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Hydrogeology • Mineral Resources Waste Management • Geological Engineering • Mine Hydrology

August 13, 1985
Contract No. 02-82-044
Fin No. B-7372-3
Communication No. 138

Mr. Matthew Gordon
Division of Waste Management
Mail Stop 623-SS
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Matt:

We have reviewed the document entitled "Numerical Modeling of the Ground Water Flow System at the Location, Hanford Site, Washington." We recognize that this is a rough draft of the early chapters of the document to be produced by SANDIA. We have enclosed a marked up copy of this rough draft to facilitate the conveyance of our comments. We have noted some minor editorial points which are more easily conveyed in this manner. We do have several major comments.

We suggest that a more detailed discussion of the purpose of the document be included in this report. The purpose of the report should list the major topics which will be presented in the report. We have reorganized the draft report so that the figures and tables occur in their proper sequence in the text; we reorganized the report to facilitate our review. We found several instances in which the figure numbers are incorrect.

We suggest that figure 3-52 from the SCR be included in the general discussion of bedrock structures under section 3.4.5. This figure, in the SCR, illustrates the hydrogeologic complexity at the site due to geologic structures. We believe this figure or a similar figure would illustrate the complexity over and above what is described in this section.

A paragraph or two should be inserted under the topic "Hydraulic Heads" (Section 3.4.7). This additional discussion should include the measurement error and apparent low hydraulic gradients which have been detected at the site. The discussion can certainly be expanded to discuss the results of the continuous data being derived from the multi-piezometer completions at DC-19, -20, and -22. The discussion of error and low gradients should place the potentiometric maps in their proper perspective.

2309

The format used to present a review of a groundwater model is confusing. Our confusion may stem from the pages being out of order; at least we think the pages are out of order in our draft. We suggest that the format be simplified.

Several references are missing from the List of References at the end of Chapter 3. We have listed the first author and date of the publication based on the citation given in the text. Please call if we can be of further assistance.

Sincerely,

Gerry

Gerry Winter

NUMERICAL MODELING OF THE GROUND-WATER FLOW SYSTEM AT THE LOCATION, HANFORD SITE, WASHINGTON

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) has identified the Reference Repository Location (RRL) at the Hanford Site, Washington, as one of nine potentially acceptable sites for a mined geologic repository for spent nuclear fuel and high-level radioactive waste. This report will provide the NRC staff with assessments of groundwater modeling studies that have been performed to date of the area in and around the RRL. In this report the geologic and hydrologic setting are characterized as a framework for evaluating hydrogeologic conceptual models of the flow system(s) at the Hanford Site.

*

2.0 REGIONAL GEOLOGY

2.1 LOCATION

The RRL is in DOE's Hanford Reservation near Richland, Washington. The RRL is in the central portion of the Cold Creek Syncline within the Pasco Basin, a structural and topographic basin located within the Columbia Plateau (Figure 1).

Major surface features of significance in the area include:

The Columbia River, Umtanum Ridge, Gable Butte, and Gable Mountain to the north;

Yakima Ridge to the west; Hills on Fig. 2.

Rattlesnake Mountains to the south;

The Columbia River to the east and Yakima River to the south-east (Figure 2).

2.2 GENERAL GEOLOGY

The Columbia Plateau coincides with the distribution of Miocene flood basalts of the Columbia River Basalt Group. The Plateau is a large structural and topographic depression, with its low point near the location of the RRL. The maximum thickness of the Columbia River Basalt Group, including its interbedded sediments, is approximately 5,000 meters (Mitchell and Bergstrom, 1983). The flood basalts, underlain by metamorphosed sedimentary and volcanic units, were erupted from a series of north-northwest-trending linear vents (e.g., Waters, 1961). Individual flows range in thickness

* insert a more detailed discussion of the purpose of this document stating what the major topics are in this document

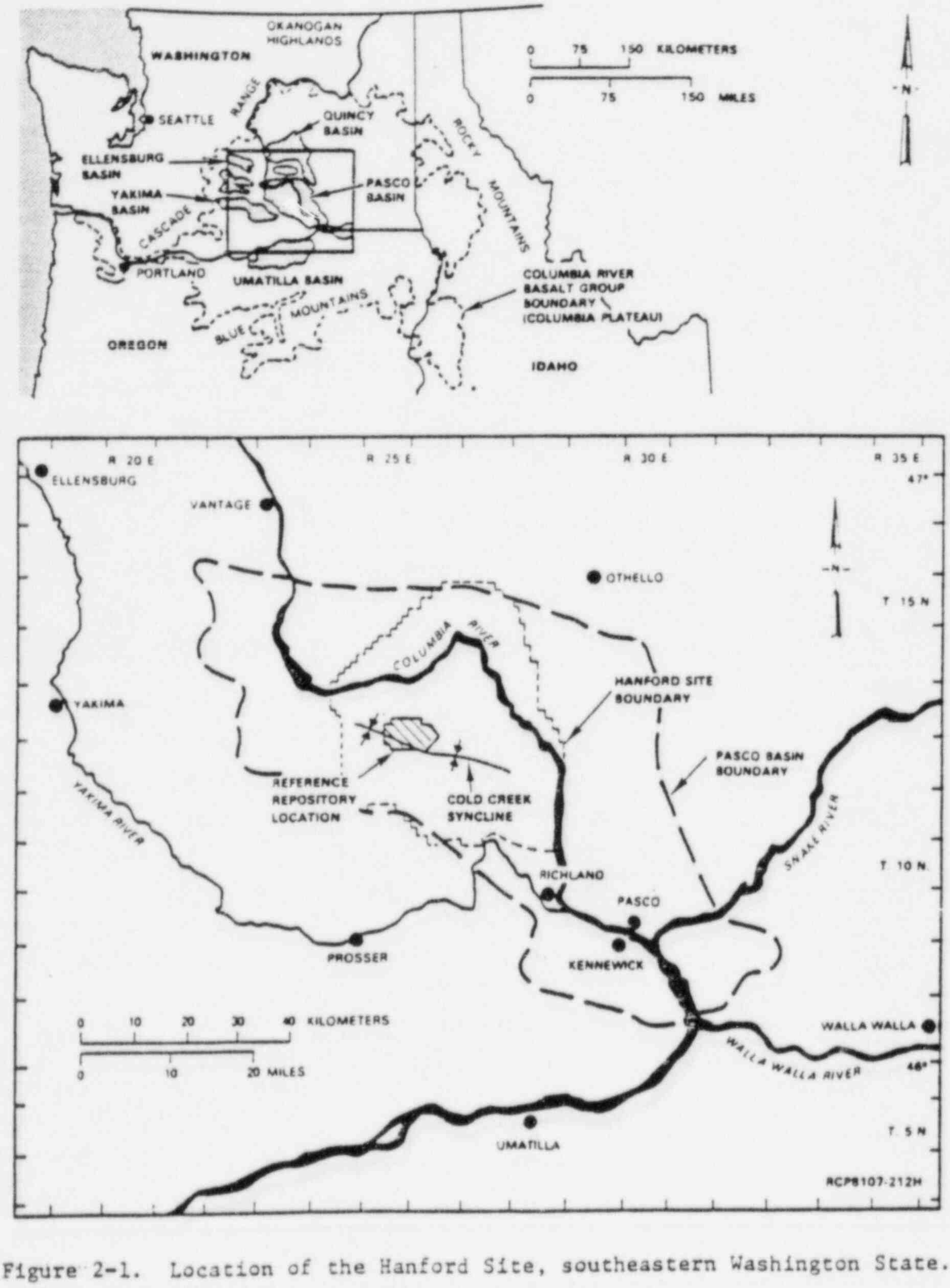

Figure 2-1. Location of the Hanford Site, southeastern Washington State.

Figure 1

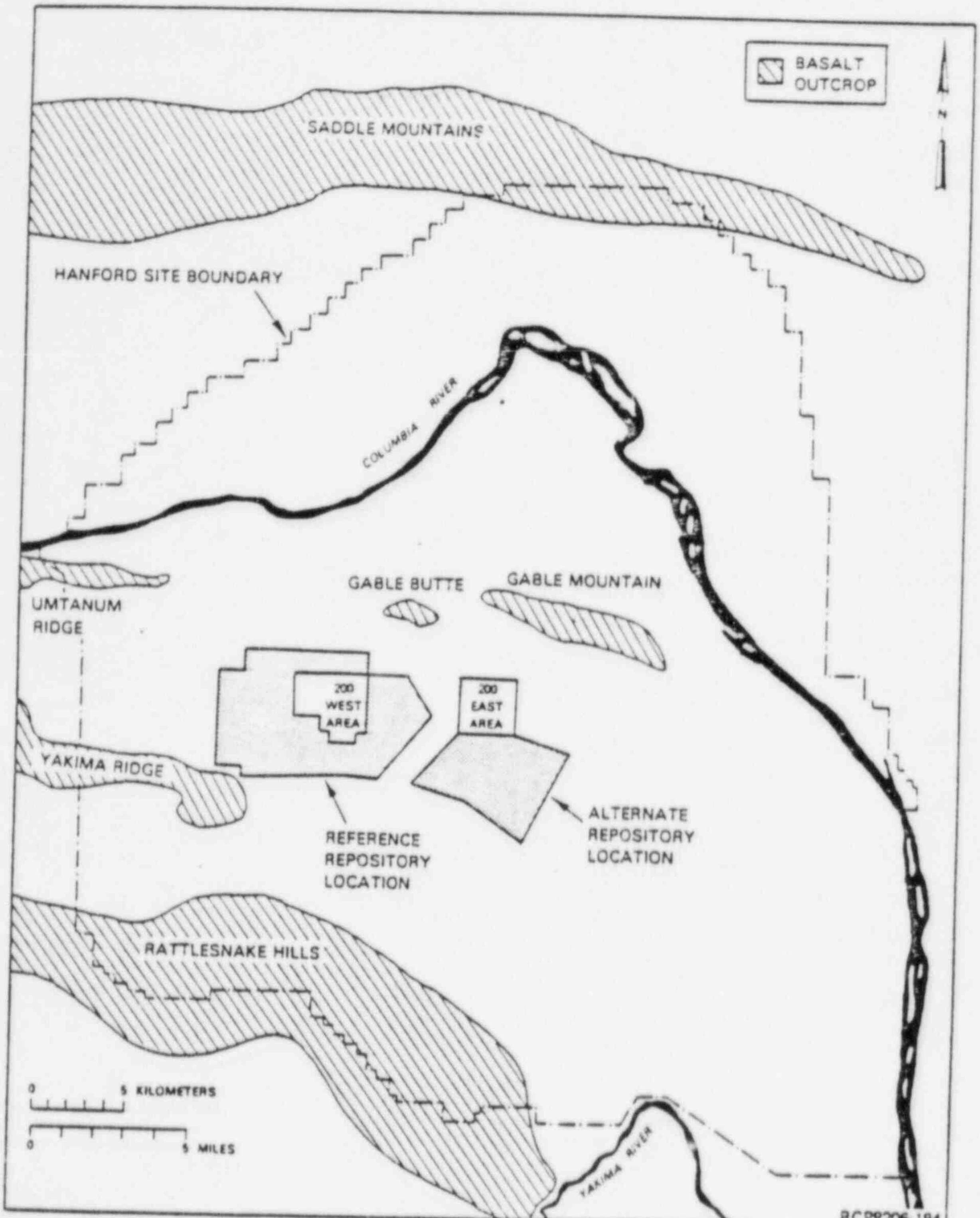

Figure-2-26. Location of the reference repository location and alternate repository location.

Figure 2

from a few centimeters to approximately 100 meters, with most flows between 20 and 40 meters thick. The basic disposal concept for the Hanford Site is that the HLW would be placed in a repository that would be excavated within the dense interior of one of the Columbia River Basalt flows.

The Columbia River Basalt Group has been divided inot 5 formations and 19 members (Swanson and others, 1979; Camp, 1981) (Figure 3). The areal distribution of the Columbia River Basalt Group is shown on Figure 4. ~~Because~~ the Imnaha and Picture Gorge Basalts do not crop out in the area of interest and because they are well below the repository level, ~~they~~ will not be discussed further.

The Grande Ronde Basalt, extruded 17 to 15.6 mybp, is the most areally extensive and volminous of the Columbia River Basalt Group. The known thickness rages from tens of meters along the Plateau margins to over 1,000 meters in the Pasco Basin. The only regional (i.e., at the scale of the Plateau) subdivisions are four magnetostartigraphic units, indicated on Figure 3. However, at a subregional scale, there are a number of "through-running" flows that extend over areas of at least 250 square kilometers (Long and Landon, 1981). Four of these through-running flows within the Pasco Basin are currently being considered as candidate horizons for the geologic repository (see Section 3.2.1, below).

The Grande Ronde Basalt is overlain by the Wanapum Basalt, extruded 14 to 13.5 mybp. The Wanapum Basalt has been subdivided into four recognized members regionally (Figure 3).

The youngest formation of the Columbia River Basalt Group is the Saddle Mountains Basalt, which has been divided into at least 10 members (Figure 3). The extrusion period, 13.5 to 6 mybp, was characterized by declining volcanism, the deposition of interbedded sediments (Ellensburg Formation), folding and canyon cutting.

The stratigraphy of the suprabasalt sedimentary formations is shown in Figure 5. The Ellensburg Formation is primarily weakly lithified clastic and volcanoclastic sediments derived from the Cascades. Units of the Ellensburg Formation are interbedded with and overlie Wanapum and Saddle Mountains Basalts. Fluvial deposits of the Mio-Pliocene Ringold Formation overlie the Columbia River Basalt Group. Pleistocene and Holocene deposits of alluvium, colluvium, eolian loess overlie Ringold sediments.

The Cold Creek Snycline is one of a series of eastward-trending folds that comprise the Yakima Fold Belt. The anticlines in the fold belt are typically narrow, linear and somewhat assymetrical; the synclines are typically broader than the anticlines. The ridges, buttes and mountains listed in Section 2.1 are the surface expression of the anticlines adjacent to the Cold Creek Syncline. Major faults are generally associated with the anticlines. Fault plane solutions for shallow swarm earthquakes suggest that the faults

vesicular and brecciated basalt can form up to half the thickness. The flow interior consists of entablature and colonnade. The entablature is composed of jointed rock with relatively small columns (approximately 0.2- to 1.0-meter (0.7- to 3.0-foot) diameter). The orientation of columns ranges from vertical to horizontal. The colonnade consists of relatively well-formed columns (approximately 0.5- to 2-meter (1.6- to 6.5-foot) diameter) with fewer fractures than the entablature. Columns are normally upright but radiate locally and exhibit a variety of internal features. In some flows, the entablature overlies a single colonnade; in other flows, colonnade and entablature zones may be repeated in the flow interior (Long and Davidson, 1981). The basal portion of a basalt flow is usually a thin (approximately 0.5-meter (1.6-foot)) zone of fractured, glassy basalt. Spiracles (zones of fissured glassy rock) may extend a few meters (feet) into the lower portion of a flow.

Fracture logging of basalt flows indicates that fracture abundances in core samples range from approximately 1 to 40 fractures per meter (less than 1 to 12 fractures per foot) (Long and WCC, 1984, p. I-69). Most of these fractures have narrow widths (less than 0.5 millimeter (0.02 inch)) now filled with multiple generations of secondary minerals. The exact mineral distribution in fractures will differ among basalt flows in response to varying depths of burial, fracture widths, and basalt (low composition. Dominant secondary minerals are clay, zeolite, silica, and pyrite (Long and Davidson, 1981, pp. 5-38 to 5-40). The volume of unfilled fractures, particularly in the dense interior of basalt flows, is typically small, less than 0.4 volume percent.

2.1.1.1 Stratigraphy

Regional geologic maps at a scale of 1 to 250,000 define the stratigraphy and structure of the Columbia River Basalt Group that is generally coincident with the Columbia Plateau (Swanson et al., 1979a, 1981). A compilation of these maps shows a plateau-wide basalt stratigraphy. Figure 2-4 gives the stratigraphic nomenclature for the Columbia River Basalt Group of the Columbia Plateau. Basalt flows throughout the region can be correlated through a combination of chemical, paleomagnetic, and field techniques.

The Columbia River Basalt Group has been divided into 5 formations, 19 members, and 4 informal paleomagnetic subdivisions (Swanson et al., 1979b, pp. 6 and 7; Camp, 1981, pp. 669 through 678). The oldest formation (approximately 17 million years old), the Imnaha Basalt, crops out only within the extreme southeastern portion of the Columbia Plateau where it is conformably overlain by flows of the Grande Ronde Basalt. The Picture Gorge Basalt that is 15.8 to 14.6 million years old crops out only in the southwestern portion of the plateau and is considered partly equivalent in age to the Grande Ronde Basalt.

The Grande Ronde Basalt is the most areally extensive and voluminous unit of the Columbia River Basalt Group underlying most of the Columbia Plateau (Fig. 2-5). The basalt comprising this formation was extruded

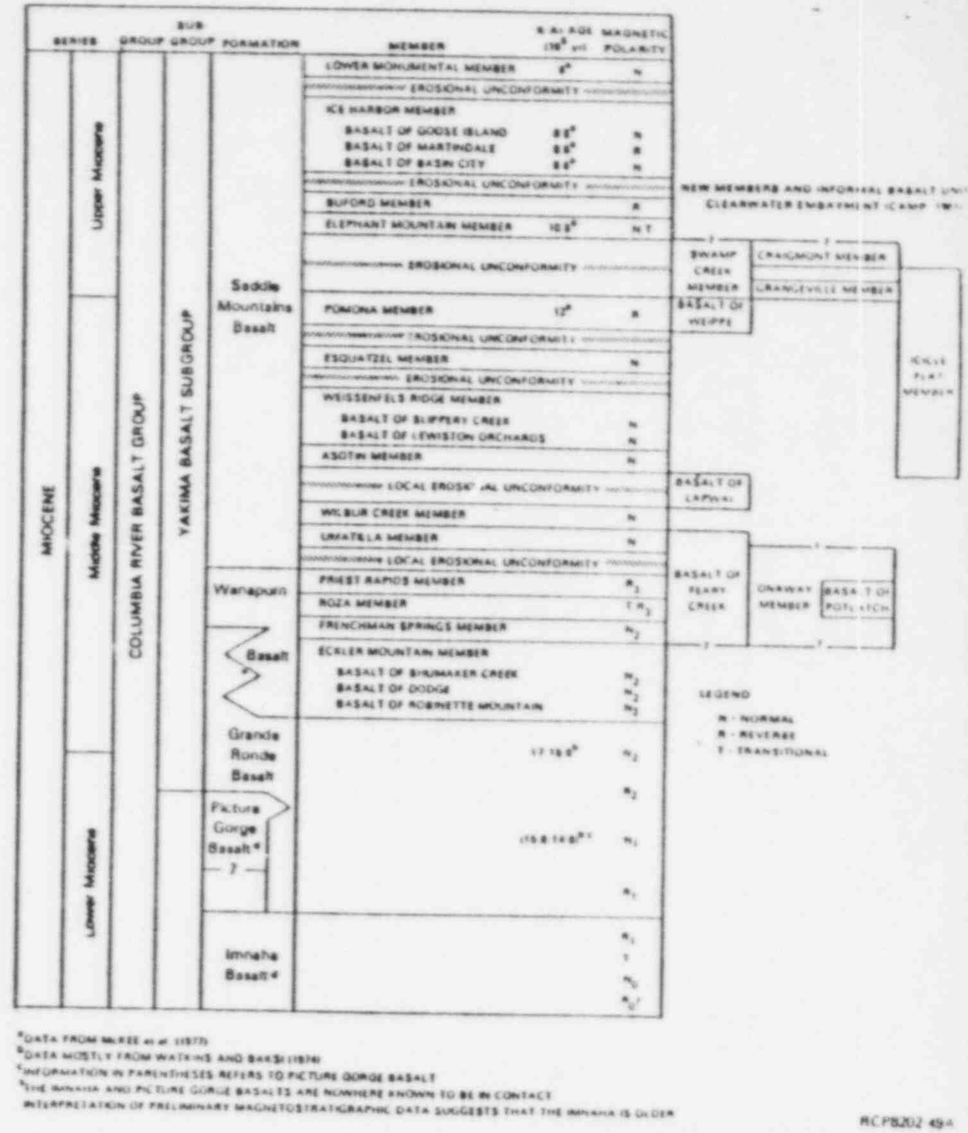

Figure 2-4. Stratigraphic nomenclature for the Columbia River Basalt Group of the Columbia Plateau (after Swanson et al., 1979b).

Figure 3

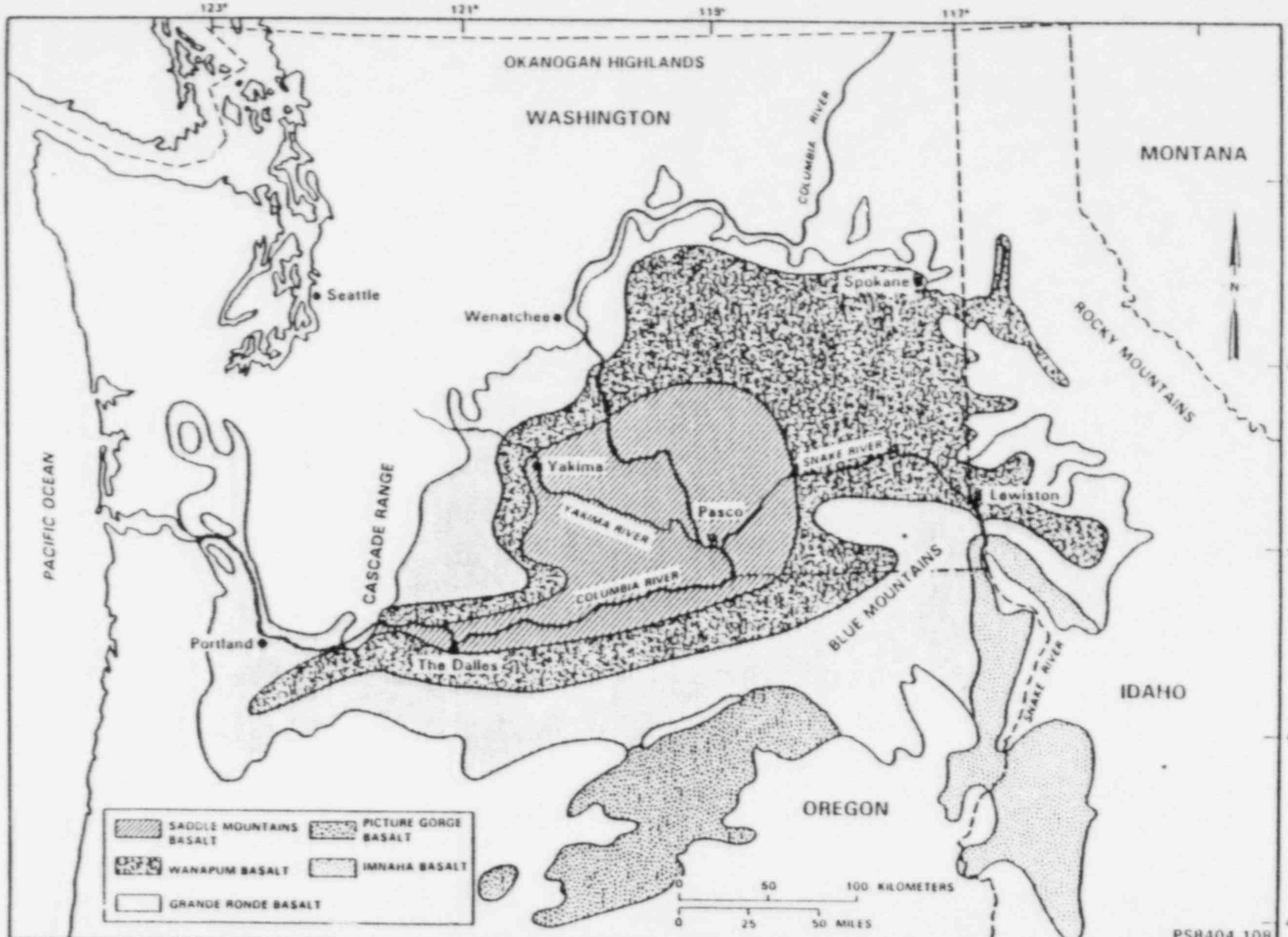

Figure 2-5. Distribution of Columbia River Basalt Group (after Wright et al., 1973).

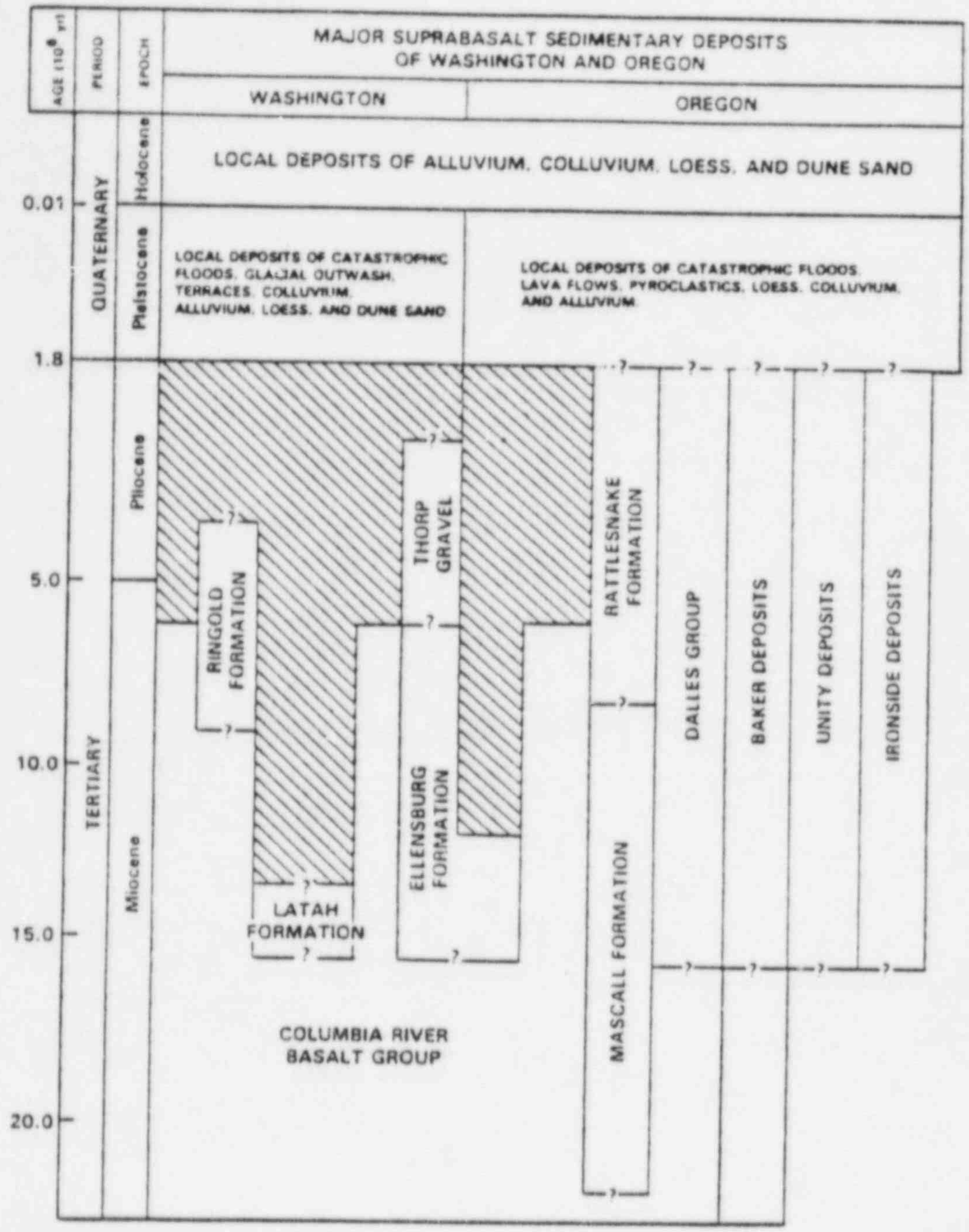

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Figure 2-6. General stratigraphic relationship of suprabasalt sediments.

