the Brothers fault zone.

Between Steens Mountain and the Oregon-Nevada border the Brothers fault zone is not an obvious feature. Lawrence (1976) believes that the Brothers fault zone terminates at Steens Mountain while Stewart and others (1975) believe it carries through this area. Mickey Hot Springs, one of the most interesting hot spring systems in Oregon, is located on the Oregon-Nevada lineament. On the Adel AMS sheet hole A-20 (T32S-R36E) has a gradient of $12^{\circ}\text{F}/100'$. This suggests that this extension of the Brothers fault zone may be worthy of further exploration.

Recommendations

At the present time Phillips has a severe Federal acreage chargeability problem in Oregon. Phillips has leased about 20,000 Federal acres in the

Glass Buttes area. The other major land holder in the area, Trend Exploration, has leased much of the most promising land in the Glass Buttes thermal anomaly. To date discussions with Trend regarding cross assigning acreage or allowing Phillips to earn half interest by drilling a combination of strat. tests and production holes have not been successful. Recent discussions with Trend suggest that it will be at least six months to a year before serious negotiations begin again. If Phillips hopes to cross assign acreage with Trend, then Phillips should retain all the federal leases in the area as long as possible.

Due to this acreage problem Phillips cannot file on the federal land in the large anomaly southeast of Glass Buttes at the present time. About 70 to 80 percent of the land in this anomaly is Federal. The state of Oregon owns two sections per township. It is possible that leases in this area could be issued in less than one year from the date of filing. Known competitor activity in the Brothers fault zone has been minimal to date and has been confined to the Glass Buttes area. Therefore, it is recommended that additional shallow temperature-gradient holes be drilled in the anomaly during the summer of 1979. Up to 20 holes ranging in depth from 300 to 500 feet may be needed to adequately evaluate this thermal anomaly. It is always somewhat risky to take a drill rig back into an unleased area but the very low level of competitor activity in this area suggests that the risk of losing the Federal acreage to competitors is acceptable.

It is also recommended that a concerted effort be made to obtain temperature profiles from all available wells and drill holes located along the Eugene-Denio lineament, and along the southern belt of rhyolitic domes, during the summer of 1979.

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APPENDIX I

GRADIENT HOLE INFORMATION

ADEL, OREGON AMS SHEET

HOLE #	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE AT		
					98.4'	196.8'	295.2'
<u>BOWEN 1975, OPEN-FILE REPORT 0-75-3</u>							
A-1	T38S R37E S25	495	3.9	100-495	69.4	75.4	77.4
A-2	T39S R34E S2	1246	3.0	656-1246	56.4	59.9	63.9
A-3	T38S R37E S24	328	4.8	131-328	58.1	62.5	67.6
A-4	T38S R37E S26	164	3.9	98-164	59.5		
A-5	T39S R37E S17	361	5.2 2.7	98-246 295-361	58.9	64.4	68.8
A-6	T39S R37E S2	347	7.7	100-347	62.8	70.5	78.0
<u>HULL 1976, OPEN-FILE REPORT 0-76-2</u>							
A-7	T30S R31E 23BC	98	2.9	57-98	55.7		
A-8	T32S R32E 16BA	197	1.0	98-197	51.9	52.9	
<u>HULL 1977, OPEN-FILE REPORT 0-77-2</u>							
A-9	T35S R37E 14DB	377	isothermal 2.8	197-295 295-377	56.2	57.1	57.4
<u>SASS 1976, OPEN-FILE REPORT 76-217</u>							
A-10	T33S R31E 19BD	295	2.8	147-295	52.2	54.5	57.0
A-11	T33S R31E 22CB	299	2.7	213-299	51.5	53.6	56.3
A-12	T34S R31E 8DC	305	2.9	213-305	51.9	54.2	57.1
A-13	T35S R31E 4D	311	3.3	164-311	52.2	54.4	57.0
A-14	T35S R31E 2D	295	3.9	115-295	51.4	53.6	56.3
A-15	T30S R29E 15AD	351	4.3	200-351	47.2	49.5	54.4
A-16	T35S R34E 1B	315	4.2	180-315	55.4	59.1	63.1
A-17	T34S R35E 31D	315	3.2	193-315	53.4	55.9	59.2
A-18	T33S R35E 14A	113	15.9	32-113	70.0		
A-19	T33S R35E 23B	167	8.0	131-167	61.2	70.2*	

*Projected

GRADIENT HOLE INFORMATION

ADEL, OREGON AMS SHEET

HOLE#	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE AT		
					98.4'	196.8'	295.2'

PROBED BY BENOIT

A-20	T32S R36E 14CC	150'	12.0	100-150	62.4		
A-21	T37S R33E 9AC	120'	8.5		65.6		
A-22	T31S R29E 2D	297	2.43	140-300	52.0	54.9	57.0
A-23	T32S R31E 31C	128	5.0	60-120	55.1		
A-24	T30S R32E 11BD	380	4.4 2.1	160-240 240-380	59.3	60.4	63.5
A-25	T31S R31E 23CB	510	5.3 2.8	200-300 300-490	51.3	51.9	57.2
A-26	T30S R32E 8DB	190	4.0	170-190	61.5	62.7*	

DOGAMI MISCELLANEOUS PAPER 19, 1977

A-27	T33S R34E 24AB	770	0	75-770			
A-28	T30S R32E 1DC	317	4.5	100-310	53.9	57.8	63.1
A-29	T30S R33E 22DB	170	2.0	100-150	52.3	54.5*	

—* Projected

STATE OF OREGON

GRADIENT HOLE INFORMATION

BURNS AMS SHEET

HOLE #	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE °F AT		
					98.4'	196.8'	295.2'
<u>SASS AND MUNROE OPEN-FILE REPORT 1973</u>							
BU-1	T24S R33E 9D	656	4.5		53.9	58.1	62.4
BU-2	T24S R34E 19C	656	3.8		52.2	54.9	58.5
BU-3	T25S R31E 30D	656	4.6		61.5	64.8	69.8
<u>HULL OPEN-FILE REPORT 0-77-2</u>							
BU-4	T21S R38E 17CD	90	not deep enough		54.9		
BU-5	T23S R26E 25AB	410	4.0	311-410	50.8	51.4	53.0
BU-6	T23S R27E 29BB	377	2.7	328-377	48.3	48.7	48.9
BU-7	T24S R25E 3BD	197	5.46 isothermal	66-148 148-197	54.5	57.4	
BU-8	T24S R26E 13DC	476	2.6	164-476	56.6	59.8	62.4
BU-9	T24S R37E 33BC	648	4.2	98-648	57.6	61.3	65.3
BU-10	T27S R38E 23CC	590	6.0	492-590	50.6	52.4	55.4
<u>BOWEN OPEN-FILE REPORT 0-75-3</u>							
BU-11	T19S R31E 13	787?	2.0 isothermal	98-558 558-787	56.0	58.2	59.9
BU-12	T21S R35E 11	328	2.8	197-328	52.6	54.8	57.5
BU-13	T27S R30E 13DD ✓	426	3.3	246-426	58.7	65.8	69.9
BU-14	T27S R30E 19DC ✓	353	7.2	150-350	54	61.5	68.5
BU-15	T27S R30E 26DC ✓	187	6.6	98-180	57.6	63.9	
BU-16	T27S R30E 27AC ✓	246	8.7	98-213	60.0	68.6	
BU-17	T27S R30E 21DD	361	7.3	164-361	66.1	74.1	80.8
BU-18	T27S R30E 36BA ✓	156	4.1	65-147	56.1		
BU-19	T23S R23E 27	722	11.9	200-656	56.6	64.4	76.1

HOLE #	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE °F AT		
					98.4'	196.8'	295.2'

HULL 1975 OPEN-FILE REPORT 0-76-2

BU-20	T25S R33E 3BD	94	11.1 6.7	49-82 82-94	61.3*		
BU-21	T27S R33E 33CB	100	isothermal		52.3		
BU-22	T28S R32E 36CC	180	2.5	100-180	55.3	57.7	
BU-23	T29S R32E 34DC	171	8.8	131-171	57.1	66.5*	
BU-24	T27S R30E 36CC	221.4	4.9	98-221	55.0	59.7	
BU-25	T26S R30E 20DB	82.0	too shallow		54.9*		
BU-26	T27S R29E 21AC	147.6	3.1	98-148	54.2		
BU-27	T26S R30E 3BB	98.4	1.8	66-98	55.9		
BU-28	T25S R31E 4BB	196.8	1.5	98-197	51.2	52.7	
BU-29	T23S R28E 18D	196.8	1.7	98-197	53.2	54.9	
BU-30	T24S R26E 24AC	201.7	4.3	148-202	62.4	69.2	
BU-31	T25S R26E 4CC	90.2	5.1	74-90	53.6*		
BU-32	T26S R25E 20BB	73.8	too shallow				
BU-33	T28S R24E 4BA	98.4	2.7	57-98	50.7		
BU-34	T26S R24E 24AD	196.8	4.6	98-197	54.6	59.1	
BU-35	T21S R23E 26C	196.8	2.2	98-197	54.1	56.3	
<u>PROBED BY BENOIT</u>							
BU-36	T29S R25E 23DA	277	3.2	100-270	52.1	55.1	59.0
BU-37	T29S R25E 20AA	420	3.4	100-420	53.3	56.5	60.1
BU-38	T26S R25E 1BB	260	8.0	110-260	55.8	63.0	71.1
BU-39	T24S R26E 19BA	470	3.4 5.4	100-290 290-410	53.0	56.2	60.0
BU-40	T28S R29½E 2D	150	1.9	50-150	56.4		
BU-41	T28S R29½E 17BB	340	4.1 5.4	100-200 250-350	54.8	59.9	66.8
BU-42	T27S R28E 26CA	295	3.2	150-295	51.4	55.2	58.3
BU-43	T26S R30E 26CC	82	too shallow		57.9*		

