RHO-BWI-LD-4
Informal Report

Geology of the Saddle Mountains Between Sentinel Gap and 119° 30′ Longitude

S. P. Reidel

September 1978

Prepared for the United States
Department of Energy
Under Contract EY-77-C-06-1030

Rockwell International

Rockwell Hanford Operations
Energy Systems Group
Richland, WA 99352

DISCLAIMER

Rockwell International

Rockwell Hanford Operations
Energy Systems Group
Richland, WA 99352

PREPARED FOR THE UNITED STATES DEPARTMENT OF ENERGY
UNDER CONTRACT EY-77-C-06-1030

PRELIMINARY REPORT

This Report contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final Report. It was prepared primarily for internal use within The Rockwell Hanford Operations. Any expressed views and opinions are those of the Author and not necessarily of the Company.

RHO-BWI-LD-4

Informal Report

GEOLOGY OF THE SADDLE MOUNTAINS BETWEEN SENTINEL GAP AND 119° 30' LONGITUDE

S. P. Reidel

Basalt Geosciences Unit
Research Department

for

Basalt Waste Isolation Program

September 1978

Rockwell International
Rockwell Hanford Operations
Energy Systems Group
Richland, Washington 99352

ABSTRACT

Members and flows of the Grande Ronde, Wanapum, and Saddle Mountains basalts of the Columbia River Basalt Group were mapped in the Saddle Mountains between Sentinel Gap and the eastern edge of Smyrna Bench. The Grande Ronde Basalt consists of the Schwana (low-MgO) and Sentinel Bluffs (high-MgO) members (informal names). The Wanapum Basalt consists of the aphyric and phyric units of the Frenchman Springs Member, the "Roza-Like" Member, and the Priest Rapids Member. The Saddle Mountains Basalt consists of the Wahluke, Huntzinger, Pomona, Mattawa, and Elephant Mountain basalts.

The Wanapum and Saddle Mountains basalts are unevenly distributed across the Saddle Mountains. The Wanapum Basalt thins from south to north and across a northwest-southeast-trending axis at the west end of Smyrna Bench. The Priest Rapids, "Roza-Like," and aphyric Frenchman Springs units are locally missing across this zone.

The Saddle Mountains basalt has a more irregular distribution and, within an area between Sentinel Gap and Smyrna Bench, is devoid of the basalt. The Wahluke, Huntzinger, and Mattawa flows are locally present, but the Pomona is restricted to the southern flank west of Smyrna Bench, and the Elephant Mountain Basalt only occurs on the flanks and in three structurally controlled basins on the northwest side.

The structure of the Saddle Mountains is dominated by an east-west trend and, to a lesser degree, controlled by a northwest-southeast and northeast-southwest trend. The geomorphological expression of the Saddle Mountains results from the east-west fold set and the Saddle Mountains fault along the north side. The oldest structures follow the northwest-southeast trend.

The distribution of the flows, combined with the structural features, indicates a complex geologic history for the Saddle Mountains.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

PURPOSE

The U. S. Department of Energy, through the Basalt Waste Isolation Program within Rockwell Hanford Operations, is investigating the feasibility of terminal storage of radioactive wastes in deep caverns constructed in Columbia River Basalt. This report represents a portion of the geological work conducted during fiscal year 1978 to assess the geological conditions in the Saddle Mountains of the Pasco Basin.

The objective of the geological work in the Saddle Mountains was to describe and map, at a scale of 1:24,000, the stratigraphic units and geologic structure which form the north side of the Pasco Basin. Those geologic features in the Saddle Mountains that might relate to hydrologic conditions and tectonic stability of the Pasco Basin were emphasized during mapping. These included stratigraphic relationships of the Columbia River Basalt; the location of faults, folds, and fracture zones, as well as landslides and other geomorphologic features.

LOCATION

The Saddle Mountains form the northern boundary of the Pasco Basin (Figure 1) in Grant County, south-central Washington. Sentinel Gap was arbitrarily selected as the western boundary of the mapping area and the eastern edge of Smyrna Bench (119^{o} 30' longitude) as the eastern boundary. The mapped area is covered by the Beverly and Beverly Southeast 7-1/2-minute U. S. Geological Survey quadrangle maps and the southern half of the Smyrna 15-minute quadrangle map.

PHYSIOGRAPHY AND CLIMATE

The Saddle Mountains are an asymmetrical, east-west-trending ridge with 1,700 to 2,000 feet of topographic relief. The ridge is relatively broad between Sentinel Gap and Smyrna Bench and has a steep north face with a gently sloping south face, but is more narrow and symmetrical farther east.

Wahatis Peak has the greatest topographic relief; Crab Creek lies directly north, the Wahluke slope forms the southern flank, and the

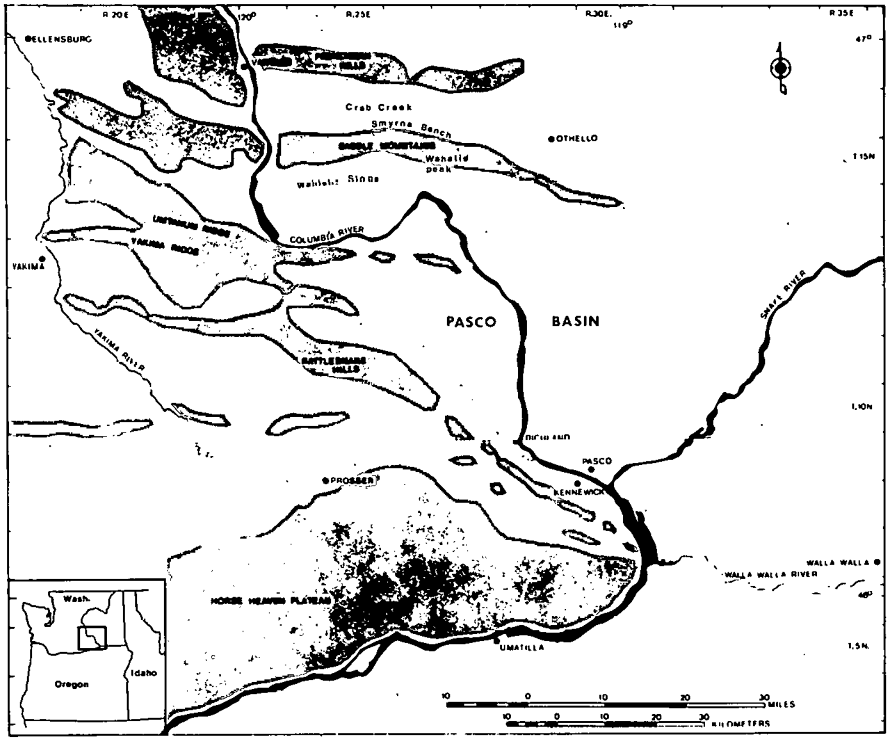


FIGURE 1

LOCATION MAP OF THE SADDLE MOUNTAINS IN SOUTH-CENTRAL WASHINGTON

Columbia River crosses the Saddle Mountains at Sentinel Gap. The Saddle Mountains lie in the mountainous, shrub-steppe of south-central Washington. The mean annual precipitation is less than six inches, generally allowing only sagebrush and various grasses to grow on the slopes. Locally, however, irrigation on Wahluke Slope has made some agriculture possible.

PREVIOUS INVESTIGATIONS

The Saddle Mountains were first investigated geologically in the late 1800s and early 1900s (Symons, 1882; Russell, 1893, 1901; Smith, 1901, 1903; Calkins, 1905), but these studies were of a general nature with little emphasis on the basalt stratigraphy.

Twiss (1933) described some of the basalt stratigraphy and produced the first geologic map of the Saddle Mountains. Laval (1956) studied the entire basalt stratigraphy and mapped part of the area. Mackin (1955) studied the basalt stratigraphy in the Sentinel Gap-Priest Rapids area and produced detailed geologic maps of the Wanapum and Priest Rapids dam sites. In 1961, Mackin published a detailed description of the stratigraphy of the area that has been a primary source of field descriptions in subsequent studies.

Schmincke (1964, 1967) studied the Ellensburg Formation and intercalated basalt flows in the Saddle Mountains and described, in detail, the stratigraphic variations. Grolier (1965) mapped the Big Bend area of Washington, which included the Saddle Mountains, and described the basalt and Quaternary geology. He published a revised map with Bingham in 1971, but the text that accompanied the map was not published until 1978. Brown and Ledgerwood (1973) collected, described, and obtained chemical analyses of the basalt flows exposed at Sentinel Gap. Myers (1973) described the basalt stratigraphy along the Columbia River north of Sentinel Gap.

Taylor (1976) produced the most recent geologic map of the western portion of the Saddle Mountains near Sentinel Gap and described the chemistry and petrology of four stratigraphic sections along the north face. One of Taylor's four sections, the Sentinel Gap Section, is the same as that sampled by Ledgerwood, et al., (1973). Jones and Deacon (1966), Bingham, et al., (1970), and Jahns (1967) described and interpreted geologic features in the Saddle Mountains and, in particular, the Smyrna Bench area. In 1977, the Washington Public Power Supply System, Inc., funded a geologic study of the Pasco Basin that included remote sensing studies of the Saddle Mountains.

DIVISION OF WORK AND RESPONSIBILITY

All mapping used in this report was done by the author. Whole rock X-ray fluorescence analyses, Table I, used for verification of field-identified flows were done in the Basalt Research Laboratory at Washington State University under contract to Rockwell Hanford Operations. Selected samples were also analyzed for CaO, TiO_2, and BaO by Mr. R. D. Landon and Ms. M. G. Jones of Rockwell Hanford Operations using an onsite energy dispersive X-ray unit.

METHODS AND PROCEDURES

Field work was begun November 1, 1977 and ended May 25, 1978. Mapping generally progressed from west to east and the south flank of the Saddle Mountains was mapped prior to the steep north scarp. This was logistically desirable and permitted a more continuous tracing of structures and contacts.

Individual stratigraphic units of Columbia River Basalt were identified on the basis of physical characteristics, whole rock major element chemical analyses, and paleomagnetic polarity. Basalt field samples collected for identification were checked for magnetic polarity using a flux gate magnetometer (Calex Model 70). The readings and sample locations were recorded in controlled field notebooks and on the geologic map.

Judgments were made if the sample should be submitted for a complete X-ray fluorescence major element analysis, if an energy dispersive X-ray analysis would be sufficient (Table II), or if chemical analysis was necessary. In many instances, magnetic polarity (Table II), combined with known stratigraphic relationships at a particular locality, was sufficient. Geologic mapping and sampling followed standard operating procedures. All sample locations are recorded in Table III by township, range, section, and quarter section and shown in Figures 2 and 3.

TABLE I

X-RAY FLUORESCENCE ANALYSES OF BASALT SAMPLES COLLECTED FROM THE SADDLE MOUNTAINS

GRANDE RONDE BASALT

Samples Number	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
					Flow A						
C8012	55.35	14.86	1.91	2.00	10.10	.22	7.58	3.56	1.80	2.34	.28
C8013	55.31	15.03	1.92	2.00	10.09	.21	7.56	3.68	1.92	2.01	.27
					Flow B						
C9036	55.33	14.47	2.11	2.00	10.77	.21	6.96	3.28	2.06	2.46	.35
C9039	55.17	14.96	1.92	2.00	10.34	.21	7.39	3.50	1.85	2.36	.31
C8014	55.40	14.85	1.94	2.00	10.22	.21	7.22	3.49	1.97	2.40	.30
C8015	55.45	14.66	1.92	2.00	10.45	.20	7.13	3.48	1.87	2.21	.32
C8016	55.63	14.72	1.91	2.00	10.09	.21	7.30	3.43	1.98	2.36	.31
C8017	55.67	14.70	1.91	2.00	10.36	.20	7.12	3.46	1.94	2.32	.31
C8018	55.21	15.33	1.92	2.00	10.01	.20	7.25	3.38	2.02	2.39	.30
					Flow C						
C9041	55.89	14.74	1.92	2.00	9.86	.20	6.98	3.40	2.06	2.58	.32
C8019	55.21	15.33	1.92	2.00	10.01	.20	7.25	3.38	2.02	2.39	.30
C8020	55.26	14.92	1.91	2.00	10.44	.20	7.24	3.51	1.96	2.26	.31
C4313	54.98	14.14	2.13	2.00	10.98	.22	7.22	3.60	1.67	2.73	.34
					Flow D						
C8021	54.61	14.33	2.16	2.00	11.73	.22	7.20	3.50	1.66	2.84	.35
C9042	54.83	14.27	2.21	2.00	11.21	.22	7.18	3.43	1.82	2.48	.36
C9043	54.08	14.42	2.17	2.00	11.44	.22	7.46	3.73	1.82	2.33	.34
C8022	54.44	14.64	2.18	2.00	11.34	.23	7.31	3.27	1.90	2.34	.35
C8023	54.75	14.36	2.11	2.00	11.33	.22	7.21	3.57	1.73	2.46	.35
C8024	54.26	14.54	2.13	2.00	11.22	.22	7.39	3.48	1.84	2.56	.34
C8025	54.58	14.19	2.13	2.00	11.47	.22	7.16	3.39	2.03	2.48	.36
C8026	54.42	14.67	2.15	2.00	11.06	.23	7.36	3.41	1.79	2.57	.35
C8030	54.54	14.50	2.14	2.00	11.33	.19	6.99	3.25	1.65	3.03	.37
C8029	54.30	14.31	2.13	2.00	11.38	.21	7.13	3.48	1.79	2.92	.36
C4312	54.72	14.09	2.17	2.00	11.24	.22	7.29	3.49	1.95	2.46	.35
					Flow E						
C4289	53.25	14.78	1.87	2.00	10.56	0.21	8.70	4.70	1.17	2.43	0.30
C4290	53.28	14.83	1.89	2.00	10.85	0.20	8.44	4.55	1.12	2.59	0.27
C4295	53.44	14.57	1.90	2.00	10.74	0.21	8.56	4.66	1.16	2.46	0.30
C4296	53.45	14.27	1.92	2.00	10.79	0.22	8.45	4.56	1.24	2.82	0.28
C4298	53.26	14.62	1.93	2.00	10.85	0.22	8.43	4.43	1.18	2.79	0.30
C4299	53.34	14.71	1.93	2.00	10.70	0.22	8.48	4.51	1.18	2.64	0.29
C4300	53.02	14.71	1.90	2.00	10.84	0.21	8.61	4.57	1.18	2.67	0.30
C4301	53.13	14.41	1.95	2.00	10.96	0.22	8.56	4.54	1.21	2.71	0.31
C4304	53.08	14.72	1.88	2.00	10.94	0.22	8.57	4.63	1.17	2.51	0.29

Table I (continued)

Grande Ronde Basalt (continued)

Sample	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
Flow F											
C4279	53.34	14.82	1.90	2.00	9.68	0.20	9.38	5.08	0.86	2.45	0.29
C4280	53.13	14.75	1.83	2.00	10.49	0.21	8.96	4.93	1.11	2.31	0.28
C4281	53.14	14.73	1.95	2.00	10.31	0.21	8.92	4.77	1.12	2.52	0.32
C4311	53.58	14.66	1.75	2.00	9.95	0.20	9.09	5.06	0.95	2.50	0.27
Flow G											
C9014	53.28	15.05	1.83	2.00	9.50	0.21	9.32	5.25	0.93	2.36	0.27
C4278	53.01	15.05	1.78	2.00	9.64	0.21	9.41	5.15	0.92	2.57	0.27
Flow H											
C4272	52.96	15.08	1.76	2.00	9.98	0.21	9.13	5.07	1.07	2.47	0.28
C4273	52.84	14.97	1.74	2.00	10.36	0.21	9.07	5.08	1.06	2.41	0.26
C4275	54.01	14.57	1.94	2.00	10.11	0.21	8.35	4.48	1.24	2.72	0.38
C9016	53.28	15.11	1.77	2.00	9.86	.21	9.06	5.04	1.14	2.24	0.28
Flow I											
C9019	53.47	14.64	1.81	2.00	9.97	0.21	9.00	4.99	1.11	2.52	0.29
C4269	53.41	14.63	1.80	2.00	10.04	0.21	8.83	4.88	1.14	2.73	0.32
C4270	53.13	14.98	1.77	2.00	10.09	0.21	9.03	5.10	1.17	2.24	0.28
C4271	53.21	14.99	1.78	2.00	9.86	0.21	9.12	5.13	0.95	2.47	0.28
Flow J											
C4232	53.91	14.79	1.71	2.00	9.77	0.20	8.92	5.10	1.10	2.24	0.25
C4266	53.55	15.29	1.78	2.00	9.20	0.20	9.37	5.00	0.97	2.35	0.28
C4267	54.07	15.16	1.73	2.00	8.58	0.20	9.38	5.13	1.01	2.47	0.26
C4268	53.53	15.22	1.72	2.00	9.19	0.20	9.21	5.25	1.12	2.28	0.27
C9020	53.38	14.93	1.78	2.00	9.61	0.19	9.23	5.23	0.90	2.49	0.27
Rocky Coulee Flow											
C4218	54.07	14.78	1.74	2.00	9.95	0.20	8.66	4.27	1.40	2.60	0.33
C4263	54.56	15.25	1.71	2.00	8.21	0.20	9.40	4.99	1.16	2.25	0.27
C4264	54.59	15.31	1.75	2.00	8.67	0.20	8.94	4.56	1.32	2.34	0.31
C4265	54.12	15.01	1.77	2.00	9.67	0.20	8.61	4.42	1.32	2.56	0.31
C4305	53.81	14.79	1.77	2.00	9.94	0.21	8.57	4.62	1.50	2.45	0.34
C4022	53.85	15.40	1.72	2.00	8.41	0.21	9.45	4.97	1.13	2.58	0.28
C8003	54.01	14.73	1.80	2.00	9.93	0.21	8.62	4.52	1.33	2.53	0.33
C8005	54.06	15.05	1.74	2.00	9.39	0.21	8.75	4.78	1.29	2.44	0.29
C8007	53.72	15.06	1.72	2.00	9.53	0.20	8.86	4.83	1.45	2.35	0.27
C8009	54.30	14.99	1.76	2.00	9.32	0.20	8.66	4.77	1.26	2.51	0.30
C8011	53.57	14.94	1.71	2.00	9.96	0.20	8.78	4.78	1.36	2.40	0.28

Table I (continued)

Grande Ronde Basalt (continued)

Sample Number	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
					Museum Flow						
C4126	54.90	15.02	1.71	2.00	9.07	0.19	8.95	5.05	1.24	1.58	0.29
C4217	53.76	15.28	1.70	2.00	8.89	0.19	9.42	5.00	0.86	2.64	0.28
C4219	54.15	14.65	1.66	2.00	9.87	0.21	8.45	4.74	1.23	2.75	0.30
C4226	54.12	15.12	1.73	2.00	10.04	0.21	8.88	4.19	0.88	2.50	0.31
C4227	54.88	14.62	1.75	2.00	9.12	0.20	8.59	4.56	1.61	2.38	0.30
C4228	54.34	14.64	1.72	2.00	9.51	0.20	8.74	4.59	1.34	2.60	0.31
C4229	54.27	14.83	1.69	2.00	9.33	0.19	8.67	4.74	1.53	2.46	0.28
C4242	54.06	15.22	1.70	2.00	9.32	0.20	9.10	4.59	1.21	2.31	0.29
C4249	55.19	15.66	1.75	2.00	7.43	0.16	9.21	4.75	1.19	2.34	0.32
C4257	54.19	15.47	1.67	2.00	8.63	0.20	9.42	4.61	1.11	2.42	0.28
C4258	54.65	14.88	1.77	2.00	9.22	0.20	8.54	4.53	1.53	2.39	0.31
C4259	54.97	15.12	1.72	2.00	8.61	0.21	8.77	4.64	1.35	2.31	0.31
C4260	54.63	14.67	1.68	2.00	9.78	0.21	8.36	4.66	1.38	2.33	0.30
C4261	54.76	14.66	1.72	2.00	10.14	0.19	8.05	4.30	1.38	2.48	0.30
C4282	53.91	15.06	1.78	2.00	9.74	0.21	8.60	4.61	1.41	2.35	0.32
C4283	54.96	14.83	1.78	2.00	9.26	0.19	8.16	4.42	1.45	2.63	0.31
C4286	54.66	14.93	1.70	2.00	9.23	0.19	8.29	4.73	1.37	2.61	0.29
C4287	54.10	14.98	1.67	2.00	9.55	0.19	8.49	4.67	1.39	2.63	0.32
C4306	53.39	15.62	1.62	2.00	9.20	0.19	9.15	5.02	1.11	2.41	0.29
C4320	54.27	15.57	1.70	2.00	8.74	0.19	9.05	4.94	1.11	2.15	0.29
C4321	54.28	15.04	1.72	2.00	9.28	0.19	8.47	4.68	1.50	2.52	0.32
C9023	54.10	15.20	1.69	2.00	10.01	0.21	8.29	4.53	1.22	2.48	0.28

WANAPUM BASALT

Frenchman Springs Phyric Flows

C4253	50.53	13.87	3.01	2.00	13.47	0.24	8.20	4.14	1.27	2.72	0.56
C4122	51.27	13.95	2.96	2.00	12.99	0.22	8.30	4.16	1.41	2.21	0.52
C4107	50.76	13.84	3.15	2.00	13.17	0.23	8.39	4.17	1.34	2.36	0.58
C4118	52.46	14.23	2.84	2.00	12.18	0.23	7.92	4.14	1.49	1.98	0.53
C4119	52.23	13.94	2.95	2.00	12.28	0.23	8.13	4.21	1.39	2.12	0.53
C4220	50.95	13.97	2.98	2.00	12.79	0.24	8.19	4.17	1.50	2.67	0.54
C4234	51.19	14.04	2.97	2.00	12.80	0.23	8.03	4.05	1.45	2.66	0.58
C4241	50.37	14.58	3.03	2.00	11.78	0.23	9.00	4.42	1.30	2.72	0.55
C4307	50.81	13.63	3.01	2.00	13.17	0.24	8.19	4.18	1.46	2.72	0.59
C4319	50.93	13.81	2.98	2.00	13.13	0.24	7.93	4.13	1.60	2.63	0.62
C4284	51.05	14.10	2.97	2.00	13.18	0.24	7.95	3.99	1.33	2.61	0.56
C4285	51.16	13.92	3.05	2.00	12.96	0.24	8.13	3.99	1.30	2.64	0.59

Table I (continued)

Wanapum Basalt (continued)

Sample Number	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
					Frenchman Springs Aphyric Flows						
C4010	51.06	14.28	3.01	2.00	12.28	0.23	8.37	4.07	1.49	2.65	0.55
C4011	50.64	13.94	2.99	2.00	13.27	0.23	8.18	4.28	1.43	2.50	0.53
C4012	50.82	14.03	2.99	2.00	13.00	0.23	8.21	4.14	1.54	2.47	0.56
C4013	51.02	13.87	2.96	2.00	12.91	0.23	8.20	4.23	1.55	2.47	0.56
C4015	51.35	13.80	3.00	2.00	12.54	0.23	8.25	4.32	1.59	2.30	0.56
C4016	51.45	13.54	3.08	2.00	12.41	0.23	8.58	4.05	1.71	2.39	0.56
C4021	51.56	13.98	2.97	2.00	12.68	0.23	8.07	4.43	1.81	2.26	0.52
C4050	50.45	14.81	3.06	2.00	11.86	0.20	9.14	4.46	0.83	2.59	0.59
C4052	52.11	14.23	3.04	2.00	12.08	0.22	8.33	3.98	1.29	2.19	0.53
C4094	52.08	14.44	3.05	2.00	11.79	0.26	8.28	4.42	1.30	1.87	0.51
C4103	50.98	13.54	3.06	2.00	13.13	0.23	8.40	4.31	1.46	2.35	0.55
C4109	51.62	14.18	3.00	2.00	12.64	0.21	8.22	4.26	1.30	2.04	0.52
C4181	51.29	14.00	3.09	2.00	12.38	0.24	8.43	4.21	1.46	2.35	0.55
C4220	50.95	13.97	2.98	2.00	12.79	0.24	8.19	4.17	1.50	2.67	0.54
C4230	49.59	13.86	3.63	2.00	14.12	0.27	8.77	4.37	0.69	2.19	0.51
C4243	51.96	14.22	2.96	2.00	11.92	0.23	8.40	3.58	1.62	2.53	0.58
C4250	51.60	13.96	2.90	2.00	12.66	0.23	8.01	3.87	1.80	2.39	0.58
C4254	51.54	14.15	3.05	2.00	12.78	0.23	8.04	3.72	1.44	2.49	0.56
C4288	50.68	13.94	3.07	2.00	13.04	0.23	8.35	4.20	1.49	2.48	0.53
C4327	51.32	13.70	2.99	2.00	12.78	0.23	8.29	4.21	1.56	2.37	0.54
					"Roza-Like" Flows						
C4009	50.61	14.11	3.14	2.00	12.72	0.21	8.47	4.29	1.30	2.59	0.61
C4049	50.27	14.31	2.96	2.00	12.33	0.23	9.03	4.67	1.16	2.52	0.53
C4192	50.76	14.59	2.77	2.00	11.66	0.22	8.88	4.83	1.15	2.63	0.52
C4053	52.49	14.51	3.11	2.00	12.33	0.23	8.85	2.60	1.10	2.21	0.59
C4093	51.82	13.33	3.08	2.00	11.76	0.22	9.21	4.14	1.19	2.72	0.54
C4120	50.27	14.15	3.13	2.00	12.60	0.23	9.12	4.74	1.01	2.19	0.57
C4136	50.54	14.00	3.06	2.00	13.03	0.23	8.73	4.66	1.23	1.95	0.57
C4314	50.03	14.27	2.97	2.00	12.58	0.22	8.51	4.77	1.25	2.85	0.54
C4326	50.45	14.27	3.05	2.00	12.39	0.22	8.60	4.60	1.25	2.60	0.56
C4339	50.37	14.25	3.05	2.00	12.44	0.22	8.42	4.69	1.23	2.78	0.56

