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Abstract

This document summarizes the available geotechnical information from the Rattlesnake Mountain area, located along the southwestern boundary of the Hanford Site. The discussion emphasizes the geohydrologic environment of the anticlinal ridges in the vicinity of Rattlesnake Mountain. Included in the document is information concerning the stratigraphy, structure, geomorphology, seismology, climatology, and hydrology, as well as the resource potential of the Rattlesnake Mountain area.

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SUMMARY OF GEOTECHNICAL INFORMATION IN THE RATTLESNAKE MOUNTAIN AREA

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SUMMARY

The Basalt Waste Isolation Project is compiling data from a basalt sequence in a geohydrologic setting above the water table in the unsaturated zone that could be used in repository siting decisions. The site selected for the compilation is a portion of the Rattlesnake Hills centered around Rattlesnake Mountain, which is situated in a basaltic ridge along the western boundary of the Hanford Site. This report summarizes existing geotechnical information from the Rattlesnake Mountain area. The principal geotechnical characteristics of the Rattlesnake Mountain area discussed in the report are outlined below.

- Topography
  - Anticlinal ridges in the Rattlesnake Mountain area form the highest topography on the Hanford Site, rising as much as 915 m (3,000 ft) above the central Hanford plain. Topographic highs, such as Rattlesnake Mountain, are recharge areas for groundwater flow systems within the basalts of the Columbia Plateau.
- Stratigraphy
  - Grande Ronde, Wanapum, and Saddle Mountains Basalts crop out and have been penetrated by boreholes in the Rattlesnake Mountain area. The distribution of boreholes and outcrops are sufficient to demonstrate the lateral continuity of basalt flows throughout the area and the general thinning of Wanapum and Saddle Mountains Basalt flows across ridge crests.
  - Hanford Formation, Ringold Formation, and surficial sediments are >60 m (200 ft) thick in the lowlands of Cold Creek and Dry Creek Valleys. These sediments thin and essentially pinch out onto the lower flanks of the anticlinal ridges. Loess, dune sand, landslide debris, and colluvium veneer much of the ridge terrain.
- Structure
  - Rattlesnake Mountain and the southeast extension of an inferred structure to its terminous near Milton-Freewater, Oregon form the Rattlesnake-Wallula alignment (RAW), a structural element of the Cle-Elum Wallula lineament. The RAW structure is conservatively assumed by the U.S. Nuclear Regulatory Commission to have a capability for earthquakes with a magnitude (M_s) of 6.5, with very low fault slip rates at long recurrence intervals.

- Faults exposed along the RAW within the Rattlesnake Mountain area are segmented from other faults farther southeast along the RAW. Therefore, the RAW structure is not continuously faulted along the length of its alignment.

- Surficial sediments overlying faults in the Rattlesnake Mountain area do not appear deformed, suggesting the last fault movement occurred prior to sediment deposition.

- Rattlesnake Mountain is typical of anticlinal ridges in the Yakima Fold Belt of the Columbia Plateau. It is asymmetrical with a north vergence and a faulted north limb. Two high-angle reverse to thrust faults occur along the north flank near the base of the anticline.

- A high-angle, east-trending cross fault is present on Rattlesnake Mountain that disrupts the continuity of the Rattlesnake Mountain fault and the fold geometry on either side of the cross fault. The cross fault pinches out on the south limb of the fold near the Rattlesnake Mountain crest.

- Snively Basin is interpreted to be an imbricate thrust fault zone that developed at the intersection of the RAW and the east-west trending segment of the Rattlesnake Hills.

- Clockwise rotation appears to be the potential strain mechanism that may have generated the faults, fractures, and breccia zones associated with the crest-hinge area of the Rattlesnake Mountain anticline.

- Initiation of deformation of Rattlesnake Mountain area is interpreted to have begun at least by late Grande Ronde time.

- The present structural elevation of Rattlesnake Mountain can be explained by extrapolating the late Miocene growth rate to the present. This results in an interpreted relatively continuous growth at a rate of 70 m (230 ft) per million years (combined anticlinal uplift and basin subsidence).

- Geomorphology

  - Present-day geomorphic processes are limited in the Rattlesnake Mountain area due to the arid, but mild climate.

- Degradational processes are most active along the crest and upper flanks of ridges, with surface runoff being one of the most effective geomorphic agents in modifying the land surface. Erosion associated with running water has formed an extensive drainage network of rills and gullies.

- Various sizes and types of landslides occur within the area, with the Mabton interbed apparently being the primary failure surface for many of the larger landslides.

- Chemical processes active in the suprabasalt sediments and the top of basalt have formed crusts and pans primarily cemented by $CaCO_3$, with older crusts cemented by Fe_2O_3 and SiO_2.

- Seismology

  - The frequency of earthquakes >4 km (2.5 mi) deep is about the same as the surrounding region.

  - The frequency of earthquakes <4 km (2.5 mi) deep is much less than the average observed rate of seismicity in the surrounding region.

  - The seismicity pattern indicates that earthquakes are not concentrated onto known faults or anticlinal structures.

  - Focal mechanism solutions suggest that ongoing deformation is by thrust or reverse faulting and that strike slip movement is relatively minor.

- Climatology

  - The maximum annual average precipitation in the Rattlesnake Mountain area of about 28 cm (11 in.) occurs near the ridge crests. This precipitation is about twice that received in the surrounding lowlands.

- Hydrology

  - The juvenile hydrochemistry of the spring and well water (low total dissolved solids, calcium-bicarbonate chemical type) appears to be characteristic of a recharge area.

  - Stable isotopic composition of precipitation falling in the Rattlesnake Mountain area during the groundwater recharge period of the cooler months is similar to water sampled in the shallow basalts beneath the central Hanford Site. This suggests similar climatic origin.

- Apparent downward head gradient in borehole RSH-1 is characteristic of a recharge area.

- Tritium concentrations of a few tens of picocuries per liter suggest a mixture of both pre- and post-1953 age spring waters in the Rattlesnake Mountain area; overall the spring waters are considered young.

- The water table is interpreted to lie about 450 m (1,500 ft) below the crest of Rattlesnake Mountain. The estimated depth places the water table in the Grande Ronde Basalt throughout most of the crestal area of Rattlesnake Mountain. A large uncertainty is associated with this estimate because of data scarcity.

- Perched water occurs within the basalts of the unsaturated zone based on the presence of numerous springs and points of vegetation along the upper flanks of the ridges.

- Natural Resources

  - The area contains few known mineral or fossil fuel resources.

  - Low-unit-value industrial rocks, including sand and gravel, basalt, and pumicite, have been quarried from the lower slopes of the area. Sustained commercial production of these rocks seems unlikely.

  - Coal and peat seams penetrated in borehole RSH-1 are lignite or peat in rank and are probably not of sufficient thickness to attract development in the predictable future.

  - Commercial quantities of natural gas (methane) in the abandoned Rattlesnake Hills gas field appears unlikely since most wells had remained open to the atmosphere, depleting the gas quantity available. The potential for deeper sources of commercial quantities of gas and oil beneath the Rattlesnake Mountain area is unknown.

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1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The objective of the Basalt Waste Isolation Project (BWIP) is to determine the feasibility of long-term disposal of commercial high-level nuclear waste in basalt flows beneath the Hanford Site located in southeastern Washington State (Figure 1-1). Waste disposal would be in underground openings constructed at depth within the interior of a basalt flow. The proposed geographic area for such a repository is a 47 km^2 (18 mi^2) area designated the reference repository location (RRL). This area contains nearly flat-lying basalt flows with potential candidate basalt horizons situated deep [approximately 850 to 1,160 m (2,800 to 3,800 ft) below land surface] within the saturated zone. The BWIP is also compiling geotechnical information on a basalt sequence in a geohydrologic setting above the water table in an unsaturated zone. The site chosen for the compilation is the Rattlesnake Mountain area, located in the Rattlesnake Hills along the western boundary of the Hanford Site south of the RRL (Figures 1-1 and 1-2). The geotechnical information is being compiled so it could be used in decision processes to evaluate the merits of Rattlesnake Mountain as a potential repository site for nuclear waste. Siting of a repository in Rattlesnake Mountain has been suggested as a possible alternative to a deep site beneath the central Hanford Site area by the National Research Council (1978), Penberthy (1983), Bennett (1983), as well as by other sources. The near-surface geohydrologic conditions within the Rattlesnake Mountain area appear to have certain advantages over conditions deep within the RRL. These advantages include the following:

- A site located in the unsaturated zone (i.e., above the water table) and at atmospheric pressure
- Considerably less cost for construction and operation of a repository
- Easier retrieval of waste canisters if necessary
- Less difficult to seal repository once filled.

Disadvantages of siting a repository in the Rattlesnake Mountain area compared to the RRL include:

- Characterization of a more complex geohydrologic setting, which includes perched water tables and greater stratigraphic/structural discontinuities
- Repository construction in potentially active fault zones
- Repository construction closer to the land surface and accessible environment
- Increased potential for natural resource production.

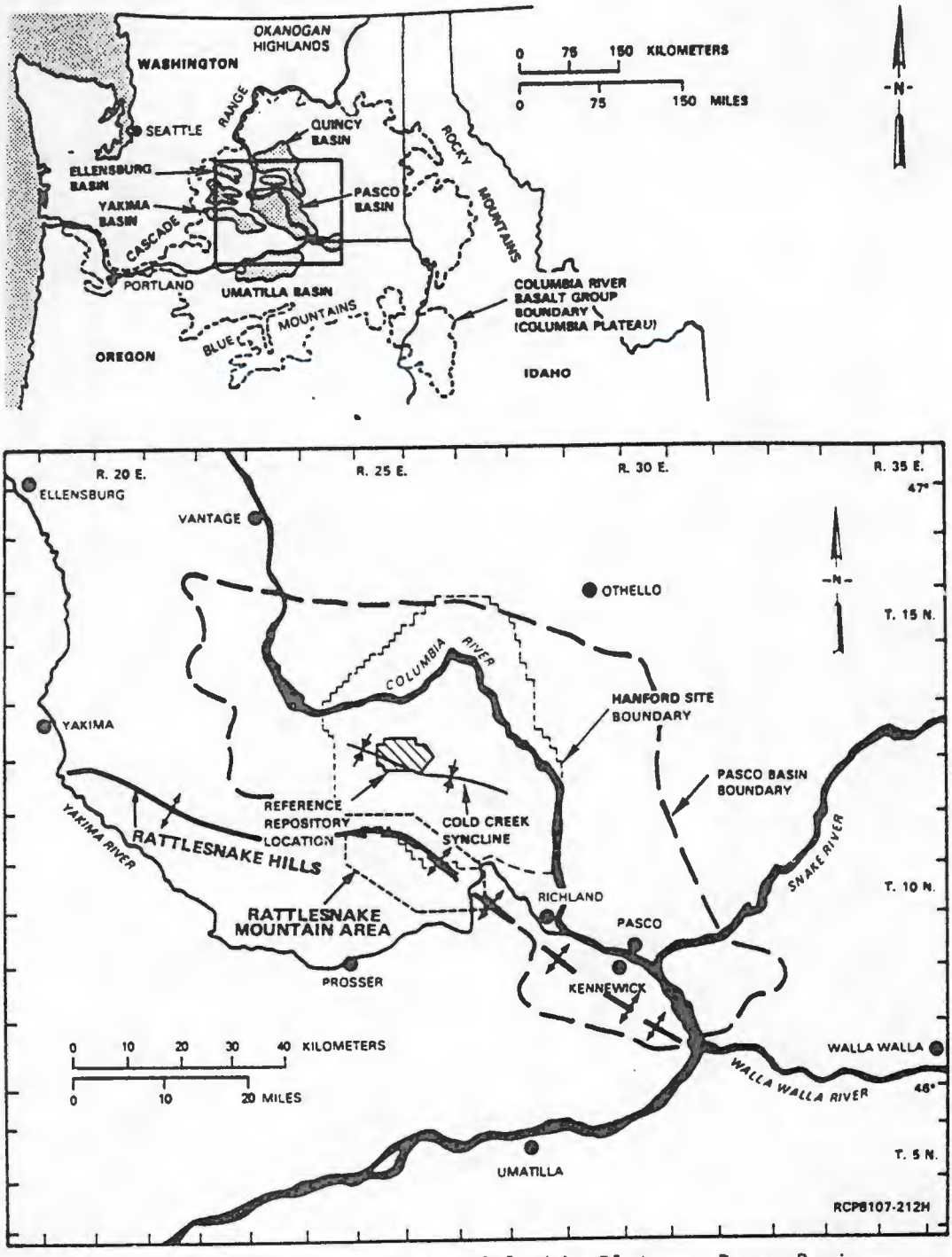


Figure 1-1 Location of the Columbia Plateau, Pasco Basin, Hanford Site, and Rattlesnake Mountain Area.

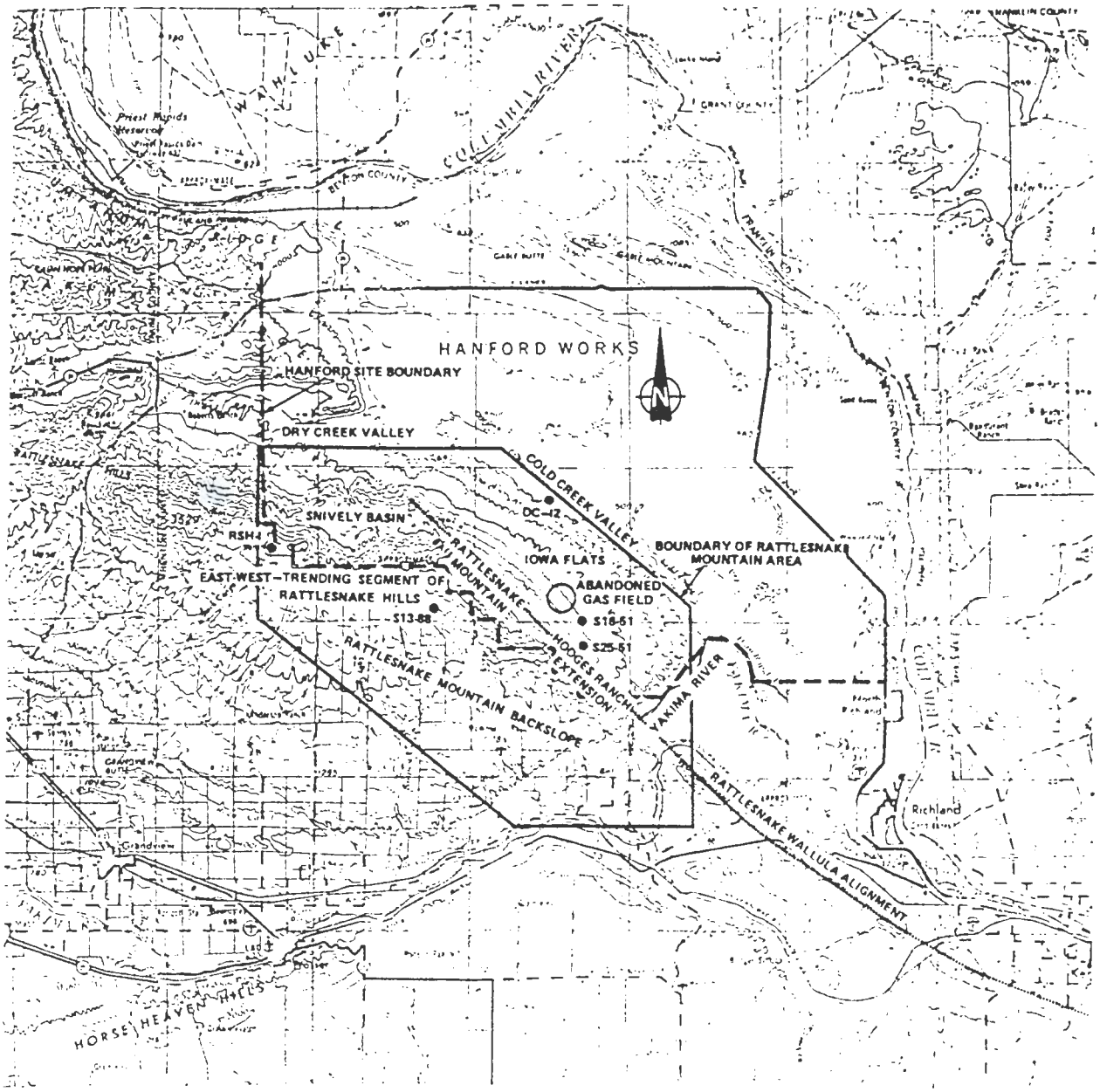


FIGURE 1-2. Topographic and Feature Map of the Rattlesnake Mountain Area.

The compilation of geotechnical data from the Rattlesnake Mountain area has been summarized in this report. The summary contains specific information relative to stratigraphy, structure, geomorphology, seismology, climatology, hydrology, and resource potential. The information in the report is intended to serve as a technical data volume that could be used in repository siting decisions. No attempt was made in the report to evaluate the merits of Rattlesnake Mountain as a potential repository site.

1.2 LOCATION AND DESCRIPTION OF THE RATTLESNAKE MOUNTAIN AREA

The Rattlesnake Mountain area is located along the western boundary of the Hanford Site on a segment of the Rattlesnake Hills. The Rattlesnake Hills is one of a series of major basaltic ridges in central Washington State that form the Yakima Fold Belt. Yakima folds are generally east-west trending, asymmetrical anticlines with north vergence and faulted north limbs.

Major topographic features within the Rattlesnake Mountain area include: (1) the eastern end of the east-west trending segment of Rattlesnake Hills, (2) Rattlesnake Mountain and its southeastern extension, known as Hodges Ranch extension, (3) Snively Basin, (4) Iowa Flats, and (5) The Rattlesnake Mountain backslope (Figure 1-2). The east-west trending segment of Rattlesnake Hills, Rattlesnake Mountain, and Hodges Ranch extension form the ridge crests in the area and rise as much as 915 m (about 3,000 ft) above the broad sediment plain of the central Hanford Site; maximum ridge elevation is 1,091 m (3,581 ft) above mean sea level. The Hanford Site boundary generally follows along the ridge crests (Figure 1-2). Snively Basin and Iowa Flats form the north flanks of the ridges. The upper portion of the north flanks are generally faulted and steeply folded. The lower flanks gently slope into the Pasco Basin. Land on the north flanks of the ridges lies within the Hanford Site and is dedicated to the Pacific Northwest Laboratory Arid Lands Ecology Reserve. The south flanks form the Rattlesnake Mountain backslope that gently slope southwest into the Yakima Valley. Small, low-amplitude folds locally interrupt the gently dipping backslope (Plate 1). Land on the backslope is privately owned and is primarily used for dry-land wheat farming.

1.3 TYPES OF DATA ON THE RATTLESNAKE MOUNTAIN AREA

This section is a general discussion of the types of geotechnical data available concerning the stratigraphy, structure, geomorphology, seismology, climatalogy, hydrology, and natural resources of the Rattlesnake Mountain area. Each type is addressed in individual sections. No new data were collected specifically for this report.

The stratigraphic, structural and geomorphic data presented (Sections 2.0, 3.0, and 4.0) are derived principally from geologic mapping and two deep boreholes (RSH-1 and DC-12). A preliminary geologic map (see Plate 1) was produced for this report that is based on mapping in progress by S. P. Reidel, K. R. Fecht, and M. A. Chamness of

Rockwell Hanford Operations. Sources used in producing this map include earlier geologic mapping by WPPSS (1977), Bond et al. (1978), and Gardner in Myers/Price et al. (1979). Data from the deep boreholes and other boreholes (i.e., shallow water and abandoned gas wells), as well as the geologic map, were used to produce the geologic cross sections. A geomorphic map (Plate 2) was produced from the new geologic map and U.S. Geological Survey topographic maps (Corral Canyon and Grandview 15-min maps).

Available seismic data for the Rattlesnake Mountain area (Section 5.0) were derived from the eastern Washington seismic network established by the U. S. Geological Survey in 1969. This network currently consists of 36 stations and includes a station atop Rattlesnake Mountain. The network has a station spacing of about 25 km (15 mi) in the Hanford Site area. This spacing has provided the capability to locate all earthquakes larger than magnitudes of 1.5 to 1.8. Magnitudes are determined using coda-length-magnitude relationships developed for the region (UWGP 1979) that have been approximately calibrated with Wood-Anderson magnitudes. Prior to 1972, Richter magnitudes were determined from trace amplitudes (Pitt 1971).

Data on present climatic and meteorological conditions (Section 6.0) are derived from two principal sources. General Hanford Site area conditions are from measurements collected at the Hanford Meteorological Station located 13 km (8 mi) north of Rattlesnake Mountain. Information from this station is based on records dating back to 1946. This information is supplemented with precipitation and temperature data taken from U.S. Weather Bureau cooperative observers at a location 16 km (10 mi) east-northeast of the meteorological station during the period 1912 to 1943. Site-specific meteorological data for the Rattlesnake Mountain area are based on the Arid Lands Ecology Reserve Climatology System. This system was a network of 26 stations set up to measure specific climatic elements on the northeast flank of Rattlesnake Mountain from near the crest [elevation 1,091 m (3581 ft)] to Cold Creek Valley [elevation 204 m (670 ft)] (Hinds and Thorp 1977; Stone et al. 1983). The system was established in 1968 and operated to the end of 1981.

The hydrologic data (Section 7.0) used in this report are derived principally from (1) a few hydraulic head measurements in one deep borehole [RSH-1 that penetrates to a depth of 3,250 m (10,665 ft)] on top of Rattlesnake Mountain, supplemented by data from shallower boreholes and (2) a series of springs located throughout the area of study. Borehole RSH-1 is the only boring atop Rattlesnake Hills in the Rattlesnake Mountain area. Data from RSH-1 should be interpreted only broadly since the borehole had been open to groundwater cross-flow and downhole hydrologic tests were conducted for only short durations. The occurrence, distribution, and characteristics of springs in the area have been reported by Schwab et al. (1979), Gephart et al. (1979), and Graham (1983). The basic geohydrologic setting of the Rattlesnake Mountain area is discussed in Gephart et al. (1979) and DOE (1982).

Data on natural resources (Section 8.0) are primarily based on a report by GG/GLA (1981). The report is a resource inventory and

economic evaluation of high-unit-value metallic minerals, low-unit-value industrial rocks and minerals, and fossil fuels in the Hanford Site area that includes the Rattlesnake Mountain area. Data on natural resources (excluding groundwater) are supplemented by field observations and borehole information made during geologic field studies. Groundwater resources are based primarily on spring data (Schwab et al. 1979; Gephart et al. 1979), a few shallow water wells, abandoned gas wells, and two deep boreholes (RSH-1 and DC-12).

2.0 STRATIGRAPHY

2.1 REGIONAL STRATIGRAPHIC SETTING

The Columbia Plateau is underlain by a thick sequence of Miocene tholeiitic basalt flows that are, in places, interbedded with and overlain by clastic sediments of Miocene or younger age (see Figures 1-1 and 2-1; Myers/Price et al. 1979). These basalt flows collectively form the Columbia River Basalt Group that consists of three formations beneath the Pasco Basin and vicinity: Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt (Swanson et al. 1979; Reidel et al. 1981). Sedimentary rocks of Miocene age, interbedded with the basalts in the Pasco Basin and the western plateau, are designated the Ellensburg Formation (Smith 1901, 1903; Waters 1955; Brown 1959; Newcomb et al., 1972).

Overlying the basalts and interbedded sediments in topographic and structural lows of the central plateau are semiconsolidated sediments of the Mio-Pliocene Ringold Formation (Merriam and Buwalda 1917; Tallman et al. 1981). The thickest sequence of Ringold sediments occurs in the Pasco Basin where approximately 365 m (1,200 ft) of coarse-to-fine-grained clastic sediments were deposited by ancestral rivers. In the central Pasco Basin, the Ringold Formation is informally subdivided into four textural facies: basal, lower, middle, and upper Ringold units (Tallman et al. 1981).

The Quaternary system in the central Columbia Plateau is dominated by catastrophic flood deposits. During the Pleistocene, proglacial lakes formed behind glacial ice lobes northeast of the Columbia Plateau. Failure of the glacial lobes resulted in the release of debris-laden meltwaters across the plateau that scoured the Channeled Scablands and deposited glaciofluvial sediments in topographic lows. In the Pasco Basin, these glaciofluvial sediments are designated the Hanford Formation (Myers/Price et al. 1979).

Loess, dune sand, and alluvium, as well as landslide debris, colluvium, and talus, veneer the flanks of the basaltic ridges bounding the Pasco Basin. These deposits range from Pleistocene to present in age (Myers/Price et al. 1979).

2.2 STRATIGRAPHY OF THE RATTLESNAKE MOUNTAIN AREA

The major geologic units present in the Rattlesnake Mountain area are the Grande Ronde, Wanapum and Saddle Mountains Basalts and the Ellensburg, Ringold and Hanford Formations (Figure 2-1). A thin veneer of surficial sediments is present over much of the area. Stratigraphic descriptions of the geologic units given below are from borehole data (mainly boreholes DC-12 and RSH-1) and geologic mapping of basalt outcrops and sediment exposures in the Rattlesnake Mountain area.