* Projected

GRADIENT HOLE INFORMATION BURNS AMS SHEET

HOLE #	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE °F AT			
					98.4'	196.8'	295.2'	
<u>HULL OPEN-FILE REPORT 0-77-3</u>								
U-44	T24S R32½E 23DD	492	3.0	262-459	60.3	60.8	62.9	
			4.8	98-246				
BU-45	T24S R33E 35AD	279	2.6	246-279	60.6	65.3	68.9*	
BU-46	T25S R33E 11BB	213	2.0	164-213	57.1	60.1		
BU-47	T25S R33E 3BD	94	9.4	66-94	61.1*			
BU-48	T27S R32E 23BB	459	4.1	312-459	54.4	57.4	60.2	
BU-50	T22S R32E 34CC	312	1.1	98-312	79.0	79.9	81.1	
<u>SASS 1976 OPEN-FILE REPORT 76-217</u>								
BU-51	T28S R31E 36D	298	5.3	131-298	54.1	59.0	64.2	
BU-52	T29S R31E 2B	305	4.1	197-328	51.4	54.3	58.3	
<u>PROBED BY BENOIT</u>								
BU-53	T23S R25E 31CB	160	1.8	50-150	51.3	53.1*		
BU-54	T26S R26E 13CD	109			51.2			
BU-55	T27S R30E 36DD	85			54.5*			
			1.8	260-380				
BU-56	T26S-R28E 2CA	900	2.8	380-490	51.3	52.2	53.6	
			3.2	100-300				
BU-57	T27S R27E 14AA	360	2.7	300-360	53.1	55.8	59.4	
BU-58	T27S R27E 5CC	220	3.6	100-200	56.1	59.7		
BU-59	T26S R30E 9DA	210	3.6	100-210	60.8	64.4		
BU-60	T26S R30E 18D	365	4.9	100-360	56.9	61.9	66.4	
BU-61	T25S R29E 29D	100			49.5			
BU-62	T26S R30E 4D	110			75			
BU-63	T28S R23E 1	100			64.3			
BU-64	T27S R32E 33AC	430	4.8	340-430	55.4	57.6	59.4	
BU-65	T27S R33E 20DB	190	1.7	130-190	50.4	53.3*		
BU-66	T28S R33E 8AB	127	reversed		62.6			

* Projected

GRADIENT HOLE INFORMATION BURNS AMS SHEET

HOLE#	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE °F AT		
					98.4'	196.8'	295.2'
BU-67	T28S R33E 22BC	490	4.9 isothermal 2.7	100-240 260-420 420-490	54.6	59.7	61.8
BU-68	T28S R33E 25BD	290	3.0	190-290	51.3	52.2	
BU-69	T29S R33E 28DB	190	2.5 1.0	100-160 160-190	55.9	57.8	
BU-70	T29S R33E 33BD	150	1.3	110-150	53.8		
BU-71	T27S R34E 17CA	220	2.8	100-190	57.2	61.2	
BU-72	T27S R34E 30CD	290	5.3 2.0	100-260 260-290	55.9	61.5	65.0*
BU-73	T27S R34E 32CD	150	5.8	100-150	56.7		
BU-74	T28S R34E 3CC	136	3.4	80-130	53.6		
BU-75	T28S R34E 17BC	780	2.2	100-780	54.0	55.6	57.9
BU-76	T27S R35E 28BA	90			52.8*		
BU-77	T28S R35E 21DC	200	2.8	100-200	60.3	61.1	
BU-78	T27S R36E 33A	200	isothermal	40-200	51.2	51.2	
BU-79	T28S R36E 9AC	250	2.7	160-250	66.7	72.5	

GRADIENT HOLE INFORMATION

CRESCENT AMS SHEET

HOLE#	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE °F AT		
					98.4'	198.6'	295.2'
C-45	T23S R21E 24BB	290	8.3 3.4	160-240 240-290	53.2	58.9	64.3
C-46	T20S R14E 2AD	240?	3.4	100-200	46.6	50.0	
C-47	T23S R20E 11AD	100			51.1		
C-48	T22S R20E 27BA	190	4.4 9.2	70-150 150-190	54.9	61.6*	
C-49	T23S R21E 20BC	280	12.8 2.3	150-210 210-280	54.5	64.2	65.9
C-50	T24S R22E 23BB	370	4.6 2.4 1.3	100-200 200-340 340-370	53.1	57.7	60.6
C-51	T25S R17E 16DC	270	0.9	120-260	48.7	49.7	50.6*
C-52	T25S R16E 25DA	600?	1.4	100-290	48.7	50.3	51.6
C-53	T25S R16E 21CC	200	0.9	60-180	52.1	52.9	
C-54	T23S R17E 31AD	350	1.7	100-350	51.1	52.7	54.2
C-55	T24S R17E 22DD	100	1.0	70-100	48.8		
C-56	T24S R14E 24DB	170	1.7	50-170	49.1	50.7*	
C-57	T20S R14E 13AA	300?	1.1	100-300	51.0	52.2	53.1
C-59	T24S R16E 19CC	400	3.8	300-400	50.9	51.9	53.6

* Projected

GRADIENT HOLE INFORMATION

CRESCENT AMS SHEET

HOLE#	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE °F AT		
					98.4'	198.6'	295.2'

HULL 1976 OPEN-FILE REPORT O-77-2

C-1	T18S R11E 25BD	426	reversal at 361' isothermal below 361'		46.2	47.9	49.6
C-2	T19S R11E 25BA	403	2.1	305-403	45.8	45.6	46.5
C-3	T19S R16E 16DC	984	3.1	246-984	55.0	56.5	57.9
C-4	T20S R14E 25AA	410	1.9	131-410	51.4	53.7	55.5
C-5	T21S R11E 25BB	115	irregular gradient		46.4		
C-6	T21S R15E 16AB	500	3.0	246-500	47.7	49.2	51.9
C-7	T21S R17E 1AD	295	4.6	131-295	51.7	56.7	61.1
C-8	T22S R14E 3AC	246	0.5	180-246	42.2	42.2	
C-9	T22S R15E 35AD	131	1.1	57-131	45.4		
C-10	T22S R19E 32AD	164	2.3 5.0	82-131 131-164	50.2		
C-11	T23S R 9E 36BB	426	isothermal 131-426		44.6	44.6	44.6
C-12	T23S R19E 5B	492	5.6 2.8	131-230 230-492	50.1	54.7	58.3
C-13	T24S R 7E 7DB	147	isothermal		41.8		

OPEN-FILE REPORT O-75-3

C-14	T21S R21E 9		1.5	65-148	55.0		
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HULL 1975 OPEN-FILE REPORT O-76-2

C-15	T23S R23E 18C	205	7.3	115-205	57.4	65.2	
C-16	T24S R22E 2DD	197	6.8	98-197	57.7	64.3	
C-17	T24S R22E 20AA	197	4.2	98-197	53.8	58.0	
C-18	T21S R19E 12D	197	6.0 4.0	115-180 180-197	50.5	55.8	
C-19	T20S R21E 7BA	189	2.9	98-189	51.5	54.3*	
C-20	T22S R19E 5CC	123	3.4	66-123	51.3		

PROBED BY BENOIT 1975

C-21	T22S R22E 11BD	157	3.6	100-150	52.0		
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*Projected

