Attachment C

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SECTION NO.	REFERENCE NO.	DOCUMENT NO.
2.6	023	JABE-WADCO 04

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SUPPLEMENTARY GEOLOGIC INVESTIGATIONS FOR SEISMIC EVALUATION OF THE FFTF SITE NEAR RICHLAND WASHINGTON

Hanford Engineering Development Laboratory

Operated by the Westinghouse Hanford Company

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FOR DRAWINGS SEE APERTURE CARD

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Sec. No.	Ref. No.
2.6	023

1. Geologic Map and Cross Sections Along a Portion of the Horn Rapids Lineament Near Richland Washington Plate III

2. Photographs of the Ringold Formation on Bluffs East of the Columbia River Part 2, Plate 2

3. Geologic Map and Cross Sections Along a portion of the Horn Rapids Linament Near Richland, Washington Plate IV

4. Geologic Map and Cross Sections Along a Portion of the Horn Rapids Linement Near Richland Washington Plate V

5. Reconnaissance Geologic Map of Fast Flux Test Facility Site and Vicinity. Part 2 Plate 1

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FOR DRAWINGS SEE APERTURE CARD

Geol. Index -04

Sec. No. 2.6 ... No. 023

6. Geologic Map and Cross Sections Along a Portion of the Horse Heaven Hills, near Benton City in Benton County, Washington. Plate I
7. Geologic Map and Cross Sections Along a Portion of the Horse Heaven Hills, near Badger Canyon in Benton County, Washington Plate II

JAEE-WADCO-04

Supplementary Geologic Investigations for Seismic Evaluation of the FFTF Site Near Richland, Washington

Prepared for WADCO
of
Richland, Washington

February 1971

SUPPLEMENTARY GEOLOGIC INVESTIGATIONS FOR SEISMIC EVALUATION OF THE FFTF SITE NEAR RICHLAND, WASHINGTON

Prepared for WADCO

of

Richland, Washington

February 1971

by

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San Francisco, California 94105

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SUPPLEMENTARY GEOLOGIC INVESTIGATIONS FOR SEISMIC EVALUATION OF THE FFTF SITE NEAR RICHLAND, WASHINGTON

CONTENTS

Page

GEOLOGIC STRUCTURE

Illustrations, Part I, Section I.

Illustrations, Part I, Section I.

0 8 8 8 8 8 8 8 1 2 0

Part 1, Section 2

Geology Along the Horn Rapids Lineament

Illustrations, Part I, Section 2

Part 2

Geologic Reconnaissance in the Vicinity of the Fast Flux Test Facility Site near Richland, Washington.

Illustrations, Part 2

PREFACE

This document contains results of two recent geologic investigations and updates a report on an earlier investigation, all of which were located in or near the Hanford Atomic Energy Commission reservation in Washington. The investigations were required for seismic evaluation of the Fast Flux Test Facility (FFTF) site. The primary purpose was to identify and delineate faults which are near enough to the FFTF site to be considered in its seismic evaluation.

Two types of possible seismic hazard must be considered in seismic evaluation. One is vibratory motion due to a distant earthquake and the other is due to surface rupture along a fault which passes beneath, or very close to the facility. Therefore, geologic studies were carried out near the site to locate any possible evidence of surface faulting and geologic mapping was done at some distance from the site to evaluate faults or possible faults along which a major earthquake might be localized.

The first geologic study was carried out in May 1970 and consisted of geologic reconnaissance within 5 to 10 miles of the site. This survey was intended to reveal any possible evidence of faulting which might pass directly under the site or very close to it. No such evidence was found. A report on this investigation was submitted to Battelle Memorial Institute Pacific Northwest Laboratory (BNW) of Richland, Washington on June 17, 1970. It was titled, "Geologic Reconnaissance in the Vicinity of the Fast Flux Test Facility Site at Hanford, Washington." It has been updated and comprises Part 2 of this document.

Part 1 of this report is titled, "Geology Along A Portion of the Wallula Gap Fault Near Benton City, Washington With A Section on

Geology of the Horn Rapids Lineament." These two investigations were carried out separately. Geologic mapping along a line of basalt hills extending from Horn Rapids on the Yakima River to 1 mile south of Richland, Washington, called the Horn Rapids Lineament, was done in July 1970. Geologic mapping along part of the Wallula Gap fault was done in August and September 1970 and is the most comprehensive study. The report is accordingly more detailed and parts of it are applicable to the other two phases of field investigations. Therefore, the report pertaining to the Wallula Gap fault comprises the first section, the Horn Rapids Lineament report follows in Part 1, and the Geologic Reconnaissance report in Part 2 is last.

A chronological sequence of work performed by John A. Blume & Associates, Engineers related to seismic site evaluation of the Fast Flux Test Facility (FFTF) is given below.

A report titled, "Preliminary Report: Seismic and Geologic Siting Evaluation and Seismic Design Criteria for the Fast Flux Test Facility Site Near Richland, Washington" was submitted to BNW on December 1, 1969. This evaluation was based upon literature review and work done by others.

In May 1970, geologic reconnaissance was carried out near the site and a draft report describing the reconnaissance was submitted to BNW on June 17, 1970. The report was titled, "Geologic Reconnaissance in the Vicinity of the Fast Flux Test Facility Site at Hanford, Washington."

The reconnaissance report has been updated and is resubmitted as Part 2 of this document. In mid July 1970 ten man days were spent in geologic mapping along the Horn Rapids Lineament. The report on this work comprises the second section of Part 1 of this document.

In August 1970, a report titled "Seismic and Geologic Siting Evaluation Fast Flux Test Facility Near Richland, Washington" was submitted to WADCO.

In August and September 1970, thirty-six man days were spent in geologic mapping along a portion of the Wallula Gap fault near Badger Coulee and Benton City, Washington. Results of this work are described in the first section of Part 1 of this document.

Field work was done by Blume geologists Larry Tabor and Andrew Cunningham under the direction of Andrew Cunningham who also prepared the report.

Part 1, Section 1

GEOLOGY ALONG A PORTION OF THE WALLULA GAP FAULT IN THE HORSE HEAVEN HILLS NEAR BENTON CITY, WASHINGTON

with a section on

The Horn Rapids Lineament

Prepared for

WADCO

of

Richland, Washington

February 1971

By

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INTRODUCTION

This report describes a geologic investigation in the vicinity of Badger Coulee, about 7 miles southwest of Richland, Washington. The investigation was carried out by John A. Blume & Associates, Engineers (Blume), of San Francisco for WADCO of Richland, Washington.

The purpose of the study was to identify and delineate faults along the northeast slope of the Horse Heaven Hills. Knowledge of faulting in this region is necessary in determining seismic design criteria for the Fast Flux Test Facility (FFTF). Seismic and geologic evaluation of the FFTF site is presented in a prior report by Blume (August, 1970).

Because of the special aspect of this investigation which is concerned particularly with faulting, some topics normally included in a geologic study are omitted or abbreviated. Also, the mapped area was not examined in its entirety, but those areas which appeared to contain a maximum of structural information were mapped more completely than others.

The mapped area extends along the north slope of the Horse Heaven Hills from Badger Canyon northwest to the Yakima River and continues 2 miles beyond the river. It is about 14 miles long and varies in width from 1 to 2 miles. The hills are paralleled by Badger Coulee in the eastern and central part of the area. Thirty-six man days were spent during July and August, 1970, in geologic mapping which was done on aerial photographs at a scale of 1 in. equals 500 ft. Fifty-one samples of basalt were taken and submitted for chemical analysis of iron, calcium, potassium and barium content.

The cooperation of Randall E. Brown of Battelle Northwest Institute and Donald J. Brown of Atlantic Richfield Hanford Corporation in providing unpublished data and other assistance is gratefully acknowledged. However, John A. Blume & Associates, Engineers is responsible for the contents and conclusions of this report.

GENERAL GEOLOGY AND SUMMARY

Geology of the Columbia Plateau has been the subject of numerous studies, most of which were concerned with broad regional aspects. In recent years the work of Laval (1956), Schmincke (1967), and others has provided a background of structural and stratigraphic information which is applicable to the Horse Heaven Hills area. Laval did limited geologic mapping in the area as part of a study which included a much larger region. Schmincke's work was primarily concerned with correlating stratigraphic units. His sample locations and cross sections traversed the area. The impetus for the present investigation was provided partly by recent work of Bingham, Londquist and Baltz (1970) who noted that the projected extension of the Wallula Gap fault mapped by them at Yellepit would lie along the north margin of the Horse Heaven Hills where it would be buried by Touchet beds.

Figure 1 shows the location of the mapped area in relation to the FFTF Site and of geologic maps Plate I and Plate II.

The rocks exposed in the study area consist of Mio-Pliocene age basalt flows which are the uppermost part of the Yakima basalt formation. The flows are separated by intercalated beds of unconsolidated volcanoclastic sediments belonging to the Ellensberg formation. Stratigraphic terminology adopted by Schmincke (1967) and Bingham, Londquist and Baltz (1970) has been followed in this study with minor changes in each. From oldest to youngest the mapped units are the Priest Rapids Flow No. 3, the Mabton interbed, Priest Rapids Flow No. 4 (Umatilla), the Selah interbed, the Pomona Flow, the Rattlesnake Ridge interbed, and the Elephant Mountain Flow.

Figure 2 is a simplified stratigraphic section and shows the relationship of flows and interbeds.

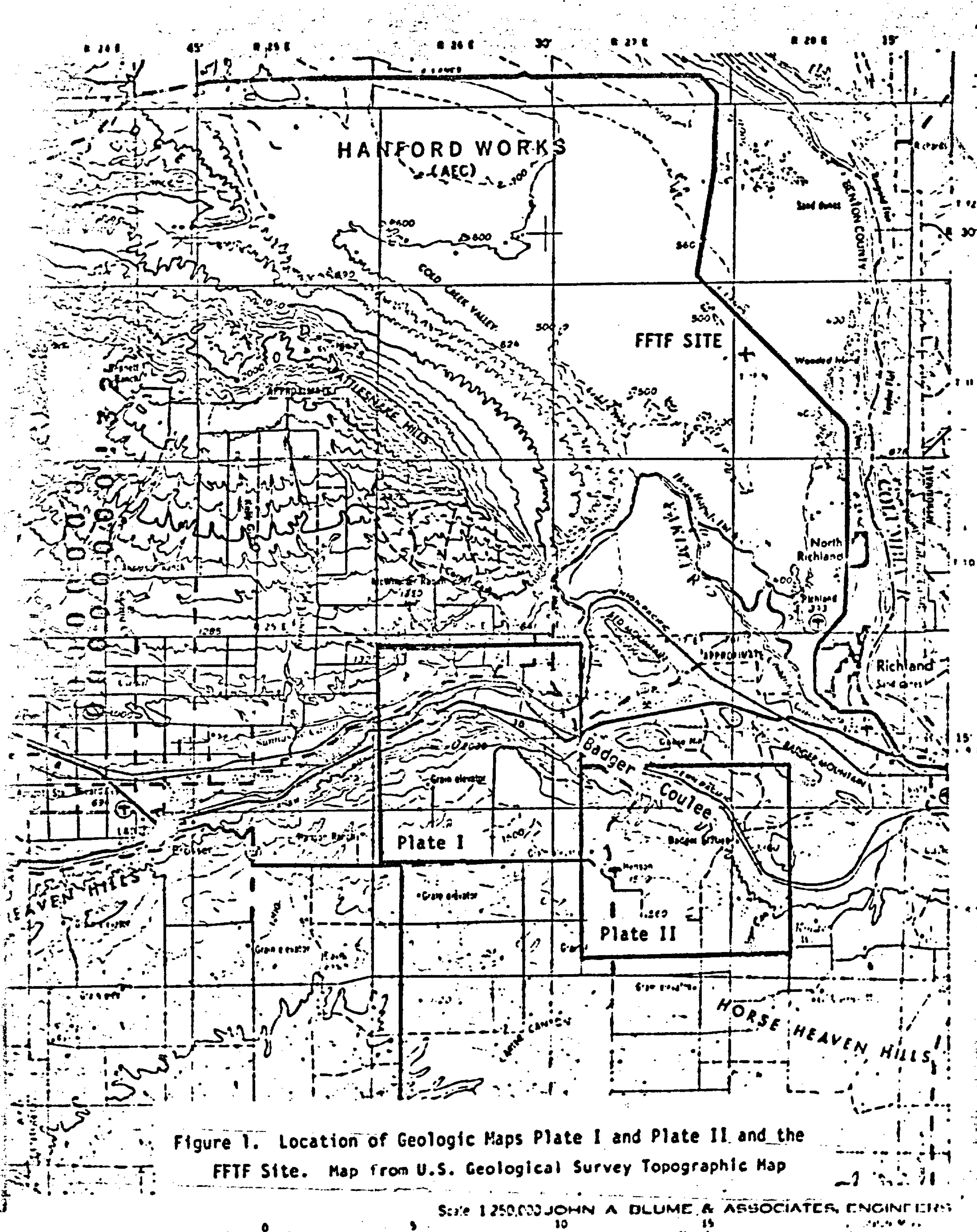

Figure 1. Location of Geologic Maps Plate I and Plate II and the FFTF Site. Map from U.S. Geological Survey Topographic Map

