CENTRAL WESTERN AND HIGH CASCADES GEOLOGICAL RECONNAISSANCE, AND HEAT FLOW HOLE LOCATION RECOMMENDATIONS

NORMAN V. PETERSON
State Department of Geology and Mineral Industries

and

WALTER YOUNGQUIST
Consultant

November 1, 1975

WALTER YOUNGQUIST, PH. D.
Consulting Geologist
BOX 5501
EUGENE, OREGON 97405

MEMBER
AMERICAN INSTITUTE OF PROFESSIONAL GEOLOGISTS
CERTIFIED PROFESSIONAL GEOLOGIST NO. 770

TELEPHONE
(503) 343-9768

LETTER OF TRANSMITTAL

November 1, 1975

R. E. Corcoran, State Geologist
State Department of Geology and Mineral Industries
1069 State Office Building
Portland, Oregon 97201

Dear Mr. Corcoran:

Transmitted herewith in four (4) copies, is a report entitled:

CENTRAL WESTERN AND HIGH CASCADES
GEOLOGICAL RECONNAISSANCE,
AND HEAT FLOW HOLE LOCATION RECOMMENDATIONS

This report was prepared by Norman V. Peterson of the State Department of Geology and Mineral Industries, and Walter Youngquist, consultant to that Department.

The study summarizes results and conclusions obtained during a reconnaissance of this area during the month of August, 1975, which reconnaissance built on previous acquaintance with the area by Walter Youngquist over a period of 18 years.

A brief summary of the geological framework of this region is presented, together with a statement as to where eight holes might be drilled to best advantage, what some of the site location and drilling problems might be, and what quality of resulting data might be expected. Brief notes explaining the reasons for picking each site are also included.

Distribution of this report is as follows:

State Department of Geology and Mineral Industries	4 copies
Eugene Water and Electric Board	1 copy
Walter Youngquist	1 copy

This study was supported by funds provided jointly by the State of Oregon and the U. S. Geological Survey, and a contribution by the Eugene Water and Electric Board.

Yours truly,

Walter Youngquist

Walter Youngquist

CENTRAL WESTERN AND HIGH CASCADES
GEOLOGICAL RECONNAISSANCE,
AND HEAT FLOW HOLE LOCATION RECOMMENDATIONS

NORMAN V. PETERSON
State Department of Geology and Mineral Industries
and
WALTER YOUNGQUIST
Consultant

November 1, 1975

TABLE OF CONTENTS

TABLE OF ILLUSTRATIONS

TABLE OF ILLUSTRATIONS
(continued)

TABLE OF TABLES

PURPOSE AND SCOPE OF REPORT

This report has been prepared to provide, in part, the basis for decisions as to where a Western Cascades-High Cascades heat flow drill hole program might be conducted which would produce the largest amount of good quality information for the resources available for this project. As presently envisioned, a heat flow drill hole program will be conducted in this area in 1976, and it has been assumed for the purposes of this study that approximately eight holes, each taken to a depth of about 500 feet, will be drilled. All these figures, however, are to be considered tentative, and subject to adjustment.

The area to be examined by means of this heat flow study, and the area which is the topic of this report is shown outlined on Figure 1 (next page).

The area embraces the region from and including Breitenbush Springs and southward along the western side of the Cascades from near their crest to a distance westward of about three townships. The north-south extent of this region is about 14 townships, and terminates a few miles south of the Kitson Hot Spring-McCredie Hot Spring area near Oakridge. The total area involved is somewhat in excess of 1500 square miles.

It is the purpose of this report to briefly consider the geology of this area, with special reference as to the quality of information which might be expected from heat flow holes here. Particular attention is paid to the matter of the possible effect of subsurface shallow water circulation on the data obtained. The report also proposes to reduce this larger area to several geological and geographical subdivisions for purposes of insuring that a reasonable geographic spread is obtained by the drilling program, and that ultimately a map with sufficiently well distributed points can be prepared which will give a significant picture of the heat flow variations and trends in this region.

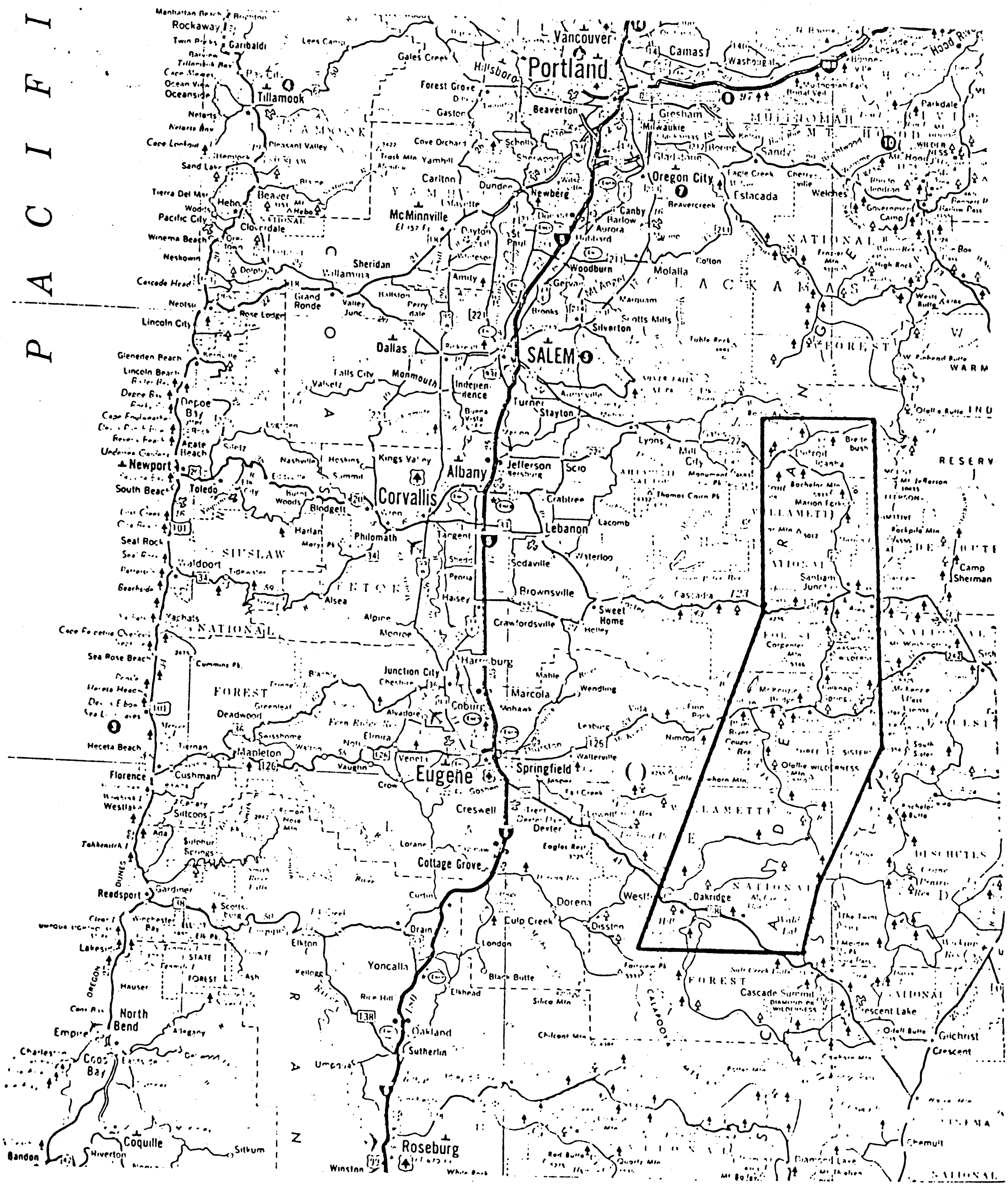


FIGURE 1. Index map showing in outline the area concerned in this report.

GEOLOGICAL RECONNAISSANCE OF THE REGION

Previous studies and present work. The Western Cascades have not been studied in any great detail except for a few local areas. The terrain is rugged, with local relief to several thousand feet. Rock exposures are poor, the vegatative cover is heavy, and the region exhibits a great variety and complexity of rock units even in a short distance. It can be conservatively stated that in many areas if there is a continuous exposure for a distance of 100 yards horizontally, it is rare that only one rock type is exposed. Commonly, several quite different rocks are present in this distance. Lacking any substantial economic reason to spend exploration money in this region to date, it has been studied only in a general way for the most part. The work of Peck, et al., 1964, remains the only large study. However, more recently Dr. Paul Hammondof Portland State University, and his students, have been doing detailed stratigraphic work in selected areas, notably in the Breitenbush Valley and adjacent terrains. In view of the designation of Breitenbush as a KGRA, and the leasing interest in this area, this is a fortunate circumstance.

During this present study, which was conducted chiefly in the month of August, 1975, all major drainages were studied, and many minor drainages were also examined. Extensive rock sampling was done, and comparisons of rock types were made directly in the field.

Peck, et al., 1964, note that natural rock outcrops in the Western Cascades make up less than 1 percent of the total area, and these exposures are confined chiefly to ridgetops and stream bottoms. More recently, an extensive series of logging roads has provided the best outcrops, and afford a relatively rapid method of geological reconnaissance and a view of most of what good rock exposures as do exist. Again, however, the total area of exposed rock relative to the total area involved is very small. When this fact is combined with the great complexity of the geology, the difficulties of preparing accurate maps in any detail quickly become apparent.

Peck, _et al._,(1964, p. 1) have noted that

> "The calc-alkalic volcanic rocks of the Western Cascade Range in Oregon have a total volume of about 25,000 cubic miles, and an average composition of silicic andesite or dacite. Andesite that has a silica content of about 56 percent is the most abundant rock type; rocks containing 63 to 68 percent silica are sparse, and rocks containing 70 percent silica are moderately abundant. Most of the volcanic activity in the Cascade Range was apparently concentrated in northward-trending belts, which in general have shifted progressively eastward during the Cenozoic."

During Eocene time, volcanism took place along the Oregon coastline which at that time lay somewhat eastward of Eugene. As volcanism became more intense, the land rose, the sea retreated westward, and the volcanic activity, as noted by Peck _et al._, appears to have shifted gradually eastward.

More than half the Western Cascade volcanic rocks are pyroclastics, and, as has been noted, basaltic andesite, andesite, and dacite are the most common rock types. In detail, the sections consist of numerous ash flow tuffs, ash falls, interbedded lava flows, volcanic breccias and agglomerates in a very large range of fragment sizes, dikes and dike swarms, small intrusives other than dikes of various shapes and sizes, and minor pond and lake deposits formed in drainages which were interrupted by landslides, mudflows, and/or lava flows (as is the case of Clear Lake at preeent, formed by lava flows about 3,000 years ago which came across the upper portion of the North Fork of the McKenzie River). Tuff breccias, vitric tuffs, and related rock types, in an almost infinite variety, are abundant. Of all the various lithologic units, huge mudflows consisting of weathered ash with very poorly sorted angular to well rounded pebbles, cobbles, and boulders are one of the most common. Some typical outcrops of these various rock types are shown in Figures 2-5.