Table I (continued)

Wanapum Basalt (continued)

Sample Number	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
			Priest Rapids - Rosalia Chemical Type								
C4240	49.76	13.87	3.57	2.00	12.99	0.23	8.76	4.22	1.39	2.51	0.68
C4008	49.05	13.70	3.44	2.00	13.71	0.25	8.59	4.67	1.23	2.70	0.67
C4048	49.88	13.58	3.43	2.00	13.13	0.24	8.45	4.89	1.26	2.50	0.64
C4063	50.05	13.98	3.55	2.00	12.62	0.23	8.79	4.42	1.18	2.47	0.70
C4092	48.84	13.46	3.65	2.00	14.14	0.26	8.75	4.74	1.05	2.47	0.66
C4104	50.57	13.99	3.34	2.00	12.73	0.23	8.64	4.38	1.19	2.21	0.69
C4164	51.75	14.08	3.60	2.00	11.74	0.21	8.93	3.57	1.21	2.24	0.68
C4190	51.04	14.03	3.58	2.00	12.11	0.24	8.88	4.10	1.01	2.34	0.67
C4244	49.20	13.60	3.54	2.00	13.95	0.26	8.52	4.44	1.47	2.35	0.68
C4245	50.63	13.60	3.61	2.00	14.06	0.24	7.97	3.83	1.13	2.21	0.71
C4247	51.46	14.10	2.82	2.00	12.75	0.22	8.00	3.82	1.67	2.57	0.59
C4248	49.30	13.67	3.46	2.00	13.67	0.23	8.60	4.15	1.34	2.88	0.69
C4255	49.66	13.55	3.45	2.00	13.65	0.25	8.51	4.35	1.30	2.61	0.68
C4256	49.16	13.64	3.48	2.00	14.41	0.25	8.58	4.04	1.12	2.65	0.66
C4308A	49.79	13.84	3.52	2.00	13.38	0.24	8.74	4.10	1.28	2.45	0.66
C4308B	49.54	13.44	3.54	2.00	13.80	0.25	8.91	4.02	1.29	2.57	0.65
C4315	50.20	13.95	3.50	2.00	12.74	0.23	8.55	4.45	1.01	2.68	0.68
C4316	49.50	13.50	3.44	2.00	13.54	0.25	8.32	4.59	1.41	2.76	0.70
C4317	49.49	13.98	3.44	2.00	13.63	0.25	8.38	4.46	1.46	2.24	0.67
C4318	49.27	13.74	3.52	2.00	13.41	0.25	8.48	4.42	1.38	2.84	0.69
C4328	49.71	13.48	3.48	2.00	13.47	0.24	8.65	4.47	1.27	2.59	0.65
C4329	49.58	13.48	3.52	2.00	13.79	0.25	8.75	4.31	1.14	2.53	0.65
C4333	49.69	13.60	3.45	2.00	13.68	0.24	8.35	4.46	1.24	2.61	0.66
C4335	49.50	13.56	3.58	2.00	13.51	0.24	8.76	4.43	1.22	2.55	0.66
C4336	49.73	13.66	3.57	2.00	13.24	0.25	8.88	4.21	1.24	2.57	0.66
C4337	49.75	13.47	3.46	2.00	13.50	0.25	8.59	4.54	1.31	2.42	0.66
C4065	51.85	13.86	3.01	2.00	12.28	0.22	8.13	4.10	1.48	2.54	0.53
C4028	49.81	14.01	3.50	2.00	12.55	0.25	8.65	4.58	1.44	2.56	0.65
			Priest Rapids - Lolo Chemical Type								
C4225	50.62	14.17	3.58	2.00	12.48	0.22	9.25	3.28	1.07	2.61	0.71
C4007	49.33	14.28	3.27	2.00	14.14	0.24	9.73	4.75	1.11	2.46	0.69
C4159	50.28	14.26	3.16	2.00	12.44	0.24	9.32	4.39	1.02	2.22	0.66
C4163	49.45	13.97	3.19	2.00	12.44	0.25	9.51	5.35	0.97	2.18	0.67
C4187	50.71	14.31	3.82	2.00	11.81	0.18	9.43	3.93	0.79	2.37	0.64
C4251	49.60	13.86	3.57	2.00	12.94	0.23	9.02	4.26	1.26	2.58	0.68
C4216	52.09	14.57	3.83	2.00	10.06	0.18	9.43	3.30	1.26	2.57	0.71

Table I (continued)

SADDLE MOUNTAINS BASALT

Sample Number	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
Wahluke Flow											
C4161	53.17	15.60	1.65	2.00	8.03	0.17	10.08	6.03	1.13	1.82	0.32
Huntzinger Flow											
C4160	51.80	16.01	1.36	2.00	7.39	0.17	11.01	7.74	0.33	1.99	0.20
C4166	50.92	16.00	1.41	2.00	8.51	0.18	11.11	7.83	0.38	1.45	0.21
C4235	52.06	16.04	1.56	2.00	8.96	0.16	10.24	5.42	1.02	2.24	0.31
C4236	51.48	15.31	1.63	2.00	8.83	0.20	10.80	6.86	0.55	2.11	0.24
C4239	51.20	15.60	1.61	2.00	7.85	0.21	11.37	6.18	1.19	2.47	0.32
Pomona Flow											
C4006	51.44	15.24	1.60	2.00	9.07	0.19	10.78	6.67	0.55	2.23	0.23
C4018	51.51	15.30	1.59	2.00	8.80	0.18	10.82	7.09	0.48	1.98	0.24
C4035	51.70	15.66	1.63	2.00	8.98	0.20	10.29	6.15	0.67	2.40	0.32
C4036	51.60	15.43	1.59	2.00	8.69	0.18	10.76	6.61	0.23	2.70	0.21
C4055	52.28	15.20	1.62	2.00	8.43	0.18	10.64	6.95	0.57	1.88	0.24
C4088	51.89	15.39	1.60	2.00	9.07	0.18	10.89	6.04	0.52	2.18	0.24
C4177	51.06	15.83	1.36	2.00	7.98	0.17	11.04	8.11	0.46	1.77	0.21
C4178	51.00	15.91	1.40	2.00	7.81	0.18	11.13	8.17	0.50	1.69	0.21
C4182	50.92	16.06	1.45	2.00	8.58	0.16	10.73	6.76	0.85	2.21	0.28
C4197	51.56	15.66	1.61	2.00	8.66	0.18	11.05	6.23	0.44	2.37	0.22
C4199	51.46	15.33	1.57	2.00	8.81	0.18	10.74	7.16	0.36	2.17	0.21
C4233	52.30	15.28	1.59	2.00	8.57	0.18	10.37	6.71	0.64	2.14	0.21
C4238	51.49	15.78	1.63	2.00	8.17	0.19	10.92	6.85	0.53	2.20	0.24
C4237	51.91	15.76	1.64	2.00	7.98	0.19	10.81	5.92	1.20	2.27	0.32
C4246	51.34	17.23	1.61	2.00	8.12	0.16	11.32	6.26	0.34	2.46	0.26
C4340	51.97	15.24	1.59	2.00	8.41	0.19	10.65	6.70	0.72	2.31	0.23
Mattawa Flow											
C4039	51.89	15.45	1.62	2.00	8.76	0.18	9.96	6.37	1.24	2.21	0.31
C4040	51.00	15.89	1.52	2.00	8.32	0.18	10.21	7.35	1.11	2.13	0.29
C4041	50.90	15.76	1.47	2.00	8.08	0.21	10.90	7.56	0.84	2.07	0.22
C4046	52.59	15.79	1.44	2.00	8.53	0.17	10.31	5.95	0.83	2.12	0.27
C4069	51.36	15.21	1.59	2.00	9.08	0.19	10.62	6.63	0.61	2.47	0.24
C4080	50.83	16.20	1.38	2.00	8.27	0.18	10.93	7.32	0.53	2.15	0.21
C4087	50.43	16.29	1.36	2.00	8.30	0.18	10.77	7.66	0.61	2.18	0.23
C4089	51.46	16.32	1.46	2.00	8.75	0.18	10.41	6.37	0.89	1.88	0.27
C4090	50.71	16.28	1.45	2.00	8.53	0.19	10.61	7.00	0.80	2.18	0.26
C4139	51.30	16.09	1.36	2.00	8.20	0.18	11.01	8.03	0.34	1.28	0.21
C4172	51.31	15.82	1.39	2.00	7.83	0.17	11.06	8.08	0.52	1.60	0.21
C4183	52.19	15.77	1.56	2.00	8.82	0.17	10.37	6.07	0.73	2.03	0.29
C4184	50.94	16.10	1.37	2.00	8.10	0.17	10.99	7.14	0.53	2.34	0.23

Table I (continued)

Saddle Mountains Basalt (continued)

Sample Number	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
					Elephant Mountain Flows						
C4019	50.44	13.64	3.48	2.00	13.36	0.22	8.52	4.13	1.34	2.36	0.50
C4020	50.54	13.79	3.54	2.00	12.64	0.23	8.62	4.38	1.29	2.45	0.52
C4028	50.07	13.51	3.49	2.00	12.77	0.25	8.72	4.59	1.43	2.54	0.63
C4135a	51.42	13.56	3.53	2.00	13.23	0.22	8.62	4.12	1.11	1.68	0.50
C4140	50.74	13.58	3.53	2.00	13.12	0.22	8.31	4.21	1.29	2.51	0.50
C4141	50.64	14.05	3.72	2.00	12.10	0.24	8.84	4.22	1.22	2.44	0.51
C4186	51.49	13.58	3.48	2.00	13.00	0.21	8.32	4.29	1.00	2.14	0.50
C4188	50.23	13.36	3.53	2.00	13.43	0.23	8.91	4.53	0.95	2.34	0.48
C4215	51.52	13.94	3.58	2.00	12.14	0.23	8.78	3.67	1.22	2.41	0.50
C4222	51.17	13.27	3.51	2.00	14.02	0.22	8.02	4.06	1.25	2.01	0.48
C4252	50.57	13.56	3.46	2.00	13.82	0.22	8.23	4.12	1.27	2.23	0.51
C4330	50.92	13.56	3.54	2.00	13.15	0.20	8.79	3.78	1.14	2.41	0.51
C4332	50.95	13.61	3.51	2.00	13.30	0.21	8.52	3.95	1.23	2.22	0.50
C4334	50.84	13.61	3.46	2.00	13.11	0.22	8.42	4.16	1.24	2.45	0.50
C4322	50.27	13.82	3.48	2.00	13.65	0.22	8.44	4.12	1.20	2.29	0.50
C4243	49.94	13.94	3.15	2.00	12.96	0.22	8.69	4.80	1.15	2.71	0.45
C4324	52.13	11.59	3.61	2.00	13.64	0.21	8.62	4.20	1.22	2.25	0.53
C4325	50.16	13.49	3.55	2.00	13.54	0.22	8.33	4.48	1.30	2.43	0.50
C4338	49.90	13.15	3.47	2.00	13.91	0.23	8.61	4.90	1.17	2.21	0.45
C4185	51.25	13.46	3.46	2.00	12.84	0.24	8.67	4.12	1.18	2.30	0.49

TABLE II

PALEOMAGNETIC POLARITY AND ENERGY DISPERSIVE X-RAY CHEMICAL COMPOSITION OF SAMPLES COLLECTED FROM THE SADDLE MOUNTAINS

Sample	Mag	CaO	TiO_2
4001	ND		
4002	-	9.3	2.7
4003	-	7.6	2.9
4004	-	7.6	2.9
4005	ND	7.9	3.8
4006	-(?)	10.0	1.4
4007	ND	8.4	3.0
4008	ND	7.9	2.6
4009	ND	9.3	2.6
4010	ND	8.4	4.1
4011	ND	7.9	2.6
4012	ND	7.7	3.3
4013	-	8.6	4.4
4014	+	7.9	4.1
4015	ND	7.9	2.2
4016	ND	8.4	2.8
4017	-	7.7	2.5
4018	-	10.2	1.6
4019	+	8.5	3.3
4020	+	7.8	3.5
4021	-	7.8	3.5
4022	+	7.8	3.2
4023	ND	8.2	2.7
4024	ND	9.7	1.6
4025	+(?)	8.8	1.2
4026	-	11.2	2.1
4027	-	9.0	2.5
4028	ND	7.8	2.1
4029	-	6.9	2.6
4030	-	9.7	1.5
4031	-	9.9	1.6
4032	-	9.7	1.5
4133	-	9.8	2.0
4034	-		
4035	+		
4036	-		
4037	ND	10.6	2.0
4038	ND	9.8	2.0
4039	+	9.8	2.0
4040	+	11.8	1.3
4041	ND	9.8	1.3
4042	+	9.0	1.3
4043	ND	9.4	1.3
4044	ND	9.0	1.3
4045	+	9.3	1.3
4046	ND		
4047	ND	9.0	1.6
4048	-		
4049	+		
4050	+		
4051	+		
4052	+		
4053	+		
4054	-	9.4	1.6
4055	-		
4056	ND		
4057	ND	9.3	2.0
4058	+		
4059	+	9.0	1.3
4060	-	8.4	1.3
4061	-	7.3	2.6
4062	+		
4063	ND		
4064	ND	7.8	3.3
4065	ND	8.2	3.2
4066	-	7.3	2.6
4067	ND	10.0	1.6
4068	-		
4069	+	10.0	1.8
4070	-		
4071	ND	9.5	1.8
4072	ND		
4073	ND	9.5	1.4
4074	-	9.6	1.5
4075	-		
4076	-	9.6	1.8
4077	-	7.6	2.3
4078	-	10.0	1.8
4079	ND	9.2	1.5
4080	+	8.9	1.5
4081	+	10.3	1.8
4082	+	9.6	1.8
4083	+	8.9	1.5
4084	+(?)	9.6	1.8
4085	-	9.6	1.5
4086	-	9.6	1.8
4087	+	8.5	1.2
4088	ND	10.3	1.8
4089	+	7.3	1.5
4090	+	8.1	1.2
4091	ND	7.7	3.5
4092	-		
4093	+		
4094	+		
4095	-	8.9	1.6
4096	ND	9.1	1.4
4097	ND	9.1	1.4
4098	ND	7.8	2.2
4099	ND	9.5	1.3
4100	-	9.0	1.4

Table II (continued)

Sample	Mag	CaO	TiO_2
4101	-	9.3	1.4
4102	-	7.9	2.5
4103	+		
4104	-		
4105	-	9.3	1.5
4106	-	9.2	1.5
4107	ND		
4108	+		
4109	+		
4110	+	7.2	2.0
4111	+	6.6	3.1
4112	+	6.4	3.1
4113	+	6.8	2.2
4114	-	9.4	1.5
4115	+		
4116	ND		
4117	ND		
4118	+		
4119	+		
4120	+		
4121	+		
4122	+		
4123	+		
4124	-		
4125	ND		
4126	+	6.2	1.4
4127	+	6.2	1.8
4128	+	6.7	2.0
4129	+	6.2	2.0
4130	+	6.2	2.0
4131	+		
4132	ND	6.4	2.2
4133	+	6.7	2.2
4134	ND	6.7	2.2
4135	-	8.2	1.4
4135a	-	8.4	4.0
4136	-	8.4	2.4
4137	+	8.9	1.3
4138	-	9.1	1.3
4139	+		
4140	ND	8.2	2.4
4141	ND	7.6	2.2
4142	ND	7.8	2.6
4143	+		
4144	+		
4145	+		
4146	+		
4147	+	7.6	3.3
4148	+	7.9	2.2
4149	+		

Sample	Mag	CaO	TiO_2
4150	+		
4151	ND		
4152	+		
4153	ND	7.9	3.6
4154	ND	7.9	3.6
4155	+		
4156	+		
4157	-	7.8	2.7
4158	+	7.9	2.9
4159	+		
4160	+	10.0	1.5
4161	+	10.2	1.5
4162	-	8.7	1.4
4163	+		
4164	-		
4165	-		
4166	+		
4167	-		
4168	+		
4169	+		
4170	+		
4171	+		
4172	ND		
4173	ND		
4174	-		
4175	+(?)		
4176	-		
4177	-		
4178	-(?)		
4179	ND		
4180	ND	8.1	3.9
4181	ND		
4182	ND	9.3	1.6
4183	+	9.9	1.6
4184	+		
4185	ND		
4186	-		
4187	+		
4188	+	7.5	2.5
4189	ND	9.2	1.8
4190	-		
4191	ND		
4192	ND		
4193	ND		
4194	ND	8.1	2.3
4195	ND		
4196	ND		
4197	ND	9.3	1.6
4198	ND		
4199	-	10.7	2.1

Table II (continued)

Sample	Mag	CaO	TiO_2
4200	Standard		
4201	Standard		
4202	Standard		
4203	Standard		
4204	Standard		
4205	Standard		
4206	Standard		
4207	Standard		
4208	Standard		
4209	Standard		
4210	Standard		
4211	Standard		
4212	+		
4213	-		
4214	ND		
4215	+ ?		
4216	+ ?		
4217	+		
4218	+		
4219	+		
4220	ND		
4221	ND		
4222	ND		
4223	ND		
4224	ND		
4225	-		
4226	ND		
4227	+		
4228	ND		
4229	+		
4230	+		
4231	+(?)		
4232	ND		
4233	-		
4234	ND		
4235	+		
4236	-		
4237	ND		
4238	-		
4239	+		
4240	-		
4241	+		
4242	ND		
4243	+		
4244	ND		
4245	ND		
4246	-		
4247	ND		
4248	-(?)		
4249	ND		
4250	ND		
4251	ND		
4252	ND		
4253	+		
4254	ND		
4255	ND		
4256	ND		
4257	+		
4258	+		
4259	+		
4260	+		
4261	+		
4262	+		
4263	+		
4264	+		
4265	+		
4266	+		
4267	+		
4268	+		
4269	+		
4270	+		
4271	+		
4272	+		
4273	+		
4274	+		
4275	+		
4276	+		
4277	+		
4278	+		
4279	+		
4280	+		
4281	+		
4282	ND		
4283	ND		
4284	ND		
4285	ND		
4286	ND		
4287	ND		
4288	ND		
4289	+		
4290	+		
4291	+		
4292	+		
4293	+		
4294	+		
4295	+		
4296	+		
2497	+		
4298	+		
4299	+		

Table II (continued)

Sample	Mag	CaO	TiO_2
4300	+		
4301	+		
4302	+		
4303	+		
4304	+		
4305	+		
4306	ND		
4307	ND		
4308	ND		
4309	ND		
4310	ND		
4311	ND		
4312	ND		
4313	ND		
4314	ND		
4315	ND		
4316	ND		
4317	-		
4318	ND		
4319	ND		
4320	ND		
4321	ND		
4322	ND		
4323	ND		
4323a	+		
4324	ND		
4325	+		
4326	+		
4327	+		
4328	-		
4329	-		
4330	ND		
4331	-	7.8	4.4
4332	ND		
4333	ND		
4334	+		
4335	-		
4336	-		
4337	-		
4338	+		
4339	+		
4340	-		
4341	-		

Mag is Magnetic polarity
+ is Normal
- is Reversed
ND is Not Determined

TABLE III

SAMPLE LOCATIONS

Sample		Sec	T	R
4001	NW¼	23	15N	23E
4002	SE¼	14	15N	23E
4003	SE¼	14	15N	23E
4004	SE¼	14	15N	23E
4005	NW¼	24	15N	23E
4006	NW¼	24	15N	23E
4007	SW¼	13	15N	23E
4008	SW¼	13	15N	23E
4009	SW¼	13	15N	23E
4010	SW¼	13	15N	23E
4011	SW¼	13	15N	23E
4012	SW¼	13	15N	23E
4013	SW¼	13	15N	23E
4014	NW¼	13	15N	23E
4015	NW¼	13	15N	23E
4016	NW¼	13	15N	23E
4017	SE¼	13	15N	23E
4018	NE¼	24	15N	23E
4019	NE¼	24	15N	23E
4020	NE¼	24	15N	23E
4021	NW¼	18	15N	24E
4022	NW¼	18	15N	24E
4023	SW¼	7	15N	24E
4024	NE¼	18	15N	24E
4025	NE¼	18	15N	24E
4026	SW¼	18	15N	24E
4027	NW¼	19	15N	24E
4028	NW¼	19	15N	24E
4029	NW¼	17	15N	24E
4030	SW¼	17	15N	24E
4031	NW¼	20	15N	24E
4032	NE¼	20	15N	24E
4033	NE¼	20	15N	24E
4034	NW¼	21	15N	24E
4035	NW¼	21	15N	24E
4036	SE¼	20	15N	24E
4037	SW¼	21	15N	24E
4038	SE¼	21	15N	24E
4039	SW¼	22	15N	24E
4040	SW¼	22	15N	24E
4041	SW¼	22	15N	24E
4042	NE¼	21	15N	24E
4043	SW¼	16	15N	24E
4044	SW¼	15	15N	24E
4045	NW¼	22	15N	24E
4046	NW¼	22	15N	24E
4047	SW¼	22	15N	24E
4048	NE¼	22	15N	24E
4049	SE¼	15	15N	24E
4050	SE¼	15	15N	24E
4051	SE¼	10	15N	24E
4052	SE¼	10	15N	24E
4053	NE¼	15	15N	24E
4054	NE¼	22	15N	24E
4055	NE¼	22	15N	24E
4056	NE¼	22	15N	24E
4057	NW¼	14	15N	24E
4058	NE¼	15	15N	24E
4059	NW¼	22	15N	24E
4060	SE¼	22	15N	24E
4061	NW¼	15	15N	24E
4062	NW¼	10	15N	24E
4063	NE¼	10	15N	24E
4064	NE¼	15	15N	24E
4065	NE¼	15	15N	24E
4066	NW¼	14	15N	24E
4067	SW¼	14	15N	24E
4068	SW¼	13	15N	24E
4069	SE¼	14	15N	24E
4070	NW¼	24	15N	24E
4071	SE¼	18	15N	25E
4072	NW¼	18	15N	25E
4073	SE¼	24	15N	25E
4074	SE¼	24	15N	25E
4075	NW¼	19	15N	25E
4076	SW¼	17	15N	25E
4077	SE¼	17	15N	25E
4078	SE¼	17	15N	25E
4079	NE¼	18	15N	24E
4080	SE¼	18	15N	24E
4081	NE¼	19	15N	24E
4082	SE¼	18	15N	24E
4083	NW¼	20	15N	24E
4084	NW¼	20	15N	24E
4085	NW¼	20	15N	24E
4086	NW¼	20	15N	24E
4087	NW¼	20	15N	24E
4088	NW¼	20	15N	24E
4089	NW¼	20	15N	24E
4090	NE¼	20	15N	24E
4091	SW¼	24	15N	24E
4092	SW¼	16	15N	25E
4093	NE¼	17	15N	25E
4094	NE¼	17	15N	25E
4095	SW¼	9	15N	25E
4096	SW¼	9	15N	25E
4097	SE¼	9	15N	25E
4098	NW¼	15	15N	25E
4099	SE¼	16	15N	25E
4100	NE¼	15	15N	25E

Table III (continued)

