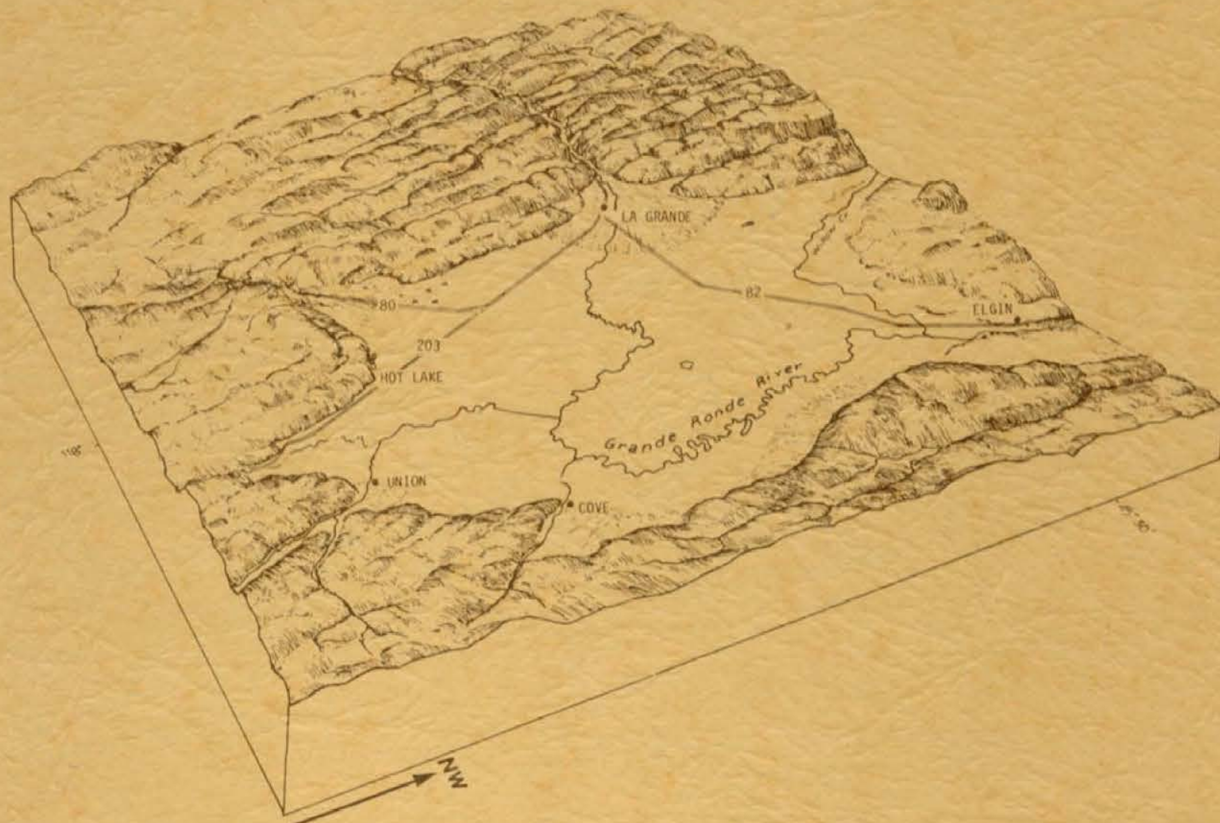
SPECIAL PAPER 6

GEOLOGY OF THE LA GRANDE AREA, OREGON



1980

STATE OF OREGON

DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

D.A. HULL, STATE GEOLOGIST

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1069 State Office Building, Portland, Oregon 97201

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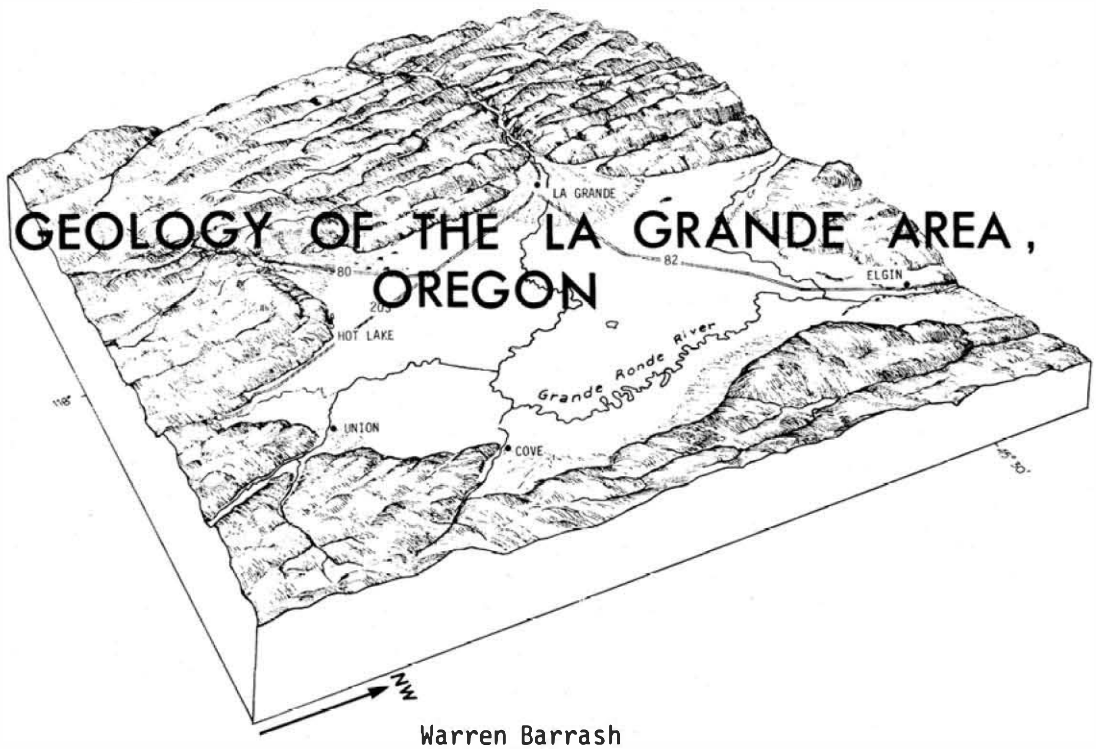

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Conducted in conformance with ORS 516.030
Funded by the Oregon Department of Geology and Mineral Industries
under contract with the U.S. Department of Energy
DE-FC07-79ET27220

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INTRODUCTION

Purpose and Scope

The La Grande-area mapping program was undertaken by Geoscience Research Consultants for the Oregon Department of Geology and Mineral Industries to provide stratigraphic and structural data concerning rocks of the Columbia River Basalt Group exposed west of the upper Grande Ronde Valley. These bedrock parameters are to be incorporated in the State's program to evaluate the availability of geothermal energy near La Grande.

The emphasis of the field examination was 1) to determine the stratigraphic sequence and structural configuration of Tertiary volcanic and interflow units which are exposed in the uplands west and south of La Grande and 2) to project these data to the lowlands of the Grande Ronde Valley near La Grande. Photo interpretation of linear and structural features is included in the evaluation and has been extended to adjoining areas to gain added structural and geothermal perspective. Post-Tertiary sedimentary units were examined to interpret relative ages of the latest structural adjustments.

Acknowledgments

The writers thank the personnel of the Oregon Department of Geology and Mineral Industries for their field conferences and prompt assistance throughout the project. We thank Dr. William H. Taubeneck of Oregon State University for his discussions and comments about our geologic observations and interpretations during the field study. As noted in the text of this report, we have drawn freely upon his comments and on the stratigraphic setting he has reported for correlative rock units in adjoining areas. We wish to acknowledge the consultation provided by Boyd Hadden, Oregon State Water Master in La Grande and his assistance in obtaining well-log data relative to the field area.

We also thank Dr. Susan A. Price of Rockwell Hanford Operations for incorporating rock samples from the La Grande field program into the on-going Columbia Plateau regional geologic and X-ray fluorescence analytical study. As a result, La Grande-area geochemical data are directly comparable to those of Columbia River Basalt Group samples from across the Columbia Plateau.

Program Summary

Chronology and presentation of 1979 study

The field portion of the 1979 La Grande-area study began in early June and continued until early September. Field procedures followed routine basalt-mapping techniques including use of portable fluxgate magnetometers. Field data and observations are presented on geologic maps and cross sections. Photo interpretation of black-and-white, vertical stereo airphoto pairs was completed during July; interpretation of 35 mm color oblique stereo airphotos was completed in mid-September. Photo data are on geologic maps and in schematic diagrams. Examination of logs and cuttings from the Magma-La Grande Well No. 1 was completed in September. Outcrop samples, together with cuttings samples, were submitted for X-ray fluorescence analysis near the end of the field program; data are summarized in tabular form in the stratigraphic discussion.

Division of work

Field work was conducted by geologists Warren Barrash, John D. Kauffman and John G. Bond in the general areas of Craig Mountain-Glass Hill, Hilgard uplands and Grande Ronde Canyon, respectively. Photo interpretation and linear analysis was by Ramesh Venkatakrishnan of the Geophotography and Remote Sensing Center of the University of Idaho. X-ray fluorescence analysis was performed by the Basalt Study Group of the Department of Geology, Washington State University.

General Setting

Location and access

Field mapping near La Grande concentrated on an area covered by four 7 1/2-minute quadrangles: Hilgard, La Grande SE, Glass Hill, and Craig Mountain; these quadrangles include the southwestern portion of the Grande Ronde Valley and adjacent uplands (Figure 1). The area encompasses approximately 200 sq mi (575 sq km) and includes locales informally referred to in this report as Hilgard uplands, Grande Ronde Canyon, La Grande front, Glass Hill, Craig Mountain, Craig Mountain front, Ladd Canyon, Hot Lake and Grande Ronde Valley (Figure 2).

The principal vehicular access route to the La Grande area is US Interstate Highway 80 North (I80N).* This highway connects the study area with Pendleton to the northwest and Baker to the south by way of Hilgard and Ladd Canyon respectively. State Highway 82 connects the study area with Enterprise to the east by way of Island City and Elgin. Farm-to-market roads provide access to most lowland areas near La Grande; numerous haulage and logging roads offer fair-weather access to undeveloped uplands. However, most private lands in rural portions of the study area are posted for no trespassing; specific permission must be obtained for field entry.

Physiography and climate

The study area is within the Blue Mountain section of the Columbia Plateau (Fenneman, 1931). Topographically, the area about La Grande is characterized by sediment-filled lowlands of the Grande Ronde Valley on the east and basalt-bedrock uplands of the Blue Mountain backslope on the west. Abrupt, linear escarpments mark the boundary between the two types of landforms.

The Grande Ronde River has incised a meandering course across the Hilgard uplands west of La Grande and a basalt-bedrock section is well exposed there. South of La Grande, in the Glass Hill area, a comparable stratigraphic section of basalt has been exposed by Ladd Creek and its youthful tributaries. Overall relief in these areas is up to 2300 ft (700 m).

The climate of the study area is typical of temperate areas (Hampton and Brown, 1964, p. 4-8). Summer high temperatures typically exceed 90° F (32° C); winter low temperatures often fall below 10° F(-12° C). Average yearly precipitation is between 13 and 23 in (33-58 cm) in the general vicinity of the study area; highlands commonly receive greater amounts of precipitation. Most precipitation falls in cooler months with July through September showing a marked summer-time decrease.

Previous Work

Early geologic studies in eastern Oregon used physiography and stream-pattern development to interpret structural geology. Buwalda (1921) observed that the La Grande-Baker-Huntington series of valleys was a structural depression between the Wallowa Mountains on the east and the Blue Mountains on the west. Livingston (1938) described post-Miocene structures in northeastern Oregon and placed the Grande Ronde Valley in a setting of

*At the time of report preparation, I80N was being redesignated I82.

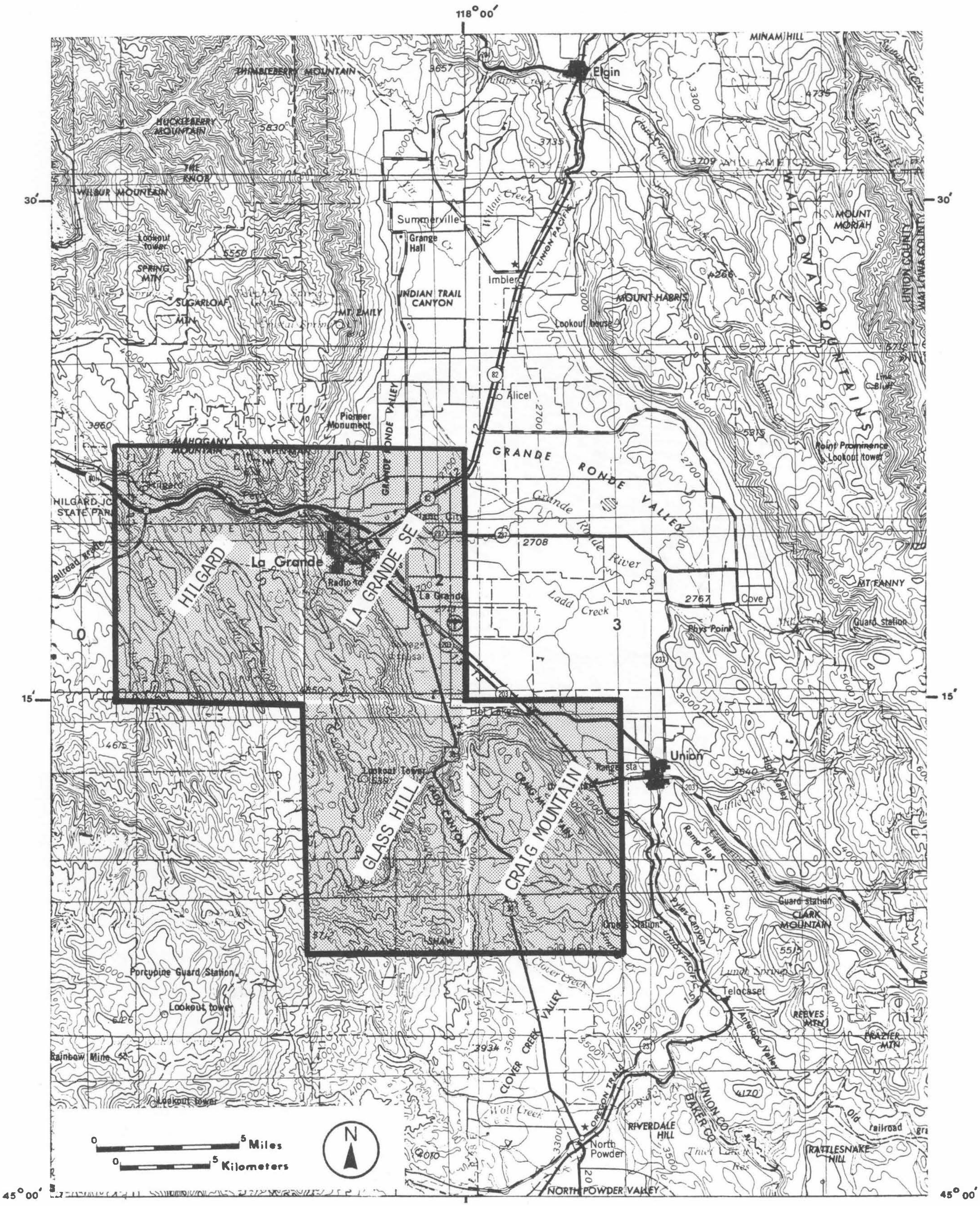

Figure 1. Location of 7 1/2-minute quadrangle base maps.

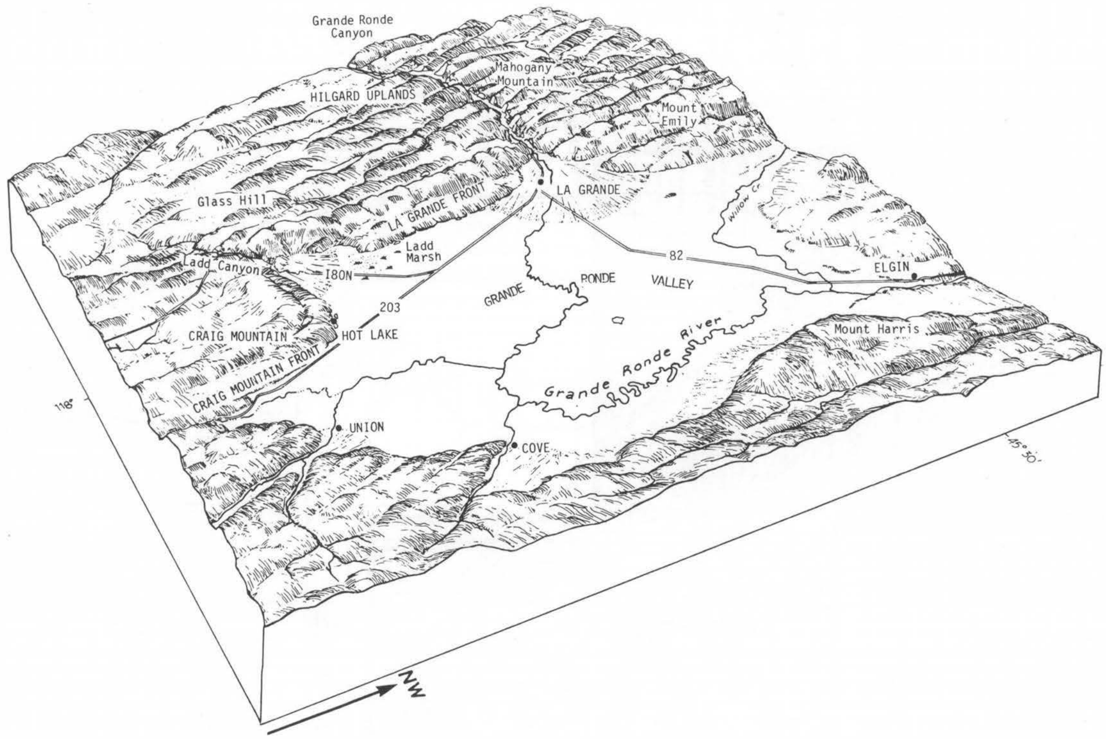

Figure 2. Location of reference features near La Grande.

drainage-pattern development and topographic relief formed by relatively young faulting and uplifts. He observed stream-drainage changes as in the Powder River south of the study area. He interpreted eastward deflection of this stream to have resulted from relatively rapid structural uplift along the margin of the Grande Ronde Valley and blockage of the ancestral north-flowing stream. Livingston also noted that Union and Hot Lake hot springs are at the base of a major northwest-trending (Craig Mountain front) fault scarp.

Several investigators have conducted geologic mapping more recently in and around the study area. Hampton and Brown (1964) mapped the upper Grande Ronde watershed at the scale of 1:62,500. They described the major pre-Tertiary, Tertiary and Quaternary geologic units and structures and discussed ground-water resources of the area. Schlicker and Deacon (1971) mapped 70 sq mi (180 sq km) near La Grande and concentrated on environmental and engineering aspects of geology. They emphasized the presence of interbeds within the basalt section and the relation of interbeds to landslides along escarpments.

On a plateau-wide basis, Newcomb (1970) depicted the structural configuration of the Columbia Plateau. His geologic map(1:500,000) clearly demonstrates the marked northwesterly trending horst-graben-step faulting displacement present in the study area and the Grande Ronde Valley-Hilgard upland position relative to the Blue Mountains. Walker (1973b, 1979) published two reconnaissance geologic maps at the scale of 1:250,000; these place the present study area in the regional geologic framework of northeastern Oregon (Figure 3).

Gardner and others (1974) prepared an unpublished report for Amax Exploration, Inc. which dealt with the geology and geothermal potential of the La Grande-Baker area. They compiled earlier work and added new mapping at the scale of 1:62,500. Magma Energy, Inc. drilled the exploratory Magma-La Grande Well No. 1 in the fall of 1974 to test the geothermal potential of the Hot Lake area. Total drill depth was reported to be 2929 ft (893 m). Neutron-formation, density-dual induction-lateral, and temperature logs were run; these geophysical logs, plus descriptive logs and cutting samples, are on file with the Oregon Department of Geology and Mineral Industries in Portland.

Baxter and others (1978) summarized the geothermal resources of Union and Baker counties of northeastern Oregon and published data from wells with water temperatures greater than that expected from a normal subsurface temperature gradient. Using chemical-composition data obtained from thermal-water analysis they concluded that warm water in the vicinity of the study area is part of a deep ground-water circulation system in which temperatures reach 212° F (100° C).

Other recent and current mapping programs in northeastern Oregon have encountered stratigraphic settings within the Columbia River Basalt Group which contribute to the understanding of the stratigraphy in the La Grande area. These include Taubeneck (1970, 1979), Wright and others (1973), Price (1974, 1977), Kleck (1976), Ross (1978), Reidel (1978), Hooper and others (1979) and Shubat (1979). Observations also were obtained from geologists of the on-going Rockwell Hanford Operations-U.S. Geological Survey Columbia Plateau regional-mapping and geochemical program.

Regional Overview

The La Grande-study area lies near the southern margin of the Columbia Plateau. This plateau originally was a constructional surface created about 15 million years ago (Watkins and Baksi, 1974) when flow upon flow of flood basalt spread across large portions of northeastern Oregon, southeastern Washington and west-central Idaho. These Miocene flows progressively submerged a pre-existing mature topography which, in Oregon, generally was eroded in Mesozoic and Paleozoic rocks (Figure 3). By the time extrusive activity waned, the plateau-basalt margin had spread south of the study area and burial by basalt was complete in the La Grande area. Although no ancestral highlands protruded above plateau level, local irregularities in the plateau surface were present near La Grande as a result of eruptions of andesite which made low mounds on the basalt plateau.