Figure 5

are reverse faults parallel to the axial planes of the anticlines. A generalized structure cross-section is presented in Figure 6.

Internal structures that formed during the emplacement and subsequent cooling of the lava are termed "intraflow structures" (DOE, 1984). Particularly important are the cooling joints that produce polygonal columns ~~are~~ and hackly blocks. In general, three major intraflow structures are regognized: Vesicular or brecciated flow tops; irregular and discontinuously jointed entablature near the middle of a flow; and more regularly jointed colonnade near the bottom of the flow (Figure 7). The bottom of a flow is typically a thin (approximately 0.5 meter) zone of fractured, glassy basalt. The three major intraflow structures may vary in thickness, be absent from a given flow, or occur repeatedly within a single flow. The orientation of joints and fractures is typically nearly vertical, but occasionally approach horizontal. Radiating Columnar joints have been observed in surface exposures of basalt flows. Limited core data indicates that ~~there is~~ secondary mineralization occurs in the fractures.

3.0 GEOLOGY OF THE PASCO BASIN AND RRL

3.1 PHYSIOGRAPHY AND GEOMORPHOLOGY

The RRL is located in the west-central portion of the Pasco Basin, near the boundary between the Yakima Folds and the Central Plains morphologic sections of the Columbia Intermontaine province. Shown in Figure 8 are the major landform systems of the Pasco Basin. The basin-and-valley terrain in which the RRL is located consists of low-relief, sediment-filled portions of the Central Plains and synclinal valleys of the Yakima Folds.

Four geomorphic units are defined within the RRL (Figure 9). The Umtanum Ridge Bar and the 200 Areas Bar are gravel bars formed during catastrophic Pleistocene flooding. The Central Hanford Sand Plain was formed by the deposition of finer grained sediments on the lee of the Umtanum Ridge Bar. The predominant materials are granules of fine grained sand and silt. Holocene alluvium along Cold Creek is superimposed on the western portion of the Central Hanford Sand Plain.

3.2 STRATIGRAPHY

The stratigraphic units present in the Pasco Basin are illustrated in Figure 10. The Columbia River Basalt Group is represented by the Grande Ronde, Wanapum and Saddle Mountains Basalts. Interbedded Miocene sediments are ~~referred to~~ the Ellensburg Formation. The basalt sequence is overlain by semiconsolidated to unconsolidated sediments of the Ringold and Hanford Formations and by unconsolidated surficial deposits.

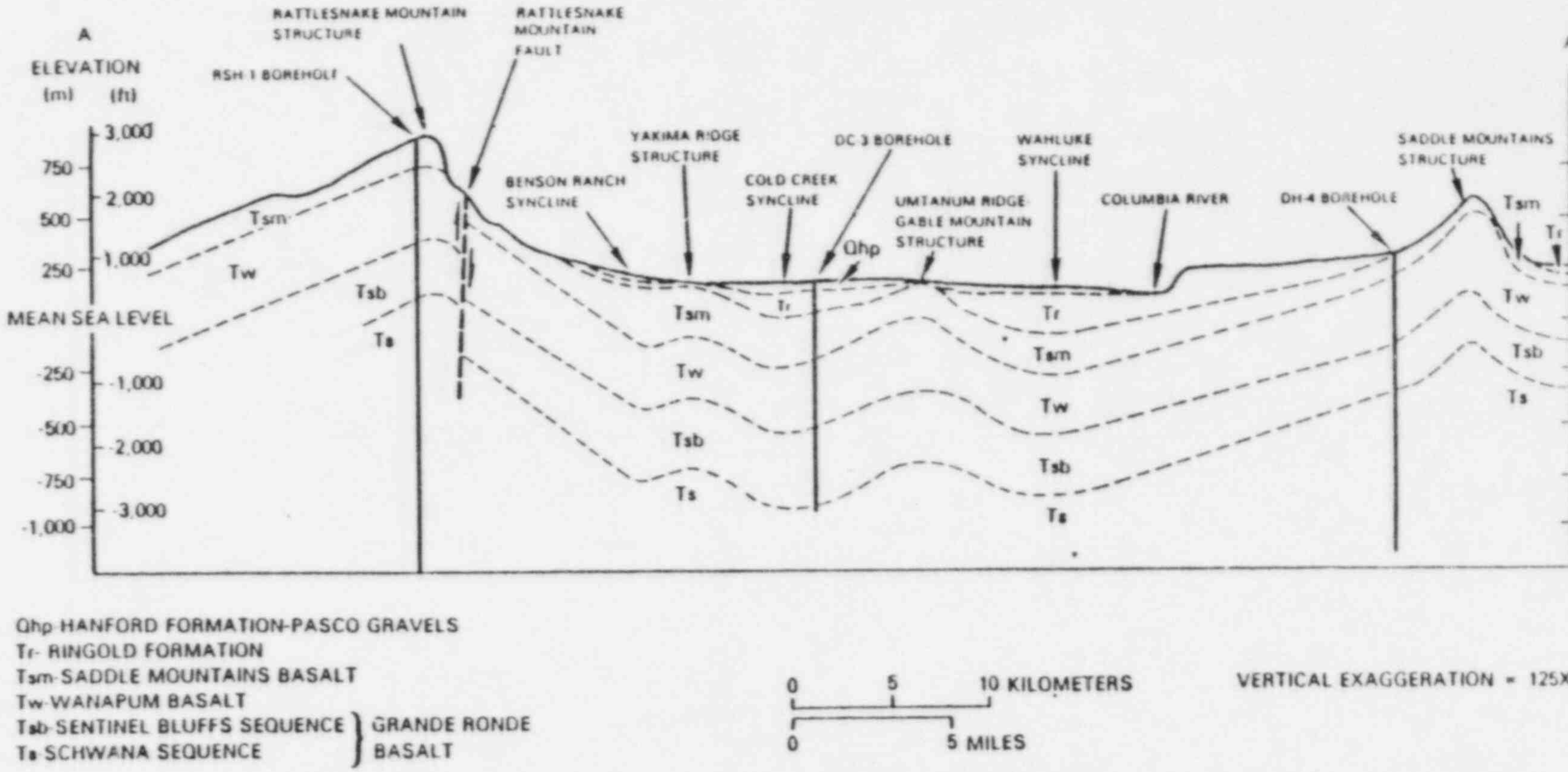

Figure 2.2 Generalized structure cross section

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Figure 6

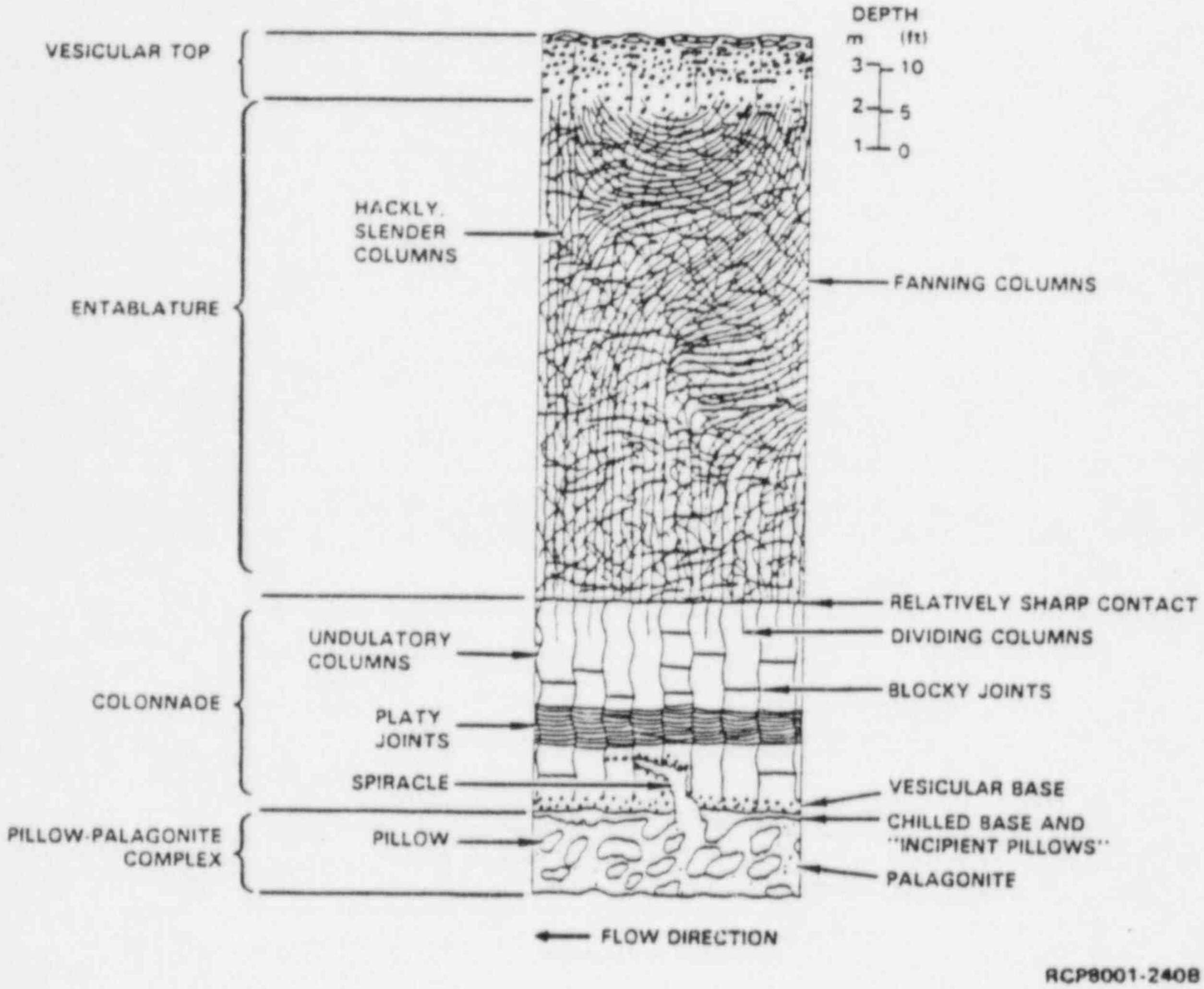

Figure 2-3. Cross section of a typical flow in the Columbia River Basalt Group illustrating, in idealized form, jointing patterns and other structures (from Swanson and Wright, 1976).

Figure 7

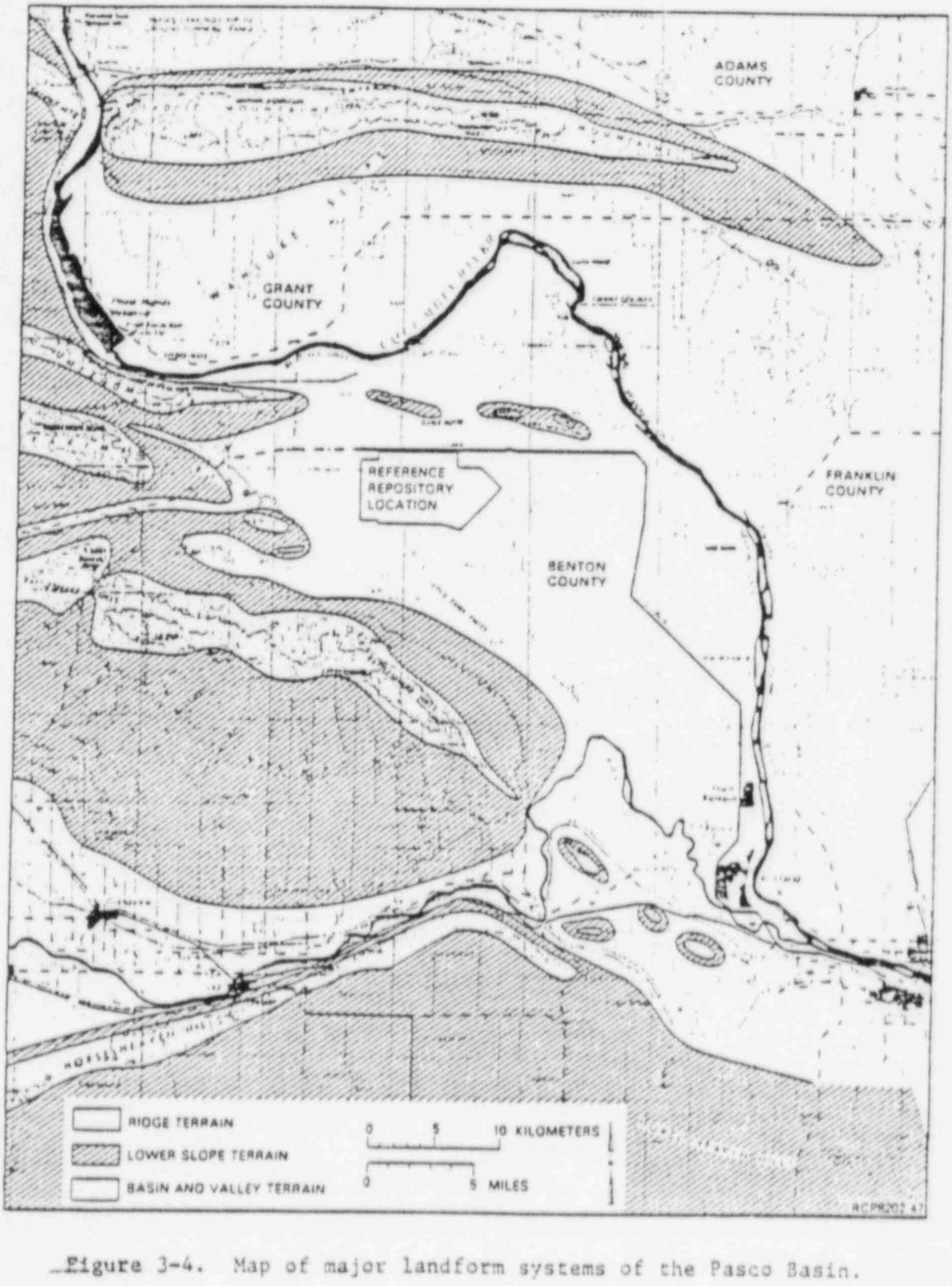

Figure 3-4. Map of major landform systems of the Pasco Basin.

Figure 8

Figure 9
3-7

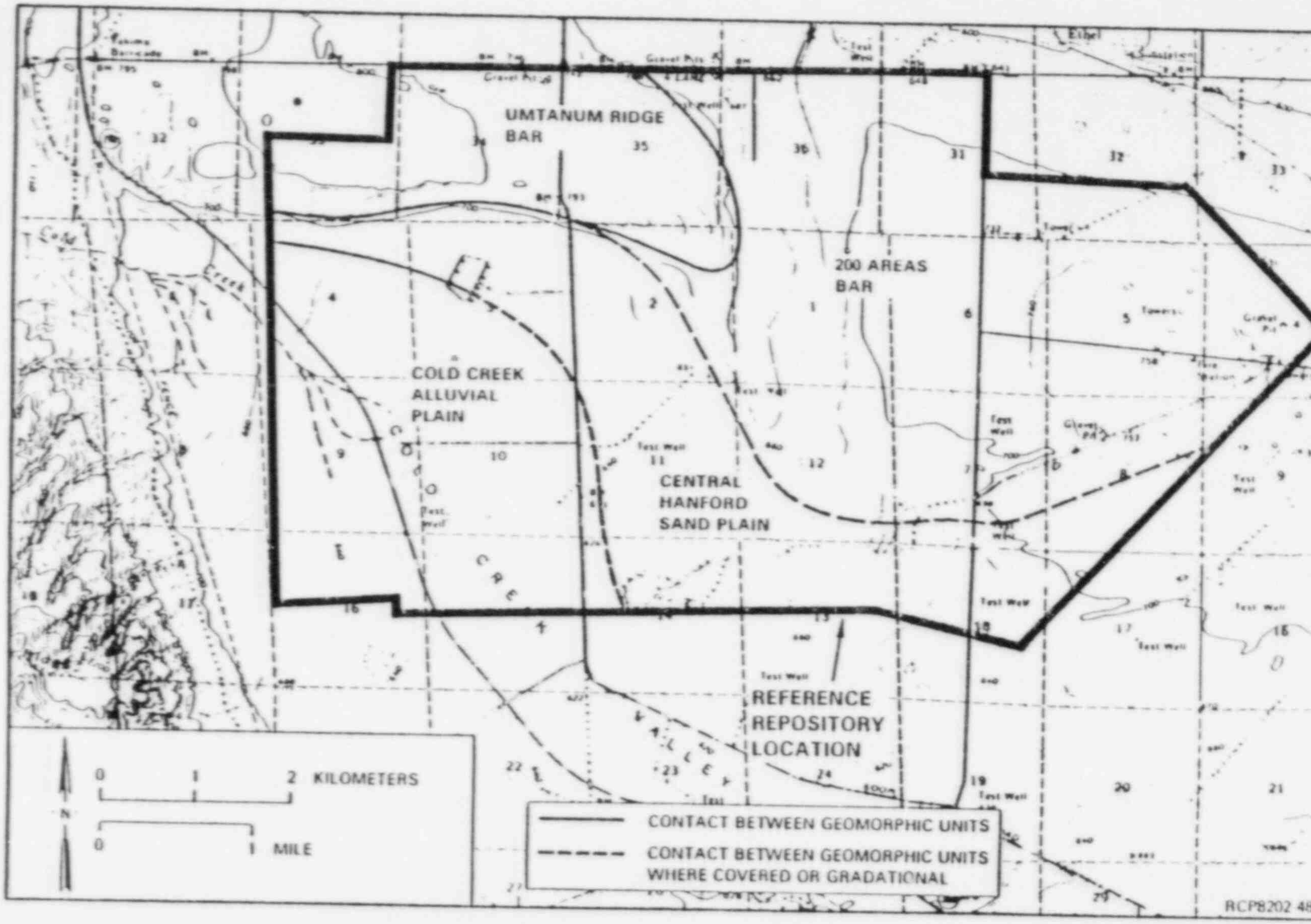

Figure 3-5. Geomorphic map of the reference repository location.

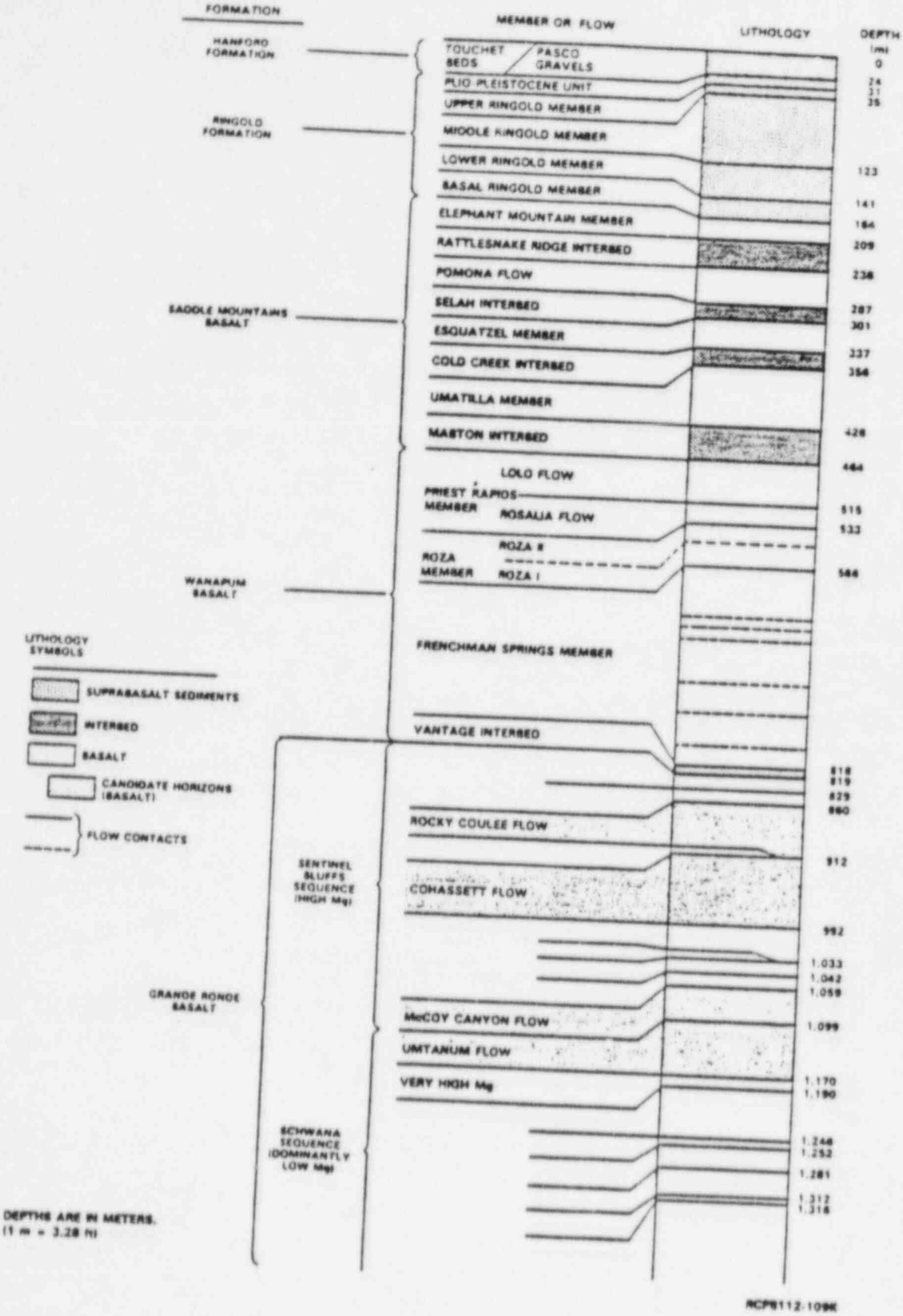

Figure 2-29. General stratigraphy of the reference repository location showing position of the candidate horizons. Depths are from borehole RRL-2.

Figure 10

3.2.1 Grande Ronde Basalt

In the Pasco Basin the Grande Ronde basalt comprises at least 56 flows. The basalt is typically fine grained a aphyric or sparsely microphyric with few consistent textural differences. Flows are correlated on the basis of magnetostratigraphy and chemical composition. Two informal "through-runner" units identified in the basin are termed the Schwana and Sentinel Bluffs sequences. Four flows in the Grande Ronde have been identified as potential candidate horizons: the Umtanum Flow of the Schwana Sequence and the McCoy Canyon, Cohassett and Rocky Coulee Flows of the Sentinel Bluffs Sequence. Figure 11 is a generalized geologic section through the RRL illustrating the subsurface distribution of the major stratigraphic units of interest.

3.2.1.1 Umtanum flow

The Umtanum flow is the lowermost candidate horizon; the top of the flow lies at approximately 1059 to 1135 meters below ground surface in the RRL. The Umtanum appears to be thicker to the northwest and southeast of the RRL than it is in the center of the Cold Creek syncline area. In the RRL, the Umtanum varies in thickness, ranging from about 60 to about 70 meters (figure 12). The dense interior of the flow also varies in thickness (Figure 13), but appears to be everywhere greater than about 24 meters thick, based on current borehole informaton. Within the RRL the brecciated flow top appears to be quite thick and highly variable, apparently similar to the exposed section at Emerson Nipple. ~~based~~ The thick flow top is particularly evident ~~on the results from~~ in Borehole RRL-2.

3.2.1.2 McCoy Canyon flow

The McCoy Canyon flow is the lowermost of the Sentinel Bluffs flows; the top of the flow ~~lies from~~ is approximately 1025 to 1090 meters below ground surface. The flow generally thins from northwest to southeast, ranging from about 45 meters to about 34 meters thick across the RRL (Figure 14). Multitiered intraflow entablature and colonnade structures give a total dense interior of about 30 meters across the RRL, but the dense interior has sporadic vesicular zones that reduce the potentially available dense interior volume for a repository. Fig 15 ?

3.2.1.3 Cohassett flow

The Cohassett flow is stratigraphically near the middle of the Sentinel Bluffs sequence; the top of the flow ~~lies~~ is 896 to 943 meters below the ground surface. The flow is thickest in the central Pasco Basin, is relatively constant near 80 meters in thickness across the RRL, and thins to the southeast (Figure 150). Although the Cohassett flow is the thickest candidate flow within the RRL, the multitiered entablature/colonnade structures cannot be correlated from borehole to borehole. ~~and there is a~~ A laterally continuous vesicular zone of

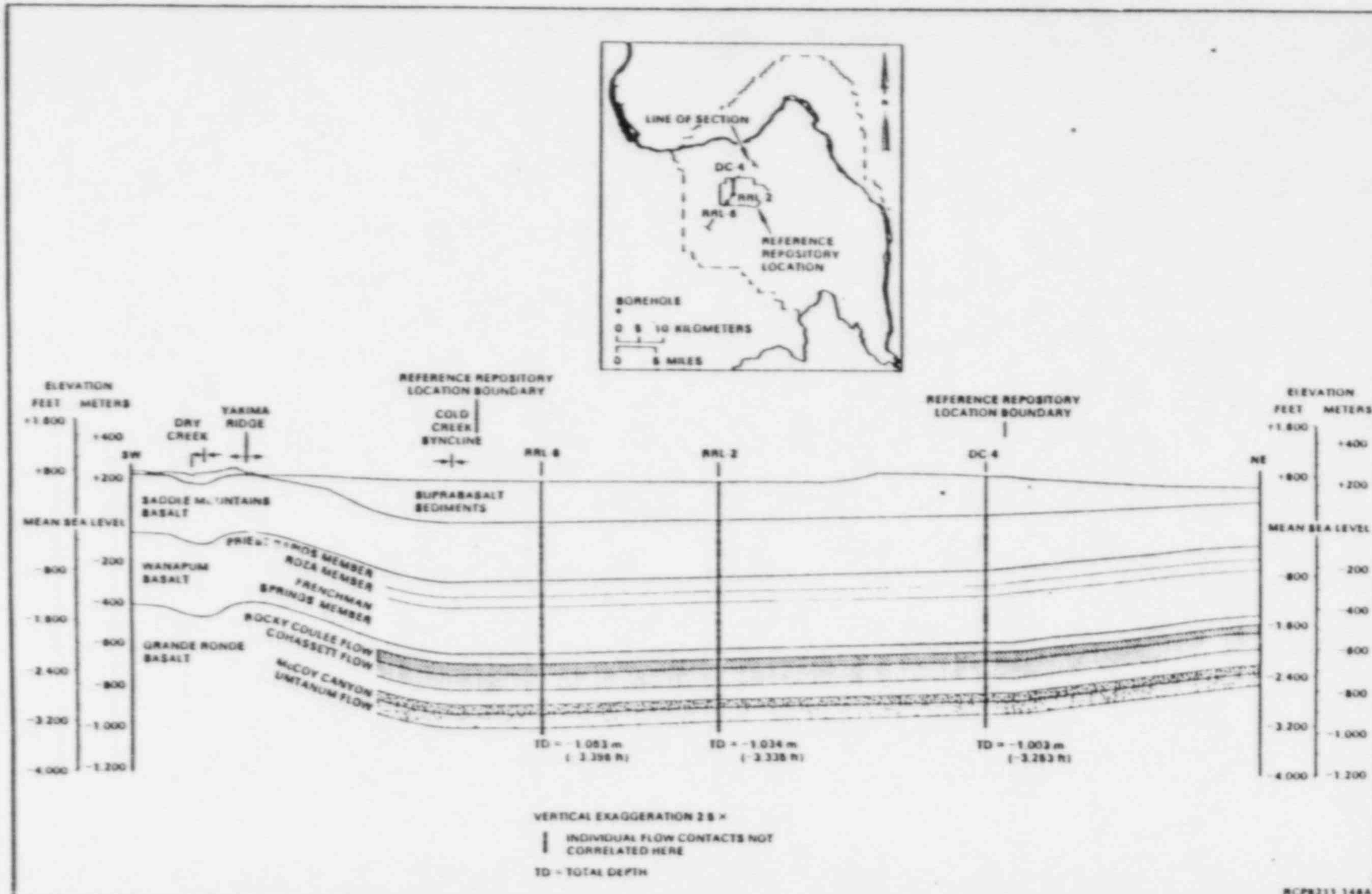

Figure 3-8. Geologic cross section through the reference repository location.