GRADIENT HOLE INFORMATION

CRESCENT AMS SHEET

HOLE#	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE °F AT		
					98.4'	198.6'	295.2'
<u>PROBED BY BENOIT AND HOLMES 1977</u>							
C-22	T27S R22E 12CB	120	10.2	40-120	59.3		
C-23	T25S R23E 31BB	532	5.8	200-400	53.1*	58.5	64.1
C-24	T26S R22E 23B	383	4.9	200-400	(calculated gradient based on C-23 data)		
C-25	T27S R22E 21A	130	9.6	100-130	59.0		
C-26	T27S R20E 12B	250	1.5	170-250	50.7	51.7	
<u>PROBED BY BENOIT AND HOLMES AUGUST 1977</u>							
C-27	T19S R18E 31CC	490	2.5	200-490	50.7	54.0	56.7
C-28	T20S R17E 27AB	600	3.4	100-280	52.2	55.8	59.0*
C-29	T20S R18E 1BD	300	4.0	100-300	50.4	54.3	58.5
C-30	T23S R18E 4AB	600	2.0	100-320	47.3	49.7	51.3
C-31	T22S R16E 14D	360	1.4	100-360	48.1	49.5	50.9
C-32	T22S R17E 6CC	900	2.4	200-400	46.5	47.4	49.6
C-33	T22S R18E 8DB	532	4.0	440-532	48.8 50.8	51.0 52.7	52.9 55.6
C-34	T20S R18E 30AA	370	3.5	100-370	54.9	58.3	61.4
C-35	T21S R20E 31CC	195	2.4	130-195	48.9	50.6	
C-36	T20S R20E 30CB	250	3.6	150-250	53.3	56.1	61.2*
C-37	T20S R19E 15CB	290	3.6	150-290	54.0	57.4	61.2*
C-38	T19S R16E 33DC	160	2.9	50-160	51.0		
C-39	T20S R16E 3DC	220	5.1	100-220	53.8	58.9	
C-40	T24S R20E 36DC	330	3.2	220-320	51.0	52.3	55.8
C-41	T24S R21E 18C	380	6.6	250-370	49.8	53.2	58.8
C-42	T24S R14E 1B	300	3.1	230-330	47.5	48.2	51.0
C-43	T24S R16E 10CC	396	9.2	320-396	45.9	45.2	47.3
C-44	T22S R21E 5D	470	3.5	200-470	53.2	62.4	65.5

* Projected

GRADIENT HOLE INFORMATION

CRESCENT AMS SHEET

HOLE #	LOCATION	DEPTH IN FEET	GRADIENT °F/100'	DEPTH INTERVAL	TEMPERATURE °F AT		
					98.4'	198.6'	295.2'
NC-1	T19S R12E C30	218	Isothermal	0 - 218	43.9	42.5	
NC-2	T19S R12E C25	190	Isothermal	0 - 190	43.2	43.2*	
NC-5	T21S R13E C6	105	Isothermal	0 - 105	38.5	—	
NC-6	T21S R13E SESE 15	200	Isothermal	0 - 200	38.5	38.5	
NC-7	T21S R14E CNW 32	137	Isothermal	0 - 137	41.5	—	

Projected

CALCULATED GRADIENTS

CRESCENT AMS SHEET

WELL	LOCATION	TEMPERATURE OF PUMPED WATER	DEPTH IN FEET	ESTIMATE TEMP at 100' (°F)	CALCULATED GRADIENT (from 100' to TD) °F/100'
Cc-1 Government	19S 17E 32 DC	57.1	≈ 220	51	5.1
Cc-2 Moorhouse	19S 16E 23 B	76.3	≈ 970	55	2.4
Cc-3 Moffit #2	20S 16E 24 CC	71.1	500	53	4.5
Cc-4 Moffit #3	20S 16E 27 AD	61.3	640	53	1.5
Cc-5 Unnamed	20S 16E 6 DB	71.6	600	51	4.1
Cc-6 Bradetich	20S 15E 3 BA	67.3	420	50	5.4
Cc-7 Deep Well	20S 15E 14 DC	67?	900	50	2.1
Cc-8 Cook Well	23S 16E 23 DC	69.6	565	49	4.4
Cc-9 Evans Well	20S 14E 10 BB	56.5	600?	47	1.9
Cc-10 Cougar Mtn.	25S 15E 13 CC	60.1	217	50	8.6
Cc-11 Edes Well	26S 22E 23B	66.0	383	55	3.9
Cc-12	24S 16E 7B	61.9	≈ 600	47	3.0

GLASS BUTTES
GRADIENT HOLE INFORMATION

Hole #	Location	Depth	Temp. at 100 ft.		Temp. at 200 ft.		Temp. at 300 ft.		Gradient °F/100 Ft. °C/Km		Interval of Gradient
			°F	°C	°F	°C	°F	°C			
GB-1	NW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec14 T23S - R23E	230	57.3	14.05	69.0	20.55	_____	_____	12.94	235.89	40'-140'
GB-2	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec25 T23S - R23E	320	51.35	10.75	56.3	13.5	61.7	16.5	5.47	99.72	200-320
GB-3	SW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec12 T24S - R23E	150	52.9	11.62	_____	_____	_____	_____	8.85	161.34	110-150
GB-4	NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec 9 T24S - R23E	260	52.63	11.47	57.74	14.3	*64	17.8	4.8	87.50	100-260
GB-5	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec18 T24S - R23E	300	57.29	14.05	65.3	18.5	74.39	23.55	10.1	184.12	220-300
GB-6	SE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec 9 T24S - R22E	220	54.68	12.6	60.89	16.05	_____	_____	7.3	133.08	150-220
GB-7	C Sec 30 T23S - R22E	300	59.54	15.3	69.53	20.85	79.43	26.35	10.3	187.77	120-300
GB-8	NE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec17 T23S - R22E	176	57.83	14.35	*69	20.6	_____	_____	10.4	189.59	100-170
GB-9	NE $\frac{1}{4}$ NW $\frac{1}{4}$ Sec 7 T23S - R23E	300	61.25	16.25	72.14	22.3	82.67	28.15	10.7	195.06	100-300
GB-10	SE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec14 T23S - R22E	65	_____	_____	_____	_____	_____	_____	_____	_____	_____
GB-11	SW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec 7 T23S - R22E	298	53.96	12.2	59.63	15.35	*65.5	18.3	5.63	102.63	100-290
GB-12	NE $\frac{1}{4}$ SW $\frac{1}{4}$ Sec34 T22S - R22E	196	54.5	12.5	*62	16.7	_____	_____	7.4	134.9	100-190
GB-13	NE $\frac{1}{4}$ NW $\frac{1}{4}$ Sec11 T23S - R23E	218	52.79	11.55	57.74	14.3	_____	_____	4.8	87.5	100-218
GB-14	SE $\frac{1}{4}$ SW $\frac{1}{4}$ Sec18 T23S - R24N	120	50.0	10.0	_____	_____	_____	_____	5	91.15	100-120
GB-15	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec21 T23S - R23E	130	65.84	18.8	_____	_____	_____	_____	13	236.99	90-130
GB-16	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec29 T23S - R23E	160	52.43	11.35	*55	12.8	_____	_____	2.55	46.49	100-160

* Projected

Hole #	Location	Depth	Temp. at 100 ft.		Temp. at 200 ft.		Temp. at 300 ft.		Gradient °F/100 ft. °C/Km		Interval of Gradient
			°F	°C	°F	°C	°F	°C			
GB-17	SE $\frac{1}{4}$ SW $\frac{1}{4}$ Sec14 T23S - R22E	235	51.44	10.8	55.49	13.05	_____	_____	5.4	98.44	160-230
GB-18	NW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec29 T22S - R23E	160	58.64	14.8	*63	17.2	_____	_____	4.8	87.5	90-160
GB-19	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec15 T23S - R21E	196	52.5	11.4	60	15.55	_____	_____	9.15	167.3	130-190
GB-20	SW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec 1 T24S - R21E	200	50.36	10.2	52.9	11.6	_____	_____	2.54	46.3	100-200
Unnamed	SW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec30 T24S - R23E	350	48.02	8.9	50.18	10.15	54.14	12.35	4.0	72.92	200-300
Dogami BR75-23	NE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec20 T24S - R22E	200	52.43	11.35	56.84	13.8	_____	_____	4.5	82.04	100-190
Dogami BR75-22	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec12 T24S - R22E	200	56.6	13.65	63.5	17.5	_____	_____	6.9	125.79	100-200
Dogami BR-75-21	NE $\frac{1}{4}$ NW $\frac{1}{4}$ Sec19 T23S - R23E	205	56.84	13.8	64.94	18.3	_____	_____	8.1	147.66	100-200
yan#1	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec27 T23S - R23E	490	55.14	13.0	59.2	15.1	63.3	17.4	12.6	229.70	200-400
Musser Well	NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec32 T23S - R22E	490	55.22	12.9	62.60	17.0	70.16	21.2	7.89	143.83	100-400
Misery Flat Well	CntrNW $\frac{1}{4}$ Sec11 T22S - R22E	157	51.98	11.1	*55.5	13.0	_____	_____	3.6	65.63	100-150