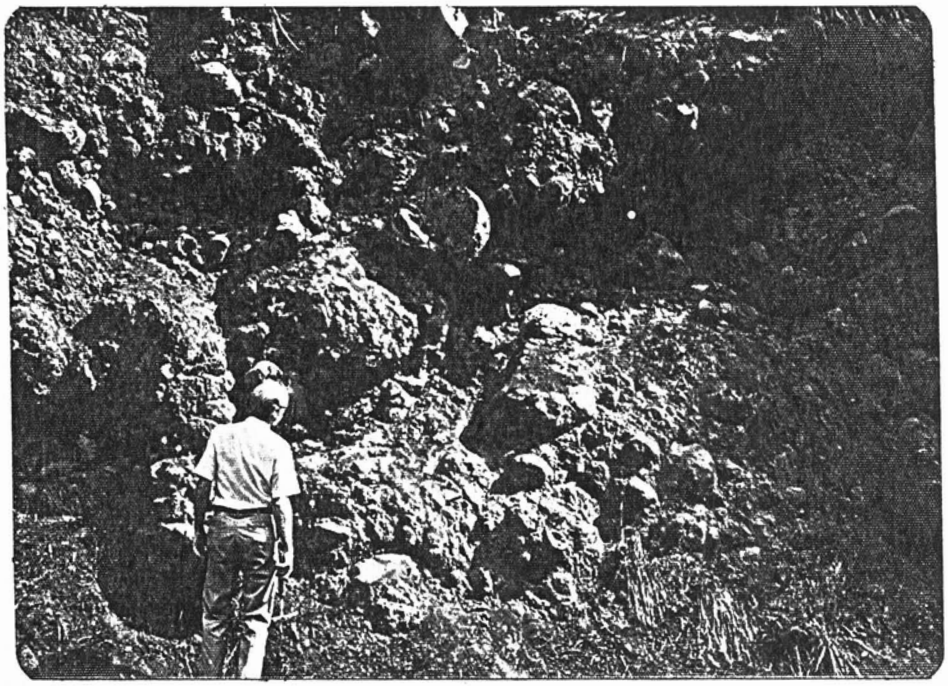


FIGURE 2. Mudflow complex exposed in lower portion of Deer Creek Canyon, tributary to North Fork of the McKenzie River.

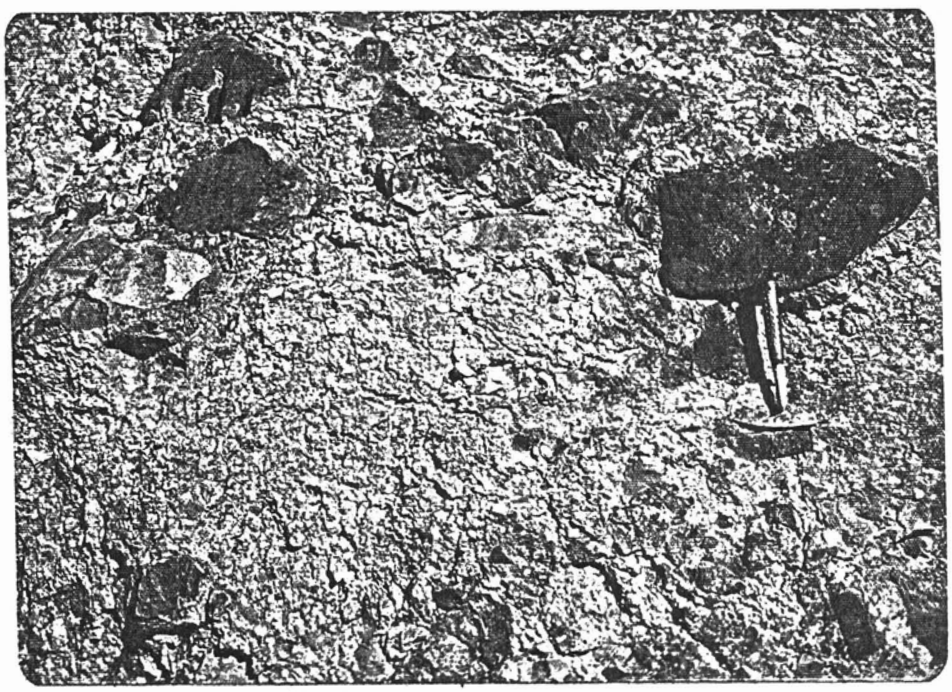


FIGURE 3. Mudflow exposed on west side of Cougar Reservoir, a dammed portion of South Fork of the McKenzie River.

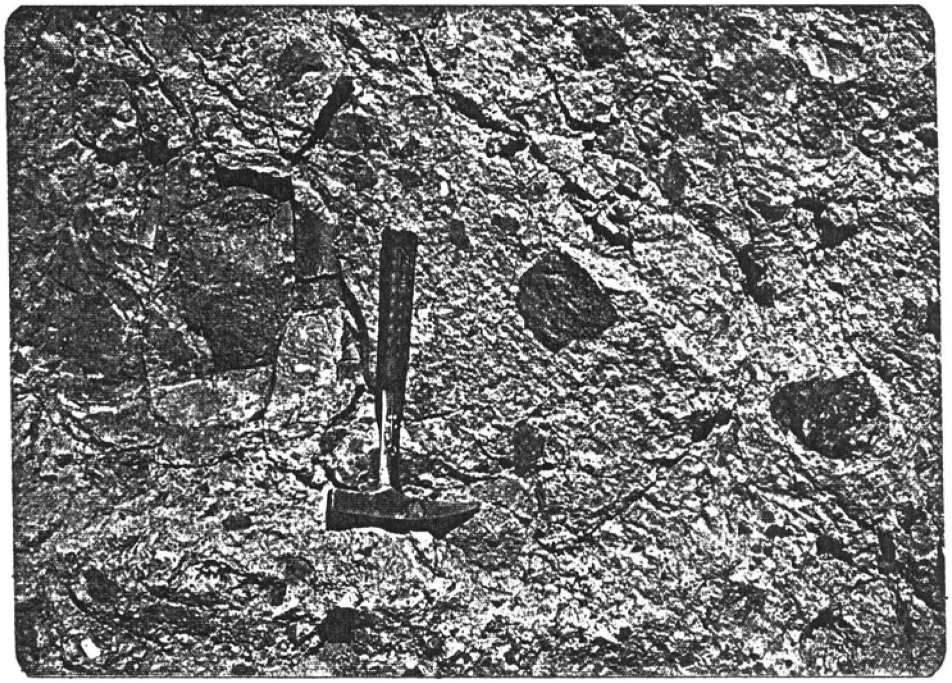


FIGURE 4. Lithified mudflow exposed in east abutment of Hills Creek dam, southeast of Oakridge, on Middle Fork Willamette River. Some rock debris in this section are 10 feet or more in long dimension. A granitic fragment was obtained from this exposure.

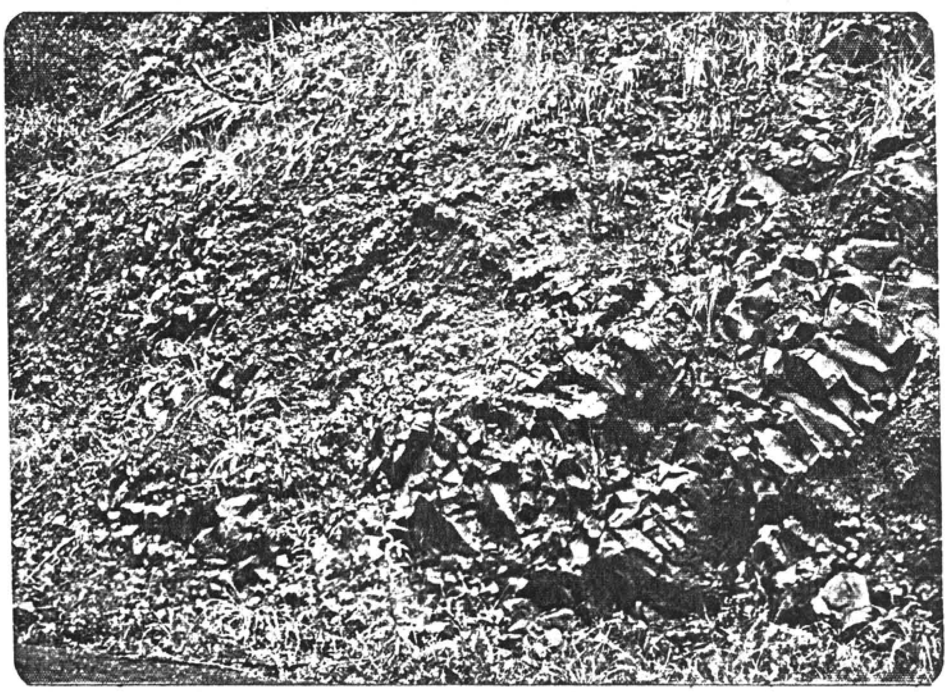


FIGURE 5. Lava flow which filled small gully, exposed on Lookout Ridge, which is the north valley wall of the McKenzie River, on Mill Creek road, north of the small community of Rainbow.

Some of the lava flows are thin, in places only a foot or two thick, and may occur in a series of half dozen or more flow units in a short vertical interval, as well shown by the section exposed in the spillway at the Smith River Reservoir, seen here in Figure 6.

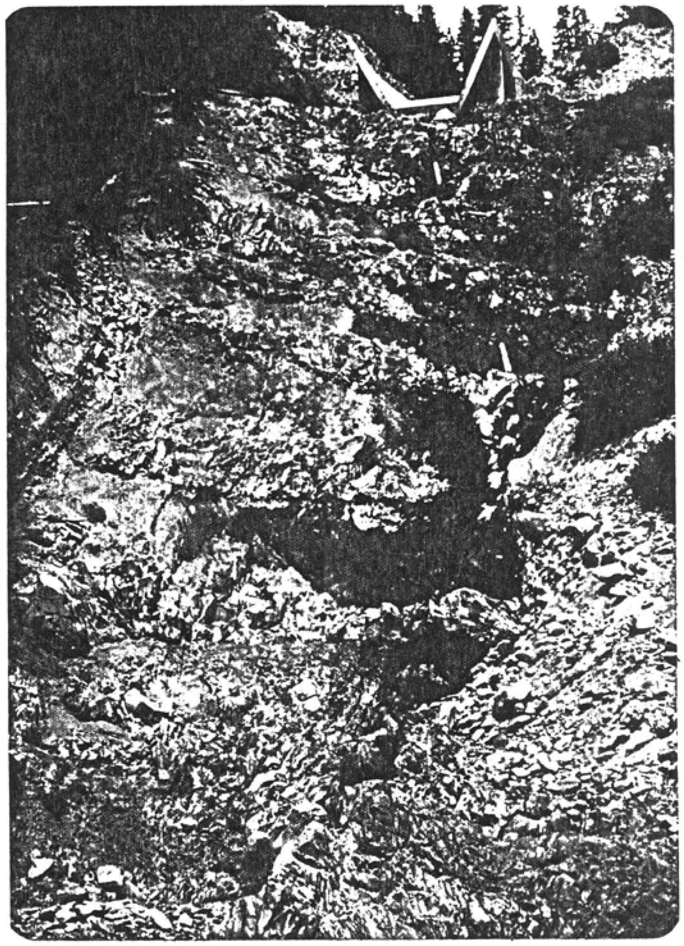


FIGURE 6. Spillway at Smith River Reservoir, showing numerous thin lava flows interbedded with volcanic tuffs and breccias.

