GeothermEx 1961 MARIN AVENUE
BERKELEY, CA. 94707

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

La Grande-Hot Lake, Oregon

Geothermal Prospect

Reconnaissance Evaluation and Work Plan

for

AMAX Exploration, Inc.
4704 Harlan Street
Denver, Colorado 80212

Attention: Dr. Harry J. Olson

CONCLUSIONS

1. The La Grande-Hot Lake area, extending from the central Grande Ronde Valley southward to the Medical Hot Springs area has high potential for geothermal resource discovery and development as discussed in the appended Reconnaissance Evaluation. Crustal extensional faulting, junction between major crustal provinces, late Tertiary volcanism, and warm to hot wells and springs all support the potential value of the target.

2. Geology of the area is insufficiently known. The heat source is neither located nor dated, the subsurface structure is unknown and the deep reservoir is neither located nor its hydraulic parameters known. Conditions of recharge, storage, flow and discharge in the shallow reservoir are in support of existance of a deep reservoir, in fractured flows.

3. Adequate land position is available on fee lands in the area. The work currently underway by Mr. W. Armstrong appears competent to develop position.

4. A thorough preliminary geological and geophysical survey is necessary according to the plans recommended herein. The survey would have the objectives of defining a regional geothermal target in terms of crustal structure details, reservoir boundaries, and heat source. A heat source too old (greater than 10 million years) may require re-evaluation.

5. The general geothermal target is identified in terms of a map blocking out the area recommended for completion of leasing and detailed survey work.

RECOMMENDATIONS

1. Continue to obtain leases to complete a contiguous block in the area. Restrict new leases to the area indicated on the accompanying map.

2. Conduct geological exploration, namely photogeology, field geology, and radiometric age dating to define principal structures, and obtain absolute as well as relative igneous and sedimentary rock relationships. An Exploration Plan is appended, together with an anticipated time chart plan.

3. Apply geophysical techniques in an orderly fashion to extend and support geological interpretations; determine basement configuration and subsurface structure, and define reservoir position, size and character.

5. Extend existing hydrological models to the deep reservoir; utilize

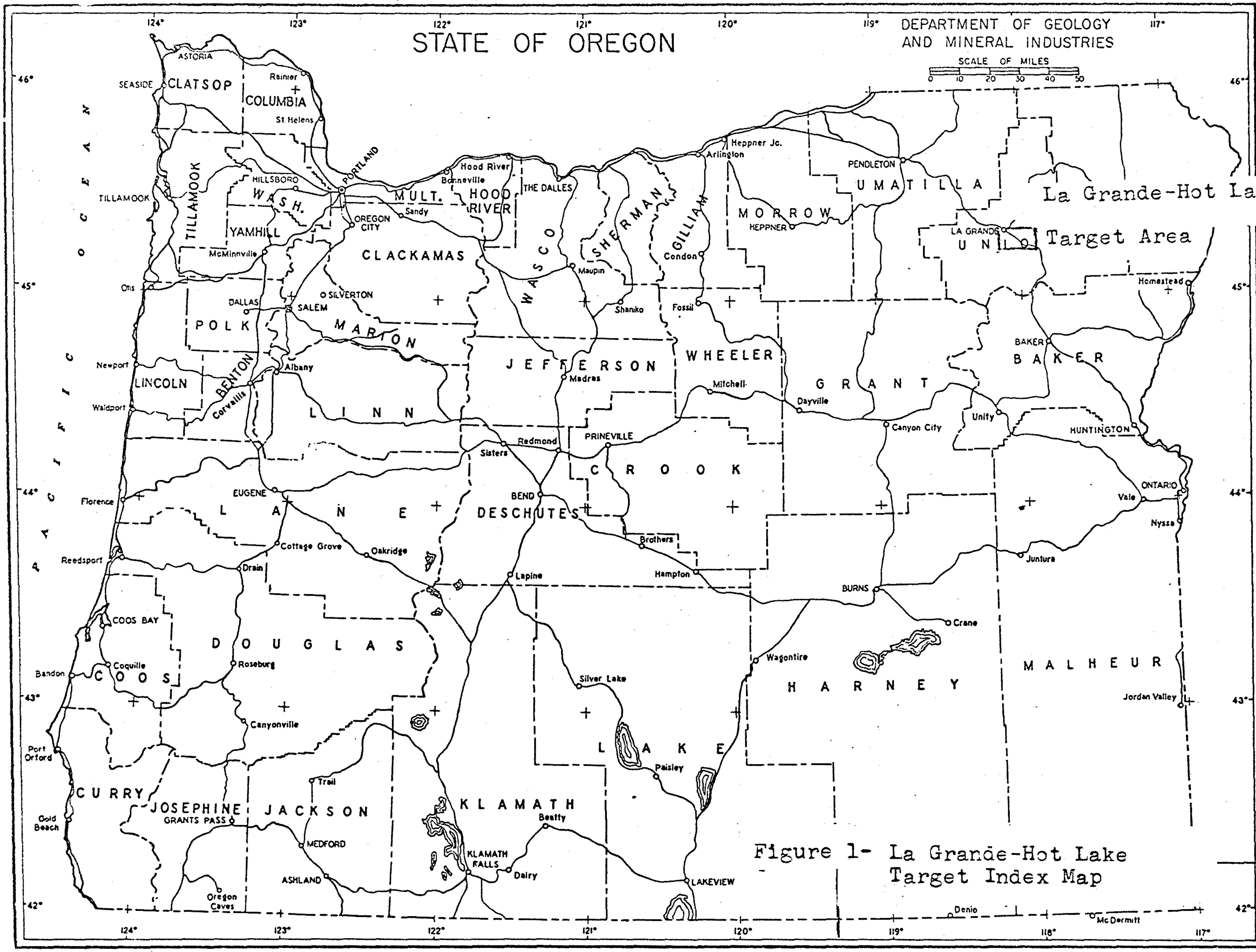


Figure 1- La Grande-Hot Lake Target Index Map

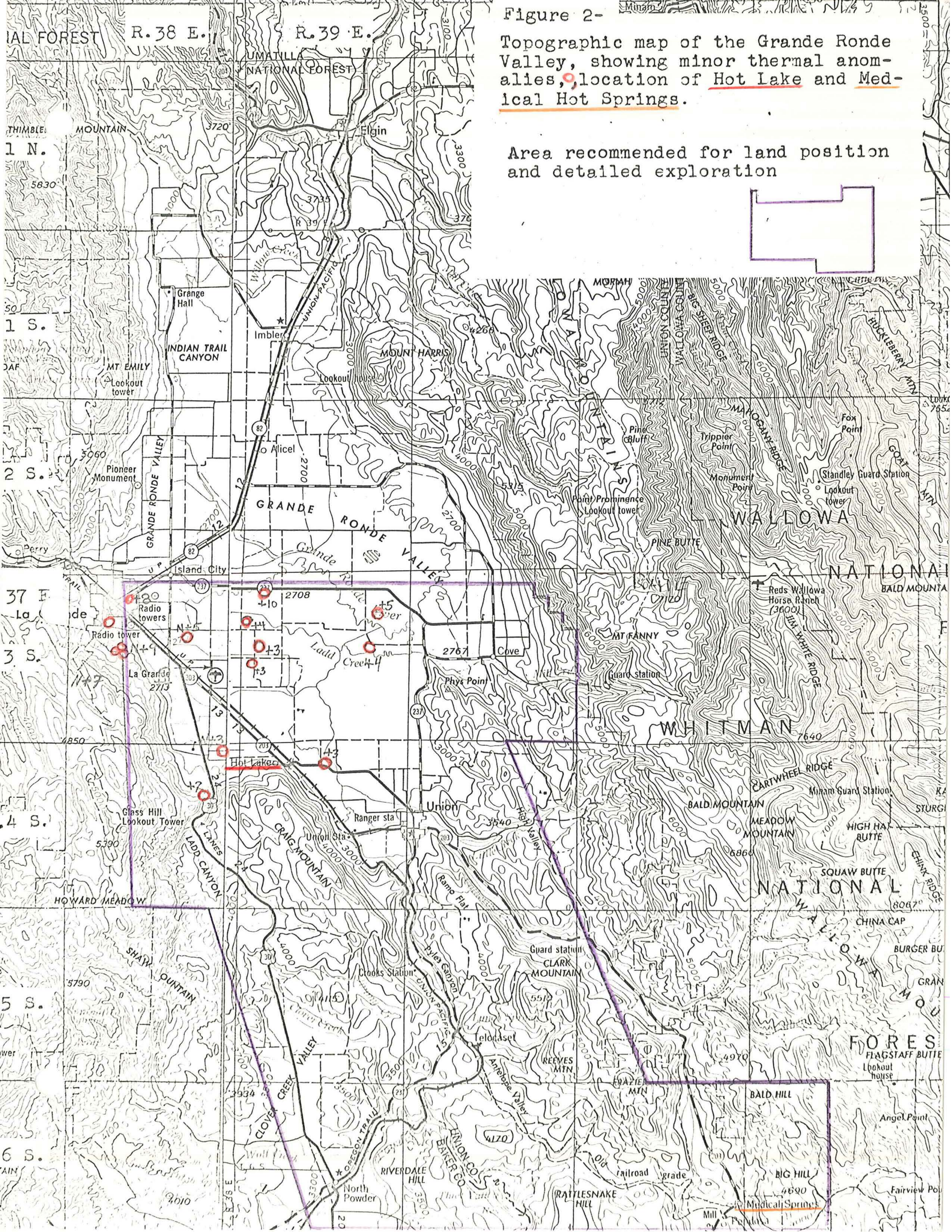


Figure 2-

Topographic map of the Grande Ronde Valley, showing minor thermal anomalies, location of Hot Lake and Medical Hot Springs.