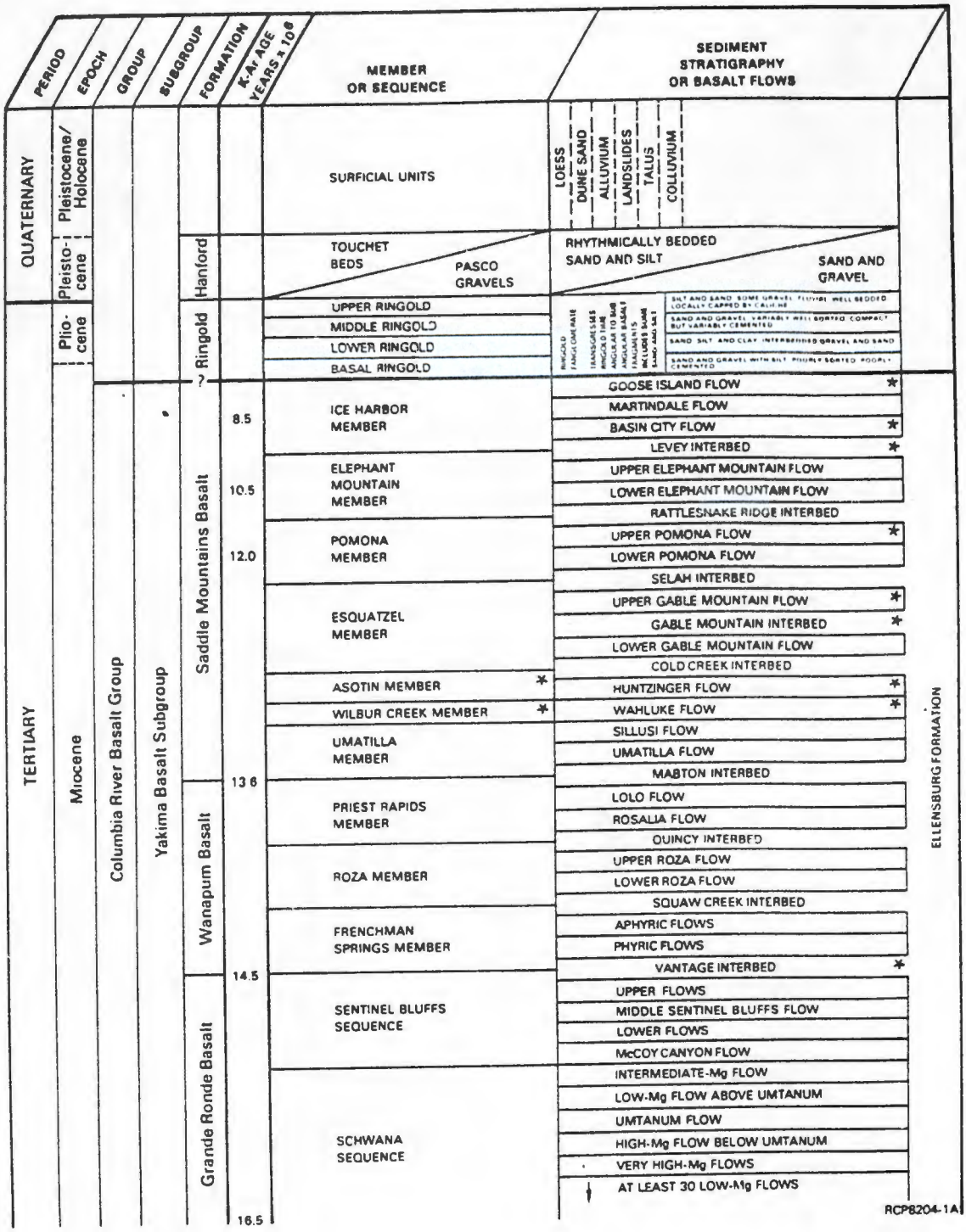


FIGURE 2-1. Stratigraphic Nomenclature for the Pasco Basin.

2.2.1 Grande Ronde Basalt

The Grande Ronde Basalt is a thick sequence of at least 56 basalt flows that are typically fine grained and aphyric or sparsely microphyric with few consistent textural differences among flows (Long and WCC 1984). Flows of this formation erupted between 16.5 and 14.5 mybp. Grande Ronde flows are correlated regionally on the basis of magnetostratigraphic units (from oldest to youngest; R_1, N_1, R_2, N_2) defined by reversals in the paleomagnetic polarity of the flows (Swanson et al. 1979). Flows recognized within the Pasco Basin are of the N_2 and R_2 magnetostratigraphic units (Long and Landon, 1981). Two major informal sequences of flows distinguished primarily on the basis of chemical composition have been recognized in the Pasco Basin and Rattlesnake Mountain area: the Schwana sequence and the Sentinel Bluffs sequence (Myers/Price et al. 1979).

2.2.1.1 Schwana sequence. The Schwana sequence lies within the R_2 and N_2 magnetostratigraphic units and consists of dominantly low Mg-flows (3.55 $\pm$ 0.03 wt% MgO), however, three flows near the top of the sequence are high-Mg (4.88 $\pm$ 0.03 wt% MgO) or very high-Mg (5.78 $\pm$ 0.05 wt% MgO) flows (Long and Landon 1981). The thickest flow near the top of the sequence is the Umtanum flow which is over 60 m (200 ft) thick in boreholes RSH-1 and DC-12 (Figures 2-2 and 2-3). The Umtanum flow is one of the reference candidate horizons for a geologic repository in the RRL. The Schwana sequence is not exposed in the Rattlesnake Mountain area.

2.2.1.2 Sentinel Bluffs sequence. The Sentinel Bluffs sequence in the Rattlesnake Mountain area consists of 8 to 11 flows all of high-Mg chemical type. Basalt flows in this sequence lie within the N_2 magnetostratigraphic unit (Long and Landon 1981). Two flows from the upper part of this sequence crop out on the north end of the north face of Rattlesnake Mountain (see Plate 1; Bond et al. 1978). Individual flows within the sequence vary in thickness from 8.5 m (28 ft) to over 60 m (200 ft). The Rocky Coulee, Cohassett, and McCoy Canyon flows, which are leading reference candidate horizons for a deep geologic repository in the RRL, occur in this sequence and are present in boreholes RSH-1 and DC-12 (see Figures 2-2 and 2-3).

2.2.2 Wanapum Basalt

Wanapum Basalt in the Rattlesnake Mountain area consists of three members: Frenchman Springs, Roza, and Priest Rapids. These basalts were erupted between 14.5 to 13.6 m.y.b.p.

2.2.2.1 Frenchman Springs Member. The Frenchman Springs Member is the oldest member of the Wanapum Basalt in the Rattlesnake Mountain area with as many as nine flows present in borehole RSH-1 (see Figure 2-2). The thickness of the Frenchman Springs varies from about 146 m (479 ft)

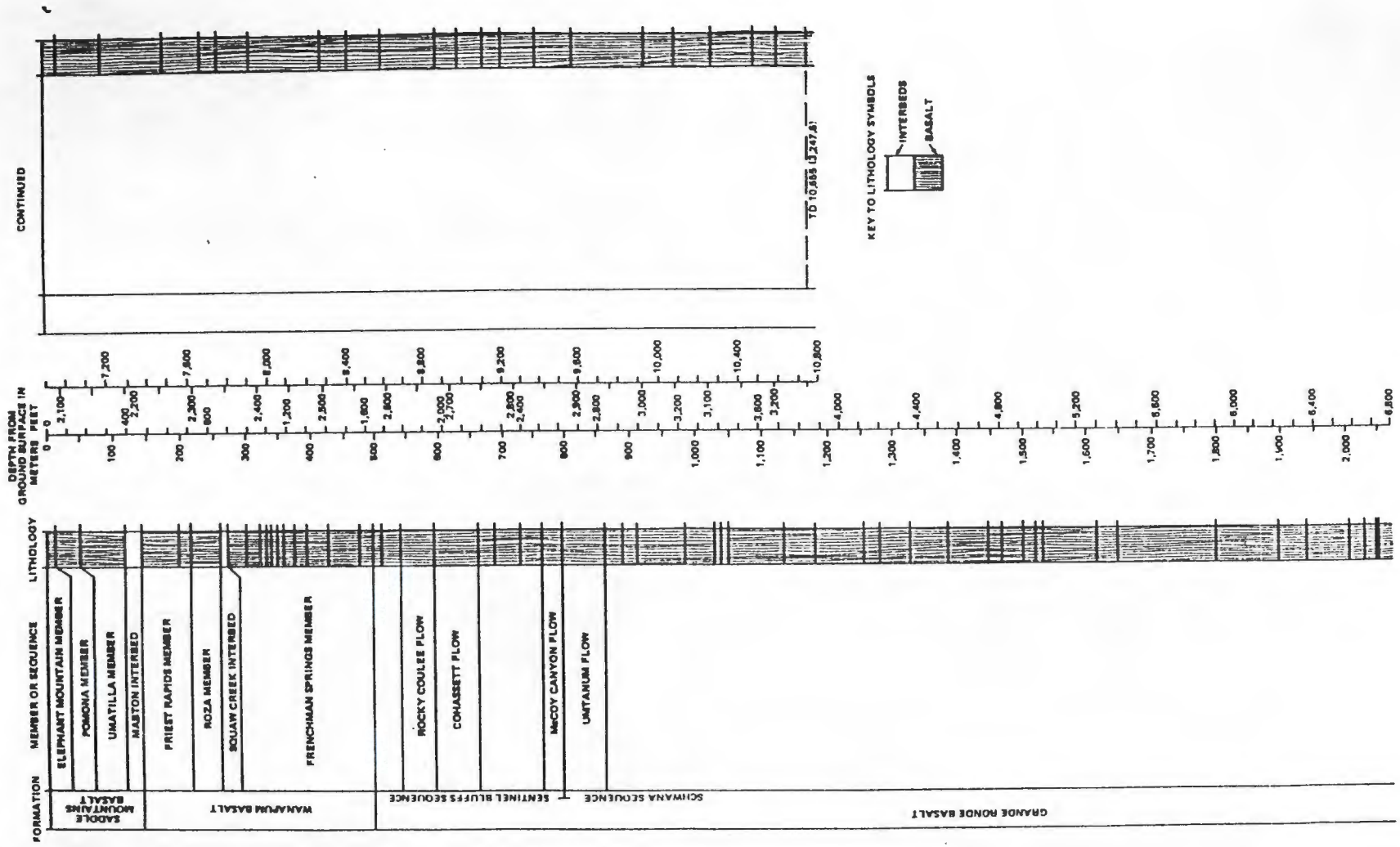


FIGURE 2-2. Borehole RSH-1 Stratigraphic Correlation Chart.

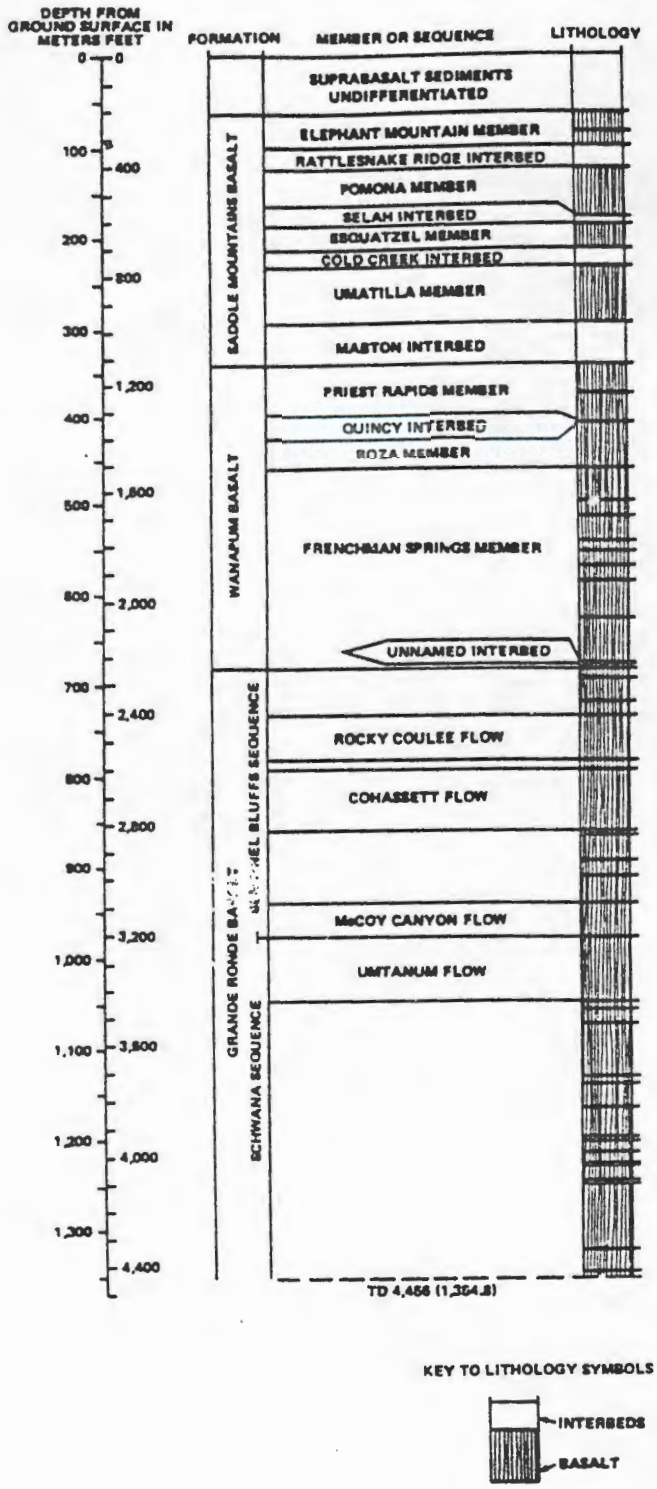


FIGURE 2-3. Borehole DC-12 Stratigraphic Correlation Chart.

along the north face of Rattlesnake Mountain to about 255 m (835 ft) on the eastern end of the east-west trending Rattlesnake Hills segment (see Plate 1). These thicknesses vary considerably compared to the central Hanford Site where the Frenchman Springs ranges between 213 and 228 m (699 and 748 ft) thick. The thin [146 m (479 ft)] Frenchman Springs section on Rattlesnake Mountain is interpreted to be the result of thinning over the emerging Rattlesnake Mountain structure (Reidel and Fecht 1981). Based on boreholes RSH-1 and DC-12, individual flows or flow lobes in the Frenchman Springs range in thickness from 5.5 to 51 m (18 to 168 ft) with the thicker flows located in the lower part of the member. Flows of this member fall within the Frenchman Springs chemical type of Wright et al. (1973) and have normal magnetic polarity (Rietman 1966; Kienle et al. 1978; Sheriff and Bentley 1980; Van Alstine and Gillett 1981).

2.2.2.2 Roza Member. One to three flows or flow lobes comprise the Roza Member in the Rattlesnake Mountain area. The flows or flow lobes crop out along the north face of Rattlesnake Mountain where the Roza Member is about 43 m (140 ft) thick (see Plate 1). The member locally thickens on the lower flanks of ridges to about 47 m (154 ft). The Roza Member falls within the Frenchman Springs chemical type of Wright et al. (1973) and cannot be distinguished from Frenchman Springs Member on chemical composition alone. However, it can be distinguished from the Frenchman Springs Member in hand specimens, typically by the presence of single plagioclase phenocrysts up to 1.5 cm (0.6 in.) in size surrounded by a fine-grained groundmass. Rietman (1966) determined the magnetic polarity of the member to be transitional. Recently, Choinier and Swanson (1979) discovered that the oldest flow in the Roza Member of the southeastern Columbia Plateau has reversed polarity.

2.2.2.3 Priest Rapids Member. The Priest Rapids Member is the youngest member of the Wanapum Basalt (Swanson et al. 1979) and consists of two flows in the Rattlesnake Mountain area. The Priest Rapids Member crops out on the north face of Rattlesnake Mountain and in the western portion of Snively Basin (see Plate 1). The lower flow is typically coarser grained with rare phenocrysts of olivine and plagioclase (Reidel and Fecht 1981) and falls into the Rosalia chemical type of Swanson et al. (1979). The upper flow has small olivine phenocrysts [<5 mm (<0.2 in.)] and rare glomerocrysts or phenocrysts of plagioclase and is compositionally similar to the Lolo chemical type of Wright et al. (1973). Both flows have reversed magnetic polarity (Swanson et al. 1979). The Priest Rapids Member thins over Rattlesnake Mountain, with 31 m (102 ft) of Priest Rapids basalt cropping out near the crest and over 60 m (200 ft) present at borehole DC-12 in the Cold Creek Valley and at borehole RSH-1 west of Rattlesnake Mountain.

2.2.3 Saddle Mountains Basalt

Saddle Mountains Basalt was erupted during a period of waning volcanism between 13.6 and 6 m.y.b.p. Within the Rattlesnake Mountain

area the formation is comprised of five members: Umatilla, Esquatzel, Pomona, Elephant Mountain, and Ice Harbor (Bond et al. 1978; Reidel and Fecht 1981).

2.2.3.1 Umatilla Member. The Umatilla Member is the oldest member of the Saddle Mountains Basalt and occurs throughout the Rattlesnake Mountain area, although outcrops of the member are limited to areas of extensive faulting and erosion (see Plate 1). In the Pasco Basin, the Umatilla Member consists of two flows (Reidel and Fecht, 1981), but only one flow is generally present on Rattlesnake Mountain. The member thins over Rattlesnake Mountain; it is 60 m (200 ft) thick at borehole DC-12 east of the mountain, as little as 15 m (50 ft) thick near the Rattlesnake crest, and 67 m (220 ft) thick at borehole RSH-1 west of the mountain. Field exposures and core samples display fine-grained to glassy texture with rare microphenocrysts of plagioclase and olivine (Reidel and Fecht 1981). The member falls within the Umatilla chemical type of Wright et al. (1973) and has normal magnetic polarity (Reitman 1966).

2.2.3.2 Esquatzel Member. The Esquatzel Member consists of one flow in the Rattlesnake Mountain area. It is present north of the east-west trending segment of the Rattlesnake Hills and east of the Rattlesnake Mountain crest (see Plate 1; Reidel and Fecht, 1981). The maximum thickness of the Esquatzel Member is 27 m (90 ft) at borehole DC-12 in the Cold Creek Valley (see Figure 2-3). Texturally, the flow is plagioclase phyric to glomerophyric and contains microphenocrysts of clinopyroxene, with some localities, such as in Snively Basin, that are completely void of phenocrysts. This flow fits within the Esquatzel chemical type of Swanson et al. (1979) and has normal magnetic polarity (Choinier and Swanson 1979).

2.2.3.2 Pomona Member. The Pomona Member is present throughout the Rattlesnake Mountain area, except where locally eroded, and crops out (1) in gullies within Snively Basin and on the Rattlesnake Mountain backslope, (2) along the escarpment on the east-west trending Rattlesnake Hills segment, and (3) on the crest of Rattlesnake Mountain (see Plate 1; Bond et al., 1978). The member varies in thickness across the area from about 15 m (50 ft) at borehole S13-88 near the Rattlesnake Mountain crest to 53 m (173 ft) at borehole DC-12 in Cold Creek Valley. Only one of the member occurs in the area and it is typically fine-grained to glassy with wedge-shaped plagioclase phenocrysts and rare olivine (Reidel and Fecht 1981). It has reversed magnetic polarity (Rietman 1966; Choinier and Swanson 1979) and fits the Pomona chemical type of Wright et al. (1973). The Pomona Member has been radiometrically dated at 12 m.y.b.p. (McKee et al. 1977).

2.2.3.4 Elephant Mountain Member. The Elephant Mountain Member consists of two separate flows: Elephant Mountain flow (Waters 1955) and Ward Gap flow (Schmincke 1967). The Elephant Mountain flow is the lower flow within the member and is present on the middle and lower slopes of the Rattlesnake Mountain area (see Plate 1). The Ward Gap flow pinches

out onto the lower slopes of the Rattlesnake Mountain area (Bond et al. 1978). The member is 37 m (120 ft) thick at borehole DC-12 in the Cold Creek Valley, thins on the flanks of the ridges, and pinches out onto the Rattlesnake Mountain crest (see Plate 1 and Figure 2-3). Both flows are of the Elephant Mountain chemical type (Wright et al. 1973), have transitional to normal magnetic polarity (Choinier and Swanson 1979; Rietman 1966) and are about 10.5 m.y.b.p. (McKee et al. 1977). The texture of the flows is medium-to-fine grained with abundant microphenocrysts of plagioclase (Reidel and Fecht 1981).

2.2.3.5 Ice Harbor Member. The Ice Harbor Member is the youngest member of the Saddle Mountains Basalt in the Rattlesnake Mountain area (Bond et al. 1978). The Ice Harbor Member occurs in one small area on the south flank of the Hodges Ranch extension along the southern boundary of the Rattlesnake Mountain area (see Plate 1) and consists of one flow of reversed magnetic polarity. The flow is compositionally similar to the Martindale chemical type of Swanson et al. (1979). The flow is <9 m (30 ft) thick and is typically fine-to-medium grained with phenocrysts of plagioclase and olivine. The Ice Harbor Member has been radiometrically dated at about 8.5 m.y.b.p. by McKee et al. (1977).

2.2.4 Ellensburg Formation

Intercalated with the Columbia River Basalt Group are sediments of the Ellensburg Formation (Mackin 1961; Schmincke 1967; Waitt 1979). These sediments generally consist of fine-to-medium grained continental clastic sediments that are locally mixed with volcanic ash to form tuffites (Reidel and Fecht 1981). On the lower slopes of the area, the Ellensburg sediments form the Rattlesnake Ridge, Selah, Cold Creek, and Mabton interbed, that are intercalated with Saddle Mountains Basalt, and the Quincy interbed and an unnamed interbed that are locally present within Wanapum Basalt. The interbeds associated with the Saddle Mountains Basalt range between about 9 to 44 m (30 to 150 ft) thick in borehole DC-12 in the Cold Creek Valley (see Figure 2-3). The two interbeds intercalated with the Wanapum Basalt are <1 meter (3 ft) thick. On Rattlesnake Mountain the interbeds thin onto the lower slopes and pinch out toward the crest (Reidel and Fecht 1981). The Mabton interbed is an exception in that it does not pinch out, but rather thins across the ridge ranging from 46 m (152 ft) thick at borehole DC-12 to about 12 m (40 ft) thick near the Rattlesnake Mountain crest, and measures 25 m (83 ft) thick on the upper Rattlesnake backslope at borehole RSH-1.

2.2.5 Surficial Sediments

The post-Columbia River basalt sediments in the Rattlesnake Mountain area are comprised of four units: (1) Ringold Formation, (2) Hanford Formation, (3) alluvium, and (4) loess and dune sand deposits. Other minor sedimentary units include landslide debris, talus, and colluvium. The Ringold Formation, Hanford formation and alluvium are thickest at

borehole DC-12 [64 m (210 ft)] in Cold Creek Valley and at the Benson Ranch Well [82 m (270 ft)] in Dry Creek Valley and thin and pinch out onto the basaltic ridges (see Plate 1; Fecht and Lillie 1982). A thin cover of loess and sand deposits veneer most of the Rattlesnake Mountain area (see Plate 1).

2.2.5.1 Ringold Formation. Deposition of the Ringold Formation by the ancestral Columbia River started near the end of Columbia River basalt volcanism (late Miocene) and continued to the mid-Pliocene (Fecht et al. 1982). Thin and poorly exposed gravel deposits composed of a mixture of basaltic clasts from the Columbia Plateau and exotic lithologies derived from off the plateau are found resting on the Elephant Mountain Member of the Saddle Mountains Basalt in the southern Rattlesnake Mountain area. These gravels are interpreted to be remnants of the basal Ringold unit that forms an arcuate path from Sentinel Gap in the Saddle Mountains southeast through the northern Pasco Basin and southwest around the south end of the Hodges Ranch extension (Fecht et al. 1982). The distribution of gravels of the basal Ringold unit delineates the course of the ancestral Columbia River through the Pasco Basin during the late Miocene to possible early Pliocene.

Immediately north of the east end of Snively Basin is a small exposure of thinly bedded, tan-colored siltstone that is similar in appearance to the lower and upper Ringold units (see Plate 1). These sediments are interpreted to be of Ringold age, but their stratigraphic position within the Ringold Formation is not accurately known.

2.2.5.2 Hanford Formation. Deposition of the Ringold Formation was followed by an interval of major incision between the mid-Pliocene and early Pleistocene (Myers/Price et al. 1979). The next major aggradational event in the basin was the deposition of glaciofluvial sediments of the Hanford formation in the Pleistocene. The Hanford formation was deposited by catastrophic floodwaters that periodically inundated the Pasco Basin to an elevation below about 366 m (1,200 ft) (Tallman et al. 1981). The Hanford formation is divided into two major textural units: Pasco gravels (Brown 1975) and Touchet Beds (Flint 1938). The Pasco gravels range in texture from boulders to fine sand and represent varied energy environments during flooding (Tallman et al. 1981). Within the Rattlesnake Mountain area, the sands and gravels occur mainly along the Yakima River, with scattered deposits in the lower Cold Creek Valley. The Touchet Beds are composed of rhythmically bedded, fine-grained sands and silts deposited in low-energy, slackwater environments on Iowa Flats and in Cold Creek and Dry Creek Valleys (Myers/Price et al. 1979). The Touchet Beds are capped by scattered ice-rafted erratics and bergmounds throughout Iowa Flats (Bretz 1930; Fecht and Tallman 1978). The age of the glaciofluvial deposits in the Rattlesnake Mountain area is about 13,000 yr. This age is based on the presence of the Mount St. Helens set "S" ash near the top of the glaciofluvial deposits that has been dated (13,000 yr) by Mullineaux et al. (1977).

2.2.5.3 Alluvial Deposits. Alluvial deposits in the Rattlesnake Mountain area consist of normal stream deposition, as opposed to glaciofluvial flood deposits of Hanford Formation. The alluvial deposits are divided into three units: (1) the basaltic gravel unit, (2) the mixed-lithology gravel unit, and (3) the fine-grained sand and silt unit. The basaltic gravel unit consists primarily of angular to subangular basaltic clasts that have been deposited by the ephemeral streams in the Rattlesnake Mountain area as a result of erosion of the basaltic ridges. The age of the basaltic gravels ranges from Pleistocene to present. Older Pleistocene gravels of this unit occur on the north flank of Rattlesnake Mountain and form a series of coelescing alluvial fans that are capped in places by a strong calcic horizon and buried beneath younger sediments. The younger late Pleistocene and Holocene basaltic gravels generally occur in the lower reaches of gullies in the middle and lower slopes of the ridges and form alluvial fans at the lower reaches of the larger ephemeral drainages. Only the laterally extensive deposits of the basaltic gravel unit are shown in Plate 1.

The mixed-lithology gravel unit occurs along the present-day Yakima River channel near the southern boundary of the Rattlesnake Mountain area. Exposures of this unit are too small to be shown on the geologic map (see Plate 1). These gravels are composed of about 30% to 40% basaltic clasts derived from the Columbia River Basalt Group and 60% to 70% exotic clasts derived from off the Columbia Plateau. The deposits are Holocene in age and mainly represent the reworking of Hanford Formation gravels in the lower Yakima Valley and along the channel of the Yakima River.

Deposits of the fine-grained sand and silt unit occur at the distal ends of the ephemeral streams in Cold Creek and Dry Creek Valleys (not depicted in Plate 1). The deposits are of Holocene age and are composed predominantly of sand and silt with some minor angular basaltic gravel clasts. These sediments formed as a result of the erosion of loess and the Touchet Beds in and around the Rattlesnake Mountain area.

2.2.5.4 Eolian Deposits. Loess and dune sand deposits in the Rattlesnake Mountain area occur primarily on the middle and upper slopes (see Plate 1). These sediments are generally thicker on the north flank or lee side of the ridges. The age of the loess and dune sand deposits ranges from Pleistocene to the present. Older Pleistocene loess and dune sand deposits are orange-tan in color and argillic with a superimposed calcic to petrocalcic horizon capping the deposits. Exposure of the older loess and sand deposits occurs throughout Snively Basin and in the deeply incised gullies on the lower and middle slopes of the north flank of Rattlesnake Mountain. Younger loess and sand deposits are typically tan colored and veneer most of the Rattlesnake Mountain area except along steep escarpments and in gullies. Loess and dune sand partially obscure much of the bedrock in the Rattlesnake Mountain area.