Some of the lava flows, however, are quite thick (to 100 feet or more), and many appear to have flowed down steep-walled narrow canyons, in some instances for distances of several miles. These massive flows now tend to stand out as steep ridges (Figure 7), as they are much more resistant to erosion than are the volcanoclastics which make up the bulk of the Western Cascades. In some instances, High Cascade lavas have flowed down valleys into the Western Cascades region for distances of a few to up to more than 10 miles and now stand out as prominent landforms. Foley Ridge, a well-known physiographic feature northeast of McKenzie Bridge, appears to us to have had this origin.

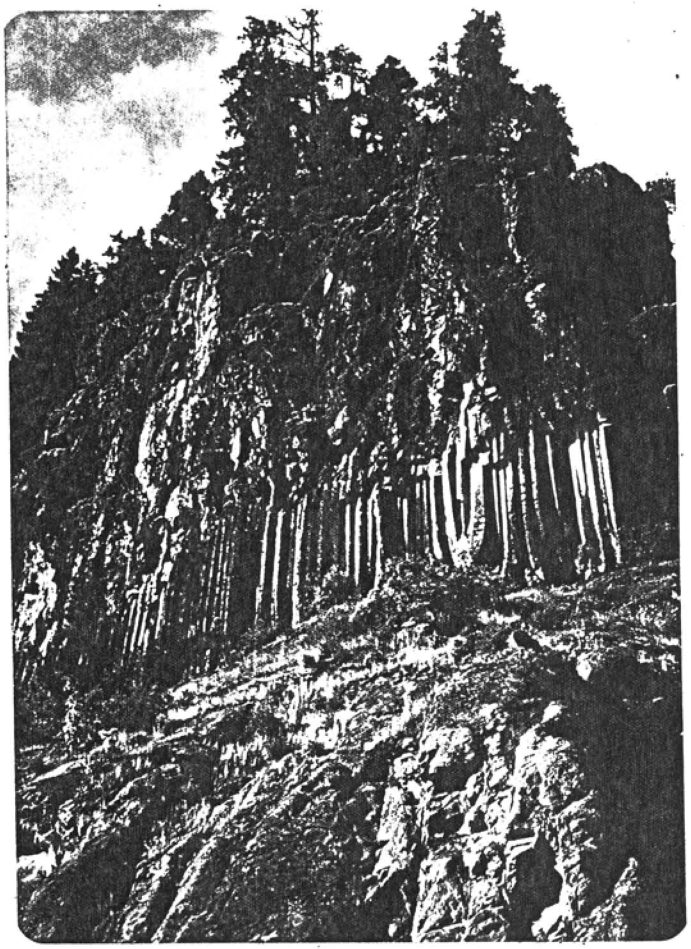


FIGURE 7. Massive lava flow, forming prominent ridge along mid-portion of west side of Cougar Reservoir, South Fork of the McKenzie River.

Peck et al., 1964, indicate that the volcanic sequence in the Western Cascades in the vicinity of Glide, and Illahee Rock, Oregon, totals some 6,000 to 15,000 feet in thickness. Their stratigraphic section for this area is shown on Figure 8. One can only conjecture as to the thickness of the Tertiary volcanic section in the central Cascades--the area under consideration in this report, but thicknesses of 20,000 to 30,000 feet do not seem impossible.

It is noteworthy that Peck et al. were able to recognize

FORMATION	LITHOLOGY	THICKNESS IN FEET	DESCRIPTION
Sardine Formation			Andesite flows; medium- and dark-gray platy flows of pyroxene andesite containing phenocrysts of labradorite, hypersthene, augite, and magnetite
			UNCONFORMITY
Little Butte Volcanic Series		1000-6000	Andesitic and dacitic lapilli tuff; includes fine tuff and a few flows; mostly massive light-gray and greenish- or brownish-gray vitric lapilli tuff containing pumice lapilli, felsite fragments, and crystals of sodic plagioclase in a matrix of altered vitric ash; a few layers are thin- to medium-bedded fluviatile carbonaceous tuff; upper part of unit poorly exposed
		500-1500	Flows of olivine basalt and basaltic andesite; include less abundant flow breccia and tuff breccia; chiefly dark-gray columnar-jointed flows that have vesicular and amygdaloidal flow tops, and contain 10 to 20 percent phenocrysts of bytownite-labradorite, as much as 5 percent olivine, and 5 percent augite in an intergranular or fluidal groundmass
		1000-5000	Dacitic and rhyodacitic tuff; includes welded tuff, lapilli tuff, and fine tuff; chiefly massive very light gray and greenish-gray vitric tuff containing flattened pumice lapilli, crystals of andesine-oligoclase, and, in part, quartz in a matrix of altered vitric ash
		500-3000	Andesite flows; include less abundant flow breccia and tuff; medium- to dark-gray blocky and platy flows containing as much as 25 percent phenocrysts of sodic labradorite and as much as 10 percent phenocrysts of hypersthene and augite in a hyalopilitic or pilotaxitic groundmass; a few flows contain green biotite and xenocrysts of quartz
		1000-3000	Andesite tuff; includes a few andesite flows and beds of volcanic conglomerate; chiefly greenish-gray and olive-gray massive vitric lapilli tuff but includes thin- to medium-bedded fine tuff
		0-1000	Rhyodacitic welded tuff; very light gray vitric crystal tuff containing crystals of oligoclase, quartz, sanidine, magnetite, and biotite in a devitrified matrix of shards and ash
			UNCONFORMITY
Colestin Formation			Andesitic tuff, tuff breccia, conglomerate, sandstone, and flows of olivine andesite and pyroxene andesite
		Total 6000-15,000	

Generalized columnar section of the Little Butte Volcanic Series along the Little River and the North Umpqua River between Glide and Illahee Rock, Oreg.

FIGURE 8. A stratigraphic column of a portion of the Western Cascades, taken from Peck, <u>et al.</u>, 1964.

only very broad subdivisions in this thick volcanic sequence. We have made consistent effort to recognize distinctive rock types and to try to carry these rock types beyond local areas in our studies, but results have been almost uniformly negative. The persistence of a given rock unit as such over any great distance (more than a few tens of miles) seems to us unlikely. On the other hand, there may have been certain episodic volcanic events during the Tertiary which for a given time might produce a characteristic rock type from numerous vents over a wide area. As our studies have been relatively local rather than regional, we are not in a position to comment on this matter with any authority. It does seem clear to us that there were numerous volcanic centers. Some were well defined, typical cones, others were fracture zones. They differed greatly in size. Numerous parasitic volcanic centers developed around larger centers. The general nature of these centers was that the more solid, large, and denser rocks and flows tended to form and remain near these centers, and the peripheral areas received the finer pyroclastics, which, upon weathering, are less durable than the coarser pyroclastics and thick flows which tended to occur and remain nearer the vents. As a result, in the erosional processes which formed the present topography of the Western Cascades, the old volcanic centers even now tend to be the higher, prominent mountain ridges and peaks, and the present valleys follow around the margins of these volcanic centers and coincide therefore to some extent with the positions of the valleys in the Tertiary. That is, the present day topography reflects to a considerable degree the topographic highs and lows which developed during Tertiary volcanism (See, for example, Figure 19, page 27 showing Crescent Mountain volcanic center in well defined present day relief).

Further evidence of this comes from the fact that logging roads around these centers expose what we believe to be, for the most part, initial dips, and a plot of these dips indicates the locations of the various centers from which these materials have come. These centers in many cases are now topographic highs. One example of this is the very distinctive rock type described by Taylor (in Dole, 1968, p. 12) which is exposed along U. S. Highway 126 at Trail Bridge Reservoir, and which is exposed also on the ridge to the west. The rock on the ridge has a 28 degree dip to the east (Figure 9) which can be projected down to the outcrop on the valley floor along the highway, and this 28 degree dip seems clearly to be an initial dip.

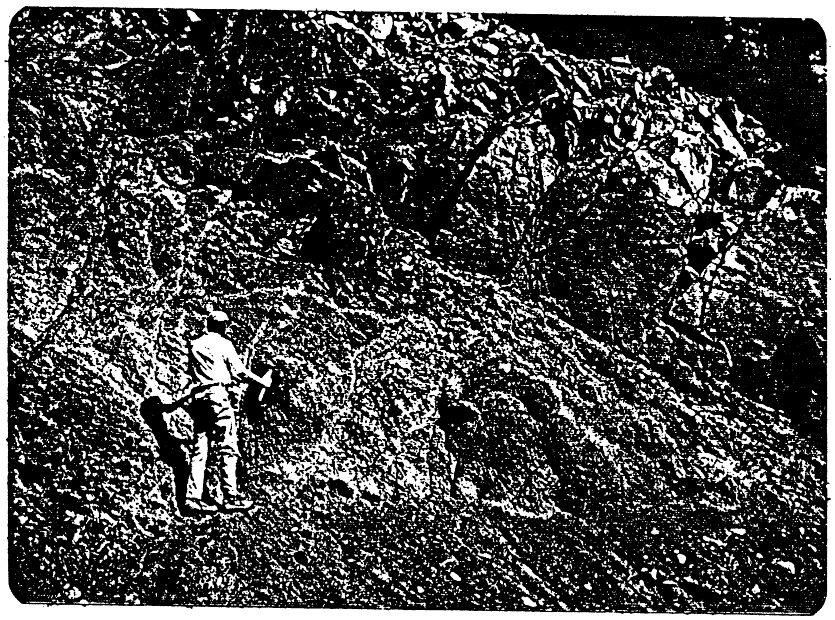


FIGURE 9. Flow or welded tuff now consisting of devitrified glass, with rock fragments, dipping 28 degrees off volcanic center to the west of Trail Bridge Reservoir, North Fork of McKenzie River.

Thus, in brief, the Western Cascades consist of numerous (hundreds) of volcanic centers, some cones, some fissures, which, erupting at various times, modified the topography and drainage lines. One side of a volcanic center will commonly show quite a different stratigraphic section in detail than another side. Direction and intensity of the prevailing wind during an eruption, rainfall, the location of drainage lines, varying intensities of the eruption, the breaking out of lava on one side of a cone versus another, and differing viscosities of flows, all contributed to an exceedingly complex picture. It is difficult to visualize how any individual rock unit could persist very far over this rough and varied topography, except possibly an ash fall or ash flow tuff. Even an ash fall would almost immediately be dissected by streams, washed down the numerous steep slopes of the region, and otherwise be modified so that its recognition and use as an horizon marker would be difficult at best.

Each volcanic center appears to have its own stratigraphic column, mingled at its periphery with sections from other adjacent volcanic centers, and with each of these centers, as just noted, exhibiting somewhat to considerably different stratigraphic sections from one side of the center to another. Cause of many of these differences undoubtedly was the rugged topography of the region in the Tertiary, as evidenced not only by the high initial dips which are still preserved, but also by the tremendous mudflows and the size and angularly of the debris which are incorporated into them.

Notable also in the Western Cascades section is the presence of a number of silicic plutons which have been mineralized in minor amounts. These include the so-called Nimrod Granite (called by Peck, et al., 1964, a quartz monzonite) of the McKenzie drainage, a granodiorite stock west of Detroit, and the plutons of the Quartzville Creek area and adjacent drainages, and other mineralized areas such as on Crhisty Creek, on the North Fork of the Middle Fork of the Willamette drainage, presumably related to a shallow pluton. A map of these intrusives, taken from Peck, et al., 1964, is shown by Figure 10.