Area recommended for land position and detailed exploration geophysical survey information, additional geochemistry, and samples from temperature gradient holes.

6. Eliminate sizable areas of the leaseholding as exploration procedes and designation of high priority and low potential areas becomes possible. Eventually, a position of about 40,000 acres in two to three parcels of 20,000 to 15,000 acres, is possible, unless exploration indicates a strong, homogeneous target.

RECONNAISSANCE EVALUATION

The Hot Lake area covers T. 3-4 S., R. 38-39 E., in Union County, northeastern Oregon. Hot Lake itself is a marshy pond a few acres in extent associated with at least two adjacent hot springs. A third hot spring is located about one-half mile to the southeast. All occur along the southwestern margin of the Grande Ronde Valley, about six miles southeast of the town of La Grande (see Figure 1).

The Grande Ronde Valley area is at the northern edge of the Blue Mountains physiographic region, immediately adjacent to its boundary with the Columbia Plateau. The valley is broad and nearly flat-floored. The Grande Ronde River and its tributaries meander across it in a northwesterly direction. Alluvial fans are built out from the base of the adjacent mountains, and merge with the valley floor. Elevations on the valley floor range from 2,500 feet to about 2,800 feet. The elevation at Hot Lake is 2,698 feet.

The mountain ridges bounding the valley have steep, straight, fault-controlled fronts trending in a northwesterly direction. Ridge top elevations range from about 4,500 feet to 7,160 feet at Mount Fanny. Relief between the valley floor and the adjacent ridge top is as much as 2,500 feet per mile. The ridge tops are broad, moderately dissected uplands with moderate relief.

Precipitation in the area ranges from 13 inches per year in Union, at the southeast corner of the valley, to 20 inches at La Grande and about 35 inches in the adjacent mountains. Most of this precipitation falls from October through June, about one-half as snow. Although summers are hot and winters cold, Pacific marine air channeled eastward along the Columbia River Valley moderates both summer and winter temperature extremes. The mean annual temperature at La Grande is 50^{o}F.

A few perennial surface streams, tributaries of the Grande Ronde River, occupy the major valleys. Intermittent streams occur in the headwater areas. The Grande Ronde River system empties into the Snake River about 60 miles to the northeast of La Grande.

Numerous seeps and small springs issue from scoria and rubble zones in the volcanic rocks exposed in the ridges bordering the valleys. Similar springs feed water to the lower reaches of streams which would otherwise be dry in summer. Some of these springs may tap the deep flow regime. Many small springs discharge at the foot of escarpments around the valley and from the lower parts of alluvial fans. In addition to the hot spring group at Hot Lake, three other springs in the area are thermal. These are near Cove at the east-central edge of the valley, about 25 miles southwest of Hot Lake, and Medical Springs about 20 miles southeast of Hot Lake.

Ground water is obtained from the lacustrine deposits underlying the Grande Ronde Valley, and from alluvial fans and colluvium near the ridge fronts. The largest water flows are obtained from scoria and rubble zones and from joint systems in lava flows, at depth, beneath the valley floor. Well-yield from the lava flows averages about 700 gpm, and ranges from 20 to 3,500 gpm (Hampton and Brown, 1964). Some impermeable layers are found in the lacustrine sediments.

The main line of the Union Pacific Railroad between Portland and Chicago passes within a few hundred feet of Hot Lake. State Highway 203 also passes in the immediate vicinity. In general, the area is served by good farm roads in the valley and by a few logging roads in the ridge top uplands. There is infrequent road access to the steep excarpments, mostly by jeep trails branching from the canyon roads.

La Grande, with a population of 9,850, is about six miles northeast of Hot Lake. The town of Union, population 1,620, lies about 5 miles to the southeast. A small resort-spa has been operated for many years at Hot Lake. The Grande Ronde Valley in general is occupied by large farms, many more than 1,000 acres in area. The upland acres flanking the valley are forest and dry pasture lands with a low population-density.

The economy of the area is dependent on agriculture in the Grande Ronde Valley and on grazing and logging in the upland areas. Mining (gold, silver, copper) was formerly carried on in both the Blue Mountains to the southwest and in the Wallowa Mountains to the southeast, but this activity has not revived since World War II. Limestone quarrying is carried on in the Baker Valley to the south.

A 230 kVe transmission line passes through the area and ties into the Idaho Power Company system near Hot Lake.

The Blue Mountain uplift to the west and southwest of the Grande Ronde Valley and the Wallowa Mountains to the east both expose complexly folded, faulted and metamorphosed Mesozoic and Paleozoic greenstone, phyllite, slate and marble, and Late Mesozoic quartz diorite and other medium-grained intrusive rocks.

Late Mesozoic or Early Tertiary gravels up to 50 feet thick were deposited over an erosional surface developed on the igneous-metamorphic terrain (Taubeneck, 1955). These in turn are overlain by andesite tuff breccias and lava flows of probable middle to late Miocene age.

The next younger unit is a thick (to 8,000 feet) sequence of flows, all of which have been assigned to the Columbia River Basalt, and are of the middle or late Miocene to possibly early Pliocene age. Within the area of the report, the so-called Columbia River Basalt, as mapped by Hampton and Brown (1964) and Walker (unpublished) includes two main rock types. The older is a dark grey to black, blocky-jointed basalt. This rock is present in individual flows from 10 to 50 feet in thickness, separated by thin scoria and fossil-soil zones. Fractured basalt, and some of the scoria and soil interbeds, are porous, permeable and water filled. Dense parts of flows and excessively clayey interbed zones form barriers to water migration (Hampton and Brown, 1964). The source of these basalt flows appears to be major swarms of dikes, largely buried beneath the flows themselves.

The younger part of the Columbia River sequence is predominately platy andesite with subordinate basalt. This section is at least 300 feet thick in the hills bordering the Grande Ronde Valley. The younger flows are very frequently exposed in roadcuts in the southern hills bounding the valley; these rocks appear to have limited porosity potential in joints (Hampton and Brown, 1964). The platy andesites are associated with large shield volcanoes, the eroded remnants of several of which are present in a northwestly-trending alignment from Sawtooth Butte (T. 7 S., R. 42 E.) to Clark Mountain (T. 5 S., R. 40 E.). These andesitic eruptive centers are of special significance, as they produced large volumes of magma in Late Tertiary time, along a trend striking toward the structural trench of the Grande Ronde Valley. The greatest penetration of basalt and andesite in wells in this area appears to be 590 feet, without the base of the section being reached.

Following the eruption of the older part of the Columbia River Basalt, and possibly prior to the eruption of the younger andesite, the area was gently folded into very long anticlines and synclines. One such structure, the Grande Ronde syncline, trends northeasterly to easterly into the general project area (Newcomb, 1970). The folds in the Columbia River Basalt in this area are much less steep-flanked than those in the main part of the Columbia Plateau to the north.

The most prominent structures in the study area are parallel to en echelon high-angle normal faults. These faults bound the Grande Ronde graben valley and are present in the adjacent hills to the east, west and south of Hot Lake. Faults in surface exposures in the hills and escarpments are spaced from one-quarter to one and one-half miles apart. The fault spacing beneath the Grande Ronde Valley is unknown. Aggregate vertical displacement is 4,000 feet in a series of closely spaced faults along the east side of the main graben, and bordering the west side of the valley is indicated to be as much as 4,000 feet. Generally, faults along the southwest side of the Grande Ronde Valley show displacement downward on the northeast side of the fault. On the northeast side of the valley, most of the major faults show displacement downward to the southwest. The valley may be hinged on the east, rotated downward on the west, similar to other Snake River Valley structures. However, measurements may prove greater downward displacement in the east. Most of the displacement appears to die out in a southeasterly direction. In general, individual fault blocks have been rotated less than 5°. The presence and pattern of faulting is of significance in evaluating subsurface migration of fluid, because of the development of thick, impervious clay gouge zones along certain faults and because of the offset of porous aquifers along others. These conditions give rise to discontinuous reservoir traps. The hot springs at Hot Lake appear to rise along a fault zone.

As a result of faulting, the Grande Ronde graben valley was formed as a closed basin, probably by Middle Pliocene time. This basin was filled with clay, silt and fine sand of Pliocene (?) and Pleistocene age. Coarse fan deposits and stream-delta materials interfinger with the fine lake sediments around the valley edge. More than 2,020 feet of sediments are recorded above the Columbia River Basalt in a water well north of Elgin in section 5, T. 3 N., R. 39 E. The valley fill is thinner in other areas, such as in section 5, T. 3 N., R. 38 E., where 845 feet of alluvial and lacustrine deposits were encountered above basalt. Other water-well data indicate that the thickness of undifferentiated alluvium and lake sediment is usually in excess of 400 feet.