JOHN A. BLUME & ASSOCIATES, ENGINEERS

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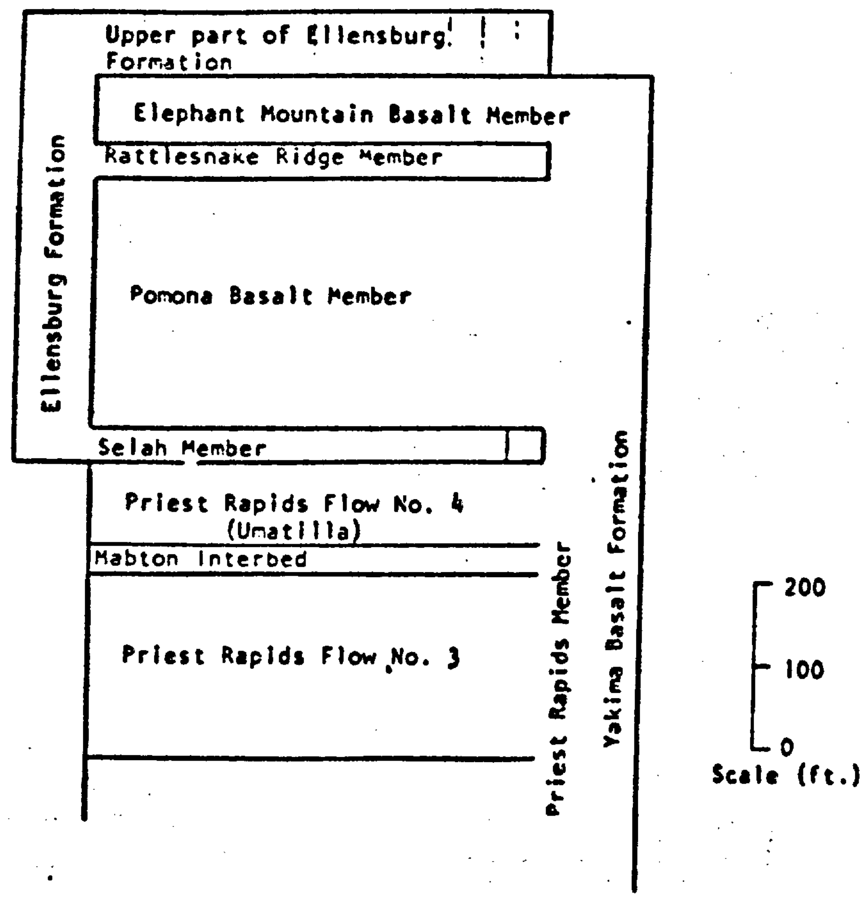
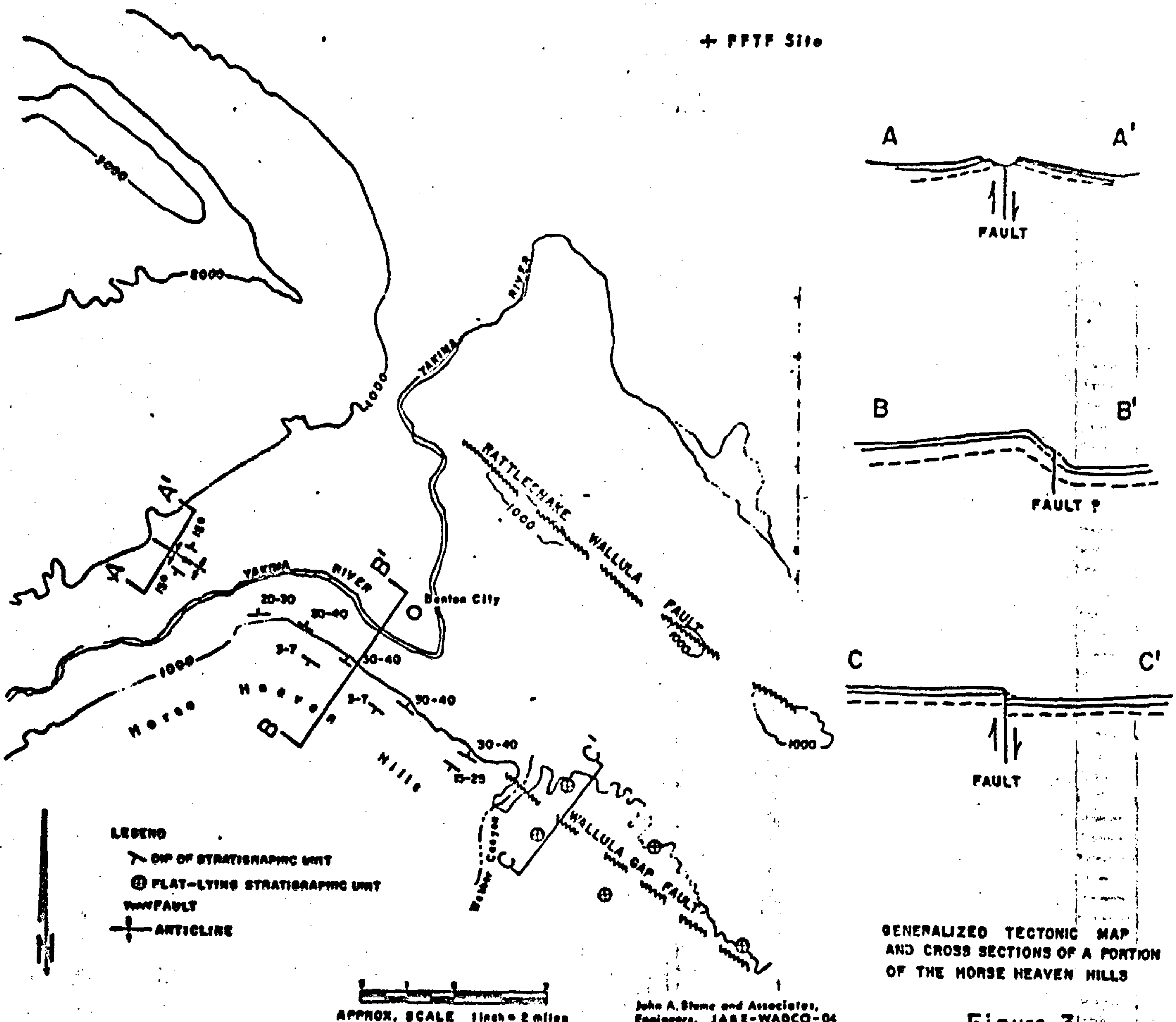


Figure 2. Simplified stratigraphic section showing upper basalt flows of the Yakima basalt formation and interstratified sediments of the Ellensburg formation. Modified after Schmincke (1967). Field mapping included all of the units shown below the upper Ellensburg.

The geologic structures in the area are of three distinct types. A small breached anticline is located in the northwest sector with an axial plane fault having about 50 ft displacement downward to the northeast (See section A-A', Figure 3). A monocline forms part of the crest of the Horse Heaven Hills in the central sector. Limited exposures do not provide sufficient data to determine whether or not faulting which might have contributed to elevation of the hills occurs along the steep northeast flank of the monocline (See section B-B', Figure 3). The southeasterly sector is occupied by flat-lying basalt flows and interbeds which are transected by the Wallula Gap fault. Displacement of about 300 ft downward to the northeast has taken place on the fault. The geologic structure is simplified and illustrated in Figure 3, section C-C'.

This investigation therefore confirms that the Wallula Gap fault extends northwest from Yellepit to the Horse Heaven Hills as suggested by the U.S. Geological Survey (Bingham, Londquist and Baltz, 1970). It is concluded that the Wallula Gap fault is a lesser fault or at most, it might be considered equal in size. As the Wallula Gap fault is a greater distance from the FFTF site it is concluded that the Rattlesnake-Wallula fault is the fault capable of producing maximum vibratory ground motion at the site.



GENERALIZED TECTONIC MAP AND CROSS SECTIONS OF A PORTION OF THE HORSE HEAVEN HILLS

Figure 3

CHEMICAL ANALYSIS

General Statement

Mapping of the layered basalt flows is difficult because the flows are similar in appearance, and a prominent feature seen in one flow may occur in others. It is often necessary or desirable to identify a flow where only parts of it are exposed in isolated outcrops. Schmincke's work was addressed specifically to the problem of flow identification. Schmincke, (1967) studied most of the geologic properties of the flows including their physical appearance in the field, their megascopic and microscopic petrography, primary structures, weathering characteristics, optical properties of certain minerals within the flows, refractive index of fused beads from the flows, and chemical composition. Of the many properties studied, chemical composition is fundamental because other properties are influenced by or determined by the chemical composition. However, it is important to consider all properties to determine which of them if any are diagnostic of certain flows, as Schmincke has done.

Schmincke has noted that field criteria for identification of the flows is not diagnostic and, "a flow so identified should be correlated at new outcrops only if the over and underlying flows can also be identified. Although helpful, this type of identification and correlation is highly controversial."

In the present structural geology investigation, no microscopic or detailed petrographic studies were made due to time and budgetary limitations. Reliance was placed upon features of the rocks which could be observed in the field and upon chemical analysis.

Discussion of Results

Chemical analyses of the basalt flows of South Central Washington by Schmincke (1967) and others have shown that some of the flows can be distinguished by their chemical composition. Current studies being carried out by D. Brown (1970) of Atlantic Richfield Company have confirmed and added to the earlier findings of Schmincke and when completed, will provide more comprehensive chemical data on a much thicker sequence of basalt flows.

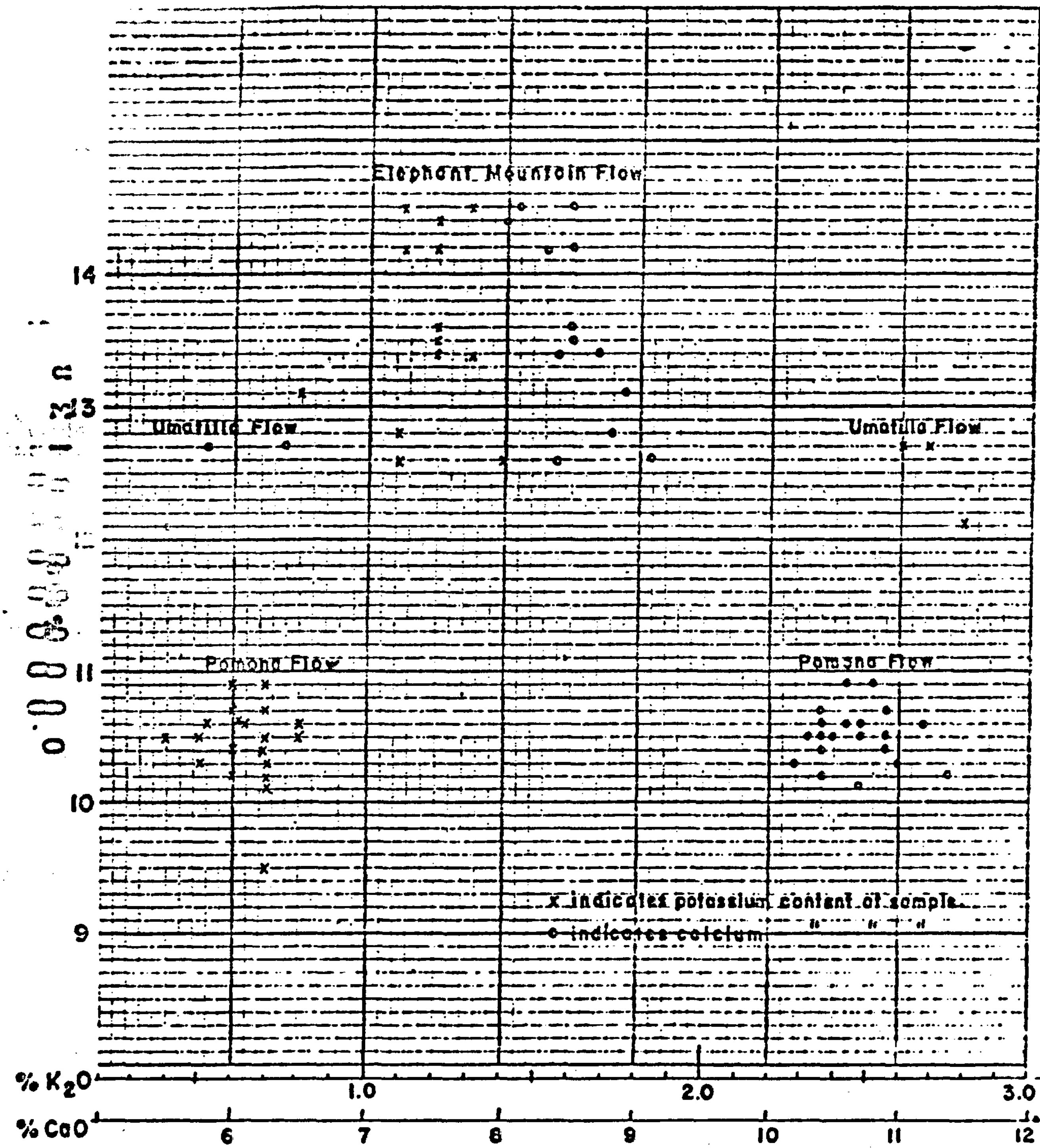
Preliminary results of work by D. Brown (1970) show that the Priest Rapids flows No. 3 and No. 4 are distinguished by their high barium content. Schmincke's work indicates that among the four flows studied by him, the Pomona Flow is distinguished by relatively low iron and potassium and high calcium content.

These chemical criteria were used to identify the Pomona and Priest Rapids flow No. 3 and Priest Rapids flow No. 4. Chemical compositions of other flows is not clearly distinctive and therefore other flows were not identified by their chemical composition.

Fifty-one rock samples from the Badger Coulee area were analyzed for iron, calcium, potassium, and barium content by Skyline Laboratories of Wheatridge, Colorado. The total iron content of these samples is reported as FeO as was done by Schmincke. Results of the analyses are plotted on Figures 5, 6, 7, and 8. Figure 4 is a similar plot of chemical data taken from Schmincke (1967).

The grouping of plotted points representing samples of the Pomona flow from the Badger Coulee area (Figure 8) is similar to the grouping of points which represent samples from the Pomona flow in Schmincke's data (Figure 4). Sample number 56 is from a locality of the Pomona which was also sampled by Schmincke. The locality is a high cut on Highway 3 about 3/4 of a mile west of Kiona.

Iron content of basalt samples as determined by Skyline Laboratories is consistently about one percent higher than the values cited by Schmincke. The reason for this discrepancy is not known; however, the distinction between basalt flows is clear in either case.



Chemical Analysis of Basalt Flows from Central Washington after Schmincke (1967)

Fig. 4

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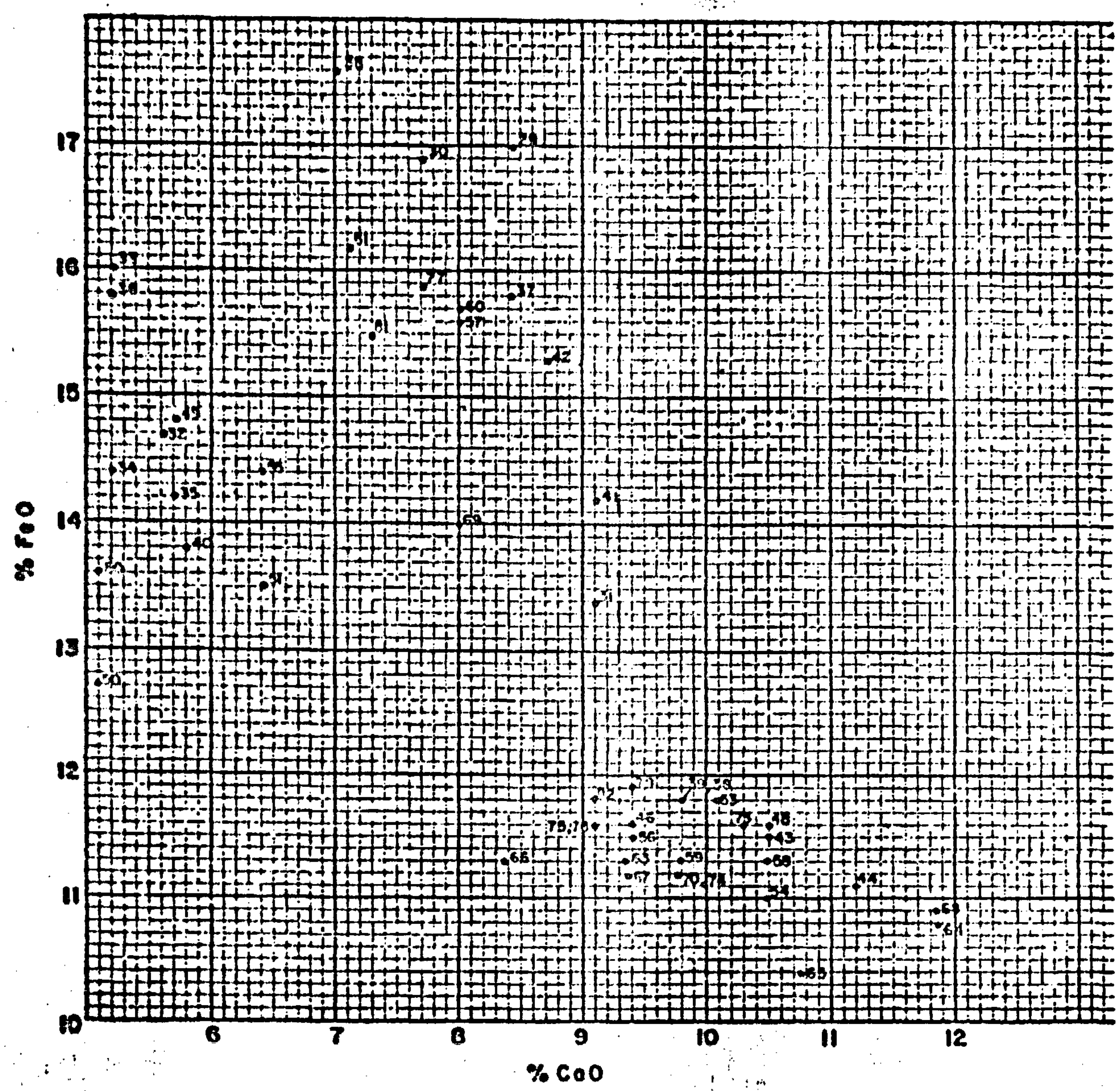
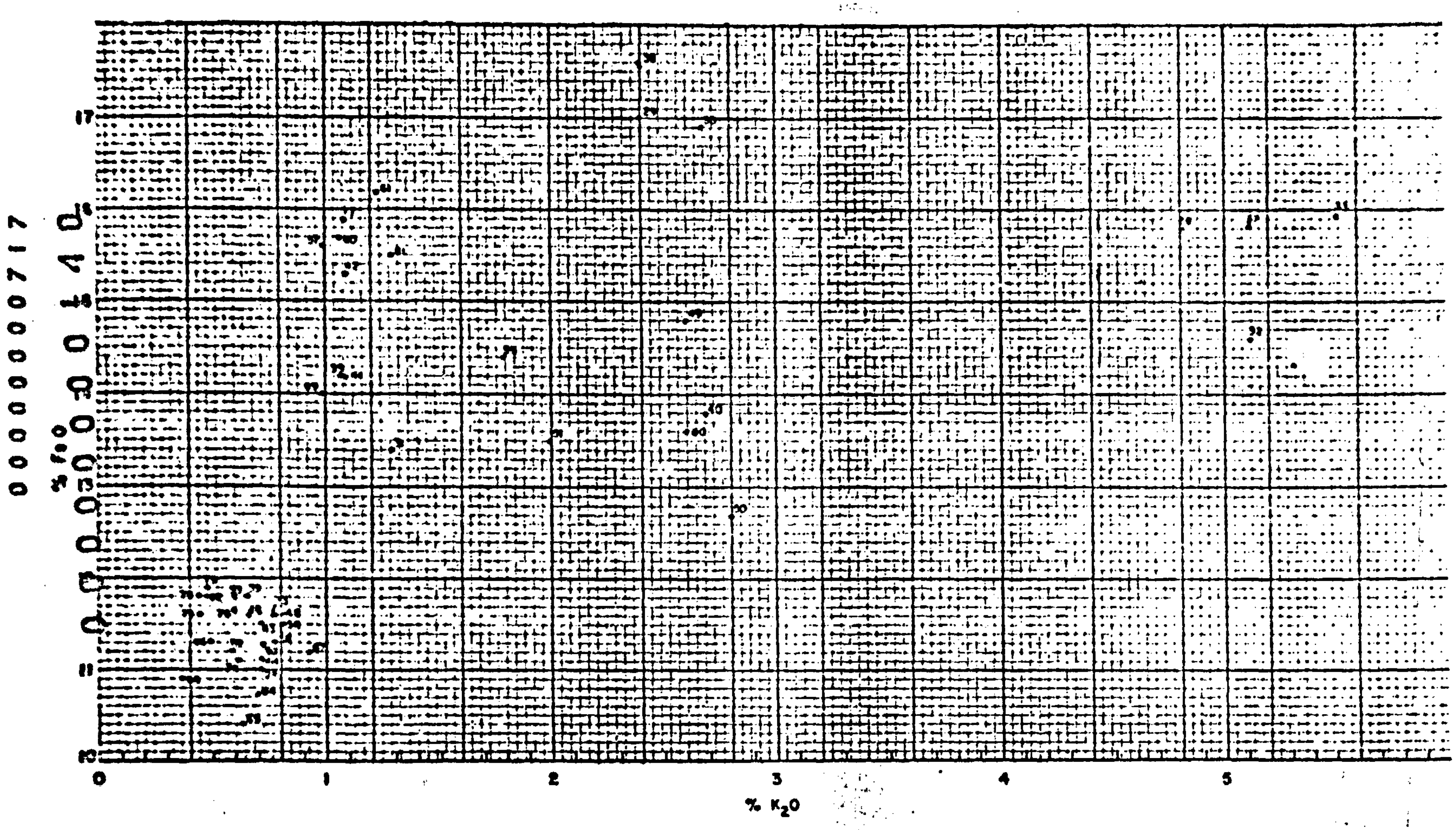