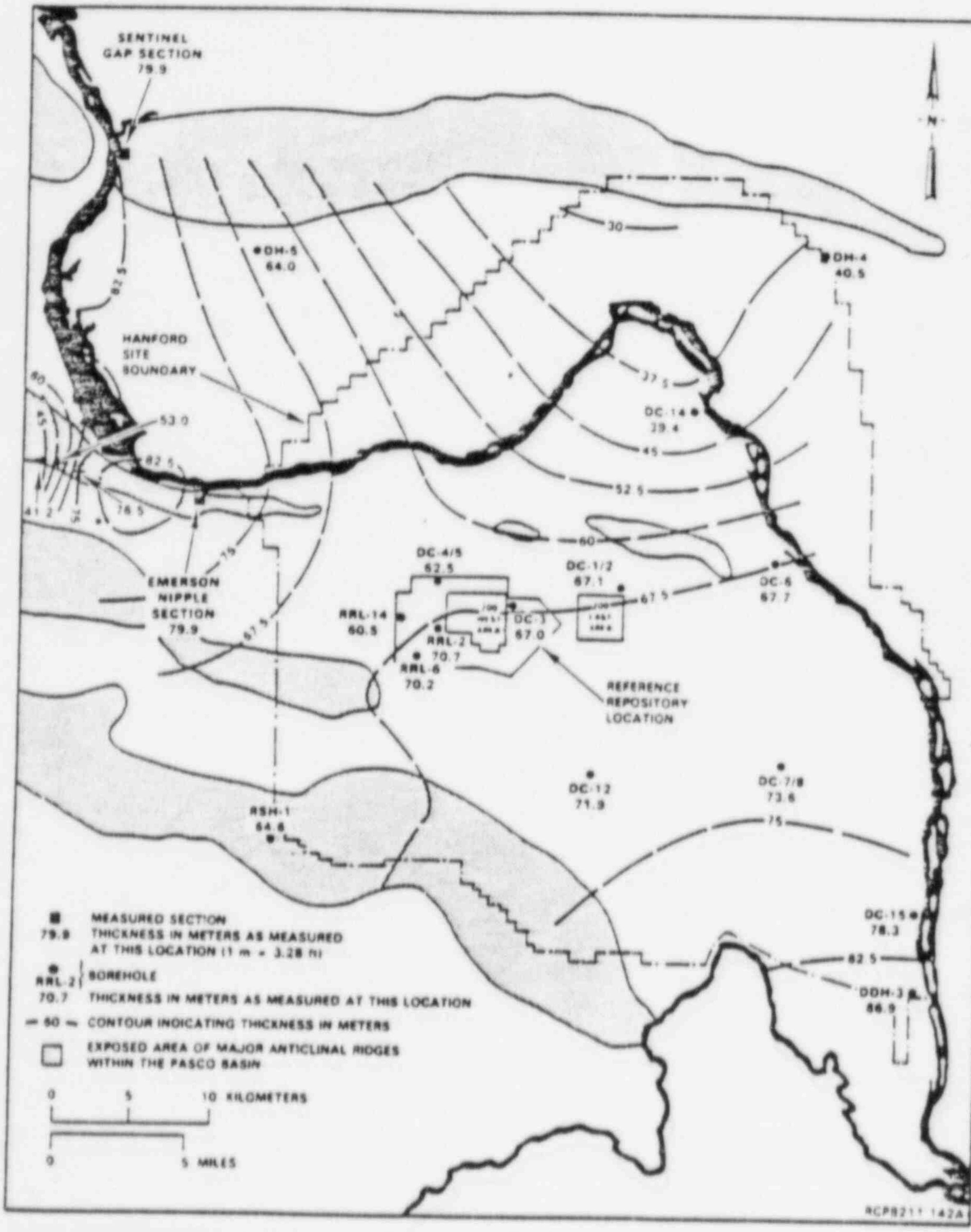

Figure 3-12. Umtanum flow isopach map.

Figure 12

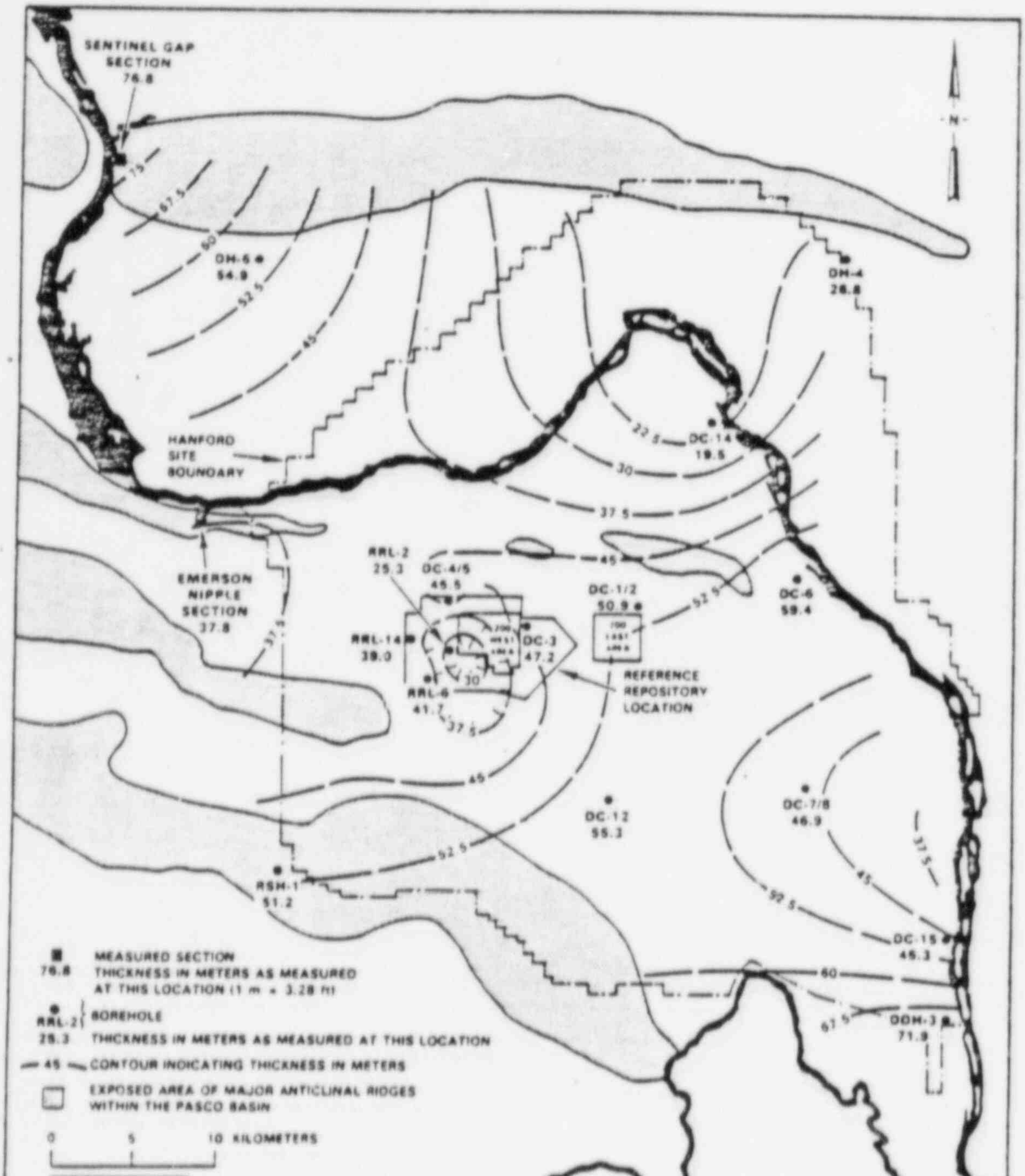

Figure 3-11. Isopach map of the dense interior of the Umtanum flow.

Figure 13

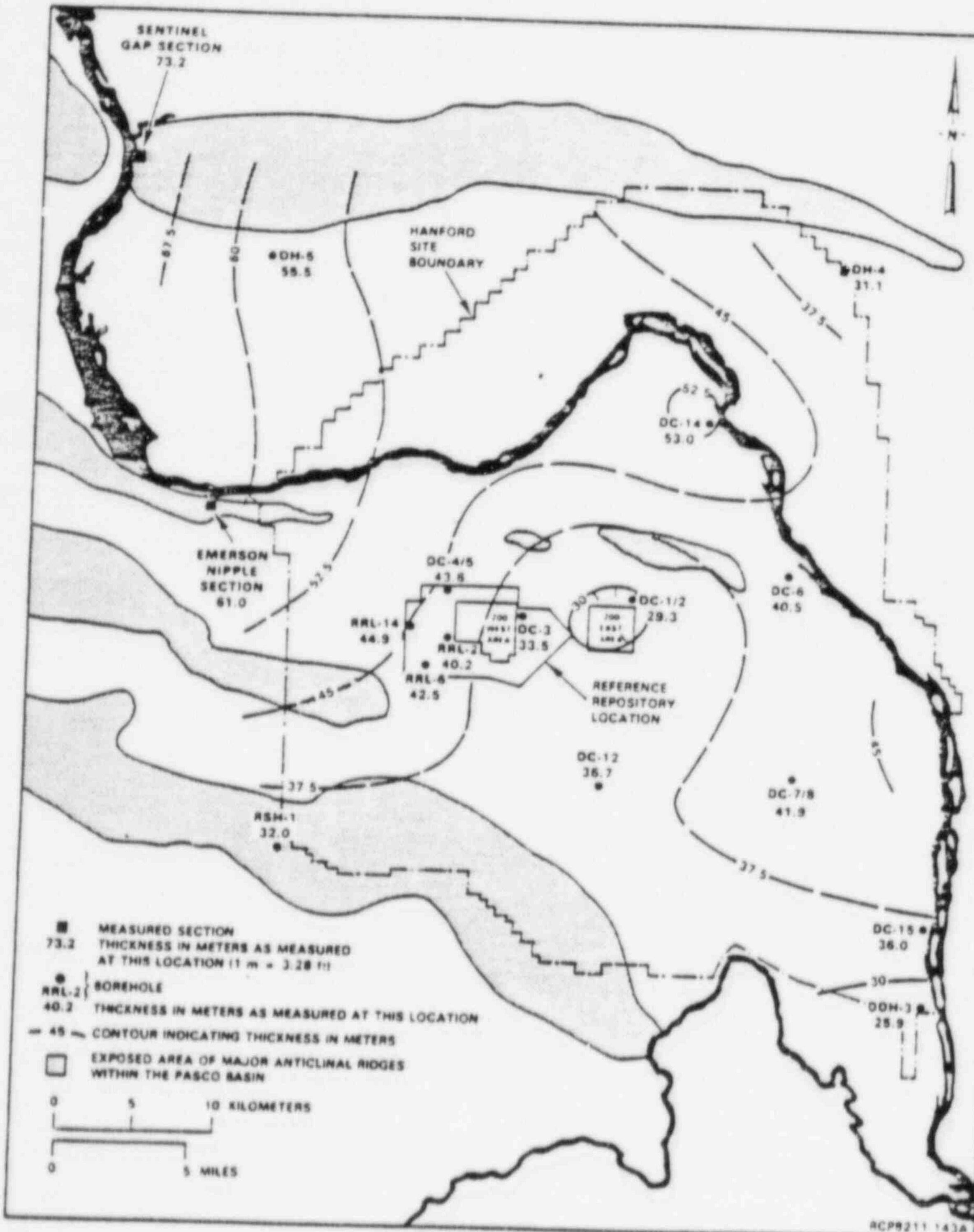

Figure 3-13. McCoy Canyon flow isopach map.

Figure 14

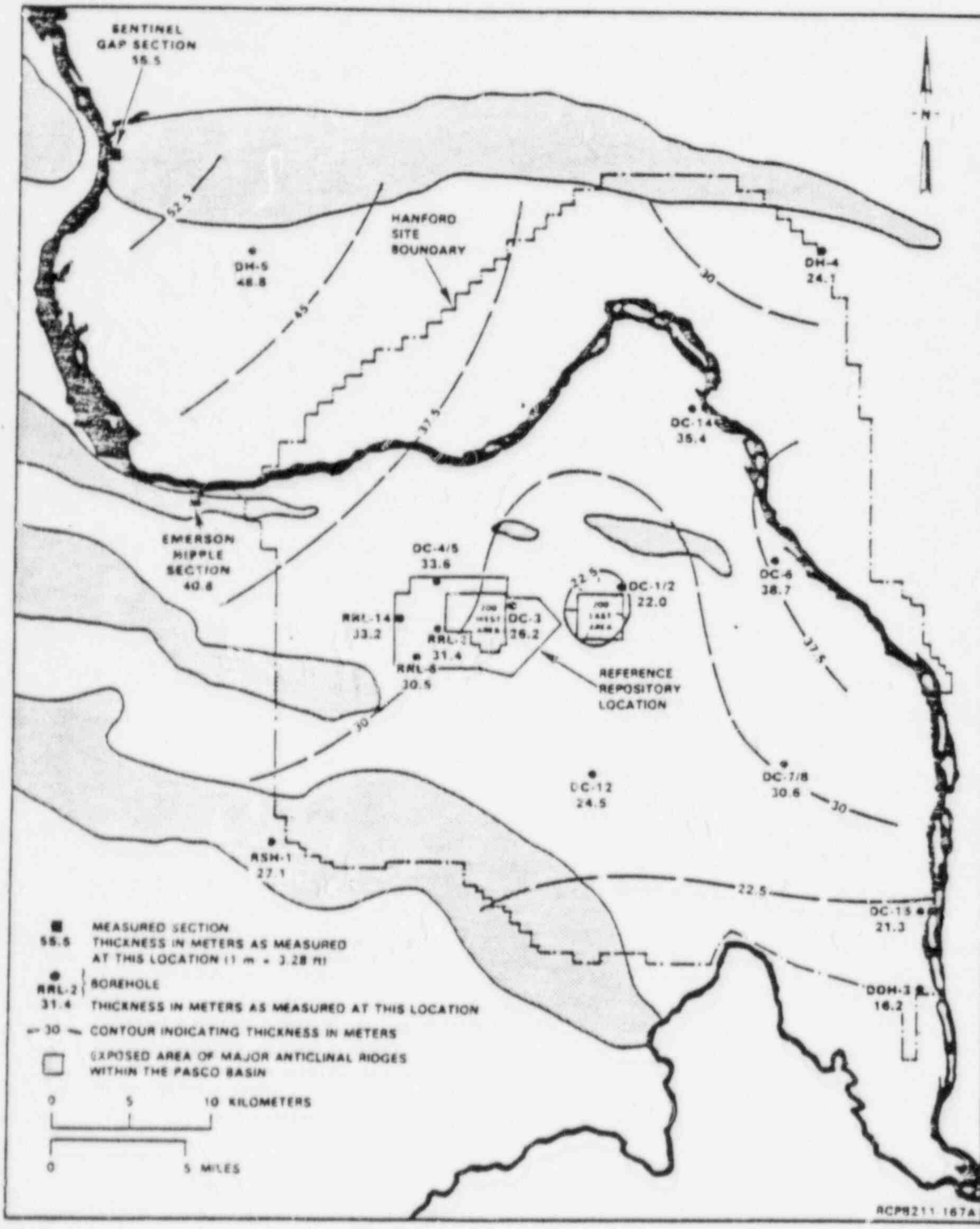

Figure 3-14. Isopach map of the dense interior of the McCoy Canyon flow.

not correctly referenced on text

Figure 15

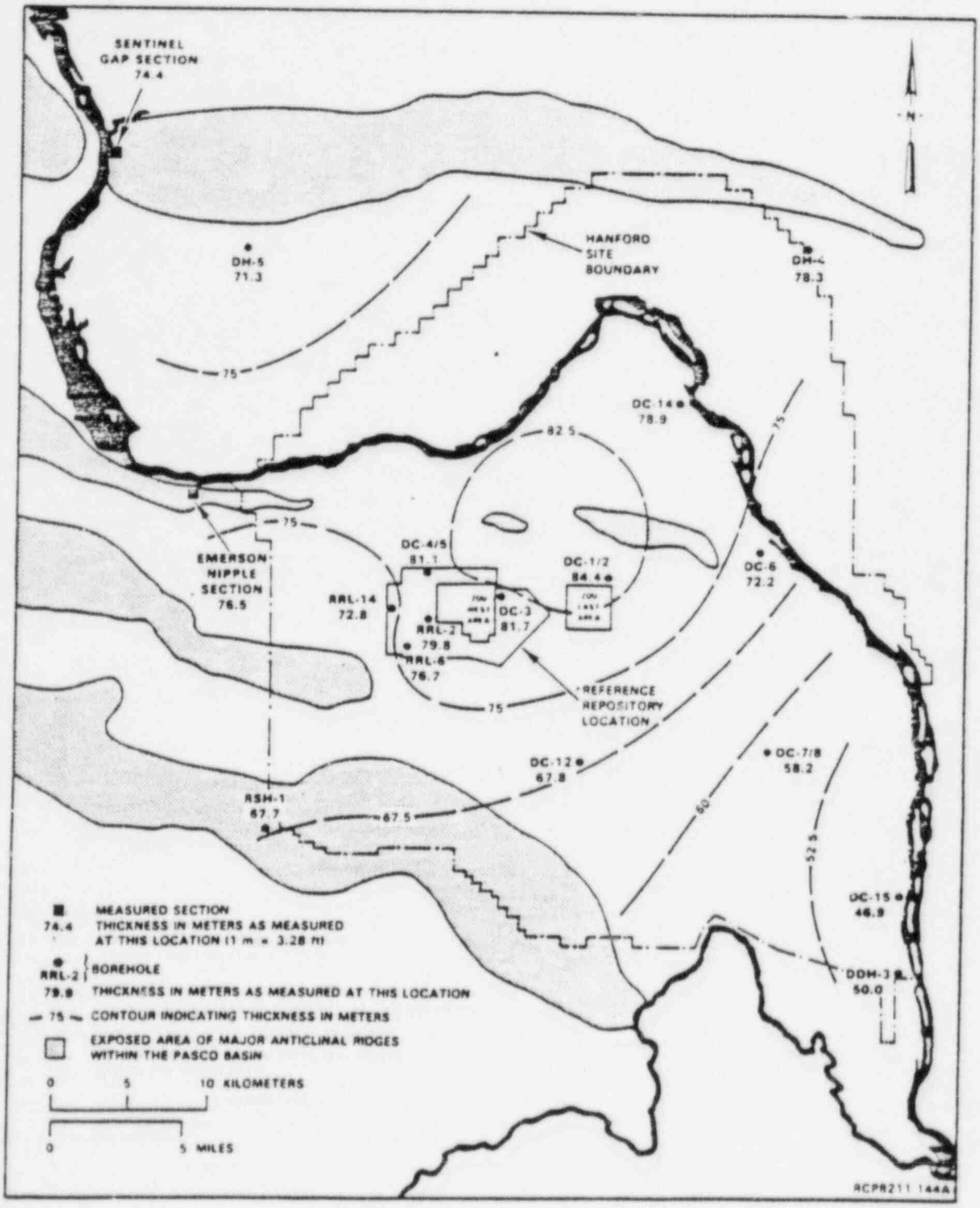

Figure 3-15. Cohassett flow isopach map.

3 to 8.5 meters thickness about 30 meters from the top of the flow that divides the dense interior into an upper and a lower zone (Figure 16 and 17). The dense interior below the vesicular zone ranges from 36 to 46 meters in thickness.

3.2.1.4 Rocky Coulee flow

The Rocky Coulee flow is the uppermost candidate horizon, occuring in the upper third of the Sentinel Bluffs Sequence. The Rocky Coulee flow thins from about 55 meters thick to about 43 meters thick from west to east across the RRL (Figure 18). The dense interior of the flow ranges in thickness from about 27 to about 47 meters, thinning significantly to the northwest across the RRL as a result of vesiculation beneath the flow top (Figure 19).

3.2.2 Wanapum Basalt

Within the Pasco Basin the Wanapum Basalt consists of three members: Frenchmen Springs, Roza and Priest Rapids. The Vantage interbed separates the formation from the undelying Grande Ronde; the Mabton interbed separates the formation from the overlying Saddle Mountains Basalt. The total thickness of the Wanapum Basalt in the RRL is about 335 meters.

3.2.2.1 Frenchman Springs Member

The Frenchman Springs is the oldest Wanapum member and consist of 7 to 9 flows or lobes within the Cold Creek syncline. The flows or flow lobes cannot be consistently correlated from hole to hole. In the RRL it is about 215 meters thick, but thins abruptly onto the Rattlesnake Mountain structure south of the Cold Creek Syncline.

3.2.2.2 Roza Member

The Roza Member is comprised of one to two flows or flow lobes in the RRL, where it is about 53 meters thick. The Roza thins across Rattlesnake Mountain and the Umtanum Ridge-Gable Mountain structure.

3.2.2.3 Priest Rapids Member

The Priest Rapids Member comprises the distinct Rosalia and Lola flows, which appear to be present throughout the Cold Creek snycline. The Priest Rapids is about 46 meters thick in the RRL, thinning across the Rattlesnake Mountain and Umtanum Ridge-Gable Mountain structures.

3.2.3 Saddle Mountains Basalt

In the RRL the Saddle Mountains Basalt is represented by four members: Umatilla, Esquatzel, Pomona, and Elephant Mountain Members.

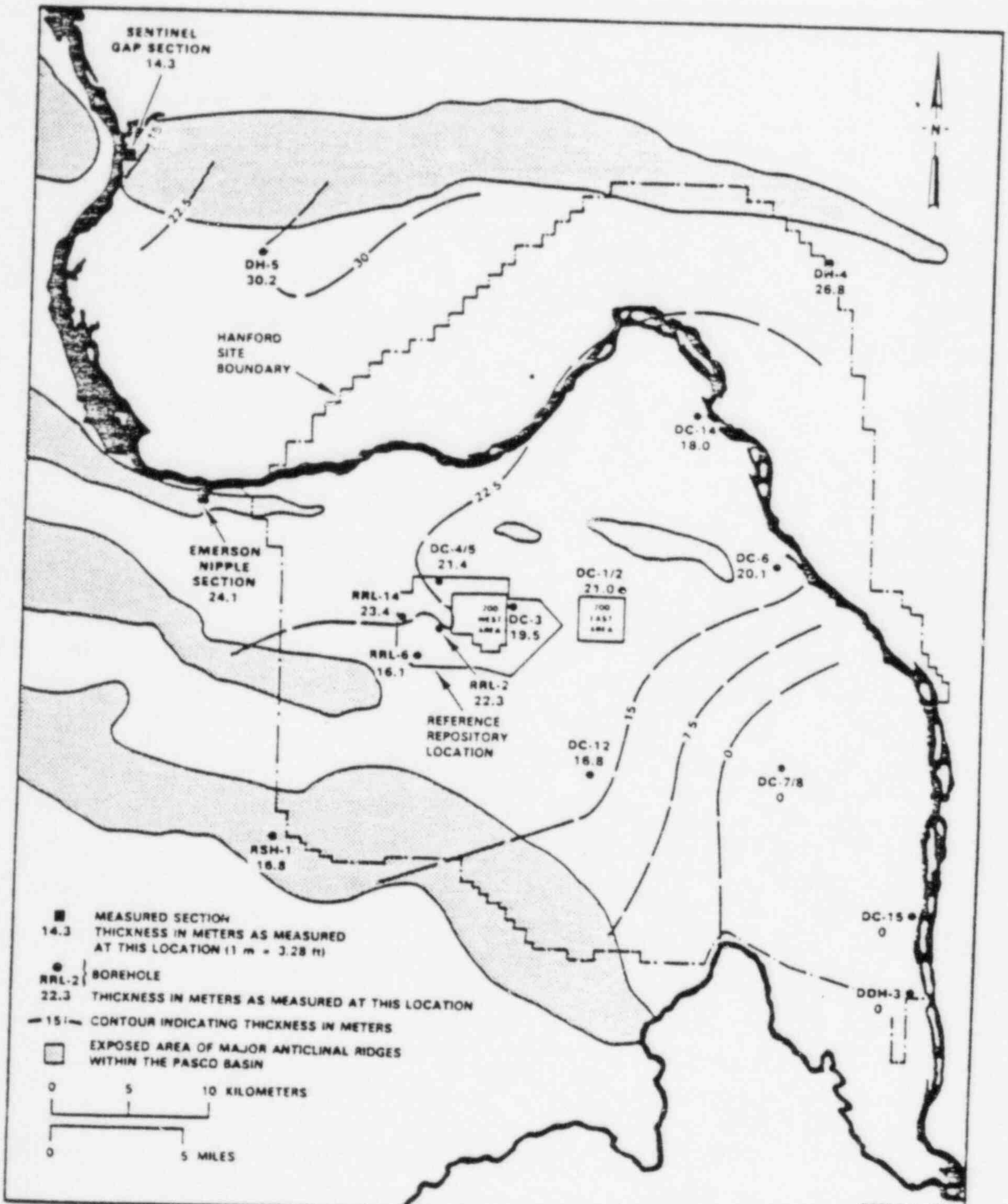

Figure 3-16. Isopach map of the dense interior of the Cohassett flow above the vesicular zone.