Rocks underlying the Miocene flows of the study area can be studied nearby, as at the margins of Baker Valley to the south (Figure 3) and in the uplifted highlands of the Elkhorn and Wallowa mountains to the southwest and east, respectively. These pre-Tertiary basement rocks include Triassic submarine metavolcanic greenstone, upper Paleozoic and lower Mesozoic metasedimentary lithologies and Mesozoic intrusive rock. The sub-basalt

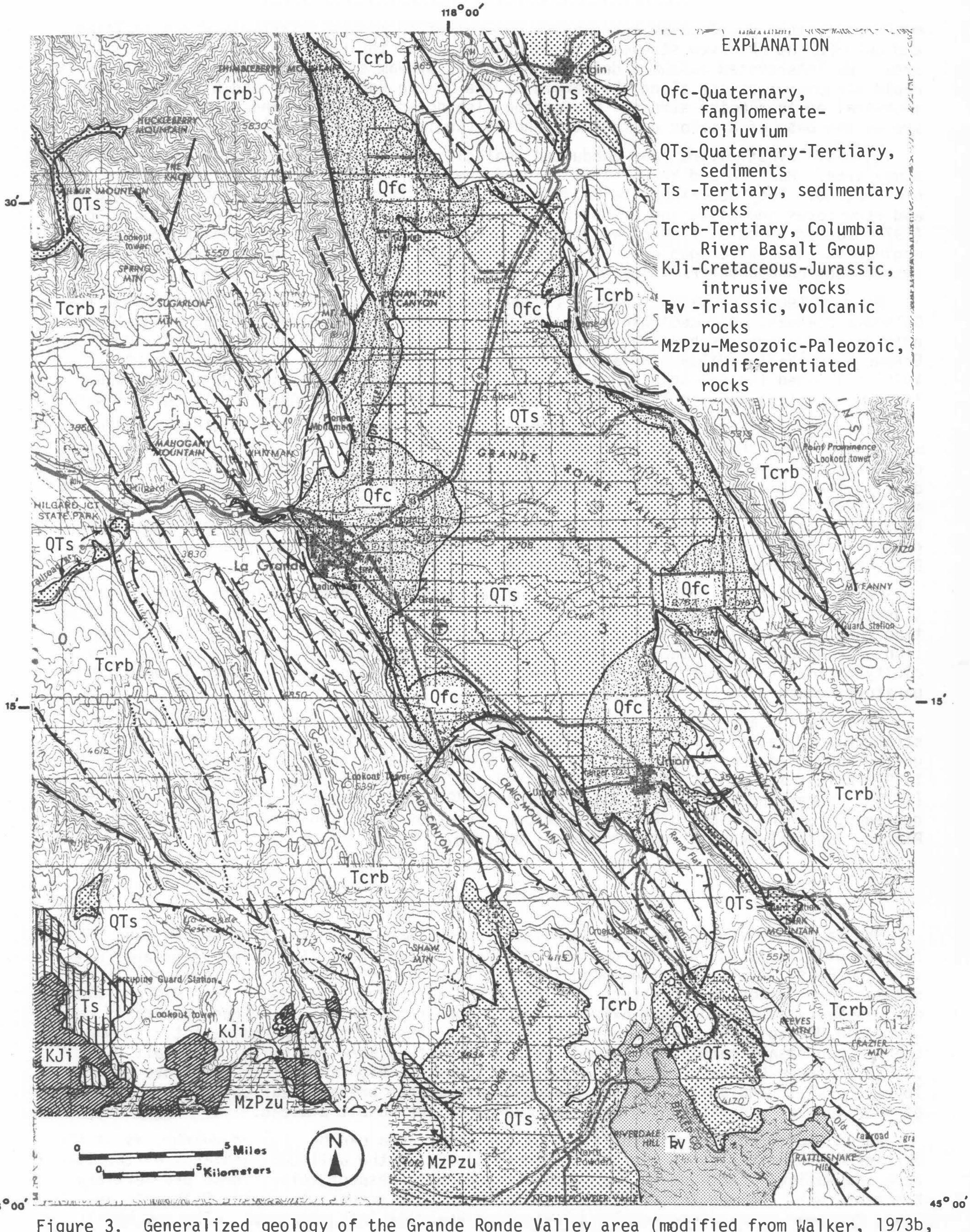

Figure 3. Generalized geology of the Grande Ronde Valley area (modified from Walker, 1973b, 1979).

basement rocks in the area record a complex geologic history of an upper Paleozoic-lower Mesozoic marine environment giving way to upper Mesozoic-lower Tertiary mountain-building episodes and stream degradation concurrent with subsurface intrusive and metamorphic activity.

Near La Grande, modification of the Columbia Plateau into its present-day form began in late Miocene time as structural deformation and surface irregularities focused runoff into consequent channels. In the study area, horst, graben and step-fault movement along northwest-trending fractures jumbled the plateau surface. Superimposed upon these vertical adjustments was the general uplift of the Blue Mountains to the northwest. This resulted in the southeasterly regional dip of the plateau rocks north of La Grande. Throughout the upper Tertiary-Quaternary deformation cycle, sediments accumulated in such depressions as the Grande Ronde and Baker valleys while stream erosion dissected bordering uplifted blocks.

Restated, the study area lies in a regional setting of nearly vertically faulted and regionally tilted Columbia River Basalt Group flows in which basalt-floored basins have been filled with sediments and basalt-bedrock uplands are being eroded by youthful and rejuvenated streams.

Thermal Springs and Wells

Regionally, the study area is included in the Deschutes-Umatilla Plateau-Blue Mountain heat flow province of Blackwell and others (1978). They evaluate this province to have a heat flow approximately 50% greater than is anticipated for continental localities; temperature gradients average about 44°/km. This heat flow province, however, is not considered to have the high-temperature thermal potential of the High Cascade Range province to the west and the combined Basin and Range-High Lava Plains-Owyhee Uplands-Western Snake River Basin provinces to the south.

Locally, thermal water was utilized commercially in the vicinity of La Grande before the turn of this century when a health resort was constructed at Hot Lake in the 1880's. Subsequently, thermal springs and wells were developed for public and commercial use in the vicinity of Cove and Union. Recently, wells yielding warm water were drilled in and around La Grande by the city, the Union Pacific Railroad and Boise Cascade Corp. In all, more than twenty thermal springs and wells are reported in the vicinity of La Grande and the Grande Ronde Valley (Figure 4; Table 1).

Thermal-water sites in the Grande Ronde Valley can most aptly be called warm springs and wells. None of the thermal water reaches boiling temperature; the 185° F (85° C) temperature reported for Hot Lake (Baxter and others, 1978) is the area's warmest. Most typically, waters are less than 100° F (38° C) (Table 1).

Distribution of thermal springs is strongly associated with fault zones. In addition, thermal springs appear to be very localized and pass to the surface through narrow conduits. At Hot Lake, for example, cool potable water used at the lodge is obtained from a shallow well no more than 150 ft (45 m) from Hot Lake hot spring.

As summarized by Baxter and others (1978), "the hot waters evidenced by the various hot springs in the study area [Grande Ronde-Baker valleys] are most likely due to deep circulation of meteoric water along fault zones." Gardner and others (1974), however, do not rule out the possibility of a shallow mafic intrusion beneath the Grande Ronde graben.

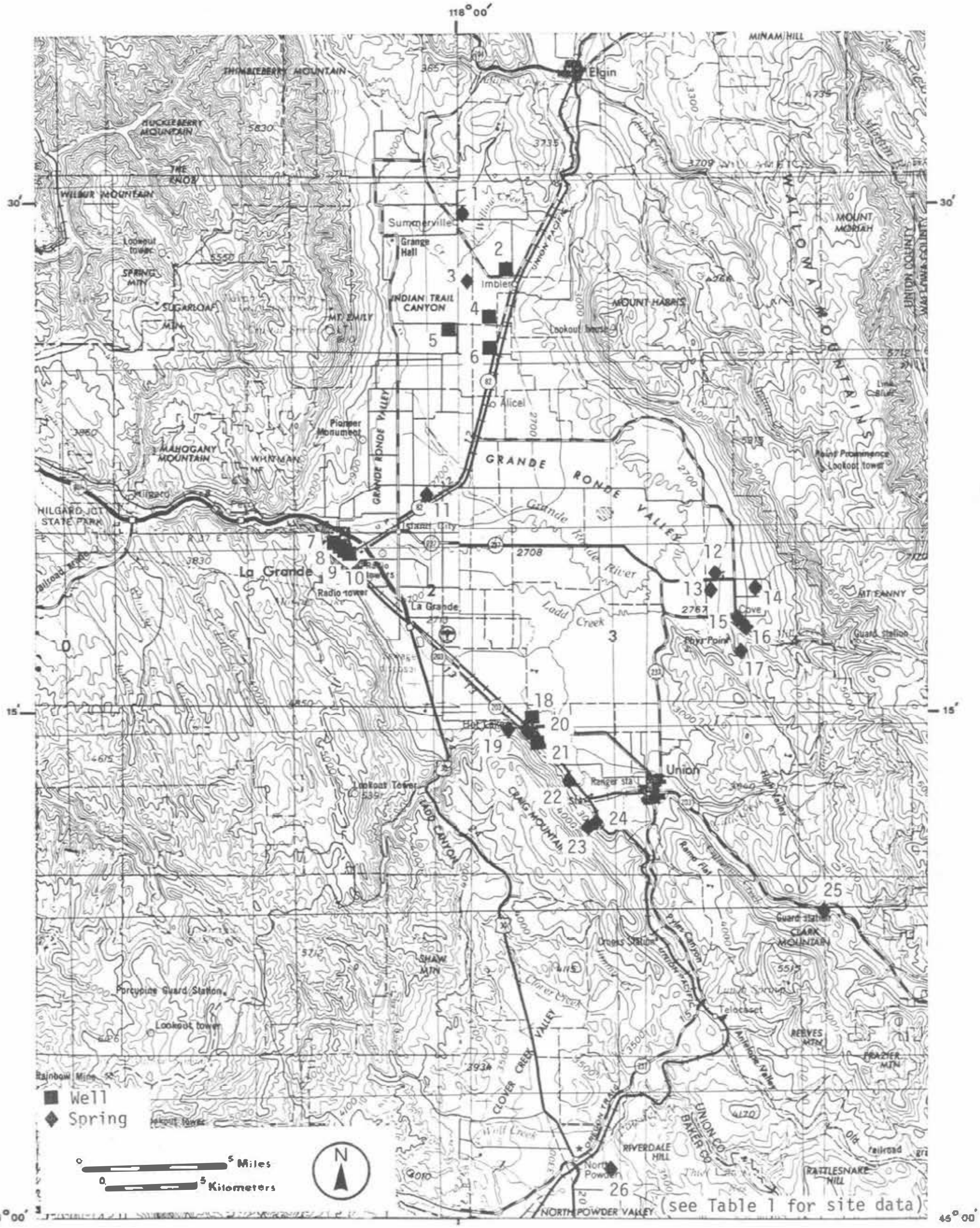

Figure 4. Location of thermal wells and springs near the Grande Ronde Valley (modified from Baxter and others, 1978, and Bowen and others, 1978).

Table 1. THERMAL SPRINGS AND WELLS NEAR LA GRANDE, OREGON

Figure 4 Location Number	Spring or Well Name*	Surface Temperature* Deg. C	Deg. F	Flow Rate GPM*	Location* Section - Township - Range
1	Unnamed (not sampled 1)	--	--	-----	Sec. 6, T1S, R39E
2	Clayton Fox Well (29)	26	79	1,250	SE 1/4, NW 1/4, Sec. 20, T1S, R39E
3	Wagner Well (19)	32	90	3,500 artesian 5,000 pumped	SE 1/4, SE 1/4, Sec. 24, T1S, R38E
4	Elwyn Bingaman Well (28)	24.5	76	50	SE 1/4, SE 1/4, Sec. 20, T1S, R39E
5	Norm Woodell Well (30)	24.6	76	900	NE 1/4, NE 1/4, Sec. 36, T1S, R38E
6	Creston Shaw Well (26)	26	79	300	SE 1/4, SE 1/4, Sec. 31, T1S, R39E
7	City Well #2 (20)	22	72	275	SE 1/4, NE 1/4, Sec. 6, T3S, R39E
8	City Well #1 (21)	21	70	500	(35 m ESE of City Well #2)
9	Union Pacific RR Well #2 (22)	26	79	75	NW 1/4, SW 1/4, Sec. 5, T3S, R38E
10	Union Pacific RR Well #1 (23)	27	81	100	(200 m WSW of #2 RR Well)
11	Boise Cascade Well (25)	20	68	300	SE 1/4, SE 1/4, Sec. 26, T2S, R38E
12	Warm Creek Spring (8)	27	81	250	NE 1/4, SW 1/4, Sec. 9, T3S, R40E
13	Grange Hall Spring (7)	26	79	15	SW 1/4, SW 1/4, Sec. 9, T3S, R40E
14	Hoofnagle Warm Spring (16)	24	75	5	SW 1/4, SE 1/4, Sec. 10, T3S, R40E
15	Cove (Swimming Pool) Hot Spring (27)	29	84	226	NW 1/4, NW 1/4, Sec. 22, T3S, R40E
16	Cove Bath House Warm Spring (15)	29	84	2	NW 1/4, NW 1/4, Sec. 22, T3S, R40E
17	Girdner Warm Spring (5)	22	72	20	SW 1/4, NW 1/4, Sec. 27, T3S, R40E
18	Hot Lake-Courtright Well (4 [A])	79	174	20	SE 1/4, SE 1/4, Sec. 5, T4S, R39E
19	Hot Lake Resort Hot Spring (3)	85	185	1,700	NW 1/4, SW 1/4, Sec. 4, T4S, R39E
20	Hot Lake-Courtright Spring (4 [B])	--	--	-----	SW 1/4, SW 1/4, Sec. 4, T4S, R39E
21	Magma-La Grande Well No. 1**	Bottom hole temp. 130° F**			Center, NW 1/4, Sec. 9, T4S, R39E**
22	Duck Pond Spring (6)	26	79	15	NW 1/4, SE 1/4, Sec. 15, T4S, R39E
23	Union Junction #1 Warm Spring (13)	37	99	15	NE 1/4, SE 1/4, Sec. 22, T4S, R39E
24	Union Junction #2 Warm Spring (14)	29	84	25	NE 1/4, SW 1/4, Sec. 23, T4S, R39E
25	Cooper Warm Spring (10)	23	73	5	NE 1/4, NW 1/4, Sec. 12, T5S, R40E
26	Cropp Hot Spring (24)	32	90	5	NE 1/4, NW 1/4, Sec. 25, T6S, R39E

*Name and number in (), temperature, flow rate, and location data are from Baxter and others, 1978.
**Data are from Magma Energy, Inc. well description and temperature logs.

STRATIGRAPHY

Stratigraphic units present in the study area are Miocene or younger. The oldest units are basaltic lava flows and associated interbeds of Miocene age; these units are assigned to the Columbia River Basalt Group. Locally, andesite flows cap the basalts. Andesites of similar appearance and relative stratigraphic position also have been included in the Columbia River Basalt Group by others (Gilluly, 1937; Pardee, 1941; Walker, 1973a; Ross, 1978 and Taubeneck, 1979).

Basaltic and andesitic rocks of the Columbia River Basalt Group form the uplands which surround the Grande Ronde Valley. Younger, alluvial and lacustrine deposits make up the exposed units in the Grande Ronde Valley. Drill-core data indicate that the fill in the Grande Ronde Valley is primarily Pleistocene-age lake deposits (Hampton and Brown, 1964). Cuttings from the Magma-La Grande Well No. 1 near Hot Lake (Appendix) fit this pattern of alluvial and lacustrine sediments over Columbia River Basalt Group units.

Columbia River Basalt Group

The Columbia River Basalt Group, as described above, is a stratigraphic unit of regional extent and is present throughout the four quadrangles of the field area. All of the flows near La Grande appear to belong to the Yakima interval of the Columbia River Basalt Group (Figure 5). Within the study area rocks of the Columbia River Basalt Group-Yakima Subgroup are separated into four map units. The four are: 1) Grande Ronde Basalt (Tgr) which is overlain by 2) basalt of Glass Hill (Tgh) which locally is overlain by 3) andesite of Mahogany Mountain (Tmm) and 4) andesite of Craig Mountain (Tcm). The latter three names are informal stratigraphic designations used in this report for mapping purposes. The basalt of Glass Hill includes both the black olivine and diktytaxitic* olivine flows of Taubeneck (1979) in quadrangles north and east of the study area. The Mahogany Mountain and Craig Mountain andesite units occur at the same stratigrapnic interval in the study area, but appear to represent accumulations from separate sources.

Regionally, Grande Ronde Basalt is the oldest unit of Yakima Basalt of the Columbia River Basalt Group. In the study area the overlying basalt of Glass Hill has not been conclusively assigned to either the Wanapum (middle) or Saddle Mountains (upper) subdivision of Yakima Basalt (Figure 5) (see Basalt of Glass Hill discussion, p. 15). Andesite mapped to the northeast in Oregon by Walker (1973a) and Ross (1978) is stratigraphically placed in the Saddle Mountains (or upper Yakima) interval; this appears to be the case near La Grande.

The various Columbia River Basalt Group subdivisions of the study area have different major-element compositions (Table 2). In addition, the basalt of Glass Hill appears to be made up of two chemically distinct types which, with more detailed field work, could be mapped separately in the La Grande area. Overall, chemical differences among Columbia River Basalt Group units are numerous. Grande Ronde flows, for example, have a silica (SiO_2) content of about 54% which matches that of correlative flows across the Columbia Plateau. In the overlying basalt of Glass Hill, the diktytaxitic units have a lower silica content (about 51-52%); the glassy flow interval contains more silica than Grande Ronde Basalt (about 57-61%). As discussed in more detail subsequently (p.15), chemical composition of the diktytaxitic flow matches that of the Levi flow (Shubat, 1979) in the Minam Canyon area. The andesite units at the top of the Columbia River Basalt Group section have the highest silica content (61-66%). Other major-element data which help to document the geochemical differences include oxides of magnesium (MgO), titanium (TiO_2) and iron (FeO). For additional information concerning chemical identification of Columbia River Basalt Group units the reader is referred to Wright and others (1973), Price (1977), and Reidel (1978).

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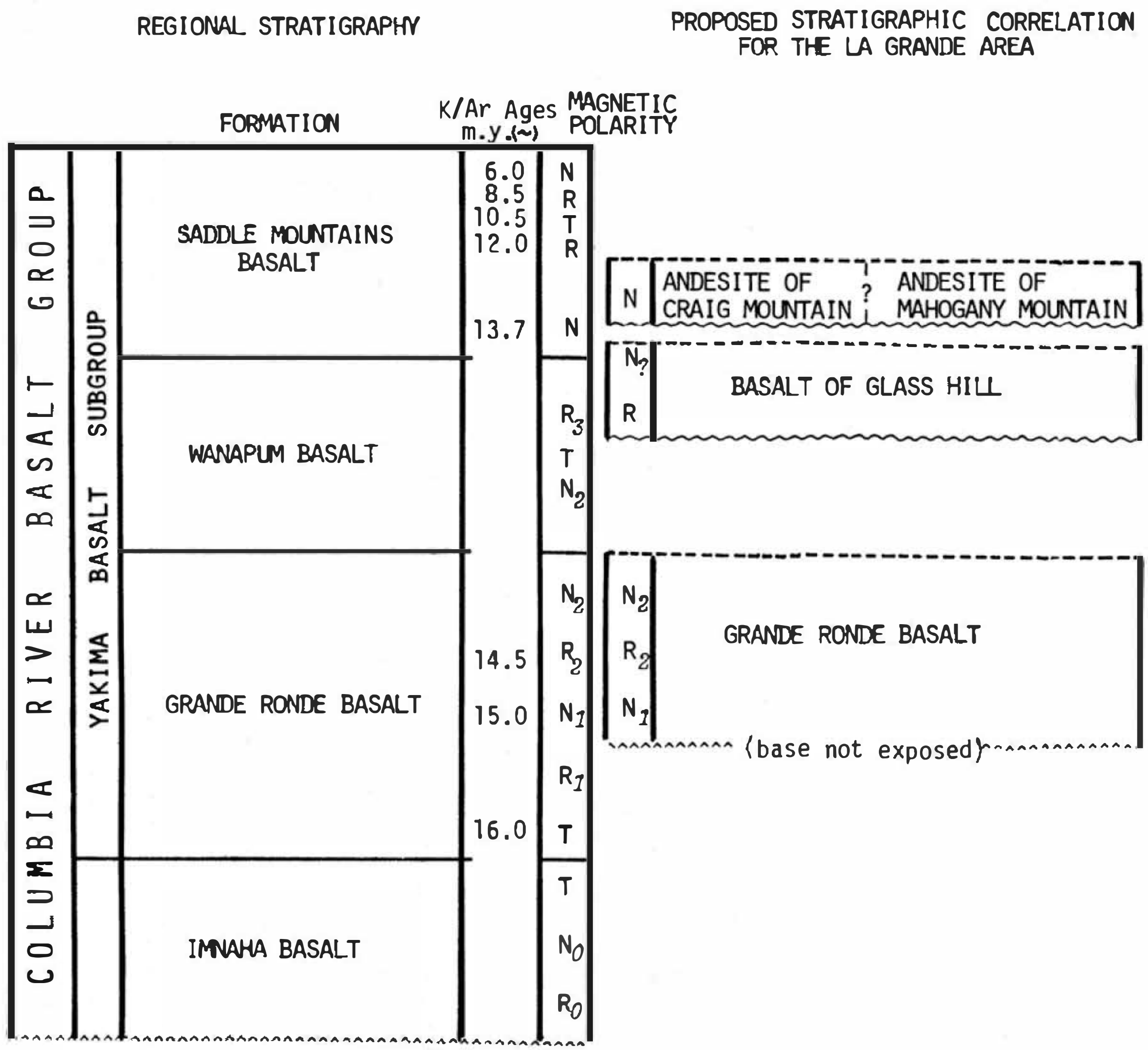
*Diktytaxitic denotes an igneous rock texture characterized by numerous small, angular, irregularly shaped voids bounded by crystal intergrowths, some of which protrude into the cavities.



(After Hooper and others, 1979)

Figure 5. Stratigraphic subdivisions of the Columbia River Basalt Group.