Chemical analysis of iron and calcium content of samples from Badger Coulee area.
Showing sample numbers



Chemical analysis of iron and potassium content of samples from Badger Coulee area showing sample numbers.

Fig. 6

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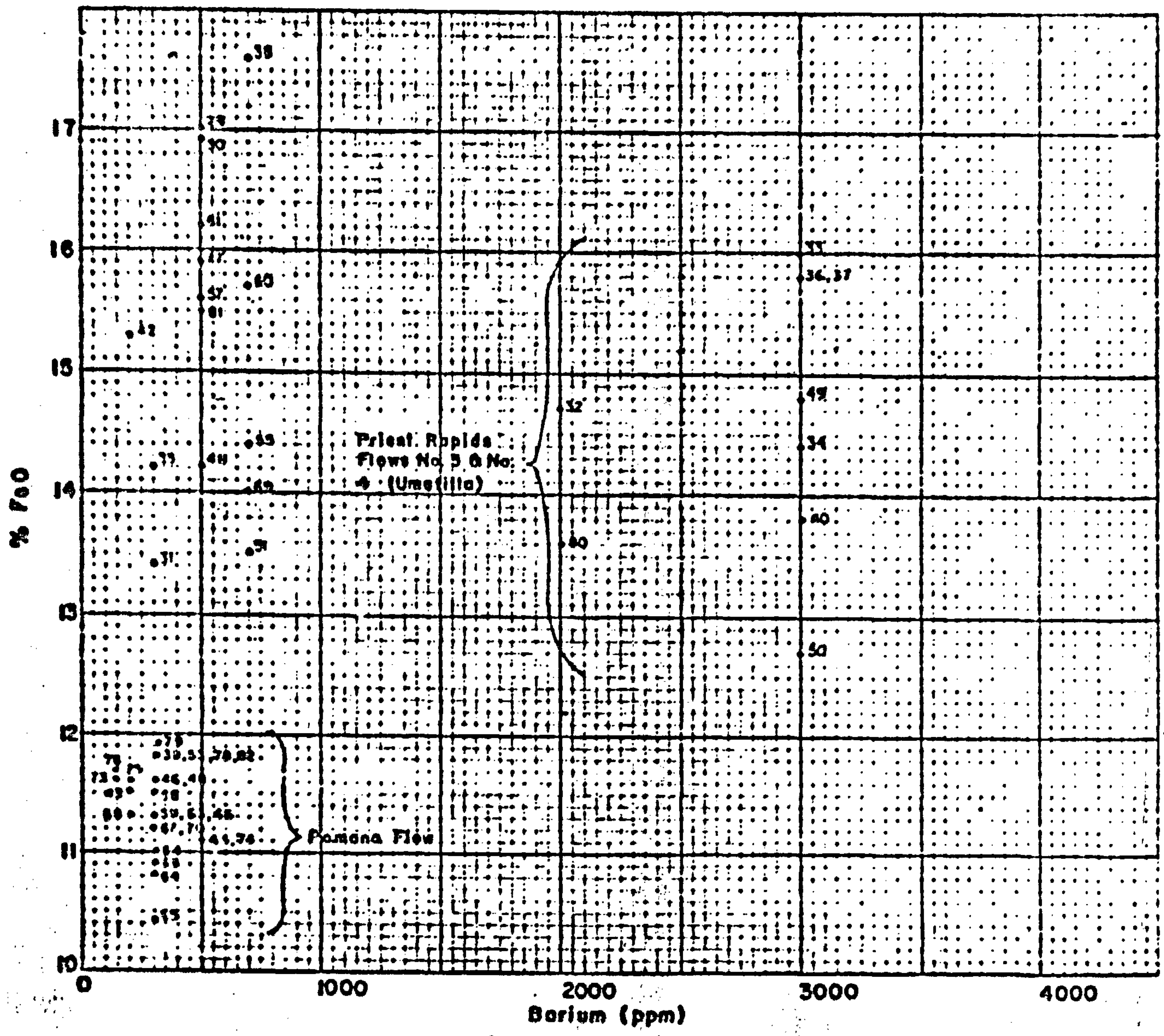
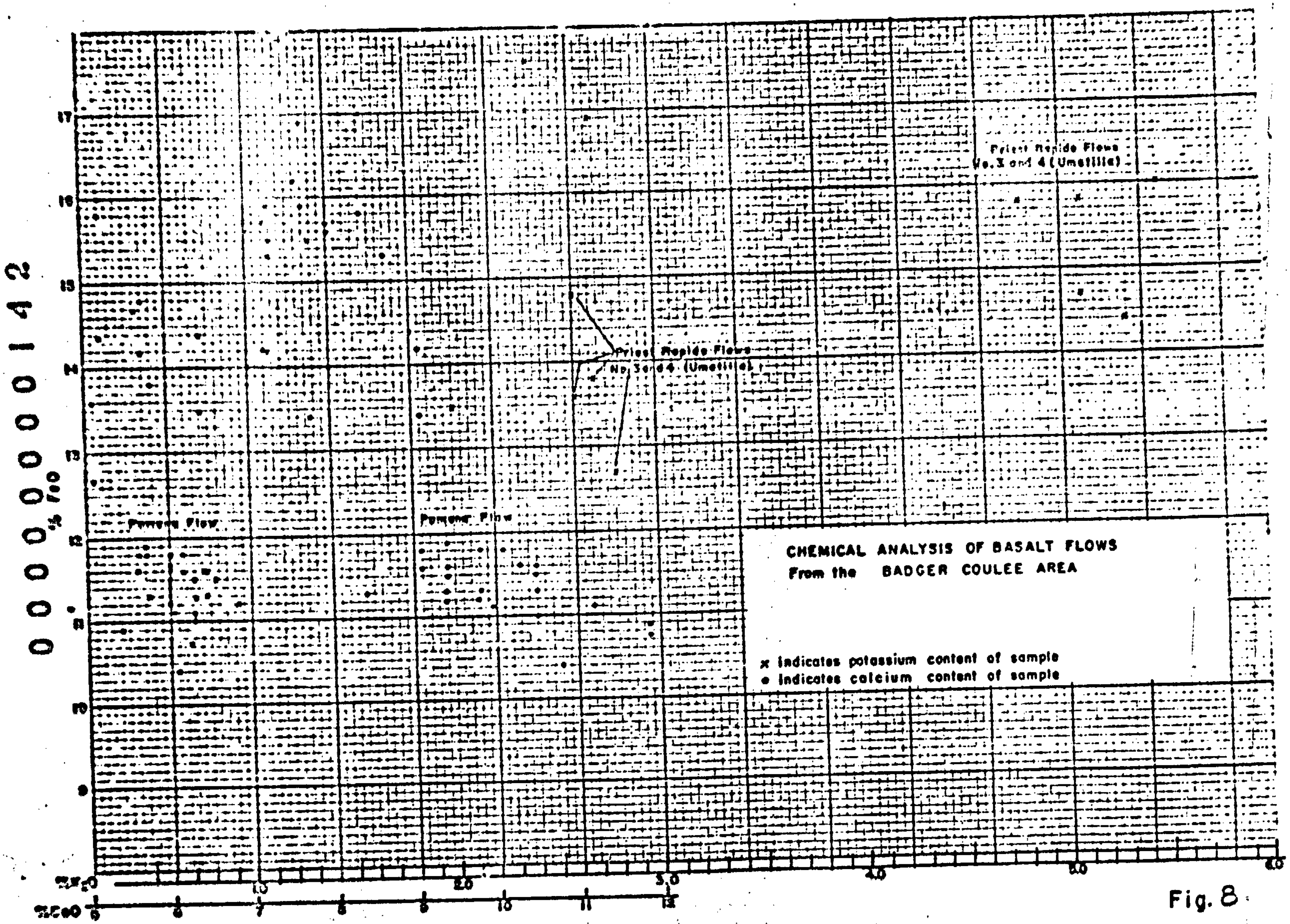


Chemical analysis of iron and barium content of samples from Badger Coulee area. Showing sample numbers



CHEMICAL ANALYSIS OF BASALT FLOWS
From the BADGER COULEE AREA
x indicates potassium content of sample
• indicates calcium content of sample
Pomona Flow
Pomona Flow
Priest Rapids Flows
No. 3 and 4 (Umatilla)
Priest Rapids Flows
No. 3 and 4 (Umatilla)
% FeO
% K_2O
% CaO

Fig. 8

Barium content of samples is plotted in Figure 7. Nine samples contain 2000 or more parts per million (ppm) of barium while the remaining samples contain 700 ppm or less. The nine samples are from the two flows of the upper part of the Priest Rapids member of the Yakima Basalt formation.

The chemical data show that two flows sampled in sec. 15, T.9 N., R.29 E., which are separated by a sedimentary interbed are both high in barium. The uppermost of these flows lies below the Pomona flow and corresponds to the Umatilla flow of Schmincke and Laval. They considered the sedimentary interbed to be the Mabton bed. Bingham, Londquist and Baltz designate the flow below the Pomona as "Priest Rapids flow No. 4" and accordingly the 2nd flow would correspond to their Priest Rapids flow No. 3. These workers placed the Mabton bed below flow No. 3 rather than above it, as Schmincke and Laval had done. Laval (1965, p. 43) refers to the red alteration zone at the top of the Mabton interbed in this locality which clearly corresponds to the interbed between Priest Rapids flow No. 3 and 4 in sec. 15. In this report the terminology of Bingham, Londquist and Baltz will be followed. The uppermost flow is therefore the Priest Rapids flow No. 4 (Umatilla) and the second barium-rich flow is the Priest Rapids flow No. 3. The interbed which separates these two flows will be called the Mabton interbed in accordance with the work of Schmincke and Laval.

Three samples were run in duplicate to determine approximately what amount of variation is present within a single sample. Duplicate samples were prepared by selecting two identical 1/2 lb. samples from an original 10 lb. sample. The samples which were run in duplicate were numbers 73, 74, and 75. Variations in iron and calcium content were on the order of several tenths of a percent and variations in potassium content amounted to several hundredths of a percent. The spectrographic method used in determining barium is not highly accurate but shows that the values for duplicated determinations of barium are comparable. The results are in agreement with Schmincke (1967) who found that analyses of basalt flows were reproduceable within similar limits.

Four analyses gave anomalous results. That is, the results did not correspond to results of other samples or to flow identification based upon geologic evidence. The samples are numbered 31, 35, 41 and 42. The results are being evaluated based upon more comprehensive chemical data.

Results of analyses and flow identification derived from the data are compiled in Table 1. With exceptions noted above these determinations are in agreement with determinations which were made independently based upon geologic field evidence.

TABLE 1

RESULTS OF CHEMICAL ANALYSIS OF SAMPLES FROM THE BADGER COULEE AREA, SHOWING SAMPLE LOCATION AND FLOW DESIGNATION

Sample Number	Location: 1/4 Sec.	Sec.	Township (North)	Range (East)	Chemical Analysis: FeO (%)	CaO (%)	K_2O (%)	Barium (ppm)	Flow Designation
29	NE	22	9	26	17.0	8.4	2.4	500	
30	NE	22	9	26	16.9	7.7	2.7	500	
31	NE	22	9	26	13.4	9.1	1.3	300	
32	SE	15	9	26	14.7	5.6	5.1	2,000	Typr3 or Typr4
33	SE	15	9	26	16.0	5.2	5.5	3,000	- same -
34	SE	15	9	26	14.4	5.2	5.3	3,000	- same -
35	SE	33	9	27	14.2	5.7	1.1	300	
36	NW	4	8	27	15.8	5.2	5.1	3,000	Typr3 or Typr4
37	NE	8	8	27	15.8	8.4	4.8	3,000	- same -
38	SE	33	9	27	17.6	7.0	2.4	700	
39	NW	29	8	28	11.8	9.8	0.7	300	Pomona
40	NW	29	8	28	13.8	5.8	2.7	3,000	Typr3 or Typr4
41	SE	30	8	28	14.2	9.1	1.1	500	
42	NE	19	8	28	15.3	8.7	1.1	200	
43	SE	18	8	28	11.5	10.5	0.7	200	Pomona
44	SE	18	8	28	11.1	11.2	0.7	500	Pomona
46	SE	12	8	27	11.6	9.4	0.7	300	Pomona
48	NE	11	8	27	11.6	10.5	0.8	300	Pomona
49	NW	15	9	26	13.8	5.7	2.6	3,000	Typr3 or Typr4
50	NW	15	9	26	12.7	5.1	2.8	3,000	- same -
51	NW	15	9	26	13.5	6.4	2.0	700	
53	SE	15	9	26	11.8	10.1	0.6	300	Pomona
54	SE	15	9	26	11.0	10.5	0.7	300	Pomona
55	SE	15	9	26	14.4	6.4	1.8	700	
56	NW	19	9	27	11.5	9.4	0.8	300	Pomona