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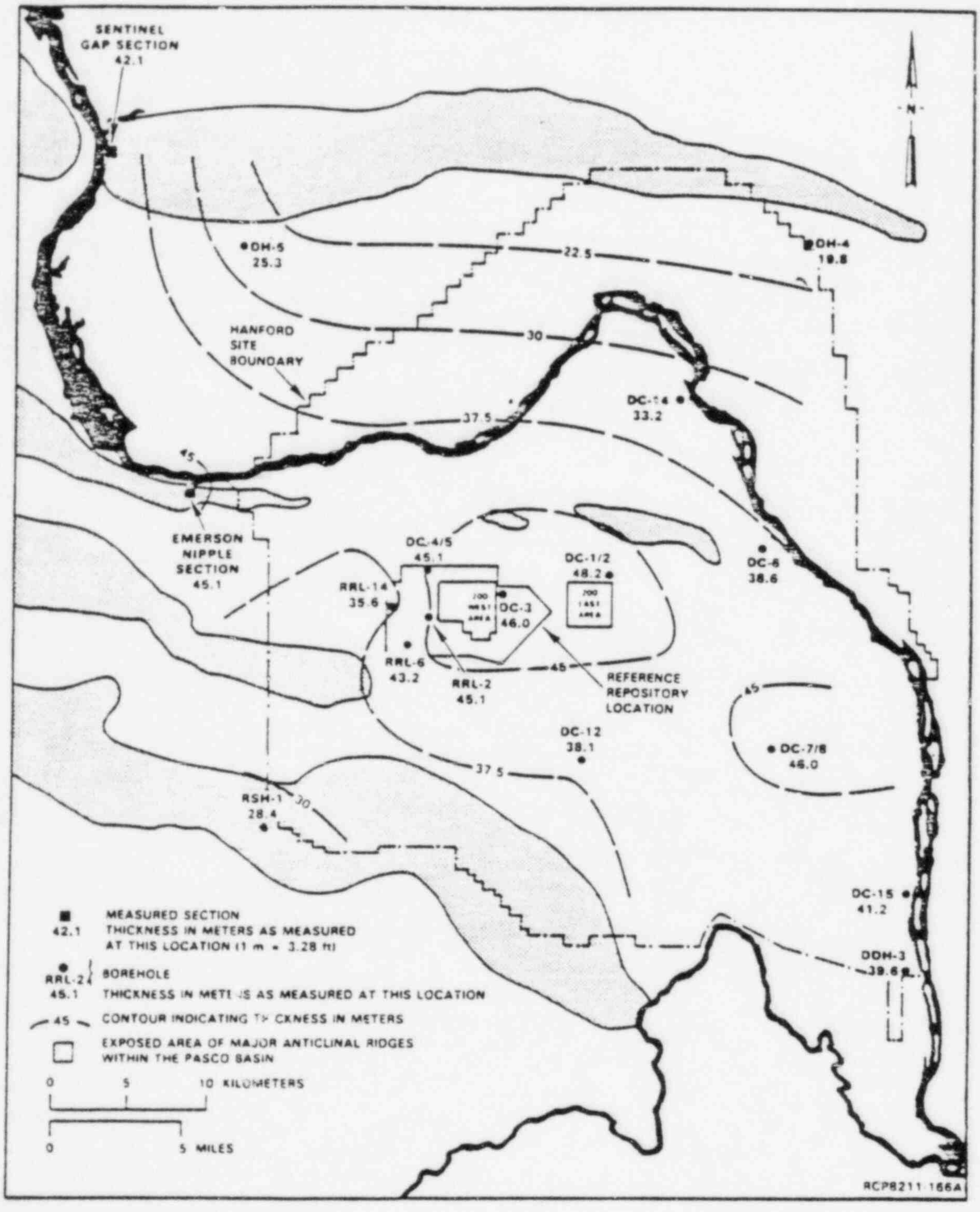

Figure 3-17. Isopach map of the dense interior of the Cohassett flow below the vesicular zone.

Figure 18

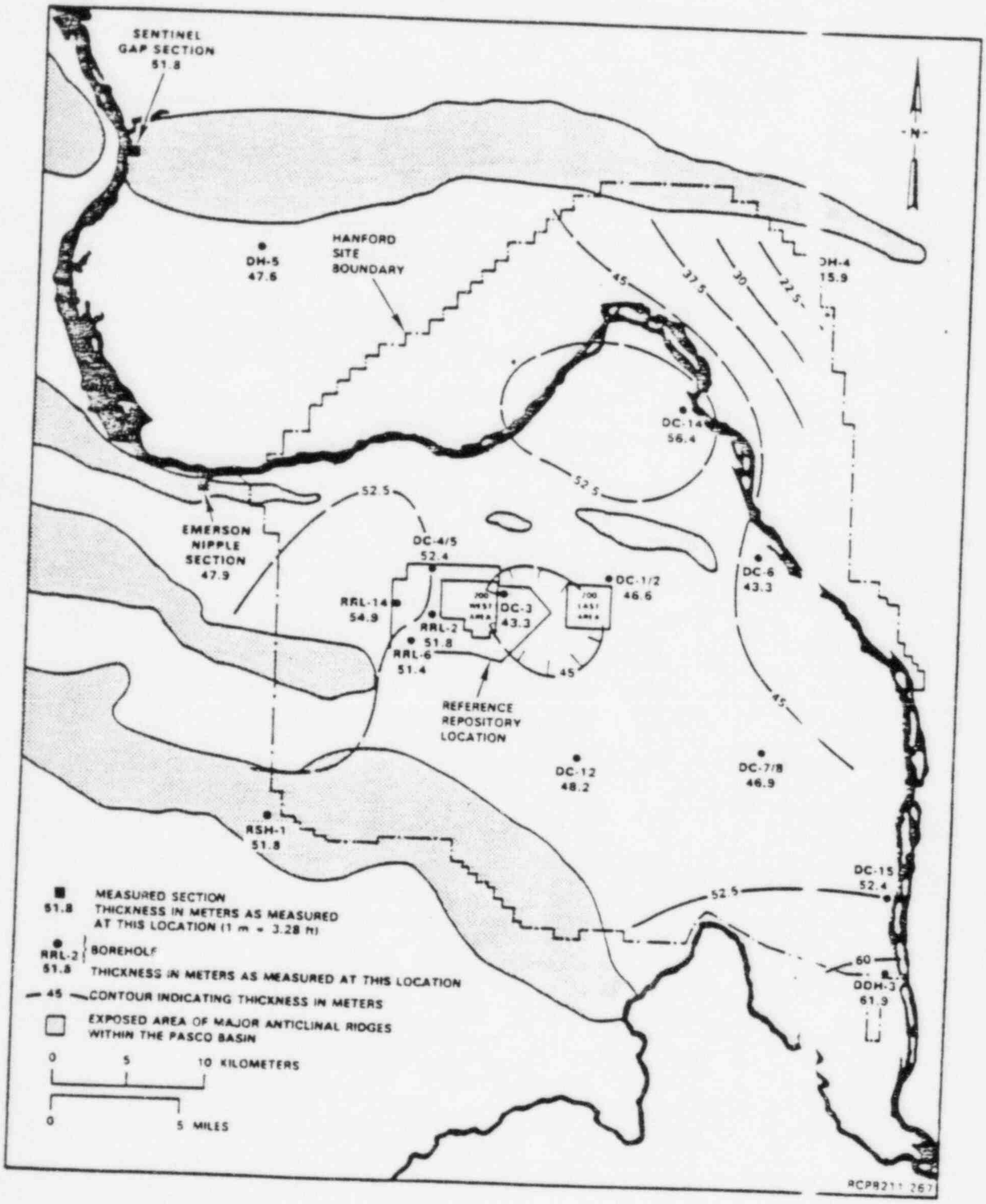

Figure 3-18. Rocky Coulee flow isopach map.

Figure 19

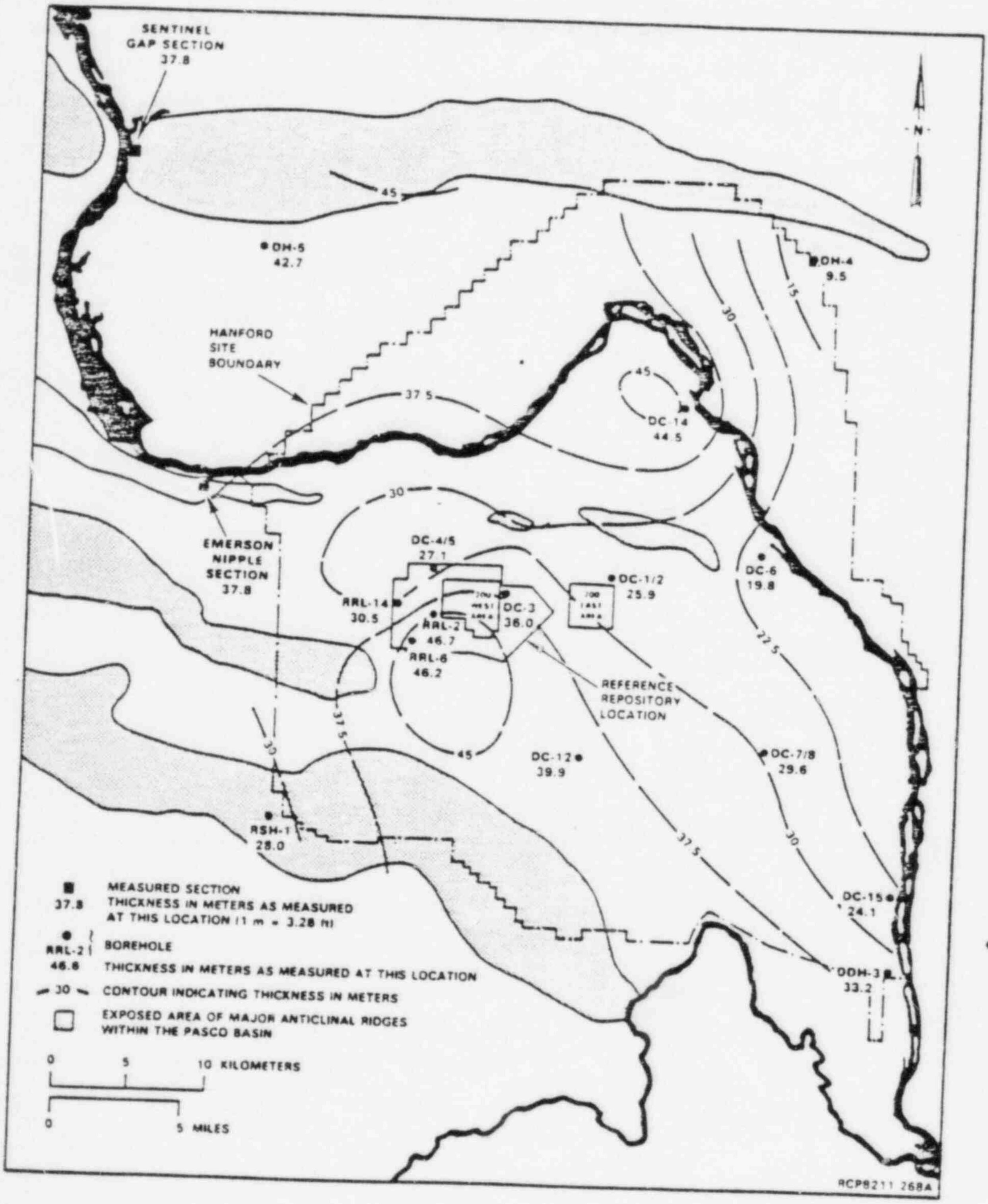

Figure 3-19. Isopach map of the dense interior of the Rocky Coulee flow.

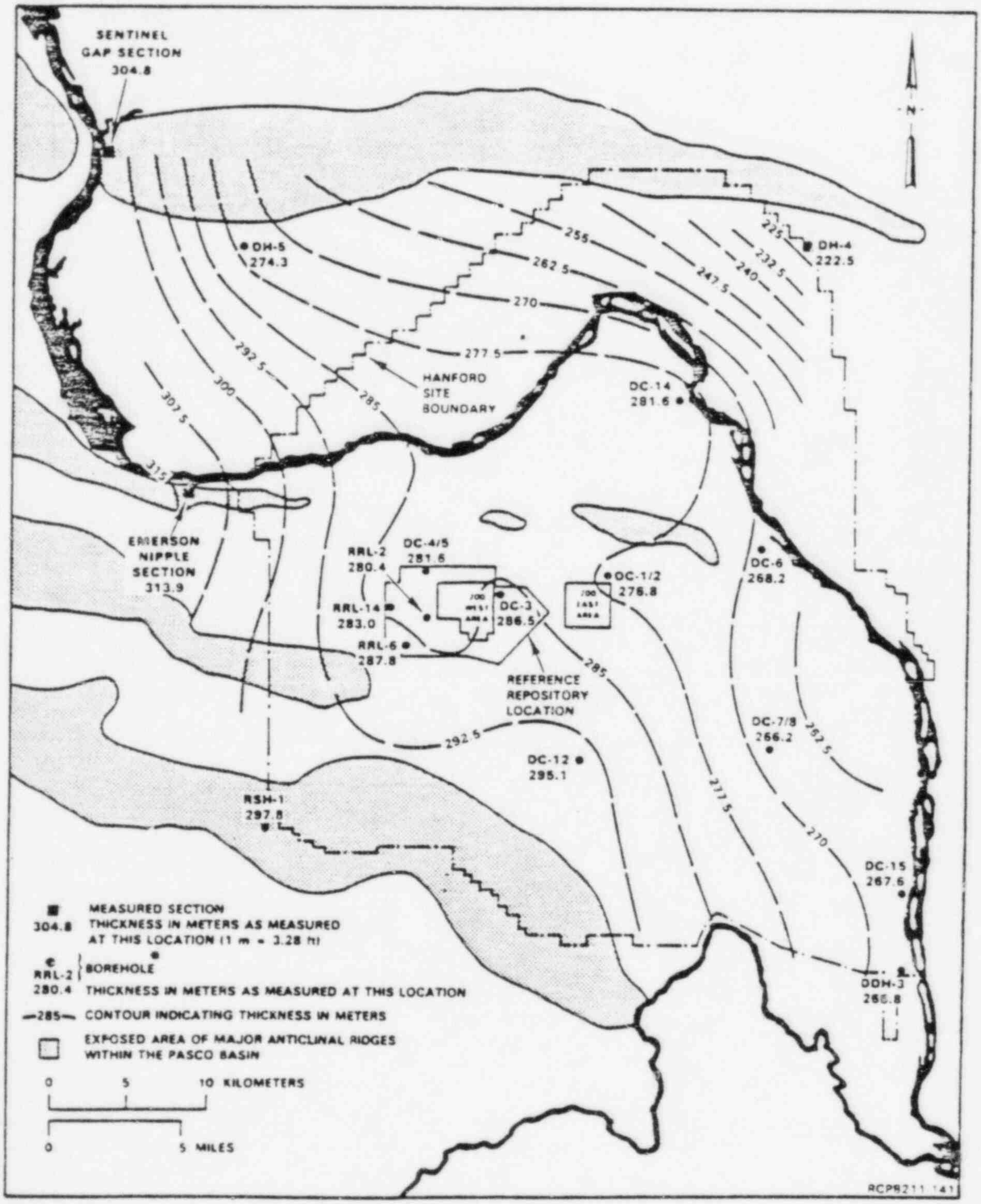

Figure 3-9. Sentinel Bluffs sequence isopach map.

Figure not referenced

Figure 21

3.2.3.1 Umatilla Member

The Umatilla Member comprises the Sillusi and Umatilla flows, which together total about 70 meters thickness in the RRL. The member has a wedge-shaped geometry, thinning to the north and pinching out north of the Umtanum Ridge-Gable Mountain structure and east of the Cold Creek syncline.

3.2.3.2 Esquatzel Member

The Esquatzel Member consists of one to two flows or flow lobes, locally separated by a vitric tuff; total thickness in the RRL is about 70 meters. The member is confined to the southern and eastern parts of the Pasco Basin, pinching out on the Rattlesnake Mountain and Umtanum Ridge-Gable Mountain Structures.

3.2.3.3 Pomona Member

Although one to two flows are present in the Pasco Basin, within the RRL the Pomona member is represented by only one flow, approximately 80 meters thick. As with the other members of the Saddle Mountains Basalt, the Pomona thins over the anticlinal structures that bound the Cold Creek syncline.

3.2.3.4 Elephant Mountain Member

Within the Pasco Basin the Elephant Mountain Member consists of two flows, but in the RRL only the Elephant Mountain flow is present. The flow is about 25 meters thick in the RRL. The member is thickest in the eastern part of the Cold Creek syncline, thinning both toward the Rattlesnake Mountain anticline and to the northwest within the syncline, The Elephant Mountain defines the top-of-basalt over most of the Cold Creek syncline on the Hanford reservation.

3.2.4 Ellensburg Formation

The Ellensburg Formation is a Miocene fluvial sequence with volcanoclastic sediments; interbedded primarily with the Wanapum and Saddle Mountains Basalts. There are two distinct lithologies, representing distinct provenance: volcanoclastic sediments deposited as ashfalls and as fluvial sediments derived from the Cascade Range and clastic plutonic and metamorphic sediments deposited by westward flowing fluvial systems draining the Rocky Mountains. Nomenclature of the Ellensburg Formation is given in Figure 20.

Figure ?

3.2.5 Suprabasalt Stratigraphy

The Columbia River Basalt Group (including the interbedded Ellensburg Formation) is overlain across the Pasco Basin by Miocene the Holocene sediments. The suprabasalt stratigraphy is summarized in Figure 22.

3.2.5.1 Ringold Formation

The Columbia River Basalt Group (and interbedded Ellensburg Formation) are overlain over most of the Pasco Basin by the Ringold Formation, dominantly fluvial sediments with some lacustrine and fanglomerate facies (Figure 22). Within the RRL the Ringold Formation is 105 to 215 meters thick.

Within the RRL the Ringold unconformably overlies the Elephant Mountain Member of the Saddle Mountains Basalt. The basal Ringold represents a fining-upward fluvial cycle, capped by a paleosol formed on the fine grained uppermost materials of the cycle. Laminated silt and clay of the lower Ringold disconformably overlie the basal Ringold paleosol. Up to several meters of local erosional relief separate the sandy gravels (with some intercalated sand and mud) of the middle Ringold from the lower Ringold. The upper Ringold, bedded and laminated sand and mud, conformably overlies the middle Ringold. Shown in Figure 23 is an incised paleochannel in the Ringold across the RRL, illustrating that the variation in thickness of the formation is probably due primarily to erosion.

3.2.5.2 Plio-Pleistocene Unit

The Ringold Formation is unconformably overlain across the RRL by a Plio-Pleistocene unit that consists of a fanglomerate and a paleosol. The fanglomerate probably represents mass wastage of material from the surrounding ridges. The fanglomerate is thickest (up to 24 meters) beneath the Cold Creek Valley and thins and fines to the northeast, where it grades into a paleosol formed after the incision of the Ringold.

3.2.5.3 Hanford Formation

Catastrophic late Pleistocene floods deposited coarse-grained (Pasco Gravels) and fine-grained (Touchet Beds) facies sediments across much of the Pasco Basin. The gravels are present at the Umtanum Ridge Bar and its extension, the 200 Areas Bar (see Section 3.1). The slackwater flood facies were deposited away from the gravel bars and are most common in the southern and western parts of the RRL and beneath the gravels of the 200 Areas Bar.

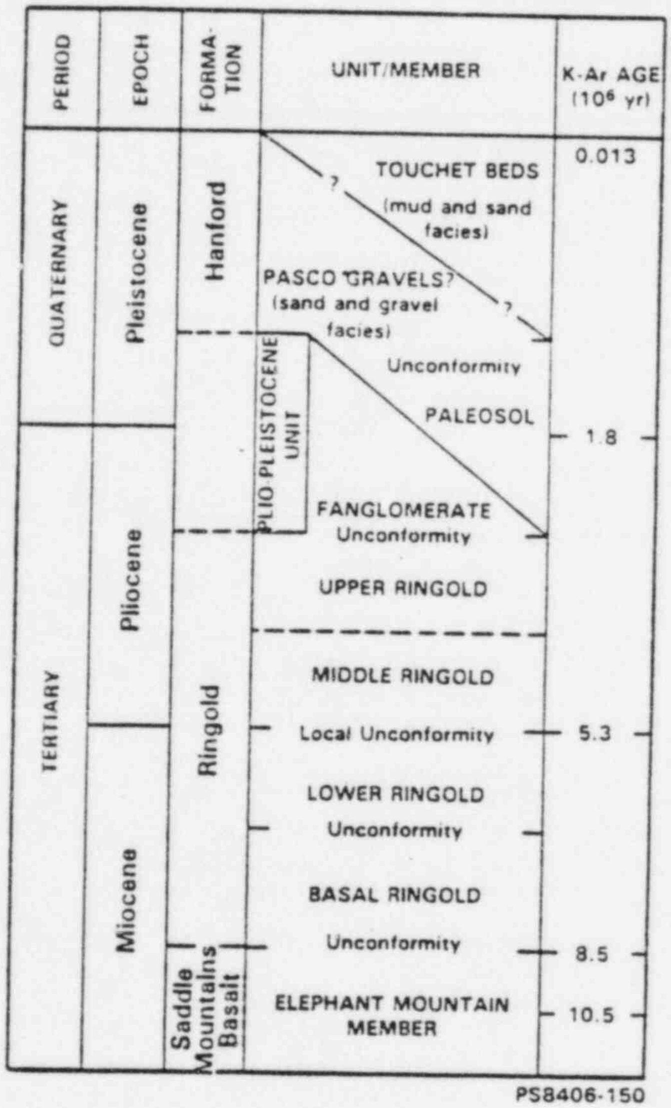

Figure 3-21. Suprabasalt stratigraphy in the reference repository location.

Figure 22

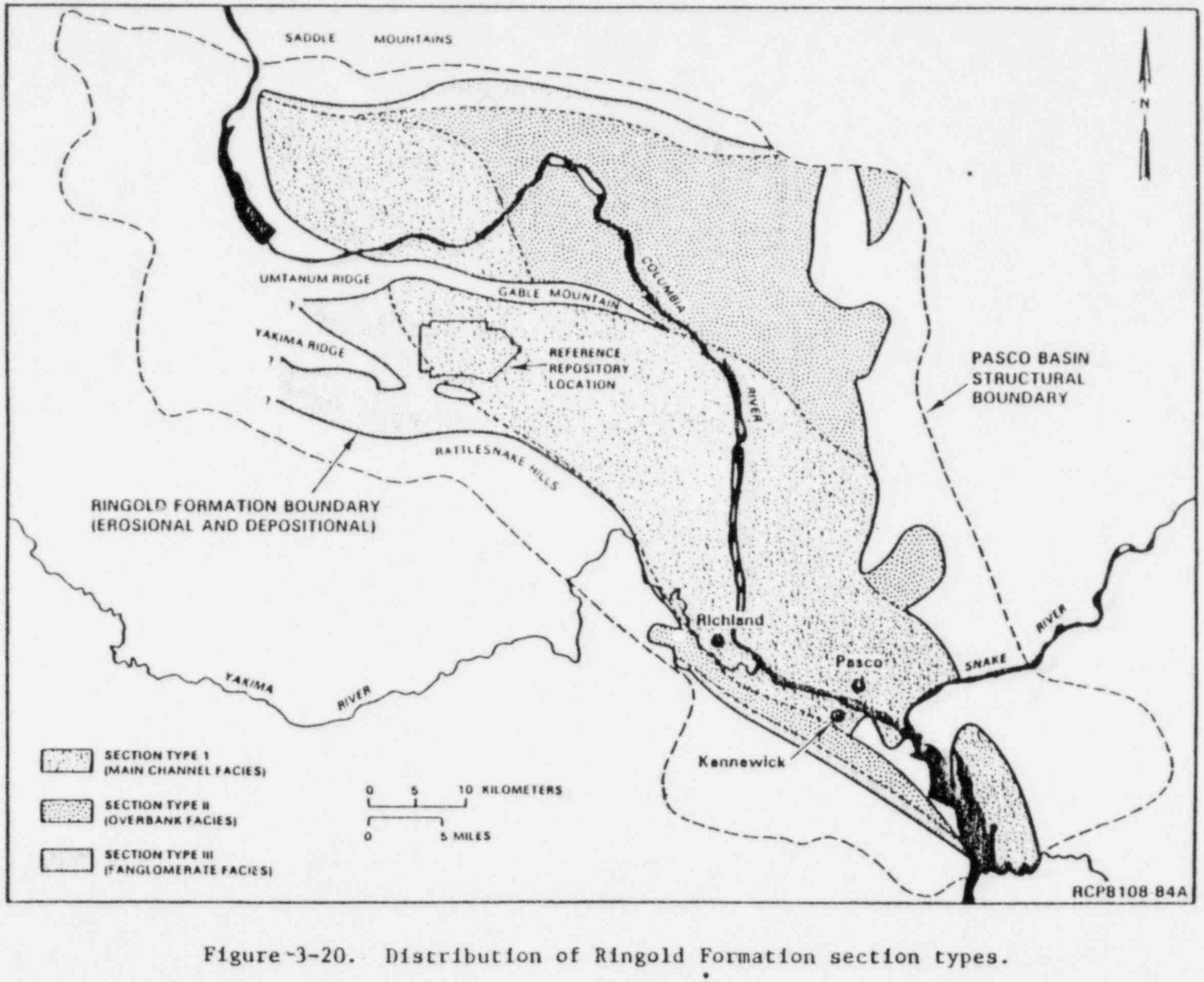

Figure 3-20. Distribution of Ringold Formation section types.

3-4
Figure 23

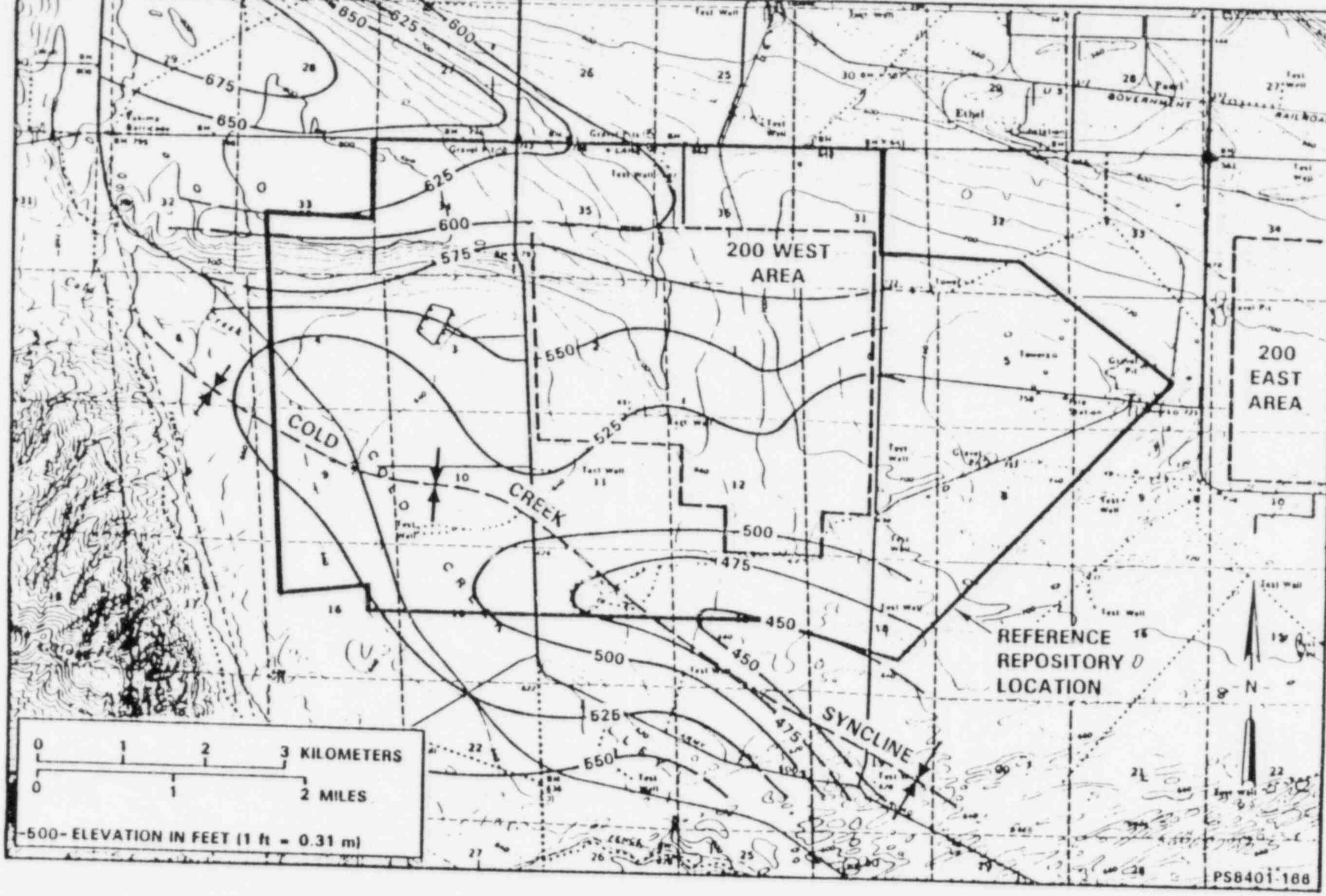

Figure 3-22. Top of the Ringold Formation. Contour pattern indicates maximum post-Ringold incision occurred near the trend of the present Cold Creek Valley.