Table 2. X-RAY FLUORESCENCE ANALYSIS OF OUTCROP AND CUTTING SAMPLES FROM THE LA GRANDE AREA

Field Sample Number	Analytical Number	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	NA_2O	P_2O_5	Rock Unit
GRC 106	GRC 1005	66.48	17.42	0.56	2.00	0.96	0.08	4.79	1.41	1.95	3.96	0.32	Tmm
GRC 278	JDK 05	61.08	18.90	0.52	2.00	2.22	0.08	7.17	2.98	1.22	3.63	0.18	Tcm
GRC 240A	JDK 03	64.06	17.62	0.76	2.00	1.59	0.10	5.12	2.21	2.02	4.20	0.33	Tcm
GRC 261	JDK 04	61.67	17.65	0.75	2.00	3.23	0.14	5.61	2.45	2.67	3.43	0.40	Tghg
GRC 259	JDK 09	61.80	17.75	0.74	2.00	3.35	0.12	5.47	2.17	2.20	4.00	0.40	Tghg
GRC 140	JDK 02	57.28	17.07	1.27	2.00	6.24	0.18	6.39	3.37	2.30	3.26	0.64	Tghg
GRC 539	JDK 10	58.19	17.88	1.33	2.00	4.86	0.14	6.46	2.94	2.06	3.47	0.66	Tghg
GRC 139	JDK 01	51.09	16.91	1.97	2.00	8.87	0.18	8.89	6.23	0.82	2.53	0.49	Tghd
GRC 282	JDK 06	50.92	16.41	1.53	2.00	9.11	0.17	9.47	7.03	0.56	2.42	0.38	Tghd
GRC 500	JDK 07	50.74	16.52	1.44	2.00	9.20	0.17	9.81	6.65	0.52	2.59	0.37	Tghd
GRC 501	JDK 08	52.13	16.58	1.24	2.00	7.71	0.18	9.48	7.10	0.78	2.42	0.39	Tghd
GRC 100	GRC 1004	54.28	15.01	2.18	2.00	10.56	0.22	7.69	3.91	1.48	2.28	0.40	Tgr
GRC 115	GRC 1006	53.24	14.54	2.06	2.00	11.70	0.23	7.79	4.01	1.35	2.72	0.36	Tgr
Standard Tgr	BCRP 900	54.67	14.76	2.28	2.00	10.63	0.18	6.83	3.56	1.77	2.97	0.35	Tgr
------	JDK 11*	51.19	16.90	1.47	2.00	7.22	0.20	10.37	7.40	0.35	2.54	0.37	Tghd
------	JDK 12**	51.84	16.79	1.40	2.00	7.42	0.18	10.01	7.05	0.39	2.55	0.37	Tghd

Tmm andesite of Mahogany Mountain
Tcm andesite of Craig Mountain
Tghg basalt of Glass Hill, glassy
Tghd basalt of Glass Hill, diktytaxitic
Tgr Grande Ronde Basalt

*Sample of cuttings from Magma-La Grande Well No. 1 at well depth of 1170-1320 ft.
**Sample of cuttings from Magma-La Grande Well No. 1 at well depth of 1320-1410 ft.

Grande Ronde Basalt

Grande Ronde Basalt (Tgr) crops out in all upland portions of the study area; rock exposures, however, are sparse in the southwestern part of the area. Grande Ronde Basalt consists of numerous similar-appearing basalt flows which average 50 ft (15 m) in thickness; locally they may be more than 165 ft (50 m) thick. Approximately 1475 ft (450 m) of Grande Ronde flows are exposed on the east side of Glass Hill. However, total thickness of the flow stack within the field area is not known; the base of the Grande Ronde unit is not exposed in the four quadrangles studied. In addition, the Grande Ronde section in the Magma-La Grande Well No. 1 is shortened by faulting and does not give an accurate vertical dimension to the extrusive units (Appendix).

Flow-structure characteristics are remarkably consistent in Grande Ronde units. The lower three-fourths to two-thirds of relatively thin flows consist of a basal colonnade which has 3-10 ft (1-3 m) diameter, smooth-faced columns. Flows which are thicker than 65 ft (20 m) commonly have an entablature above the basal colonnade consisting of 6-20 in (0.2-0.5 m) diameter hackly columns. Scattered, elongate vesicles and microvesicle layers are common throughout the colonnade and entablature; the lower 12-20 in (0.3-0.5 m) of some flows are markedly vesicular.

Grande Ronde flow tops are 10-30 ft (3-10 m) thick and may form one-third of the flow thickness. Exposed flow tops are orange-to-purple, rubbly, permeable breccias of vesicular and partly massive angular blocks. Ground water commonly seeps from flow tops to form spring and vegetation lines on slopes. Flow-top surfaces and parting surfaces within the massive parts of flows may be hummocky with 6 ft (2 m) or more relief on swales.

Outcrops of Grande Ronde flows generally are ledges 3-10 ft (1-3 m) high. They consist of light-brown or gray, smooth undulating columns which may be cut by random to nearly rectangular fracture sets. Less commonly, rubbly flow-top breccias or massive vesicular flow tops form jutting pinnacles above low rubbly ledges.

Local variations do occur and serve as marker units. In the Grande Ronde Canyon near Perry, for example, two anomalously thick brickbat flows (Figure 6) make distinctive and locally mappable units within the Grande Ronde sequence. These appear to thin westward, however, and become generally unrecognizable near Hilgard. Another local marker is a glassy flow at the top of the Grande Ronde section in the northwestern corner of the study area. This probably is an extension of the glassy Grande Ronde flow reported by Taubeneck (1979) to the northeast. The unit is recognizable by the presence of large, up to 3 ft (1 m) across, dense glassy boulders on upland surfaces.

Most Grande Ronde flows are aphyric, although a few plagioclase, pyroxene or olivine phenocrysts are scattered through some flows. The groundmass of Grande Ronde flows generally is dull black, very fine grained and sparsely vesicular.

Sedimentary interbeds were not found in the Grande Ronde sequence within the study area. Locally, a few thin layers of very fine-grained, brightly colored pyroclastic debris or ash crop out between Grande Ronde flows; these can serve as marker horizons over short distances. Two reddish-pink ash layers are well exposed along I80N and railroad cuts in the Grande Ronde Canyon near Perry and can be used for identifying minor structural offsets. A reddish ash layer and oxidized flow top higher in the Grande Ronde section also makes a good stratigraphic marker south of Hilgard.

Field identification of Grande Ronde Basalt in the La Grande study area was confirmed by geochemical analysis of samples from two basalt flows (GRC-100, 115) in the Grande Ronde Canyon (Plate I). X-ray fluorescence data (Table 2) show these flows to have similar major-element composition to a Grande Ronde standard (BCRP 900) for the Columbia Plateau.

Paleomagnetism of Grande Ronde flows, as determined in the field with a portable fluxgate magnetometer, appears to be a normal(N)-reverse(R)-normal(N) up-section sequence. This sequence is interpreted to be a southwestward extension of the N_1-R_2-N_2 portion of the magnetostratigraphic sequence present nearer the center of the Columbia Plateau (Hooper and others, 1979; Taubeneck, oral communication).

It was common, however, to obtain inconsistent paleomagnetic readings within some Grande Ronde flows and at single outcrops. The inconsistencies did not appear to be

Figure 6. Grande Ronde Basalt near Perry.

View is to the northeast in the Grande Ronde Canyon in Sec. 34, T2S, R37E. This exposure is slightly west of that depicted by Hampton and Brown (1964, p. 21). Brickbat entablatures (vertical bars) of two thick Grande Ronde Basalt flows form cliff faces and make local stratigraphic markers for structural interpretation. The magnetostratigraphic reverse(R_2)-normal(N_2) contact is in the upper slope (dashed-line). Large float blocks of andesite of Mahogany Mountain are near the ridge line (arrows).

related to position within a flow and occurred both at flow interiors and at flow tops and bottoms. Paleomagnetic determinations of N_1-R_2-N_2 are based on data from clusters of field measurements taken at basalt outcrops in which a vertical sequence of flows is exposed. Consistent reversals which occurred at specific stratigraphic levels within the basalt pile have been so indicated on the geologic maps (Plates I-IV). The lower reversal, from normal(N_1) to reverse(R_2), occurs approximately 1000 ft (300 m) down in the Grande Ronde section in the Ladd Canyon area. The upper reversal, from reverse(R_2) to normal(N_2), occurs approximately 350 ft (100 m) down in the section in the Grande Ronde Canyon. Thinning of the normal(N_2) section in a southerly direction is suggested by the location of the reverse-normal (R_2-N_2) break which occurs approximately 250 ft (75 m) below the top of the Grande Ronde section in Ladd Canyon.

Basalt of Glass Hill

Basalt of Glass Hill (Tgh) consists of a number of flows and interbedded lithic and tuffaceous sediments which occur above the Grande Ronde Basalt sequence and, in places, below the andesite of Mahogany Mountain and Craig Mountain. As observed previously, the Glass Hill sequence probably is the lateral equivalent of the black olivine and diktytaxitic olivine basalts of Taubeneck (1979).

Basalt of Glass Hill has an irregular vertical and lateral distribution pattern thoughout much of the upland areas. Outcrops are most abundant near the La Grande front north of the Grande Ronde River and in the Hilgard uplands between the Grande Ronde Canyon and Glass Hill. Scattered outcrops are present on Craig Mountain. The unit does not occur in the northwestern portion of the study area. The thickness of the Glass Hill sequence ranges from less than 6 ft (2 m) near probable accumulation margins to greater than 500 ft (150 m); the greatest thickness occurs in the upper Sheep Creek area (Plates I-III).

A slight angular unconformity is interpreted to exist between Grande Ronde and Glass Hill sequences. Thickness and distribution patterns suggest westerly onlap of Glass Hill units onto a slightly easterly tilted Grande Ronde Basalt surface. Warping of the surface and/or nearness to a source may have led to the thick accumulation of Glass Hill units in the vicinity of Glass Hill.

The basalt of Glass Hill sequence is recognized in the field by stratigraphic position and by lithologic differences from the underlying, more uniform-appearing Grande Ronde flows and overlying platy andesite units. As observed in the introductory remarks of this chapter, X-ray fluorescence analysis data also distinguish the Glass Hill sequence from underlying and overlying units. The Glass Hill sequence is recognizable in cuttings from Magma-La Grande Well No. 1 and is a good marker unit, or structural datum, near the Grande Ronde Valley.

Basal diktytaxitic units of the Glass Hill sequence commonly have reverse(R) paleomagnetism and overlie Grande flows with normal(N_2) paleomagnetism. A few field measurements suggest that an uppermost diktytaxitic flow and upper obsidian-like mottled units have normal(N?) paleomagnetism; the authenticity of this polarity reversal was not conclusively determined during the field study. The lower reverse(R) portion of the basalt of Glass Hill may be time equivalent to the paleomagnetically reverse(R_3) portion of the Wanapum Formation (Figure 5). However, Shubat (1979) tentatively places a diktytaxitic flow (Levi) near Minam in the Saddle Mountains interval. This diktytaxitic flow has normal paleomagnetic polarity although its major-element geochemistry is similar to diktytaxitic basalt of this study. In the La Grande-study area no significant erosional cycle and only minor, local structural discordances are interpreted to have occurred in the time interval between the end of Grande Ronde Basalt accumulation and the beginning of the extrusion of basalt of Glass Hill. Based on these field relations near La Grande, this report favors the Wanapum (R_3) correlation for the lower reverse(R) diktytaxitic flows in the Glass Hill sequence. The upper normal?(N?) diktytaxitic and obsidian-like flows may correlate with the lower normal portion of the younger Saddle Mountains Formation.

Several of the Glass Hill flows exhibit vertical and lateral variations in hand-specimen texture, and flows of different lithologic types may be interfingered locally. None of the individual lithologic types could be traced laterally throughout the map area. Figure 7 is a schematic diagram of stratigraphic sections of Glass Hill units at numerous locations in the La Grande field-study area. A brief description of flow types and

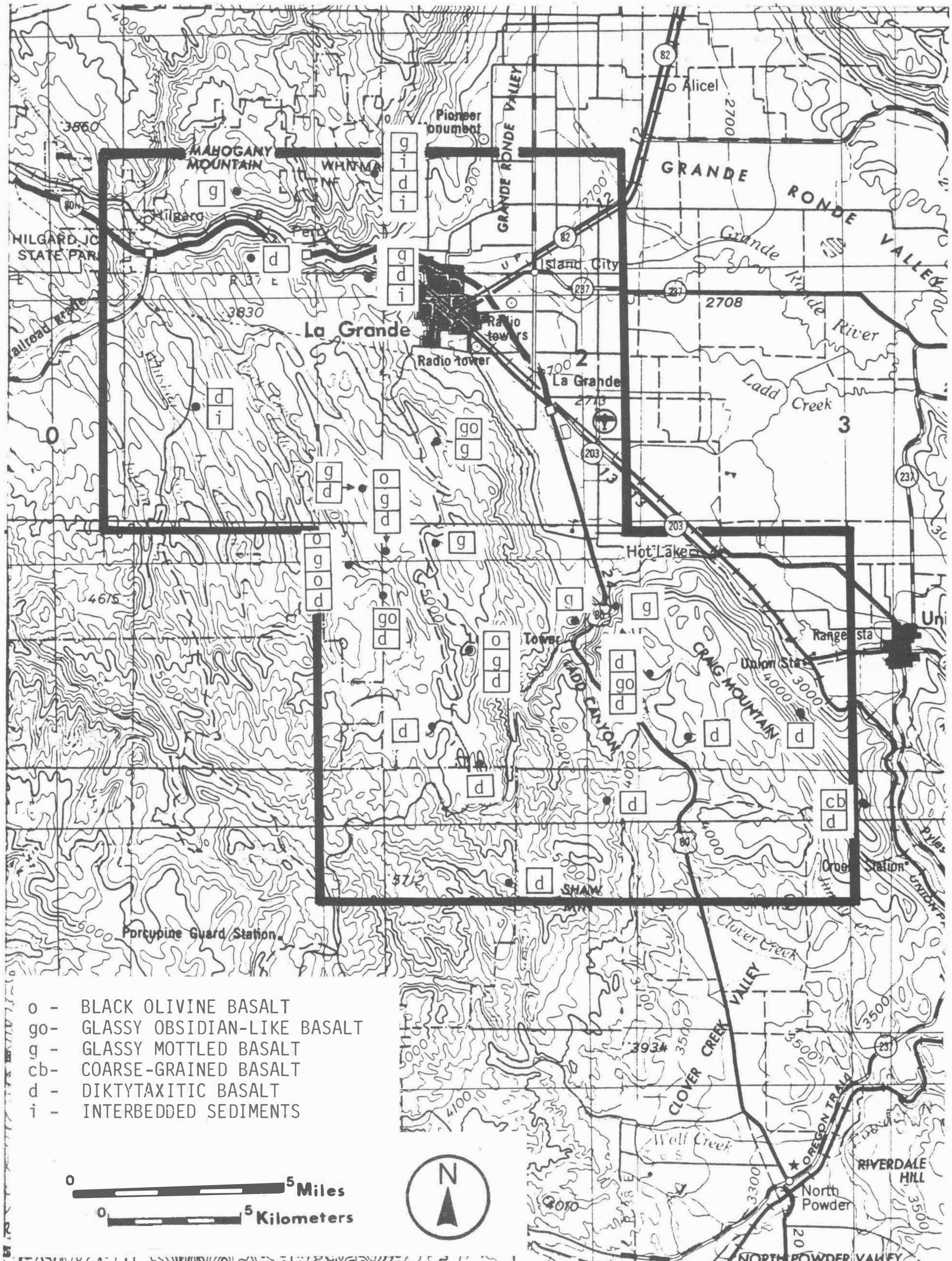


Figure 7. Schematic diagram of basalt of Glass Hill distribution.

sedimentary interbeds included in the Glass Hill sequence follows; geochemical data for outcrop samples GRC-139, 282, 500 and 501 and Magma-La Grande Well No. 1, samples JDK-11 and 12 are presented in Table 2.

Diktytaxitic basalt (Tghd): Diktytaxitic basalt is the most widespread flow type in the Glass Hill sequence. Diktytaxitic basalt ranges from one to six or more flows and reaches approximately 400 ft (120 m) total thickness east of I80N in the upper Ladd Canyon area. Individual flows are generally 30-50 ft (10-16 m) thick.

At least two flows of diktytaxitic basalt are abundantly phyric with 1-2 mm olivine grains. These flows serve as stratigraphic markers over much of the field area and in the Magma-La Grande Well No. 1. Locally, black glassy intervals occur within or between diktytaxitic basalt units; these may be chilled portions of the diktytaxitic flows and/or interfingerings with glassy basalt.

Outcrops of diktytaxitic basalt commonly form ledges 3-20 ft (1-6 m) in height that consist of large, moderately rounded blocks. Individual flows consist of a vesicular flow top up to 10 ft (3 m) thick and a colonnade that forms the remainder of the flow. Weathering of the unit typically produces rounded spalled cobbles and a grus-like soil.

Glassy basalt (Tghg): Glassy aphyric mottled basalt* occurs in the southwestern and eastern portions of the Hilgard uplands from Ladd Creek northward to the tableland around Morgan Lake and westward to the boundary of the map area. At least four Glass Hill glassy basalt flows or flow units, totalling more than 200 ft (60 m), are present on both sides of Ladd Creek above the mouth of its canyon. A thick sequence of glassy flows or flow units is exposed in the headwall scarp above the major landslide west of Taylor Creek in Secs. 19 and 20, T3S, R38E. The upper five to six flows or flow units in this Taylor Creek section are dense, black and obsidian-like; the lower two to three have prominent thin platy joints. The obsidian-like flows were observed primarily in the Taylor Creek area and interpreted to be near-source, late-stage products of the glassy, aphyric, mottled basalt eruptive cycle.

Outcrops of the glassy, aphyric, mottled basalt generally are ledges of moderately rounded columns, 3-5 ft (1-1.5 m) in diameter, with pitted surfaces. Vesicular flow tops are massive. Some flows have thin, irregular platy partings (Figure 8); other flows have smooth column faces which are cut by planar joint sets.

Fresh surfaces are black, very fine grained-to-glassy and slightly vesicular with round to elongate vesicles. Evenly distributed, pale-yellow to dull-green, amoeboid-shaped 1/8-1/2 in diameter (3-12 mm) discolorations give the flows a distinctive "splotchy" pattern on unweathered surfaces. However, this splotchy mottling occurs sporadically in a few underlying Grande Ronde flows or portions of flows of other Glass Hill lithologic types and, therefore, is not diagnostic as a single criterion.

Coarse-grained basalt (part of Tgh undifferentiated): Coarse-grained black basalt is best exposed in the headwall of a large landslide on Craig Mountain front in Sec. 1, T4S, R39E. Two flows totalling 50-65 ft (15-20 m) occur above diktytaxitic basalt of the Glass Hill interval and below platy andesite of Craig Mountain. Coarse-grained black basalt has a sparkly rough-textured fresh surface. Individual grains are 2-5 mm in length. The flows have massive, vesicular tops and basal columns which are 3-5 ft (1-1.5 m) in diameter.

Black olivine basalt (Tgho): Black olivine basalt occurs in the northwestern portion of the Glass Hill 7 1/2-minute quadrangle and underlies Glass Hill lookout. At least two black olivine basalt flows crop out in Sec. 1, T4S, R37E; here they are separated by one glassy aphyric mottled basalt flow. Black olivine basalt typically is dull black, very fine grained and "peppered" with 1 mm translucent bronze-colored olivine grains. The

*It should be noted that Glass Hill glassy basalt samples GRC-259 and GRC-261 taken in the Taylor Creek section have more andesitic than basaltic chemical characteristics (Table 2). In hand-specimen and outcrop characteristics, however, a basalt texture and appearance typifies the glassy flows. The term basalt is retained in this text to be compatible with previous and current work of others in the area and to be compatible with the more basaltic chemical character of other glassy Glass Hill basalt samples analyzed (GRC-140 and 539).

Figure 8. Platy jointing in basalt.

Platy jointing of this Glass Hill flow typifies that of several flows within the Glass Hill sequence. Similar appearing jointing also is exhibited by andesite in the Mahogany Mountain and Craig Mountain units. Joints are curvilinear and may change from horizontal to vertical within a single outcrop. The exposure depicted is east of I80N in Sec. 32, T4S, R39E.

needle of a Brunton compass is deflected from magnetic north when the compass is held within 1 ft (0.3 m) of a black olivine basalt outcrop. Outcrop characteristics are similar to those of glassy basalt flows.

Interbedded sediments (Tghi): Interbeds of tuff breccia, mudstone and lithic sandstone occur within the Glass Hill sequence; however, they are not laterally extensive. Sedimentary units appear to be thickest and most abundant near the La Grande front in the vicinity of the Grande Ronde Canyon (Plate II). North of the Grande Ronde Canyon near Fox Hill Road (Sec. 25, T2S, R37E), for example, a massive tuff breccia, lying below a diktytaxitic basalt flow, is up to 50 ft (15 m) thick. A layered mudstone, which also lies near the base of the Glass Hill sequence, is up to 25 ft (8 m) thick. Near the top of the Glass Hill sequence, a poorly sorted water-laid lithic sandstone, composed primarily of volcanic detritus, is up to 13 ft (4 m) thick. These sedimentary units appear to thin abruptly to the west; they were not present in Glass Hill outcrops north of the Grande Ronde River about 2 mi (3 km) west of the La Grande front. South of the Grande Ronde River, however, scattered outcrops occur west of the La Grande front in the Rock Creek area.

The massive tuff unit noted above probably is the southwestward extension of the tuff reported by Taubeneck (1979) to be at the base of the sequence which overlies Grande Ronde Basalt. Most exposures of the tuff are on slopes north and south of the mouth of Grande Ronde Canyon (Plate II), along the Mill Creek-Morgan Lake road west of the center of Sec. 18, T3S, R38E (Plate II) and along Ladd Creek near the Ladd Road-I80N intersection (Plate III).

Andesites of Mahogany Mountain and Craig Mountain

At least two separate areas of andesite accumulations are exposed within the study area; they occur from the Grande Ronde Canyon northward and from Craig Mountain westward. As observed at the beginning of this chapter, these are informally designated the andesite of Mahogany Mountain (Tmm) and the andesite of Craig Mountain (Tcm), respectively. The andesite is the youngest Tertiary volcanic unit in the area (Figure 5). These accumulations are composed primarily of gray platy and massive andesitic lava flows.

North of the Grande Ronde Canyon the thickness of the andesite of Mahogany Mountain increases northeastward from the accumulation's distal margin to more than 650 ft (200 m) at the La Grande-study area north boundary. In the southern part of the area, thickness of the andesite of Craig Mountain increases eastward across the Craig Mountain 7 1/2-minute quadrangle from approximately 100 ft (30 m) to greater than 700 ft (215 m). It is possible that the two andesite accumulations were originally distal parts of a much larger, perhaps coalesced, accumulation to the east which, in part, is now sediment-covered below the floor of the Grande Ronde Valley. The Morris Hill area and Tamarack Mountain may be minor centers of accumulation.