Sample		Sec	T	R
4101	NE¼	15	15N	25E
4102	SE¼	10	15N	25E
4103	NW¼	11	15N	25E
4104	SE¼	10	15N	25E
4105	SE¼	3	15N	25E
4106	NW¼	10	15N	25E
4107	NE¼	11	15N	25E
4108	NE¼	11	15N	25E
4109	NE¼	11	15N	25E
4110	NE¼	11	15N	25E
4111	SE¼	11	15N	25E
4112	SE¼	11	15N	25E
4113	SE¼	11	15N	25E
4114	SE¼	11	15N	25E
4115	NE¼	11	15N	25E
4116	NW¼	11	15N	25E
4117	NW¼	11	15N	25E
4118	NW¼	12	15N	25E
4119	SW¼	12	15N	25E
4120	SW¼	12	15N	25E
4121	NW¼	12	15N	25E
4122	SW¼	1	15N	25E
4123	NW¼	12	15N	25E
4124	NW¼	12	15N	25E
4125	SE¼	12	15N	25E
4126	NE¼	12	15N	25E
4127	NE¼	12	15N	25E
4128	NE¼	12	15N	25E
4129	NE¼	12	15N	25E
4130	NE¼	12	15N	25E
4131	NE¼	12	15N	25E
4132	NW¼	7	15N	26E
4133	NW¼	7	15N	26E
4134	SW¼	7	15N	26E
4135	SW¼	7	15N	26E
4135a	SW¼	24	15N	24E
4136	NW¼	15	15N	24E
4137	SE¼	22	15N	24E
4138	SE¼	22	15N	24E
4139	NE¼	22	15N	24E
4140	NW¼	35	16N	26E
4141	NE¼	35	16N	26E
4142	SW¼	4	15N	27E
4143	SW¼	7	15N	26E
4144	SW¼	7	15N	26E
4145	SW¼	7	15N	26E
4146	SW¼	7	15N	26E
4147	NE¼	7	15N	26E
4148	SE¼	8	15N	26E
4149	SE¼	8	15N	26E
4150	NE¼	8	15N	26E

Sample		Sec	T	R
4151	NE¼	8	15N	26E
4152	SW¼	9	15N	26E
4153	SW¼	9	15N	26E
4154	SW¼	9	15N	26E
4155	SW¼	9	15N	26E
4156	SW¼	9	15N	26E
4157	NE¼	9	15N	26E
4158	NE¼	9	15N	26E
4159	NE¼	9	15N	26E
4160	NW¼	10	15N	26E
4161	NW¼	10	15N	26E
4162	NW¼	10	15N	26E
4163	NE¼	16	15N	26E
4164	NE¼	16	15N	26E
4165	NW¼	15	15N	26E
4166	NW¼	15	15N	26E
4167	NW¼	15	15N	26E
4168	NW¼	15	15N	26E
4169	NW¼	15	15N	26E
4170	NW¼	14	15N	26E
4171	NE¼	15	15N	26E
4172	SE¼	15	15N	26E
4173	NE¼	14	15N	26E
4174	NE¼	14	15N	26E
4175	NE¼	14	15N	26E
4176	NW¼	11	15N	26E
4177	NW¼	12	15N	26E
4178	SW¼	12	15N	26E
4179	NE¼	14	15N	23E
4180	NW¼	8	15N	24E
4181	NE¼	7	15N	24E
4182	SE¼	8	15N	24E
4183	SE¼	8	15N	24E
4184	NE¼	18	15N	24E
4185	NE¼	9	15N	24E
4186	NW¼	3	15N	24E
4187	NW¼	3	15N	24E
4188	NE¼	3	15N	24E
4189	SE¼	11	15N	24E
4190	NW¼	1	15N	24E
4191	NW¼	1	15N	24E
4192	NW¼	12	15N	24E
4193	NE¼	12	15N	24E
4194	SE¼	1	15N	24E
4195	SE¼	1	15N	24E
4196	SW¼	6	15N	25E
4197	NW¼	7	15N	25E
4198	NW¼	5	15N	25E
4199	NE¼	5	15N	25E

Table III (continued)

Sample		Sec	T	R
4200	-	Standard*	-	
4201	-	Standard*	-	
4202	-	Standard*	-	
4203	-	Standard*	-	
4204	-	Standard*	-	
4205	-	Standard*	-	
4206	-	Standard*	-	
4207	-	Standard*	-	
4208	-	Standard*	-	
4209	-	Standard*	-	
4210	-	Standard*	-	
4211	-	Standard*	-	
4212	SE¼	4	15N	25E
4213	SE¼	4	15N	25E
4214	NW¼	5	15N	25E
4215	SW¼	34	16N	25E
4216	SW¼	34	16N	25E
4217	SW¼	34	16N	25E
4218	SE¼	33	16N	25E
4219	SE¼	33	16N	25E
4220	SW¼	34	16N	25E
4221	SW¼	34	16N	25E
4222	SE¼	34	16N	25E
4223	NE¼	3	15N	25E
4224	NE¼	4	15N	25E
4225	SW¼	3	15N	25E
4226	NE¼	3	15N	25E
4227	SW¼	2	15N	25E
4228	NW¼	2	15N	25E
4229	SE¼	2	15N	25E
4230	NW¼	1	15N	25E
4231	SE¼	1	15N	25E
4232	SE¼	1	15N	25E
4233	NW¼	6	15N	26E
4234	SW¼	6	15N	26E
4235	SE¼	1	15N	26E
4236	SE¼	1	15N	26E
4237	SE¼	1	15N	26E
4238	SE¼	1	15N	26E
4239	SE¼	1	15N	26E
4240	SW¼	1	15N	26E
4241	NE¼	10	15N	26E
4242	SE¼	4	15N	26E
4243	SE¼	4	15N	26E
4244	SW¼	3	15N	26E
4245	NE¼	4	15N	26E
4246	NW¼	4	15N	26E
4247	SW¼	4	15N	26E
4248	SW¼	4	15N	26E
4249	SW¼	4	15N	26E

Sample		Sec	T	R
4250	NE¼	5	15N	26E
4251	NE¼	5	15N	26E
4252	NE¼	5	15N	26E
4253	NE¼	12	15N	26E
4254	NE¼	12	15N	26E
4255	NW¼	12	15N	26E
4256	NW¼	12	15N	26E
4257	NE¼	15	15N	23E
4258	NW¼	11	15N	23E
4259	SW¼	11	15N	23E
4260	SW¼	11	15N	23E
4261	SW¼	11	15N	23E
4262	SE¼	10	15N	23E
4263	SE¼	10	15N	23E
4264	SE¼	10	15N	23E
4265	SE¼	10	15N	23E
4266	SE¼	10	15N	23E
4267	SE¼	10	15N	23E
4268	SE¼	10	15N	23E
4269	SE¼	10	15N	23E
4270	SE¼	10	15N	23E
4271	SE¼	10	15N	23E
4272	SE¼	10	15N	23E
4273	SE¼	10	15N	23E
4274	SE¼	10	15N	23E
4275	SE¼	10	15N	23E
4276	SE¼	10	15N	23E
4277	SE¼	10	15N	23E
4278	SE¼	10	15N	23E
4279	SE¼	10	15N	23E
4280	SE¼	10	15N	23E
4281	SE¼	10	15N	23E
4282	NE¼	11	15N	23E
4283	SW¼	1	15N	23E
4284	NW¼	1	15N	23E
4285	NW¼	1	15N	23E
4286	NW¼	6	15N	24E
4287	NW¼	6	15N	24E
4288	NW¼	6	15N	24E
4289	SE¼	10	15N	23E
4290	SE¼	10	15N	23E
4291	SE¼	10	15N	23E
4292	SE¼	10	15N	23E
4293	SE¼	10	15N	23E
4294	SE¼	10	15N	23E
4295	SE¼	10	15N	23E
4296	SE¼	10	15N	23E
4297	SE¼	10	15N	23E
4298	SE¼	10	15N	23E
4299	SE¼	10	15N	23E

Table III (continued)

Sample		Sec	T	R
4300	SE¼	10	15N	23E
4301	SE¼	10	15N	23E
4302	SE¼	10	15N	23E
4303	SE¼	10	15N	23E
4304	SE¼	10	15N	23E
4305	SE¼	33	16N	24E
4306	SE¼	33	16N	24E
4307	SE¼	33	16N	24E
4308	NW¼	35	16N	23E
4309	NE¼	2	15N	23E
4310	NW¼	1	15N	23E
4311	NW¼	1	15N	23E
4312	NW¼	1	15N	23E
4313	NE¼	8	15N	23E
4314	NE¼	5	15N	25E
4315	NE¼	5	15N	25E
4316	NE¼	6	15N	25E
4317	NE¼	1	15N	24E
4318	NE¼	33	16N	25E
4319	SW¼	33	16N	25E
4320	SW¼	33	16N	25E
4321	SE¼	33	16N	25E
4322	SE¼	33	16N	25E
4323	SE¼	33	16N	25E
4323a	NW¼	35	16N	26E
4324	NE¼	35	16N	26E
4325	NW¼	17	16N	26E
4326	SW¼	22	16N	23E
4327	NE¼	21	16N	23E
4328	SE¼	16	16N	23E
4329	SW¼	16	16N	23E
4330	SE¼	15	16N	23E
4331	NW¼	14	16N	23E
4332	NE¼	24	16N	23E
4333	SW¼	26	16N	23E
4334	NE¼	25	16N	23E
4335	SW¼	30	16N	24E
4336	NE¼	25	16N	25E
4337	NE¼	28	16N	25E
4338	SE¼	24	16N	24E
4339	SW¼	20	16N	23E
4340	NW¼	29	16N	26E
4341	NW¼	29	16N	26E

Sec is Section
T is Township
R is Range
* Standards are Umatilla Basalt from Finley Quarry, Benton County, Washington, used for internal application.

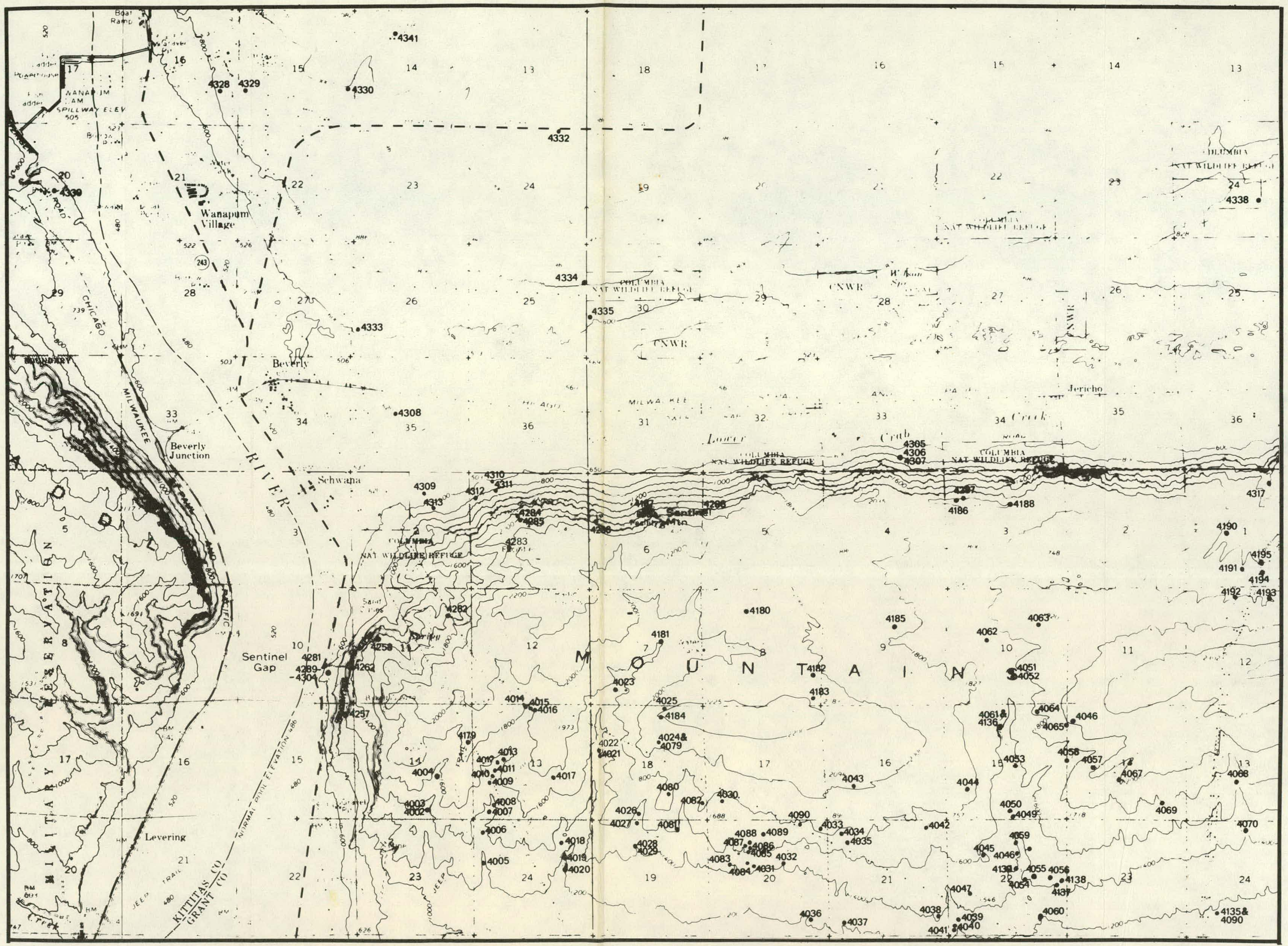


FIGURE 2

SAMPLE LOCATION MAP FOR THE BEVERLY QUADRANGLE

(● Indicates sample location; all sample numbers preceded by C; also see Table III.)

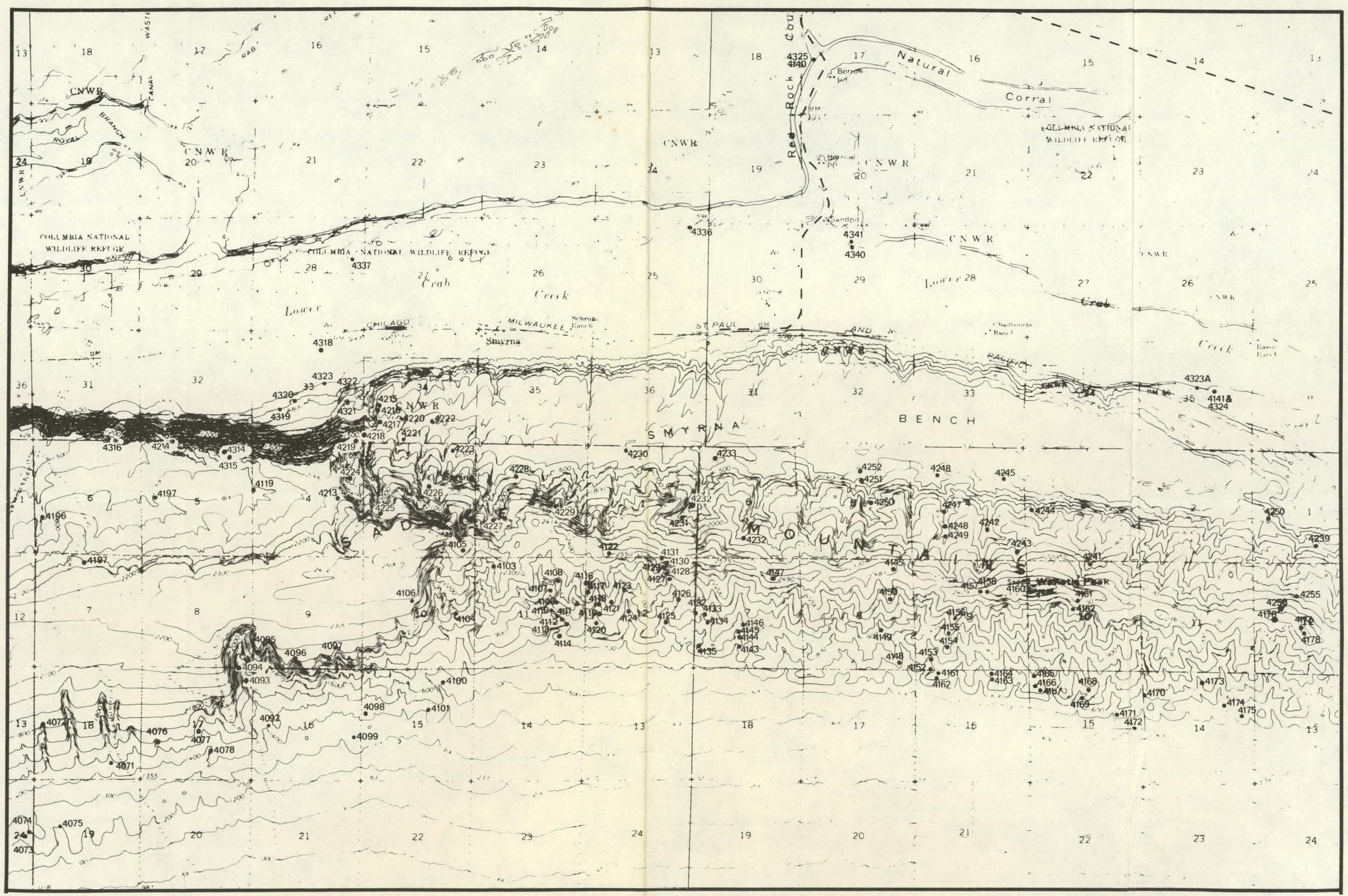


FIGURE 3

SAMPLE LOCATION MAP FOR THE SMYRNA QUADRANGLE

(● Indicates sample location; all sample numbers preceded by C; also see Table III.)

ACKNOWLEDGMENTS

I would like to thank the many Rockwell Hanford Operations' geologists for their stimulating discussions regarding the results of this study. In particular, I would like to thank Drs. C. W. Myers, F. E. Goff, S. M. Price, P. E. Long, J. G. Bond, and Messrs. K. R. Fecht, R. K. Ledgerwood, J. T. Lillie, R. D. Landon, D. Miller, J. Kauffman, and Ms. M. G. Jones. I would especially like to thank Drs. Myers and Long and Mr. Ledgerwood for critically reviewing the manuscript and Messrs. R. W. Cross and G. M. Clark for the technical drafting.

REGIONAL SETTING

The Saddle Mountains lie in the west-central portion of the Columbia Plateau (Figure 4). The Columbia Plateau is one of the great accumulations of flood basalt having an estimated volume of 200,000 square kilometers (Turner and Verhoogen, 1960). These basalts were erupted in the Miocene between 16 and 6 million years before present (Watkins and Baksi, 1974). For the most part, but with many exceptions, the younger basaltic lavas crop out near the Pasco Basin, and the older basaltic lavas crop out near the plateau margin. The greatest total thickness of the basalt also occurs in the Pasco Basin, although the actual base of the section is not exposed and the actual thickness is unknown.

The Saddle Mountains represent one of a series of east-west-trending anticlinal ridges (the Yakima fold belt) in the western Columbia Plateau. These anticlinal ridges are generally asymmetrical with steep north limbs. The structural relief on the ridges demonstrates that they die out toward the eastern part of the Columbia Plateau. The Olympic-Wallowa Lineament, a topographic feature extending from northwest Washington to the Wallowa Mountains of northeast Oregon, is defined, in part, on the western edge of the plateau by an alignment of some of the Yakima folds.

The major known source of many of the flows appears to be on the southeastern edge of the Columbia Plateau. Price (1977), in the most comprehensive study to date, has identified dikes in the Chief Joseph swarm, that correspond to most of the known Columbia River Basalt

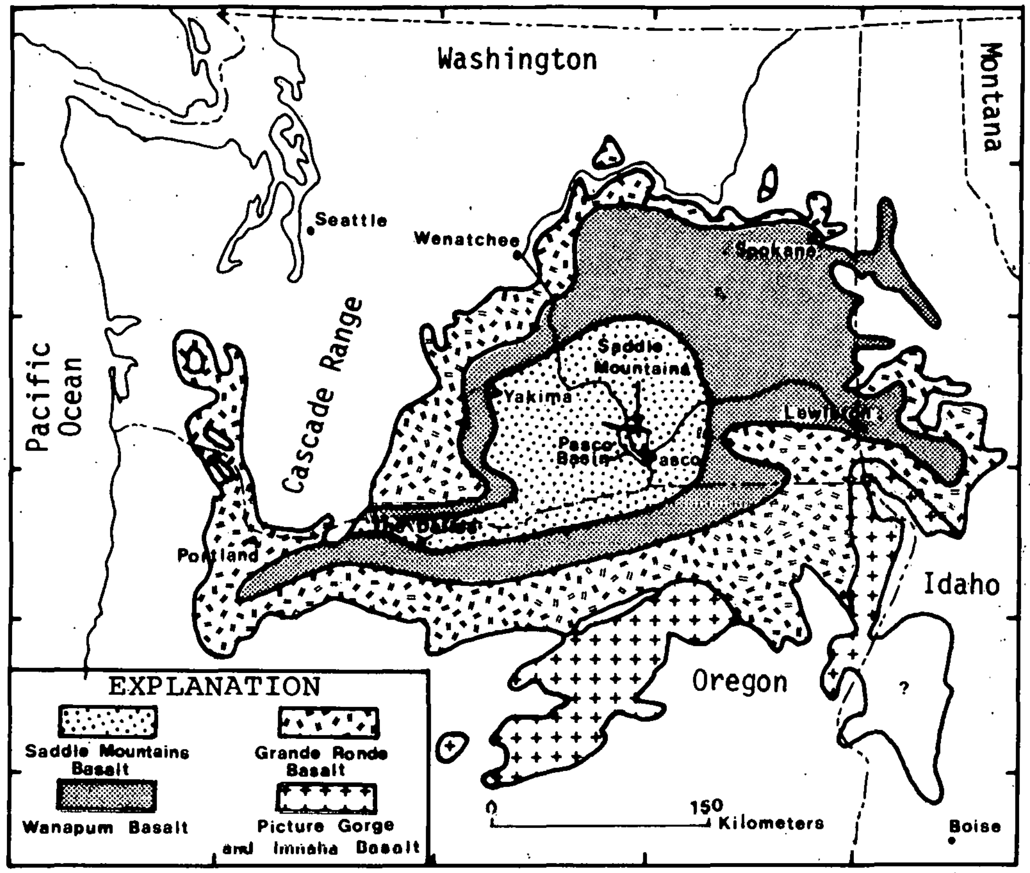


FIGURE 4

DISTRIBUTION OF THE COLUMBIA RIVER BASALT
ON THE COLUMBIA PLATEAU

chemical types defined by Wright, et al. (1973). Swanson, et al., (1975) have suggested that most flows were erupted from linear vent systems. No major sources have been discovered on the Columbia Plateau west of approximately 119° 15' longitude (Swanson, et al., 1975).