3.3 Structure

The Pasco Basin is located along the eastern margin of the Yakima Fold Belt. Structures in the area are characterized by long, narrow anticlines and broad snyclines trending generally eastward from the western part of the Columbia Plateau to the Pasco Basin, where they die out (Figure 24). Most of the major faulting is associated with the anticlinal folds. Most of the faults are reverse faults (including thrust faults) that are parallel or subparallel to the axial planes of the anticlines; it is likely that these faults formed during the deformation that resulted in the folding. Structural relief on the anticlinal basalt ridges is up to approximately 1200 meters; and the wavelengths of the folds are typically 5 to 10 kilometers. Anticlines are typically concentric, gentle to tight and upright to inclined. The tighter, inclined folds are usually asymmetric, with the steep limb up to vertical or even overturned. The asymmetric folds usually verge to the north.

Significant characteristics of major structures in the Pasco Basin are summarized below.

3.3.1 Wahluke Snycline

The Wahluke Syncline is broad (up to 13 Kilometers), Asymmetric trough lying between the Saddle Mountains structure and the Umtanum Ridge-Gable Mountain structure; the southern limb is steeper than the northern limb. In the lowest part of the syncline, the top-of-basalt is approximately 61 meters below mean sea level.

3.3.2 Umtanum Ridge-Gable Mountain Structure

The eastward-trending structure extends 110 kilometers from Ellensburg, Washington, to Gable Mountain. Within the Pasco Basin, the anticline is flanked by the Wahluke syncline to the north and the Cold Creek syncline to the south. Maximum structural relief is approximately 880 meters. The eastern Umtanum Ridge segment is a complex structure: an asymmetric, overturned, eastward-plunging anticline whose crestal surface splinters into several en echelon folds along trend. Structural relief and complexity decrease toward the center of the Pasco Basin, where the structure appears to be an asymmetric, eastward-plunging anticline with a steeply dipping north limb. Thrust faulting observed in the Priest Rapids Dam area to the west is believed to die out as structural relief decrease to the east.

Gable Mountain and Gable Butte are surface expressions of en echelon, eastward-trending, second-order anticlines and synclines that are a structural segment of the large, first-order northward-verging anticline. Three significant eastward-trending reverse faults and one north-trending normal fault has been described on Gable Mountain. It is likely that these tear faults are associated with second-order folds, and therefore have likely

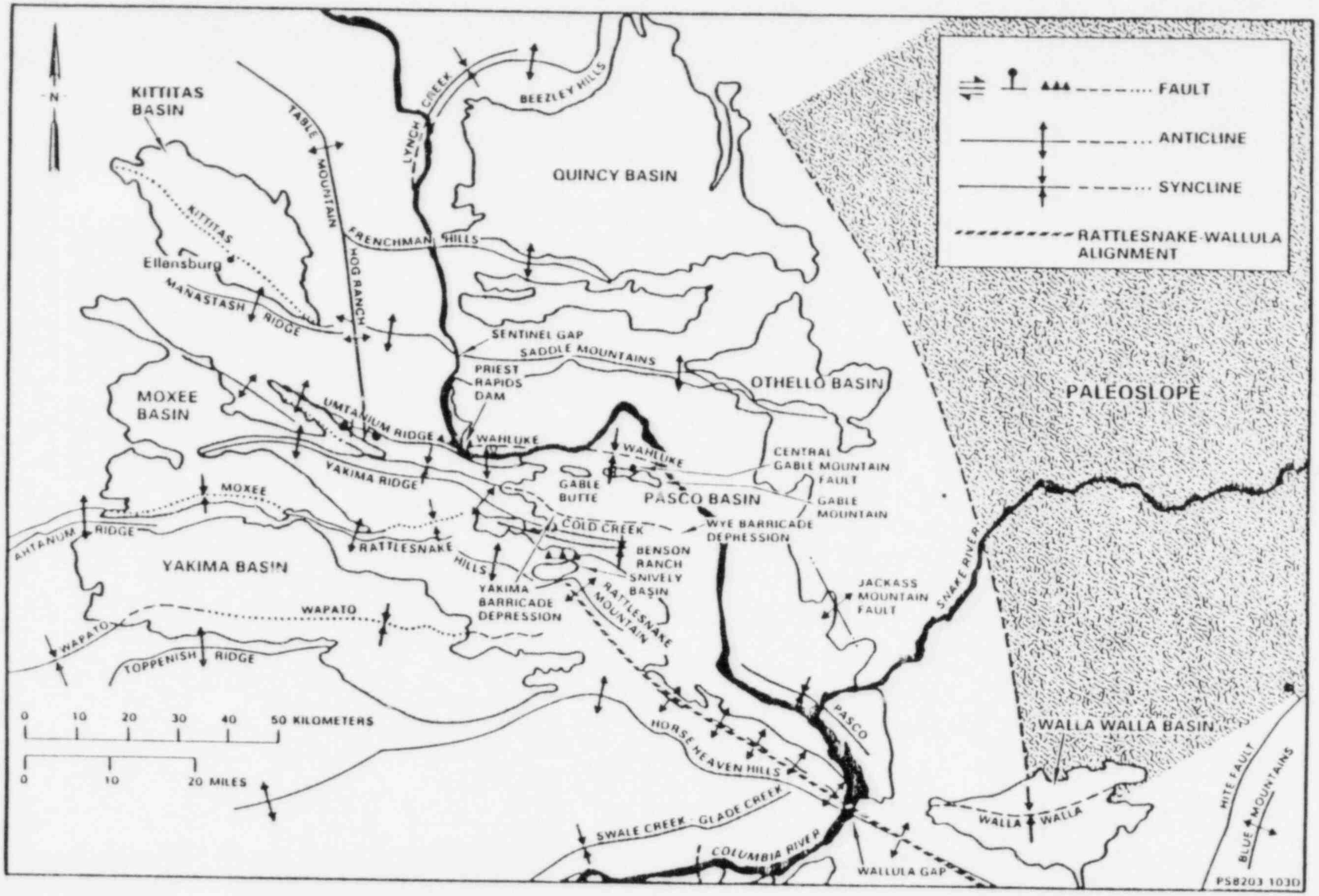

Figure 3-23. Generalized geologic structure map of central Columbia Plateau.

lengths of about 1.6 kilometers or less. Fractures in fluvioglacial sediments are continuous with reverse faults in the underlying basalts.

3.3.3 Cold Creek Syncline

The Cold Creek syncline is a broad, open, asymetric, eastward-plunging, almost flat-bottomed syncline that occupies the structural low between the Umtanum Ridge-Gable Mountain structure and the Yakima Ridge structure.

3.3.4 Yakima Ridge Structure

A group of topographic ridges are the surface expression of the plunging anticlines, monoclines and faults that comprise the Yakima Ridge Structure. Within the Pasco Basin, the dominant structure is a northward-verging asymmetric, southeastward-plunging anticline (Cairn Hope Peak anticline), whose southern flank includes two monoclines, one of which may extend into a major fault zone of uncertain geometry (Silver Dollar fault). The major structure plunges into the basin as a series of second-order folds and associated, probably reverse faults. There is a buried structural high along the trend of the Yakima Ridge structure to the southeast of the surface expressions. A saddle or shallow syncline with possible faulting are believed to separate the two segments.

3.3.5 Benson Ranch Syncline

The shallow Benson Ranch syncline lies between the Yakima Ridge and the Rattlesnake Hills structures on the western side of the Pasco Basin. The syncline plunges to the east and apparently dies out toward the Wye Barricade depression.

3.3.6 Pasco Syncline

The Pasco syncline is a broad, low amplitude depression with a sinuous trend in the southeast part of the Pasco Basin. Overall the syncline plunges to the north, dying out against the Wye Barricade depression.

3.3.7 Rattlesnake - Wallula Alignment

The Cle Elum - Wallula lineament is a 200 kilometer - long, 40 kilometer - wide deformed belt that parallels the western and southern boundaries of the Pasco Basin. Along the southwestern boundary of the basin, the Rattlesnake Hills - Rattlesnake Mountain segment is a major anticlinal structure. Geomorphic continuity along strike to Wallula Gap is considered to reflect continuity of deformation, probably as a right lateral strike slip or oblique slip fault.

3.0 HYDROLOGY

The Pasco Basin hydrologic system consists of four parts: surface waters, unsaturated (vadose) zone, confined aquifers, and unconfined aquifers. The confined and unconfined aquifers will be discussed herein ~~in this paper; and~~ the surface waters and vadose zone will be only discussed in the context of discharge and recharge. from and to the groundwater system.

Ground-water movement in the Pasco Basin occurs in the dense interiors, at the flow contacts, in the interbeds of the basalt flows, and in the alluvium ~~at the surface~~. Shown in figure 1 are the stratigraphic units of the study area. There are over fifty basalt flows and associated rubble zones and interbeds in the Pasco Basin.

3.1 PREVIOUS INVESTIGATIONS

A good general review of the Pasco Basin hydrology and geology prior to 1972 was done by Newcomb, and others (1972). The report contains a general description of the geologic and hydrologic units in the Pasco Basin and a review of the tectonic history of the area. The report also contains a discussion of the history of ground disposal of radioactive wastes. Gephart and others (1979) have summarized existing hydrogeologic reports pertaining to the Pasco Basin with emphasis on the deeper basalt flows. Meyers and others (1979) have provided a compilation of borehole studies, geophysical surveys, and tectonic studies.

3.2 GROUND-WATER FLOW

3.2.1 Unsaturated Zone

The unsaturated zone varies in thickness from several inches at the Columbia River to over 300 feet thick in the 200 Areas plateau (Gephart, and others 1979). The role of the unsaturated zone in this analysis of waste disposal in the deep basalts is restricted to its effect on ground-water recharge.

3.2.2 Unconfined Aquifers

Unconfined aquifers in the Pasco Basin are mostly restricted to the Hanford and Ringold Formations. Unconfined conditions may be found in the Saddle Mountain and Wanapum Basalts in areas where the alluvium is absent and the basalts are exposed at the surface. The unconfined aquifer in the aluvium ranges from very thin up to 250 feet thick along the eastern edge of the

Fig. 1

Period	Epoch	Group	Subgroup	Formation	K-Ar Age Years x 10^6	Member or Sequence	Geologic Mapping Symbol	Sediment Stratigraphy or Basalt Flows
QUATERNARY	Pleistocene/ Holocene					SURFICIAL UNITS	Ql	LOESS
							Qd	SAND DUNES
							Qa, Qaf	ALLUVIUM AND ALLUVIAL FANS
							Qld	LANDSLIDES
							Qt	TALUS
							Qco	COLLUVIUM
	Pleistocene			Hanford		TOUCHET BEDS; PASCO GRAVELS	Qht Qhp	
								PLIO PLEISTOCENE UNIT
TERTIARY	Pliocene			Ringold			Trs	UPPER RINGOLD (FANGLOMERATE)
							Trc	MIDDLE RINGOLD (FANGLOMERATE)
							Trls	LOWER RINGOLD (FANGLOMERATE)
							Trg	BASAL RINGOLD (FANGLOMERATE)
	Miocene	Columbia River Basalt Group	Yakima Basalt Subgroup	Saddle Mountains Basalt	8.5	ICE HARBOR MEMBER	Ti: Tig	GOOSE ISLAND FLOW
							Ti: Tim	MARTINDALE FLOW
							Ti: Tib	BASIN CITY FLOW
								LEVEY INTERBED
					10.5	ELEPHANT MOUNTAIN MEMBER	Tem: Tem_2	UPPER ELEPHANT MOUNTAIN FLOW
							Tem: Tem_1	LOWER ELEPHANT MOUNTAIN FLOW
								RATTLESNAKE RIDGE INTERBED
					12.0	POMONA MEMBER	Tp: Tp_2	UPPER POMONA FLOW
							Tp: Tp_1	LOWER POMONA FLOW
								SELAH INTERBED
						ESQUATZEL MEMBER	Te: Te_2	UPPER GABLE MOUNTAIN FLOW
								GABLE MOUNTAIN INTERBED
							Te: Te_1	LOWER GABLE MOUNTAIN FLOW
								COLD CREEK INTERBED
						ASOTIN MEMBER	Ta	HUNTZINGER FLOW
						WILBUR CREEK MEMBER	Tw	WAHLUKE FLOW
						UMATILLA MEMBER	Tu: Tu_s	SILLUSI FLOW
							Tu: Tu_u	UMATILLA FLOW
					13.6			MABTON INTERBED
				Wanapum Basalt		PRIEST RAPIDS MEMBER	Tpr: Tpr_l	LOLO FLOW
							Tpr: Tpr_r	ROSALIA FLOWS
								QUINCY INTERBED
						ROZA MEMBER	Tr: Tr_2	UPPER ROZA FLOW
							Tr: Tr_1	LOWER ROZA FLOW
								SQUAW CREEK INTERBED
						FRENCHMAN SPRINGS MEMBER	Tf: Tf_a	APHYRIC FLOWS
							Tf: Tf_p	PHYRIC FLOWS
					15.6			VANTAGE INTERBED
				Grande Ronde Basalt		SENTINEL BLUFFS SEQUENCE	Tsb	UNDIFFERENTIATED FLOWS
								ROCKY COULEE FLOW
								UNNAMED FLOW
								COHASSETT FLOW
								UNDIFFERENTIATED FLOWS
								McCOY CANYON FLOW
								INTERMEDIATE Mg FLOW
						SCHWANA SEQUENCE	Ts	LOW Mg FLOW ABOVE UMTANUM
								UMTANUM FLOW
								HIGH Mg FLOWS BELOW UMTANUM
								VERY HIGH Mg FLOW
					16.1			AT LEAST 30 LOW Mg FLOWS

ELLENSBURG FORMATION Te

Stratigraphic units present in the Pasco Basin.

reference to Fig. 2 ?

repository site. The Hanford Formation extends below the water table and is composed of coarse sand, gravel, and cobbles with occasional finer grained sediments.

The Ringold Formation is dominated by a middle unit composed of sorted sands and gravel with various degrees of cementing which directly affects hydraulic conductivity. The lateral boundaries of the unconfined aquifer include the Saddle Mountains to the north, Umtanum and Yakima Ridges on the west, Rattlesnake and Horseheaven Hills on the south and a broad monocline on the east. The bottom boundary is a thick relatively impervious relatively extensive layer of silts and clays above the Saddle Mountain basalts.

3.3.3 Recharge and discharge in the unconfined layer

Precipitation in the Pasco Basin ranges from less than 7 inches in the area of the proposed repository to around 15 inches in the Rattlesnake Mountain area. Gephart and others (1979) estimate the precipitation over the entire basin at 800,000 acre feet annually or less than 8 inches. Fig 3 ?

Jones (1978) estimated that precipitation in the Pasco Basin did not penetrate the soil deeper than 12 meters (39 feet) at any time of the year. This limit would indicate there would be no recharge due to precipitation. Consequently, recharge must occur at the basin periphery, through inter-basin flow, through stream loss mechanisms, or through artificial mechanisms such as irrigation.

Most of the recharge for the unconfined aquifer probably originates at the margins where runoff infiltrates the basalts and alluvium and by the Columbia and Yakima Rivers losing water during high stages. Some recharge occurs where the upward hydraulic gradient from the underlying basalts is sufficient and conditions exist where water can move upward. About 20 to 40 percent of water put on fields during irrigation becomes recharge (Gephart and others, 1979).

Liquid waste disposal ponds from ordinary industrial plant and radioactive waste disposal has caused "mounding" of the water table at two sites and produced minor changes in the water table elsewhere in the area (Newcomb and others, 1972). The widespread effects of the mounds show a rise of 80 feet below U Pond in the 200 East area, a rise of 20 feet below B Pond, and 10 feet below Gable Mountain Pond (Figure 4). ✓

Discharge in the Pasco Basin is principally to the Columbia River with some of the water going to the Snake and Yakima rivers. A net discharge from the basin of about 2.657 million acre-feet per year is shown in Figure 5. ✓

no Figure ?
Table 1

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HORIZONTAL HYDRAULIC CONDUCTIVITY FOR LAYERS IN LOCAL MODEL

LAYER NUMBER	UNIT	K_h (m/s)
25	HANFORD & UPPER RINGOLD FMS	$10^{-5}-10^{-2}$
24	MIDDLE & LOWER RINGOLD FMS	$10^{-7}-10^{-3}$
23	ELEPHANT MTN. BASALT	Ft $10^{-7}-10^{-3}$ (I $10^{-12}-10^{-11}$)
22	RATTLESNAKE RIDGE INTERBED	$10^{-7}-10^{-5}$
21	POMONA BASALT	(Ft $10^{-7}-10^{-4}$ I $10^{-12}-10^{-11}$)
20	SELAH INTERBED	$10^{-7}-10^{-5}$
19	ESQUATZEL BASALT	Ft 10^{-6} (I $10^{-12}-10^{-10}$)
18	COLD CREEK INTERBED	$10^{-7}-10^{-4}$
17	UMATILLA BASALT	Ft $10^{-7}-10^{-5}$ (I $10^{-12}-10^{-11}$)
16	MABTON INTERBED	$10^{-9}-10^{-4}$
15	PRIEST RAPIDS FLOW TOP	$10^{-9}-10^{-2}$
14	PRIEST RAPIDS INTERIOR AND ROZA BASALT	Ft $10^{-10}-10^{-3}$ (I $10^{-12}-10^{-11}$)
13	FRENCHMAN SPRINGS BASALT	Ft $10^{-8}-10^{-3}$ (I $10^{-12}-10^{-11}$)
12	VANTAGE INTERBED	$10^{-8}-10^{-6}$
11	UPPER SENTINNEL BLUFFS BASALTS	Ft $10^{-8}-10^{-5}$ (I $10^{-13}-10^{-12}$)
10	COHASSETT FLOW TOP	$10^{-8}-10^{-5}$
9	COHASSETT INTERIOR	$10^{-13}-10^{-12}$
8	LOWER SENTINNEL BLUFFS BASALTS	Ft $10^{-9}-10^{-6}$ (I $10^{-13}-10^{-12}$)
7	UMTANUM FLOW TOP	$10^{-7}-10^{-5}$
6	UMTANUM INTERIOR AND SCHWANA BASALTS	I $10^{-14}-10^{-13}$, Ft $10^{-10}-10^{-7}$
1-5		

Ft-FLOW TOP
I-INTERIOR

Z8000.59

Figure 3

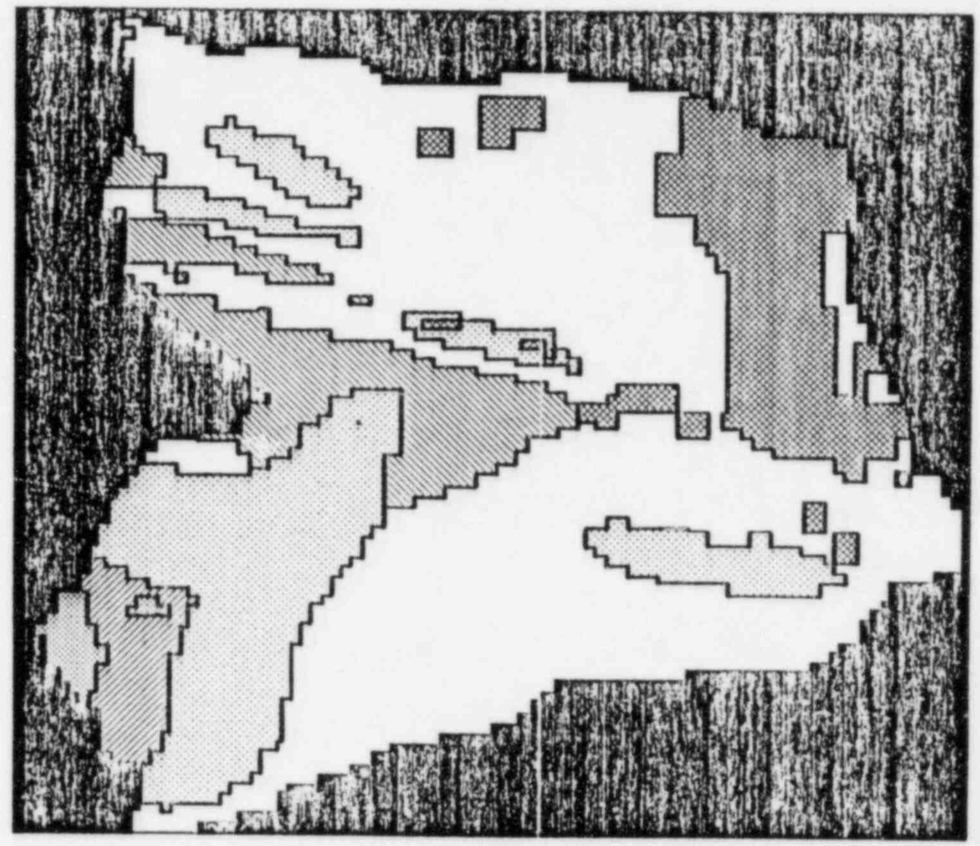
DISTRIBUTION OF RECHARGE

RAINFALL

- 20-25 INCHES
- 15-20 INCHES
- 10-15 INCHES
- <10 INCHES

IRRIGATION

- APPROXIMATE DISTRIBUTION OF IRRIGATION IN MODEL AREA THAT IS PART OF COLUMBIA BASIN PROJECT (FROM AEGIS TECHNOLOGY DEMONSTRATION)
- APPROXIMATE DISTRIBUTION OF IRRIGATION IN MODEL AREA THAT IS PART OF YAKIMA PROJECT (ESTIMATED FROM COLOR LANDSAT PHOTO, REPT. RHO-BWI-ST-5)



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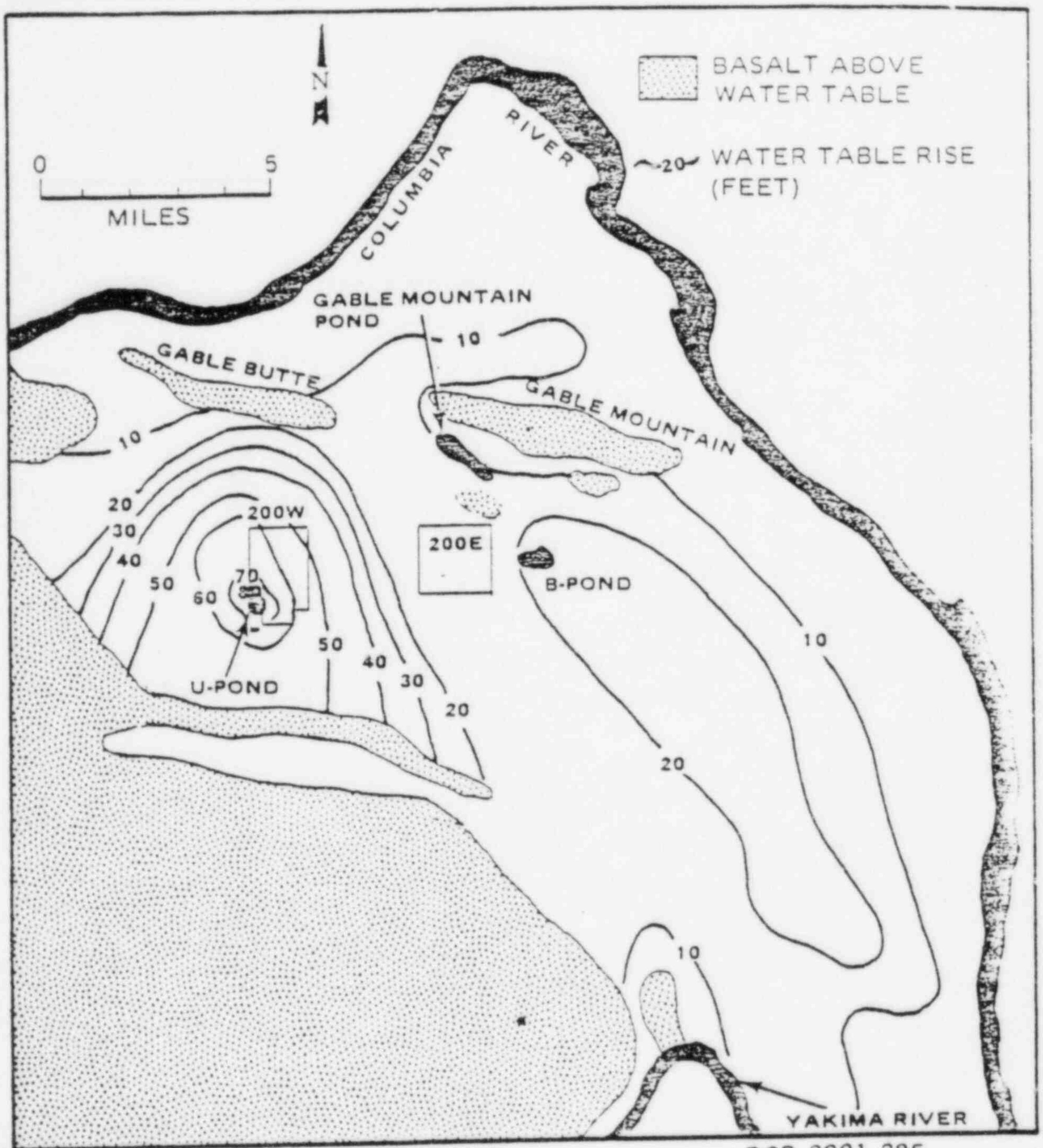


FIGURE ~~III-16~~ 3A. Water Table Rise beneath the Hanford Site, 1944-1978.

(Abstracted from RHO-BWI-ST-5)

~~c. Pasco Basin~~

Precipitation/Infiltration/Deep Percolation

Parameter	AF/yr
Precipitation (P)	756,000
Evapotranspiration (ET)	750,000
Runoff (RO)	0

$PR = P - ET - RO$

$= 6,000$ AF/yr (Probable groundwater recharge from precipitation)

Stream Reach Inventory

Parameter	AF/yr
Inflow (IF), Priest Rapids Dam	87,230,000
Tributaries (TR)	43,832,000
Return Flows (RF)	225,000
Outflow (OF), McNary Dam	134,200,000

$PSL = IF + TR + RF - DW - OF$

$= -2,913,000$ AF/yr (Probable groundwater discharge to the Columbia River)

Water Use Inventory

	AF/yr	
Parameter	GW	SW
Municipal (M)	8,961	20,372
Industrial (IN)	15,361	403,675
Irrigation (IR)	47,760	907,600

$AR = 0.1\ IN_{sw} + 0.3\ IR_{sw} = 313,000$ AF/yr

$WG = 0.35\ M_{gw} + 0.8\ IN_{gw} + IR_{gw} = 63,000$ AF/yr

$RAM = AR - WG$

$= 250,000$ AF/yr (Probable groundwater recharge from artificial mechanisms)

Net Exchange

Recharge Parameter	AF/yr
Precipitation (PR)	6,000
Stream loss (PSL)	-2,913,000
Artificial mechanisms (RAM)	250,000

$NR = PR + PSL + RAM$

$= -2,657,000$ AF/yr (Probable groundwater discharge from basin)

~~The balance shows a net discharge from the basin of about -2,657,000 acre-feet per year. This suggests probable groundwater inflow from adjacent basins.~~

Table 1 Water Budget of the Pasco Basin.

