

MASTER

Geology of the Nine Canyon Map Area

M. G. Jones
R. D. Landon

September 1978

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

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Informal Report

GEOLOGY OF THE NINE CANYON MAP AREA

M. G. Jones
R. D. Landon

Basalt Geosciences Unit
Research Department

for
Basalt Waste Isolation Program

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A B S T R A C T

The basalt stratigraphy and structure of a 175-square kilometer area (the Nine Canyon Map Area) along the southern margin of the Pasco Basin have been studied to help assess the feasibility of a nuclear waste terminal storage facility. Detailed mapping shows that uplift of the Horse Heaven Hills began prior to extrusion of the Priest Rapids Member of the Wanapum Basalt, Columbia River Basalt Group. Both the Pomona and the Elephant Mountain members (Saddle Mountains Basalt, Columbia River Basalt Group) are widespread throughout the basin, but thin considerably along the Horse Heaven Hills in the vicinity of Wallula Gap. The Ice Harbor Member is present only along the northern margin of the map area and possibly occupies a paleo-channel. The Rattlesnake Hills-Wallula Gap Lineament trends north 60 degrees west and intersects the older Horse Heaven Hills anticline in Wallula Gap. Four faults of short length and small vertical displacement are located along this structure. Within the map area, the intensity of folding increases, and the style of faulting changes from normal to reverse with proximity to the Wallula Gap area. No evidence for Quaternary deformation was found.

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INTRODUCTION

PURPOSE

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

The objective of the geological work in the Nine Canyon Map Area was to describe and map, at a scale of 1:24,000, the stratigraphic units and geologic structures which form the southern end of the Pasco Basin (Figure 1). Those geologic features in the map area that might relate to hydrologic conditions and tectonic stability of the Pasco Basin were emphasized during mapping. These included stratigraphic relationships of the Columbia River Basalt, the location of faults, folds, and fracture zones, plus landslides and geomorphologic features.

LOCATION AND PHYSICAL CHARACTERISTICS

The Nine Canyon Map Area, about 175 square kilometers, lies south of the city of Kennewick in south-central Washington (Figure 2) and borders the southern margin of the Pasco Basin. The Columbia River flows southeast along the northern boundary of the map area, and then turns to the south through Wallula Gap bordering the map area on two sides (see Figure 1). The terrain varies from low rolling hills to fairly steep bluffs, relief is nowhere more than 350 meters. Although most of the land is under cultivation (wheat primarily) small portions are still used as range land and along the northern margin suburban developments are expanding into the area.

DIVISION OF WORK AND RESPONSIBILITY

Mr. R. D. Landon was responsible for mapping along the north flank of the Horse Heaven Hills and Game Farm Hill. Ms. M. G. Jones was responsible for Basalt Hill, Pipeline Hill, The Butte, and The Last Rattle. The responsibility for the remaining area mapped was shared.

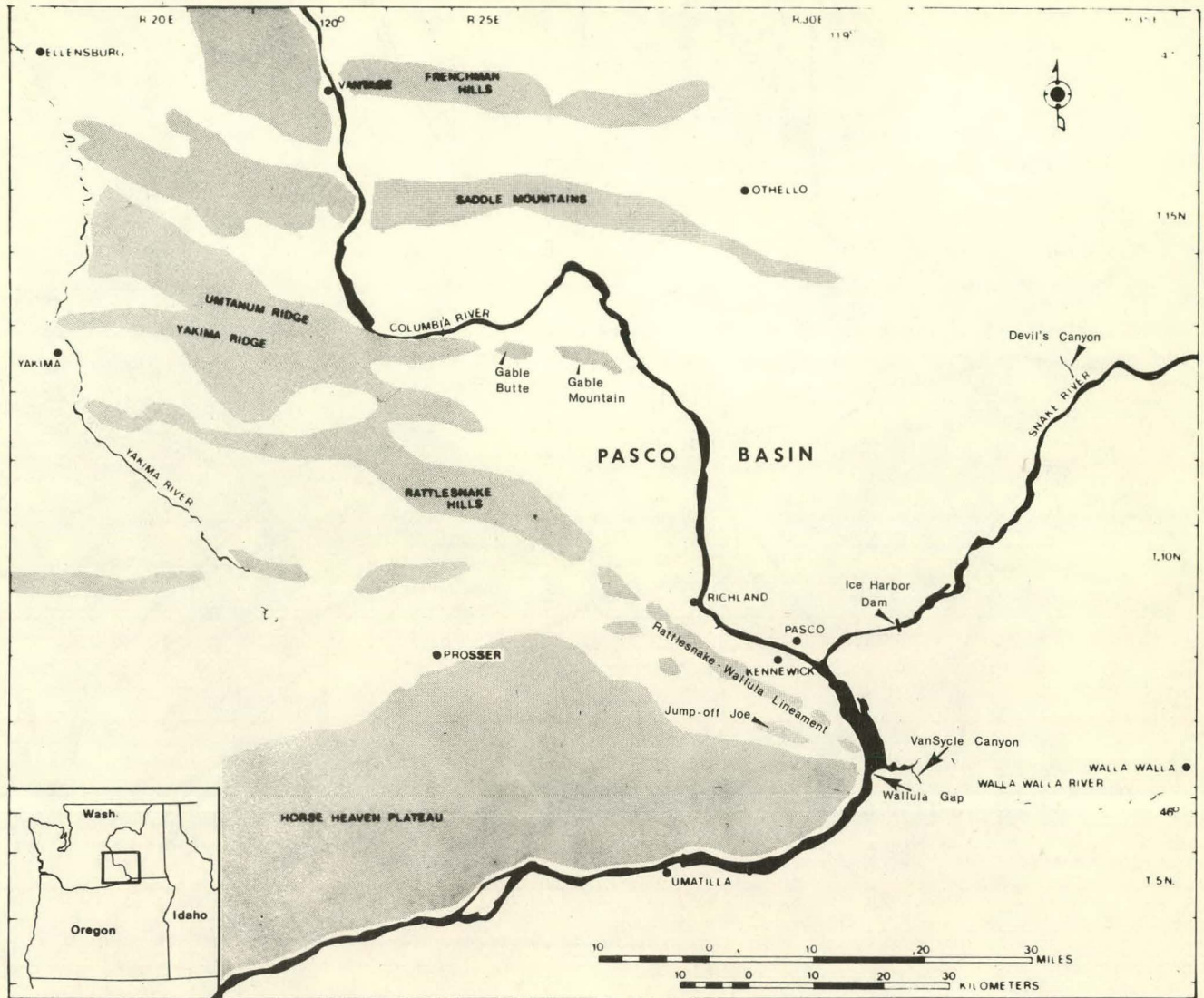


FIGURE 1

GENERAL LOCATION MAP OF THE PASCO BASIN AND VICINITY

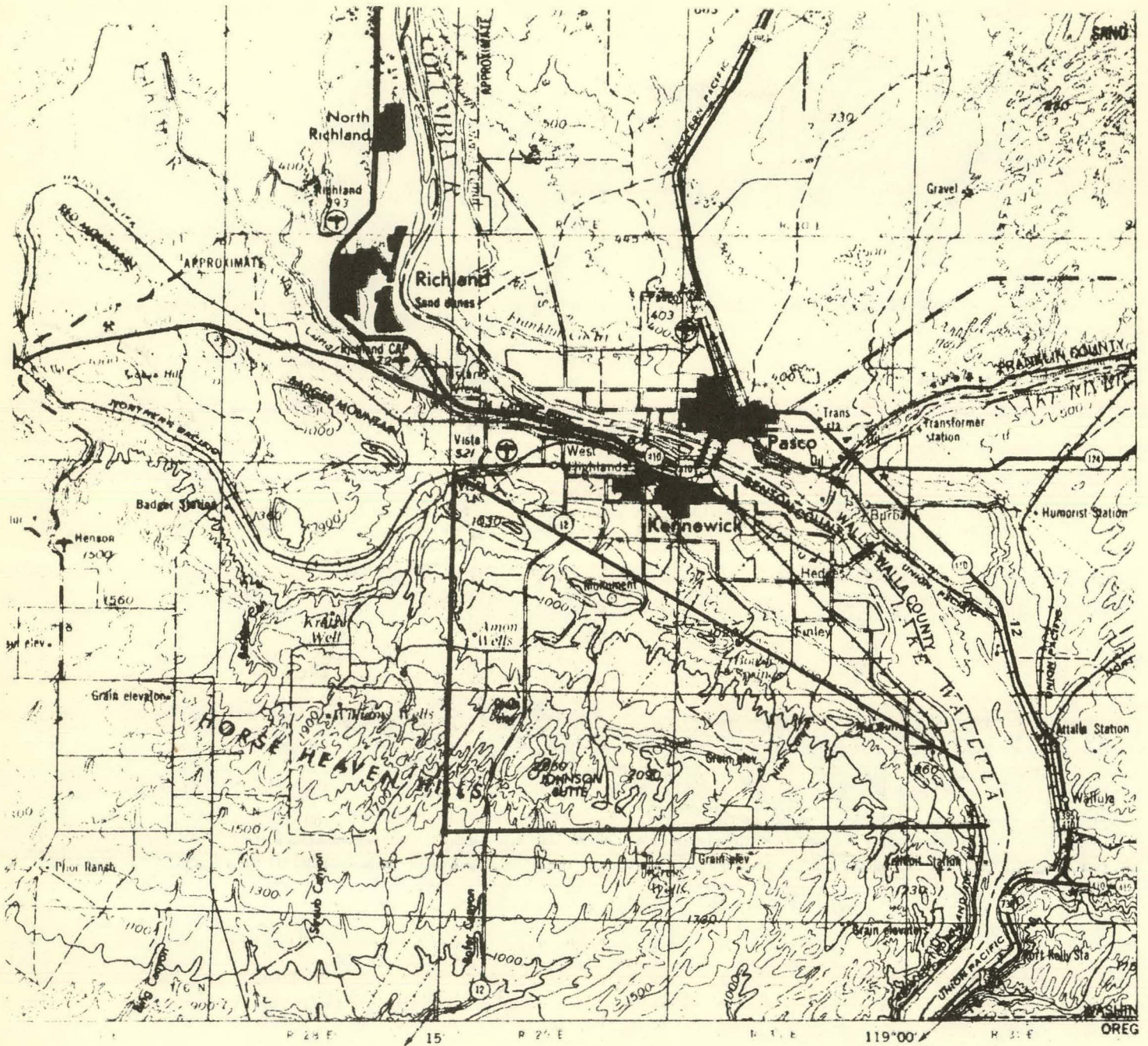


FIGURE 2

LOCATION MAP OF THE NINE CANYON MAP AREA AND VICINITY

(———Indicates boundary.)

METHODS OF INVESTIGATION

Geologic mapping was done on U. S. Geological Survey 7.5-minute topographic sheets and transferred to a composite map at 1:24,000 scale. A total of 60 days was spent in the field between October 1977 and July 1978.

Individual stratigraphic units of Columbia River Basalt were identified on the basis of physical characteristics, whole rock major element chemical analysis using X-ray fluorescence analysis, semi-quantitative chemical analysis for CaO , TiO_2 , and BaO using an onsite energy dispersive X-ray unit and magnetic polarity using a Calex Model 70 Fluxgate Magnetometer. Field notes and sample localities were recorded in controlled field notebooks and shown on Figures 3-A and 3-B.

Judgment was made if the sample should be submitted for a complete X-ray fluorescence major element analysis, if an energy dispersive X-ray analysis would be sufficient, or if no chemical analysis was necessary (in many instances, magnetic polarity, combined with known stratigraphic relationships at a particular locality, were sufficient). Geologic mapping, sampling, magnetic polarity measurements, and other aspects of this work were performed in accordance with Rockwell Hanford Operations standard operating procedures.

PREVIOUS WORK

Although geologic studies of the Columbia Plateau are becoming increasingly abundant, previous work in the Nine Canyon Map Area (Figures 1 and 2) has been limited. Raisz (1945) first noted the physiographic alignment of hills in the Rattlesnake Hills-Wallula Gap area and postulated the existence of a major structural lineament extending from the Olympic Mountains in western Washington to the Wallowa Mountains in northeastern Oregon.

Laval (1956) measured several detailed sections throughout central Washington, two of which lie within the Nine Canyon Map Area (Area VIII, No. 14, Finley Quarry on the west end of The Butte; and, No. 15, Nine Canyon). He noted breccia outcrops along the Rattlesnake Hills-Wallula Gap alignment, but stated they were not traceable for more than 30 meters. He also reported a fault zone some 150 meters wide at the west

end of The Butte. Laval, however, recognized only two basalt members: the Priest Rapids; and, the "Wenas" basalts.

Jones and Deacon (1966) studied portions of the Nine Canyon Map Area and, on the basis of a photogeologic study, inferred a zone of faulting extending from the eastern part of Rattlesnake Hills southeasterly to Wallula Gap and a fault along the base of the Horse Heaven Hills from Benton City east to the Wallula Gap area.

Schminke (1964, 1967) reported fused tuffs and peperites in the Nine Canyon Map Area and distinguished two Elephant Mountain flows at Ward Gap.

Waldron and Bonilla (1968) conducted a brief field study of possible recent faulting in the Hanford area and recommended that the Rattlesnake Hills-Wallula Gap Lineament be further investigated in detail in order to determine the age, extent, and mode of origin of those geologic features "suggestive of recent faulting."

Brown (1968) concluded there was insufficient evidence to justify faulting either at Wallula Gap or along the north flank of the Horse Heaven Hills.

Bingham, et al., (1970) conducted a detailed investigation of the area and concluded there was sufficient indirect evidence to demonstrate that a fault existed along the Horse Heaven Hills. They also reported linear breccia outcrops along the Rattlesnake Hills-Wallula alignment and judged the breccias were tectonic in origin rather than primary flow-related structures. Faulting was also reported along the north side of The Butte.

Gardner (1977) mapped in detail the east side of Wallula Gap. He demonstrated that the Priest Rapids and Roza members of the Wanapum Basalt are absent in Wallula Gap. Gardner also showed stratigraphic offset along the eastern Wallula Gap fault.

Jones and Fecht (1977) examined the western side of Wallula Gap at Yellepit Station, where trenching performed for Atlantic Richfield Hanford Company exposed the western extension of the Wallula Gap Fault.

Washington Public Power Supply System, Inc., (1977) did mapping in the area.

REGIONAL GEOLOGIC SETTING

The Columbia Plateau is made up of a thick sequence of Miocene tholeiitic flood basalts erupted from a series of linear fissures which vented an estimated 200,000 square kilometers of basalt. The study area

lies on the southern border of the Pasco Basin which contains the thickest known section of Columbia River Basalt on the plateau. The Pasco Basin is a structural and topographic low which is bounded on three sides by a series of east-west-trending anticlinal ridges: the Saddle Mountains to the north; Umtanum and Yakima ridges and Rattlesnake Hills to the west; and, the Rattlesnake Hills-Wallula alignment to the south (Figure 1).

ACKNOWLEDGMENTS

We express appreciation to the staff of the Basalt Geosciences Unit of Rockwell Hanford Operations for their stimulating discussions regarding the results of the study. In particular, we would like to thank Drs. C. W. Myers, S. P. Reidel, P. E. Long, F. E. Goff, and Messrs. K. R. Fecht and J. T. Lillie. Special thanks is given to Dr. D. A. Swanson of the U. S. Geological Survey.

STRATIGRAPHY

INTRODUCTION

The Columbia River Basalt Group is comprised of five formations: the Picture Gorge; the Imnaha; the Grande Ronde; the Wanapum; and, the Saddle Mountains basalts. Of these, only two are found within the Nine Canyon Map Area: the Wanapum; and, the Saddle Mountains basalts.

A third formation, the Ellensburg Formation which was deposited concurrently with the Wanapum and Saddle Mountains basalts, is composed of clastic and volcanoclastic sediments. Time stratigraphic problems complicate relationships between the two basalt formations and the Ellensburg Formation and, therefore, the Ellensburg Formation is not included in the Columbia River Basalt Group.