Late in the geologic history of the region, small basaltic eruptions built cinder cones in several areas south of Hot Lake. The precise age of these is unknown. Probably they are Pleistocene in age. One such feature is located in sections 30 and 31, T. 4 S., R. 40 E. (Hampton and Brown, 1964). Recent mapping (Walker, unpublished) retains a Pleistocene age estimation, but eliminates the previously mapped Pleistocene cones to the north of Elgin.

At least one geothermal exploration company, Thermex, has conducted microseismic survey of the eastern part of the valley. No geophysical surveys of public record are known for this area. Without such data, subsurface projections are limited to the data of surface geology and well logs.

A number of water wells have been drilled in the Grande Ronde Valley. Most of these obtain water from fan or lacustrine sediments. The water potential of the underlying basalt is relatively unknown (Hampton and Brown, 1964) The deepest known well in the area was drilled to 2,020 feet in depth. Ground-water conditions deeper than that are speculative.

Temperature data were collected from many well logs on file with the Office of the Oregon State Engineer. These data are usually minimum temperatures, as in many cases the driller does not record data within the well, but simply measures temperature of discharging water. These temperatures often are measured before the well has attained equilibrium. From available data, geothermal gradients were calculated and compared with temperatures to be expected from a "normal" gradient of 1°F per 50 feet of depth below the first 50 feet within a well. A small cluster of slightly anomalous gradients results, concentrated in the vicinity of the town of La Grande, adjacent to the fault scarp.

There are two main hot spring orifices at Hot Lake, with maximum temperatures variously reported as 180° to 200°F. Discharge is about 100 gallons per minute (gpm), to a holding pond and tank. About one-half mile southeast, just south of State Highway 203, is another spring that has been drilled, and which flows at about the same temperature. Total discharge from all warm and hot sources at Hot Lake is about 400 gpm. The major springs are aligned on the principal range bounding fault. No mineralization or hydrothermal alteration was reported or observed at the area.

Other thermal features in the area are Cove Springs with a temperature of 85°F, and mildly thermal wells in sections 5 and 6, T. 3 S., R. 38 E. that discharge at temperatures of 77° to 81°F. Three warm-water wells are located about 12 miles north-northeast of La Grande, near the village of Summerville. Their temperature is not higher than 84°F. Twenty miles southeast of Hot Lake is Medical Springs, a mineralized hot springs whose discharge is 50 gpm at 140°F. Farther southwest, in Baker County, are Radium Hot Springs (300 gpm at 130°F), and Sam-O Spring (4oo gpm at about 80°F). These, and others still farther southeast, all show a rough en echelon alignment, parallel both to the trend of the faults bounding Grande Ronde Valley and to the broad topographic low extending into the Snake River lowland of Idaho.

Another spring, located off the general trend, with a temperature of 83°F., is 25 miles southwest of La Grande, in section 12, T. 6 S., R. 35 E.

Cove Springs, which yields over 200 gpm, is used to heat a swimming pool; water from the Hot Lake orifices is used both for heat and therapy at the adjacent sanatorium. Medical Hot Springs is now used for space heating and irrigation and seasonal recreation at a swimming pool.

Chemically, cool waters of the region (see Table 1) are sodium-calcium bicarbonate, with abundant magnesium and very low sulphate and chloride ion. With increasing temperature, a change in composition occurs; chloride becomes the principal anion. Sulphate is more abundant than bicarbonate, and potassium becomes as plentiful as calcium. Magnesium is very low in concentration. Silica in warmer waters is present at 71 to 84 ppm, but is low, 48 ppm at Hot Lake. Fluorine and Boron are high in the warm waters. Mariner (1974) estimated thermal aquifer temperatures at 214°F. at Hot Lake and at 257°F. at Medical Hot Springs by silica thermometry; sodium/potassium estimations were highly variable. Appreciable dilution is suspected, with hot water mixing with cool, meteoric water in near-surface aquifers.

Table 1- *Chemical analyses of water from wells and springs of the upper Grande Ronde River basin—*

Well, spring, or river Date of collection	2/39-30H1 4/17/58	3/38-5M1 1/21/55 [a]	3/38-5M2 1/21/55 [a]	3/38-6H2 5/10/57	3/38-8K1 7/31/57	3/39-7N1 7/31/57	3/39-30B1 7/31/57	3/40-22D1 6/2/57	4/39-5K1 5/10/57 (1)	4/39-11H1 8/22/57	4/40-7H1 7/31/57	Grande Ronde River 1 mi. below Five Point 4/19/58	Grande Ronde River at Rhinehart 4/19/58	4-39-5K1 3/74 (2)	6-41-25 3/74
(Well, spring, or river)	Well	Well	Well	Well	Well	Well	Well	Spring	Spring	Well	Well	River	River	Spring	Spring
Temperature (°F)	50	77	80	81	---	54	52	85	180	58	---	40	45	180	140
Silica (SiO_2)	53	72	84	71	43	42	44	29	81	34	36	31	31	48	80
Iron (Fe):															
Total	.02	Tr.	Tr.	.03	---	---	---	.03	.00	.00	---	.38	.49	—	—
In solution	---	---	---	.02	---	---	---	.00	.00	.00	---	---	---	—	—
Manganese (Mn)	.02	0	0	.01	---	---	---	---	---	.03	---	.02	.02	—	—
Calcium (Ca)	30	4.8	5	10	30	36	14	1.6	3.6	11	25	5.0	5.5	4.9	72
Magnesium (Mg)	13	1.3	.3	.2	13	16	6.6	.0	.3	4.3	12	1.6	1.8	0.1	0.2
Sodium (Na)	13	30	27	19	15	87	15	30	128	25	16	3.1	3.4	130	190
Potassium (K)	1.9	5	5	5.0	4.0	5.8	4.6	.5	2.7	4.2	5.5	1.5	1.7	2.7	7.0
Bicarbonate (HCO_3)	185	63	(?)	84	135	134	118	5	0	104	181	31	24	75	26
Carbonate (CO_3)	0	---	0	0	0	0	0	32	31	0	0	0	0	12	Tr
Hydroxide	---	---	---	---	---	---	---	---	4	---	---	---	---		
Sulfate (SO_4)	1.2	4.8	3.3	4.5	---	---	---	8.8	56	7.4	---	.9	1.2	56	400
Chloride (Cl)	1.5	2.1	3.2	1.0	10	28	---	5.0	120	8.8	---	.2	.5	140	77
Fluoride (F)	.1	.5	.5	.5	---	---	.8	.3	1.6	.3	.8	.0	.0	1.7	1.2
Nitrate (NO_3)	2.0	---	---	.0	19	---	---	.0	.0	.4	---	.3	.6	—	—
Boron (B)	.03	---	---	---	---	.4	.4	.08	---	---	.3	.61	.02	2.9	2.2
Dissolved solids:															
Calculated	207	166	163	---	---	---	---	109	---	148	---	59	63	—	—
Residue at 180°C	201	---	---	146	238	421	146	112	461	152	186	76	79	—	—
Hardness as $CaCO_3$	130	15	18	26	128	156	62	4	10	45	112	19	21	—	—
Noncarbonate hardness	0	---	---	0	17	46	0	0	0	0	0	0	0	—	—
Sodium-adsorption ratio (SAR)	.50	3.1	3.1	1.6	.57	3.0	.82	5.3	12.4	1.0	.66	1.7	1.8	—	—
Specific conductance (micromhos at 25°C)	286	---	---	146	327	658	188	150	676	207	280	54	61	688	1,173
pH	8.2	7.9	7.9	---	7.1	8	7.4	9.8	9.5	8.0	7.5	7.2	7.2	9.2	8.2
Color	0	3	4	---	---	---	---	---	---	---	---	35	40	—	—

From Hampton and Brown (1964), except last two analyses from R.H.Mariner, J.B.Rapp, L.M.Willey, and T.S.Presser, 1974, The Chemical Composition and Estimated Minimum Thermal Reservoir Temperatures of Selected Hot Springs in Oregon: U.S. Geological Survey Open File Report, 27 pages.

Table 2-

HOT LAKE AREA

TABLE OF WATER WELL TEMPERATURE DATA

(from well files in the office of the Oregon State Engineer and from Hampton and Brown, 1964.)