3.3.4 Hydrologic Parameters

In the Pasco Basin, and in particular, the Hanford Reservation, the principle hydrologic parameters tested for are storage coefficient (specific yield), transmissivity, and hydraulic conductivity. These parameters are obtained from aquifer tests while outside the reservation the principle test is the production test on irrigation wells. Gephart and others (1979) and Guzowski (1982) have compilations of tables of tests of the unconfined unit and lists of calculated conductivities (K), transmissivities (T), and storage (S). Shown in Table 2 are representative hydraulic parameters of the unconfined aquifer.

Most hydrologic parameters listed in Table 2 show an obvious difference between the Hanford and Middle Ringold Formations. The Hanford Formation has a hydraulic conductivity between 1000 and 10000 feet per day and the Ringold is a lot lower averaging about 130 feet per day. Figure 4 is a plot indicating a correlation between hydraulic conductivity and the unit. Consequently, a unit composed of Ringold sediments, such as in the area 699-31-31, that has a high conductivity indicative of Hanford sediments may be showing the result of reworking Ringold sediments with the fines removed and cementation dissolved.

Representative hydraulic parameters of the unconfined aquifer are shown in Table 3. The results indicate that permeable Hanford Formation gravels occur along the northern and southern flanks of Gable Mountain trending southeast to the Columbia River. The Ringold Formation with its moderate to low permeabilities is found throughout the Pasco Basin.

3.3.5 Hydro Chemistry

The major ion geochemistry of the ground water in the Pasco Basin basalts has been summarized in Smith and other (1980) and Guzowski (1981) summarized the major ion similarities in all the Hanford waters in Piper (trilinear) diagrams (Figure 6). A table listing the trace element concentration in ground water at the Hanford Reservation is also provided (Table 4). Figure 6 will also be referred to in the discussion of the Saddle Mountains, Wanapum, and Grande Ronde water chemistry.

3.4 CONFINED HYDROSTRATIGRAPHIC UNITS

3.4.1 Previous Investigations

Before 1960, most hydrologic testing was done in the Hanford and Ringold Formations because developed wells were mainly for water supply. Because of the complex morphology of the rock units in the Pasco Basin, determination of hyydraulic conductivity is difficult. Hydraulic parameters within a unit are affected horizontally and vertically by flow morphology,

Table 2

Stratigraphic Interval	Hydraulic Conductivity (feet per day)
Hanford formation	500 - 20,000
Undifferentiated Hanford and Middle Ringold unit	100 - 7,000
Middle Ringold unit	20 - 600
Lower Ringold unit	0.11 - 10

Region	Transmissivity (square feet per day)
North of Gable Butte and Gable Mountain	4,000 - 25,000
On the flank of Gable Butte and Gable Mountain and along paleochannels	40,000 - 600,000
Other areas on the Hanford Site	2,000 - 40,000

	Storage Coefficients
Throughout the unconfined aquifer	0.01 - 0.1

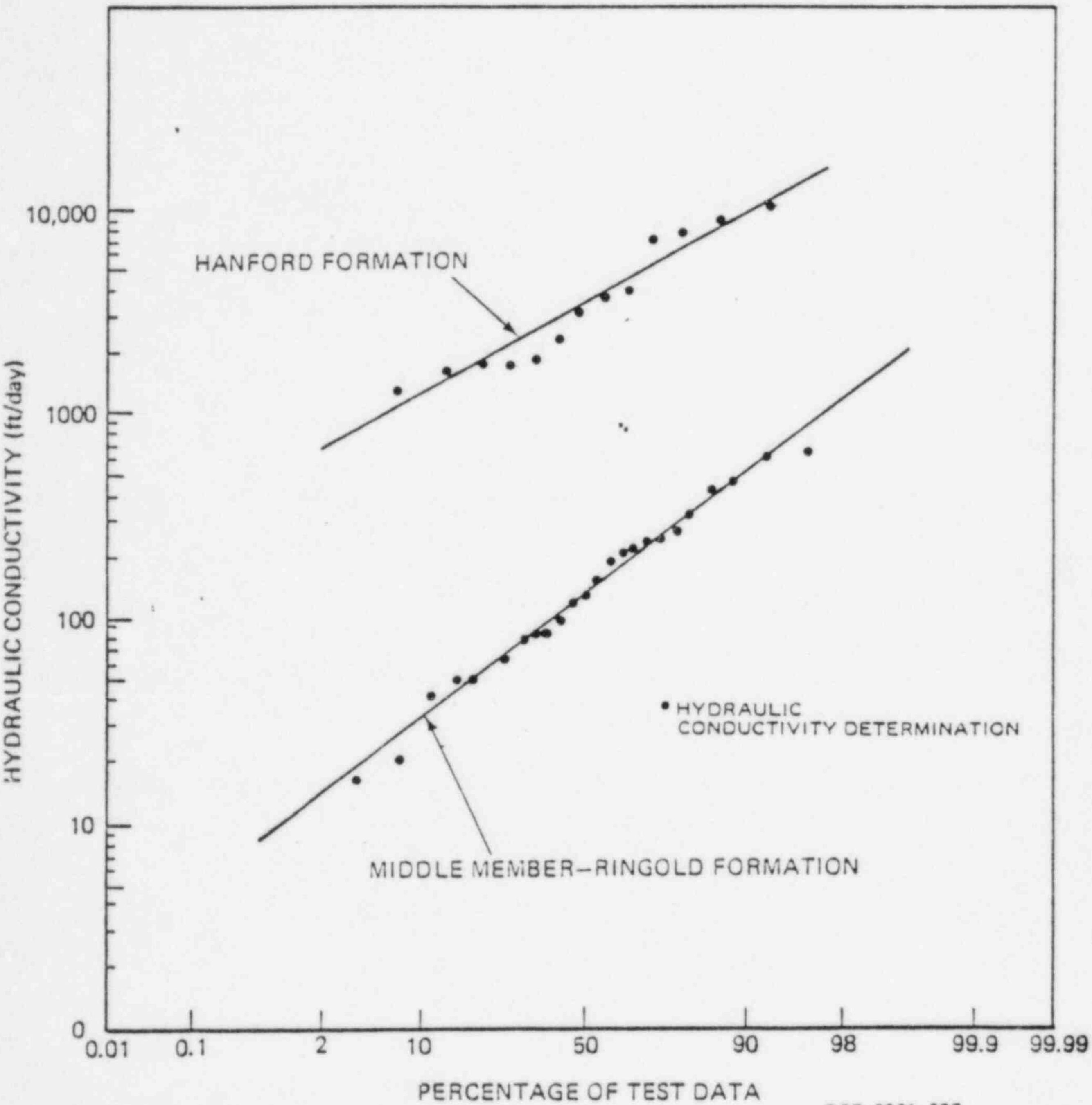


FIGURE III-~~18~~5. Probability Relationship between Hydraulic Conductivity and Two Geologic Units.

TABLE 3. Results of Pumping Tests Completed within the Unconfined Aquifer.
(From Gephart et al, 1979)

Sources of Data[a]	Hanford Test Site Coordinates[b]	Tested Interval[c]	Hydraulic Conductivity[d] (ft/day)	Transmissivity[d] (ft^2/day)	Coefficient of Storage[d]	Remarks
1	199-F7-1	MR-H	520	7,800		Data as reported
3	199-K-10	MR	53	4,500	0.04	48-hour test, observation wells
3	299-W21-1	MR	150	29,000		4-hour test
5	299-E28-15	MR-H	3,685	135,000		7-hour test, insufficient stress
1	699-1-18	MR	61	10,000		2-hour test, variable discharge
3	699-2-3	MR	420	25,000		6-hour test, variable discharge
2	699-8-17	MR	640	35,000		8-hour test
3	699-8-32	MR	20	1,000		6-hour test
1	699-17-5	MR	17	750		8-hour test
2	699-17-47	MR-LR	50	5,300		Multiple aquifers
3	699-20-20	MR	150	30,000		No drawdown data, 3-hour recovery
2	699-20-39	LR		8		Short duration, poor well construction
1	699-24-33	MR-H	8,600	373,000		Data as reported
2	699-26-15	MR	200	9,500		6-hour test

Table III-14 (continued)

Sources of Data[a]	Hanford Test Site Coordinates[b]	Tested Interval[c]	Hydraulic Conductivity[d] (ft/day)	Transmissivity[d] (ft^2/day)	Coefficient of Storage[d]	Remarks
2	699-28-40	LR		5		Poor construction
1	699-31-31	MR-H	7,000	246,000		Data as reported
3	699-31-53	MR	120	14,000	0.06	8-hour test
3	699-32-77	MR	260	57,000		6-hour test
3	699-33-56	MR	230	21,000		8-hour test
3	699-35-9	MR	220	11,000		4-hour test
2	699-36-61	MR	43	2,800	0.05	Variable discharge rate
1	699-40-33	LR?	1.3	210		Data as reported
3	699-41-23	MR	190	28,000		Variable discharge rate
3	699-42-12	MR-H	460	60,000		No drawdown data, 5-hour recovery
3	699-43-89	MR?	85	19,000	0.016	24-hour test
2	699-47-60	MR	80	3,300		7-hour test
2	699-55-50	H	9,100	594,000	0.07	48-hour test, observation wells
3	699-61-66	MR-H	600	51,000		Insufficient stress
3	699-62-43	H	1,700	50,000	0.06	13 observation wells
2	699-63-90	H	2,300	296,000		Insufficient stress

Table III-14 (continued)

Sources of Data[a]	Hanford Test Site Coordinates[b]	Tested Interval[c]	Hydraulic Conductivity[d] (ft/day)	Transmissivity[d] (ft^2/day)	Coefficient of Storage[d]	Remarks
1	699-65-50	H	1,800	64,000		8-hour test
3	699-71-77	MR	84	1,600		4-hour test, variable discharge rate
3	699-77-54	MR	175	13,000	0.03	24-hour test
2	699-84-35	LR	0.11	4		Very short duration
2	699-87-55	MR	130	4,500		24-hour test
3	699-S8-19	MR	57	9,100		Poor drawdown, 6-hour recovery
1	699-S12-3	MR-LR	7	280		8-hour test
4	10/28 14K	MR-H		144,000		Data as reported

[a]Sources of data:

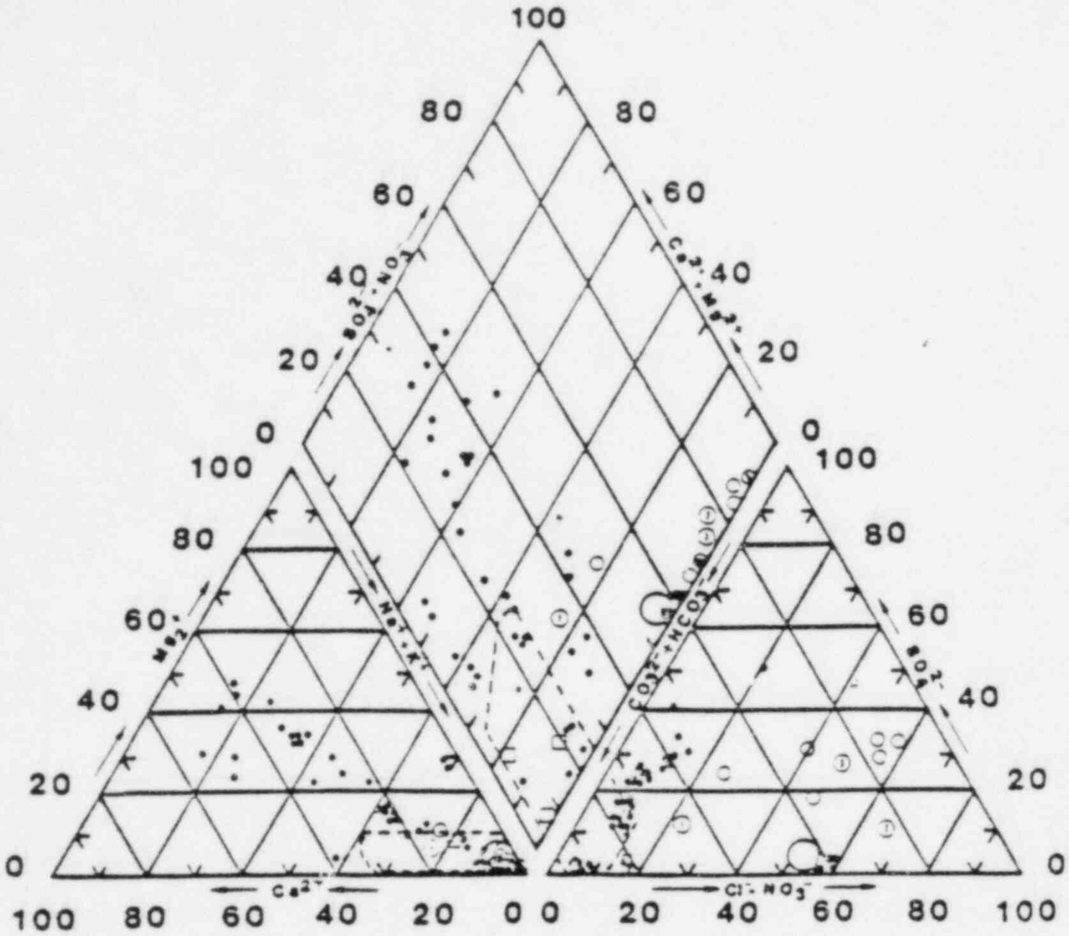
1. Bierschenk (1959);
2. Deju (1974);
3. Kipp and Mudd (1973);
4. Newcomb and Others (1972).
5. Information on file at Rockwell Hanford Operations.

[b]Refer to McGhan and Damschen (1979) for explanation of Hanford Site Coordinate System.

[c]Tested interval:

H - Hanford formation;
MR - middle member of Ringold Formation;
LR - lower member of Ringold Formation.

[d]Blank spaces indicate information not reported.



● Samples from surface aquifers at Hanford Site; from USGS WSP 1199-N:

① Synthetic GR-1; see text:

② Synthetic GR-2; see text:

③ Synthetic RSGC; see text:

○ Samples from boreholes in Grande Ronde Formation; from RHO-BWI-80-100-2Q, RHO-BWI-80-100-3Q and RHO-BWI-78-100:

□ Mean composition of samples from the Mabton Interbed; from RHO-BWI-80-100-2Q:

■ Samples from Priest Rapids Interflow; from RHO-BWI-80-100-2Q:

---- Delineates chemical composition of ground water within the Saddle Mountains basalt boreholes DC-14 and DC-15; from RHO-BWI-80-100-3Q:

◯ Delineates chemical composition of ground waters within the Wanapum basalt at Boreholes DB-15 and DC-12; from RHO-BWI-80-100-3Q:

Figure N-1. Piper (trilinear) Diagram of Major Ion Composition of Various Ground Waters Associated with the Hanford Site.

Table N-5. Trace Element Concentrations in Ground Water at the Hanford Site

Confined aquifers of Grande Ronde Formation

	Apps and others 1979		Gephart and others 1979	Priest Rapids Member of Upper Wanapum basalt, Gephart and others 1979		Mabton Interbeds Gephart and others 1979	Unconfined Ground water at Hanford Site Gephart and others 1979
Ag	<0.010	--	--	--	--	--	<0.010 - 0.002
Al	--	--	0.11	<0.05	0.086	<0.020 - 2.170	<0.050 - 0.470
As	<0.002	0.001	--	--	--	--	0.001 - 0.014
B	--	--	1.39	0.10	0.013	<0.005 - 0.550	<0.009 - 0.150
Ba	0.150	<0.112	<0.005	0.027	0.053	<0.005 - 0.065	0.007 - 0.100
Br	0.201	0.285	--	--	--	--	
Cd	0.007	0.089	<0.005	<0.005	<0.005	<0.005 - 0.009	<0.003 - 0.140
Co	<0.017	0.047	<0.020	<0.005	<0.005	<0.005	<0.002 - 0.010
Cr	<0.0002	<0.0004	<0.005	<0.005	<0.005	<0.005	<0.050 - 0.100
Cu	0.050	0.060	<0.005	0.005	<0.005	<0.005	<0.010 - 0.047
Fe	0.017	0.015	0.054	0.228	0.181	<0.005 - 4.700	<0.005 - 3.9
Mm	0.004	<0.009	<0.010	<0.100	<0.10	<0.010	<0.001 - 0.480
Mo	0.270	0.31	0.310	<0.020	<0.020	<0.010	<0.001 - 0.030
Ni	0.070	--	<0.005	<0.005	<0.005	<0.005 - 0.030	--
Sr	0.012	0.003	<0.005	--	--	0.009 - 0.111	--
Zm	0.260	0.240	0.096	<0.005	<0.015	<0.005 - 0.093	<0.005 - 1.6

from Guzowski [illegible] p. N.14

erosion, alteration, and the infilling of fractures (Guzowski, 1982).

In the mid 1960's a drillstem test was conducted of the Grande Ronde and pre-Grande Ronde basalts in well RSH-1 across seven 76-foot long intervals with multiple tests carried out for each run. Permeabilities and hydraulic heads were obtained from the flow data and shut-in pressure data (Raymond and Tillson, 1968).

Borehole RSH-1 was re-tested by Gephart and others (1979) with 11 additional production and injection tests that were conducted opposite specific zones. Summarized in Table 5 are the basalt hydrologic tests prior to 1980 and the principal organizations involved. Since 1979 many aqufier tests have been performed at the Hanford site. Some of them are discussed below and many others remain in the form of "interval reports" that have not been compiled or summarized.

3.4.2 Ground Water Occurance

As described in the geology section, ground-water flow in basalt is ultimately governed by the genesis of basalt. The movement of a lava flow has a definite effect on its permeability. In the study area, the basalts are composed of successive layers of basalt interbedded with stream gravels and interflow rubble that forms a high permeability layer. Older flows have been compacted and undergone recrystalization. Weathered flows have a high porosity but low permeability. Sedimentary interbeds in the Pasco Basin consist of silts and clays with intermitant sand and gravel lenses. The interbeds are thickest in the center of the basin and thinning toward the basin margin. Flow in the interbeds is poor to moderate (Gephart and others, 1979).

Ground water moves through entablature and colonade fractures in the dense interior basalt to the interbed material, flow contacts, and bedrock structures (Figure 7). Shown in Table 5 is the percentage of dense basalt compared to interflow and sedimentary interbeds. Three trends are shown:

1) Percentage of sedimentary interbeds decreases with depth.
2) Percentage of dense basalt remains nearly the same with depth.
3) Percentage of interflow material increases with depth.

3.4.3 Flow Interiors

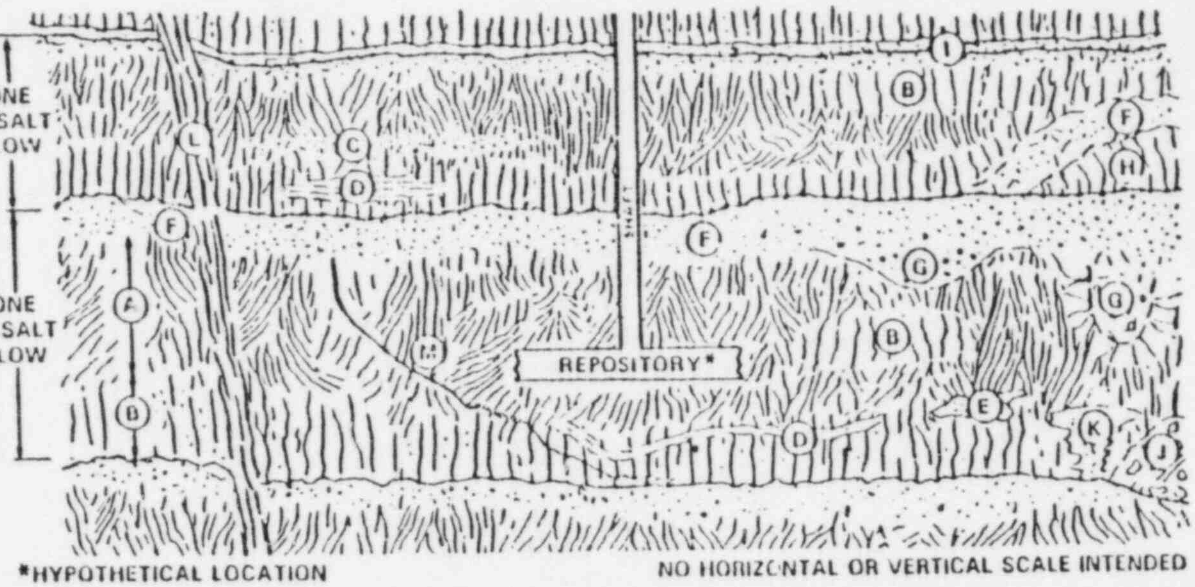
Horizontal hydraulic conductivities from ten hydrologic tests of flow interiors using pulse and constant head injection test methods at depths ranging from 350 m to 1190 m were less than or equal to 10e-11 m/s (10e-6 ft/d) (Gephart, 1983). Lasala and Doty (1971) and Newcomb (1984) also reported low

TABLE III-19. Principal Organizations Involved in Basalt Hydrologic Testing.

([illegible])

Date	Organization	Borehole***	Work Accomplished	Basalt Tested
1968	Raymond and Tillson (1968)	RHS-1	7 DST and 7 head measurements	Grande Ronde and pre-Grande Ronde
1969	LaSala and Doty (1971)	DC-1	4 pumping tests 11 fluid injection and withdrawal tests 22 head measurements Water samples	Saddle Mountains, Wanapum, and Grande Ronde
1977	Gephart and Others (1979)	RSH-1	7 withdrawal and injection tests Water samples	Grande Ronde
1978	Science Applications, Inc. (1978)	DC-2	6 injection tests 2 head measurements	Grande Ronde
1978	Apps and Others (1979)	DC-2	6 head measurements 1 water sample	Grande Ronde
		DC-6	15 head measurements 12 flow tests 1 water sample	Grande Ronde
		DC-8	4 head measurements	Wanapum
1978	W. K. Summers and Associates*	DC-6	5 injection tests 9 head measurements	Grande Ronde
1978	Rockwell Hanford Operations **	DB-1,2,4 5,7,9,10, 12,13,14 and DH-d	20 head measurements 12 pump tests	Saddle Mountains
		DB-11	Water samples and head measurements	Wanapum
1978-79	Rockwell Hanford Operations **	Several boreholes. Refer to text.	Pump tests, water samples, and head measurements	Saddle Mountains and Wanapum

*Data on file in the Basalt Waste Isolation Project Library.
**Results of data analyses presented in this report.
***McGhan and Damschen (1979).



FLOW INTERIOR DISCONTINUITIES

- A ENTABLATURE JOINTS
- B COLONNADE JOINTS
- C VESICULAR ZONE
- D PLATY ZONE
- E LOCAL FRACTURED ZONE

FLOW CONTACT

- F FLOW TOP
- G LOCAL THICKENING OF FLOW TOP BRECCIA
- H FLOW TERMINATION
- I SEDIMENTARY INTERBED
- J PILLOW BRECCIA
- K SPIRACLE OR SPIRACLE-LIKE FEATURE

BEDROCK STRUCTURAL DISCONTINUITIES

- L FAULT OR FRACTURE ZONE, HINGE OF FOLD, OR SHEAR ZONE
- M LOCALIZED TECTONIC FRACTURE

PS8310-60B

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FIGURE 5. Composite Cross Section of Possible Geologic Features in a Layered Basalt Sequence.

From Gephart, et al

TABLE 6(?). General Basalt Lithology Given as a Percentage of Formation Thickness Drilled in Borehole DC-1.

(After LaSala and Doty, 1971.)

Columbia River Basalt	Interval Thickness (ft)	Dense Basalt (%)	Interflows of Vesicular or Brecciated Basalt (%)	Sedimentary Interbeds (%)
Saddle Mountains	625	54	4	42
Wanapum	1,120	61	11	28*
Grande Ronde	2,055	62	32	6

*Percentage probably high because LaSala and Doty (1971) reported several weathered basalt zones as tuff.

From Gephart et al (1979) p. III-95

conductivities. Vertical conductivity tests are rare, but one test suggests a vertical conductivity of less than 10e-10 m/sec (10e-5 foot/day) for one flow interior at one location (Spane and others, 1983).

3.4.4 Flow Contact and Sedimentary Interbeds

Flow tops have a higher conductivity than flow interiors and may extend over many square kilometers (several thousand). Nearly 200 single hole hydrologic tests in about 35 wells indicate hydraulic conductivities in the Saddle Mountains and Wanapum basalts range from 10e-4 to 10e-7 m/s (10 to 10e-2 ft/day) with a geometric mean of about 10e-5 m/s (1 ft/day). The Grande Ronde has a range of conductivities of 10e-5 to 10e-9m/s (1 to 10e-4 ft/s) and a geometric mean of about 10e-7 m/s (10e-2 ft/day) Gephart and others, 1983. ~~Hydraulic conductivities are consistent within a flow top and may vary spatially only slightly.~~ ~~Also,~~ Ground-water flow in basalt flow tops may occur in intervals less than one meter thick which results in a high local ~~permeability~~ hydraulic conductivity but a low transmissivity.

3.4.5 Bedrock Structures

Pasco Basin bedrock structures, as discussed in the geology section of this report, have areas where ~~high conductivities result in~~ high anisotropy rations may occur due to fractures. These zones of high conductivity may provide potential pathways between flow systems above and below a repository.

Zones of tectonic breccia occur along the limbs of the gently dipping anticlines and synclines. The zones are generally about 1 meter thick and have an unknown lateral extent. A thick zone (5 meters) in the Frenchman Springs member of the Wanapum was tested using a pulse technique and yielded conductivities of approximately 10e-11 m/s (10e-6 ft/day).

Synclinal troughs, such as the Cold Creek Syncline, are difficult to assess as to the amount of fracturing that occurs but it is assumed that less strain occurs on the nearly flat lying strata. Nevertheless, observations of cliffs and roadcuts indicate a network of tectonic fractures occur and may extend tens of hundreds of meters (tens to hundreds of feet). The genesis of the fractures is doubtful but may be the result of cooling or related to deposition.

West of the repository site (Figure 8) is a bedrock "structure" referred to as the "Cold Creek Barrier" (DOE, 1984). The barrier is almost normal to the Cold Creek Syncline and is an impediment to ground-water flow as indicated by a hydraulic head drop of 150 meters (500 Feet) across the "structure".

