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HYDRATION DATING OF VOLCANISM AT NEWBERRY CRATER, OREGON

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Abstract.—Obsidian hydration dating of pumice and obsidian from Newberry Crater, Oreg., shows that the postcaldera activity began about 6700 yr ago and that the latest major eruptive event occurred about 1400 yr B.P. Two of the hydration dates correlate with ^{14}C-dated pumice eruptions.

Dating of rhyolitic volcanism by measuring the hydration rind on obsidian was first attempted by Friedman (1968). Shortly after publication of that paper, N. V. Peterson, E. A. Groh, and R. E. Corcoran suggested that Newberry Crater would be an excellent area in which to apply the hydration-dating technique. Not only were there multiple events whose relative ages were known, but a rate of hydration that might be applicable to the site had been published by Johnson (1969).

This is not the report of an exhaustive and definitive study of the many eruptive events at Newberry Crater. Rather it is a reconnaissance in the application of a new tool to an interesting and complex area.

Newberry Crater, a caldera at the summit of Newberry volcano, was described first by Russell (1905) and more recently by Williams (1935) and Higgins and Waters (1967). The caldera is situated about 30 km (kilometers) south of Bend, Oreg. Figure 1 is an aerial photograph of the area showing some of the volcanic features. Peterson and Groh (1969) have described Holocene eruptive events on the flanks of Newberry volcano and have shown that much of the activity took place from about 6400 yr B.P. (years before present) to about 1200 yr B.P. (radiocarbon years). Mount Mazama ash (6600 yrs B.P.) is found within the caldera, but it does not mantle many flows that erupted after the caldera collapse. Therefore, much of the volcanic activity that occurred after caldera collapse appears to be younger than 6600 yr B.P. M. W. Higgins (written commun., 1975) concludes that some of the postcollapse features are covered with Mazama ash and that the collapse may predate 6600 years.

N. V. Peterson, E. A. Groh, and R. E. Corcoran accompanied the author on several collecting trips; during these trips attempts were made to collect obsidian samples that contained at least one surface judged to have been formed during the emplacement of the flow or dome. Some of the criteria that were used are as follows:

1. Tension cracks, similar to those shown by Friedman (1968). Unfortunately, this type of crack is rare in the flows sampled.
2. Surfaces showing a white deposit of silica that appears to have been deposited by steam that was probably emitted during cooling of the flow. Whereas this criterion is valid, a silica deposit makes measurement of the underlying hydration difficult.
3. Samples that contained vesicles produced by released gas during flowage. Many of these vesicles were pulled out into elongate, sheetlike cavities. Fracture of the obsidian, while flowing or during cooling, allowed the atmosphere to penetrate into these large, cracklike vesicles.

Five to ten hand specimens were collected from different areas of each feature. Usually two or more thin sections were cut from each specimen.

Over 200 thin sections were examined. Although precise measurements were made on only about 85 of the best sections, preliminary measurements on the discarded sections were in general agreement with the results reported here. All measurements were made using a Vickers image-splitting eyepiece, and the results are precise to ± 0.1 μm (micrometers).

In order to convert hydration thickness into an age, the rate of hydration must be known. Johnson (1969) measured a number of obsidian artifacts from archeological horizons that he had dated by ^{14}C. These archeological sites were all in the Klamath Basin, about 200 km south of Newberry Crater and 1000 m (meters) lower in elevation. The rate that he calculated was 3.5 μm^2/1000 ^{14}C years. If we convert ^{14}C years to calendar years, using published conversions (Olsson, 1970, p. 3), the corrected rate is 3.1 μm^2/1000 yr. Because the hydration rate is temperature dependent, we would expect the hydration to proceed somewhat more slowly in Newberry Crater than in the Klamath Basin. The hydration rate is dependent on the chemical composi-

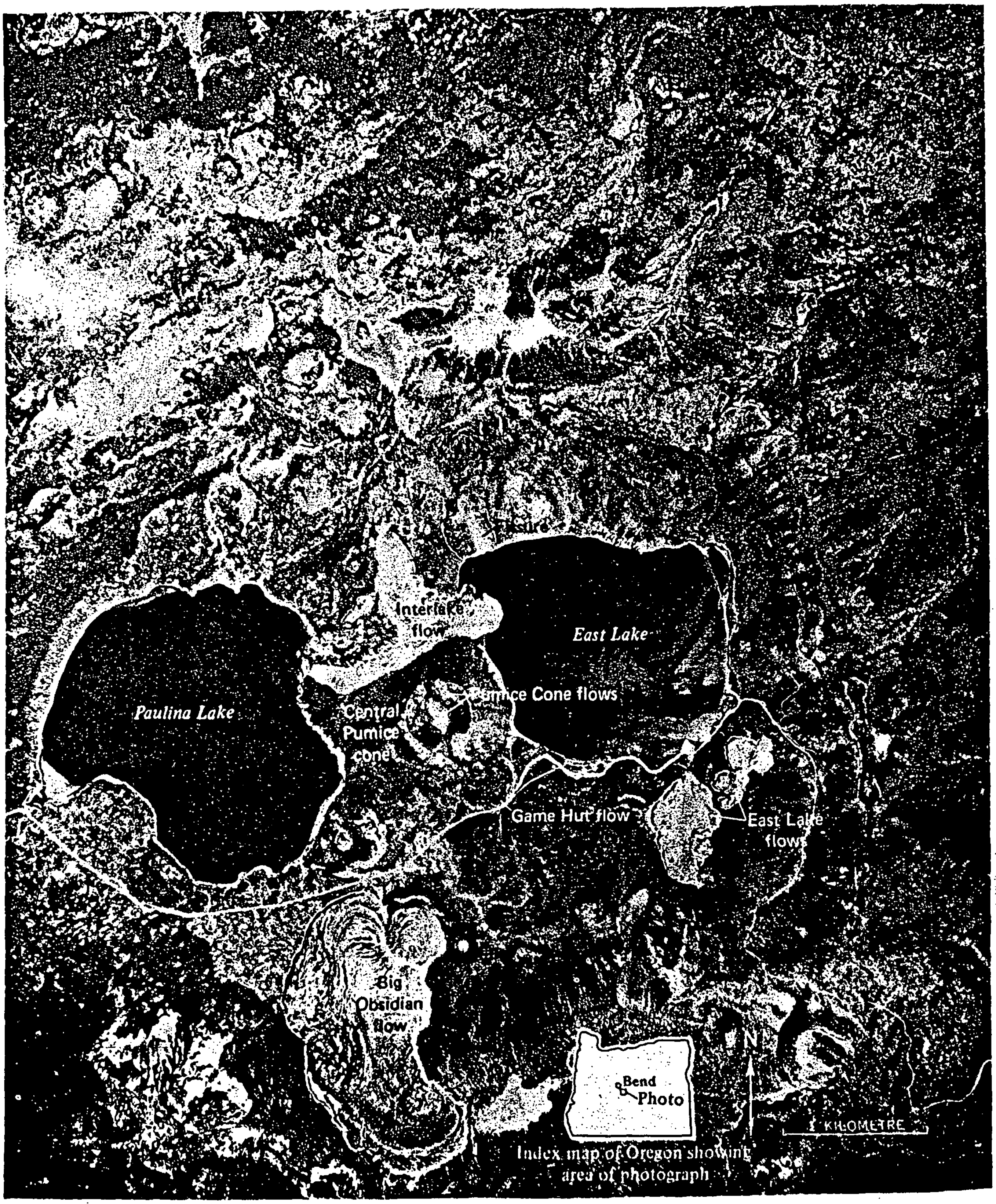

Figure 1.—Aerial photograph of Newberry Crater area, central Oregon.

tion of the volcanic glass; the chemical composition of the obsidian used by Johnson is not reported, and the hydration rate that he derived may not apply to the obsidian from Newberry.

Johnson's rate, however, was measured on archeological material that was buried and that did not experience the wide and frequent temperature fluctuations of obsidian exposed at the Earth's surface. A higher rate of hydration can be expected for obsidian at or near the surface. Not only does such material experience the normal air-temperature fluctuation, but solar heating can cause temperatures of obsidian to exceed 50°C during a bright, sunny day.

From September 1971 through September 1972, temperatures were recorded at Pine Mountain Observatory, 20 km east-northeast of East Lake, Newberry Crater. The data for Pine Mountain are given in table 1. In calculating the hydration rate, the equation relating hydration rate to temperature, derived experimentally (Friedman and Long, 1976) on obsidian from the east lobe of the East Lake flow, Newberry (rate in $\mu m^2/10^3$ years $=1.429\times10^{15}e^{-9668.8(1/T)}$, where T is temperature in kelvins), was solved for the temperatures measured hourly at Pine Mountain Observatory. These hourly determined rates of hydration were then averaged for one calendar year. This average rate was then substituted in the above equation to calculate the effective hydration temperature. This temperature, if maintained continuously, will cause the obsidian sample to hydrate at the calculated rate.

TABLE 1.—*Rates of hydration and effective temperature of hydration, Pine Mountain Observatory, Deschutes County, Oreg.*

[Mean annual air temperature, 1931–60 = 4.67°C]

	Rate of hydration ($\mu m^2/10^3$ yr)	Effective temperature (°C)
Surface of obsidian exposed to Sun	7.2	20.4
Probe in soil, 30 cm depth	2.3	10.6
Probe in soil, 60 cm depth	2.1	9.8
Probe in air	2.8	12.2

The elevation at the observatory is 1902 m as compared with 1930 m at East Lake. Both sites have very similar climates, except that the snow cover at Newberry is more extensive and persists for a longer time than at the observatory. The effective temperature of hydration at Newberry is probably about 2°C higher than at Pine Mountain Observatory.

Because most of the samples were collected 30–60 cm (centimeters) below the surface, the effective hydration temperature as measured at Pine Mountain at the 30-cm depth was increased by 2.0°C to compensate for the increased snow cover at Newberry as compared with Pine Mountain. This correction results in a rate of hydration of 2.9 $\mu m^2/10^3$ yr. The hydration rate is also dependent on the chemical composition and, particularly, the SiO_2 content of the glass. With the exception of Big Obsidian flow, all the glasses collected at Newberry have a SiO_2 content of 73.2–74.2 percent. Big Obsidian flow has a silica content of 72.2–72.9 percent and hydrates at a much lower rate than the other Newberry glasses. The hydration rate used for Big Obsidian flow, based on the previously quoted published hydration experiments at elevated temperatures and water pressures, is 0.7 $\mu m^2/10^3$ yr.

The hydration rate that was used in calculating the ages of the Interlake and Game Hut flows cannot be significantly less than 2.9 $\mu m^2/10^3$ yr, inasmuch as a lower rate would yield an age greater than the Mount Mazama eruption, an event that preceded these events. The rate that applies to Interlake and Game Hut flows cannot be very different from that used for the Pumice Cone and East Lake flows because the groupings of hydration thickness between the four sets of flows indicate a common rate of hydration.

The results of the measurements are plotted in figure 2. On many specimens more than one thickness of hydration were found, and in several, hydration layers of different thicknesses could be found on the same thin section. In some sections, vesicles were found that had been ruptured upon emplacement. In all instances, these vesicles showed the maximum thickness of hydration found on any specimens from the unit sampled.

In any unit showing multiple hydration thicknesses, the measurements always occurred in definite groupings rather than in a continuous distribution of thicknesses. For example, samples from Game Hut flows show hydrations of 4.4, 4.1, 3.6, 3.2, and 2.9 μm, whereas samples from Pumice Cone flows have thicknesses of 3.6, 2.9, and 2.2 μm. The conclusion is drawn that the Game Hut eruption occurred 6700 yr ago (4.4-μm hydration thickness) and that the eruption of Pumice Cone flow at 4500 yr B.P. (3.6 μm) caused cracking of the obsidian in Game Hut flows about 1 km away. An event that could have caused additional cracking at about 1700 yr B.P. (2.2 μm) was the pumice eruption that was radiocarbon-dated by Higgins and Waters (1970) at about 1700 yr B.P.

Interlake flow, which also erupted 6700 yr ago (4.4 μm), similarly records cracks at 4500 yr B.P. (3.6 μm) (eruption of Pumice Cone central flow); 3500 yr B.P. (3.2 μm) (eruption of East Lake west and east flows); and 1400 yr B.P. (1.9 μm) (pumice eruption ^{14}C dated[1] and eruption of Big Obsidian flow).

[1] C-657, 2054±230 yr B.P. (Libby, 1952); TX-245, 1270±60 yr B. P. (Pierson and others, 1966); W-2777, 1390±200 yr B.P. (Meyer Rubin, written commun., 1974).

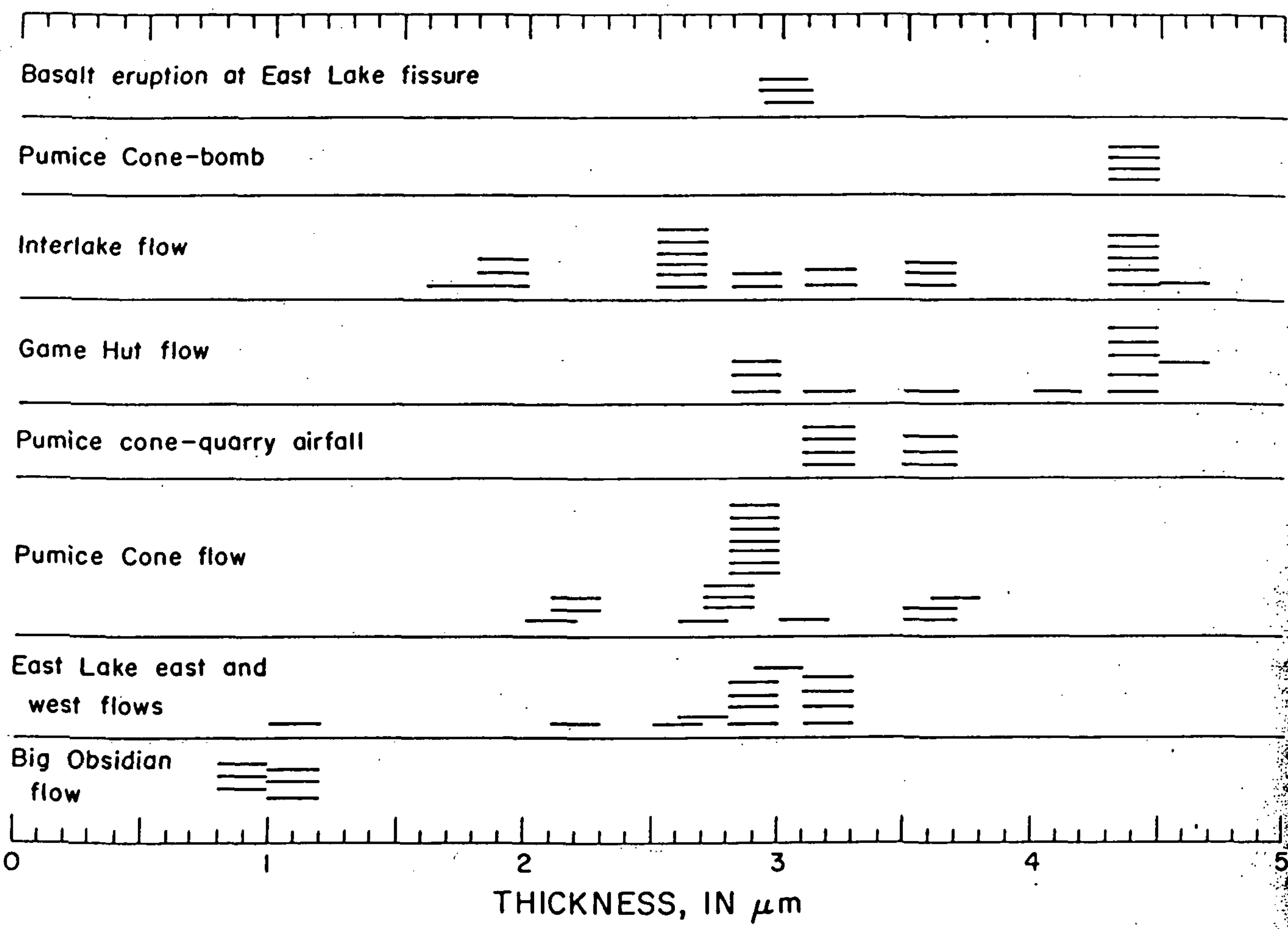

FIGURE 2.—Plot of measured hydration thickness of samples from Newberry Crater. Position of each horizontal line represents thickness of hydration along crack or edge. Length of line represents estimated measuring error.

In all samples, the thickest hydration is believed to represent the surface created during the eruptive event that originally emplaced the material. Subsequent cracking is assumed to have been due to either earthquakes or renewed movement of the flow or dome caused by nearby eruptions. It should be noted that all the eruptive events were very close geographically—all occurred within a square of about 5 by 5 km.

Pumice Cone flows (4500 yr B.P.), a series of flows that occupies the crater of Central Pumice cone, seemingly give an anomalous age. From the field relations, it is clear that Interlake flow (dated at 6700 yr B.P.) forked when it reached Central Pumice cone and that Central Pumice cone must therefore be older than Interlake flow. Dating of some of the coarser pumice bombs from Central Pumice cone gave a date of 6700 yr (4.4 μm, fig. 3), indicating that Central Pumice cone was formed by a pumice eruption just prior to the eruption of Interlake flow. Subsequent eruptions, probably from the same vent area, resulted in the emplacement of the Pumice Cone obsidian flows.

Game Hut flows erupted from a vent near the base of Central Pumice cone also at 6700 yr B.P. (4.4 μm), and, from the relationship to Central Pumice cone, they must have erupted after the pumice eruption that created the cone. The flows that now occupy the craterlike depression in the top of Central Pumice cone must have been erupted about 2200 yr after the formation of Central Pumice cone. These flows were preceded by a pumice eruption; large blocks of pumice and fragments of obsidian having a hydration thickness of 3.6 μm are found in the upper part of Central Pumice cone, just below the breached crater.

Higgins (1969) has studied the distribution of a 1,700-year-old ash and pumice layer present in most of the Newberry Crater area. From isopach maps, he has concluded that the ash originated from Central Pumice cone. Since the vent in Central Pumice cone was plugged about 4500 yr ago by Pumice Cone flow, the ash layer must have been derived from another vent in the vicinity. It is possible that Big Obsidian flow (1400 yr B.P.) has covered the source of the ash layer studied by Higgins.

Higgins and Waters (1970) reevaluated the mixed basalt-rhyolite material found in the East Lake fissure and showed that the obsidian at this locality was formed by remelting of older rhyolite by the basalt flow. They dated the event as less than 1,970 years old, because the fissure is not covered by ash from Central Pumice cone, dated previously by Higgins as 1720±250 yr B.P. Friedman and Peterson (1971) measured the hydration thickness of the obsidian and found a thickness of 3.0±0.2 μm. They reported an age of 2900±400 yr B.P. for this event, using a hydration rate of 3.1 μm^2/1000 yr. As discussed previously, this event would have occurred 2600 to 3400 yr ago. The obsidianlike material from this locality is reported by Higgins and Waters (1970) as having a silica content of 71.8 percent. Analysis of the samples used by Friedman, Peterson, and Groh (1972) shows a silica variation from 69 to 72 percent. Glasses of these compositions may hydrate at a different, probably slower, rate than the other obsidians found at Newberry. Therefore the date given for this event may be too low, in which case the discrepancy between the results reported by Higgins and Waters and the results reported in this paper increase. The possibility of hydrothermal activity affecting the hydration rate of the "fissure" was suggested by Higgins and Waters (1972) and rejected by Friedman, Peterson, and Groh (1972).

The absence of pumice cover on the fissure must be used with caution as an age indicator. The 1720-yr-B.P. pumice studied by Higgins probably did not originate from Central Pumice cone. If it erupted from a vent southwest of Central Pumice cone, Central Pumice cone may have acted as a deflector and shielded the fissure, which is located about 1 km northeast of the flanks of Central Pumice cone (fig. 1).

This shielding by Central Pumice cone may account for the fact that the 1400-yr-old pumice, which is found near the southwest base of Central Pumice cone and which probably originated from a vent under Big Obsidian flow, is also not found on the fissure. According to both Higgins and Waters (1970) and Friedman and Peterson (1971), this fissure must be older than the ^{14}C-dated pumice fall.

The sequence of events that occurred during the past 6700 yr, as deduced by hydration and ^{14}C dating, is summarized in figure 3.

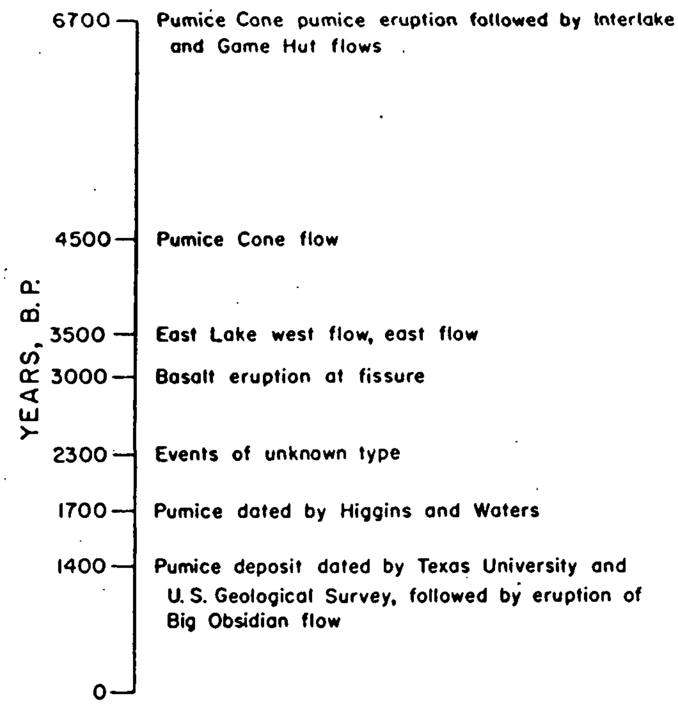

FIGURE 3.—Sequence of major eruptive events during the past 6700 yr at Newberry Crater.

ACKNOWLEDGMENTS

This report was reviewed by N. V. Peterson and M. W. Higgins. The latter reviewer does not agree with all of the conclusions reached by the author. The author acknowledges the help of Mel Johnson and especially of William Long, both of the U.S. Geological Survey, for their help in making the thin sections. The aid of Norman Peterson and Edward Groh both in suggesting the problem and helping with the interpretation of the data is also gratefully acknowledged.

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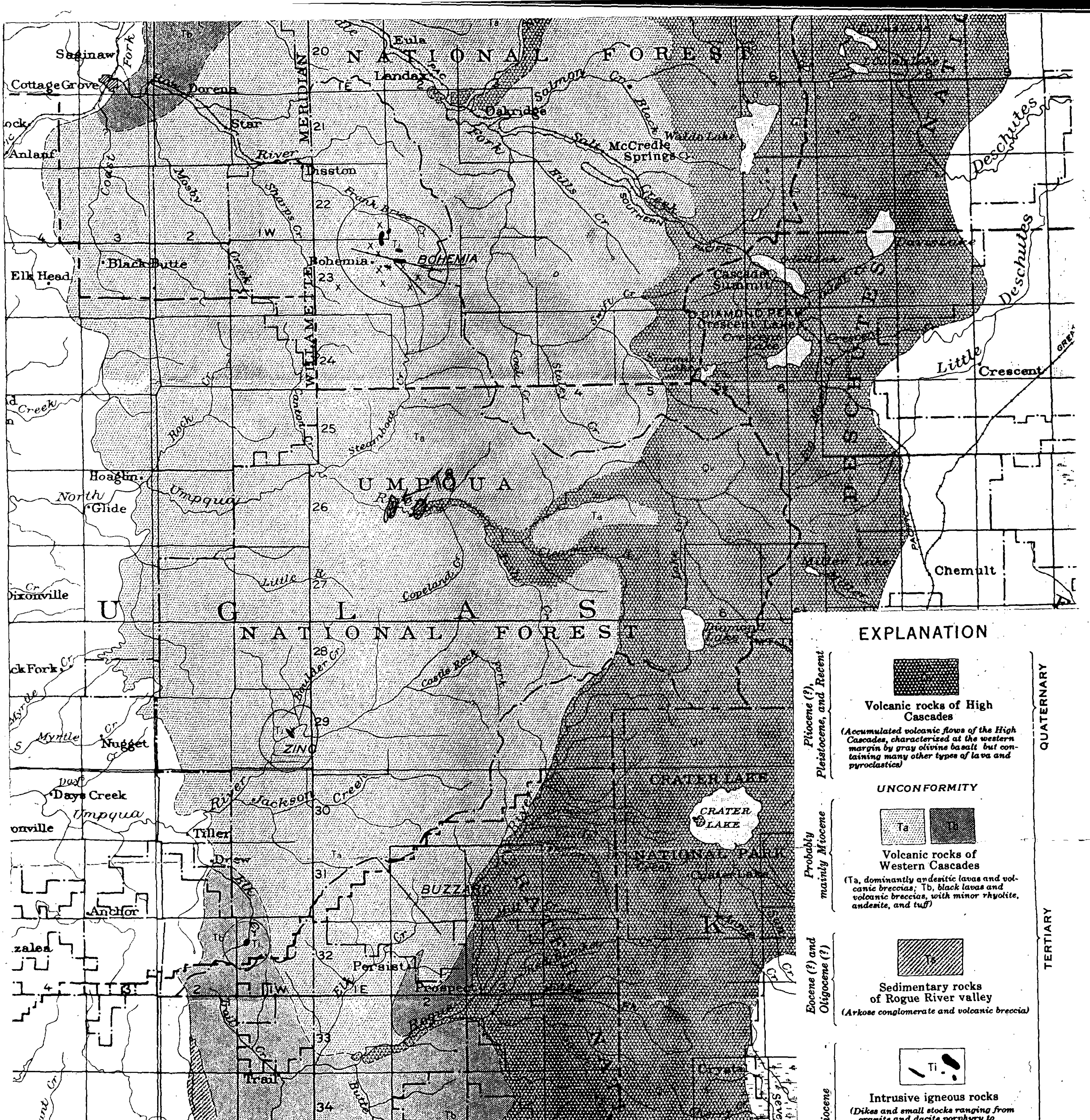
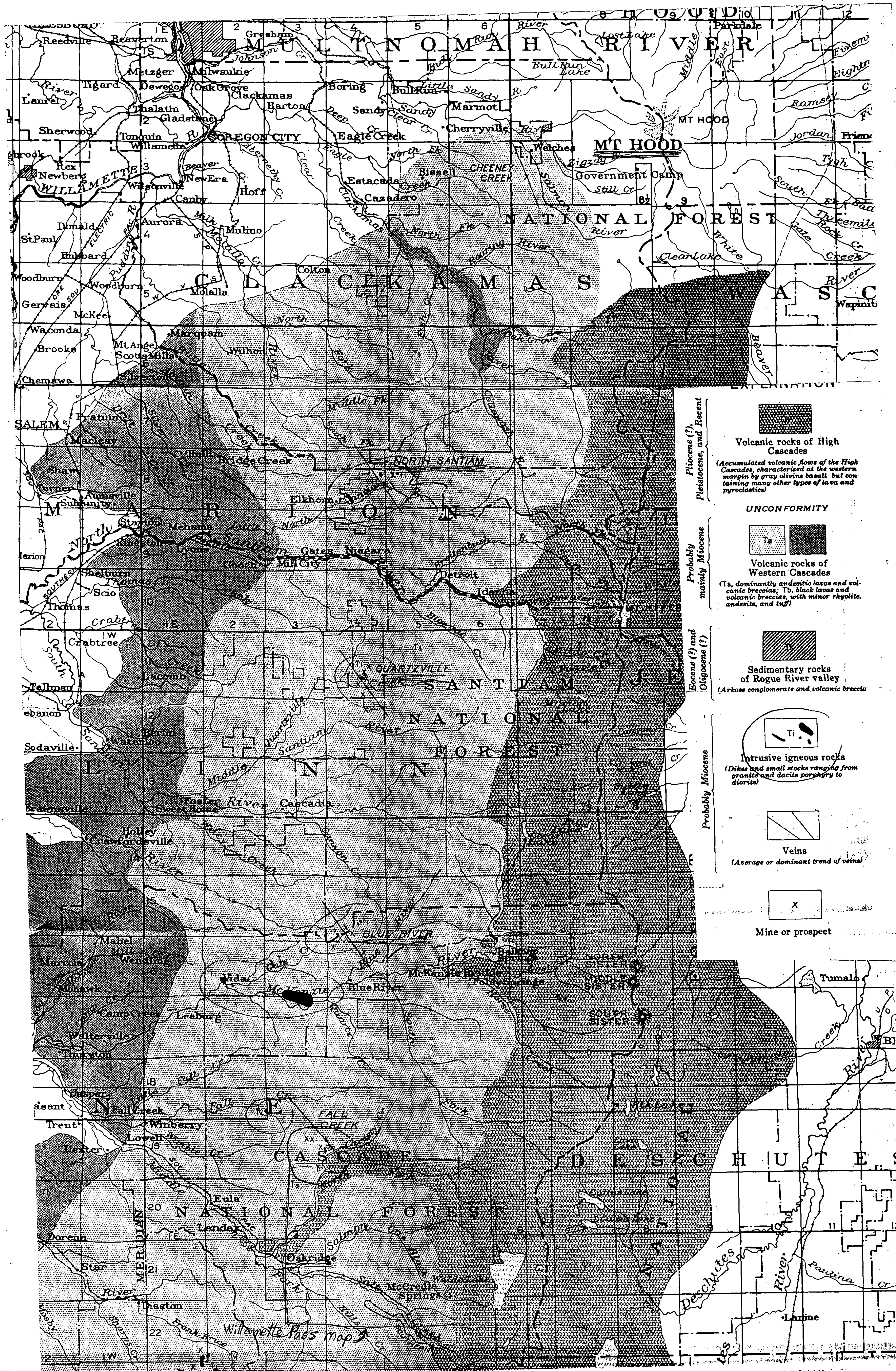

EXPLANATION
Volcanic rocks of High Cascades
(Accumulated volcanic flows of the High Cascades, characterized at the western margin by gray olivine basalt but containing many other types of lava and pyroclastics)
Pliocene (?) Pleistocene, and Recent
QUATERNARY
UNCONFORMITY
Ta
Tb
Volcanic rocks of Western Cascades
(Ta, dominantly andesitic lavas and volcanic breccias; Tb, black lavas and volcanic breccias, with minor rhyolite, andesite, and tuff)
Probably mainly Miocene
Ts
Sedimentary rocks of Rogue River valley
(Arkose conglomerate and volcanic breccia)
Eocene (?) and Oligocene (?)
TERTIARY
Ti
Intrusive igneous rocks
(Dikes and small stocks ranging from granite and dacite porphyry to diorite)
Veins
(Average or dominant trend of veins)
Probably Miocene
X
Mine or prospect
NATIONAL FOREST
UMPQUA
NATIONAL FOREST
DESCHUTES
CRATER LAKE
NATIONAL PARK
JACKSON
CRATER NATIONAL FOREST
KLAMATH NAT. FOR.
WILLAMETTE MERIDIAN
Saginaw
Cottage Grove
Dorena
Star
Disston
Anlauf
Black Butte
Elk Head
Bohemia
BOHEMIA
Oakridge
McCredie Springs
Waldo Lake
Cascade Summit
DIAMOND PEAK
Crescent
Chemult
Hoaglin
Glide
Dixonville
Nugget
Days Creek
Tiller
ZINC
BUZZARD
Persist
Prospect
Trail
Anchor
Beagle
Sams Valley
Eagle Point
Brownsboro
GRAND COVE
Rogue River
Gold Hill
Wellen
Lake Creek
Central Point
MEDFORD
Jacksonville
CARBONATE VEIN
Climax
Phoenix
SHALEHURST OIL SHALE
Talent
Applegate
Ruch
Ashland
BARRON
Siskiyou
MT. MCLOUGHLIN
Recreation
KLAMATH FALLS
Lake Ewauna
Olene
Keno
Midland
LOWER KLAMATH L.
123°
122°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MULTNOMAH
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LANE
DESCHUTES
WASCO
JEFFERSON
MT HOOD NATIONAL FOREST
SANTIAM NATIONAL FOREST
CASCADE NATIONAL FOREST
MT HOOD
NORTH SISTER
MIDDLE SISTER
SOUTH SISTER
OREGON CITY
SALEM
WILLAMETTE MERIDIAN
NORTH SANTIAM
QUARTZVILLE
BLUE RIVER
FALL CREEK
Gresham
Beaverton
Milwaukie
Clackamas
Estacada
Molalla
Silverton
Stayton
Mill City
Detroit
Idanha
Sweet Home
Cascadia
Lebanon
Brownsville
Oakridge
Lowell
Vida
Leaburg
Blue River
McKenzie Bridge
Marcola
Dexter
Tumalo
Willamette Pass map

Tectonic setting of the southern Cascade Range as interpreted from its magnetic and gravity fields

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ABSTRACT

We have compiled and analyzed aeromagnetic data from the southern Cascade Range and compared them with residual gravity data from the same region in order to investigate regional aspects of these young volcanic rocks and of basement structures beneath them. Various constant-level aeromagnetic surveys were mathematically continued upward to 4,571 m and numerically mosaicked into a single compilation extending from lat. 40°10′N to lat. 44°20′N. These data were reduced to the pole, upward continued an additional 10 km, and compared with a magnetic topographic model and with residual gravity data upward continued to the same level. Several intriguing regional features are suggested by these data. (1) The Trinity ophiolite complex that is exposed west of Mount Shasta probably dips at a shallow angle to the east and continues in the subsurface at least 10 km east of Mount Shasta. (2) Mount Shasta, Lassen Peak, and Medicine Lake volcanoes are located in a widespread magnetic low possibly caused by an upwarp of the Curie-temperature isotherm. (3) Crater Lake caldera is located at the intersection of various linear anomalies interpreted to be related to structure in basement rocks below the Cascade Range. (4) Three Sisters volcanoes and Newberry Crater are connected to each other by an arcuate magnetic source. (5) The High Cascades, from lat. 40°10′N to at least lat. 44°30′N, are marked by a residual gravity low which includes the Three Sisters volcanoes, Mount Shasta, Medicine Lake volcano, Mount McLoughlin, and Crater Lake. (We believe this gravity feature represents a major structural depression beneath the High Cascades.) (6) Except for Newberry Crater, every major volcano of the study area is located on the perimeter of a local gravitational low. We suggest that the gravity lows reflect subsidence of low-density volcanic material relative to denser country rock and that the major volcanoes have developed over structures at the perimeters of their respective depressions.

COMPILATION AND ANALYSIS OF THE DATA

During the past six years, Oregon State University has systematically collected aeromagnetic data of exceptional quality over the entire southern part of the Cascade Range, from lat. 40°10′N to lat. 44°20′N (Connard, 1979; Connard and others, 1983; McLain, 1981; Huppunen and others, 1982). These data consist of various surveys, each flown at constant elevation. East-west flightlines were spaced 1.6 km apart or less, north-south flightlines were spaced 8 km apart, and there was synchronous operation of a ground magnetometer for diurnal corrections. Aircraft locations were determined by a ground-based transponder navigation system. Consequently, crossing errors rarely exceeded 10 nT, and most were <5 nT, exceptionally small errors for aeromagnetic surveys over volcanic terrane.

Our objective was to combine these individual surveys into a single constant-elevation survey of the northern California and southern Oregon Cascade Range (Fig. 1). First, we calculated x, y coordinates for each datum using a transverse mercator projection, and transformed each survey to a consistent rectangular grid with 1-km spacing in both the x and y directions using standard interpolation techniques (Webring, 1981). Second, we upward continued each survey grid to an altitude of 4,571 m,

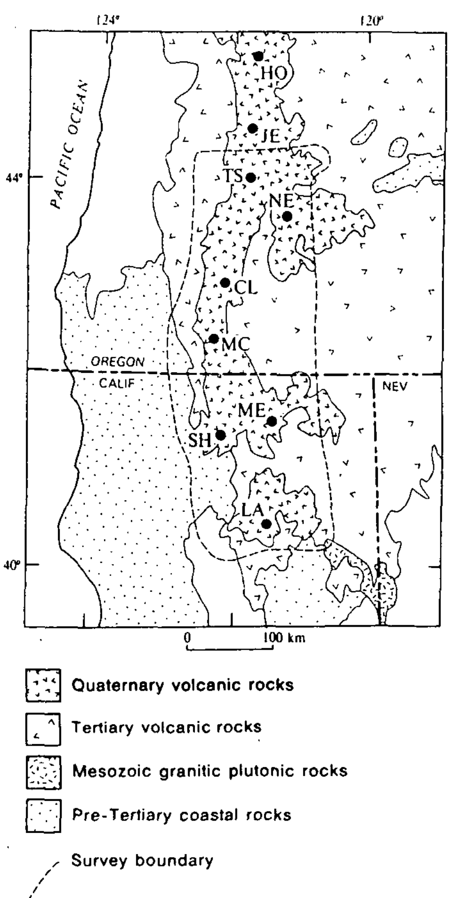

Figure 1. Generalized geology of southwestern Oregon, northern California, and northwestern Nevada, modified after King (1969). Dashed line shows the boundary of aeromagnetic compilation. Solid dots show location of major volcanoes: LA = Lassen Peak, SH = Mount Shasta, ME = Medicine Lake, MC = Mount McLoughlin, CL = Crater Lake, NE = Newberry Crater, TS = Three Sisters, JE = Mount Jefferson, and HO = Mount Hood.