Well No.	Owner	+ Drilled Depth	+ Producing Depth	Temperature °F	* + -Normal	Miscellaneous
3/38-3B	-	300	300?	54°	N	Lake beds fanglomerate
3/38-3F	City of La Grande	528	115-520	55°	N(?)	Lake beds
3/38-4	Jeffers	340	340?	54°	N	Lake beds
3/38-4	Courtwright	70	70	57°	+8°	Valley fill
3/38-4cd	Carter	300	300?	54°	N	Lake beds
3/38-4L1	Corriell	46	44	48°	N	Valley fill
3/38-4M1	Jeffers	180	150+	53-56°	+3°-6°	Valley fill
3/38-4N1	Pratt	31	23	55°	+6°	Valley fill
3/38-5dc	Boise Cascade	1,387	?	53°	N(?)	Lake beds
3/38-[illegible]J	Union Pacific R.R.	1,000	650-990	53°	N(?)	Lake beds
3/38-5M(2)	Union Pacific R.R.	1,536	1,036-1,536	80°	N to + 13°(?)	Lake beds
3/38-5R	Connel	100	100	57°	+7°	Valley fi Lake beds
3/38-6B	Blakeney	266	252	56°	+4°	Valley fi Lake beds
3/38-6H(2)	Union Pacific R.R.	1,391	?	80°	N to ?	Lake beds
3/38-6H(1)	Union Pacific R.R.	?	?	77°	?	Lake beds
3/38-7H(1)	Zion Lutheran Church	74	69	47°	N	Valley fill
3/38-8	Hill	85	85	57°	+7°	
3/38-8A(1)	Miller	43	42	51°	N	Valley fill
3/38-8K(3)	Winn	44	32	50°	N	Valley fill
3/38-9	Brown	140	140	48°	N	Valley fi or Lake be
3/38-9	Schwelke	100	100	57°	+7°	Valley fi or Lakebe
3/38-9D(2)	Hutchinson	41	40	50°	N	Valley fill
3/38-[illegible]E(1)	Kaup	44	43	45°	(-)	Valley fill
3/38-12Q(1)	Harrison	20	?	51°	N	?
3/38-13D1	Atkinson	?	?	47°	?	H_2S Odor

Well No.	Owner	+ Drilled Depth	+ Producing Depth	Temperature °F	* + -Normal	Miscellaneous
3/38-14C(1)	Kidd	30	30	55°	+5°	Valley fill
3/38-14C(2)	Kidd	-		50°	N	Temperatu does not agree wit C(1) well
3/38-14D(1)	Wing	?	?	52°	?	
3/38-17	Clemens	214	214	56°	+3°	
3/38-17H	Epling	85	85	59°	+9°	
3/38-17K	Seigrist	421	421	56°	N	
3/38-17L	Rangitsch	225	225	48°	N	
3/38-22	McCall	329	300	58°	+4°	
3/38-23D3	DeLong	100	?	52°	N	
3/39-5L	Weisbaar	377	308	52°	N	
3/39-6H	Weisbaar	134	134	60°	+10°	
3/39-[illegible]N(1)	Anson	68	68	54°	+4°	
3/39-18G(1)	Henderson	60	60	53°	+3°	
3/39-18K	Brogoitti	300	100-285	55°	?	
3/39-19C(1)	Rayburn	62	?	53°	+3°	
3/39-19H(1)	Spencer	200	?	54°	+2°	
3/39-30B(1)	Heslop	171	?	52°	N	
4/38-1ab	Amstead	140	140	54°	+3°	
4/38-1E	Igo	87	86	50°	N	
4/38-12CC	State Hwy. Dept.	130	130?	53°	+2°	
4/39-3N(1)	Wilde	87	87	53°	+3°	
4/39-6F	State Game Comm.	200	200?	52°	N	
4/39-11H(1)	Woodruff	337	310	58°	+5°	
4/39-[illegible]B(1)	Pyatt	107	98	44°	(-)	Temp. appears inaccurate
4/39-14db	Murphy	90	90	54°	+4°	

*"Normal" is approximately 50° + 1° (Depth of Production-50'). Temperatures ± 2° of the normal temperature are classified as normal.

No corrosion or significant sealing was noted at Hot Lake or at Cove but the pipes at Medical Hot Springs corrode rapidly.

There are several possible sources of heat for the geothermal anomaly. Circulation of meteoric water down the fault to great depth has often been suggested, but is in turn dependent upon the existence of a temperature gradient of at least 3° per 100 feet in depth. This cannot be explained without invoking volcanic or magmatic heat at depth.

The alignment of post-Miocene andesite shield volcanoes extending from Sawtooth Butte to Clark Mountain may be associated with buried intrusive bodies. There may be a positive crustal element south of Hot Lake indicating young intrusive activity. The younger basalt eruptive centers may be associated with deeper, mafic intrusions. In a broader sense, all of thses features may be related to deep-seated processes which produced not only the volcanic eruptions but also the crustal extension and collapse responsible for the formation of the Grande Ronde graben. In this connection it is noteworthy that there is a significant alignment of thermal waters and structural and topographic features all the way southeast into the Snake River lowlands of Idaho. Much present-day data suggest that the Snake River is the locus of major crustal rifting.

The most likely reservoir for any geothermal fluid is the Columbia River Basalt. Evidence of existing ground water production from wells in this unit indicates that fractures in basalt and inter-flow scoria zones have significant porosity and permeability. The thickness of this unit down-faulted beneath the valley floor is likely to be in excess of 3,000 feet, as derived from the thickness of basalt and andesite exposed in the adjacent fault block ridges. This may not be the maximum value. The best potential cap rock in the valley is the lake beds, generally exceeding 400 feet in thickness, and overlying the Columbia River Basalt. Additional cap rock may exist in clay and tuff interbeds between lava flows and in unfractured flows. Therefore, there may be several thermal aquifers at increasing depth, each separated from the other.

Structural trapping mechanisms depend on faulting which, from water-well data, appears to isolate existing ground water units into separate blocks. In addition, interflow porous zones are lenticular and may provide a stratigraphic trap factor.

The upland areas immediately adjacent to the valley should be examined but two factors make the ridge areas adjacent to the valley appear less favorable for prospecting. One of these is the absence of valley fill to act as a cap rock and the second is the depth of drilling required to reach reservoirs which do not drain to the surface along the fault scarps bounding the main valleys. However, impervious faults or major displacement may isolate reservoirs from surface leakage in the upland blocks. Without geophysical data, it is impossible to determine just where the principal deep-seated heat source is.

Large amounts of water enter the Columbia River Basalt at its erosional edge on the flanks of the Blue Mountains and Wallowa Mountains uplifts. Present-day water production indicates that a large amount of water is in storage in this unit.

The geologic mapping in the Hot Lake project area is of reconnaissance nature related to water supply studies and regional, small scale (1:250,000). Further work should be done to establish the age and extent of the andesite volcanism associated with the shield volcanoes southeast of Hot Lake as described in the work plan. Additional field work should also be done to establish whether there is any hydrothermal alteration along faults or elsewhere in the Columbia River Basalt sequence. Geophysical work, especially passive seismic and electrical resistivity surveys, is important to define a target; the work plan describes the sequence of geophysical tasks.

Most land of interest in the area is privately owned as the land play has indicated. The Umatilla National Forest and Wallowa-Whitman National Forest border the region at a distance of upwards of 8 miles, little or no application for federal land is anticipated or recommended. Some sections northeast of Medical Hot Springs are public lands.

Areas for geothermal leasing have been outlined on the accompanying map. We prefer to straddle the major range-bounding faults, especially near La Grande, near Hot Lake, and perhpas, speculatively, near Medical Springs.

We consider the area to show strong potential, despite the lack of detailed information.

EXPLORATION PLAN

The exploration program plan is listed in chronological order of procedures. The accompanying chart indicates anticipated time durations of procedures.

1. Photogeo logic detailing of the townships in the area from about the latitude of Island City southward and inclusive of the area designated on the accompanying map is first priority of work. The interpretation is necessary to define structures and assist in siting geophysical survey operations, as well as analyzing stratigraphy. Field completion of a geologic map of the area described and photo-analyzed, is next highest priority of work.

2. Concurrently, sampling of igneous rocks for radiometric age dating should be accomplished as well as supplemental water sampling and locating and identifying seismic and some Electrical Resistivity stations. Water samples should be submitted for chemical analysis and selective isotope analysis and age dating.

3. A detailed gravity survey of the area, (12 to 14 townships), should be accomplished to assist in drawing cross sections to the basement. Location of stations to obtain a density of 2 to 4 square miles per station is required, in order to obtain a map accurately contoured at 2 mgals or less. Therefore as many as 450 stations will be necessary, requiring about 75 instrument days. This may permit early use of summer field assistants.

4. An aeromagnetic survey should be flown to attempt to designate young, high cooling magmas and rift zones in the graben and southern hills filled with intrusive masses and feeders of Holocene eruptive rocks.

5. Passive seismic surveys, already underway, should procede into 3rd and fourth stages, but as interpretation indicates value of the technique in the area and geological knowledge permits locating arrays meaningfully.

6. Electrical Resistivity, consisting of dipole-dipole and Schlumberger surveys, may begin immediately to a) help define the basement structure in the main Grande Ronde graben and b) examine the resistivity in the vicinity of Hot Lake and changes that occur on rays extending from the known thermal manifestation northwestward, northeastward, eastward, and southeastward. This is an initial survey. Extensions and other work near Medical Springs and northward will have later scheduling. The ER contractor may be sought to advise whether a roving dipole or telluric technique would provide the same results.

7. Temperature gradient measurements should be made in areas a) of greatest potential, b) where information from the prior steps indicates that rock and fluid conductivities will allow recovery of

meaningful data reflective of the deep aquifer. Holes may be to depths of 1,500 feet to penetrate below effects of shallow aquifers. Formation fluids should be recovered and submitted for chemical and isotope analysis. Initially, available holes may be tested with in-house apparatus, using trained field assistants.