* consider expansion to include fig 3-52 from SCR – there are other hydrogeologically relevant structures that should be discussed

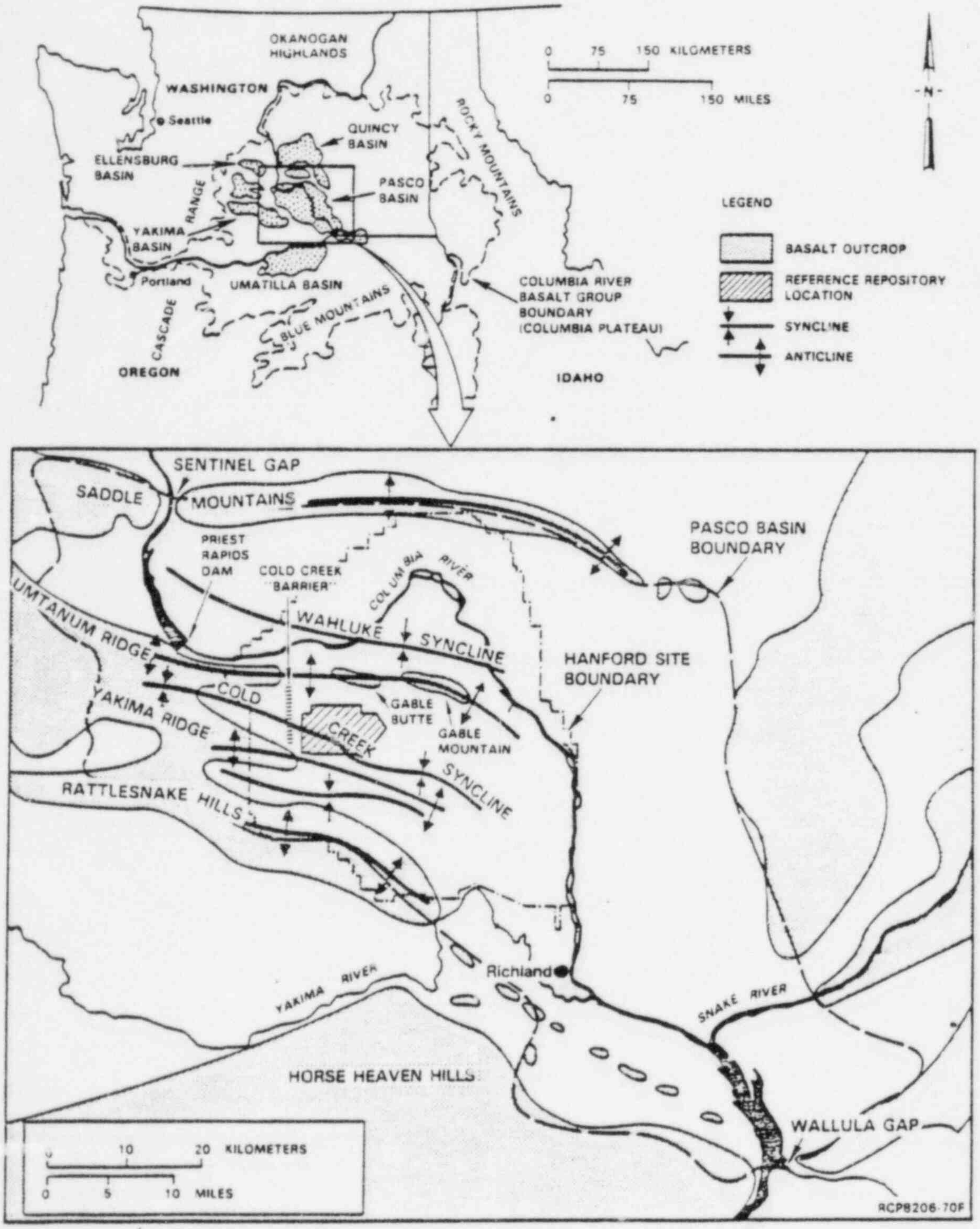

Figure ~~3-1~~ 8. Extent of the Columbia River Basalt Group, Pasco Basin, and reference repository location.
(From EA)

3.4.6 Alternative Flow Concepts

Sometimes data are too scarce to reach conclusions about a particular flow system, consequently, alternative concepts may be developed in order to concentrate efforts in the direction of a narrow range of models suitable for detailed study. Gephart and others (1983) have conceptualized four types of ground-water movement (Figure 7). The concepts (quoted freely from Gephart and others, 1983) are as follows:

• CONCEPT A: This concept illustrates ground-water moving principally within heterogeneous, permeable flow tops separating flow interiors of relatively low vertical and horizontal permeability. Upward movement into shallower systems occurs as a result of (1) the positioning of flow where the front of one basalt flow of limited extent terminates atop a more continuous flow creating a direct conduit between two flow tops, or (2) ground-water movement across low permeability flow interiors over large areas. In concept A, local features of relatively high permeability (such as thickening of flow top breccia atop a spiracle) are not commonly juxtaposed. Basically, Concept A depicts an anisotropic, heterogeneous flow system undisturbed by major folds and faults.

• CONCEPT B: In this concept, basalt flows are crossed by bedrock structural discontinuities having potentially larger vertical permeabilities than the aquitards. On a local scale of several square kilometers, such discontinuities might represent individual tectonic fractures or shear zones. Regionally, these features could depict major fault zones. If rock movement has occurred, such structures could depict zones where the lateral continuity of flow contacts is disrupted causing a flow contact to terminate against a flow interior of permeability. In this concept, structural discontinuities are heterogeneities having the potential for vertically connecting shallow and deep flow systems. Dependent upon the extent of fracture mineral infilling and/or fine gouge material, these discontinuities could act as high permeability conduits or ground-water barriers. Overall, this concept depicts rock volumes of relatively low vertical leakage bounded by structural discontinuities.

• CONCEPT C: This concept represents a flow system characterized by lateral ground-water movement in flow tops bounded by basalt interiors of relatively high leakage. The anisotropy between flow top and interior is considerably less than in Concept A. In this concept, ground-water movement between deep and shallow systems occurs as a result of stratigraphic positioning/inter-section of flow contacts and vertical leakage through unfilled or partially filled cooling fractures and other relatively high permeability primary features that are juxtaposed.

• CONCEPT D: This concept superimposes bedrock structural discontinuities on Concept C. As described under Concept B, such discontinuities might act as vertical conduits and/or low permeability barriers. This concept depicts rock zones of relatively high vertical leakage bounded by structural discontinuities.

3.4.7 Hydraulic Heads

Hydraulic head data from selected wells (Figure 9) can be used to determine horizontal flow direction in a particular hydrostratigraphic unit and the direction and magnitude of potential vertical flow. In the Pasco Basin, values of the hydraulic head gradient tend to be related to depth. Head values in the Saddle Mountains Formation are erratic but seem to increase with depth (Table 7). In the Wanapum (Tables 8 and 9), head values are uniform or decrease with depth. The Grande Ronde Formation has head values that decrease with depth. In the area of well DC-15, Grande Ronde values increase with depth. Shown in Figures 10, 11, 12, 13, and 14 are the available data on potentiometric levels on the Hanford Reservation. The arrows indicate the direction of flow. Gephart and others (1979) provide a summary which shows a comparison of Hydraulic heads for boreholes DC-1, DC-6, and DC-8 (Tables 10-12).

* insert discussion of measurement error & apparent low gradients & continuous data from multi-piezo wells

3.4.8 Additional Hydraulic Properties

The following is a discussion of additional hydraulic properties at the respostory site:

Transmissivity

Transmissivity is the rate water at prevailing kinematic viscosity is passed through a given unit width of aquifer under a unit hydraulic gradient. Transmissivity values in the Pasco Basin are from mostly unconfined aquifers. The scarcity of data is the result of poor records, the method of well construction, and the large intervals tested.

Storage Coefficient

The storage coefficient of confined aquifers is the volume of water released from storage per unit surface area per unit change in head. Storage coefficients for the confined aquifer in the Hanford area range from about 1.0e-5 to 1.0e-3.In the Pasco Basin, storage coefficient values from 2 wells penetrating the Wanapum and Grande Ronde Basalts range from 1.4e-6 to 3.0e-3 (Lasala and Doty, 1971). Higher permeability zones along flow contacts have storage coefficient values of 1.0e-4 to 1.0e-3 which are within the range typically reported for confined aquifer systems (Gephart and others, 1979). The storage coefficients at the lower end are probably

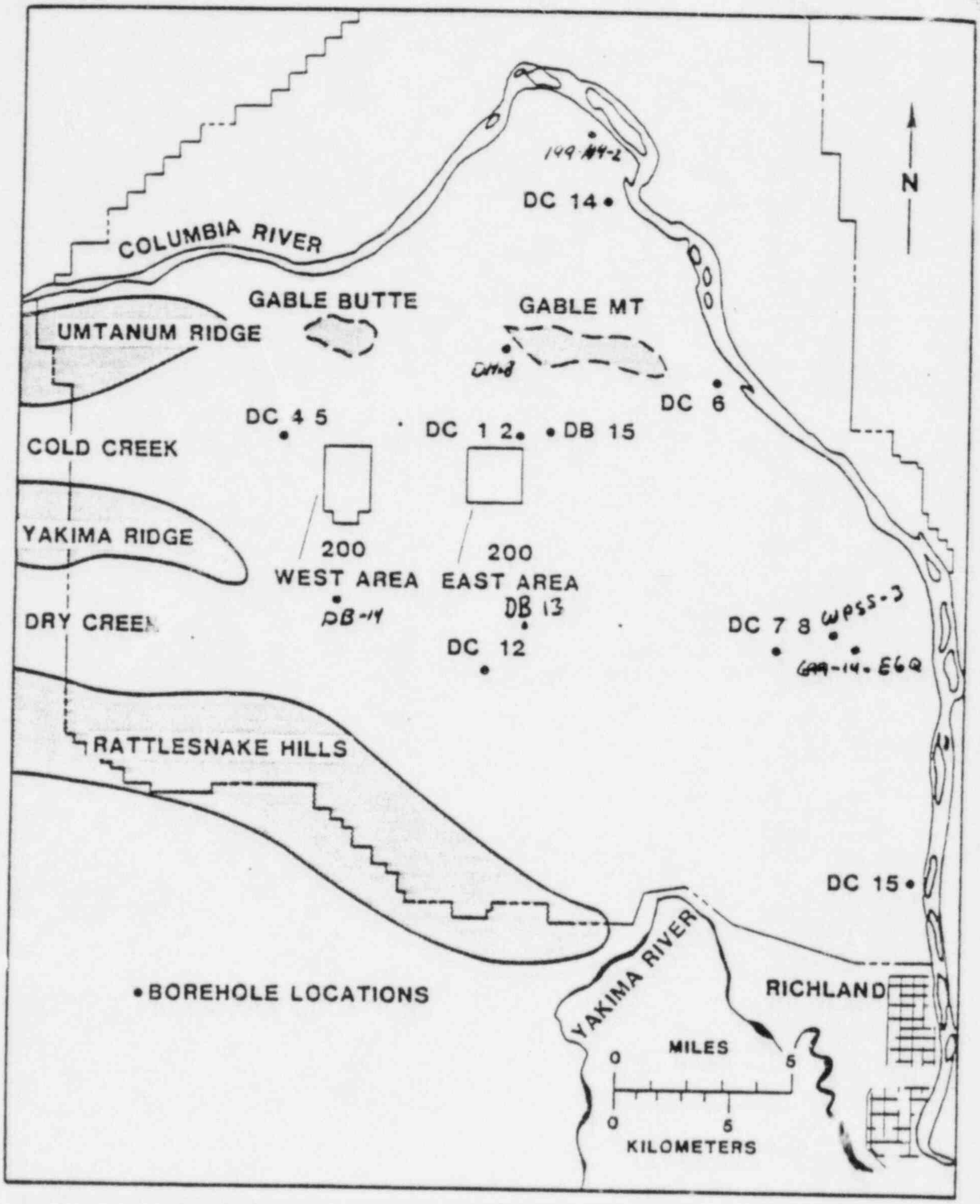

Figure ~~21~~ 9. Location of Selected Drill Holes in Pasco Basin (Deju, 1980e).

Fama Gasmuski (1972)

TABLE ~~III-21.~~ 7 Hydraulic Heads within Selected Stratigraphic Intervals in the Saddle Mountains Basalt.

From Gephart

Borehole Identification*	Aquifer**	Year of Measurement	Hydraulic*** Head Elevation (feet)
DB-1	Mabton	1979	385
DB-2	Mabton	1979	385
DB-4	Mabton	1979	419
DB-5	Mabton	1979	407
DB-7	Mabton	1979	404
DB-9	Mabton	1979	403
DB-10	Mabton	1979	405
DB-12	Selah	1978	402
	Mabton	1979	402
DB-13	Elephant Mountain interflow	1978	417
	Rattlesnake Ridge	1978	418
	Cold Creek	1978	420
	Mabton	1979	421
DB-14	Rattlesnake Ridge	1978	449
	Selah	1978	424
	Cold Creek	1978	423
	Mabton	1979	422
DC-1	Selah	1969	407
	Cold Creek	1969	409
	Mabton	1969	400 (?)
DH-8	Mabton	1979	403
WPPSS-3	Rattlesnake Ridge	1979	380
699-14-E6Q	Rattlesnake Ridge	1969	389
199-H4-2	Rattlesnake Ridge	1968	414

*Refer to McGhan and Damschen (1979) for explanation of Hanford Coordinate System.
**Interbeds except where noted.
***Accuracy ± 0.1 foot, except DC-1 which is ± 20 feet.
Elevations in feet above mean sea level.

TABLE 8 ~~III-1~~2. Hydraulic Heads within the Wanapum Basalt in Borehole DC-1.*

Test Interval (feet below ground level)**	Head*** (feet above mean sea level)	Comment
820 - 1,190	402	Straddles bottom of Saddle Mountains and top of Wanapum Basalt
1,130 - 1,190	409	
1,330 - 1,520	405	Value estimated
1,560 - 1,750	405	
1,760 - 1,950	407	
1,970 - 2,160	407	Straddles bottom of Wanapum and top of Grande Ronde Basalt

*Data from LaSala and Doty (1971).
**Ground level elevation 572 feet.
***Accuracy ± 20 feet.

TABLE ~~III-13~~ 9. Hydraulic Heads within the Wanapum Basalt in Borehole DC-8.*

Test Interval (feet below ground level)**	Head*** (feet above mean sea level)
1,710 - 1,740	433
1,810 - 1,840	431
1,990 - 2,020	435
2,033 - 2,063	422

*Apps and Others (1979).
**Ground level elevation 545 feet.
***Reported accuracy ± 2.5 feet.

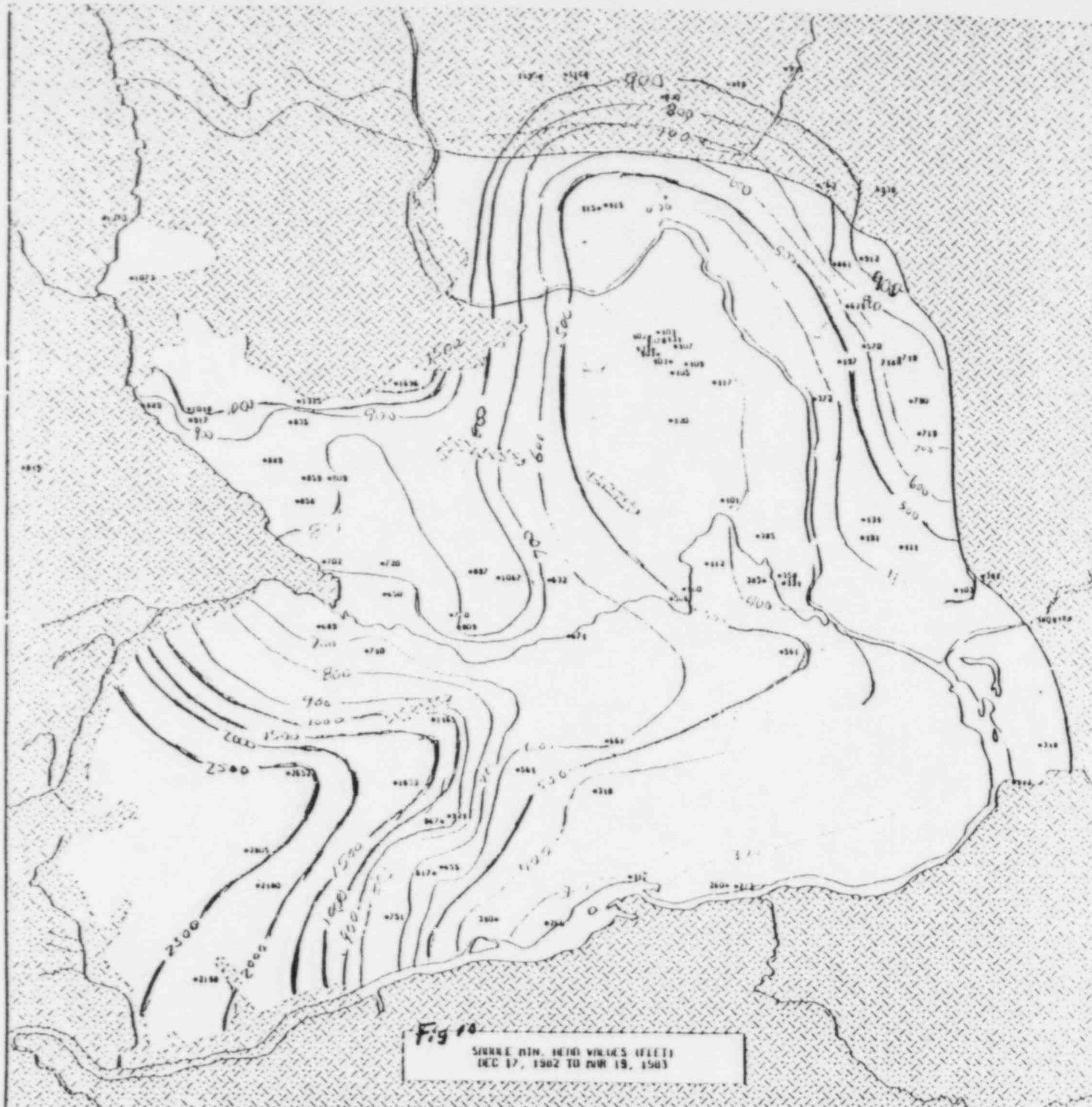

Fig 10

SADDLE MTN. HEAD VALUES (FEET)
DEC 17, 1982 TO MAR 19, 1983

Fig 10

F·g 11
SADDLE MOUNTAIN HEAD VALUES (FT)
SPRING 1984

Fig 11

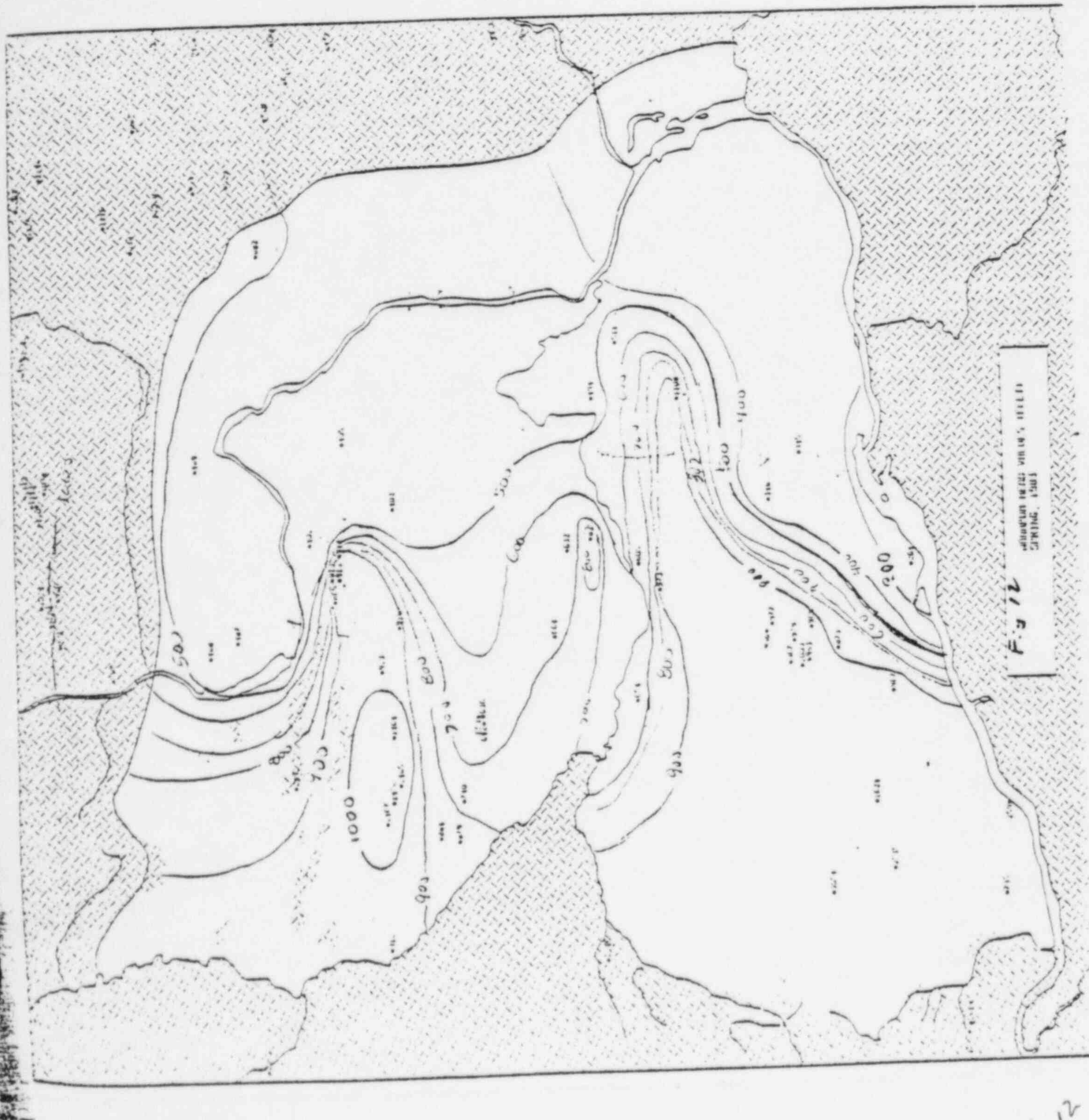

Fig 12

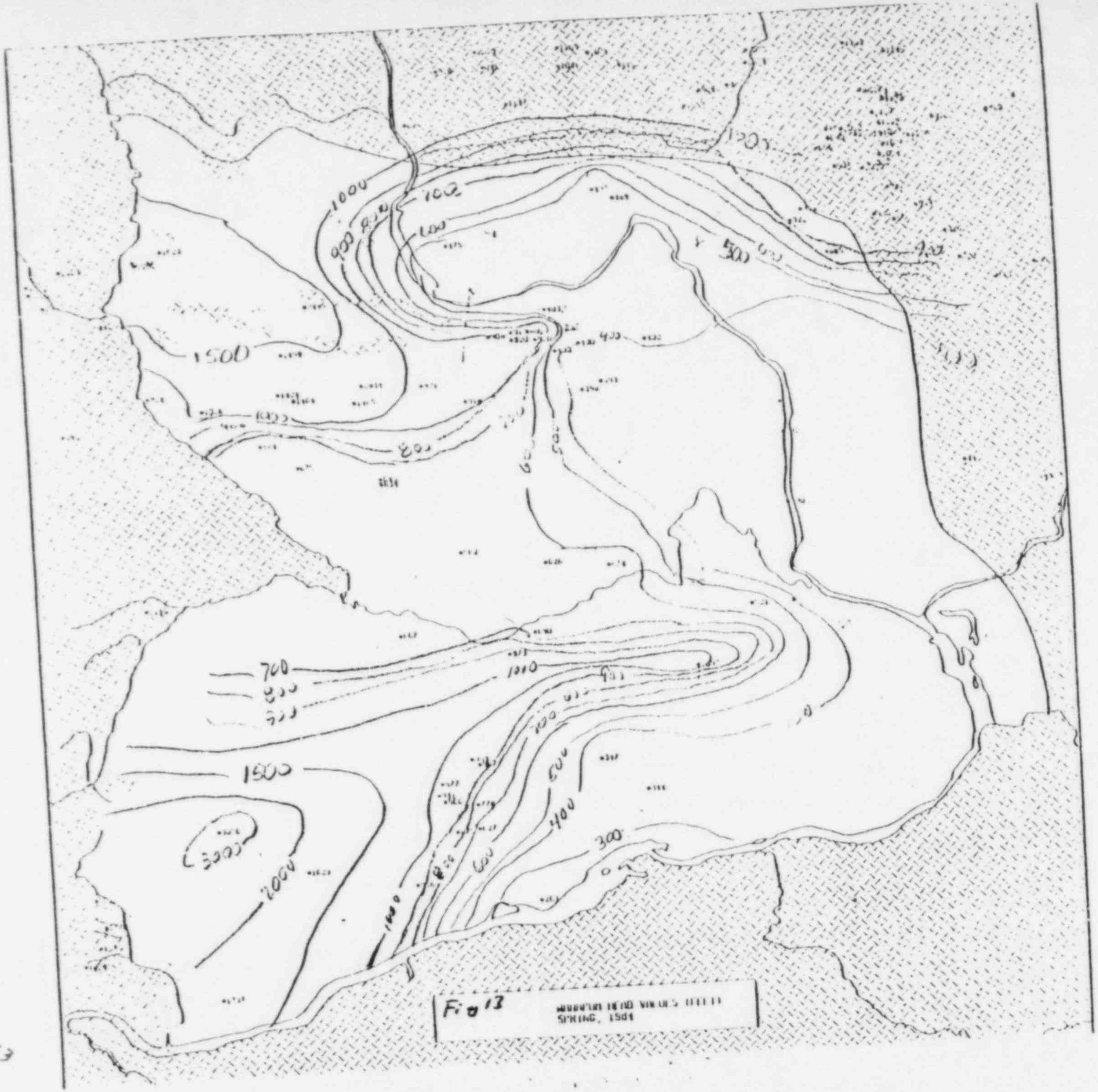

Fig 13 — [illegible] HEAD VALUES [illegible] SPRING, 1981

Fig 13

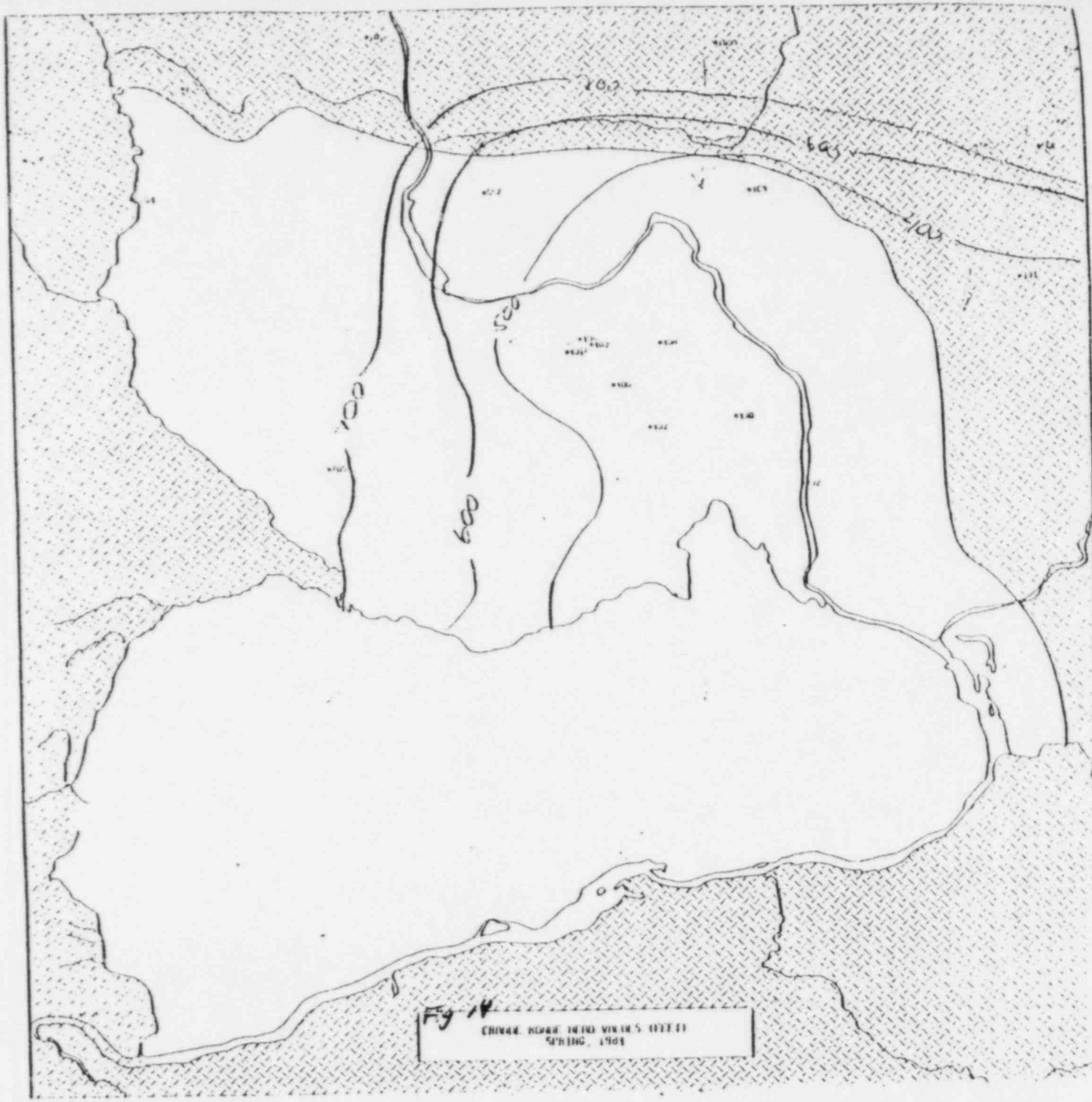

Fig 14

TABLE ~~III-~~10 5. Hydraulic Heads within the Grande Ronde Basalt of Borehole DC-1.