*Projected temperatures

ALVORD DESERT

GRADIENT HOLE INFORMATION

Hole #	Location	Depth	Temp. at 100 ft. °F	Temp. at 200 ft. °F	Temp. at 300 ft. °F	Gradient °F/100 ft.	Interval of Gradient
AD-1	NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec17 T32S - R36E	170	63.1	65.5*		2.4	120-170
AD-2	SE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec32 T32S - R36E	300	60.5	64.6	70.2	5.2	150-300
AD-3	SW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec7 T33S - R36E	250	73.9	82.5		10.6 Isothermal	100-180 180-250
AD-4	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec23 T33S - R35E	300	57.8	63.1	64.2	5.2 1.1	100-200 200-300
AD-5	NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec15 T33S - R35E	77	78*				
AD-6	SE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec5 T34S - R35E	280	58.2	62.6	67.0	4.4	100-280
AD-7	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec20 T33S - R35E	300	54.7	55.9	57.9	1.9	130-300
AD-8	NE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec15 T34S - R35E	300	59.9	63.1	65.8	3.0	100-300
AD-9	SW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec3 T35S - R35E	270	62.9	71.9	81.0	9.0	100-270
AD-10	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec19 T33S - R36E	180	57.4	59.5*		2.2	100-180
AD-11	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec35 T34S - R34E	300	53.7	58.5	63.4	4.9	100-300
AD-12	NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec19 T34S - R35E	300	55.1	59.4	63.7	4.3	100-300
AD-13	SE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec18 T35S - R35E	300	52.6	53.7	55.4	1.1 1.7	100-200 200-300
AD-14	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec14 T35S - R34E	270	53.2	55.9	58.7*	2.9	150-270
AD-15	SE $\frac{1}{4}$ NW $\frac{1}{4}$ Sec4 T35S - R34E	300	63.6	68.8	71.7	4.7 1.1	100-150 250-300
AD-16	SE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec17 T37S - R33E	280	61.9	67.2	72.7*	5.4	100-280
AD-17	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec24 T37S - R33E	260	54.1	57.1		3.0	100-260

<u>Hole #</u>	<u>Location</u>	<u>Depth</u>	<u>Temp. at 100 ft. °F</u>	<u>Temp. at 200 ft. °F</u>	<u>Temp. at 300 ft. °F</u>	<u>Gradient °F/100 ft.</u>	<u>Interval of Gradient</u>
AD-18	SE $\frac{1}{4}$ NW $\frac{1}{4}$ Sec17 T38S - R35E	280	59.1	63.3	68.0	4.5	100-280
AD-19	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec32 T37S - R33E	180	58.8	60.4		1.6	100-180
AD-20	SW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec27 T36S - R34E	220	55.7	58.5		3.6	100-220
AD-21	SW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec7 T37S - R34E	300	55.6	57.9	60.8	2.6	100-300
AD-22	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec4 T37S - R33E	300	61.8	65.7	69.4	3.8	100-300
AD-23	NW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec22 T36S - R33E	300	62.3	64.6	66.3	1.9	120-300
AD-24	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec6 T36S - R34E	260	58.1	58.4		Isothermal	100-260
AD-25	NE $\frac{1}{4}$ SW $\frac{1}{4}$ Sec27 T34S - R35E	300	59.5	62.5	65.8	3.2	150-300
AD-26	SE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec8 T35S - R35E	200	53.0	55.4		2.4	100-200
AD-27	SE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec32 T34S - R35E	210	53.1	55.7		2.5	100-210
AD-28	SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec31 T34S - R35E	210	56.8	63.4		6.6	100-210
AD-29	SE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec4	169	53.9	57.6*		3.6	100-160

*Projected

GEOLOGIC MAP OF THE BURNS QUADRANGLE, OREGON

By

Robert C. Greene, George W. Walker and Raymond E. Corcoran

Description of map units

- Qp** *Playa deposits.*—Clay, silt, sand, and some evaporite deposits.
- Qal** *Alluvium.*—Sand, gravel, and silt.
- Qf** *Alluvial-fan deposits.*—Poorly sorted mixtures of gravel and sand, commonly found where small streams enter main valleys; locally include talus.
- Qlb** *Late basalt.*—Basalt, agglomerate, cinders, and ash of Diamond Craters (T. 28-29 S., R. 32 E.). Basalt mostly vesicular, medium gray, micrograined; contains less than 1 percent plagioclase and olivine phenocrysts; thin flows with ropy surfaces. Many small craters are rimmed with spatter, cinders, and bombs, and floored with basalt flows. Includes basalt flow(s) that show original flow surfaces in southeast corner of quadrangle.
- Qa** *Ash.*—Grayish red; mantles much of Diamond Craters; separately mapped where underlying flows concealed.
- Qs** *Sedimentary deposits.*—Mostly unconsolidated silt and clay, generally pale brown; sand and gravel locally present; coherent where diagenetically altered or cemented by caliche. Mostly lacustrine, in part fluvial.
- Qb** *Basalt.*—Medium gray, micrograined, diktytaxitic. Seriate texture with large and small grains of plagioclase, olivine, and augite; also minor magnetite and glass. Several thin flows, tumuli at surface. Present in lowland south of Malheur Lake, canyon of South Fork Malheur River, near southeast corner of quadrangle, and in west part of quadrangle south of Squaw Butte (T. 24 S., R. 25 E.).
- Qls** *Landslide deposits.*—Unsorted mixtures of basalt blocks and tuffaceous sediments. Present near Warm Springs Reservoir and South Fork Malheur River, mostly where Drinkwater Basalt overlies poorly consolidated sedimentary rocks. Also occurs east of Calamity Butte.
- Qmv** *Mafic vent complexes.*—Basalt and andesite scoria, cinders, agglomerate, and thin flows, commonly reddish. Cinders dominant immediately south of Malheur Lake. Farther south and in southwest part of quadrangle forms small shields and domes.
- QTtg** *Terrace gravels.*—Unconsolidated deposits of gravel and sand. North of Burns consists of rounded welded-tuff pebbles and coarse sand. Near Juntura mostly gravel. Gravel of well-rounded quartzite cobbles as much as 12 inches in diameter near Gold Hill (T. 18 S., R. 31 E.) and south of Twelvemile Creek in T. 20 S., R. 23 E.
- QTsb** *Sedimentary rocks and basalt.*—Sandstone, siltstone, conglomerate, and interbedded thin flows of basalt; some flows, deposited in shallow lacustrine environment, highly fragmented and altered. Age, late Pliocene and early Pleistocene.
- QTs** *Sedimentary rocks.*—Tuffaceous sandstone and siltstone; locally contains abundant palagonitized basaltic debris and some pebble conglomerate. Exposed mostly in Sagehen Valley (T. 23-24 S., R. 28-29 E.) east and southeast of Riley (T. 23-24 S., R. 27 E.), and along south margin of Silver Creek Valley (T. 23 S., R. 25-26 E.). Includes some of the sedimentary part of the Harney Formation of Piper, Robinson, and Park (1939) in T. 24-25 S., R. 29-31 E.
- QTb** *Basalt.*—Mostly diktytaxitic olivine-bearing basalt, commonly vesicular but locally dense or platy; generally nonporphyritic. In places consists of several thin flows separated by thin layers of sedimentary rocks. Includes the basalt part of the Harney Formation of Piper, Robinson, and Park (1939) in T. 24-25 S., R. 29-31 E. Basalt flow capping Wrights Point (T. 24-25 S., R. 31 E.), which is at or near top of unit, is 2.4 million years old (potassium-argon date by J. C. Engels, 1968).
- QTP** *Pyroclastic rocks of cinder cones.*—Subaerial deposits of unconsolidated reddish fine to coarse scoriaceous basaltic ejecta. Some cones modified by erosion to low, rounded hills with slopes of cindery red soil that contains sparse bombs and bomb fragments. Locally includes some unfragmented basalt flows and dikes.
- QTps** *Subaqueous pyroclastic deposits.*—Partly consolidated yellowish-brown palagonitized basaltic ejecta; occurs as palagonitic tuff and breccia cones and rings surrounding maars and, in a few places, as tuff ridges. Locally contains intermixed fragments of older basalt, tuff, sedimentary rocks, and small basalt dikes.
- QTmv** *Mafic vent complexes.*—Basalt and andesite scoria, cinders, agglomerate, and thin flows, commonly reddish; forms lava cones and small shield volcanoes.
- Tobt** *Olivine basalt of Twelvemile Table.*—Basalt, medium-dark-gray, micrograined, commonly diktytaxitic; sparse olivine phenocrysts in ophitic groundmass of plagioclase, olivine, augite, magnetite, and glass. A few thin flows cap Twelvemile Table (T. 18-19 S., R. 23 E.). Overlies welded tuff of Twelvemile Table. Age 5.92 ± 0.41 m.y. (potassium-argon date by J. C. Von Essen, 1967).
- Tobg** *Olivine basalt and andesite of Gum Boot Canyon.*—Basalt, medium-dark-gray, fine- to medium-grained, aphyric and diktytaxitic; contains olivine in the groundmass. Andesite, medium-gray with brownish mottling, aphanitic and nonporous; con-