8. Hydrologic modelling should be attempted to analyze the deep flow regime at desireable target locations prior to siting of deep exploratory holes.

EXPLORATION PLAN

TASK	Time; 1974 April	May	June	July	August	Sept.	October	Nov.	Dec.	1975 Jan.-Dec.
1. Photogeology and Field Geology		XXXXXXXXXXXXXXXXXXXX 4 man weeks								
2. Hydrogeochemistry and Rock and Water Age Dating		XXXXXXXXXXXXXXXX								
3. Gravity Survey		XXXXXXXXXXXXXXXXXXXXXXXXX			XXXXXX					
4. Aeromagnetic Survey		XXX								
5. Passive Seismic Survey	XXXXXXXXXXX			XXXXXXX						
6. Electrical Resistivity		XXXXXXX				XXXXXXXX				
7. Temperature Gradient Measurements (± heat flow study)			XXXXXX (available holes)							X X X X X
8. Hydrologic Modelling							XXXXXXX			

SELECTED REFERENCES

Hampton, E. R. and Brown, G., 1964, Geology and ground-water resources of the upper Grande Ronde River basin, Union County, Oregon: U. S. Geological Survey Water Supply Paper 1597. OUT OF PRINT

Newcomb, R. C., 1970, Tectonic structures of the main part of the basalt of the Columbia River Group, Washington, Oregon and Idaho: U. S. Geological Survey Misc. Geol. Inv., Map I 587.

Peterson, N. V., 1968, Hot Lake geothermal area, Union County, Oregon: Oregon Department of Geology and Mineral Industry. Unpublished report.

Taubeneck, W. H., 1955, Age of the Bald Mountain batholith, northeastern Oregon: Northwest Science, Vol. 29, No. 3, p. 93-96.

Walker, G. W., 1973, Reconnaissance geologic map of the Pendleton Quadrangle, Oregon and Washington: U. S. Geological Survey Misc. Geol. Inv., Map I 727.

Walker, G. W., 1973, Reconnaissance geologic map of the Grangeville Quadrangle, Oregon, Washington and Idaho: U. S. Geological Survey, unpublished data and geologic mapping.

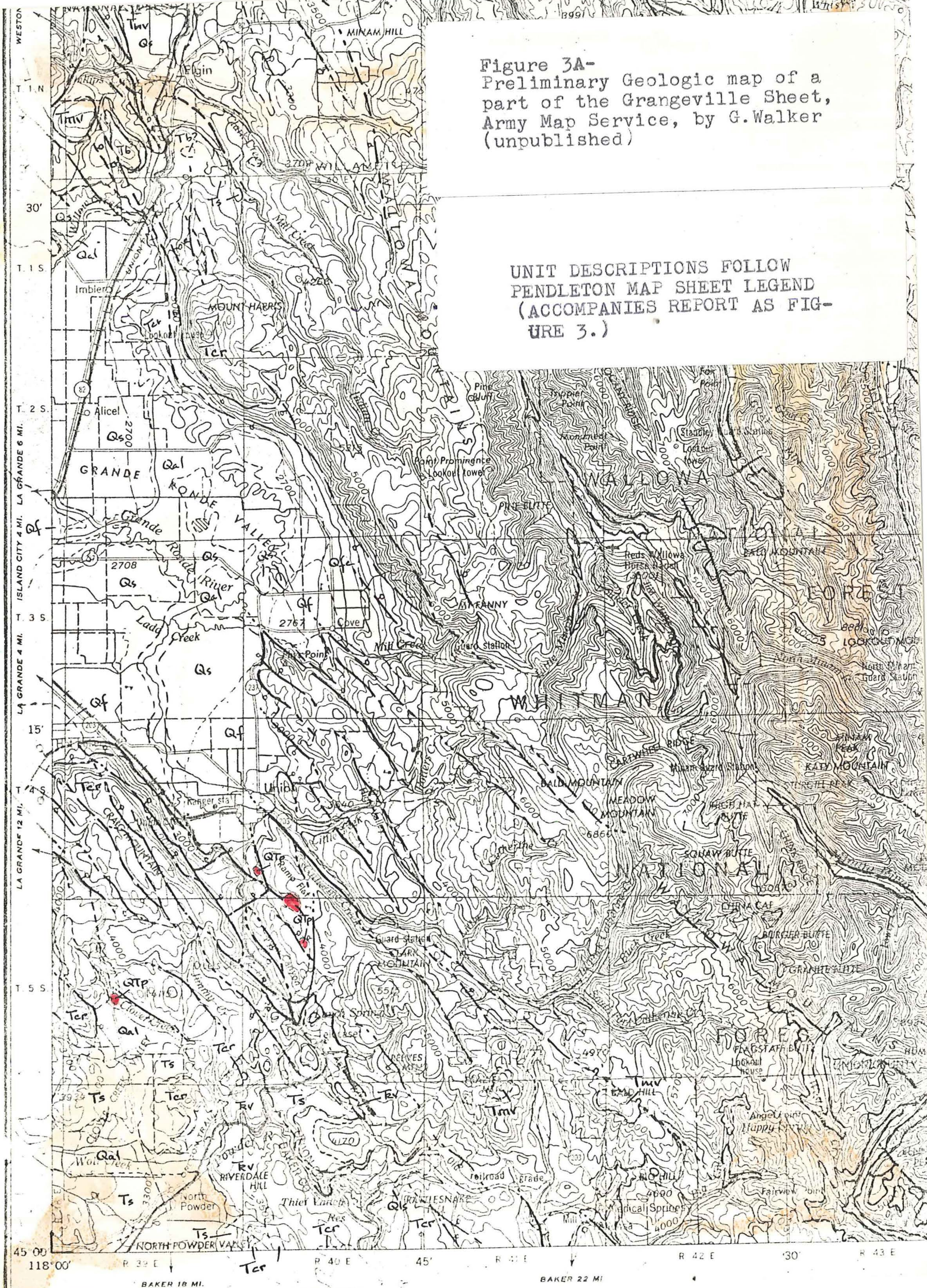
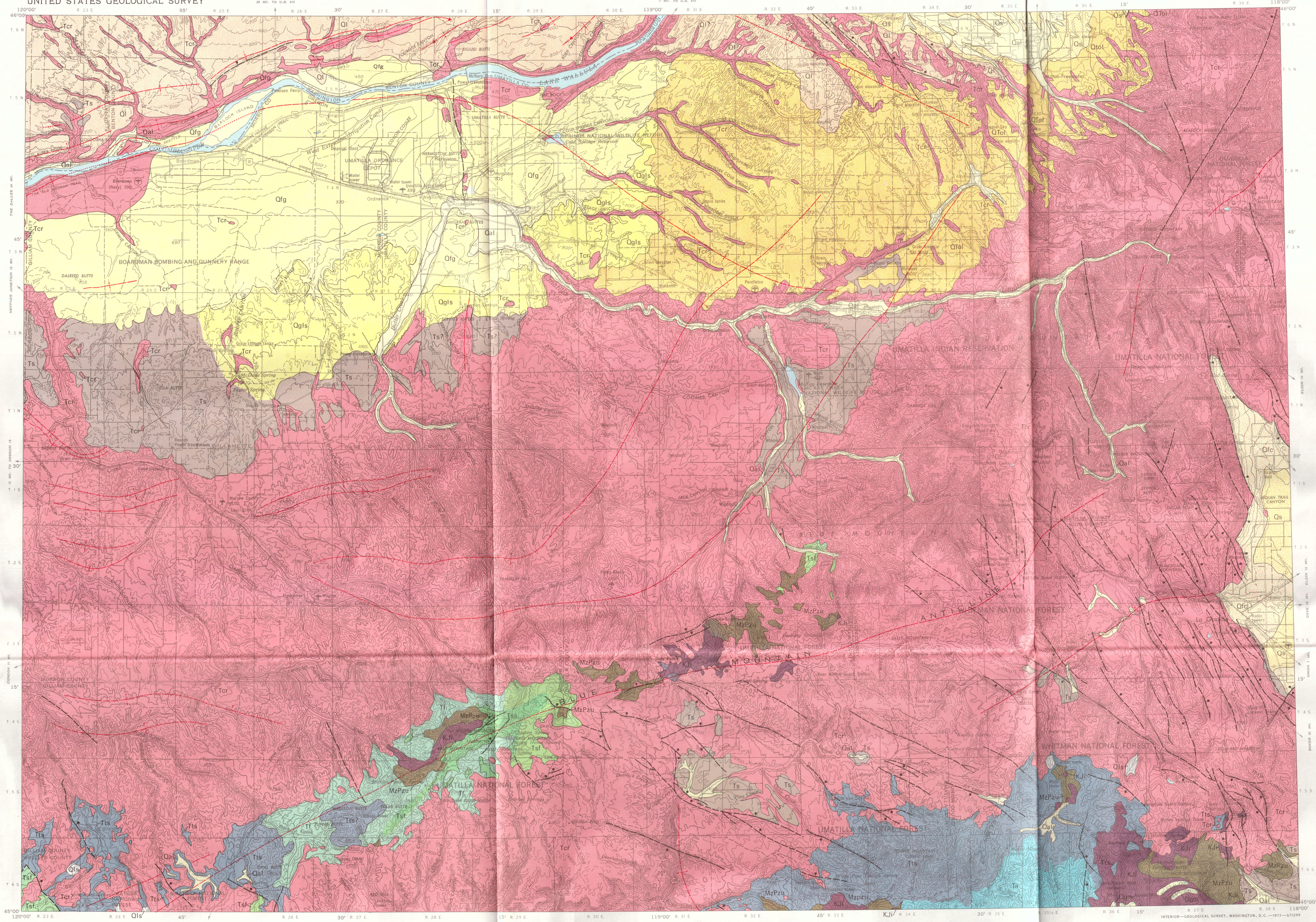


Figure 3A- Preliminary Geologic map of a part of the Grangeville Sheet, Army Map Service, by G.Walker (unpublished)

UNIT DESCRIPTIONS FOLLOW PENDLETON MAP SHEET LEGEND (ACCOMPANIES REPORT AS FIGURE 3.)