Sample Number	Location				Chemical Analysis				Flow Designation
	1/4 Sec.	Sec.	Township (North)	Range (East)	FeO (%)	CaO (%)	K_2O (%)	Barium (ppm)	
57	NE	24	9	26	15.6	8.0	1.0	500	
58	NE	25	9	26	11.3	10.5	0.7	200	Pomona
59	SW	33	9	27	11.3	9.8	0.7	300	Pomona
60	SE	32	9	27	15.7	8.0	1.1	700	
61	NW	32	9	27	16.2	7.1	1.3	500	
63	NW	25	9	26	11.3	9.4	0.7	300	Pomona
64	NE	33	9	27	10.6	11.9	0.7	300	Pomona
65	NW	34	9	27	10.4	10.8	0.6	300	Pomona
66	NE	8	8	27	11.3	8.4	0.5	300	Pomona
67	NW	4	8	27	11.2	9.4	0.5	300	Pomona
68	NW	33	9	27	10.9	11.9	0.4	300	Pomona
69	SW	30	9	27	14.6	8.0	1.0	700	
70	NE	23	9	26	11.2	9.8	0.6	300	Pomona
73	NE	22	9	26	11.6	10.5	0.78	150	Pomona
73B	NE	22	9	26	11.5	10.1	0.75	100	
74	NW	23	9	26	11.3	10.5	0.60	500	Pomona
74B	NW	23	9	26	10.9	9.4	0.61	500	
75	NW	23	9	26	11.9	9.1	0.49	200	Pomona
75B	NW	23	9	26	11.3	9.1	0.41	200	
76	SE	33	9	27	11.6	9.1	0.6	200	Pomona
77	SE	8	8	27	15.9	7.7	1.1	500	
78	NE	8	8	27	11.8	9.8	0.5	300	Pomona
79	NE	8	8	27	11.9	9.4	0.5	300	Pomona
80	NE	8	8	27	13.6	5.1	2.6	2,000	Typr3 or Typr4
81	SE	29	9	27	15.5	7.3	1.3	500	
82	SW	28	9	27	11.8	9.1	0.5	300	Pomona

STRATIGRAPHY

General Statement

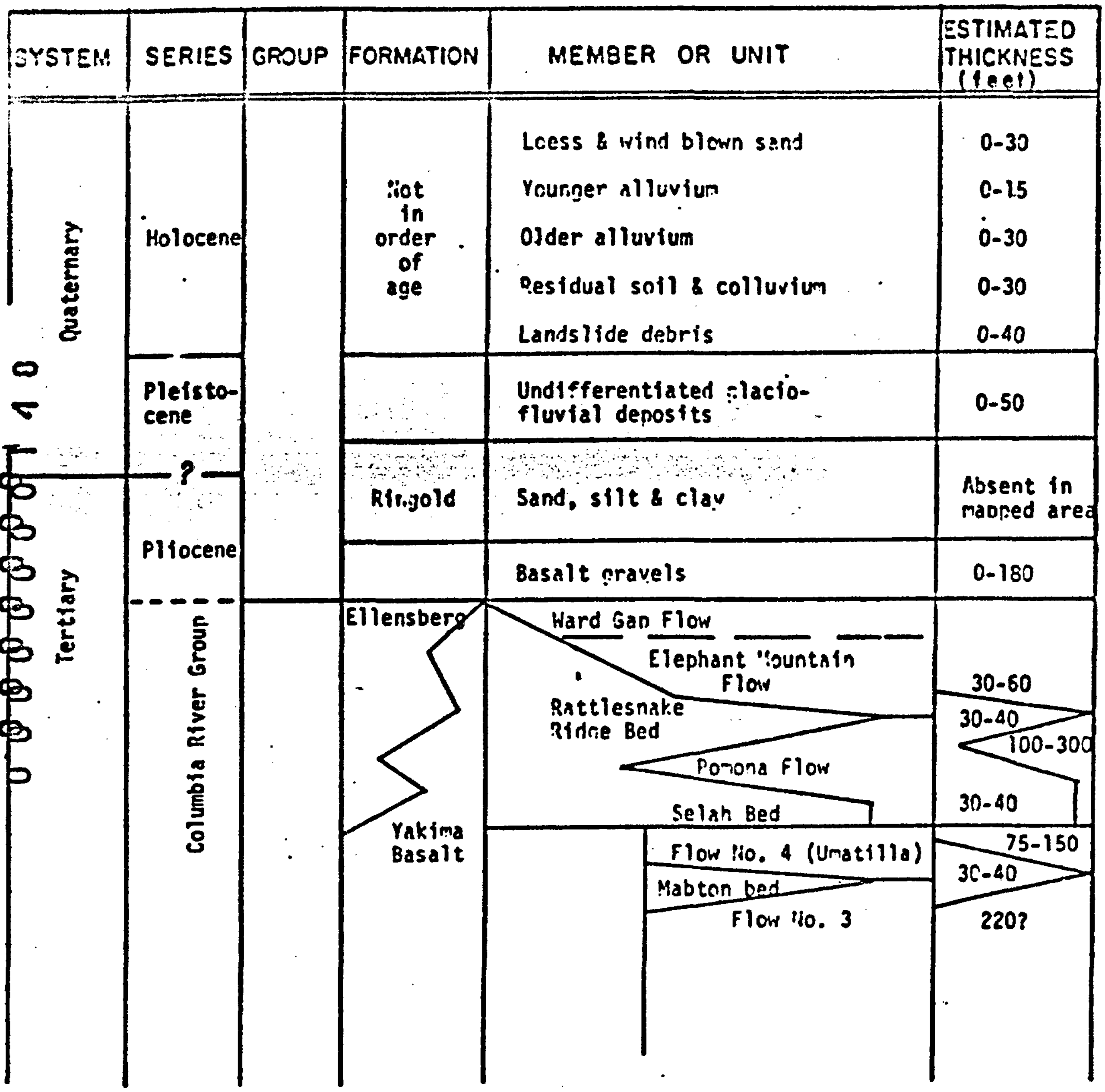
The nomenclature adopted by the U.S. Geological Survey (Bingham, Londquist and Baltz, et al, 1970) is followed in this work with one minor modification which places the Mabton interbed between Priest Rapids flows No. 3 and 4 instead of below Priest Rapids flow No. 3. This nomenclature also corresponds closely to that followed by Schmincke (1967). (See Figure 9).

The stratigraphic units which were observed and mapped in the field from oldest to youngest are the Priest Rapids flow No. 3, the Mabton interbed, Priest Rapids flow No. 4, the Selah interbed, the Pomona flow, the Rattlesnake Ridge interbed, and the Elephant Mountain flow. Surficial materials which are not listed in order of age consist of residual soil and colluvium, loess, younger alluvium, older alluvium, basalt gravels, landslide debris, and glaciofluvial deposits.

Sedimentary interbeds are not generally useful as recognizable stratigraphic horizons because of their great lateral variability in petrography and thickness and the scarcity of outcrops.

The Ward Gap flow, a thin unit lying upon the Elephant Mountain flow was not differentiated. The petrography of the basalt flows and sedimentary interbeds has been described most recently in detail by Schmincke and previously by others. The flows are tholeittic basalt. Tholeittic basalt is common to most continental flood basalt provinces throughout the world and its occurrence is usually continental. As described by Schmincke, the chief mineral constituents in the flows are "plagioclase, clinopyroxene, iron titanium ores and olivine. Apatite occurs in all the flows but cristobalite and zeolite are rare. A mineraloid (green, yellow or brown chlorophaeite) is ubiquitous in vesicles, cracks and along grain boundaries."

FIGURE SHOWING PRINCIPAL MAP UNITS, THEIR THICKNESS AND AGE RELATIONSHIPS



Modified after Bingham
Londquist and Baltz (1970)

FIGURE 9

Differences in crystallinity and other textural variations as well as compositional differences occur within flows. Schmincke (1967) states, "In addition to intraflow variations significant interflow differences in textures and modal, mineral, and chemical compositions also exist between most flows. They are most obvious in comparisons of rocks of similar crystallinity."

Useful criteria in field identification of flows are the usually coarser grain size and lighter color of the Elephant Mountain flow and the finer grain size and darker, nearly blue-black color of the Pomona flow. Sinuous columnar jointing forming columns 6" to 9" in diameter is typical of the Pomona while the Elephant Mountain flow is often more massive. The Pomona tends to weather into equidimensional, angular blocks and the Elephant Mountain flow often weathers to sub-rounded, bouldery shapes. The Priest Rapids flow No. 4 resembles the Pomona flow in most of its megascopic features. Priest Rapids flow No. 3 is also a dense, dark blueish-black, fine grained basalt. A distinctive feature of the central part of this flow in the mapped area consists of closely spaced fracturing which forms elongate, prismatic, or tabular pieces. The fragments are typically 6" to 9" in width and often up to 2 or 3 ft in length. These fragments usually produce a distinctive ringing sound when struck.

Priest Rapids Flow No. 3

The Priest Rapids flow No. 3 is the oldest known rock unit exposed in the mapped area. Its base is not known to be exposed. It crops out in Webber Canyon, in sec. 15 and sec. 22, T.9N., R.29 E., and possibly in Badger Canyon.

The upper portion of the flow is widely exposed in sec. 15 and 22 about 3 miles west of Kiona where it consists of highly scoriaceous and vesicular basalt or clinker. It forms rough, jagged, spinose outcrops consisting of aphanitic, dark blue grey basalt intermixed with red to purple scoria pieces and pale brown silica gel. Most outcrops are isolated and appear to project vertically, perpendicular to the surrounding flow surface. They have a distinctly elongate form which parallels the structural trend of the Horse Heaven Hills. Similar scoriaceous material or clinker was not observed at other localities where the Priest Rapids flow No. 3 crops out.

The interior of the flow exhibits distinctive, closely spaced fracturing which produces smooth sided tabular or prismatic fragments up to 2 or 3 ft in length.

In the north half of sec. 15, three miles west of Benton City, the uppermost part of the flow crops out at the base of a well exposed, steeply dipping sequence of rocks. Successively exposed above the Priest Rapids flow No. 3 are the Mabton bed, Priest Rapids flow No. 4 (Umatilla), and the Selah bed. The Priest Rapids flows at this locality were identified by their high barium content.

A few hundred feet south of this sequence the scoriaceous crust of flow No. 3 crops out again dipping gently to the north. The distinctive prismatic interior of the flow is exposed in the deep canyon near the center of section 15.

The Priest Rapids flow No. 3 crops out along Webber Canyon Road in sec. 4 and sec. 5, T.8 N., R.27 E. The distinctively fractured prismatic phase of the flow is well exposed in several road cuts. The basalt flows in Webber Canyon comprise a flat lying, layered sequence and successively younger flows are exposed in the canyon as it rises to the south.

Northward in sec. 33 nearer the mouth of the canyon the rocks exposed at the base of the canyon walls belong to the Pomona flow. This abrupt transition from older to younger rocks is explained by movement on the Wallula Gap fault which has displaced the northeasterly block downward. The fault is not exposed in Webber Canyon.

In Badger Canyon a high barium flow crops out on the south side of the Wallula Gap Fault in the NW/4 of sec. 29, T.8 N., R.28 E. The basalt is dark greyish to blueish black, dense and fine grained. Columnar jointing is well developed in outcrops along the banks of the stream channel. Thirty to fifty feet above the stream, scoriaceous and vesicular basalt crops out irregularly. The Mabton bed is not exposed and other evidence which might serve to distinguish between Priest Rapids flow No. 3 and 4 is lacking. Therefore, it is concluded that the high barium rocks represent the upper part of either Priest Rapids flow No. 3 or Priest Rapids flow No. 4.

Thickness of the Priest Rapids flow No. 3 cannot be estimated because the base of the flow is not exposed in the map area. However, core drilling in the Hanford reservation shows that the combined thickness of the high barium flows is about 300 ft. If 80 ft is deducted for the thickness of flow No. 4, which is its thickness where exposed 3 miles west of Benton City, it appears that the Priest Rapids flow No. 3 is about 220 ft thick.

Age of the various basalt flows is being determined by the potassium-argon method and results will be published in the future. (Donald Brown, 1970). These determinations are part of continuing investigations being carried out by Atlantic Richfield Hanford Co. Bingham, Londquist and Baltz (1970) assign a Mio-Pliocene age (about 12 million years) to the upper Priest Rapids flows.

The Mabton Interbed

The Mabton interbed is well-exposed in the north half of sec. 15 about 3 miles west of Benton City. It consists of well-bedded white tuff with minor amounts of sand and silt. The uppermost 2 to 3 feet of the tuff are baked and stained pale grey. Below this greyish baked zone is a brightly reddish stained zone about 3 or 4 feet in thickness. The total thickness of the interbed at this locality is about 35 feet. The Mabton is overlain by Priest

Rapids flow No. 4 and is underlain by Priest Rapids flow No. 3. Soft sedimentary interbeds such as the Mabton outcrop very poorly. No other exposures of the Mabton are known in the map area.

Priest Rapids Flow No. 4 (Umatilla)

The Priest Rapids flow No. 4 is the uppermost of two of barium-rich flows which have been identified by Donald Brown (1970). It is separated from the Pomona flow above by the Selah interbed. Flow No. 4 is separated from flow No. 3 below it by the Mabton interbed. It is called the Priest Rapids flow No. 4 by the U.S. Geologic Survey and it corresponds to the Umatilla of Schmincke (1967).

The flow consists of dark greyish black to dark blueish black fine-grained basalt exhibiting well developed columnar jointing which is generally more regular and of larger diameter than that of the overlying Pomona flow. In local areas where the rock has been stressed and folded as in parts of sec. 15, the Priest Rapids flow No. 4 becomes highly brecciated. Small fractures in the breccia pieces vary from about one inch to four inches in size. The rock is weathered and stained yellowish, reddish brown, and greenish.

Priest Rapids flow No. 4 comprises the central flow in a sequence of well-exposed rocks in the north half of sec. 15, T.9 N., R.26 E. The flow has a steep northerly dip in sec. 15. Its outcrop continues to the southeast where it forms a prominent ridge for a distance of 1-1/2 miles.

Flow No. 4 also outcrops in Webber Canyon in sec. 5, T.9 N., R.27 E. At this locality the flat lying flow is in contact with the overlying Selah interbed, which in turn is in contact with the Pomona flow above. The Pomona flow and Priest Rapids flow No. 4 were sampled and identified by their diagnostic chemical characteristics. The Mabton interbed underlying flow No. 4 does not outcrop well in Webber Canyon but flow No. 3 beneath the Mabton interbed is well-exposed at lower elevations in the canyon.

Priest Rapids flow No. 4 may also outcrop in Badger Canyon along the southwest side of the Wallula Gap fault. Local outcrops of basalt at this locality which is in sec. 29, T.8 N., R.28 E. were sampled and found to be high in barium content indicating that the basalt belongs to one of the uppermost Priest Rapids flows. There is insufficient evidence to indicate whether the rocks belong to Priest Rapids flow No. 4 or flow No. 3.

In the north half of section 15 about three miles west of Benton City, the base and top of flow No. 4 are both well exposed. The thickness of the flow here is about 80 feet. In Webber Canyon the base of the Priest Rapids flow No. 4 is not well exposed. However, estimates of its approximate elevation indicate a thickness for the flow here on the order of 100 feet.

Most recent estimates of age of these rocks are contained in a U.S. Geological Survey report by Bingham, Londquist and Baltz (1970). These writers assigned a Mio-Pliocene age to the Priest Rapids flow No. 4.

The Selah Interbed

The Selah interbed lies between Priest Rapids flow No. 4 and the Pomona flow. It consists of poorly consolidated tuff with varying amounts of sand and silts. Local occurrences of gravel in the Selah were described by Schmincke (1967). One such occurrence was observed within the mapped area of this survey in the SE/4 of sec. 12, T.8 N., R.27 E. A zone of dark grey vitreous fused tuff about 2 feet thick usually marks the top of the Selah interbed. Fused tuff at the base of the Pomona and at the top of the Selah interbed crops out in sec. 15, T.9 N., R.26 E., sec. 4, 8, and 12, T.8 N., R.27 E., and in sec. 18 and 19, T.8 N., R. 28 E.

Where surface soils are underlain by the Selah interbed the soil frequently exhibits well-developed shrinkage cracks and clay bloom indicating a high content of montmorillonite clay.

The thickness of the Selah interbed is difficult to estimate due to poor exposures. It appears to be about 30 to 40 feet in thickness.

The age of the Selah interbed as given by Bingham, Londquist and Baltz (1970) is Mio-Pliocene.