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the level of the highest survey, which is located directly over Mount Shasta (elevation 4,316 m). Third, individual survey grids were numerically mosaicked into a single regional grid. The boundary of each survey overlapped its neighboring surveys by several kilometres but, in every case, the discrepancies in the overlap regions after upward continuation were minimal (<10 nT), which greatly facilitated the mosaicking procedure. The resulting compilation (Fig. 2) represents a continuous, constant-elevation aeromagnetic data set of the southern Cascade province, which includes a number of major volcanic features: Lassen Peak, Mount Shasta, Medicine Lake volcano, Crater Lake caldera, Mount McLoughlin, Newberry volcano, and Three Sisters volcanoes.

Young volcanic rocks often have high magnetic susceptibilities and significant natural remanent magnetizations, and so aeromagnetic maps of relatively undeformed volcanic topography often contain a complex pattern of high-amplitude, short-wavelength magnetic anomalies. Although these are of importance to localized studies (for example, see Blakely and Christiansen, 1978; Flanagan and Williams, 1982), they tend to encumber regional interpretations. To reduce topographic effects, the aeromagnetic compilation was continued upward to various higher elevations. Figure 3, for example, shows the data upward continued to 14,571 m, which is 10 km above the altitude of the original compilation. The data in Figure 3 also have been reduced to the pole in order to remove the dependence of the shape of the anomalies on the direction of magnetization and on the direction of the ambient field. In so doing, we have assumed that the average direction of magnetization is parallel or antiparallel to the field of a geocentric dipole (inclination = 61°, declination = 0°), the average directions of the normal and reversed Earth's field during the formation of most of the Cascades.

Figure 3 shows many anomalies with wavelengths of 10 km and greater. To investigate the possibility that some of these anomalies may be caused by long-wavelength topographic features, a topographic model was constructed (Blakely and Grauch, 1983) using terrain digitized at ~400-m intervals. The model assumes that the top of the magnetic layer corresponds to the digital terrain, the bottom is a horizontal plane, and the magnetization is uniform. The amplitude of anomalies calculated from the topographic model is proportional to the intensity of magnetization chosen for the calculation. We selected 10 A m^{-1}, by trial and error, as the intensity which best matches amplitudes of calculated anomalies with amplitudes of observed anomalies. Figure 4 shows the anomalies calculated from this topographic model. These calculated anomalies are also reduced to the pole and upward continued to 14,571 m so that they are comparable to the data shown in Figure 3. Observed anomalies that have counterparts in Figure 4 are probably produced by topographic sources, whereas observed anomalies that do not have corresponding model anomalies may be caused by magnetic features below the topographic surface. Interpretations of our aeromagnetic data should include comparisons with Figure 4.

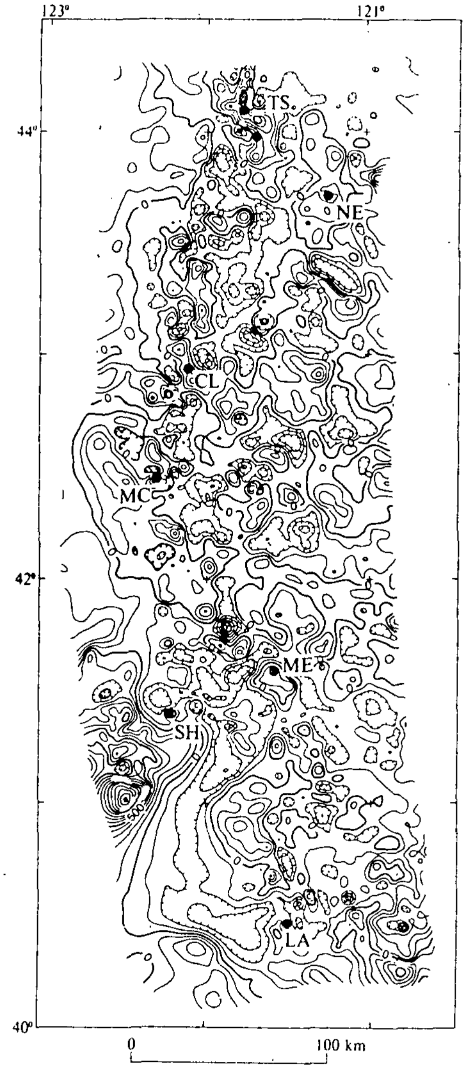

Figure 2. Low-level compilation of aeromagnetic data. Various constant-level surveys were gridded, upward continued to 4,571 m, and numerically mosaicked together. See text for sources of data. Contour interval = 100 nT. See Figure 1 for description of symbols.

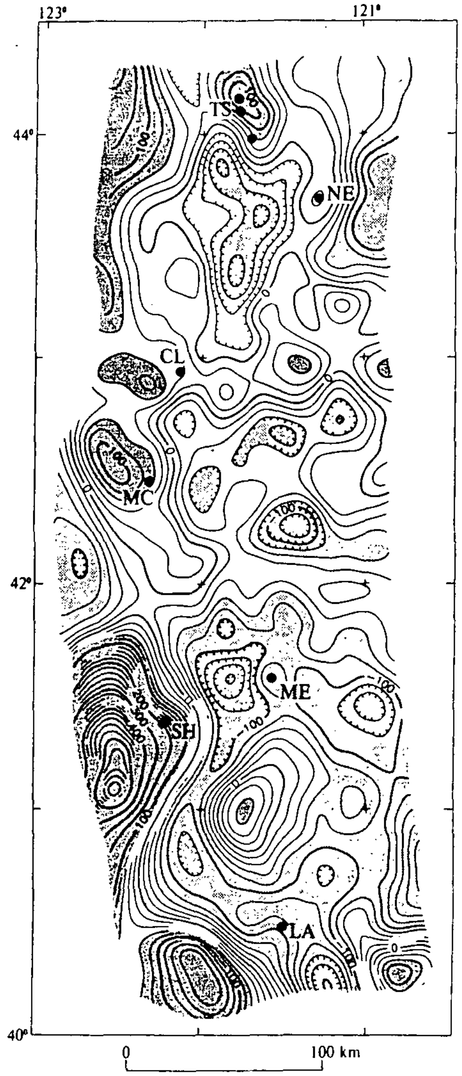

Figure 3. Upward-continued aeromagnetic data. The compilation of Figure 2 was reduced to the pole and continued upward 10 km to 14,571 m. Contour interval = 20 nT; hachures indicate direction of decreasing magnetic intensity; stipple patterns indicate anomaly values >60 nT and <−60 nT. See Figure 1 for description of symbols.

The following discussion will refer occasionally to the gravity map shown in Figure 5. This map was produced from a recent compilation of gridded Bouguer values for the conterminous United States (Godson and Scheibe, 1982) by calculating and subtracting a regional gravity field according to an isostatic model (Simpson and others, 1983) and upward continuing the residual 10 km to conform with the aeromagnetic map of Figure 3. Topography was assumed

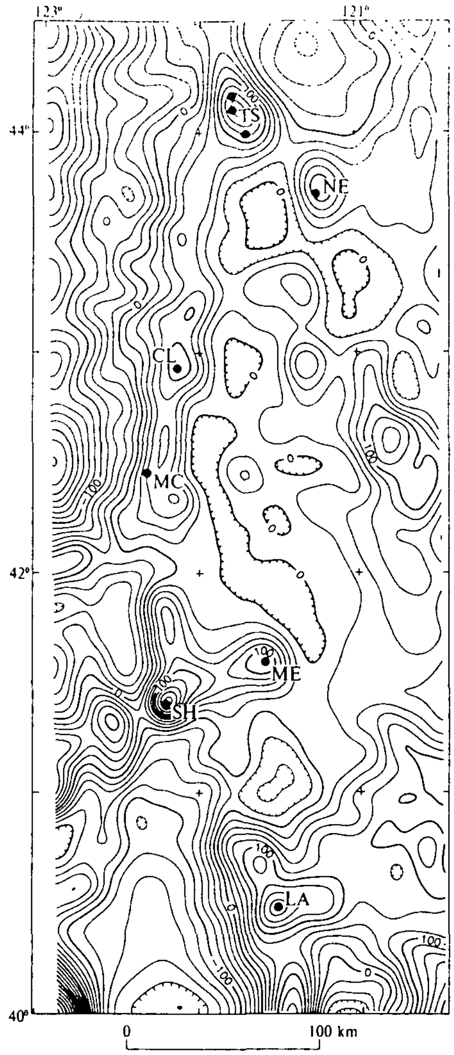

Figure 4. Calculated magnetic anomalies due to uniformly magnetized upper crust. The magnetic source is approximated with a top surface equal to topography digitized at 400-m intervals, with a horizontal flat bottom, and with uniform magnetization of 10 A m^{-1}. Anomalies are calculated on a level plane at 14,571 m and with vertical magnetization in order to conform with upward continued data of Figure 3. Contour interval = 20 nT; hachures indicate direction of decreasing magnetic intensity. See Figure 1 for description of symbols.

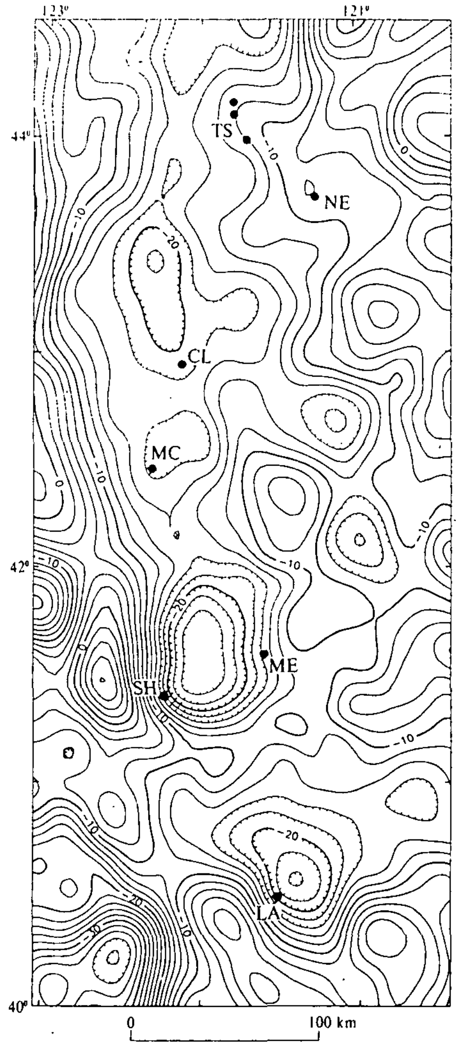

Figure 5. Upward-continued gravity data. A regional field, calculated by assuming isostatically compensated topography (Simpson and others, 1983), was subtracted from the Bouguer gravity compilation of Godson and Scheibe (1982), and residual anomalies were upward continued 10 km to conform with Figure 3. Contour interval = 2 mgal; hachures indicate direction of decreasing gravity. See Figure 1 for description of symbols.

to have a density of 2.67 g/cm^3 for these computations.

INTERPRETATIONS

Trinity Ultramafic Sheet of Irwin (1977)

The most striking anomaly of Figure 3 is centered southwest of Mount Shasta (SH), over part of the Klamath Mountains that includes the Trinity ophiolite complex. The Trinity ophiolite complex contains the largest exposed ultramafic body in North America (Irwin, 1966) and is the source of this high-amplitude anomaly (Griscom, 1977). The mapped boundary of the ultramafic body with the younger volcanic rocks of the Cascade Range is located ~20 km southwest of Mount Shasta (Fig. 6). The magnetic anomaly associated mainly with the ultramafic body, however, extends ~30 km east and northeast from this geologic boundary. Whether this indicates continuation of the ultramafic body below the volcanic terrane depends on the cross-sectional shape of the ultramafic body. If the ultramafic sheet dips and thins to the east, as shown by detailed modeling experiments using other aeromagnetic data (A. Griscom, 1983, oral commun.), the leading edge of the sheet is located near the outer limits of its anomaly. We have confirmed this interpretation by comparing three-dimensional magnetic models of the ultramafic sheet to the upward-continued magnetic data. Moreover, Fuis and others (1985) have concluded from seismic refraction and velocity data that rocks similar to the Trinity ultramafic sheet underlie Mount Shasta at a depth of ~5 km below sea level. Our interpretation of the magnetic data (Fig. 7, feature A) shows the lateral extent of these rocks beneath Mount Shasta and the surrounding volcanic terrane.

The magnetic data also indicate that the Trinity ophiolite complex continues north of its mapped extent at shallow depth below less magnetic rocks of the eastern Klamath belt, as shown earlier by LaFehr (1966) based on Bouguer gravity data and by Griscom (1977) based on magnetic data. The magnetic anomaly ends abruptly at about lat. 41°44′N, coincident with the south-dipping thrust fault, which is basal to the Trinity ophiolite complex (Irwin, 1966). Although the magnetic data indicate that the ultramafic sheet ends at this thrust contact, the gravity high over the northern part of the Trinity ultramafic sheet appears to continue ~25 km farther to the north (Fig. 5) (Griscom, 1980). The continuity of the gravity anomaly across the magnetic boundary reflects the juxtaposition of two high-density units: the Trinity ophiolite complex to the south (Griscom, 1980) and a unit that includes high-grade metamorphic rocks (Irwin, 1981; Coleman and others, 1983) of the western Paleozoic and Triassic belt to the north (Jachens and Elder, 1983). The low-level magnetic data (Fig. 2; Fig. 7, feature B) also suggest that a northeast-trending discontinuity exists in the ultramafic sheet roughly coincident with the Mallethead thrust fault. This feature may manifest the suture proposed by Hamilton (1978) within the Trinity ophiolite complex.

The southeastern boundary of the Trinity anomaly is formed by a broad gradient and indicates that the Trinity ophiolite complex continues laterally at least 25 km beneath less magnetic Paleozoic rocks of the eastern Klamath

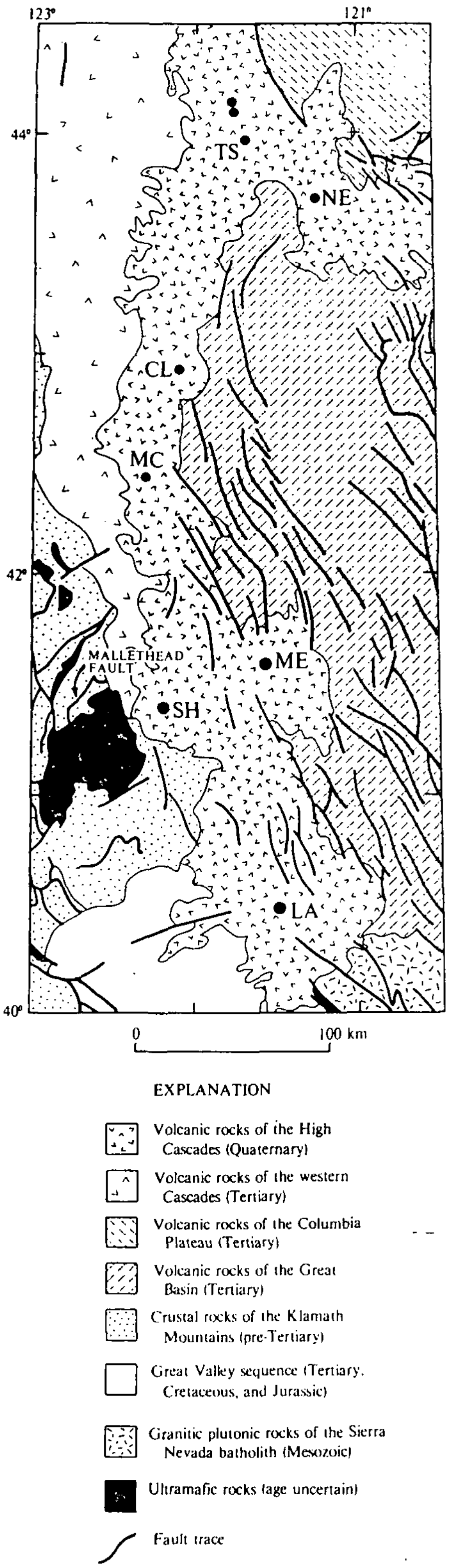

Figure 6. Geologic map of the southern Oregon and northern California Cascade Range (simplified from King and Beikman, 1974). Dashed lines indicate strike-slip fault zones discussed by Lawrence (1976). See Figure 1 for description of other symbols.

belt. Griscom (1973) suggested that the Trinity ophiolite complex may extend even farther southeast to approximately lat. 40°20′N and long. 122°00′W on the basis of a low-level aeromagnetic survey and on Bouguer gravity data.

Regional Minimum over Medicine Lake Volcano and Lassen Peak

The upward-continued magnetic data (Fig. 3) show that the Medicine Lake (ME) and Lassen Peak (LA) volcanoes produce minor positive anomalies within a widespread magnetic depression (Fig. 7, feature C). The depression is bounded on the west by the Trinity anomaly and along the north by an east-west magnetic ridge (Fig. 7, feature G discussed below). The depression is interrupted at the southwest by the hypothesized extension (Fig. 7, feature D) of the Trinity ophiolite complex (Griscom, 1973) and at the southeast by a positive anomaly (Fig. 7, feature E) located over a mapped sequence of Paleozoic metavolcanic rocks (Lydon and others, 1960) which possibly is underlain by an ultramafic body (A. Griscom, 1983, personal commun.).

An oval-shaped, positive anomaly (Fig. 7, feature F) occurs within the magnetic depression. We believe that this anomaly is caused by an isolated fragment of mafic or ultramafic rock buried at shallow depth below the younger rocks of the Cascade Range. The upward continued gravity data (Fig. 5) show a linear, positive anomaly trending ~N70°E which passes 20 km northwest of the center of this magnetic anomaly and may be related to the same buried feature. Chapman and Bishop (1968) and Griscom (1980) have proposed that near-surface basement rocks are the cause of the gravitational high. Moreover, near long. 121°W, the gravity anomaly coincides with a basement high inferred from seismic refraction data—a high that is composed of material with a seismic P-wave velocity similar to that of the Trinity ultramafic sheet to the west (Fuis and others, 1985).

Comparison of Figure 3 to Figure 4 clearly indicates that the magnetic depression is not caused by topography. The topographic model (Fig. 4) shows high-amplitude, positive anomalies over Mount Shasta, Medicine Lake, and Mount Lassen and a negative anomaly centered between these volcanoes, whereas the observed magnetic data (Fig. 3) show the opposite relationship. Huppunen and others (1982) applied a spectral-analysis technique to these data and showed an unusually shallow depth-extent of magnetic sources at four locations within the magnetic depression. Moreover, the upward-continued gravity data (Fig. 5) show two prominent lows northeast of Mount Shasta and of Lassen Peak. LaFehr (1965) showed that these anomalies are caused by near-surface sources, perhaps partly by graben subsidence of volcanic material into higher density basement rock and partly by thermal expansion of intrusive rocks below Mount Shasta and Lassen Peak. We suggest that the entire magnetic depression represents an upwarp of the Curie-temperature isotherm.

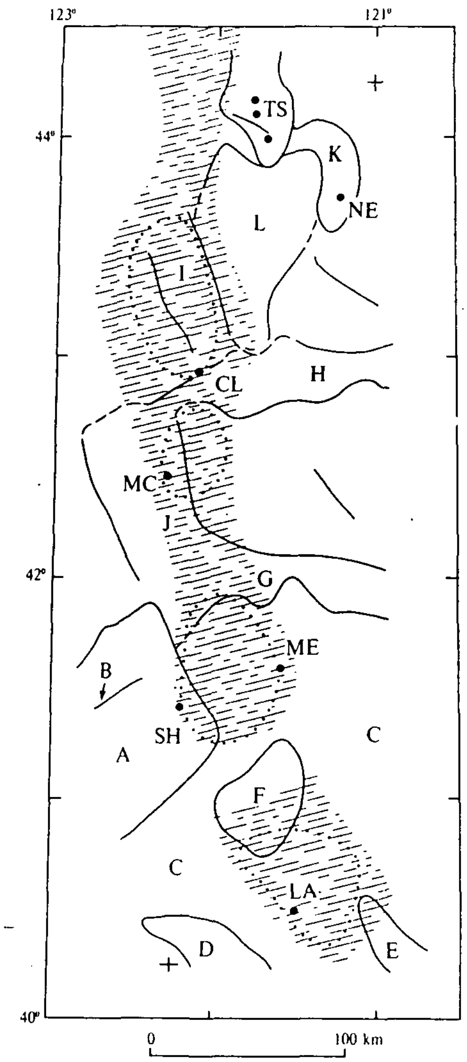

Figure 7. Map showing anomaly interpretations. Solid lines (dashed where uncertain) indicate approximate boundaries of magnetic and gravity sources interpreted from Figures 2, 3, and 4. Stipple pattern and dotted ovoids indicate north-south graben and local subsidence structures, respectively, as interpreted from the gravity data of Figure 5. Double-letter symbols are described in Figure 1; single-letter symbols are keyed to discussions in text.

East-West Magnetic Ridges

Two east-trending magnetic anomalies are present in the upward-continued magnetic data (Figs. 3 and 7) at latitudes 42°00′N (Fig. 7, feature G) and 43°00′N (Fig. 7, feature H). The topographic model (Fig. 4) demonstrates that they are not the consequence of topographic anomalies, nor are they related to exposed geologic features. These anomalies probably reflect either two narrow, east-west zones of volcanic rocks with higher concentrations of magnetite or two east-west structural features in the basement rocks below the Cascade volcanic rocks. They remain problematical because they are not parallel to the generally north-northeast– and northwest-trending structure of the Basin and Range province, which likely forms the basement of the Cascade Range in this area (Fig. 6), nor are they reflected in the upward-continued gravity data (Fig. 5).

Crater Lake (CL), the caldera remains of Mount Mazama, is located near the western end of the east-west anomaly at lat. 43°00′N (Fig. 3). Using older data, Blank (1968) noted a pattern of northwest-trending magnetic anomalies in the vicinity of Crater Lake and suggested that they reflect deeply buried magnetic sources. Specifically, he identified a northwest-trending anomaly with a right-lateral offset at Crater Lake and ascribed the offset to a northeast-trending fault in the magnetic basement below Crater Lake. These short-wavelength magnetic features (discussed by Blank) are also present in our low-level compilation (Fig. 2) but do not remain when the data are upward-continued (Fig. 3), which argues against a deep-seated, regional source. The upward-continued data do show, however, that Crater Lake is situated at the intersection of the east-west anomaly at lat. 43°00′N (Fig. 7, feature H) and a 60-km long, north-northwest–trending anomaly (Fig. 7, feature I). These anomalies may reflect major structural features related to the evolution of Crater Lake. A third linear anomaly (Fig. 7, feature J) in the vicinity of Crater Lake and coincident with Mount McLoughlin (MC) trends northwest and extends for nearly 100 km. It is approximately coincident with mapped massive basaltic andesite and andesite flows and breccias of the Western Cascades (Wells and Peck, 1961), but there is no particular reason to believe that these units are exceptionally magnetic. This linear anomaly also may reflect buried structures.

Anomalies over Three Sisters Volcanoes and Newberry Crater

The upward continued anomalies (Fig. 3) over the Three Sisters volcanoes (TS) and Newberry Crater (NE) also appear with similar shapes in the topographic model (Fig. 4), which probably indicates that these regional anomalies are largely a consequence of the topographic relief of this part of the High Cascades. The upward continued data, however, include an arcuate positive anomaly (Fig. 7, feature K) not related to the topography which connects the Three Sisters and Newberry Crater anomalies. A similar connection appears in the upward-continued gravity data (Fig. 5). Couch and others (1982) postulated from more detailed gravity data that the Three Sisters and Newberry volcanoes are structurally connected at depth by fractures or lithologic discontinuities. Apparently, this structural connection is also represented in the magnetic data.

A pronounced negative magnetic anomaly occurs directly south of the Three Sisters volcanoes (Fig. 3; Fig. 7, feature L). It is caused partly by the topographic relief of the area (Fig. 4), but it is too widespread and too intense to be produced entirely by the topography. Connard and others (1983) concluded from low-pass filtered aeromagnetic data that this negative anomaly is caused by a basin structure several kilometres deep.

GRAVITY DEPRESSION

Thayer (1936) proposed that an eastward-facing, north-trending fault scarp, which he termed the "Cascade fault," forms the structural boundary between the Western and High Cascades in Oregon. Movement along the Cascade fault raised the older Western Cascades at least 600 m relative to the eastern block and was followed by initiation of High Cascade volcanism to the east which largely buried the surface expression of the fault. Allen (1965) proposed a second north-trending fault, down-dropped to the west, parallel to and ~30 km east of the Cascade fault. The resulting graben includes Mount Hood, Mount Jefferson, the Three Sisters, and Crater Lake. South of Crater Lake, the trend of the graben swings southeast to exclude Mount McLoughlin (Allen, 1965).

A structure of this size should be detectable by geophysical techniques. Couch and others (1981, 1982) examined residual gravity data from the Cascades. Finding a narrow, north-trending gravitational minimum that extends from the Columbia River to nearly the Oregon-California border, they proposed that this minimum delineates a major fracture or brecciated zone. The gravitational minimum is approximately coincident with the graben of Allen (1965), but it lies west of Mount Jefferson and the Three Sisters.

The upward-continued gravity data should help to describe the regional characteristics of this major geologic feature and how it continues south of the Oregon-California border. Figure 5 shows that the major volcanoes of our study (Three Sisters volcanoes, Crater Lake caldera, Mount McLoughlin, Mount Shasta, and Medicine Lake volcano) are located along the edge of a long (370 km), north-trending, gravitational depression. The position of the gravitational depression in Oregon agrees with the location of the buried graben proposed by Allen (1965), except that the depression includes Mount McLoughlin. Lassen Peak is also located in a regional gravitational depression that is separated from the main depression by the east-trending high at about lat. 41°10′N, discussed above. All of these volcanoes are located at the edge of local gravity minima.

It might be argued that both the inferred graben and the local depressions are artifacts of the data reduction. Originally, topographic features were assumed to have a density of 2.67 g/cm^3 in order to calculate the gravity map of Figure 5, but because this density might possibly have been too high for typical Cascade volcanic rocks, we recomputed the upward-continued, isostatic residual map using densities of 2.43 and 2.28 g/cm^3 and, without exception, the gravity features described earlier were preserved. Consequently, the gravity minima are not a result of our selection of an improper density for the Cascade Range.

We propose that each of these minima reflects subsidence of major volumes of low-density volcanic material and that the volcanoes have formed along the related perimeter faults where magma can more easily progress to the surface. Except for Medicine Lake volcano, each of these volcanoes is near the southern end of their respective depressions. In at least two cases, the structural features causing the gravity depressions are also reflected in the magnetic data. A magnetic minimum (Fig. 3) exists between Mount Shasta and Medicine Lake volcano in approximately the same position as the gravity depression here, which suggests that the subsided, low-density volcanic material causing the gravity depression is also relatively nonmagnetic or else it is composed predominantly of reversely magnetized material. The opposite relationship seems to exist north of Crater Lake, where positive magnetic feature I (Figs. 3 and 7) corresponds with the gravity minimum extending north from Crater Lake caldera.

CONCLUSIONS

We had anticipated at the outset of this study to find certain consistencies in the regional characteristics of the major volcanoes of the southern

Cascade Range. Although some consistencies do exist, we are left with an obvious conclusion: all volcanoes are not alike. As expected, all of the volcanoes produce short-wavelength anomalies in the low-level aeromagnetic compilation (Fig. 2) related to their topographic edifices, but the regional magnetic anomalies that remain after upward continuation (Fig. 3) vary from volcano to volcano. The southern volcanoes (Mount Shasta, Medicine Lake, and Lassen Peak) are associated with a widespread regional magnetic depression, whereas the northern volcanoes (Crater Lake, Mount McLoughlin, Three Sisters, and Newberry Crater) are associated with smaller positive magnetic anomalies. The regional gravity characteristics of Newberry Crater are markedly different from those of the other volcanoes of the study area. For example, Newberry Crater is not associated with a gravity minimum; its evolution may have been influenced by its location to the east and to the outside of the graben structure which contains the other volcanoes.

Highly magnetic rocks and high topographic relief in volcanic terranes often hinder the application of aeromagnetic data to the solution of regional geologic and tectonic problems. However, the combined interpretation of aeromagnetic, gravity, and topographic information using the computational tools of upward continuation and forward modeling has proven useful toward this goal in the southern Cascade Range.

ACKNOWLEDGMENTS

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Bulletin 893

METALLIFEROUS MINERAL DEPOSITS OF THE CASCADE RANGE IN OREGON

BY

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AND

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CONTENTS

ILLUSTRATIONS

veal sufficient ore to justify a custom mill or, better still, a mill handling ore from several veins in the productive area as a unit operation. Probably some sulphide ore, particularly in the Bohemia district, is of high enough grade to bear shipment to a smelter, but no assays revealing such ore as blocked out were available to the writers. Sampling and further exploration may reveal ore shoots which, with the prices of precious metals prevailing in 1935 and with augmented prices for the base metals, may be attractive for profitable exploitation.

Small sulphide ore shoots are exposed in the North Santiam district, but so far as is known their precious-metal content is very low and their profitable exploitation will probably be obliged to await higher prices for base metals. No ore shoots containing appreciable sulphides were seen in the Quartzville district, though some small pockets of free gold ore near the surface undoubtedly remain. The proportion of sulphides in most of the veins in the Blue River district is very low, though streaks of sulphides are exposed over a length of several hundred feet in the lowest level of the Lucky Boy mine. The smaller mineralized areas probably cannot be depended on for any appreciable production, though one or more veins comparable to those already found may be discovered. In general, the Bohemia district has by far the best possibilities for future production of all the mineralized areas in the Cascade Range.

It is suggested for future prospecting and development that bodies of sulphide vein matter already revealed be carefully sampled and that, if the results warrant, further work be done to block out the ore. Additional prospecting might be done on veins known to have contained minable shoots of sulphide ores and on veins of demonstrated continuity in the productive area. Vein intersections are not necessarily highly mineralized but are nevertheless regarded as favorable areas for prospecting. Prospecting around the margins of the productive areas of the larger districts, particularly the Bohemia district, or in the smaller mineralized areas would be expected to reveal only minor amounts of sulphides, but it might result in finding small shoots or pockets of gold ore that may yield a profit if worked in a very small way with a minimum of overhead and investment.

MINERALIZED AREAS AND MINING DISTRICTS

BOHEMIA DISTRICT

The Bohemia district is described first because it is the most extensively developed, has had the largest production, furnishes the best examples and greatest variety of factors influencing mineralization, and was studied in greater detail than the other districts. The remaining districts and mineralized areas are described in the order of their occurrence from north to south.

LOCATION AND ACCESSIBILITY

The Bohemia mining district is in Lane County, 35 miles southeast of Cottage Grove, largely within Tps. 22 and 23 S., Rs. 1 and 2 E. The productive part of the district is in one of the highest parts of the divide between the Willamette and Umpqua drainage systems. The district is larger than the area represented by the geologic map (pl. 13), as it includes a roughly circular area of about 60 square miles.

A good macadamized road follows the valley of the Row River from Cottage Grove to the mouth of Frank Brice Creek. Two mountain roads branch from this road, one following Frank Brice and Champion Creeks and the other following Sharps Creek; they join at the Bohemia district. According to F. S. Day the Champion road has been largely rebuilt and improved since 1931. A railroad connecting with the Southern Pacific line at Cottage Grove and extending to Rujada, near the mouth of Frank Brice Creek, is used for hauling logs and lumber, but it has never been extended to the Bohemia district. There are numerous trails through most of the district.

SURFACE FEATURES

The Bohemia district lies in a rugged, maturely dissected area in the Western Cascades. The most conspicuous feature is a group of sharp peaks rising 1,000 feet or so above the general summit of the range. (See pl. 2.) This group includes Bohemia Mountain, with an altitude of 5,987 feet; Fairview, 5,933 feet; Grouse, 5,570 feet; Grizzly, 5,450 feet; North Fairview, 5,550 feet; and Elephant, 5,522 feet. These mountains are the highest in the central part of the Western Cascades. The first four—Bohemia, Fairview, Grouse, and Grizzly—all lie on the ridge known as Calapooya Mountain, which divides the drainage basins of the Umpqua and Willamette Rivers. Narrow ridges and valleys radiate in all directions from the central part of the area, and steep forested slopes are characteristic. Glaciation has modified the upper parts of the valleys, particularly on northern and eastern slopes, and glacial debris extends down the valley of Champion Creek possibly as far as the mouth of Golden Curry Creek, or to an altitude of 3,100 feet. Glacial cirques, some of them with lakes and muskegs, are best represented by Crystal, Golden Curry, Champion, Horseheaven, and Musick Basins. Some of the veins, particularly the Musick, have been eroded by glaciers. Possibly others have been covered by glacial debris, as in the vicinity of the old Champion mill.

GEOLOGY

GENERAL FEATURES

More than nine-tenths of the mapped area of the Bohemia district is underlain by a series of bedded volcanic rocks of Miocene (?) age, having a maximum thickness of 6,500 feet. These rocks comprise tuffs, volcanic breccias, and andesite lavas in about equal amounts, with minor lenses of coarse volcanic breccia and agglomerate and flows of rhyolite intercalated in the tuffs. The andesites range between very calcic and very sodic extremes, but the calcic type (labradorite or basaltic andesite) is the most characteristic of the district. There are many irregularities in the stratigraphic relations of the volcanic rocks, and all their characters are consistent with an origin through subaerial accumulation from volcanoes of the centric type. These rocks commonly dip at low angles to the northeast and east, although locally the dips vary, and some east-southeast dips were observed. Several dikes of andesite varying widely in strike traverse the bedded volcanic rocks and are presumed to be closely related to them. A considerable number of small plugs, dikes, and a stock of dioritic intrusive rocks occur in a belt extending northward through the central part of the area. They are included in an area of hornfels 3½ miles long and half to three-quarters of a mile wide.

VOLCANIC ROCKS

Andesites, chiefly of the calcic or labradorite variety, make up the greater part of the ridge that includes Grouse Mountain and Noonday Ridge, as shown on plate 13. The high points in the western part of the area, including Bohemia, Fairview, Elephant, and Cat Mountains, are also characterized by labradorite andesite. Monte Rica Ridge, in the southwestern part of the area, contains about 700 feet of andesite.

A large lenticular mass of rhyolite occurs in the Sharps Creek Basin, on the west side of the area, and smaller masses occur in Champion Saddle; on the spur south of Crystal Creek; on the Johnson Meadows trail in sec. 8, T. 23 S., R. 2 E.; 500 feet south of the Golden Slipper tunnel on Horseheaven Creek, in sec. 20, T. 23 S., R. 2 E.; and on the Oregon-Colorado road in sec. 19, T. 23 S., R. 2 E.

The remainder of the area is made up chiefly of fragmental rocks—greenish tuffs, volcanic breccias, and agglomerate. Many flows of andesite, particularly of the light-gray andesine-bearing variety, are included. The andesite rocks are particularly prominent on the west slope of South Grouse Mountain and on Jackass Butte. Coarse volcanic breccia occurs at several places, including the band above the Oregon-Colorado mine, at the Mayflower mill on Horseheaven Creek, in the bed of Champion Creek a short distance above the mouth of Cat Creek, and in crosscut 9 of the Champion mine, where the material has a rude cross-bedding. A somewhat different breccia or agglomerate constitutes the whole ridge top between Fairview Peak and North Fairview Mountain. The smaller fragments are about 1½ inches and the larger fragments several inches in diameter. Some of the andesite of the fragments is massive, and some is highly amygdular. There is very little difference between fragment and groundmass, and the aggregate weathers uniformly and breaks smoothly. It forms a lens between flows and may be a flow breccia.

As the whole series of volcanic rocks dips mainly to the east or northeast, the series is believed to be essentially conformable, possibly except the flows of Bohemia Mountain, with the oldest rocks at the southwest side of the area and the youngest at the east. The stratigraphic relations of the rock groups that crop out along the lines represented by A–A′ and B–B′, plate 13, are shown in the sections on the same plate.

Local unconformities occur at various places, but they probably have no great significance. The seven upper flows of the series forming Bohemia Mountain are in conformable sequence without intercalated tuff, but the two lower flows interfinger with tuff and do not appear on the south side of the mountain, suggesting a possible unconformity. An erosional unconformity appears on the southwest side of Grouse Mountain, where beds of tuff and a small fault are cut off on the erosion surface beneath a succession of flows.

DIORITIC INTRUSIVE ROCKS

Numerous small bodies of dioritic intrusive rocks occur in the Bohemia district, and 26 different bodies ranging from thin dikes to cylindrical plugs and a small stock are shown on the geologic map (pl. 13). Doubtless some bodies, obscured by the forest litter, have been overlooked. These rocks are most prominent in a belt extending in a northeasterly to northerly direction from the south end of Bohemia Mountain through Champion Saddle and down the valley of Champion Creek. Several appear on Noonday Ridge. Elongate bodies trend chiefly to the west or northwest except for the stock in the valley of Champion Creek, which is elongate in a northerly direction. Most of the plugs are less than 250 feet wide, most of the large dikes are less than 600 feet wide, and the stock on

Champion Creek is about 1¼ miles long and about 2,000 feet wide. Most of the dikes are less than a mile long.

The intrusive rocks are medium to light gray, porphyritic, and variable in texture and composition, though characterized chiefly by augite. The stock and the large dikes consist chiefly of granodiorite or granodiorite porphyry, some of the small plugs are diorite or diorite porphyry, but most of the small plugs and dikes are dacite porphyry. A large part of the workings of the Champion, Helena, and Leroy mines are in the intrusive rocks. The body at the south side of the area mapped is a porphyritic rhyolite and is not definitely related to the group of dioritic intrusives.