High Cascades and Western Cascades. A distinction is commonly made between the High or Young Cascades, and the Western Cascades. Peck et al., 1964, p. 1, state:

> "The Cascade Range in Oregon comprise two physiographic divisions: The Western Cascade Range, which includes a wide, deeply dissected belt of volcanic formations making up the western slope of the range, and the High Cascade Range, which includes chiefly younger cones and lava flows forming the nearly undissected crest of the range. The volcanic rocks of the Western Cascade Range are deformed and partially altered flows and pyroclastic rocks that range in age from

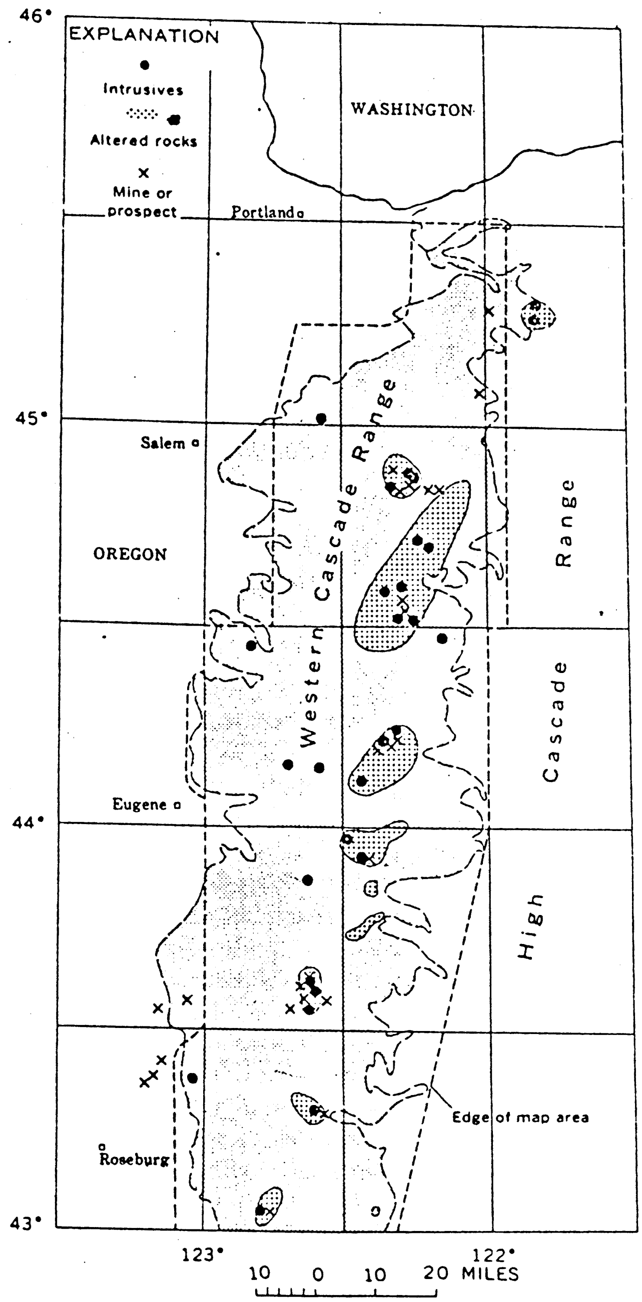


FIGURE 10. Location of diorite, quartz diorite, granodiorite, and quartz monzonite intrusives, areas of propylitically altered rocks, and mines and prospects in the Western Cascade Range in Oregon north of Latitude 43°. Western Cascade Range lightly shaded. (From Peck, et al., 1964).

late Eocene to late Miocene, as determined chiefly from fossil plants from more than 50 localities."

The divisions of High Cascades and Western Cascades, are, as Peck, et al., pointed out, physiographic divisions, and there is a question as to how sharp a geological distinction can be made between these two provinces, and how it should be done.

The High Cascade lavas lap over on to the Western Cascade complex, and in some cases tongues of High Cascade lavas run down for several miles into valleys of the Western Cascades. What are termed Western Cascade volcanics are buried beneath these younger volcanics to the east so that the eastern margin of the so-called Western Cascade volcanics is unknown. The Young or High Cascade volcanics tend to form a relatively undissected plateau surmounted by the several Pleistocene and/or Holocene volcanoes such as the Three Sisters, Mount Washington, Mount Jefferson, etc. Figure 11 is a view looking south from Sand Mountain, a series of Holocene cinder cones, on the High Cascade volcanic plateau. The slight prominence on the east (left) horizon is Scott Mountain, a shield volcano on the plateau. The dissected ridges to the west (right) in the photograph are part of the Western Cascades, and the intervening valley marked by a haze line is that of the McKenzie River.

Various lines have been drawn between High Cascade and Western Cascade rocks. Peck et al., as noted, date the Western Cascade rocks as those which are Miocene or older. Another definition, and one which can be utilized in the field with proper small geophysical equipment, is simply to draw the line between High Cascade rocks and Western Cascade rocks (or Western Cascade time) at the most recent magnetic reversal (some 690,000 years ago).

Taylor (in Dole, 1968, p. 3) states:

"In spite of the general contrast between the Western and High Cascades, their common boundary is difficult to locate. In many areas, adjacent rocks of both provinces are flat-lying, unaltered, and are similar in chemical and mineralogical composition. To resolve this problem, individual rock units must be traced from areas in which

FIGURE 11. Looking south from Sand Mountain, across the Belknap Plateau. Prominence on the left (east) horizon Scott Mountain, a shield volcano on the plateau. Dissected ridges to the right on the horizon are part of the Western Cascades. Haze area marks approximate position of the McKenzie River Valley.

the boundary is easily fixed, into areas in which the position of the boundary would be otherwise obscure. This has now been accomplished in the central Cascades and several important relations are apparent: (1) A distinctive and widespread unit of homogeneous coarse-grained basalt marks the base of the High Cascade sequence. It is usually diktytaxitic and occurs in thick sections of many thin flows. (2) A more variable, finer grained, dense basalt overlies the coarse-grained diktytaxitic section and forms the bulk of the High Cascade platform. (3) The High-Western Cascade boundary is outlined by the western limit of the coarse-grained diktytaxitic rocks. Locally, where they overlap the coarse-grained section, the fine-grained, dense basalts form the boundary. (4) A profound erosional and/or angular unconformity exists at the boundary. Coarse-grained, diktytaxitic <u>early</u> High Cascade basalt inundated eastern foothills of previously deformed Western Cascade rocks and, in places, poured west for 10 miles through the same major valleys which penetrate the Western Cascades today. (5) If the boundary is controlled by a major north-south fault, as has been suggested by several authors, this fault is not exposed to view and has not displaced the High Cascade rocks. In fact, the principal faults along the boundary are generally less than one mile in length, trend northwest, and involve displacements of less than 100 feet. They are restricted to the Western Cascades."

We do not presume to pursue this matter of High Cascade-Western Cascade boundary in any great detail. Whatever distinction is drawn would seem to be arbitrary to some degree as this is a region where volcanism has been a more or less on-going situation since the early Tertiary, although some episodic volcanic activity may perhaps be recognized.

For our studies, the principal significant difference between the High Cascades and Western Cascades is simply the degree of weathering of the rocks. All these volcanic materials are relatively unstable under the climatic conditions of the Cascades now and apparently those of the Tertiary, and the Western Cascades rocks have, in places, been altered entirely or very nearly so to clay. All degrees of alteration occur. Also, ancient geothermal areas can be identified where either over an area of several miles, or simply locally, hydrothermal alteration has occurred, or minor mineralization has taken place. Peck _et al_., have marked on their map the areas of propylitically altered rock (see also our Figure 10, taken from Peck _et al_.). The significance of these altered and locally mineralized areas is not known with regard to geothermal matters, and exploration of one or several such areas with heat flow holes might be warranted.

In general, the High Cascade volcanics have protected the underlying rocks from present and Pleistocene erosion and also have filled the valleys in the underlying rocks so that the High Cascades west of the crest present the appearance of a broad, gently sloping plateau. Where these younger rocks stop, and erosion has cut deeply into the Western Cascade volcanics is where the hot springs occur.

HOT SPRINGS OF THE REGION

Parallel to, but lying some distance west from the crest of the Cascades in this region is a line of hot springs. In this study, the northernmost such area is Breitenbush, and the southernmost hot spring is Kitson--the distance between these two being some 70 miles. The hot springs all occur in Western Cascade volcanic rocks, and very close to the surficial junction of the High Cascade rocks with these Western Cascade volcanics. Most of the springs occur in the lowest points in the valleys, at stream level or close to it, but there are some exceptions such as Foley Hot Springs, and Rider Hot Spring. Locations of these and other hot springs in Oregon are shown on the map by Bowen and Peterson (1970). A tabulation of the location and some characteristics of the springs which occur in the area under discussion is shown on Table 1, next page.

It should be noted that more hot springs exist than the ones shown on the map by Bowen and Peterson (1970), which was an initial preliminary map. For example, there is a hot spring in the region under consideration in this report along the west bank of the McKenzie River at river level about 200 yards downstream from the mouth of Deer Creek.

Almost all these Western Cascade hot springs, with the exception possibly of Kitson, appear to issue from a medium to coarse (with blocks up to several feet across in the case of Foley Springs) volcanic breccia facies of the Western Cascades.

Figure 12 shows a general view and Figure 13 a closer view of Foley Springs, which issue from several closely spaced vents in a hillside about 150 feet above the stream bottom of nearby Horse Creek.

Temperatures of these springs range from about 190°F down to about 90°F. Largest discharge is that of Breitenbush Springs

TABLE 1

HOT SPRINGS OF THE CENTRAL PART OF THE WESTERN CASCADES

Name	Location S	T	R	Surf. temp. °C	°F	Flow	Elevation	Use	Other information
Breitenbush	20	9S	7E	92	198	900gmp 40-60 orifices	2250'	Spa	Believed to be hot water convection system with subsf. temp. 150°C.
Deer Creek	SE22	15S	6E	est 70	158	small	1850'	None	
Belknap	NW11	16S	6E	71	160	75 gpm	1700'	Heats house and pool	Believed to be hot water convection system subsf. temp 140 C
Foley	NW28	16S	6E	79	174	25gpm	1700'	Pool	Geochem. indicates 114-135°C.
Rider	7	17S	5E	54	130	60 gpm	est.2000'	None	
Wall Creek	NW26	20S	4E	37	98	3 gpm	2080'	None	
McCredie	36	21S	4E	73	164	20 gpm	2000'	None	Several orifices in bank of Salt Creek. Geochem shows subsf. of 81°C (D. Hull, personal comm.).
Kitson	6	22S	4E	46	114	35 gpm	1575	Spa	Resort built over spring orifice.