The Pomona Flow

The Pomona flow was named by Schmincke (1967), who showed that the flow could be identified over large areas and that it has distinctive petrographic and chemical characteristics. The Pomona flow is underlain by the Selah interbed and overlain by the Rattlesnake Ridge interbed. The petrography and chemistry of this flow have been described elsewhere in this report. The reader is referred to the work of Schmincke (1967) for detailed descriptions.

A well sampled outcrop of the Pomona flow is located in a road cut in Highway 81 about 3/4 of a mile northwest of Kiona. This locality was sampled by Schmincke (1967) for analysis and also by Blume geologists. The Pomona flow outcrops extensively on the northwest side of the Yakima River in sections 7, 8 and 9, T.9 N., R.26 E., where it comprises the lowermost exposed unit. It is overlain by the Rattlesnake Ridge interbed which in turn is overlain by the Elephant Mountain flow. The Pomona flow also outcrops in sec. 10 on the southeast side of the Yakima River and from there intermittently along the base of the Horse Heaven Hills. A quarry situated at the base of the hill in sec. 23, T.9 N., R.26E., has exposed the Pomona flow. The flow dips from 50 to 65° to the northeast and strikes N 60°W parallel to the mountain ridge. Parts of the flow at this locality have a scoriaceous, vesicular and brecciated crust similar to the crust of flow No. 3. This clinker, as it is called by Laval (1956), or scoriaceous crust outcrops intermittently along the base of the hills for about two miles southeast of the quarry. The Pomona flow was also identified along the crest of the Horse Heaven Hills in sec. 22 and 23, T.9 N., R.26 E., and sec. 31, T.9 N., R.27 E.

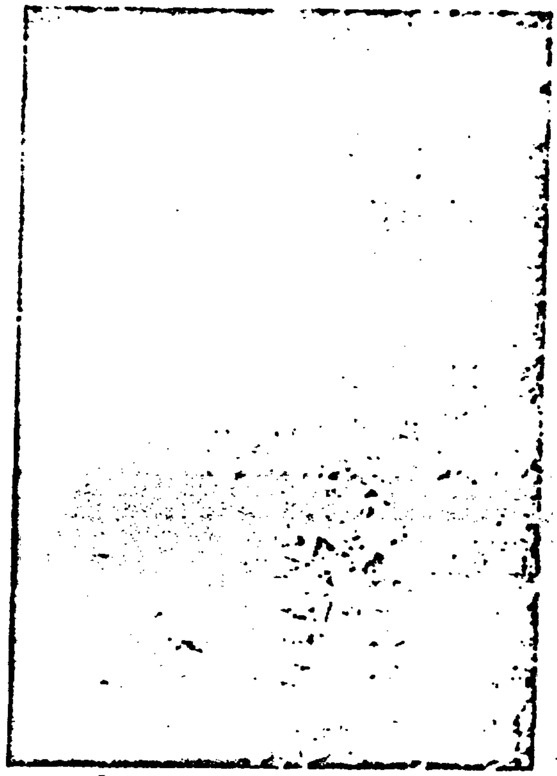


Figure 10. Outcrop of Pomona flow with columnar jointing in stream bottom. SW/4, sec. 35, T.9 N., R.27 E.

A prominent ridge trending down the northeast slope of the Horse Heaven Hills in sec. 25, T.9 N., R.26 E., is formed by the Pomona flow. The Pomona flow also outcrops as part of the flat lying series in the upper portion of Webber Canyon and again as the lowermost flow of a flat lying series of rocks at the mouth of Webber Canyon. The difference in elevations of the flows at the mouth of the canyon and at the head of the canyon is due to vertical displacement on the Wallula Gap fault. The flow underlies a broad flat plateau situated between Webber Canyon and Badger Canyon and outcrops extensively along the cliffs at the north margin of this plateau. The Pomona flow outcrops near the mouth of Badger Canyon and upstream as far as sec. 9, T.8 N., R.28 E., where it is terminated on the Wallula Gap fault. The lower contact of the Pomona flow is exposed intermittently along the base of the cliffs which face Badger Coulee between Badger Canyon and Webber Canyon. The base of the flow is also well exposed in sec. 8, T.8 N., R.27 E., in the upper part of the canyon. At locations where the elevation of the base of the Pomona is known the elevation of the top of the flow has been estimated giving thicknesses of from 250 to 300 feet.

Bingham, Londquist and Baltz (1970) give a lower Pliocene age for the Pomona flow.

The Rattlesnake Ridge Interbed

The Rattlesnake Ridge interbed crops out in five locations northwest of the Yakima River but it is not known to crop out in the map area southeast of the river. Good exposures of the bed are located immediately north of the road in sec. 9, T.9 N., R.26 E. Farther to the northwest along the trend of this small breached anticline, the Rattlesnake Ridge bed appears in small isolated outcrops of well-cemented grey tuffaceous sand. The thickness of the bed in this locality is from 30 to 40 feet. Its age is given by Bingham, Londquist and Baltz (1970) as lower Pliocene.

The Elephant Mountain Flow

The Elephant Mountain flow lies upon the Rattlesnake Ridge interbed and is the uppermost rock unit mapped during this survey.

The petrography of the Elephant Mountain flow is summarized elsewhere in this report and has been treated in detail by Schmincke (1967). Chemical analyses made during the course of this study indicate that the chemical characteristics of the Elephant Mountain flow using the analyses employed for this study are not sufficiently distinctive to serve as a means of identifying the flow.

The flow crops out extensively along the trend of the small breached anticline on the northwest side of the Yakima River. The flow crops out locally southeast of the Yakima River in sec. 9, 15, and 16, T.9 N., R.26 E.

A localized outcrop of the Elephant Mountain flow forms the top of the rounded hill in sec. 22, T.9 N., R.26 E. The flow also crops out locally at other places along the ridge forming the crest of the Horse Heaven Hills southeast toward Webber Canyon. The Elephant Mountain flow is also present, although poorly exposed, as the uppermost rock unit on parts of the plateau at 1100 ft elevation northwest and southeast of Webber Canyon.

The Elephant Mountain flow is best exposed in the vicinity of a small breached anticline northwest of the Yakima River where it is approximately 80 feet thick. Elsewhere in the map area where the Elephant Mountain flow is exposed its thickness appears to be comparable.

The age of the Elephant Mountain flow according to Bingham, Londquist and Baltz (1970) is lower Pliocene.

<u>Surficial Deposits</u>

<u>Basalt Gravels</u> - Basalt gravel crops out at two localities along the crest of the Horse Heaven Hills within the mapped area. One of these is in sec. 23, T.9 N., R.26 E. where the gravels appear to be about 20 feet thick and consist predominantly of basalt clasts averaging 3 to 4 inches in diameter. The second locality is in sec. 32 and 33, T.9 N., R.27 E. and sec. 4 and 5, T.8 N., R.27 E. on the crest of a high ridge overlooking Webber Canyon. Here the gravels are similar in size and composition. They outcrop over an area of about 1/4 square mile and appear to be about 100 ft thick.

The basalt gravels are unusual in that their composition is predominantly basalt indicating a local origin within the Colombia plateau itself for most of the gravel constituents. Secondly, the gravels are of interest because no basalt gravels have been found at low elevations. The known outcrops are restricted to higher elevations along the ridge top. It is clear that the gravels indicate the former presence of a stream or river at their place of deposition. A possible explanation for the presence of these gravels is that they were deposited by a pre-glacial southwesterly flowing river which existed before elevation of the Horse Heaven Hills.

Older Alluvium - Older alluvium was mapped at a single locality in sec. 16, T.9 N., R.26 E. It forms an old river terrace at an elevation of 830 feet or about 330 feet above the present elevation of the Yakima River.

Loess - Loess has been deposited widely throughout the area. It is present on most level ground, and many steep slopes are also blanketed.

Residual Soil and Colluvium - In many places residual soil forms a thin blanket 1 or 2 feet thick above the underlying rock units. Such soil is typically developed on gently sloping hillsides. Areas covered by residual soil have been identified and are indicated on the geologic map.

Younger Alluvium - Younger alluvium has been deposited along the Yakima River and in Badger Canyon and Webber Canyon in places where the stream gradient becomes low. Some alluvium has been deposited at higher elevations where drainage has been trapped by landslides, especially in sec. 15, 16, 21 and 22, T.9 N., R.26 E. Two landslides can be definitely identified on the north slopes of Horse Heaven Hills in sec. 15 and 16, T.9 N., R.26 E. In many other places closed depressions suggest the presence of landsliding but the actual slide and its margin cannot be located.

The structure along portions of the north slope of the Horse Heaven Hills where it consists of moderately to steeply dipping basalt flows underlain by poorly consolidated sediments is highly conducive to landsliding. In the past when river erosion cut away the basalt flows at the base of the hills the flows themselves became unsupported and landsliding must have resulted.

Glaciofluvial Gravels - These gravels are intermixed with sand and silt, and individual clasts are composed of many different rock types. Large boulders called glacial erratics which may have in part been transported by ice are common in this formation. Glaciofluvial gravels crop out in an area about 2 miles southwest of Goose Hill.

GEOLOGIC STRUCTURE

Folding

Folding in the area is of three types and is confined to three different portions of the mapped area. Northwest of the Yakima River the geologic structure along the trend of the Wallula Gap Fault consists of a small anticline which has been eroded out along its center. The flows on either flank of the anticline dip about 10° away from the axis while those nearer the axis dip more steeply at about 15° with some dips locally as high as 30°. Thus the anticline appears to be somewhat unusual in that the dips become steeper toward the anticlinal axis. The structure is illustrated in plan and cross section on Geologic Map Plate I. A minor fault trends along the axis and in one place where outcrops were such that the offset could be estimated it is about 50 ft. The displacement is downward on the northeast side.

Southeast of the Yakima River in the Horse Heaven Hills the structure is that of a large monocline. It is illustrated in plan and cross section on Geologic Map Plate I and II. The basalt flows southwest of the crest of the Horse Heaven Hills dip very gently to the southwest while northeast of the crest they dip steeply down the north slope of the hills and upon reaching the valley floor bend sharply to a horizontal attitude. There appears to be a small flexure along the base of the hills in which the lowermost beds exposed dip rather steeply and then flatten abruptly a few hundred yards up slope to a more moderate dip. The more moderate dip then persists without change to the crest of the hill.

Some of the flows outcropping along the north slope of the hills do not strike parallel to the ridge but instead appear to strike in a more eastwesterly direction. The attitudes of these flows are unconformable to the Horse Heaven Hills monocline. They are probably related to minor structural irregularities which are not well exposed. Laval (1967) described the major structure of the Horse Heaven Hills as having been superimposed upon minor east-westerly trending folds. The minor structural features observed in this area could be explained in this way and are considered to lend support to Laval's interpretation.

Overturned bedding occurs at the base of the monocline in sec. 15, about 3 miles west of Benton City. Here the lower contact of the Pomona flow is exposed adjacent to fused tuff of the Selah inter-bed, both of which dip about 70° to the southwest and strike north-westerly. The Pomona basalt is cut by two fault zones about six inches in width which parallel the attitude of the flow. These features could be interpreted as overturned folding and related thrust faulting, but they could also be explained as the result of landsliding and slumping at the base of the hill.

The monoclinal section of the Horse Heaven Hills structure lying within the mapped area extends from Webber Canyon northwesterly to a point about 3 miles west of Benton City.

The difference in elevation between the crest of Horse Heaven Hills and the floor of the canyon to the north is greatest in this monoclinal section and less in the section to the southeast where the bedding is flat.

The basalt flows south of the Horse Heaven Hills crest slope gently upward to the northeast on the broad plateau until reaching the crest of the hill where they bend abruptly and plunge down the north face of the hill until reaching the base where they again flatten out. The generally heavy cover of loess along the north slope of the hill and overall paucity of out-crops have rendered most of this portion of the structure ob-scure. Therefore, in this area it could not be determined within the scope of this survey whether or not the flows have been displaced by faulting between the crest of the hill and the valley floor. The structural conditions which are known do not require faulting in their interpretation. However, a fault could lie concealed along the slope of the hill or along the base of the hill.

A third area which consists of predominantly flat-lying basalt flows occupies Webber Canyon and extends southeast to Badger Canyon. No large scale folding is present in this area but some possible minor folding was observed in Badger Canyon adjacent to the Wallula Gap fault and apparently related to the fault. The Wallula Gap fault also cuts across Webber Canyon where alluvium occupies the area traversed by the fault. Some minor folding could lie concealed beneath the alluvium adjacent to the fault but there is no evidence to suggest this.

Faulting

The primary purpose of this survey is to identify and delineate faults along the probable trend of the Wallula Gap fault. This purpose has been accomplished. Faulting has been identified and delineated at the northwest extremity of the mapped area, and in the southeast portion of the mapped area. The fault in the southeast area appears to be a continuation of the Wallula Gap fault as was suggested by the U.S. Geologic Survey in a recent report by Bingham, Londquist and Baltz. The fault at the northwest end of the mapped area is a minor fault and yet is directly on the continuation of the Wallula Gap fault and thus may be considered to be a portion of that fault. The Wallula Gap fault where exposed in the southeasterly part of the mapped area is vertical in attitude and has undergone displacements of 200 to 300 ft downward on the northeast side.

The Wallula Gap fault crops out in sec. 29, T.8 N., R.28 E. The fault zone is well exposed in the west bank of the canyon near the stream bottom over a width of about 50 ft. The total width could be as great as 80 ft if it extends beneath nearby alluvial areas. The rock making up the zone itself is predominantly dark fine-grained highly vesicular basalt. It is

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cut by numerous vertical fault structures about 1 inch in thickness which are filled with fine sand sized and pebble sized breccia. Three such fault structures are 1 to 2 feet in width. They strike from north 60 to north 70 west and are normally spaced at 1 or 2 foot intervals. Locally these individual fault structures are filled with from 1 to 5 inches of chalcedony.

Some apparent flow banding occurs within the fault zone which is parallel to the general strike and dip of the fault. The vertical flow structures could represent irregularities in an otherwise normal horizontal basalt flow. It might also indicate flowage of a dike-like intrusion which invaded the fault zone. Or it is possible that fault movements taking place before final solidification of the flow could produce vertically oriented banded structures parallel to the fault. Figure 11 is a photograph of a portion of the fault zone which shows the vertical fault structures, fault breccia and intervening fine-grained basalt.

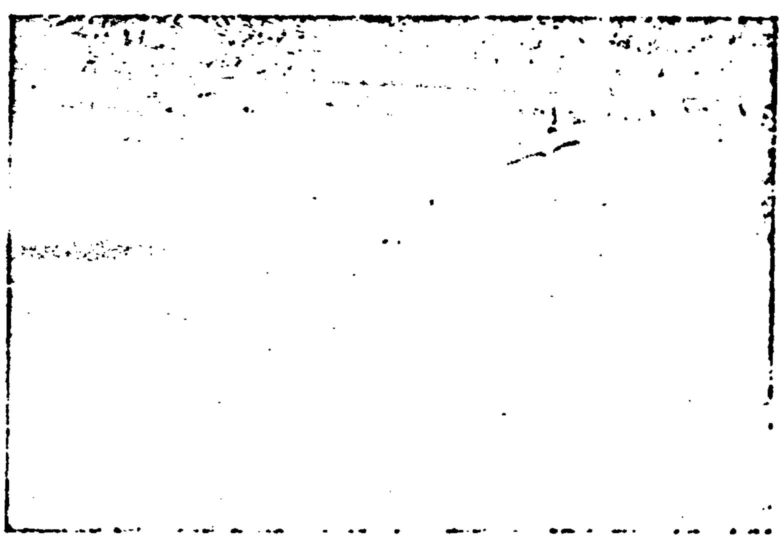

Figure 11: A portion of the Wallula Gap fault zone in Badger Canyon.

Basalt flows outcrop within 30 ft of the fault zone on either side of it but are not in actual contact with the fault. The flow outcropping downstream on the northeast side of the fault is exposed on the steep canyon walls where it exhibits well-developed columnar jointing which becomes fanning columns near the top of the slope. The columns are capped by scoriaceous and highly vesicular basalt at the crest of the hill. About 200 yards downstream below the fault a displaced block of tuff and fused tuff crops out in the stream bank. Although this block of tuff is not in place it must have originated from nearby and thus the base of the flow must be very close to this elevation. The vertical distance between the upper scoriaceous crust of the flow and the estimated base of the flow is about 275 ft. This flow was sampled a short distance from the fault zone. It was analyzed and found to have the distinctive chemical characteristics of the Pomona flow. The attitude of this flow as judged from the vertically oriented columns and the horizontally oriented scoriaceous crust appears to be essentially horizontal.