- tains less than 1 percent plagioclase and olivine phenocrysts. Several flows, each a few feet to a few tens of feet thick; maximum thickness of unit about 200 ft. Overlies welded tuff of Double O Ranch, present in two areas near Dry Mountain (T. 23 S., R. 24 E., to T. 22 S., R. 25 E.; and T. 23 S., R. 27 E.).
- Tdo** *Welded tuff of Double O Ranch.*—Pumiceous welded ash-flow tuff extensively exposed in western part of map area and adjacent areas to south and southwest. Informally named for Double O Ranch, which is about 5 miles north-northwest of the reference section. Reference section is on a southwest-facing fault scarp in SW 1/4 sec. 23, T. 27 S., R. 28 E. The section is about 210 ft thick and consists of a basal vitric zone about 4 ft thick, a lower dense devitrified zone about 8 ft thick, a lithophysal zone about 190 ft thick and an upper dense zone about 8 ft thick. A similar sequence, 50–200 ft in total thickness, characterizes the unit in much of its area of occurrence. Tuff of the basal vitric zone is medium to dark gray, commonly porous, and contains abundant pumice. This zone grades upward into light-brownish-gray devitrified lithophysal tuff, which in turn grades upward into pale-brown dense devitrified tuff that also contains abundant pumice. Locally, as near Dry Mountain (T. 22 S., R. 26 E.) and east of Soldier Creek (T. 22 S., R. 32 E.), the tuff may be all dense devitrified or porous vitric. Many small erosional remnants not shown. Tuffs of all zones contain less than 1 percent phenocrysts. Phenocrysts are alkali feldspar, plagioclase, quartz, and augite; devitrified groundmass is alkali feldspar, cristobalite, tridymite, and quartz. A possible vent area for all or part of this tuff is located on Buzzard Creek (T. 28 S., R. 28 E.) (Walker, 1969). In central part of area, constitutes upper part (including tuff breccia member) of Danforth Formation of Piper, Robinson, and Park (1939); included in Rattlesnake Formation in Paulina Basin (T. 15–17 S., R. 23–25 E., north of map area) by Brown and Thayer (1966). Age, about 6 m.y., based on two potassium-argon dates, one of 6.82 ± 0.33 m.y. from near Burns by J. C. Von Essen and J. C. Engels (1967), and one of 5.40 ± 0.20 m.y. from Cricket Creek (T. 21 S., R. 28 E.) by J. C. Engels (1970).
- Tsb** *Tuffaceous sedimentary rocks and basalt.*—Sedimentary rocks and basalt, interlayered and not separately mappable.
- Tst** *Tuffaceous sedimentary rocks.*—Well- to semi-consolidated tuffaceous sedimentary rocks and tuffs, typically pale brown to yellowish gray and poorly stratified; commonly consists of poorly sorted mixture of pumice, scoria, other rock fragments, plagioclase grains, and glass shards in clay matrix; locally light gray to white, well stratified, and consisting of fresh pumice and glass shards. Mostly lacustrine, in part fluvial, in part of air-fall origin. A few feet to a few hundred feet thick, generally present between major welded-tuff and basalt units, separately mapped where thick enough to show. Includes blanket of coarse pumice in matrix of finer pumice and rock fragments on east slope of Horsehead Mountain (T. 27–28 S., R. 25 E.), the site of a rhyodacite dome. Poorly fossiliferous. Age, mostly early and middle Pliocene, in many places bracketed by age of overlying and underlying welded tuffs or basalts. In central part of area includes sedimentary parts of
- Danforth Formation of Piper, Robinson, and Park (1939). Correlative, in part, with Idaho Group of Malde and Powers, (1962).
- Tob** *Basalt.*—Olivine-bearing basalt, dense dark-gray basalt, and some andesite not assigned to a specific unit. Locally includes thin interbeds of tuffaceous sediments.
- Twt** *Welded tuff.*—Welded ash-flow tuffs not assigned to a specific unit.
- Toa** *Olivine andesite.*—Andesite, medium-gray, mottled in shades of dark gray and grayish red, in part aphyric, in part porphyritic. Consists of phenocrysts of plagioclase, olivine, clinopyroxene, and magnetite; groundmass of oriented plagioclase microlites, cryptofelsite, and magnetite grains. Some flows contain clots of plagioclase phenocrysts. Locally flow banded, commonly strongly flow jointed, local hackly jointing, locally scoriaceous. Age, early or middle Pliocene. Includes separate flows and flow sequences west-southwest of Riley (T. 23–24 S., R. 26 E.), on flanks of Squaw Butte (T. 24 S., R. 25 E.), northeast flank of Egli Ridge (T. 25 S., R. 25 E.), and southwest of Wagontire Mountain (T. 26–27 S., R. 23 E.).
- Ta** *Andesite.*—Andesite, dark-gray with brownish mottling, aphanitic; less than 1 percent phenocrysts of plagioclase and augite. Several thin flows, total thickness a few tens to 100 ft. Present between Little Emigrant Creek (T. 20 S., R. 27 E.) and Burns. Underlies welded tuff of Double O Ranch and locally overlies welded tuff of Devine Canyon.
- Twtp** *Welded tuff of Prater Creek.*—Welded ash-flow tuff, pale-reddish-brown, no phenocrysts, little pumice, nearly all devitrified. West of Devine Canyon (T. 21 S., R. 31 E.) consists of a dense lower zone, a highly inflated lithophysal central zone, and a dense upper zone; east of Devine Canyon, central zone is absent, and tuff is light gray and finely porous. Present at scattered localities as far west as Sawtooth Creek (T. 20 S., R. 28 E.), where the unit is too thin to map. Thickness commonly 20–40 ft. Main area of occurrence is in north-central part of quadrangle; small occurrence on Jackass Mountain (T. 29 S., R. 30–31 E.). Overlain by welded tuff of Double O Ranch and underlain by welded tuff of Devine Canyon, commonly with nonwelded tuff and tuffaceous sedimentary rocks intervening. Part of Danforth Formation of Piper, Robinson, and Park (1939).
- Tdw** *Drinkwater Basalt.*—Named by Bowen, Gray, and Gregory (in Shotwell, 1963, p. 31–32). Type section is at Drinkwater Pass (sec. 34, T. 20 S., R. 34 E.). Thicker and better exposed on the south part of Drinkwater Mountain (sec. 1, T. 22 S., R. 36 E.; sec. 6, T. 22 S., R. 37 E.), designated a reference section. Basalt, medium-dark-gray, micrograined, diktytaxitic, in part porphyritic. Phenocrysts and glomerocrysts of plagioclase and olivine locally abundant; ophitic groundmass of plagioclase, olivine, augite, magnetite, and glass. Commonly one, locally several flows, total thickness 20 to 200 ft. Caps mesas in eastern third of quadrangle. Age, 6.91 ± 1.09 m.y., potassium-argon date by J. C. Engels (1970) on a sample from Crane (T. 25 S., R. 34 E.).
- Tr** *Rhyodacite.*—Medium to light gray, pale red or pale brown; commonly streaked, mottled, or flow banded; aphanitic or vitrophyric, locally vesicular. Some flows aphyric, others porphyritic containing as much as 20 percent plagioclase phenocrysts