STRATIGRAPHY OF THE SADDLE MOUNTAINS

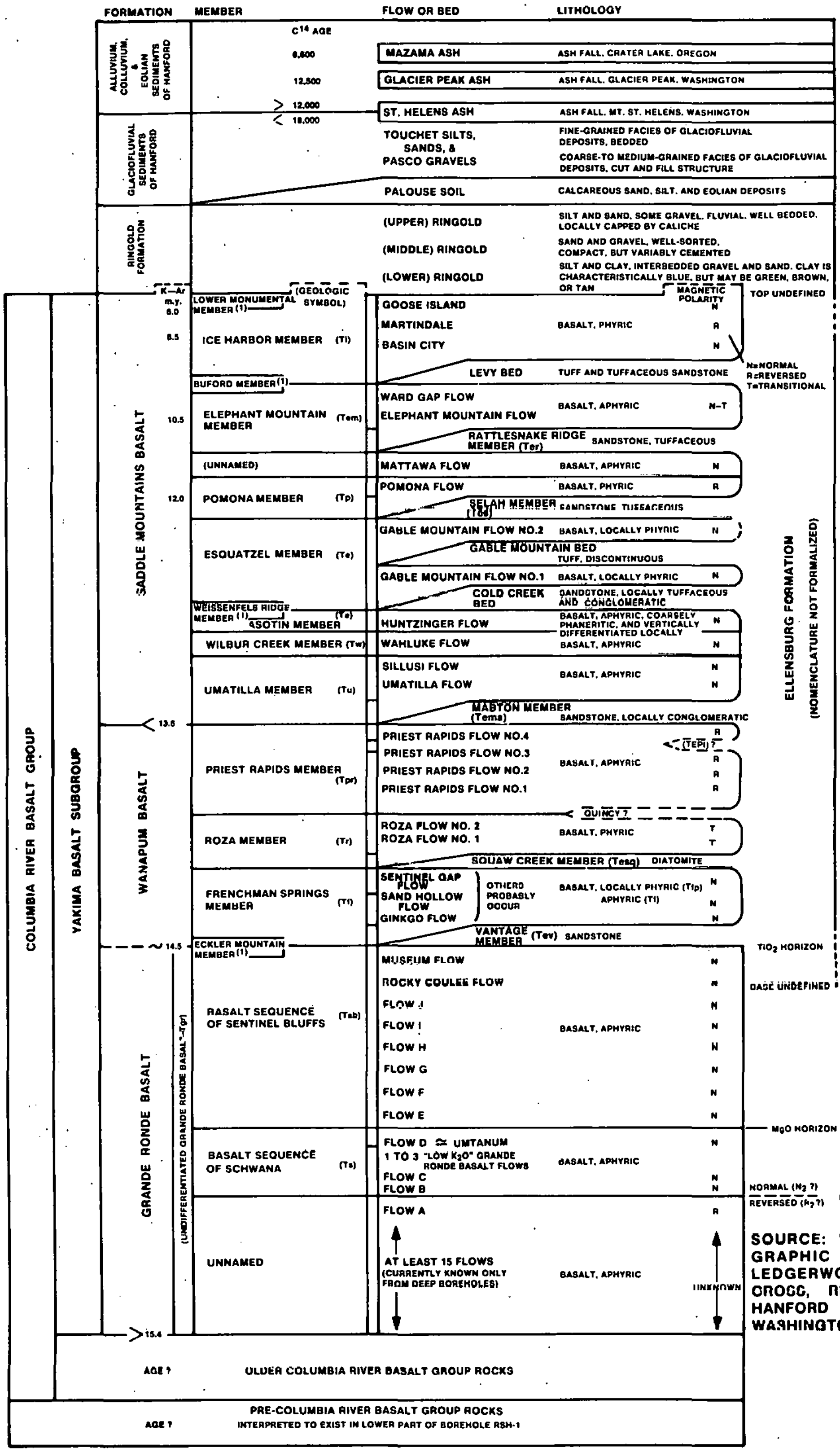
INTRODUCTION

The stratigraphic nomenclature used in this study is shown on Figure 5. It generally conforms to revisions recently proposed by Swanson, et al., (1978). Three Columbia River Basalt Group formations are present in the Saddle Mountains: (1) the Grande Ronde Basalt; (2) the Wanapum Basalt; and (3) the Saddle Mountains Basalt. The Grande Ronde Basalt has been informally subdivided into the Sentinel Bluffs Member (high-MgO basalt) and the Schwana Member (low-MgO basalt). The Wanapum Basalt has been subdivided into the Frenchman Springs Member, a member occupying the position of the Roza Member (informally referred to as the "Roza-Like" Member), and the Priest Rapids Member. The Saddle Mountains Basalt is represented by the Wilbur Creek Member, the Asotin Member, the Pomona Member, the Mattawa Flow (informal name for a new unit), and the Elephant Mountain Member.

DESCRIPTION OF INDIVIDUAL ROCK UNITS

The Grand Ronde Basalt

The Grande Ronde Basalt is best exposed in the Saddle Mountains at Sentinel Gap. The lithology and chemical composition of the basalt flows from this exposure was first described by Ledgerwood, et al., (1973). Taylor (1976) divided the Grande Ronde Basalt at Sentinel Gap into two groups: (1) a high-MgO group; and, (2) a low-MgO group. These groups were informally named by Ledgerwood, et al., (1978), the Schwana Member (low-MgO), and the Sentinel Bluffs Member (high-MgO). A detailed study of the intraflow structures and chemical composition of these flows at Sentinel Gap has recently been completed by Long (1978). Paleomagnetic properties of the flows have been studied by Coe, et al., (1978).



(1) MEMBER KNOWN FROM AREAS OUTSIDE THE PASCO BASIN, BUT NOT RECOGNIZED TO DATE WITHIN THE PASCO BASIN.

SOURCE: "PASCO BASIN STRATIGRAPHIC NOMENCLATURE," R.K. LEDGERWOOD, C.W. MYERS, R.W. CROSS, RHO-BWI-LD-1, ROCKWELL HANFORD OPERATIONS, RICHLAND, WASHINGTON (MAY 1978).

V7808-6

FIGURE 5

BASALT STRATIGRAPHY OF THE PASCO BASIN

The Schwana Member

The oldest exposed Grande Ronde Basalt flows in the Saddle Mountains have a low-MgO composition (Table IV and Figure 6). Chemical analyses for samples collected during this study are listed in Table I; averages are given in Table IV. Four Schwana Member flows are exposed at Sentinel Gap. The oldest, Flow A, exposed in Crab Creek, has reversed paleomagnetism (Coe, et al., 1978) and is assigned to the R_2 magnetic zone of Swanson, et al., (1978). The top three flows, B, C and D, have normal paleomagnetic polarity (Coe, et al., 1978) and are interpreted to correlate with the N_2 magnetic zone of Swanson, et al., (1978).

All Schwana Member flows are generally fine-grained, aphyric, and some have a well-developed colonnade and entablature. The top flow of the member is correlated with the Umtanum Flow (informal name) on Umtanum Ridge based upon relative stratigraphic position and physical appearance. The Umtanum Flow at Sentinel Gap is approximately 200 feet thick with 100 feet of well-developed colonnade and 100 feet of well-developed entablature. Hackly jointing is characteristic of the entablature.

The Sentinel Bluffs Member

The eight high-MgO flows above the Schwana Member at Sentinel Gap are informally named the Sentinel Bluffs Member (Ledgerwood, et al., 1978). The contact between the Schwana and Sentinel Bluffs members is marked by a thick pillow-palagonite zone. All Sentinel Bluffs flows have normal paleomagnetic polarity and are assigned to the N_2 magnetic zone. Most Sentinel Bluffs flows are fine grained and aphyric. Taylor (1976) correlated the top two flows at Sentinel Gap to the Museum and Rocky Coulee flows, respectively, of Mackin (1961).

The Wanapum Basalt

The Vantage horizon marks the contact between the Grande Ronde Basalt and Wanapum Basalt. The Vantage horizon is a sandstone composed of quartz and feldspar with some petrified wood occurring locally. It reaches its greatest thickness near Sentinel Gap and at the west end of Smyrna Bench.

TABLE IV

MEAN AND ONE STANDARD DEVIATION OF FLOWS AND MEMBERS FROM THE SADDLE MOUNTAINS

Also see Figure 6.

GRANDE RONDE BASALT

Flow or Member			SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
A		$\bar{X}$	55.33	14.95	1.92	10.10	.22	7.57	3.62	1.86	2.18	.28
	N = 2	σ	.03	0.12	.01	0.01	.01	.01	.08	0.08	.23	.01
B		$\bar{X}$	55.41	14.82	1.95	10.32	.21	7.20	3.43	1.96	2.40	.31
	N = 7	σ	0.19	0.27	0.07	.25	.01	.14	0.08	0.08	.07	01
C		$\bar{X}$	55.45	15.00	1.93	10.10	.20	7.16	3.43	2.01	2.41	.31
	N = 3	σ	.38	.30	0.03	.30	.00	.15	.07	0.05	0.16	.01
D		$\bar{X}$	54.50	14.43	2.16	11.26	.22	7.28	3.47	1.82	2.51	.35
	N = 8	σ	.25	.17	.03	.14	.01	.11	.14	.11	.16	.01
D		$\bar{X}$	54.50	14.40	2.13	11.32	.21	7.14	3.40	1.68	2.85	.36
	N = 3	σ	.18	.10	.01	.07	.02	.16	.13	.10	.21	.02
E		$\bar{X}$	53.29	14.64	1.91	10.76	.21	8.52	4.57	1.18	2.63	.29
	N = 7	σ	.140	.19	.02	.11	.01	.10	.09	.04	.15	.01
F		$\bar{X}$	53.20	14.77	1.89	10.16	.21	9.09	4.93	1.03	2.43	.30
	N = 3	σ	.12	.05	.06	.43	.01	.26	.16	.18	.11	.02
G		$\bar{X}$	53.15	15.05	1.81	9.57	.21	9.37	5.20	.93	2.47	.27
	N = 2	σ	.19	0.00	.04	.10	.00	.06	.07	.01	.15	.01
H		$\bar{X}$	53.27	14.93	1.80	10.08	.21	8.90	4.92	1.13	2.46	.30
	N = 4	σ	.53	.25	.09	.21	.00	.37	.29	.08	.20	.05
I		$\bar{X}$	53.31	14.81	1.79	9.99	.21	9.00	5.03	1.09	2.49	.29
	N = 4	σ	.16	.20	.02	.10	.00	.12	.11	.10	.20	.02
J		$\bar{X}$	53.63	15.15	1.75	9.15	.20	9.30	5.15	1.0	2.40	.27
	N = 4	σ	.30	.16	.03	.42	.01	.09	.11	.09	.10	.01
Rocky Coulee		$\bar{X}$	54.09	15.08	1.74	9.23	.20	8.90	4.73	1.29	2.44	.29
	N = 9	σ	.35	.21	.03	.65	.01	.32	.20	.10	.11	.02
Museum		$\bar{X}$	54.62	14.91	1.70	9.64	.21	8.37	4.53	1.33	2.40	.30
	N = 4	σ	.37	.29	.02	.70	.01	.30	.17	.08	.09	.01
Museum		$\bar{X}$	54.40	15.04	1.69	9.24	.20	8.73	4.67	1.29	2.42	.30
	N = 21	σ	.46	.33	.12	.59	.01	.39	.22	.20	.24	.01

Table IV (continued)

WANAPUM BASALT

Flow or Member			SiO_2	Al_2O_3	TiO_2	FeO*	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
Frenchman Springs Phyric		$\bar{X}$	51.14	13.99	2.99	12.83	.23	8.20	4.15	1.40	2.50	.56
	N = 12	σ	.62	.24	.07	.50	.01	.29	.11	.10	.26	.03
Frenchman Springs Aphyric		$\bar{X}$	51.25	14.01	2.89	12.66	.23	8.38	4.17	1.43	2.37	.54
	N = 21	σ	.63	.28	.68	.53	.01	.32	.23	.28	.20	.02
'Roza-Like'		$\bar{X}$	50.78	14.15	3.03	12.41	.22	8.77	4.42	1.17	2.48	.56
	N = 10	σ	.78	.32	.12	.37	.01	.29	.69	.10	.29	.03
Priest Rapids Rosalia Chemical Type		$\bar{X}$	49.92	13.72	3.47	13.32	.23	8.58	4.30	1.27	2.52	.66
	N = 27	σ	.79	.21	.17	.64	.01	.25	.30	.15	.18	.04
Priest Rapids Lolo Chemical Type		$\bar{X}$	50.30	14.20	3.49	12.04	.22	9.38	4.18	1.07	2.43	.68
	N = 7	σ	.97	.23	.28	.94	.03	.22	.75	.17	.18	.03

SADDLE MOUNTAINS BASALT

Flow or Member			SiO_2	Al_2O_3	TiO_2	FeO*	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
Waluke		$\bar{X}$	53.17	15.60	1.65	8.03	.17	10.08	6.03	1.13	1.82	.32
	N = 1											
Huntzinger		$\bar{X}$	51.49	15.79	1.51	8.31	.18	10.91	6.81	.69	2.05	.26
	N = 5	σ	.46	.32	.12	.67	.02	.43	1.03	.39	.38	.06
Pomona		$\bar{X}$	51.56	15.56	1.49	8.51	.18	10.82	6.71	.56	2.18	.24
	N = 15	σ	.41	.28	.26	.42	.01	.27	.77	.23	.27	.04
Mattawa		$\bar{X}$	51.18	15.83	1.47	8.47	.18	10.65	7.05	.73	2.02	.25
	N = 13	σ	.80	.43	.09	.35	.01	.38	.71	.26	.30	.04
Elephant Mountain		$\bar{X}$	50.74	13.51	3.51	13.20	.22	8.54	4.25	1.21	2.32	.60
	N = 19	σ	.60	.52	.11	.53	.01	.23	.31	.11	.22	.04

* Fe_2O_3 is 2.00%
N is the number of samples
$\bar{X}$ is mean of number of samples
σ is one standard deviation

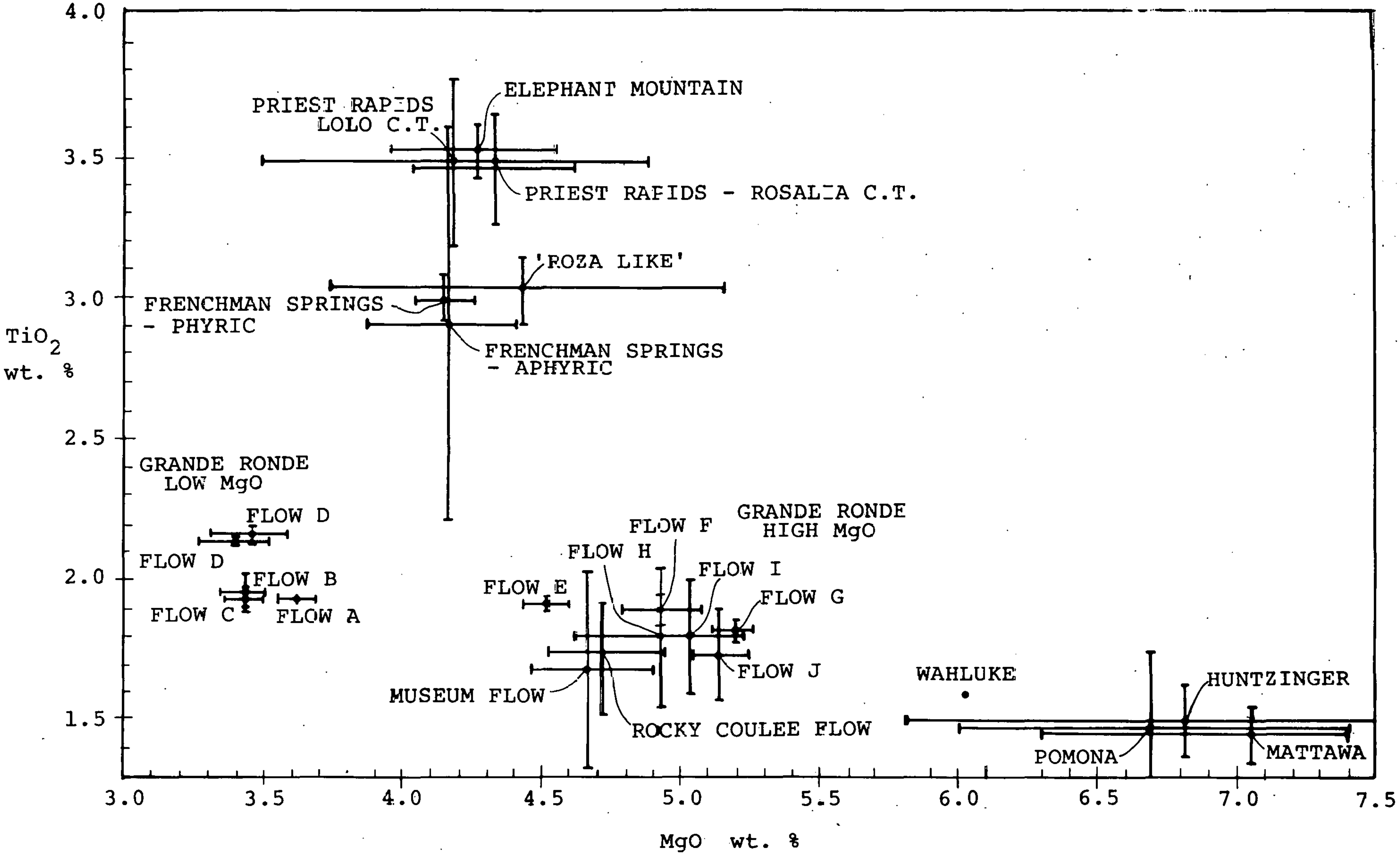


FIGURE 6

MEAN AND ONE STANDARD DEVIATION OF MgO AND TiO_2 ANALYSES FOR COLUMBIA RIVER BASALT FROM THE SADDLE MOUNTAINS

(• is the mean; —— is the standard deviation from Table I; and, C.T. is the chemical type.)

The Frenchman Springs Member

The Frenchman Springs Member is divided into two mappable units in this study: (1) an older plagioclase-phyric unit; and, (2) a younger aphyric unit. The Ginkgo Flow of Mackin (1961), mapped by Taylor (1976) at Sentinel Gap, is correlated to the phyric unit and the Sand Hollow and Sentinel Gap flows are equivalent to the aphyric unit. The number of flows comprising each unit varies across the Saddle Mountains, but the relationships are consistent, thus justifying the phyric/aphyric subdivision of the member.

The Plagioclase-Phyric Frenchman Springs Unit

The unit consists of one to three flows with an approximate total thickness of 200 feet. Chemical analyses for samples collected from the unit are listed in Table I; averages are given in Table IV and plotted on Figure 6. All flows have normal paleomagnetic polarity as determined with a flux gate magnetometer. Only one plagioclase-phyric flow occurs at Sentinel Gap, but several miles to the east three flows are present (Sections 7 and 9, Township 15 North, Range 26 East) (abbreviated Sec. 7 and 9, T15N, R26E).

These flows are fine grained with plagioclase phenocrysts, usually greater than 1 centimeter in size, and have a poor- to well-developed entablature and colonnade, commonly with fanning columns (Sec. 11, T15N, R25E). Sedimentary interbeds between the flows are locally present (T15N, R25-26E), but none are traceable for more than several miles.

The Aphyric Frenchman Springs Unit

The aphyric Frenchman Springs unit generally consists of two flows throughout most of the Saddle Mountains, but locally is 4 flows (or flow units) with a maximum thickness of 200 feet. The unit is apparently absent in Sec. 7, T15N, R26R. Chemical analyses for samples collected from these flows are listed in Table I, the average is given in Table IV, and plotted on Figure. 6. All flows have normal paleomagnetic polarity as determined using a flux gate magnetometer. In Sec. 9, T15N, R26E, there are 4 flows or flow units with well-developed pillows.

The aphyric flows have distinct physical features that can be traced throughout much of the study area. The lowest flow has a well-developed colonnade, while the uppermost flow has a prominent entablature with hackly jointing. These two parts, respectively, form the more resistant part of each flow.

The "Roza-Like" Member

Stratigraphically above the Frenchman Springs Member are two plagioclase-phyric flows. Chemical analyses for samples collected from the flows are listed in Table I, the average is given in Table IV, and plotted on Figure 6. All flows have strong normal paleomagnetic polarity as determined using a flux gate magnetometer and physically resemble the plagioclase-phyric Frenchman Springs flows. They generally have a well-developed colonnade and are fine- to medium-grained with plagioclase phenocrysts. In the Saddle Mountains, there are two flows which vary in total thickness from 10 to 100 feet, but locally there may be only one (Sec. 7 and 18, T15N, R24E).

In the past, these flows have been mapped as Roza (Grolier and Bingham, 1971) based upon relative stratigraphic position and physical characteristics. The Roza Member, however, has transitional paleomagnetic polarity (Wright, et al., 1973) at the type locality, but these flows on the Saddle Mountains have a strong and consistent normal paleomagnetic polarity. Because of the lack of distinguishing chemical and physical characteristics between this member and the Frenchman Springs Member, and the lack of difference in paleomagnetic polarity between the two, these flows are referred to as the "Roza-Like" Member in this study.

A major interbed is developed between the "Roza-Like" Member and the Priest Rapids Member. This bed is thick and marked by an abundance of petrified wood.

The Priest Rapids Member

The Priest Rapids Member consists of up to two flows in the Saddle Mountains area. The flows have reversed paleomagnetic polarity as determined with a flux gate magnetometer. Chemical analyses for samples collected from these flows are listed in Table I, the average analyses are given in Table IV, and are plotted on Figure 6.

The younger Priest Rapids flow has higher CaO than the older and generally corresponds to the Lolo chemical type (Swanson, et al., 1978), except the P_2O_5 is lower here, while the older corresponds to their Rosalia chemical type (the Rosalia chemical type differs from Elephant Mountain only in having higher P_2O_5). Both Priest Rapids flows generally have well-developed, massive colonnades. The older, thicker flow often develops curvi-platy jointing above the colonnade. Both flows are usually diktytaxitic and medium-grained with a thin interbed separating the flows. The older flow is generally coarser grained than the younger and ophitic.

The Saddle Mountains Basalt

The Saddle Mountains Basalt in the Saddle Mountains is represented by the Wilbur Creek Member (Wahluke Flow), the Asotin Member (Huntzinger Flow), the Pomona Member, the Mattawa Flow (informal name for a new unit), and the Elephant Mountain Member. The interbeds intercalated with the basalt flows are part of the Ellensburg Formation.

The Wilbur Creek Member

The Wilbur Creek Member is the oldest member of the Saddle Mountains Basalt in the Saddle Mountains (no Umatilla Member was found) and is represented by the Wahluke Flow. The Wahluke Flow is approximately 50 feet thick with a massive colonnade. The flow is fine-grained and generally aphyric, but some phenocrysts of plagioclase are present. Only one sample was analyzed (Tables I and IV and plotted on Figure 6) and it has normal paleomagnetic polarity as determined with a flux gate magnetometer.

The Wahluke Flow is poorly exposed on the east side of Wahatis Peak. It probably fills a valley that was cut into the Priest Rapids Member.

The Asotin Member

The Asotin Member is represented in the Saddle Mountains by the Huntzinger Flow. It is best exposed on Wahatis Peak as a valley fill above the Wahluke Flow, but is locally present on both the north and south sides of the Saddle Mountains. Chemical analyses of samples collected from this flow are listed in Table I, the average is given in Table IV, and plotted on Figure 6). The flow has normal paleomagnetic polarity as determined with a flux gate magnetometer.

At Wahatis Peak, the flow has fanning columns two feet in diameter. The flow is fine- to medium-grained with plagioclase phenocrysts and olivine microphenocrysts. Ward (1976) has described, in detail, the Huntzinger Flow at other localities in the Pasco Basin.

The Pomona Member

The Pomona Member lies stratigraphically above the Huntzinger Flow and is primarily found along the southern flank of the Saddle Mountains. Chemical analyses for samples collected from the flow are listed in Table I, the average is given in Table IV, and plotted on Figure 6. The flow has reversed paleomagnetic polarity as determined using a flux gate magnetometer.

The Pomona Member is represented by only one flow in the Saddle Mountains. It has a well-developed colonnade with one-foot diameter columns and an entablature with hackly jointing. The Pomona is plagioclase-phyric with microphenocrysts of olivine. It is fine grained to glassy and locally coarse. Schmincke (1964) described a peperite facies at the Beverly Quarry (Sec. 23, T15N, R24E) where the flow is invasive into the Ellensburg Formation. The Pomona commonly has a pillow-palagonite base with local occurrences of spiracles.

The Mattawa Flow

The Mattawa Flow overlies the Pomona Flow and is restricted to the south flank of the Saddle Mountains. Chemical analyses for samples collected from the flow are listed in Table I, the average is given in Table IV, and plotted on Figure 6. No description of this flow is present in the published literature. It is compositionally similar to the Huntzinger and Pomona, but overlies the Pomona and has normal paleomagnetic polarity (measured using a flux gate magnetometer at 30 localities).

The Mattawa Flow has a well-developed colonnade with columns two feet in diameter. It differs from the Pomona, in that it is diktytaxitic to microvescular and is much coarser. It also has rare plagioclase pheneocrysts and olivine microphenocrysts. An interbed is present between the Pomona and Mattawa flows. The Mattawa Flow commonly has a pillowed base and, at one locality (Sec. 22, T15N, R24E), fills a paleovalley cut in the Pomona and is invasive into stream sediments.

The Elephant Mountain Member

There are two Elephant Mountain flows that are fine-grained with microvesicles; each flow usually has a well-developed colonnade. The flows generally have a pillowed base with a thin interbed between them. In Crab Creek (Sec. 30, T16N, R23E), an abrupt intraflow facies change occurs where the massive columns of the colonnade change laterally within a few feet to thin columns of the entablature. This was mapped as the Jericho flow tongue by Grolier and Bingham (1971, 1978).

The Ellensburg Formation

This formation was best described by Schmincke (1964, 1967) from the Beverly Quarry at Sentinel Gap (Sec. 23. T15N, R24E). From the base upward, the formation consists of 18 meters of conglomerate, 6 meters of sandstone and siltstone, 15 meters of vitric tuff, 6-15 meters of an upper conglomerate, and 3-5 meters of an upper vitric tuff. This adequately describes the Ellensburg Formation at other localities in the Saddle Mountains (Sec. 2 through 5, T15N, R24E; Sec. 34, T16N, R25E).