On the southwest side of the fault zone a very fine-grained dark blueish-black basalt crops out in the stream bottom. Well-developed columnar jointing in this basalt indicate that it is also horizontal in attitude. About 200 ft upstream from the fault zone, a highly brecciated section of dark very fine-grained basalt is exposed in the east stream bank. Fractures in this breccia are spaced from 2 inches to 6 inches apart and breccia pieces vary from about 1/16 of an inch up to 12 inches. The basalt which makes up this breccia zone is very dense and non-vesicular, and does not show glassy selvages or local baking effects. The breccia pieces are angular, very sharp edged and fresh appearing. Fracture surfaces may be smooth or rough but none are striated or slickensided. Some horizontal fractures which are probably primary features of the rock appear to be distorted and bent downward toward the east. The general appearance of the outcrop suggests that only very small movements took place within the rock and that those movements which did take place were downward toward the east throughout the mass. Figure 12 shows a close-up view of the breccia.

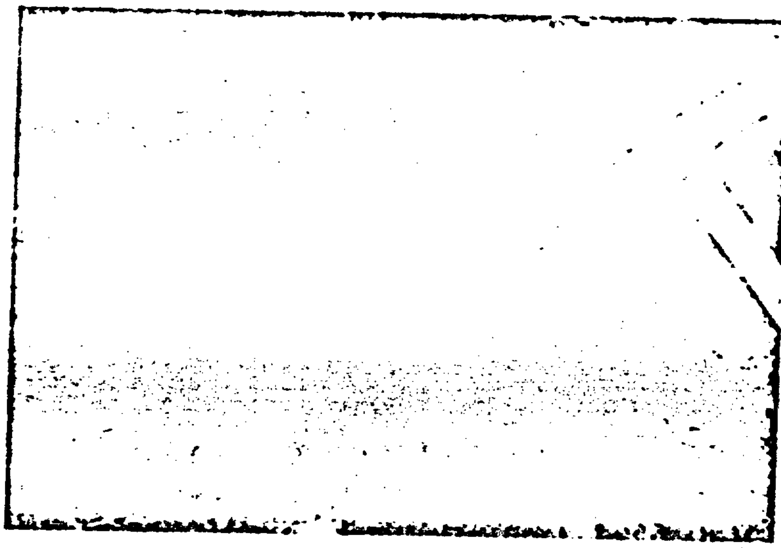

Figure 12. Brecciated basalt adjacent to the Wallula Gap fault in Badger Canyon.

The dark fine-grained basalt with columnar jointing which is exposed near the fault zone and at the breccia zone continues upstream in outcrop about 200 yards beyond the breccia zone. The columnar basalt is exposed vertically up the northwest canyon wall for a distance of 50 feet where it is capped by a scoriaceous and vesicular crust. This basalt was sampled about 50 feet southwest of the breccia outcrop in the wall of the canyon and analysis showed a high barium content indicative of the two uppermost flows of the Priest Rapids member of the Yakima basalt.

The structural conditions indicate displacement on the fault zone with downward movement on the northeast side of the fault. The amount of offset on the fault is estimated to be from 200 to 300 ft. The structure is illustrated on Cross Section D shown on Geologic Map Plate II.

Farther upstream beyond the outcropping of the upper Priest Rapids flows loess blankets the canyon walls and hills alike. An abrupt change also takes place in the lower part of the stream canyon, which downstream had exposed hard basalt in the stream bottom and canyon walls but now consists of a broad flat alluvial channel. The area in which this change takes place is centrally located in the northwest quarter of sec. 29 and can be seen on the geologic map where the alluvium in the stream channel is abruptly terminated. The upper alluvial segment of this stream channel may represent a drainage which had reached a near stable gradient before fault movement. It is apparent that fault movements have affected the drainage and topography of this area. These conditions suggest that a parallel fault, concealed beneath loess, may cross Badger Canyon near the site of the abrupt change in gradient.

The Wallula Gap fault continues northwesterly from Badger Canyon and crosses Webber Canyon. It is not exposed in the intervening areas because of the heavy cover of loess. The trace of the fault in Webber Canyon is not exposed but it can be localized to alluvial areas through which it must pass. The presence of the fault is known because of offset in flat lying basalt flows which are exposed in the canyon walls. Near the mouth of the canyon the Pomona flow is widely exposed along Webber Canyon Road. A short distance upstream in the northwest quarter of sec. 4, T.8 N., R.27 E., the Priest Rapids flow No. 3 outcrops along the road. The position and elevation of the base of the Pomona flow in the canyon southwest of the fault is known and the top of the Pomona flow in the canyon on the northeast side of the fault can be estimated rather closely. Based upon this information the total offset on the fault is about 300 ft. Another method of estimating total displacement is to consider that the plateau in the central part of sec. 5 at the 1500 ft contour is probably underlain by the Elephant Mountain flow. Likewise, the plateau in the central part of section 33 at an elevation of about 1000 ft is also probably underlain by the Elephant Mountain flow. The total difference in elevation here is also 300 ft. The fault in Webber Canyon is shown in Cross Section C, Geologic Map Plate II.

Northwesterly beyond Webber Canyon, the Wallula Gap fault strikes directly toward the steep northeasterly slope of the Horse Heaven Hills. Due to the heavy cover of loess it could not be determined whether or not the fault is actually present along the hill slope. The hills rise much higher northwest of Webber Canyon, and there is a much greater difference of elevation between the basalt flows on the crest of the hill and the same flows on the valley floor northeast of the hills. It is known that the flows are folded at the hill crest and dip steeply down the slope to the northeast. However, it is not known whether the difference in elevation of flows on the crest and the valley floor is completely due to folding or is due to both folding and faulting.

The relationship of faulting and stratigraphy in Webber Canyon is shown on Cross Section D on Geologic Map Plate II.

Beyond the Horse Heaven Hills and across the Yakima River to the northwest, a minor fault trends along the axis of the small breached anticline in sec. 8, T.9 N., R.26 E. The fault zone itself is covered by alluvium and residual soil along the axis of the anticline. At one locality, however, where opposite limbs of the anticline are adjacent, the fault displacement can be observed. The vertical displacement is about 50 ft downward to the northeast. If any horizontal movement has taken place along the fault, it would probably not be possible to observe evidence of it. A small elongate lake near the head of this anticline appears to have been formed by scouring of a northeasterly trending breccia or fracture zone. A pronounced curvature at the north end of the small lake might be interpreted as drag indicating a left lateral movement along the fault. However, this appears highly speculative, and there is no substantial evidence at this locality either pro or con regarding possible horizontal fault movement. The structure and fault are shown on Cross Section A, Geologic Map Plate I.

Aerial photographs show a lineation trending northeast across the anticline. The lineation is about a mile in length and suggests the presence of a northeasterly trending cross fault. However, no fault could be located on the ground and in fact the structural relations are such as to preclude any significant fault movement along the lineation. It is most probable that the lineation represents a fracture zone along which there has been no displacement. It is indicated on the geologic map as an alignment of fractures. Other similar lineations were observed on aerial photos at the apex of the Horse Heaven Hills about 3 miles west of Benton City. These also may be fracture zones without significant displacement. They are indicated on the geologic map as dotted lines with question marks.

Age of faulting on the Wallula Gap fault where exposed in the southeastern area was not determined. It is known to be younger than the basalt gravels which were deposited during initial uplift of the Horse Heaven Hills. It is probable that trenching across the trend of the Wallula Gap fault in the surficial materials to exposed Holocene ash beds or other stratigraphic horizons would produce more conclusive evidence regarding the age of last movement. Such additional investigation is not recommended because the data which might be obtained is not critical to the FFTF project.

The vertical component of movement on the Wallula Gap fault in the southeastern area has been determined, but if any horizontal movement took place it would not be observable in the flat lying sequence of flows and interbeds. It might, however, be observable on the ground surface where any possible recent horizontal movement would be expected to displace stream channels. There is no clearcut evidence of displacement of stream channels, and one stream flowing to the northeast through sec. 11, T.8 N., R.27 E., does not show any curvature at all but on the contrary is quite straight. It is concluded therefore, that the predominant movement on the Wallula Gap fault has probably been vertical without significant horizontal component. The Wallula Gap fault is therefore probably a normal fault.

The structure in the map area undergoes changes from east to west and can be divided into three distinct types. The eastern area situated southeast of Webber Canyon consists of flat lying basalt flows and interbeds which are displaced downward to the northeast by the Wallula Gap fault. The central part of the map area extends from Highway 3 at the northwest to Webber Canyon at the southeast and includes the northern apex of the Horse Heaven Hills monocline. This portion consists of the gently sloping plains on the southwest side of the Horse Heaven Hills monocline and the steeply dipping northeastern slope of the hills where the basalt flows and interbeds plunge to the valley floor below and there become horizontal. Exposures are poor along the hill slopes and particularly poor at the base of the hill. The extent of faulting along this region on the possible northwesterly extension of the Wallula Gap fault is difficult to determine.

In the northwesterly area beyond the Yakima River the structure consists of a small symmetrical anticline with a minor fault along its axis.

The structural trend within the map area is seen to consist of a fault zone in flat lying volcanics, a monocline combined with possible faulting and a small anticline. This trend could correctly be called a lineament even though this term is usually applied to larger regional features.

Part 1, Section 2

GEOLOGY ALONG THE
HORN RAPIDS LINEAMENT

Prepared for WADCO

of

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February 1971

by

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San Francisco, California 94105

INTRODUCTION

This report describes the results of geologic mapping along a line of low basalt hills called the Horn Rapids Lineament. The line of hills extends from about 1 mile north of the Horn Rapids Dam on the Yakima River along the west side of the river to an area two miles south of Richland. The line of hills was shown on a regional geologic map by Jones and Deacon (1966) as the axes of an anticline striking in a northwesterly direction. Bingham, Londquist and Baltz (1970) referred to the line of hills as the Horn Rapids Lineament. They noted similarities of this alignment with the adjacent line of hills called the Olympic-Wallowa Lineament, which is known to be associated with faulting, and pointed out that the Horn Rapids Lineament might also be associated with faulting.

If a large fault should lie concealed along the Horn Rapids Lineament, it could serve as the locus of a major earthquake. These considerations indicated that geologic mapping should be carried out along the lineament to investigate the possibility of faulting.

Ten man-days were spent by Blume geologists in mid-July of 1970 in detailed mapping of the Horn Rapids Lineament. This work was done for WADCO of Richland, Washington, who have been in charge of the FFTF project since July 1, 1970. Air photos at a scale of 500 feet to the inch were used for geologic mapping in conjunction with topographic maps. Geologic mapping was compiled on air photo mosaics at the same scale as the prints. Approximate control was provided for the mosaics from available topographic maps and approximate 100-foot contour lines were added to the mosaics from the same source. Therefore, the contours, scale and orientation of the mosaics are approximate but adequate for the purposes of the investigation.

By far the greatest part of the map area is blanketed by surficial deposits consisting of wind blown sand, loess and alluvium. No significant mappable features were observed in the surficial deposits and mapping was confined to areas of basalt outcrop. For convenience the hills are numbered 1 through 6 beginning with the northerly most hill which is called Hill No. 1 and ending with the southerly most Hill, 2 miles south of Richland, which was called Hill No. 6.

Geology and cross sections through each hill are shown on geologic maps, Plate III, IV and V. Figure 13 shows locations of the cross sections, the hills, and the geologic map plates in relation to the FFTF site.

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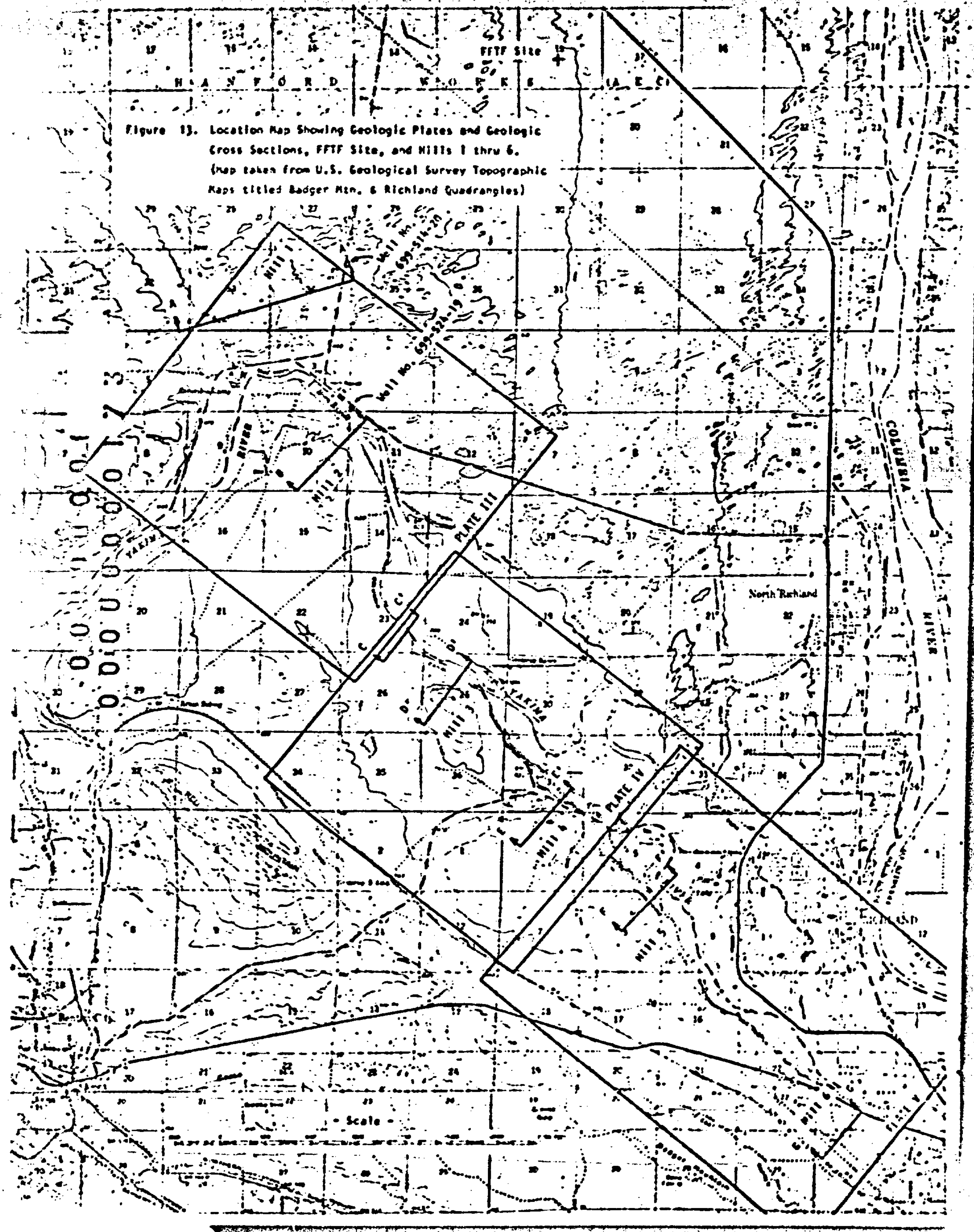


Figure 13. Location Map Showing Geologic Plates and Geologic Cross Sections, FFTF Site, and Hills 1 thru 6. (Map taken from U.S. Geological Survey Topographic Maps titled Badger Mtn. & Richland Quadrangles)

SUMMARY

Two distinct linear features along the lineament can be observed on the topographic map. One of these is an alignment along which the northeast sides of hills 3, 4 and 5 appear to have been truncated. The second alignment is along the margin of a north-south trending bench which is clearly defined over a distance of about 3 miles beginning at the east margin of Hill No. 2 and extending south.

Neither of these linear features trends directly toward the site. No evidence was found during this survey to indicate that either of these linear features is due to faulting. Because neither of these features is well exposed the possibility of faulting cannot be completely eliminated.