- and sparse phenocrysts of augite, hypersthene, and magnetite. Groundmass is alkali feldspar, plagioclase, silica minerals, and glass. Forms a prominent hill (Burns Butte, T. 23 S., R. 30 E.) and adjacent highlands. Much angular debris, including obsidian, at surface. Age, 7.82 ± 0.26 m.y., potassium-argon date by J. C. Engels (1970).
- Tvs** *Volcanic sedimentary rocks.*—Pumice and pumiceous sedimentary rocks, light-brown to white, slightly to moderately well consolidated; ash-flow tuff with abundant lump pumice, in part densely welded. Present on south side of Burns Butte (T. 23 S., R. 30 E.).
- Twtt** *Welded tuff of Twelvemile Table.*—Welded tuff, generally two zones: lower zone vitric, medium gray, abundant pumice, commonly porous and friable; upper zone devitrified, medium light gray, dense. Both zones contain less than 1 percent alkali feldspar phenocrysts. Thickness, 25 to 50 ft. Present near Twelvemile Creek, T. 19 S., R. 34 E., extends west to Hampton Butte, in Crescent quadrangle (Walker and others, 1967). Overlain by olivine basalt of Twelvemile Table, underlain by Miocene basalt and andesite (Tba) and pre-Tertiary rocks. Age, 9.29 ± 0.23 m.y., potassium-argon date by J. C. Engels and M. A. Lanphere (1966), from east side of Hampton Butte.
- Tdv** *Welded tuff of Devine Canyon.*—Crystal-rich welded ash-flow tuff extensively exposed in map area and adjacent areas to north and south. Informally named for Devine Canyon (T. 21 S., R. 31 E.). Reference section (NW¼ sec. 32, T. 21 S., R. 31 E.) is located along Poison Creek about 1 mile from its junction with Devine Canyon, and is 104 ft thick. Vitric tuff, light-gray to light-greenish-gray, moderately dense and coherent; flattened pumice common; forms basal part of thick sections and all of thinner sections. Devitrified tuff, medium-light to greenish-gray, generally streaked and mottled; commonly dense but may have large lenticular voids; weathers to small bits. Phenocrysts of alkali feldspar commonly 2–25 percent, of quartz $\frac{1}{2}$ –6 percent, augite, trace amounts. A multiple-flow simple cooling unit. North of Burns 80–104 ft thick, thins to 20 ft near Juntura (T. 21 S., R. 28 E.), 35 ft near Follyfarm (T. 29 S., R. 37 E.), and 25 ft near Swamp Creek (T. 22 S., R. 24 E.). In central part of area apparently forms the basal part of Danforth Formation of Piper, Robinson, and Park (1939). In northeast part of area, mapped as welded tuff member of Drewsey Formation by Bowen, Gray, and Gregory (in Shotwell, 1963) and by Haddock (1967). North of map area not separated from marginal facies of Columbia River Group, undivided volcanic and fluvial deposits of Tertiary and Quaternary age, and Strawberry Volcanics (Brown and Thayer, 1966). Part of unit Tst on Adel quadrangle (Walker and Repenning, 1965) and of unit Ttu of Owyhee Region (Kittleman and others, 1967). Age, about 9.2 m.y., average of following potassium-argon dates: 8.5 ± 0.3 m.y. from near Diamond (T. 29 S., R. 33 E.) by R. W. Kistler, H. C. Whitehead, and Lois Schlocker; 8.9 m.y. from Drinkwater Pass (T. 20 S., R. 36 E.) (Evernden and others, 1964, sample KA122S); 9.21 ± 0.50 m.y. from Devine Canyon (T. 21 S., R. 31 E.) by J. C. Von Essen (1967); 9.45 ± 0.21 m.y. from near Swamp Creek (T. 22 S., R. 23 E.) by J. C. Engels and M. A. Lanphere (1966); and 9.7 ± 0.3 m.y. from the west edge of Catlow Valley (T. 34 S., R. 29 E.) by R. W. Kistler and F. G. Walthall.
- Ttb** *Ash-flow tuff near Buchanan.*—Tuff, medium-gray where vitric and yellowish-gray where devitrified, slightly welded. Contains abundant pumice. About 20 ft thick. Present near Buchanan (T. 22 S., R. 33½ E.).
- Tb** *Basalt.*—Medium to dark gray, locally grayish red, fine grained, subophitic and diktytaxitic, locally porphyritic. Near Donnelly Butte (T. 20 S., R. 26 E.) contains abundant plagioclase phenocrysts and groundmass olivine. Many flows, maximum total thickness about 400 ft; underlies welded tuff of Devine Canyon. Age, 11.8 ± 5.1 m.y., potassium-argon date by J. C. Engels (1970). In T. 27–28 S., R. 26 E., southwest of Harney Lake, the basalt contains 1–5 percent slightly altered olivine phenocrysts. May intertongue locally with sedimentary rocks of units Tst and Tts. Consists of several flows, each 10–20 ft thick and totaling about 150 ft. Age, late Miocene(?) and early Pliocene.
- Tha** *Hypersthene andesite.*—Andesite, dark-gray with greenish or brownish spots, aphanitic to fine-grained; contains less than 1 percent olivine phenocrysts; groundmass of plagioclase, hypersthene, augite, magnetite and pyrite, and glass. Many flows; forms a large shield volcano (Dry Mountain, T. 22 S., R. 26 E.).
- Tsts** *Tuffaceous sedimentary rocks.*—Well-consolidated to semi-consolidated tuffaceous sediments and tuffs; contains abundant white diatomite in the area between Drewsey and Juntura (T. 20 S., R. 35–36 E., and T. 21 S., R. 35–37 E.). Yellowish-brown palagonitic sediment locally abundant between Drewsey (T. 20 S., R. 35 E.) and Van (T. 18 S., R. 33½ E.). A combination of units Tst and Tts, used where welded tuff of Devine Canyon is thin or absent. In Drewsey-Juntura area, has yielded Barstovian (late Miocene) plant fossils and Hemphillian (early Pliocene) vertebrates (Shotwell, 1963). Includes Drewsey and Juntura Formations of Shotwell (1963).
- Trmv** *Mafic vent complexes.*—Basaltic and andesitic agglomerate, breccia, scoria, cinders, flows, and intrusive masses forming lava cones and small shield volcanoes.
- Tir** *Intrusive rhyodacite.*—Pale red; aphanitic groundmass with 10–20 percent phenocrysts of alkali feldspar and quartz. Present on Stinkingwater Mountain (T. 23 S., R. 34 E., and T. 22 S., R. 33 E.). Smaller bodies not shown.
- Trr** *Rhyolite and rhyodacite.*—Light-gray, light-brownish-gray, pale-red, and grayish-orange, commonly flow banded, vitrophyric, hyalopilitic, or pilotaxitic rhyolite and rhyodacite; mostly porphyritic with phenocrysts of plagioclase, alkali feldspar, and quartz. Varietal minerals include biotite, basaltic hornblende, hypersthene, and, rarely, olivine. Glass of groundmass commonly devitrified and spherulitic. Locally flow jointed or brecciated. Contains masses of obsidian or perlite glass and, locally, masses of opalite. Occurs as exogenous domes and related flows and plugs. Age, late Miocene(?) and Pliocene.
- Tts** *Tuffaceous sedimentary rocks.*—Tuffaceous sedimentary rocks and pumiceous tuffs, white or

- light shades of yellow, brown, or gray, mostly fine grained and poorly to moderately well bedded. Contains local beds of pebble conglomerate. Glass fragments, commonly fresh, in some beds, devitrified. Flood-plain or shallow-lake deposits. Includes welded tuff in canyon of Silvies River (T. 19-20 S., R. 30-31 E.). Underlies welded tuffs of Devine Canyon and Twelve-mile Table and basalt (Tb). Correlative, in part, with Mascall Formation (Merriam, 1901) and Juntura Formation of Shotwell (1963). Includes rocks of late Miocene and early Pliocene age.
- Ttp** *Tims Peak Basalt.*—Tims Peak Basalt was named and described from exposures in the SE¼ sec. 34, T. 21 S., R. 40 E., the type locality (Kittleman and others, 1965, p. 20). The type locality is 3½ miles east of Tims Peak (sec. 31, T. 21 S., R. 40 E.) and 14 miles east of Juntura (T. 21 S., R. 38 E.). Medium- to dark-gray, fine-grained and diktytaxitic basalt. Some flows contain plagioclase phenocrysts; olivine in groundmass; locally interbedded with volcanic sandstone and diatomite. Several flows, each several tens of feet thick; maximum total thickness about 400 ft (Haddock, 1967, p. 25). Present near northeast corner of quadrangle (T. 18-20 S., R. 38 E.). Overlies Hunter Creek Basalt.
- Tba** *Basalt and andesite.*—Medium to dark gray, commonly streaked or mottled with lighter grays or browns. Aphanitic to fine grained, generally nonporous. Mostly aphyric, locally contains a few percent plagioclase phenocrysts or less than 1 percent olivine phenocrysts. Fresh or slightly altered. Color indices range from 30 to 40 (andesite) and from 40 to 50 (basalt). Tuffaceous sedimentary rocks locally interbedded, as on Stinkingwater Mountain (T. 21-22 S., R. 34 E.) and west of North Fork Malheur River (T. 19-20 S., R. 37 E.). Mostly porphyritic andesite (equant plagioclase phenocrysts) on King Mountain and west side of Calamity Butte (T. 19-20 S., R. 32 E.). On Steens Mountain (T. 28-29 S., R. 34-37 E.) some flows contain abundant elongate plagioclase phenocrysts. Many flows, each a few feet to several tens of feet thick; maximum total thickness about 2,000 ft on Steens Mountain near Follyfarm (T. 29 S., R. 36 E.). In northwest part of quadrangle, partly equivalent to flows of Columbia River Group as mapped in adjacent areas (Walker and others, 1967; Swanson, 1969; and Brown and Thayer, 1966). In north-central part of quadrangle, partly equivalent to Strawberry Volcanics of Brown and Thayer (1966). In northeast part of quadrangle, includes unnamed igneous complex of Haddock (1967) and of Kittleman, in part, and others (1965, 1967), equivalent to their Owyhee Basalt. In southeast part of quadrangle continuous with Steens Basalt of Fuller (1931). Mapped as units Tfb, Tbf, and Taf on Adel quadrangle (Walker and Repenning, 1965) and on Jordan Valley quadrangle (Walker and Repenning, 1966). Ages shown by following potassium-argon dates: 19.4 ± 0.8 m.y., west of Calamity Butte (T. 20 S., R. 32 E.) (J. C. Engels, 1970), 12.1 m.y. at Stinkingwater Pass (T. 22 S., R. 34 E.) (Evernden and others, 1964), and 15.3 ± 1.0 m.y. on Riddle Mountain (T. 29 S., R. 35 E.) (J. C. Von Essen, 1968). Steens Basalt dated at 14.5 m.y. (Evernden and others, 1964) and about 15 m.y. (Baksi, York, and Watkins, 1967) for flows on Steens Mountain south of the map area.
- Thc** *Hunter Creek Basalt.*—Hunter Creek Basalt was named and described from exposures along Hunter Creek, the type locality, in SW¼ NW¼ sec. 26, T. 21 S., R. 39 E., 8 miles east of Juntura (Kittleman and others, 1965, p. 19). Basalt, dark-gray, aphanitic and aphyric; shows characteristic closely spaced columnar jointing and flow jointing. Maximum total thickness 140 ft; may be one or several flows (Haddock, 1967, p. 15-16). Present near northeast corner of quadrangle (T. 19-22 S., R. 38 E.). Overlies Dinner Creek Welded Tuff and is equivalent in age to part of unit Tba.
- Tps** *Pumiceous sedimentary rocks.*—Sandstone and conglomerate composed of angular pumice, scoria, basalt, and andesite fragments in clay matrix; light olive gray to yellowish gray, well consolidated. Present east of Cottonwood Creek (T. 19 S., R. 36 E.) and on Stinkingwater Mountain (T. 22 S., R. 34 E.).
- Tdc** *Dinner Creek Welded Tuff.*—Dinner Creek Welded Tuff was named and described from exposures on Dinner Creek and at the type locality in the NW¼ SE¼ sec. 30, T. 21 S., R. 39 E., on Conroy Creek 1½ miles west of Dinner Creek and 5 miles east of Juntura (Kittleman and others, 1965, p. 18). A threefold unit, lower part pumice lapilli tuff, middle part welded ash-flow tuff, upper part pumice lapilli tuff and pumiceous sandstone (Haddock, 1965, p. 12-13). Welded tuff of middle part complexly zoned into vitric, dense devitrified, cavernous, and lithophysal zones. Devitrified tuff commonly brownish to grayish red. Tuff contains 1 to 3 percent alkali feldspar phenocrysts. Maximum thickness 248 ft, north of Beulah Reservoir (T. 18 S., R. 37 E.), thins south and eastward. Equivalent in age to part of unit Tba.
- Trd** *Rhyodacite.*—Light to dark gray, pale red, and reddish brown, commonly streaked, mottled, or banded. Mostly aphanitic; commonly contains less than 1 percent phenocrysts of one or more of the following: plagioclase, alkali feldspar, quartz, augite, hypersthene, hornblende, biotite. Groundmass commonly alkali feldspar, plagioclase, cristobalite, and glass. Vitrophyres commonly associated, including perlite near Buchanan (T. 23 S., R. 33½-34 E.). Underlies basalt and andesite of unit Tba. Most occurrences are exogenous domes. Maximum thickness about 2,000 ft on Duck Butte. Equivalent to rocks mapped as Littlefield Rhyolite near Crowley by Kittleman and others (1967).
- Tsv** *Sedimentary and silicic volcanic rocks.*—Rhyodacite or dacite and andesite flows and intrusive rocks, tuffaceous sedimentary rocks, and ash-flow tuffs. Present north of Calamity Butte (T. 18 S., R. 32 E.). Mapped as Strawberry Volcanics in adjacent area to north (Brown and Thayer, 1966), equivalent in age to part of unit Tba.
- Jlt** *Lonesome and Trowbridge Formations of Lupher (1941).*—Upper part (Lonesome) is interbedded volcanic sandstone and mudstone. Sandstone is medium gray, fine to coarse grained and pebbly, commonly in graded beds; composed mostly of plagioclase grains and volcanic rock fragments. Mudstone is dark gray and massive. Lower part (Trowbridge) is dark-gray, massive to faintly laminated mudstone. Poorly fossiliferous but yields diagnostic ammonites. Age, Callovian (Late Jurassic) (Dickinson and Vigrass, 1965, p. 67; Bateman, 1961, p. 28). May include unrec-