One Pliocene unit, tentatively correlated with the Ringold Formation, one Plio-Pleistocene unit, the Hanford Formation (informal name), and Holocene sediments, overlie the basalt.

The stratigraphic nomenclature used in this report is shown in Figure 4 and is consistent with Swanson, et al., (1978).

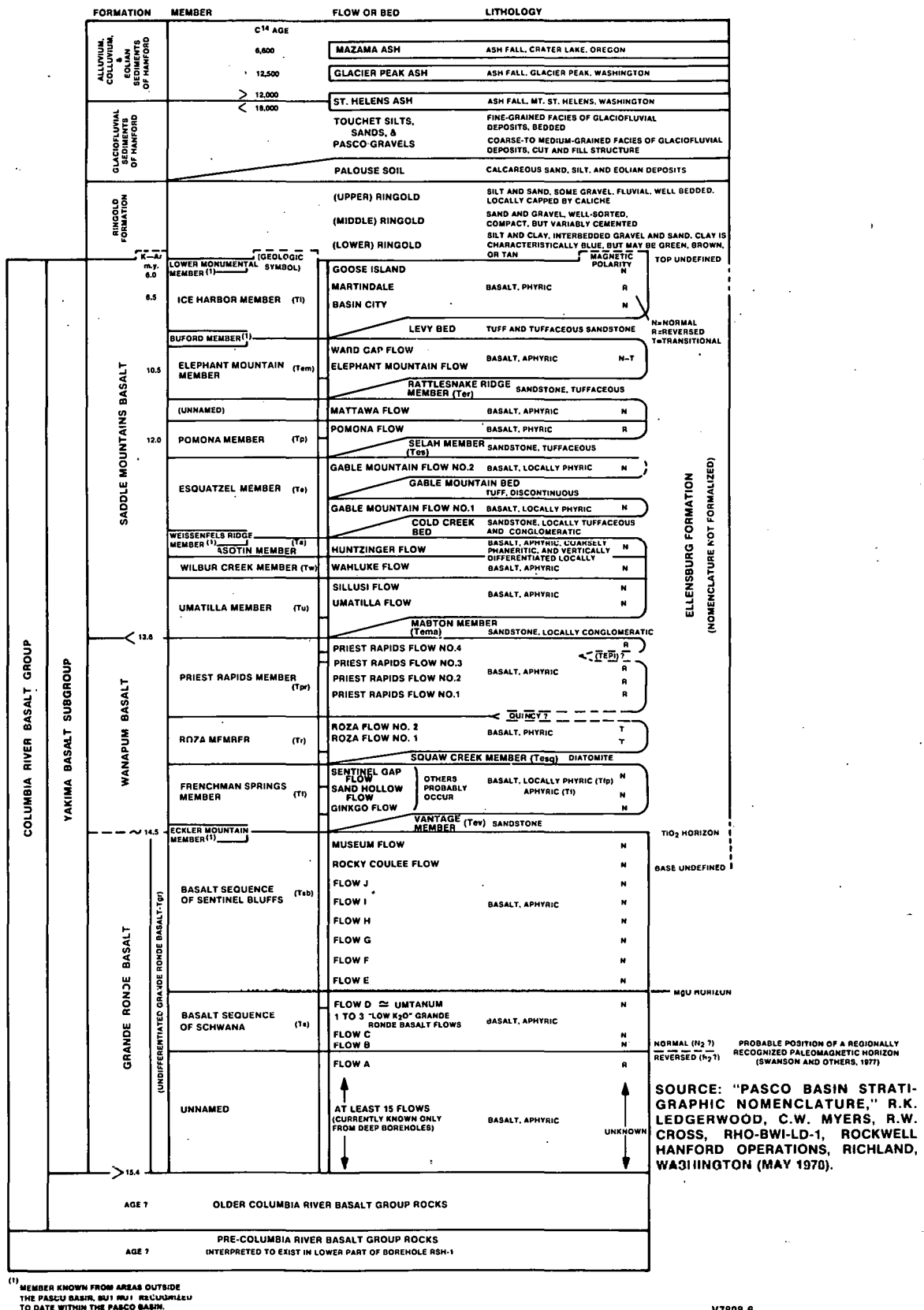


FIGURE 4

PASCO BASIN STRATIGRAPHIC NOMENCLATURE

WANAPUM BASALT

Flows of the Wanapum Basalt are exposed in only a few localities in the Nine Canyon Map Area. Recent mapping by Mr. J. N. Gardner in 1977 on the east side of Wallula Gap has shown that the Priest Rapids and Roza members of the Wanapum Basalt are absent in the immediate Wallula Gap area. Our findings are consistent with this in the eastern portion of the Nine Canyon Map Area; however, Priest Rapids flows are found approximately 16 kilometers due west along the south side of Game Farm Hill and in Zintel Canyon.

Frenchman Springs Member

One or possibly two flows of the Frenchman Springs Member are exposed at the west end of the Last Rattle on the very eastern-most edge of the Nine Canyon Map Area. Exposure is limited to a small portion underlying the Umatilla Member south of the canal siphon (Section 7, Township 7 North, Range 31 East) (abbreviated Sec. 7, T7N, R31E) and a faulted block just north of the siphon. In hand specimen, the rock is greenish-gray medium-grained, and sparsely plagioclase-phyric. The Frenchman Springs Member exhibits normal natural remanent magnetism throughout. The Frenchman Springs Member has been dated by the $^{40}\text{K}/^{40}\text{Ar}$ method at between 14.5 million years and 13.6 million years old (Swanson, et al., 1978). Brecciated outcrops of Frenchman Springs Member are present 0.6 kilometer east. The breccias are composed of red, orange, brown, and black angular fragments of massive and vesicular basalt set in a matrix of brownish clay. Due to poor exposure of the Frenchman Springs Member, flow thickness and intraflow structures are uncertain.

Priest Rapids Member

The Priest Rapids Member is typically gray-green in color, diktytaxitic, and sparsely plagioclase-phyric. The Priest Rapids is distinct from the other Wanapum Basalt members chemically, as well as in hand specimen.

Swanson, et al., (1978) distinguished two distinct chemical types for the Priest Rapids Member: the Lolo (Wright, et al., 1973); and, the Rosalia chemical type, with the Lolo having higher MgO and CaO than the Rosalia type. In the study area, these two types are seen with the Lolo type flow overlying the Rosalia type flows (Table I). The Priest Rapids

TABLE I
X-RAY FLUORESCENCE ANALYSIS

| <u>SAMPLE NO.</u> | <u>SiO₂</u> | <u>Al₂O</u> | <u>TiO₂</u> | <u>Fe₂O₃</u> | <u>Fe₂O</u> | <u>MnO</u> | <u>CaO</u> | <u>MgO</u> | <u>K₂O</u> | <u>Na₂O</u> | <u>P₂O₅</u> | <u>MEMBER NAME</u> |
|-------------------|------------------------|------------------------|------------------------|------------------------------------|------------------------|------------|------------|------------|-----------------------|------------------------|-----------------------------------|--------------------|
| C7024 | 52.53 | 15.12 | 1.66 | 2.00 | 8.22 | 0.17 | 11.25 | 5.90 | 0.48 | 2.41 | 0.24 | Pomona |
| C7037 | 51.52 | 15.15 | 1.56 | 2.00 | 9.06 | 0.18 | 10.73 | 6.73 | 0.54 | 2.28 | 0.23 | Pomona |
| C7055 | 50.87 | 13.26 | 3.41 | 2.00 | 12.93 | 0.22 | 8.65 | 4.40 | 1.38 | 2.43 | 0.44 | Elephant Mt. |
| C7104 | 54.77 | 14.09 | 2.73 | 2.00 | 11.15 | 0.21 | 6.57 | 1.90 | 2.79 | 2.94 | 0.84 | Umatilla |
| C7113 | 53.75 | 14.18 | 3.19 | 2.00 | 10.62 | 0.21 | 7.10 | 2.97 | 2.34 | 2.93 | 0.69 | Umatilla |
| C7119 | 50.33 | 13.29 | 3.40 | 2.00 | 13.23 | 0.21 | 9.49 | 4.06 | 1.02 | 2.48 | 0.49 | Elephant Mt. |
| C7124 | 52.43 | 14.88 | 1.58 | 2.00 | 8.47 | 0.18 | 10.70 | 6.74 | 0.67 | 2.12 | 0.23 | Pomona |
| C7128 | 52.19 | 14.73 | 1.58 | 2.00 | 8.88 | 0.18 | 10.83 | 6.77 | 0.44 | 2.16 | 0.24 | Pomona |
| C7129 | 50.64 | 13.45 | 3.41 | 2.00 | 13.12 | 0.21 | 8.63 | 4.39 | 1.45 | 2.21 | 0.48 | Elephant Mt. |
| C7130 | 50.45 | 13.43 | 3.39 | 2.00 | 12.77 | 0.21 | 8.87 | 5.01 | 1.16 | 2.22 | 0.49 | Elephant Mt. |
| C7134 | 50.38 | 13.49 | 3.40 | 2.00 | 13.28 | 0.22 | 8.66 | 4.44 | 1.43 | 2.23 | 0.48 | Elephant Mt. |
| C7141 | 50.46 | 13.82 | 3.19 | 2.00 | 11.70 | 0.21 | 9.54 | 4.52 | 1.15 | 2.74 | 0.69 | Priest Rapids |
| C7303 | 49.88 | 14.01 | 3.11 | 2.00 | 11.91 | 0.23 | 9.17 | 5.67 | 1.01 | 2.38 | 0.63 | Priest Rapids |
| C7305 | 50.64 | 14.06 | 3.11 | 2.00 | 12.95 | 0.22 | 8.66 | 4.08 | 1.06 | 2.66 | 0.57 | Priest Rapids |
| C7306 | 49.66 | 14.08 | 3.08 | 2.00 | 12.29 | 0.23 | 9.19 | 5.35 | 1.08 | 2.41 | 0.64 | Priest Rapids |
| C7333 | 49.72 | 14.32 | 3.07 | 2.00 | 12.40 | 0.23 | 9.05 | 5.15 | 0.90 | 2.51 | 0.65 | Priest Rapids |
| C7334 | 50.85 | 13.93 | 3.07 | 2.00 | 12.79 | 0.24 | 8.38 | 4.29 | 1.34 | 2.59 | 0.52 | Priest Rapids |
| C7338 | 47.76 | 14.03 | 3.52 | 2.00 | 13.83 | 0.24 | 9.68 | 5.31 | 0.51 | 2.38 | 0.73 | Ice Harbor |
| C7339 | 50.82 | 13.93 | 3.56 | 2.00 | 12.39 | 0.21 | 8.89 | 4.21 | 1.07 | 2.42 | 0.50 | Elephant Mt. |
| C7340 | 51.81 | 15.30 | 1.61 | 2.00 | 8.78 | 0.18 | 10.84 | 6.59 | 0.41 | 2.25 | 0.23 | Pomona |
| C7341 | 51.54 | 15.08 | 1.68 | 2.00 | 9.00 | 0.19 | 10.71 | 6.85 | 0.48 | 2.22 | 0.25 | Pomona |
| C7342 | 54.97 | 14.68 | 2.57 | 2.00 | 10.60 | 0.22 | 6.14 | 2.60 | 2.92 | 2.42 | 0.89 | Umatilla |

flows have reversed natural remanent magnetism and have been dated by the $^{40}\text{K}/^{40}\text{Ar}$ method at greater than 13.6 million years (Swanson, et al., 1978).

The Priest Rapids Member is exposed in two localities: along Zintel Canyon (Sec. 3, T7N, R29E), where three flows are exposed; and, on the south side of Game Farm Hill (Sec. 30, T8N, R30E), where two flows are exposed. In Zintel Canyon, 1 meter of baked tuffaceous silt lies between the lower and middle flows. The lower and middle flows are very similar in outcrop, both exhibiting a vesicular reddish flow top. The top two flows are extensively spheroidally weathered (Figure 5) and appear to be composed of large columns 0.9 to 1.2 meters in diameter with horizontal partings every 0.3 to 0.45 meter. The lower flow also exhibits large columns 0.9 to 1.2 meters in diameter with horizontal partings every 0.45 meter. A pillowed zone is present at the base of the upper flow exposed on Game Farm Hill. Within the Nine Canyon Map Area, the top of the Priest Rapids Member appears absent and the lower portion of the flow may be unconformably overlain by the Umatilla Member of the Saddle Mountains Basalt.

SADDLE MOUNTAINS BASALT

Within the map area, there are four Saddle Mountains Basalt members exposed: the Umatilla Member (13.6 million years); Pomona Member (12.0 million years); Elephant Mountain Member (10.5 million years); and, the Ice Harbor Member (8.5 million years) (dates from Swanson, et al., 1978).

Umatilla Member

The Umatilla Member is the thickest and most distinctive flow in the area. In hand specimen, the rock is very black and glassy and consistently aphyric, although rare plagioclase phenocrysts to 0.7 centimeter in length have been found. Glass content is so high (up to 60 percent) as to produce an excellent conchoidal fracture when the rock is broken, and a yellow-orange pseudo-palagonite upon weathered surfaces. The unusually high barium content ($3,000 \pm$ parts per million) enables rapid distinction from other flows using the energy dispersive X-ray unit. The Umatilla has a strong normal natural remanent magnetism throughout.



FIGURE 5

HIGHLY WEATHERED PRIEST RAPIDS MEMBER, ZINTEL CANYON

The flow maintains a relatively consistent thickness (45 meters) throughout the map area. The entablature is typically 80 percent of the flow and forms prominent cliffs that often spall off in tall hackly blocks (Figure 6). The flow top development of the Umatilla is locally pronounced, varying in thickness from 1.3 meters to as much as 10 meters and is composed of red, orange, and lavender clinker and scoriaceous rubble. In at least two localities (Pipeline Hill, Sec. 24, and the quarry, Sec. 23, T18N, R29E), the flow top of the Umatilla was removed by erosion prior to deposition of the Pomona Member.

Pomona Member

The Pomona Member in the Nine Canyon Map Area consists of a single, moderately phyrific flow, distinguishable by its stratigraphic position, reversed natural remanent magnetism, and Pomona-type chemistry (Table I) (Wright, et al., 1973). In hand specimen, the rock is gray-black or bluish-green in color, medium- to fine-grained, with moderately abundant lath-shaped plagioclase phenocrysts 0.3 to 1 centimeter in length. Sparse plagioclase glomerophenocrysts up to 2 centimeters in length occur. Olivine phenocrysts are present, but are commonly altered and recognizable only by their remnant crystal habit. Flow thickness varies from 3 to 27 meters; the variation is interpreted as due to erosion and thinning as the flow advanced onto the growing Horse Heaven Hills anticline. In two localities on the eastern edge of the map area, the Pomona is absent. In outcrop, the Pomona is characterized by a gray- or lavender-colored base, very vesicular where it overlies the Selah Interbed, with poorly developed columns 0.3 to 0.75 meter in diameter. The entablature has small, well-formed, wavy or fanning columns 0.3 to 0.45 meter across. Figure 7 shows a Pomona exposure on the east end of Game Farm Hill (Sec. 29, T8N, R30E).

Elephant Mountain Member

The Elephant Mountain Member is characterized by its black color and fine-grained diktytaxitic texture. Although only very sparsely plagioclase-phyritic, it is abundantly micro-porphyritic resulting in a felty textured appearance on weathered surfaces. The member has Elephant Mountain chemical type (Wright, et al., 1973) of moderate calcium (8.7 percent) and high titanium (3.4 percent) (Tables I and II).