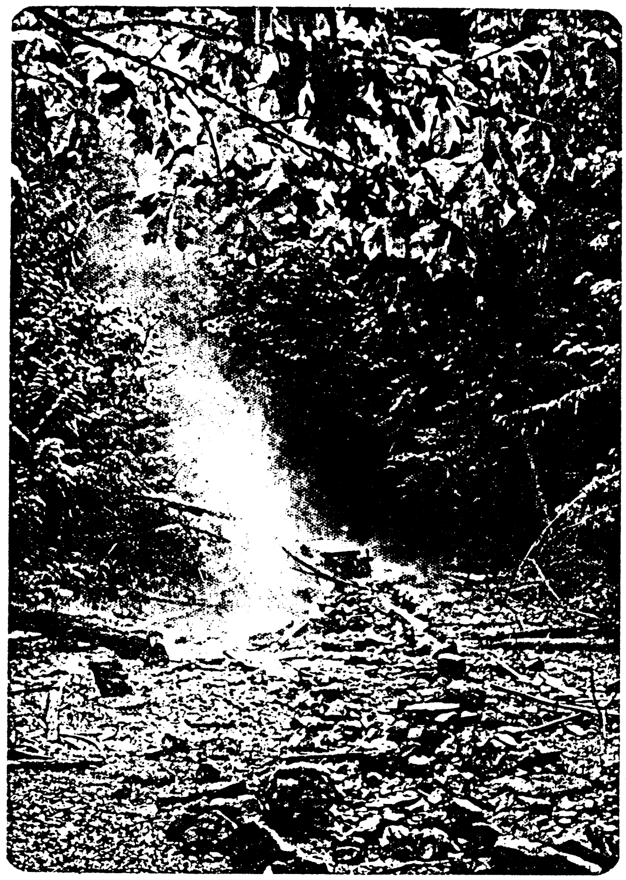


FIGURE 12. Foley Springs, general view, on Horse Creek drainage, about 4 miles eastsoutheast of McKenzie Bridge, Lane County.

FIGURE 13. Close view of Foley Springs showing the coarse volcanic breccia from which the spring issues.

estimated to be about 900 gpm from about 40 orifices. Belknap Springs (Figure 14) is the next largest with a discharge of about 75 gpm.

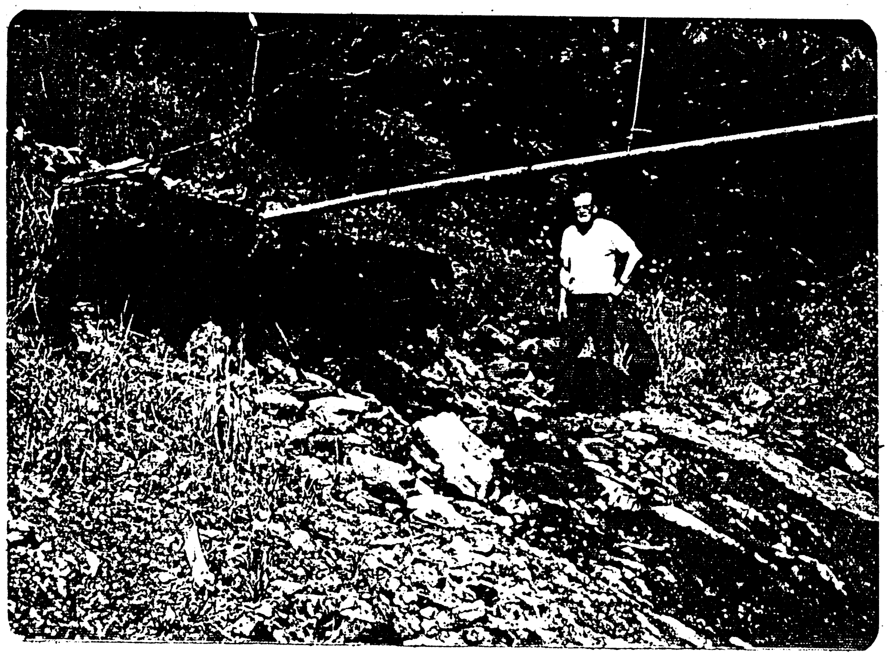


FIGURE 14. View of Belknap Springs--the main spring--which issues from volcanic breccia about 15 feet above low water on the McKenzie River. Several other smaller vents exist right at stream level. It is reported that at very low water additional hot spring vents can be detected in the river bottom. Bedrock here is volcanic breccia with fragments to about a foot in diameter.

Rider Hot Spring (Figure 15) also issues from volcanic breccia, but is unusual in that it comes from fairly high up the wall of a tributary valley (Rider Creek) to the South Fork of the McKenzie. The South Fork here is now flooded as part of Cougar Reservoir, but it is estimated that Rider Spring is about 400 feet above the old valley floor of the adjacent South Fork. All these hot springs come out within a few hundred feet, one way or another of the 1800 foot contour. The significance of this is not known, but it may represent a regional water table.

FIGURE 15. Close view of Rider Hot Spring, located near Rider Creek, a small tributary on the west side of the South Fork of the McKenzie River. S ring is about 400 feet above valley floor of nearby South Fork of Mckenzie River (before area was flooded by Cougar Reservoir).

One of the questions in regard to these springs is whether they are more or less directly over their heat sources, or do they perhaps represent isolated vents here and there which, from distances of several miles, are carrying up hot waters from geothermal systems which may lie to the east of this line of hot springs, and are related to the volcanism which has given rise to the High Cascades? A third possibility is that the entire region is one of high heatflow, and where the Cascades have been most deeply incised by erosion is where this geothermal system is leaking. No hot spring could reasonably be expected to occur in the plateau area of the High Cascades as it is underlain by young, relatively unweathered volcanic rocks, many of which are ā'ā flows, highly porous and permeable. Surface drainage here is virtually non-existent. Any hot waters coming up into this volcanic complex would be diverted laterally through permeable zones and ultimately mixed with cold surface waters (rainfall here in excess of 80 inches, and snow persists into late June and early July many places). Accordingly, such hot waters would not survive to the surface. It is remarkable, in fact, that any hot waters reach the surface, even in the valley areas, given the thick, moist, weathered cover, and the cold streams (McKenzie River is 46°F).

The volcanic rocks of the Cascades fill a broad north-south trending downwarp. Alteration by weathering and other means of the Western Cascades has resulted in what appears to be a complex which for the most part is relatively impermeable, and would act as a fairly effective seal on any hot water systems (or steam) which might lie beneath. The abundance of silicic ash, relatively easily yielding silica to solution, might suggest that it would be possible at some critical depth and temperature to have formed a silica roof over a geothermal system, and that the true nature of the hot water and/or steam systems in this area at depth is not evident from the surface indications. The hot springs which we know now at the surface may simply be recirculating relatively near-surface waters, and may be more or less sealed off from major geothermal systems at depth.

Dr. Paul Hammond and his students, in their studies in the Breitenbush area have suggested that the Western Cascades weathered volcanics do indeed act as a gigantic seal on whatever geothermal systems exist here, and we are inclined to agree with this observation. When one examines the highly altered nature of many of these volcanics, it appears that it would be only a very special circumstance--perhaps a very persistent fracture--which would allow hot water to come up through this seal.

In the McKenzie River drainage, which includes a number of hot springs (Foley, Belknap, Deer Creek, and other reported but not recorded springs), no wells deeper than a few hundred feet appear to have been drilled for any purpose, and no heat flow information is available from any of these. We have virtually no subsurface data of any kind. This general situation also exists elsewhere in the region under consideration, and therefore initiation of a heat flow drilling program will be a major advance in gaining a view of the geothermal potential of this area.

Under any circumstances, we presently know so little about the heat flow and possible hot water systems in the Cascades, and the volume of volcanics, some as young as 700 years old, is so great, that it obviously is an attractive and worthwhile area in which to conduct extensive geothermal investigations, of which this heat flow study is but an initial step.

REGION SUBDIVISIONS

In part because of the differing geology, and in part due to the geography and the way in which the KGRA's have been designated, for purposes of this report we have recognized six subdivisions of the region under consideration. These are shown in rough sketch form on Figure 16 (next page) and are designated from north to south as:

BREITENBUSH AREA

BREITENBUSH TO SANTIAM AREA

BELKNAP AREA

WEST NORTH FORK AREA

SOUTH FORK MCKENZIE-NORTH FORK OF MIDDLE FORK OF WILLAMETTE AREA

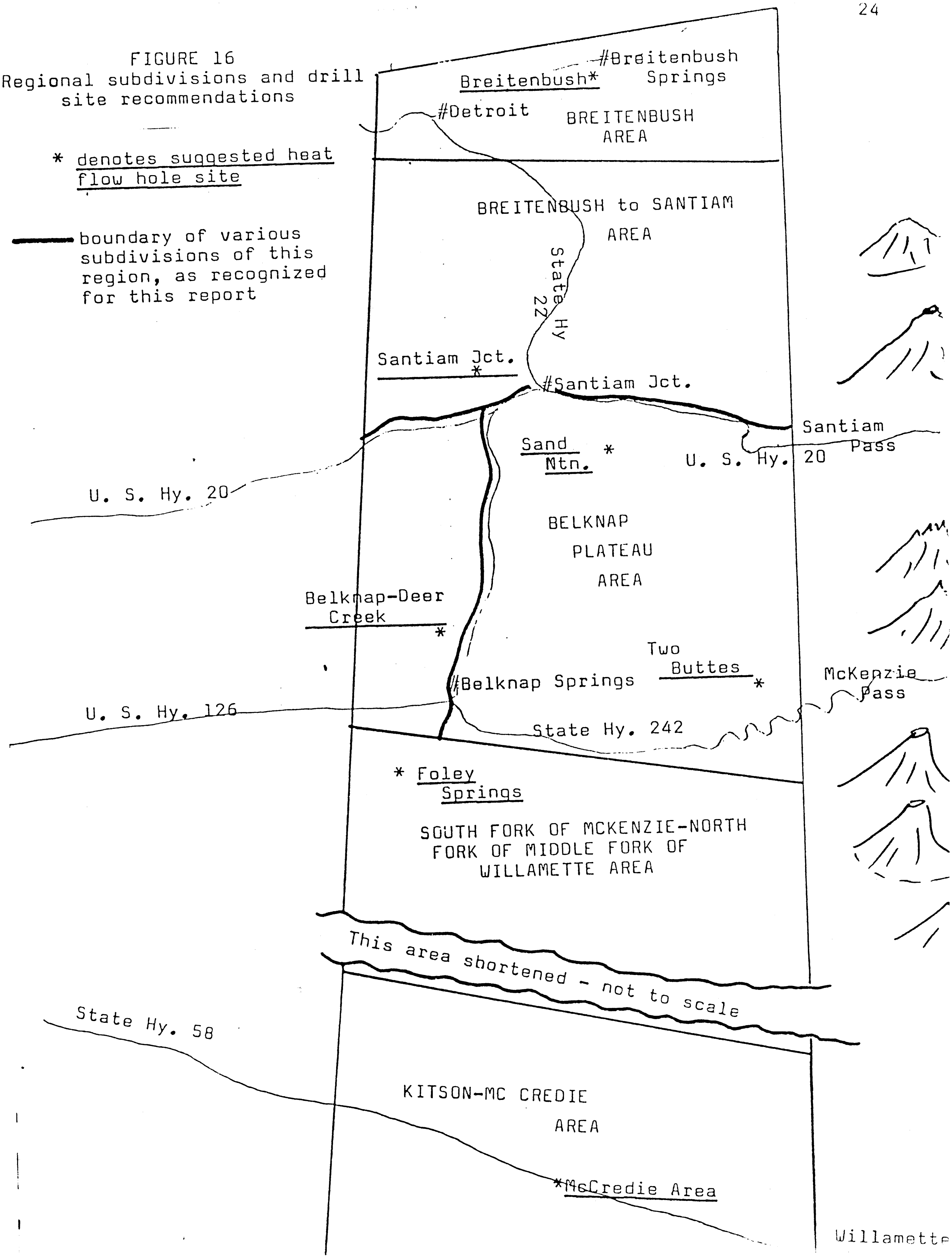
KITSON-MCCREDIE AREA

We recommend that at least one heat flow hole be drilled in each of these areas. We have shown these tentatively recommended locations by an asterisk (*) on Figure 16. These sites are briefly described here, with specific suggestions as to where (by legal description) these heat flow holes might be located.