3.0 STRUCTURE

3.1 STRUCTURAL SETTING

The Rattlesnake Mountain area lies within the Yakima Fold Belt, one of the three structural subdivisions of the Columbia Plateau (see Figure 3-1). Collectively, the Rattlesnake Mountain area consists of three distinct structural segments (see Plate 1 and Figure 1-2): Rattlesnake Mountain and its southeast (Hodges Ranch) extension to the Yakima River, Snively Basin, and the east-west trending segment of the Rattlesnake Hills. These structural features are anticlinal ridges and form the southern and western boundary of the Pasco Basin (see Figure 1-1).

In addition to the Yakima folds, the Cle Elum-Wallula lineament (CLEW) (Laubscher 1981) is interpreted to be a fundamental structural feature of the Columbia Plateau (Laubscher 1977, 1981; Davis 1981; Bentley 1980) that transects the Yakima Fold Belt with a trend of N. 50° W. Rattlesnake Mountain and its extension to Wallula Gap comprise part of the CLEW that has been termed the Rattlesnake-Wallula alignment (RAW) (see Figure 1-2).

Snively Basin marks the intersection of the typical east-trend of the Yakima folds with the N. 50° W. trend of the CLEW (see Figure 1-2). There are no geologic or geophysical data available that indicate either a continuation of Rattlesnake Mountain to the northwest along the trend of the CLEW or a continuation of the east-trending Rattlesnake Hills anticline east of Snively Basin. The Yakima Ridge anticline, the next anticlinal ridge to the north, appears to change trend from east to N. 50° W. north of Snively Basin but not along the trend of the RAW.

3.2 STRUCTURE OF THE RATTLESNAKE MOUNTAIN AREA

3.2.1 Rattlesnake Mountain

Rattlesnake Mountain is typical of the anticlinal ridges that characterize the Yakima Fold Belt. It is asymmetrical with a northeast vergence and a faulted north limb (Plate 1). There are approximately 520 m (1,700 ft) of structural relief along the crest of Rattlesnake Mountain as measured from the top of the Elephant Mountain Member. Structural relief decreases southeast along the Hodges Ranch extension to the Yakima River where the basalt flows are nearly horizontal (see Plate 1). Southeast of the Yakima River the structural trend continues as a series of doubly plunging anticlines or domes (see Figure 1-2).

Presently, only the gently southwest dipping and faulted northeast flanks of Rattlesnake Mountain are exposed (Figure 3-2, Sections B-B' and C-C'). Erosion has removed the crest and hinge area of the

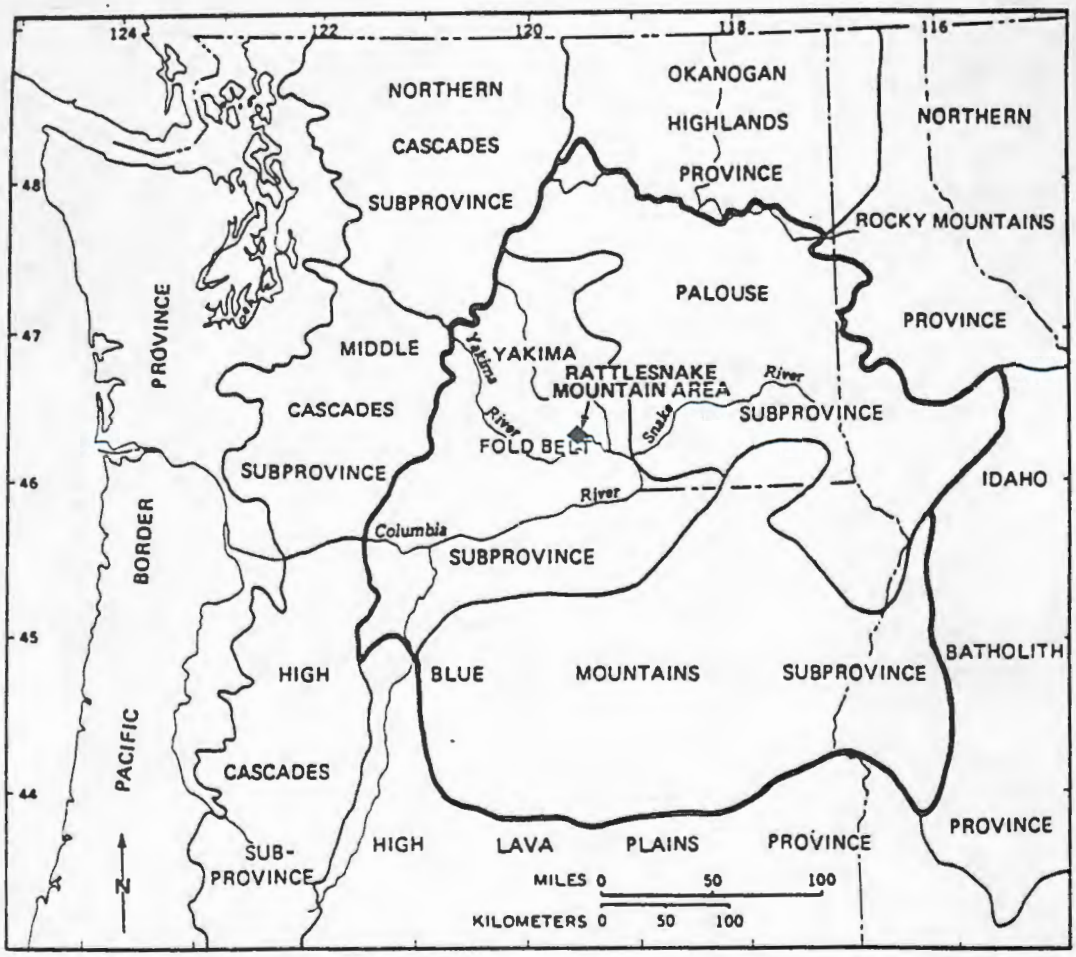


Figure 3-1 Informal Geologic Subdivisions of the Columbia Plateau Province. (Modified from Myers/Price et al., 1979)

anticline but farther to the southeast on the Hodges Ranch extension (see Figure 3-2, Section A-A'), the hinge and crest are apparently preserved.

High-angle reverse to thrust faults occur along the northeast flank of Rattlesnake Mountain. The Rattlesnake Mountain fault that lies along the base of the anticline has been mapped from Snively Basin to the Hodges Ranch extension (see Plate 1). Poor exposure along the Hodges Ranch extension does not permit accurate estimates of its total length. Mapping to the southeast indicates that the fault ends before reaching the Yakima River because the Pomona Member appears to be unfaulted along the length of the river. Total length of the Rattlesnake Mountain fault may be as much as 16 km (10 mi) along the N. 50° W. trend.

At Rattlesnake Mountain, a second high-angle reverse to thrust fault occurs immediately southwest and above the Rattlesnake Mountain fault (see Figure 3-2, Section B-B'). This fault has a mapped length of about 4 km (2.5 mi) and appears to die out to the southeast at the junction of the Rattlesnake Mountain and Hodges Ranch extension segments of the Rattlesnake Mountain anticline and to the northwest at an east-trending cross fault along Rattlesnake Mountain (see Plate 1). The upper fault is interpreted to have developed in response to folding of the basalt over the Rattlesnake Mountain fault. As the basalt steepened during folding, it ruptured along this plane when the strength of the rock would no longer permit it to fold.

A high-angle, east-trending cross fault occurs along Rattlesnake Mountain (see Plate 1) and disrupts the continuity of the Rattlesnake Mountain fault. The fault dies out on Rattlesnake Mountain as shown by the Pomona Member which can be traced continuously along the fault projection. The fault is approximately 3 km (2 mi) in length and is covered by sediments along most of its length. It apparently offsets the Rattlesnake Mountain fault and is the northwest point of termination of the upper high-angle reverse to thrust fault along Rattlesnake Mountain.

The geometry of the Rattlesnake Mountain anticline changes on either side of the cross fault (see Figure 3-2, Sections B-B' and C-C'). Northwest of the cross fault, the south limb dips 25° southwest, while to the southeast it dips 12° southwest. The termination of the upper high-angle reverse to thrust fault and apparent offset of the Rattlesnake Mountain fault are the principle differences on the north flank.

Several smaller scale geologic structures are associated with the Rattlesnake Mountain anticline (see Plate 1). The most prominent is a low amplitude anticline 1 km (0.6 mi) northeast of the Rattlesnake Mountain fault. The apparent northwest termination of the anticline occurs along the cross fault of Rattlesnake Mountain and the southeast termination occurs approximately 3 km (2 mi) southeast of the cross

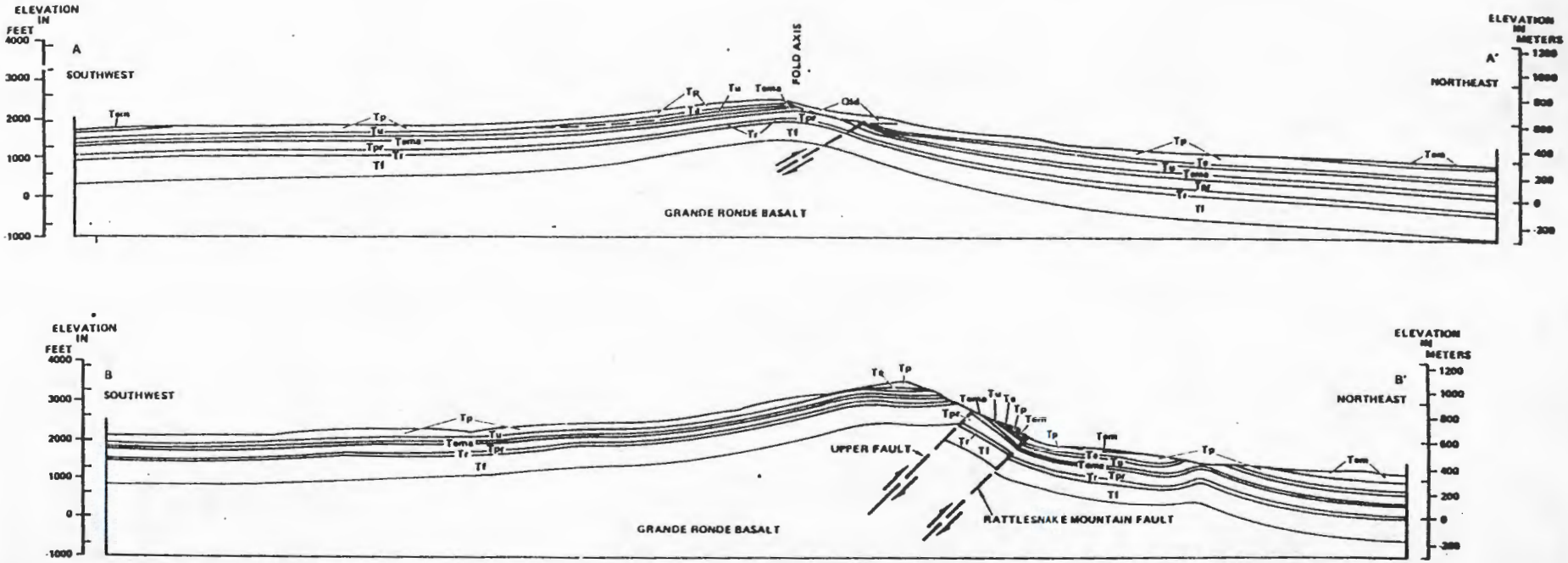
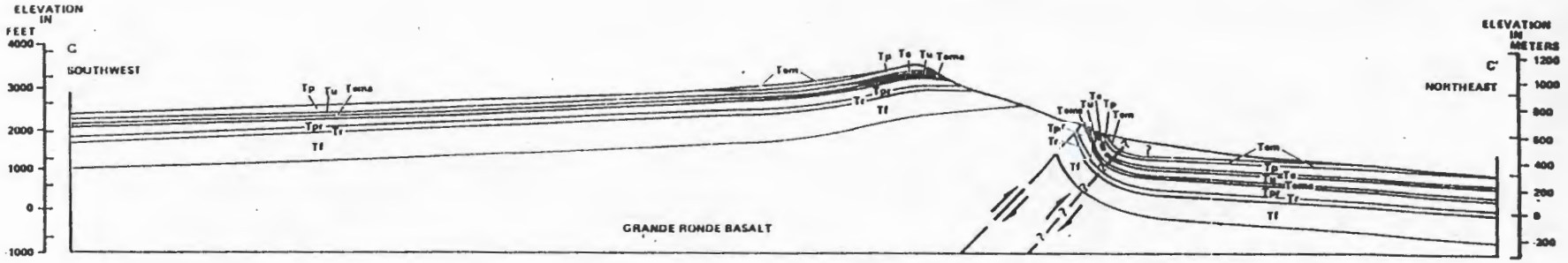


FIGURE 3-2. Generalized Geologic Cross Sections Through the Rattlesnake Mountain Area.



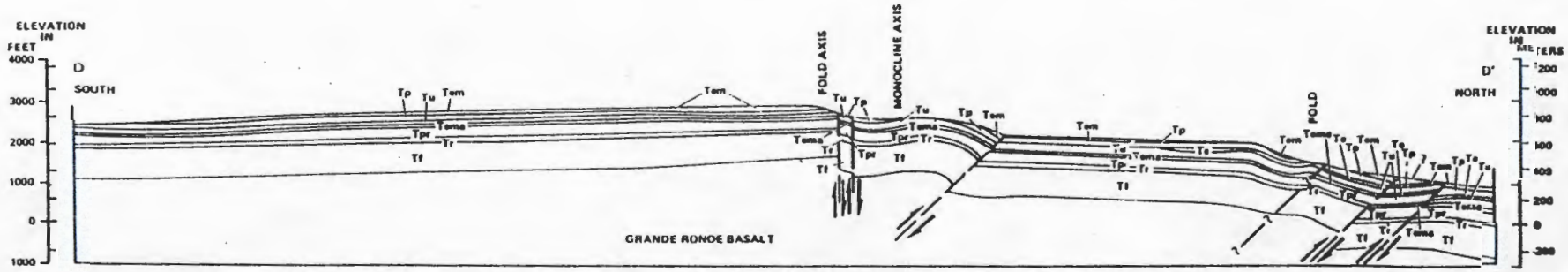


FIGURE 3-2 Cont. Generalized Geologic Cross Sections Through the Rattlesnake Mountain Area.

fault.

A second geologic structure is a small monocline on the Rattlesnake Mountain backslope that occurs 1 km (0.6 mi) southwest of the Rattlesnake Mountain crest. Dips change from 12° to 5° across the monoclinal axis.

3.2.2 Snively Basin

At the northwest end of Rattlesnake Mountain, the rocks plunge apparently unfaulted, into Snively Basin and change strike from northwest to west. Detailed geologic mapping has not yet been completed and the local structures are not well understood. A preliminary cross section is shown in Figure 3-2 (Section D-D'). Snively Basin is atypical for a Yakima fold in that it consists of gently folded basalts bounded by a series of high-angle reverse to thrust faults. The zone of surface faulting is spread over a width of 10 km (6 mi) [as opposed to 1 km (0.6 mi) on other folds] and structural relief is not as great as on the other Yakima folds. Snively Basin is interpreted as an imbricate thrust fault zone that developed at the intersection of the RAW and the east-trending segment of the Rattlesnake Hills.

The primary fault through Snively Basin appears to be a continuation of the Rattlesnake Mountain fault (see Plate 1). The fault has been mapped along the northern margin of Snively Basin and apparently connects with a high-angle to reverse fault that occurs to the west along the north-flank of the Rattlesnake Hills anticline. Possibly 2 or 3 other high-angle reverse to thrust faults occur within 2 km (1.2 mi) south of the Rattlesnake Mountain fault. These faults appear to be local, with respect to Snively Basin and cannot be traced into the Rattlesnake Mountain or east-trending Rattlesnake Hills anticline. A 5-km (3-mi) wide, gently folded syncline occurs south of this fault zone forming the geographic Snively Basin. This basin is bounded on the south by another high-angle reverse to thrust fault in which the basalt is steeply folded. Between this fault and the topographic crest of the ridge, several normal faults occur that may have developed in response to extension resulting from anticlinal folding above the southern most high-angle reverse to thrust fault. These faults cannot be traced into the Rattlesnake Mountain or Rattlesnake Hills anticlines.

Although mapping is not yet complete, major zones of faulting with a generally north-south grain have not been observed. This observation is important because it suggests that the RAW apparently does not continue northwest beyond the Rattlesnake Mountain-Snively Basin area.

2.3.2 East-West Trending Segment of the Rattlesnake Hills

The western edge of Snively Basin grades apparently unfaulted into the Rattlesnake Hills anticline. The Rattlesnake Hills anticline is typical of a Yakima fold and its cross-sectional geometry is similar to Rattlesnake Mountain (Figure 3-2, Section B-B').

3.3 AGE OF DEFORMATION

The initiation of deformation for Rattlesnake Mountain is interpreted to have begun at least by late Grande Ronde time (15.5 m.y.b.p., Reidel et al. 1983; Reidel and Fecht 1983) and continued through the Miocene. The latest age of deformation in the Rattlesnake Mountain area is not accurately known. Surficial sediments overlying the fault zones do not appear to be deformed, but the age of the sediments is poorly understood. However, the present structural elevation of Rattlesnake Mountain can be explained by extrapolating the late Miocene growth rate to the present. An interpretation of relatively continuous growth at a rate of about 70 m (230 ft)/m.y. (combined uplift and subsidence) is consistent with that interpreted for other Yakima folds in the central Columbia Plateau (Reidel et al. 1983; Reidel and Fecht 1983) and is the best interpretation presently available for the area.

Deformation along the RAW adjacent to Rattlesnake Mountain has been interpreted by many workers to be related to a right-lateral strike slip movement along a deep seated fault (see Duncan 1983). The RAW has been conservatively classified by the NRC (1982) as a capable structure based on offset in Quaternary sediments near Wallula Gap and using 10 CFR 100 criteria. Two areas adjacent to Rattlesnake Mountain may constrain the last movement along the northern portion of the RAW. One area along the Yakima River, the Pomona Member (12 m.y.b.p.), appears to be unfaulted across the trend of the RAW. If further work shows that this interpretation is correct, that would indicate that the RAW is segmented with respect to lateral movement and deformation is confined to the anticlinal structures. A second area is the cross fault on Rattlesnake Mountain (see Plate 1). If datable sediments cover the cross fault at this point and the last movement can be dated, the age of the last movement along Rattlesnake Mountain can thus be constrained. More work is necessary to verify the age of last movement, however.

3.4 MECHANICS OF DEFORMATION

At present, no detailed mechanical or kinematic analyses have been done for Rattlesnake Mountain. This is because the amount of rock exposure is not adequate for such a study. Some idea of the types and distribution of strain features can be made, however, from the work of

Price (1982) on Umtanum Ridge. Price determined that folding strain within an anticlinal ridge of the Yakima Fold Belt consists of localized layer-internal faulting, extensive shattering, and limited layer-parallel faulting. Price found the strain to be relatively consistent both laterally along a fold and within different folds. It is believed that this study may be applicable to Rattlesnake Mountain.

Price (1982) compared the distribution of strain and the structural geometry of Umtanum Ridge with other folds in the Yakima Fold Belt and developed a flexural flow buckle model. Most strain in this model is concentrated in the anticlinal ridges, with faults, fractures, and breccia zones less abundant away from the crest-hinge area and the greatest strain occurring in the vertical beds. Most strain occurred by cataclastic flow, but Price (1982) observed that the glassy flow tops appear to have been more ductile. He concluded that most strain in the fold is by simple shear. The large, high-angle reverse to thrust faults associated with the anticlines were interpreted to be folding strain required by the concentric folding and indicate that folding preceeded faulting.

A recent study of rotation as a potential strain mechanism (Reidel et al. 1984) has shown that the Pomona Member on Rattlesnake Mountain has recorded up to 14° of clockwise rotation relative to the Pomona Member in the synclinal areas. The mechanism of rotation is interpreted to be the faults, fractures, and breccia zones associated with the crest-hinge area of the anticlines. This interpretation is consistent with the distribution of strain features observed by Price (1982) and the areal distribution of rotation in the rock.

4.0 GEOMORPHOLOGY

4.1 REGIONAL GEOMORPHOLOGY

The Pasco Basin lies within the Yakima Folds and Central Plains sections of the Columbia Basin subprovince of the Columbia Plateau physiographic province (Freeman et al. 1945, Figure 4-1). Within these sections, present-day aggradational and degradational processes are limited because of the arid but moderate climate.

The dominant topographic features of the Yakima Folds section are the series of anticlinal ridges that rise as much as 915 m (3,000 ft) above the adjacent synclinal valleys. Major through-going streams within this section include the Columbia and Yakima Rivers. These streams have cut water gaps through several of the anticlines. Lesser drainages in the section generally have courses controlled within synclinal valleys. Along ridge crests and upper slopes, aggradational processes are predominantly eolian consisting of loess and some sand deposits. Mass wasting and fluvial erosion are the most prominent degradational processes. Mass wasting has formed escarpments and hummocky topography on many of the northern flanks of the ridges. Fluvial erosion has formed an extensive network of rills and gullies on the ridges.

The Central Plains section lies near the center of the Columbia Basin subprovince (see Figure 4-1). The dominant features of this section are the Quincy and Pasco Basins, two major depocenters for fluvial and glaciofluvial sediments in the late Miocene through Pleistocene. Many of the present-day landforms observed in the Central Plains section are attributed to Pleistocene catastrophic flooding. The landforms include coulees and other abandoned channelways of the Channeled Scablands and large pendant and eddy bars that commonly form on sand and gravel plains in topographic lows. Major streams flowing through this section are the Columbia, Snake, and Walla Walla Rivers. Present-day fluvial aggradational and degradational processes are most active within the channels and flood plains of these streams. Eolian aggradational and degradational processes are also active, as attested by the extensive network of partially stabilized dunes that mask much of the surface of the section.

4.2 GEOMORPHOLOGY OF RATTLESNAKE MOUNTAIN

Gravity, running water, and wind are the primary causes of erosion and mass wasting of the Rattlesnake Mountain landscape. Gravity through the action of rock creep, talus formation, and debris slides transports rock and sedimentary debris to lower terrain. Running water, the most effective agent in modifying the land surface, has formed an extensive ephemeral drainage network. The sparse vegetation over much of the area permits eolian processes to pick up and transport fine-grained sediment to other sites.

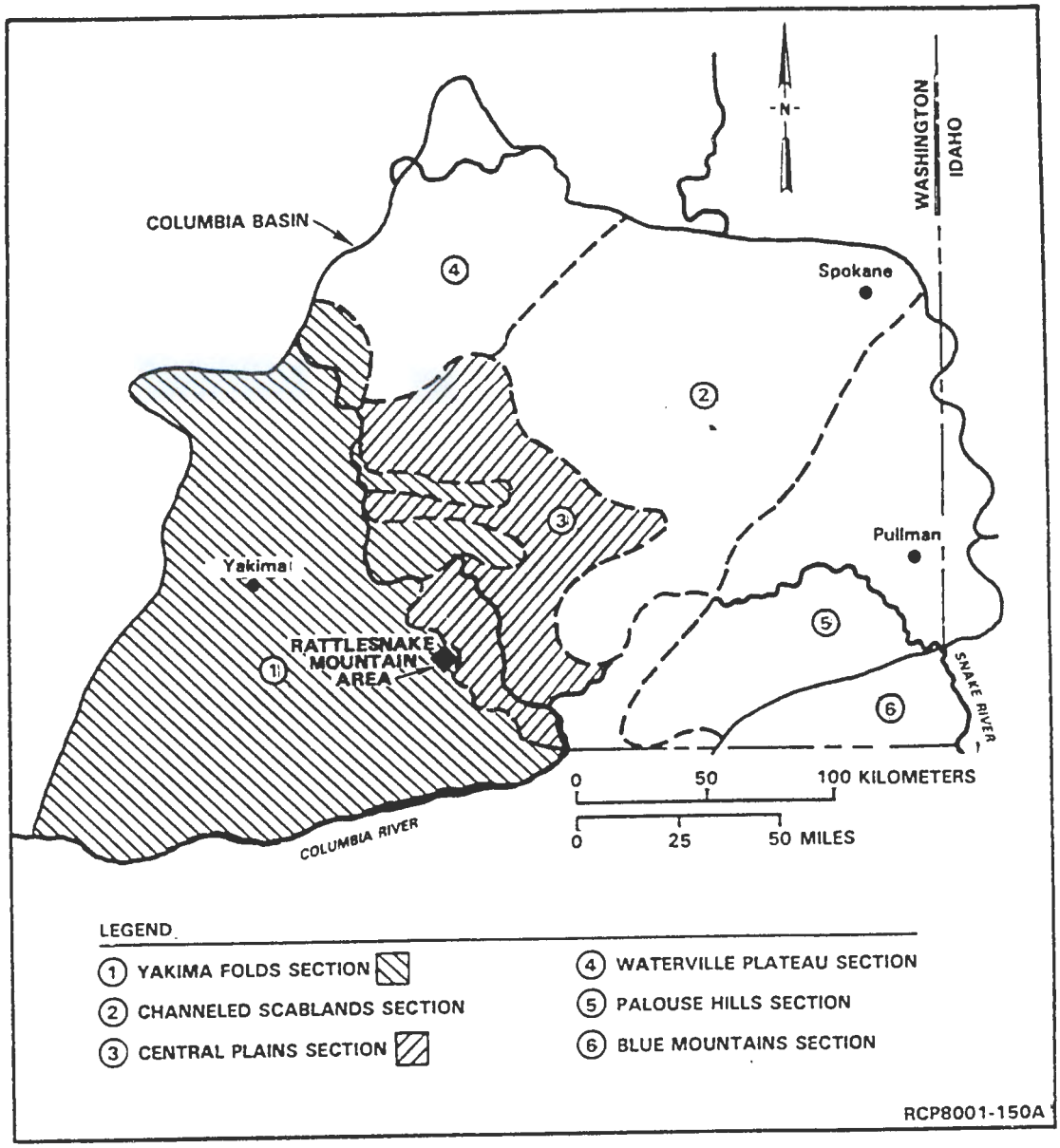


FIGURE 4-1 Physiographic Subdivisions of the Columbia Basin Province.

Chemical processes have resulted in the decomposition of rocks and the formation of crusts, pans, and horizons that are cemented with $CaCO_3$, SiO_2, and Fe_2O_3. Calcium carbonate formation is common to sediments of the area and ranges from weakly calcic to petrocalcic. Silcretes and ferricretes are rarely observed and are confined to the oldest suprabasalt sediments in the area. Dissolution features in the basalt and sediments in the area have not been observed.