North of the Grande Ronde Canyon in the Hilgard and La Grande SE 7 1/2-minute quadrangles (Plates I and II), andesite of Mahogany Mountain overlies the basalt of Glass Hill sequence. Because andesite outcrops and down-slope colluvium in this area are restricted to north of the Grande Ronde River and east of Hamilton Canyon, it is interpreted that the course of the Grande Ronde River and the development of some side streams were controlled locally by the southern margin of andesite accumulation.

In the Craig Mountain to Tamarack Mountain region, and in the patches in western and central portions of the Glass Hill 7 1/2-minute quadrangle (Plates III and IV), andesite of Craig Mountain is in contact with both Grande Ronde Basalt and basalt of Glass Hill. In lower Ladd Creek area of the northeastern portion of the Glass Hill 7 1/2-minute quadrangle, an angular unconformity separates gently dipping (<5°) andesite of Craig Mountain from underlying, more steeply dipping (15°-20°) black aphyric mottled basalt of Glass Hill. Farther up stream in Ladd Canyon in Secs. 23 and 26, T4S, R38E, gently dipping (1°-2°) andesite overlies more steeply dipping (10°-15°) Grande Ronde Basalt.

In the Ladd Canyon area of west-central Craig Mountain 7 1/2-minute quadrangle, an erosional unconformity is interpreted to be present between andesite of Craig Mountain and basalt of Glass Hill with possibly 500 ft (150 m) of relief developed on diktytaxitic Glass Hill flows and underlying Grande Ronde Basalt (Plate IV). Elsewhere, however, clear evidence of interformational erosional relations between andesite and basalt flows is not evidence of interformational erosional relations between andesite and basalt flows is not exposed and is not indicated by general field relations.

Outcrops of both andesite units typically consist of gray blocky cliffs or ledges of columnar platy to massive andesite. Platy joints develop in broad swirl patterns in which joint attitudes range from flat lying to vertical, commonly within short lateral or vertical distances. Rapid mechanical weathering and sapping of plates near the base of outcrops result in abundant massive blocks of andesite float which may obscure geologic relations for many hundreds of feet downslope.

Neither vesicular zones nor flow-top breccias were observed at the tops of andesite flows. Consequently, recognition of interflow contacts is difficult. However, the upper surfaces of two flows are exposed or interpreted to be present in the Craig Mountain area. A small fresh-appearing flow lobe with a raised marginal rampart and smoothly sloping, but slightly hummocky, upper surface occurs south of Jimmy Creek Meadow in SW 1/4 Sec. 2, T5S, R39E, (Figure 9). A less-fresh flow surface is interpreted to be approximated by the nearly flat topographic surface south of Ladd Creek in Secs. 23 and 26, T4S, R38E, and west of I80N in Secs. 5, 6 and 7, T5S, R39E.

Fresh hand specimens of andesite are light to dark gray, very fine grained to glassy and aphyric to slightly phyric (generally with 2-5 mm plagioclase grains). In portions of some flows, irregularly shaped void spaces occur along platy partings. Platy partings commonly are highlighted by pink or gray tones which contrast with a darker groundmass color.

Included stratigraphically with the andesites are one or more thin (less than 50 ft [15 m] thick) black, glassy, massive flows, or zones. Although locally present within, or at the base of andesite flows, they rarely form outcrops. Generally, these glassy units, or zones, are aphyric; locally white plagioclase grains up to 1 cm have been observed. One geochemical analysis of a black glassy interval (sample GRC-240A) is included in Table 2; its composition is similar to that of the andesite. In hand specimen these intervals are similar in appearance to some of the obsidian-like Glass Hill flows which occur west of Taylor Creek and in the northwestern portion of the Glass Hill 7 1/2-minute quadrangle.

The Craig Mountain interval also includes a thin sedimentary interbed between two andesite flows. The interbed is exposed in a small outcrop directly east of the dirt road in E 1/4, NW 1/4, Sec. 24, T4S, R38E; it is at least 20 in (0.5 m) thick and consists of gray, medium-grained, moderately well-sorted, crossbedded lithic sandstone. Lithic clasts are andesitic.

Quaternary deposits

Quaternary units are carried on La Grande-study geologic maps only where the deposits are sufficiently thick to mask underlying bedrock. Deposits in upland areas consist of colluvial debris (Qco) and thick soil cover (Qs). Dense stands of timber commonly are associated with the latter. Throughout much of the area, fine white ash deposits occur in the soil and colluvium. The ash is most likely derived from modern Cascade volcanism.

Also incorporated in the map units depicting upland colluvium and soil (Qco and Qs) are scattered, thin lag deposits of well-rounded river gravels. The gravels appear as scattered pebbles on the upland surfaces. The lithic gravels consist of chert, quartzite, marble and granitic and metamorphic rock types similar to basement lithologies exposed in mountainous areas to the south and west. The gravels typically are pebble size; scattered cobbles range up to 4 in (10 cm) in long dimension. In the north, general upland localities of these lag concentrations are east and west of Hilgard and near Whiskey Creek road. In the south, scattered gravels are present in the uplands around Ladd Canyon. These gravels are interpreted to be remnants of alluvial deposits of ancestral streams, including the Grande Ronde, which flowed across the plateau surface prior to major down-cutting or entrenchment.

A lobate-shaped incipient rock glacier (included in Qco) is moving downslope southward from the eastern scarp of Tamarack Mountain in NE 1/4 Sec. 13, T5S, R38E (Figure 10). The maximum width near the lobe front is approximately 600-650 ft (185-200 m); the length is approximately 1200 ft (365 m). Material for the rock glacier is andesite talus from the east escarpment of Tamarack Mountain.

Figure 9. Andesite flow lobe.

Oblique stereo view is looking northward at andesite of Craig Mountain in Secs. 2 and 11, T5S, R39E. An abrupt edge and a hummocky, patterned surface denote the small flow lobe within the andesite sequence. The northeast end of the lobe may mark a local feeder.

Figure 10. Incipient rock glacier.

Oblique stereo view looking west toward a small rock glacier on the east slope of Tamarack Mountain (Sec. 13, T5S, R38E). Lobate flow lines are faintly visible in the lower portion of the feature. The incipient rock glacier consists of mechanically weathered andesite of Craig Mountain.

The Grande Ronde Valley and other local lowland areas consist mainly of modern alluvium plus older alluvial and flood-plain deposits (Qa). The latter typically are developed into agricultural lands. Alluvial fans and fanglomerates from major and minor streams (Qaf) spread onto lowland areas. A few remnant (Pleistocene?) stream-channel deposits and gravel terraces (Qg) occur locally along lower valley slopes and along the margin of the Grande Ronde Valley.

Undeformed clayey lacustrine deposits (Ql) are found north of La Grande at the mouth of the Grande Ronde Canyon. These slack-water deposits form thin aprons on the slopes as high as 215-230 ft (65-70 m) above the elevation of the present-day Grande Ronde Valley floor. The extent of these sediments is uncertain, but they appear to represent Pleistocene ponding deposits.

Numerous landslides and other mass-gravity features (Qls) are found within the study area, particularly along the La Grande and Craig Mountain fronts where tilting and oversteepening of slopes occur. Small slides and slumps, as in Rock Creek Valley, occur along slopes of several drainages. A "textbook" example of an earth flow can be seen just north of La Grande in Sec. 30, T2S, R38E (Figure 11). Here the intersection of a vertical fault zone with nearly horizontal Glass Hill interbeds has provided the structural incompetence which contributed to the slope failure. As observed by Schlicker and Deacon (1971), many of the slides and slumps originate at interbed horizons; these are mostly in post-Grande Ronde Basalt units.

Jumbled blocks (Qjb) are map units which denote tilted but nearly coherent masses of structurally disturbed bedrock. They generally are interpreted to reflect recurrent fault adjustments along major structural trends with the rotation of near-surface units in the direction of throw. The Quaternary symbol for the unit is not intended to indicate recognizable recent structural adjustments or the absence of Tertiary (Pliocene) movement.

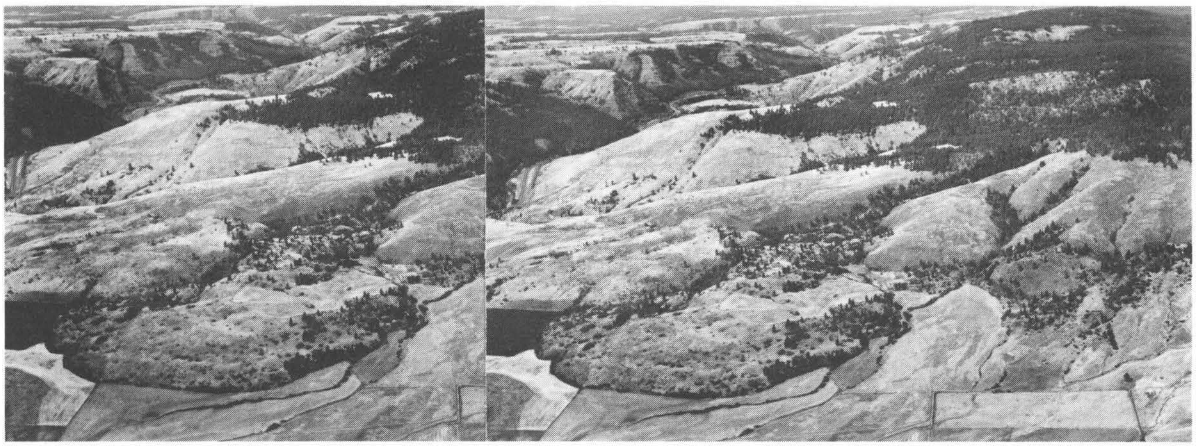


Figure 11. Earthflow north of La Grande.

Oblique stereo view is looking westward at the La Grande front in Sec. 30, T2S, R38E. A hummocky, jumbled surface and an abrupt steepened margin characterizes the earthflow. This large mass-gravity feature originated in the narrow, fault-controlled canyon in the right middleground and spread onto the gently sloping sedimentary fill of the Grande Ronde Valley. Rock debris making up the earthflow is principally from flows and interbeds of the Glass Hill sequence.

The Mount Emily fault is at the break in slope near the base of the front in lower right middleground. This fault extends southward beneath the neck of the earthflow to the La Grande sanitary landfill where it intersects the La Grande fault.

Bedrock in the steep slope of the La Grande front is Grande Ronde Basalt. Base of the timber cover in right middleground marks the base of basalt of Glass Hill sequence. Andesite of Mahogany Mountain is beneath the thick timber cover in upper right.

Grande Ronde Canyon is in center background. Hilgard uplands, near the trough of the Grande Ronde syncline, is the step-faulted upper surface in left background.

STRUCTURE

As discussed in the INTRODUCTION, the La Grande-study area includes the southwestern portion of the Grande Ronde Valley and adjacent uplands to the west. Structurally, the Grande Ronde Valley is the middle of three northerly aligned and northwesterly elongate structural depressions, or grabens, which are located between the Blue Mountains on the west and the Wallowa Mountains on the east.

When considered in overview, folding in Columbia River Basalt Group units has occurred on both regional and local scales, both during and after volcanism. On a broad scale, the Grande Ronde syncline (Hampton and Brown, 1964; Walker, 1973b) is aligned northeasterly through the study area (Plate I) and is nearly parallel with the Blue Mountain anticline (Hogenson, 1964; Walker, 1973b) to the northwest. This folding is primarily a post-Columbia River Basalt Group feature. On a local scale, eastward downwarping or subsidence can be inferred to have started in Grande Ronde Basalt time by the unconformable-onlap relation of the Glass Hill sequence to underlying Grande Ronde Basalt in the Ladd Canyon area. Monoclinal folding east of Glass Hill occurred after the accumulation of Grande Ronde Basalt and younger volcanic units (Plate III-IV).

Faulting has occurred across the area; observable traces and patterns are post-Columbia River Basalt Group in age. Step and scissor faulting associated with horst and graben movement in and surrounding the La Grande-study area has resulted in a prominent northwesterly trending topographic grain. Relative uplift of structural blocks west of the Grande Ronde Valley graben has not been uniform. The Craig Mountain structural block in the southern part of the study area is intermediate in structural offset between the main Glass Hill portion of the Hilgard uplands on the west and the Grande Ronde Valley graben on the east.

Fault recognition is difficult in the field because of the soil and vegetation cover common to the area. Displacement can be documented only where outcrops show visible offset (Figure 12) or where different stratigraphic or magnetostratigraphic units crop out juxtaposed. Fault zones within any one stratigraphic unit, in particular Grande Ronde Basalt, are extremely difficult to document unless breccia or gouge is exposed.

Geographically, the major structural blocks within the study area are informally designated the Hilgard uplands, La Grande front, Craig Mountain, Craig Mountain front and Grande Ronde Valley (Figure 2). Details of deformation within major structural blocks and their relation to regional photo-linear patterns are discussed in subsequent sections. Throughout these discussions references are made to the geologic maps (Plate I-IV) and structural cross sections (Plate V).

Photo-Linear Fabric

A photo-linear analysis was conducted to evaluate the general structural grain of the area about the Grande Ronde Valley. Thirty-one panchromatic black-and-white aerial photographs at a scale of 1:63,000 were used in conjunction with three high-altitude photo-positive transparencies and three color-infrared transparencies at a scale of 1:125,000. Linears were annotated on all frames, measured for azimuth under stereo vision, and transferred by zoom-transfer scope to 7 1/2-minute quadrangle topographic base maps. A small-scale composite of the linear fabric is shown in Figure 13.

Linears were measured and classified into one of three categories:

1) <u>Long linears</u>--over 3 mi (5 km) in length with little or no expression of topographic offset.
2) <u>Topographic linears</u>--over 3 mi (5 km) in length with expression of topographic offset.
3) <u>Short linears</u>--under 3 mi (5 km) in length with minor, local expression of topographic offset.

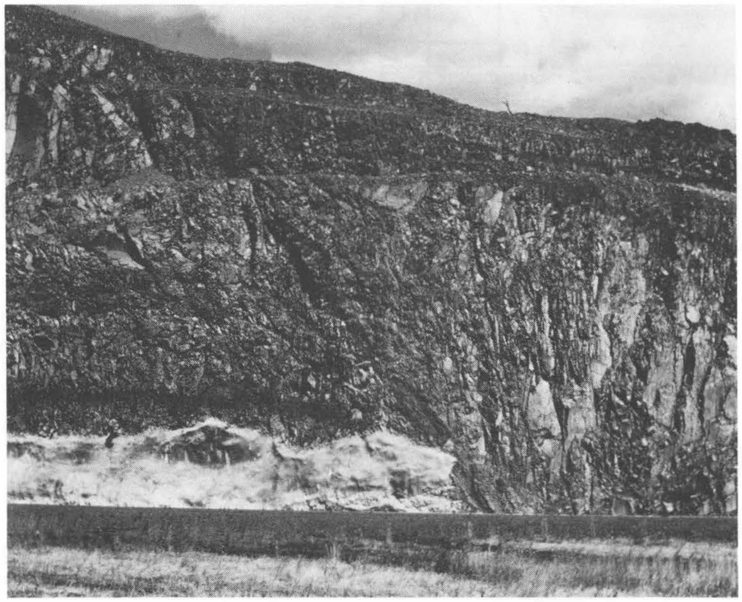


Figure 12. Fault zone in the La Grande front.

Grande Ronde Basalt flows exposed at the mouth of the Grande Ronde Canyon show nearly vertical shearing and gravity fault displacement. View is to the north across I80N in Sec. 36, T2S, R37E. The fault plane in photo center dips approximately 65° to the east; offset is down to the east (right). This fault, with displacement of about 30 ft (10 m), is one of many minor faults within the fault zone. It depicts the nature of internal adjustments found in the nearly vertical fault zone.

Light-colored material on the left near the base of the road cut is concrete sealer over a thin interflow ash layer; the ash marker unit is faulted below road level on the right.

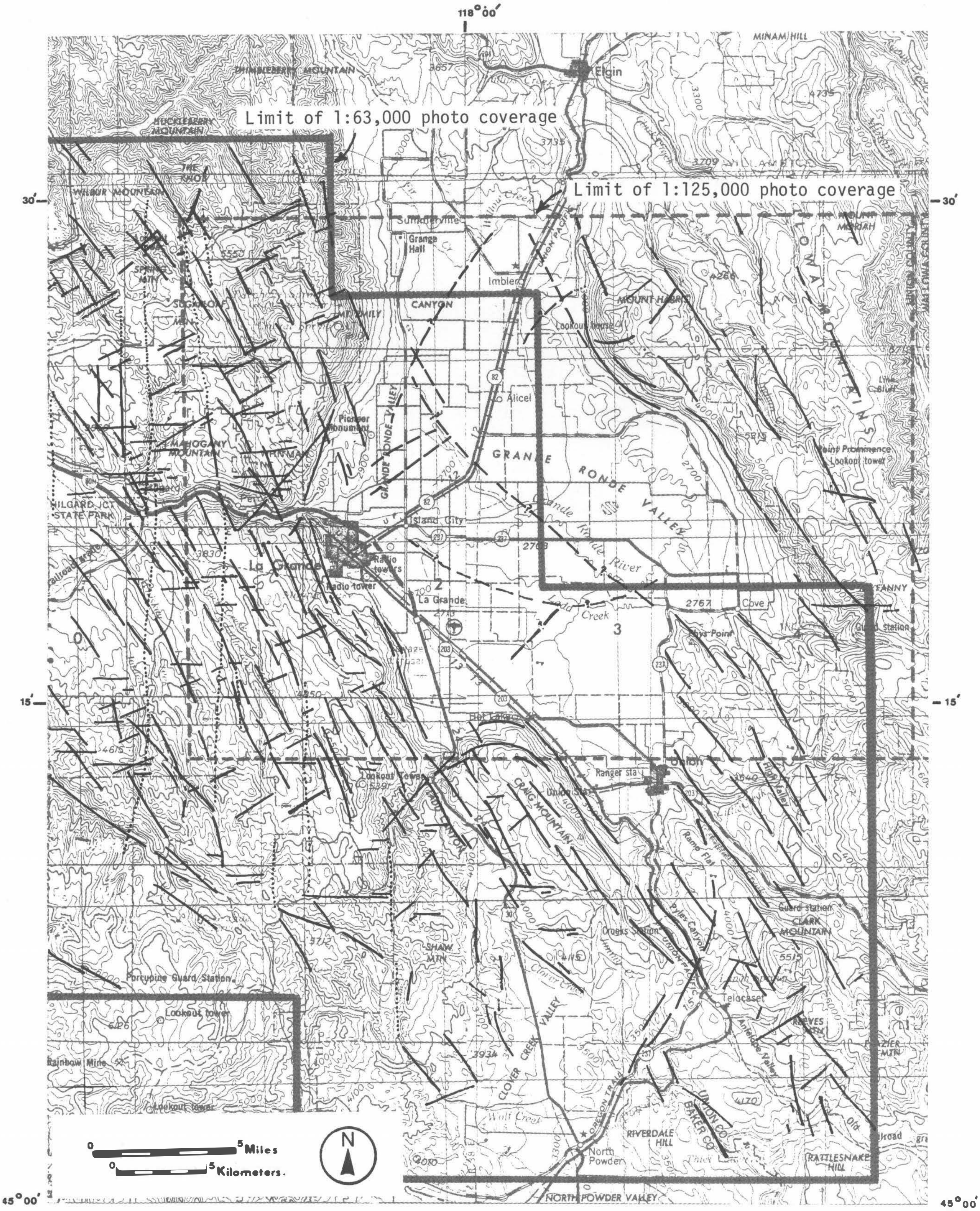


Figure 13. Pattern of photo linears near La Grande. See discussion on page 27 for explanation of types of linears shown on this map.

Directional distribution of the linears was evaluated by means of histograms and rose diagrams developed for each category (Figure 14a-c). A brief discussion of each linear category follows.

Long linears

Long linears (shown as dotted lines in Figure 13) are widely separated, but typically persist for several tens of miles. They are unique in that they could be recognized only in the western part of the area examined. Azimuth measurements were taken at 3 mi (5 km) intervals along each linear; the long linears generally trend north-south ± 15° (Figure 14a). Long linears have little topographic expression but seem pervasive across drainages, lithologies and vegetation types. They commonly exhibit splaying along their lengths.

Topographic linears

Topographic linears prevail in upland areas. Most follow the N30°-45°W structural grain which characterizes the La Grande area (Figure 3). Subordinate topographic linears were also measured and plotted to determine if other regional trends or fracture patterns were present. The dominant linear concentration found for topographic linears was at about N35°W (145°) (Figure 14b). Three subordinate sets of about equal distribution were noted at N15°E (15°), N45°E (45°) and E-W (90°).