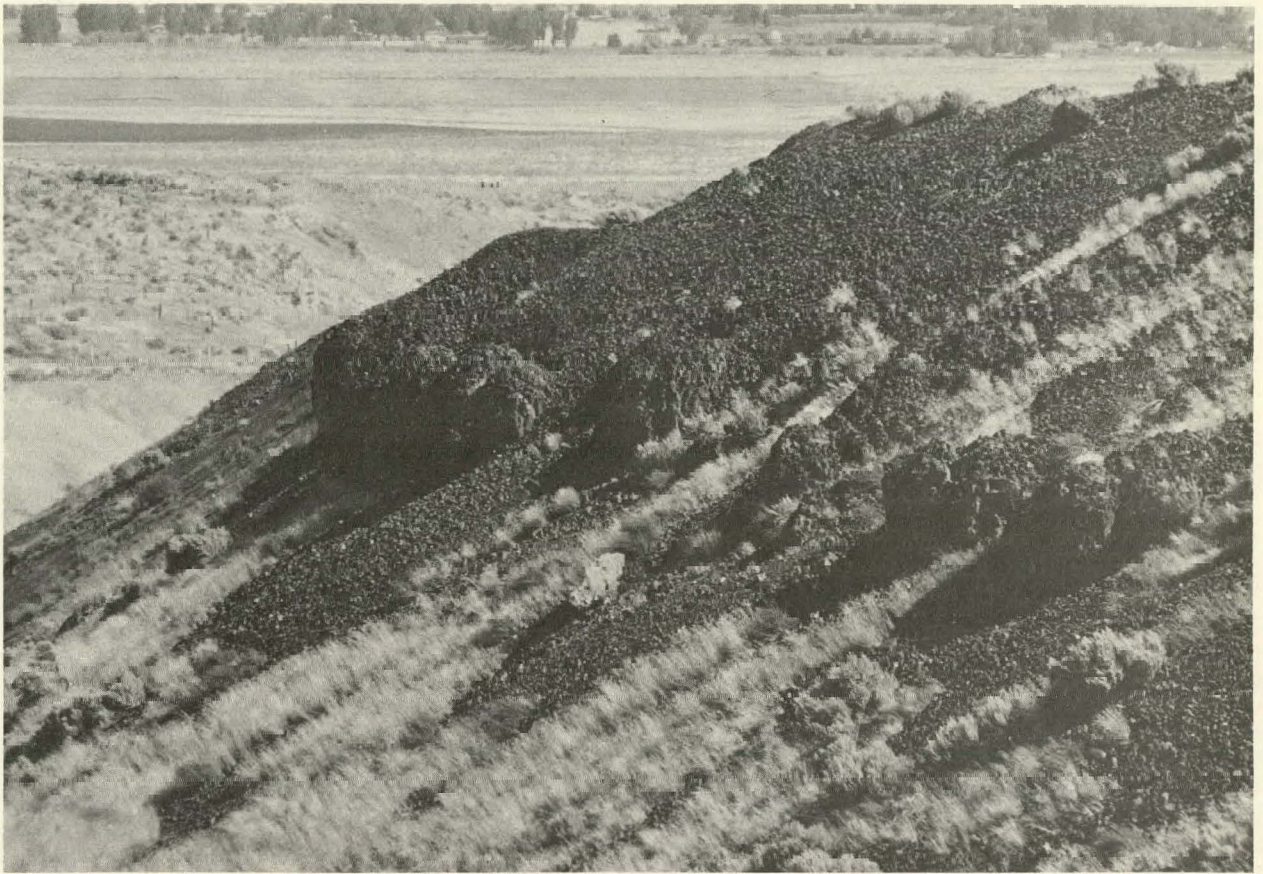


FIGURE 6

TYPICAL UMATILLA MEMBER OUTCROP, THE BUTTE



FIGURE 7

TYPICAL POMONA MEMBER OUTCROP, GAME FARM HILL

TABLE II

SEMI-QUANTITATIVE ENERGY DISPERSIVE X-RAY CHEMISTRY RESULTS

(All values in weight percent)

| <u>SAMPLE NUMBER</u> | <u>CaO</u> | <u>TiO₂</u> | <u>Ba</u> | <u>MEMBER NAME</u> |
|----------------------|------------|------------------------|-----------|--------------------|
| C7011 | 6.7 | 2.1 | low | Elephant Mt. |
| C7012 | 6.3 | 2.1 | low | Elephant Mt. |
| C7013 | 6.7 | 2.8 | low | Elephant Mt. |
| C7014 | 9.2 | 1.8 | low | Pomona |
| C7015 | 8.1 | 2.7 | low | Ice Harbor* |
| C7016 | 9.6 | 2.6 | low | Ice Harbor* |
| C7017 | 7.8 | 2.4 | low | Elephant Mt. |
| C7018 | 7.6 | 2.7 | low | Elephant Mt. |
| C7019 | 7.8 | 2.7 | low | Elephant Mt. |
| C7020 | 7.5 | 2.5 | low | Elephant Mt. |
| C7021 | 8.5 | 2.3 | low | Elephant Mt. |
| C7024 | 7.2 | 1.4 | low | Pomona |
| C7025 | 7.7 | 1.4 | low | Pomona |
| C7026 | 7.2 | 1.8 | low | Pomona |
| C7027 | 6.7 | 2.6 | low | Ice Harbor* |
| C7028 | 7.2 | 2.2 | low | Elephant Mt. |
| C7029 | 6.7 | 1.8 | low | Pomona |
| C7030 | 7.2 | 1.2 | low | Pomona |
| C7031 | 7.8 | 1.3 | low | Pomona |
| C7032 | 7.0 | 2.4 | low | Elephant Mt. |
| C7033 | 7.0 | 2.4 | low | Elephant Mt. |
| C7034 | 7.6 | 3.2 | low | Elephant Mt. |
| C7036 | 8.6 | 2.4 | low | * |
| C7037 | 8.7 | 2.4 | low | * |

* = Results are inconclusive.

Table II (continued)

| <u>SAMPLE NUMBER</u> | <u>CaO</u> | <u>TiO₂</u> | <u>Ba</u> | <u>MEMBER NAME</u> |
|----------------------|------------|------------------------|-----------|--------------------|
| C7038 | 8.0 | 1.9 | low | Pomona |
| C7039 | 7.0 | 2.6 | low | Elephant Mt. |
| C7040 | 7.4 | 2.6 | low | Elephant Mt. |
| C7042 | 5.9 | 2.5 | high | Umatilla |
| C7043 | 9.4 | 1.6 | low | Pomona |
| C7045 | 8.3 | 3.0 | low | Elephant Mt. |
| C7050 | 8.7 | 4.0 | low | Elephant Mt. |
| C7051 | 10.6 | 1.7 | low | Pomona |
| C7052 | 10.2 | 1.5 | low | Pomona |
| C7053 | 8.0 | 3.1 | low | Elephant Mt. |
| C7056 | 8.3 | 3.1 | low | Elephant Mt. |
| C7075 | 8.7 | 4.2 | low | Elephant Mt. |
| C7076 | 7.7 | 2.9 | low | Elephant Mt. |
| C7077 | 8.5 | 4.2 | low | Elephant Mt. |
| C7078 | 8.3 | 4.2 | low | Elephant Mt. |
| C7079 | 9.4 | 3.3 | low | Ice Harbor* |
| C7081 | 8.7 | 4.0 | low | Elephant Mt. |
| C7082 | 10.6 | 1.5 | low | Pomona |
| C7087 | 6.1 | 2.4 | low | Elephant Mt. |
| C7088 | 10.7 | 2.8 | low | Ice Harbor* |
| C7089 | 10.9 | 3.3 | low | Ice Harbor |
| C7090 | 8.6 | 2.7 | low | Elephant Mt. |
| C7091 | 10.8 | 1.9 | low | Pomona |
| C7092 | 7.7 | 2.8 | low | Elephant Mt. |
| C7093 | 10.1 | 2.7 | low | Ice Harbor |
| C7094 | 7.4 | 3.1 | low | Elephant Mt. |
| C7095 | 8.3 | 2.6 | low | Elephant Mt. |
| C7096 | 8.3 | 3.2 | low | Elephant Mt. |
| C7097 | 8.9 | 1.5 | low | Pomona |
| C7099 | 5.9 | 2.5 | high | Umatilla |

* = Results are inconclusive.

Table II (continued)

| <u>SAMPLE NUMBER</u> | <u>CaO</u> | <u>TiO₂</u> | <u>Ba</u> | <u>MEMBER NAME</u> |
|----------------------|------------|------------------------|-----------|--------------------|
| C7100 | 7.6 | 2.3 | low | * |
| C7101 | 8.8 | 2.8 | low | * |
| C7102 | --- | --- | high | Umatilla |
| C7103 | --- | --- | high | Umatilla |
| C7104 | --- | --- | high | Umatilla |
| C7105 | 7.8 | 2.4 | low | Priest Rapids |
| C7106 | 8.2 | 3.6 | low | Priest Rapids |
| C7107 | 8.0 | 2.0 | low | Priest Rapids |
| C7108 | 7.6 | 2.9 | low | Priest Rapids |
| C7109 | 8.4 | 2.8 | low | Priest Rapids |
| C7110 | 9.3 | 1.5 | low | Pomona |
| C7111 | --- | --- | high | Umatilla |
| C7112 | 9.1 | 3.5 | high | Umatilla |
| C7113 | 9.0 | 3.1 | moderate | Umatilla |
| C7114 | 6.6 | 3.6 | moderate | Umatilla |
| C7115 | 7.3 | 3.6 | moderate | Umatilla |
| C7116 | 5.4 | 2.9 | high | Umatilla |
| C7118 | 6.6 | 3.1 | high | Umatilla |
| C7119 | --- | --- | low | Pomona |
| C7120 | 7.3 | 2.9 | low | Elephant Mt. |
| C7121 | 8.2 | 1.6 | low | Pomona |
| C7122 | 5.0 | 2.0 | high | Umatilla |
| C7123 | 7.3 | 2.4 | low | Elephant Mt. |
| C7124 | 8.4 | 1.6 | low | Pomona |
| C7125 | 8.1 | 1.4 | low | Pomona |

* = Results are inconclusive.

Table II (continued)

| <u>SAMPLE NUMBER</u> | <u>CaO</u> | <u>TiO₂</u> | <u>Ba</u> | <u>MEMBER NAME</u> |
|----------------------|------------|------------------------|-----------|--------------------|
| C7126 | 5.6 | 2.5 | high | Umatilla |
| C7127 | 5.6 | 2.5 | high | Umatilla |
| C7128 | 8.1 | 1.4 | low | Pomona |
| C7129 | 6.7 | 2.1 | low | Elephant Mt. |
| C7130 | 7.2 | 2.1 | low | Elephant Mt. |
| C7131 | 7.7 | 1.1 | low | Pomona |
| C7132 | 6.7 | 2.1 | low | Elephant Mt. |
| C7133 | 6.7 | 2.8 | low | Elephant Mt. |
| C7134 | 6.3 | 2.1 | low | Elephant Mt. |
| C7135 | 6.7 | 2.1 | low | Elephant Mt. |
| C7136 | 6.3 | 1.4 | low | Pomona |
| C7137 | 6.7 | 2.1 | low | * |
| C7138 | 6.3 | 1.8 | low | * |
| C7139 | 4.8 | 2.1 | high | Umatilla |
| C7140 | 7.7 | 2.1 | low | Priest Rapids |
| C7141 | 8.2 | 2.6 | low | Priest Rapids |
| C7142 | 5.3 | 2.9 | moderate | Umatilla |
| C7143 | --- | --- | high | Umatilla |
| C7147 | 6.9 | 2.1 | low | Ward Gap Type |
| C7148 | 5.6 | 2.5 | high | Umatilla |
| C7149 | 6.6 | 3.3 | high | Umatilla |
| C7150 | 7.6 | 2.0- | low | Pomona |
| C7151 | 7.8 | 2.0 | low | Pomona |
| C7153 | 9.9 | 1.6 | low | Pomona |
| C7154 | 8.5 | 3.0 | low | Elephant Mt. |
| C7155 | 8.7 | 1.6 | low | Pomona |
| C7156 | 7.7 | 3.0 | low | Elephant Mt. |
| C7157 | 7.7 | 2.7 | low | Elephant Mt. |
| C7159 | 8.1 | 2.9 | low | Elephant Mt. |
| C7160 | 8.3 | 2.8 | low | Elephant Mt. |

* = Results are inconclusive.

Table II (continued)

| <u>SAMPLE NUMBER</u> | <u>CaO</u> | <u>TiO₂</u> | <u>Ba</u> | <u>MEMBER NAME</u> |
|----------------------|------------|------------------------|-----------|--------------------|
| C7161 | 6.3 | 2.5 | high | Umatilla |
| C7162 | 10.7 | 2.0 | low | Pomona |
| C7165 | 8.4 | 3.0 | low | Elephant Mt. |
| C7166 | 8.2 | 3.3 | low | Elephant Mt. |
| C7167 | 9.8 | 2.7 | low | Priest Rapids |
| C7168 | 9.7 | 3.0 | low | Priest Rapids |
| C7170 | 8.9 | 4.2 | low | Elephant Mt. |
| C7171 | 9.0 | 3.6 | low | Elephant Mt. |
| C7172 | 9.0 | 2.7 | low | Elephant Mt. |
| C7173 | 8.4 | 3.6 | low | Elephant Mt. |
| C7174 | 10.3 | 1.4 | low | Pomona |
| C7176 | 8.5 | 3.0 | low | Elephant Mt. |
| C7177 | 11.4 | 1.5 | low | Pomona |
| C7181 | 7.1 | 3.6 | low | * |
| C7182 | 7.1 | 3.6 | low | * |
| C7183 | 10.5 | 1.6 | low | Pomona |
| C7184 | 10.2 | 1.5 | low | Pomona |
| C7185 | 10.2 | 1.5 | low | Pomona |
| C7186 | 10.3 | 1.4 | low | Pomona |
| C7187 | 9.8 | 1.4 | low | Pomona |
| C7188 | 10.5 | 1.4 | low | Pomona |
| C7189 | 8.0 | 2.7 | low | Elephant Mt. |
| C7194 | 10.1 | 2.0 | low | Pomona |
| C7195 | 10.2 | 1.8 | low | Pomona |
| C7197 | 10.1 | 1.5 | low | Pomona |
| C7198 | 6.4 | 2.8 | low | Priest Rapids |
| C7199 | 10.8 | 1.9 | low | Pomona |
| C7200 | 8.9 | 1.4 | low | Pomona |
| C7201 | 8.2 | 1.5 | low | Pomona |
| C7202 | 8.3 | 1.5 | low | Pomona |
| C7204 | 7.1 | 2.6 | low | Frenchman Spr. |
| C7205 | 7.7 | 2.7 | low | Frenchman Spr. |

* = Results are inconclusive.

Table II (continued)

| <u>SAMPLE NUMBER</u> | <u>CaO</u> | <u>TiO₂</u> | <u>Ba</u> | <u>MEMBER NAME</u> |
|----------------------|------------|------------------------|-----------|--------------------|
| C7300 | 10.0 | 1.5 | low | Pomona |
| C7301 | 10.5 | 1.9 | low | Pomona |
| C7302 | 10.3 | 1.8 | low | Pomona |
| C7303 | 8.4 | 2.4 | low | Priest Rapids |
| C7304 | 9.0 | 3.6 | low | Priest Rapids |
| C7306 | 8.7 | 2.8 | low | Priest Rapids |
| C7311 | 8.4 | 2.4 | low | Priest Rapids |
| C7315 | 7.5 | 2.4 | low | Priest Rapids |
| C7316 | 7.9 | 2.5 | low | Priest Rapids |

Elephant Mountain flows have normal to transitional remanent magnetism making it an unreliable tool for positive identification. The Elephant Mountain Member, while widespread throughout the map area, is poorly exposed due to its tendency to form rounded slopes. It commonly weathers to a "grussic" sand and generally only the base is exposed revealing large red-brown stubby columns 1.3 to 1.5 meters across with subdued horizontal partings. In two locations (Sec. 20 and 21, T7N, R30E), the base of the Elephant Mountain Member is pillowed. On the eastern edge of the map area, along the Columbia River, there appears to be two Elephant Mountain flows separated by a vesicular zone containing lenses of cherty clay. This flow has anomalous magnetics, but Elephant Mountain-like chemistry, and is tentatively correlated with the Ward Gap flow of Schminke (1967).