The geomorphology of the Rattlesnake Mountain area is discussed in relationship to land systems or areas of recurring patterns of landforms. Rattlesnake Mountain along the western Pasco Basin is a basaltic anticlinal ridge that rises 915 m (3,000 ft) above the basin floor and lies within the Yakima Folds section of the Columbia Basin subprovince (see Figures 1-1, 1-2, and 4-1). Rattlesnake Mountain is bounded to the northeast by the Cold Creek Valley, which lies along the western margin of the Central Plains section (see Figure 1-2). Within the Rattlesnake Mountain area, three major landforms are designated: (1) ridge terrain, which includes the ridge crests and upper ridge slopes of Rattlesnake Mountain, the Hodges Ranch extension, and the eastern end of the east-west trending segment of the Rattlesnake Hills; (2) lower slope terrain, which includes Iowa Flats, Snively Basin, and the Rattlesnake Mountain backslope (southwest slope); and (3) basin and valley terrain, which includes Cold Creek and Dry Creek Valleys (see Figure 1-2).

4.2.1 Ridge Terrain

The ridge terrain consists of the prominent basaltic ridge crests and upper ridge slopes of the northwest trending Rattlesnake Mountain and Hodges Ranch extension and the eastern portion of the east-west trending Rattlesnake Hills segment (see Figure 1-2). The upper flanks of the ridges are asymmetrical with moderately steep south slopes (generally 5 to 15°) and north slopes that generally exceed 30° (see Plate 2). On Rattlesnake Mountain and the east-west trending Rattlesnake Hills, segment the north slopes form escarpments that are interrupted by a series of prominent benches. The escarpments were formed as a result of degradation of the ridge by erosion and mass wasting of the crest-hinge area of the folds, and the benches are remnants of individual basalt flows or flow units. Along the Hodges Ranch extension, the north slope of the fold is interpreted to be essentially intact with the basalt surface closely approximating the plunging dip slope of the basalt southeast to the Yakima River.

Erosion by ephemeral streams in the ridge terrain has formed an extensive network of rills and gullies in a parallel drainage pattern. The rills and gullies that head in the ridge terrain are relatively shallow on the south upper ridge slopes and more deeply incised on the north slopes.

Mass wasting along the prominent escarpment of the east-west trending Rattlesnake Hills segment has formed numerous small slump blocks that are associated with the series of normal faults (see Plates 1 and 2). Near the crest at the southeast end of Rattlesnake Mountain

is a relatively small scarp above a relatively large debris flow (see Plates 1 and 2). The failure surface of this debris flow is interpreted to have been the Mabton interbed.

Aggradation of the ridge terrain is minimal and consists predominantly of a very thin veneer of loess, which typically mantles the more gentle slopes of the ridge crests (see Plate 1). Minor accumulations of talus occur locally in the ridge terrain.

4.2.2 Lower Slope Terrain

The lower slope terrain consists of the middle and lower slopes of Rattlesnake Mountain and the Hodges Ranch extension, the south slope of the east-west trending Rattlesnake Hills segment, and Snively Basin. The lower slopes of the northeast flank of Rattlesnake Mountain and the Hodges Ranch extension are designated Iowa Flats (see Figure 1-2).

The middle slopes of the Rattlesnake Mountain area are moderately steep (5 to 15°) and scarred with rills and gullies that mainly head in the ridge terrain and continue downslope through the lower slopes and into the basin and valley terrain (see Plate 2). The drainage system in the middle slopes primarily forms a parallel pattern as in the ridge terrain. The interfluves between rills and gullies on the north flank of Rattlesnake Mountain are generally formed of basaltic debris that accumulate as talus and collescing alluvial fans from debris transported downslope from the ridge terrain. Elsewhere, the interfluves are formed of basaltic bedrock. A thin veneer of loess typically caps the talus and alluvial debris in the interfluves.

Two landforms of hummocky topography occur on the north flank of Rattlesnake Mountain (see Plate 2). The southern most hummocky feature represents the bulbous toe of a landslide from debris that originated in the ridge terrain (see Plate 1). The other hummocky feature was originally interpreted to be a landslide (Bond et al. 1978). This feature has been reinterpreted to be a small, low amplitude, northwest trending anticline that has been partially eroded to form the hummocky surface (see Plate 1).

Snively Basin lies in the middle slope area north of the east-west trending Rattlesnake Hills segment and forms a complex topographic, as well as complex structural landform (see Plates 1 and 2). Snively Basin has a highly irregular surface with moderately steep to very steep slopes (5 to 15° to >30°) near the margins of the "basin" and very gentle (<5°) slopes in the interior except where deeply incised by streams. Hummocky topography in Snively Basin, which was interpreted by Bond et al. (1978) to be landslide debris, has been reinterpreted to be tilted sheets formed on the front of a series of imbricate thrust faults. The new interpretation is based on the lateral continuity of basalt flows through the hummocky areas of Snively Basin. However, small landslides are locally present (see Plate 1).

The lower slopes of the lower slope terrain are characterized by gentle slopes <5°, except where scarred by rills and gullies in which

slopes are often moderately steep (5 to 15°) and locally very steep (>30°) (see Plate 2). The drainage network forms parallel and dentritic patterns in the lower slopes. The interfluves consist primarily of basalt bedrock, but on the north flank of Rattlesnake Mountain, the interfluves consist of sediment aggraded primarily from the ridge terrain intermixed with loess. Catastrophic flood deposits blanket large portions of the lower slopes below an elevation of 366 m (1,200 ft). The most common facies of the flood deposits in this area is the Touchet Beds, which are commonly capped with ice rafted erratics and bergmounds throughout Iowa Flats (Bretz 1930; Fecht and Tallman 1978). Less common are the Pasco gravels which are found only on the lower slopes of the Hodges Ranch extension near the Yakima River. Most degradation of the lower slopes is restricted to erosion within the ephemeral drainage network and the channel of the Yakima River. The prominent escarpments that occur parallel to and above the present-day Yakima River were formed as a result of Pleistocene erosion by multiple catastrophic floods and recent erosion by the Yakima River. Another series of parallel, small, subtle escarpments occur at about 275 m (900 ft) elevation east of Snively Basin on Iowa Flats. These features were examined through trenching by the Washington Public Power Supply System. The Touchet Beds that formed the walls of the trench did not appear to be deformed. Although the origin of the features is not known, they are not considered tectonic in origin.

4.2.3 Basin and Valley Terrain

The basin and valley terrain of the Rattlesnake Mountain area consists of the low lying, sediment-filled valleys and includes (1) the Cold Creek Valley located north and east of Rattlesnake Mountain and (2) the Dry Creek Valley situated north of Snively Basin (see Figure 1-2). In this terrain, the Columbia and Yakima Rivers, Pleistocene catastrophic floods, and short-lived ephemeral streams have aggraded sediments that increase in thickness eastward toward the central Pasco Basin. Also, eolian processes have aggraded extensive sand dunes that are primarily longitudinal in form. The orientation of these dunes is primarily northeast along the direction of strongest wind path but locally vary in trend and form due to orographic effects. Denudation by eolian, fluvial, and mass wasting processes in this terrain are relatively minor.

5.0 SEISMOLOGY

5.1 GENERAL REGIONAL SEISMICITY

The seismicity of the Columbia Plateau region has been monitored in detail since 1969, when the U.S. Geological Survey (USGS) installed a seismic network at the Hanford Site (Myers/Price et al. 1979; Rohay and Davis 1983). Earthquakes detected and located using the seismic network tend to occur as earthquake swarms at shallow depths [<4 km (2.5 mi)]. Seismic activity during a swarm is clustered spatially within a volume of rock with typical dimensions of about 5 km (3 mi). The frequency of earthquake occurrence tends to increase and decay gradually during a swarm without a distinctly large, main earthquake. The temporal duration of swarms varies from several days to several months. Earthquake swarms generally consist of roughly 10 to 100 earthquakes in the magnitude range of 1.0 to 3.5. Overall, the frequency of earthquakes has been low to moderate in the central Columbia Plateau since detailed monitoring was initiated in 1969.

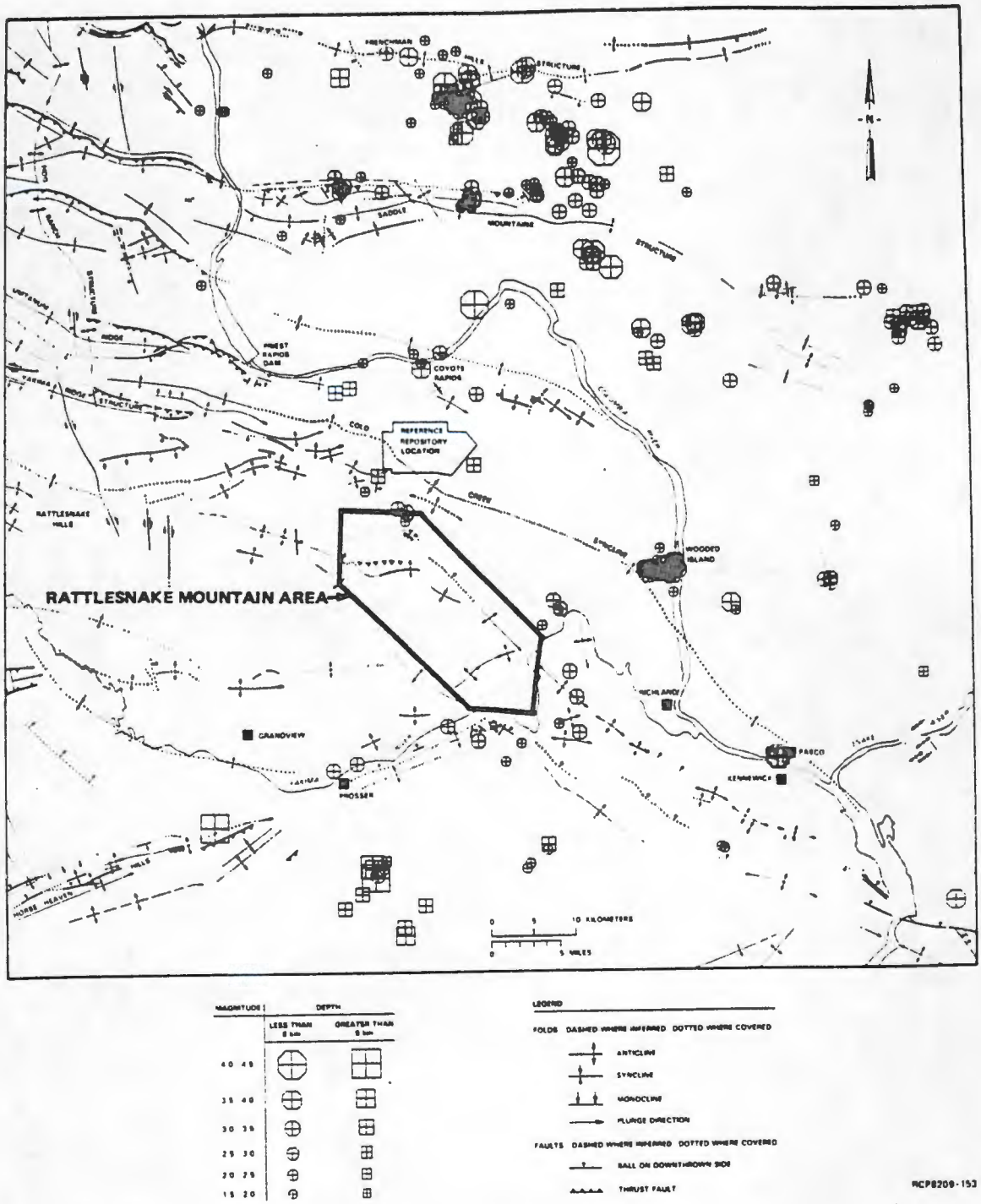
5.2 SEISMICITY OF THE RATTLESNAKE MOUNTAIN AREA

The seismicity of the Rattlesnake Mountain area is significantly lower than near several other major structures of the Columbia Plateau. The Frenchman Hills and Saddle Mountains are associated with concentrations of shallow seismicity (see Figure 5-1). Deep earthquakes are associated with the Horse Heaven Hills. The seismicity pattern does not, in general, indicate that the earthquakes are concentrated on known faults or anticlines.

The seismicity of the Rattlesnake Mountain area is shown in Figures 5-2 and 5-3. The seismic activity at depths less than 4 km (2.5 mi) is shown in Figure 5-2 while the seismicity at depths greater than 4 km (2.5 mi) is shown in Figure 5-3. The frequency of earthquakes deeper than 4 km (2.5 mi) is approximately the same as in surrounding regions, but the frequency of shallow seismicity is much less than the average observed rate of seismicity for the region.

An earthquake swarm in the northern area of Rattlesnake Mountain was active in 1979. Nine of the eleven events in this swarm occurred on September 9, 1979, all located at depths 4 km (2.5 mi). An earlier swarm in the same location was observed during 1971, which included deeper events. The largest event of the 1979 earthquake swarm had a magnitude of 2.4.

More diffuse clusters of shallow seismicity are observed in the southeastern part of the Rattlesnake Mountain area near the horn of the Yakima River. Although this is partially due to several small earthquake swarms in 1971 and 1972, most of this activity does not have



MAGNITUDE	DEPTH: LESS THAN 6 km	DEPTH: GREATER THAN 6 km
40 45		
35 40		
30 35		
25 30		
20 25		
15 20		

LEGEND

FOLDS DASHED WHERE INFERRED DOTTED WHERE COVERED

ANTICLINE

SYNCLINE

MONOCLINE

PLUNGE DIRECTION

FAULTS DASHED WHERE INFERRED DOTTED WHERE COVERED

BALL ON DOWNTHROWN SIDE

THRUST FAULT

RCP8209-153

FIGURE 5-1 Instrumental Seismicity of the Central Columbia Plateau.

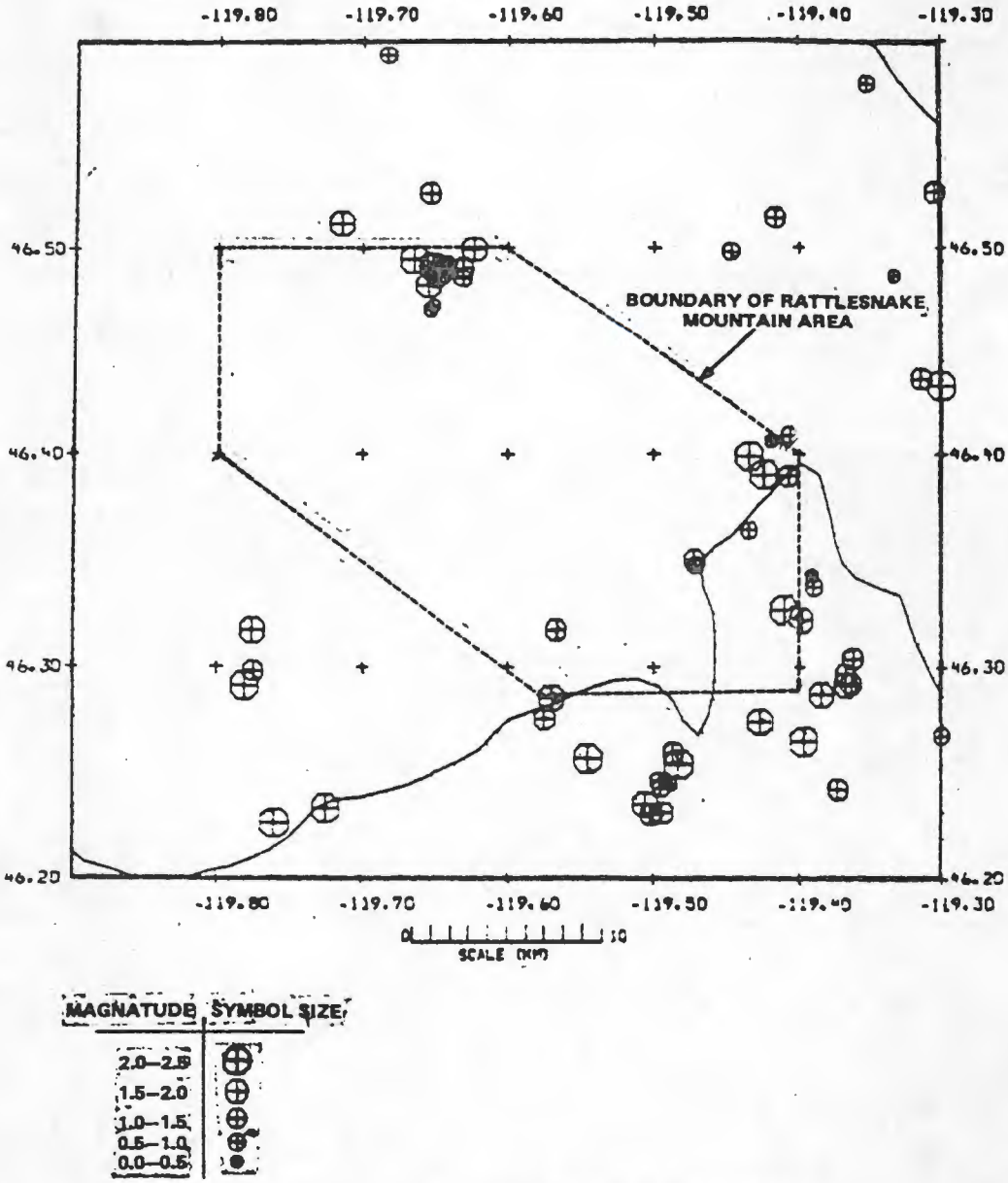


FIGURE 5-2 Seismicity Between 0 and 4 Kilometer (0 and 2.5 Mile) Depth in the Rattlesnake Mountain Area, 1969 to 1983.

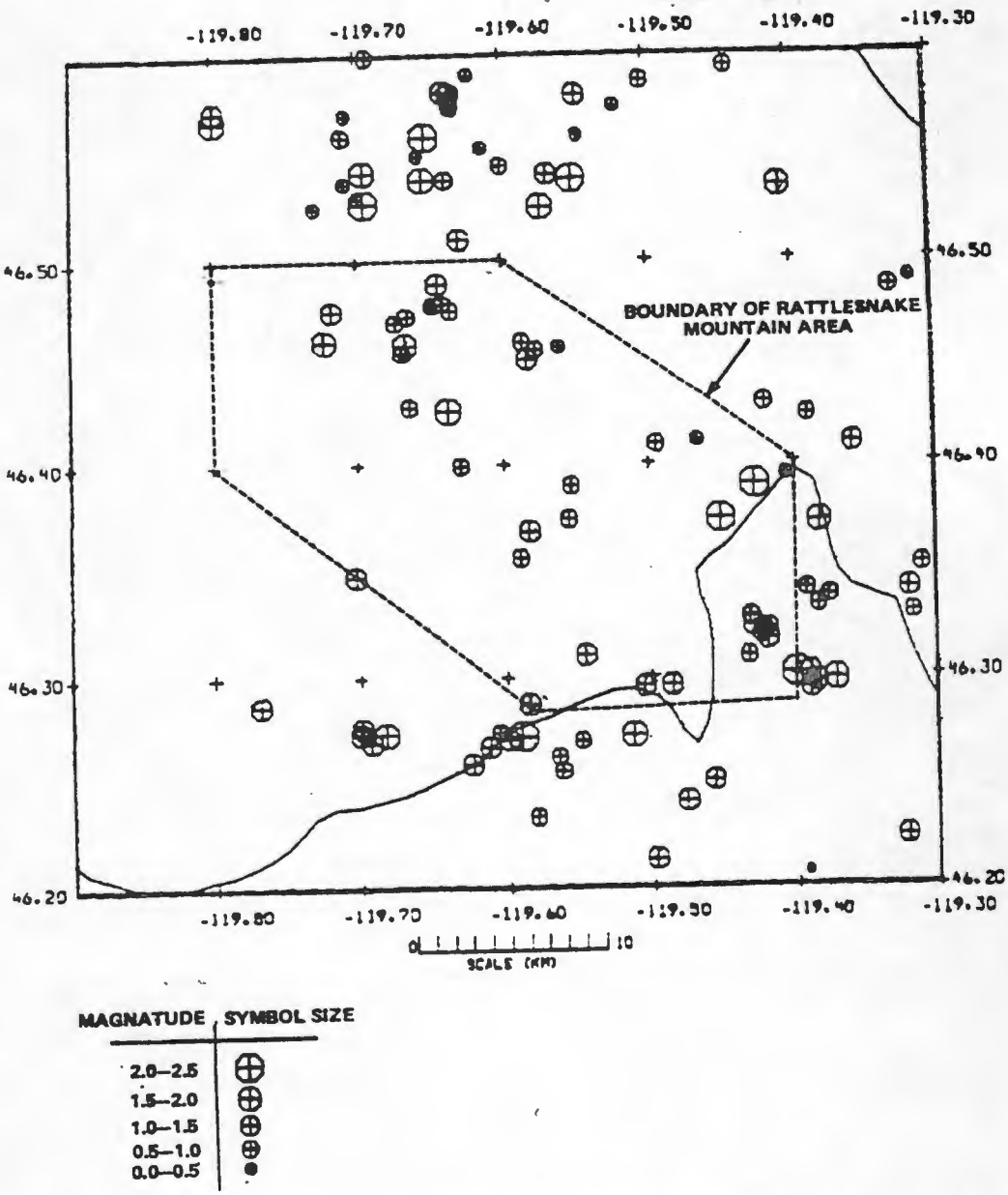


FIGURE 5-3 Seismicity Deeper than 4 Kilometers (2.5 Miles) in the Rattlesnake Mountain Area, 1969 to 1983.

the characteristic temporal clustering of earthquake swarms.

No similar concentrations of seismicity are observed in the seismicity at depths >4 km (2.5 mi) (see Figure 5-3) and there does appear to be a relatively quiet region west of 119° 50'.

Profiles showing earthquake locations within 10 km (6.2 mi) of the northwest-southeast projection of the Rattlesnake Mountain fault trace are shown in Figure 5-4. The cross-section looking northwest along the fault trace is shown in Figure 5-4a. An apparent vertical alignment is created by this projection, but does not necessarily indicated faulting along this trend. The vertical alignment is due to the superposition of several widely separated swarm areas Due to a greater inaccuracy in determining the depth of earthquakes (relative to the epicentral accuracy), earthquake swarms may tend to appear elongated in a vertical sense. There also appears to be a relatively aseismic zone in the 10 to 15 km (6.3 to 9.3 mi) depth range.

A perpendicular cross-section of the same earthquakes as viewed from the northeast is shown in Figure 5-4b. The separate swarm concentrations forming the apparent vertical alignment in Figure 5-4a are now seen clearly separated by the relatively aseismic region beneath Rattlesnake Mountain. The apparent vertical alignment does not really correlate with the Rattlesnake Mountain fault. The aseismic zone between 10 to 15 km (6.3 to 9.3 mi) depths can also be seen in Figure 5-4b, but no conclusions should be drawn from this observation at present.

Focal mechanisms of earthquakes in the Columbia Plateau indicate north-south oriented maximum compressive stress. Focal mechanisms of both deep and shallow earthquakes in the central Columbia Plateau also show that the minimum compressive stress is oriented near vertical. The state of in situ stress is consistent with the formation of the east-west anticlinal ridges comprising the Yakima Fold Belt. Earthquakes on the western margin of the plateau indicate an east-west oriented minimum compressive stress consistent with right-lateral strike slip movement on planes parallel to the Rattlesnake Mountain fault.

A composite focal mechanism was determined for the 1979 Cold Creek earthquake swarm north of Rattlesnake Mountain that indicates thrust or reverse faulting on east-west planes (north-south compression and vertical tension).

A composite focal mechanism of deep earthquakes beneath Rattlesnake Mountain indicates north-south compression and a tension axis that is 40° from vertical (Rohay and Davis 1983). This should not be considered an anomaly because of possible errors of 20° or more.