CONTACT-METAMORPHIC ROCKS

The volcanic rocks near all the dioritic intrusive bodies have been modified to some extent by the heat and solutions given off by the intrusive mass. In addition to the narrow zones or aureoles of contact-metamorphic rock around the small isolated intrusive bodies, there is a large continuous zone of contact-metamorphic rock extending from City Creek southwest of Champion Saddle northward to the Cape Horn vein, a distance of 3½ miles.

The contact-metamorphic rocks, called hornfels, range from those which are only slightly modified to those in which the original minerals and structure are obliterated. Tourmaline hornfels, which represents the most intense degree of metamorphism, occurs in the vicinity of the Champion mine and particularly on the north side of the dike west of the United States mineral monument. Rugged outcrops of hornfels occur along the valley of Champion Creek, particularly along the west side of the stock and on to the northwest for half a mile downstream beyond the stock. The group of veins in the vicinity of the Champion mine and the old Champion mill and the Cape Horn vein are the only prominent veins lying partly or wholly within the large zone of contact-metamorphic rock.

STRUCTURE

A gentle regional deformation has affected the volcanic rocks, which dip prevailingly to the northeast. (See pl. 13.) The most notable variations are along Champion Creek, where the dip is north to north-northeast, and in the area south of Grouse Mountain and east of Champion and City Creeks, where the dip is mainly east-northeast, changing to east for 2 miles north of Champion Saddle and resuming the northeasterly direction farther north. There are southeasterly dips in some places. The steepest dips for any considerable area were observed in the vicinity of Fairview Mountain, where the contact between the lavas and tuffs underlying the northeast spur of the mountain dips about 30° NE. North of Crystal

Basin the angle of dip is smaller than that of the surface. Diller[65] has suggested that the Bohemia district is on the limb of an anticline, but the prevailing easterly or northeasterly dip continues as far south as the writers' investigation extended, and the axis of such an anticline must therefore be well outside the district. The flows forming the caps of Bohemia, Elephant, and Cat Mountains dip at low angles to the east or northeast. The average dip of the lavas in Noonday Ridge and Grouse Mountain was not ascertained, but dips of 20° or less are inferred in the sections. The tuffs east of Horseheaven Creek also dip to the east at low angles.

Faults are not abundant, so far as could be ascertained. The most prominent fault is that along the Crystal vein, which strikes N. 70° W. and dips 56° S. In the saddle between North Fairview and Elephant Mountains the vertical component of the displacement amounts to about 200 feet, but the presence of horizontal striations leaves the actual direction and amount of displacement in doubt. Faulting is indicated along the fracture of the Yucon vein, which strikes about N. 80° W. through the narrow gap in the north spur of Bohemia Mountain. It is followed for about 350 feet by the Musick vein, and there may be that much displacement of the original Musick fracture. A slight displacement was also noted along the Yellow Jacket vein. The walls of many of the veins show slickensides and striations, but because of the lack of marker beds no measurement of the displacement could be made. The striations on the walls of the veins are usually more nearly horizontal than vertical.

The major structural axis of the area is the curving line through the center of the district, trending north-northwest in the north and southwest in the south. It largely marks the change of strike of the volcanic rocks from the northeast to east, and also coincides with the belt of intrusive and contact-metamorphic rocks. The trend of the large stock is parallel to this axis, but the smaller elongate bodies trend west or northwest.

By far the greater part of the joints in the western part of the area strike N. 60°–90° W. and dip 70°–90° S., but lower and northerly dips occur in some places. There are two minor joint systems, one with a strike of N. 20°–40° W. and the other with a strike of N. 20°–40° E. Some joints striking in other directions were found. On the east spur of North Grouse Mountain, and farther northeast there are two sets of joints, one striking N. 45°–70° E. and dipping 60°–80° NW. and the other striking N. 75°–90° W. and dipping 50°–90° N., with a minor set striking N. 20°–40° W. A set of joints

[65] Diller, J. S., The Bohemia mining region of western Oregon, with notes on the Blue River mining region and on the structure and age of the Cascade Range: U. S. Geol. Survey 20th Ann. Rept., pt. 3, p. 10, 1900.

north of the Mayflower claims strikes N. 50°–65° W. and dips 70°–90° NE. In general there is a set of joints within 20° of the direction of dip of the beds.

The veins likewise have a dominant trend to the northwest and west. About half of them strike N. 50°–70° W., about a quarter N. 70°–90° W., and the remainder N. 30°–50° W. Dips are mainly 60°–80° S. Most of the veins with a northwesterly strike are in the southern half of the area, and those with a westerly strike are in the northern part.

MINERAL DEPOSITS

GENERAL FEATURES

Though the Bohemia district covers a roughly circular area of about 60 square miles, the main mineralized belt occupies an area 5½ miles long and 1½ miles wide trending N. 60° W. It includes the Mayflower, Riverside, and Oregon-Colorado mines at the southeast and the Utopia, Sweepstakes, and Musick at the northwest. Gold has been the principal ore mined and has been obtained largely from the oxidized parts of sulphide veins. The veins are younger than any of the other rocks in the district, including the intrusive bodies. The vein matter in most places consists of brecciated, altered, and partly replaced country rock cemented by or containing fissure fillings of drusy or comb quartz that locally contains sulphides. In some veins there are bodies of cherty quartz with pyrite crusts along intersecting short fractures. The dominant sulphide, sphalerite, is associated with galena, chalcopyrite, and pyrite in varying amounts, and in some places with a little tetrahedrite. Galena is the dominant sulphide in the Musick vein, chalcopyrite in the Oregon-Colorado, and stibnite in the Tall Timber. Primary specularite is associated with quartz in several of the veins. The gold content of the unweathered sulphide ores is low in most places, though a few high-grade pockets have been found. There is a rough areal zonal distribution of mineral deposits in relation to intrusive rocks. Base-metal quartz shoots with variable amounts of gold and in places with specularite and dolomite are grouped in the area of most intensive igneous intrusion; and veins with generally less sulphide, more carbonate (commonly calcite), and in places stibnite occur in an area to the south, where there are fewer intrusive bodies.

HISTORY AND PRODUCTION

Diller [66] gives the following account of the early history of the region:

[66] Diller, J. S., op. cit. (20th Ann. Rept., pt. 3), p. 7.

The Bohemia mining region was discovered, according to Dr. W. W. Oglesby, of Junction City, Oreg., by himself and Frank Brass [Brice?] in August 1858. The region was named for James Johnson, also called Bohemia Johnson, who, with George Ramsey, reached it in 1863 from Roseburg by way of the North Fork of Umpqua River and Steamboat and City Creeks. Free gold was found in a small vein near the headwaters of City Creek but gave out at a depth of 6 feet. Bird Farrier discovered what, by purchase, became later the Knott claim, where a 5-stamp mill was put up in 1875. It shut down in 1877, and the Bohemia region was almost forgotten until interest in it was revived by Dr. W. W. Oglesby, O. P. Adams, and others in 1891. The first ledge of importance located the same year, was the Musick, which has been running a 5-stamp mill almost continuously ever since. In 1892 the Annie (since called the Noonday) was opened. The Champion put in a 10-stamp mill in 1895 and the Noonday a 20-stamp mill in 1896. Over a hundred claims have been located in the district.

In 1902 operation of the Champion, Helena, and Musick mines was consolidated under the West Coast Mines Co., and a 30-stamp mill was erected at the Champion mine. Kimball [67] reports that in 1902 there were—

not less than 2,000 mining claims of record, some of which, as may be assumed, are fractional and some relocations. * * * The district numbers about 60 head of stamps.

The Noonday mine was productive between 1896 and 1908, when it was closed down. MacDonald [68] states that in 1908 no ore was being milled in the district, nor had any milling been done since the preceding summer. In 1912 the combined Champion, Helena, and Musick mines were shut down. W. W. Elmer [69] states that from 1912 to 1918 the Champion was held under lease and bond by two operators who did a little development work and mining but ceased operations in 1917. Development and some mining was carried on by the Vesuvius Mines Co. for several years prior to 1921. The Evening Star mine, on the eastern part of the Champion vein, has been worked in a small way in recent years on oxidized ores. In the summer of 1930 there was no mining and only sufficient prospecting to satisfy the requirements of assessment work.

Within the area shown on the map (pl. 13) there are 78 patented claims and 59 claims surveyed for patent. To the west of this area, in the vicinity of Glenwood and Mineral and farther south, there are 30 claims surveyed for patent. About 200 adits and 75 veins are shown on the map (pl. 13).

The recorded production of the district is given in the table below. Undoubtedly metal was produced that was not recorded, especially in

[67] Kimball, J. P., Bohemia mining district of western Oregon: Eng. and Min. Jour., vol. 73, p. 889, 1902.

[68] MacDonald, D. F., Notes on the Bohemia mining district, Oreg.: U. S. Geol. Survey Bull. 380, p. 83, 1909.

[69] Elmer, W. W., private report.

the earlier years and some of the mines that are known to have produced are not mentioned in the records. Consequently the total production very probably exceeds the figure given, but not by any very large amount.

Output of gold and silver in Lane County, 1880–1900 [1]

[From records of United States Mint]

Year	Gold (ounces)	Silver	Year	Gold (ounces)	Silver
1880	131.87		1892	1,523.81	$247.50
1881	181.41		1893	2,757.37	
1882 [3]			1894	1,572.19	
1883 [2]			1895	1,647.80	29.51
1884 [2]			1896	2,709.00	
1885 [2]			1897	117.99	10.47
1886	145.13		1898 [3]		
1887	241.88		1899	2,015.01	1,131.31
1888	241.88		1900 [2]		
1889	169.31				
1890	145.13		Total	14,590.96	1,418.79
1891	991.18				

[1] Probably almost entirely from Bohemia district.
[2] No record.
[3] Small production.

Output of metals in the Bohemia district, 1901–30

[From data supplied by V. C. Heikes]

Year	Crude ore (tons)	Concentrates (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)
1901 [1]						
1902	420		167.10			
1903	1,000		290.25			
1904 [1]						
1905	6,100		2,231.92	1,024		
1906	6,000		2,633.73	1,049		
1907	7,647	134	1,816.92	727		
1908	26		42.38	143	629	2,138
1909	2,312		648.85	349		
1910	1,337		213.10	73		
1911	4,650	8	1,465.48	451		
1912	8,104	120	2,465.19	1,681	5,098	35,785
1913	1,375	118	290.11	1,604	7,308	59,204
1914	631		188.08	29		
1915	2,142	73	470.11	57	406	5,979
1916	49		159.98	128	1,390	16,348
1917	24		95.93	328		
1918	15		46.01	88		1,362
1919 [1]						
1920 [1]						
1921	20		42.96	229		
1922	Sluice		25.44	6		
1923	200		94.88	44		
1924	100		97.06	46		
1925	78		63.48	29		
1926	178		61.93	27		
1927						
1928	100		63.75	29		
1929	15		7.94	3		
1930	25		11.96	4		
Total	42,548	453	13,694.59	8,148	14,831	120,816

[1] No record.

NOTE.—Approximate values, 1880–1930: Gold (at $20.67 per fine ounce), $584,662; silver, $6,473; coppe[r] $2,480; lead, $5,775; total, $599,390.

The value per ton in terms of recovered metals for outputs of 100 tons or more for the various mines since 1902 has ranged from $1.20 to $16 (with gold figured at $20.67 an ounce), as deduced from data of V. C. Heikes, of the United States Bureau of Mines. The value per ton for small shipments of sorted ore has been as much as $100 or more. The average value per ton for the largest operation, that of the combined Musick and Champion mines, was $6.90 for 14 years. Annual averages for years in which more than 1,000 tons was milled range from slightly less than $5 to slightly more than $9 a ton ($20.67 an ounce for gold). Zinc was a liability rather than an asset in these complex ores during the years when concentrates were produced, and the price of lead was high only in 1916–18, when there was base-metal production. No data on costs during the productive years are available, but the obvious difficulties of transportation and the cost of mining relatively small ore shoots must have made the cost per ton relatively high. From the scanty data available it seems unlikely that the original cost of the elaborate plant and equipment of the largest company was amortized.

CLASSIFICATION

Base-metal veins with variable amounts of gold.—Most of the production has come from the base-metal veins, of which the Champion, Helena, Musick, Noonday, Vesuvius, Crystal, Grizzly, Shotgun, Utopian, Vindicator, and War Eagle are examples. The features of this type of vein have been described in the general descriptive part of this report (pp. 24–29). The metal content of the sulphide ore shoots is highly variable. Such assays of minable shoots as are available indicate that most of the gold ranges from a trace to slightly more than 1 ounce to the ton, with an average of about 0.4 ounce. Most of the silver ranges from a trace to 4 ounces to the ton, with an average of about 2 ounces. Copper ranges between a trace and 1.5 percent and averages 0.75 percent. Lead ranges from a trace to 6 percent, with an average of about 3 percent; and zinc ranges from 1 to 14 percent, with an average of about 5 percent. Variations occur in the proportions of the various minerals in the base-metal veins, and some, such as the Cross vein, of the War Eagle group, a vein of the Orofino group, the Alpharetta vein, and shoots on the Sultana and Cape Horn veins, contain abundant specularite. The California vein contains johannsenite.

Veins of quartz and clay minerals.—The veins containing quartz and clay minerals consist of kaolinized and silicified country rock with sparse to abundant seams and lenses of quartz that in some places contain a little sulphide. Examples of such veins include some near the west border of the granodiorite stock along Champion

Creek and the North Fairview and Syndicate veins. They have not been productive.

Pyrite and cherty quartz veins.—Parts of the Sultana, Cape Horn, and Orofino veins, the northern vein east of Helena No. 2 camp, and the Golden Slipper vein are made up of cherty quartz with many small fractures faced with pyrite containing some intergrown marcasite.

Chalcopyrite-quartz veins.—The only example of the chalcopyrite-quartz veins is the Oregon-Colorado vein, which is described on pages 72–73.

Gold-quartz and gold-calcite-quartz veins.—Low-grade gold-quartz veins occur in the western part of the district, outside the mapped area. At the Star mine the ore consists of white massive and vuggy quartz with calcite and pyrite. Sphalerite, chalcopyrite, and galena are present in some veins in minor amounts. A shoot on the Western vein of the Cripple Creek group consists of massive quartz with very sparse sulphide and some coarse gold. Calcite is the major gangue mineral in the El Capitan vein on St. Peters Creek, where it is associated with sulphides, principally galena, and comb quartz.

Stibnite-pyrite-quartz veins.—Stibnite veins are represented by one of the veins of the Tall Timber group described on page 78.

Specularite and magnetite veinlets and disseminated specularite.—Fractures in hornfels adjacent to many of the intrusive bodies contain specularite and magnetite. Specularite and pyrite are disseminated in bleached zones of andesite or tuff near intrusive masses.

Disseminated pyrite.—Pyrite is disseminated in the contact zones around the smaller intrusive bodies and in the outer part of the large areas of contact-metamorphic rock.

ZONAL ARRANGEMENT

No evidence of vertical zoning and only poorly defined evidence of areal zoning of sulphide minerals has been found. Veins with sulphides have a vertical range of 2,800 feet, though the maximum depth within any single mine is only about 400 feet, but sulphides persist through this range without any apparent change.

A rough areal zoning is indicated in the principal mineralized belt, which extends west-northwestward from the Mayflower to the Utopia. This belt is characterized by shoots in which the gold content is variable and the chief sulphides are sphalerite, galena, and pyrite, with subordinate amounts of chalcopyrite, in a gangue of quartz, sericite, clay minerals, and a little dolomite in vugs. In the center of this belt, in the vicinity of the Champion mine and the area of large intrusive bodies and extensive contact metamorphism, primary specularite is associated with quartz in several veins, and metamorphic rock nearby contains tourmaline. Vein matter in the Grizzly, Cape Horn, and Sultana veins, farther north, is similar.

Farther south and southwest there are fewer intrusive bodies, fewer veins, and fewer shoots that contain noteworthy proportions of sulphides. Sphalerite and galena are less abundant. Stibnite occurs at the south end of the Western vein and in the El Capitan and Tall Timber veins and is reported to occur in veins in the vicinity of Twin Rocks, farther southwest. Carbonates are common in some of the veins in this area. Dolomite forms considerable bodies in the Western vein, and calcite is abundant in the El Capitan vein. Sulphides are sparse in the Glenwood and Combination veins and at the Star mine. All these characters are consistent with mineralization at lower temperatures than those in the area to the north and northeast.

HYDROTHERMAL AND SUPERGENE ALTERATION OF WALL ROCK

The wall rocks of all the veins have been altered and new minerals have been formed. Several veins, such as the Oregon-Colorado, are accompanied by altered rock characterized by chlorite. In these the rock is greenish and superficially appears fresh, though the microscope shows that original minerals are partly or completely destroyed. Large areas of altered rock that is bleached and iron-stained at the surface occur in Champion Saddle, in Bohemia Saddle, in the saddle between Fairview and North Fairview Mountains, in the saddle between North Fairview and Elephant Mountains, in Grizzly or Helena Saddle, in the saddle in the eastern part of sec. 7, T. 23 S., R. 2 E., in the western part of sec. 8, T. 23 S., R. 2 E., on Monte Rica Ridge, in sec. 23, T. 23 S., R. 1 E., and on the south and west slopes of Jackass Butte. Similar altered rock occurs in the vicinity of the Knott shafts, in the saddle between North Grouse and South Grouse Mountains, and in the western part of the district, outside the area represented by the geologic map. Smaller areas accompany many of the veins throughout the district. The bleached altered rock is characterized in outcrop by its light color (white or various tints of yellow), craggy or pitted weathered surface, and low resistance to weathering and erosion, hence its occurrence in saddles and other relatively low places. Samples collected from the Champion workings and discussed on pages 31–32 are made up largely of very fine grained quartz, abundant pyrite, a little sericite, and abundant clay minerals. Some of the clayey material tends to slough in underground workings. Thoroughly weathered material contains no pyrite but is iron-stained.

and below the prospect are light-gray andesites, dark labradorite andesites, tuffs, and volcanic breccias, with an apparent dominance of flow rocks. No dioritic intrusive bodies were found. The country rock at the prospect is a light-gray andesite, only slightly altered. The open cut above the tunnel reveals two thin seams of vein matter on intersecting fractures that are neither large nor persistent. The more persistent fracture strikes N. 20° W. and dips 59° SW., and the other strikes N. 22° E. The vein matter consists of fragments of country rock altered to an aggregate of quartz and clay minerals on which are crusts of galena and sphalerite with quartz and dolomite. The remaining spaces are filled with dolomite and a little calcite. Galena equals or exceeds sphalerite, and both are more abundant than pyrite. No chalcopyrite was observed.

NORTH SANTIAM DISTRICT

LOCATION AND ACCESSIBILITY

Most of the mines and prospects included in the North Santiam district (pl. 16) are in T. 8 S., Rs. 4 and 5 E., mainly within the drainage basin of the Little North Santiam River, in Marion County. The central part of the area is known locally as the Lester mining district, and the eastern part has been called the Mineral Harbor district.[83] Several outlying mineralized areas or claims include the calcite vein on Elkhorn Creek in sec. 1, T. 9 S., R. 3 E.; the Ogle Mountain mine, designated the Molalla district by Stafford,[83] on Ogle Creek, a tributary of the Molalla River; a group of three patented claims in sec. 12, T. 7 S., R. 4 E., on the Table Rock Fork of the Molalla River; and a prospect on Humbug Creek near Dunlap Lake, in the northwestern part of T. 9 S., R. 6 E.[83] The areas on the Table Rock Fork and Humbug Creek were not visited by the writers. All those properties in the drainage basin of the Little North Santiam River are served by a mountain road that extends from the Amalgamated mine, on Battle Ax Creek, to Lyons, on the Detroit branch of the Southern Pacific Railroad. The distance is about 22 miles from the center of the district. The Ogle Mountain mine was reached by a road that followed the ridge tops to Scotts Mills, on the margin of the Willamette Valley.

SURFACE FEATURES

The North Santiam district is the most rugged of all the mineralized areas of the Cascade Range in Oregon (pl. 12, B), partly on account of the relief, but largely on account of the large proportion of lava flows to fragmental rocks. The altitude of the bed of the river within the district ranges from 1,100 to 2,500 feet, whereas the surrounding mountains within 2 miles of the river attain altitudes of 4,000 feet, and Battle Ax Mountain, east of the district, reaches an altitude of 5,547 feet. Steep slopes are common, and high cliffs occur in Henline Mountain. Most of the mines and prospects are less than 500 feet above the river or its larger tributaries.

[83] Stafford, O. F., Mineral resources and mineral industries of Oregon: Oregon Univ. Bull., new ser., vol. 1, no. 4, p. 58, 1904.

GEOLOGY

VOLCANIC ROCKS

The most significant features of the volcanic rocks in those parts of the North Santiam district that were studied are the dominance of flow rocks over fragmental rocks and the dominance of light-colored oligoclase andesites and rhyolites over the more calcic andesites. Most of the flows within 1,000 feet vertically of the Little North Santiam River are oligoclase andesites—light-colored rocks in which oligoclase is the dominant feldspar and in which chlorite represents the original ferromagnesian minerals—though labradorite andesite occurs at the Riverside prospect. Epidote is an unusually abundant alteration product in the oligoclase andesites. Rhyolite, a light-gray or brownish rock with flow bands and fragments, makes up the bulk of Henline Mountain above an altitude of about 2,800 feet. White altered rhyolite also occurs at the Crown and Santiam or Minnie E. mines, and dikes of white rhyolite with quartz phenocrysts are exposed in workings at the Amalgamated. Hypersthene andesites occur on or near the tops of the ridges, such as near the summit of the trail between the Silver King and Ogle Mountain mines, in a sharp peak whose altitude is 4,633 feet, in the NW¼ sec. 13, T. 8 S., R. 4 W., and in the peaks in the vicinity of Silver King Mountain, east of Whetstone Mountain. A lens of coarse volcanic breccia 300 feet thick is exposed between the upper and lower workings of the Silver King mine on Henline Creek. Laminated fine-grained greenish-gray tuffs occur in several places in the district. Oligoclase andesite on the north bank of the river at the Santiam mine has a fragmental appearance and may be a flow breccia. A dike of hornblende-biotite andesite occurs in the Crown workings.

DIORITIC INTRUSIVE ROCKS

Small intrusive bodies are widely scattered through an area from the Crown mine on the west to the Amalgamated properties on the east. They are mostly dikes of dacite porphyry trending to the northwest, such as the bodies at the Silver King property and those on Gold Creek. A dacite porphyry plug 200 feet wide occurs in the upper reaches of Horn Creek and is nearly surrounded by a resistant contact zone that weathers out as a circular wall 40 feet high in places. The body at the Bimetallic prospect, on Gold Creek, is probably a plug. A larger body of quartz diorite of undetermined shape occurs at the Crown mine. The large area of contact-metamorphic hornfels on the river near Stony Creek indicates the presence of intrusive rock nearby, but the intrusive rock was not found.

CONTACT-METAMORPHIC ROCKS

Tourmaline-quartz-sericite hornfels occurs near the quartz diorite at the Crown mine and along the river near Stony Creek. Near Stony Creek the tourmaline rosettes are as much as an inch in diameter, and the rock contains cavities lined with quartz crystals. A hornfels with dark spots made up of quartz, sericite, chlorite, and a halo of magnetite around the margin occurs at the Mineral Harbor prospect. A hornfels derived from volcanic breccia at the crosscut at the Silver King mine contains dark spots 2 to 10 millimeters in diameter which, under the microscope, are revealed as sheaflike aggregates of magnetite in brown chlorite. Narrow zones of hornfels surround the smaller bodies.

STRUCTURE

There appears to have been little deformation in this area, as most of the structural features observed can be explained as originating during volcanic accumulation. Local warps occur, and their directions are shown on plate 16. In general, dips on the north side of the valley of the Little North Santiam River have a dominant northerly component, whereas those on the south side have a dominant southerly component, suggesting that the valley is on the crest of an anticline. No faults of measurable displacement were observed. The amount of movement along the veins was not sufficient to bring recognizably different rocks into juxtaposition.

Most of the elongate intrusive bodies trend N. 20°–40° W. Dips are vertical so far as could be determined. From a few observations on joints it was ascertained that a more persistent system strikes N. 20°–50° W. and dips steeply (70°–90°), mainly southwest, whereas the other system strikes N. 40°–60° E. and dips steeply either southeast or northwest. The trend of the veins ranges from N. 80° W. in the No. 1 and No. 2 veins at the Crown to N. 10° E. in the Blende Oro vein. The calcite vein on Elkhorn Creek, at the west side of the district, strikes N. 65° E. The average strike is about N. 40° W. Two-thirds of the veins dip steeply northeast, and one-third dip steeply southwest.

MINERAL DEPOSITS

HISTORY AND PRODUCTION

The early history of discovery of metalliferous minerals in the North Santiam district is largely lost. R. E. Peery,[84] who is interested in the Crown mine, stated that so far as he could learn ore was discovered by Indian Hirn in 1896 at what is now the main tunnel of the Amalgamated mine. Fred Buesche located claims nearby in 1897. Most of the properties now known are reported by Stafford [85] for 1903. J. B. Fairclough [86] stated that the Ogle Mountain mine was worked from 1903 to 1914 and again in 1918–19. Ore was shipped from what is now the Santiam mine in 1915–17 and again in 1924. Operators of the Amalgamated mine were active in 1930, and a shipment of ore was made. The recorded production is given in the table below. The production for 1926 may be erroneously ascribed to this district.

Production of North Santiam district

[From data supplied by V. C. Heikes]

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1915	47	68.55	48			
1916	40	80.93	9	6,504		
1917	5			1,000		
1918	75	67.00	14			
1919	118	50.98	129			
1924	71		105	6,219		
1926	35	10.17	1,352	112	276	
1930	43		102	371	3,060	12,528
Total	434	277.63	1,759	14,206	3,336	12,528

NOTE.—Approximate values: Gold (at $20.67 an ounce), $5,739; silver, $1,146; copper, $2,914; lead, $191; zinc, $564; total, $10,554.

MINERALOGY AND TYPES OF VEINS

The veins are broadly similar to those in the Bohemia district, yet certain differences are apparent. Chalcopyrite, sphalerite, pyrite, galena, and gold are the principal metallic minerals. Gold was the principal mineral sought in the Ogle Mountain mine. The gold content of the sulphide ores is very low, however. Veins characterized by chalcopyrite are more numerous in this district than in the Bohemia district. Relatively little quartz occurs with the chalcopyrite. An unidentified white mineral containing copper, bismuth, silver, and sulphur was observed under the microscope in chalcopyrite from the Santiam mine. Sphalerite at the Silver King mine is unusual in that

[84] Personal communication.
[85] Stafford, O. F., op. cit., pp. 57–58.
[86] Personal communication.

it is light green. One of the ore shoots of the Amalgamated mine is unusual in having a gangue of minute epidote needles and calcite. Specularite occurs only in the Mineral Harbor and Silver Star veins in contact rock and is not nearly so abundant as in the Bohemia district. Ankerite and adularia occur at the Ogle Mountain mine. As the veins are mostly down in the valleys, erosion has nearly kept pace with weathering and oxidation. No weathered zones comparable with those in the Bohemia district were seen. Oxidation was probably deepest at the Ogle Mountain mine, but its exact depth is not known to the writers.

Though at least three of the usual sulphides are common to almost all the veins, the variations in their proportions are sufficient to suggest a classification of the veins. Complex sulphide veins characterized by sphalerite as the dominant sulphide, with variable proportions of galena, chalcopyrite, and pyrite, include the Amalgamated, Blende Oro, Capital, Mineral Harbor, Silver King, Wolz, and the vein on the mountain side northeast of the mouth of Gold Creek. Veins characterized by pyrite as the principal sulphide include those at the Gold Creek M. & M. tunnels and the Santiam group of tunnels on Gold Creek. The Bimetallic vein is transitional between the pyritic type of the Gold Creek M. & M. and the complex sulphide type of the Blende Oro. Chalcopyrite is the dominant sulphide in the Minnie E. vein of the Santiam group and the Crown veins, as well as in the Black Eagle and Silver Star. In the Silver Star vein early epidote and specularite are traversed by quartz containing both sphalerite and chalcopyrite, but the chalcopyrite has also invaded the epidote. Oxidation and leaching of chalcopyrite veins in the Black Eagle and Crown has produced a little chrysocolla, malachite, and azurite. Carbonate veins include the calcite vein on Elkhorn Creek and the Ogle Mountain vein, which also contains sparse sulphides.

In general, the veins in the North Santiam district are less persistent, are narrower, and contain narrower ore shoots and less gold than those in the Bohemia district. The veins and the dioritic intrusive bodies are also more scattered than those of the Bohemia district.

However, the areal zoning of the veins of different types is more evident here than in the Bohemia district. The chalcopyrite veins from the Crown mine to the Santiam form a central zone. This is succeeded in the section up Gold Creek by the pyrite veins, and that in turn by the complex sulphide vein of the Blende Oro. The outer limits of mineralization are represented by the calcite vein on Elkhorn Creek and the Ogle Mountain mine. Probably the zones are not continuous and the pyrite zone appears to be largely absent except on

Gold Creek. No prospects have been opened south of the chalcopyrite veins.

The wall rock of the veins is altered, generally to an aggregate of chlorite, epidote, sericite, quartz, clay minerals, and carbonate. The carbonate is probably mostly calcite, but ankerite occurs in some places, and mesitite occurs in the wall rock of the Capital vein. Sericite is the principal alteration product at the Blende Oro and Bimetallic. Though there are narrow zones of soft altered rock along the veins, none of the large areas of bleached and partly silicified altered rock, such as occur in the Bohemia district, were observed.

Future development in the district should depend largely on high prices for the base metals. Small shoots of complex sulphide and chalcopyrite ores have been explored, but they contain almost no gold and very little silver, according to available assays. Possibly more shoots of base-metal ores will be found, as the district covers a large area, is heavily forested, and has not been thoroughly prospected. Further prospecting might reveal gold-ore shoots like that of the Ogle Mountain mine, in the outlying parts of the district. Only small ore shoots may be expected, and plant and development work should be planned accordingly.

MINES AND PROSPECTS

Amalgamated.—Three contiguous groups of claims—the Amalgamated, Columbia, and Blue Jay—constitute the Amalgamated properties, which lie mainly on the south side of the Battle Ax Fork of the Little North Santiam River in unsurveyed T. 8 S., R. 5 E., about 26 miles by road from Lyons. The main workings were formerly the property of the Lewis & Clark Mining & Milling Co.[87] The present owners were active in 1930. A road 4 miles long was built to the mine, buildings and ore bins were constructed, and foundations were started for a mill, though almost no new development work was done. An ore shoot previously developed was mined, and 43 tons of crude ore was shipped to the smelter.

The underground workings consist of about 1,350 feet of drifts, of which about 1,020 feet is in the workings on the main drift. There are also several short adits and open cuts. The main tunnel enters the south side of the valley several hundred feet above Battle Ax Creek and trends S. 55° E. but curves to the east near the face. The country rock is mainly oligoclase andesite, but a dike of porphyritic rhyolite about 5 feet wide crosses the tunnel near the portal and

[87] Stafford, O. F., Mineral resources and mineral industries of Oregon: Oregon Univ. Bull., new ser., vol. 1, no. 4, p. 58, 1904. Parks, H. M., and Swartley, A. M., Handbook of the mining industry of Oregon: Mineral Resources of Oregon, vol. 2, no. 4, p. 140, Oregon Bur. Mines and Geology, 1916.

but the strike is N. 85° W. and the dip 40°–50° S. Dacite porphyry forms both walls of the vein in this drift.

Another vein near the south boundary of the property, on a rock terrace southeast of the portal of the crosscut, has been prospected by a shaft reported to be 80 feet deep but now filled with water and debris to a point within a few feet of the surface. The vein matter is very similar to that of the Queen of the West.

The assays given below are taken from a prospectus supplied by the owners. Samples 1 and 2 were taken from the shaft. Samples 3, 4, and 5 were taken progressively inward along the drift on the Queen of the West vein on the east side of the creek, sample 5 being at the face. The remainder were taken progressively inward along the drift on the west side of the creek, sample 12 being near the face. Zinc was not determined in those samples where its quantity is not given.

Assays of samples from Silver King property

	1	2	3	4	5	6	7	8	9	10	11	12
Width ...... inches..	------	------	20	10	18	------	75	------	------	18	60	------
Gold ounces to the ton..	0.05	0.06	0.045	0.02	0.04	0.07	Trace	Trace	0.06	0.02	Trace	0.02
Silver ounces to the ton..	1.6	2.1	3.1	9.8	4.4	5.2	7.4	14.6	39.1	40.8	4.2	5.2
Lead .... percent..	.53	.1	2.1	3.2	2.92	3.8	3.2	3.7	2.93	1.73	3.9	4.7
Zinc .... do....	3.74	4.2	------	1.44	------	------	------	------	------	3.38	3.7	------

Silver Star.—The Silver Star and Helvetia claims are on the road west of Tincup Creek, in the SE ¼ sec. 23, T. 8 S., R. 4 E. The owner was actively prospecting in 1931. The main tunnel is at the side of the road and runs 30 feet N. 25° W., then 35 feet N. 37° E. The vein, which is approximately vertical, appears mainly in the inner part of the tunnel. The country rock is greenish-gray altered oligoclase andesite containing much epidote.

The vein ranges from a few inches to 18 inches in width and consists chiefly of epidote and quartz, though some quartz veins without epidote cut epidote veins. Dark sphalerite and chalcopyrite are associated in the later vuggy quartz veins, and chalcopyrite is disseminated or occurs in veinlets in the epidote. A little chalcopyrite occurs with knots and vugs of coarse specularite. Near the vein is a dioritic intrusive body that strikes N. 10° E. Near the end of the drift the ore minerals appear to occur in jointlike fractures rather than in a well-defined vein.

Wolz.—The Wolz property is between the road and the Little North Santiam River near the mouth of Cold Creek and between Tincup and Stack Creeks at the north side of sec. 26, T. 8 S., R. 4 E. It is reached by a trail that joins the road near Cold Creek. The vein strikes N. 35° W. and dips 75° NE. It has been explored by

an open cut in the bank of the river, a drift 20 feet long above this, and a drift 80 feet long about 50 feet above the short drift. The country rock is greenish porphyritic andesite. The open cut reveals 18 inches of vein matter that consists of fragments of altered rock cemented by quartz. Sphalerite and chalcopyrite are disseminated through this material in nearly equal proportions, and there is a little pyrite. Some thin seams of comb quartz with these three sulphides occur in the hanging wall. The short drift reveals two thin seams of gouge without perceptible sulphides. The upper drift is lagged throughout, but at the face it shows 8 to 15 inches of brecciated andesite with moderate amounts of sulphides, which are partly leached. Greenish porphyritic andesite 2½ feet thick with thin seams of vuggy quartz occurs in the hanging wall. The vein also appears on the south bank of the river.

Other prospects.—A prospect tunnel 30 feet long in andesite is located on the southwest ~~slope~~ of Whetstone Mountain, about 500 feet above the road and 0.9 mile east of the mouth of Gold Creek. An open cut lies about 240 feet to the northwest along the strike. The vein strikes N. 25° W. and dips 65° SW. It consists of 1½ to 2 feet of partly leached vein matter and fragments of altered rock with some sphalerite and chalcopyrite and a little pyrite.

QUARTZVILLE DISTRICT

LOCATION AND ACCESSIBILITY

The Quartzville district is second to the Bohemia district in production and takes its name from the camp and post office, long ago destroyed by fire, which served the Lawler mine. (See pl. 18.) It is in eastern Linn County, 40 miles nearly due east of Albany, on the headwaters of Quartzville Creek, a tributary of the Middle Santiam River. Most of the actively prospected part of the district lies in the southeastern part of T. 11 S., R. 4 E., but the district extends into the northeast corner of T. 12 S., R. 4 E. Almost all the production has come from the ridge south of Dry Gulch in secs. 22 and 23, T. 11 S., R. 4 E. Though formerly served by a road from Gates on the North Santiam River, the district was accessible only by trail in 1931. The distance from Quartzville to Detroit, on the North Santiam River, is 22 miles; to Gates, 21 miles; and to Foster, near the junction of the Middle Santiam and South Santiam Rivers, 34 miles. A road up Quartzville Creek, under construction by the United States Forest Service in 1931, has since been completed.

SURFACE FEATURES

The district is a part of the rugged and deeply dissected Western Cascades. The altitude ranges from 1,800 feet at the mouth of

Canal Creek to 5,000 feet on Galena Mountain, but most of the prospects are within 1,000 or 1,500 feet in vertical distance above the major streams. Both the mountain sides and the gradients of all but the major streams are steep. The entire district is drained by Quartzville Creek and its tributaries. A series of terraces and alluvial fills extending from the mouth of Canal Creek to the eastern boundary of the Lawler placer claims on Dry Gulch (pl. 18) constitutes a noteworthy feature. Bedrock is not exposed in the lower 2 miles of Dry Gulch, and the stream flows on the surface only during periods of excessive run-off.

GEOLOGY

VOLCANIC ROCKS

Flows of labradorite andesite, normal andesite with andesine or oligoclase, and rhyolite are interbedded with one another or with tuff or volcanic breccia. The volume of flows appears to equal or possibly to exceed that of the fragmental rocks. The normal andesites make up the bulk of the flows in the area between Quartzville and Detroit and along Quartzville Creek. Labradorite andesites are common south of Quartzville Creek and along the trail from Quartzville to Gates. Rhyolite is prominent in the lower part of White Bull Mountain. It forms the wall rock of the Crosscut tunnel of the Albany and most of the Lawler mine and occurs on the south side of the ridge at the Silver City prospects, on Silver Creek. A thick flow or series of flows of vesicular gray olivine basalt occurs on Galena Mountain and on the top of the ridge both to the east and to the west. Tuff or volcanic breccia makes up the greater part of White Bull Mountain above the rhyolite, but it contains intercalated flows of andesite. It also occurs in the ridge north of Dry Gulch and forms the wall rock of the Savage mine, in the southern part of the district. Andesite dikes are common, though not readily distinguished from flows in small isolated outcrops.