The Ringold Formation

The Ringold Formation of Pliocene-Pleistocene-age consists of four facies (Grolier and Bingham, 1978), a tuffaceous sand and silt, a quartzite-bearing conglomerate, a buff, laminated clay, silt and sand, and a basalt fanglomerate, all capped by caliche in the Saddle Mountains. Grolier and Bingham (1978) proposed Smyrna Bench as the type locality for the basalt fanglomerate facies and interpreted the Ringold on Smyrna Bench to indicate that a basin-ward interfingering of three Ringold units (conglomerate excluded) occurred in the southern part of the Othello Basin.

Ringold-like sediments also occur in the small structurally controlled valleys exposed on the north face of the Saddle Mountains between Sentinel Gap and Smyrna Bench. These are probably slightly older than the Ringold at Smyrna Bench or at least as old as the basal part of the section.

The Quaternary Units

The Quaternary was subdivided during mapping into loess, flood sand and gravels, talus, active sand dunes, and alluvium. A more detailed map of the Quaternary units is being compiled by Dr. S. M. Price of Rockwell Hanford Operations.

DISTRIBUTION OF COLUMBIA RIVER BASALT UNITS IN THE SADDLE MOUNTAINS

The Grand Ronde Basalt

The Schwana Member crops out only at Sentinel Gap; flows of the Sentinel Bluffs Member are exposed throughout the area, but talus and discontinuous exposure prevent continuous correlation. Although continuous outcrop does not exist, the first flow below the Wanapum Basalt is interpreted to be the Museum Flow and the second flow below to be the Rocky Coulee Flow. No more than four Grande Ronde flows below the Wanapum-Grande Ronde contact are exposed south of Smyrna Bench.

The Wanapum Basalt

An isopach map of the Wanapum Basalt (Figure 7) shows a general northward thinning between Sentinel Gap and Smyrna Bench. South of Smyrna Bench, the formation thins along an approximate northwest trend and thickens to the east. Thickness variations of individual units within the Wanapum Basalt are described below.

The Frenchman Springs Member

The thickness of the Frenchman Springs Member remains relatively constant across the area (approximately 400 feet), except on the west side of Smyrna Bench (Sec. 34, T16N, R25E) where both the aphyric and plagioclase-phyric units thin. The overall thinning and absence of the aphyric unit coincide with the northwest-southeast axis of thinning in the Wanapum Basalt (Figure 7). The number of flows in the plagioclase-phyric unit increases eastward from Sentinel Gap, even though

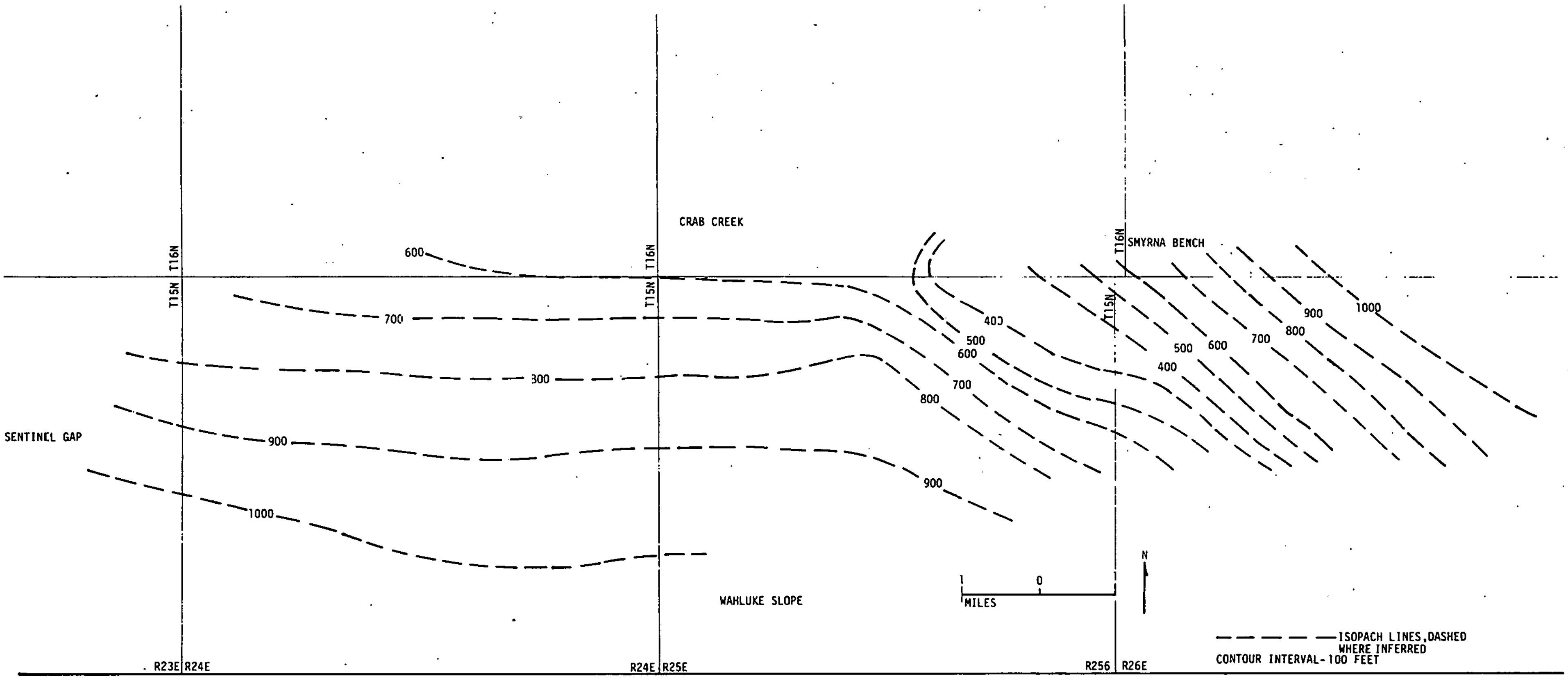


FIGURE 7

ISOPACH MAP OF THE WANAPUM FORMATION IN THE SADDLE MOUNTAINS the total thickness of the members remains nearly constant. The aphyric unit consists of two flows throughout the area, except in Sec. 12 and 32, T15N, R25E, where the unit is missing, and in Sec. 9, T15N, R25E, where there are four flows or flow units.

The "Roza-Like" Member

The "Roza-Like" Member is approximately 100 feet thick across the Saddle Mountains, except it is missing along the northwest-southeast-trending zone in the Wanapum Basalt (south flank Sec. 17, T15N, R26E; north flank Sec. 34, T16N, R25E; Sec. 1 and 2, T15N, R25E; and Sec. 6, T15N, R26E), and thins north of Wahatis Peak (Sec. 3, T15N, R26E) and over the axial trace of the Saddle Mountains anticline (Sec. 7 and 18, T15N, R24E; Sec. 12 and 13, T15N, R23E).

The Priest Rapids Member

The Priest Rapids flows have a relatively uniform total thickness between Sentinel Gap and Smyrna Bench. However, along a 4-mile-wide zone (Sec. 1, 2, 3, 11, and 12, T15N, R25E; Sec. 6, 7, 8, and 9, T15N, R26E; Sec. 34 and 35, T16N, R25E) west of Wahatis Peak, the Priest Rapids Member is missing. This zone trends north 40 degrees west across the Saddle Mountains and coincides with the zone of thinning in the Wanapum Basalt (Figure 7). Elsewhere, (Sec. 1, 2, 3, and 4, T15N, R24E; Sec 6, T15N, R25E) local thinning of the Priest Rapids Member is probably due to erosion before deposition of the upper Ellensburg Formation. Wherever only one Priest Rapids flow is present, it is of the Rosalia chemical type. However, in Taylor's (1976) Field Section Number 3, two samples were collected: an upper sample of Lolo chemical type (?); and, a lower sample of Rosalia chemical type. North of the Saddle Mountains in Crab Creek, all samples analyzed are Rosalia chemical type. If the Lolo chemical type is present, it is thin and covered by talus.

The Saddle Mountains Basalt

An isopach map (Figure 8) of the Saddle Mountains Basalt indicates thinning of the basalt onto the Saddle Mountains, non-deposition near the northwest corner, and thickening to the east. The northwest-southeast zone of thinning in the Wanapum Basalt (Figure 7) is present to a lesser degree in the Saddle Mountains Basalt. Three prominent northwest-southeast-trending zones on the northwest side of the Saddle Mountains (Sec. 2, 3, 4, and 5, T15N, R24E) contain anomalously thick accumulations of Saddle Mountains Basalt and are interpreted to be paleovalleys. The Ellensburg Formation reaches its greatest thickness near Sentinel Gap in the Beverly Quarry (Sec. 23, T15N, R23E), on the northwest side of Smyrna Bench (Sec. 34, T16N, R25E), and in the 3 valleys on the north face (Sec 2, 3, 4, and 5, T15N, R24E). In general, this formation thins toward the ridge crest of the Saddle Mountains.

The Wahluke Flow

The Wahluke Flow has been identified below the Huntzinger Flow on Wahatis Peak, but not on the south or north flanks; this could result from post-depositional erosion or failure to find it during mapping due to poor exposure of the flow.

The Huntzinger Flow

The Huntzinger Flow is primarily restricted to the area south of Smyrna Bench (Sec. 15, T15N, R26E, to the eastern limit of the map), on Wahatis Peak, and to the northeast of the Saddle Mountains map area (Sec. 1, T15N, R26E). The flow is interpreted to be a valley fill that probably spread in a northeast-southwest direction. The Wahluke Flow probably occupied a valley with the same directional trend.

The Pomona Flow

The Pomona Flow is present along the entire south slope and locally on the north slope of the Saddle Mountains. It is invasive into the Ellensburg Formation at the Beverly Quarry on the south slope

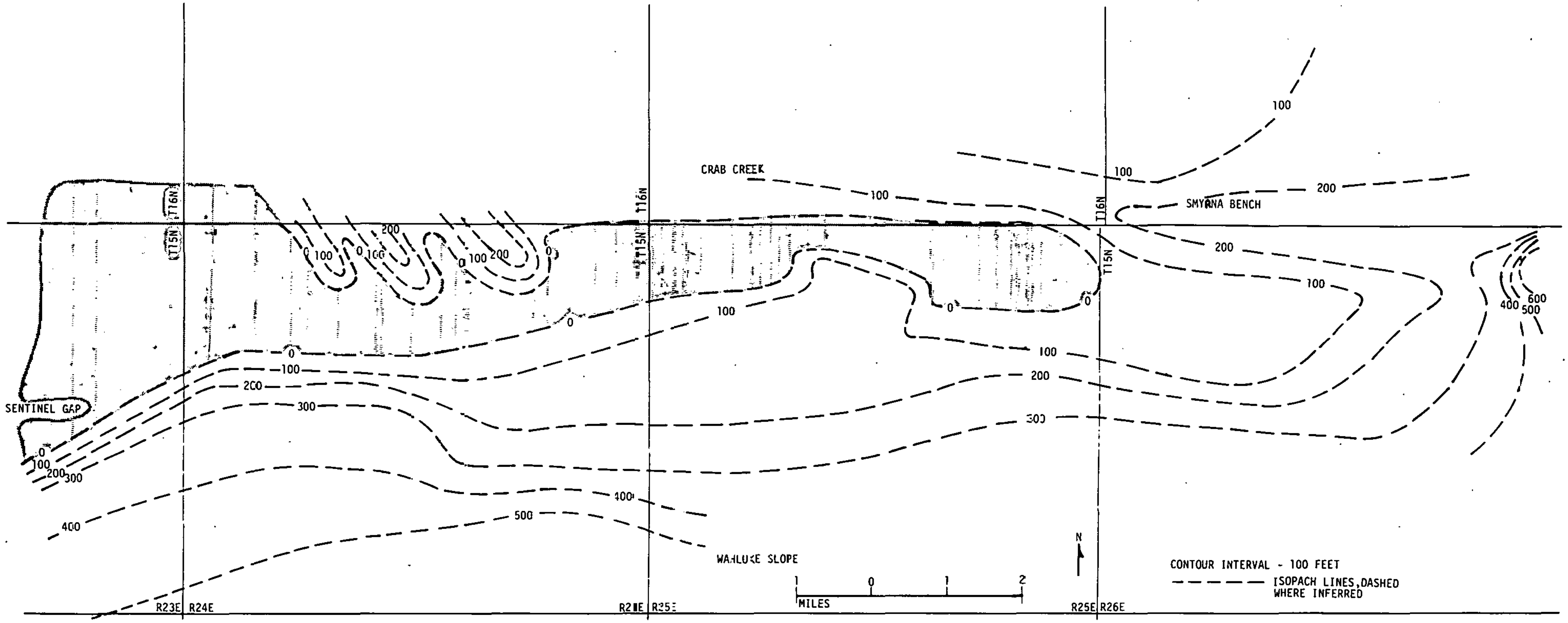


FIGURE 8

ISOPACH MAP OF THE SADDLE MOUNTAINS FORMATION IN THE SADDLE MOUNTAINS near Sentinel Gap (Schmincke, 1967), but is present on the crest of the Saddle Mountains between Sentinel Gap and Smyrna Bench and again on the eastern edge of the mapped area. On the north flank, it crops out along the eastern edge of the area to Sec. 5, T15N, R26E. West of Smyrna Bench (Sec. 3 and 4, T15N, R25E), the Pomona flowed north of the present ridge crest of the Saddle Mountains, but did not spread very far to the north or west.

The Mattawa Flow

The Mattawa Flow is restricted to the southern flank of the Saddle Mountains between Sec. 13, T15N, R25E, and the eastern edge of the map area. It is found on the ridge crest of the Saddle Mountains only in Sec. 16 and 17, T15N, R24E. The flow overlies the Pomona Member, except near Sec. 18 and 19, T15N, R24E, and in the southwest quarter of Sec. 22, T15N, R24E, where it filled and then overflowed the edges of a northwest-southeast-trending paleovalley in the Pomona Member.

The Elephant Mountain Member

The Elephant Mountain Member is the youngest basalt unit exposed on the Saddle Mountains and is restricted to lower elevations, except on the northwest scarp. It is exposed on the southern flank at Sentinel Gap in the Beverly Quarry (Sec. 23 and 24, T15N, R23E), and in a quarry in Sec. 23 and 24, T15N, R24E. It is invasive into sediments of the paleovalleys on the northwest face (Sec. 2, 3, 4, and 5, T15N, R24E), but did not overflow the valleys. The Elephant Mountain Member is exposed along the north slope of the Saddle Mountains near Smyrna Bench, except in Sec. 1 and 2, T15N, R25E, which coincides with the zone of thinning in the Wanapum Formation (Figure 7). The Elephant Mountain Member crops out in Crab Creek and on the north side of Smyrna Bench at approximately the same elevation, but crops out at higher elevations along the north face between Sentinel Gap and Crab Creek.

STRUCTURE OF THE SADDLE MOUNTAINS

INTRODUCTION

Two major and one minor structural trends are present in the Saddle Mountains. The predominant major structural trend is east-west, the other major structural trend is northwest-southeast, and the minor structural trend is northeast-southwest. In the discussion of structures that follows, frequent reference should be made to the geologic maps (Figures 9, 10, 11, and 12), the structure contour map (Figure 13) and the structure cross sections of Plate 1.

THE SADDLE MOUNTAINS ANTICLINE

The Saddle Mountains anticline is the major structural feature (Figure 9) in the area. It extends east-west across the entire area and is primarily responsible for the topographic relief of the Saddle Mountains. On the western edge of the area near Sentinel Gap, the anticline bifurcates (Figure 10, Sec. 8, T15N, R24E), with the southern axial trace forming the Saddle Mountains Anticline proper and continuing across the Columbia River. The northern axial trace swings northwest (Sec. 6, T15N, R24E) and is interpreted to be related to an extension of the Rye Grass anticline. The southern axial trace swings south 62 degrees west (Sec. 7, T15N, R24E) and then abruptly north 50 degrees west (Sec. 11, 12, 13, and 14, T15N, R23E) across the Columbia River and along the north face of the escarpment (Bentley, 1977). East of Sentinel Gap, the Saddle Mountains anticline strikes south 77 degrees east (Figures 10 and 11, Sec. 8 and 9, T15N, R24E) and then northeast (Sec. 11, T15N, R24W) toward Smyrna Bench. Near Birkett (Sec. 2, T15N, R23E), its axial trace trends south 68 degrees east and the anticline plunges to the east. The axial trace does not coincide with the topographic ridge crest of the Saddle Mountains south of Smyrna Bench, but follows the south flank. In Figure 12, Sec. 8, T15N, R26E, the axial trace is almost east-west north 80 degrees west, but trends north 80 degrees east and then north 75 degrees west at the eastern edge of the area (Sec. 11 and 12, T15N, R26E).

Saddle Mountains anticline is complicated by smaller folds, faulting, and a change in overall fold geometry along its axis. South of Smyrna

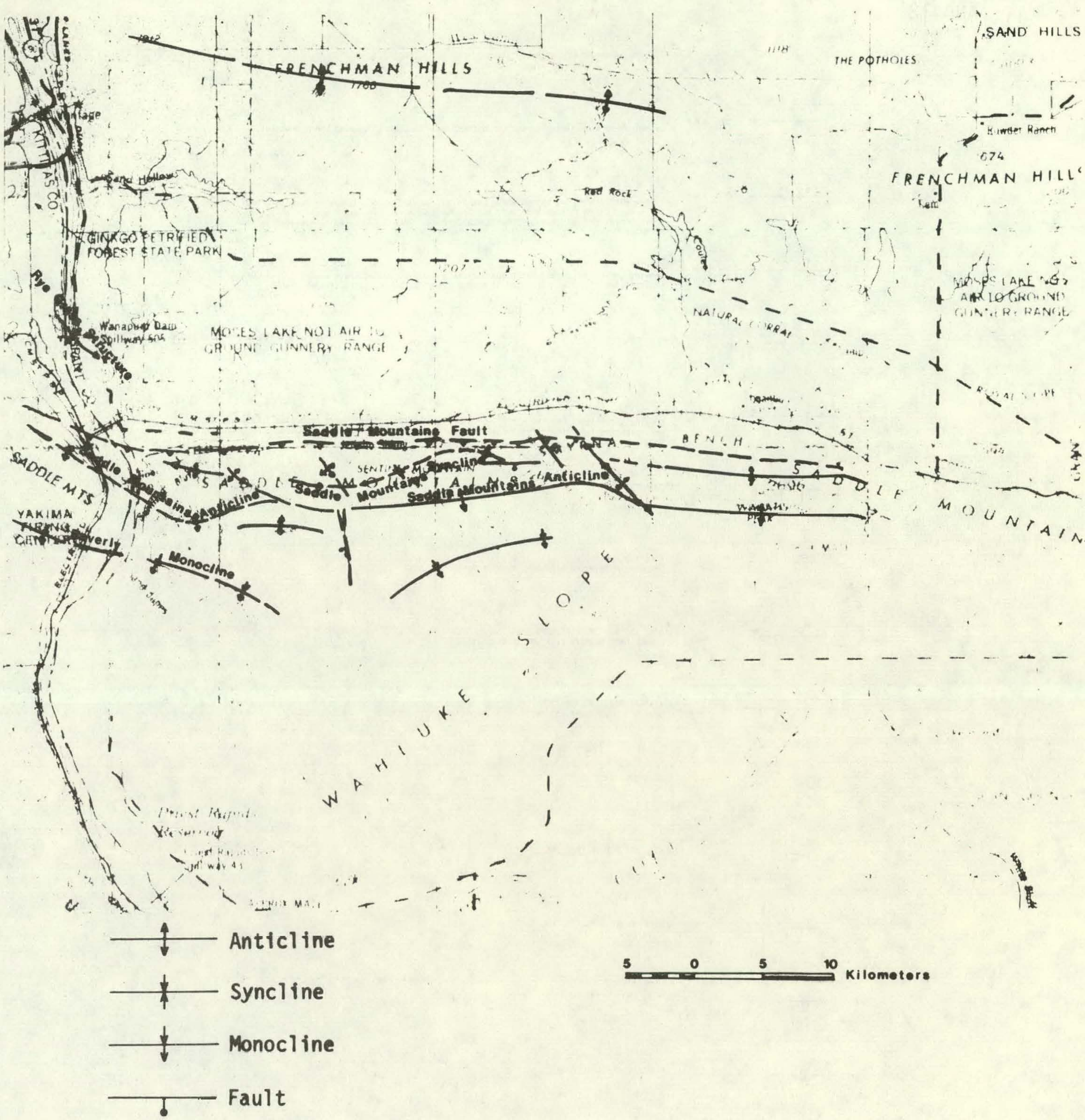


FIGURE 9

MAJOR STRUCTURAL FEATURES MAPPED IN THE SADDLE MOUNTAINS

(See Figures 10, 11, and 12 for more detailed locations of structures.)

LEGEND FOR FIGURES 10, 11, AND 12

PILLOW-PALAGONITE ZONE

BRECCIA
Flow top, deposited or tectonic in origin

CONTACT
Dashed where approximately located; dotted where concealed; queried where doubtful.

FAULT
Dashed where inferred; dotted where concealed; queried where unknown or doubtful; ball and bar appear on downthrown side or D appears on downthrown side and U appears on upthrown side; arrows indicate apparent horizontal offset. Thrust indicated by sawteeth on side of upper plate.

ANTICLINE
Showing crestline; dashed where approximately located; dotted where concealed; arrowhead on crestline indicates direction of plunge; short arrow indicates steeper limb.

Overturned Anticline

SYNCLINE
Showing troughline; dashed where approximately located; dotted where concealed; arrowhead on troughline indicates direction of plunge; short arrow indicates steeper limb.

Overturned Syncline

STRIKE AND DIP
Symbol broken where attitude is estimated.

STRIKE AND DIP OF OVERTURNED BEDS
Symbol broken where attitude is estimated.

STRIKE OF VERTICAL BEDS
Symbol broken where estimated.

HORIZONTAL BEDS

STRIKE AND DIP OF FRACTURE

STRIKE OF VERTICAL FRACTURE

STRIKE AND DIP OF JOINTS

STRIKE OF VERTICAL JOINT

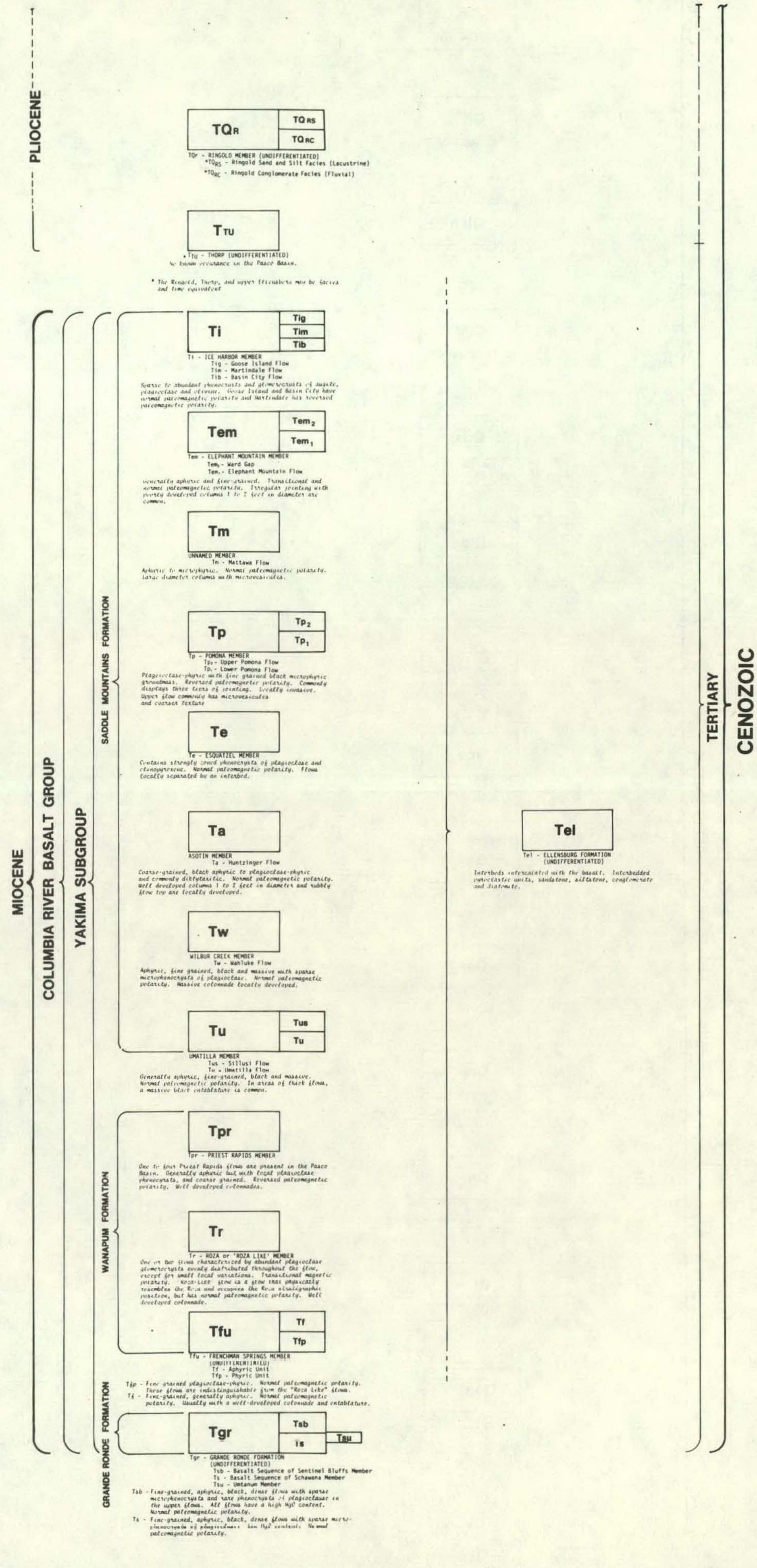
FAULT ZONE OR SHEAR ZONE

MONOCLINE
Showing trace of axis; dashed where approximately located; arrows indicate direction of dip; dotted where concealed.