The possible fault planes for these two focal mechanisms do not parallel the Rattlesnake Mountain fault. However, they do support

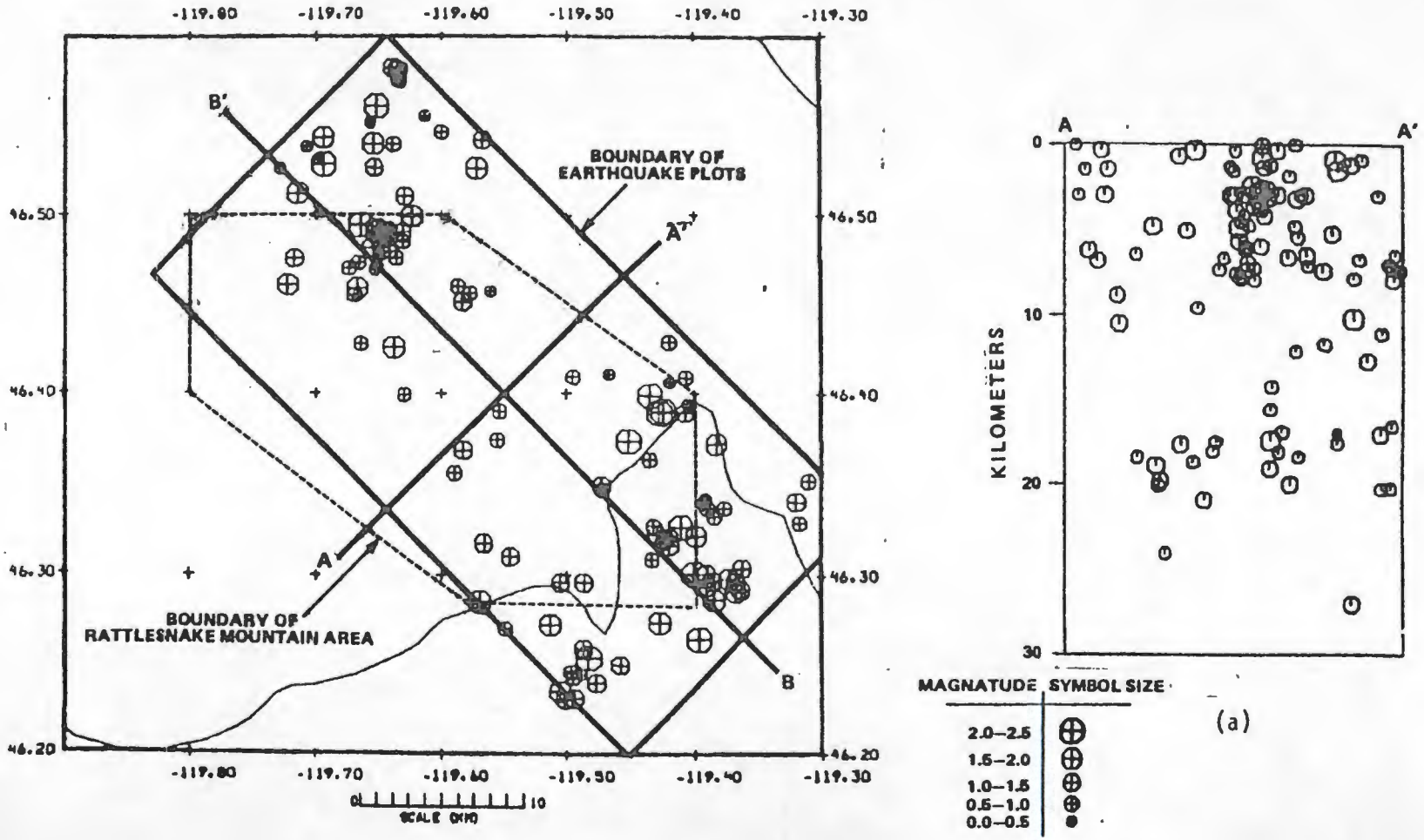
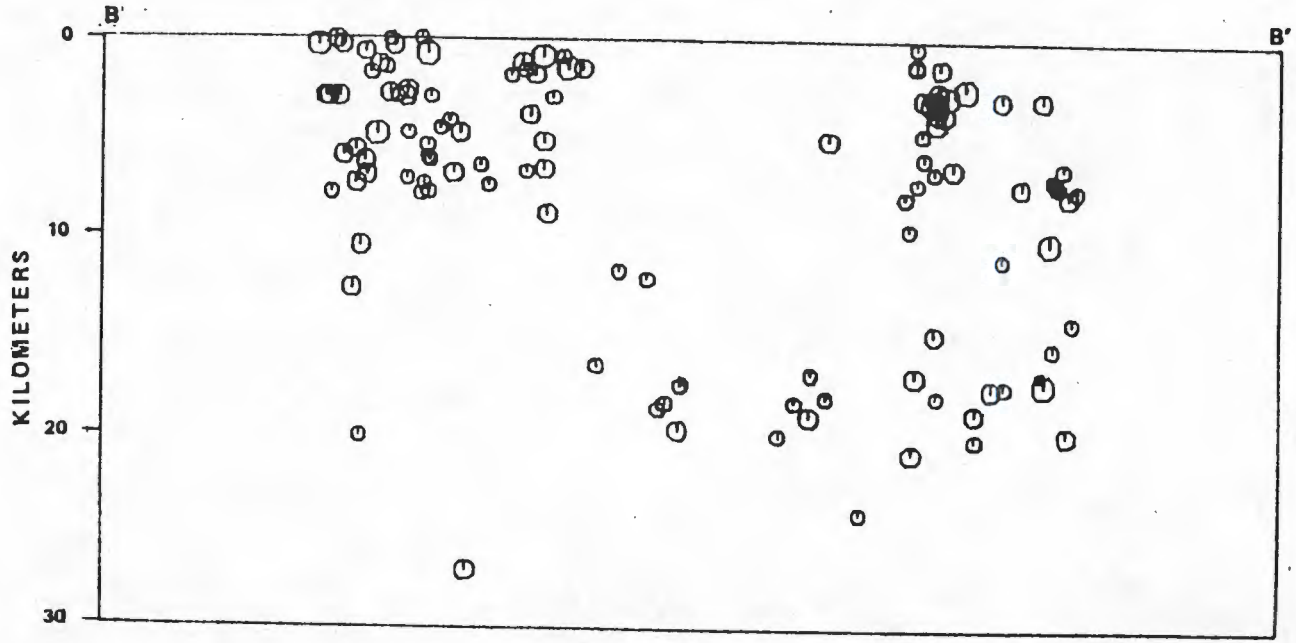


FIGURE 5-4 Cross Sections of Earthquakes in the Rattlesnake Mountain Area. (a) Shows Earthquakes Projected to Cross Section A-A'. (b) Shows Earthquakes Projected to Cross Section B-B'.



(b)

FIGURE 5-4 (Con't)

dominantly thrust or reverse faulting as the source of current seismic activity.

In summary, the Rattlesnake Mountain region is an area of relatively low seismicity in the 0 to 4 km (0 to 2.5 mi) depth range. Although earthquakes to the northwest and southeast of Rattlesnake Mountain produce an apparent vertical alignment in cross section, these do not correlate with the Rattlesnake Mountain fault. Focal mechanism solutions suggest that ongoing deformation continues to be dominated by thrust or reverse faulting consistent with the formation of east-west anticlines and that ongoing strike-slip movement is relatively minor.

6.0 CLIMATOLOGY

6.1 GENERAL CLIMATE OF THE REGION

The Hanford Site region is classified as a midlatitude, semiarid desert with cool, wet winters (DOE 1982; Stone et al. 1983). Summers are sunny, warm, and dry; winters are mild. In the winter, Pacific storm systems move eastward through the region causing frequent changes in cloudiness, wind, pressure, and precipitation events. Occasionally, cold modified arctic air will result in low temperatures [< -18°C (0°F)] in the region.

The climate of the Hanford Site region is greatly influenced by the surrounding mountain ranges that have significant effects on wind, precipitation, and temperature (Figure 6-1). The Hanford Site is situated in the rain shadow of the Cascade Range, which contributes significantly to the low average rainfall [15 to 18 cm (approximately 6 to 7 in.] over much of the region. The Cascade Range and other mountain ranges to the north and east of the Hanford Site effectively protect the area from more severe winter storms and low temperatures associated with modified arctic air masses that move southward through Canada. The location of the Hanford Site, with respect to the surrounding mountain ranges, results in a continental-type climate.

6.2 METEOROLOGICAL DATA FROM RATTLESNAKE MOUNTAIN

The meteorological observations discussed below are based on data collected from the Arid Lands Ecology Reserve Climatology System. This system was a network of 26 stations set up to measure specific climatic elements on and around Rattlesnake Mountain (Hinds and Thorp 1977; Stone et al. 1983). The system was established in 1968 and operated to the end of 1981.

The average monthly precipitation, annual precipitation, and annual average distribution of precipitation on Rattlesnake Mountain are given in Table 6-1, Table 6-2, and Figure 6-2, respectively. Over the 12-yr period, November, December, and January were the wettest months, while June, July, and September were the driest months. The precipitation maximum [approximately 28 cm (approximately 11 in)] occurred north of Rattlesnake Mountain crest near the eastern portion of Snively Basin. Precipitation decreases rapidly to the north to about 15 cm (6 in) into Cold Creek and Dry Creek Valleys. Precipitation decreases from the maxima south to the Rattlesnake Mountain crest [about 20 to 24 cm (8 to 9.5 in)] and gradually decreases from the crest to about 17 to 20 cm (7 to 8 in) in the lower Yakima Valley. The lower than maxima precipitation on the Rattlesnake Mountain crest may be the result of strong southwest winds preventing precipitation from entering the collection gages (Stone et al. 1983). Less variation in the average amount of annual precipitation on the south flank than on the north flank of Rattlesnake Mountain is shown in Figure 6-2.

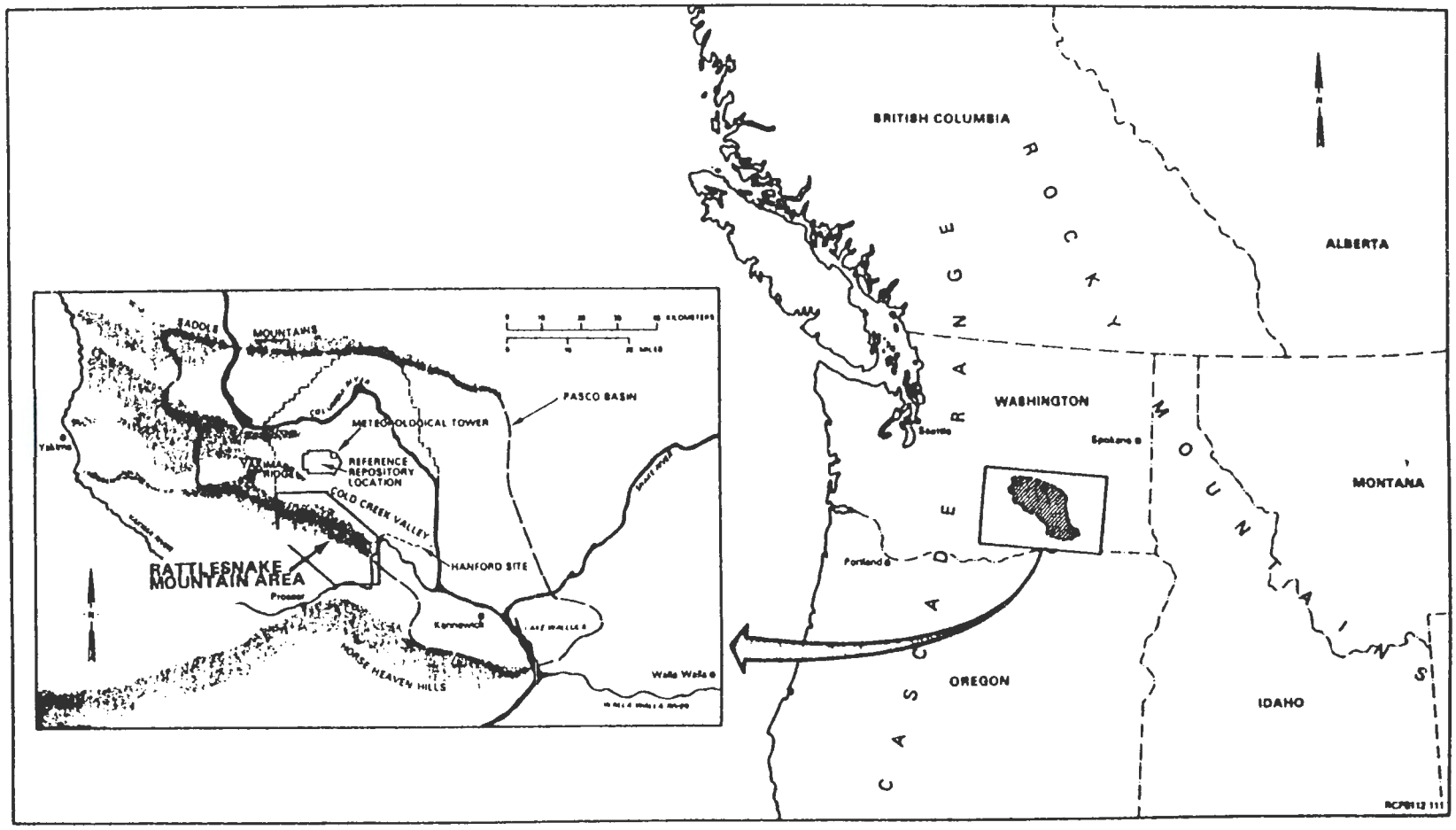


FIGURE 6-1. The Rattlesnake Mountain Area in Relation to Surrounding Terrain.

TABLE 6-1 Average Monthly Precipitation (cm) in the Rattlesnake Mountain Area for Years 1969 Through 1980. Station Locations Shown in Figure 6-2 (Source from Stone et al.,1983)

STATION	ELEV. (M)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1. UPPER COLD CR	(204)	3.09	1.55	1.14	0.90	1.40	0.51	0.31	1.20	0.60	0.87	2.04	2.79	16.40
2. RATTLESNAKE SPG	(210)	3.34	1.64	1.09	0.99	1.30	0.54	0.31	0.94	0.65	0.86	2.12	2.97	16.77
3. LOWER SNIVELY	(323)	4.06	2.37	1.62	1.19	1.58	0.70	0.36	1.12	0.83	1.19	2.67	4.09	21.78
4. UPPER SNIVELY	(533)	4.55	2.98	2.27	1.50	1.96	1.04	0.52	1.22	0.96	1.53	2.93	4.54	25.98
5. BENSON RANCH	(189)	3.34	1.72	1.14	0.93	1.42	0.69	0.37	1.08	0.73	0.85	2.09	3.08	17.44
6. UPPER BENSON	(234)	3.77	1.90	1.37	1.01	1.36	0.67	0.42	1.05	0.67	1.01	2.20	3.52	18.96
7. ALLUVIAL FAN	(347)	4.22	2.54	1.84	1.28	1.71	0.65	0.42	1.19	0.77	1.23	2.55	4.38	22.77
8. LWR LARK SPUR *	(488)	4.25	2.87	2.18	1.29	1.83	0.75	0.52	1.63	0.78	1.29	2.58	4.42	24.38
9. LARK SPUR	(588)	4.47	3.11	2.37	1.58	1.87	0.86	0.51	1.43	0.97	1.34	3.21	4.61	26.32
10. BENSON BASIN	(744)	4.79	3.26	2.49	1.77	2.25	1.16	0.76	1.59	1.17	1.45	3.52	4.66	28.85
11. ANDERSON RIM	(884)	4.49	3.09	2.26	1.69	2.32	1.27	0.77	1.71	1.24	1.57	3.23	4.52	28.17
12. ANDERSON FIELD	(939)	4.33	2.35	1.75	1.41	2.15	1.13	0.70	1.54	1.07	1.39	3.09	3.83	24.75
13. HOPSAGE	(158)	3.26	1.68	1.21	0.94	1.34	0.65	0.34	1.29	0.51	0.93	1.91	2.88	16.92
14. TELEMETER	(366)	4.68	3.04	2.30	1.38	1.56	0.81	0.42	1.13	0.77	1.40	2.96	4.46	24.92
15. R MT CREST NE	(1020)	4.80	2.65	1.95	1.59	2.32	1.47	0.72	1.77	1.06	1.16	2.61	3.77	25.87
16. R MT CREST *	(1079)	3.53	1.91	1.35	0.97	1.82	1.04	0.65	1.64	0.79	1.07	2.48	2.97	20.22
17. R MT CREST SW	(1067)	3.12	1.55	1.26	1.16	1.77	1.12	0.55	1.44	0.78	0.89	2.32	2.59	18.55
18. WINTERFAT	(206)	3.65	1.96	1.56	0.88	1.36	0.68	0.43	1.07	0.66	1.01	2.55	3.49	19.31
19. CALOCHORTUS	(381)	4.47	2.83	2.36	1.49	1.66	0.93	0.50	1.19	0.84	1.36	2.97	4.27	24.88
20. BEETLE PLOT 7	(954)	4.13	2.25	2.05	1.58	2.35	1.31	0.64	1.72	1.04	1.33	3.05	3.89	25.33
21. LOWER COLD CR	(134)	3.52	1.81	1.34	1.05	1.48	0.81	0.52	1.13	0.73	0.91	2.23	3.18	18.70
22. BEETLE PLOT 3	(192)	3.55	1.95	1.44	1.18	1.42	0.98	0.43	1.09	0.69	1.05	2.60	3.39	19.75
23. BEETLE PLOT 4	(286)	3.96	2.07	1.80	1.17	1.47	0.92	0.47	1.15	0.76	1.11	2.62	3.53	21.04
24. ERC WYE	(329)	3.84	2.22	1.81	1.18	1.54	1.04	0.46	1.18	0.81	1.10	2.74	3.74	21.66
25. BEETLE PLOT 5	(448)	4.11	2.12	2.10	1.36	1.95	1.05	0.57	1.33	1.05	1.20	2.67	3.55	23.07
26. BEETLE PLOT 6	(756)	4.04	2.05	1.83	1.35	2.06	1.23	0.59	1.56	0.96	1.18	2.74	3.56	23.14
27. H.M.S.	(223)	2.51	1.47	0.97	1.05	1.60	0.83	0.45	1.17	0.75	0.96	1.94	2.73	16.43

*1970-1980 DATA

TABLE 6-2 Calendar Year Precipitation (cm) in the Rattlesnake Mountain Area for Years 1969 Through 1980. Station Locations Shown in Figure 6-2 (Source from Stone et al.,1983)

STATION	ELEV. (M)	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	AVG
1. UPPER COLD CR	(204)	13.49	16.18	17.17	13.46	18.47	13.87	18.77	7.44	15.06	20.45	16.43	25.76	16.40
2. RATTLESNAKE SPG	(210)	14.17	16.84	15.93	13.69	21.36	14.55	19.91	8.66	15.57	16.66	15.39	28.52	16.77
3. LOWER SNIVELY	(323)	17.30	20.98	21.41	18.39	27.46	19.08	27.79	12.24	20.45	20.95	22.07	33.27	21.78
4. UPPER SNIVELY	(533)	20.93	24.76	26.09	21.26	31.14	25.27	29.26	14.53	26.03	26.16	26.59	39.75	25.98
5. BENSON RANCH	(189)	15.01	18.36	16.51	13.72	20.70	15.39	21.26	8.99	16.38	17.70	16.76	28.50	17.44
6. UPPER BENSON	(234)	15.27	21.18	18.54	14.30	24.49	15.95	24.64	10.67	16.69	18.90	16.92	30.00	18.96
7. ALLUVIAL FAN	(347)	16.79	24.94	22.86	18.77	28.09	22.76	27.56	14.81	22.48	21.56	21.06	31.55	22.77
8. LWR LARK SPUR	(488)		24.99	25.37	19.58	27.25	23.93	28.96	16.84	22.07	23.14	23.62	35.64	24.66
9. LARK SPUR	(588)	20.09	27.71	24.94	21.64	30.02	25.96	31.27	17.98	25.45	28.60	27.30	34.87	26.32
10. BENSON BASIN	(744)	22.81	30.48	26.92	24.31	30.51	27.10	33.45	18.80	30.43	32.56	29.41	39.45	28.85
11. ANDERSON RIM	(884)	24.08	28.65	25.04	24.28	32.66	26.82	32.05	18.31	25.15	28.42	32.41	40.13	28.17
12. ANDERSON FIELD	(939)	19.56	23.57	21.64	19.02	27.33	21.44	28.27	14.91	22.99	31.27	29.72	37.29	24.75
13. HOPSAGE	(158)	16.23	20.52	15.16	13.36	20.95	15.14	21.13	10.39	14.99	17.04	13.26	24.92	16.92
14. TELEMETER	(366)	18.72	27.86	24.92	18.52	29.39	24.36	34.01	15.04	21.72	26.24	24.23	34.09	24.92
15. R MT CREST NE	(1020)	20.19	23.29	22.78	26.67	30.07	21.82	30.73	17.86	23.06	29.74	25.83	38.38	25.87
16. R MT CREST	(1079)		16.69	15.27	19.02	21.39	15.47	18.59	10.41	21.36	28.96	21.62	35.86	20.42
17. R MT CREST SW	(1067)	20.32	16.54	14.73	16.64	18.95	13.67	15.27	9.42	20.47	26.29	20.90	29.46	18.55
18. WINTERFAT	(206)	15 06	22.86	19.68	14.83	23.60	17.17	24.28	9.98	17.65	21.82	16.74	27.99	19.31
19. CALOCHORTUS	(381)	20.88	29.16	25.04	19.18	28.65	22.63	32.23	15.09	22.56	25.60	23.24	34.14	24.88
20. BEETLE PLOT 7	(954)	21.29	24.49	24.82	24.33	27.15	28.32	26.34	14.71	25.68	31.88	23.34	39.62	25.33
21. LOWER COLD CR	(134)	16.81	21.77	18.26	16.69	21.41	14.63	22.63	8.59	19.25	20.78	16.92	28.78	18.70
22. BEETLE PLOT 3	(192)	17.98	21.41	20.73	17.91	25.68	15.19	23.00	8.71	19.74	19.53	18.08	28.30	19.75
23. BEETLE PLOT 4	(286)	18.03	24.21	21.29	19.53	25.15	16.43	24.23	9.48	20.62	21.92	20.00	30.86	21.04
24. ERC WYE	(329)	19.79	21.18	22.22	18.19	26.62	17.55	25.76	10.34	22.30	21.95	21.77	32.28	21.66
25. BEETLE PLOT 5	(448)	21.64	24.26	25.04	20.98	25.76	19.35	24.56	12.88	20.68	25.15	21.56	35.00	23.07
26. BEETLE PLOT 6	(756)	21.11	22.30	21.06	22.43	24.66	19.00	24.33	14.27	22.81	28.63	21.29	35.84	23.14
27. H.M.S.	(223)	16.15	16.08	16.00	16.23	21.01	13.46	18.92	7.62	16.28	16.69	14.12	24.59	16.43

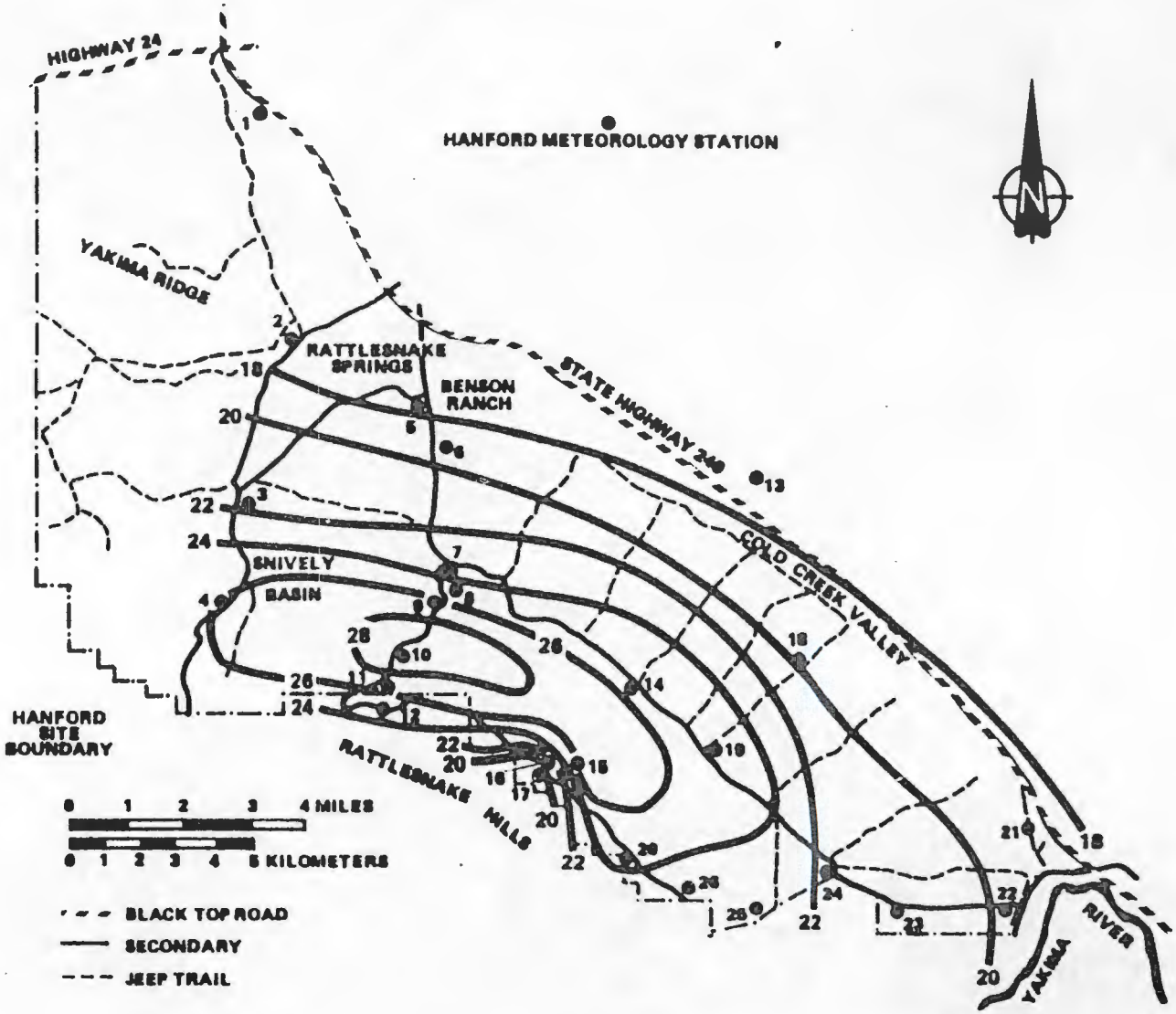


FIGURE 6-2 Annual Average Distribution of Precipitation (cm) in the Rattlesnake Mountain Area. Meteorological Stations Shown by Dots. (Modified from Stone et al., 1983)

The maximum and minimum monthly temperatures from the Arid Lands Ecology Climatology System for the period from October 1968 through December 1969 are given in Tables 6-3 and 6-4 (Hinds and Thorp 1977). The data were selected because they represent a relatively complete set for a calendar year. The temperature on Rattlesnake Mountain is elevation-dependent with the average lowest temperature in a month occurring near the Rattlesnake Mountain crest and the average highest temperature occurring on the lower flanks of Rattlesnake Mountain and in Cold Creek and Dry Creek Valleys. Overall, the coldest temperatures occurred during the months of January, February, and March and the warmest temperatures recorded in the months of June, July, and August. The warmest and coldest months on Rattlesnake Mountain for the observed period generally correspond to the average warmest and coldest months recorded at the Hanford Meteorological Station (HMS) over the last 40 yr. The HMS is located about 13 km (8 mi) north of Rattlesnake Mountain (Figure 6-1).

Gravity winds are common in the summers on Rattlesnake Mountain and the surrounding area but are seldom strong unless associated with a frontal system. June has the highest average wind speed [14 km (9 mi)/hr at the HMS] and November and December the lowest [approximately 10 km (6 mi)/h at the HMS], but June has fewer winds of a 50-km (30 mi)/h average than December (Stone et al. 1983). The prevailing wind direction in the Hanford Site region is west-northwest or northwest year round and is partially attributed to wind channeling. The strongest wind speeds are from the south-southwest, southwest, and west-southwest.

Unusual meteorologic phenomena observed in the Rattlesnake Mountain area include a tornado near the east end of Rattlesnake Mountain on June 16, 1948, and a funnel cloud above the north flank of Rattlesnake Mountain on July 15, 1970 (Stone et al. 1983). The 1948 tornado was located in a barren area and resulted in no apparent damage. The funnel cloud observed in 1970 did not reach the ground.