DIORITIC INTRUSIVE ROCKS AND CONTACT METAMORPHISM

Dikes and possibly some plugs, chiefly of dacite porphyry, are scattered through the district. The width of these bodies was nowhere found to exceed 200 feet, and most of those observed range from 14 to 40 feet. The intrusive rock on the trail west of McQuade Creek is porphyritic diorite, and float from the area of tourmaline-quartz-sericite hornfels near the head of Galena Creek is similar. The dacite porphyry varies somewhat in the several other dikes that occur at the United States location monument, on Quartzville Creek near the mouth of Canal Creek, at the mouth of McQuade Creek, in the central part of the district, and in the northeastern part of the district north of Gold Butte. An isolated group of dikes occurs on the Quartzville-Detroit trail in the southwestern part of T. 10 S., R. 5 E.

Narrow aureoles of hornfels are associated with the intrusive bodies, and tourmaline-quartz-sericite hornfels occupies a considerable area near the head of Galena Creek.

STRUCTURE

Outcrops are not sufficiently continuous to yield definite information concerning folding and faulting. No angles of dip were observed that exceed possible initial dips of flows. In several places along Quartzville Creek flows between beds of tuff dip 5°–10° upstream, to the east or northeast, suggesting a regional dip in this direction. No good indication of major faulting was observed. Both walls of all the veins observed except part of the Bonanza tunnel of the Albany mine contain rock of the same kind. Striae on the walls of veins are more nearly horizontal than vertical.

Five diorite dikes trend N. 30°–60° W. One trends due north. The striae of most of the veins is N. 20°–60° W. and averages N. 40° W. The dip ranges from 63° to vertical and averages 80°. Equal numbers of veins dip to the northeast and to the southwest, and nearly as many are vertical. Some gouge seams in the veins curve from a northeast dip to a southwest dip.

MINERAL DEPOSITS

HISTORY AND PRODUCTION

According to R. E. Peery,[94] the first location in the district was made by Jeremiah Driggs on September 5, 1863. The White Bull was located in June 1864 by C. S. Woodworth, A. L. Buckingham, S. L. Clarke, H. C. Sterling, and I. J. Dennis; and the Red Bull by David Wood, William Chrisman, Robert Carey, and J. A. Crabtree. A mining district was organized July 29, 1864. Apparently interest in the district waned, for the White Bull and Red Bull claims were again located July 11, 1887. The Lawler and Albany mines were developed, and mills were installed in the early 1890's. Apparently most mining operations had ceased by 1900. A Chilean mill was installed at the Albany, and a small amount of ore was treated in 1925. Prospectors have been in the district almost every summer since the period of mining operations and have recovered some gold from pockets and from placers.

The recorded production, largely from records of the United

[94] Personal communication.

States Mint, is given in the table below. Though the district is in Linn County, much of the production is reported from Marion County, as the traffic was almost entirely through Marion County.

Production of Marion and Linn Counties [1]

[From U. S. Mint reports]

Year	Marion County		Linn County	
	Gold (ounces)	Silver	Gold (ounces)	Silver
1884	50.65	$119		
1887	725.63			
1888	[2] 483.75			
1890			314.44	
1891			232.20	
1892			661.77	$750
1893			202.93	
1894	47.69		241.88	
1895	406.83	2,000	302.83	
1896	749.81		3,938.92	
1924 [3]			42.96	25
Total	2,464.36	2,119	5,937.93	775

[1] Probably almost entirely from Quartzville district.
[2] Recorded as Madison County.
[3] From data of V. C. Heikes, U. S. Bureau of Mines.

NOTE.—Value of gold (at $20.67 an ounce), $173,690.74; silver, $2,894; total, $176,584.74.

MINERALOGY AND TYPES OF VEINS

The veins of the Quartzville district are much less extensive and contain much less sulphide than those of the Bohemia district. They differ from those of the North Santiam district in having less sulphide but more gold and silver. Most of the prospects and mines have developed only the upper weathered parts of the veins. Some large stopes were made on the Lawler vein and a smaller one on the Albany, but the production from the others has been largely from pockets—rich streaks within a few feet of the surface—which have been found at various times since the discovery of the metalliferous area. Some of these pockets are reported to have yielded as much as $5,000 in gold and a little silver, but generally a few hundred dollars is the limit. No large shoots of sulphide ore were open to view in 1931.

Few of the veins have been prospected below the zone of oxidation and leaching, but it appears that most are complex sulphide veins in which sphalerite predominates. Some of the veins, such as the Mammoth Reef, Snowstorm, or Edson, and to a certain extent the Bob and Betty, consist of broad zones of brecciated country rock cemented by massive or vuggy quartz veinlets without appreciable sulphides. Some, such as the Golden Fleece and Munro, consist of altered rock, cherty quartz veinlets, and no sulphide except pyrite. Those with appreciable sulphides occuring in streaks and lenses include parts of the Bob and Betty, Silver Signal, and Winter. Material on the dump indicates that the Galena and Paymaster, in the southern part of the district, contain sulphides in appreciable quantity. Small grains of bournonite and tetrahedrite were recognized in sulphide vein matter of the Bob and Betty. Barite occurs on the surface of vugs in vein matter from the Galena and Winter veins and in one of the veins at the mouth of McQuade Creek. Ankerite occurs in the Winter vein, and clear calcite is intimately associated with the sulphides in the Bob and Betty. In the Bob and Betty a breccia of cherty quartz or silicified pyritized country rock is cemented by the sulphides and calcite. Gold occurs as little plates and wires in the pockets. The Riverside vein reveals postmineral brecciation. There is no definite evidence of zonal arrangement of sulphide minerals.

Large areas of bleached and iron-stained altered rock occur on White Bull Mountain. Zones of altered rock are commonly present along the veins.

Though prospecting has been rather extensive it seems probable that small pockets yielding gold will continue to be found in unexplored parts of known veins or in veins that have heretofore escaped attention because of soil and forest litter. If worked in a small way with a minimum of cost in plant and development work, these small ore shoots might possibly be made to yield a profit. There is nothing to indicate the probable development of large shoots of sulphide ores.

MINES AND PROSPECTS

Albany.—The Albany property consists of three patented and four unpatented claims, not all contiguous, located largely in Dry Gulch, in sec. 23, T. 11 S., R. 4 E. It is now reached by a short branch of the Quartzville-Detroit trail and is at the end of the road that formerly connected the district with Gates. According to local reports, most of the development was undertaken between 1888 and 1893, when the Crosscut and Bonanza tunnels were driven and ore was removed from the Bonanza and milled in a small mill. Later a 10-stamp mill, operated by steam power, was installed. Stafford [95] reported 1,100 feet of tunnel and a 10-stamp mill in 1903. According to Parks and Swartley,[96] development work was done during the "past summer", presumably in 1916, by the Lincoln Mines Co. In 1925 a Chilean mill was installed, and ore was brought by cable tram from the open cut to the southeast. The mine is credited with

[95] Stafford, O. F., op. cit. (Oregon Univ. Bull. new ser., vol. 1, no. 4), p. 58.
[96] Parks, H. M., and Swartley, A. M., op. cit. (Mineral Resources of Oregon, vol. 2, no. 4), p. 141.

a production of $13,500 (653 ounces) in gold for the years 1890, 1892, and 1893 in the records of the United States Mint. The equipment includes a Chilean mill, a cable tram in disrepair, a dilapidated 10-stamp mill, two cabins, and outbuildings. A total of 1,090 feet of tunnel was accessible in 1931. The distribution of all workings except the Lincoln and Goodman is shown in figure 4, and details of all the workings are shown in plate 19.

The Crosscut tunnel penetrates the south bank of Dry Gulch a few feet above the stream bed at the cabins. It follows a zone of shearing, alteration, and some quartz veining for 444 feet in an average direction of S. 52° E. to a fork, then turns in 40 feet to a course due east for 237 feet. The last part is definitely a crosscut but intersects no veins. The other fork continues for 50 feet but leaves the shear zone on which it started. A large part of the tunnel

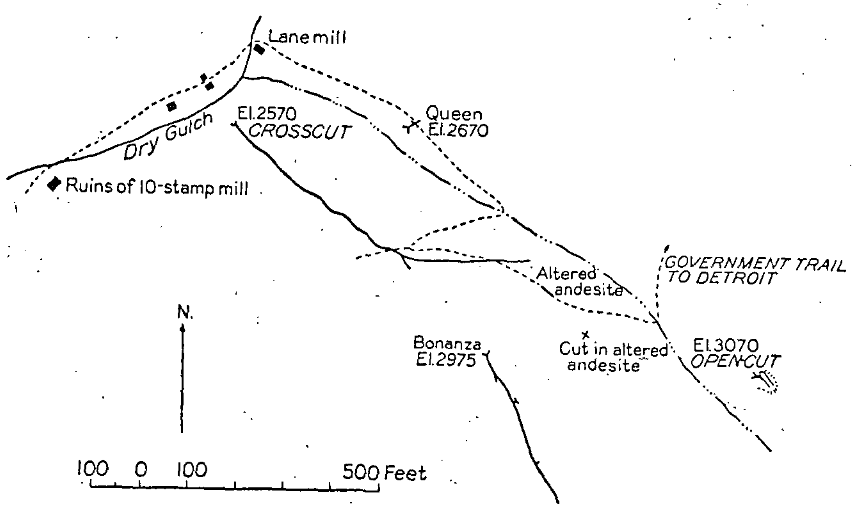
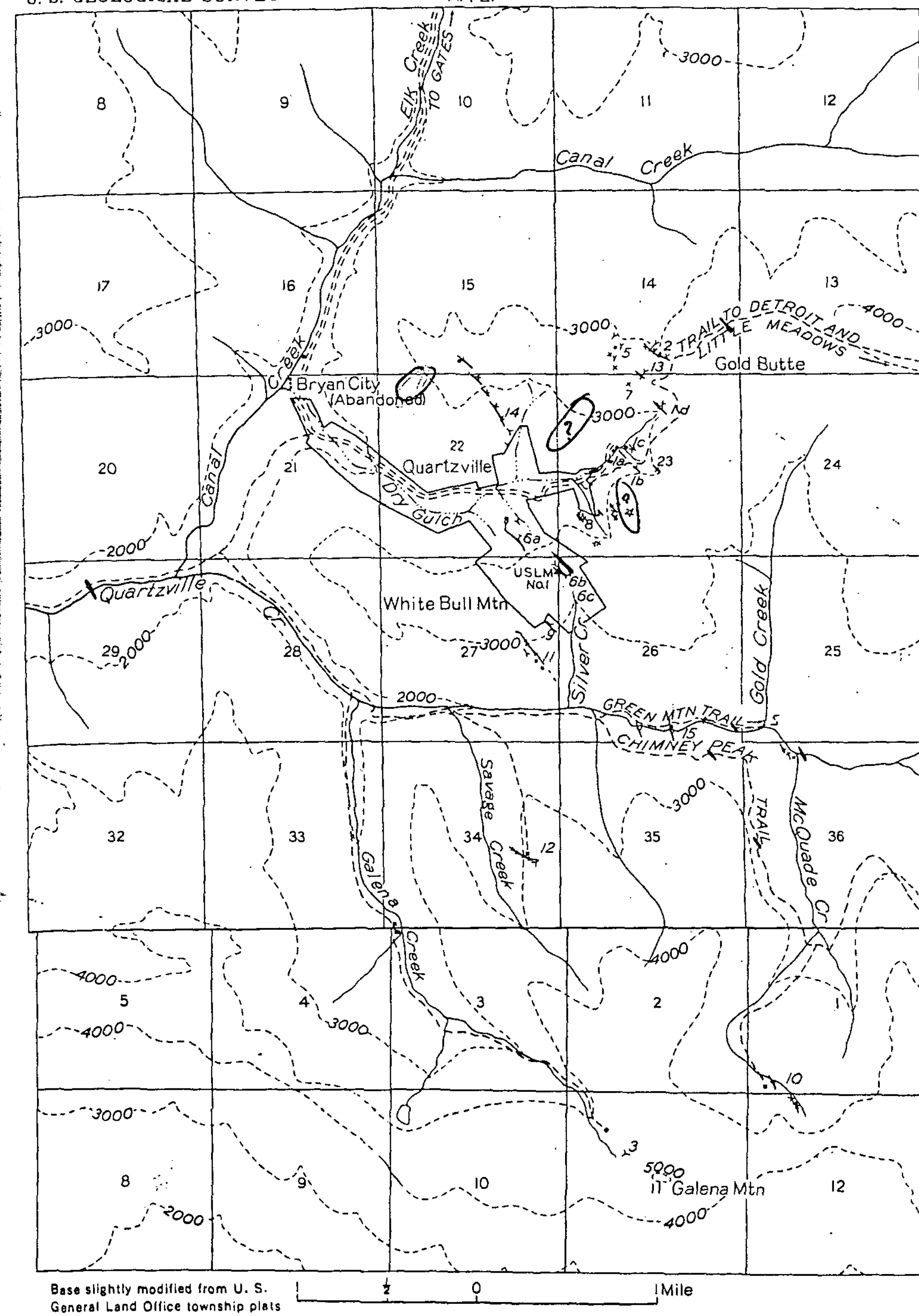


Figure 4.—Sketch showing distribution of workings on Albany claims, Quartzville district. From tape and compass traverse.

is lagged, so only a few quartz stringers and no sulphides but pyrite were seen. The country rock is rhyolite.

The Bonanza tunnel is 400 feet higher on the mountain side southeast of the Crosscut tunnel and above the Quartzville-Detroit trail. It follows a vein for 350 feet in an average direction S. 26° E. The two drifts are in line and are probably on the same vein, though the strike is different. The Bonanza drift reveals more quartz than the Crosscut, and a stope 95 feet long has been opened on the vein. Pyrite was the only sulphide seen. Most of the vein matter is weathered and leached. The country rock is largely volcanic breccia on the east side of the drift and altered andesite or rhyolite on the west side.



SKETCH MAP SHOWING APPROXIMATE LOCATION OF PROSPECTS, VEINS, AND DIORITIC INTRUSIVE BODIES, QUARTZVILLE DISTRICT, LINN COUNTY, OREGON

EXP

LIST

...0 (653 ounces) in gold for the years 1890, ...e records of the United States Mint. The equip- ...Chilean mill, a cable tram in disrepair, a dilapi- ...mill, two cabins, and outbuildings. A total of 1,090 ...as accessible in 1931. The distribution of all work- ...Lincoln and Goodman is shown in figure 4, and ...workings are shown in plate 19.

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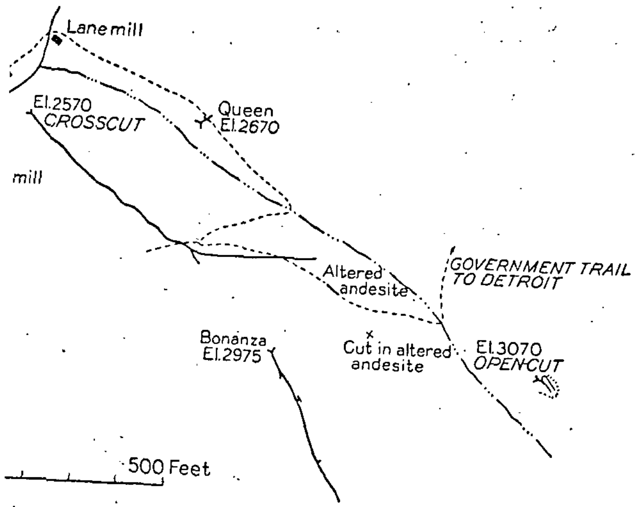

...ying distribution of workings on Albany claims, Quartzville district. From tape and compass traverse.

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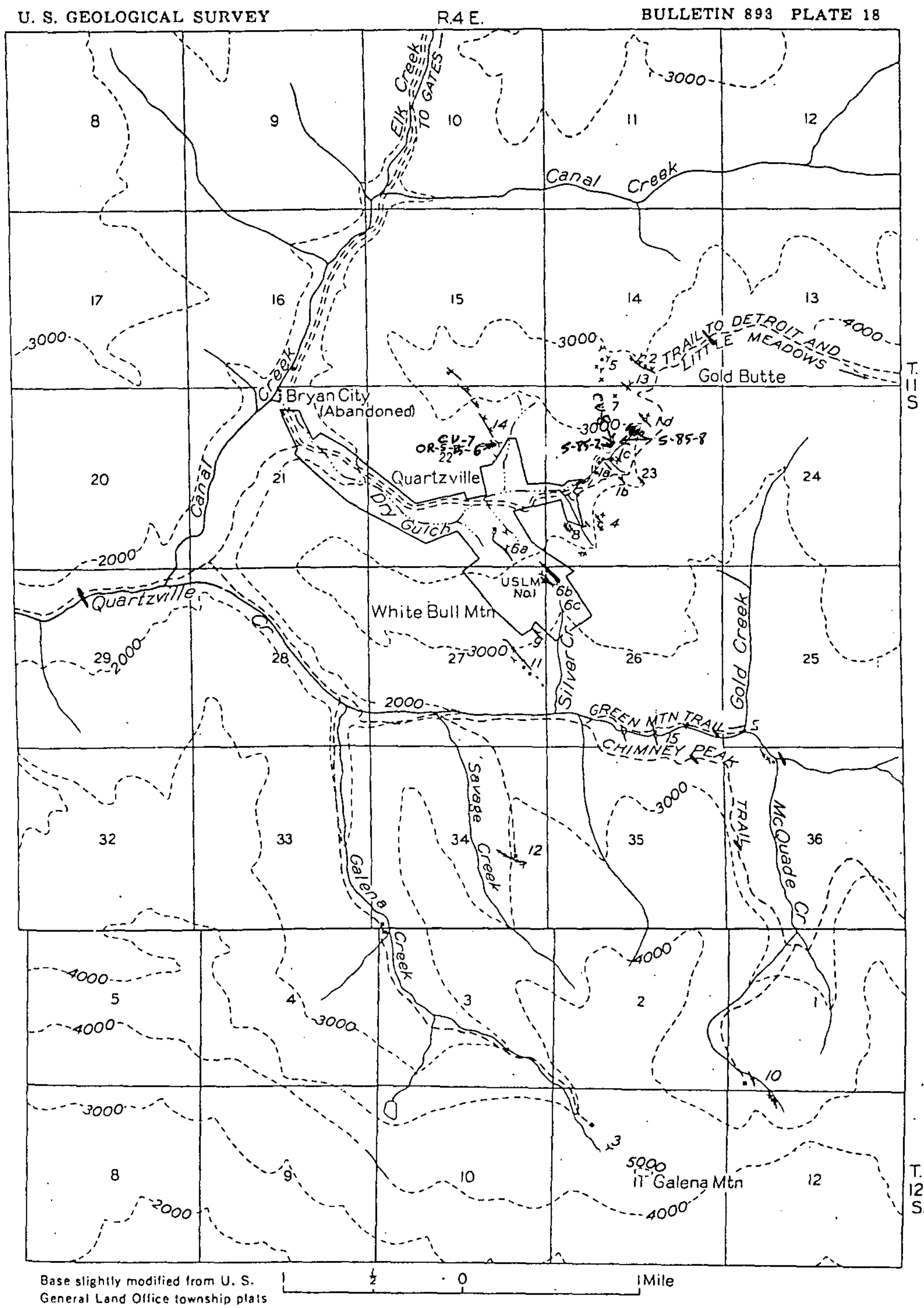
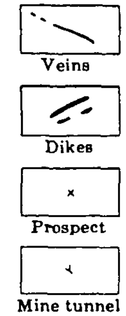


EXPLANATION

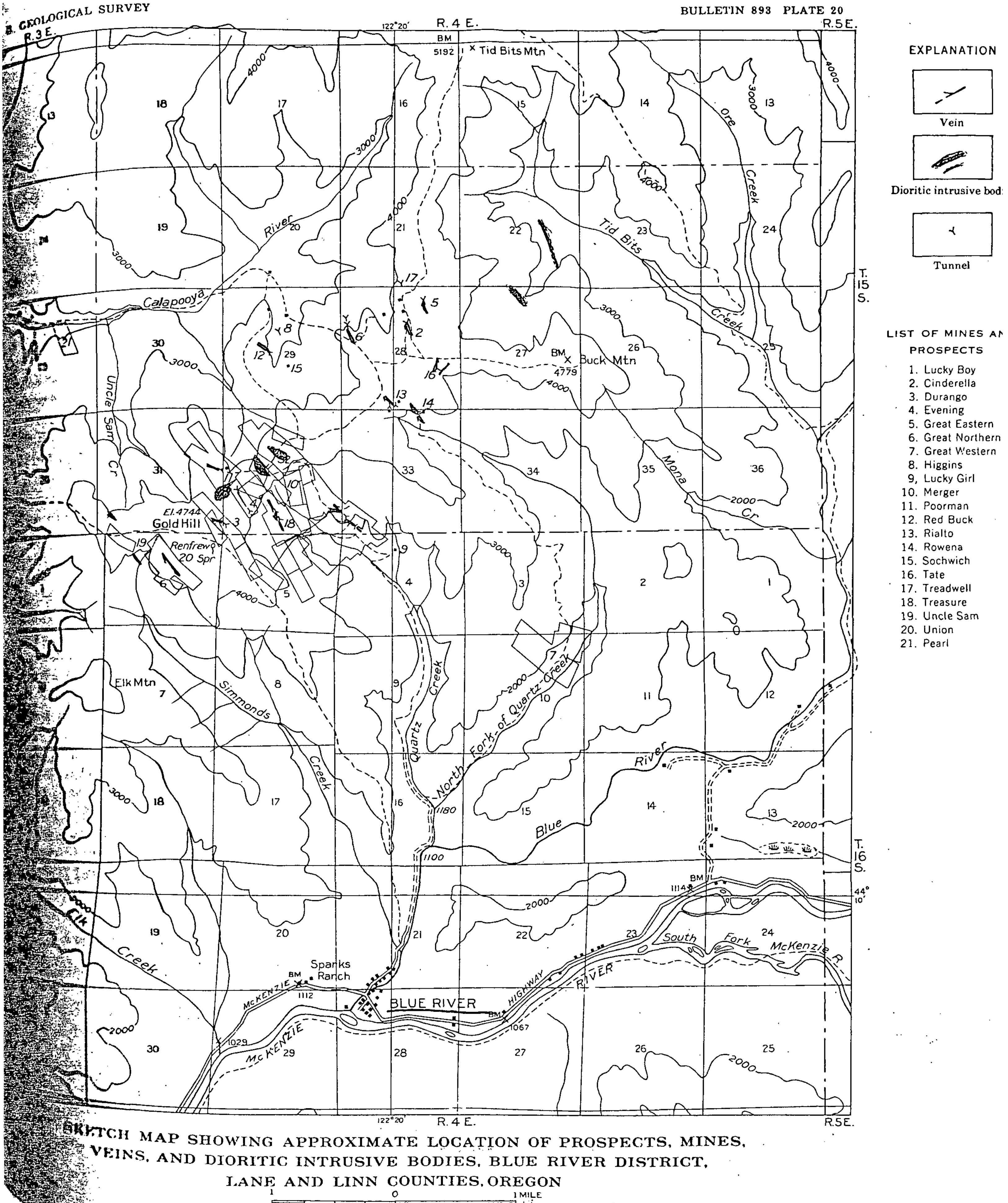


LIST OF PROSPECTS

1. Albany (mine)
   - 1a Crosscut
   - 1b Bonanza
   - 1c Queen
   - 1d Lincoln
2. Bob and Betty or Smith and McLeary
3. Galena
4. Golden Fleece
5. Hastings
6. Lawler (mine)
   - 6a Lawler
   - 6b White Bull
   - 6c Silver City
7. Mammoth Reef
8. Munro
9. Mule
10. Paymaster
11. Riverside
12. Savage or Vandalia
13. Silver Signal
14. Snowstorm or Edson
15. Winter

Enclosed area Lawler patented claims

SKETCH MAP SHOWING APPROXIMATE LOCATION OF PROSPECTS, VEINS, AND DIORITIC INTRUSIVE BODIES, QUARTZVILLE DISTRICT, LINN COUNTY, OREGON



SKETCH MAP SHOWING APPROXIMATE LOCATION OF PROSPECTS, MINES, VEINS, AND DIORITIC INTRUSIVE BODIES, BLUE RIVER DISTRICT, LANE AND LINN COUNTIES, OREGON

There are several cuts on altered rock with cherty quartz veinlets in the basin of Gold Creek at an altitude of about 3,000 feet. The trend is N. 45° W., and the zone of alteration is about 200 feet wide. Several cuts have been made in the saddle and along the trail southwest of the Silver Signal.

There are some pits in small zones of altered rock on Savage Creek south of the Savage prospect, and a zone of altered rock with quartz striking N. 55° W. occurs on the top of the ridge between Galena and Savage Creek, in the NE¼ sec. 3, T. 12 S., R. 4 E.

Some cuts have been made on altered rock on the ridge south of the Snowstorm or Edson, in sec. 22, T. 11 S., R. 4 E.

A prospect on Fourbit Creek, southwest of the Quartzville district, in sec. 34, T. 11 S., R. 3 E., is reached by trail from the main trail along Quartzville Creek. There is a good cabin, and a compressor has been installed at a cut on the bank of the creek. The vein matter consists of intersecting veinlets of pyrite and in a few places a little sphalerite with white calcite in andesite, which is bleached and altered to an aggregate of very fine grained quartz and some clay minerals. No comb quartz was observed. There appears to be no definite vein, but most of the fractures trend N. 20° W. and dip from vertical to 78° NE.

Some prospect pits have been opened in altered andesite on Elk Creek along the road to Gates.

Several placer claims have been located along Quartzville Creek. Gold is reported to be obtained from crevices in the bedrock. A large deposit of gravel known as Donica Bar, near the junction of Quartzville Creek and the Middle Santiam River, southwest of the district, has been worked at various times. According to records of the United States Mint it produced a total of $814.75 (39.4 ounces) in gold in the years 1892, 1895, and 1896.

BLUE RIVER DISTRICT

LOCATION AND ACCESSIBILITY

The Blue River district is in Lane and Linn Counties, 45 miles east of Eugene. Almost all the prospects are included in an area of about 14 square miles in Tps. 15 and 16 S., Rs. 3 and 4 E. (See pl. 20.) The Lucky Boy mine, the largest in the district, is 4½ miles north of Blue River post office, on the McKenzie Highway. A road formerly reached the mine, but only 2 miles of it could be traveled by car in 1930. A trail, formerly a road, extends from the mouth of Gate Creek, on the McKenzie River, along the divide between the McKenzie River and Calapooya River drainage systems throughout the district. Another trail follows the Calapooya River. Mines and prospects are reached by short trails from one or more of the principal trails.

SURFACE FEATURES

The conspicuous topographic feature of this district is the high divide between the drainage areas of the Calapooya River on the north and the McKenzie River on the south. (See pl. 20.) The divide, though sharp and irregular, has an average altitude of about 4,400 feet. West of the district its trend is nearly east, but within the district the trend changes to north. The difference in altitude between Gold Hill, the highest point, with an altitude of 4,744 feet, and the McKenzie River, slightly more than 4 miles away, is 3,800 feet. Consequently, the headwaters of the streams have a steep gradient, about 1,500 feet to the mile. Glaciation has modified the heads of those valleys near the summit of the divide that slope to the east or north. Most of the mines and prospects are within 1,500 feet of the summit of the divide.

GEOLOGY

VOLCANIC ROCKS

The proportions of flows and fragmental rocks appear to be about equal. Tuffs and volcanic breccias range throughout the section from Blue River to Durango Flat, which is about 200 feet below the summit of Gold Hill. Normal andesites with phenocrysts of andesine or oligoclase are more abundant than the labradorite andesites, so far as could be determined. Some have a fragmental appearance and contain streaks of chlorite. This variety is particularly prominent in the vicinity of the Great Eastern and Tate properties, in the northern part of the district. The most conspicuous flow of labradorite andesite is that on the summit of Gold Hill, where it is about 200 feet thick. Rhyolite occurs on the north side of the divide, on the headwaters of Uncle Sam and Badger Creeks. Dikes of labradorite andesite occur in tuff or volcanic breccia in crosscut 7 of the Lucky Boy mine, and a dike of hornblende andesite occurs in the main drift of the Rowena prospect.

DIORITIC INTRUSIVE ROCKS AND CONTACT METAMORPHISM

Two groups of dioritic dikes and plugs occur in the district, one north and northeast of Gold Hill and the other on the south fork of Tid Bits Creek, in the northeastern part of the district The plug of porphyritic augite diorite on the north side of Gold Hill, between the Evening and Poorman workings, is the largest intrusive body found. It was noted by Tuck.[99] Dikes of dacite porphyry crop out on the ridge to the east. One dike of moderately coarse diorite and two dikes of very fine grained diorite occur on the south fork of Tid Bits Creek.

Narrow aureoles of hornfels occur at the contacts of the intrusives. Metamorphosed tuff on the south fork of Tid Bits Creek retains its greenish-gray fragmental appearance but contains numerous nodules of loose specularite. No tourmaline hornfels was found, and the effects of contact metamorphism are not so prominent as in the other districts.

STRUCTURE

So far as could be determined, the bedding of the fragmental rocks is nearly horizontal. The flow on the summit of Gold Hill appears to have an irregular contact with the underlying rocks and to dip to the south. No faults were observed, and the amount of movement on the veins does not appear to have been sufficient to bring different types of rock into juxtaposition. Striations on vein walls are more nearly horizontal than vertical. Trends of veins range between N. 70° W. and north and average N. 40° W. The dip is 65° to vertical, mainly southwest. Elongate dioritic intrusive bodies trend toward the northwest.

MINERAL DEPOSITS

HISTORY AND PRODUCTION

The history and production of the Blue River district is largely that of the Lucky Boy mine. According to Tuck[99] the deposit on which it is located was discovered in 1887. Development was well under way in the 1890's, and the most productive period was in the early 1900's. Mills were installed at several of the mines and prospects other than the Lucky Boy, where there was a 40-stamp mill and elaborate equipment, but practically all activity ceased with the closing of the Lucky Boy in 1912 or 1913. Most of the area is patented and has lain idle, but a few prospectors have been active in the northern part of the district. The recorded production is given in the table below. Possibly the actual production prior to 1902 would increase this total by $50,000 or $100,000.

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[99] Tuck, Ralph, The geology and ore deposits of the Blue River mining district (Oregon Univ. thesis), 1927.

Production of Blue River district

[Data of V. C. Heikes]

Year	Crude ore (tons)	Concentrates (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)
1896			[1] 2.42		
1902	[2] 10,350		2,247.12	1,007	
1903	6,700		1,499.63	972	
1904	[2] 10,000		241.87		
1905	19,983		2,162.65	1,160	
1906	28,275		1,427.00	12,784	
1907	1,000		28.97		
1909	1,000		50.02	1,000	
1911	14		.53	15	
1913	85	27	53.26	216	257
1918	8		4.98	5	
1924	Sluice		9.44	3	
Total	77,415	27	7,727.89	17,162	257

[1] From U. S. Mint report. [2] Estimated.

NOTE.—Approximate values: Gold ($20.67 an ounce), $159,749.66; silver, $8.601; copper, $39; total, $168,389.66.

MINERALOGY AND TYPES OF VEINS

Only the weathered parts of many of the veins are revealed in accessible workings, but there are several workings in which the nature of the primary vein matter is apparent. One vein, the Rowena, is characterized by chalcopyrite but contains minor amounts of sphalerite and pyrite and possibly a little galena. The Great Northern vein is characterized by massive calcite and minor quantities of the sulphides. Calcite is exposed in the Higgins workings, and its former existence in the Cinderella vein is indicated by a brown powder of manganese oxide. The other veins are of the usual type, with varying amounts of the sulphides, chiefly sphalerite. Vein matter from the Lucky Boy contains small grains of tetrahedrite and considerable pyrite in addition to sphalerite, galena, and chalcopyrite. Quartz is the dominant gangue mineral, occurring as coarse crystals or as cryptocrystalline aggregates with colloform structure, as at the Durango prospect. (See pl. 8, *B*.) Adularia is more abundant in the Blue River district than in any of the other districts, and at the Tate property it makes up nearly half of the vein matter in the main drift. A little barite occurs with calcite in vein matter from the Treasure mine. Vein matter in the weathered zones is leached, but in some places films of chalcocite and covellite remain, and there are very small amounts of chrysocolla, malachite, cerusite, and anglesite and larger amounts of limonite. A brown powder of oxides of iron and manganese occurs in the weathered parts of the carbonate veins.

The veins in the Blue River district are smaller and less persistent than those in the Bohemia district. The only large ore shoot was that at the intersection of the Lucky Boy and Daisy Creek veins, a favorable location for weathering. The sulphides appear to have a

low content of the precious metals. The Lucky Boy vein has been explored by drifts for more than 1,100 feet, and the drift on the Union vein is 700 feet long. According to Parks and Swartley[1] the main drift in the Treasure mine followed the vein for 1,800 feet.

Possibly some pockets or small shoots of gold ore from the weathered parts of the veins may be found, though considerable prospecting was done in the early days of the camp. Probably moderate quantities of sulphides with a low gold content remain in the Lucky Boy mine and might be extracted when prices of base metals become sufficiently high. The discovery of large ore bodies is not anticipated, and any newly developed ore should be blocked out prior to selection and installation of milling equipment.

MINES AND PROSPECTS

Cinderella.—The Cinderella workings are in the basin on the north side of the drainage divide in sec. 28, T. 15 S., R. 4 E. Ruins of a small stamp mill remain. The vein was explored by two levels; the upper level, 40 feet above the lower, was inaccessible. A shaft extends from the surface to the lower level, which consists of a crosscut running 50 feet to the vein and a drift running 90 feet southeast, which leaves the vein but returns to it near the face. The wall rock, probably andesite, is completely altered and iron-stained. The vein matter consists of altered rock containing a band 12 to 15 inches wide of brownish-black powder that is largely manganese oxide. No sulphides remain.

Durango.—The three patented claims of the Durango group cross Gold Hill near the summit. Several pits and at least one tunnel have been opened on the southeast slope of Gold Hill. The tunnel is 130 feet long and follows a vein trending N. 61° W. and dipping 71° NE. The vein is 1 to 6 feet wide and consists of brecciated iron-stained labradorite andesite with stringers of quartz in a wider zone of altered rock. Several cuts to the southeast, in Durango Flat, expose quartz. Other veins and areas of altered rock occur on both sides of the main vein. An open cut over 30 feet wide on the northwest slope of Gold Hill reveals stringers of quartz and brecciated country rock cemented by quartz. (See pl. 8, *B*.) Most of this material is weathered and leached, but some of the solid silicified material contains disseminated fine-grained pyrite.

Evening.—Two patented claims—the Evening and Morning—cross the east peak of Gold Hill. According to Stafford[2] the vein on the Evening claim is developed by two tunnels and a shaft 50 feet deep.

[1] Parks, H. M., and Swartley, A. M., Handbook of the mining industry of Oregon: Mineral Resources of Oregon, vol. 2, no. 4, p. 224, Oregon Bur. Mines and Geology, 1916.

[2] Stafford, O. F., Mineral resources and mineral industries of Oregon: Oregon Univ. Bull., new ser., vol. 1, no. 4, p. 59, 1904.

which is followed by drifts both ways for a total distance of 700 feet. An extension of the crosscut intersects two parallel veins that in places contain about 2 inches of quartz. One of these veins has been partly stoped. The strike of the main vein is variable but averages N. 43° W., and the dip is 58°–75° SW. The country rock is black extremely fine grained andesite. The vein consists of brecciated altered rock ranging in width from a few inches to 5 feet, which in some places is cemented by quartz but in others contains stringers and lenses of quartz as much as 1 foot wide. Some of the more massive quartz fragments contain disseminated sulphides, but most of the material is thoroughly weathered and leached.

Other prospects.—Several patented claims, in addition to those described, are shown on the map but were not investigated because the workings, if such exist, could not be found.

FALL CREEK DISTRICT

LOCATION AND ACCESSIBILITY

The Fall Creek district is in Lane County, 35 miles east-southeast of Eugene. It extends from the junction of Portland and Logan Creeks to Christy Creek (fig. 7) and includes parts of Tps. 18 and 19 S., Rs. 3 and 4 E. A mountain road extends from Lowell, on the Southern Pacific Railroad, to the junction of Portland and Logan Creeks, a distance of 20 miles. From this point it is 5½ miles by trail up to the summit of Sinker Mountain and 2½ miles down the southeast slope to the Ironsides prospect. The distance from Oakridge to the Christy and Ironsides prospects is about 18 miles, of which 8 miles is road and the remainder is trail.

SURFACE FEATURES

The surface is very rugged, and nearly all slopes are steep. The principal features are Alpine Ridge, which extends northeastward through the district, and Sinker Mountain, at an altitude of 4,752 feet, from which four high ridges radiate. The relief within a distance of 4 miles is 3,400 feet.

GEOLOGY

Most of the rocks are tuffs and volcanic breccias, which are especially prominent in the Portland Creek Basin. Volcanic necks and dikes of dark fine-grained labradorite andesite project through the fragmental rocks. Some of these are shown in figure 7. Flows of normal andesite and labradorite andesite occur at many places in the district. A labradorite andesite on Gold Point has a schistose appearance because of the perfection of the flowage orientation. Andesite flows occur on Nevergo Creek and in the vicinity of the prospects

southeast of Sinker Mountain. A remnant of an olivine basalt flow lies in the area between Perdue and Christy Creeks. It belongs to the large group of flows that once filled most of the valley of the North Fork.