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I–727



SCALE 1:250 000

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
DATUM IS MEAN SEA LEVEL

1973 MAGNETIC DECLINATION FOR THIS MAP VARIES FROM 20°30' EASTERLY FOR THE CENTER OF THE WEST EDGE TO 20°00' EASTERLY FOR THE CENTER OF THE EAST EDGE. MEAN ANNUAL CHANGE IS 0°02' WESTERLY

EXPLANATION

QUATERNARY

Holocene

Qal — Alluvium
Unconsolidated fluviatile gravel, sand, and silt

Pleistocene or Holocene

Qls — Landslide debris
Mostly unstratified mixture of basaltic and tuffaceous sedimentary bedrock

Qgm — Glacial moraine

Qfc — Fanglomerate, talus, and colluvium
Composed largely of basaltic debris, but includes clay, silt, sand, and gravel. Forms talus slopes at the base of fault scarps

Ql — Loess
Silt and fine sand derived largely from Touchet Beds of Newcomb (1965; 1969). In part reworked older loess (QTol)

Pleistocene and Pleistocene(?)

Qs — Sedimentary rocks
Poorly to semiconsolidated lacustrine, fluviatile, and fluvio-glacial deposits of clay, silt, sand and gravel. Includes Touchet Beds and upper valley terrace deposits of Newcomb (1965; 1969) and Pleistocene(?) lacustrine deposits in Grande Ronde Valley of Hampton and Brown (1964)

Qfg — Fluvioglacial deposits
Gravel, sand, and silt. Deposited during glacial-meltwater transport by the Columbia River (Newcomb, 1969)

TERTIARY OR QUATERNARY

Pliocene or Pleistocene

QTglb — Glacial-lake sediments
Mostly crudely stratified silt and sand with ice-rafted gravel and boulders (Hogenson, 1964)

QTol — Older loess
Clayey and silty loess. Derived in part from the glacial-lake sediments. Includes Palouse Formation (Pleistocene) of Umatilla Basin (Hogenson, 1964) and "older loess" of Newcomb (1965)

TERTIARY

Pliocene

Ts — Sedimentary rocks
Mostly fluviatile silt, sand, basaltic gravel, and minor tuff that is partly indurated. Includes extensive fanglomerate deposits in the Umatilla Basin (Hogenson, 1964), sedimentary deposits of Pliocene(?) age (Newcomb, 1965), and mixed fanglomerate and terrace deposits [?] that contain vertebrate fossils of Pliocene (Hemphillian) age (Shotwell, 1956; Hogenson, 1964, p. 25) and the Shutler Formation of Hodge (1932; 1942, p. 19-20)

Miocene and Pliocene

Tcr — Columbia River Group
Mostly columnar jointed basalt flows, 10 to 100 feet thick, with local interbeds of tuffaceous lacustrine sediments and minor fluviatile gravels. Some interbeds contain fossil plants identified by R.W. Brown as Miocene from one locality (Hogenson, 1964, p. 23) and as late Miocene or early Pliocene from another locality (Hampton and Brown, 1964, p. 23). Includes the Elephant Mountain, Ward Gap, and Pomona Basalt Members of the Yakima Basalt Formation of Schmincke, (1967) and the Rattlesnake Ridge and Selah Members of the Ellensburg Formation of Schmincke, (1967)

Oligocene and Miocene

Ta — Andesite
In upper drainage basin of Grande Ronde River includes altered porphyritic hornblende andesite and dacite, pyroxene andesite, and nonporphyritic platy andesite flows and flow breccias; also includes some tuff breccia and minor flows of basalt and rhyodacite or rhyolite. A potassium-argon date by J.C. Von Essen (written commun., 1971) on plagioclase from a porphyritic hornblende andesite on Sheep Creek (sec. 22, T. 6 S., R. 35 E.) indicates an age of (28.1±) m.y.

Tts — Tuffs, tuffaceous sedimentary rocks, and minor interbedded flows
Dominantly white, grayish-yellow, very-pale-orange, and pinkish-gray thin-bedded tuff, lapilli tuff, thin welded ash-flow tuff, and fine-grained ashy sedimentary rocks. Locally contains fairly abundant porphyritic rhyolite or rhyodacite flows and some platy andesite flows. Locally, at base of unit, contains a thin conglomerate with boulders, cobbles, and pebbles of quartzite and minor chert, argillite, greenstone, diorite, and metamorphic rocks. Tuffs in unit contain plant fossils identified by R.W. Brown (see Hampton and Brown, 1964, p. 18) as of middle and late Miocene age. A potassium-argon date by J.C. Engels (written commun., 1970) on anorthoclase from a porphyritic rhyodacite flow on North Fork of Cable Creek (sec. 11?, T. 6 S., R. 33 E.) indicates an age of 27.4 ±1.5 m.y. and a date by J.C. Von Essen and M.A. Lanphere (written commun., 1970) on biotite from a rhyodacite flow exposed between Grande Ronde River and Beaver Creek (sec. 9?, T. 5 S., R. 36 E.) indicates an age of 27.0± 0.8 m.y. Correlative with John Day Formation as mapped in Canyon City quadrangle (Brown and Thayer, 1966) to south, and in the east half of the Bend quadrangle (Swanson, 1969) to southwest, but may include some younger middle Miocene rocks and some older early or middle Oligocene rocks in upper drainage basin of Grande Ronde River

Eocene and Oligocene

Tsf, Tf, Tss — Sedimentary rocks and flows
Tsf, continental sedimentary rocks, including quartzose and feldspathic medium- to fine-grained sandstone, micaceous and carbonaceous siltstone and shale in lower part of unit, and altered porphyritic andesite flows in upper part. Thin coal seams, in part bituminous, occur as interbeds in carbonaceous shale (Mendenhall, 1909). Fossil plants associated with coal beds on Willow Creek have been identified by F.H. Knowlton (see Mendenhall, 1909, p. 407) as late Eocene and from several other localities south and southwest of Pendleton as Eocene by R.W. Brown (see Hogenson, 1964, p. 21). Mendenhall (1909) and Hogenson (1964) consider all these rocks as part of the middle Eocene to early Oligocene Clarno Formation, whereas Pigg (1961) considers the volcanic rocks as Clarno Formation and the conformably underlying sedimentary rocks as an older, unnamed unit. In places separated into:
Tf, altered andesite flows
Tss, sandstone, siltstone, and shale

JURASSIC OR CRETACEOUS

KJi — Intrusive rocks
Dominantly biotite and hornblende quartz diorite (tonalite), locally foliated, small amounts of norite (Hogenson, 1964, p. 19), and granodiorite. Includes Bald Mountain Tonalite and Anthony Lake Granodiorite of Taubeneck (1957) and part of diorite intrusive rocks of Brown and Thayer (1966). Age: Late Jurassic or Cretaceous (Taubeneck, 1955; Thayer and Brown, 1964, p. 1258-1259); isotope age determinations include: Bald Mountain batholith, 99 m.y., and related intrusive rocks from adjacent areas, 145 m.y. and 120 m.y. (Thayer and Brown, 1964). On Willow Creek and adjacent areas (T. 4 S., R. 28 E.) includes quartz-rich intrusive rocks (trondhjemite?) of Triassic(?) age