RECOMMENDED DRILLING LOCATIONS

Breitenbush location. This area has already been designated a KGRA. Industry information which we believe to be reliable, as well as USGS data (Circular 726 in particular) indicate that this is one of the hottest heat flow anomalies in the region under study. Because it has already been declared a KGRA and therefore is now a competitive leasing situation, no individual company is likely to spend money test drilling the area before leases are issued. This clearly seems to be a place where an agency like the Oregon State Department of Geology and Mineral Industries could make a significant contribution by drilling at least one hole, and perhaps two heat flow holes. The valley floor proper within a mile more or less of Breitenbush Hot Springs is recommended as a location. Interest in this area being as considerable as it is, another hole might be justified, and this could be a mile or two east, northeast, or

FIGURE 16
Regional subdivisions and drill site recommendations



south of Breitenbush Valley. Ample access and good drill sites exist, especially south of the Breitenbush Hot Springs area. Another reason for putting two holes down in this area is the relatively good geological information we have here. As a result of the work of Dr. Paul Hammond and his students, this area is the most thoroughly studied geologically of any of the subdivisions of this region which we have established. A general view across the Breitenbush Valley, looking to the northeast, is shown in Figure 17. A close view of some of the terrain south of Breitenbush is shown in Figure 18.

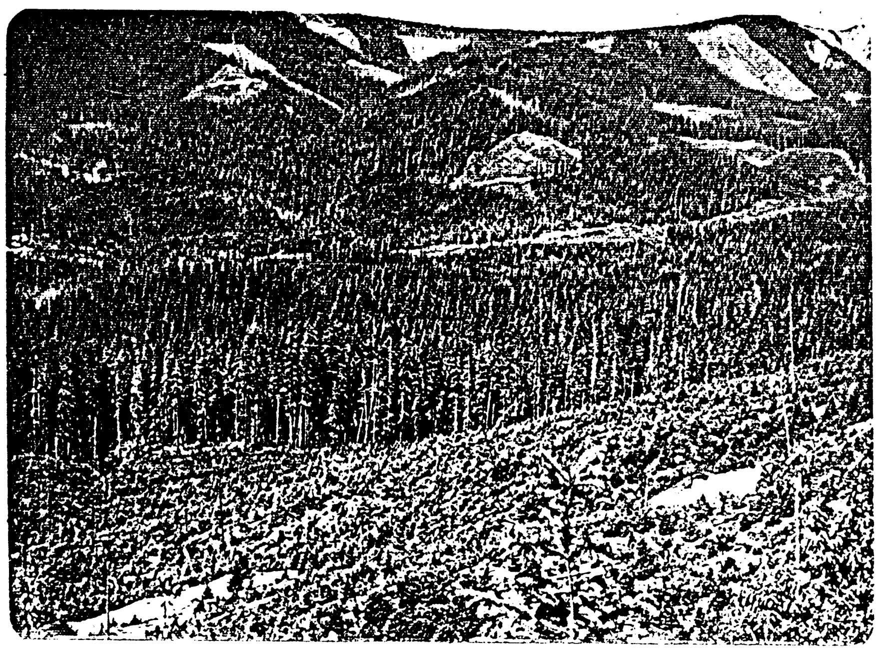


FIGURE 17. General view looking northeast across the valley of the Breitenbush River. The Breitenbush Hot Springs area proper lies slightly to the left (west) of the margin of the photograph.

Specifically, we recommend looking at a site in the south part of section 28, T 9 S, R 7 E, and/or in section 16, or 21 of the same township for one of the locations.

FIGURE 18. View of terrain, looking southeast, about 3 miles southsouthwest of Breitenbush Hot Springs.

Santiam Junction. This is an area of quite recent volcanism. It is relatively undissected with the result that little is known about the geologic section here as exposures in depth are limited. However, the several fracture systems of the area and the attendant volcanic activity here are impressive. The area is also geographically situated so as to complement information which would be obtained from a hole recommended to be drilled east of Sand Mountain (see next location). It also is almost directly on a north-south line between Breitenbush Hot Springs and the hot springs known in the southern portion of the North Fork of the McKenzie River. We recommend a location in the vicinity of section 36, T 12 S, R 6 E. The south center of this section would be satisfactory, as would the N½ section 1, T 13 S, R 6 E.

General view of this area is shown in Figure 19. Big Nash Crater is the prominence in the middle right (east) of the photograph. Photo taken looking northwest from Sand Mountain. The area of interest lies in the middle distance over the left (west) flank of Big Nash Crater in this photo. As shown on Figure 1, the area would be southeast about 1½ miles from South Pyramid Mountain.

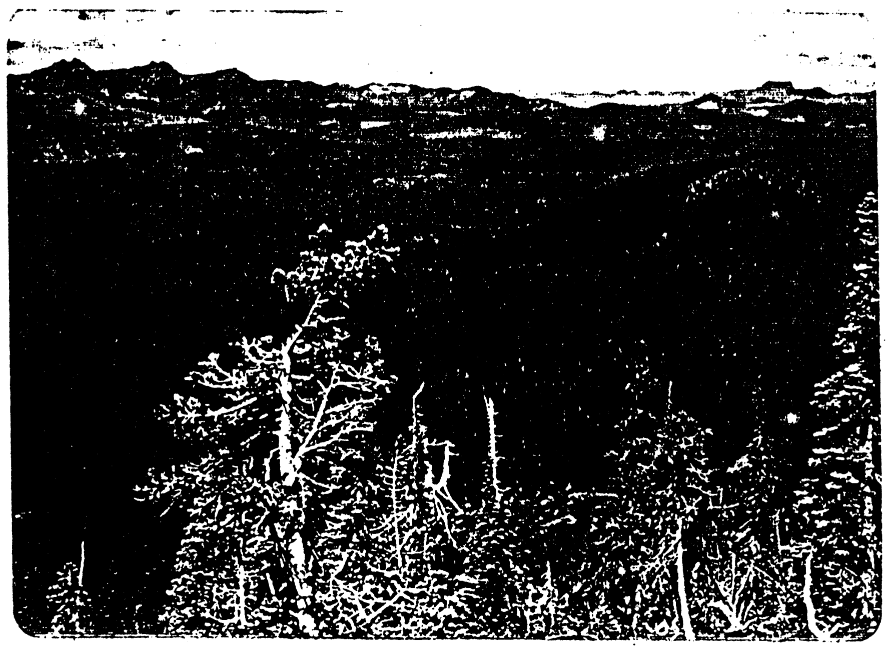


FIGURE 19. View looking northwest from Sand Mountain. Big Nash Crater in right middle distance. Peak on left horizon is Crescent Mountain--a large volcanic center which has been breached by erosion (probably glaciation in part), or explosion, or combination of both, on the east side.

Sand Mountain. Sand Mountain is a linear series of cinder cones along a north-south fracture (See Figures 21 and 22). Volcanic activity in this area is generally less than 5000 years old, and includes such volcanic centers as Hoodoo Butte, Hayrick Butte, Sand Mountain (several craters), and Big and Little Nash craters. A location in the shallow topographic basin just east of Sand Mountain is recommended. View of this area from Sand Mountain is shown in Figure 20. A fairly detailed map showing direction of flow movement and the vents of this area is shown on Figure 22.

A map of the Santiam Junction-Sand Mountain area, taken from Howel Williams (1957) is shown on Figure 21. There is in this area an impressive amount of Holocene volcanism. Drilling here, however, is subject to the general problem that these young volcanics are highly permeable and porous and would allow water to circulate

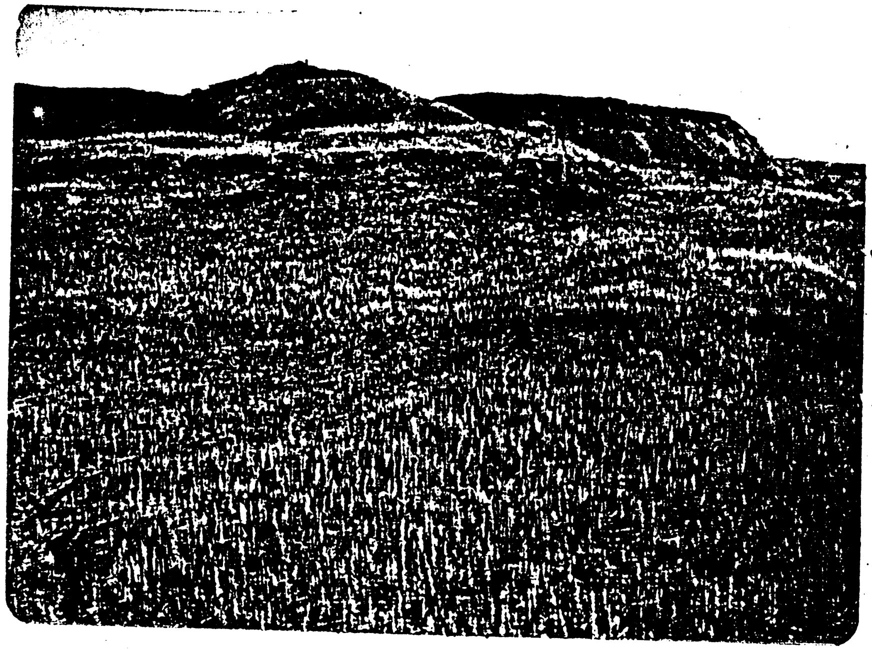


FIGURE 20. View northeast from Sand Mountain, with Hoodoo Butte the pointed peak in the middle skyline, and Hayrick Butte the flat-topped prominence to the right and slightly farther away. Basin in foreground is a cinder-ash covered plain, with a recently burned stand of jackpine (all the grey, barkless dead tree trunks--mostly still standing). Access to all of this area is very good.

through them. There is the question of how thick these porous young volcanics are. In some places even fairly extensive fields of these High Cascades volcanics prove to be fairly thin when seen in canyon wall exposures. This area is near the margin of the High Cascades volcanic field and the flows might not be particularly thick. In any case, at some place these lava fields with their attendant Holocene vents should be drilled, and the Santiam Junction-Sand Mountain area would seem to be a logical place.