On Portland Creek 2.1 miles above its confluence with Fall Creek is a plug or dike of dacite porphyry that trends N. 35° W. A dike

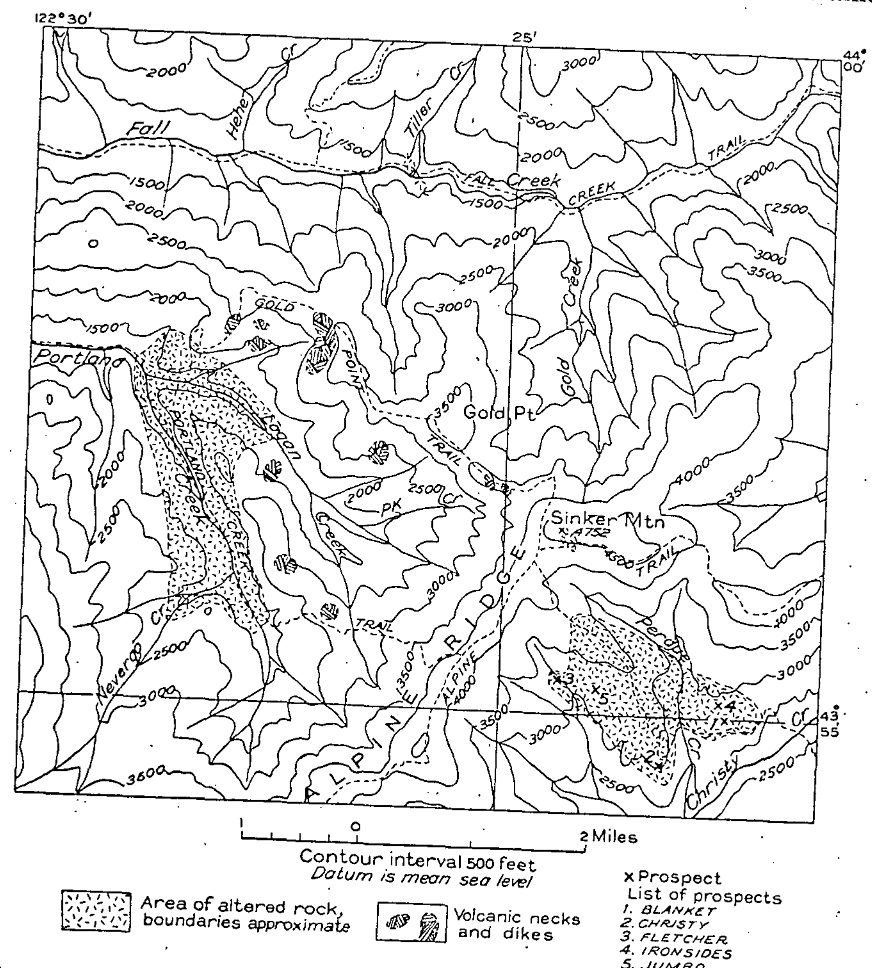


FIGURE 7.—Sketch map of Fall Creek district, Lane County. Base from Geological Survey map of Waldo Lake quadrangle.

of augite diorite occurs at the Jumbo, and at the contact of the dacite porphyry is a zone of spotted hornfels 10 feet wide.

So far as could be determined there has been little tilting or deformation in this area. Volcanic breccia was observed to dip away from one of the volcanic necks. Finely laminated tuff on Portland Creek strikes N. 60° W. and dips 10°–20° NE. Silicified zones in the vicinity of Nevergo Creek trend N. 70° W.

MINERAL DEPOSITS

According to a note by Dodwell and Rixon,[7] the deposit was discovered "last summer", presumably 1901. Stafford [8] mentions the district as being actively prospected in 1903. Apparently little was done after the initial prospecting, though the Ironsides has been operated on a very small scale for several years, and the Blanket claim nearby was being prospected in 1931. No production is recorded.

There are two large areas of altered rock and many smaller ones in the district (fig. 7). One extends from a point a short distance below the confluence of Logan and Portland Creeks 1½ miles up Logan Creek, 2½ miles up Portland Creek, and an undetermined distance up Nevergo Creek. The other large area includes most of the prospects and occupies the ridge between Perdue Creek and the creek to the south. There are smaller areas on Sinker Mountain, along the Alpine trail to the southwest, and a zone 15 feet wide trending N. 40° W. at the junction of Tiller and Fall Creeks. Most of the material in this zone is bleached or iron-stained and contains disseminated pyrite in the unweathered parts.

The mineral deposits in this district are of low grade and consist (1) of zones without definite veinlike appearance in weathered altered rock which, according to prospectors, yields a little gold on panning; (2) of silicified zones in altered rock that apparently do not yield any appreciable gold; and (3) of veins in altered rock with stringers of quartz in comb or cockade structure. Only leached vein matter was found on the dumps of caved workings, and pyrite was the only sulphide seen. No appreciable production is expected in this area.

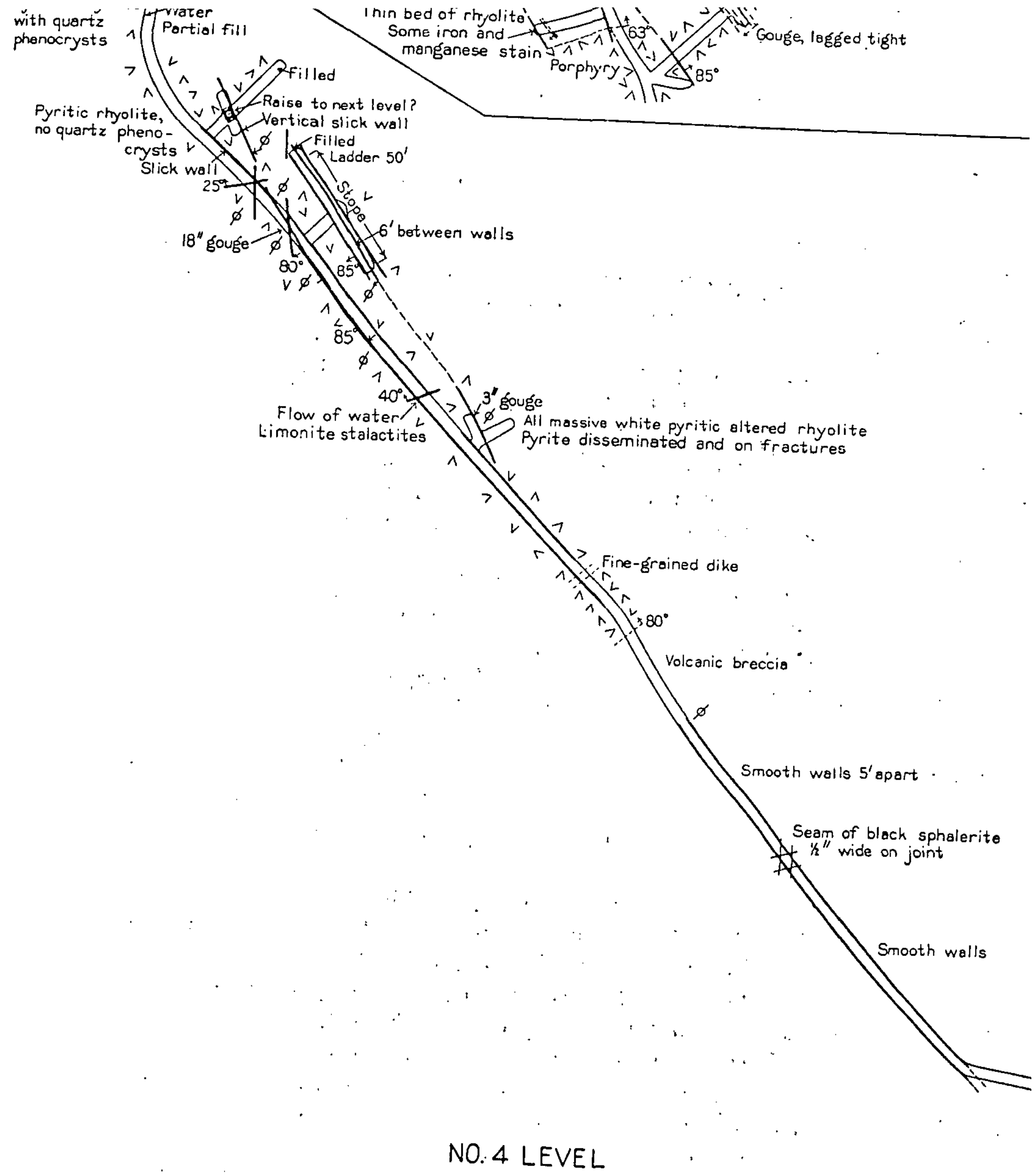
PROSPECTS

Blanket.—The Blanket claim lies southeast of the Ironsides prospect, about half a mile east of Perdue Creek, on a moderate southerly slope. It was being prospected in 1931. Numerous trenches and pits were excavated in deeply weathered iron-stained coarse volcanic breccia. No definite vein was observed, though one fracture was found to trend N. 10° W. The owner stated that he had discovered two zones with this same trend that yielded more gold on panning than the remainder of the rock. The gold content is very low.

Christy.—The Christy prospect is on the south side of the point of the ridge between Perdue Creek and the creek to the south and

[7] Langille, H. D., Plummer, F. G., Dodwell, Arthur, Rixon, T. F., and Leiberg, J. B., Forest conditions in the Cascade Forest Reserve, Oreg.: U. S. Geol. Survey Prof. Paper 9, p. 152, 1903.

[8] Stafford, O. F., Mineral resources and mineral industries of Oregon: Oregon Univ. Bull., new ser., vol. 1, no. 4, p. 61, 1904.



SKETCHES OF LEVELS OF BUZZARD MINE,
From compass and tape traverse except crosscut to drift 4, which

United States location monument. Some prospects are reported to occur on Nevergo Creek, but only altered rock and an outcrop of resistant silicified tuff trending N. 70° W. was found on the creek in the east side of sec. 8, T. 19 S., R. 3 E. Prospect pits in altered rock occur along the Alpine trail on Sinker Mountain, a short distance east of the line between secs. 11 and 12, T. 19 S., R. 3 E. Some pits in yellowish tuff occur along the Portland Creek trail three-quarters of a mile southeast of the mouth of Nevergo Creek.

OAKRIDGE AREA

The area surrounding the confluence of the North Fork and Middle Fork of the Willamette River west of Oakridge is of interest because of extensive alteration of the country rock, though there are no mines or large prospects. No sulphides other than pyrite were observed, and no gold is known to have been obtained. The country is rugged with the exception of the bench known as High Prairie, which lies along the east side of the North Fork, nearly 1,000 feet above the river, and a few remnants at a corresponding altitude. These surfaces are on a valley flow of olivine basalt that is younger than the altered rocks. The older rocks include rhyolite, andesite, tuff, and volcanic breccia. An outcrop of bedded tuff at Westfir exhibits a group of small faults. It varies in dip and strike, though the dominant trend is N. 40° W. and the dip 15° SW.

An outcrop of resistant silicified rock trending N. 40° W. occurs on the east side of the valley of the North Fork about 1½ miles northeast of Westfir. Another similar zone, striking roughly N. 65° W. and dipping 85° SW., occurs on the same side of the valley about half a mile northeast of Westfir. Here tuff is altered to an aggregate of clay minerals and cherty quartz, and vugs are filled with crystals of barite averaging about 1 centimeter in length. A group of pits on a steep hillside about 600 feet above the south bank of the Middle Fork at Black Canyon, near the southwest corner of sec. 27, T. 20 S., R. 2 E., prospect a vein that strikes approximately N. 70° W. and dips 60° S. The vein is largely a seam in altered tuff, but it contains a small lens of dark, extremely hard cherty quartz that has been brecciated and cemented with comb quartz. No pyrite occurs in the coarse quartz, but it is both disseminated and in bands in the cherty quartz, which shows a colloform structure under the microscope. No appreciable production is expected in this area.

ZINC AREA

An isolated prospect on the South Umpqua River between Straight and Boulder Creeks, in sec. 23, T. 29 S., R. 1 W., and 13.3 miles by road east of the bridge at Tiller, in Douglas County, is known locally as the Zinc mine. Drifts penetrate both banks of the river slightly above the stream. The country rock is volcanic breccia that has been cut by two dikes of augite diorite, each about 150 feet wide and 200 feet apart. They lie on both sides of the vein on the north bank of the river and strike about N. 20° W., though the vein, judged from an altered zone in the road, strikes N. 60° W.

The vein matter on the dump is chiefly altered volcanic breccia containing disseminated pyrite and composed largely of ankerite and clay minerals. Sphalerite occurs as irregular lenses associated with pyrite and galena. Some sphalerite contains blebs of galena and chalcopyrite visible only with the aid of the microscope. Calcite and marcasite are associated in vugs. Some of the calcite is black because of finely divided pyrite. No coarse quartz was observed, and there appears to have been little, if any, silicification. The precious-metal content is not known, but it is expected that the amount of any ore developed will be small.

BUZZARD AREA

The Buzzard mine is in northeastern Jackson County, and the 10 claims constituting the property are in secs. 19, 20, and 29, T. 31 S., R. 2 E. It is about 47 miles from Medford and 20 miles from the Crater Lake Highway at the mouth of Elk Creek. The first 11 miles of the Elk Creek road, which serves the Buzzard area, is surfaced, but the remainder is unimproved, and the last 5 miles is very steep.

The mine is on a heavily timbered ridge trending nearly north in rugged country near the divide between the drainage systems of the Rogue and Umpqua Rivers, on the headwaters of Elk Creek. The ridge is 4,000 feet in altitude, according to aneroid measurement, and slopes toward the south; the ravine on the east side is about 700 feet below the summit, and that on the west side is about 300 feet below the summit.

The rocks exposed in the mine workings are volcanic breccias and dikes of rhyolite and andesite, all altered and bleached. The vein appears to be near the center of a large area of altered rocks. Fragmental rocks appear to be dominant both in the vicinity of the mine and along the road to the south, though flows of rhyolite, andesite, and labradorite andesite occur. No dioritic intrusive rocks were found.

No evidence of folding or tilting was seen in the mine, as no bedding was revealed. Outcrops in the valley of Elk Creek suggest that the region has been only slightly deformed. The strike of the vein on which almost all the work has been done is N. 40° W., and the dip is vertical to 85° E. Most of the dikes trend to the northwest.

Gold was discovered in Elk Creek below the mine, and the ...

were located in 1897 by Peter and Mark Applegate, according to the latter. The Pearl Mining Co. was incorporated in 1898, but the first ore was not shipped until 1909. W. L. Freres, under an option, shipped ore in 1912 and 1913, and the Pearl Mining Co. was active in 1914 and 1915. The mine was leased in 1916 to Paul Wright, who drove tunnel 4 on the east side of the ridge and shipped considerable ore. The total production, 1909–18, was nearly $24,000, chiefly in gold, but it included some silver and lead.

According to the owners, the mine workings consist of 3,334 feet of drifts and crosscuts, 1,000 feet of raises and winzes, and 75 feet of open cuts and trenches. About 3,200 feet of drifts and crosscuts (pl. 22) were accessible, but only a few of the raises and winzes were examined. Levels 1, 2, and 4 reach the vein and expose it for lengths of 430 feet, 160 feet, and 720 feet, respectively. Small stopes were opened on all these levels. The difference in altitude between level 4 and the summit of the ridge is about 500 feet.

The vein matter consists chiefly of altered rock, gouge seams, very little cherty quartz, and no comb quartz, and contains streaks and lenses of sulphides, chiefly sphalerite, and smaller amounts of pyrite and galena. Chalcopyrite was observed only with the aid of the microscope as blebs in sphalerite (pl. 6, *A*). Arsenopyrite was found in a small seam on level 1. Sphalerite occurs as black crystals and aggregates ranging in size from a fraction of a millimeter to more than an inch. The occurrence of sulphide veinlets without quartz in altered rock is very different from that of the quartz veins characteristic of the larger districts. The original nature of the gold in the main vein is not known to the writers, but the specimen of dendritic gold shown in plate 3 was obtained, according to the owner, from a small lens or pipe, called level 6, which is 360 feet northeast of the main vein (pl. 22). Wire gold was also reported to have been found in a small pocket here, associated with manganese oxide and with sphalerite and pyrite nearby.

Apparently the veins shown in plate 22 are the only ones found up to the present time, though it seems possible that so large an area of altered rock might contain similar veins. No large production is anticipated.

GRAND COVE AREA

The Grand Cove prospect, in Jackson County, reveals native copper as nodules in volcanic breccia between vesicular flows of dark labradorite andesite or basalt without any vein or any indications of sulphides. It thus differs markedly from the mineral deposits previously described. The seven claims of the property comprise parts of secs. 29, 32, 33, and 35, T. 35 S., R. 2 E., 5 miles north of Lakecreek, on an open gently sloping upland bench. The distance by road from Medford, by way of Brownsboro and Salt Creek, is 26 miles. The 1½ miles nearest the prospect could not be traveled by car in 1931.

The workings consist of an open cut 60 feet long with a maximum depth of 10 feet and a shaft reported to be 30 feet deep on a gently sloping open bench at an altitude of nearly 2,900 feet. The deposit was discovered in 1917 by L. A. Obenchain, the owner, while searching for manganese. A carload of ore is said to have been shipped to the Tacoma smelter, but no data on the shipment are available.

The copper is confined to volcanic breccia associated with vesicular black labradorite andesite or basalt that is nearly horizontal but dips slightly to the west at the prospect. The flow rock contains red spots that are iddingsite pseudomorphs after olivine and calcite amygdules that are stained greenish near the rock. The breccia is largely altered to clay minerals and contains little greenish spots and veinlets consisting mainly of chrysocolla with a little malachite and very little azurite. Limonite and some manganese oxide occur in irregular black spots and fracture fillings through the altered rock. The copper occurs in dendritic form in nodules, some of which are 6 inches long. The copper is partly changed to cuprite (pl. 7, *B*), which is in turn surrounded by opal and chalcedony, with small amounts of chrysocolla and malachite. Openings are partly filled with the chocolate-colored clay mineral beidellite.

Prospecting has not been sufficient to reveal the full extent of the deposit. The copper ore appears to be very erratic in its distribution.

CLIMAX AREA

Large areas of altered tuff and a vein of aragonite occur in the vicinity of Climax, on the headwaters of Antelope Creek, nearly 8 miles in a direct line northeast of Ashland, in Jackson County. Climax is reached by an unimproved road that follows Antelope Creek.

The aragonite vein is on a steep slope on the east side of the valley at Climax, in a coarse volcanic breccia. The vein is vertical and strikes N. 60°–70° W. It has been traced for several hundred feet and consists of irregular lenses of aragonite, some containing fragments of country rock and irregular small masses of chalcedony surrounding vugs or geodes lined with quartz crystals. Fragments of country rock are surrounded by calcite, rarely over 2 millimeters thick, from which the coarse acicular crystals of aragonite radiate. No sulphides were found, and no precious metals are known to occur.

Volcanic tuff and breccia over 1 mile west of Climax are changed to a soft brown and white aggregate of clay minerals and an isotropic substance, possibly a form of opal. Oxidation of disseminated pyrite has led to the formation of numerous crystals and crusts of gypsum. The altered tuff is leached by a secret process devised by one of the local residents to make a medicine.

Rhyolite underlying the oil shale in secs. 9 and 16, T. 38 S., R. 2 E., is bleached and contains chalcedony in openings.

BARRON AREA

The Barron mine is in Jackson County, nearly 8 miles in a direct line east-southeast of Ashland, and the property consists of three 40-acre tracts in sec. 23, T. 39 S., R. 2 E. It is reached by a steep mountain road 3 miles in length from the Green Springs Highway. The mine is in a gulch that slopes toward the valley of Sampson Creek at an altitude of 3,400 feet, or 1,200 feet above Emigrant Creek. The mountain slopes are open rather than thickly forested as in most of the other mineralized areas.

The country rocks are chiefly coarse andesite breccias, but there are flows and dikes of labradorite andesite, some basalt, and some rhyolite on the slope above the mine. A dike of dacite porphyry trending N. 30° W. is exposed in Sampson Creek over a mile south of the mine; the trend changes locally to N. 5° E. on the ridge north of the creek.

The breccias do not show bedding, and few data on structure could be obtained. A thin flow exposed in the crosscut strikes N. 52° W. and dips 16° NE. Observations at other points indicate that the regional strike is near N. 40° W. and the dip 10°–20° NE. Dikes in the mine strike north, N. 40° W., and N. 60° W., and dip both east and west. The belt of altered rock in which the vein lies strikes N. 40° W., and the vein has an average strike of N. 38° W. and dips variably but averages 80° NE.

The early history of the property has been lost. It is reported to have been patented on grazing rights in 1883, acquired by the Barron family in 1885, and held by them until recently. The Gold Mound Co. was renovating the plant in 1931. So far as could be learned the production, largely since 1917, has been about $9,000. According to an engineer's report, 59 tons was milled at the old Ashland mill, yielding $518, and later H. J. Sallee under lease shipped the ore recorded below. The main level is reached by a crosscut 390 feet long. The drift is 300 feet from the portal of the crosscut and 150 feet below the outcrop of the vein. Drifts follow the vein irregularly 175 feet N. 36° W. to a cave-in and 160 feet S. 38° E. A winze 15 feet from the crosscut is reported to be 35 feet deep with a drift 20 feet long at the bottom. A raise 25 feet northwest of the crosscut extends to the surface. Three short drifts extend from the raise, and two stopes lie south of the raise. The largest stope extends down 60 feet

from the surface. The equipment includes a 10-stamp mill engine, crusher, Wilfley table, and two slimers, track, and cabins in good condition.

Smelter returns from Barron mine, 1917–18

[From report by J. Carlton McDonald]

Ore (tons)	Gold		Silver (ounces)	Value per ton	Value of shipment
	Value	Ounces			
52	$15.01	0.73	20.11	$31.12	$1,618.24
15	66.31	3.20	34.11	100.42	1,506.30
39	5.31	.25	6.66	11.97	466.83
9	41.23	1.99	42.80	84.03	756.27
44	7.79	.36	13.08	20.87	918.28
43	11.78	.57	13.64	25.42	1,093.06
3	57.38	2.76	69.11	126.49	379.47
Total value					6,738.45

The vein, as shown on the lower level, consists of a series of branching and intersecting fractures, some of which are filled with gouge, some with fragments of altered rock, and some with altered rock cemented by cherty quartz, which in places contains sulphides. Comb quartz is inconspicuous. The vein is over 10 feet wide at the crosscut but pinches to 1 or 2 feet both to the northwest and to the southeast. This is essentially the lower limit of the ore shoot that has been partly stoped. An open cut reveals 40 feet of altered rock between the main vein and one lying to the west. Sulphides exposed in the drift occur in small stringers and consist chiefly of sphalerite with a little galena, chalcopyrite, pyrite, and arsenopyrite. Winchell[9] mentions in addition stibnite, malachite, wire silver, realgar, and probable pyrargyrite. Altered rock consisting chiefly of clay minerals and a little sericite and carbonate, cherty quartz, calcite, and a little barite occurs with the sulphides. Most of the gold has been obtained from the leached and iron-stained vein matter, and leaching has extended to the main level, though it has not been complete.

According to an engineer's report, assays in the upper workings range from $6.42 to $13.77 to the ton in gold and silver, with gold valued at $20.67 an ounce, for widths of 3½ to 12 feet. An assay on the south end of the stope just above the main drift shows minerals valued at $20.34 to the ton for 7 feet, and opposite it in the raise an assay shows $1.42 to the ton for 4 feet. An assay of 4 feet of the face of the south drift yielded 90 cents to the ton, but assays just

[9] Winchell, A. N., Petrology and mineral resources of Jackson and Josephine Counties, Oreg.: Mineral Resources of Oregon, vol. 1, no. 5, p. 123, Oregon Bur. Mines and Geology, 1914.

Energy

GEOTHERMAL

DOE/ET/27014-T17
(DE84012547)

TARGETING GEOTHERMAL EXPLORATION SITES IN THE MOUNT ST. HELENS AREA USING SOIL MERCURY SURVEYS

Open File Report 83-10

By
Jenny Holmes
Kathleen Waugh

November 1983

Work Performed Under Contract No. AC07-79ET27014

Washington Department of Natural Resources
Division of Geology and Earth Resources
Olympia, Washington

Technical Information Center
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Raymond Lasmanis, State Geologist

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INTRODUCTION

The measurement of levels of mercury in soil has been found to be useful in locating areas with high geothermal gradients (Matlick and Buseck, 1976; Phelps and Buseck, 1978). It has been shown that soils overlying geothermal areas are generally enriched in Hg which has absorbed onto organic and organometallic compounds and clays. This enrichment occurs because higher temperatures near a geothermal reservoir tend to increase the mobility of Hg with its high vapor pressure. The Hg comes from hydrothermal alteration or weathering of small amounts of sulfides containing trace amounts of Hg. Analysis of soil for mercury content in order to locate geothermal sites has been found to be particularly useful in areas which, like those discussed in this paper, may have few surface manifestations of geothermal activity. In this study, high-sensitivity measurements of soil samples were made in areas centered around features suggestive of geothermal activity near Mount St. Helens, including suspected fault zones, a mineral spring, and Pleistocene volcanic centers, in an effort to target areas for heat flow drill holes.

AREA STUDIED

Mount St. Helens has long been suspected to be a promising geothermal area. The May 18, 1980 eruption and subsequent eruptions attest to the presence of a magmatic heat source relatively close to the surface in the Mount St. Helens area. Seismic activity around the mountain indicates the presence of a fault zone, though a surface expression has yet to be identified. Post-May 18 seismic patterns have more sharply delineated this fault zone. These seismic patterns indicated two major faults (see figure 1): a 35-km-long right-lateral strike-slip (?) fault with north-northwest striking fault planes north of Mount St. Helens, and, south-southeast of the

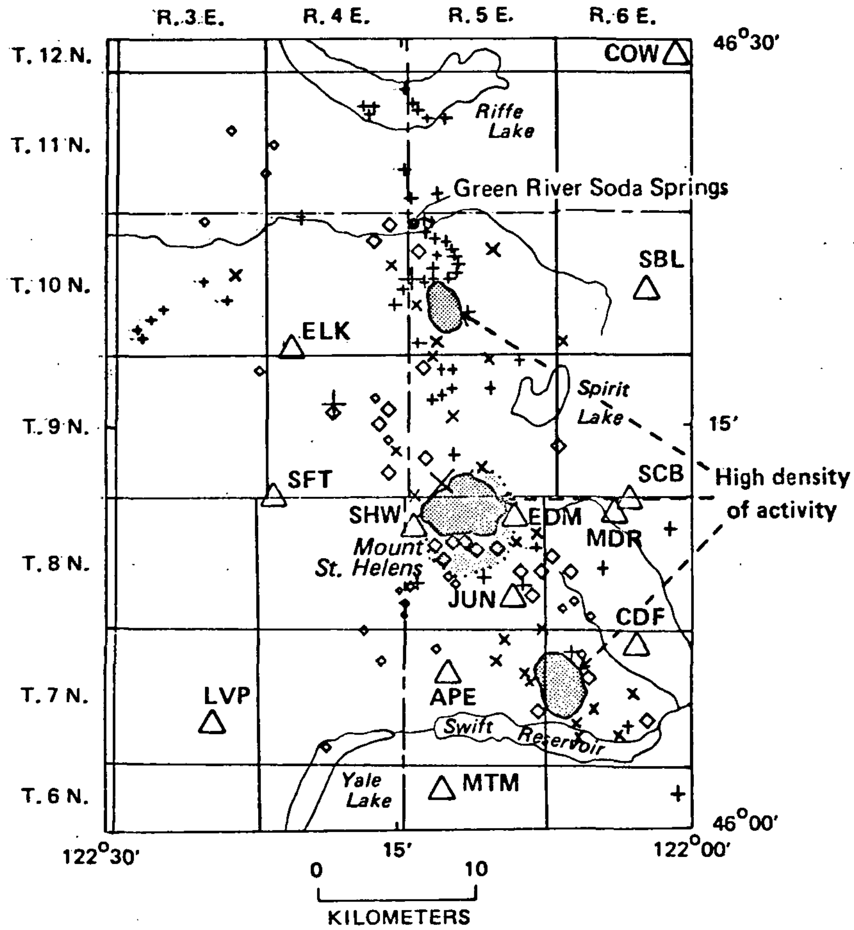

Figure 1. – Composite seismicity pattern from May 18 to August 31, 1980. Triangles, seismic stations. Symbol size indicates magnitude: small symbols, events with magnitudes less than 2.8; large symbols, events with magnitudes greater than 2.8. Depth indicated as follows: +, 0-5 km; x, 5-10 km; square, 10-15 km; diamond, greater than 15 km. (from Weaver and others, 1981).

mountain, a 20-km-long right-lateral strike-slip fault striking N 25 W (Weaver and others, 1981). An active fault zone could have a close connection with volcanic activity and might provide opportunities for circulation of fluids down to a volcanic heat source. If this fault system is open, the soil above the faults should contain anomalous amounts of Hg. A method of targeting high heat-flow areas for drilling along this fault zone has been of interest for those involved in assessing the geothermal potential of the Mount St. Helens area. Lack of surface manifestations of geothermal systems and a "cold meteoric water blanket" which may cool and mask geothermal waters result in the lack of specific targets for geothermal drilling (Korosec and others, 1980). Other investigators have questioned whether the "cold water blanket" prevents Hg anomalies in the soil, either by lateral transport and removal of Hg or by slowing the upward migration of the volatile Hg at depth, where the cool water dilutes the geothermal fluids. This method has not been extensively used in the Cascades or areas with similar climatic, vegetative, geomorphic, and pedalogical conditions. Thus another purpose of the study was to assess the applicability of the soil-mercury exploration method for the Cascades and similar areas.

Two sampling areas north and south of the mountain were selected because of features possibly indicative of geothermal activity (see figure 2). An area of about 100 square kilometers, located within Range 4 and 5 East, and Township 10 and 11 North, in the Green River drainage north of the mountain, was selected because of seismic patterns indicating an active fault zone, and the presence of a low-temperature mineral thermal spring (Green River Soda Springs) in a marshy area north of the river. Small springs or seeps were found during the survey on the south side of the river across from Green River Soda Springs. A fracture zone is probably responsible, in part, for the existence of these springs. The CO_2-rich waters of Green River Soda

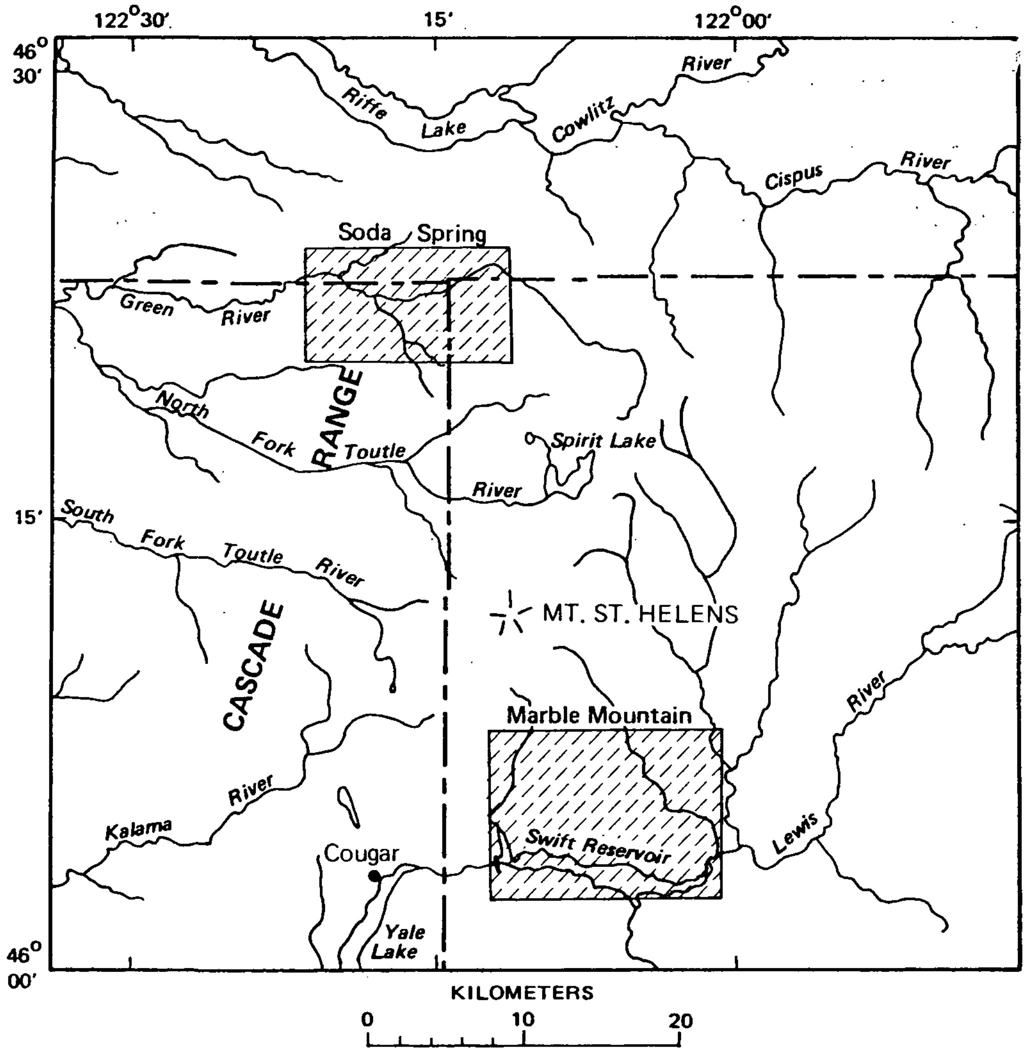

Figure 2. — Location of study areas

Springs, relatively high in lithium and boron, may be the result of circulation of water in close proximity to a magmatic heat source (Korosec, personal communication 1983). The Green River site was almost entirely within the blow-down and singe zones created by the May 18 blast. The area has been extensively logged in the past, and post-eruption salvage operations have taken place in much of the area. Generally, soils on the north side of the valley were thinner than on the south side. Ash covered all the sample sites at depths ranging from 4 to 18 cm. The bedrock of the area consists of primarily volcanic breccias of the Oligocene Ohanapecosh Formation.

The second site is a 150 square kilometer area south of Mount St. Helens surrounding Marble Mountain. The area was selected because of the presence of Quaternary volcanic centers and an andesite flow with a K-Ar date of 160,000 years (Hammond, personal communication, 1983) and seismic patterns indicative of a fault on the southeast side of Marble Mountain. A light cover of pumice and ash from the recent eruptions of Mount St. Helens was present in much of the study area. Almost every hole dug disclosed a layer of pumice at about the 10- to 15-cm level below the organic horizon. This layer of pumice may be set W or X of the Kalama Eruptive Period of 350 to 450 years ago, during which tephra was erupted and pyroclastic flows moved down the south flank of the volcano. Both sets include phenocrysts of hypersthene and hornblende (Mullineaux and Crandell, 1981; Mullineaux and others, 1975).

SAMPLING AND ANALYTICAL METHODS

Sample stations were spaced along existing logging roads at two different distance intervals. The Soda Springs area was about 100 square kilometers, inside which a smaller area of about 36 square kilometers was designated. Similarly, the Marble Mountain section covered about 150 square kilometers, inside which was selected a smaller area of about 70 square kilometers. In each case, samples were collected every 0.32 kilometers inside the smaller area, with a station spacing of 0.8 km for the rest of the study areas. The smaller area in each case was considered to be more likely to yield anomalies, and so was sampled more intensively.

Sample sites were chosen that were at least 10 meters from the road. Care was taken to find sites that were on relatively level ground (to avoid distortions due to hydrology and horizontal migration), and that were as undisturbed as possible by logging, trails, or other activity.

Soil samples were taken from the A horizon from within the 10-15 cm depth interval, measured from the bottom of the obvious organic horizon. The A horizon was selected since it has been shown to have a higher concentration of Hg than the B and C horizons (Jonasson and Boyle 1972), probably because it contains a greater amount of organic material to retain the Hg. To sample the soil, a stainless steel spoon was used to tunnel into the side of a pit (dug with a shovel) to be sure that organic material falling from above would not contaminate the sample. The sample was scraped from the entire 5 cm interval between the 10 and 15 cm depth, and immediately transferred to a plastic bag and sealed. Samples were air-dried in the lab. When completely dry, the samples were sieved using a 100-mesh sieve and transferred to air-tight glass vials.

A Jerome Instruments 301 mercury detector was used to determine relative concentrations of mercury in the soil samples employing the low-temperature method. The instrument has an absolute sensitivity of better than 0.05 ppb mercury. A volumetric scoop was used to measure approximately 0.1 g of soil (soil density was assumed to be 1.1 g/cm3) which was placed into a glass bulb on a hot plate at 290°C. The soil was heated for one minute to volatilize a standard fraction of the mercury. The mercury vapor is collected on a gold film. The difference between the electrical resistance of the sensor film (on which the Hg is collected) and the reference film are digitally displayed as a number proportional to Hg concentration.