LOCATION OF STRUCTURAL CROSS-SECTION

Dash - Dot line indicates contact between Quaternary sediments and basalt units.

LEGEND FOR FIGURES 10, 11, AND 12



LEGEND FOR FIGURES 10, 11, AND 12

CENOZOIC — QUATERNARY

HOLOCENE

Qda

Qda - ACTIVE SAND DUNES

Barcan, longitudinal, parabolic, source material glacial deposits, loess, Ringold

PLEISTOCENE

Qd

Qd - SAND DUNES(UNDIFFERENTIATED)

Qbm

Qbm - BERG MOUNDS

x's on map @ location

Qge

Qge - GLACIAL ERRATICS

▼ on map @ location

Qds

Qds - STABILIZED SAND DUNES

Mostly longitudinal to present wind directions

Qld

Qld LANDSLIDE DEBRIS

Mass movement - blockslides; both on basalt (stippled) and Ringold; arrows indicate direction of movement.

Qt

Qt - TALUS

Assumed to be late Pleistocene at present time

Qco

Qco - COLUVIUM

Age uncertain, most are post floods however, some are pre flood. Undifferentiated at this time.

Qa

Qa - ALLUVIUM

Mostly reworked Qhp and Qht of late Pleistocene age

Qaf

Qaf - ALLUVIAL FANS

Qhp

Qhp - PASCO MEMBER OF HANFORD FORMATION

Torrentially deposited sand and gravel occurring as bars, [illegible] with some upstream "exotics". Size range medium sand to boulders

Qht

Qht - TOUCHET MEMBER OF HANFORD FORMATION

Silt and sand facies of flood deposits, backwater deposits, possible density current deposits - found up to 1100 MSL

Ql

Ql - LOESS

Up to four different deposition units based on soil profile development. Undifferential here

Qag

Qag - GRAVEL (UNDIFFERENTIATED)

Includes Quaternary and Tertiary Gravels

FIGURE 10

GEOLOGIC MAP OF THE BEVERLY 7-1/2-MINUTE QUADRANGLE MAP

(See pocket for 1:24,000 scale.)

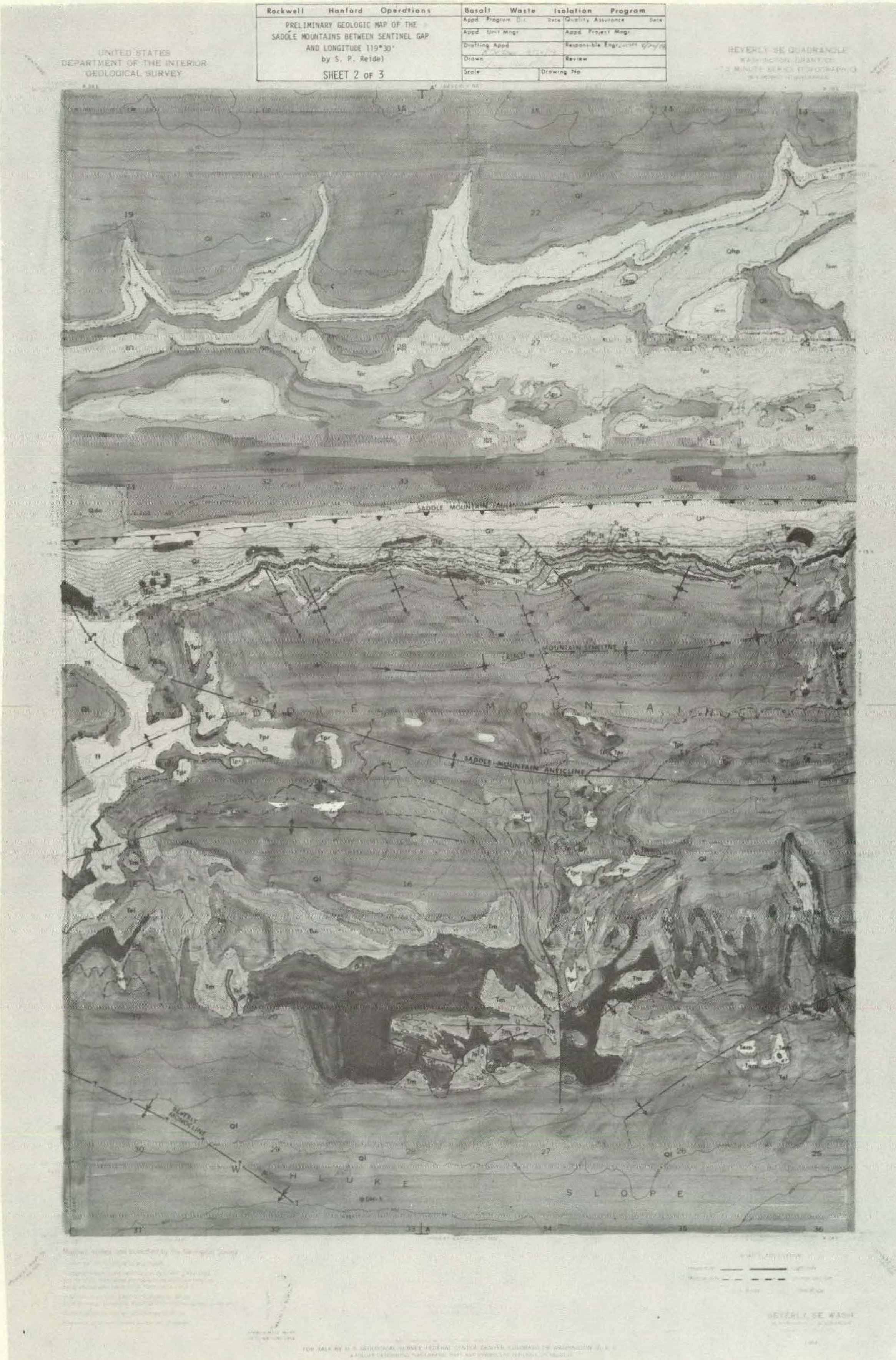


FIGURE 11

GEOLOGIC MAP OF THE BEVERLY SOUTHEAST 7-1/2-MINUTE QUADRANGLE MAP

(See pocket for 1:24,000 scale.)

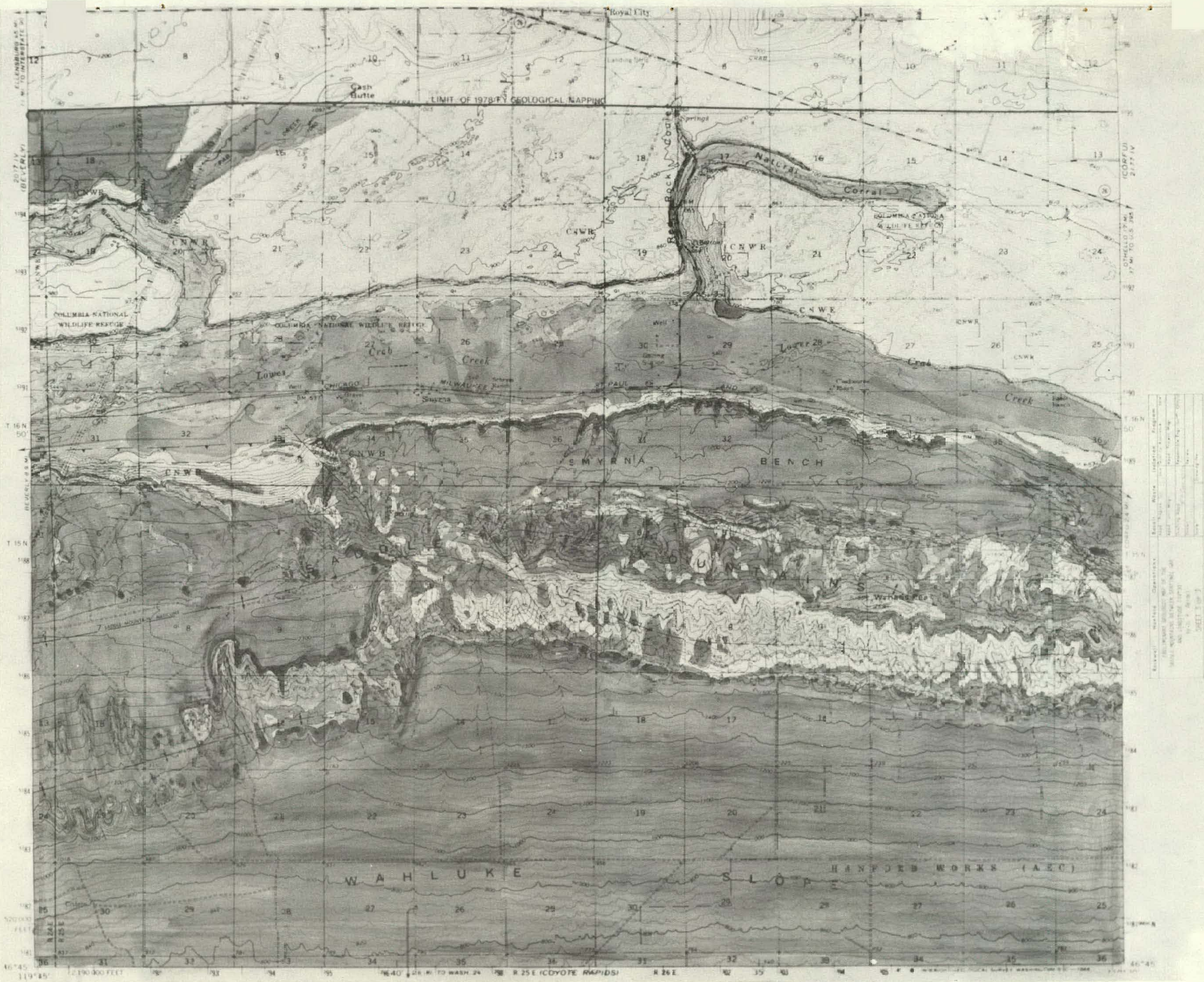


FIGURE 12

GEOLOGIC MAP OF THE SOUTHERN HALF OF THE SMYRNA 15-MINUTE QUADRANGLE MAP

(See pocket for 1:24,000 scale.)

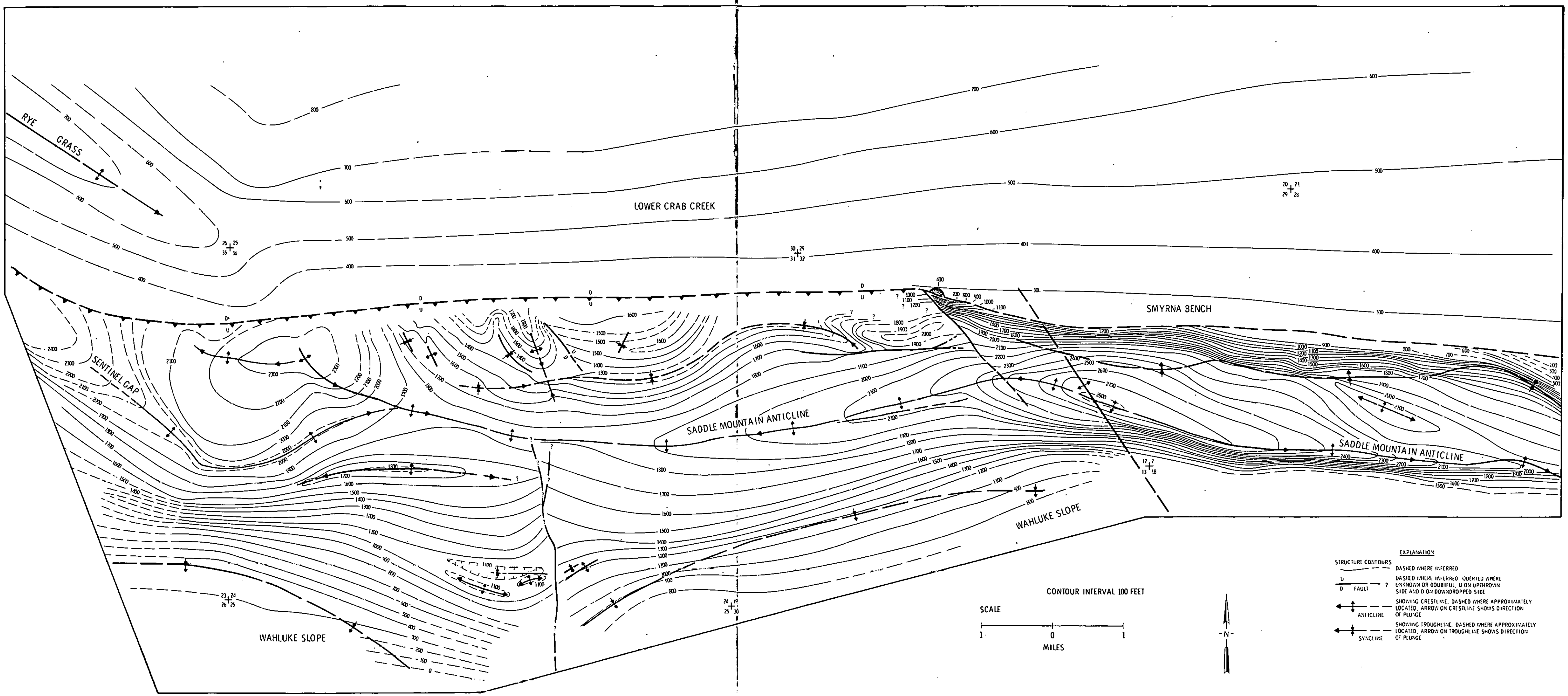


FIGURE 13

STRUCTURE CONTOUR MAP ON SURFACE OF THE FRENCHMAN SPRINGS MEMBER IN THE SADDLE MOUNTAINS

Bench, it is a tight fold, resembling a box fold (Grolier and Bingham, 1965, and this study); however, between Sentinel Gap and Smyrna Bench, it is a broad asymmetrical fold. A complex zone of deformation (Figure 12, Sec. 2, 3, 10, and 11, T15N, R25E) marks the change in fold geometry. The anticline plunges both east and west from this zone.

South of the Saddle Mountains anticline near Sentinel Gap (Figure 11, Sec. 16, 17, and 18, T15N, R24E), is a small, doubly plunging anticline with an east-west axial trace. It is truncated on the east by a north-south fault and dies out to the west. No extension of this structure was found east of the fault.

THE BEVERLY MONOCLINE

The Beverly Monocline is represented by an abrupt change in dips observed in the exposures of the Elephant Mountain Basalt south of the Beverly Quarry (Figure 10, Sec. 23, T15N, R23E). The monocline strikes southeast from the quarry (based upon structure contours determined using DH-5, see Figure 13). A northeast-southwest-trending monocline, present east (Figure 11, Sec. 26, T15N, R24E) of the structure and considered to be same, trends toward the east (Sec. 15, T15N, R25E) where it is covered by overburden. The change in trend of axial trace of the monocline occurs (Figure 11, Sec. 27, T15N, R24E) where it intersects a north-south-trending fault (Sec. 10, 15, 22, and 27, T15N, R24E). North of the Beverly monocline is a series of smaller east-west-trending folds (Figure 11, Sec. 21, 22, and 23, T15N, R24E) that parallel both the Beverly Monocline and the Saddle Mountains anticline. A flexure between the northwest- and northeast-trending folds occurs where the Mattawa Flow overflowed a northwest-trending paleovalley in the Pomona. The coincidence of the flexures in the Saddle Mountains anticline, the Beverly monocline, the smaller folds occurring between them, the paleovalley in the Pomona Flow, and the north-south fault indicate this to be an area of complex deformation, perhaps with a long and complicated history.

West of the Beverly Quarry, the monocline trends northwest and parallels the axial trace of the Saddle Mountains anticline (Bentley, 1977)

THE WAHATIS PEAK STRUCTURE

The Wahatis Peak structure, located on the northeast side of the peak, is a small northwest-southeast-trending asymmetrical anticline with a steep northeast limb and a nearly horizontal southwest limb. The structure approaches a monocline and makes a 30-degree angle to the trend of the Saddle Mountains anticline.

THE SADDLE MOUNTAINS SYNCLINE

North of the Saddle Mountains anticline, the Saddle Mountains Syncline (Figures 10, 11, and 12, Sec. 5, T15N, R24E to Sec. 5, T15N, R25E) trends east-west between Sentinel Mountain and Smyrna Bench. In Figure 11, Sec. 2, 3, and 4, T15N, R24E, the syncline has an east-west axial trace and is broken into two small basins by a series of northwest-trending folds. The north face of the Saddle Mountains terminates the north limb of the Saddle Mountains syncline, forming a prominent topographic feature. In Sec. 1, T15N, R24E, the axial trace trends northeast, then southeast in Sec. 5, T15N, R24E, where it terminates against an east-west fault. The western edge of the Saddle Mountains syncline terminates near the inferred extension of the Rye Grass anticline in the Saddle Mountains.

The east-west fault terminating the eastern edge of the Saddle Mountains syncline extends 2-1/2 miles west of Smyrna Bench (Sec. 3, 4, 5, and 6, T15N, R24E). The maximum displacement is approximately 200 feet (Sec. 5), inferred from locations where the Pomona Basalt is faulted against "Roza-Like" and Priest Rapids members. The fault dies out to the east and west.

THE SADDLE MOUNTAINS FAULT

The Saddle Mountains fault has been a topic of considerable discussion (Laval, 1956; Grolier, 1965; Grolier and Bingham, 1971, 1978; Jahns, 1967; Jones and Deacon, 1966; Taylor, 1976).

Laval (1956) interpreted it as a thrust fault based on an exposure near Sentinel Gap, but Grolier and Bingham (1965) interpreted it as a near-vertical shear zone, noting that:

> "Exposures with conclusive evidence of a major fault zone along the north side of the Saddle Mountains are very scarce."

Between Smyrna Bench and Sentinel Gap, the flows have a maximum displacement of 1,800 feet (Sec. 1, T15N, R24E), but no where is the fault plane exposed. The approximated fault zone is shown on the geologic maps (Figures 10, 11, and 12).

Exposures are also poor along the Saddle Mountains near Smyrna Bench. Only one locality (Sec. 33 and 34, T16N, R24E) was found with enough exposure for some inference of the nature of the fault to be made. Exposed in a north-south gully are vertically standing Grande Ronde, Frenchman Springs, "Roza-Like," Priest Rapids, and Elephant Mountain basalts with some overturning (Laval, 1956; Grolier and Bingham, 1965) and horizontally standing Ringold against the vertical Elephant Mountain. Within a short distance (southwest quarter of the southwest quarter of Sec. 32), the Grande Ronde Basalt is folded and sheared from nearly horizontal (in the south) to nearly vertical (in the gully). Considerable shearing is present. When tracing out the Grande Ronde flows, it is impossible to follow all the flows through the sheared zone; the two lower flows have been faulted from the vertical section. Grolier and Bingham (1965, 1971, 1978) interpreted the east-west Saddle Mountains fault to pass through the Frenchman Springs Member. The vertically standing Grande Ronde Basalt is sheared with mylonitized zones striking north 20 degrees east and dipping 60 degrees west. The last movement based upon slickensides and displaced flows was north side down. This fault zone is interpreted to be associated with a northwest-southeast fault zone. Evidence for this fault is based on: offset in Sec. 3, T15N, R25E; the tectonic shear zone in the Grande Ronde Basalt mentioned above; and, a tectonically brecciated Elephant Mountain Basalt outcrop along the projection of the fault and shear zones (southwest quarter of the southwest quarter of the northeast third of Sec. 33, T16N, R25E).

The shear zone in the Grande Ronde Basalt is extremely complex. Mylonitized zones of basalt parallel the main joint set, and displacement occurs on a series of shear planes accompanied by block rotation. The shearing is more pronounced on the west side of the gully where the greatest displacement is interpreted to have occurred.

East of the fault, the "Roza-Like" and Priest Rapids flows pinch out where the Ellensburg Formation outcrops. There is a prominent north 20 degrees west, 25 degrees northeast-dipping joint set cutting the tuffaceous interbed at this location.

The contact between the vertically standing Elephant Mountain and the horizontal Ringold appears to have some fault displacement. The Elephant Mountain Basalt is apparently faulted near the bottom of the gully. This could be erosional; however, the zone apparently continues across the gully to the west, where vertically standing Priest Rapids is in contact with a gently south-dipping Priest Rapids flow overlying a "Roza-Like" flow.

The Priest Rapids and "Roza-Like" flows lie on a horizontal and undeformed Elephant Mountain Basalt. This is interpreted to be a thrust fault with the "Roza-Like" thrust over the Elephant Mountain Basalt. Even though landsliding occurred to the west (Sec. 33), these flows and the ones along the gully are not interpreted as being a landslide. The landsliding is thought to be relatively young and the Priest Rapids flows are not present higher up the hill, indicating the Priest Rapids is not a part of the landslide block. Also, all flows up the gully (south) from this outcrop appear to be in place with no other evidence of landsliding. It would more likely be landslide debris if Grande Ronde and Frenchman Springs basalts were overlying the Elephant Mountain Basalt, rather than Priest Rapids and "Roza-Like," since the nearby slide blocks (Sec. 34) are composed of Grande Ronde and Frenchman Springs basalts.

On the east side of Smyrna Bench, Grolier and Bingham (1965, 1978) described another exposure of the Saddle Mountains fault (east half of the southwest quarter, Sec. 1, T15N, R25E). No significant displacement could be found there during the field study. This area was, however, found to be the western-most limit of the Huntzinger and Wahluke flows on the north slope of the Saddle Mountains and is interpreted to be a valley that trends northeast-southwest. The Saddle Mountains fault is interpreted to lie under the Ringold Formation (Figure 12) beneath Smyrna Bench.

Along the southern side of Smyrna Bench, there is a considerable amount of fracturing and shearing (Grolier and Bingham, 1965). No significant displacements were found and most shearing was interpreted to be related to faulting along the probable fault zone now buried by Ringold sediments.

THE NORTHWEST-SOUTHEAST FOLDS

Grolier and Bingham (1978) considered the northwest-southeast-trending fold system to be the least pronounced in the much larger area they examined. However, in the Saddle Mountains, it is second only to the east-west fold system.

There are two major northwest-southeast folds and several smaller ones. The most obvious structure (Figures 9 and 13) is the Rye Grass anticline, whose axial trace passes near Wanapum Dam (Mackin, 1955), and extends into the Saddle Mountains west of Sentinel Mountain (Sec. 6, T15N, R24E) before dying out to the south in Sec. 20, T15N, R24E.

A major northwest-southeast anticline is near the west end of Smyrna Bench (Figure 12, Sec. 34, 35, and 36, T16N, R25E; Sec. 1, 2, 3, 10, 11, and 12, T15N, R25E; Sec. 6, 7, 8, 9, 16, 17, and 18, T15N, R26E). Folding along the east-west Saddle Mountains anticline has all but obliterated this structure, but its axis represents the present structural high (Figures 12 and 13) along the Saddle Mountains anticline.

The structure was primarily recognized on observed stratigraphic relationships in the area. Based upon flow distribution, an anticlinal ridge several miles wide is inferred to have existed from Frenchman Springs time through Pomona time. The anticline apparently reached its greatest topographic relief during Priest Rapids time, when it formed a barrier at least four miles wide. This structure is now bounded on the west by a younger fault. On the east side of the study area is the suggestion of a third structure, as indicated by a flexure in the Saddle Mountains anticline, but more work is needed to verify this. The northwest-southeast-trending anticlines are the oldest structural features identified in the area.