Short linears

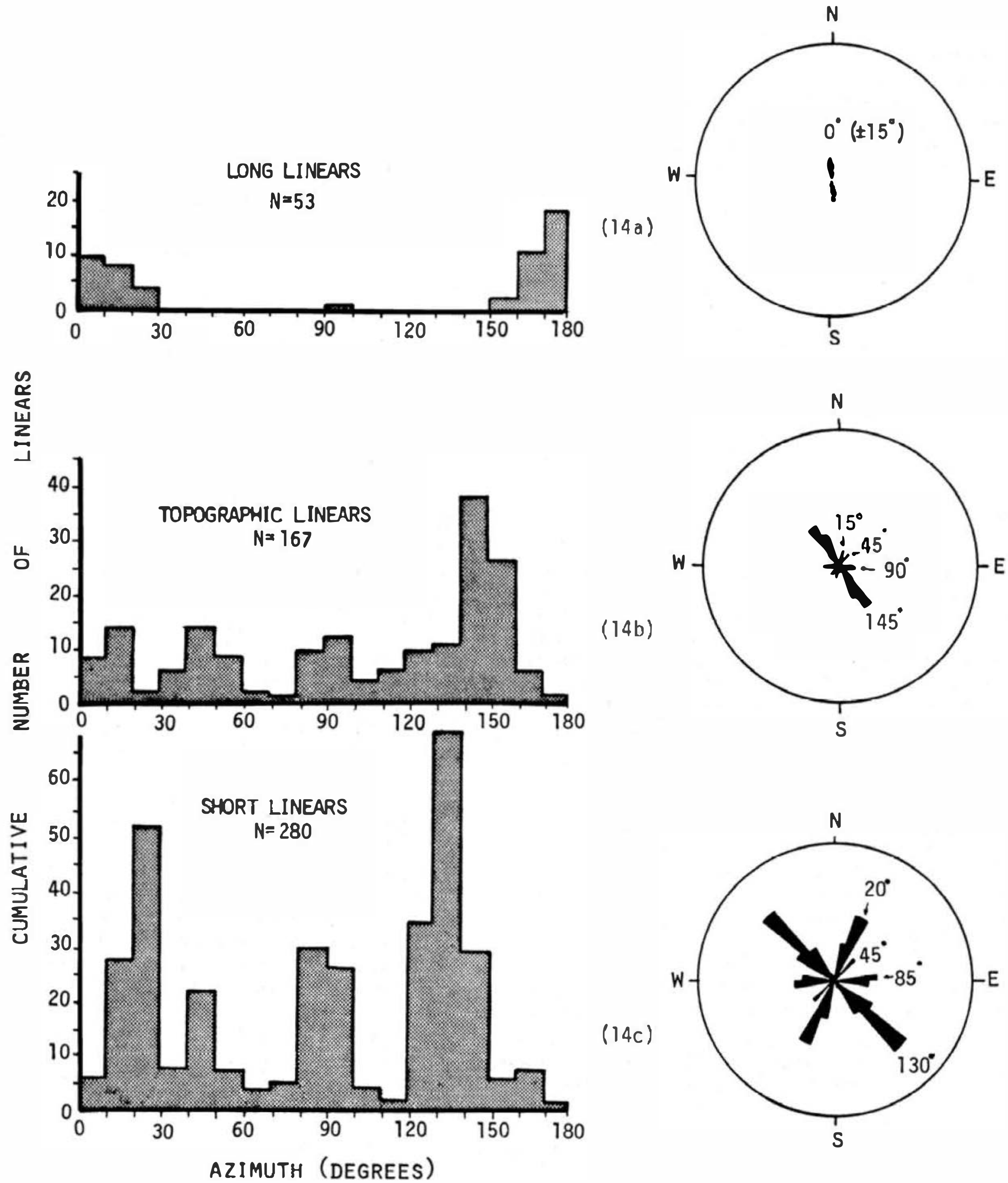
The density of short linears is greatest along the Grande Ronde River and the axial trough of the Grande Ronde syncline. Here the linears are discontinuous and occupy short stream valleys. Trends can be extrapolated across stream divides, but they cannot be extended visually across ridges and knolls to generate a long linear. Two dominant azimuth-distribution peaks are apparent from the short linears at N20°E (20°) and N50°W (130°). Two minor peaks are present at N45°E (45°) and N85°E (85°) (Figure 14c). The latter fall within 5° of subordinate topographic linears and may be closely related. Comparison of short-linear occurrences to lithology at the ground surface indicates that the northeast-trending linears have the greatest concentration within areas underlain by andesite. The concentration of short linears noted near the Grande Ronde River may be an expression of more effective differential erosion resulting from steeper side-stream gradients.

Photo-linear fault-trace associations

Comparisons of the locations of photo linears in all three categories with fault traces mapped in upland areas show some discrepancies. Major northwest-trending fault traces typically border, rather than lie in, the straight-line stream valleys which make up the topographic linears. Dominant topographic linears, then, are mostly the result of erosion by consequent streams which took initial courses on downthrown blocks parallel to fault traces, rather than of erosion by subsequent streams which developed by differential, headward erosion along fault zones. Short linears, however, more commonly mark subsequent stream development through differential erosion along small fracture zones; many of the zones have no recognizable displacement across them.

Comparisons of photo-linear interpretations with geologic conditions in jumbled blocks (Qjb) and landslides (Qls) of the steep slopes along the La Grande and Craig Mountain fronts suggest that topographic linears in these areas are weak surficial traces of fault planes in underlying basalt bedrock. When mapping on the La Grande and Craig Mountain fronts, topographic linears can seldom be recognized from ground-level observations. Locally, however, where bedrock is exposed, faulting can be confirmed to be related to photo linears by offset of correlative strata.

During the field study, long linears could not be equated to any geologic features exposed at the surface except perhaps the north-south-aligned Glass Hill monocline. Reinspection of air photos did not lead to the conclusion that long linears were artifacts or were induced by film processing. Based on their broad spacing and extreme length, long photo linears are considered possibly to be an expression of subtle bedrock response to minor adjustments along pre-existing basement structures.



"N" is the total number of linears in each category.

Figure 14. Histograms and rose diagrams of photo-linear trends.

Tectonic considerations

The dominant northwesterly linear fabric apparent from photo-linear analysis for the area around the Grande Ronde Valley, and the confirmation that this trend is the dominant fault trend in the field area near La Grande (discussed subsequently in detail) provide a framework for briefly considering the tectonic setting of the study area. This involves a brief review of general tectonic factors affecting the Columbia Plateau followed by a consideration of which of these factors best fits the structures of the La Grande area.

Tectonic evolution of the Columbia Plateau and its bordering areas, during and since Miocene time, is commonly related to a number of dynamic structural episodes and/or sub-basalt, basement controls. These did not necessarily act singularly; as a result many areas within the Columbia Plateau record mixed tectonic settings. A common resolution of the individual episodes and controls (Geoscience Research Consultants, 1978, p. 142-144) is:

- General upper Cenozoic, approximately N20°W-S20°E compression related to northwesterly slippage of the Pacific Plate past the North American Plate.
- General upper Cenozoic, approximately east-west compression generated by subduction of the Pacific Plate beneath the North American Plate.
- Regional upper Cenozoic subsidence of the center of the Columbia Plateau, perhaps as an isostatic response to basalt loading and magma withdrawal.
- Regional post-basalt adjustments focused by pre-existing sub-basalt basement structures; this includes variations in crustal thickness and/or composition.

The N20°W-S20°E compression episode is recorded in the Columbia Plateau by such features as the major northwesterly trending dike swarms which fed the plateau basalts. These feeders developed along tensional fissures which resulted from extension at right angles to the northwesterly compression. Portions of the Blue Mountain-Yakima Ridge fold set, where the anticlinal and synclinal axes are aligned northeasterly, also have been attributed to this compressional field.

The east-west compression episode is reflected in the north-south flexures and uplifted flanks of the northern Casades. This episode appears to have overprinted the Blue Mountain-Yakima Ridge set by uplifting the folds at the western margin of the Columbia Plateau; this episode, then, persisted while the northwesterly compression waned.

Subsidence of the center of the Columbia Plateau during and after Columbia River Basalt Group extrusion is recorded by the general centerward, centripetal distribution pattern of progressively younger basalt flows cropping out at the surface of the plateau (Wright and others, 1973) and by post-basalt development of the present-day Pasco Basin. The antithesis of this regional subsidence is the general uplift of granitic rocks of the Idaho batholith east of the basalt plateau.

Basement structures have been proposed as controls for a number of features on the Columbia Plateau; these include some near the La Grande study area. The aligned ridges of the Olympic Wallowa Lineament (OWL) (Raisz, 1945) north of the study area may reflect a continental-oceanic crustal selvage (Skehan, 1965) which has focused deformation in overlying basalt flows. Right-lateral strike-slip movement may also be involved along this interpreted basement discontinuity. Left-lateral slippage within blocks of a crustal plate has been considered for the fault deformation pattern and an offset of anticlinal fold axes of the eastern Blue Mountains (Gardner and others, 1974). Basement control, in the form of crustal thinning, has been proposed for the movements creating structural depressions from the Grande Ronde Valley southeastward to the Snake Plain (Gardner and others, 1974).

When the structural pattern of folding and faulting near the La Grande-study area is viewed in conventional stress-field relations, particularly in light of structural episodes and controls common to the Columbia Plateau, the simplest interpretation is one of response to the northwesterly compressional episode. In a compressional field, major fold axes trend at right angles to compression and the Blue Mountain anticline and the Grande Ronde syncline fit this pattern. Direction of extension is at right angles to compression and the northwesterly oriented, nearly vertical faults which dominate the study area fit this pattern. In addition, northwest-trending faults would be in tension and lead to horst and graben development; this is common in the study area. Short linears, which appear not to be related to large-scale vertical faulting (in contrast to topographic linears) have two of their trends at angles from 45°-60° away from the dominant northwesterly compression. Short linears in these trends with little or no topographic expression would fit the expressions of incipient shear planes.

The northwesterly compressional vector for La Grande-area structures would have to be approximately N35°W-S35°E. This is a difference of about 15° from the N20°W-S20°E overall compressional field considered for older fissures which developed to the east and north during Columbia River Basalt Group extrusion. It is also slightly misaligned with subsequent folding in the Yakima Ridge area to the northwest. However, crustal variations, rock inhomogeneities, shifts with geologic time and statistical evaluation procedures may account for this amount of variation from regional generalizations.

In summary, consistencies of structural trends, compatability of the Blue Mountain folding to backslope faulting in the La Grande area and systematic distribution in the orientation of linear trends favor northwesterly compression as the tectonic control in the study area. Furthermore, the general lack of interference, or lateral offset of linears or of any of the intersecting faults, as is discussed in the next sections, suggests that all of the post-Columbia River Basalt Group structures in the area near La Grande have been created in response to only one major tectonic episode.

Hilgard Uplands

The Hilgard uplands structural block encompasses most of the Hilgard and the western half of the Glass Hill 7 1/2-minute quadrangles (Plates I and III). The area is characterized by gently southwesterly dipping basalt flows north of the Grande Ronde River and gently northwesterly dipping units from the vicinity of Glass Hill northward. This latter northerly dip persists through portions of Whiskey Creek, Little Graves Creek and Sheep Creek drainages; basalt flows are nearly horizontal directly south of the Grande Ronde River.

Within the Hilgard uplands are numerous major and minor northwest-trending vertical faults. Vertical displacement across the faults ranges from less than 3 ft (1 m) to over 250 ft (80 m) (Plate V). Some faults are scissor-like with relative movement along the same fault zone reversing over distances of less than 1 mi (1.5 km). Examples of this are noted in more detail under discussions of individual structural features.

Rock units exposed in the Hilgard uplands structural block include as much as 1000 ft (300 m) of Grande Ronde Basalt and various flows and interbeds of the basalt of Glass Hill. Andesite of Mahogany Mountain is present north of the Grande Ronde River and remnant knobs of andesite of Craig Mountain crop out south of the river in the vicinity of Glass Hill. Mapped structures post-date the Columbia River Basalt Group and all Miocene bedrock units are involved in the folds and faults carried on the geologic maps.

Grande Ronde syncline

In the Hilgard uplands the Grande Ronde syncline (Hampton and Brown, 1964; Walker, 1973b) can be defined as a bowl-like, concave surface with several monoclinal to synclinal flexures (Plates I and II). In detail, the synclinal axial trough is a broad flexure rather than a single synclinal hinge.

Hilgard monocline: This structure is within the Grande Ronde syncline and follows the northeast-trending segment of the Grande Ronde River (Plate I) in Secs. 1 and 12, T3S, R36E, and Sec. 6, T3S, R37E. Dips decrease from 6°-4° to 2°-0° across the monoclinal axis. The monocline appears to die out near the mouth of Rock Creek.

The Hilgard monocline is interpreted to be the initial axis of the Grande Ronde syncline and is believed to be responsible for establishing the initial northeasterly course of the Grande Ronde River across the area. The more east-west trending segment of the river from near Hilgard to La Grande was established against the southern margin of the mound of andesite of Mahogany Mountain (see page 19) and is not a reflection of ancestral structure.

Sheep Creek monocline: Southeast of the Hilgard monocline is the Sheep Creek monocline which changes from monoclinal to synclinal geometry from west to east along its axis. It is a monocline where it follows (approximately) the northeast short-linear trend of portions of Whiskey Creek, Little Graves Creek, and Sheep Creek. In NW 1/4 Sec. 10 and SW 1/4 Sec. 3, T3S, R37E, the Sheep Creek structure is synclinal and lies in the trough of the larger Grande Ronde syncline. The Sheep Creek monocline dies out in the vicinity of Wilson Canyon to the northeast, and becomes indiscernible near Jordan Creek to the southwest.

The axis of the Sheep Creek monocline appears to have acted as the hinge line for scissor faulting. Some breakage is inferred along this trace because of elevation differences of the Grande Ronde Basalt-basalt of Glass Hill contact on the north and south sides of Sheep Creek. The Sheep Creek monocline may have formed after the Hilgard monocline as a result of continued regional uplift of the Blue Mountains and southward migration of the axial trough within the broad Grande Ronde syncline.

Whiskey Creek fault system

A number of faults have been identified and inferred in the Jordan Creek-Whiskey Creek-Little Graves Creek area (Plate I). These faults, grouped as the Whiskey Creek fault system, trend N30-40°W and generally bound elongate horst and graben structural blocks. Offset varies considerably along any one fault as well as from one fault to another. Maximum offset is about 50-65 ft (15-20 m) for the fault on the east slope of Jordan Creek. Maximum offset is about 100 ft (30 m) across the faults cutting the north-south section of Whiskey Creek. In the Whiskey Creek fault system several subdued faults of probable minor displacement are inferred from slight topographic breaks and linear trends.

Rock Creek fault system

The Graves Creek-Rock Creek-Coyote Creek area has the greatest density of faults within the study area. At least six major and several minor northwest-trending faults of the Rock Creek fault system occur in the area (Plate I). The Graves Creek fault can be traced from the eastern edge of Sec. 7, T3S, R37E to the southern boundary of the Hilgard 7 1/2-minute quadrangle, a distance of about 6 mi (10 km). The Graves Creek fault probably extends farther southeastward beyond the map area. Offset across this fault is approximately 265 ft (80 m) in Sec. 34, T3S, R37E.

Rock Creek, from its mouth to its juncture with Little Rock Creek, flows in a graben formed by the downthrown sides of the Rock Creek West fault and Little Coyote Canyon fault. The Rock Creek East fault is of lesser magnitude but also contributes to the structural control of Rock Creek. Maximum displacement across the Rock Creek West and Little Coyote Canyon faults is 200-230 ft (60-70 m). The Little Coyote Canyon fault extends north of the Grande Ronde River beyond the map area (Figure 15). The Rock Creek West fault appears to merge to the southeast with the Graves Creek fault.

The headward part of the Coyote Canyon drainage is also controlled by a graben formed by downdropping along an unnamed fault on the northwest and the Coyote Canyon fault on the northeast. Where the traces of these two faults cross the Sheep Creek monocline, relative movements of both faults reverse along strike and the block between them becomes a horst. These faults die out 1-1.3 mi (1.5-2 km) southeast of the mouth of Sheep Creek.

Peach Canyon fault

The Peach Canyon fault is a topographically pronounced structural feature (Figure 16) that extends from near the head of Blacksmith Canyon in NW 1/4, Sec. 29, T3S, R37E to at least the southeastern border of the Hilgard 7 1/2-minute quadrangle, a distance of about 8 mi (13 km) (Plate I). The relative movement along the Peach Canyon fault changes where it crosses the Sheep Creek monocline. North of the monoclinal axis, the fault is downthrown to the northeast; south of the axis, it is upthrown to the northeast. Displacement is about 100-165 ft (30-50 m) along the west slope of Peach Canyon, and possibly as much as 230-265 ft (70-80 m) along the east slope of Rock Creek in Secs. 26 and 35, T3S, R37E.

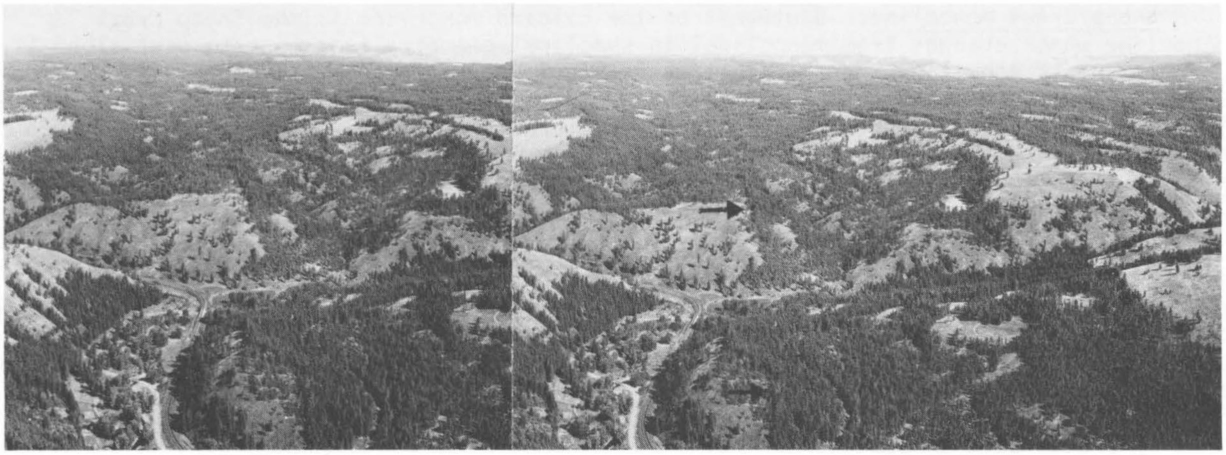


Figure 15. Little Coyote Canyon fault.

Oblique stereo view is looking northwestward along the trace of the Little Coyote Canyon fault (arrows). The fault trace is expressed by differential timber growth. Stream confluence in the left centerground is one-half mile north of Hilgard in Sec. 30, T2S, R37E. Bedrock is Grande Ronde Basalt.

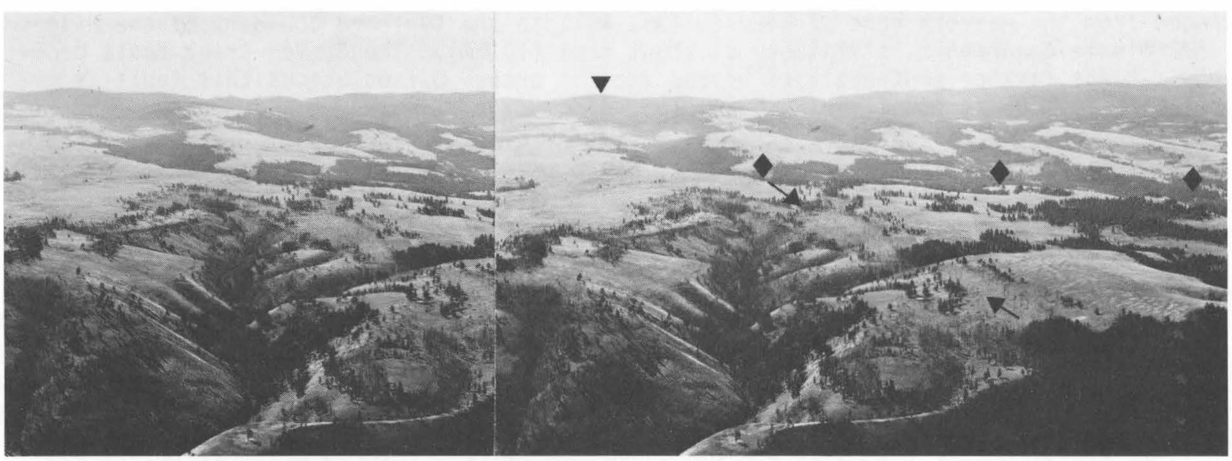


Figure 16. Peach Canyon fault.

Oblique stereo view is looking southeastward up Peach Canyon; center foreground is in Sec. 33, T2S, R37E. The fault occupies the bench on the west slope of the canyon (arrows). Sheep Creek monoclinal flexure, which forms part of the Grande Ronde synclinal trough, is in the middle distance (diamonds); Glass Hill is on the left skyline (triangle).

Morris Hill fault

To the southeast of the Peach Canyon fault is the northwesterly trending Morris Hill fault. This fault extends for at least 3 mi (5 km) in the southwestern portion of the Glass Hill 7 1/2-minute quadrangle (Plate III). Approximately 500 ft (150 m) of displacement occurs across the Morris Hill fault west of Howard Meadow; the southwest side is upthrown relative to the northeast side.

Long Prairie fault

The Long Prairie fault can be traced from SW 1/4 Sec. 25, T3S, R37E, to NW 1/4 Sec. 28, T4S, R38E where it either dies out or becomes unrecognizable within the sequence of Grande Ronde Basalt flows. In Sec. 7, T4S, R38E, the southwest side is downthrown about 115-130 ft (65-70 m).

West of the Long Prairie fault, in Sec. 24, T4S, R37E, and Sec. 19, T4S, R38E, is a minor syncline which parallels the northeast-trending portion of Rock Creek. East of the Long Prairie and Peach Canyon faults is a relatively undisturbed tableland about 1.3-2.5 mi (2-4 km) wide on which Morgan Lake and Twin Lake are found. This flat upland surface extends eastward to the Wilson Creek-Mill Creek faults; these faults form the boundary between the Hilgard uplands and La Grande front structural blocks.

La Grande Front

As noted above, the La Grande front structural block is bounded on the west by the Wilson Creek and Mill Creek faults. The eastern boundary is the La Grande and Foothill Road faults; the southern boundary is the front faults of the Craig Mountain structural block. The La Grande front extends to the northern boundary of the field area. All major rock units of the Columbia River Basalt Group are present in this block. Vertical displacement across the front is at least 1400 ft (430 m) and may be as much as 1600-2300 ft (500-700 m). The front is characterized by basinward-tilted jumbled blocks and landslides that form a chaotic zone one to three miles wide. The basinward inclination of the basalt flows of the internally coherent jumbled blocks is interpreted to indicate tilting and step-fault rotation of shallow units rather than downslope gravity movement along fault scarps.

South of La Grande the structures within the front have northwesterly trends. North of La Grande the main front fault swings northward to slightly northeastward and cuts across the general trend of the northwesterly linears and faults of the study area.

Wilson Canyon-Mill Creek faults

The Wilson Canyon fault can be traced southeastward from near the mouth of Wilson Canyon for about 1.2 mi (2 km) (Plate I). Maximum vertical displacement across the fault is about 100 ft (30 m). The southwest side is downthrown. Where the structure crosses Deal Creek, the relative movement reverses to downthrown on the northeast side. From this location southward, the fault is named the Mill Creek fault. The fault continues southeastward to Ladd Creek, and may continue along the west side of Ladd Canyon to S 1/2, Sec. 25, T4S, R38E. Maximum displacement along the Mill Creek fault is interpreted to be 425-540 ft (130-165 m) near the southern border of the La Grande SE 7 1/2-minute quadrangle.