RESULTS AND DISCUSSION

During the Spring of 1983, a total of 269 soil samples were taken from both survey areas; 101 from the Marble Mountain area, and 168 from the Soda Springs area. The background level of Hg in the soil was calculated as the mean for each area (see figure 3 and Appendix A). Anomalous values were defined as those which exceeded two standard deviations above the mean, as was done in previous studies (Phelps and Buseck 1978). Hg concentrations in both areas appeared to have log-normal distributions (see Appendix B). The samples from the Soda Springs area had a mean of 60 ppb with a standard deviation of 28. The mean for the Marble Mountain area was 48 ppb with a standard deviation of 24. Thus the threshold level for the Soda Springs area was considered to be 116 ppb, and for the Marble Mountain area 96 ppb (see figure 3).

Statistically anomalous values of Hg generally appeared to be erratically distributed in the areas. No prominent Hg haloes could be discerned, though in both areas there appear to be clusters of stations with relatively higher values which include several statistically anomalous mercury concentrations. More intensive sampling is warranted around these clusters within the sampling areas.

Soil intervals that show the greatest variation in Hg are most favorable for Hg surveys. Most researchers determine an appropriate depth of sampling using analysis of variance in test pit profiles. Some have found a consistent increase in Hg with depth (Hadden and others, 1981). Others have noted just

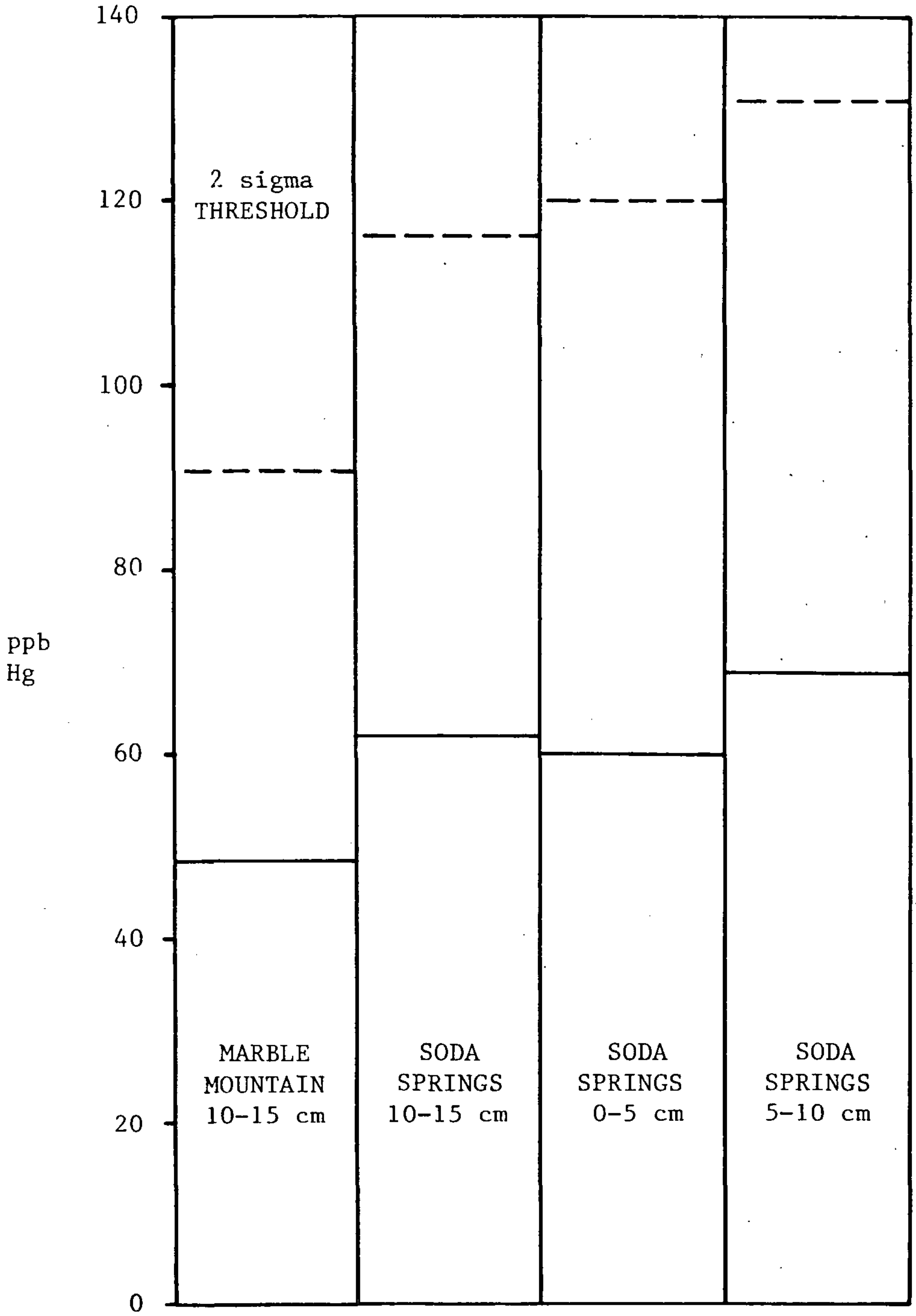

Figure 3. Background Hg levels for soils of both study areas and different depth intervals from the Soda Springs area. Two standard deviations above the mean are represented by the dashed lines.

the opposite (Korosec, personal communication, 1983). For the first 33 holes, 10-15, 5-10, and some 0-5cm depth intervals were sampled to determine if there was a similar trend. A definite tendency toward increasing or decreasing Hg levels with depth was not evident from the data collected. Collecting from the 5-10 and 0-5cm intervals was abandoned for the rest of the project because of time constraints.

During this study, several questions emerged concerning the applicability of this method to the sample areas. There was considerable variation in the nature of the sites chosen which may limit the ability to define anomalies attributable to geothermal activity. One question concerned the inability to find relatively level and/or undisturbed sites in some areas. The extensive log-salvaging activity in the Soda Springs area since the 1980 blast made it difficult to find sites which had not been markedly disturbed by human activity. Since the soil horizons of some of the sample sites may have been disturbed, their Hg-absorbing characteristics may have been significantly changed. The ability to measure a consistent depth for the soil sample was also a concern. In some parts of the Soda Springs study area, the organic layer was missing, possibly due to burial by the May 18, 1980 volcanic blast or erosion. Two other factors made it difficult to measure intervals at consistent depths in some places in the study areas; a greatly undulating soil horizon, and an extensive covering of rotting wood.

An important question may be how inconsistency in soil horizon characteristics affects the ability to discern Hg anomalies. Some factors found to affect soil retention of Hg include the amount of organic matter in the soil. Much organic material will increase the Hg content since Hg adsorbs to some humic substances. North-facing slopes may have higher Hg levels than south-facing slopes since they have been less exposed to the sun and therefore may have more vegetation and more organic material in the soil. The amount of clay in the soil may also affect retention of Hg. Klusman and Landress (1978) found that the influence of these factors is secondary in significance to variations produced by the presence of geothermal activity.

Topography influences the hydrologic characteristics of a given area and may affect the importance of the above secondary controls. Both sample areas, especially Soda Springs, had significant variation in topography. This type of variation was minimized by sampling relatively level sites whenever possible.

Some relationships between the nature of the environment and the Hg levels in samples taken there were apparent from the data. Samples taken from an area almost level with the Green River yielded Hg values significantly lower than the mean of 60 ppb (11 and 29 ppb for 5-10 cm and 32 ppb for 10-15 cm). These lower than average values can probably be attributed to the high water table and lateral transportation of the Hg down-gradient. Samples from 8 wet or swampy sites in the Soda Springs area ranged from 12 to 65 ppb with an average of 39 ppb. A high water table appears to result in generally lower Hg levels in these soils. More samples could be collected to confirm these suspected relationships.

The soil around thermal springs is often enriched in mercury. But a sample taken within one meter of the main spring at Soda Springs had a relatively low 12 ppb Hg concentration. Since Soda Springs lies in the flood plain of the river, this low Hg value may be a result of a high water table. Additionally, the low value may be related to the incomplete volatilization of Hg with the low temperature method. The soil within about a 3 m radius of Soda Springs was clayey, hard, coarse, and extremely oxidized. Given the nature of the soil, the Hg may be locked up in oxides that do not allow for complete Hg volatilization at the temperature used.

When plotted on a map of the Soda Springs area, the Hg readings show no distinct trends (see plate 1). Single high values are usually surrounded by lower ones. There is, however, a cluster of several relatively high values (76-107 ppb) south of the Green River (directly across the river and south of Green River Soda Springs) on several parallel roads all less than a mile from the spring. One mile north of the spring are two more relatively high readings (103 and 118). These readings, plus their distribution along a line of earthquake hypocenters which may define a major fault zone, and the presence of a thermal spring, made the Green River Soda Springs an interesting target for a geothermal test hole. Sampling at more frequent intervals might well be useful to pinpoint areas of potential high geothermal gradient.

In the Marble Mountain area (see plate 2), five samples taken along the upper part of a road bordering the northeast side of Pine Creek Valley range from 20 to 38 ppb with an average of 27 ppb. These values are lower than the mean of 48 ppb, possibly because of the thick layers of pyroclastic and mudflow material in the area which could make the soils less prone to significant Hg adsorbtion.

A cluster of values above the mean, including three above the threshold (94, 99 and 144 ppb), was found in section 15 of T. 7 N., R. 5 E. in the Marble Mountain area. It should be noted that this area almost parallels the contact between Quaternary Basalts of Marble Mountain and the Tertiary volcanics of the Ohanapecosh Formation. It is possible that a contact between differing lithologies or structural characteristics of the contact may allow Hg to flux out at a relatively higher rate and consequently accumulate at a relatively high concentration in soils above the contact.

CONCLUSIONS

The main accomplishment of this study was to determine the background mercury level for the areas studied, providing preliminary information for future work. Identification of areas which might merit more intensive sampling was also accomplished. The clusters of samples with high Hg concentrations in both areas may indicate high heat flow and should be investigated further. Problems involving the use of this method in the Cascades were also identified. A thorough study of the influence of secondary controls might be useful for further work in this type of geographic province. Both areas had approximately the same standard deviation (expressed as a percentage of the mean), even though the sampling horizons seemed much more consistent and less disturbed in the Marble Mountain area. This may indicate that for these areas, secondary controls are more important, or that Hg anomalies are much smaller than indicated in studies of other areas. More work should be done using analysis of variance to determine appropriate sampling intervals and grid spacing for these areas. It may be that a closer grid spacing is needed because geothermal Hg anomalies may not appear with the grid spacing used in this and previous studies.

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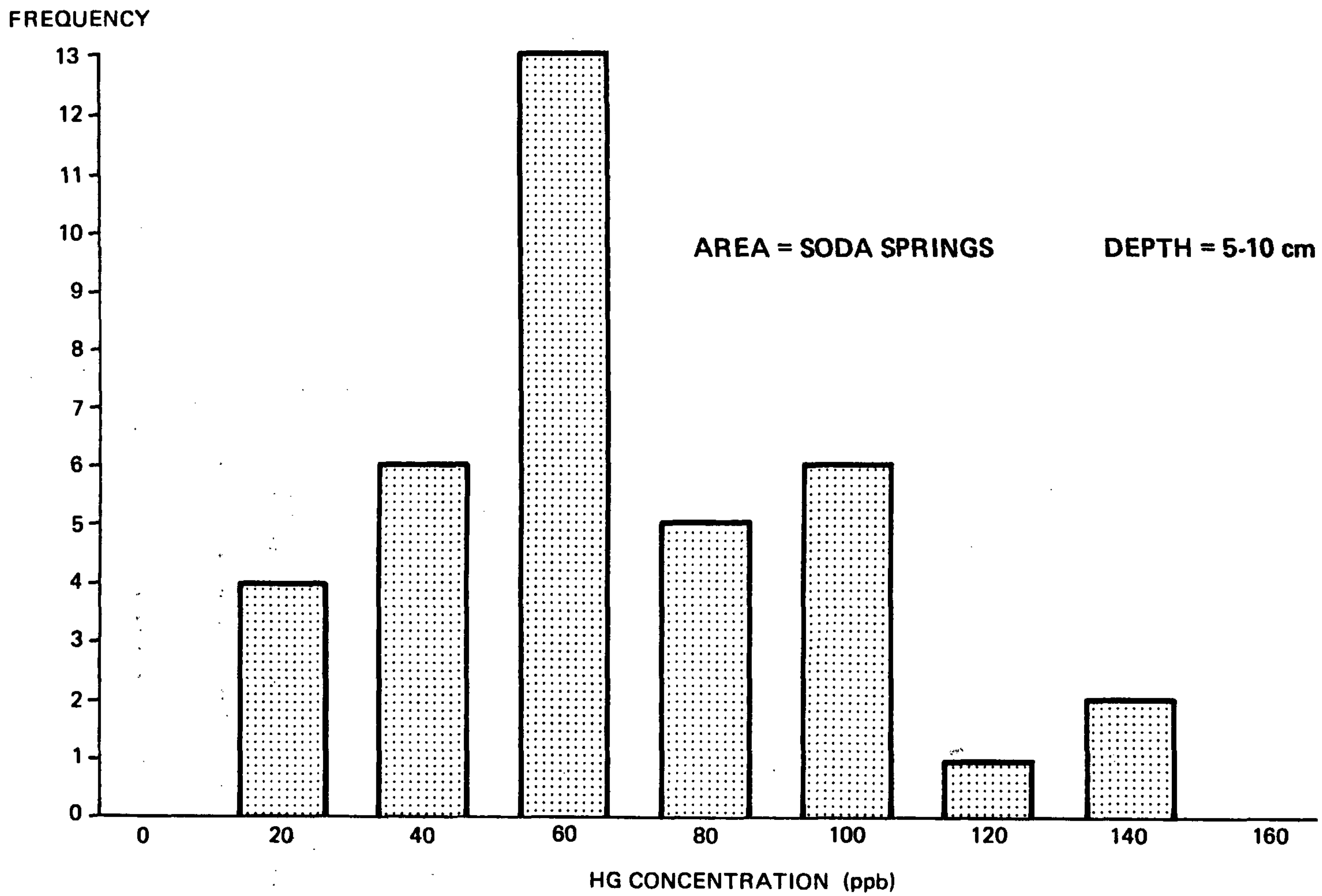
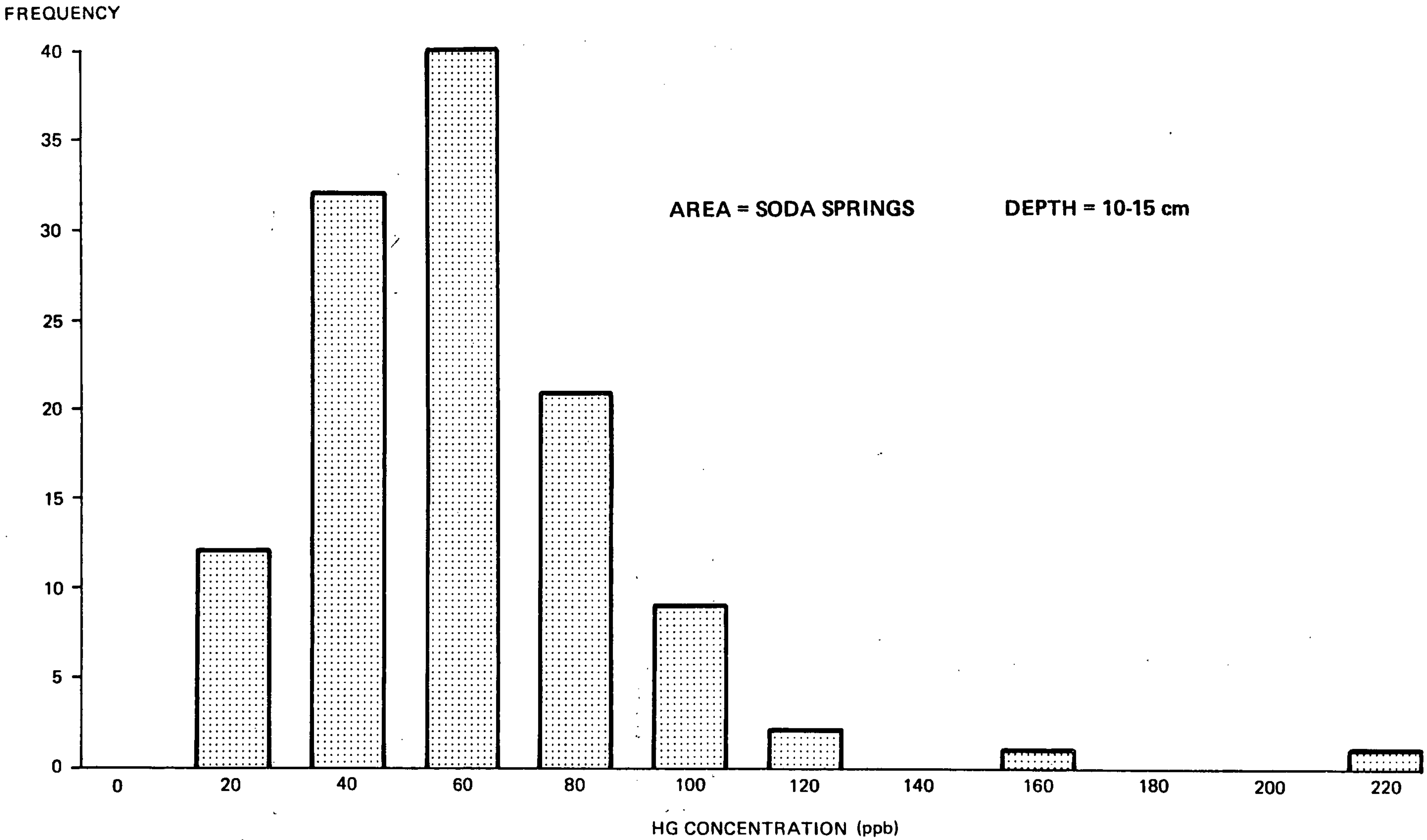
APPENDIX A

TABLE A-1. - Mercury Survey, Southern Cascades, Washington

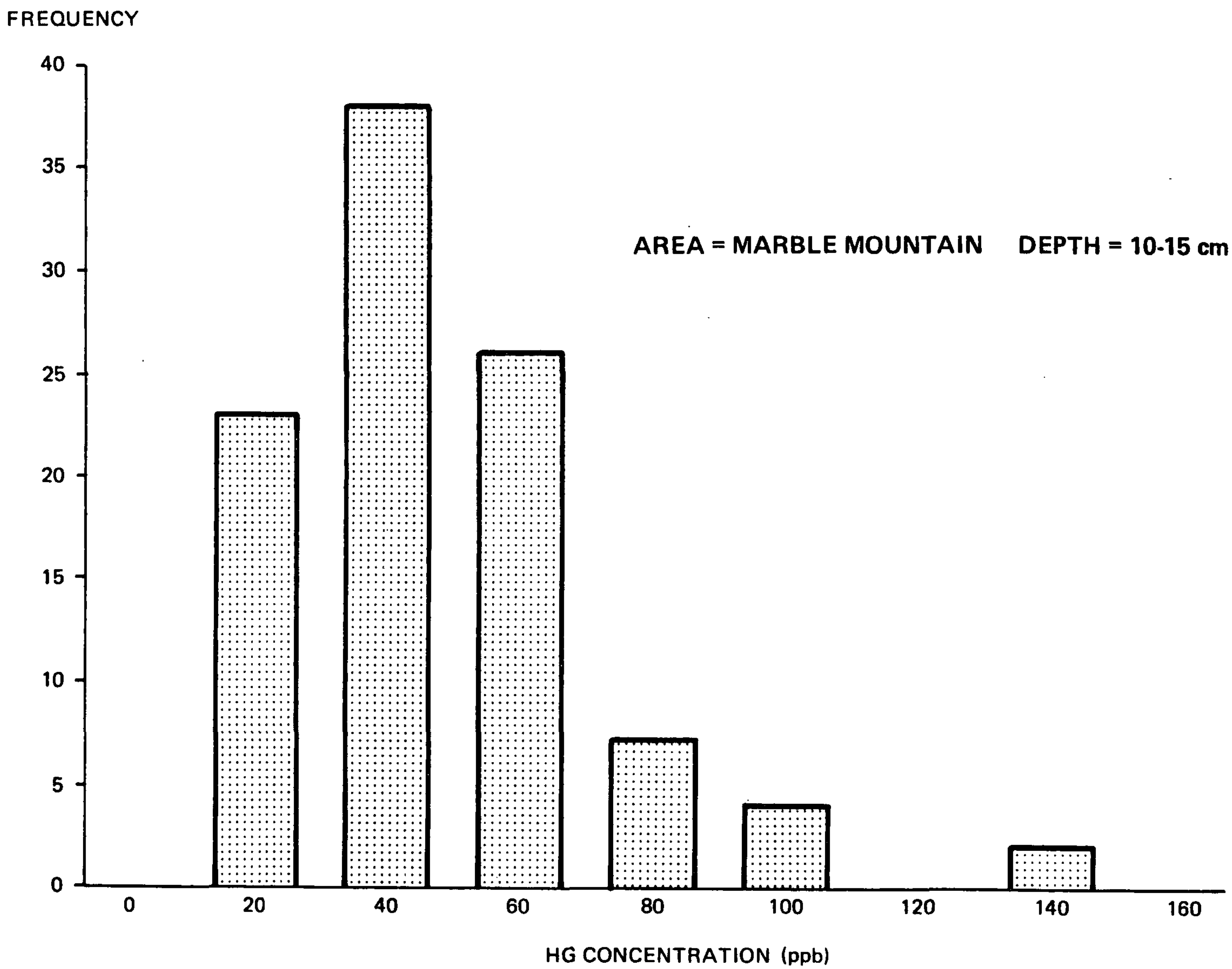
AREA	NUMBER	MINIMUM VALUE	MAXIMUM VALUE	RANGE	MEAN	STANDARD DEVIATION	STD ERROR OF MEAN	COEFFICIENTS OF VARIATION
Marble Mtn. Depth = 10-15	101	18.00	144.00	126.00	48.25	24.09	2.39	49.93
Marble Mtn. Depth = 20-25	1	47.00	47.00	0	47.00			
Seaquest State Park Depth = 05-10	2	165.00	175.00	10.0	170.00	7.07	5.00	4.15
Seaquest State Park Depth = 10-15	8	28.00	125.00	97.00	63.12	32.17	11.37	50.97
Soda Springs Depth = 00-05	12	13.00	103.00	90.00	59.50	30.33	8.75	50.99
Soda Springs Depth = 05-10	37	11.00	149.00	138.00	68.18	31.61	5.19	46.36
Soda Springs Depth = 10-15	118	12.00	211.00	199.00	60.47	27.66	2.54	45.75



Appendix B - Frequency bar chart for Soda Springs area; depth interval 5-10 cm.



Appendix B cont. - Frequency bar chart for Soda Springs area; depth interval 10-15 cm.



Appendix B cont. - Frequency bar chart for Marble Mountain area; depth interval 10-15 cm.

APPENDIX C

TABLE C-1.

MERCURY SURVEY, SOUTHERN CASCADES, WASHINGTON

SAMPLING AREA = SODA SPRINGS SAMPLE DEPTH (CM)=00-05

SAMPLE NUMBER	MERCURY CONCENTRATION (PPB)
3	17
8	59
9	103
12	90
15	74
20	63
21	83
26	92
33	13
83	36
93	55
151	29

APPENDIX C

TABLE C-2.

MERCURY SURVEY, SOUTHERN CASCADES, WASHINGTON

SAMPLING AREA = SODA SPRINGS

SAMPLE DEPTH (CM)=05-10

SAMPLE NUMBER	MERCURY CONCENTRATION (PPB)
1	54
4	62
6	140
10	109
13	78
16	149
19	57
22	98
24	65
27	93
29	66
32	66
35	94
37	70
39	38
41	11
42	29
44	69
46	58
48	46
50	80
52	53
54	100
56	67
59	58
60	43
62	36
64	75
66	57
68	75
70	47
72	19
75	44
76	99
77	87
79	13
92	118

APPENDIX C

TABLE C-3.

MERCURY SURVEY, SOUTHERN CASCADES, WASHINGTON

SAMPLING AREA = SODA SPRINGS SAMPLE DEPTH (CM)=10-15

SAMPLE NUMBER	MERCURY CONCENTRATION (PPB)
2	55
5	107
7	99
11	97
14	85
17	85
18	71
23	156
25	84
28	54
30	67
31	76
34	65
36	124
38	105
40	37
43	32
45	62
47	68
49	42
51	66
53	67
55	60
57	75
58	74
61	40
63	40
65	65
67	60
69	80
71	40
73	12
74	53
78	211
80	22
81	79
82	55
84	30
85	75
86	55
87	56
88	38
89	54

TABLE C-3. (CONT'D)

MERCURY SURVEY, SOUTHERN CASCADES, WASHINGTON

SAMPLING AREA = SODA SPRINGS SAMPLE DEPTH (CM)=10-15

SAMPLE NUMBER	MERCURY CONCENTRATION (PPB)
90	83
91	55
94	103
95	50
96	53
97	26
98	17
99	46
100	55
101	86
102	42
103	30
104	40
105	37
106	48
107	57
108	80
109	68
110	95
111	54
112	56
113	38
114	62
115	50
127	30
128	40
129	58
130	91
131	30
132	37
133	22
134	44
135	82
136	46
137	53
138	51
139	30
140	57
141	39
142	46
143	45
144	39
145	123

APPENDIX C

TABLE C-3. (CONT'D)

MERCURY SURVEY, SOUTHERN CASCADES, WASHINGTON

SAMPLING AREA = SODA SPRINGS SAMPLE DEPTH (CM)=10-15

SAMPLE NUMBER	MERCURY CONCENTRATION (PPB)
146	44
147	46
148	42
149	54
150	41
152	74
153	41
154	26
155	62
157	40
260	57
261	52
262	42
263	91
264	79
265	70
266	63
267	52
268	56
269	73
270	52
271	56
272	40
273	43
274	84
275	26
276	97
277	83
278	52
279	84
280	61
281	81

APPENDIX C

TABLE C-4.

MERCURY SURVEY, SOUTHERN CASCADES, WASHINGTON

SAMPLING AREA = MARBLE MOUNTAIN SAMPLE DEPTH (CM)=10-15

SAMPLE NUMBER	MERCURY CONCENTRATION (PPB)
158	70
159	26
160	18
161	54
162	34
163	43
164	60
165	60
166	32
167	20
168	57
169	59
170	33
171	38
172	20
173	22
174	36
175	20
176	87
177	37
178	40
179	55
180	35
181	73
182	22
183	55
184	108
185	21
186	32
187	44
188	18
189	30
190	138
191	24
192	68
193	18
194	62
195	20
196	38
197	40
198	30
199	49
200	72
201	46
202	55

APPENDIX C

TABLE C-4. (CONT'D)

MERCURY SURVEY, SOUTHERN CASCADES, WASHINGTON

SAMPLING AREA = MARBLE MOUNTAIN SAMPLE DEPTH (CM)=10-15

SAMPLE NUMBER	MERCURY CONCENTRATION (PPB)
204	53
205	67
206	69
207	99
208	94
209	144
210	43
211	47
212	78
213	23
214	61
215	42
216	109
217	78
218	51
219	79
220	50
221	37
222	36
223	42
224	19
225	60
226	30
227	71
228	41
229	63
230	40
231	40
232	50
233	70
234	46
235	51
236	62
237	51
238	47
239	72
240	33
241	47
242	24
243	40
244	51
245	31

APPENDIX C

TABLE C-4. (CONT'D)

MERCURY SURVEY, SOUTHERN CASCADES, WASHINGTON

SAMPLING AREA = MARBLE MOUNTAIN SAMPLE DEPTH (CM)=10-15

SAMPLE NUMBER	MERCURY CONCENTRATION
246	56
247	40
248	28
249	32
250	38
251	55
252	38
253	25
254	25
255	30
256	26
257	33
258	32
259	56

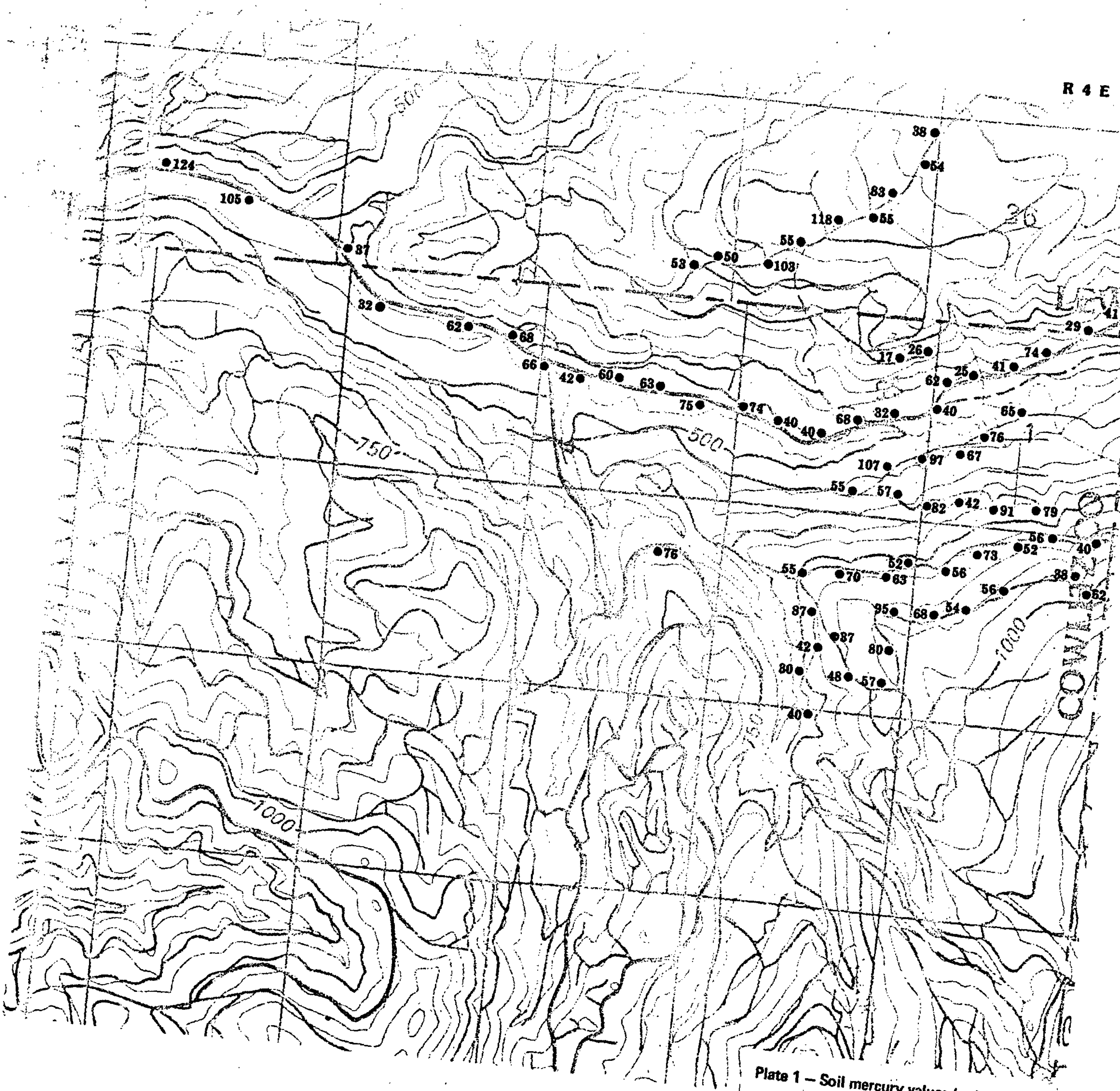
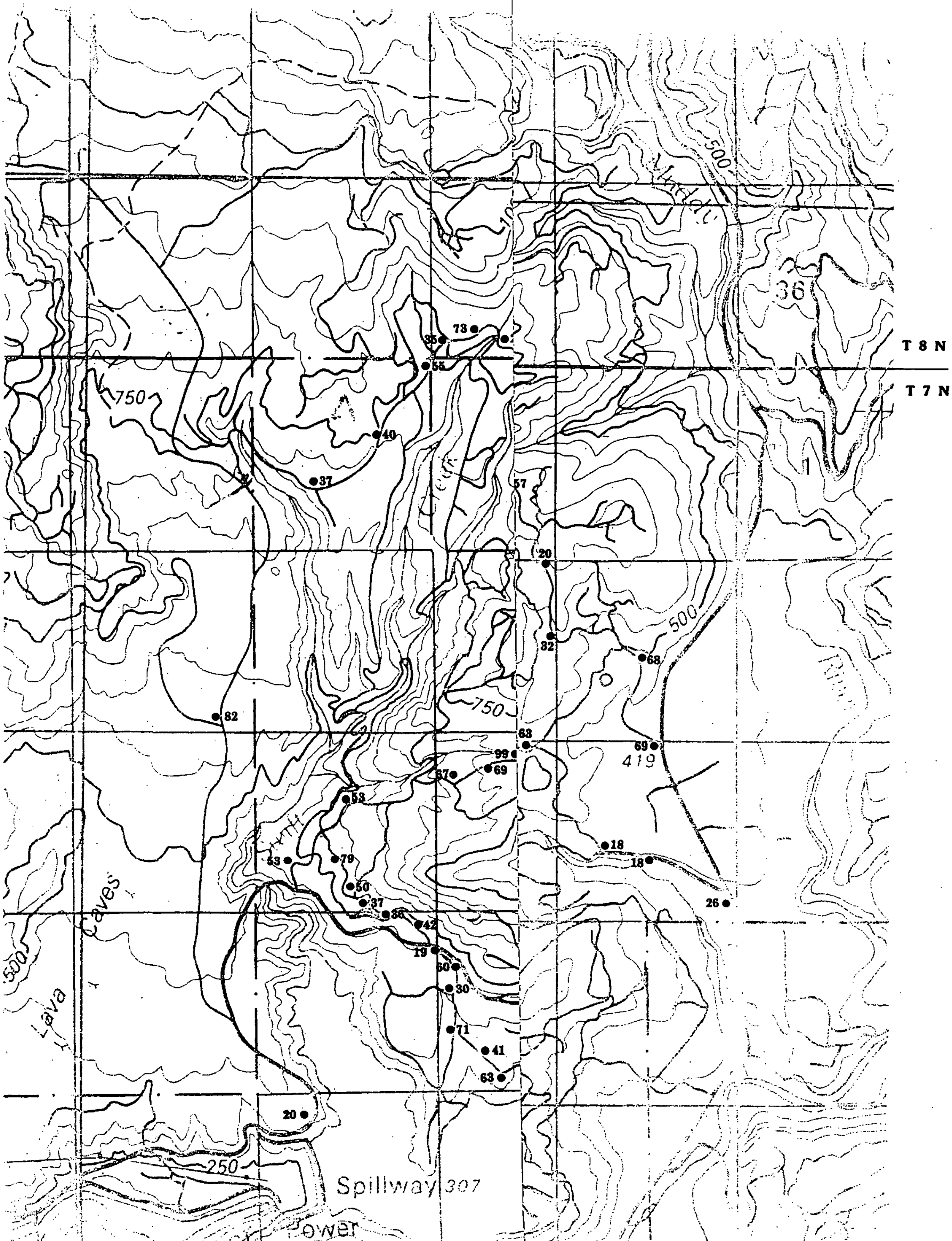


Plate 1 – Soil mercury values (ppb) for the Gre



ntain area (depth interval 10-15 cm.). OF 83-10

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TARGETING GEOTHERMAL EXPLORATION SITES IN MOUNT ST. HELENS AREA USING SOIL MERCURY

Hydrothermal alteration in Oregon's Newberry Volcano No. 2

Fluid chemistry and secondary-mineral distribution

by
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Abstract

Newberry 2 was drilled in the caldera floor of Newberry Volcano, Oregon, by the U.S. Geological Survey during 1979-81. The maximum temperature measured was 265°C at the bottom of the hole, 932 m below the surface.

Rocks recovered from the drill hole are divided into three intervals on the basis of hydrothermal alteration and mineral deposition: (1) 0-290 m consists of unaltered, largely glassy volcanic material, with present temperatures ranging from 20° to 40°C; (2) 290-700 m consists of permeable tuff layers, tuff breccia units, and brecciated and fractured rhyodacitic to dacitic lava flows, with temperatures ranging from 40° to 100°C; (3) 700-932 m consists of impermeable andesitic to basaltic lava flows that generally show little effect of alteration, interlayered with permeable hydrothermally altered flow breccia, with temperatures gradually increasing from 100°C at 700 m to 265°C at 932 m.

Hydrothermal alteration throughout the system is controlled by rock permeability, temperature, composition of geothermal fluids, and composition and crystallinity of host rocks. Rock alteration consists mainly of replacement of glass by clay minerals and, locally, zeolites, partial replacement of plagioclase phenocrysts by calcite ± epidote ± illite, and whole-rock leaching adjacent to fluids channels. Open-space deposition of hydrothermal minerals in fractures, vesicles, and interbreccia pore space is far more abundant than replacement. Although much overlapping and codeposition of phases occurs, the general paragenetic sequence is clay minerals, sulfides, silica minerals, and carbonates. Anhydrite and epidote are late deposits and occur only below 900 m. A cooling shallow convection system in the upper 700 m is indicated by the occurrence of hydrothermal minerals that were deposited in a slightly higher temperature environment than presently exists. Below 700 m, the heat flow is conductive, and fluid flow is controlled by horizontal lava flows. Homogenization temperatures of secondary quartz fluid inclusions were as high as 370°C. Paucity of self-sealing and absence of refracturing, as well as incomplete alteration in permeable intervals, indicate that the hydrothermal system is relatively young.