The less than 5000 year age date on the volcanism in the Sand Mountain area makes it an interesting site to test. Most available information suggests that these basaltic volcanic centers derive their heat and materials from fairly deep in the Earth's crust, and rise through narrow dike-like vents. High heat flow here would be significant, although it should be noted that a low heat flow might not be conclusive as to the depth of the magma chambers for, as noted, there is a question as to the

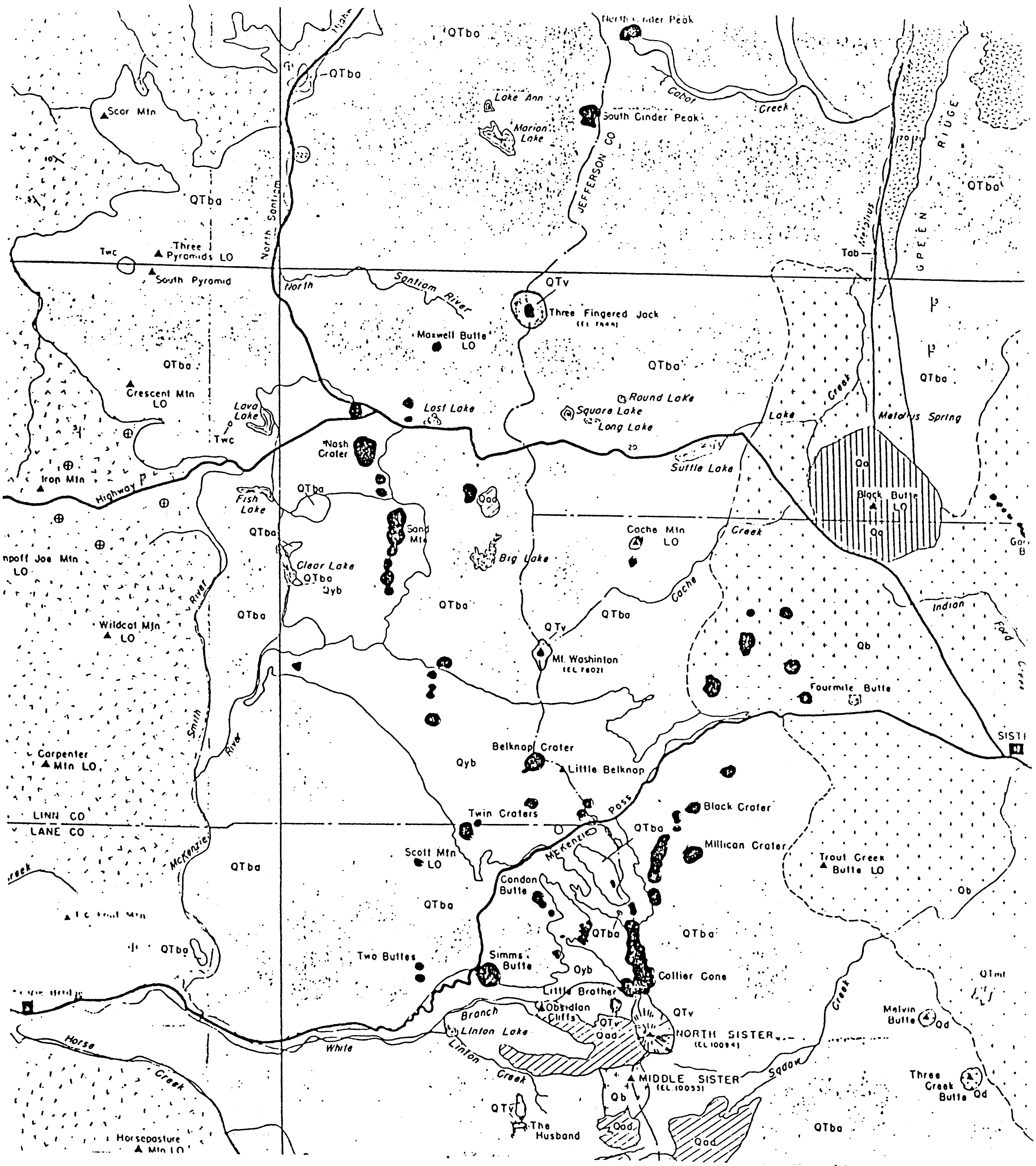


FIGURE 21. Map of Santiam Junction-Sand Mountain area, and Belknap Plateau area, map taken from Williams (1957).

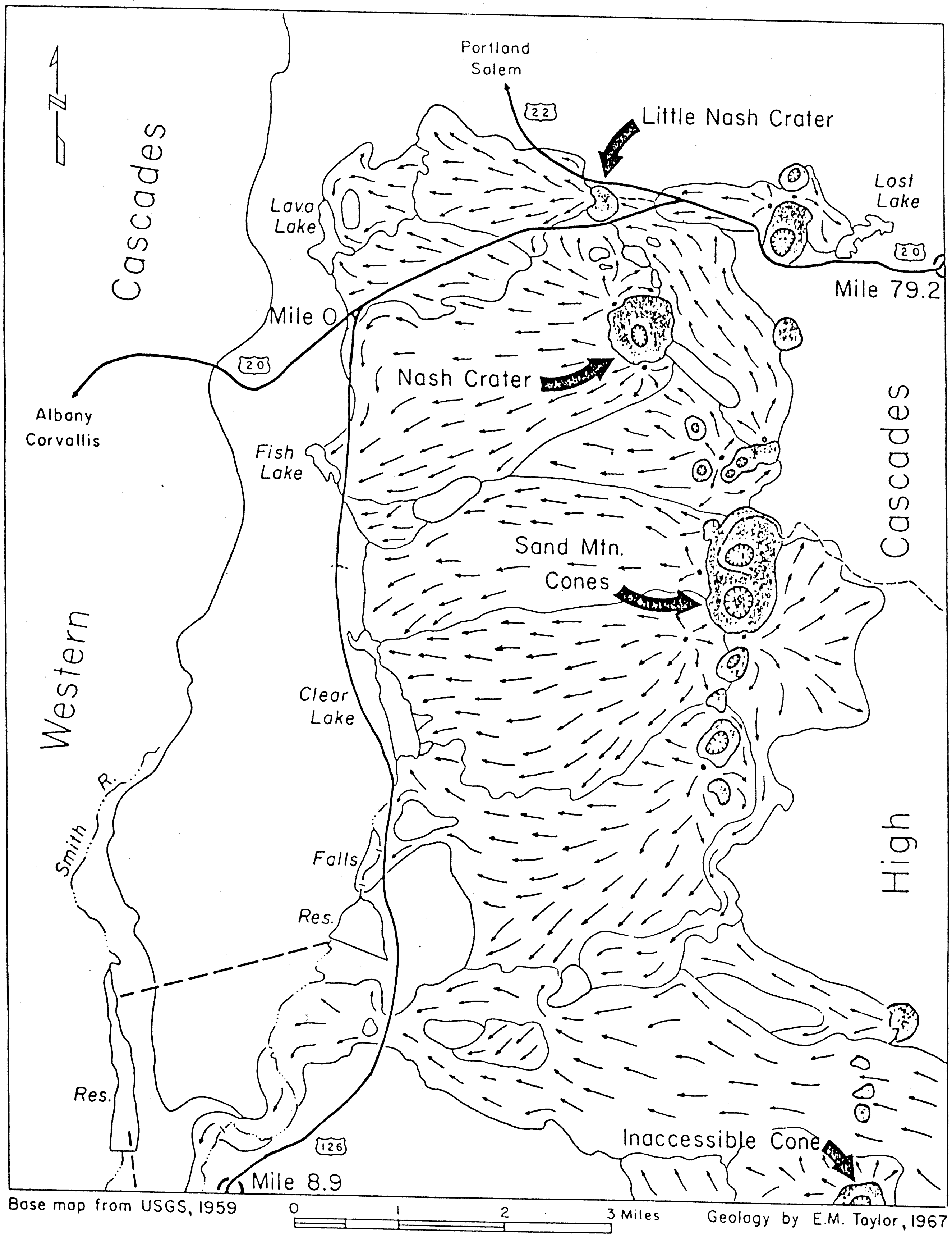


FIGURE 22. Flow directions and vents in Sand Mountain area, map from Taylor <u>in</u> Dole, 1968.

reliability of data in these relatively permeable and porous young volcanics. Nevertheless, this Sand Mountain area in the midst of so much very young volcanism seems a prime area in which to drill at least one heat flow hole. Most anywhere in the shallow basin east of Sand Mountain would be satisfactory. Access is excellent.

Two Buttes. This area lies at the southern end of what we have called the Belknap Plateau, so named because the flows from Belknap Crater dominate much of the area. Two Buttes are relatively young (but somewhat dissected) volcanic cones, and adjacent Deer Butte is perhaps slightly older (see Figure 21 for locations of these features). This recommended drill site represents the closest practical drill location in this region to the Three Sisters volcanic area of relatively recent activity. A view of this Two Buttes area from across the North Fork of the McKenzie River near Frissell Point is shown in Figure 23. The large valley in the foreground is that of Scott Creek. Deer Butte lies in line with the south base of the Middle Sister, and Two Buttes are the two small peaks to the north (left) of Deer Butte. A location perhaps in E$\frac{1}{2}$ section 9, or W$\frac{1}{2}$ section 10, T 16 S, R 7 E is suggested. This entire plateau would afford numerous sites for geothermal plant locations. There are no identified distinctive recreational features of this region. It is undergoing extensive logging and recently a well developed system of logging roads has been developed here. A view of a recent shelterwood cut, showing some of the terrain of the plateau, is present in Figure 24. Photograph was taken in section 3, T 15 S, R 7 E.

Deer Creek-Belknap area. This area has a number of hot springs of which only Belknap shows on the preliminary map by Bowen and Peterson. The springs show a marked north-south alignment, in agreement with the general trend of hot springs in this region. There is a hot spring about 200 yards downstream from the mouth of Deer Creek, along the west bank of the North Fork of the McKenzie River. This is about six miles north of Belknap Hot Springs. A location is suggested between these two springs, and in fact a good site exists. It lies just

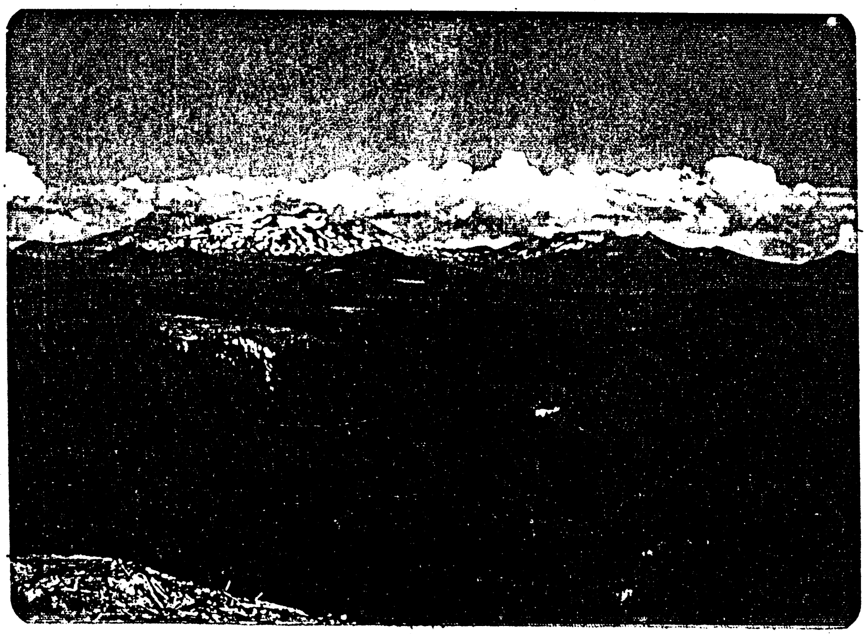


FIGURE 23. View of Belknap Plateau from west, looking across valley of North Fork of McKenzie River. Large valley in right foreground is that of Scott Creek. Deer Butte is single peak in line with south base of Middle Sister, and Two Buttes are the two small buttes to the north (left) of Deer Butte.