TABLE 6-3 Monthly Maximum Temperatures (^{o}C) for Meteorological Stations in the Rattlesnake Mountain Area from October 1968 through December 1969. Station Locations Shown in Figure 5-1. (Source from Hinds and Thorp, 1971)

STA-TION	STATION NAME	ELEV. M	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	LOWER COLD CREEK	134	31.0	19.0	16.5	6.5	10.0	23.5	27.0	40.0	43.5	43.0	41.5	39.5	31.5	24.5	20.5
12	HOPSAGE	158	33.0	18.5	16.5	7.0	9.5	25.0	30.0	39.5	*****	43.0	41.5	39.0	31.5	25.5	19.0
5	BENSON RANCH	189	33.5	18.0	15.5	6.5	*****	22.0	28.5	42.0	48.0	48.0	46.5	41.5	34.0	28.0	19.5
21	BEETLE PLOT 3	192	32.0	19.0	16.5	6.5	10.5	24.5	28.0	40.0	44.5	44.5	43.5	41.0	32.0	25.5	18.5
1	UPPER COLD CREEK	204	33.0	19.5	16.5	6.5	9.0	21.5	28.0	42.0	48.0	49.0	47.0	43.0	34.0	28.5	20.0
17	WHITEBEAT	206	31.0	18.0	15.5	6.5	*****	24.5	29.0	39.0	43.0	42.0	41.0	39.5	38.0	25.0	18.0
2	RATTLESNAKE SPRINGS	210	33.0	18.0	15.5	8.0	*****	21.0	28.5	39.0	43.0	43.5	41.5	38.0	29.5	24.0	17.0
6	UPPER BENSON	244	32.0	18.0	15.5	6.5	*****	22.0	30.0	39.0	43.0	44.0	41.5	39.0	30.5	25.0	18.5
22	BEETLE PLOT 4	286	31.5	19.0	15.5	5.5	10.0	23.5	28.0	40.0	44.5	43.5	42.0	40.5	31.5	25.5	19.0
3	LOWER SNIVELY	323	31.0	16.5	13.5	5.5	*****	20.0	26.5	38.0	44.0	44.0	43.0	38.0	31.0	24.0	17.0
23	E. R. C. (Y)	329	31.0	16.5	15.5	6.5	9.5	22.0	26.5	36.5	41.0	42.0	39.5	36.5	28.5	22.0	16.5
7	ALLUVIAL FAN	347	31.0	16.5	14.0	5.0	*****	20.0	26.5	37.0	42.0	43.0	41.0	37.0	29.5	23.0	17.0
15	TELLMETER	366	31.0	16.5	12.0	6.5	8.0	21.0	26.0	38.5	41.0	43.5	40.5	38.5	30.5	23.0	16.5
16	CALOCHORTUS	381	31.0	16.5	12.0	8.0	9.0	20.0	26.5	37.0	42.0	42.0	40.0	38.0	30.5	24.0	17.0
24	BEETLE PLOT 5	448	30.0	16.5	13.5	9.0	8.0	20.0	26.0	36.0	40.0	41.0	39.0	36.5	28.0	21.5	16.5
7A	LOWER LARK SPUR	488	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	13.0
4	UPPER SNIVELY	533	31.0	15.0	12.0	8.5	*****	20.5	24.0	35.5	41.5	41.5	40.5	38.0	29.5	24.0	17.0
8	LARK SPUR	588	30.5	14.5	11.0	9.0	*****	19.0	24.5	35.0	41.0	41.0	39.0	36.5	29.0	21.5	16.0
9	BENSON BASIN	734	29.0	13.5	10.5	8.0	*****	19.5	23.5	33.5	38.5	40.5	36.5	34.5	26.0	23.5	15.5
25	BEETLE PLOT 6	756	26.0	14.5	9.5	6.5	5.5	18.5	23.5	33.5	38.0	38.0	36.5	34.0	25.0	23.5	15.5
10	ANDERSON RIM	884	25.5	17.0	9.0	6.0	*****	18.0	21.0	31.0	36.5	37.0	35.5	34.0	24.5	23.0	16.5
11	ANDERSON FIELD	939	28.5	19.0	9.0	6.5	*****	18.5	21.0	31.5	38.0	39.0	38.0	36.0	26.5	24.0	18.5
13	BEETLE PLOT 7	954	28.0	20.0	10.0	8.0	5.5	18.0	22.0	32.0	37.0	36.5	37.0	34.0	25.5	24.0	19.5
14	RATTLESNAKE CREST NE	1020	24.5	18.0	8.0	6.5	*****	13.5	19.0	28.0	34.0	35.0	32.0	30.5	23.0	22.0	16.0
19	RATTLESNAKE CREST SW	1067	26.5	10.5	8.5	6.5	3.5	16.5	21.0	30.5	36.0	35.5	35.0	32.0	23.5	22.0	18.5
18	RATTLESNAKE CREST	1079	25.5	16.5	8.0	6.5	5.0	16.5	20.0	30.0	35.5	34.5	33.5	31.0	23.0	21.0	16.5

TABLE 6-4 Monthly Minimum Temperatures (^{o}C) for Meteorological Stations in the Rattlesnake Mountain Area from October 1968 through December 1969. Station Locations Shown in Figure 5-1. (Source from Hinds and Thorp, 1971)

STA-TION	STATION NAME	ELEV. M	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
20	LOWER COLD CREEK	134	-4.0	-7.0	-8.0	-26.0	-21.0	-8.0	-6.0	-2.0	4.5	5.5	3.5	.0	2.0	-11.0	-12.0
12	HOPSAGE	158	-4.0	-7.0	-9.0	-26.0	-24.0	-8.0	-5.0	.0	5.0	8.0	4.0	.0	3.0	-9.0	-11.0
5	BENSON RANCH	189	-3.0	-5.0	-7.0	-26.0	*****	-15.0	-7.0	-1.0	4.0	4.5	1.0	-2.0	1.0	-13.0	-13.0
21	BEETLE PLOT 3	192	-1.0	-4.0	-5.0	-23.0	-17.0	-7.0	-1.0	1.0	8.5	8.5	9.0	4.0	6.0	-7.0	-7.0
1	UPPER COLD CREEK	204	-3.0	-5.0	-7.0	-26.0	-21.0	-8.0	-4.0	.5	5.0	6.5	4.0	-1.0	3.0	-12.0	-11.0
17	WINTERFAT	206	1.0	-3.0	-6.0	-23.0	*****	-15.0	-1.0	3.0	6.0	10.0	8.0	7.0	5.0	-4.0	-7.0
2	RATTLESNAKE SPRINGS	210	.0	-3.0	-5.0	-26.0	*****	-18.0	-2.0	2.0	6.5	8.0	5.5	4.0	4.5	-5.0	-7.0
6	UPPER BENSON	244	.5	-2.0	-4.0	-24.0	*****	-12.0	.0	4.5	7.0	11.0	8.5	6.0	6.5	-4.0	-6.0
22	BEETLE PLOT 4	286	.0	-4.0	-6.0	-24.0	-17.0	-6.0	-1.0	.5	6.5	7.0	6.5	3.0	6.0	-7.0	-7.0
3	LOWER SNIVELY	323	2.0	-1.0	-7.0	-26.0	*****	-14.0	-1.0	3.0	8.0	10.5	8.5	8.0	8.0	-4.0	-6.0
23	E. R. C. (Y)	329	.0	-2.0	-6.0	-24.0	-19.0	-7.0	-2.0	1.5	6.5	4.5	7.0	3.5	4.0	-6.0	-7.0
7	ALLUVIAL FAN	347	2.0	.0	-6.0	-24.0	*****	-13.0	.5	4.5	6.5	9.5	7.0	8.0	9.0	-5.0	-7.0
13	TELEMETER	366	1.0	-1.0	-5.0	-24.0	-14.0	-6.0	-1.0	4.5	6.0	10.5	7.0	6.0	6.5	-3.0	-6.0
18	CALOCHORTUS	381	.5	-2.0	-5.0	-24.0	-16.0	-5.0	-1.0	5.0	6.0	10.0	7.0	4.0	8.0	-3.0	-7.0
24	BEETLE PLOT 5	448	1.0	-1.0	-5.0	-25.0	-15.0	-6.0	-1.0	4.0	6.5	9.5	8.5	6.0	7.0	-2.0	-5.0
7A	LOWER LARK SPUR	488	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	-6.0
4	UPPER SNIVELY	533	.0	-2.0	-8.0	-27.0	*****	-17.0	-2.0	1.5	5.5	6.0	5.5	1.5	6.0	-8.0	-9.0
8	LARK SPUR	588	.0	-4.0	-9.0	-28.0	*****	-21.0	-2.0	2.0	5.0	8.0	8.5	4.5	6.5	-4.0	-8.0
9	BENSON BASIN	734	.0	-4.0	-7.0	-28.0	*****	-19.0	-1.0	2.0	6.0	6.5	7.0	4.0	5.5	-6.0	-7.0
25	BEETLE PLOT 6	756	2.0	.0	-6.0	-25.0	-16.0	-4.0	.5	4.0	7.0	8.0	10.0	6.5	6.0	-1.0	-6.0
10	ANDERSON RIM	884	-3.0	-6.0	-9.0	-29.0	*****	-18.0	-4.0	-1.0	3.0	4.0	4.0	-1.0	3.0	-9.0	-11.0
11	ANDERSON FIELD	939	-1.0	-3.0	-9.0	-28.0	*****	-15.0	-2.0	.5	3.0	5.0	4.5	3.5	3.0	-5.0	-9.0
14	BEETLE PLOT 7	954	.0	-2.0	-7.0	-26.0	-16.0	-7.0	-3.0	.5	4.0	3.5	3.5	.5	3.0	-3.0	-9.0
1[illegible]	RATTLESNAKE CREST NE	1020	.0	-3.0	-8.0	-27.0	*****	-17.0	-3.0	.0	3.5	5.0	5.5	4.0	2.0	-4.0	-8.0
1[illegible]	RATTLESNAKE CREST SW	1067	.0	-3.0	-9.0	-29.0	-17.0	-8.0	-3.0	.0	4.5	5.0	4.5	4.0	1.5	-5.0	-9.0
1[illegible]	RATTLESNAKE CREST	1079	.0	-3.0	-9.0	-29.0	-18.0	-8.0	-3.0	.0	4.0	5.0	5.0	4.0	1.5	-5.0	-9.0

7.0 HYDROLOGY

7.1 GENERALIZED GEOHYDROLOGIC SETTING

Groundwater beneath the Hanford Site and vicinity exists within shallow sediments and the underlying basalts. Groundwater within sedimentary formations is under unconfined conditions except where locally semiconfined beneath clay units (ERDA 1975). Groundwater recharge occurs from both precipitation in nearby hills and artificial recharge from water disposal in ponds associated with the Hanford Site waste management activities. Discharge is to the Columbia and Yakima Rivers.

The existing geohydrologic data base is too preliminary to conclusively support a single conceptual groundwater flow model in basalt; however, several hypotheses have been developed (Gephart et al. 1983). The model believed to be most supported involves groundwater laterally moving within heterogeneous, permeable flow tops separating flow interiors of relatively low vertical and horizontal hydraulic conductivity. Groundwater movement between stratigraphic horizons occurs as a result of the stratigraphic positioning of basalt flow fronts and/or groundwater leakage across flow interiors over large areas. In addition, basalt flows are periodically crossed by bedrock structural discontinuities (folds, faults, and shear zones). These structures represent heterogeneities having the potential for either hydraulically connecting shallow and deep flow systems or, if fracture mineral infilling and/or gouge materials are extensively present, acting as groundwater flow barriers.

Groundwater recharge of the basalts appears to be from a combination of local precipitation along basalt outcrops, regional interbasin groundwater movement, and vertical leakage across structural and stratigraphic discontinuities. Groundwater discharge is to the major rivers, though the exact location(s) remains unknown. Along these groundwater flow paths, water is under artesian conditions.

7.2 GENERAL HYDROLOGIC CHARACTERISTICS OF THE RATTLESNAKE MOUNTAIN AREA

7.2.1 Introduction

Meyboom (1966) and Toth (1966) have shown that it is possible to map the recharge and discharge areas of a groundwater system based on field observations. As discussed by Freeze and Cherry (1979), the five indicators for mapping a groundwater system are as follows:

- Topography-this is the simplest indicator, as discharge areas are topographically low and recharge areas are topographically high.

- Hydraulic Heads-this is the most direct indicator for determining groundwater movement. An upward head gradient is

characteristic of discharge areas, and a downward head gradient denotes recharge areas.

- Hydrochemical Trends-as groundwater moves through a flow system, it undergoes geochemical changes. These changes (e.g., increase in total dissolved solids or ionic exchanges) can be used to infer groundwater flow directions.

- Environmental Isotopes-groundwater ages and undergoes isotopic changes as it moves from recharge to discharge areas. Stable isotopes can be used to determine sources of recharge and reconstruct water history, whereas radioactive isotopes can be used to determine groundwater residence times.

- Land Surface Features-in semiarid climates, the detection of springs, seeps, and points of lush vegetation identify groundwater discharge areas for either an areally extensive flow system or local perched water bodies.

Information available regarding the above topics relative to Rattlesnake Mountain area is briefly discussed in the following sections.

7.2.2 Rattlesnake Mountain Area Springs

A study of spring occurrence, distribution, and characteristics in the Rattlesnake Hills was reported by Schwab et al. (1979) and Gephart et al. (1979). Field work was performed by W. K. Summers and Associates of Socorro, New Mexico, from November 1978 to April 1979. The area studied encompassed 470 square km^2 (approximately 182 mi^2[a]) centered in Rattlesnake Mountain bordering the Hanford Site, lying between Ranges 23E and 27E and Townships 10N to 12N. The Schwab et al. (1979) study concentrated on the numerous, high elevation springs issuing from specific stratigraphic points in the basalt outcrops of the Rattlesnake Mountain area. At lower elevations, outside the study area of Schwab et al. (1979), some larger springs [e.g., as reported in ERDA 1975, Rattlesnake Springs near Snively Basin flows at about 0.7 m^3/min (190 gal/min] also occur that discharge from sediments overlying the basalts.

Springs or suspected spring locations identified were grouped into several qualified categories including:

- Spring or seep-natural discharge of water at land surface in sufficient quantity that a water sample could be collected

- Developed spring-a spring modified so that water is, or has been, diverted from its natural course

- Damp location-sites where natural discharge apparently occurs, but the rate is so slow that a water sample was not collected

- Iced-over location-sites presumed to be springs or seeps (developed or undeveloped) that could not be sampled because they were frozen at the time of investigation

- Dry location-sites where published reports mentioned a spring but which, when inspected, proved to be erroneous (probably due to improper statement of spring location)

- Dry spring-sites where evidence indicated that a spring flow probably occurred in the past or where, with a water-table rise, a spring might flow. Evidence included vegetation

- Cistern-holding tanks that received or appear to have received discharge from one or more springs.

A total of 125 springs or suspected spring locations were identified in Schwab et al. (1979). These springs are listed in Table 7-1 and located on a map of the Rattlesnake Mountain area shown in Plate 3.

7.2.2.1 Spring Occurrence and Frequency. Springs occur in the Rattlesnake Mountain area where natural recharge waters (e.g., from direct precipitation or snow melt) seeps into the rock and moves down a hydraulic gradient, preferentially along zones of higher hydraulic conductivity until it encounters a zone of decreased conductivity. Such zones of lower conductivity are commonly the dense interiors of basalt flows. Clay layers in sedimentary interbeds could serve the same purpose. Some of the water then moves in the direction of bedrock dip or along a bedrock structure of higher conductivity until it reaches land surface. Geologic features providing the more permeable conduits for water to enter Rattlesnake Hills include:

- Flow top and interbed exposures

- Fracture discontinuities within flow interiors that are not sealed with secondary minerals

- Major and minor tectonic features (such as faults, shear zones, and fold hinges where higher than normal fracturing is present).

In the basalt outcrops of the Rattlesnake Mountain area, most springs appear to issue near basalt flow tops, interbeds, and along structural discontinuities. Water discharge then travels a limited distance before evaporating or infiltrating. During the majority of the year, most spring water discharges appear to reinfiltrate except during summer months when rainfall is minimal and evapotranspiration is greatest.

The relationship between spring frequency and elevation for the Rattlesnake Mountain area is shown in Figure 7-1. The springs inventoried existed over an elevation of 320 to 1,005 m (1,050 to 3,300 ft), with about 20% occurring between 320 to 610 m (1,050 to 2,000 ft), 65% between 610 to 915 m (2,000 to 3,000 ft), and 15% above 915 m (3,000

TABLE 7-1 Spring Locations in the Rattlesnake Hills

Designation (Name if Known)	Location	Altitude (ft)
Army	11N26E30Q1	3170
Unnamed #2	11N26E30Q2	3110
Unnamed #3	11N26E29N	2120
Doke	11N25E13F	1285
Unnamed #4	11N25E12N	1150
--	11N25E11N2	1390
Benson	11N25E11N1	1480
Unnamed #5	11N25E14D	1740
Lower Snively	11N25E 8D	1265
Snively	11N25E 8L1	1475
Upper Snively	11N25E20M	2270
--	11N25E19L	2520
Unnamed #6	11N24E24H	2550
--	11N24E24J	2740
--	11N25E23C	2550
--	11N25E22K	2800
Unnamed #7	11N25E23F	2590
Unnamed #8	11N26E33N	1950
--	10N26E 4D	1980
--	11N26E33M	1920
--	11N24E11H	1580
Unnamed #9	11N24E14A	2090
--	11N24E14H	2350
--	11N24E11J	1780
--	11N25E20J	2560
--	11N25E20K	2560
--	11N25E21M	2500
Lonesome (Upper)	10N26E 8N	1810
Lonesome (Middle)	10N26E17D1	1755
Lonesome (Cistern)	10N26E17D2	1740
Unnamed #10	10N26E18A	1820
Unnamed #11	10N26E18B	1800
--	10N26E 7K	1820
Unnamed #11A	10N26E 7Q	1750
Virgil O. McWhorter	10N26E 7R	1880

Designation Name if Known	Location	Altitude (ft)
Twin Troughs	10N26E 9D	2310
--	10N26E 9E	2150
Unnamed #12	11N26E31M	2810
Sam White	10N26E 6H	2790
Unnamed #13	11N26E31N	2860
--	10N27E18M	700
Unnamed #14	11N24E36L	2440
--	11N24E36L2	2500
Unnamed #15	11N24E35J	2430
(Lower)	11N24E35R	2310
Unnamed #16	11N24E36E	2520
Unnamed #16A	11N24E36D	2565
Matney*	10N24E2Q	2065
Section 5*	11N24E 5M	1965
Unnamed #17*	11N24E 5P	2340
--*	11N24E 5N	2400
Joe Spring*	12N24E32N	1645
Unnamed #18*	11N24E 6K1	2280
(Ice)	11N24E 6K2	2380
(Middle)	11N24E 6J1	2150
(Lower)	11N24E 6J2	2070
Railroad*	11N24E 6D	1880
Unnamed #19*	11N24E 6E	2150
--*	11N24E 6E2	2280
--*	11N24E 6E3	2200
Unnamed #20*	11N24E 6F1	2160
Unnamed #21*	11N24E 6F3	2225
Lower	11N24E 6F2	2175
Section 9	11N24E 9H	2360
Unnamed #22*	11N24E18K	2650
--	11N24E18Q	2620
Lower Maiden*	11N24E18P	2485
Maiden*	11N24E18J1	2845
Unnamed #23*	11N24E18J2	2840
--*	11N24E18G	2840
West Maiden*	11N24E18F	2875
Unnamed #24	11N24E17A	3220

Designation Name if Known	Location	Altitude (ft)
Sulphur*	11N23E25E2	1850
Olson	11N24E34F	2365
Unnamed #25	10N25E11D1	2270
Unnamed #25A	10N25E 2N	2295
Unnamed #26	10N25E12R1	1940
Unnamed #27	10N25E 2B	2410
Unnamed #26A	10N25E12R2	1900
Unnamed #28	11N25E34N	2510
Unnamed #29	10N25E 3D	2490
Unnamed #30	10N25E 3E	2400
Unnamed #31	11N25E26L	2780
Unnamed #32	11N24E22R	2615
--	11N23E24Q	2040
Unnamed #33	11N25E11R	1205
Canyon*	11N23E13A	2965
--*	11N23E14C	2440
Colby*	11N23E10R	2200
Two Spring* or Butler or Dispute	11N23E14G	2440
Unnamed #34*		
Lower Sheep Camp*	12N23E35Q	2125
Upper Sheep Camp*	11N23E 2A	2350
Upper Railroad*	11N23E 1H	2265
--*	11N23E 1A	2170
Bennett	11N24E14F	2590
Unnamed #35*	11N23E13D	2940
Unnamed #36	11N25E36P	2580
--	11N25E36H	3000
Snively Basement	11N25E 8L2	1475

Designation Name if Known	Location	Altitude (ft)
--	10N26E27E	1080
--	11N24E16M	2920
--	11N24E16E	3110
Unnamed #37	11N24E16D	3140
--	11N24E17A2	3170
--	11N24E17H	3120
Unnamed #38	11N24E17R	2730
--	11N24E 8K	3360
Unnamed #39*	11N24E 8F	3275
--	11N25E 9G	1660
Unnamed #40	11N25E31L	2555
Unnamed #41	11N25E36R	2715
Unnamed #42	11N26E31H	3250
--	11N24E 5R	1990
--	11N24E 9Q	3020
--	11N24E 9P	3290
--	11N24E 9R1	3070
--	11N24E 9R2	3210
Unnamed #43	10N25E11K	2060
Katie Fleck	10N26E15K	1620
Unnamed #44	10N26E22B	1480
Unnamed #45	11N25E36B	2840
--	11N26E31F	3120
--	11N26E31K	3150
Unnamed #46	11N26E31P	2920
--	10N26E 7F	2000

Notes:
1. Modified from Schwab et al., 1979
2. (--) denotes spring or suspected unnamed spring location
3. (*) denotes springs located in Rattlesnake Hills immediately west of the Rattlesnake Mountain Area
4. Location explanation

11N26E30Q1
- Township
- Range
- Section
- ¼,¼ Section
- Serially Numbered in ¼,¼ Section

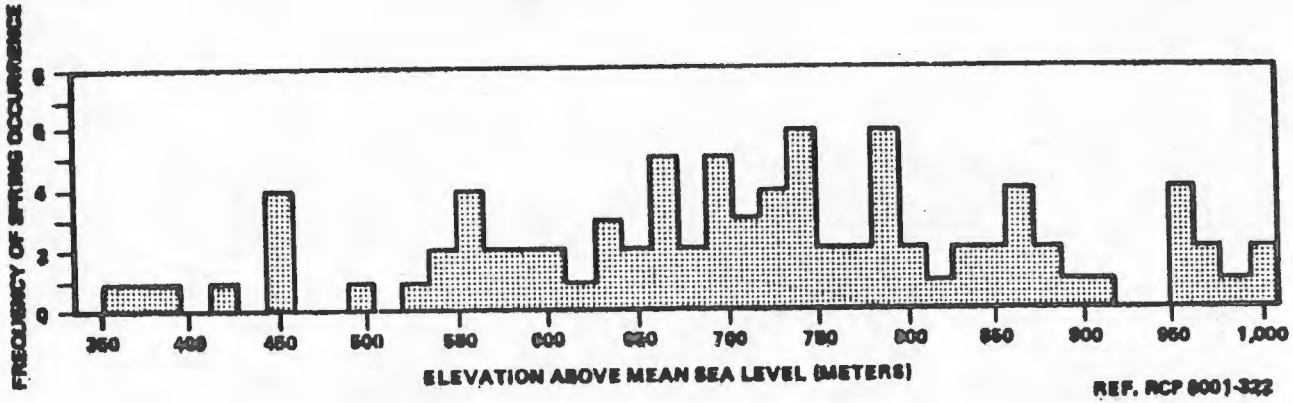


FIGURE 7-1. Frequency of Spring Occurrence as a Function of Elevation in the Rattlesnake Hills. (After Gephart et al. 1979)

ft). At higher elevations (upper flanks of the ridges), the presence of springs suggests perched water within the basalts of the unsaturated zone.

The sampled springs individually discharge from <4 L (1 gal)/min to 95 L (25 gal)/min. Total spring discharges increase with decreasing elevation, as shown in Figure 7-2, reaching a peak discharge of about 380 L (100 gal)/min between the elevations of 490 and 610 m (1,600 and 2,000 ft) for the area of study. An alluvial cover hides most water discharge occurring below about 330 m (1,100 ft).

7.2.2.2 Hydrochemistry. Hydrochemical data for 22 springs within the Rattlesnake Hills were reported by Gephart et al. (1979). The springs were sampled between November 1978 and March 1979. All springs sampled discharged directly from basalt or overlying alluvial sediments.

The average composition and range in concentration of major chemical constituents for springs within and adjacent to the Rattlesnake Mountain area are listed in Table 7-2. The data indicate that the spring water, on average, possesses a low total dissolved solids content average concentration of about 250 mg/L (250 ppm). Principal chemical constituents include bicarbonate, silica, calcium, and sulfate.

The chemical composition of springs sampled from the Saddle Mountains Basalt in the Rattlesnake Mountain area, which have an acceptable ionic balance (i.e., Σ anions- Σ cations/Σ cations $<\pm 5\%$), are shown on the trilinear diagram in Figure 7-3. The close proximity of plotting points suggests an overall uniformity in chemical composition. Analysis of Figure 7-3 indicates that the spring water is of a calcium-bicarbonate chemical type. This chemical type and ratios of selected cations (i.e., sodium/calcium and calcium/magnesium) appear consistent with chemical data reported by White et al. (1963) and Garrels (1976) for groundwater in equilibrium with basalt rock types and suggest that the origin of spring waters is from local recharge. These waters are considered young or juvenile and represent the beginning end of an evolutionary trend for basalt groundwater. Such an area is termed the "upper zone" of a groundwater system by Domenico (1972) because bicarbonate is the dominant anion and the water is low in total dissolved solids.

Graham (1983) has studied the stable isotopic composition (oxygen-18 and deuterium) of precipitation in the Rattlesnake Mountain area and compared this to shallow isotopic data from nearby basalt groundwaters collected beneath the Hanford Site. It was concluded that the shallow basalt groundwater on the Hanford Site is similar isotopically to precipitation falling during the winter months on the Rattlesnake Mountain area. This association suggests that past recharge of the shallow basalt groundwater system was similar to precipitation now falling on the Rattlesnake Mountain area during the cooler months. Thus, Rattlesnake Mountain area appears to be a recharge area for shallow basalt groundwater existing beneath the Hanford Site.