- ognized Snowshoe Formation of Dickinson and Vigrass (1965).
- Jsv *Sedimentary and volcanic rocks.*—Sandstone, siltstone, shale, and porphyritic andesite. Present south of Allison Guard Station (T. 19 S., R. 26 E.). Age uncertain.
- Jsn *Middle member of Snowshoe Formation of Dickinson and Vigrass (1965).*—Approximate equivalent of Basey Member of Snowshoe Formation of Dickinson and Vigrass (1965). In T. 18 S., R. 27 E., and to the west and southwest, dominantly massive dark-gray volcanic sandstone, poorly sorted, composed mostly of plagioclase grains and rock fragments; interbedded, especially in upper part, are thin-bedded greenish-gray siltstone and mudstone and minor amounts of tuff and chert. Porphyritic basalt at base in parts of T. 18-19 S., R. 25 E. In T. 18-19 S., R. 30-31 E., the unit is fine- to medium-grained greenish-gray volcanic sandstone. In south part of T. 20 S., R. 28 E., it consists of gray volcanic sandstone, thin bedded, in part fine grained, in part coarse grained and poorly sorted. Sparsely fossiliferous but yields diagnostic ammonites. Age, Bajocian (Middle Jurassic) (Dickinson and Vigrass, 1965, p. 49, 57).
- Jsw *Warm Springs and Weberg Formations of Lupher (1941).*—Upper part (Warm Springs), dark-gray calcareous shale and mudstone with minor interbedded siltstone and limestone; lower part (Weberg), sandy limestone, calcareous sandstone, and pebble conglomerate. Mapped by Dickinson and Vigrass (1965) in part as Warm Springs and Weberg Members of the Snowshoe Formation, in part as lower member of the Snowshoe Formation. Abundant ammonites and pelecypods give a Bajocian (Middle Jurassic) age. (Dickinson and Vigrass, 1965, p. 52-54, table 9.)
- Jwb *Basalt.*—At base of Weberg Formation.
- Js *Sedimentary rocks.*—In T. 18 S., R. 26-27 E., Mowich Group of Dickinson and Vigrass (1965), including Robertson, Suplee, Nicely, and Hyde Formations: sandstones composed of plagioclase grains and volcanic-rock fragments; calcareous sandstone, black shale and mudstone, lenses of limestone, and basal pebble conglomerate. Abundant fossils, mostly ammonites and pelecypods. Age, Pliensbachian and Toarcian (Early Jurassic) (Dickinson and Vigrass, 1965, p. 36-43; Imlay, 1968, p. C8-C16). In T. 19 S., R. 25 E., thin-bedded argillaceous limestone, sandy siltstone, and tuffaceous sandstone. Contains ammonites establishing a Hettangian (Early Jurassic) age (Buddenhagen, 1967, p. 137). In northwest part of T. 20 S., R. 38 E., mostly siltstone and shale, some sandstone and conglomerate with basalt boulders, and minor amount of limestone. Ammonites give a Sinemurian (Early Jurassic) age (H. J. Buddenhagen, written commun., 1968). Mapped as the Donovan Formation by Lupher (1941, p. 235).
- Ksv *Sedimentary and volcanic rocks.*—In T. 18 S., R. 26 E., and adjacent part of Rs. 25 and 27 E., Begg and Brisbois Formations of Dickinson and Vigrass (1965). Upper part (Brisbois), dark-gray thin-bedded shale and siltstone, with minor interbedded sandy limestone, calcareous sandstone, and limestone boulder conglomerate; lower part (Begg), mostly greenish-black to black shale and siltstone, with interbedded calcareous and coarse volcanic sandstones, conglomerates, and minor keratophyre flows. Diagnostic ammonite collections in secs. 29 and 32, T. 17 S., R. 26 E., north of the map area. Age, Karnian (Late Triassic) (Dickinson and Vigrass, 1965, p. 26-27). In north part of T. 19 S., R. 25 E., and adjacent part of T. 18 S., R. 25 E., upper part is black shale and mudstone, lower part is mostly massive coarse argillaceous sandstone, in part containing angular chert and siltstone fragments and limestone pebbles. In T. 18 S., R. 24 E., and adjacent R. 25 E., mostly coarse argillaceous sandstone with angular chert fragments, some fine- to medium-grained sandstone and siltstone, minor amount of conglomerate without limestone clasts (H. J. Buddenhagen, written commun., 1968).
- KPs *Sedimentary rocks.*—Thinly interbedded fine-grained sandstone, siltstone, siliceous shale, bedded chert, sandstone with chert fragments, and sandstone composed of volcanic detritus. Overlies Permian beds; contains blocks of limestone with Permian fossils which may have been transported (H. J. Buddenhagen, written commun., 1968).
- KPv *Volcanic rocks.*—Dacite and andesite, massive, aphanitic.
- PDs *Sedimentary rocks.*—Includes fossiliferous beds of Permian, Pennsylvanian, Mississippian, and Devonian age. Permian rocks are gray limestones, thin bedded and lenticular, interbedded with chert, siliceous shale, and sandstone. Limestones contain brachiopods, crinoids, bryozoans, and diagnostic fusulinids. Pennsylvanian rocks are predominantly fine- to medium-grained feldspathic sandstone, conglomeratic sandstone, and conglomerate with boulders of plutonic and volcanic rocks; greenish mudstone in upper part. Contains fossil plants. Mississippian rocks are limestone and calcareous shale with fossils, also unfossiliferous sandstone, siltstone, and black limestone. Devonian rocks in one occurrence only, NW¼NW¼ sec. 30, T. 19 S., R. 25 E.—limestone, light-brown, massive, contains corals, stromatoporoids, and brachiopods (H. J. Buddenhagen, written commun., 1968; Kleweno and Jeffords, 1961).