FIGURE 24. Shelterwood cut NW$\frac{1}{4}$ section 3, T 15 S, R 7 E, Linn County, on mid-portion of Belknap Plateau. Ample sites exist in this area for geothermal plants if resource can be found.

west of the bridge over the North Fork of the McKenzie River on the Frissell Point road. This location is in NE$\frac{1}{4}$ section 2, T 16 S, R 6 E, Lane County. A second location in this general area might be on the private land of John Bigelow who has 160 acres a short distance west of Belknap Springs. He has tentatively offered his acreage for a drill hole site. Again, as in the case of Breitenbush, this Belknap Springs area has been designated a KGRA. The State Department of Geology and Mineral Industries is a logical vehicle for doing heat flow drilling here, and it would be useful to have such data available before any KGRA sales are decided upon, or held.

Foley Springs. This is a fairly hot spring (174°F) and is part of the Belknap area KGRA. General view of this spring is shown in Figure 12, page 19. A number of lease applications have been filed in the vicinity of Foley Springs and adjacent Foley Ridge. A location somewhere between the springs and the ridge is suggested, perhaps in E$\frac{1}{2}$ section 28, or W$\frac{1}{2}$ section 27, T 16 S, R 6 E. The location should be as far north as possible to get between Foley Springs and Foley Ridge. Note, however, that topography here in the Horse Creek Valley will be somewhat of a problem and will limit location possibilities.

Kitson-McCredie area. This geothermal area, at the southern end of our study region, is somewhat isolated from the rest of the thermal areas, and as such it provides a significant point geographically for a heat flow map of this region. It includes not only Kitson and McCredie hot springs, but also a warm spring in the valley of Wall Creek, tributary to Salmon Creek. With the McCredie Springs designated as a KGRA and with three thermal springs in this area, it is worthy of a heat flow hole. We recommend the easily accessible McCredie Springs area, which is also the area of the hottest of the three springs. Numerous drill sites exist within a mile or two of these springs which emerge from three or four fairly closely spaced vents in a volcanic breccia along the north edge of Salt Creek, about 50 yards south from State Highway 58 (Willamette Pass highway).

SUMMARY OF SUGGESTED DRILLING LOCATIONS

In total, we have suggested seven locations which are, in summary:

1. Breitenbush area, sections 16, 21, or 28, T 9 S, R 7 E.
2. Santiam Junction, south center section 36, T 12 S, R 6 E, or $N\frac{1}{2}$ section 1, T 13 S, R 6 E.
3. Sand Mountain, just east or northeast of Sand Mountain which is a few miles southeast of Santiam Junction.
4. Two Buttes, $E\frac{1}{2}$ section 9, or $W\frac{1}{2}$ section 10, T 16 S, R 7 E.
5. Deer Creek-Belknap area, $NE\frac{1}{4}$ section 2, T 16 S, R 6 E, with another possible location on property of John Bigelow, west of Belknap Springs. Bigelow's property is in section 10, T 16 S, R 6 E.
6. Foley Springs, $E\frac{1}{2}$ section 28, or $W\frac{1}{2}$ section 27, T 16 S, R 6 E. Topography limits locations.
7. Kitson-McCredie area, within a mile or so of McCredie Hot Springs which are in $NW\frac{1}{2}$ section 36, T 21 S, R 4 E, Lane County.

To bring this total to eight, the following possibilities are offered:

1. Drill an additional hole in the Breitenbush area, with one being put in the valley proper, and one in the surrounding hills, preferably south.
2. Drill the additional hole recommended in the Deer Creek-Belknap area.
3. Drill one of the mineralized zones showing hydrothermal activity in the past such as up Christy Creek (off North Fork of Middle Fork of Willamette River), or in the Quartzville Creek area near Detroit.

DRILLING PROBLEMS AND QUALITY OF RESULTS

It is evident that much drilling will be done largely through suc volcanic debris as shown in Figure 25. Difficulty may be encountered if some of these boulders or angular debris rotate or cave into the hole during drilling. A bridge or stuck bit could result. However,

FIGURE 25. Volcanic debris in Tertiary mudflow, along Horse Creek road, southeast of Foley Springs. Tremendous volumes of this same general sort of material characterize much of the Western Cascades.

much of this material is rather highly indurated and this problem could prove to be minimal.

The question of whether or not shallow subsurface cold water flows will erase any heat anomalies present has been considered frequently during our field investigations. In general, the holes will be located so that at total depth they are likely to be in Western Cascade volcanic materials. These are relatively impermeable as far as we can determine. Where water does emerge it appears to come from local pockets or trains of relatively unweathered materials in contrast to most of the rock materials in the section. There is no general sheet flow evident through these volcanics in their presently weathered form. We are inclined to the view that there will be no problem of any large scale erasure of heat flow anomalies by near-surface cold water flow in Western Cascade volcanics. Some such problems could occur, however, in the younger or High Cascade rocks. For example, streams of water emerge from what Taylor (<u>in</u> Dole, 1968) has identified as thin High Cascade diktytaxitic flows in the lower High Cascades volcanics in a road cut at Trail Bridge Reservoir (Figure 26).

FIGURE 26. Road cut and emerging water streams from thin diktytaxitic flows in the lower High Cascade volcanics, in road cut at Trail Bridge Reservoir, North Fork of the McKenzie River.

It is recommended that, where possible, the lowest topographic point consistent with a good bedrock location and avoiding shallow subsurface water flow be utilized for the drill site. Also, a fairly detailed local geological study should be made of each area before final drill site determination is made.

All things considered, many suitable heat flow drilling sites appear to exist, well located geologically and geographically, in the region under consideration. Geological conditions suggest that the quality of information which might be obtained from 500-foot holes should be quite good, and we believe implementation of the drilling program as outlined here will be a scientifically efficient use of funds, and will result in a significant contribution to knowledge of heat flow, and of probable geothermal potentials of this region.

SUMMARY AND CONCLUSIONS

The Western Cascades and the High Cascades, in total, represent a volume of igneous rocks which can be measured in many thousands of cubic miles. Geological evolution of this region involved the activity of many hundreds if not thousands of volcanic centers, great and small, and the details of stratigraphy are very complex in detail. Only in a broad way can the stratigraphy be defined and outlined at present. Pyroclastics and especially mudflow breccias on a very large scale make up more than half the volume of materials of this region. Numerous volcanic centers can still be clearly identified. Steep dips and large quantities of huge clastic debris indicate that the region was one of high relief as it developed during the Tertiary.

Far from being strictly a basaltic province, andesite appears to be a common rock type, and other even more silicic rocks exist in some abundance. In a few places rocks which approach granites in texture and composition exist, as, for example, the so-called Nimrod Granite on the McKenzie River drainage. Fragments of granite exist in the tuffaceous mudflow which is the abutment on the east side of Hills Creek dam. The source of this granite is not now known.

In general, the Western Cascade volcanics are more highly weathered and otherwise altered than are the High Cascade rocks. These Western Cascade rocks, in their altered form, appear now to act as a huge and quite effective seal on any geothermal systems which may exist at depth.

The region, for purposes of this report, has been divided into six subprovinces, based in part on geology, but also on the KGRA designations, and the geography. Satisfactory drilling sites exist in all these subprovinces, and specific locations and comments about each recommended site have been made.

Drilling through the debris-filled mudflows could cause problems, although much of this material is rather highly indurated. Some problems may be encountered in drilling through the highly permeable and porous young volcanics of the High Cascades. In the Western Cascades, where most of the drilling will be done, large scale erasure of heat anomalies by sheet flow of shallow subsurface waters is not considered very likely, and, given proper diligence in locating the particular drill sites, good quality results can be expected. In the case of the High Cascade rocks, some subsurface cool water flow might be expected and could affect results. This could prove to be a substantial problem or it could be quite modest. One or two holes will not be conclusive but we do recommend that some such holes should be drilled in this initial program (Santiam Junction, Sand Mountain, and Two Buttes locations are High Cascade volcanic sites).

Implementation of this drilling program should greatly increase our knowledge of the geothermal potential of this region, and point the way to where additional and more detailed studies are likely to yield further significant scientific and also economically important results. We do know, from personal conversations, that this central Western and High Cascades area is regarded by a number of industry and academic geologists and geophysicists as "one of the prime geothermal targets in the United States." As such it deserves early and extensive investigation, of which this drilling program would be a significant step.

****

ADDENDUM

Position and prognosis for geothermal leases in Willamette National Forest. At the present time (November, 1975) the situation with regard to the federal lease applications for geothermal resources in this forest is as follows:

An overall land use plan is being evolved for the WNF, and public hearings are currently being held.

The Forest Service expects but is by no means certain that it will have all the hearings completed and a decision made by early 1976--perhaps February or March.

An environmental impact statement for geothermal for the Breitenbush area has been prepared by Allen Prigge, Forester with WNF, and is now on the desk of the District Ranger in Detroit, Oregon.

A pencil draft of the geothermal environmental impact statement for the rest of the forest has been prepared by Mr. Prigge, but he proposes to go no further with it until the Breitenbush statement has been approved in final form. Then Mr. Prigge plans to use that foremat for the environmental statement for the rest of the forest.

The WNF states (John Alcock, Forest Supervisor) that no move on geothermal environmental statements will be made until the overall land use planning program is finalized (February or March, 1976, maybe).

Possibly by March 1976, the environmental impact statement for geothermal on the Breitenbush area may come to public hearing. This might be concluded by May. The statement for the rest of the WNF could then perhaps be completed in preliminary form, heard, and then finalized by June or July (relatively optimistic time schedule).

After the Forest Service has completed its work on these environmental statements, they are sent on to the BLM in Portland. It takes the BLM, in non-competitive lease application situations, about four months to process the papers and attach the proper environmental statements and restrictions to the various lease applications and forward them on to the applicants for a cceptance or rejection. Adding up all these times, it seems unlikely that any leases will be issued to applicants before late summer or early fall 1976. This would seem to be the very earliest possible time; if any difficulties arise during public hearings on these environmental statements, or if the statements simply move slowly through administrative channels, this date could well move back into 1977.

****

BIBLIOGRAPHY

The principal informational sources drawn upon during this study are here listed. However, numerous maps and miscellaneous shorter reports were also utilized.

BOWEN, R. G., and PETERSON, N. V., 1970, Thermal springs and wells in Oregon: Oregon State Department of Geology and Mineral Industries, Portland, Miscelleneous Paper 14 (Map with text).

DOLE, H. M. (ed.), 1968, Andesite Conference Guidebook: Oregon State Department of Geology and Mineral Industries, Portand, Bulletin 62, 107 p.

PECK, D. L., et al., 1964, Geology of the central and northern parts of the western Cascade Range in Oregon: U. S. Geological Survey Professional Paper 449, 56 p., 1 pl. (Map).

PETERSON, N. V., and GROH, E. A. (eds.), 1964, State of Oregon Lunar Geological Field Conference Guidebook: Oregon State Department of Geology and Mineral Industries, Portland, Bulletin 57, 51 p.

TAYLOR, E. M., 1965, Recent volcanism between Three Fingered Jack and North Sister Oregon Cascade Range: The Ore Bin, Oregon State Department of Geology and Mineral Industries, p. 121-148.

WHITE, D. F., and WILLIAMS, D. L., 1975, Assessment of geothermal resources of the United States: U. S. Geological Survey circular 726.

WILLIAMS, HOWEL, 1957, A geologic map of the Bend Quadrangle, Oregon, and a reconnaissance geological map of the central portion of the High Cascade Mountains: Oregon State Department of Geology and Mineral Industries, Portland.