Ice Harbor Member

The Ice Harbor Member in the area consists of one abundantly plagioclase-phyric flow with sparse glomeroporphyritic clots of plagioclase and pyroxene to 2 centimeters or more in length. High calcium and high titanium distinguish it chemically (Table I). Reversed natural remanent magnetism indicates it is the Martindale Flow of the Ice Harbor Member. Generally, only the basal portion of the flow is exposed exhibiting large reddish stubby columns 1.5 to 2.4 meters across. In hand specimen, the rock is brownish-gray and medium grained. The Ice Harbor Member is present along the northern portion of the map area, along all of the ridges composing the Rattlesnake Hills-Wallula Gap Lineament, except Pipeline Hill, and along the Columbia River south of The Last Rattle.

ELLENSBURG FORMATION

The Ellensburg Formation in the Nine Canyon Map Area consists of the Priest Rapids, Selah, Rattlesnake Ridge, and Levy interbeds. These interbeds are composed of tephra and fine-grained clastic sediments. All of the interbeds are discontinuous and appear to represent low areas where the sediments were protected from erosion.

Priest Rapids Interbed (Informal Name)

The Priest Rapids Interbed (Figure 8) lies between the lower and the middle flows of the Priest Rapids Member in Zintel Canyon. The light



FIGURE 8

SECOND PRIEST RAPIDS FLOW OVERLYING THE PRIEST RAPIDS INTERBED

gray sediment is composed of tephra and fine-grained silts. The top 5 centimeters of the 1-meter-thick interbed is baked to a lavender color by the overlying flow.

Selah Interbed

The Selah Interbed underlies the Pomona Member of the Saddle Mountains Basalt. This white vitric tuff varies in thickness from a few centimeters to 1.5 meters. In several localities (Sec. 5 and 6, T7N, R29E and Sec. 16, T7N, R29E), well-preserved ripple marks attest to the water-laid depositional character of this clean, well-sorted ash. The top-most portion of the Selah (0.5 to 2.5 centimeters) has been fused to a black perlitic glass by the overlying Pomona and serves as an excellent marker where present. Occasionally, only pebble-sized fragments of the black glass mark the Pomona-Umatilla contact. An excellent peperite is exposed on the southeast end of The Last Rattle, presumably resulting from the Pomona Flow plowing into a thick pile of wet, unconsolidated sediments.

Rattlesnake Ridge Interbed

The Rattlesnake Ridge Interbed lies between the Pomona Member and the Elephant Mountain Member. This buff, yellow, and gray tuffaceous silt is exposed at three localities in the map area (Sec. 20, T7N, R31E, and Sec. 30, T8N, R29E) and varies in thickness from 1 to 5 meters. In the thick exposure along the Columbia River, dehydration of the top-most gray clayey portion has produced curious pseudo-columns 1 centimeter across.

Levy Interbed

The Levy Interbed underlying the Ice Harbor Member (Martindale Flow) has been found in only one locality, the eastern section bordering on the Columbia River. There, the cream-colored silty clay is approximately 3 meters thick.

PLIOCENE SEDIMENTS

The pliocene unit consists of coalesced fanglomerates exposed only along the southern flank of the anticlines composing the Rattlesnake Hills-Wallula Gap Lineament. It is composed of angular to subangular basalt clasts, moderately well-indurated, and cemented by thick,

well-developed calcium carbonate, rendering it fairly resistant to erosion. Absolute thickness of this unit is unknown; however, in places, it blankets slopes lower than 300 meters in elevation, and, in one locality (Sec. 32, T8N, R30E), it is directly overlain by Hanford Formation sediments. Stratigraphic position (although equivocal) and degree of lithification suggest this unit is more properly correlative with the Ringold Formation than with the Hanford Formation; although, due to limited exposures, we have mapped it as Hanford Formation.

PLIO-PLEISTOCENE SEDIMENTS

The Hanford Formation (Informal Name)

The Hanford Formation consists of Touchet and Touchet-like sediments and glaciofluvial sediments. The Hanford Formation is generally found at elevations less than 320 meters and was arbitrarily mapped up to that elevation.

The Touchet sediments consist of fine-grained, rhythmically bedded sands and silts, presumably lacustrine and fluvial deposits, left by glacial melt water floods impounded by the Horse Heaven Hills. Pebble-sized non-basalt clasts of slate, quartzite, chert, granitics, and gneisses are common. Unspecified glaciofluvial sediments refer to glacial erratics--large (as much as 1.8 to 2.4 meters) granitic and gneissic boulders--apparently transported to their present locations by catastrophic flood waters or rafted in on icebergs.

STRUCTURE

GENERAL

Structural trends in the Nine Canyon Map Area are dominated by the east-west-trending Horse Heaven Hills anticline and the northwest-southeast Rattlesnake Hills-Wallula Gap Lineament. The Horse Heaven Hills anticline is a broad arch with subdued synclines and anticlines superimposed on it. Jump-Off-Joe is one of these anticlines and forms part of the northern flank of the anticline. The Rattlesnake Hills-Wallula Gap Lineament is the southern extension of the Rattlesnake Hills anticline and is expressed as a series of low, linear hills. The structure also marks the location of the controversial Olympic-Wallawa

Lineament, thought by some (Raisz, 1945; Bingham, et al, 1970) to be a broad zone of deformation related to regional tectonics. Some of the anticlinal structures have been modified by faulting and all by recent erosional processes.

JUMP-OFF-JOE ANTICLINE

Jump-Off-Joe is a doubly plunging asymmetrical anticline that extends for approximately 9.6 kilometers along the north side of the Horse Heaven Hills. The anticline is steeply dipping to the north; the gentle southern flank merges with the broad crest of the Horse Heaven Hills. The steepness of the fold along the north flank is shown along Owens Road in Zintel Canyon (cross section G-G') where steeply dipping (50 degrees northwest), heavily weathered Priest Rapids Member flows flatten out to the south into a gentle north dip. These change to a south dip farther to the south. They flatten to the north into the gently northerly dipping Pomona Member.

The east-west plunge of the anticline is seen by following the top of the Umatilla Member down slope to the east and to the west.

It has been reported in previous work (Jones and Deacon, 1966, Plates 2 and 3; Bingham, et al., 1970; Washington Public Power Supply System, Inc., 1977) that a fault exists along the north side of Jump-Off-Joe anticline. A magnetic profile done in Zintel Canyon by J. T. Lillie (1978), see Figure 9, is consistent with the interpretation of a heavily weathered basalt zone and steeply dipping interbed to the south (Figures 10, 11, and 12). Our findings show no conclusive evidence for the fault; however, additional near-surface geophysical studies are imperative for resolution of this question.

At the western end of the map area, along Washington State Highway 14 (Sec. 4, T7N, R29E), a small normal fault is exposed in the Umatilla with only a slight offset (less than 6 meters). This fault is along the projection of the fault discussed above.

WALLULA GAP FAULT

The Wallula Gap Fault (Yellepit Station Canyon, eastern border of the map area) trends north 65 degrees west and juxtaposes Frenchman Springs Basalt with Umatilla Basalt with a minimum offset of 50 meters. Several workers have speculated that this structure continues along the northern

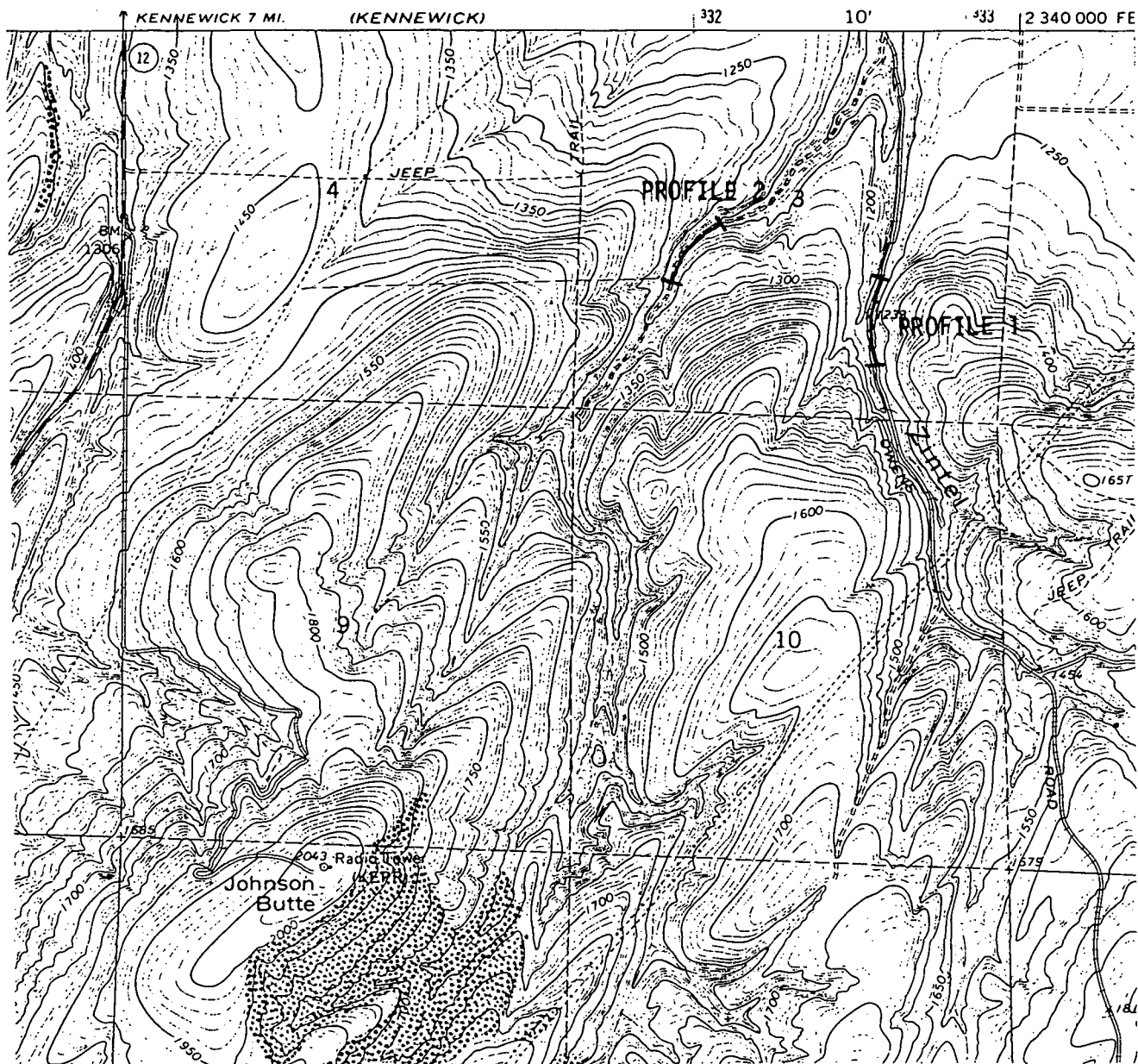


FIGURE 9

LOCATION MAP OF MAGNETIC PROFILES IN ZINTEL CANYON

(After J. T. Lillie, 1978.)

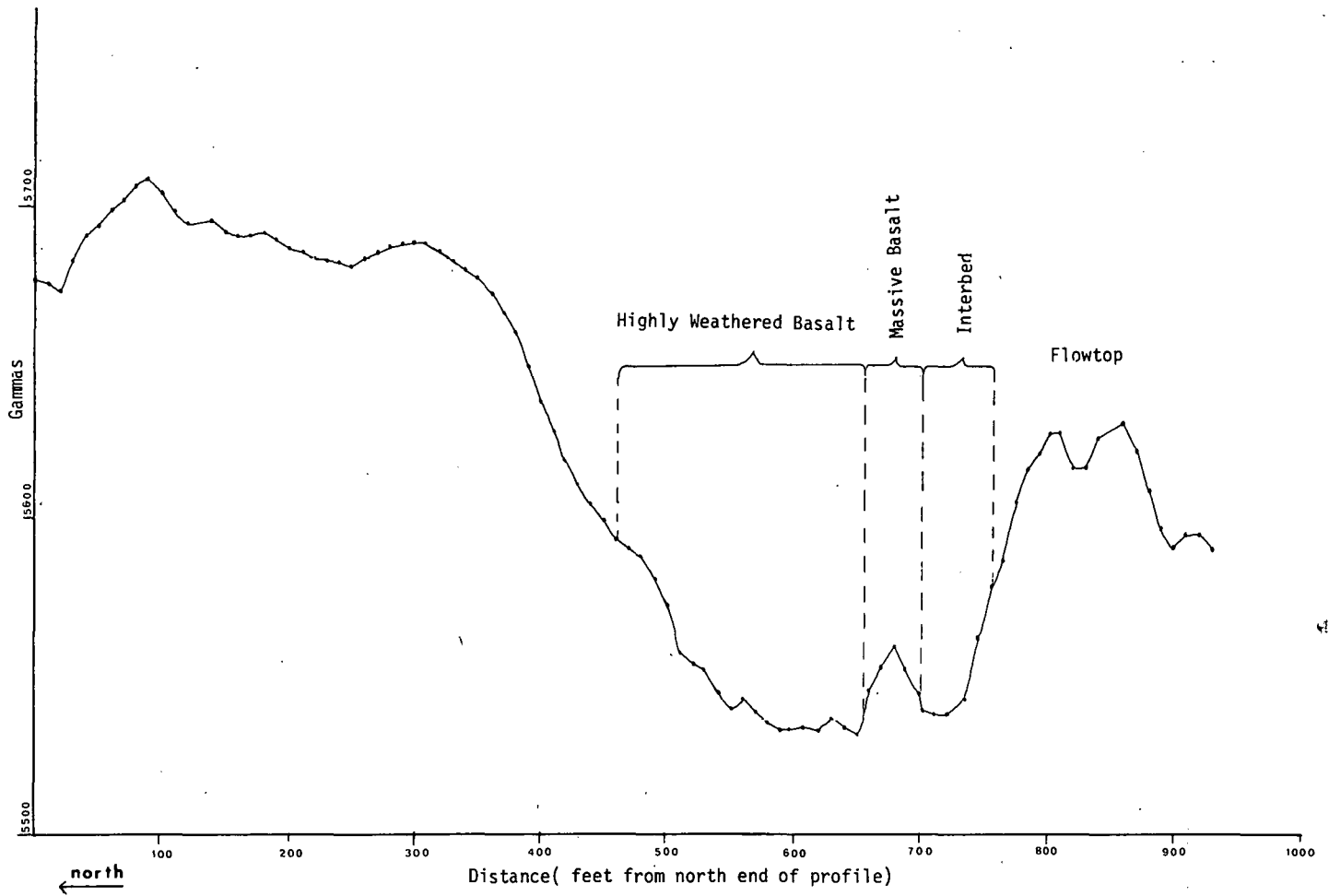


FIGURE 10

TOTAL FIELD OF PROFILE 1 VERSUS KNOWN GEOLOGY

(After J. T. Lillie, 1978.)