A series of northwest-trending folds of lesser magnitude are present between the two broad anticlines (Figure 11, Sec. 3, 4, and 5, T15N, R24E). These structures are older than the Saddle Mountains fault, but probably younger than the two northwest-southeast-trending anticlines and show a relatively long history of deformation. They apparently became active during Priest Rapids time, as indicated by local variations in the Priest Rapids flows. The synclinal troughs are filled with thick accumulations of sediment, Elephant Mountain Basalt which did not overflow the trough, and Ringold sediments. The Ringold sediments and caliche covering the sediments are deformed, indicating post-Ringold deformation along this trend. One syncline has a normal fault (Figure 11, Sec. 3) bounding its west side.

THE NORTHEAST-TRENDING STRUCTURES

Northeast-trending structures were found at only two locations on the Saddle Mountains. The first location is in Sec. 1 and 2, T15N, R24E, where small northeast-trending folds occur; one was mapped as a fault by Taylor (1976), but is interpreted here as an anticline. The second location is between Wahatis Peak and Sec. 1, T15N, R26E (Figure 12), where the Huntzinger Flow is restricted to a northeast-southwest-trending valley that, in part, may be structurally controlled; no other evidence for this structure was found.

AEROMAGNETIC SURVEY

An aeromagnetic survey covering much of central Washington was completed in 1977 by Weston Geophysical Research, Inc. for the Washington Public Power Supply System, Inc. This survey revealed some anomalies on the northern Pasco Basin and vicinity (Figure 14) that relate to geologic features mapped during this study. The most prominent aeromagnetic anomalies are discussed below.

A north-south-trending anomaly south of Wahitis Peak corresponds most closely to the eastern edge of the northwest-trending anticline that crosses the western edge of Smyrna Bench (Figure 12). The Rye Grass structure is expressed on the aeromagnetic anomaly map as well as the continuation of the Juniper Springs anomaly. The Juniper Springs anomaly roughly coincides with the trend of the Huntzinger Flow in the Saddle Mountains.

GEOMORPHOLOGY

GENERAL

As discussed previously, the main topographic expression of the Saddle Mountains is produced by the east-west fold system. The main

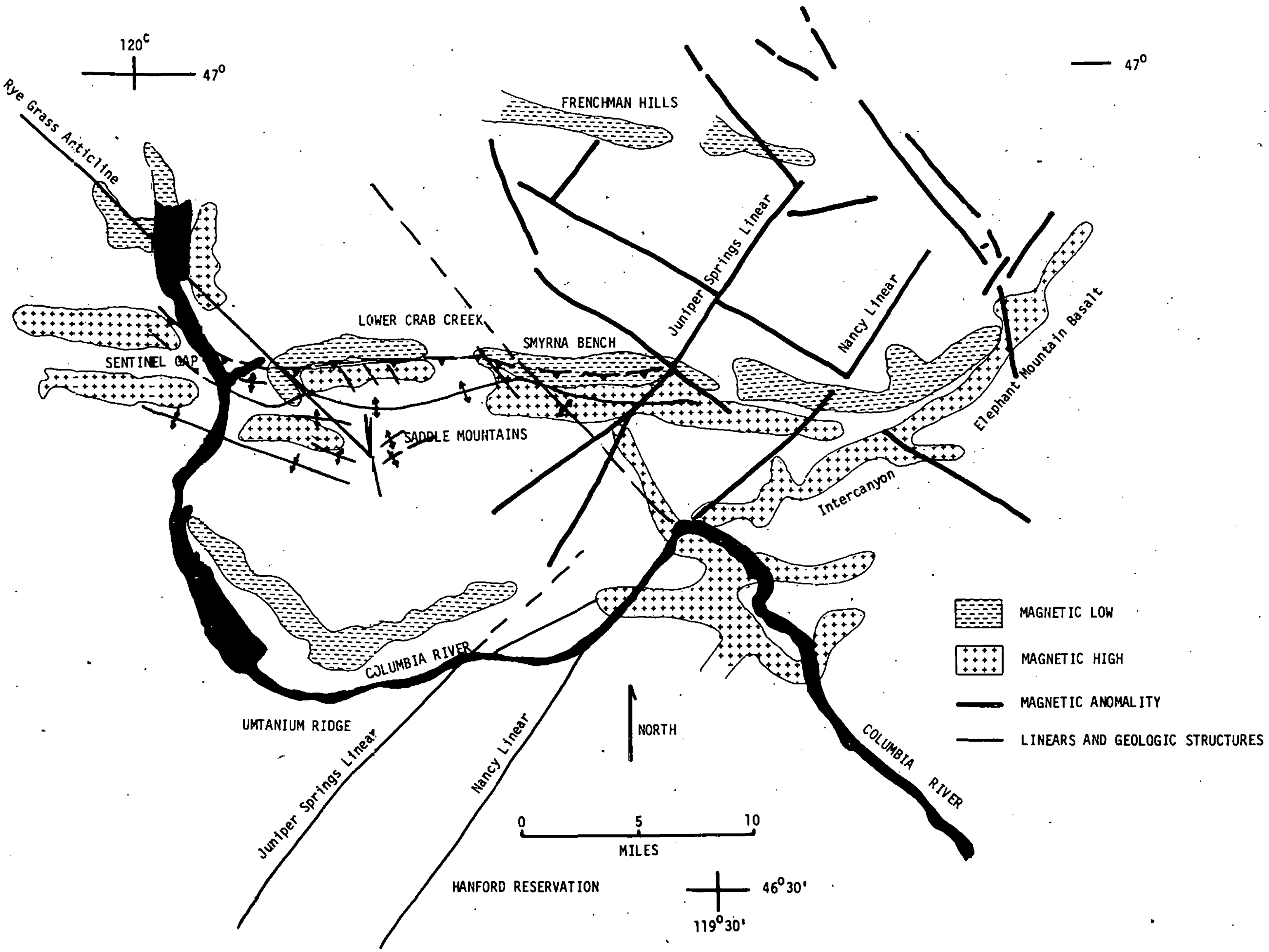


FIGURE 14

AEROMAGNETIC ANOMALY MAP OF THE PASCO BASIN AND VICINITY anticlines are expressed as topographic highs and synclines as lows. Relatively little erosion has occurred between Sentinel Gap and Smyrna Bench (except at Sentinel Gap) since uplift of the Saddle Mountains. The structurally complex area in Figure 11, R24E has been more susceptible to erosion than the surrounding area and a major north-south gap has resulted.

The Columbia River cut through the Saddle Mountains at Sentinel Gap. Grolier and Bingham (1965) have suggested a syncline may have controlled the Columbia River; however, mapping has not been completed on the west side of the river so this cannot be verified. A preliminary cross section (B-B', Plate 1) suggests there is a westward dip, but no indication of a syncline. A flexure in the axis of the Saddle Mountains anticline at the Columbia River may have produced a weakness allowing the Columbia River to cut through.

A considerable amount of erosion has occurred along the Saddle Mountains south of Smyrna Bench. The highest point, Wahatis Peak, is a valley fill of Huntzinger Basalt. Evidence on the north and south flanks indicates it did not fill a valley cut into basalt. This suggests that over several hundred feet of basalt have been eroded from the crest. The erosion south of Smyrna Bench, but not west, suggests a geomorphic feature similar to Smyrna Bench did not exist west of the present outcrop area and implies that uplift along the Smyrna Bench section of the Saddle Mountains occurred contemporaneously with deposition of the Ringold sediments on Smyrna Bench.

Landslides

Landslides have been located within one area (Figure 12, Sec. 33, T16N, R25E). On the west side of Smyrna Bench, Grande Ronde Basalt and plagioclase-phyric Frenchman Springs Basalt have slumped into Crab Creek. It has been argued earlier that the Priest Rapids and "Roza-Like" members have not slumped, but have been faulted into place and erosion probably removed the Priest Rapids prior to landsliding.

Grolier and Bingham (1978) have found evidence for slumping on Smyrna Bench and this study supports their interpretation. More work is needed, however, to define the extent of this.

Natural Corral Canyon

The western limit of the Pomona occurs at Natural Corral Canyon (Figure 12). Erosion in Crab Creek removed the Elephant Mountain Basalt along the edge of the Pomona Basalt forming the present Natural Corral Canyon. Sediment in Natural Corral Canyon indicates this erosion occurred during the glacial floods.

THE GEOLOGICAL HISTORY OF THE SADDLE MOUNTAINS

After the eruption of the Grande Ronde Basalt, the Vantage Sandstone was locally deposited on top of the Grande Ronde Basalt with no significant erosion. Between Sentinel Gap and Smyrna Bench, the Vantage interbed is either absent or very thin, suggesting the existence of a topographic high.

A topographic high near Sentinel Gap is implied by an increasing number of Frenchman Springs flows south and east from the gap. This is especially true for the plagioclase-phyric Frenchman Springs flows and less so for the aphyric flows. East of Sentinel Gap, thick interbeds are developed between the flows and pillow-palagonite complexes occur at the base of some aphyric flows.

There is evidence for the development of a northwest-trending high near Smyrna Bench in Frenchman Springs time. This is indicated by the absence of the aphyric flows along a northwest-southeast zone that later was a prominent structure.

Between the eruption of the last aphyric Frenchman Springs Flow and the "Roza-Like" flows, the Saddle Mountains anticline began forming. Near Sentinel Gap, the "Roza-Like" flows thin over an east-west axis with thickening on either side. North of Wahatis Peak, thinning along an east-west zone also occurs, suggesting the first movement on the Saddle Mountains anticline began before the eruption of the "Roza-Like" Member. The paleo-axis of the Saddle Mountains anticline did not apparently coincide with the present axis.

The northwest-trending structure near Smyrna Bench became more prominent as demonstrated by the absence of the "Roza-Like" Member on both flanks of the present Saddle Mountains. This structure had its greatest topographic relief during Priest Rapids time, since these flows are missing over a four-mile-wide zone and pinch out on the edges.

The ancestral Pasco Basin was a prominent feature by Priest Rapids time. There are three Priest Rapids flows in DH-5 in the Pasco Basin, yet only two are present in the Saddle Mountains and possibly only one in the northern rim of Crab Creek. This implies progressively higher relief from the present basin toward the north.

There was a major time break between erupting of the "Roza-Like" and Priest Rapids flows, with one of the thickest accumulations of sediments in the Saddle Mountains occurring at this time. The thickest accumulation occurs on the south slope west of the Smyrna Bench northwest-trending structure. The interbed thins toward the ridge crest implying the existence of higher relief.

The absence of the Umatilla Member and the limited occurrences of the Waluke and Huntzinger flows also indicate a prominent topographic high.

The Saddle Mountains Basalt flows in DH-5 indicate the Saddle Mountains were probably not much wider than they are at present. The occurrence of the Huntzinger and Wahluke flows at Wahatis Peak and on the east side of the area suggests the western part was topographically higher. The Saddle Mountains were breached only at Wahatis Peak along a northeast-southwest valley, which could possibly have been structurally controlled.

By the time the Pomona was erupted, the Saddle Mountains formed the northern boundary of the paleo-Pasco Basin. The crest of the Saddle Mountains anticline was north of its present position, as indicated by the northern extent of the Pomona Flow between Sentinel Gap and Smyrna Bench. The Pomona Member was restricted on the north by a topographic high and later folded; its northern limit is beyond the present Saddle Mountains anticline. The Pomona flowed over the anticline on the west side of the Smyrna Bench northwest-trending fold, but its spread was stopped by a topographic high to the west and north. This further indicates the Saddle Mountains west of Smyrna Bench was a topographic high.

The northwest-trending fold was submerged on the southern flank, impling the Pasco Basin was flooded by basalt as far north as the Saddle Mountains in Pomona time. The western limit of the Pomona occurs at Natural Corral Canyon, which is directly north of the western limit of the Pomona on the north flank of the Saddle Mountains. Swanson, et al., (1977) have shown that the northern limit of the Pomona Member, east of Natural Corral Canyon, is at an equivalent latitude.

A period of erosion followed the Pomona Flow and is marked by a local interbed between the Pomona and Mattawa flows. A northwest-trending paleovalley was cut into the Pomona and later filled by the Mattawa Flow. The Mattawa Flow encroached from the south onto the Saddle Mountains which were sufficiently high to prevent its northward spread. The structurally complex zone on the south flank in R24E was a topographic low that the Mattawa Flow flooded. This is the first indication of a low area along the Saddle Mountains between Sentinel Gap and Smyrna Bench. Deformation along a north-south or northwest-southeast zone probably produced this low. The Mattawa Flow is faulted against the Pomona Flow, indicating continuing deformation at least until after Mattawa time.

Following Priest Rapids volcanism, deformation along a northwest-southeast trend between Sentinel Gap and Smyrna Bench produced a series of folds; folding was accompanied by faulting in several places. With the eruption of the Elephant Mountain Basalt, the Saddle Mountains stood as an east-west topographic high across the area. The voluminous Elephant Mountain Basalt completely surrounded the Saddle Mountains and filled the small northwest-trending valley. Upper Ellensburg and early Ringold sediments were deposited in these valleys and later deformed.

The Saddle Mountains fault began sometime after Priest Rapids time, but did not produce any significant relief until after Elephant Mountain time. Displacement occurring before Elephant Mountain time could not have been more than a few hundred feet based on the relationships observed in the northwest-trending valleys between Sentinel Gap and Smyrna Bench.

Final folding and faulting along the Saddle Mountains were probably synchronous. The northwest-trending fold near Smyrna Bench formed a topographic high, as well as a structural high during the folding.

Near the end of the major east-west deformation, the northwest-trending fault near the west side of Smyrna Bench appears to have become active. The first movement is interpreted to be right lateral based upon the northwest bending of flows along the fault trace north of Smyrna Bench, a flexure in the axis of the Saddle Mountains anticline, and slickensides along the fault. The final movement on the fault was vertical with down-dropping of the north.

The difference in style of deformation along the Saddle Mountains structure is difficult to explain. The deformation south of Smyrna Bench is greater, yet younger than that to the west. This could be related to deformation produced by right lateral faulting.

Apparently related to the deformation is the formation of Smyrna Bench. With continued deformation and erosion, sediments were deposited forming Smyrna Bench. No similar feature was formed to the west because erosion was not as great. The deformation along the northwest fault on the west side of Smyrna Bench occurred later.

The last stage in the development of the area occurred when the glacial flood water removed part of Smyrna Bench and basalt from Crab Creek and essentially formed the present landscape.

SUMMARY

Three stratigraphic formations of the Columbia River Basalt Group are present in the area: the Grande Ronde; the Wanapum; and, the Saddle Mountains basalts. Over 1,000 feet of Grande Ronde Basalt are exposed at Sentinel Gap, but only the upper part of the section is exposed along the length of the Saddle Mountains. The Grande Ronde Basalt consists of the younger, high-MgO Sentinel Bluffs Member and the older low-MgO Schwana Member. All but the oldest Schwana flow exposed at Sentinel Gap have normal paleomagnetic polarity; it has reversed paleomagnetic polarity. The flows are fine grained, some with well-developed colonnades and entablatures, and are predominantly aphyric. Interbeds are found between the flows and the Vantage Sandstone occurs at the top of the section.

All members of the Wanapum Basalt are present in the Saddle Mountains. The Frenchman Springs Member has been subdivided for mapping into plagioclase-phyric and aphyric units. The number of flows and interbeds varies, but all Frenchman Springs flows have normal paleomagnetic polarity and similar chemical compositions. Two plagioclase-phyric flows occur above the Frenchman Springs Member; they physically resemble the Roza Member and have the same approximate stratigraphic position, but, due to their strong normal paleomagnetic polarity, they are referred to as the "Roza-Like" Member. Two Priest Rapids flows, with an interbed between them, lie on a thick interbed above the "Roza-Like" flows and are diktytaxitic with reversed paleomagnetic polarity; the younger is the Lolo chemical (?) type and the older is the Rosalia chemical type.

The Saddle Mountains Basalt is only partially complete, compared to the number of flows in deep core holes in the Pasco Basin. The Pomona is the most widespread flow; the Wahluke, Huntzinger, Elephant Mountain, and Mattawa flows are locally present; and, the Umatilla is absent. The Huntzinger, Mattawa, and Pomona flows have similar chemical compositions and, except for the Pomona, have normal paleomagnetic polarity. The Mattawa Flow has not been described previously in the literature.

The Wanapum and Saddle Mountains basalts have an irregular distribution across the Saddle Mountains. The Wanapum Basalt thins northward and across a northwest-southeast axis at the west end of Smyrna Bench. The Priest Rapids, "Roza-Like," and aphyric Frenchman Springs members are locally absent along this axis.

The distribution of Saddle Mountains Basalt is more complex than the Wanapum Basalt. The Saddle Mountains Basalt also thins northward and across the northwest-southeast zone, but there is an east-west zone between Sentinel Gap and Smyrna Bench that is devoid of the Saddle Mountains Basalt. The Pomona is restricted to the south flank of the Saddle Mountains, west of Smyrna Bench; while the Elephant Mountain Member occurs only on the flanks and in three small structurally controlled basins on the north side. The Mattawa, Wahluke, and Huntzinger flows are local and primarily restricted to the southern flank.

The structure of the Saddle Mountains is dominated by an east-west trend and, to a lesser degree, by a northwest-southeast and a northeast-southwest trend. The northwest-southeast trend is the least obvious. The main geomorphological expression of the Saddle Mountains results from an east-west-trending fold set dominated by the Saddle Mountains anticline and bounded on the north by the Saddle Mountains fault, interpreted here to be a thrust. Between Sentinel Gap and Smyrna Bench, the Saddle Mountains anticline is a broad fold with a complex set of smaller folds on the southern flank. Eastward, along Smyrna Bench, the structure is narrower and more tightly folded resembling a box fold. The axial trace of the anticline is south of the ridge crest and a monocline is north of the ridge crest.

Three structurally complex areas exist. One is on the south flank between Sentinel Gap and Smyrna Bench near DH-5. This is marked by a flexure in the Saddle Mountains anticline, a series of small folds, and a north-south fault along the trace of the flexure. The second is on the west edge of Smyrna Bench at the exposure of the Saddle Mountains fault. This area is marked by the intersection of several faults and the presence of a major northwest-southeast fold. The third is on the east edge of the area near a major flexure in the Saddle Mountains anticline.

The stratigraphic distribution of the flows, combined with the structural features, indicates a complex geologic history for the Saddle Mountains. The approximate sequence of events can be summarized as follows:

- Deposition of the Grande Ronde Basalt followed by the Vantage Sandstone;
- Uplift (?) near Sentinel Gap during the phyric Frenchman Springs time;
- The beginning of deformation along a northwest-southeast trend (the Smyrna Bench structure and Rye Grass structure?) in late Frenchman Springs time;
- Continued deformation along the northwest-southeast trend and development of an east-west-trending fold from Sentinel Gap to east of Wahatis Peak in "Roza-Like" time;
- Folding along the northwest-southeast trend and continued development of an east-west high in Priest Rapids and Umatilla time;

- Persistence of the topographic high between Sentinel Gap and Smyrna Bench, but breaching of the lower eastern part by streams during Wahluke and Huntzinger time;
- Persistence of the topographic high between Sentinel Gap and Smyrna Bench blocking the Pomona from spreading north of the Saddle Mountains ridge crest or west of Smyrna Bench (the Smyrna Bench fold was covered by the Pomona Flow on the southern flank, but flowed north on both sides of the structure);
- Deformation occurred along a northwest-southeast trend between Sentinel Gap and Smyrna Bench; Elephant Mountain flows filled structural troughs, but did not overflow onto the Saddle Mountains that formed a topographic high;
- Displacement on the Saddle Mountains fault after the Elephant Mountain flows;
- Continuation of folding along the Saddle Mountains anticline and deposition of sediment on Smyrna Bench, right lateral strike slip faulting associated with the different geometry along strike of the Saddle Mountains, and normal faulting on the west side of Smyrna Bench;
- Glacial flooding and erosion of Smyrna Bench and Crab Creek.

BIBLIOGRAPHY

Bentley, R. D., 1977, "Stratigraphy of the Yakima Basalts and Structural Evolution of the Yakima Ridges in the Western Columbia Plateau," in Brown, E. H., and Ellis, R. C., editors, Geological Excursions in the Pacific Northwest, Western Washington University, Bellingham, Washington, p. 339-389.

Bingham, J. W., Londquist, C. J., and Baltz, E. H., 1970, "Geologic Investigation of Faulting in the Hanford Region, Washington," with a section on the occurrence of microearthquakes by A. M. Pitt, U. S. Geological Survey, Open-File Report, 104 p.

Brown, D. J., and Ledgerwood, R. K., 1973, "Stratigraphy and Structure of Yakima Basalt in Pasco Basin, Washingtion," in Geologic Field Trips in Northern Oregon and Southern Washington, Bulletin 77, State of Oregon, Department of Geology and Mineral Industries, pp 171-181.

Calkins, F. C., 1905, "Geology and Water Resources of a Portion of East-Central Washington," U. S. Geological Survey Water-Supply Paper 118, 96 p.

Coe, R. S., Bogue, S., and Myers, C. W., 1978, Paleomagnetism of the Grande Ronde (Lower Yakima) Basalt Exposed at Sentinel Gap: Potential Use for Stratigraphic Correlation, RHO-BWI-ST-2, Rockwell Hanford Operations, Richland, Washington.

Grolier, M. J., 1965, Geology of Part of the Big Bend Area in the Columbia Plateau, Washington, Ph.D. Thesis, The Johns Hopkins University, Baltimore, Maryland, 264 p.

Grolier, M. J., and Bingham, J. W., 1965, Geologic Map and Sections for Parts of Grant, Adams, and Franklin Counties, Washington, U. S. Geological Survey, Washington State Department of Conservation Division of Water Resources Open-File Report.

Grolier, M. J., and Bingham, J. W., 1971, Geologic Map and Sections of Parts of Grant, Adams, and Franklin Counties, Washington, U. S. Geological Survey Miscellaneous Geologic Investigations Map I-589.

Grolier, M. J. and Bingham, J. W., 1978, "Geology of Parts of Grant, Adams, and Franklin Counties, East-Central Washington," Washington State Department of Natural Resources Division of Geology and Earth Resources Bulletin Number 71, 91 p.

Jahns, R. H., 1967, Geological Factors Relating to Engineering Seismology in the Hanford Area, Washington, DUN-3100, Douglas United Nuclear Industries, Inc., Richland, Washington, 32 p.

Jones, F. O. and Deacon, R. J., 1966, Geology and Tectonic History of the Hanford Area and its Relation to the Geology and Tectonic History of the State of Washington and the Active Seismic Zones of Western Washington and Western Montana, DUN 1410, Douglas United Nuclear Industries, Inc., Richland, Washington, 42 p.

Laval, W. N., 1956, Stratigraphy and Structural Geology of Portions of South-Central Washington, Ph.D Thesis, University of Washington, Seattle, Washington, 223 p.

Ledgerwood, R. K., Brown, D. J., Waters, A. C., and Myers, C. W., 1973, Identification of Yakima Basalt Flows in the Pasco Basin, ARH-2768, Atlantic Richfield Hanford Company, Richland Washington.

Ledgerwood, R. K., Myers, C. W., and Cross, R. W., 1978, Pasco Basin Stratigraphic Nomenclature, RHO-BWI-LD-1, Rockwell Hanford Operations, Richland, Washington.

Long, P. E., 1978, Characterization and Recognition of Intraflow Structures, Grande Ronde Basalt, RHO-BWI-LD-10, Rockwell Hanford Operations, Richland, Washington.

Mackin, J. H., 1955, Geology of the Priest Rapids Development, Priest Rapids Hydroelectric Development, Columbia River, Washington, Grant County Public Utility District, Ephrata, Washington, 43 p.

Mackin, J. H., 1961, "A Stratigraphic Section in the Yakima Basalt and the Ellensburg Formation in South-Central Washington," Washington Division of Mines and Geology, Report of Investigation Number 19, 45 p.

Myers, C. W., 1973, Yakima Basalt Flows Near Vantage, and from Core Holes in the Pasco Basin, Washington, Ph.D. Thesis, University of California at Santa Cruz, Santa Cruz, California, 147 p.

Price, S. M., 1977, An Evaluation of Dike-Flow Correlations Indicated by Geochemistry, Chief Joseph Swarm, Columbia River Basalt, Ph.D. Thesis, University of Idaho, Moscow, Idaho.