Several unnamed faults of vertical displacement occur east of the Wilson Canyon fault; they appear to merge to the southeast with the Mill Creek fault.

Deal Creek fault

The Deal Creek fault truncates the east side of Mahogany Mountain, crosses the Grande Ronde River, Deal Creek, and is lost beneath soil cover south of Mill Creek in the SW 1/4, Sec. 18, T3S, R38E. Relative movement is down to the northeast. Offset along the fault ranges from 100-135 ft (30-40 m) in the Mahogany Mountain-Grande Ronde Canyon area, to at least 430 ft (130 m) west of Table Mountain.

La Grande fault system

The La Grande fault system, or fault zone, is the northwest-trending zone along which major displacement between the La Grande front structural block and Grande Ronde Valley has occurred. The main fault passes west of La Grande at the base of the frontal scarp. North of the Grande Ronde River, in the La Grande sanitary landfill, the fault is expressed by intensely sheared and fractured basalt and brecciated tuff interbeds (Figure 17). Deformation in this location is also influenced by the intersection of the Mount Emily fault with the La Grande fault system. The former is a north-to-northeast-trending fault that forms the frontal escarpment of the Grande Ronde Valley northward from the Grande Ronde River.

North of the landfill the La Grande fault is interpreted to die out in a monoclinal flexure. To the southeast the fault becomes unrecognizable in the vicinity of Ladd Canyon where several small faults are present which may represent the breakup of this fault zone.

The Foothill Road fault forms the easternmost escarpment of the La Grande front and has accommodated major offset southeast of La Grande (Figure 18). This fault may extend northwestward beneath La Grande to connect with the unnamed northwest-trending fault in Sec. 30, T3S, R38E. As such it may be a deep ground-water conduit responsible for the thermal wells at the railyard. A weak northwesterly photo-linear extends from the trace of the Foothill Ronde fault south of La Grande into the Grande Ronde Valley fill. This photo linear and a weak topographic break in slope north of La Grande (Figure 19) may be indications of minor recent fault movement in the study area.

Craig Mountain

The Craig Mountain structural block occupies the southeastern portion of the study area (Plates III and IV). The western boundary of the Craig Mountain structural block is a combination of the Glass Hill monocline, the Clover Creek fault and the interconnecting Tamarack Mountain fault. The eastern and northern boundary is the Craig Mountain front. The southern boundary is out of the study area.

Western boundary structures

The Glass Hill monocline, together with the Clover Creek and Tamarack Mountain faults, accommodates approximately 1000 ft (300 m) of elevation difference between the Craig Mountain structural block and the structurally higher Glass Hill portion of the Hilgard uplands structural block.

The Glass Hill monoclinal hinge parallels the north-trending segments of the Glass Hill and Ladd Canyon roads for at least 4.5 mi (7 km). Nearly horizontal basalt flow attitudes in the Glass Hill lookout-to-Vincent Ranch area pass eastward to 10°-to-20° dips with northerly to northwesterly strikes. These attitudes are well exposed in the Ladd Creek area; dips up to 30° occur at the mouth of Ladd Creek above the westbound lanes of highway I80N. Increased dips in the basalt at the north edge of the Craig Mountain block are compatable with drag on the northeast-trending range-front fault.

The Clover Creek fault is a north-trending, steeply dipping fault across which offset increases southward from no displacement directly south of highway I80N in Sec. 30, T4S, R39E, to 1000 ft (300 m) at the southern boundary of the area in the southwest portion of the Craig Mountain 7 1/2-minute quadrangle. Numerous jumbled blocks and landslides mark the trace of the Clover Creek fault.

West of the Clover Creek fault is the northwest-trending Tamarack Mountain fault. This fault appears to merge with, or die out in the vicinity of the southern end of the Glass Hill monocline in SW 1/4 Sec. 3, T5S, R38E; beyond the map area the southeast end of the fault probably terminates against the Clover Creek fault. Maximum displacement across the Tamarack Mountain fault is at least 500 ft (150 m).

Also between the Glass Hill monocline and Clover Creek fault is the N30°W-trending Baldy fault. It can be traced from northeast of Tamarack Mountain northwestward where it

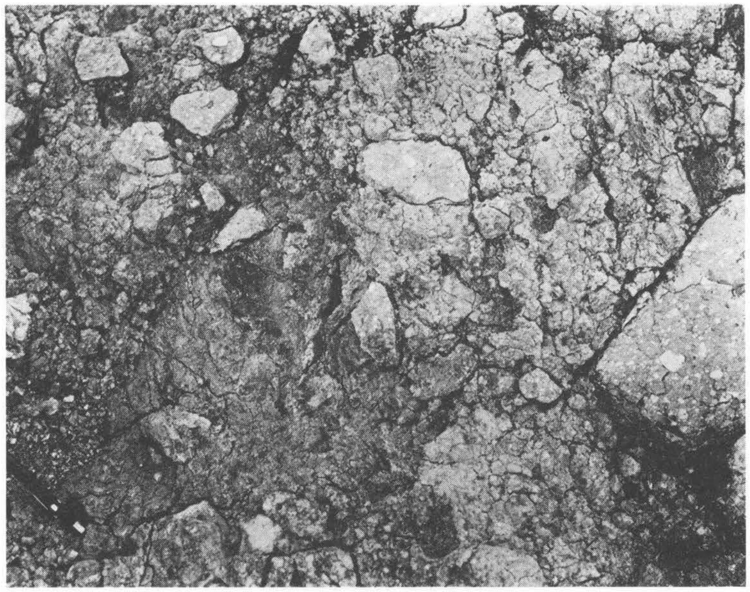


Figure 17. Brecciated tuff interbed.

A slope cut in the La Grande sanitary landfill in SE 1/4, Sec. 36, T2S, R37E, exposes brecciated tuff of the base of the Glass Hill interval. Breccia blocks in the Mount Emily fault zone are up to 1 ft (0.3 m) across; these blocks preserve the original tuff-breccia texture of the interbed. Pen in lower left gives scale.

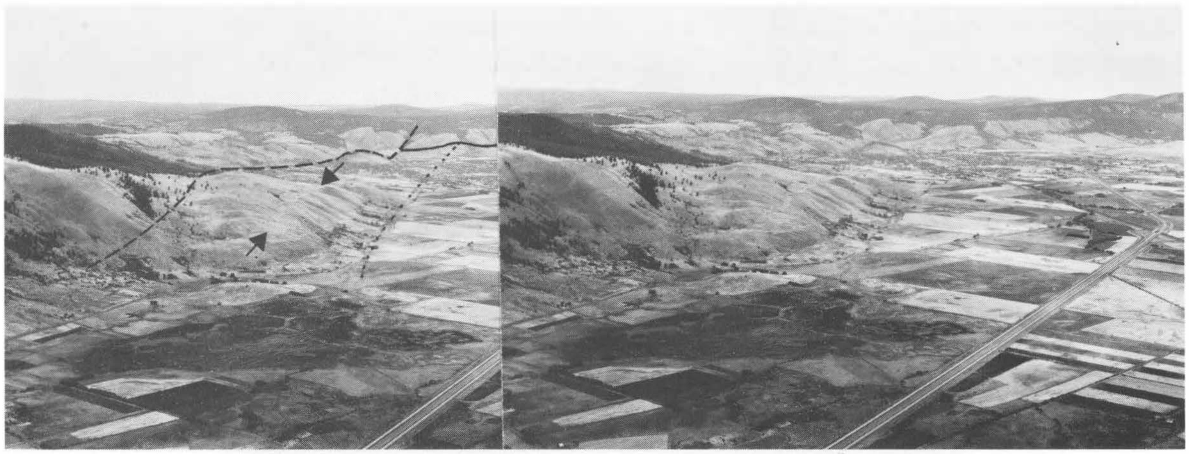


Figure 18. La Grande front south.

Oblique stereo view is looking northwestward along the trace of the Foothill Road fault (dotted line) toward La Grande. Ladd Marsh is in the left foreground in Secs. 34 and 35, T3S, R38E. The approximate trace of the La Grande fault is shown as a dashed line; the Mount Emily fault in the background is shown by a solid line. An example of a topographic linear in jumbled blocks (Qjb) is between the Foothill Road and La Grande faults (arrows).

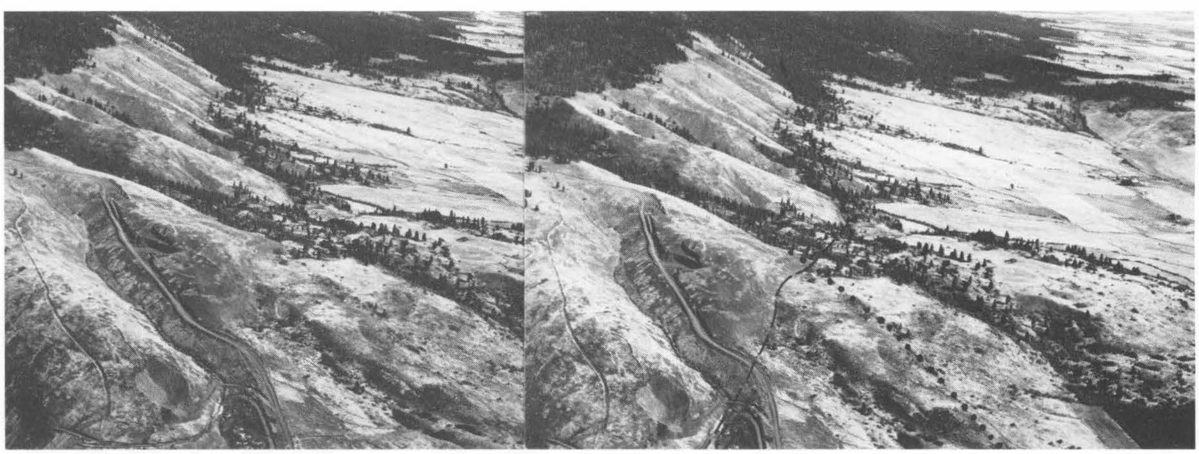


Figure 19. La Grande front north.

Colluvium at the base of the La Grande front in SW 1/4, Sec. 30, T2S, R38E shows a weak break in slope. This topographic break suggests recent offset along the unnamed fault (dotted line) which extends southeastward from the earthflow canyon toward La Grande. This fault and the break in slope are on line with the Foothill Road fault south of La Grande. Mount Emily fault is at the base of the slope in the middleground (dashed line). Earthflow is at right.

merges with the Glass Hill monocline. Maximum offset is about 200-235 ft (60-70 m) with relative movement upthrown to the west.

Structures within the Craig Mountain structural block

Uplift within the Craig Mountain block was not uniform. Within the block uplift was greatest north of the boundary between T4S and T5S. North of this township line the more uplifted andesite units are nearly horizontal to slightly westerly dipping; volcanic units south of the line have a gentle southerly dip.

Northwest-trending high-angle dip-slip faults (as reflected by topographic linears) and a narrow graben are present within the Craig Mountain block east of highway I80N. Vertical displacements range from less than 15 ft (5 m) to approximately 200 ft (60 m); generally the southwest blocks are downthrown relative to the northeast blocks. This down-to-the-southwest pattern within the Craig Mountain structural block is opposite to the down-to-the-northeast pattern of structural blocks and major faults in much of the map area. As in the Grande Ronde synclinal trough, the northwest-trending structures within the Craig Mountain block cut all Tertiary volcanic units.

Craig Mountain Front

Craig Mountain front structural block is denoted by the narrow, steep foreslope which bounds Craig Mountain on the northeast to northwest. The front, in turn, is bounded on the northeast to northwest by the Grande Ronde Valley. The steep frontal slope extends southeastward to the boundary of the study area. Near the mouth of Ladd Canyon, the northwestern portion of the Craig Mountain front merges with the La Grande front through a series of small faults. Because overall structural offset is very similar along the two fronts, marked discordance between the two structures does not exist, and major deformation is not a part of the intersection of the two features.

The principal constituent of the Craig Mountain front is the Hot Lake fault zone. Displacement across the Hot Lake fault zone is as much as 2400 ft (730 m); it is accommodated in a map distance of 1.2 mi (2 km). The vertical displacement is calculated as the difference between ridge-top andesite at an elevation of 4595 ft (1401 m) and the elevation of 2195 ft (670 m) which is the top of the andesite in the Magma-La Grande Well No. 1, (Plate IV, Appendix).

The Hot Lake fault zone exhibits a narrow zone of northwest-trending topographic linears; these can be traced southeastward out of the study area from Hot Lake through Pyles Canyon, a distance of 11 mi (18 km). As with the La Grande front, these topographic linears are interpreted to be fault traces which are being reflected through the jumbled blocks at the surface.

The major hot spring in the study area occurs at Hot Lake where the northwesternmost surface expression of the Hot Lake fault trace intersects an unnamed range front fault which trends easterly from the mouth of Ladd Creek.

Grande Ronde Valley

The Grande Ronde Valley, a southwestern portion of which lies in the study area (Plates II, IV), is a structural basin formed by vertical displacement along step faults of the La Grande-Craig Mountain fronts on the southwest and the "Mount Harris front" on the northeast (Figure 3). The southeastern and northwestern margins of the basin are not as structurally abrupt and are characterized by basinward dip of Columbia River Basalt Group units. The northwest-oriented structural grain of linears and faults prominent in bedrock areas has been masked by Quaternary valley fill within the graben. However, linear salients and angular indentations made into the fill by basinward-dipping bedrock units along the southeastern and northwestern margin indicate the persistence of this grain into the graben.

Depth to bedrock in the center of the Grande Ronde graben is reported to be as much as 2020 ft (615 m) (Hampton and Brown, 1964, p. 24). Within the study area shallower depths to bedrock are to be expected. As a generalization for the La Grande vicinity, a decreasing depth to bedrock can be anticipated in a southwesterly direction (Plate V). Near the center of the community, drillers' logs from railroad and city wells record depths to "basalt" of 845-996 ft (257-304 m). Closer to the La Grande front "broken basalt" is encountered at a drill depth of 302 ft (92 m) in the Carey well near the high school. At the base of the Craig Mountain front, as observed previously, bedrock is reported at a drill depth of 518 ft (158 m) in the Magma-La Grande Well No. 1.

Well data (from Hampton and Brown, 1964, and Union County Water Master files) are inadequate to be used to locate fault zones passing beneath the valley fill. Most potable and industrial water wells outside of La Grande fail to drill to bedrock, and a structural datum surface cannot be reconstructed nor can offset be recognized. As noted in the La Grande front discussion, however, the location of the railroad and city thermal wells in La Grande are on the projected trend and photo-linear extension of the Foothill Road fault. Similar northwest-trending major faults exposed at the margins of the graben are interpreted to persist laterally for many miles in bedrock beneath the fill. It is also interpreted that scissor-fault movement comparable to that in the Hilgard uplands will be present in the graben along the projected trend of the Grande Ronde synclinal trough.

Based on distribution of bedrock units exposed in upland areas, it is interpreted that basalt flows and interbedded sediments of the Glass Hill sequence will be the first bedrock unit encountered beneath the valley fill at La Grande. Its thickness there is projected to be approximately 350 ft (105 m). The andesite of Mahogany Mountain probably does not extend south of the Grande Ronde River in the La Grande area except possibly for thin distal flow edges. The andesite of Craig Mountain, which is greater than 500 ft (150 m) thick in the Magma-La Grande Well No.1, is interpreted to thin northwestward and be absent from Ladd Marsh to La Grande. These two units may coalesce or interdigitate in the subsurface east of La Grande.

Grande Ronde Basalt will underlie the Glass Hill sequence; it probably is over 2000 ft (600 m) thick at La Grande. The greenstone (Triassic metavolcanic rock?) encountered in the Magma-La Grande Well No. 1 probably is the uppermost sub-basalt unit in the Grande Ronde Valley near La Grande.

GEOLOGIC HISTORY

Geologic history of the La Grande-study area can be reconstructed from outcrop observations only as far back in geologic time as represented by Miocene basalt flows of the Grande Ronde interval in the Yakima Basalt Subgroup (Figure 5). Features which present indications of geologic events and local conditions during and since accumulation of Columbia River Basalt Group flows in the area include:

- Relatively uniform distribution of Grande Ronde flows and lack of sedimentary interbeds in that basalt sequence.
- Normal(N_1)-reverse(R_2)-normal(N_2) up-section magnetostratigraphic sequence in Grande Ronde Basalt.
- Possible southward thinning of the normal(N_2) Grande Ronde flows.
- Limited geographic distribution of Glass Hill flows and common occurrence of interbedded sediments and pyroclastic debris near the La Grande front.
- Local distribution and marked thickness variations in the accumulations of andesites of Mahogany Mountain and Craig Mountain north and south of the Grande Ronde River, respectively.
- Recognizable angular discordances between Grande Ronde, Glass Hill and Craig Mountain sequences near lower Ladd Canyon.
- Contact of Craig Mountain andesite against an irregular erosional surface on Glass Hill and Grande Ronde flows in upper Ladd Canyon.
- Presence of chert, quartzite and other "exotic" fluvial gravels on upland Grande Ronde and Glass Hill basalt-flow surfaces.
- Association of the Grande Ronde synclinal trough and the margin of Mahogany Mountain andesitic flows with the through-flowing Grande Ronde River.
- Dominant northwesterly structural grain consisting of nearly vertical faults cross cutting all Tertiary rock units.
- Right angle intersection of northwest-trending faults with northeast-trending fold axes.
- Persistence of north-south oriented long linears without obvious topographic expression.
- Incised meander pattern of the Grande Ronde River with trellis-to-parallel drainages developed in tributary streams.
- Accumulation of fluvial and lacustrine deposits in the Grande Ronde graben and their preservation on lower slopes bordering the graben.
- Association of thermal-water sites with major northwest-oriented fault zones.
- Presence of modern ash deposits in soil and colluvial deposits near stream levels and on side slopes.
- General absence of recent fault scarps and truncated spurs along fault traces.

Based on these field observations and those of previous workers in the region, the geologic history of the La Grande-study area is interpreted as follows:

Grande Ronde flows of the Columbia River Basalt Group began spreading across a mature basement topography in the La Grande area approximately 15 million years ago (Watkins and Baksi, 1974; Gardner and others, 1974) as the regional Columbia Plateau was being constructed. Very fluid sheets of basalt spread rapidly southwestward across the area from fissure eruptions of the Chief Joseph dike swarm to the east (Taubeneck, 1970; Price, 1974). At the end of Grande Ronde extrusions the La Grande area was completely submerged by basalt flows; the southern margin of the plateau was south of the Baker area. Lack of interbedded sediments between flows is interpreted to signify that the dike-swarm area to the east was separating the La Grande area from major sediment-bearing streams flowing onto the eastern margin of the growing plateau. That the La Grande area had a Grande Ronde Basalt history similar to other areas of the Columbia Plateau is confirmed by a correlative N_1-R_2-N_2 magnetostratigraphic sequence; possible southward thinning of the N_2 interval may denote weak plateauward subsidence during late Grande Ronde time.

Weak easterly to southeasterly tilting of the area followed the cessation of Grande Ronde fissure eruptions. Glass Hill basalt units, which are interpreted to be correlative with upper Wanapum to lower Saddle Mountains basalt flows to the northeast, were extruded next and spread onto the surface into the La Grande area. West of La Grande, onlap onto a very gently dipping Grande Ronde surface is interpreted to explain the general westward thinning and local absence of the Glass Hill units near Hilgard. Incipient graben movement, or weak downward folding, near the present-day western margin of the Grande Ronde Valley may also have begun following Grande Ronde Basalt accumulation. This is the interpretation made of the thicker accumulations of Glass Hill flows, the localization of interbeds and the slight angular discordances between the Grande Ronde and Glass Hill basalt sequences. Glass Hill flows did not spread as uniformly as did the fluid basalts of the underlying Grande Ronde sequence. The Glass Hill sequence accumulated as varying numbers of flows and interbeds with different local thicknesses. Interbedded sediments in the Glass Hill sequence are derived from volcanic rocks, demonstrating that the area was still isolated from streams originating in mountainous uplands bordering the plateau. A thick tuff unit near the base of the sequence in the study area and to the northeast (Taubeneck, 1979), together with the presence of the thick sequence of glassy flows near Glass Hill, suggests nearby eruptive centers for Glass Hill units.

A period of erosion followed Glass Hill flow and interbed accumulation. Surface relief, however, remained relatively low and may have been due, in part, to original topographic irregularities of the Glass Hill surface and geographic distribution of the Glass Hill flows.

Local centers of eruption, probably during the Saddle Mountains extrusive episode, next spread andesite flows into the La Grande area on the low-relief Grande Ronde-Glass Hill basalt surface. Greater flow viscosity controlled spreading of this interval so that andesite flow margins were more abrupt and flow lobes more irregular than those formed by any of the older, less viscous basaltic lavas. The southwestern margin of the andesite of Mahogany Mountain was north of La Grande; the northern margin of the andesite of Craig Mountain was south of Ladd Marsh. These formed topographic highs on the broad plateau surface.

Easterly tilting, probably in conjunction with weak uplift of the Blue Mountains, continued, and present-day streams began to develop in the study area in adjustment to regional structures and local topography. The Grande Ronde River took its general northeasterly course at the base of the Blue Mountain backslope in the initial Grande Ronde synclinal trough. In the vicinity of Hilgard, the stream took a more easterly course around the southwestern margin of the Mahogany Mountain andesite lobe. Stream gradients were low, as was the regional easterly dip, and a meandering pattern typified the developing Grande Ronde River. Uplift to the southwest and west of the study area also was concurrent with Grande Ronde meandering stream development, and stream-bed loads of "exotic" basement rock were deposited locally on the yet undissected basalt surface of the study area.

Major deformation continued in response to northwesterly compression. Based on comparable structural events on the Columbia Plateau to the northwest (Geoscience Research Consultants, 1978, 1979a, 1979b), this structural episode probably was well underway by the end of the Miocene, reached a maximum during the Pliocene and approached quiescence during the Pleistocene. Accompanying the uplift of the Blue Mountains and depression of the Grande Ronde synclinal fold axes was the development of a northwesterly set of high-angle faults and fractures. Major horst-and-graben movement proceeded along step faults of the northwesterly vertical-fault set. In areas of folding and weak compression, as at the base of the Blue Mountain backslope along the Grande Ronde synclinal trough, differential response of the vertically faulted basalt pile occurred, and weak scissor-and-hinge movement characterized displacement among the long, narrow slice blocks.