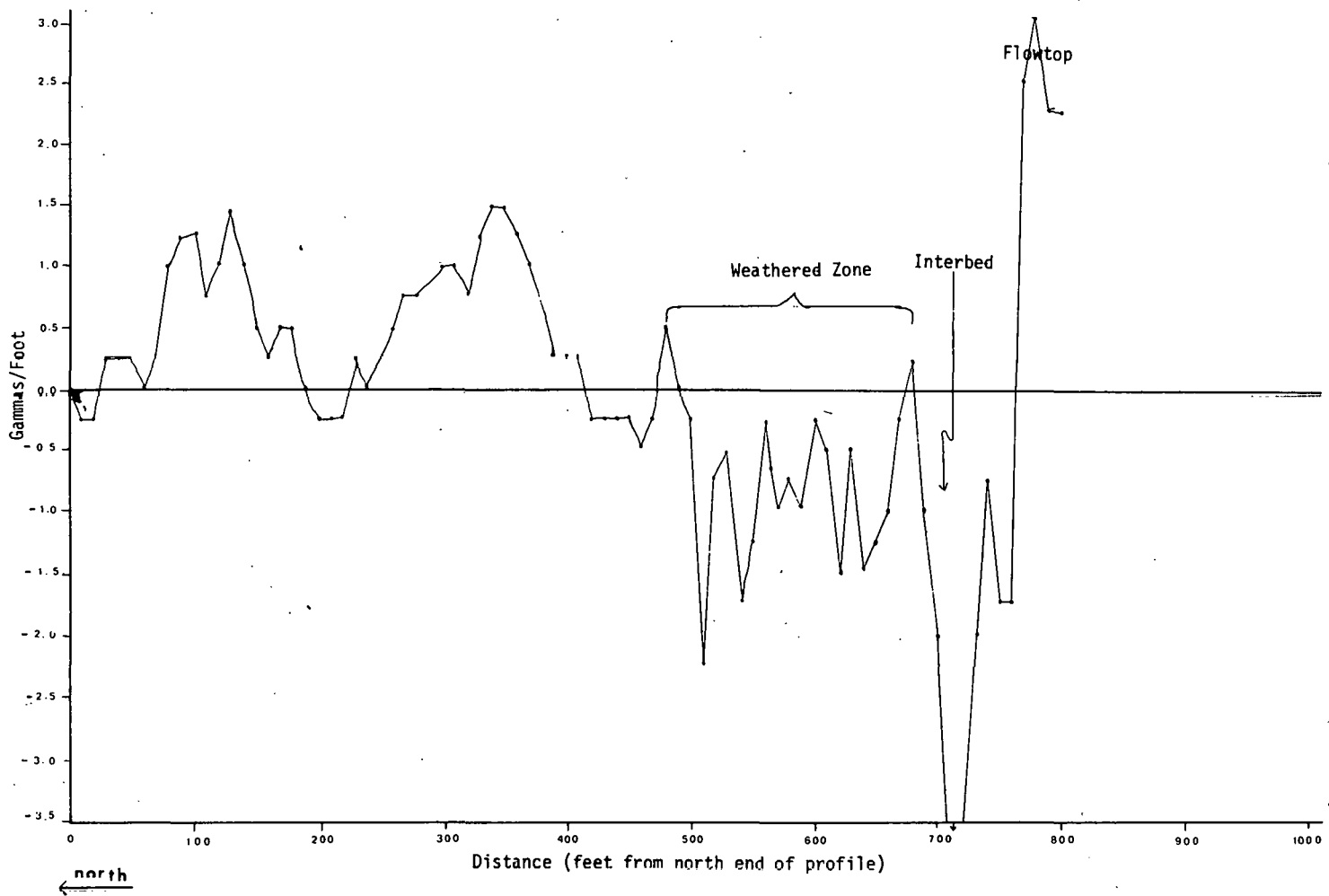


FIGURE 11

VERTICAL GRADIENT OF PROFILE 1 VERSUS KNOWN GEOLOGY

(After J. T. Lillie, 1978.)

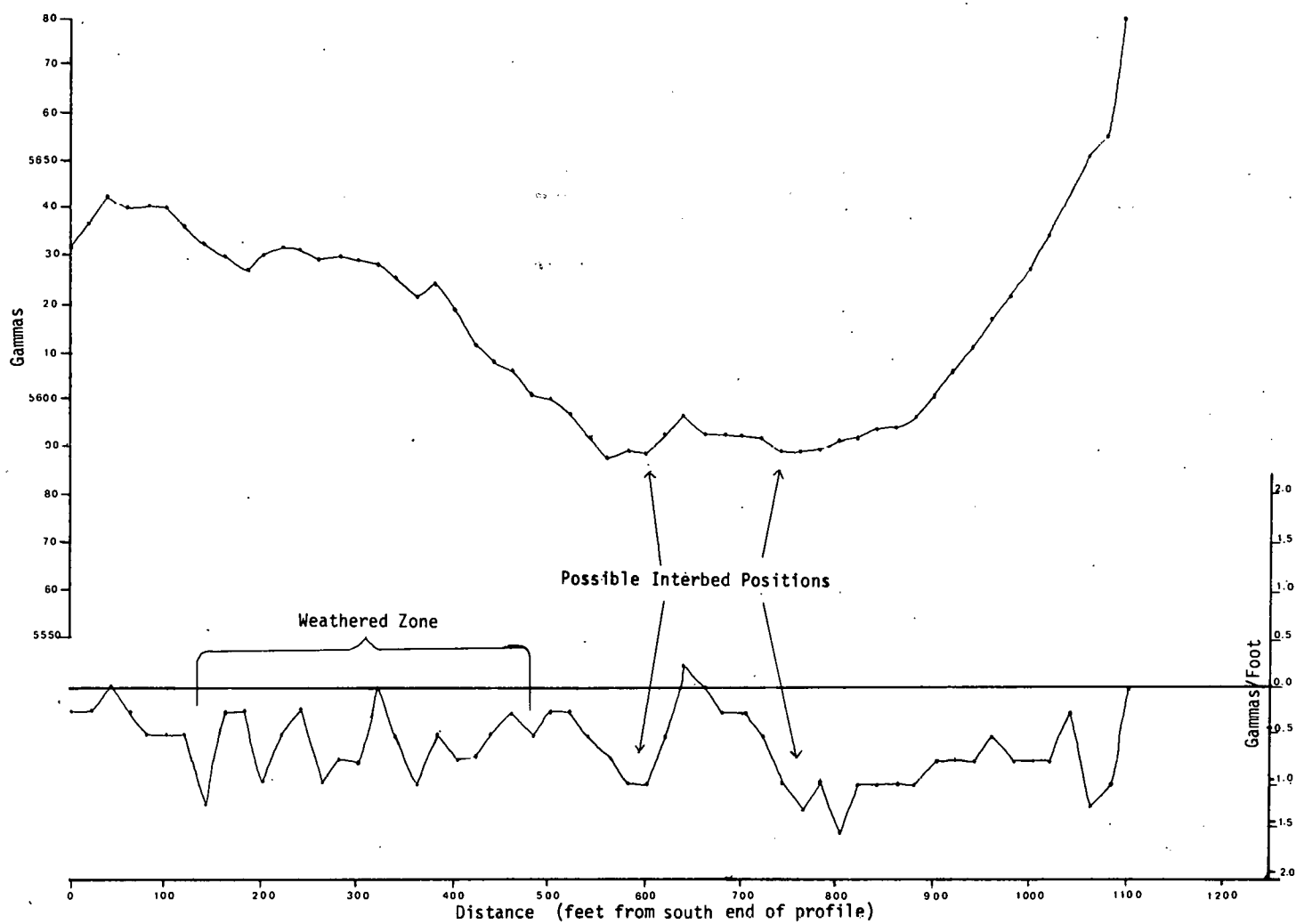


FIGURE 12

PROFILE 2 IN ZINTEL CANYON
TOTAL MAGNETIC FIELD AND VERTICAL GRADIENT

(Top is total field; bottom is vertical gradient. After J. T. Lillie, 1978.)

flank of Jump-Off-Joe. We find no evidence for continuity farther than about 1.3 kilometers west of the Columbia River, where offset apparently dies out. However, the Wallula Gap area is being studied extensively by Mr. J. N. Gardner (University of California at Davis), Mr. K. R. Fecht and Ms. M. G. Jones (Rockwell Hanford Operations) and, therefore, is not discussed in this report.

RATTLESNAKE HILLS-WALLULA GAP LINEAMENT

The Rattlesnake Hills-Wallula Gap Lineament (Figure 13-A and 13-B) in the Nine Canyon Map Area extends 30 kilometers southeast from the mouth of Badger Coulee to Wallula Gap. For ease of reference, the hills are referred to informally as (east to west) The Last Rattle, The Butte, Game Farm Hill, Pipeline Hill, and Basalt Hill (Figures 13-A and 13-B). The five linear hills constitute four doubly plunging anticlines, their crestal traces are sinuously en echelon. Shallow synclines parallel the anticlines on the south, forming a trough that possibly drained the Horse Heaven Hills paleoslope.

The Last Rattle

The Last Rattle is the most tightly folded of the anticlines (Plate 6, cross section A-A'), trending north 60 degrees west and plunging approximately 30 degrees to the southeast under the Columbia River as it enters Wallula Gap. Two faults located on this craggy hill define a small horst. The more southerly fault parallels the Rattlesnake Hills-Wallula Gap Lineament and is probably related to The Butte fault. It juxtaposes Umatilla and Frenchman Springs members and is marked by linear breccia outcrops that trend approximately north 60 degrees west; offset is probably less than 30 meters. The second and shorter fault juxtaposes Ice Harbor and Frenchman Springs members. Three thick interbeds, plus a wedge of Ice Harbor Basalt, suggest that the synclinal trough to the south of The Last Rattle deepens and plunges to the southeast.

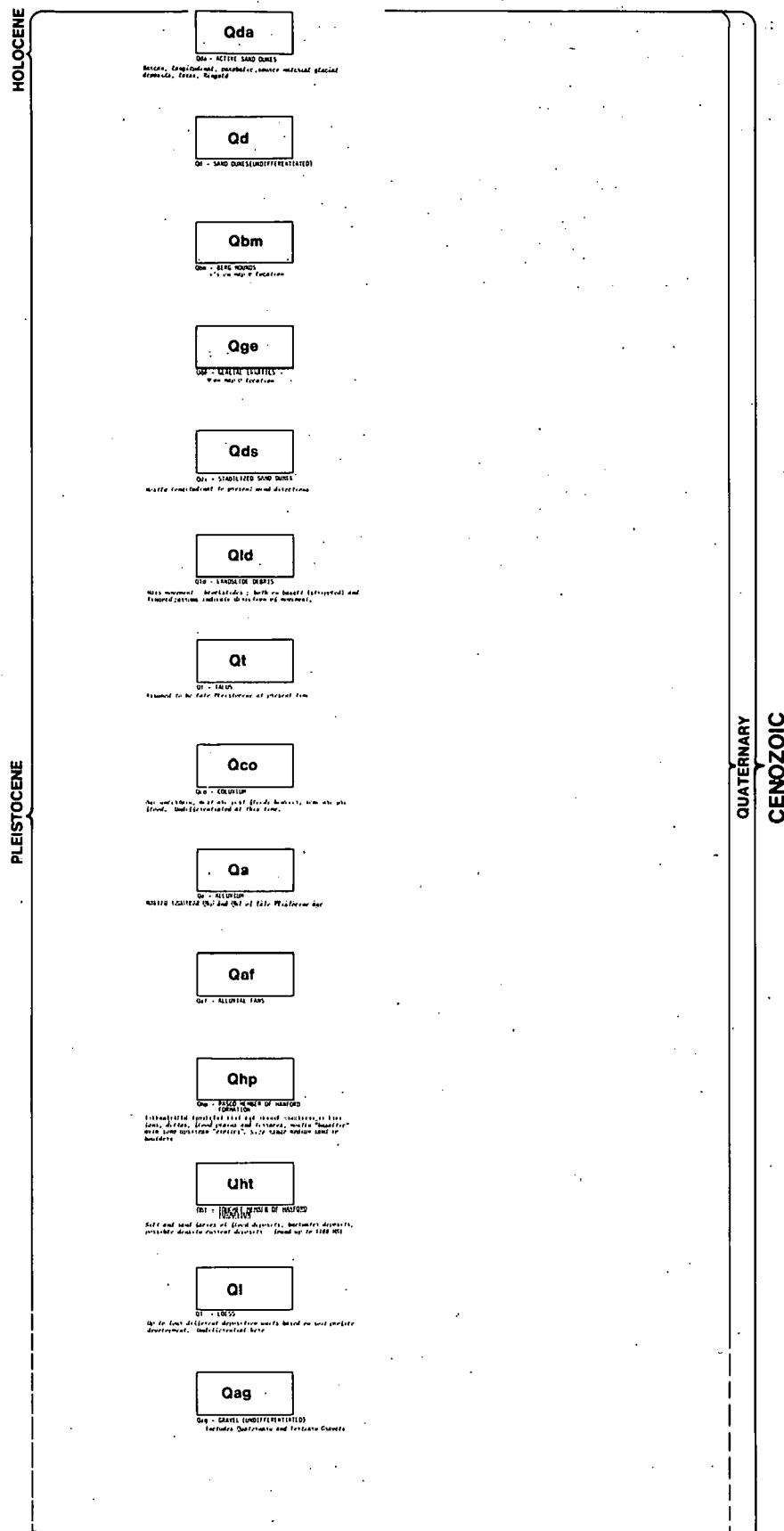
The Butte

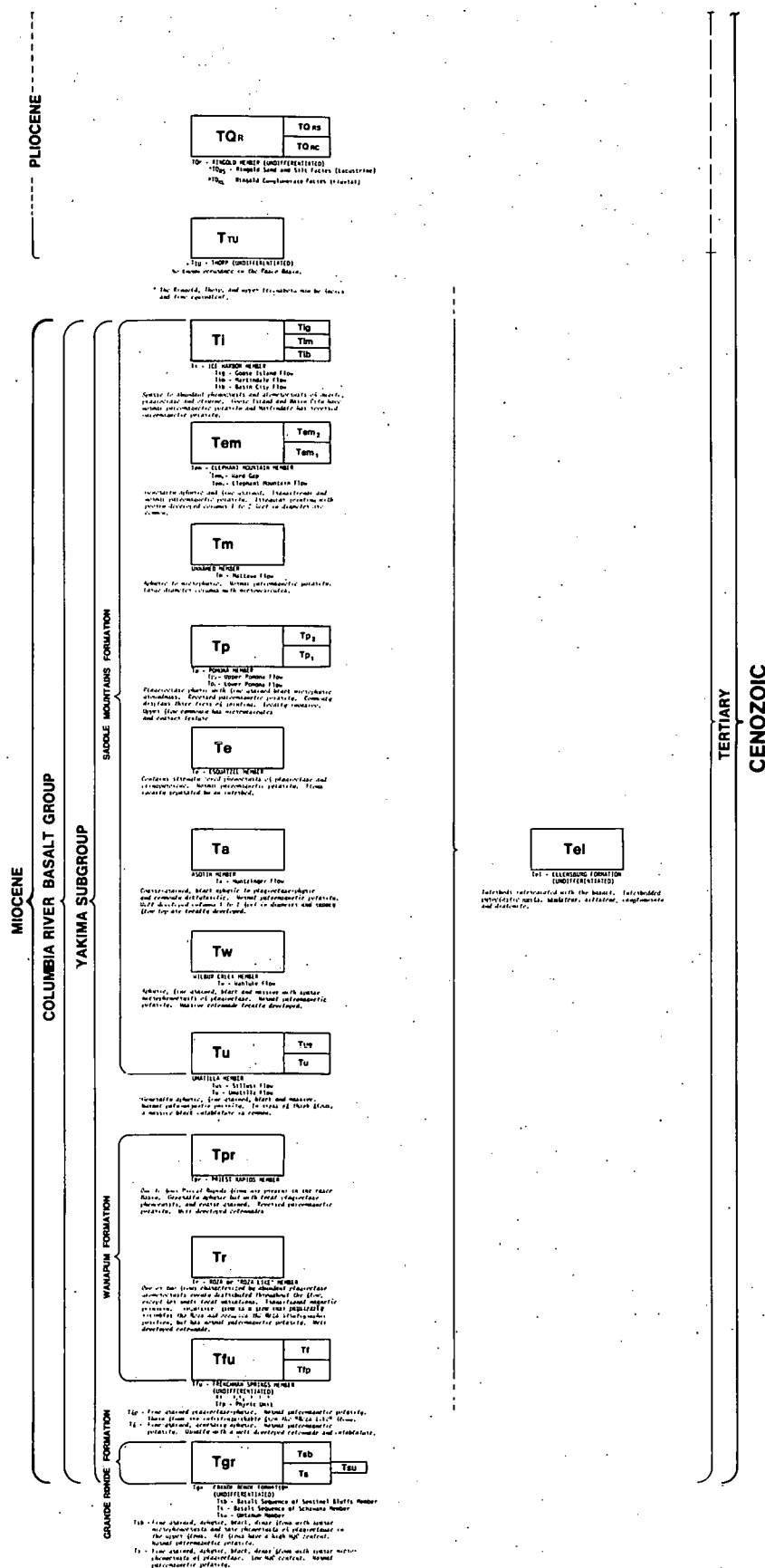
The Butte is a north-dipping monocline that has been faulted along its hinge line. The fault trends north 60 degrees west and apparently dips as low as 50 degrees to the northeast, but the pattern of the fault trace suggests steeper dips. The fault thrusts Umatilla up next to the