PALEOZOIC AND MESOZOIC

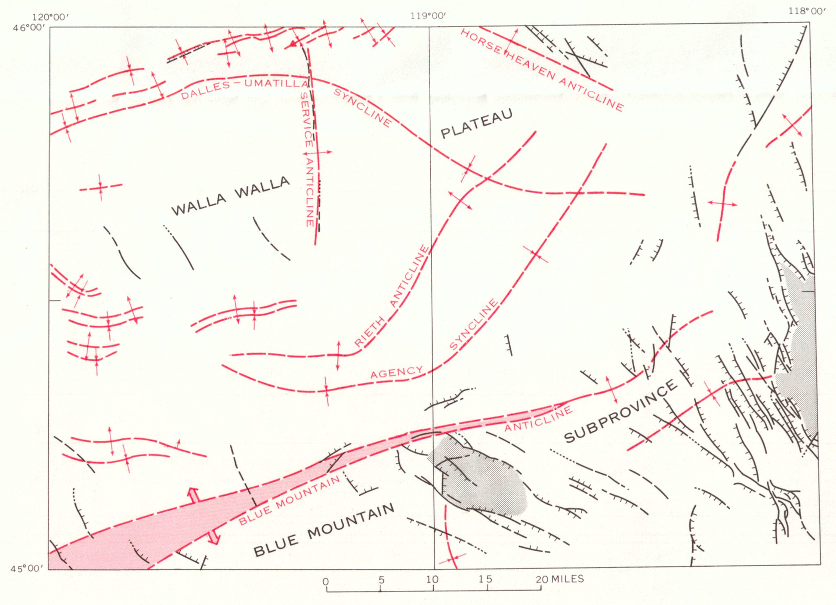
MzPzu — Undifferentiated metasedimentary, metavolcanic, metamorphic, and igneous rocks
Includes poorly exposed argillite, chert, dark carbonaceous limestone, greenstone, phyllite, hornfels, quartz-actinolite-tremolite-graphite schist, hornblende and hornblende-garnet schist, and amphibolite, probably representing metamorphosed parts of the Elkhorn Ridge Argillite and the Clover Creek Greenstone (Gilluly, 1937) of Permian and Triassic age (Bostwick and Koch, 1962, Thayer and Brown, 1964). In places adjacent to Jurassic or Cretaceous intrusive rocks, injected with numerous dikes of quartz diorite and, locally, intruded by pegmatite (Hogenson, 1964, p. 19). May include some metasedimentary and metavolcanic rocks of Early Jurassic age. Also includes several varieties of gabbro, metagabbro (Taubeneck, 1955), and altered and serpentinized plagioclase peridotite, probably all of Triassic age and correlative to the Canyon Mountain Complex of Thayer (1963) and Brown and Thayer (1966)

Contact, approximately located

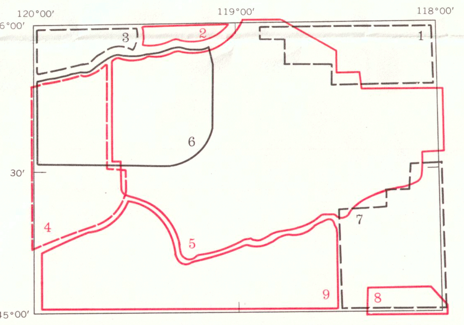
Fault
Dashed where approximately located; dotted where concealed. Bar and ball on relatively downthrown side

Anticline — Syncline — Monocline
Fold axis, showing direction of plunge
Dashed where approximately located; dotted where concealed

[1] Unmapped discontinuous patches of volcanic ash, probably part of deposits from Mount Mazama (Powers and Wilcox, 1964) cover parts of surface in southern part of quadrangle

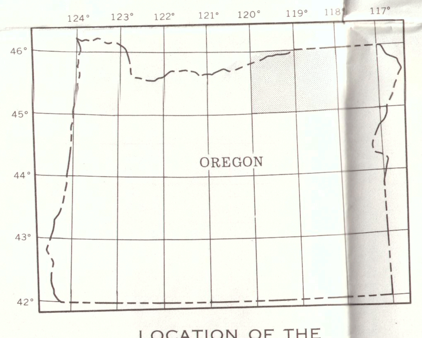


TECTONIC MAP OF THE PENDLETON QUADRANGLE



INDEX TO GEOLOGIC MAPPING USED IN PREPARING PRESENT COMPILATION

1. Newcomb (1965)
2. Newcomb, unpub. map; G.R. Walker, reconnaissance mapping, 1970
3. Newcomb (1969 b)
4. Newcomb, unpub. map
5. Hogenson (1964)
6. Robison, J.H. (1971)
7. Hampton and Brown (1964)
8. Taubeneck (1957)
9. Reconnaissance mapping by G.R. Walker, 1968, 1969, and by R.C. Greene, 1968



LOCATION OF THE PENDLETON QUADRANGLE

RECONNAISSANCE GEOLOGIC MAP OF THE PENDLETON QUADRANGLE, OREGON AND WASHINGTON

By
George W. Walker

1973

GENERAL GEOLOGY AND RELATION TO NATURAL RESOURCES

The Pendleton 1 by 2-degree quadrangle is centrally located within the Columbia River Plateau, a vast region covering parts of Washington, Oregon, and Idaho, noted for voluminous amounts of Miocene and early Pliocene flood basalts. Fenneman (1931) subdivided this part of his Columbia Plateaus Province into the topographically lower Walla Walla Plateau or subprovince, characterized by rolling upland surfaces with young incised valleys, and the elevated Blue Mountain section or subprovince that consists of "...complex mountains and dissected volcanic plateaus..." The northward-sloping margin between these two subprovinces has been designated as the Blue Mountain slope by Hogenson (1964). Dissection of these plateau areas is related largely to drainage systems of the Walla Walla, Umatilla, and John Day Rivers, and by Willow and Butter Creeks, all tributary to the Columbia River. The Grande Ronde River, a tributary of the Snake, dissects the southeast corner of the quadrangle.

The Walla Walla Plateau is underlain by hundreds to several thousands of feet of basalt flows of the Columbia River Group, which are extensively exposed in nearly all stream drainages and in many highway cuts. These flows, which erupted from fissures apparently lying chiefly to the east in Wallowa and Union Counties, blanketed almost the entire quadrangle. Pliocene and younger sedimentary deposits of fluviatile, lacustrine, eolian and glacial origin veneer intervening upland surfaces. They are generally less than 100 feet thick and in many places only a few feet thick. Larger areas of these deposits occupy structural and physiographic depressions, mostly along the Dalles-Umatilla, Agency, and Walla Walla synclines. These clastic sediments, particularly the wind-deposited loessial soil, support extensive wheat farming; cattle are grazed on many rocky slopes where the sedimentary deposits are excessively thin or discontinuous.

South of the Walla Walla Plateau, the elevated Blue Mountain upland section is manifested by thinning of the basalt sequence on a broad northeast-trending regional warp (Blue Mountain anticline) which locally is breached, exposing older Cenozoic volcanic and sedimentary rocks and Paleozoic and Mesozoic sedimentary and volcanic rocks. The pre-Cenozoic rocks locally have been intruded and altered by several varieties of crystalline intrusive rocks, mostly quartz diorite and granodiorite of Jurassic or Cretaceous age, comprising the Bald Mountain batholith and associated plutonic masses, and lesser amounts of gabbro and plagioclase peridotite of Triassic(?) age. Pliocene and younger sediments (silt, sand, and gravel) overlie the basalt flows of the Columbia River Group, mostly in graben or structural downwarps in the basalts. Glacial sculpturing and deposits of glacial debris in moraines are evident in the elevated southeast corner of the quadrangle, and both are much more prominent in higher areas near Anthony Lakes, south of the quadrangle. Most of the Blue Mountain upland section is timber covered, representing a source of logs for several sawmills in the region. Local large mountain meadows are used for summer grazing. The tree-bordered streams and open meadows create a scenic environment well suited to a variety of summer and winter recreational uses.

FAULTING AND STRUCTURAL TRENDS

Detailed structures in the pre-Tertiary rocks are obscured by the extensive cover of Cenozoic volcanic and continental sedimentary rocks, but the regional structural trends in these rocks seem to be east-northeast. Most of the pre-Tertiary rocks appear to be tightly and complexly deformed. Near and within the intrusive rocks of middle and late Mesozoic age, local trends, manifested by orientation of bedding, foliation, or shearing, diverge from the regional pattern to conform to the irregular outlines of the batholithic masses. Cenozoic structures, characterized by open folds and normal faults, are more erratic in orientation but conform mostly to a strong northeast trend, dominated by folds, or to a northwest trend, dominated by faults. Paired anticlines and synclines in the western part of the region are mostly open, gentle, asymmetric folds that, in places, approach monoclinal form. These Cenozoic structures, apparently all related to the same stress field, are mostly of Pliocene age, although some warping in the northern part of the quadrangle may be of Pleistocene age (Newcomb, 1969a, p. 62). Also, thinning of the basalt sequence of the Columbia River Group on the Blue Mountain anticline (or anticlinorium) indicates that deformation occurred either before or during eruption of the flows. The distribution and lithologic character of the underlying John Day Formation in areas to the southwest indicated to Fisher (1967) that the Blue Mountain anticline predates, in part, this Oligocene and early Miocene formation.

MINERAL DEPOSITS

Minor coal prospects are present on Willow Creek south of Heppner in the Eocene sedimentary sequence (Mendenhall, 1909; Collier, 1914). Although lenses and thin beds of pure, good-grade bituminous coal are present locally, they apparently are too thin, intimately intermixed with carbonaceous shale, and structurally deformed to be of commercial interest.

Traces of tungsten (wolfram), in the form of scheelite, have been found in minute fractures in limestone near a contact with altered metavolcanic rocks (greenstone) near the southeast corner of the quadrangle (Wolfe and White, 1951). Other small limestone masses that may contain similar occurrences of tungsten are locally present in the unit of undifferentiated pre-Tertiary rocks exposed along and to the south of the Blue Mountain anticline.