As deformation continued, the through-flowing Grande Ronde incised its meandering channel (Figure 20) into basalt bedrock of major horst blocks. At the same time, local

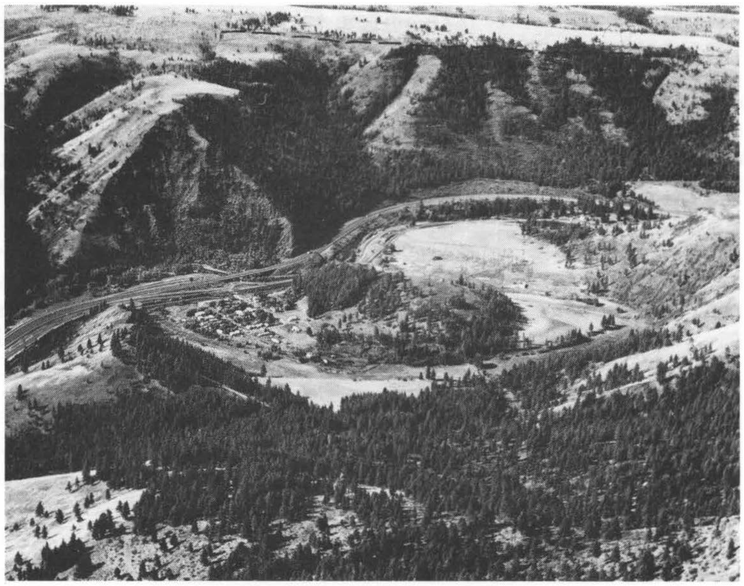


Figure 20. Grande Ronde incised meander.

Oblique view is to the southwest into the Grande Ronde Canyon in Secs. 34 and 35, T2S, R37E. The community of Perry is located in a cutoff, incised meander. The present-day meandering canyon of the rejuvenated Grande Ronde River is a relict of an earlier stream regimen. Rock in canyon slopes is Grande Ronde Basalt. The upland surface (above dashed line) is formed by a diktytaxitic Glass Hill flow.

tributary streams took consequent courses on down-dropped slice blocks and eroded headward along conjugate fault and fracture zones. Streams flowing into the subsiding Grande Ronde graben were ponded and deposited their sediments in the lowlands. Locally, deformation along major faults was rapid enough and of large enough magnitude to deflect streams into new courses (Buwalda, 1921). The Grande Ronde River, however, was capable of maintaining the established northeasterly course out of the Grande Ronde graben. Nevertheless, at times the strandline of the lake which formed in the graben when the outlet was dammed by faulting was high enough to leave slack-water deposits on the lower slopes of the valley-bounding fault scarps. Accompanying development of the structural relief were mass-gravity movements along the oversteepened slopes of major step faults and incised canyons. Structural activity appears to have nearly ceased during the Pleistocene. The only evidence of modern structural movement found during this study is the possible offset of modern sediments and colluvial deposits in the projected trend of the Foothill Road fault trace.

With the development of major vertical faults and high structural relief came the geologic setting necessary for development of regional, deep ground-water flow systems. Local thermal-water sites appeared in the lowlands along major fault planes where regional ground-water systems, under hydraulic heads originating in uplands, piped heated water to the ground surface through narrow conduits.

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APPENDIX

Magma-La Grande Well No. 1
Union County, Oregon
NW 1/4, Sec. 9, T4S, R39E
(1150' S of N line; 1900' E of W line)

Sampled Drilling Depth (Feet)	Bulk Lithology	Remarks	Rock Unit Drilled
0-30	Mixed rock types	Andesite and basalt	Alluvium and Colluvium
30-60	Mixed rock types	Basalt dominant, rounded fragments common	
60-90	Mixed rock types	Basalt, andesite, and many cavings	
90-120	Mixed rock types	As above, iron-oxide cement abundant	
120-150	Mixed rock types	As above, rounded fragments, iron-oxide staining	
150-180	Mixed rock types	As above, cavings common	
180-210	Mixed rock types	As above, rounded fragments common	
210-240	Mixed rock types	As above	
240-270	Mixed rock types	As above	
270-300	Mudstone	As above, minor cavings, micaceous flecks common	Lacustrine deposits
300-330	Mudstone	As above	
330-360	Mudstone	As above	
360-390	Mudstone	As above	
390-420	Mudstone	As above	
420-450	Mudstone	As above	
450-480	Mudstone	As above	
480-510	Mudstone	As above	
510-540	Mixed rock types	Abundant red mottled-to-gray glass-rich andesite, bedrock reported at 518 ft	Andesite of Craig Mountain
540-570	Glassy andesite	As above, microcavities lined with silica, less mottling	
570-600	Glassy andesite	As above, silica overgrowths	
600-630	Glassy andesite	As above, red discoloration present	
630-660	Glassy andesite	As above	
660-690	Glassy andesite	As above	
690-720	Glassy andesite	As above	
720-750	Glassy andesite	As above, red-gray mottling common	
750-780	Glassy andesite	As above	
780-810	Glassy andesite	As above	
810-850	Glassy andesite	As above	
850-870	Glassy andesite	As above	
870-900	Glassy andesite	As above	
900-930	Glassy andesite	As above	
930-960	Glassy andesite	As above	
960-990	Glassy andesite	As above	
990-1020	Glassy andesite	As above	
1020-1050	Glassy andesite	As above	
1050-1080	Mixed rock types	Andesite, minor volcanic rock fragments, much alteration	Basalt of Glass Hill
1080-1110	Mixed rock types	Volcanic rock fragments, andesite (cavings), opalized material	
1110-1140	Mixed rock types	As above	
1140-1170	Med.-grained basalt	Grainy, greenish-gray basalt, reddish andesite (cavings)	
1170-1200	Med.-grained basalt	Grainy, greenish-gray, olivine-rich basalt, minor red discoloration	
1200-1230	Med.-grained basalt	As above	
1230-1260	Med.-grained basalt	As above	

Sampled Drilling Depth (Feet)	Bulk Lithology	Remarks	Rock Unit Drilled
1260-1290	Med.-grained basalt	As above	Basalt of Glass Hill
1290-1320	Med.-grained basalt	As above, reddish discoloration common, olivine content decreased	
1320-1350	Med.-grained basalt	As above	
1350-1380	Med.-grained basalt	As above	
1380-1410	Med.-grained basalt	As above	
1410-1440	Mixed basalt types	Medium-grained and fine-grained basalt	Grande Ronde Basalt
1440-1470	Mixed basalt types	As above, minor flow banding, glassy, vesicular textures present	
1470-1500	Mixed basalt types	As above, much fine-grained vesicular material	
1500-1530	Fine-grained basalt	Fine-grained and vesicular basalt, minor medium-grained basalt, weak blue-green (copper ?) stain, siliceous void fillings	
1530-1560	Fine-grained basalt	Gray basalt, much medium-grained basalt (cavings) green staining and fillings	
1560-1590	Fine-grained basalt	As above, many cavings	
1590-1620	Mixed rock types	Everything up hole, much quartz filling material	
1620-1650	Mixed rock types	Coarse cuttings, all cavings	Hot Lake fault zone
1650-1680	Cavings	As above, (lost circulation interval)	
1680-1710	Cavings	As above	
1710-1740	Cavings	As above	
1740-1770	Cavings	As above	
1770-1800	No returns		
1800-1830	No returns		
1830-1860	No returns		
1860-1890	Mixed rock types	Much lost-circulation material	
1890-1920	Greenstone	Mottled green, white lithologies, coarse cuttings	Pre-Tertiary metamorphic rock
1920-1950	Greenstone	As above, pyrite mineralization	
1950-1980	Greenstone	As above, (much lost-circulation material)	
1980-2010	Greenstone	As above, pyrite mineralization, metamorphic texture	
2010-2040	Greenstone	As above	
2040-2070	Greenstone	As above	
2070-2100	Greenstone	As above	
2100-2130	Greenstone	As above	
2130-2160	Greenstone	As above	
2160-2190	Greenstone	As above	
2190-2220	Greenstone	As above	
2220-2250	Greenstone	As above, pyrite mineralization, quartz veinlets	
2250-2280	Greenstone	As above	
2280-2310	Greenstone	As above	
2310-2340	Greenstone	As above	
2340-2370	Greenstone	As above	
2370-2400	Greenstone	As above	
2400-2430	Greenstone	As above	
2430-2460	Greenstone	As above	
2460-2490	Greenstone	As above, cavings common	
2490-2520	Greenstone	As above	
2530-2550	Greenstone	As above	
2550-2580	Greenstone	As above	
2580-2610	Greenstone	As above, pyrite mineralization, minor apple green coloration	

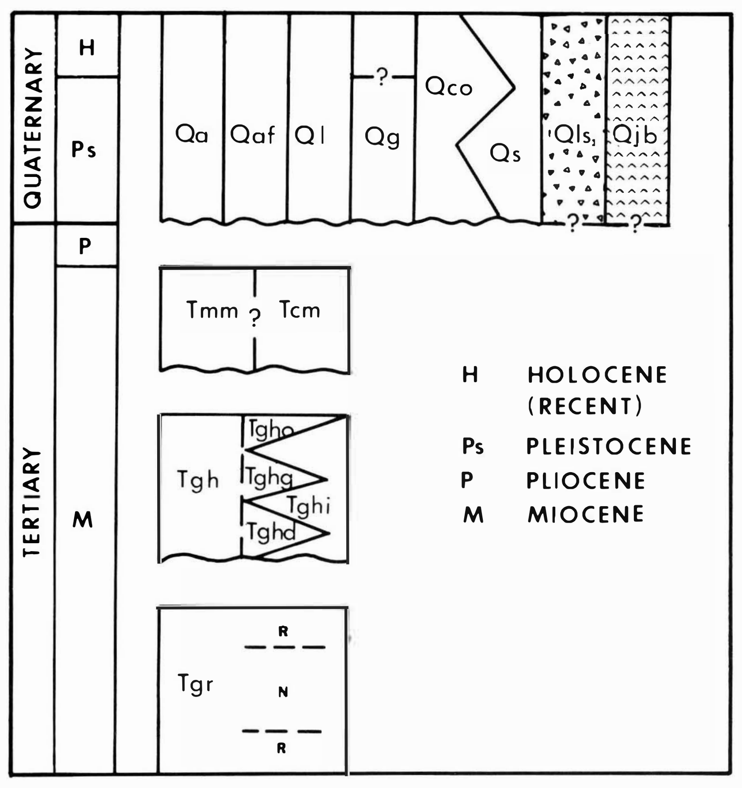
Sampled Drilling Depth (Feet)	Bulk Lithology	Remarks	Rock Unit Drilled
2610-2640	Greenstone	As above, pyrite mineralization	Pre-Tertiary metamorphic rock
2640-2670	Greenstone	As above	
2670-2700	Greenstone	As above	
2700-2729	Greenstone	As above	

PLATE I

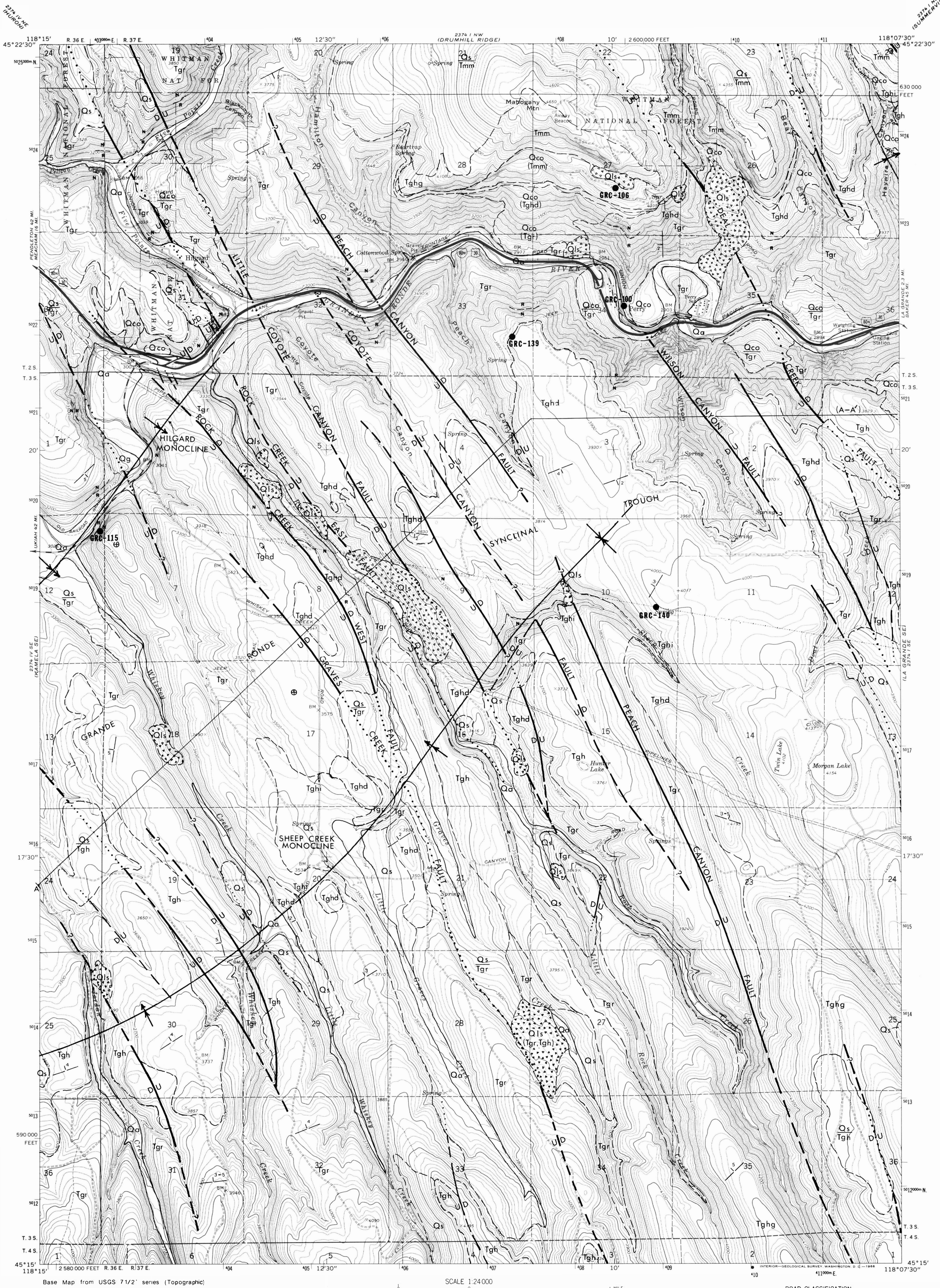
GEOLOGIC MAP of the HILGARD QUADRANGLE OREGON

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

CORRELATION OF MAP UNITS



H HOLOCENE (RECENT)
Ps PLEISTOCENE
P PLIOCENE
M MIOCENE



Base Map from USGS 7 1/2' series (Topographic)
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1957. Field checked 1963
Polyconic projection. 1927 North American datum
10,000-foot grid based on Oregon coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks, zone 11,

UTM GRID AND 1963 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
Interstate Route — U S Route

DESCRIPTION OF MAP UNITS

Quaternary units

- Qa — Alluvium
- Qaf — Alluvial fan and fanglomerate
- Ql — Lacustrine sediments
- Qg — Gravel; stream channel and terrace deposits undifferentiated
- Qco — Colluvium
- Qs — Soil, commonly with timber or brush cover
- Qls — Landslide deposit
- Qjb — Jumbled block

Tertiary units (Miocene)

- Tmm — Andesite of Mahogany Mountain
- Tcm — Andesite of Craig Mountain
- Tgh — Basalt of Glass Hill undifferentiated
  - Tgho — Olivine-rich, black, glassy basalt
  - Tghg — Glassy, dense, locally platy basalt
  - Tghd — Diktytaxitic, generally olivine-rich basalt
  - Tghi — Interbedded sediments
- Tgr — Grande Ronde Basalt

DESCRIPTION OF MAP SYMBOLS

Qls, Tcm, Tgr... Rock unit exposed in outcrop
(Tgh),(Tcm)... Rock unit making up bulk of jumbled block--Qjb, or landslide--Qls
Tgr, Tmm.. Rock unit interpreted to underlie surficial cover

Observed Inferred Covered

Contact between geologic units

Major fault; large offset and/or length; relative vertical displacement indicated; queried where uncertain

Minor fault; small (or probable) offset and/or short length; relative vertical displacement indicated; queried where uncertain

Lineament; probable fault with long trace; "L" is on apparent downdropped block

Monocline; longer arrow indicates steeper limb

Syncline

Strike and dip of stratified unit
measured
estimated

N (normal) / R (reverse) Paleomagnetic signature of basalt as determined by fluxgate magnetometer

■ Thermal wells
◆ Thermal springs
● Location of sample site of rock analyzed

(Boundaries are approximate: statements are general; site evaluations require on site investigation.)

Conducted in conformance with ORS 516.030
Funded by Oregon Department of Geology and Mineral Industries
under contract with U.S. Department of Energy
DE-FC07-79ET27220

GEOLOGY BY

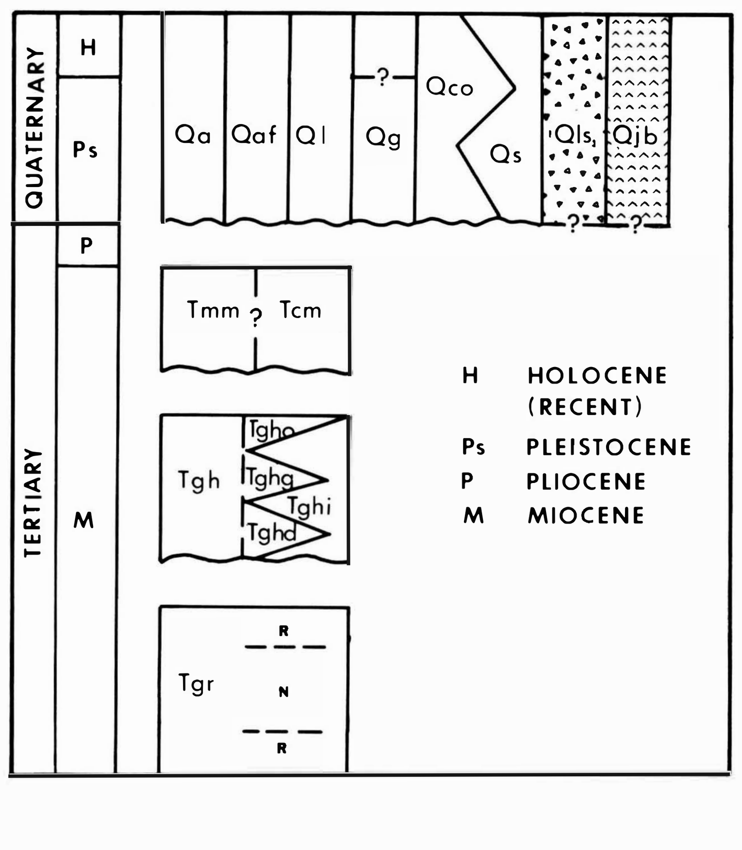
WARREN BARRASH
JOHN D. KAUFFMAN
JOHN G. BOND
1980

PLATE II

GEOLOGIC MAP *of the* LA GRANDE SE QUADRANGLE OREGON

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

CORRELATION OF MAP UNITS



H HOLOCENE (RECENT)
Ps PLEISTOCENE
P PLIOCENE
M MIOCENE

DESCRIPTION OF MAP UNITS

Quaternary units

Qa	Alluvium
Qaf	Alluvial fan and fanglomerate
Ql	Lacustrine sediments
Qg	Gravel; stream channel and terrace deposits undifferentiated
Qco	Colluvium
Qs	Soil, commonly with timber or brush cover
Qls	Landslide deposit
Qjb	Jumbled block

Tertiary units (Miocene)

Tmm	Andesite of Mahogany Mountain
Tcm	Andesite of Craig Mountain
Tgh	Basalt of Glass Hill undifferentiated
Tgho	Olivine-rich, black, glassy basalt
Tghg	Glassy, dense, locally platy basalt
Tghd	Diktytaxitic, generally olivine-rich basalt
Tghi	Interbedded sediments
Tgr	Grande Ronde Basalt

DESCRIPTION OF MAP SYMBOLS

Qls, Tcm, Tgr... Rock unit exposed in outcrop

(Tgh),(Tcm)... Rock unit making up bulk of jumbled block--Qjb, or landslide--Qls

Tgr, Tmm... Rock unit interpreted to underlie surficial cover

Observed Inferred Covered

Contact between geologic units

U/D Major fault; large offset and/or length; relative vertical displacement indicated; queried where uncertain

U/D Minor fault; small (or probable) offset and/or short length; relative vertical displacement indicated; queried where uncertain

L Lineament; probable fault with long trace; "L" is on apparent downdropped block