Russell, I. C., 1893, "A Geological Reconnaissance in Central Washington," U. S. Geological Survey Bulletin Number 108, 108 p.

Russell, I. C., 1901, "Geology and Water Resources of Nez Perce County Idaho," U. S. Geological Survey Water-Supply and Irrigation Paper Number 53, 141 p.

Schmincke, H. U., 1964, Petrology, Paleocurrents, and Stratigraphy of the Ellensburg Formation and Interbedded Yakima Basalt Flows, South-Central Washington, Ph.D. Thesis, The Johns Hopkins University, Baltimore, Maryland, 384 p.

Schmincke, H. U., 1967, "Stratigraphy and Petrography of Four Upper Yakima Basalt Flows in South-Central Washington," Geological Society of America Bulletin, 78, p. 1385-1422.

Smith, G. O., 1901, "Geology and Water Resources of a Portion of Yakima County," U. S. Geological Survey Water-Supply and Irrigation Paper Number 55, First Session, 65 p.

Smith, G. O., 1903, "Anticlinal Mountain Ridges in Central Washington," Journal of Geology, 11, p. 166-177.

Swanson, D. A., Wright, T. L., and Helz, R. T., 1975, "Linear Vent Systems and Estimated Rates of Magma Production and Eruption for the Yakima Basalt on the Columbia Plateau," American Journal of Science, 275 (8), p. 877-905

Swanson, D. A., Wright, T. L., Camp, V. E., Gardner, J. N., Helz, R. T., Price, S. A., and Ross, M. E., 1977, "Reconnaissance Geologic Map of the Columbia River Basalt Group, Pullman and Walla Walla Quadrangles, Southeast Washington and Adjacent Idaho," U. S. Geological Survey Open-File Report 77-100, Scale 1:250,000.

Swanson, D. A., Wright, T. L., Hooper, P. R., and Bentley, R. D., 1978, "Revisions in Stratigraphic Nomenclature of the Columbia River Basalt Group," U. S. Geological Survey Bulletin 1457, 92 p.

Symons, T. W., 1882, "The Upper Columbia River and the Great Plain of the Columbia," United States 47th Congress, 1st Session, General Executive Document 186, 133 p.

Taylor, T. L., 1976, The Basalt Stratigraphy and Structure of the Saddle Mountains of South-Central Washington, M. S. Thesis, Washington State University, Pullman, Washington, 116 p.

Turner, F. J., and Verhoogen, J., 1960, Igneous and Metamorphic Petrology, McGraw-Hill Book Company, New York, New York, 403 pp.

Twiss, S. N., 1933, Stratigraphy of the Saddle Mountains, Washington, M. S. Thesis, Washington State College, Pullman, Washington, 36 p.

Ward, A. W., Jr., 1976, Petrology and Chemistry of the Huntzinger Flow, Columbia River Basalt, Washington, ARH-SA-272, Atlantic Richfield Hanford Company, Richland, Washington, 52 p.

WPPSS, 1977, Preliminary Safety Analysis Report, Volumes 1 and 2, Amendment 23, Washington Public Power Supply System, Inc., Richland, Washington.

Watkins, N. D., and Baksi, A. K., 1974, "Magnetostratigraphy and Oroclinal Folding of the Columbia River, Steens, and Owyhee Basalts in Oregon, Washington, and Idaho," American Journal of Science, 274, p. 148-189.

Wright, T. L., Grolier, M. J., and Swanson, D. A., 1973, "Chemical Variation Related to the Stratigraphy of the Columbia River Basalt," Geological Society of America Bulletin, 84 (2), p. 371-385

DISTRIBUTION

Number of Copies	
1	J. F. T. AGAPITO
1	CENTRAL WASHINGTON UNIVERSITY
	Department of Geology
1	COLORADO SCHOOL OF MINES
1	J. W. CORWINE
1	GEOSCIENCE RESEARCH CONSULTANTS
	J. G. Bond
1	IDAHO BUREAU OF MINES AND GEOLOGY
	M. M. Miller
1	OREGON STATE DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
	J. D. Beaulieu
1	OREGON STATE UNIVERSITY
	Department of Geology

Distribution (continued)

Number of Copies	
1	PACIFIC NORTHWEST LABORATORY J. R. Raymond
1	F. L. PARKER
1	I. REMSON
1	R. SCHNEIDER
1	G. SERVOS
1	U. S. BUREAU OF RECLAMATION Columbia Basin Project Geologist
1	U. S. DEPARTMENT OF ENERGY-COLUMBUS PROGRAM OFFICE J. Neff
2	U. S. DEPARTMENT OF ENERGY-HEADQUARTERS M. W. Frei D. L. Vieth
3	U. S. DEPARTMENT OF ENERGY-RICHLAND OPERATIONS OFFICE R. B. Goranson D. J. Squires (2)
1	U. S. GEOLOGICAL SURVEY-WATER RESOURCES DIVISION C. Collier
1	U. S. GEOLOGICAL SURVEY-WESTERN DIVISION D. A. Swanson
1	UNIVERSITY OF IDAHO Department of Geology
1	UNIVERSITY OF WASHINGTON Department of Geology
1	WASHINGTON PUBLIC POWER SUPPLY SYSTEM, INC. D. D. Tillson
1	WASHINGTON STATE DEPARTMENT OF ECOLOGY P. M. Grimstad
1	WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES V. E. Livingston
1	WASHINGTON STATE UNIVERSITY Department of Geology

Distribution (continued)

Number of Copies	
1	A. C. WATERS
1	H. C. WEISENECK
1	WESTERN WASHINGTON UNIVERSITY Department of Geology
39	ROCKWELL HANFORD OPERATIONS H. Babad D. J. Brown D. J. Cockeram T. A. Curran (5) R. A. Deju (2) R. C. Edwards R. E. Gephart R. J. Gimera R. E. Isaacson C. W. Myers W. H. Price (5) Basalt Waste Isolation Program Library (15) Document Control (4)

Rockwell Hanford Operations	Basalt Waste Isolation Program	
PRELIMINARY GEOLOGIC MAP OF THE SADDLE MOUNTINS BETWEEN SENTINEL GAP AND LONGITUDE 119°30'	Appd. Program Dir. Date	Quality Assurance Date
	Appd. Unit Mngr. J. A. Curran 9/28/78	Appd. Project Mngr.
	Drafting Appd. Stephen Riedel 9/28/78	Responsible Engr. C. W. Myers 9/28/78
	Drawn Greg Clark 9/28/78	Review
	Scale	Drawing No. H-06-4600-1

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BEVERLY QUADRANGLE
WASHINGTON
7.5 MINUTE SERIES (TOPOGRAPHIC)
SW/4 BEVERLY 15' QUADRANGLE

Mapped, edited, and published by the Geological Survey

Control by USGS, USC&GS, and U.S. Bureau of Reclamation

Topography by photogrammetric methods from aerial photographs taken 1953 and from planetable surveys by USGS 1944 and USBR 1939–44. Revised from aerial photographs taken 1964
Field checked 1965

Polyconic projection. 1927 North American datum
10,000-foot grid based on Washington coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 11, shown in blue

Elevations at section corners are for top of marker

GN MN 2°08' 38 MILS 21° 373 MILS

UTM GRID AND 1965 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

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

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D.C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

WASHINGTON
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Medium-duty Light-duty
Unimproved dirt
State Route

BEVERLY, WASH.
SW/4 BEVERLY 15' QUADRANGLE
N4645—W11952.5/7.5
1965
AMS 2077 IV SW—SERIES V891

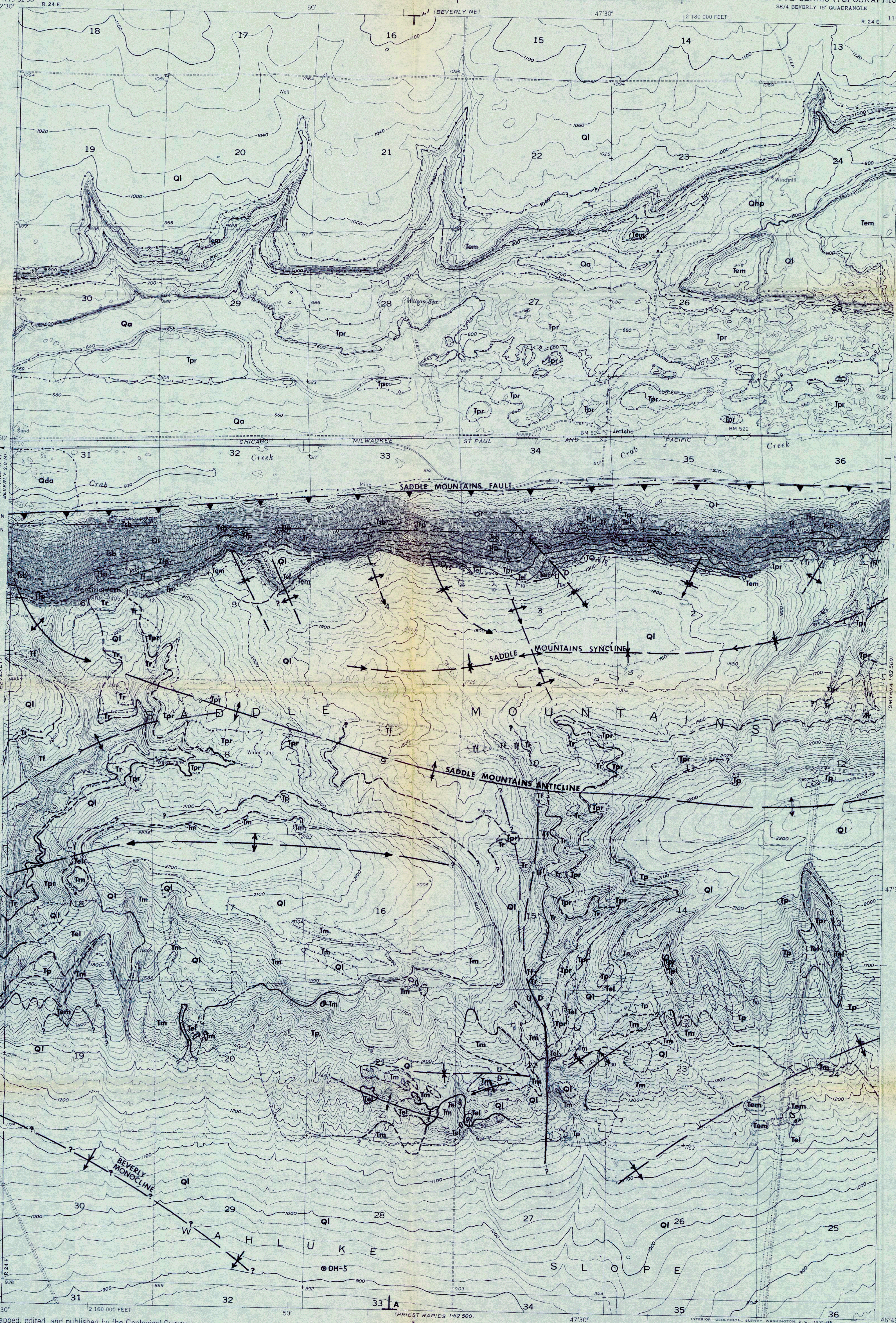
SPECIAL PRINTING
Contours and woodland symbols omitted

POCKET PART 1 OF 4 RHO-BWI-LD-4
PLATE 1 - PRELIMINARY GEOLOGIC MAP OF THE SADDLE MOUNTAINS BETWEEN SENTINEL GAP AND LONGITUDE 119° 30'

Rockwell Hanford Operations	Basalt Waste Isolation Program	
PRELIMINARY GEOLOGIC MAP OF THE SADDLE MOUNTAINS BETWEEN SENTINEL GAP AND LONGITUDE 119°30'	Appd. Program Dir. Date	Quality Assurance Date
	Appd. Unit Mngr. J.A. Cuman 9/28/78	Appd. Project Mngr.
	Drafting Appd. Stephen Riedel 9/28/78	Responsible Engr. C.W. Myers 9/28/78
	Drawn Greg Clark 9/28/78	Review
	Scale	Drawing No. H-06-4600-2

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BEVERLY SE QUADRANGLE
WASHINGTON–GRANT CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
SE/4 BEVERLY 15' QUADRANGLE



Mapped, edited, and published by the Geological Survey

Control by USGS, USC&GS and USBR

Topography from plane-table surveys by USBR 1939-1944 and by USGS from aerial photographs by multiplex methods
Aerial photographs taken 1953. Field check 1954

Polyconic projection. 1927 North American datum
10,000-foot grid based on Washington coordinate system, south zone

Dashed land lines indicate approximate locations

Elevations at section corners are for top of marker

APPROXIMATE MEAN DECLINATION, 1954

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

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

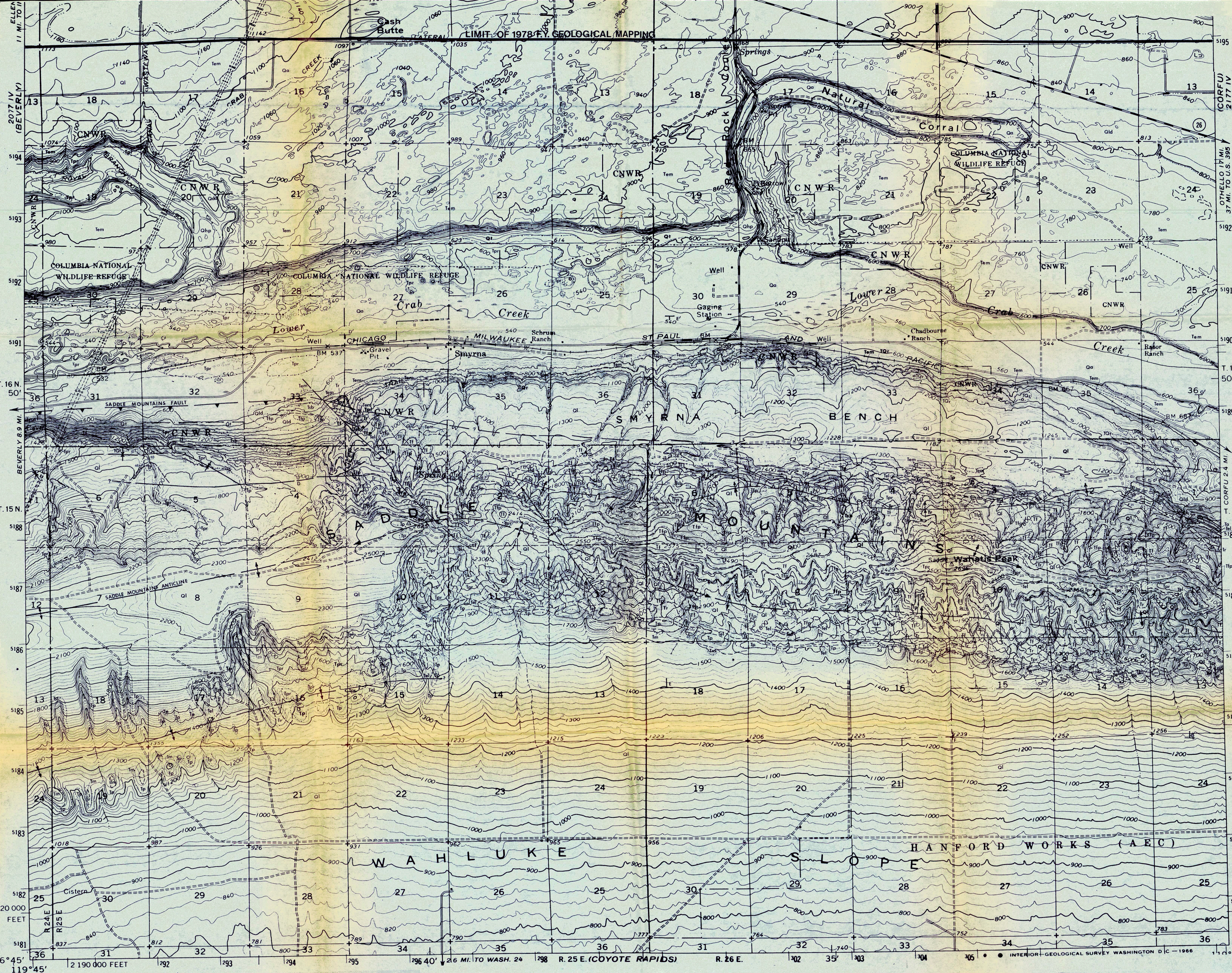
QUADRANGLE LOCATION

BEVERLY SE, WASH.
SE/4 BEVERLY 15' QUADRANGLE
N4645—W11945/7.5

1954

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER, COLORADO OR WASHINGTON 25, D. C.
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

POCKET PART 2 OF 4 RHO-BWI-LD-4
PLATE 2 - PRELIMINARY GEOLOGIC MAP OF THE SADDLE MOUNTAINS BETWEEN SENTINEL GAP AND LONGITUDE 119° 30'

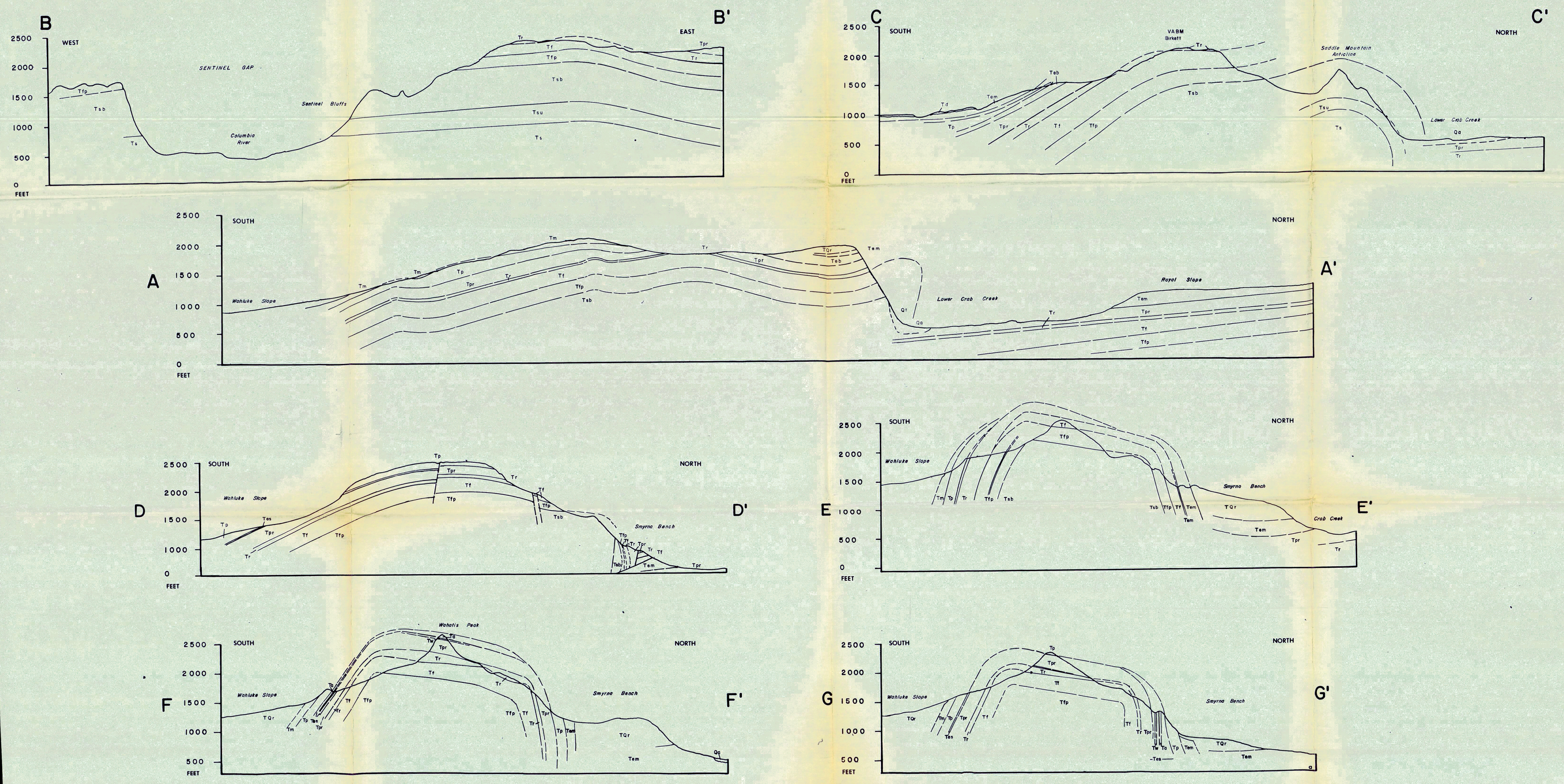


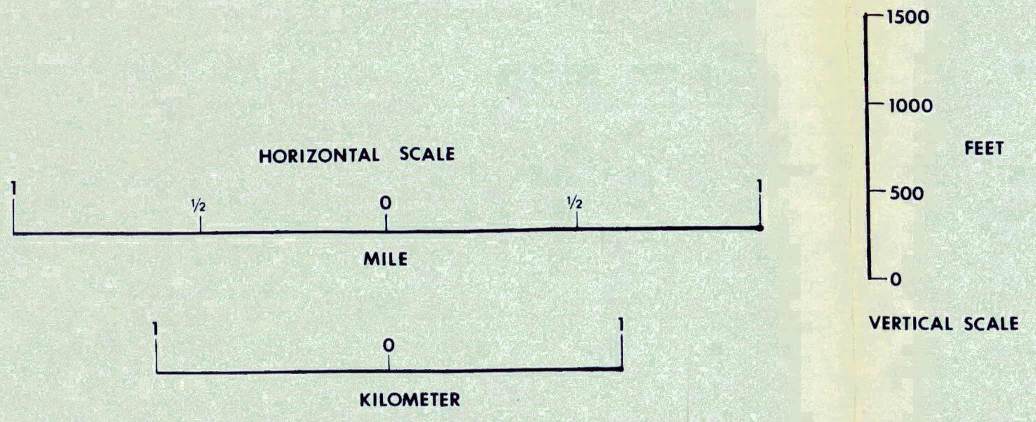
POCKET PART 3 OF 4 RHO-BWI-LD-4
PLATE 3 - PRELIMINARY GEOLOGIC MAP OF THE SADDLE MOUNTAINS
BETWEEN SENTINEL GAP AND LONGITUDE 119° 30'

Rockwell Hanford Operations	Basalt Waste Isolation Program	
PRELIMINARY GEOLOGIC MAP OF THE SADDLE MOUNTAINS BETWEEN SENTINEL GAP AND LONGITUDE 119°30'	Appd. Program Dir. Date	Quality Assurance Date
	Appd. Unit Mngr. A. Cilleran 9/28/78	Appd. Project Mngr.
	Drafting Appd. Stephen Reidel 9/28/78	Responsible Engr. R.W. Myers 9/28/78
	Drawn Greg M. Clark 9/28/78	Review
	Scale	Drawing No. H-06-4600-3

STRUCTURE CROSS SECTIONS OF THE SADDLE MOUNTAINS BETWEEN 119° 30' AND 120° 0' LONGITUDE

BY S.P. REIDEL





DRWG. NO.	DRAWING TITLE	MICRO FM'D	QUALITY ASSURANCE	RESPONSIBLE ENGINEER	DRAFTING	CHKD BY DATE	REV BY DATE	DESCRIPTION	REV. NO.
REFERENCE DRAWINGS			REVISION APPROVALS					REVISIONS	LAST REV.
NEXT USED ON			COMMENT PRT ISSUE NO.	DATE	CHECK PRT. ISSUE NO.	DATE		DRAWING STATUS	

DRAWING APPROVALS	DATE
APPD FOR QUALITY ASSURANCE	9/28/78
APPD S.A. Curren	9/28/78
APPD	
APPD	
RESPONSIBLE ENGINEER C.W. Myers	9/28/78
DRAFTING APPD Stephen Reidel	
CHECKED R.W. Cross	9/28/78
DRAWN Greg Clark	9/28/78
CLASSIFICATION	BY

U. S. Department of Energy
Richland Operations Office

Rockwell Hanford Operations
Richland, Washington 99352

STRUCTURE CROSS SECTIONS OF THE SADDLE MOUNTAINS BETWEEN 199°30' AND 120°0' LONGITUDE

SCALE | BLDG NO. | INDEX NO. 0301

DRAWING NO. H-06-4600-4 | SHEET NO. | SHEETS

POCKET PART 4 OF 4 RHO-BWI-LD-4
PLATE 4 - STRUCTURE CROSS SECTIONS OF THE SADDLE MOUNTAINS BETWEEN 119° 30' AND 120° 0' LONGITUDE