None of the limestone masses in the pre-Tertiary sedimentary sequences exposed along the southern border of the quadrangle appear large or pure enough to be of economic value as a source of cement or for other industrial uses.

Both lode and placer gold have been mined in the southeast part of the quadrangle in areas marginal to Mesozoic intrusive rocks known as the Bald Mountain batholith. Lode gold was mined from the Aurelia and Standard properties (Grande Ronde Mines), and placer gold from the Camp Carson district (Carson Hill Placers), all on the headwaters of the Grande Ronde River. Placer gold also was mined from China Diggings on Wolfe Creek.

Small quantities of gem opal have been recovered from amygdaloidal flows of Eocene age in southern Morrow County. The flows are considered to be part of the Clarno Formation (Oregon Dept. Geology and Mineral Industries, 1941, p. 154).

WATER RESOURCES

Several of the more extensive geologic studies in this region have been directed toward evaluation of ground water (Hogenson, 1964; Hampton and Brown, 1964; Newcomb, 1965; 1969b; 1970), which occurs primarily in permeable zones at the top or bottom of scoriaceous and fractured basalt flows and in gravel and sand beds in Pliocene and younger sedimentary deposits. In places, large quantities of ground water are found in favorable structures in the basalt. Numerous springs are present in the region mainly in the upland plateaus, but only a few discharge water at temperatures higher than normal, notably those at Lehman and Hideaway Hot Springs, south of Camas Creek, one on Sheep Creek in the headwaters of the Grande Ronde River, and Bingham Spring on the Umatilla River, southeast of Milton-Freewater.

GENERAL ENGINEERING FEATURES OF SOME LITHOLOGIC UNITS

Several of the geologic units delineated on the map have distinctive lithologic characteristics that bear on problems of engineering geology. Some rocks have a considerable potential for landsliding, whereas others are stable on steep slopes and are adequate foundation materials as well as excellent sources for some kinds of construction materials.

Although the pre-Tertiary rocks commonly are highly indurated, most are intensely fractured, locally sheared and altered, and steeply inclined. The bearing strength of these rocks is low to moderate, and slope stabilities generally are closely related to the amount of fracturing and the inclination of bedding. Some of the gabbroic rocks and greenstones of this unit are less shattered and have been used locally for road fill and surfacing. The Jurassic or Cretaceous intrusive rocks, though not as intensely fractured, are deeply weathered, so that hard fresh rock suitable for some fill purposes or riprap is found at the surface only in deeply dissected areas in the southeast corner of the quadrangle. Both the arkosic sandstone and siltstone and the porphyritic andesite flows of Eocene age are gently folded, generally massively layered, and, in places, highly jointed. Neither the clastic sedimentary rocks nor the flows contain a high proportion of clay minerals, and both are comparatively stable in excavations and roadcuts, although the stability varies somewhat with local joint systems and layering. In contrast, most of the Oligocene and early Miocene tuffs and tuffaceous sedimentary rocks are less well indurated, are highly fractured, in many placed thinly layered, locally contain abundant bentonitic (swelling) clays, and, hence, are characterized by low to moderate bearing strengths. Landslides within the region are confined largely to this lithologic unit and are particularly prominent where high-density (heavy) basalt flow sequences overlie these incompetent and clayey rocks on canyon walls. Because of scale limitations only a few of the larger landslide masses are shown on the geologic map; smaller landslides can be expected in areas underlain by these rocks where dissection has left moderate to steep slopes. The basalt of the Columbia River Group varies in degree of fracturing and alteration, but in general it is hard and strong, affording foundation strength capable of supporting heavy loads and also furnishing an excellent source of crushed rock for concrete aggregate, pervious fill, and road-surfacing material. The high-bearing strength is a characteristic of the basalt, except in scoriaceous and brecciated zones between flows or where local sedimentary interbeds are present. Such zones should be avoided in obtaining basalt for use as concrete aggregate. The spacing and character of columnar and flow joints affect ease of quarrying and stability of excavation faces as well as permeability. Numerous widely distributed small quarries have been developed throughout the region, and in most places the crushed rock need be trucked only for short distances. The loess deposits tend to have low strength when dry and are even weaker when saturated with water. The large unconsolidated fluvioglacial deposits generally have low to moderate bearing strengths, depending on the type of material and induration; they ensure adequate quantities of sand and gravel for construction purposes in the northwestern part of the quadrangle.

REFERENCES

Bostwick, D.A., and Koch, G.S., Jr., 1962, Permian and Triassic rocks of northeastern Oregon: Geol. Soc. America Bull., v. 73, p. 419-422.
Brown, C.E., and Thayer, T.P., 1966, Geologic map of the Canyon City quadrangle, northeastern Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-447, scale 1:250,000.
Collier, A.J., 1914, The geology and mineral resources of the John Day region: Oregon Bur. Mines and Geology, Mineral Resources of Oregon, v. 1, no. 3, 47 p.
Fenneman, N.M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co., Inc., 534 p.
Fisher, R.V., 1967, Early Tertiary deformation in north-central Oregon: Am. Assoc. Petroleum Geologists Bull., v. 51, no. 1, p. 111-123.
Gilluly, James, 1937, Geology and mineral resources of the Baker quadrangle, Oregon: U.S. Geol. Survey Bull. 879, 119 p.
Hampton, E.R., and Brown, S.G., 1964, Geology and ground-water resources of the Upper Grande Ronde River Basin, Union County, Oregon: U.S. Geol. Survey Water-Supply Paper 1597, 99 p.
Hodge, E.T., 1932, Geologic map of north-central Oregon: Oregon Univ. (Eugene) Pub. Geology ser., v. 1, no. 5, scale 1:250,000; accompanying text, 7 p.
———1942, Geology of north central Oregon: Oregon State College, Corvallis, Monograph, Studies in geology no. 3, 76 p.
Hogenson, G.M., 1964, Geology and ground water of the Umatilla River Basin, Oregon: U.S. Geol. Survey Water-Supply Paper 1620, 162 p.
Mendenhall, W.C., 1909, A coal prospect on Willow Creek, Morrow County, Oregon: U.S. Geol. Survey Bull. 341, p. 406-408.
Newcomb, R.C., 1965, Geology and ground-water resources of the Walla Walla River Basin, Washington-Oregon: Washington Div. Water Resources Water Supply Bull. 21, 151 p.
———1969a, Geology of the Deschutes-Umatilla Plateau, in Weissenborn, A.E., ed., Mineral and water resources of Oregon: Oregon Dept. Geology and Mineral Industries Bull. 64, p. 60-66.
———1969b, Geologic map of the proposed Paterson Ridge pumped-storage reservoir, south-central Washington: U.S. Geol. Survey open-file rept., 8 p.
———1970, Tectonic structure of the Columbia River basalt and its relation to ground water: U.S. Geol. Survey Misc. Geol. Inv. Map I-587, scale 1:500,000.
Oregon Department of Geology and Mineral Industries, 1941, Oregon Metal Mines Handbook; Grant, Morrow, and Umatilla Counties: Oregon Dept. Geology and Mineral Industries Bull. 14-B, 157 p.
Pigg, J.H., Jr., 1961, The lower Tertiary sedimentary rocks in the Pilot Rock and Heppner areas, Oregon: Oregon Univ., Eugene, M.S. thesis, 67 p.
Powers, H.A., and Wilcox, R.E., 1964, Volcanic ash from Mount Mazama (Crater Lake) and from Glacier Peak: Science, v. 144, no. 3624, p. 1334-1336.
Robison, J.H., 1971, Hydrology of basalt aquifers in the Hermiston-Ordnance area, Umatilla and Morrow Counties, Oregon: U.S. Geol. Survey Hydro. Inv. Atlas HA-387, scale 1:125,000.
Schmincke, Hans-Ulrich, 1967, Stratigraphy and petrography of four upper Yakima Basalt flows in south-central Washington: Geol. Soc. America Bull., v. 78, p. 1385-1422.
Shotwell, J.A., 1956, Hemphillian mammalian assemblage from northeastern Oregon: Geol. Soc. America Bull., v. 67, no. 6, p. 717-738.
Swanson, D.A., 1969, Reconnaissance geologic map of the east half of the Bend quadrangle, Crook, Wheeler, Jefferson, Wasco, and Deschutes Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-568, scale 1:250,000.
Taubeneck, W.H., 1955, Age of the Bald Mountain batholith, northeastern Oregon: Northwest Sci., v. 29, no. 3, p. 93-96.
———1957, Geology of the Elkhorn Mountains, northeastern Oregon—Bald Mountain batholith: Geol. Soc. America Bull., v. 68, p. 181-238.
Thayer, T.P., 1963, The Canyon Mountain Complex, Oregon, and the alpine mafic magma stem in Geological Survey research 1963: U.S. Geol. Survey Prof. Paper 475-C, p. C82-C85.
Thayer, T.P., and Brown, C.E., 1964, Pre-Tertiary orogenic and plutonic intrusive activity in central and northeastern Oregon: Geol. Soc. America Bull., v. 75, p. 1255-1262.
Wolfe, H.D., and White, D.J., 1951, Preliminary report on tungsten in Oregon: Oregon Dept. Geology and Mineral Industries Short Paper 22, 24 p.