Monocline; longer arrow indicates steeper limb

Syncline

Strike and dip of stratified unit

measured

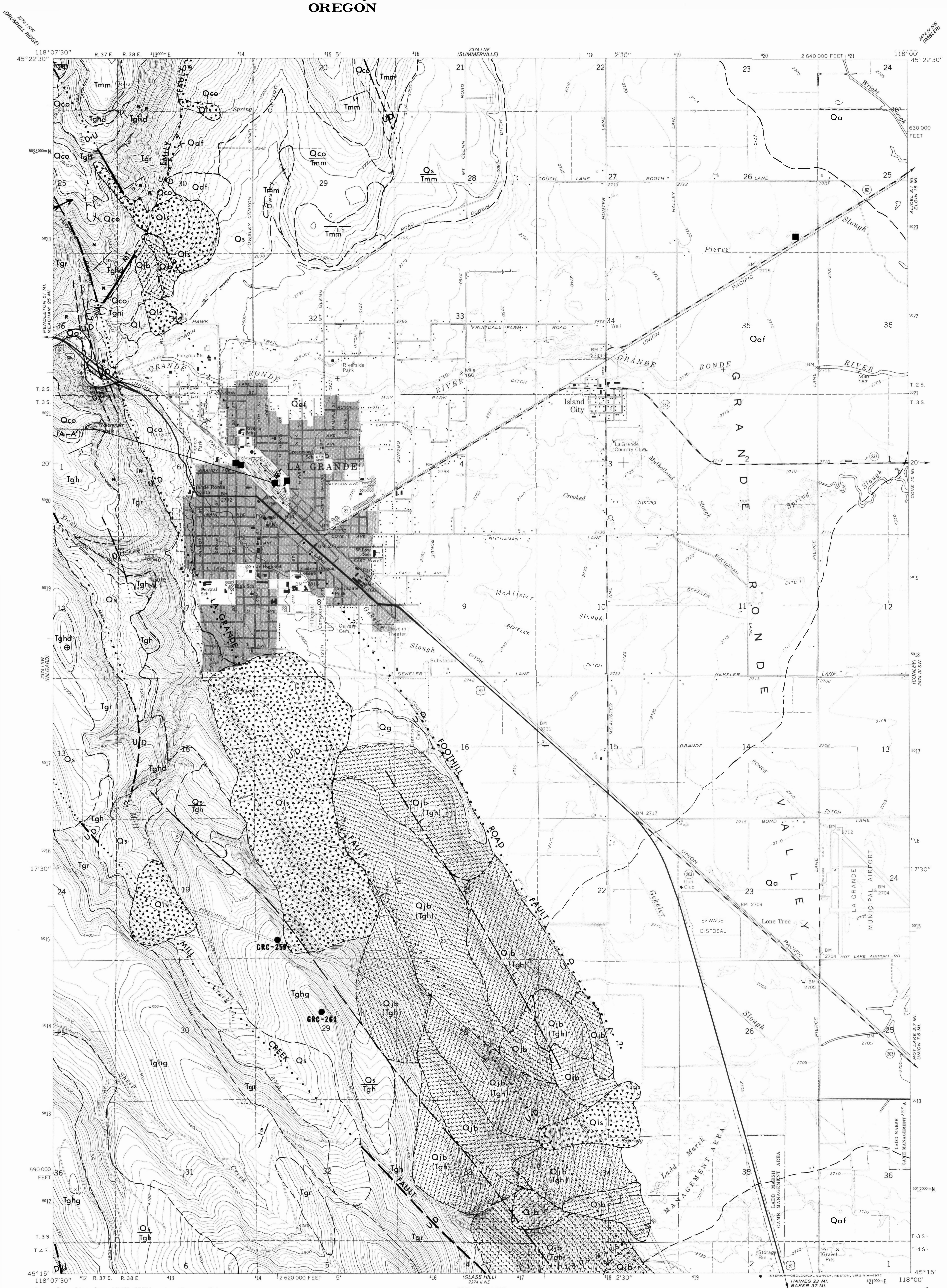
estimated

N (normal) / R (reverse) Paleomagnetic signature of basalt as determined by fluxgate magnetometer

■ Thermal wells

◆ Thermal springs

● Location of sample site of rock analyzed



Base Map from USGS 71/2' series (Topographic)

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1957 and planetable surveys 1963

Polyconic projection. 1927 North American datum
10,000-foot grid based on Oregon coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks, zone 11,

tint indicates area in which only landmark buildings are shown

UTM GRID AND 1963 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

0°45' 13 MILS
20° 356 MILS

SCALE 1:24 000

1 MILE
7000 FEET
1 KILOMETER

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

OREGON
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty Light-duty
Medium-duty Unimproved dirt
Interstate Route U S Route State Route

Conducted in conformance with ORS 516.030
Funded by Oregon Department of Geology and Mineral Industries
under contract with U.S. Department of Energy
DE-FC07-79ET27220

GEOLOGY BY

WARREN BARRASH
JOHN D. KAUFFMAN
JOHN G. BOND
1980

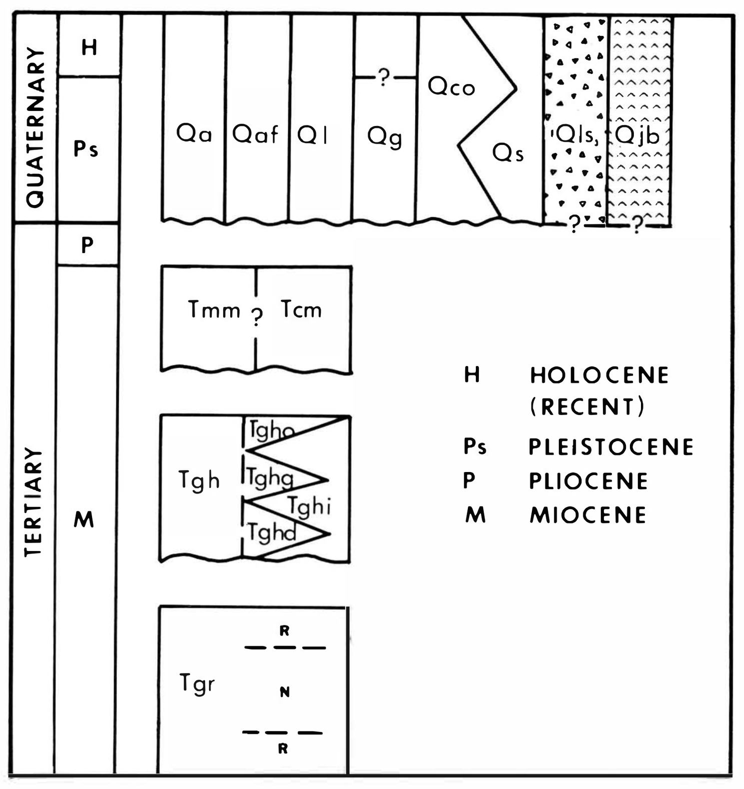
(Boundaries are approximate: statements are general; site evaluations require on site investigation.)

PLATE III

GEOLOGIC MAP of the GLASS HILL QUADRANGLE OREGON

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

CORRELATION OF MAP UNITS



H HOLOCENE (RECENT)
Ps PLEISTOCENE
P PLIOCENE
M MIOCENE

DESCRIPTION OF MAP UNITS

Quaternary units

- Qa — Alluvium
- Qaf — Alluvial fan and fanglomerate
- Ql — Lacustrine sediments
- Qg — Gravel; stream channel and terrace deposits undifferentiated
- Qco — Colluvium
- Qs — Soil, commonly with timber or brush cover
- Qls — Landslide deposit
- Qjb — Jumbled block

Tertiary units (Miocene)

- Tmm — Andesite of Mahogany Mountain
- Tcm — Andesite of Craig Mountain
- Tgh — Basalt of Glass Hill undifferentiated
  - Tgho — Olivine-rich, black, glassy basalt
  - Tghg — Glassy, dense, locally platy basalt
  - Tghd — Diktytaxitic, generally olivine-rich basalt
  - Tghi — Interbedded sediments
- Tgr — Grande Ronde Basalt

DESCRIPTION OF MAP SYMBOLS

Qls, Tcm, Tgr... Rock unit exposed in outcrop

(Tgh), (Tcm)... Rock unit making up bulk of jumbled block--Qjb, or landslide--Qls

Tgr, Tmm... Rock unit interpreted to underlie surficial cover

Observed Inferred Covered

Contact between geologic units

Major fault; large offset and/or length; relative vertical displacement indicated; queried where uncertain

Minor fault; small (or probable) offset and/or short length; relative vertical displacement indicated; queried where uncertain

Lineament; probable fault with long trace; "L" is on apparent downdropped block

Monocline; longer arrow indicates steeper limb

Syncline

Strike and dip of stratified unit
measured
estimated

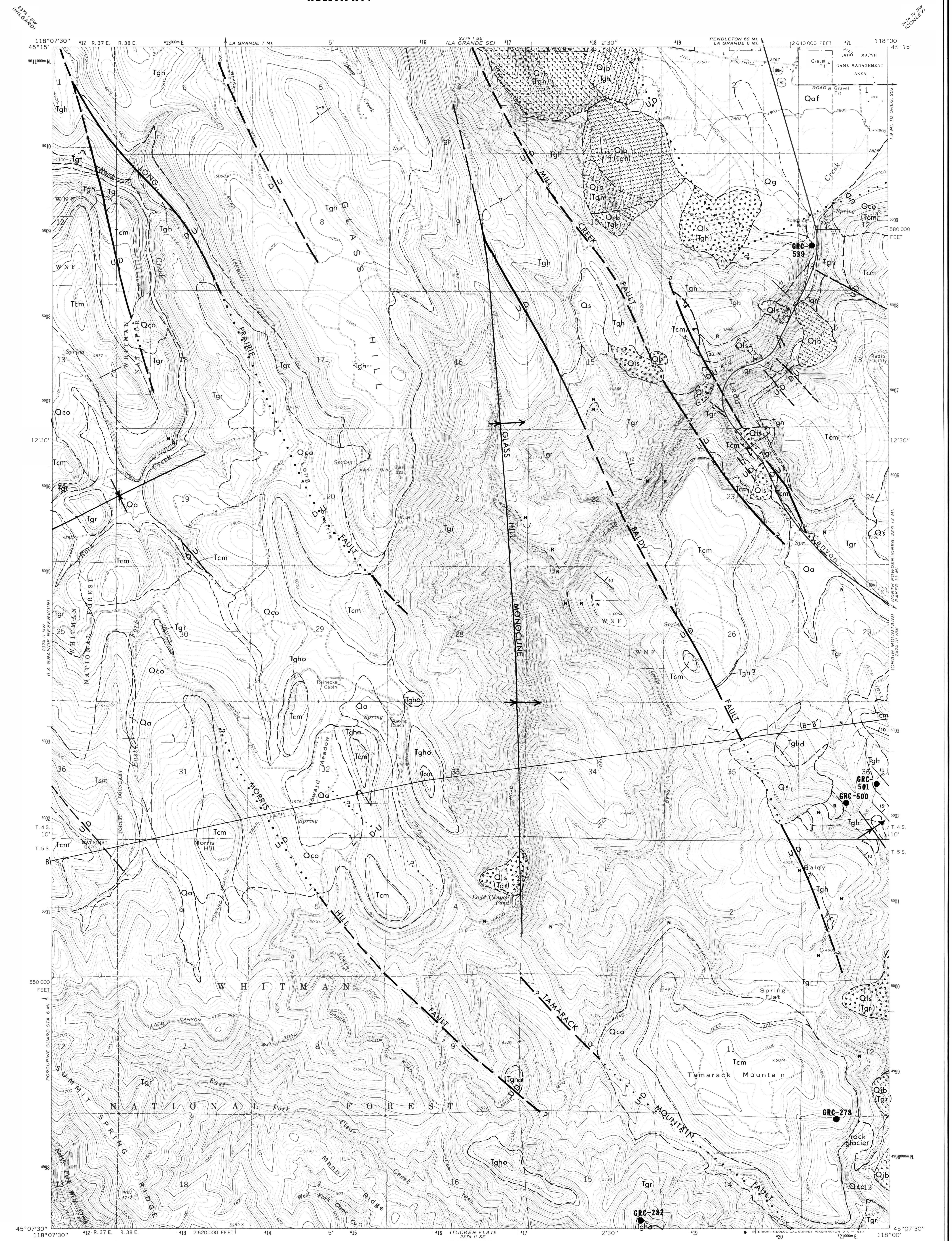
N (normal) / R (reverse) Paleomagnetic signature of basalt as determined by fluxgate magnetometer

■ Thermal wells

◆ Thermal springs

● Location of sample site of rock analyzed

(Boundaries are approximate: statements are general: site evaluations require on site investigation.)



Base Map from USGS 7½' series (Topographic)
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1960. Field checked 1965
Polyconic projection. 1927 North American datum
10,000-foot grid based on Oregon coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks, zone 11.

UTM GRID AND 1965 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty Light-duty
Unimproved dirt
Interstate Route U.S. Route

Conducted in conformance with ORS 516.030
Funded by Oregon Department of Geology and Mineral Industries
under contract with U.S. Department of Energy
DE-FC07-79ET27220

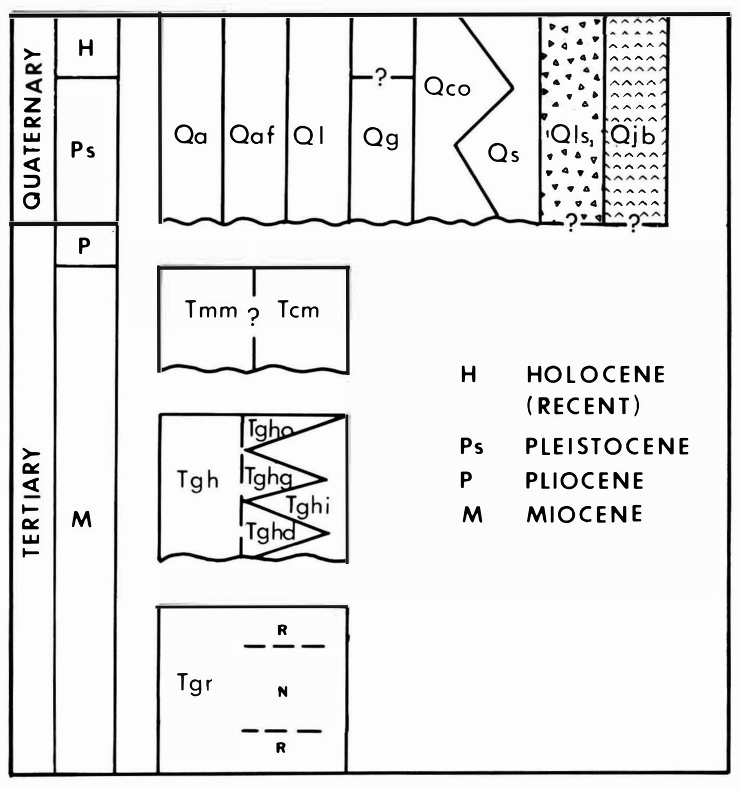
GEOLOGY BY
WARREN BARRASH
JOHN D. KAUFFMAN
JOHN G. BOND
1980

PLATE IV

GEOLOGIC MAP *of the* CRAIG MOUNTAIN QUADRANGLE OREGON

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

CORRELATION OF MAP UNITS



H HOLOCENE (RECENT)
Ps PLEISTOCENE
P PLIOCENE
M MIOCENE

DESCRIPTION OF MAP UNITS

Quaternary units

Qa	Alluvium
Qaf	Alluvial fan and fanglomerate
Ql	Lacustrine sediments
Qg	Gravel; stream channel and terrace deposits undifferentiated
Qco	Colluvium
Qs	Soil, commonly with timber or brush cover
Qls	Landslide deposit
Qjb	Jumbled block

Tertiary units (Miocene)

Tmm	Andesite of Mahogany Mountain
Tcm	Andesite of Craig Mountain
Tgh	Basalt of Glass Hill undifferentiated
Tgho	Olivine-rich, black, glassy basalt
Tghg	Glassy, dense, locally platy basalt
Tghd	Diktytaxitic, generally olivine-rich basalt
Tghi	Interbedded sediments
Tgr	Grande Ronde Basalt

DESCRIPTION OF MAP SYMBOLS

Qls, Tcm, Tgr... Rock unit exposed in outcrop

(Tgh),(Tcm)... Rock unit making up bulk of jumbled block--Qjb, or landslide--Qls

Tgr, Tmm... Rock unit interpreted to underlie surficial cover

Observed Inferred Covered

Contact between geologic units

U D — Major fault; large offset and/or length; relative vertical displacement indicated; queried where uncertain

U D — Minor fault; small (or probable) offset and/or short length; relative vertical displacement indicated; queried where uncertain

L — Lineament; probable fault with long trace; "L" is on apparent downdropped block

Monocline; longer arrow indicates steeper limb

Syncline

Strike and dip of stratified unit
8 measured
6? estimated

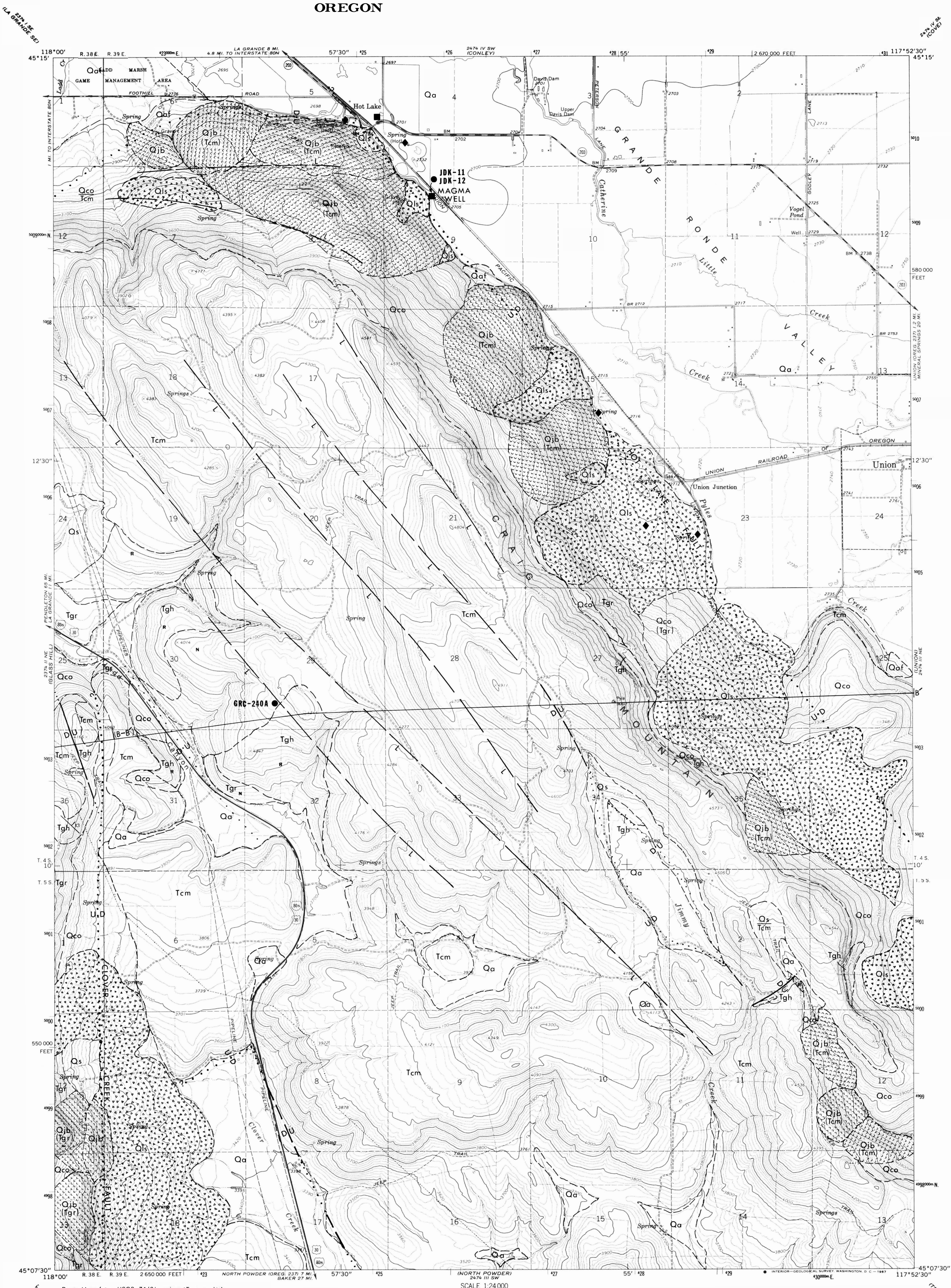
N (normal) / R (reverse) Paleomagnetic signature of basalt as determined by fluxgate magnetometer

■ Thermal wells

◆ Thermal springs

● Location of sample site of rock analyzed

(Boundaries are approximate: statements are general; site evaluations require on site investigation.)



Base Map from USGS 7 1/2' series (Topographic)
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1963 and planetable surveys 1966
Polyconic projection. 1927 North American datum
10,000-foot grid based on Oregon coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks, zone 11.

UTM GRID AND 1966 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
Interstate Route — U.S. Route — State Route

QUADRANGLE LOCATION

Conducted in conformance with ORS 516.030
Funded by Oregon Department of Geology and Mineral Industries
under contract with U.S. Department of Energy
DE-FC07-79ET27220

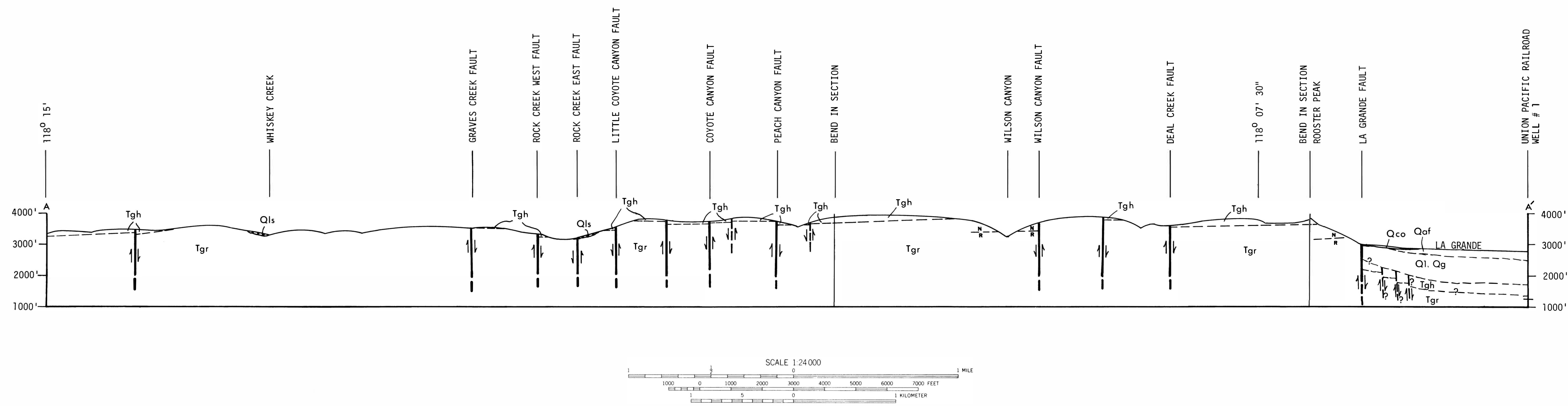
GEOLOGY BY
WARREN BARRASH
JOHN D. KAUFFMAN
JOHN G. BOND
1980

PLATE V

GEOLOGIC STRUCTURE SECTIONS

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

GEOLOGIC CROSS SECTIONS



(Boundaries are approximate: statements are general; site evaluations require on site investigation.)

GEOLOGY BY

WARREN BARRASH
JOHN D. KAUFFMAN
JOHN G. BOND
1980

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