Tritium concentrations for spring samples are also reported in Gephart et al. (1979). Tritium concentrations vary between individual

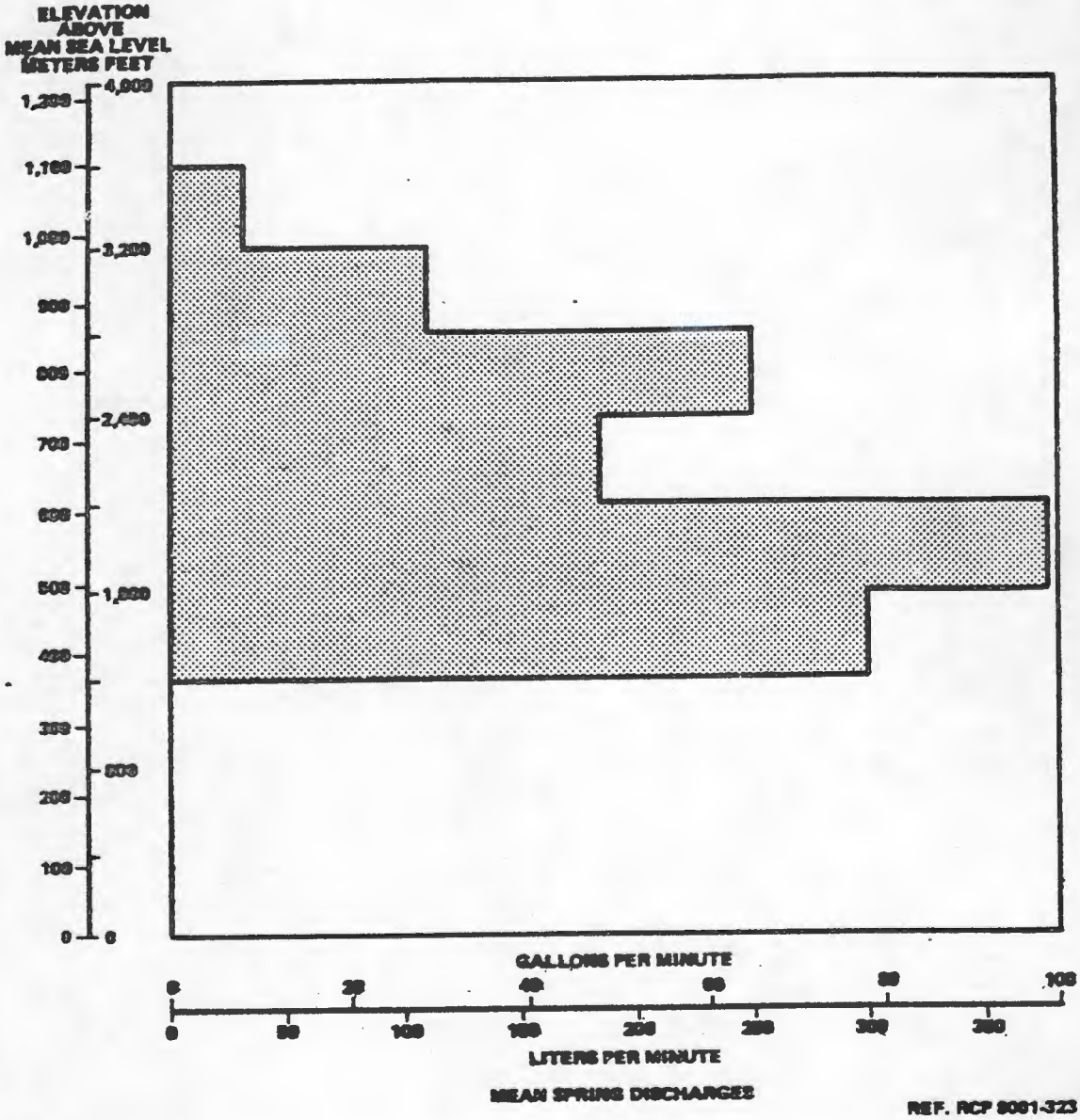
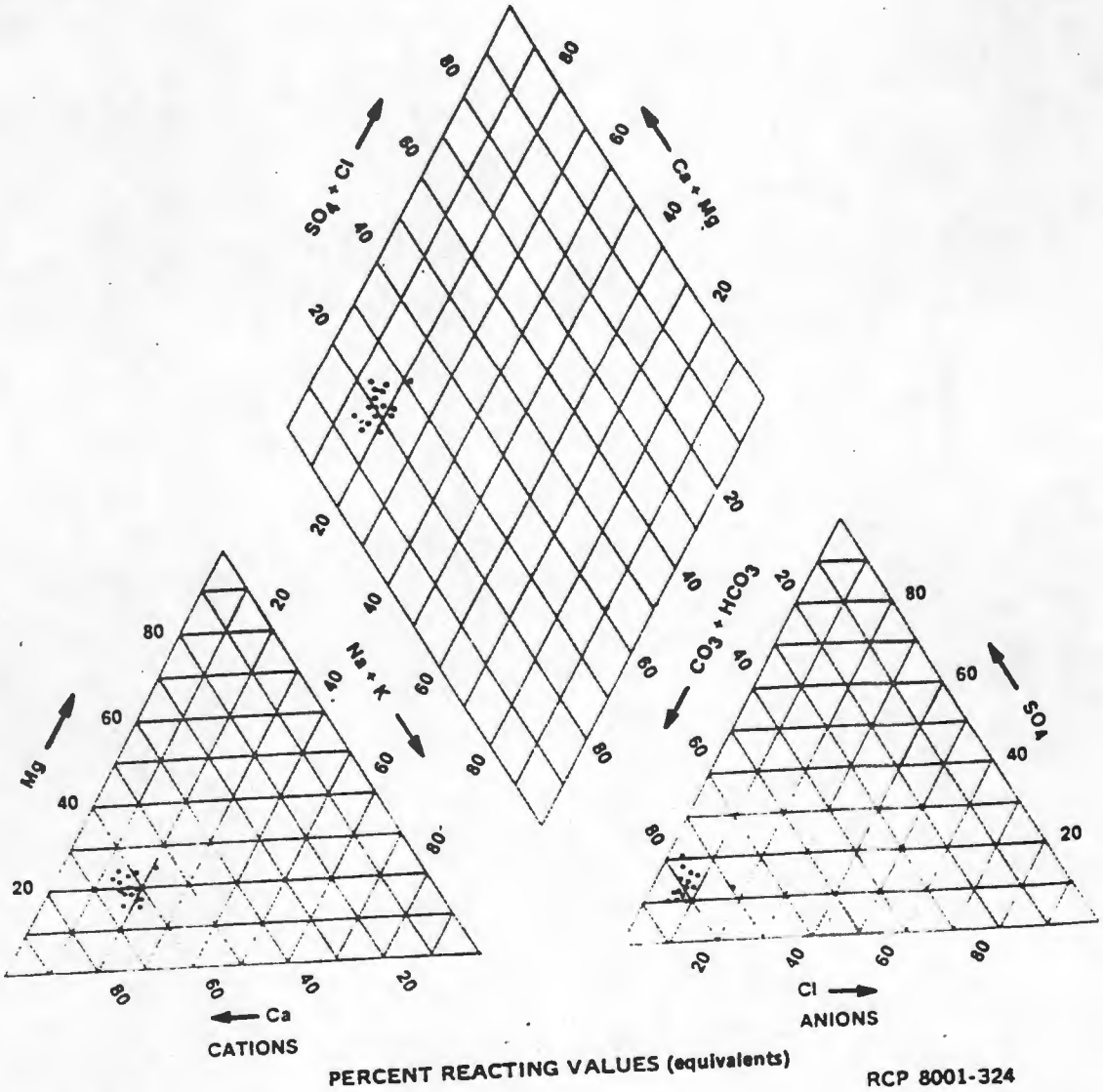


FIGURE 7-2. Sum of Mean Discharges for Specific Deviation Intervals within the Rattlesnake Mountain Area (After Gephart et al. 1979).

TABLE 7-2 Average Composition and Range in Concentration of Major Chemical Constituents within Springs in the Rattlesnake Mountain Area. (Modified from Gephart et al., 1979).

	Range (mg/L)	Average (mg/L)
Anions		
HCO_3^-	71 - 229	124
Cl^-	0.1 - 12	5.5
$SO_4^=$	10 - 41	16
F^-	0.2 - 0.64	0.3
Cations		
Na^+	5.0 - 19	9.4
K^+	1.5 - 5.1	2.4
Ca^{++}	12 - 50	27
Mg^{++}	4.9 - 17	9.7
*SiO_2	25 - 61	45
Total Dissolved Solids (Sum)	145 - 410	251

* Repeated as speciated bicarbonate (HCO_3^-) and SiO_2



· DATA POINT FOR SINGLE SPRING

FIGURE 7-3. Hydrochemistry of Springs Issuing from the Saddle Mountains Basalt within the Rattlesnake Mountain Area (Gephart et al. 1979).

springs, with most values in the range of a few tens of picocuries per liter range. This variation is due, in part, to differences in hypsometric (elevation) characteristics, precipitation distribution, and hydrologic properties of rock units within the various spring drainage basins. Variations in tritium values measured at selected spring sites during the November to March monitoring period are attributed to differences in tritium concentration for precipitation events that recharge the spring system. The lack of historical tritium measurements for precipitation within the Pasco Basin precludes their use in quantitatively age dating the spring water. However, the level of tritium concentration suggests that groundwater discharge at spring sites within the Rattlesnake Mountain area is of mixed origin and contains both pre- and post-1953 recharge water.

Borehole RSH-1 (see Figure 1-2) is the only well site atop the Rattlesnake Mountain area from which preliminary groundwater samples were analyzed as reported in Deju (1978). The specific sampling interval was not given, though it was noted that the water sample was swabbed from within the Grande Ronde Basalt. This would place the sample at least 503 m (1,650 ft) below land surface. The two samples analyzed were of a sodium-bicarbonate chemical type having relatively low (approximately 115 mg/L) total dissolved solids. The two sodium and bicarbonate values given were 25 to 30 mg/L (25 to 30 ppm) and 43 to 67 mg/L (43 to 67 ppm), respectively. Insufficient information was reported in Deju (1978) to assess groundwater sample quality; therefore, data are to be used with caution.

Groundwater samples from Grande Ronde Basalt beneath the Hanford Site have total dissolved solid concentrations of 600 to 1,200 mg/L (600 to 1,200 ppm) and are of a sodium-chloride chemical type (mean sodium and chloride concentrations are about 160 to 360 mg/L (160 to 360 ppm) and 95 to 300 mg/L (95 to 300 ppm), respectively (DOE 1982). Such chemical type and total dissolved solid concentrations appear typical of the deep groundwater system beneath the Hanford Site. Therefore, the limited and unqualified hydrochemical data from borehole RSH-1 appears to suggest that its Grande Ronde Basalt groundwater is of local origin, having less residence time (and therefore having undergone less water/rock interactions) than deep groundwater samples collected east on the Hanford Site.

7.2.3 Hydraulic Heads

Raymond and Tillson (1968) reported hydraulic head measurements from borehole RSH-1. The heads recorded, along with investigator comments as to the suggested validity of each value, are listed in Table 7-3. Head measurement accuracy using downhole pressure recorders, as available to Raymond and Tillson, are at best probably ± 6 m (20 ft) under ideal conditions for zones of relatively high permeability [i.e., $>10^{-6}$ m/s (10^{-1} ft/d)]. Data noted in Table 7-3 should be interpreted in only the broadest terms for several reasons that include the following:

TABLE 7-3. Hydraulic Heads within Basalts Penetrated by Borehole RSH-1.

Test Interval (Meters Below Ground Level)	Head** (Meters Above Mean Sea Level)	Test* Comment
588-611	557	Poor
797-820	596	Fair
979-1002	414	Good
1255-1279	292	Excellent
1473-1496	304	Excellent
1805-1829	261	Good
2522-2545	-1430	Order of Magnitude Estimate

*Data and comments from Raymond and Tillson (1968).

**Ground level elevation 888 meters.

- The borehole had been open to groundwater crossflow for 10 yr prior to the head measurements.

- The test times for measurements were on the order of hours. This is too short a time for reasonable head equilibration to take place. This is particularly applicable to the Raymond and Tillson (1968) data because the permeability values for zones tested were low [10^{-7} to 10^{-11} m/s (10^{-2} to 10^{-6} ft/d)].

If head measurements in borehole RSH-1 are broadly representative, then a general depth to the water table beneath the borehole site can be estimated. As shown in Table 7-3, the maximum head elevations in borehole RSH-1 reported by Raymond and Tillson (1968) were between 558 and 596 m (1,820 to 1,890 ft) above mean sea level. The average of these values is 577 m (1,890 ft). Since the surface elevation of borehole RSH-1 is 878 m (2,880 ft), this suggests that approximately 300 m (990 ft) of partially saturated basalt rock lies between the land surface and the water table beneath Rattlesnake Hills at borehole RSH-1. In this partially saturated zone, perched water bodies are expected to exist.

Generalized head potentials across the Pasco Basin and vicinity in the Saddle Mountains and Wanapum Basalts are shown in Figures 7-4 and 7-5 respectively. (Insufficient data are available to develop potentiometric maps for the Grande Ronde Basalt). These potentials are based upon interpretations reported to the BWIP by the Washington State Department of Ecology (Tanaka et al. 1979) and Century West Engineering. The potential distributions are inferred from mostly composite water levels measured within irrigation wells drilled across several flow tops and interbeds. These potentiometric surfaces should be interpreted in only broad, generalized terms. Few data points were reported within Rattlesnake Mountain area proper. From available information, note that head elevations around the slopes of the Rattlesnake Mountain area were estimated to be about 365 to 425 m (1,200 to 1,400 ft) above mean sea level. If these elevations approximate maximum head elevations, then the water table would lie about 640 to 700 m (2,100 to 2,300 ft) beneath the 1,067-m (3,500 ft) crest of Rattlesnake Mountain.

Since Rattlesnake Mountain appears to be a local recharge area, it is suspected that the underlying groundwater mound rises above the elevation just noted. (Groundwater "mounding" beneath recharge areas is a typical hydrologic phenomenon). Based upon available head data from borehole RSH-1 (which was not included in the Tanaka et al. 1979 report) it is conjectured that the water table may be at least 150 to 210 m (500 to 700 ft) shallower than inferred from the Tanaka et al. (1979) information. This hypothesis would then suggest that a 460-m (1,500-ft) section of partially saturated basalt lies between the crest of Rattlesnake Mountain and the underlying water table. However, because of the scarcity of data, considerable uncertainity exists as to the actual position of the water table throughout the Rattlesnake Mountain area.

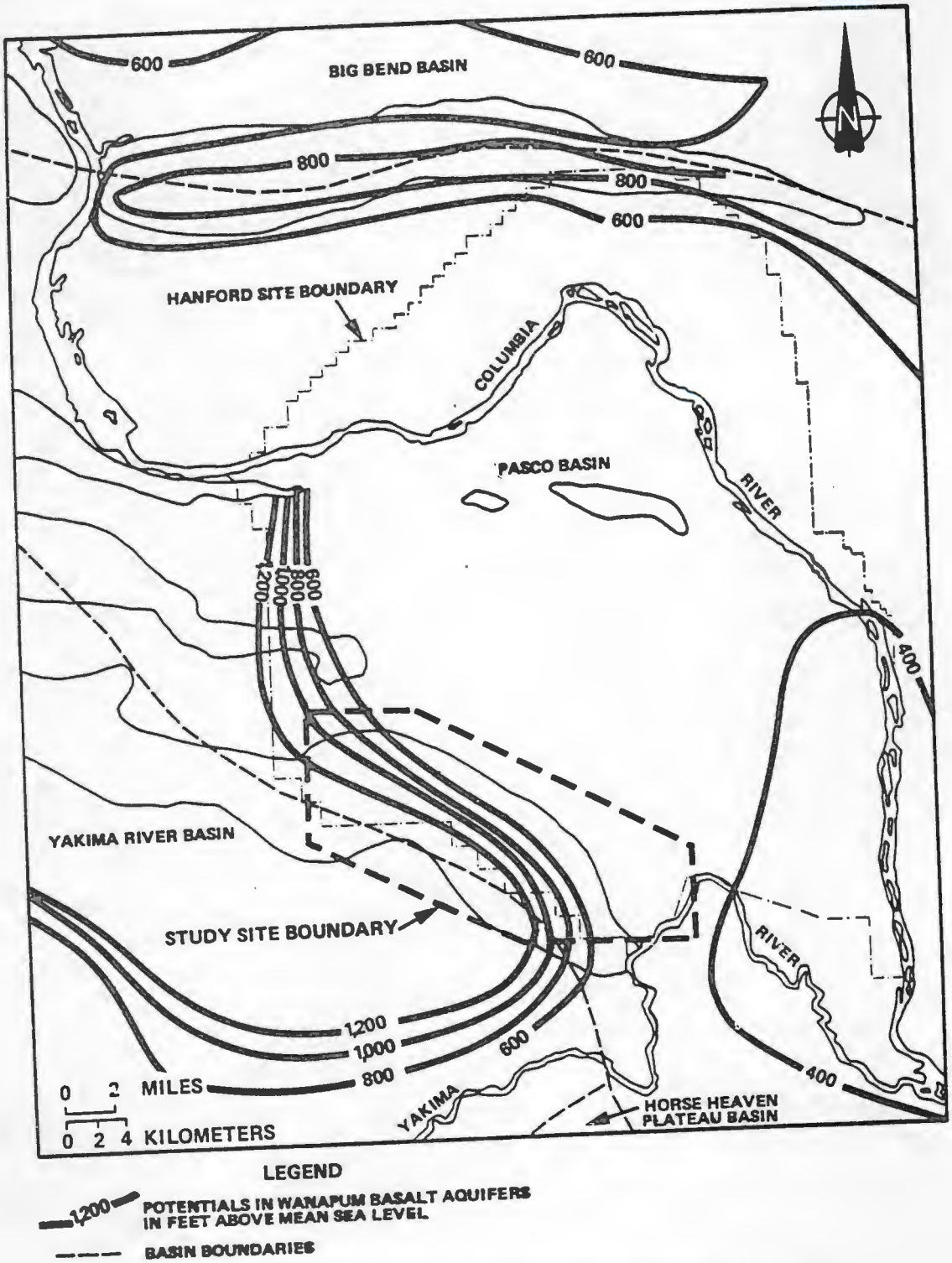


FIGURE 7-4. Generalized Composite Potentiometric Map for Groundwaters within the Saddle Mountains Basalt (Modified after Gephart et al. 1979).

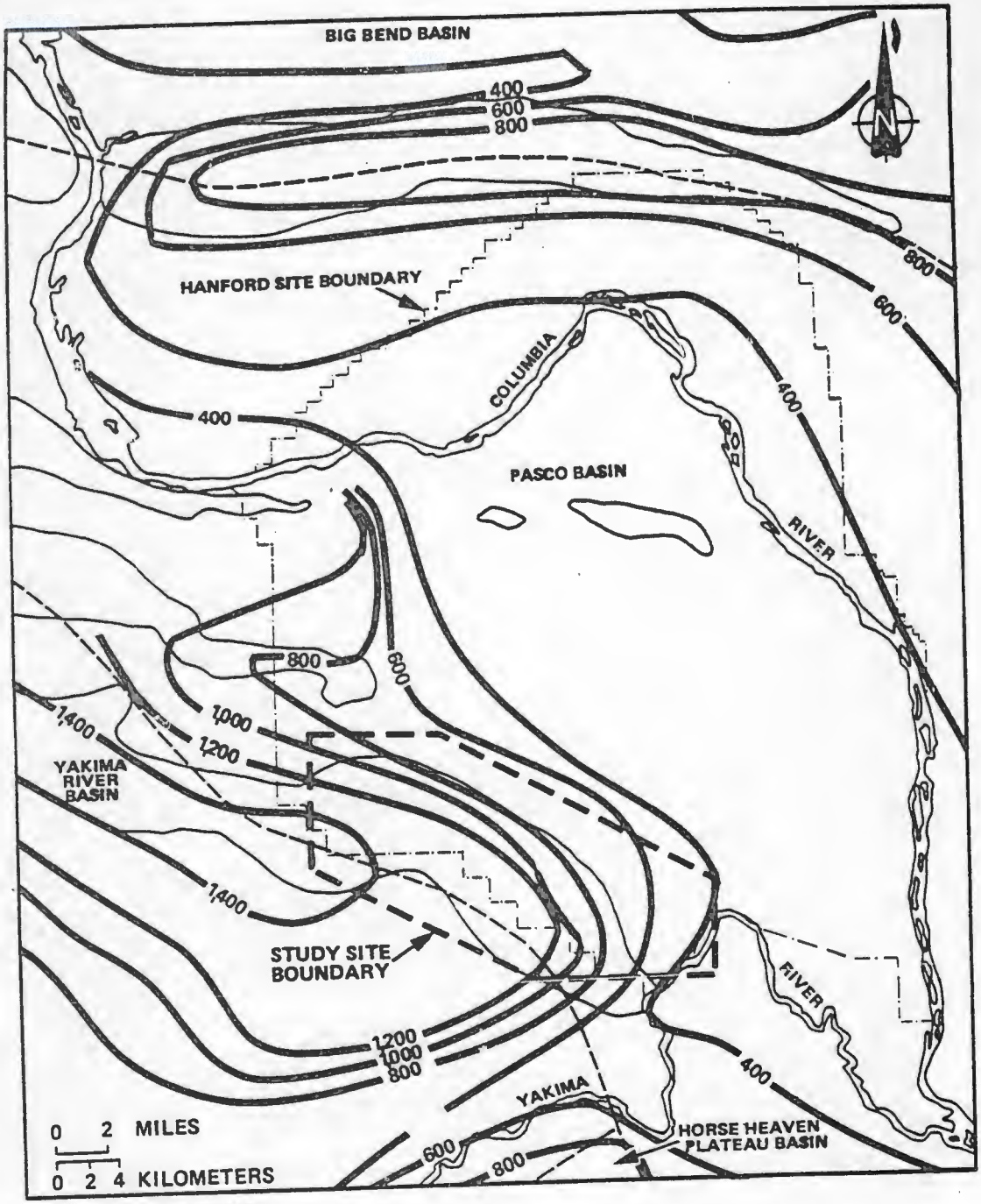


FIGURE 7-5. Generalized Composite Potentiometric Map for Groundwaters within the Wanapum Basalt (modified after Gephart et al. 1979).

7.2.4 Groundwater Recharge

Preliminary documentation of groundwater recharge estimates across the Columbia Plateau, including the Rattlesnake Mountain area, is reported by Dove et al. (1981). The primary factors considered in these estimates included precipitation, topography, soil type, vegetation type, irrigation, stream run-off, and potential evapotranspiration. The predicted areal distribution of annual recharge throughout the Columbia Plateau was reported on a nodal grid basis. Depending upon elevation and slope, recharge estimates along the crest of the Rattlesnake Hills ranged mostly between 2.5 and 7.6 cm (1 and 3 in). According to Stone et al. (1983), the mean annual precipitation across the Rattlesnake Mountain area for the years 1969 to 1980 was between 18 and 28 cm (7 to 11 in). As shown in Figure 6-2, greater precipitation occurs in the higher elevation. On an average, perhaps 10% of the precipitation falling in the Rattlesnake Mountain area enters the rock as recharge. Some of these waters eventually discharge to springs, while other portions recharge the local unconfined and confined aquifers. An exact hydrologic budget for the Rattlesnake Hills area has not been completed. Distributions of seasonal and annual evapotranspiration and precipitation measurements for the Rattlesnake Mountain area, as well as the rest of the Pasco Basin, are reported in Gutknecht et al. (1980).

As noted by Graham (1983), not all precipitation enters a groundwater system. This is especially true in arid and semiarid regions such as the Pasco Basin. In these environments, annual evaporation and transpiration can exceed total precipitation, resulting in a moisture deficit. It may be that recharge to the groundwater system only occurs every few years in such areas. Periods when recharge may occur are those when evapotranspiration is lowest. Evapotranspiration depends mainly on two factors: a water supply (precipitation) and an energy source (primarily radiation). During the winter months, long precipitation events, coupled with low temperatures, high relative humidity, and low radiative loads, reduce evapotranspiration greatly. As shown by Wallace (1978) and Gutknecht et al. (1980), little evapotranspiration occurs during the months of December and January and only slight amounts occur in November and February. However, during the spring months, evapotranspiration is highest in the Rattlesnake Mountain area. Most precipitation falling during this period never reaches the saturated zone and, therefore, never enters the groundwater flow system. It can be concluded, therefore, that precipitation falling during the winter months is most likely to contribute to groundwater recharge in the study area.

8.0 NATURAL RESOURCES

Mineral, fossil fuel, and groundwater resources occur in limited quantities in the Rattlesnake Mountain area (GG/GLA 1981). Low-unit-value industrial rocks have been the most recently utilized resource in the area. Commercial quantities of natural gas were withdrawn from the Wanapum Basalt in the Rattlesnake Hills gas field between 1929 and 1941 (McFarland 1983). Thin coaly zones have been penetrated deep below the Rattlesnake Mountain area in borehole RSH-1 (Raymond and Tillson 1968; Newman 1969). Also, small quantities of groundwater are present in the basalt sequence beneath the Rattlesnake Mountain area.

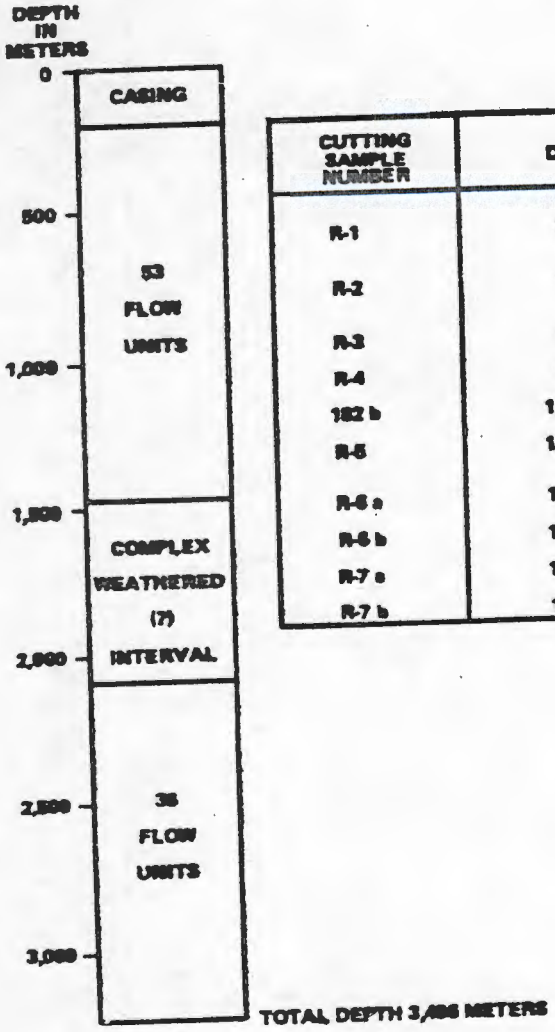
8.1 LOW-UNIT-VALUE INDUSTRIAL ROCKS

Low-unit-value industrial rocks have been quarried in and around the Rattlesnake Mountain area. These industrial rock resources include pumicite, basalt quarry rock, and sand and gravel. Pumicite deposits (tuffs and tuffites) have been quarried from the backslope of Rattlesnake Mountain (Valentine, 1960). Pumicite deposits are known to occur in the Ellensburg Formation throughout much of the Pasco Basin and are most likely to occur within the Rattlesnake Ridge and Selah interbeds in the Rattlesnake Mountain area. On Rattlesnake Mountain, these interbeds thin and pinch out onto the crest of the ridge. Therefore, it is anticipated that any future utilization of these resources would occur in the middle and lower flanks of the ridge where the interbeds and associated tuff units are thickest. It is reported in GG/GLA (1981) that any sustained commercial production of pumicite deposits during the next 25 yr is not likely.