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Base by U. S. Geological Survey, 1964
Roads modified 1971

SCALE 1:250,000
0 5 10 15 MILES
0 5 10 15 KILOMETERS

CONTOUR INTERVAL, 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
1971 MAGNETIC DECLINATION AT SOUTH EDGE OF SHEET VARIES FROM 19° TO 20° EAST

SKETCH DIAGRAM SHOWING RELATIONS OF MAJOR UNITS IN NORTH PART OF QUADRANGLE. NOT TO SCALE

GEOLOGIC MAP OF THE BURNS QUADRANGLE, OREGON

By
Robert C. Greene, George W. Walker, and Raymond E. Corcoran
1972

EXPLANATION

1. Burns quadrangle
2. Adel quadrangle (Walker and Reppening, 1965)
3. East half of Klamath Falls quadrangle (Walker, 1963)
4. East half of Crescent quadrangle (Walker and others, 1967)
5. East half of Bend quadrangle (Swanson, 1969)
6. Canyon City quadrangle (Brown and Thayer, 1966)
7. Owyhee region (Kirkman and others, 1967)
8. Michel Butte quadrangle (Corcoran and others, 1962)
9. West half of Jordan Valley quadrangle (Walker and Reppening, 1969)

INDEX MAP OF OREGON SHOWING LOCATION OF BURNS
QUADRANGLE AND ADJACENT SMALL-SCALE GEOLOGIC
MAPS

1. R. C. Greene, 1966-68
2. G. W. Walker, 1965-67
3. R. E. Corcoran, Oregon Department of Geology and Mineral Industries, 1966-68
4. H. J. Buddenhagen, Oregon Department of Geology and Mineral Industries, 1964-68
5. G. H. Haddock, 1963-64
6. M. H. Beeson, 1967

*Additional small areas of pre-Tertiary rocks also by H. J. Buddenhagen

INDEX TO GEOLOGIC MAPPING

EXPLANATION

- Structures of middle and late Tertiary age
- Large structural and physiographic basins
 - Mesozoic rocks
 - Paleozoic rocks
 - Fault: Bar on downthrown side
 - Anticline
 - Syncline
 - Arched or troughlike indicate level plunge
 - Homocline
 - Large mafic volcanoes
 - Small mafic vents
 - Large rhyolite domes
 - Small rhyolite domes

REVISIONS:	DATE

Cc CALCULATED GRADIENT
□ HOT SPRINGS

SECTIONIZED TOWNSHIP
6 5 4 3 2 1
7 8 9 10 11 12
13 14 15 16 17 18
19 20 21 22 23 24
25 26 27 28 29 30
31 32 33 34 35 36

PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA
NATURAL RESOURCES GROUP
ENERGY MINERALS DIVISION

TEMPERATURE-GRADIENT DRILL HOLES

STATE OF OREGON-CRESCENT AMS SHEET
DESCHUTES, CROOK, KLAMATH, LAKE, LANE COUNTIES, OREGON
JULY 1977

RENO, NEVADA

REVISIONS

DATE

SCALE 1:250,000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 30 KILOMETERS

CONTOUR INTERVAL=200'

1 HOT SPRINGS

office

SECTIONIZED TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
13	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

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BARTLESVILLE, OKLAHOMA

NATURAL RESOURCES GROUP

ENERGY MINERALS DIVISION

ISOTHERMAL MAP-100 FOOT DEPTH

STATE OF OREGON-CRESCENT AMS SHEET

DESCHUTES, CROOK, KLAMATH, LAKE, LANE COUNTIES, OREGON

JULY 1977

RENO, NEVADA

REVISIONS

NO.	DATE	DESCRIPTION
1		
2		
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8		
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10		

SCALE 1:250,000

0 5 10 15 20 25 30 MILES

0 5 10 15 20 25 30 KILOMETERS

CONTOUR INTERVAL 200'

● CALCULATED TEMPERATURE
 ■ HOT SPRINGS

SECTIONIZED TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24
25	26	27	28	29	30
31	32	33	34	35	36

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 NATURAL RESOURCES GROUP
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ISOTHERMAL MAP-200 FOOT DEPTH
STATE OF OREGON-CRESCENT AMS SHEET
 DESCHUTES, CROOK, KLAMATH, LAKE, LANE COUNTIES, OREGON
 JULY 1977

Office

PLATE 6

REVISIONS
add holes, revise contours
update

DATE
9/78
12/78

SCALE 1:250,000

□ HOT SPRINGS

SECTION	1	2	3	4	5	6	7	8	9	10	11	12
18	1	2	3	4	5	6	7	8	9	10	11	12
19	1	2	3	4	5	6	7	8	9	10	11	12
20	1	2	3	4	5	6	7	8	9	10	11	12
21	1	2	3	4	5	6	7	8	9	10	11	12
22	1	2	3	4	5	6	7	8	9	10	11	12
23	1	2	3	4	5	6	7	8	9	10	11	12
24	1	2	3	4	5	6	7	8	9	10	11	12
25	1	2	3	4	5	6	7	8	9	10	11	12
26	1	2	3	4	5	6	7	8	9	10	11	12
27	1	2	3	4	5	6	7	8	9	10	11	12
28	1	2	3	4	5	6	7	8	9	10	11	12
29	1	2	3	4	5	6	7	8	9	10	11	12
30	1	2	3	4	5	6	7	8	9	10	11	12
31	1	2	3	4	5	6	7	8	9	10	11	12
32	1	2	3	4	5	6	7	8	9	10	11	12
33	1	2	3	4	5	6	7	8	9	10	11	12
34	1	2	3	4	5	6	7	8	9	10	11	12
35	1	2	3	4	5	6	7	8	9	10	11	12

PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA
NATURAL RESOURCES GROUP
ENERGY MINERALS DIVISION

TEMPERATURE-GRADIENT DRILL HOLES

STATE OF OREGON — BURNS AMS SHEET
LAKE, HARNEY, DESCHUTES, CROOK, GRANT, MALHEUR COUNTIES, OREGON
JULY 1977

REVISIONS:	DATE
add holes, revise contours	9/78
update	12/78

SECTIONIZED TOWNSHIP
6 5 4 3 2 1
7 8 9 10 11 12
13 14 15 16 17 18
19 20 21 22 23 24
25 26 27 28 29 30
31 32 33 34 35 36

PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA
NATURAL RESOURCES GROUP
ENERGY MINERALS DIVISION

ISOTHERMAL MAP - 100 FOOT DEPTH
STATE OF OREGON - BURNS AMS SHEET
LAKE, HARNEY, DESCHUTES, CROOK, GRANT, MALHEUR COUNTIES, OREGON

REVISIONS	DATE
add holes, revise contours	9/78
update	12/78

SECTIONED TOWNSHIP
6 5 4 3 2 1
7 8 9 10 11 12
13 14 15 16 17 18
19 20 21 22 23 24
25 26 27 28 29 30
31 32 33 34 35 36

PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA
NATURAL RESOURCES GROUP
ENERGY MINERALS DIVISION

ISOTHERMAL MAP-200 FOOT DEPTH
STATE OF OREGON -- BURNS AMS SHEET
LAKE, HAPNEY, DESCHUTES, CROOK, GRANT, MALHEUR, CLATSOP, OREGON
JULY 1977

REVISIONS:	DATE

SCALE 1:250,000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 30 KILOMETERS

CONTOUR INTERVAL = 200'

SECTIONIZED TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24
25	26	27	28	29	30
31	32	33	34	35	36

PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA
NATURAL RESOURCES GROUP
ENERGY MINERALS DIVISION

TEMPERATURE - GRADIENT DRILL HOLES

STATE OF OREGON — ADEL AMS SHEET
LAKE, HARNEY, AND MALHEUR COUNTIES, OREGON

OCTOBER 1977

RENO, NEVADA

REVISIONS:

	DATE

SCALE 1:250,000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 30 KILOMETERS

CONTOUR INTERVAL = 200'

SECTIONIZED TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA
NATURAL RESOURCES GROUP
ENERGY MINERALS DIVISION

ISOTHERMAL MAP-100 FOOT DEPTH
STATE OF OREGON — ADEL AMS SHEET
LAKE, HARNEY, AND MALHEUR COUNTIES, OREGON

REVISIONS:

DATE

50

0

5

10

15

20

MILES

5

0

5

10

15

20

25

30

KILOMETERS

CONTOUR INTERVAL=200'

6

5

4

3

2

1

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

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29

30

31

32

33

34

35

36

PHILLIPS PETROLEUM COMPANY

BARTLESVILLE, OKLAHOMA

NATURAL RESOURCES GROUP

ENERGY MINERALS DIVISION

ISOTHERMAL MAP-200 FOOT DEPTH

STATE OF OREGON — ADEL AMS SHEET

LAKE, HARNEY, AND MALHEUR COUNTIES, OREGON