LEGEND TO
FIGURES 13-A
AND 13-B AND
PLATES 1 THROUGH 6

| | |
|--|--|
| | PILLOW-PALAGONITE ZONE |
| | BRECCIA Flow top, deposited or tectonic in origin |
| | CONTACT Dashed where approximately located; dotted where concealed; queried where doubtful. |
| | FAULT Dashed where inferred; dotted where concealed; queried where unknown or doubtful; ball and bar appear on downthrown side or D appears on downthrown side and U appears on upthrown side; arrows indicate apparent horizontal offset. Thrust indicated by sawteeth on side of upper plate. |
| | ANTICLINE Showing crestline; dashed where approximately located; dotted where concealed; arrowhead on crestline indicates direction of plunge; short arrow indicates steeper limb. |
| | Overturned Anticline |
| | SYNCLINE Showing troughline; dashed where approximately located; dotted where concealed; arrowhead on troughline indicates direction of plunge; short arrow indicates steeper limb. |
| | Overturned Syncline |
| | STRIKE AND DIP Symbol broken where attitude is estimated. |
| | STRIKE AND DIP OF OVERTURNED BEDS Symbol broken where attitude is estimated. |
| | STRIKE OF VERTICAL BEDS Symbol broken where estimated. |
| | HORIZONTAL BEDS |
| | STRIKE AND DIP OF FRACTURE |
| | STRIKE OF VERTICAL FRACTURE |
| | STRIKE AND DIP OF JOINTS |
| | STRIKE OF VERTICAL JOINT |
| | FAULT ZONE OR SHEAR ZONE |
| | MONOCLINE Showing trace of axis; dashed where approximately located; arrows indicate direction of dip; dotted where concealed. |
| | LOCATION OF STRUCTURAL CROSS-SECTION |
| | Dash - Dot line indicates contact between Quaternary sediments and basalt units. |

LEGEND TO
FIGURES 13-A
AND 13-B AND
PLATES 1 THROUGH 6





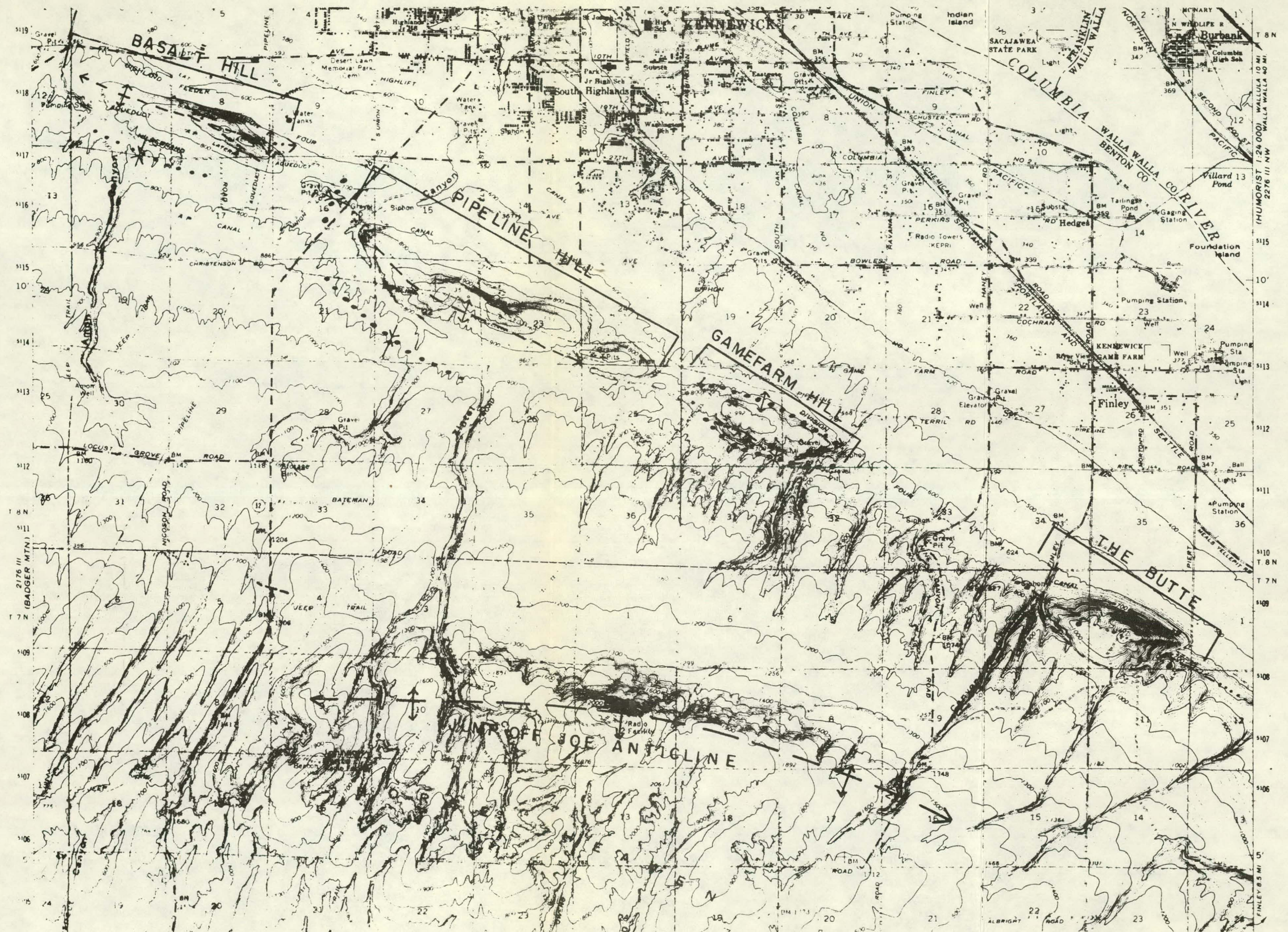


FIGURE 13-A

STRUCTURE AND LOCATION MAP - PASCO 15-MINUTE QUADRANGLE

flat-lying Ice Harbor Member. Steeply dipping Pomona and Elephant Mountain members are exposed on the northeast corner of The Butte; up the gully on the east end, the top of the Umatilla Flow is exposed (see cross section B-B'). However, north of the fault, the top of The Butte is composed of Umatilla Member. Offset appears to be as much as 50 meters. Much of the top of The Butte is littered with reworked Touchet- type sediments and pockets of large (2 meters X 2.6 meters) sized granitic glacial erratics. Apparently, the linear gully on the north side of The Butte marks the intersection of the fault with the Pomona and the underlying Selah. Finley Quarry, on the west end of The Butte, exposes Umatilla Basalt truncated against a calcite-cemented fault breccia (Figure 14).

The Butte section contains one of the most complete sections found in the Nine Canyon Map Area with only the Wanapum Formation not exposed. The measured section obtained there is presented in the Appendix and Figure A-1.

Game Farm Hill

Game Farm Hill is a doubly plunging anticline with a small fault on the south side displacing the Umatilla Member and moving the Umatilla-Pomona contact on the north block up out of alignment with the projected contact plane (cross section C-C'). The fault trace is marked by fractured and sheared basalt in the Umatilla Member. Movement has been slight (3 to 7 meters), and the fault appears to be related to the original folding. The crest of the anticline on the north side is not exposed due to erosion and only the southerly dipping flows are exposed on the hill. The northwest-southeast plunge of the fold is shown by opposing dips on the south and north ends of the hill.

Pipeline Hill

Pipeline Hill is a doubly plunging anticline whose crestal trace curves to the north on its western end. No sign of faulting was found along the steep north flank. Excavation for construction of a water storage tank on the north side affords the only exposure available there. Both the Selah and flow top of the Umatilla are absent there, suggesting they were planed off prior to deposition of the Pomona. Approximately 1 kilometer to the southeast (Sec. 25, T8N, R29E) the

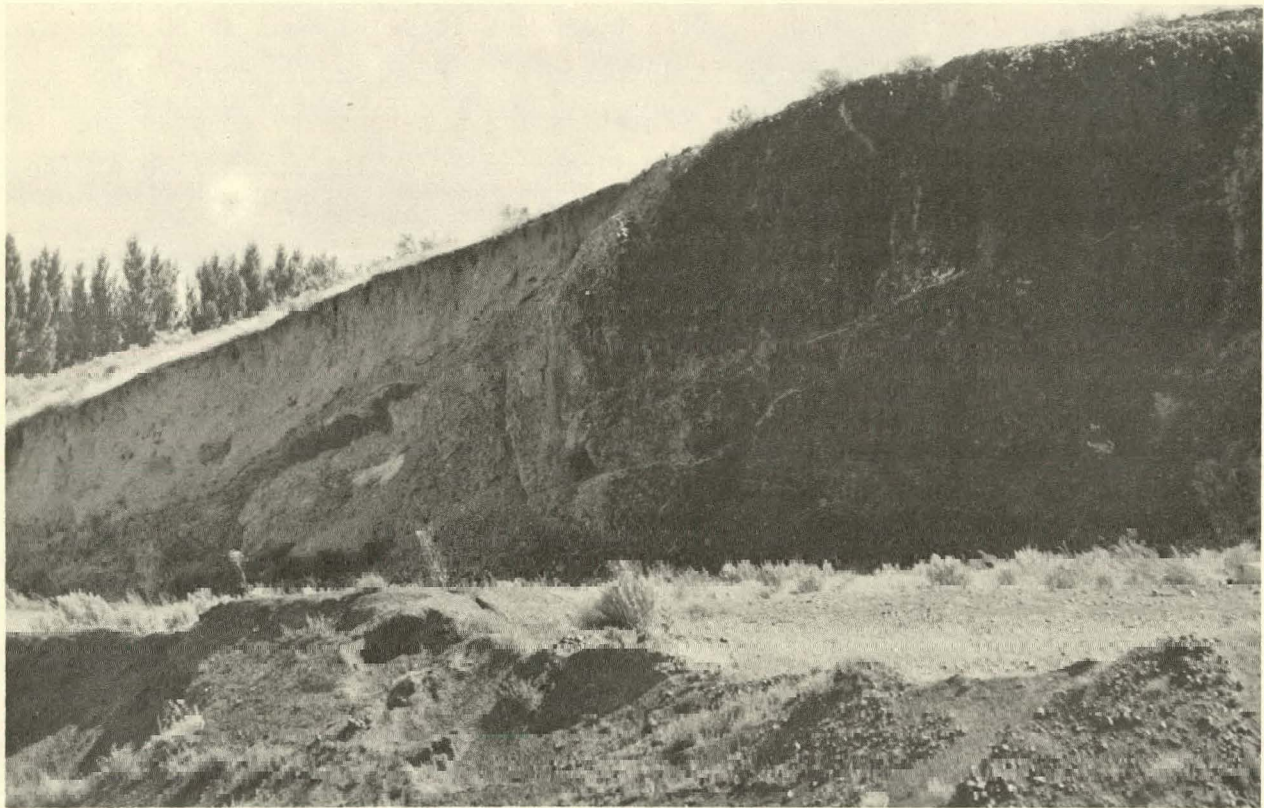


FIGURE 14

FINLEY QUARRY - THE BUTTE
CALICHE-CEMENTED FAULT BRECCIA

southeastward plunge of this anticline is demonstrated by the Umatilla, Pomona, Elephant Mountain, and Ice Harbor members occupying a lower topographic position than they would to the northwest on the top of Pipeline Hill

Basalt Hill

Basalt Hill is a doubly plunging anticline trending north 70 degrees west. A small normal fault trends north 55 degrees west across the mid-section of the ridge (see cross sections E-E' and F-F'), juxtaposing Elephant Mountain Member on the south against Umatilla Member on the north. The fault trace is marked by a shear zone (Sec. 8, T8N, R29E) and linear breccia outcrops on the west end. Offset is possibly 30 meters and apparently decreases to the west.

CONCLUSIONS

Relief existed in the immediate Wallula Gap area by at least Priest Rapids time, as indicated by the absence of any Priest Rapids flows at Wallula Gap. Whether this high was constructional or structural is unclear. The unusually thick accumulation of Frenchman Springs flows (9 to 10 flows, approximately 200 meters thick) present in the gap suggests close proximity to vent areas. Several thin flows of small areal extent could have built an edifice capable of excluding the Priest Rapids flows. Swanson and Wright (1976) mention a Frenchman Springs constructional high in the Devils Canyon-Ice Harbor Dam area (Figure 1). Alternatively, Dr. S. P. Reidel reports evidence in the Saddle Mountains suggesting older northwest-trending structural highs. He postulates these older highs may have extended down through the Wallula Gap area. No conclusive evidence for this hypothesis was found in the Nine Canyon Map Area.

Whatever its original nature, Priest Rapids flows lapped up onto the high, but did not cover it. Lower elevations existed to the west than at Wallula Gap, because Priest Rapids flows are found in Zintel Canyon and on Game Farm Hill. Priest Rapids flows apparently filled many lows and reduced relief considerably as the Umatilla Member maintains a fairly consistent thickness.

Structural uplift definitely began prior to extrusion of the Pomona and Elephant Mountain flows. Both flows lap up onto the Horse Heaven Hills; the Pomona thins from 30 meters at The Butte to only 3 meters along Nine Canyon Road 4.8 kilometers to the south, and the Elephant Mountain is not present along the anticlinal crest.

The Rattlesnake Hills-Wallula Gap Lineament is younger than the Horse Heaven Hills structure. This is indicated by the relatively constant flow thicknesses of the Pomona and Elephant Mountain members and the drainages that are deflected along the linear. Deflection increases to the west, suggesting the western portion of the lineament in the map area is older than the eastern portion. Folding along the lineament probably began post-Elephant Mountain time and continued through Ice Harbor time. It is unclear whether Ice Harbor flows once topped all of the anticlinal ridges, but, judging by its position on top of the Mound Pond Section in Wallula Gap (ARH-ST-137, 1976), it was probably present on all the anticlines and has been stripped off by subsequent glaciofluvial flood waters and the shifting courses of the ancestral Snake and Columbia rivers. The Rattlesnake Hills-Wallula Gap Lineament pinches out against the Horse Heaven Hills structure; as the termination is approached, the folding becomes markedly tighter (see Cross Sections A through E). Most of the faults found in the Nine Canyon Map Area are related to folding; generally, they suggest the failure of basically brittle rocks along the hinge lines of the folds. However, not all of the faults are genetically related to folding; the Basalt Hill fault trends obliquely across the anticline implying the fault is younger.

The east-west-trending anticlinal ridges so characteristic of the western edge of the Columbia Plateau have traditionally been attributed to north-south compression. The east-west-trend of these ridges is interrupted as they enter the Pasco Basin; there, the trend of Umtanum Ridge, Yakima Hills, and Rattlesnake Ridge swings approximately 20 degrees to the south, where they are then coincident with the Olympic-Wallawa Lineament. Raisz (1945) postulated the Olympic-Wallawa Lineament marked major structural features. Although the exact nature of the feature is uncertain, Dr. F. E. Goff reports sections along the lineament within the Pasco Basin that are coincident with zones of shearing, faulting, landsliding, and complex folding.