Basalt, sand, and gravel have been produced from a number of sites in the Rattlesnake Mountain area and are used primarily in highway construction projects. Sand and gravel pits occur in deposits of the Pasco Gravels along the Yakima River and in the southern Cold Creek Valley. Rock quarries are generally located on the lower flanks of the ridges or in the valleys near major highways where basalt outcrops at the ground surface. Past and current low-unit-value industrial rock operations in the Rattlesnake Mountain area have resulted in excavations of depths no greater than about 15 m (50 ft). Future excavations are expected to remain at shallow depths.

8.2 COAL AND PEAT

Borehole RSH-1 penetrated thin coaly zones in discrete horizons between 640 and 1,460 m (2,100 and 4,800 ft) (Figure 8-1). These carbonaceous materials were identified as lignite or peat in rank based on vitrinite reflectance of borehole cuttings conducted by the USGS (Table 8-1) (GG/GLA 1981). To assess the potential for development, GG/GLA (1981) examined geophysical logs of the carbonaceous shale intervals. The GG/GLA (1981) concluded that the carbonaceous materials



CUTTING SAMPLE NUMBER	DEPTH (m)	LITHOLOGY PROCESSED FOR PALYNOMORPHS
R-1	366-701	COAL
R-2	731-737	COAL
R-3	914-946	COAL
R-4	967-983	COAL
182 b	1,010-1,040	COAL
R-5	1,067-1,070	COAL
R-6 a	1,428-1,433	COAL
R-6 b	1,428-1,433	SHALE
R-7 a	1,457-1,463	COAL
R-7 b	1,457-1,463	SHALE

FIGURE 8-1. Diagram of Borehole RSH-1 with Location of Cuttings Samples Selected for Palynologic Studies (after Newman 1969).

TABLE 8-1 Vitrinite Reflectance Analytical Results of Carbonaceous Shale Cuttings Recovered from Borehole RSH-1 (Source from GG/GLA, 1981)

Sample no.	Well no.	Depth (ft)	Lithology	Vitrinite reflectance value	Standard deviation
2400-20	RSH-1	2,400-2,420	Sentinel Bluffs	0.30	0.05
2540-60	RSH-1	2,540-2,560	Sentinel Bluffs	0.35	0.04
LRO1C	RSH-1	3,100-3,120	Schwana sequence	0.31	0.05
LRO3C	RSH-1	3,140-3,160	Schwana sequence	0.31	0.07
LRO5C	RSH-1	3,180-3,200	Schwana sequence	0.29	0.04

penetrated in borehole RSH-1 were too thin, impure, and deep to attract exploration or development in the predictable future.

8.3 NATURAL GAS

Natural gas (methane) has been produced from a small, low-pressure field on the north flank of Rattlesnake Mountain from 1929 to 1941 (Glover 1936, with addendum; see Figure 1-2). Gas estimated at between 2,000 and 14,000 m^3 (7.0×10^4 and 5.0×10^5 ft^3)/d at a depth of 215 m (705 ft) was discovered on Rattlesnake Mountain in 1913 when Conservation Land Investment Company drilled for water in a well designated Walla Walla No. 1. In 1929 the gas field and a distribution system were developed to supply gas to seven towns in the Yakima Valley West of Rattlesnake Mountain. By the time gas was being produced, the pressure in the field had dropped from about 0.4 to 0.5 atmospheres (5.5 to 7 lbs/in^2) at discovery to about 0.1 atmosphere (2 lbs/in^2) at the start of production and an estimated 2.8×10^7 m^3 (approximately 1×10^9 ft^3) of gas had been lost to the atmosphere from uncapped wells (Glover 1936). Over the 13 yr the gas field was in operation, nearly 3.6×10^{10} m^3 (1.3×10^{12} ft^3) of methane gas was produced from 16 production wells (Tables 8-2, 8-3, and 8-4). Ethane or heavy hydrocarbons were not detected in the gas analyses from the field except for a single analysis reported by Bessemer Gas Engine Company (see Table 8-3). The gas field was abandoned in 1941 with the gas wells left uncapped and open to the atmosphere.

TABLE 8-2. Production from Rattlesnake Hills Gas Field. Source from Glover, 1936, with Addendum.

YEAR	M^3	VALUE ($)
1930	2,689	$ 45,750
1931	3,380	66,717
1932	2,940	65,313
1933	3,059	80,799
1934	3,997	92,093
1935	5,872	116,248
1936	5,188	116,982
1937	4,038	112,000
1938	3,431	75,488
1939	1,772	53,563
1940	1,020	37,000
1941	28	2,000
TOTAL	51,575	$863,953

TABLE 8-3 Analyses of Gas form the Rattlesnake Hills Gas Field
(Source from GG/GLA, 1981)

Well number	Analyzed or reported by	Methane CH_4	Ethane C_2H_6	Oxygen O_2	Nitrogen N_2	Carbon dioxide (CO_2)	Specific gravity	Btu
Walla Walla 2	U.S. Bureau of Mines[1]	71.12	0.00	5.35	23.05	0.48	-	-
Walla Walla 2	U.S. Bureau of Mines[1]	87.9	0.00	2.40	9.40	0.30	-	-
Yellowhawk 1	U.S. Bureau of Mines[1]	44.7	0.00	11.2	44.1	0.00	-	-
Well No. 2	U.S. Bureau of Mines[1]	93.0	0.00	0.70	6.00	0.30	-	-
Well No. 5	U.S. Bureau of Mines[1]	70.9	0.00	4.30	24.60	0.20	-	-
Well No. 6	U.S. Bureau of Mines[1]	94.9	0.0	0.30	4.80	0.00	-	-
Well No. 8	U.S. Bureau of Mines[1]	87.7	0.00	4.60	7.60	0.10	-	-
Walla Walla 7	U.S. Bureau of Mines[1]	44.1	0.00	11.90	43.90	0.10	-	-
Walla Walla 8	U.S. Bureau of Mins[1]	30.8	0.00	14.7	54.4	0.10	-	-
No name	Bessemer Gas Engine Co.[2]	76.70	12.00	0.40	-	0.00	0.560	-
No name	University of Oregon[3]	-	-	-	68.5	-	-	-
Well No. 1	Pacific Power and Light	98.75	-	-	1.25	-	0.560	996
Big Bend 2	Pacific Power and Light Co.	99.34	-	-	0.66	-	0.558	1,002
Big Bend 1	Pacific Power and Light Co.	99.35	-	-	0.65	-	0.558	1,002
Well No. 2	Pacific Power and Light Co.	99.35	-	-	0.65	-	0.558	1,002
Well No. 5	Pacific Power and Light Co.	99.36	-	-	0.64	-	0.558	1,002
Well No. 6	Pacific Power and Light Co.	99.35	-	-	0.65	-	0.558	1,002
Well No. 7	Pacific Power and Light Co.	99.34	-	-	0.66	-	0.558	1,002
Well No. 8	Pacific Power and Light Co.	95.57	-	-	4.63	-	0.573	914
Composite sample from Grandview Pipeline	Pacific Power and Light Co.	99.35	-	-	0.65	-	0.550	1,002
No name	Hammer (1934)	97.25	0.00	0.15	2.45	0.15	-	-

[1]Cryogenic laboratory, Amarillo, Texas.
[2]This analysis gave also: propane 7.20% and butane 3.80%.
[3]This analysis gave also: saturated hydrocarbons, 17.5% and hydrogen 14%.

TABLE 8-4 Oil and Gas Wells and Exploration Holes in the Rattlesnake Mountain Area. (Source from GG/GLA, 1981 and McFarland, 1983) (To convert feet to meters, multiple by 0.3048)

Name of operator	Well name	Location	Spud date	Depth (ft)	Information available
		BENTON COUNTY			
B-1 005-00001 Conservative Land Investment Co. of Spokane	Water well (Walla Walla No. 1)	Benton City area. SE¼SE¼ Sec. 20 (11-26E). Elev. 1,279 ft ground level	1913	1,234	Cable tools. Discovery well. Top of gas zone at 705 ft. Reported 312,000 ft³/d. Later taken over by Walla Walla Oil & Gas Co. Gas analysis, driller's log.
B-2 005-00002 Blue Hen Oil Co.	Blue Hen No. 1 (later, Walla Walla No. 2)	Benton City area, Approx. ¼ mi. from discovery well. (see Walla Walla No. 2)	1917	738	Cable tools. Gas at 705 ft. Driller's log.
B-2 005-00003 Walla Walla Oil, Gas, & Pipe Line Co.	Walla Walla No. 2	NW¼SW¼ Sec. 21 (11-26E). Elev. 1,218 ft ground level	1917	800	Cable tools. Gas produced from 705 ft. Est. 2,600,000 ft³/d. Driller's log, gas analysis.
2x 005-00004 Walla Walla Oil, Gas & Pipe Line Co.	Walla Walla No. 3	Benton City area, NE corner NE¼ Sec. 19 (11-26E). Elev. 1,283 ft ground level	1920	1,507	Cable tools. Gas produced from 750 ft.
B-9 005-00005 Seattle-Inland Empire Co.	Goodwin No. 1 (Big Bend No. 2)	Benton City area, Center, NW¼NW¼ Sec. 27 (11-26E). Elev. 1,134 ft ground level	1920	2,212	Cable tools to 295 ft. Rotary to bottom. Oily basalt & 8 gas horizons reported. Produced gas from 699 ft. Driller's log, gas analysis.
B-12 005-00006 Spokane-Benton County Natural Gas Co.	None	Benton City area. SW¼NW¼ Sec. 5 (11-25E)	Prior to 1924	1,003	Cable tools. Gas showings reported. Driller's log.
B-11 005-00007 Colfax Oil & Gas Co.	None	Benton City area. Center. SW¼SW¼ Sec. 16 (11-26E). Elev. 1,018 ft ground level	Prior to 1924	740	Cable tools. Dry hole. Driller's log.
B-8 005-00008 Big Bend Land Co.	Big Bend No. 1	Benton City area. Center. SW¼NW¼ Sec. 27 (11-26E). Elev. 1,124 ft ground level	Prior to 1920(?)	670	Cable tools. Gas produced from 670 ft. Gas analysis.
3x 005-00009 Consolidated Oil & Gas Co.	None	Benton City area. Near NW¼ cor. Sec. 27 (11-26E)	Prior to 1924	806	Cable tools. No gas. Water zone at 450 ft, clay at 600 ft.
B-13 005-00010 Prosser-Grandview Gas Co.	Prosser-Grandview	Benton City area. SW¼SW¼ Sec. 32 (10-25E)	1912	825	Drilled to 482 ft w/cable tools. Rotary to bottom. Originally drilled for water. No gas. Driller's log.
4x 005-00011 Walla Walla Oil, Gas & Pipe Line Co.	Walla Walla No. 4	Benton City area. SW cor. NE¼NE¼ Sec. 21 (11-26E). Elev. 958 ft ground level	Prior to 1925	640	Cable tools. No gas. Water at 300 ft.
B-5 005-00012 Walla Walla Oil, Gas & Pipe Line Co.	Walla Walla No. 5	Benton City area. SE¼SE¼ Sec. 20 (11-26E), due SE of discovery well. Elev. 1,332 ft ground level	Prior to 1925	780	Cable tools. Gas produced from 755 ft. Est. 1,300,000 ft³/d. Driller's log, gas analysis.
5x 005-00013 Walla Walla Oil, Gas & Pipe Line Co.	Walla Walla No. 6	Benton City area. NE¼SE¼ Sec. 18 (11-26E)	Prior to 1925	205	Cable tools. No gas.

TABLE 8-4 (Con't)

Name of operator	Well name	Location	Spud date	Depth (ft)	Information available
B-7, B-29 005-00014 Walla Walla Oil, Gas & Pipe Line Co.; Northwestern Natural Gas Corp.	Walla Walla No. 6A (Northwestern No. 6, Walla Walla No. 6, Walla Walla No. 7, Conservative, and Deep Test)	Benton City area. Center N½NW¼NE¼ Sec. 29 (11-26E) Elev. 1,437 ft (?) ground level	3-5-26; 4-22-33	803; 3,660	Cable tools. Gas at 791-800 & 992-1,039 ft. Showings of tar-like oil at 3,150 ft. Bottom in basalt. Driller's log, gas analysis.
B-28 005-00015 Scott Drilling Co.	Benson Ranch	Benton City area. NW¼SW¼ Sec. 26 (12-25E). Elev. 610 ft (?) ground level	3-1-29	2,000	Cable tools. Paraffin-base oil show reported at 1,438-1,450 & 1,540-1,553 ft. Bottom in basalt. Driller's log.
B-14 005-00016 Walla Walla Oil, Gas & Pipe Line Co.	Walla Walla No. 7	Benton City area. Center N½NE¼NE¼ Sec. 29 (11-26E). Elev. 1,368 ft (?) ground level	Prior to 1930	763+	Cable tools. Gas produced from 763 ft. Gas analysis.
B-15 005-00017 Walla Walla Oil, Gas & Pipe Line Co.	Walla Walla No. 8	Benton City area. Center N½SE¼NE¼ Sec. 29 (11-26E). Elev. 1,437 ft (?) ground level	1930	790	Cable tools. Gas production from 784 ft. Gas analysis.
6x 005-00018 Walla Walla Oil, Gas & Pipe Line Co.	Walla Walla No. 9	Benton City area. SW¼SW¼ Sec. 21 (11-26E). Elev. 1,228 ft (?) ground level	1930	700	Cable tools. Gas production from 700 ft.
7x 005-00019 Northwestern Oil & Gas Co.	Northwestern No. 1	Benton City area. Center NW¼NW¼ Sec. 28 (11-26E). Elev. 1,302 ft (?) ground level	5-23-30	712	Cable tools. Gas production from 712 ft.
B-20 005-00020 Northwestern Oil & Gas Co.	Northwestern No. 2	Benton City area. SW¼SW¼ Sec. 28 (11-26E). Elev. 1,705 ft (?) ground level	9-22-30	1,281	Cable tools. Gas produced from 982 & 1,260 ft. Driller's log
8x 005-00021 Walla Walla Oil, Gas & Pipe Line Co.	Walla Walla No. 10	Benton City area. SW¼SW¼ Sec. 20 (11-26E). Elev. 1,302 ft (?) ground level	11-7-30	663	Cable tools. No gas. Well never completed.
9x 005-00022 West Coast Gas & Oil Co.	West Coast No. 1	Benton City area. Center NE¼SE¼SE¼ Sec. 20 (11-26E)	1930	705	Lost hole by blasting. No gas. Changed from rotary to cable tools at 200 ft.
10x 005-00023 Yellowhawk Gas & Oil Co.	Yellowhawk No. 1	Benton City area. NE cor. NE¼SW¼ Sec. 20 (11-26E). Elev. 1,287 ft (?) ground level	5-12-30	715	Cable tools. Gas produced from 710 ft.
11x 005-00024 Northwestern Oil & Gas Co.	Northwestern No. 3	Benton City area. Center SE¼NW¼ Sec. 28 (11-26E). Elev. 1,330 ft (?) ground level	11-7-30	757	Cable tools. Gas produced from 757 ft.
12x 005-00025 Northwestern Natural Gas Corp.	Northwestern No. 4	Benton City area. NW¼SW¼ Sec. 34 (11-26E)	6-19-31	980+	Cable tools. Gas produced from 787 & 980 ft.
13x 005-00026 Northwestern Natural Gas Corp.	Northwestern No. 5	Benton City area. NE¼SW¼ Sec. 28 (11-26E)	7-10-31	650	Cable tools. No gas. Well never completed.
14x 005-00027 West Coast Gas & Oil Co.	West Coast No. 2	Benton City area. Center NE¼NW¼ Sec. 29 (11-26E)	1931	850	Cable tools. Gas produced from 845 ft.
15x 005-00028 North Pacific Natural Gas Co.	Donellan No. 1	Benton City area. NE¼NE¼ Sec. 32 (11-26E)	1931	100	Cable tools. No gas. Well never completed.

TABLE 8-4 (Con't)

Name of operator	Well name	Location	Spud date	Depth (ft)	Information available
16x 005-00029 Northwestern Natural Gas Corp.	N.P. No. 1	Benton City Area. Sec. 21 (9-28E) on Badger Mountain	5-25-31	600	Cable tools. No gas. Well never completed.
B-30 005-00030 Paul John Hunt	Horseshoe No. 1 (Hunt No. 1)	Benton City area. SW¼ Sec. 27 (10-25E) in Snipes Canyon	7-20-40	935	Cable tools. Dry hole. Driller's log, ditch samples.
127 005-00032 Standard Oil Co. of California	Rattlesnake Unit No. 1	Grandview area. 330 ft FSL & 330 ft FEL of Sec. 15 (11-24E). Elev. 2,872 ft ground level	7-2-57 Re-entered 2-20-78	8,418 10,655	Bottom reported to be in volcanics.

Gas from the Rattlesnake Hills field was produced from two major zones of vesicular basalt from a depth between about 213 and 366 m (700 and 1,200 ft) (McFarland 1983). An 18- to 21- m- (60 to 70 ft) green and gray clay zone formed an impervious cap on the upper vesicular basalt zone (Hammer 1934). The clay zone is interpreted to stratigraphically fall within and probably at the base of the Mabton interbed. The upper gas producing horizon probably is the flow top of the Priest Rapids Member. The lower gas producing horizon may correspond to the Priest Rapids-Roza interflow zone, or if the Quincy interbed is present, it may correspond to the flow top of the Roza Member. Hammer (1934) believed the gas was not indiginous to the basalt, but migrated from depth and collected between the clay zone (Mabton interbed) and the water table in a structural trap on the faulted north limb of Rattlesnake Mountain.

In 1957, a gas exploration well, designated Rattlesnake Hills No. 1 (RSH-1), was spudded by the Wooster Drilling Company of Vernal, Utah, under contract to Standard Oil Company of California and Shell Oil Company (Raymond and Tillson 1968). Borehole RSH-1 was drilled northwest of the Rattlesnake Hills gas field on the crest of the east-west trending segment of the Rattlesnake Hills (see Figure 1-2). The well was drilled to a depth of about 3,250 m (10,655 ft) before it was abandoned in 1958. Apparently, the well did not penetrate through the Columbia River Basalt Group, as X-ray fluorescent analytical results of cuttings from the bottom of the boring are of Grande Ronde basalt chemistry (Reidel et al. 1981). There were no reported shows of oil and gas from borehole RSH-1 (McFarland 1983).

The GG/GLA (1981) discussed the source and economic potential for methane gas throughout the Columbia Plateau, including a discussion of the Rattlesnake Hills gas field. Data on the gas from the field are limited, with most data simply percentages of the major gas components, specific gravity, and estimated BTU (see Table 8-3). There are no reported isotopic data from the gas field. However, GG/GLA (1981) have reported isotopic data on methane collected from wells located to the north and east of the gas field in the central Hanford Site. The isotopic data indicated that the majority of the gas was probably biogenic in origin, but some gases collected from the RRL may have an early stage thermocatalytic component. These data are not sufficient to determine whether the gas was generated in situ (i.e., from interbeds or flowtops in the basalt) or from a source beneath the basalts. Therefore, the economic potential of natural gas from beneath basalts of the Rattlesnake Mountain area remains unknown.

8.4 GROUNDWATER

Groundwater resources are available from Dry Creek and Cold Creek Valleys within the Rattlesnake Mountain area, as well as from the surrounding lowlands. These resources are from both the shallow unconfined aquifer consisting of fluvial sediments lying atop the basalts and from within flow tops and interbeds of the basalt sequence (Gephart et al. 1979). The groundwater resources in the southeast

portion of the Rattlesnake Mountain area along the Yakima River are not included in this summary.

Beneath the Hanford Site, the hydraulic conductivity of the unconfined aquifer is generally 10^{-2} to 10^{-3} m/s (10^{3} to 10^{2} ft/d) for coarse sand and gravels and as low as 10^{-7} m/s (10^{-2} ft/d) for finer grained, individual deposits (Gephart et al. 1979). Groundwater production of several hundred to several thousands of liters per minute are extractable from the coarser sediments of the unconfined aquifer.

Within the basalt sequence, flow tops and interbeds having the greater hydraulic conductivity values [e.g., $\geq 10^{-5}$ m/s (10^{0} ft/d)] are also capable of producing several hundred to several thousand liters of groundwater per minute. Within the Saddle Mountains Basalt, the Rattlesnake Ridge, Cold Creek, and Mabton interbeds are commonly sources of large groundwater quantities. Flow tops within the Priest Rapids, Roza and Frenchman Springs Members of the Wanapum Basalt are also known to be high production aquifers. Few aquifers appear to exist within the Grande Ronde Basalt beneath the Hanford Site.

No significant groundwater production from the high terrain within the Rattlesnake Mountain area is expected in the foreseeable future because adequate surface and groundwater supplies are available in lowland areas where pump costs are minimized. The only groundwater production in the Rattlesnake Mountain area is from boreholes S18-51 and S25-51 (see Figure 1-2). This groundwater is used as a potable water supply for a small building complex associated with the Arid Land Ecology Reserve and located on the lower north flank of the Hodges Ranch extension at borehole S18-51.

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Title/Description
Preliminary Geologic Map of the Rattlesnake Mountain Area page # 91

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Generalized Geographic Map of the Rattlesnake Mountain Area page # 92

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Spring locations in the Rattlesnake Mountain Area page # 93

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B047290

START

BWIP CERTIFIED DOCUMENT TRANSMITTAL

FOR BRMC USE ONLY

Transmittal No. BCD-84-245

INSTRUCTIONS: Columns 1-6 MUST be completed for each document submitted on transmittal. Transmittal must be signed by management and originator of transmittal. Documents will be returned if form is not complete.

1 Document Type Code	2 Document No.	3 Document Date	4 Title (120 Characters)/Description*	5 Subject Code	6 End Function Code
2109	SWO-001	3-1-84	Stop Work Order for Rockwell, PNL and WHC Laboratories conducting work for BWIP Engineer Barriers studies Permanent OCT 23 1984 Initial LH	N/A	008

*Geologic Formation, Borehole No.

BRMC Index Record No. B047290

Completed By:

Name (Print)	Signature	Organization	Phone	Date
James A. Ulseth	J.A. Ulseth	BWIP/QA	6-8817	10-2-84

Manager's Approval:

Name (Print)	Signature	Organization	Phone	Date
M. F. Nicol	M F Nicol	BWIP/QA	6-8358	10-2-84

Date Received 10/23/84

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B047290

STOP WORK ORDER (SWO)

BRMC

BOP A-5

SWO Number 001

Applicable Area/Activity/Location

2101-M - Basalt Materials Testing Labs

325 Building - Hydrothermal Studies

3720 Building - Environmechanical Studies

Existing Condition Testing has been and is being performed with equipment not calibrated. Testing is being performed without approved procedures. Test practice is deviating from approved procedures and applicable ASTM standards. Test records are incomplete. Peer review is not being applied as required. PNL and WHC are not performing adequate QA verification. Reference Surveillance Reports 83-494, 596, 639, 656, 726, 733, 735, 773, 774, 84-083, 113, 177-182. Corrective Action Request 84-010, Nonconformance Report 84-108.

for [signature] 3/1/84
Director, Quality Assurance Date

CORRECTIVE ACTION

No additional testing will be initiated at Rockwell, PNL, or WHC until it has been demonstrated that equipment requiring calibration has been calibrated and required documents have been approved. Ongoing and completed tests shall be evaluated for compliance with quality program requirements and deviations shall be identified and dispositioned via the nonconformance reporting system. Test records shall receive the required management and peer reviews and deficiencies appropriately corrected or dispositioned according to approved procedures. PNL and WHC shall demonstrate an adequate involvement by their Quality Assurance organizations in verification activities to the satisfaction of Rockwell Quality Assurance.

SEE LIST OF PERTINENT DOCUMENT TITLES AND No's (ATTACHED) [signature] 10-2-84

[signature] 3/1/84
Director, BWIP Date

Released: Corrective Action has been verified and stop work tag removed. Work identified on this SWO may proceed. [signature] 9/28/84
Director, Quality Assurance Date

Note: Work authorized to start up incrementally on a [illegible] by-lab basis [illegible]

LIST OF ATTACHMENTS

INTERNAL LETTERS-CHRONOLOGICAL ORDER

No.	Date	Subject
12010-84-040	2-14-84	Audit BWIP-84-01, 2101M Labs
12010-84-083	4-04-84	Audit report for audit BWIP-84-01
12010-84-125	5-09-84	Audit BWIP-84-02, Restart of Solid Characterization Lab-2101M
12010-84-135	5-14-84	Audit BWIP-84-03, Restart of 2101M Lab
12010-84-145	5-21-84	Audit BWIP-84-04, Restart of Backfill Testing Lab 2101M
12010-84-146	5-21-84	Audit report of Audit BWIP-84-03, Restart of Concrete/Material Testing Lab
12010-84-147	5-21-84	Audit report for Audit BWIP-84-02, Restart of Solids Characterization Lab
12010-84-152	5-22-84	Audit report of Audit BWIP-84-04, Restart of Hydraulic Conductivity Lab
12010-84-156	5-23-84	Restart of Testing in the Hydraulic Conductivity Lab
12010-84-157	5-23-84	Restart of testing in the Concrete/Material Lab
12010-84-158	5-23-84	Restart of Testing in the Solid Characterization Lab
12010-84-162	5-31-84	Restart of Testing in the Hydrothermal Lab
12010-84-163	5-31-84	Audit report of Audit BWIP-84-05, Restart of Hydrothermal Testing Lab
12010-84-239	7-17-84	Restart of Testing in the Solution Chemistry Lab, BWIP/EBD
12010-84-253	7-23-84	Restart of Testing in the Rock Mechanics Lab, BWIP/EBD
12010-84-306	8-21-84	Restart of Backfill Testing Laboratory with Respect to the Triaxial Cell Tests
12010-84-333	9-30-84	Weekly activity Report for week ending 9-19-84 Re: Section II-BWIP Laboratory Startup

EXTERNAL LETTERS-CHRONOLOGICAL ORDER

No	Date	Subject
R84-1258	4-04-84	Restart Plan for Engineered Barriers Materials Testing at Pacific Northwest Laboratory and Westinghouse Hanford Company
R84-1928	5-24-84	Restart Plan Engineered Barriers Department Materials Testing (WHC)
R84-2123	6-11-84	Restart of WHC Laboratory Operations for RHO/BWIP Canister Materials Crack Growth Studies
R84-2259	6-19-84	Restart of WHC Laboratory Operations for RHO/BWIP Hydrothermal Testing
R84-2389	6-28-84	Restart of WHC Laboratory Operations of RHO/BWIP General Corrosion Studies of Waste Package Canister Materials
R84-2828	8-06-84	Restart of Testing by PNL of the Basalt Radionuclide Solubility and Sorption Studies for the EBD, BWIP/RHO