Most of the basalt hills are very poorly exposed and therefore their structure is difficult to determine. The north half of Hill No. 2 is relatively well exposed and it is a flat topped dome. The south portion of Hill No. 2 has few outcrops but its configuration is similar to the north half and by analogy it is probably a similar structure. Outcrops on the other hills are insufficient in themselves to reveal the structure of the hills. However, the evidence which is available indicates that the hills are probably flat topped domal structures similar to Hill No. 2 with the exception of Hill No. 6. Hill No. 6 appears to be an elongate, gently dipping domal anticline.

Brecciated basalt outcropping in the northwest quarter of sec. 25 and in the southeast quarter of sec. 23, T.10 N., R.27 E. is probably a result of folding of brittle basalt. Fracturing exposed on the north slopes of Hill No. 2 is probably related to uplift of the hill.

Identification of basalt flows in the mapped area was done by examination of hand specimens in conjunction with chemical analysis.

It was concluded that with two exceptions all of the basalt exposures in the area are of the Elephant Mountain flow. The Ward Gap flow, which is a thin basalt flow overlying the Elephant Mountain flow, might be present in the area but was not distinguished. The two exceptions are small outcrops of basalt identified as belonging to the Pomona flow by chemical analysis. One of these outcrops is situated a short distance west of Hill No. 1 and the other is located about 1 mile northwest of Hill No. 3. In both instances the exposure of the older Pomona flow was due to a combination of geologic structure which brought the Pomona flow into a relatively high position and erosion which stripped away the overlying Elephant Mountain flow.

STRATIGRAPHY

The principal rock type exposed along the Horn Rapids Lineament is the Elephant Mountain basalt. The Ward Gap flow, which is a thin flow overlying the Elephant Mountain, may also be exposed in the area but it was not distinguished. Several different phases of the Elephant Mountain flow crop out in the map area. Most common is a massive, medium grained highly crystalline phase. This rock as well as the other types of Elephant Mountain basalt typically exhibits red-brown weathering color and indistinct banding. Subrounded boulders of this type of basalt reaching 10 to 15 ft in diameter crop out on Hill No. 6. A darker, dense, fine-grained to aphanitic phase of the Elephant Mountain basalt also crops widely in the area. Locally, this type of basalt is brecciated as described on Hill No. 1, Hill No. 3 and north of Hill No. 3. The breccia is probably due to stress created by folding of the basalt flows.

Jagged, spinose outcrops of very fine to aphanitic basalt crop out north and west of Hill No. 2. This rock is highly vesicular, dark bluish-black in color and often exhibits ropy structure. It is probably the upper surface of the Elephant Mountain flow or possibly the Ward Gap flow.

A less common phase of the Elephant Mountain flow is basalt which weathers into spherical shapes varying from about 6 to 12 inches in diameter. This rock was exposed in a quarry at the south end of Hill No. 6.

The base of the Elephant Mountain flow was exposed at one locality on the south bank of the Yakima River a short distance north of Hill No. 2. Here the flow rests upon slightly baked tuff of the Rattlesnake-Ridge interbed.

Two outcrops of dark dense fine-grained basalt of the Pomona flow were identified. One of these is west of Hill No. 1 and the other is about 1 mile northwest of Hill No. 3.

Flow identification was based on hand specimens examination and chemical analysis. The method of analysis and the basis of flow identification is discussed in detail in Part 1 of this report. Briefly, the chemical analysis methods of identification used in this study are based upon the work of Schmincke (1967) and more recent unpublished work by D. J. Brown (1970). The basalt analyses used for flow identification were provided by D. J. Brown of Atlantic Richfield Hanford Company (ARHCO). Results of analyses and sample locations are presented in Table 2. Figure 14 is a graphical plot of the iron, potassium and calcium content of samples which can be compared with a similar plot of Schmincke's data (Part 1, Figure 4). Sample locations are also plotted on the geologic map (Plates III, IV and V).

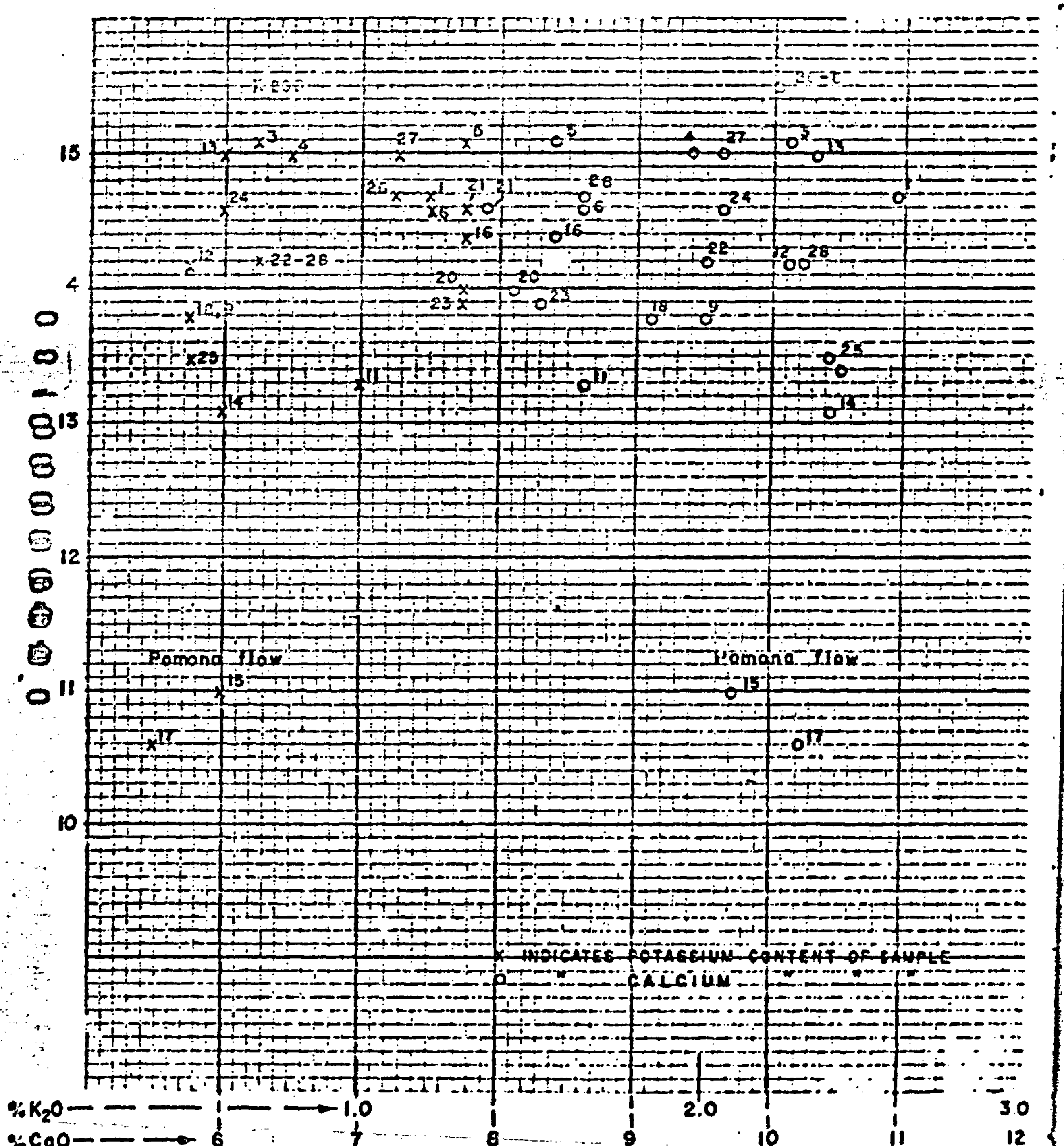
Although the method of analyses was not considered to provide a diagnostic identification of the Elephant Mountain flow, the flow can be identified with a reasonable degree of assurance by a process of elimination.

The Pomona flow lying below the Elephant Mountain can be distinguished chemically. Likewise, the uppermost two flows of the Priest Rapids member lying below the Pomona can be distinguished chemically. Therefore, if a flow does not belong to either one of these two, then it must either be from the lower part of the Priest Rapids member or the Elephant Mountain or Ward Gap flow. It is highly unlikely that any of the basalts exposed in the area could belong to the lower Priest Rapids member because this would require removal by erosion of approximately 800 feet of overlying basalt flows and interbeds. Therefore, it can be concluded that the rocks belong to the Elephant Mountain flow. This conclusion is supported by the fact that in two instances the Pomona flow was identified in a stratigraphically lower position. The reader

TABLE 2

CHEMICAL ANALYSIS OF BASALT SAMPLES FROM HORN RAPIDS LINEAMENT

Sample No.	1-18	3-18	4-34	5-34	6-34	9-10	11-10	12-15	13-10	14-15	15-23	16-23
SiO_2 (%)	51	47	50	49	48	50	49	52	50	50	49	52
Al_2O_3 (%)	12.9	13.0	12.4	12.6	12.7	13.0	13.0	13.7	13.6	13.7	14.5	12.5
FeO (%)	14.7	15.1	15.0	15.1	14.6	13.8	13.3	14.2	15.0	13.1	11.0	14.4
MgO (%)	4.5	7.1	6.0	6.0	4.7	6.3	4.4	5.8	7.0	5.6	8.0	4.3
CaO (%)	10.9	10.1	9.4	8.4	8.6	9.5	8.6	10.1	10.3	10.4	9.7	8.4
Na_2O (%)	2.3	2.3	2.7	2.4	2.5	2.4	2.5	2.3	2.4	2.5	2.4	2.9
K_2O (%)	1.2	0.7	0.8	1.3	1.2	0.5	1.0	0.5	0.6	0.6	0.6	1.3
TiO_2 (%)	3.1	2.9	3.1	3.2	3.2	2.9	3.0	3.2	3.1	2.9	1.6	3.2
Ba (ppm)	551	525	525	582	525	674	525	753	661	615	342	588
Location												
¼ Section	SE	NW	NW	NW	SW	NE	NE	NE	SE	NE	SE	SE
Section	18	17	34	34	34	10	10	15	10	15	23	23
Township (N)	10	10	11	11	11	10	10	10	10	10	10	10
Range (E)	27	27	27	27	27	27	27	27	27	27	27	27
Hill No.	-	-	1	1	1	-	2	2	2	2	-	-
Flow Designation												
Elephant Mtn.	X	X	X	X	X	X	X	X	X	X		X
Pomona											X	



IRON, CALCIUM AND POTASSIUM CONTENT OF BASALT SAMPLES FROM THE HORN RAPIDS LINEAMENT.

FIGURE 14

JOHN A. BLUME & ASSOCIATES, ENGINEERS

Table 2

CHEMICAL ANALYSIS OF BASALT SAMPLES FROM HORN RAPIDS LINEAMENT

Sample No.	17-33	18	20	26-8	21	22	23	24	25-8	26-22	27-22	28-22
SiO_2 (%)	52	48	51	46	51	47	48	49	50	52	48	50
Al_2O_3 (%)	13.9	12.9	12.7	13.0	12.4	13.0	12.3	13.1	13.2	12.8	12.6	12.8
FeO (%)	10.6	13.8	14.0	15.5	14.4	14.2	13.9	14.6	13.5	14.7	15.0	14.2
MgO (%)	7.5	6.6	4.4	6.7	4.2	6.4	4.4	1.5	4.9	4.6	4.1	6.4
CaO (%)	10.2	9.1	8.1	10.0	7.9	9.5	8.3	9.6	10.4	8.6	9.6	10.2
Na_2O (%)	2.2	2.4	2.4	2.4	2.2	2.5	2.4	2.5	2.4	2.4	2.4	2.5
K_2O (%)	0.4	0.5	1.3	0.7	1.3	0.7	1.3	0.6	0.5	1.1	1.1	0.7
TiO_2 (%)	1.6	2.9	3.0	2.6	3.2	2.9	3.1	3.0	3.1	3.2	3.0	3.1
Ba (ppm)	329	586	525	749	637	692	441	665	1050	589	525	621
Location												
¼ Section	SE	SW	SE	NE	NW	NW	NW	NW	NW	NW	NW	SE
Section	32	31	31	8	25	25	26	25	8	26	26	22
Township (N)	11	10	10	9	10	10	10	10	9	9	9	9
Range (E)	27	28	28	28	27	27	27	27	28	28	28	28
Hill No.	-	4	4	5	3	3	-	3	5	6	6	6
Flow Designation												
Elephant Mtn.		X	X	X	X	X	X	X	X	X	X	X
Pomona	X											

is referred to Part 1 of this document for further discussion of chemistry, stratigraphy and petrography of the basalt flows.

GEOLOGIC STRUCTURE

Introduction

Two different aspects of geologic structure along the Horn Rapids Lineament are considered. One of these is a broader regional structure which is formed by the alignment of the hills. The other aspect of structure consists of the individual structure of each hill.

There are two linear features of the regional structure which are of particular interest. One of these linear features extends along the northeast sides of Hills 3, 4 and 5, all of which appear to be truncated abruptly along the northeast side. This truncation could have been accomplished by erosion but the well-defined linear aspect sides of the hills suggest also that it might have been caused by faulting or by erosion along a fault or fracture zone. The second linear feature of interest is a north-south trending bench which extends along the east side of Hill No. 2 and about 3 miles south of Hill No. 2. Both of these features can be best observed on the topographic map of Figure 1. Although there are no outcrops which completely transect either one of these features, some general observations can be made regarding them. If the linear feature passing near Hill No. 2 is due to a concealed fault, it is probable that the fault has little or no vertical displacement because basalt outcrops east of Hill No. 2 near the Yakima River show no apparent dislocation or offset. If the linear feature along Hills No. 3, 4, 5 and 6 is due to a concealed fault, it could not be continuous beyond Hill No. 3 because it would be exposed on the flanks of Hill No. 2 or in the basalt outcrops north of Hill No. 2 along the Yakima River. Furthermore, it may be noted that neither of these linear features trends toward the FFTF site.

The internal structure of the hills is poorly exposed except in the case of Hill No. 2, where basalt outcrops are fairly continuous around the north end of the hill and the structure could be determined. In general, the evidence which was observed suggests that the basalt flows on the tops of the hills are more or less flat lying and the basalt flows around the sides of the hills dip outward away from the hilltops. Chemical analysis of samples collected from different parts of the hills shows that the flow which is exposed is the Elephant Mountain flow. One exception to this is an outcrop of the Pomona flow at Hill No. 1. This evidence is nowhere conclusive and is sometimes highly inconclusive. It is nevertheless compatible with the hypothesis that all of the hills are similar in their structure to Hill No. 2, which is a flat topped dome or anticline.

The hypothesized structure of the hills is not indicated on the geologic maps with the exception of Hill No. 2 where structural evidence is more conclusive. Hill No. 2 is shown on the map as an anticlinal structure. Cross sections shown on the geologic map, Plates III, IV and V illustrate the probable structure of the hills.

Seismic refraction surveys which would determine the profile of the buried basalt surface in various places have been recommended. This information would be helpful in defining the internal structure of the hills and in evaluating the larger linear features of the lineament.

<u>Hill No. 1</u>

Hill No. 1 is surrounded and partly covered by alluvial sand and gravel and by wind blown sand. The basalt flows strike about N 10W parallel to the long axes of the outcrops. Inclination, or dip, of the flows varies from about 5°E to 0. These flows probably represent the eastern flank of a very subdued domal uplift or anticline whose axes is situated somewhere to the west of Hill No. 1. The missing part of this structure was removed by erosion.

The basalt is broken in places by steep easterly trending fractures and small fracture zones. There is no evidence of movement along these fractures. Local outcrops of brecciated basalt occur along the west margin of the hill. This rock has the appearance of tectonic breccia as contrasted to a flow breccia. There is nothing to suggest that these isolated outcrops of breccia were produced by faulting or are related to faulting. It appears likely that the breccia was produced by folding and is similar to brecciated basalt at the north base of Hill No. 3.

All of the rocks exposed along the higher portion of Hill No. 1 belong to the Elephant Mountain flow or possibly the overlying Ward Gap flow. A small outcrop of basalt belonging to the Pomona flow is situated about 1 quarter of a mile west of Hill No. 1 nearer to the probable axis of the structure. The elevation of these outcrops is about 80 feet lower than that of basalt on top of Hill No. 1 and its location nearer the crest of the anticline is responsible for the flows being in relatively higher position.