Within the Nine Canyon Map Area, the Olympic-Wallowa Lineament is coincident with the Rattlesnake Hills-Wallula Gap Lineament; the youngest and most complex structure in the map area. Four en echelon, doubly plunging anticlines, locally faulted, are present. To the west, the faults are normal with small vertical displacement; to the east, they are reverse. Although evidence is inconclusive, this could suggest a sense of clock-wise rotation or right lateral movement. Dr. S. P. Reidel (1978) and Mr. K. R. Fecht (1978) indicate a possible zone of deformation extending northwest-southeast through the Saddle Mountains past the east end of Gable Mountain and down into Van Sycle Canyon east of Wallula Gap.

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APPENDIX

MEASURED SECTION NUMBER 1: THE BUTTE

Section 3, Township 17 North, Range 30 East

Figure A-1

INTERVAL 1

A ledge of large stubby columns (1 to 2 meters across) tops the section. These Ice Harbor I (basalt of Martindale) columns have a platey vesicularity and reddish brown color on weathered surfaces. The fresh rock is dark gray, medium- to coarse-grained, and diktytaxitic. Unlike the Ice Harbor in other localities, this exposure is only sparsely plagioclase-phyric. About 6.5 meters down slope, the columns lose their vesicularity and appear denser, exhibiting spheroidal weathering where exposed. Sample C-7338 (Table I) is from the top ledge of columns. This unit has reversed natural remanent magnetism.

Interval Thickness: 10.3 meters.

INTERVAL 2

This break in slope marks the approximate Ice Harbor-Elephant Mountain contact. The interval is covered with vesicular rubble down to about 12.5 meters (total thickness) where a ledge of small columns (0.4 meter across) marks the base of this interval. These gray-brown columns are the upper colonnade of the Elephant Mountain Member. Sample C-7339 (Table I) is from these small columns. The rock is very vesicular and grayish-green due to extensive alteration. In hand specimen, it is aphyric, fine- to medium-grained, and exhibits a hackly fracture.

Interval Thickness: 2.5 meters.

INTERVALS 3 AND 4

The gently sloping topography is covered with vegetation, pebble-sized glaciofluvial exotics, and fist-sized pieces of vesicular and grussic weathered basalt. The separation of this section into two

intervals is based on a change in slope--probably the Elephant Mountain entablature--colonnade juncture. (Throughout the Nine Canyon Map Area, the Elephant Mountain is a slope-former, rather than a cliff-former--presumably due to its porous texture which provides easy access to alteration.)

Interval Thickness: 19.9 meters.

INTERVAL 5

This break in slope is the approximate contact between the Elephant Mountain and Pomona flows. The bench is covered with vesicular float and glaciofluvial pebbles (quartzite, slates, chert). This, and vegetation, effectively conceals the contact and any Rattlesnake Ridge Interbed that may be present. A ledge of gray-brown columns approximately 0.3 meter across marks the base of this interval. Sample C-7340 (Table I) was taken here.

Interval Thickness: 4.6 meters.

INTERVAL 6

Although much of the upper portion of this interval is covered, isolated outcrops with small, well-formed, broken columns demonstrate that this is Pomona entablature. In hand specimen, the rock is dark gray, medium- to fine-grained and plagioclase phyric. Plagioclase phenocrysts to 2 centimeters and occasional olivine phenocrysts less than 1 centimeter are discernible. Approximately 15 meters down begin larger columns about 1 meter across. Sample C-7341 (Table I) is from the base of Interval 6.

Interval Thickness: 19.2 meters.

INTERVAL 7

This narrow bench marks the approximate top of the Umatilla Member--bright red, vesicular Umatilla float can be found down slope from here,

although the contact itself is not exposed at this location. No Selah Interbed is present, although it is present one-quarter mile northwest in Finley Quarry.

Interval Thickness: 3 meters.

INTERVALS 8 AND 9

Again, these intervals are separated on the basis of a change in slope. Interval 8 is largely covered by a mixture of float from above, mingled with Umatilla float; however, irregular hackly outcrop protrudes through the cover. Weathered surfaces are orange and red; fresh Umatilla is black, very glassy, and aphyric. Interval 9 consists of Umatilla entablature-forming hackly cliffs. Sample C-7342 (Table I) is from the upper portion of Interval 9.

Interval Thickness: 22.7 meters.

TOTAL THICKNESS: 82.2 meters.

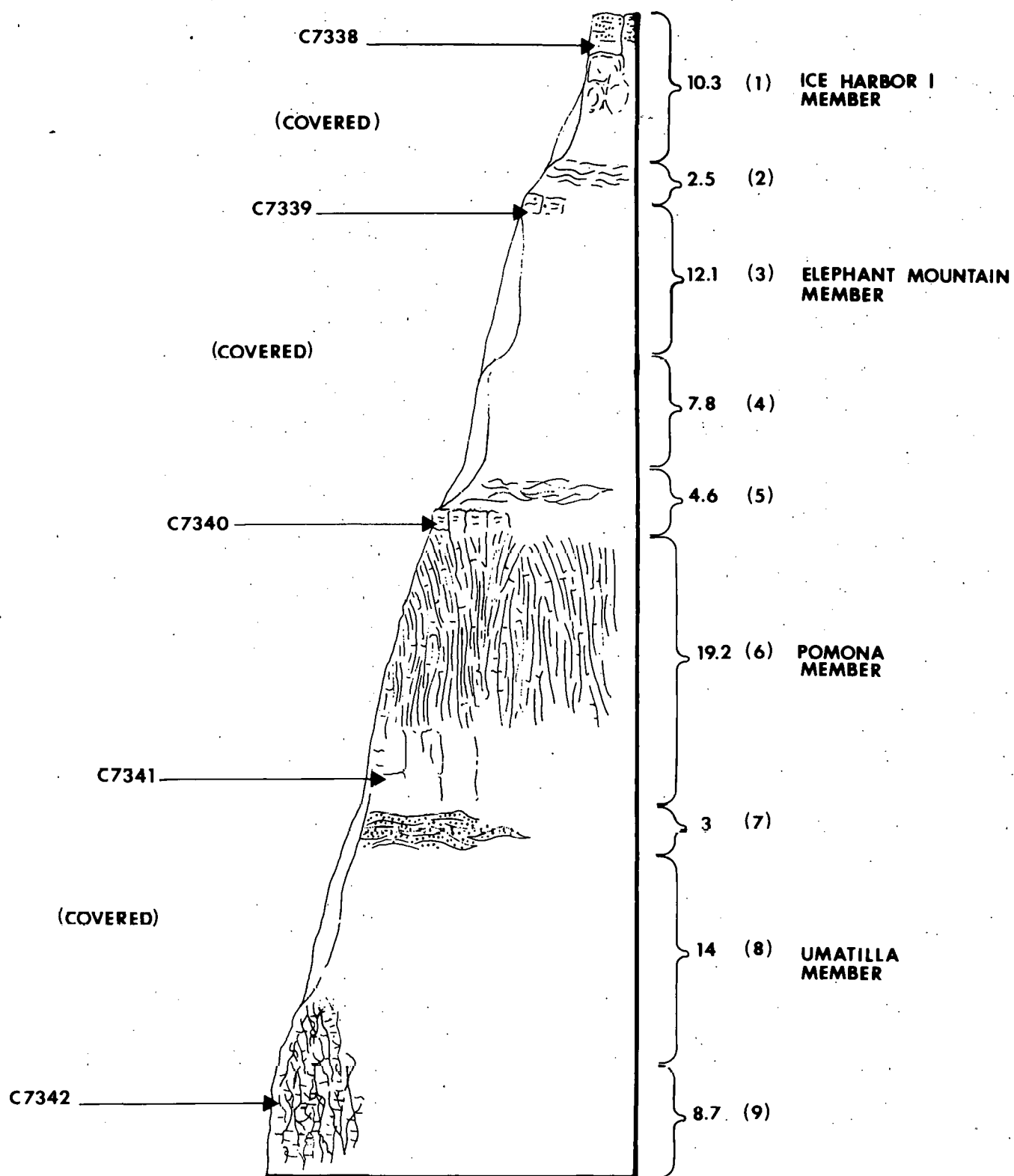


FIGURE A-1

MEASURED SECTION - THE BUTTE

(2.54 centimeters = 10 meters; horizontal not to scale.)

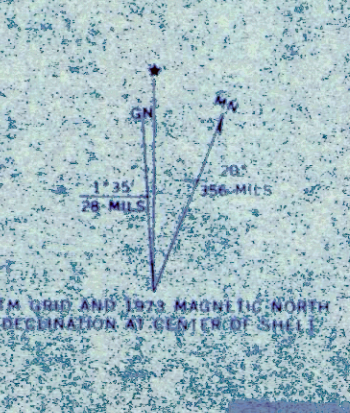
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Medium-duty ——— Unimproved dirt ———
U.S. Route ——— State Route ———
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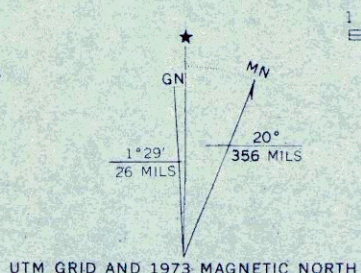
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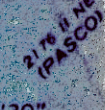
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1964
PHOTOREVISED 1973
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Revisions shown in purple compiled from aerial photographs
taken 1973. This information not field checked
Purple tint indicates extension of urban areas

2176 III NE
(BADGER)



GN

MN

20°

1° 34'


28 MILES

364 MILES

UTM GRID AND 1964 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

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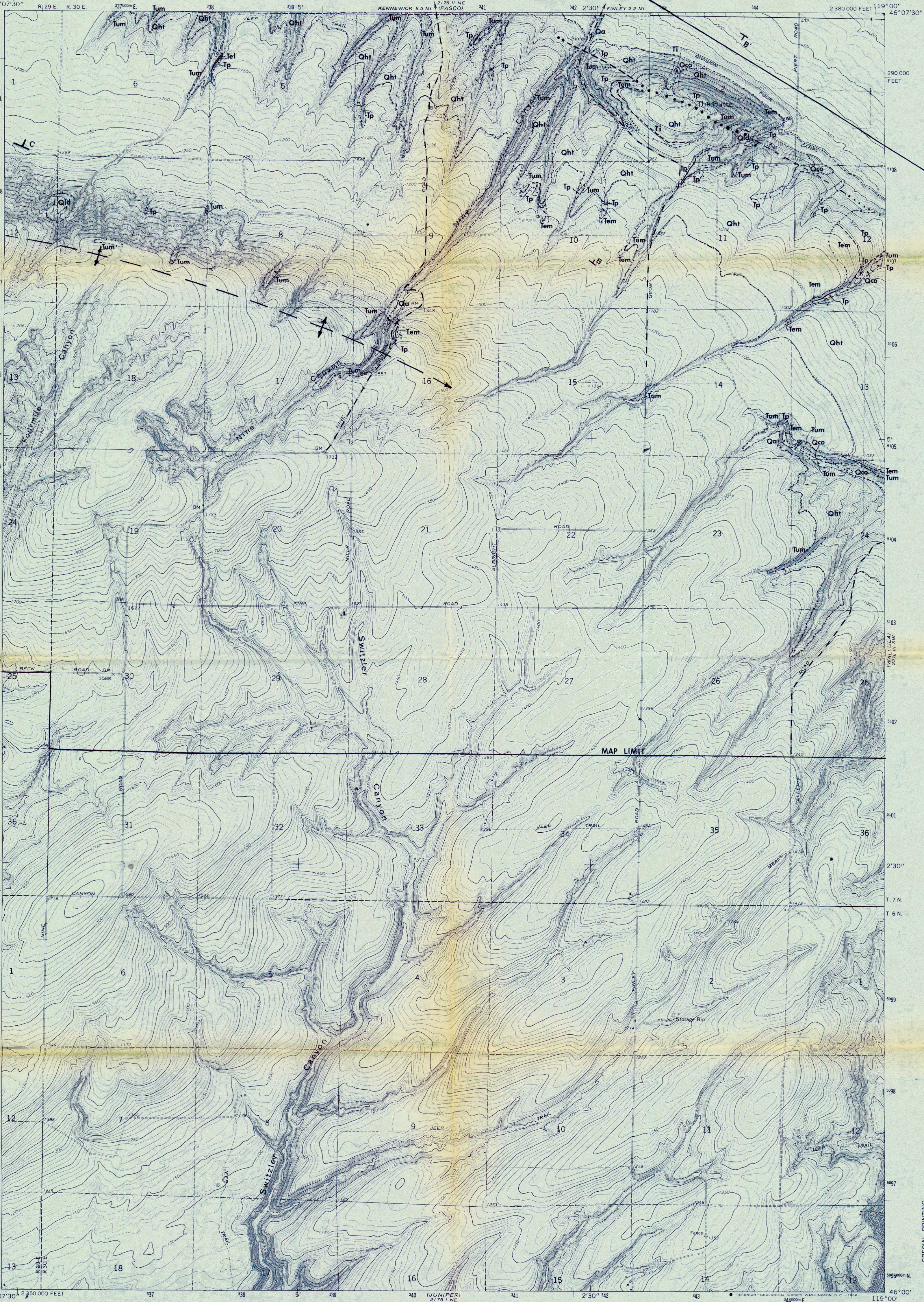
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N4600—W11907 5/7.5

1964

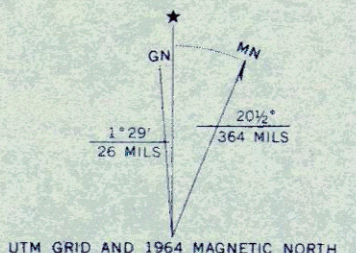
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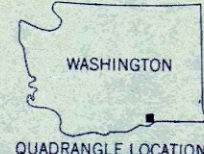