Introduction

Newberry 2 (N2) is a research hole drilled in the caldera floor of Newberry Volcano (lat 43°42.48 ft. N., long 121°13.55 ft. W.), Oregon (Figure 1). The hole was sited in the central part of the caldera (Figure 2) near the locus of vents for rhyolitic rocks less than 6,900 C^{14} years old and near the toe of the most recent rhyolitic obsidian flow within the caldera, dated at 1,350 C^{14} years B.P. (MacLeod and Sammel, 1982). The drilling was part of a geologic and geothermal study of the Cascade Range by the Geothermal Research Program of the U.S. Geological Survey and was done in several stages, beginning in summer 1978 and ending in late summer 1981 (Sammel, 1981). The maximum temperature measured in the drill hole was 265°C at the bottom, 932 m below the ground surface. The high measured temperature and the geologic setting indicate a geothermal potential at Newberry Volcano.

A study of hydrothermal alteration in the drill core of N2 was undertaken to supplement the data on the caldera gained by geologic mapping (MacLeod and others, 1982) and to interpret the relation of the hydrothermal mineralogy to the present hydrothermal system. The upper 98 m of drilling yielded only cuttings; between 98 and 300 m, core recovery was locally as low as 40 percent, and from 300 to 932 m, core recovery was generally more than 90 percent. Cores with both typical and atypical features were selected for detailed laboratory study of hydrothermal-alteration mineralogy by binocular examination of cores, petrographic study of thin sections, X-ray diffraction study of individual minerals and whole-rock samples, and scanning-electron-microscope study of mineral morphology and textural relations. Chemical analyses of both fresh and altered rocks are in progress, as are studies of isotopes, fluid inclusions, and detailed clay mineralogy.

Geology

Newberry Volcano is situated in central Oregon, 60 km east of the crest of the north-south-trending Cascade Range, which extends from northern California to southern British Columbia (Figure 1). The Cascade Range contains numerous Quaternary volcanoes, and Newberry Volcano, covering an area of 1,200 km^2, is one of the largest of these. In contrast to most of the large stratovolcanoes of the crestal part of the Cascade Range, the Newberry volcanic center generated silicic volcanism as the latest phase of a complex volcanic history. The geology of Newberry Volcano was mapped in detail by MacLeod and others (1982) and summarized by MacLeod and Sammel (1982). The complex Quaternary eruptive history includes rocks ranging from basalt to rhyolite in composition. Several episodes of caldera collapse have resulted in the present configuration of a 6- to 8-km-wide caldera at the summit of Newberry Volcano. The oldest caldera probably formed about 510,000 years B.P.; the age of the youngest caldera is poorly known but may be many tens of thousands of years (MacLeod and Sammel, 1982). Within the present caldera are numerous small domes, ash-flow deposits, explosion breccias, tephra deposits, and obsidian flows, mostly of rhyolitic composition (Higgins, 1973; MacLeod and others, 1982). The most recent known activity was the extrusion about 1,350 years B.P. of a rhyolitic obsidian flow, 2-1/2 km long, with an associated underlying pumice-fall deposit and an ash-flow deposit, on the south side of the caldera (Sherrod and MacLeod, 1979). MacLeod and Sammel (1982) noted that all the intracaldera rhyolite flows less than about 6,700 years old (dated by Mazama ash) appear to be chemically related; this relation suggests that they may have all come from parts of the same magma chamber. Inasmuch as the youngest of these rhyolite flows is only 1,350 years old, parts of the magma chamber may still be hot.

Drill-hole lithologies

Figure 3 shows the generalized lithologies below 300 m in N2 on the basis of observations by N.S. MacLeod and coworkers during logging at the drill site (MacLeod and Sammel, 1982) and our observations during core selection for alteration studies. The upper 290 m is unaltered, largely glassy volcanic material: 0-42 m is rhyolitic pumiceous ash and

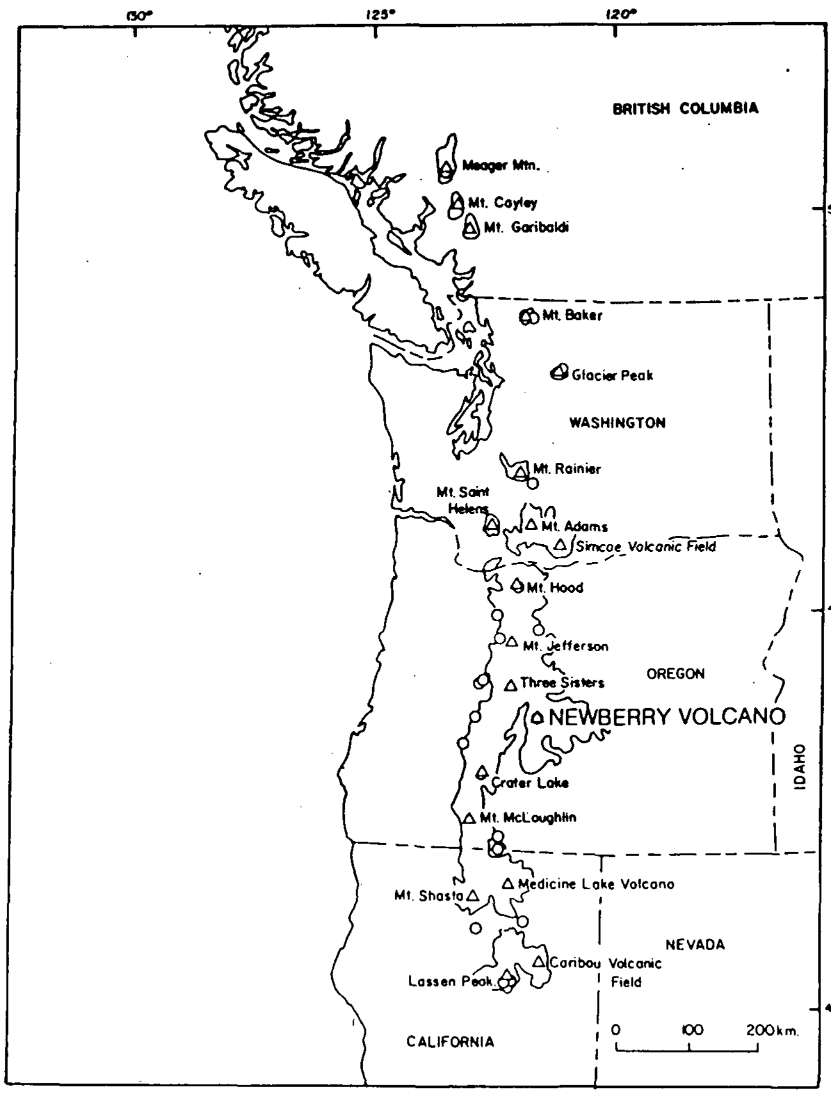
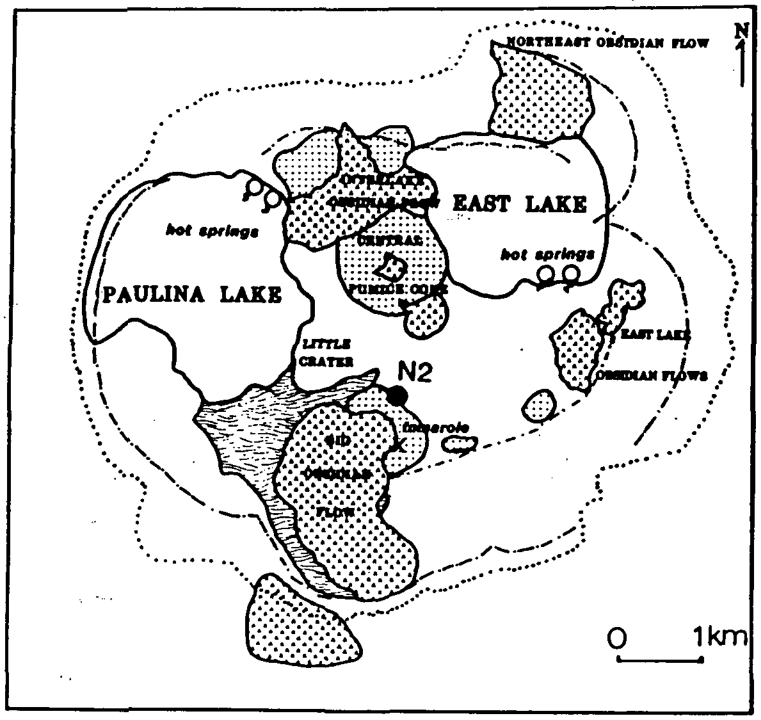


Figure 1: Cascade Range, showing locations of Newberry Volcano and major Quaternary volcanic centers.



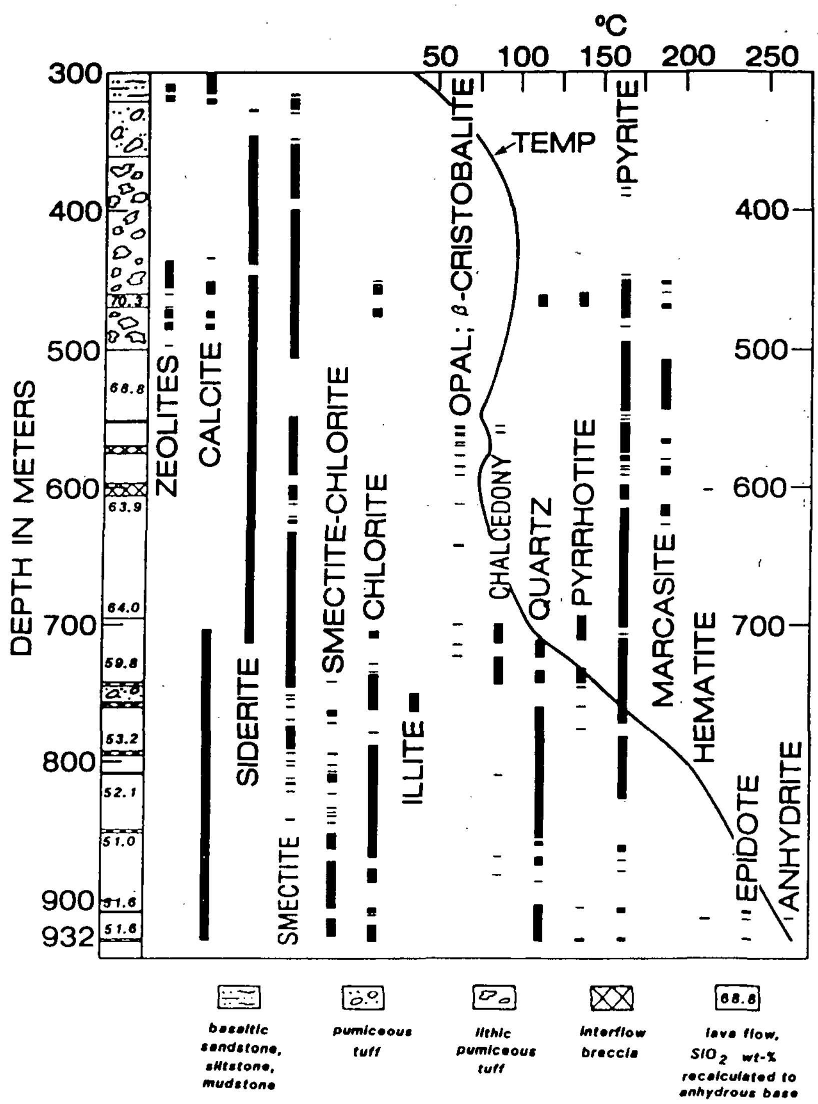
◁ **Figure 2:** Generalized geologic map of Newberry Volcano (after Macleod and others, 1982), showing locations of drill hole (N2), hot springs, "fumarole", caldera ring fractures (dot-dashed line), caldera rim (dotted line), and some of the younger volcanic deposits--obsidian flows (inverted "v" pattern), ash flow of Paulina Lake (wavy pattern), and pumice rings and cones (dotted pattern).

Figure 3: Generalized stratigraphy, hydrothermal-alteration mineralogy versus depth; and temperature measured during drilling of N2. ▽

lapilli, 42-98 m is a rhyolitic obsidian flow, and 98-290 m is glassy basaltic lapilli tuff and tuff breccia.

Incipiently altered glassy basaltic sandstone, siltstone, and mudstone from 290 to 320 m contain a few thin layers of rounded pumice fragments, as large as 3 mm in diameter. The interval from 320 to 500 m consists of several deposits of rhyodacitic to dacitic pumiceous lapilli tuff and pumice-rich lithic tuff breccia. A fractured and brecciated rhyodacite sill between 460 and 470 m is composed of aphanitic hydrothermally devitrified obsidian or perlitic rhyodacite. Rhyodacitic to dacitic flows and interflow breccia layers of fine-grained microporphyritic rocks occur between 500 and 700 m with a thin layer of pumiceous ash and lapilli at 552-553 m. A sequence of andesitic to basaltic dense fine-grained microporphyritic lava flows interlayered with interflow breccia extends from 700 m to the bottom of the hole at 932 m. One flow from 810.7 to 850.3 m is vesiculated throughout.

Significantly, no dikes or cross-cutting emplacement features were penetrated in the drill core. The lava flows and rock units are apparently all subhorizontal.



Fluids from N2 and nearby thermal features

The hydrology of Newberry Volcano has been described by Sammel and Craig (1983), who included chemical and isotopic data on the various types of fluids that occur within the caldera. Little is known about the fluids in the Newberry Volcano geothermal system except what can be inferred from the N2 samples, which are contaminated by drilling fluid, and what can be related to "fumaroles" or gas seeps within the caldera (Tables 1, 2). The "hot springs" that issue from the southeast edge of East Lake and the northeast edge of Paulina Lake (Figure 2) appear to be drowned gas vents. Temperatures in individual orifices fluctuate with the gas-discharge rate. The high silica content of thermal waters from the hot springs and the cation proportions are probably due to dissolution of the lapilli tuff units that crops out at the springs and are not a function of the subsurface temperature. The other fluid constituents--dissolved CO_2, H_2S and NH_3--are all easily transported as gases. Most of the H_2S has been oxidized to sulfate.

Deuterium-isotope data (Table 3) indicate that the thermal waters (-116.9 and -107.3°/oo) are not recycled lake waters (-83 and -97°/oo for East Lake and Paulina Lake, respectively) but represent local fresh water (-115°/oo). Paulina Hot Springs (-107.3°/oo) may have a small component of lake water. Thus, the gas vents of East Lake and Paulina Lake hot springs are drowned in the local cold ground water that discharges at the edge of the lake, rather than being drowned in the respective lake waters. The small oxygen-isotope shift (+0.35 to +0.74°/oo) observed in the thermal waters indicates either that little exchange with the country rock has taken place or that very little water from depth in the geothermal system is in the sample.

The "fumarole" at the toe of the 1,350-yr.-old Big Obsidian Flow near the N2 drillsite is actually one of many cold gas seeps that discharge principally CO_2 and trace to minor amounts of H_2S, CH_4, N_2, and H_2 (Table 2). A warm (35.5°C) well at Little Crater Campground on the southeast side of Paulina Lake is not associated with any hot springs or gas vents.

Two sets of fluid samples from N2 collected 10 hours apart contain the same dissolved gases (CO_2, CH_4, H_2S, and NH_3) observed in the hot springs (Table 2). Each set consisted of a vapor phase and a liquid phase

TABLE 1. Chemical composition of water from Newberry Volcano (concentrations in milligrams per liter (mg/L); -, not determined).

	East Lake Hot Springs	Paulina Hot Springs	Well at Little Crater Campground	N2 Well (1) Water Line	N2 Well (1) Vapor Line	N2 Well (2) Vapor Line	N2 Well (2) Water Line	Drilling Water
Temp (°C)	57	52	35.5	5.5	6.0	10	10	12
pH	6.10	7.26 at 20°C	6.46	6.14	5.73	5.31	5.59	6.36
SiO_2	197	184	161	13	.7	.7	11	44
Ca	73	50	54	1.3	.4	.24	.76	3.2
Mg	33	42	48	.09	.02	.02	.05	2.6
Na	56	110	83	48 2/	.3	.18	39 2/	6.9
K	9.7	13	10	1.8	.04	.06	1.4	1.6
HCO_3 1/	413	689	679	320	368	294	334	39
H_2CO_3	-	91	-	66 2/	1,990	3,860	2,290	-
Organic carbon (as C)	-	-	-	57	27	32	24	4
SO_4	120	2	<1	13	2	5	9	1
Cl	1.2	5.0	5.1	2	4	6	2	.7
F	.16	-	.6	.35	-	-	.25	.41
B	1.1	-	2.5	1.0	<1	<1	1.6	<1
NH_3 (as N)	1.1	-	.44	42	82	64	50	-
H_2S	<.5	<.5	-	14	16	22	25	-
Fe	-	-	4.0	1.2	.6	2	.5	-
Al	-	-	.0020	-	-	-	.0060	-
Hg	-	-	-	.0009	-	-	-	-

1/ Total alkalinity as HCO_3.

2/ May represent Na_2CO_3 added during drilling.

TABLE 2. Gas-composition data for thermal springs, "fumarole", and N2 in Newberry Volcano and other selected Cascade Range volcanoes (analysis in volume percent; -, not determined).

	East Lake Hot Springs	Paulina Hot Springs	Big Obsidian Flow "Fumarole"[1]	N2 Well (1)	N2 Well (2)	Mt. St.[2] Helens fumarole	Mt. Hood[3] fumarole	Lassen[4] vapor dominated system
He	0.005	-	<0.005	<0.005	<0.005	<0.005	<0.005	-
H_2	.015	-	.005	3.92	3.89	8.61	2.81	.01
H_2S	.42	-	3.95	1.84	1.81	2.09	3.10	6.6
Ar	.13	0.09	-	<.005	.005	<.02	<.02	.013
O_2	.03	.16	-	.05	.19	.03	<.02	0.0
N_2	8.63	4.74	1.95	.28	.81	1.64	.87	.6
CO_2	86.15	93.45	92.54	94.03	93.12	86.6	93.28	92.7
CO	<.01	-	-	.033	.029	.57	-	-
CH_4	5.43	.44	1.55	.77	.81	<.0002	<.002	.05
C_2H_6	<.01	<.05	<0.01	<.01	<.01	<.01	<.01	-
Total	100.81	99.31	100	100.92	100.86	100.45	100.06	100
Gas geothermometer temperature	168°C	-	176°C	274°C	273°C	477°C	422°C	244°C

[1]Composition corrected for 8.40% air contamination.
[2]Analysis from Evans and others (1981).
[3]Unpublished analysis collected August 9, 1980, by R. H. Mariner and W. C. Evans.
[4]Reconstructed composition of gas in vapor-dominated reservoir at Lassen Peak (Muffler and others, 1982).

(Table 1). The first set of samples was collected with the separator working at a temperature of 135°C and a pressure of 0.42 MPa; the second set of samples was collected at 131°C, but no pressure was recorded (Portable Separators, Inc., written commun., 1981). The gas phase contained low chloride concentrations, ranging from 2 to 6 mg/L (Table 1), that could represent either HCL or NH_4CL. The well was permitted to flow for fewer than 24 hours and was still discharging drilling mud and "soluble oil" when shut down. The proportion of gas-soluble constituents (CO_2, H_2S, and HCL) increased in the second set of samples. A sample collected after the well had flowed for approximately an hour contained 3-1/2% noncondensable gas. A second measurement taken just before shutdown about 10 hours later indicated 7% noncondensable gas. This measurement was very crude and should not be taken as proof that the fraction of noncondensable gas had increased; however, during the same period, gas production (both condensable and noncondensable) fell from 23,591 to 11,356 m^3/day (Portable Separators, Inc., written commun., 1981). The proportions of the various gases, one to another, however, were constant over the short period of sampling.

Attempts to use oxygen-isotopic fractionation between constituents in the gas phase, CO_2 and H_2O, to estimate equilibrium temperatures were not fruitful; they indicate a temperature near 135°C, about 140°C cooler than the measured temperature and near the separator temperature.

Estimates of subsurface temperature based on the chemical and isotopic composition of the fluids discharged by N2 should be viewed with caution because of contamination by drilling fluids. The gas geothermometer of D'Amore and Panichi (1980) gives reasonable estimates of reservoir temperature when the samples from N2 are used (274° and 273°C, respectively, on two samples). These temperatures compare favorably with the measured temperature of 265°C.

Gas samples from the hot spring at East Lake and the "fumarole" at the Big Obsidian Flow give reservoir temperatures of 168° and 176°C, respectively, using the gas geothermometer of D'Amore and Panichi (1980). These estimated temperatures, which are lower than those calculated for the reservoir in N2 may result from lower CO_2/CH_4 ratios and lower percentages of H_2S and H_2 in the gases.

Hydrothermal alteration and deposition

Hydrothermal processes affecting the N2 drill core mostly result in open-space deposition of minerals from circulating fluids and in replacement of primary material, commonly glass. Open spaces for hydrothermal mineral deposition are in fractures, vesicles, and interfragmental cavities resulting from brecciation of flows and poor sorting of tuff. In the pumice-rich lithic tuff between 290- and 500-m depth, the glass of pumice fragments and groundmass shards is partly to completely replaced by clay minerals and zeolites. Interstitial glass in lava flows below 700 m is replaced by clay minerals (commonly chlorite-and-chlorite-smectite). Plagioclase phenocrysts in the lava flows below 833.6 m locally are partly replaced by calcite and a minor amount of epidote and illite. Figure 3 shows the generalized distribution of hydrothermal minerals in the N2 drill core but does not differentiate open-space deposition and replacement and does not show the relative abundance of minerals. Most of the minerals in Figure 3 are in hydrothermal open-space deposits. Dominant replacement minerals shown in Figure 3 are the clay minerals and some calcite and zeolites.

Hydrothermal alteration in N2 is controlled primarily by rock permeablility, temperature, composition and type of geothermal fluids, and the type (glassy or crystalline) and chemical composition of host rocks. A change in several of these physical parameters is reflected at about 700-m depth (Figure 3). Changes in hydrothermal mineralogy and in the slope of the temperature curve are conspicuous and are mainly related to the difference in permeability of the rocks above and below 700 m.

Rock permeability is the major factor in controlling flow of hydrothermal fluids. Permeability is high in the pumiceous tuff units, fluviatile sediment (generally pumiceous), flow breccia units, and vesiculated and fractured parts of lava flows in the upper 700 m. The dense dacite flows are made somewhat permeable by emplacement brecciation and fracturing. In the lower part of the drill hole, below 700 m, the impermeable subhorizontal lava flows impede vertical fluid flow, and subhorizontal fluid flow dominates owing to permeable interflow breccia units and local vesiculated parts of lava flows. Many of the dense impermeable lava flows have locally abundant hairline fractures, which are filled with dark-green or black clay minerals. Local fractures, as wide as 2 mm, are lined with clay minerals and are filled with calcite and (or) quartz. Sealing of these small fractures with secondary minerals has made the lava flows virtually impermeable. Alteration of interflow breccia units and vesiculated flows is extensive in comparison with the dense lava flows, and permeability should be expected to decrease as alteration progresses. Hydrothermal alteration of the system as a whole has not proceeded to the point of total self-sealing and refracturing.

Temperatures measured during drilling in the present hydrothermal system range from 20° to 40°C in the upper, unaltered 290 m, from 40° to about 100°C between 290 and 700 m, and then gradually increase with depth from 100°C at 700 m to 265°C at 932 m (Figure 3; Sammel, 1981). A shallow convection system above 700 m in the more permeable rocks has resulted in cooling from initial temperatures. The association of deflections for lower temperatures with the more permeable layers indicates that cooler surface waters are gaining access to the hydrothermal system and that the convection system is affected by stratigraphy (Sammel, 1981). The convective system does not extend downward below 700 m because it is blocked by impermeable subhorizontal andesitic to basaltic lava flows. Below 700 m fluid flow is mainly subhorizontal through permeable interflow breccia, and so the temperature gradient must be dominantly conductive. Any vertical component of fluid flow below 700 m must be highly restricted.

Hydrothermal alteration is also affected by the type and composition of host rocks. Glassy material normally reacts more readily with fluids than do crystalline rocks, even finely crystalline rocks. Preliminary whole-rock chemical investigation of the least altered and most altered equivalent rocks in the lower part of the

TABLE 3. Isotope data for water and gases from Newberry Volcano [compositions in per mil. D and ^{18}O referred to Standard Mean Ocean Water (SMOW), ^{18}C to Peedee belemnite (PDB); -, not determined].

	East Lake Hot Springs	Paulina Hot Springs	Well at Little Crater Campground	Big Obsidian Flow Fumarole	N2 Well (1) Water Line	N2 Well (1) Vapor Line	N2 Well (2) Water Line	N2 Well (2) Vapor Line	Drilling Water
H_2O									
δD	-116.9	-107.3	-113.4	-	-100.8	-112.5	-103.9	-113.3	-115.7
$\delta^{18}O$	-15.12	-14.33	-14.60	-	-10.74	-13.98	-10.82	-14.21	-15.68
CO_2									
$\delta^{13}C$-gas	-6.35	-7.35	-	-4.40 1/	-	-8.72	-	-7.32	-
$\delta^{18}O$-gas	+21.37	+25.90	-	+29.21	-	+11.12	-	+13.14-	-
$\delta^{13}C$-dissolved CO_2	-	-	-	-	-14.98	-8.74	-11.16	-14.40	-
CH_4									
$\delta^{13}C$	-	-52.7	-	-	-	-	-	-	-

1/ Fumaroles on Mount St. Helens have a $\delta^{13}C_{CO}$ value of -10.5°/oo (Evans and others, 1981), whereas Mount Hood discharges CO_2 with a $\delta^{13}C$ value of -9.67°/oo (R. H. Mariner and others, unpub. data, 1980).

drill core shows that Si, Ca and Mg have been leached from the fresh rock. Varying migration of most elements has occurred as a result of hydrothermal solution and redeposition.

The upper 290 m of N2, though virtually unaltered except for hydration and local palagonitization, is composed largely of glassy materials that generally are readily altered. Temperatures measured during drilling range from 20^0 to 40^0C between the surface and 290-m depth. The youth of the caldera fill, and the cold, probably dilute, fluids within this interval may not have provided a suitable environment for alteration to proceed.

Below 290 m, hydrothermal minerals have been deposited in open spaces, and glassy volcanic material has generally been at least partly replaced by clay minerals and, locally, zeolites. Although much overlapping and and codeposition of hydrothermal phases has taken place, the general sequence of deposition, from early to late, above 700 m is smectite, pyrrhotite, pyrite, marcasite, opal, β-cristobalite, chalcedony, and siderite; below 700 m, the sequence is smectite, mixed-layer smectite-chlorite, chlorite, pyrrhotite, pyrite, chalcedony, quartz, and calcite. Illite, anhydrite, hematite, and epidote are additional late-deposited minerals below 900 m. In general, alteration increases with depth.

The amount of glass alteration to smectite from 290 to 700 m increases with depth and temperature. Glassy basaltic sandstone, siltstone, and mudstone between 290 and 320 m are partly altered to very fine grained zeolites and smectite. Much of the rhyodacitic glass in pumice fragments and matrix glass shards at the top of the pumiceous tuff sequence beginning at 320 m is only hydrated and incipiently altered to smectite. The fact that alteration of the glassy tuff is not so extensive over the present temperature range (50-100^0C) as might be expected indicates that the alteration process is young and incomplete.

Clay minerals have formed throughout the drill core below 290 m and at several stages of the alteration process. A significant feature of the distribution of clay minerals (Figure 3) is that clays above about 700 m are smectites, except for the chlorite occurring at 309 m and adjacent to the rhyodacite sill at 460-470 m. Downward from 700 m, the smectite clays diminish in abundance, and mixed-layer smectite-chlorite and chlorite become predominant. A small amount of illite has formed in a pumiceous tuff between 746 and 758 m. Illite occurs below 911 m in the groundmass and partly replaces plagioclase phenocrysts. The smectite has formed where present temperatures are below 100^0C; the smectite-chlorite, chlorite, and illite occur at temperatures above 100^0C. Present temperatures are close to possible crystallization temperatures for the respective clay minerals except for the chlorite at 309 m and between 450 and 480 m, which must have formed at temperatures higher than at present. Elevated temperatures due to a possible nearby dike not intersected by the drill hole might explain the higher temperature alteration minerology at 300-320 m.

Although the sulfides have generally crystallized later than some of the first-deposited clays, most of the sulfides have formed earlier than quartz and carbonate minerals. Pyrrhotite is the earliest sulfide, followed by pyrite and marcasite. Pyrrhotite in N2 was determined by X-ray diffraction to have a monoclinic structure and is thus useless as a geothermometer (Kissin and Scott, 1982). Monoclinic pyrrhotite is reported from active hot-spring systems at temperatures in the range 125^0 to 238^0C (Steiner, 1977).

In the rhyodacite sill between 460 and 470 m, pyrrhotite was deposited initially as pseudohexagonal euhedral crystals in fractures within the rhyolite. Pyrite and marcasite have subsequently replaced some pyrrhotite, and a coating of tiny pyrite and (or) marcasite crystals covers some pyrrhotite crystals. Between 500 and 680 m, pyrrhotite was initially deposited but has been totally replaced by and (or) altered to pyrite and, locally, marcasite. Pyrite and marcasite have also crystallized as euhedral single crystals. Marcasite was not found below 620 m. Fresh euhedral pyrrhotite and pyrite crystals coexist below 700 m and in some places occur as intergrowths. Most pyrrhotite below 700 m is earlier than pyrite but shows no alteration effects. The δ^{34}S value of pyrite from 930 m is $+1.6^0/oo$, and of pyrrhotite from 713 m $+1.7^0/oo$ (Steve Howe, written commun., 1982) suggesting that the sulfur component of the sulfides is of magmatic origin.

Sulfide paragenesis and alteration of pyrrhotite above 700 m reflect some cooling and oxidation by the shallow convection system. The sulfides below 700 m may have crystallized at temperatures similar to or somewhat higher than those measred during drilling. Browne (1970) noted the restriction of pyrrhotite to impermeable zones as well as to temperatures above 180°C at the Broadlands geothermal field in New Zealand. Pyrrhotite deposition probably took place in a reducing fluid environment. Recrystallization of pyrrhotite to pyrite, marcasite, and siderite is not uncommon in higher temperature ore deposits and appears to have taken place in N2 under slightly cooling and increasingly oxidizing (or less reducing) conditions.

Deposition of silica minerals appears to be controlled by temperature, as well as by the silica saturation of fluids. Locally abundant euhedral crystals of quartz occur below 700 m, and minor amounts of chalcedony mainly between 700 and 750 m. The only quartz above 700 m is in the rhyodacite sill between 460 and 470 m, where it occurs as fine-grained coatings of fracture walls. Small amounts of opal and β-cristobalite are deposited in open spaces between about 550 and 720 m. The absence of quartz and the presence of the other silica phases above 700 m indicate that water was the dominant fluid phase during this stage of deposition and that temperatures were never much higher than at present.

Fluid inclusions in quartz are sparse and generally occur in clusters of very tiny inclusions, too small (2-3 mm diam) to study. However, Bargar has studied 95 suitable secondary inclusions from four samples below 750 m. The homogenization temperatures, which range widely (about 170° to 370°C), reflect temperatures during healing of fractures in quartz crystals. The fact that all but two of these homogenization temperatures plot above the measured temperature curve suggests that past temperatures were somewhat higher than at present. The salinities of the inclusions are very nearly 0.

Carbonates formed relatively late in the system. Calcite is abundant in open spaces below 700 m and partly replaces plagioclase phenocrysts below 833.6 m. Calcite occurs in the upper part of the drill core within open fractures in the slightly altered basal part of the basaltic volcaniclastic rocks at 290 to 320 m. In the tuff adjacent to the rhyodacite sill at 460 to 470 m, calcite was deposited later than the clay minerals and has been partly replaced by siderite. Siderite occurs from approximately 330 to 700 m as small, commonly abundant pale-yellow to carmel-colored disc-shaped crystals and as fine-grained crystal aggregates. Siderite is deposited in open spaces, commonly with pyrite, on fracture surfaces and brecciated lava-flow fragments. Siderite is a late phase in the zeolitized tuff adjacent to the rhyodacite sill at 460 to 470 m, where it partly replaces calcite and is irregularly deposited throughout the tuff matrix. The occurrence of siderite may be a result of alteration of pyrrhotite above 700 m in a CO_2-rich fluid environment. Deposition of siderite requires a less reducing environment than does pyrrhotite; thus, the alteration of pyrrhotite to siderite and pyrite is an oxidation reaction, going from a strongly to a weakly reducing environment. The convective circulation of cooling surface waters through the upper 700 m is sufficient to cause the change in conditions. The formation of carbonates as a late phase indicates high pCO_2 and, possibly, boiling.

Epidote is the last-formed hydrothermal mineral below 900 m and is scarce; it has formed within small pore spaces in the lava flows and on calcite in open spaces. Locally, epidote and calcite partly replace plagioclase phenocrysts. The present temperature (265°C) falls just inside the range for epidote crystallization, and so the abundance of epidote would be expected to increase downward.

Anhydrite is present in sparse amounts as a late deposit on chlorite and quartz in groundmass pore spaces and in cavities below 911 m. In Icelandic drill holes, anhydrite occuring at depth is related to influx of seawater (Viereck and others, 1982). At Newberry Volcano, the late crystallization of anhydrite is more likely to be a result of oxidation of H_2S from the hydrothermal fluids during a late stage of secondary-mineral deposition. Oxidizing conditions below 900 m also are favorable for epidote crystallization.

Summary and Conclusions

The N2 rocks can be considered over three intervals: (1) 0-290 m--unaltered largely glassy volcanic material in the upper part of a local shallow ground-water convection system, with temperatures ranging from 20° to 40°C; (2) 290 to 700 m--permeable tuff, tuff breccia, and brecciated and fractured rhyodacitic to dacitic lava flows in the lower part of the shallow convection system, with temperatures ranging from 50° to 100°C; and (3) 700 to 932 m--impermeable andesitic to basaltic lava flows that show little effect of alteration, interlayered with permealbe flow breccia layers that are strongly altered. Temperatures in the third interval gradually increase from 100°C at 700 m to 265°C at 932 m. At greater depths, the temperature in the hydrothermal system may reach 275°C or higher, on the basis of the gas geothermometer of D'Amore and Panichi (1980).

The factors controlling hydrothermal alteration in the N2 system are: Rock permeability, temperature of the hydrothermal system, type and chemical composition of fluids, and type and chemical composition of host rocks. Hydrothermal minerals are deposited as open-space deposits within fractures, vesicles, and pore spaces in the rocks, as replacement of glass, and, below 833.6 m, as replacement of plagioclase phenocrysts. The dense fine-grained lava flows are much less altered than the volcaniclastic, tuff, and brecciated layers.

Between 290 and 700 m, secondary mineralogy indicates that slightly higher temperatures existed in the past; however, present temperatures are maintained by convective flow of cool water through permeable rocks. Alteration of pumiceous glass in the tuff between 290 and 460 m is incomplete under present conditions; temperatures in this interval could not have been much higher, nor as high as at present, for very long. The alteration mineralogy in the local rhyodacite sill between 460 and 470 m and in adjacent pumiceous tuff suggests formerly higher temperatures associated with the sill. Mineralogy in the rhyodacite and dacite lava flows and flow breccia units between 500 and 700 m indicates initial temperatures somewhat higher than at present, followed by a later stage of alteration during cooling and oxidation to present conditions. Deeper than 700 m, the alteration pattern and fluid inclusions in quartz suggest that past temperatures were somewhat higher than at present. The late carbonates may have been deposited by CO_2-rich boiling fluids such as were encountered at depth during drilling. The entire system has become less reducing over time, and the latest deposits (epidote, anhydrite) in the lower part of the drill core are a result of oxidation. This oxidation may be a result of the influx of cold water along subhorizontal permeable zones below 900 m, or the entire system may be evolving to an oxidizing environment. Hydrothermal mineralogy and textures suggest that the N2 geothermal system is a young, evolving hydrothermal regime. □

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A SUMMARY OF HEAT FLOW STUDIES IN THE CASCADE RANGE

David D. Blackwell and John L. Steele

Department of Geological Sciences
Southern Methodist University
Dallas, Texas 75275

INTRODUCTION

Because of the large geothermal potential, as indicated by the number of very young volcanoes, the Cascade Range has been the focus of geothermal interest for some time. A concentrated effort to determine the regional thermal structure of the Cascade Range began in the mid-seventies. Although some major gaps remain the the data set, a consistent pattern is beginning to appear along the whole extent of the Cascade Range from its southern end in California to its northern end in British Columbia. The object of this paper is to briefly discuss the emerging picture of heat flow in the Cascade Range.

For the purposes of this discussion, the Cascade Range will be divided into two parts: the southern Cascade Range and the northern Cascade Range. The boundary between these two areas is not arbitrary, but is based on heat flow and geothermal gradient characteristics. The boundary almost exactly coincides with the intersection of the Cascade Range and 45° N latitude. This intersection is just south of the Mt. Hood volcano in northern Oregon. Because of the different setting of volcanoes, the nature of the bedrock, and the background heat flow, characteristic geothermal systems, fluid circulation patterns, strategies for heat flow determinations and geothermal exploration will differ and thus the two areas are discussed separately.

South of 45° N latitude, much of the Cascade Range is composed of Pliocene and Recent volcanic rocks, primarily of andesitic and basaltic composition. In a few places, older Miocene and Oligocene rocks are exposed below the younger rocks. Thus Late Cenozoic volcanism has been most voluminous in the southern Cascades. The young andesite volcanoes sit on top of these late Cenozoic volcanic rocks. In addition to the andesitic stratovolcanoes, there are two large volcanoes located east of the main axis: the Medicine Lake volcano in California and the Newberry volcano in Oregon. Both of these volcanoes are characterized by bimodal volcanism. These volcanoes are much larger, lower-relief features than the andesite stratovolcanoes and have associated rhyolite flows and possibly ash flow tuffs.