Hill No. 2

Hill No. 2 is relatively well exposed at its northern end. Basalt flows dip gently away from the hill top to the northwest, north, and northeast. A small flexure strikes northeasterly from the hill top and is associated with northeasterly trending steep fractures. The top of the hill is about 1/2 mile long in its longest direction and is flat. Outcrops at the south end of Hill No. 2 are very sparse and the structure there cannot be determined. However, the topography of the south part of the hill is quite similar to that of the north part of the hill and the structure is probably similar. Hill No. 2 is a flat topped dome. Total vertical movement associated with uplift is on the order of 100 feet.

The basalt flows exposed on Hill No. 2 belong to the Elephant Mountain flow. The same flow is exposed on the Yakima River about 1/2 mile north of the hill and can be traced almost continuously exposed upstream on the south bank of the river for 5 or 6 miles. The base of the flow is exposed locally on the bank of the Yakima

River about 1/2 mile north of Hill No. 2. Here the flow rests upon greyish slightly baked tuff of the Rattlesnake Ridge Formation.

Hill No. 3

Hill No. 3 is very poorly exposed except for a few outcrops on the hill top and outcrops across the north face of the hill. It has a flat top which is a few hundred feet in length. The hill has been uplifted about 200 feet above the basalt flows in the surrounding region. The north slopes of Hill No. 3 are quite steep and the basalt flows appear to dip down the slopes. Two contrasting layers of basalt in close contact outcrop at the base of the north slope of Hill No. 3. These layers consist of a brecciated basalt about 20 feet in thickness overlying a massive basalt also about 20 feet thick. The layers strike to the northeast and dip about 22° southeast. The position of the breccia in relation to the underlying massive flow indicates that it could not have been produced by a vertically oriented fracture zone or fault zone. The breccia does not have any of the typical characteristics of flow breccia, such as vesicularity, welded points of contact, glassy selvages or local baking effects. Therefore it is concluded that this breccia has been produced by folding of a brittle layer within the flow. The lower more massive flow probably adjusted to the folding stresses along well developed columnar joints. In addition to this occurrence of breccia there is widespread breccia on the north slope of Hill No. 3 and brecciated basalt of the Pomona flow crops out about 1 mile northwest of Hill No. 3. All of these breccia occurrences have certain features in common. They are not flow breccias, they do not outcrop along a linear trend, and there is no apparent relationship to fracturing or faulting. The breccia occur in flows which have been folded. Therefore, it is concluded that these breccias have been produced in brittle portions of different basalt flows by folding.

The structure of Hill No. 3 may be similar to that of Hill No. 2. Hill No. 3 has a small flat top. The flows exposed on the north slope of the hill appear to dip down the slope but this cannot be confirmed by measurement of reliable attitudes. The attitude of the breccia occurrence at the base of the north slope is not conformable to a postulated domal structure for Hill No. 3. There appears to be an easterly or northeasterly trending fold at the north end of Hill No. 3 which is responsible for the reversed dip at the base of the hill. Alternatively, the south dipping basalt could be a remnant of a hill, now eroded away, which once was situated north of Hill No. 3.

An Eroded Hill

Some subdued outcrops of basalt located to the north of Hill No. 3 are of particular interest. These outcrops are in the W/2 of the SE/4 of S. 23, T. 10N, R. 27E, about 1 mile north of Hill No. 3.

Two elongate, northwesterly trending outcrop areas are separated by a narrow strip of alluvium. The westermost outcrop consists of Elephant Mountain basalt which strikes N 55W and dips 20° southwest. The easternmost area consists of dense, dark grey basalt which also strikes northwest and has a low south west dip. This rock is brecciated and is similar to the brecciated basalt on the north face of Hill No. 3. It has been identified as Pomona basalt.

The breccia pieces are angular, uncemented, and average about 4 inches in size. Individual pieces do not have baked surfaces or show evidences of rapid cooling as might be seen in a flow breccia. Many fractures are aligned in a common direction varying from N20 to N50 west and all fractures are steeply dipping. Individual fractures can rarely be traced more than a few feet and they often terminate abruptly on cross fractures. Many fracture surfaces are planar, while some are gently curved and others have steps of 1/8 or 1/4 inch thickness. No slickensiding or other evidence of movement could be found on fracture surfaces. The breccia zone is at least 150 ft wide perpendicular to the strike and is probably wider.

It is concluded that this breccia is similar to that at the base of Hill No. 3 and has been produced by folding. The two west dipping flows are one limb of an anticline or dome which has been eroded away. South dipping basalt near Hill No. 3 may be part of the same structure. The hill which once occupied this area probably extended to the east beyond the present site of the Yakima River. The probable structure existing today is shown on cross section C-C', geologic map Plate IV.

<u>Hill No. 4</u>

Hill No. 4 rises to an elevation of 760 ft above sea level or about 350 ft above the adjacent small community of West Richland. The scattered small outcrops on the north and east slopes of Hill No. 4 exhibit low to moderate dips away from the hill top. Analyses indicate that the basalt outcroppings are part of the Elephant Mountain flow. This evidence is not conclusive but suggests that the hill is an asymmetric domal structure. The hill is asymmetrical in that the south and west slopes are very gradual and flatten out on a relatively high plateau. The north and east sides of the hills slope down to much lower elevations and the basalt flows there dip below surficial deposits.

<u>Hill No. 5</u>

Hill No. 5, located 2 miles west of Richland rises to an elevation of about 630 ft, or 250 ft above the adjacent river valley. The northeast side of Hill No. 5 dips steeply down toward the Yakima River. The west side of Hill No. 5 slopes very gradually down to a broad plateau about 60 ft below the elevation of the hill top. The northwest and southeast slopes of the hill are gradual and the top is flat or gently undulating topography over a length of about 1/3 of a mile. Basalt outcrops are scattered over the northwest and southeast sides and on top of Hill No. 5. These rocks belong to the Elephant Mountain flow. Where dips can be observed on the flows, they dip gradually away from the hill top. Hill No. 5 appears to be an asymmetrical domal structure similar to Hill No. 4.

Hill No. 6

Hill No. 6 is a long low hill rising to an elevation of 745 ft at its south-easterly end. It is about 1-1/2 miles long in a north-westerly direction and about 1/2 mile wide. Basalt is widely exposed over most of the hill top. The rocks belong to the Elephant Mountain flow. An unusual phase of this flow is exposed over much of Hill No. 6 which consist of basalt blocks exposed and isolated by erosion. These blocks weather to irregular shapes which are 12 to 15 ft in diameter. The rock has a reddish-brown color and with poorly defined banded flow structures. Most of the structures observed in the basalt indicate very low dips but no reliable attitudes were obtained except in the quarry on the hill top at the south end where flat lying basalt flows are well exposed. Quarrying operations have exposed a 50-foot thick vertical section of the Elephant Mountain basalt which consists of an upper section 10 ft in thickness of columnar basalt, underlain by a 15-foot thickness of spherical weathering basalt, which in turn is underlain by a 25-foot section of columnar basalt. Samples taken from the uppermost and lowermost sections in the quarry indicate that the rock is probably the Elephant Mountain flow.

Basalt outcropping along the southwest margin of the hill is broken by many northwesterly trending steep fractures. These fractures parallel the margin of basalt outcropping along the edge of the hill in many places and suggest that the margin of outcrop itself, which is linear, may be controlled by a fracture zone. This possibility cannot be evaluated further because there are no outcrops within the possible fracture zone itself.

Although the evidence is inconclusive regarding the structure of Hill No. 6, it is postulated that the hill is an elongate symmetrical anticline plunging downward to the northwest and to the southeast.

Part 2

Geologic Reconnaissance in the Vicinity of the Fast Flux Test Facility Site Near Richland, Washington

Prepared for
WADCO
of
Richland, Washington

February 1971

by

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INTRODUCTION

This report describes a reconnaissance field geologic investigation carried out in the area surrounding the Fast Flux Test Facility (FFTF) site near Richland, Washington. The work was required for earthquake engineering analysis of the site which was done by John A. Blume & Associates, Engineers (Blume) of San Francisco, California. This analysis was done for Battelle Memorial Institute, Pacific Northwest Laboratory (BNW) of Richland, Washington..

A preliminary report titled, "Preliminary Report: Seismic and Geologic Siting Evaluation and Seismic Design Criteria for the Fast Flux Test Facility Site near Richland, Washington," was submitted to BNW on December 1, 1969. This preliminary study was based upon a partial review of the literature, a site exploration program by others which was then in progress, and field work carried out by the United States Geologic Survey (USGS) which covered selected areas in and adjacent to the Hanford Reservation. The USGS field investigations were carried out in an area on Saddle Mountain, on Gable Mountain and Gable Butte, and near Wallula Gap. The final site evaluation report was submitted by Blume in August 1970.

Prior work has delineated the major structural trends in the region but has not included studies to evaluate the possible presence of minor faults in the vicinity of the site. Faults in the vicinity of the site might pass directly under the plant or very close to it and thus would present a hazard of damage to the structure due to possible surface movement on the fault. Therefore, this area was examined in order to determine insofar as possible whether faults are present which might pass under or very close to the facilities.

This work was carried out by reconnaissance geologic mapping of the area within five to ten miles of the site by Blume personnel between May 10, 1970 and May 20, 1970. Reconnaissance consisted of traversing the dune areas in a four-wheel-drive vehicle and examination of outcrops of glacio-fluviatile sediments where possible. The Ringold Formation was examined along the river road south of Ringold Flats and was viewed from the river. Certain outcrop areas of basalt, where it appeared that a maximum of information could be obtained, were examined and mapped. Other areas which appear less important were examined briefly.

It was initially planned to use recent aerial photographs of the FFTF site during the field studies but they were not available at the time the field work was being done.

A supplementary examination of the low basalt hills situated on the west bank of the Yakima River was made on June 4th and June 5th. Results of this study are included in a report which is based primarily upon later, more detailed geologic mapping. The report describing geology of the low basalt hills which are also called the Horn Rapids Lineament comprises the 2nd section of Part 1 of this document.

SUMMARY AND CONCLUSIONS

A reconnaissance geologic survey of the area within 5 to 10 miles of the FFTF site has not revealed evidence of faulting which might pass directly under the site or close to it. With the exception of one minor fault, no known surface rupture or displacement by faulting was observed.

One minor fault was observed in the Yakima River gap striking N 20°E which would pass within 3 miles of the site at its nearest point if it continued northward beyond the slopes of Rattlesnake Mountain. No evidence was found to indicate that it does continue northward. It therefore does not constitute a hazard to the plant due to surface rupture.

A geologic survey of the Horn Rapids lineament was carried out which revealed an occurrence of brecciated basalt and an occurrence of fractured basalt. It was recommended that both of those tectonic structures be studied in more detail and that the lineament be mapped using 1:6,000 scale aerial photographs which were being obtained. It was noted that it might be advisable to augment future detailed studies of tectonic structures on the lineament with subsurface exploration. The detailed geologic mapping has since been completed and is described in Part I of this document. Conclusions based upon this more detailed mapping confirmed earlier work. No evidence of faulting which might pass beneath or very close to the FFTF facilities was found.

AREAL GEOLOGY

General Statement

The mapped area can be divided into three sections, each of which is distinguished by the geologic materials exposed at the surface.

The central area, lying north of Richland, is bounded on the west by Cold Creek and the Yakima River and on the east by the Columbia River. It consists primarily of sand dunes.

The eastern area is underlain by the Ringold Formation with excellent exposures along the bluffs on the east side of the Columbia River.

In the western area, west of Cold Creek and the Yakima River, basalt is the predominant rock either outcropping or lying beneath thin surficial deposits of wind blown and alluvial sand.

The Central Area

The plant site is centrally located in this area of sand dunes, being four miles west of the Columbia River and five miles northeast of the Yakima River.

The site is situated on a topographic high which slopes slightly to the west, south and north while to the east a regular slope drops from an elevation of about 560 ft to 475 ft in a distance of one quarter mile. This slope forms a well defined bench continuing 4 miles south of the site but becomes indistinct to the north. However, if the 500-ft contour line is followed northward a similar bench is seen about 1 mile southwest of Gable Mountain. The intervening area is blanketed by sand dunes. The bench as defined by the 500-ft contour line parallels the present river channel and appears to mark an old river terrace which has been partly obliterated by accumulation of wind blown sand. In the site area sand dunes are relatively thin and have not masked pre-existing topography. The dunes near the site, in contrast to dunes five to eight miles to the north which are largely active, are stabilized by a pervasive covering of sage brush, grass and a variety of small plants. All of the dunes, both active and stabilized, exhibit a marked linear orientation in directions varying from north 75° east in the northern part of the area to north 55° east in the southern part of the area.

A few man-made excavations have exposed stratified glaciofluvial sediments which lie beneath the wind blown sand. If faulting were present in these exposures it could be observed in the stratified materials because the strata would be disturbed and offset. No such evidence of faulting was observed during this survey.

If geologically young faulting of perhaps a few hundred years in age had caused surface rupture in the vicinity of the site some linear trace of the rupture might still be visible. No such linear traces could be observed.

The Eastern Area

The bluffs along the east bank of the Columbia River consist of well stratified, flat lying deposits of the Ringold Formation. A gravel and cobble conglomerate unit of the Ringold Formation outcrops prominently, extending from the water surface at elevation of about 345 ft up to elevation 455 and locally as high as 470 ft. These beds were examined where they outcrop almost continuously between Ringold Flats and the pumping plant about 8 miles south of Ringold Flats, and no evidence of disruption by faulting was observed.

Other prominent but less persistent beds crop out on the high cliffs above the conglomerate to elevations of 700 ft and higher. These strata were viewed from the river and no breaks or disruptions such as might be caused by faulting could be seen. The continuous exposures along the bluffs east of the site are illustrated in Figure 1. Locally, exposures on the cliffs are masked by alluvium, colluvium, or slide material where erosion of the cliffs by stream action or landsliding has occurred.

The primary purpose of this report and field study which was to examine the FFTF site vicinity for evidence of faulting has been completed. There are no further recommendations pertaining to this aspect of the earthquake engineering site evaluation.

The Western Basalt Area

Basalt flows which underlie younger deposits in the central area rise to the surface and crop out about 5 miles southwest of the site. These flows are exposed locally north of Horn Rapids, and along the Yakima River south of Horn Rapids. Basalt crops out extensively on Red Mountain and Rattlesnake Mountain and in the Yakima River Gap between the mountains. Although many of the outcrops nearest the site are isolated, or separated, their topographic position, structural attitude, and the petrography of the basalt comprising them, indicate that they are probably remnants of a flow which was once continuous across the channel now occupied by the Yakima River at Horn Rapids and west of Horn Rapids. This flow has been tilted upward to the northwest along the southeast slope of Rattlesnake Mountain.

The outcropping areas themselves do not reveal evidence of faulting with the exception of one small fault on the north side of the Yakima River Gap (see Geologic Map). The fault is marked by a breccia outcrop and a truncated flow at its south end and by truncated flows and abrupt dislocations of stream courses at the north end. It trends N20°E, dips about 80° to the east and appears to have a small vertical component of displacement. The horizontal component of displacement and time of most recent movement cannot be estimated on the basis of the data obtained during this brief survey. If projected northward, this fault would pass about 3 miles west of the site, and therefore does not constitute a hazard to the FFTF facilities due to possible surface rupture. There is no evidence to indicate that this fault does continue northward. The known length of this fault is four or five miles and its displacement is small. It is therefore a minor fault and is not considered to constitute a possible focus of major earthquakes.

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Horn Rapids Lineament

A line of low basalt hills rises above the surrounding terrain on the west side of the Yakima River between Horn Rapids and West Richland and southeast of West Richland. These hills were shown by Jones and Deacon as the axis of an anticline striking in a northwesterly direction. Bingham, Londquist and Baltz (1970) of the U.S. Geological Survey referred to the line of hills as the Horn Rapids Lineament.

About 2-1/2 days were spent in the field in order to examine and map this lineament. It was later mapped in detail and the results are described in Part 1 of this document. For the purpose of this section of the report it is noted that neither during the reconnaissance study, nor the detailed mapping of the Horn Rapids Lineament was any evidence of faulting observed which might pass beneath or near the FFTF site.

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