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CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION
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NINE CANYON, WASH.
SE/4 PASCO 15' QUADRANGLE
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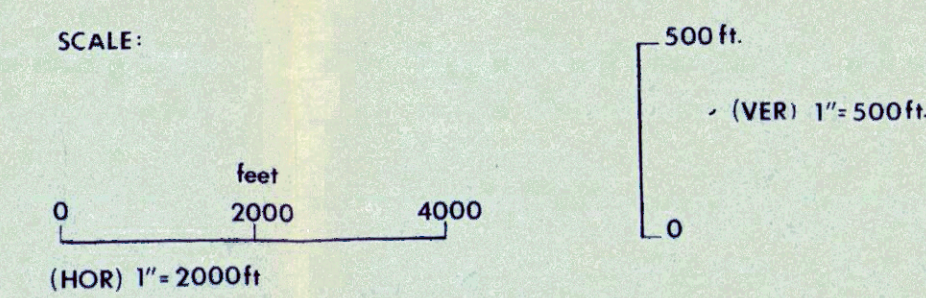
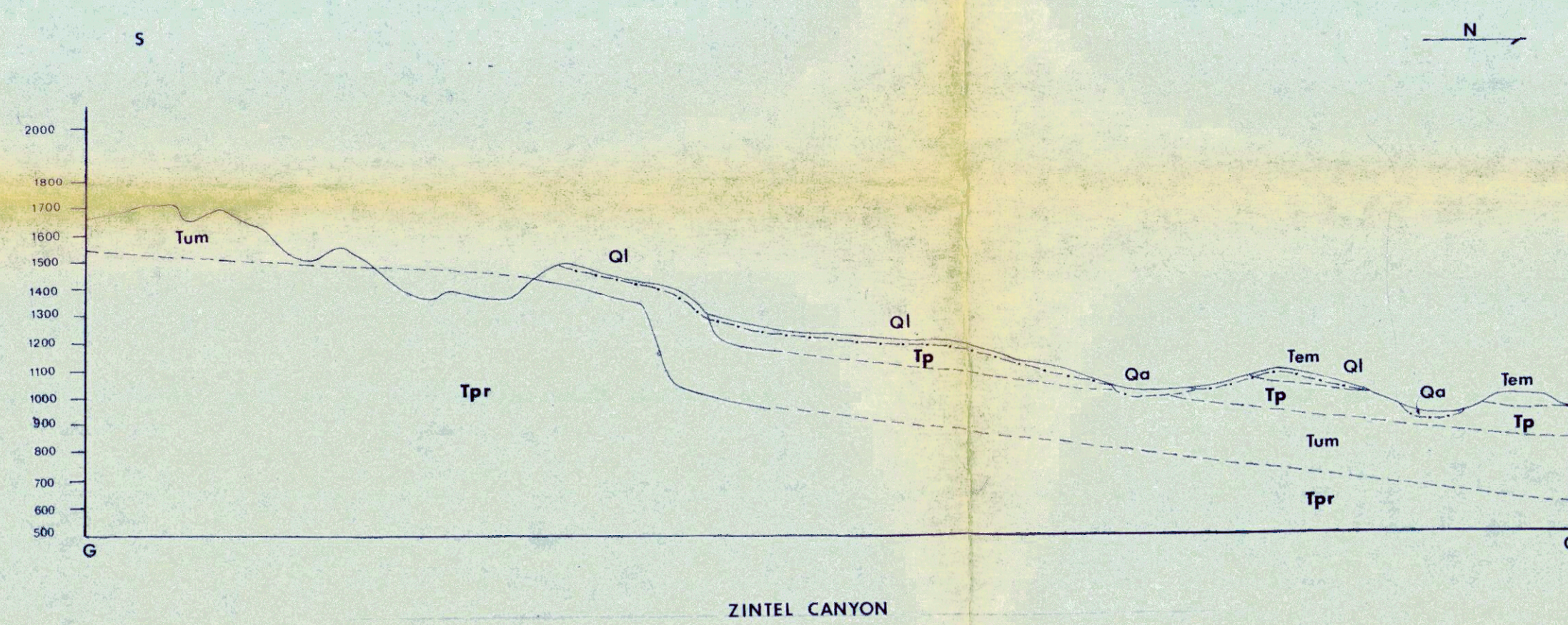
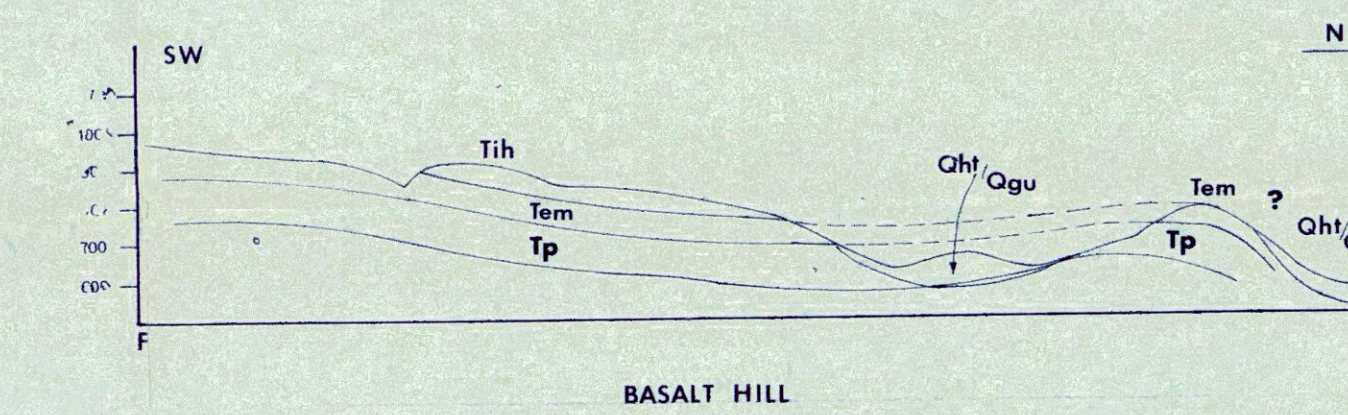
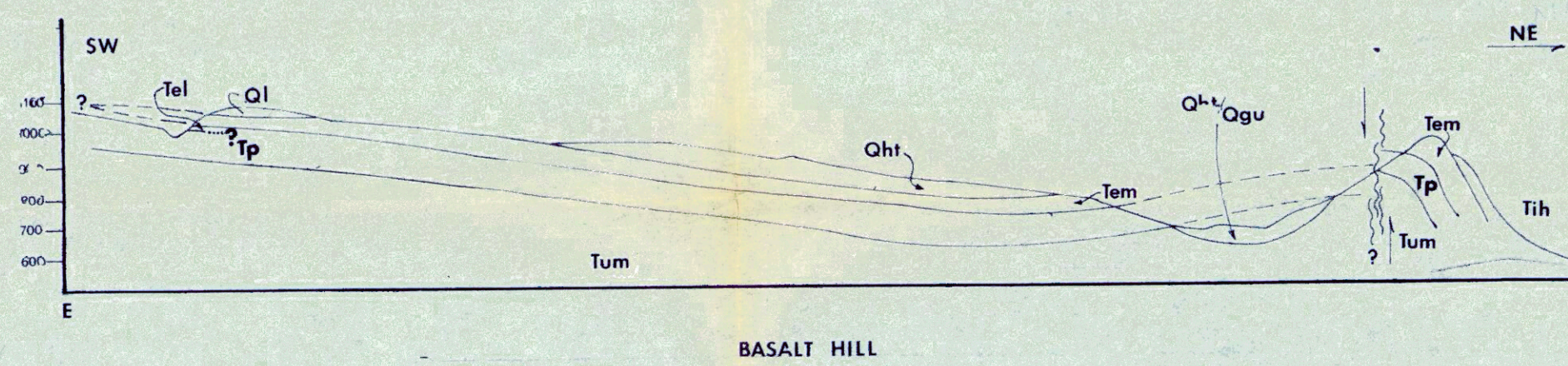
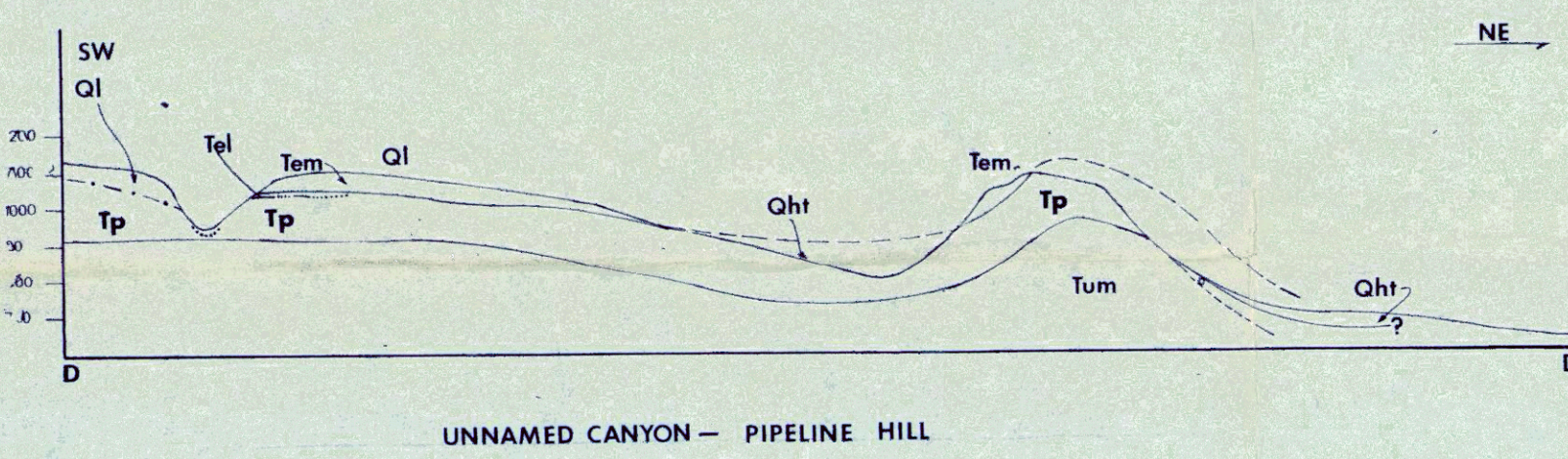
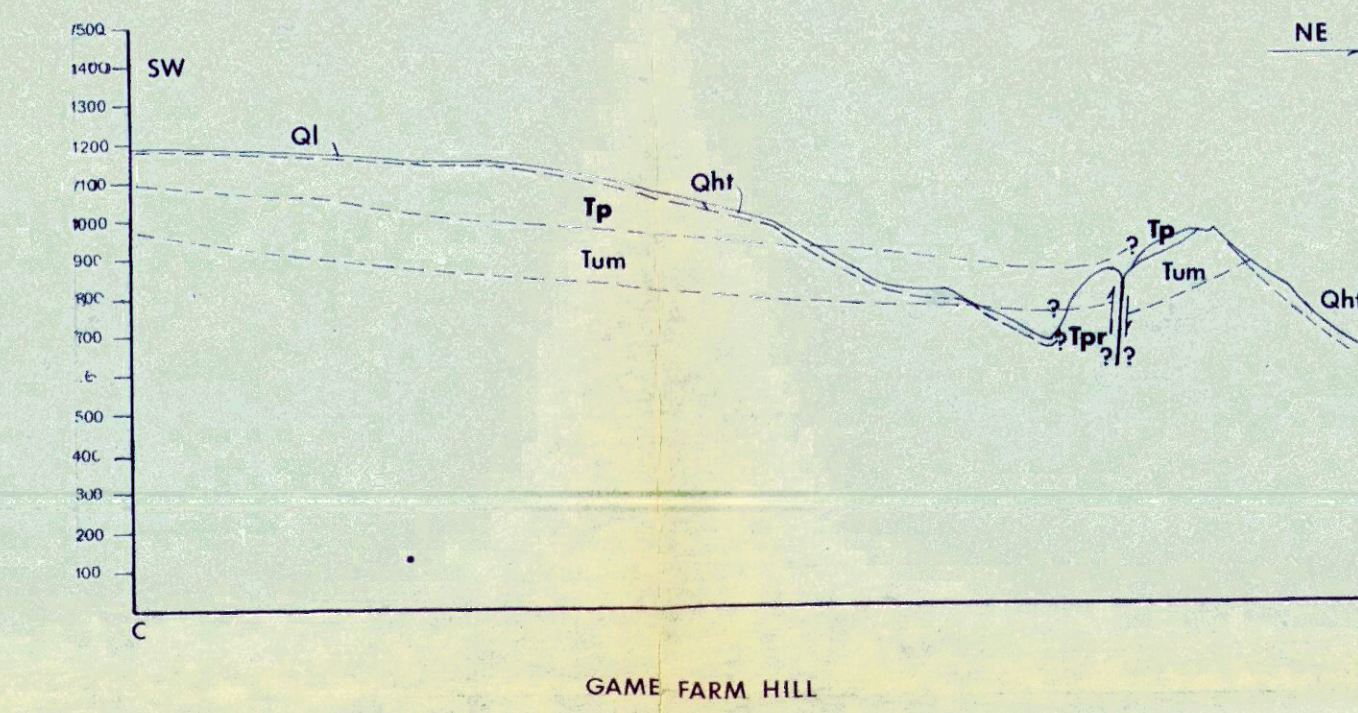
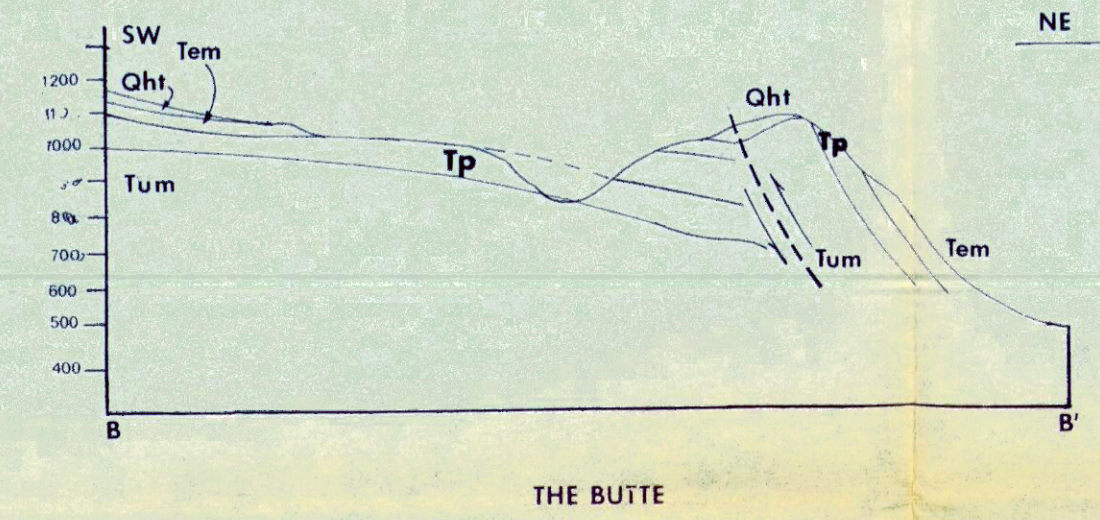
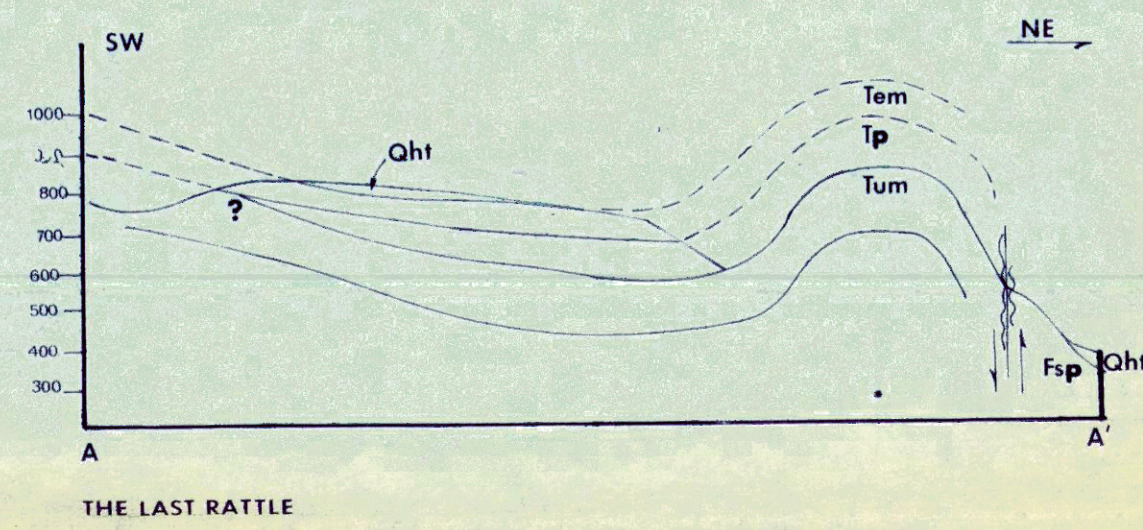
This is a detailed topographic map of the Wallula Quadrangle, covering parts of Walla Walla County, Washington, and Umatilla County, Oregon. The map is part of the 7.5 Minute Series (Topographic) and is drawn at a scale of 1 inch = 1 mile. It features a grid system with coordinates ranging from 119°00' to 118°52'30" longitude and 46°07'30" to 46°00' latitude. The map shows the Wallula River flowing through the center, with the Wallula Gap and Wallula Lake prominently featured. The terrain is characterized by numerous contour lines indicating elevation, with peaks reaching over 5000 feet. Key landmarks include the Wallula Station, Wallula Gap, Wallula Lake, and the Wallula River. The map also shows various roads, trails, and other geographical features. The map is titled "WALLULA QUADRANGLE" and "WASHINGTON-OREGON 7.5 MINUTE SERIES (TOPOGRAPHIC)". It includes a scale bar and a north arrow. The map is drawn by "G. H. Clark" and reviewed by "H. H. Clark". The drawing number is "H-06-4601-5".

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STRUCTURAL CROSS SECTIONS - NINE CANYON MAP AREA

BY M.G. JONES & R.D. LANDON



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