The northern Cascade Range as defined here consists primarily of young andesite volcanoes sitting on top of a very complicated Cenozoic and pre-Cenozoic basement. Abundant Late Cenozoic basalts and andesites are not common except in the vicinity of volcanoes and the rate of volcanism in the northern part of the Cascade Range is probably 20 to 25% as great as that in the southern Cascade Range.

A heat flow map of the Cascade Range in its entirety is shown in Figure 1. Available heat flow sites for the Cascade Range are shown, as well as major volcanoes. Where possible, heat flow contours are shown. References to published data used in compiling the map are contained in the text discussing each particular area.

SOUTHERN CASCADE RANGE

California Cascade Range. Recent heat flow studies from the southern part of the Cascade Range in northern California have been discussed by Mase et al. (1980, 1982). In addition, heat flow data in the Coast Ranges have been discussed by Lachenbruch and Sass (1980). Many of the characteristics typical of the southern Cascade Range are observed here. Heat flow values average 40-50 mWm^{-2} and all are less than 60 mWm^{-2} west of a boundary line which runs near the physiographic boundary between the Cascade Range and the Klamath Mountains. East of the boundary line, heat flow values are 80-100 mWm^{-2}. The pattern is complicated by the fact that in the very young, porous, basalt and andesite flows, lateral fluid flow in shallow groundwater aquifers commonly erases evidence of deeper heat flow. It is the shallow groundwater flow that is responsible for the low values shown in the central part of the Cascade Range in California (Figure 1). There is a relatively sharp boundary between the low and high heat flow zones, although this boundary is not as well explored as it is in central Oregon.

Southern Cascade Range. North of the California border, there are extensive heat flow data in the heat flow region west of the Cascade Range and in the local area of the Klamath Falls Basin. Heat flow in the Klamath Falls Basin is highly affected by geothermal circulation and heat flow values range from 10 to over 1000 mWm^{-2} (see Sass and Sammel, 1976). The Crater Lake volcano also occurs in southern Oregon. Although little regional heat

Scott Lindeman — Dr. James Myers
U of Wyoming

- core from Newberry
- call ahead of time

- take samples
- petrologic + isotopic
- order of 5-6" samples needed - every 15-20 m

Wed. morning

Pretty sure of NSF grant
- he will be working @ Newberry

1. How long to finish project? Should be timely.
2.

isotope
probe
bulk
petrog

tie to Scott's work on surface geol.

VICTOR ATIYEH
GOVERNOR

Department of Geology and Mineral Industries

ADMINISTRATIVE OFFICE

910 STATE OFFICE BLDG., 1400 SW 5th AVE., PORTLAND, OR 97201-5528 PHONE (503) 229-5580

MEMORANDUM

To: Interested Persons Date: August 28, 1986

From: George Priest

Subject: Results of the Rapid City conference on Scientific Drilling

The Program for Scientific Drilling in the Cascades (PSDC) was presented at the Continental Scientific Drilling (CSD) meeting in Rapid City on June 13, 1986. The PSDC was favorably received and recommended by the reviewers. A short letter from Frank Stehli summarizing some of the general review comments is enclosed. A more detailed letter with specific recommendations from the CSD reviewers to the Basic Energy Sciences Division of USDOE will be arriving soon.

I have organized a steering committee for the PSDC to facilitate proposal preparation and management. The following people will be representing the major participating organizations:

Harve Waff, University of Oregon
Richard Couch, Oregon State University
David Blackwell, Southern Methodist University
Craig Weaver, United States Geological Survey
George Priest, Oregon Department of Geology and Mineral Industries
Michael Korosec, Washington Department of Natural Resources
Norm Goldstein, Lawrence Berkeley Laboratory
John Rowley, Los Alamos National Laboratory

The steering committee will have its first meeting on September 23, 1986. Officers will be elected and final priorities for the PSDC will be set.

Enclosure

DOSECC INC.

SCIENCE ADVISORY COMMITTEE
Francis G. Stehli, Chairman
Jo Ann Ross, Admin. Assistant
601 Elm Street, Room 438C
Norman, OK 73019 • (405) 325-6111

DEEP OBSERVATION AND SAMPLING OF THE EARTH'S CONTINENTAL CRUST

August 8, 1986

Dr. George Priest
Department of Geology and Mineral Industries
1005 State Office Building
Portland, OR 97201

Dear George,

At its June meeting in Rapid City, the Science Advisory Committee of DOSECC considered the presentation you made on "First Phase of a Program for Scientific Drilling in the Cascades." The presentation is somewhat more focused than was the case at the Houston workshop and was, therefore, more favorably viewed. The subject is clearly one in which we would expect DOE, as well as DOSECC, to be involved. The next step would be to proceed to the pre-proposal stage so that serious consideration of your project could begin in terms of priorities among the various items with which it would compete for funding. This would also allow the various agencies and groups that might be interested to determine the level of that interest.

To accomplish your goal clearly requires the east-west transect you have suggested. However, such a traverse would have to begin with a first well, and the primary experiment for that well should be clearly defined and then related to the additional experiments that subsequent holes on the traverse would allow. In emphasizing the primary experiment of each hole, I do not mean to suggest that SAC is not interested in the secondary experiments that the hole will make possible, for we hope they will be many and significant. However, every hole will allow interesting secondary experiments and, therefore, it is really the quality of the primary experiment that justifies drilling at a particular site and determines priority.

I am including a copy of our guidelines for proposal and pre-proposal preparation.

Sincerely yours,

Frank

Francis G. Stehli, Chairman
Science Advisory Committee

FGS/jr

Enclosure

M. Wright

Lawrence Berkeley Laboratory
1 Cyclotron Road Berkeley, California 94720
(415) 486-4000 • FTS 451-4000

May 9, 1986

Marshall Reed
Geothermal Technology Division
Department of Energy CE-342
Washington, DC 20585

Dear Marshall:

For your information I am enclosing a copy of the notes prepared by Norm Goldstein on our recent meeting with Chevron.

Sincerely,

Marcelo

Marcelo J. Lippmann
Earth Sciences Division

Encl.

cc: M.Molloy (w/encl.)
S.Prestwich (w/encl.)

Notes from a Meeting between Jerry Epperson and Earl James of Chevron Geothermal Company of California (Chevron) and Marcelo Lippmann and Norman Goldstein of LBL, 6 May 1986

Jerry Epperson and Earl James gave brief descriptions of the Chevron geothermal properties. They discussed a little about the geological features of each and the data base available. We touched on some of the questions that need to be answered. They indicated that their main interest in any DOE cooperative study was in the area of geology-geophysics-well log interpretation.

Cascades

Chevron has four project areas in Oregon. Thermal Power has a farm-in situation on the Clackamas prospect where a DOE-industry joint venture temperature gradient hole will be drilled in June, weather permitting. Chevron has property in the Newberry caldera area. Little was discussed about any of the prospects, presumably because all are in the early stages of exploration.

Basin and Range Systems

1. **Soda Lake, NV:** Three wells have been drilled; full suites of logs are available. The reservoir seems to be associated with high-angle faults in Tertiary volcanics. Little if any core was taken, but there should be a full set of cuttings at the Chevron "core shed" in Richmond.

   Chevron thinks that a small (~2 MW) plant may be possible.

   There are several ground geophysical surveys, one of which is an EM survey done by LBL. Data have been released as part of the old DOE-Industry-Coupled Exploration Program. EM and MT data show a conductor associated with sediments overlying the volcanics. Seismic data identify the faults.

2. **Beowawe, NV:** This is another fault-charged reservoir. The Malpais fault zone seems to be a system of parallel faults into which several wells have been drilled. The deepest well is Ginn (1), drilled to 9600′. Well 85-15 was a DOE-industry coupled well for which UURI has all results; e.g., cuttings and full suite of logs.

   Fluid production is from two wells (Ginn 1 and 2) and injection is into Batz 1 well to the east. The deviated latter well was to the south to intersect the Malpais fault zone. Chevron is monitoring pressures in the three wells plus in wells 33-17 and 85-15. A 16 MW plant has been operating since December. The injection well isn't handling all the fluid and Chevron has the temporary right to use surface disposal.

   The produced fluids are a calcium-chloride type of water, 1100 to 1200 ppm TDS, but supersaturated in SiO_2. Thus far scaling has not been a problem.

   A microseismic monitoring net is being maintained by an outside contractor. Chevron also has to relevel every year.

   Suggested topics for research are to characterize the Malpais fault zone out to the west, and to use dc resistivity for monitoring reinjection.

   There is an SP anomaly associated with the Beowawe production wells. Interestingly, the amplitude of the anomaly varies with season (mainly rainfall) and with well production.

   The University of Wyoming (Scott Smithson?) has a proposal to DOE to run a VSP survey in the Rossi well.

3. **Desert Peak, NV:** Located east of Brady H.S., Desert Peak was acquired from Phillips but there has been very little published about the property (see Benoit et al., 1982).

   Prospect was discovered by Phillips while exploring Southern Pacific sections using shallow temperature holes. There are now 2 producing wells, 1 injection well and a 10 MW plant.

Geologically, Desert Peak appears to be another fractured system; the principal faults are NE-trending and the prospect may reside within a horst block.

4. **Roosevelt, UT:** A lot has already been published about this field. There are four production wells aligned roughly N-S and subparallel to the Opal Mound fault. There are three designated injection wells, but most of the fluid goes into 14-2. The field has been in operation around two years. There is complete production and pressure monitoring data for that time.

   It is widely known that production comes from the fractured-faulted Tertiary granite, but the nature of the heat source has not been established.

Imperial Valley-Salton Trough

Heber now seems to be another reservoir that may be fault-fracture controlled. On the basis of the more recent production and injection holes, Earl James believes he can identify two major faults; a normal fault running nearly N-S, and a strike-slip fault trending WNW. The faults intersect near the center of the heat flow anomaly.

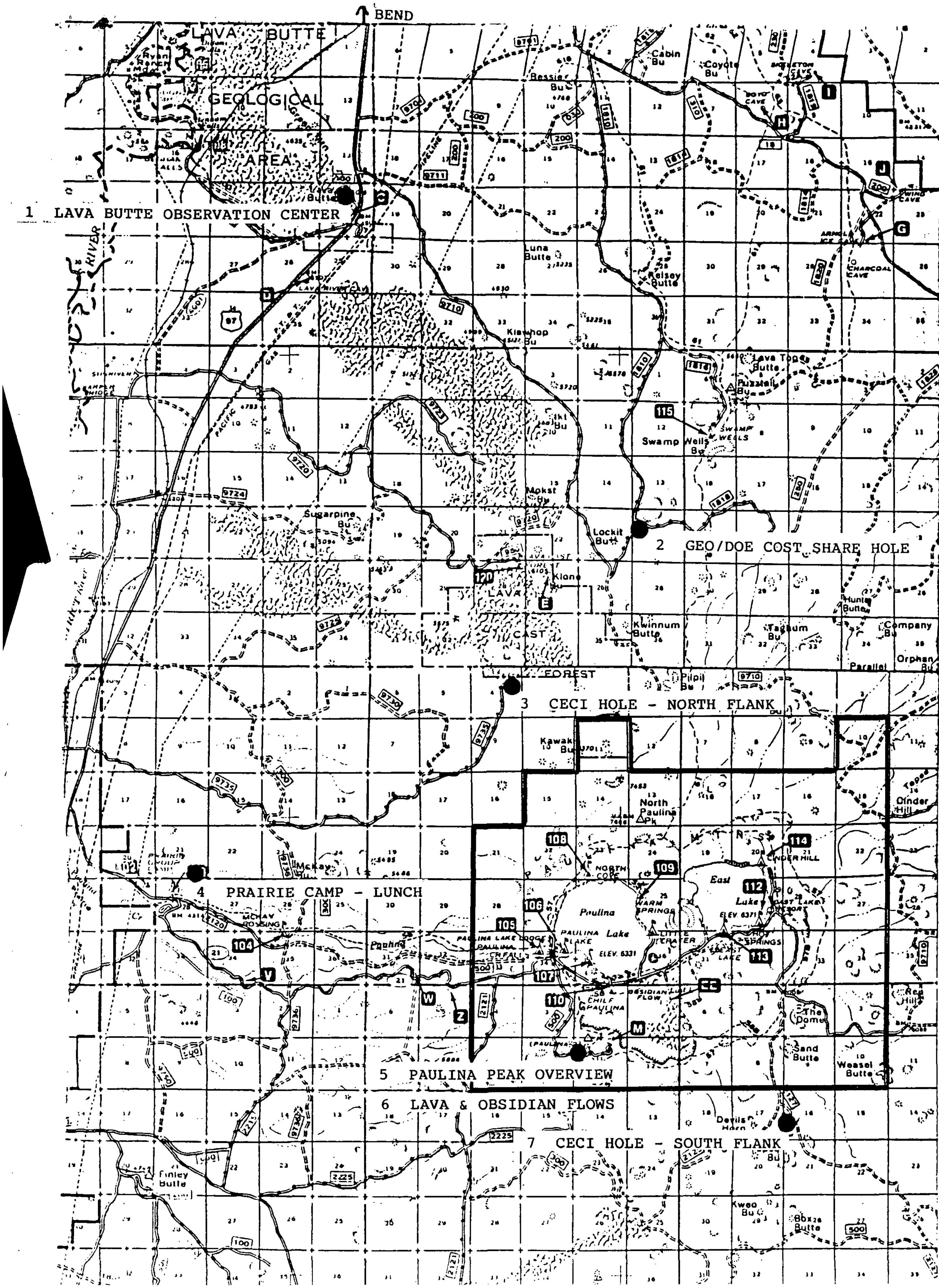
UURI has requested cuttings from one well to study hydrothermal alteration. There are some cores, but full suites of logs were run in only a few selected wells (γ, SP, Sonic, dipmeter, and neutron). Limited logs were run in the other wells. Earl said he couldn't make any easy correlations using the well logs.

There are some surface geophysical studies. Surface seismic reflection was never done and now that everyone in Chevron agrees it is needed, there is no money to do it. A Chevron contractor has acquired four years of seismic monitoring data. Chevron has tried to acquire SP on several occasions but the results do not indicate a clear anomaly.

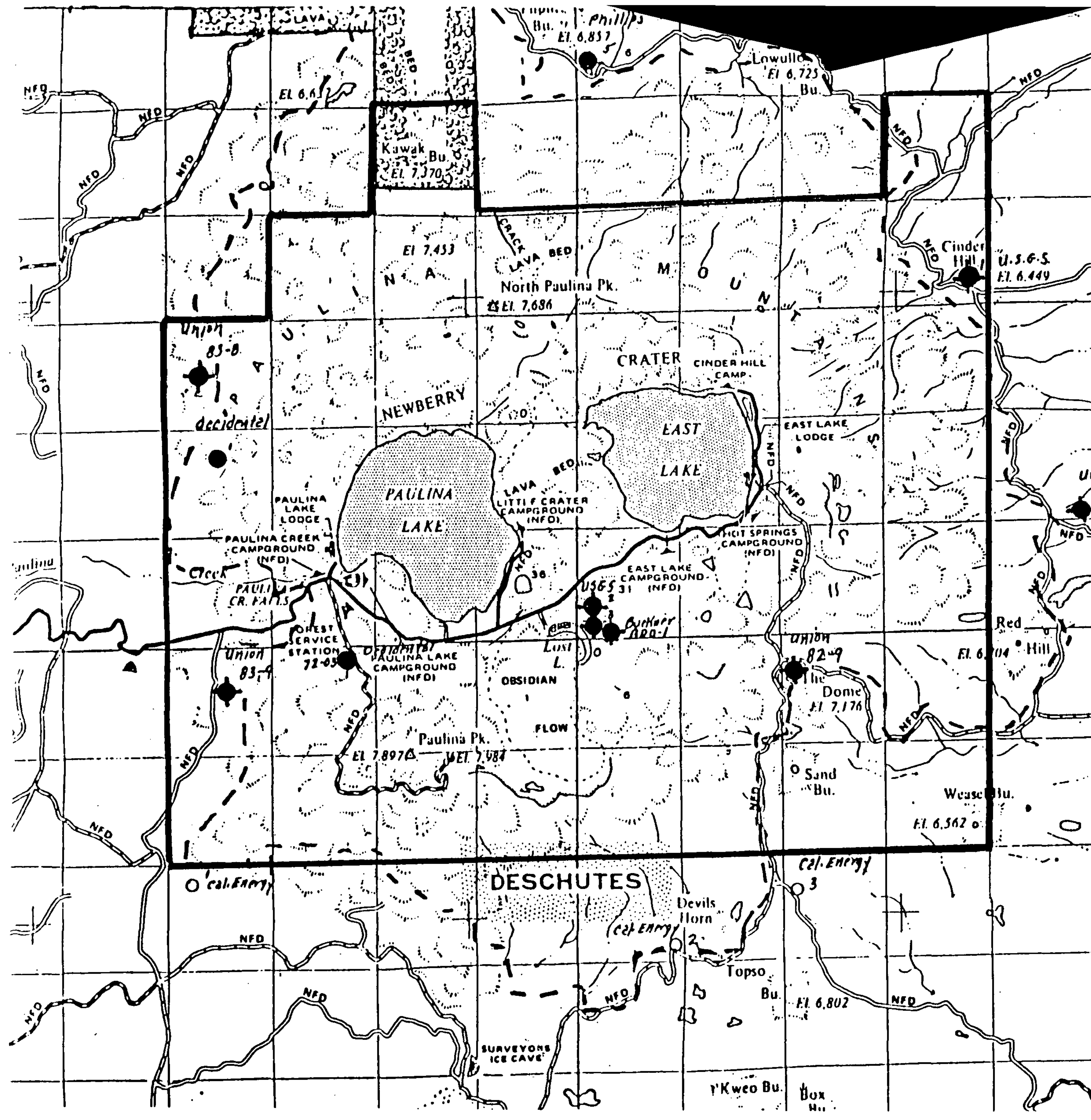
Gravity data were collected by R. Grannell in 1982, but data not yet interpreted. Goldstein showed the East Mesa gravity inversion results and it was agreed that a similar analysis of the Heber data might yield some interesting new information on the fault system.

We also discussed the possibility of a VSP survey. Chevron thinks well HGU-13, not a production well, would be good for this. The well was drilled to a depth of 11,000 feet.

Lippmann made the suggestion that S. Halfman might look at logs from a four-well spread in the center of the field to look for evidence of faulting. We all agreed that the LBL work should be coordinated with the UURI proposed study of alteration.


BEND
LAVA BUTTE GEOLOGICAL AREA
1 LAVA BUTTE OBSERVATION CENTER
2 GEO/DOE COST SHARE HOLE
3 CECI HOLE - NORTH FLANK
4 PRAIRIE CAMP - LUNCH
5 PAULINA PEAK OVERVIEW
6 LAVA & OBSIDIAN FLOWS
7 CECI HOLE - SOUTH FLANK
Paulina Lake
East Lake
North Paulina Pk
LAVA CAST FOREST

TEMPERATURE GRADIENT HOLE LOCATION MAP
NEWBERRY VOLCANO



EXPLANATION

- ● WELL LOCATION
- SUSPENDED WELL
- PLUGGED AND ABANDONED WELL
- NEWBERRY CALDERA KNOWN GEOTHERMAL RESOURCE AREA
- AREA CONSIDERED UNSUITABLE FOR THE SITING OF GEOTHERMAL POWER PLANTS BY EFSC

SCALE: 1"=1 MILE

DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1005 STATE OFFICE BUILDING
PORTLAND, OREGON 97201

JULY 26, 1984

IN CONJUNCTION WITH CALIFORNIA ENERGY COMPANY AND THE

PACIFIC NORTHWEST SECTION - GEOTHERMAL RESOURCES COUNCIL

YOU ARE CORDIALLY INVITED TO AN OPEN HOUSE

LIBATIONS AND HORS D'OEUVRES

THIS EVENING - SEPTEMBER 24, 1986

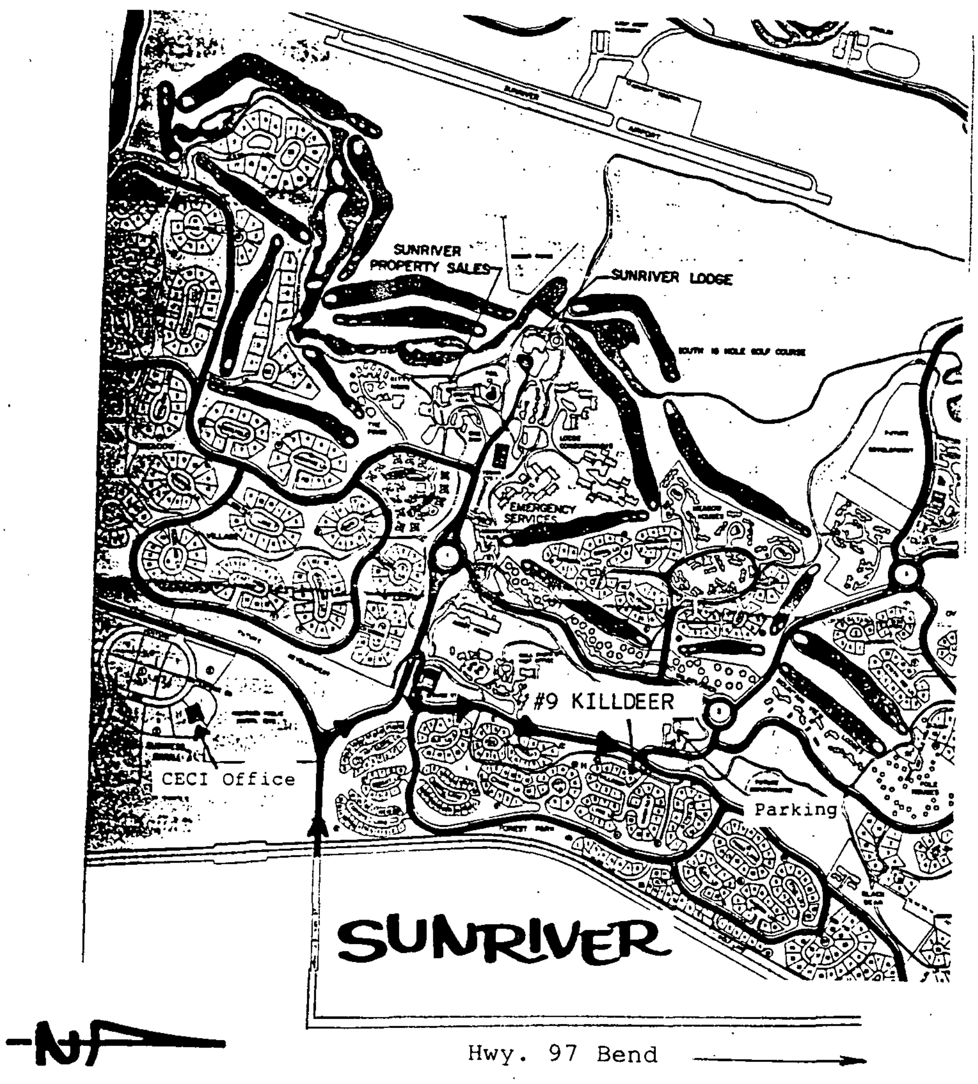
6:00 P.M. - 8:00 P.M.

#9 KILLDEER, SUNRIVER, OREGON - 593-2404

CARAVAN TRANSPORTATION PROVIDED

DEPARTING RIVERHOUSE LOBBY PROMPTLY AT 5:30 P.M.

RETURNING TO RIVERHOUSE AT APPROXIMATELY 8:00 P.M.



Steve Ingelutson

October 20, 1986

MEMORANDUM

To: Contributors to the PSDC
From: George Priest G.P.
Subject: Inclusion of an in situ stress measurement in the Willamette Valley.

I am now writing the final draft of our science plan, and it occurred to me that the in situ stress part was weak without a measurement outside of the Cascade heat flow anomaly. There are a number of abandoned oil and gas exploration holes in the Willamette Valley which can probably be reentered and deepened slightly for hydrofracturing and strain-release measurements of rock stress. Adding this task to the proposal would add about $150,000 to the budget.

I would like your reply on the necessity of adding this task to the proposal <u>as soon as possible</u>. I am in a real time crunch to get the plan written and in for a final review, so get back to me quickly on this.

STATE OF OREGON 1859
VICTOR ATIYEH
GOVERNOR

Department of Geology and Mineral Industries
ADMINISTRATIVE OFFICE
910 STATE OFFICE BLDG., 1400 SW 5th AVE., PORTLAND, OR 97201-5528 PHONE (503) 229-5580

October 8, 1986

Michael Wright
University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, UT 84108

Dear Mike:

I would like to thank you for your help and cooperation in sampling the Thermal Power hole this summer. The supplies that you provided were very helpful.

We will not have time to do very much laboratory work on the samples until after we finish our McKenzie Bridge geologic map. This will be sometime in March, 1987. We hope to complete thin section and chemical analysis of the core during the spring of 1987. It would be useful to have a good detailed log of the fractures, shear zones, and flow boundaries to add to the compositional data we will produce. The lithologic log generated by Thermal Power seems, from my cursory examination in the field, to be woefully inadequate with regard to this structural data. If your lab plans to generate this data, I would like to know when it will be available. If not, then one of our group will have to make arrangements with you to have access to the core in Salt Lake City for the week or so that it would take to relog the core.

I will be looking forward to your reply. Thanks again for your cooperation.

Best regards,

George R. Priest

George R. Priest
Regional Geologist

cc Susan Prestwitch

CALIFORNIA ENERGY COMPANY, INC.

TELECOPY TRANSMITTAL

Date: 10/27/86 — This transmission 1 pages.

TO: Susan Prestwich
U. S. Deptartment of Energy, ID
Telecopier No: (208) 526-0524
Confirmation Bernice: 526-1503

TO: Mike Wright
University of Utah Research Institute
Telecopier No: (801) 524-3453
Confirmation Beth: 524-3422

Transmitted By: Sonja Rath
California Energy Co., Inc.
3333 Mendocino Avenue, Suite 100
Santa Rosa, CA 95401
(707) 526-1000
Telecopier No: (707) 526-0504

MAZAMA I CORE HOLE MZI-11A

DAILY REPORT

DATE: DAYS SINCE SPUD:

TIME:

DEPTH:

FOOTAGE DRILLED SINCE LAST REPORT:

PERCENT RECOVERY:

COMMENTS: 10/24/86 Quit drilling @ noon @ TD of 1354'. Pulled out of hole and laid down pipe to allow temperature to stabilize.
10/25/85 Put rods back in hole and ran temperature survey.* Al Waibel (Columbia Geo Science) ran temperature log and tripped out of hole, laid down pipe and began tearing down.
10/26/86 Tearing down.
10/27/86 Tearing down.

* Calculated temperature survey--will be reported later.

JLF:sr:42

TOTAL ESTIMATED COST TO DATE: $102,000.00

By: Dave Workman

cc: CTC, HHR, GV, RT, DW

Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

MEETING REPORTS:

1). USGS WORKSHOP ON GEOTHERMAL RESOURCES OF THE CASCADE RANGE
- May 22-23, 1985, Menlo Park, CA -

2). DOE-USGS-BPA-USFS CASCADES GEOTHERMAL COORDINATION GROUP
- May 23, 1985, Menlo Park, CA -

3). PROGRAM FOR SCIENTIFIC DRILLING IN THE CASCADES
- May 24, 1985, Menlo Park, CA -

SUMMARY

A series of three, interrelated meetings were held over the May 22-24, 1985 period at the USGS Western Regional Headquarters in Menlo Park, CA. The first meeting consisted of a major presentation for the scientific community and industry of USGS geothermal research in the Cascades Range. The second meeting was a management coordination meeting of the four Federal agencies cooperating in Cascades geothermal evaluation. The third meeting was of investigators who are cooperating in a proposal to drill a deep hole in the Cascades.

In summary, major scientific insights are being gained by the separate earth sciences disciplines which are conducting geothermal research in the Cascades. However, we are in the early stages of information gathering, critical data is still missing on the High Cascades, and little integration of existing scientific information has been accomplished. Except for surface geologic mapping, little definitive knowledge of the Cascades exists. We are only beginning the attempt to draw definitive cross-sections, to propose geophysical surveys, and to suggest well sites to gather the knowledge necessary for geothermal evaluation.

USGS strategy will focus on an east-west transect across the High Cascade axis in Central Oregon at Santiam Pass. A conceptual geologic model developed here is expected to hold to the north and south through the Central Oregon Cascades. The USGS strategy will form the basis for cooperative Federal efforts to establish the Cascades geothermal potential. Information collected along the Santiam Transect will contribute to the siting of a deep hole in the Cascades, complimenting the efforts of those scientific investigators.

1). USGS WORKSHOP ON GEOTHERMAL RESOURCES OF THE CASCADE RANGE

On May 22-23, the USGS conducted a major review of their Cascades research at the USGS Western Regional Center in Menlo Park, CA. The two-day Workshop was organized into four sections: regional setting, magmatic heat sources, hydrothermal systems, and conceptual models for drilling. More than 60 attended, including all the USGS experts, exploration and management personnel from the geothermal industry (Union, California Energy, Geothermal Resources, Thermal Power, Chevron, and consultants), federal and state agencies (BLM, DOE, CDOG, CDMG, BPA, USFS, CA State Lands Commission), laboratories and universities (LBL, UURI, SMU, U. OR, Portland State, OR State). Abstracts were distributed, and publication of a Proceedings is expected.

In summary, a major gathering together of data and interpretations by individual specialists was accomplished. Many detailed insights were discussed by the most respected authorities in the many disciplines which have been brought to bear on the Cascades enigma. However, there was a major lack of integration or comparison of separate specialists' interpretations. We are at the early stages of information gathering, with few constraints to limit the proposal of fragmentary theories. The High Cascades is an almost total scientific blank. While surface geology is being mapped, few cross-section interpretations have been attempted; a fundamental requirement for siting drillholes and predicting rock formations to be penetrated at depth. Geophysics - a major exploration tool - is almost non-existent. Few springs exist for geochemical analysis; isotopic data indicate very long travel times, while geothermometry suggests we are sampling "lateral outflow" from higher temperature sources at significant distance.

Except for regional heat flow drilling, we are premature in drilling exploratory holes in the High Cascades. Extensive integration of existing data can be accomplished first. Identification of critical gaps in data, and lay-out of key geophysical surveys by a cooperative USGS-UURI-LBL-Industry team can follow. Essential calibration of geophysical surveys can be accomplished at available drillholes, and these surveys can be tightly coordinated with any new drilling. Through such careful preparation, we may be able to avoid repeating the unsuccessful drilling results of the DOE-USGS Mt. Hood effort (1978-81, est. $7.2 M).

2). DOE-USGS-BPA-USFS CASCADES GEOTHERMAL COORDINATION GROUP

On the evening at the end of the USGS Cascades Workshop, a working meeting of Federal program managers was held to review status and plans. Present were USGS/Patrick Muffler and Donald Klick (Reston); BPA/Walter Myers, John Geyer and Tom White; and, DOE-HQ/Marshall Reed and DOE-SAN/Martin Molloy. DOE-ID/Clay Nichols and DOE-SAN/Anthony Adduci were invited, but were unable to attend.

The agenda covered:

- What does the Survey's summary of Cascades knowledge at their Cascades Workshop mean; what do USGS & DOE do next as a result?

- Status of the Interagency Cascades Memorandum; relation to Memorandum of Understanding on Cascades Drilling (DOE/ID-USFS-BLM)

- List of Cascades action items to work next.

- Cascades Geothermal Forum (next annual meeting).

USGS/Muffler declined to try and summarize the knowledge resulting from the Survey's Cascade Workshop. He will be emphasizing the integration of the USGS scientific results presented at the Workshop. Pat's Cascades strategy is to focus the Survey's work on the Central Oregon transect through the High Cascades at Santiam Pass. With data from drillholes along this transect, he expects to be able to form a conceptual model which can be extrapolated to the north and south, through half of the Oregon Cascades. This strategy is based on the belief that a huge north-south trough ("graben") contains the High Cascade axis, and is filled by the major stratovolcanoes. Pat expects the geology of this part of the Cascades to be relatively consistent within the trough, from the fault margin along the Western Cascades, to the Green Ridge fault boundary on the east. He notes that the USGS strategy is complementary to DOGAMI/George Priest's proposal for a deep scientific well in the Cascades. USGS/Klick observed that drill holes will draw scientific studies to those locations.

The Interagency Memorandum was signed by BPA and USFS (Region 6), and mailed to DOE/HQ for signature and transmittal to USGS. DOE/Reed and USGS/Klick have resolved concerns relating to designation of specific individuals. This level of detail will be dropped from the Memorandum, which is then ready for signature by both agencies.

Desmond Bain of Forest Service Region 5 in San Francisco has inquired of SAN what the relationship is between the DOE-ID Cascades Drilling Memorandum of Understanding (MOU) and the Interagency Cascades Memorandum. The Cascade Drilling MOU concerns immediate implementation of permitting and land management regulations for DOE-ID drilling contracts to be announced in July. The purpose of the Interagency Cascades Memorandum is long-term regional evaluation and planning, through coordination of federal activities. The ID MOU is short-term, detailed implementation; the Memorandum is long-term, broad coordination. Both documents deal with Federal Cascades geothermal geothermal activities; the relation between the two could have been made explicit.

DOE's drilling and confirmation activity could not be discussed, since Idaho Operation Office's Source Evaluation Board has not announced the results of ID's solicitation for intermediate depth (3,000') thermal gradient holes in the Cascades, cost-shared with industry. ID plans to issue any contracts by July, to allow drilling during the 1985 season.

BPA reported that the Northwest Power Planning Council has drafted an Issue Paper on Generation Resources for the NW Region. The Council's paper emphasizes efficiency in the near-term, like hydropower and thermal improvements. For the long-term, the Council raises geothermal potential of the region (not just the Cascades). Bonneville expects to respond to the resulting Council Action Plan with the feasibility and priority of elements needed, including the geothermal scenario. BPA will work with Council consultants, Technical Advisory Groups, State Energy Offices, and Industry in responding to the Council. (USGS and DOE input will be of major importance, of course.)

In a sense, the USFS Cascades Workshop served the function of an unofficial first annual Cascades Geothermal Forum. Each January, the USGS reviews its geothermal research program. It would be timely to schedule the Cascades Forum in late winter or spring, to follow the internal USGS reviews. Muffler expects to summarize USGS results at the Forum, rather than have presentations by individual Cascades researchers. The Cascades Forum can summarize: interrelated activities of the Federal participants; understandings gained of geothermal potential; issues of concern; activities and status; results; and planned actions. By the end of the first year of cooperative federal efforts, results are expected to include: USGS geologic field season activities; DOE-ID Solicitation and drilling results; NW Council Geothermal Implementation Plans; and, USFS-BLM interrelated activities.

The draft Memorandum identifies the Forum as the principal means of informing utilities in the region of the Cascades geothermal potential. Concerns of State agencies and industry are to be covered, as well. (The USGS meets annually with State Geologists in Western States Cluster Meetings.)

The next meeting of the Coordination Group should occur after DOE-ID announces the results of their Cascades drilling proposal selection in July.

Action items and responsibilities identified at this meeting are:

1. Chart of Significant Cascades Events: agency activities in progress or planned for the Cascades Region: USGS, DOE, BPA, USFS.

2. Statement of Cascades Strategy: comprehensive identification of key resource assessment and reservoir definition activities, sequence, and relation to complimentary projects like the Cascades Deep Well: USGS, DOE.

3. Coordination of Agency Cascades Activities: through the Coordination Group: USGS, DOE, BPA, USFS.

4. Documentation of Cascades Workshop: timely "grey papers": USGS (with DOGAMI).

5. Cascades Forum Definition: what do we need to lay out at meeting; who do we need to invite?: USGS, DOE, BPA (USFS).

3). PROGRAM FOR SCIENTIFIC DRILLING IN THE CASCADES

The day following the USGS Cascades Workshop, a small group led by Dr. George Priest of Oregon Division of Geology and Mineral Industries (DOGAMI). The group has drafted a comprehensive proposal for a deep (10 km) scientific well in the High Cascades. As a result of converging strategies by Priest and USGS's geothermal leader, Pat Muffler, the group focussed on an East-West line of intermediate-depth (~3,000') heat flow holes across the axis of the High Cascades at Santiam Pass, in central Oregon. Data from these holes along the "Santiam Transect" are expected to result in information necessary for siting the deep scientific well. By June 10th the participants are to prepare cross sections and maps (geology, gravity, aeromagnetics, electrical resistivity, seismic, heat flow, hydrology, and hydrothermal alteration) for the Santiam Transect. DOGAMI/Priest will combine these inputs into a coherent proposal. The same inputs are of major importance in guiding current USGS and DOE Cascades efforts, which focus on estimating recoverable thermal energy, and locating geothermal reservoirs shallower than 10,000'.

By June 19th, SAN/Molloy had received Santiam Transect cross-sections and written summaries for geology (with gravity, aeromagnetics, and age-dates) from USGS/Sherrod, and seismics (to 200 km depth, showing the oceanic plate descending beneath Cascades) from USGS/Evans and Iyer. In addition, LBL/Goldstein distributed his summary of the Mt. Hood geophysical surveys.

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cc: HQ/Reed
BPA/Myers, Geyer, White
USGS/Muffler, Klick
USFS-R5/Patchen
ID/Nichols, Prestwich
SAN/Vaeth, Adduci, Holman
LBL/Lippmann, Goldstein
Stanford/Gudmundsson, Horne
UURI/Wright
LLNL/Kasameyer