Test Interval* (feet below ground level)	Head (feet above mean sea level)	Comment**
1,970 - 2,160	407	Straddles bottom of Wanapum Basalt and top of Grande Ronde Basalt
2,170 - 2,225	406	
2,430 - 2,610	403	
2,600 - 2,780	402	
2,730 - 2,910	411	
3,146 - 3,236	411	
3,166 - 3,196	409	
3,206 - 3,246	403	
3,320 - 3,451	408	
3,774 - 3,934	379	
3,910 - 4,070	366	
4,080 - 4,283	368	

*Data from LaSala and Doty (1971). Ground level elevation 572 feet.
**Head measurement accuracy ± 20 feet.

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TABLE ~~III-37~~. Hydraulic Heads Reported for the Grande Ronde Basalt in Borehole DC-2.

Test Interval (feet below ground level)[c]	Rock Density[d]	Head[e] (feet above mean sea level)
[a]2,269 - 2,299	High	470
2,340 - 2,370	Low	443
2,625 - 2,655	Low	438
2,795 - 2,825	Low	421
2,960 - 2,990	Low	395
3,160 - 3,190	Low	377
3,243 - 3,273	Low	362
[b]2,344 - 2,376	Low	444
2,376 - 2,409	High	423
2,955 - 3,007	Low	419
3,019 - 3,071	High	421
3,069 - 3,122	High	446
3,116 - 3,170	High	423

[a]Apps and Others (1979).
[b]Data from Science Applications Inc. (1978).
[c]Ground level elevation 572 feet.
[d]Low density--Test straddled at least one zone of low-density (≈2.4-2.6 grams/cubic centimeter) basalt. High Density--Test straddled only high-density (≈2.7-2.8 grams/cubic centimeter) basalt. Densities were determined by geophysical log interpretation.
[e]Head accuracy of ± 2.5 feet reported by Apps and Others (1979).

TABLE ~~III-28~~ 12. Hydraulic Heads Reported for the Grande Ronde Basalt in Borehole DC-6.[a]

Test Interval (feet below ground level)[b]	Rock Density[c]	Head[d] (feet above mean sea level)
*2,240 - 2,270	Low	450
2,400 - 2,430	Low	447
2,454 - 2,484	Low	456
2,708 - 2,738	Low	423
2,896 - 2,936	Low	454
3,025 - 3,055	Low	460
3,343 - 3,373	Low	443
3,620 - 3,650	Low	421
3,650 - 3,680	Low	432
3,683 - 3,713	Low	429
3,692 - 3,722	Low	432
3,341 - 4,336	Several high and low	426
3,477 - 4,336	Several high and low	437
3,601 - 4,336	Several high and low	434
3,802 - 4,336	Several high and low	466

[a]Apps and Others (1979).
[b]Ground level elevation 402 feet.
[c]Low density--Test interval includes at least one zone of low-density basalt which normally corresponds to an interflow zone. High density--Test interval in high-density basalt which normally corresponds to a section of columnar basalt.
[d]Head accuracy ± 2.5 feet as reported by Apps and Others (1979). Head elevations are above ground level. Artesian flow is ~10 gpm.

characteristic of columnar basalts which are denser and hydraulically tighter.

Porosity

Porosity is expressed quantitatively as the ratio of the volume of pore space to the total volume. Effective porosity is the volume percentage of connected pores through which flow can occur. Basalts have many large isolated voids, consequently, the total porosity is much greater than the effective porosity. The basalt porosities are from the Columbia Plateau (Table 13). The measurements are made on disturbed samples in the laboratory and the effective porosities do not reflect the actual effective porosity. Total porosity in the study area ranges from less than 1% in the dense interior basalts to greater than 30% in the scoriaceous zones and effective porosities range from 0 to about 2.5% (Guzowski, 1982). To date, two tests have been performed within the Mccoy Canyon basalt flow top on the same internal (Leonhart and others 1982, 1984). Estimates for effective thickness ranged between $2x10^{-3}$ to $3x10^{-3}$ meter (.006 to .01 feet). Effective porosity of this flow top is between .01 and 1 percent.

Specific Capacity

Specific capacity of a well may sometimes be termed the productivity of a well or the rate of water pumped in gallons per minute divided by the drawdown, in feet. Generally, high specific capacity indicates a high transmissivity and low specific capacity means low transmissivity. Tanaka and others (1974) estimated transmissivities from the specific capacities. Most specific capacity data in the Hanford area are from wells east of the Columbia River (Gephart and others, 1979) or near the cities of Pasco and Kenewick, Washington. Specific capacity data used to estimate hydraulic conductivity gives ranges from .02 to forty feet per day for interflow zones. Hydraulic conductivities of between .08 and 40 feet per day were obtained when test zones penetrated are one or more interbeds. These ranges compare with other estimates of conductivity for the Wanapum and Grande Ronde.

Longitudinal Dispersivity

The above mentioned tracer tests in the McCoy Canyon gave a longitudinal dispensivity ranging between .6 and 1.7m.

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Figure E-3. Histogram of Effective Porosity/Total Porosity Ratio for Basalt.

Table ~~E-1~~ 13. Porosity of Basalt - Columbia Plateau

SOURCE	LOCATION OR BASALT UNIT	TOTAL Ø(%)	Effective Ø (%)
Colorado School of Mines (1978)	Pomona flow	0.96->37.8	-
Deere and Miller (1966)	Columbia River basalt	-	0.75-1.92
Duvall and others (1978)	Pomona flow	-	1.60-2.39
Erikson and Krupka (1980)	Pomona flow	-	0.50-0.60
Foundation Sciences Inc. (1980a)	Pomona flow	2.71-8.14[c]	0.5 -1.4
Foundation Sciences Inc. (1980b)	Pomona flow	1.0 -7.7[c]	0.1 -0.6
Foundation Sciences Inc. (1980c)	Pomona Umtanum flows	0.71-9.68[c]	0.19-1.85
Foundation Sciences Inc. (1981)	Umtanum flow	0.71-9.68[c]	0.19-2.06
Nace and others (1959)	Columbia River basalt	3.8 -24.8	-
Podnieks and others (1972)	Columbia River basalt	-	2.0
Robertson (1970)	Columbia River basalt	18.5[c]	-
Schmidt and others (1980)	Summary, Hanford basalts	-	1.5 -2.8[a]
Stephenson and Triandafilidis (1974)	Columbia River basalt	2.2	-
White and Sarcia (1978)	Columbia River basalt	0.55-3.84	0.18-1.34

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Raymond 1968
Lasala 1971
Spane 1983
Tanaka 1974

4.0 Review of Ground-water Flow Models of the Hanford Site

This section contains reviews of available groundwater flow models of the Hanford site. The reviews are designed to provide a brief description of each model, its limitations and assumptions, and its relevance to NRC licensing rules. Following the reviews is a summary of all the modeling efforts at the Hanford site.

REFERENCE:

Arnett, R. C., 1980; "Far-Field Modeling: Simulation of the Natural Groundwater System in the Pasco Basin," in Basalt Waste Isolation Project Annual Report - Fiscal Year 1980; RHO-BWI-80-100

PURPOSE OF THE STUDY:

Understanding the groundwater flow systems in the Pasco Basin, ~~and~~ identifying data, and conceptual model limitations and calculating preliminary travel times.

SOURCES OF DATA:

Spane, F. A. Jr., 1980, RHO, BWI-80-100 ← give complete citation

remainder of pages may not be in proper order

GEOHYDROLOGIC FRAMEWORK: (Conceptual Flow Model) dictated the selection of boundaries between hydrostratigraphic units.

Hydrostratigraphic Units - See figure 1

the Selection of hydrostratigraphic units was based on "groundwater head and chemistry measurements." That is, a reversal of hydraulic head gradient with depth and abrupt changes in chemical composition with depth (see figure 2). Note, ~~however, that~~ the layers shown in figure 1 do not correspond with the model reported in this study which includes only the Grande Ronde, Wanapum, and Saddle Mountains basalt along with possibly the alluvium as an upper boundary condition.

Hydraulic Parameters

Listed in Table 1 are the parameters and their appropriate ~~used as a~~ starting values ~~point~~. However, presented results are not for these valves but correspond to ratios of Kv/Kh shown in Table 2.

BOUNDARY CONDITIONS:

The location of the model boundaries is shown in Figure 3. These boundaries correspond to the surface-water drainage boundaries of the Pasco Basin. The type of boundary condition imposed at these locations is not discussed but the report indicates that they are fixed potential or constant-head boundaries. I could not ascertain whether the top boundary was a recharge boundary or fixed potentials representing the elevation of the rivers and the water table in the sediments.

NUMERICAL IMPLEMENTATION:

- CODE DESCRIPTION

Name: RHAFE - Rockwell Hanford Finite - Element Model

Reference: Gupta, S. K., Tanji, K. K., and Jon Luthin; 1975; A Three-dimensional Finite Element Groundwater Model; Contribution Number 152, California Water Resource Center, University of California. (version of FE3D6W?)

Dimensions: 3

Equations Solved: Steady-state and transient isothermal ground-water flow equations

Method of Solution: Finite element

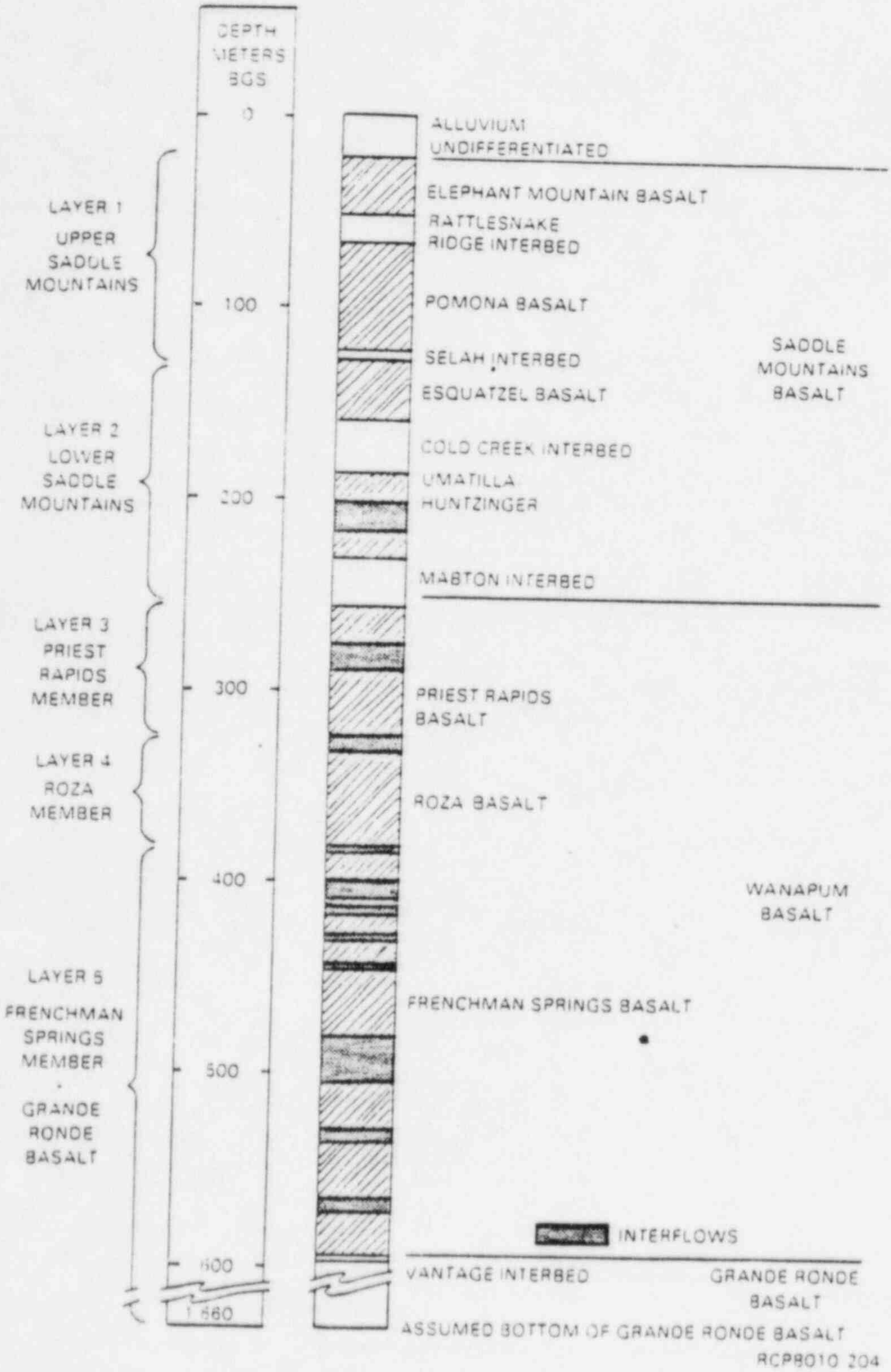

FIGURE 1. Vertical Layering for Pasco Basin Three-Dimensional Model at Well DC-15.

TABLE 1. Baseline Material Hydraulic Conductivities Used in Calculating Basalt Composite Conductivities

Basalt	Material	Percent of Total Basalt Thickness	K (feet per day)	Layer Values* (m/d) Kv	Kh	Kv/Kh
Saddle Mountains	Basalt	60	10^{-6}	1.7E-6	4	4E-7
	Interflow	20	10			
	Interbed	20	10			
Wanapum	Basalt	60	10^{-6}	1.7E-6	4	4E-7
	Interflow	35	10			
	Interbed	5	10			
Grande Ronde	Basalt	60	10^{-6}	1.7E-6	.1	1.7E-5
	Interflow	39	10^{-2}			
	Interbed	1	10			

*Data from RHO-BWI-80-100

TABLE 2. Ratios of Kv to Kh used to Produce Model-Calculated Heads in RHO-BWI-80-100

Basalt	Simulation 1 (see figure)	Simulation 2 (see figure)
Saddle Mountains	2×10^{-3}	2×10^{-5}
Wanapum	8×10^{-3}	8×10^{-5}
Grande Ronde	3×10^{-2}	3×10^{-4}

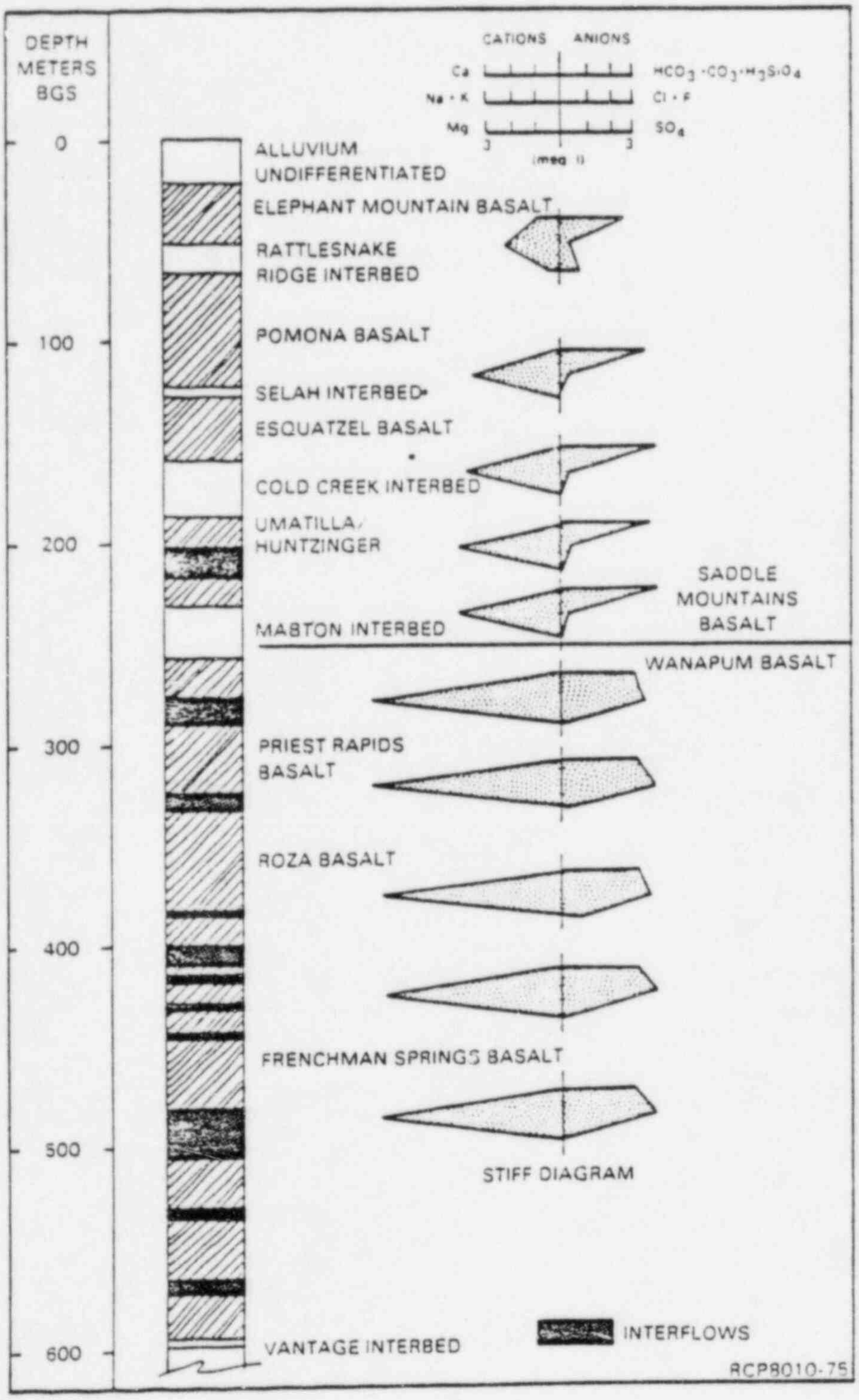

FIGURE 2 Preliminary Hydrogeologic and Hydrochemical Data within the Saddle Mountains and Wanapum Basalts at Borehole DB-15.

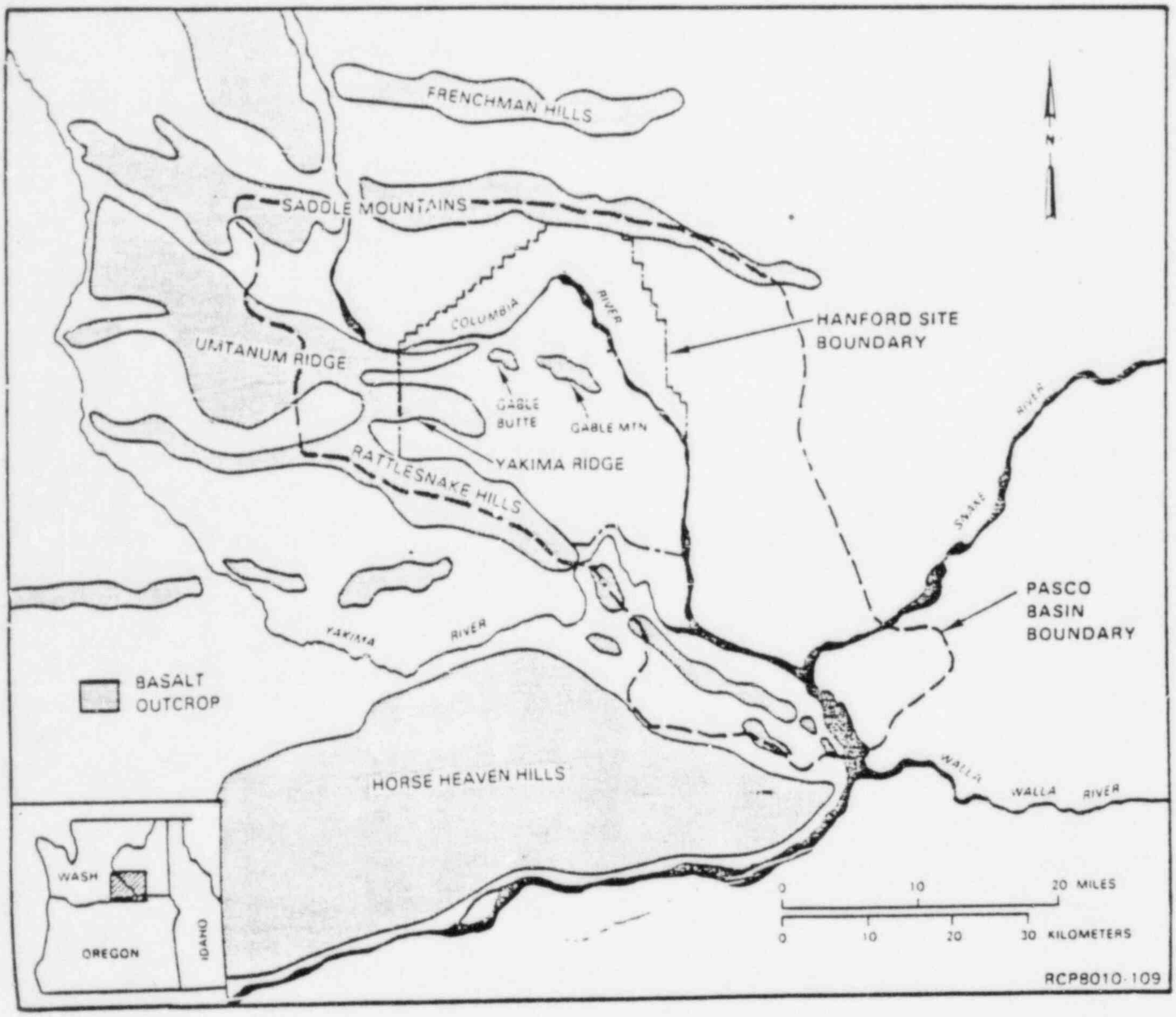

FIGURE 2. Pasco Basin and Hanford Site.

DISCRETIZATION: (see Figure 4)

Layer discretization is given in "hydrostratigraphic units."

IMPLEMENTATION OF BOUNDARY CONDITIONS: Not described.

IMPLEMENTATION OF INITIAL CONDITIONS:

Not important for steady-state simulation.

MODEL CALIBRATION:

Data Set Used for Comparison

See Spane 1980, RHO-BWI-80-100 and figure 5. Note: only Mabton heads used for comparison.

Type of Calibration Procedure: Trial and error

Type of Statistics Relating Model to Measured Heads: None

Accuracy of Calibrated Model:

All calculated heads are substantially above the measured heads

SENSITIVITY ANALYSIS: None

MODEL RESULTS: The authors state the following results:

Hydraulic Heads: (Note: only the heads for the top of the Wanapum Basalt are reported)

composite of what & ratio of what to what? →

1) A composite hydraulic conductivity ratio of 10^{-4} to 10^{-5} provides a better match of the "relative pattern" of the hydraulic head surface than a ratio of 10^{-2}.

2) With a composite hydraulic conductivity of 10^{-4} to 10^{-5}, the vertical pathway from a potential candidate site is a significant portion of the total path in terms of overall travel time to the biosphere.

3) The problem of the model-calculated heads being "significantly" higher than the measured heads is attributed to absence of the "Cold Creek Syncline Barrier" in the model.

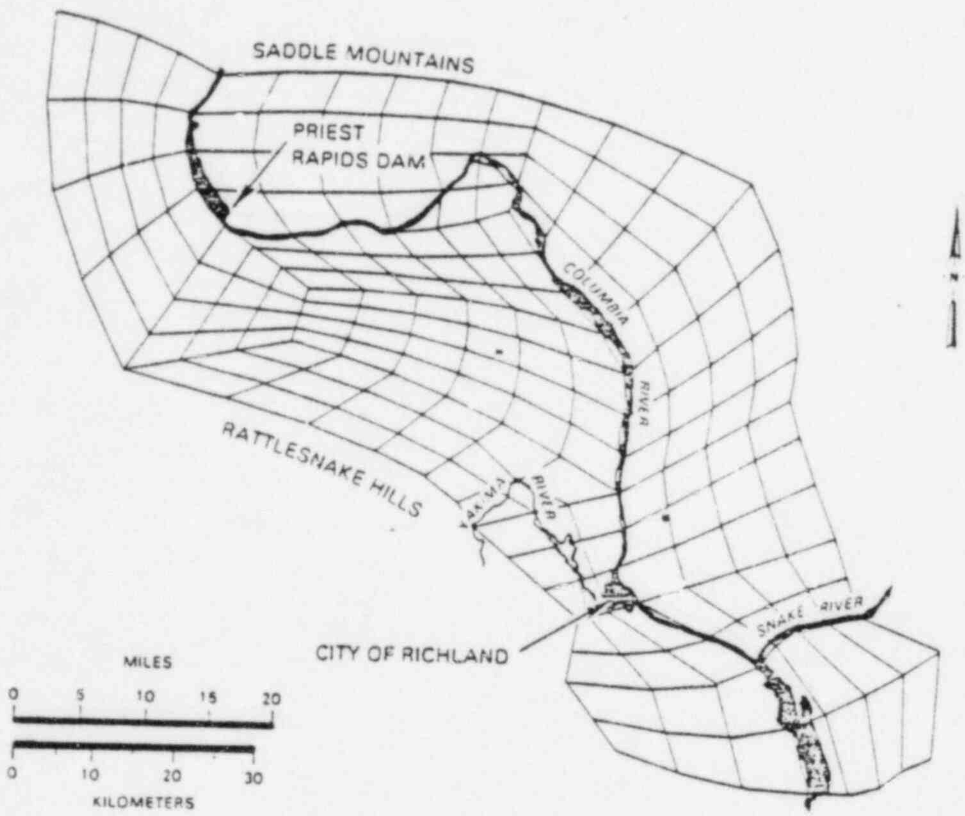

FIGURE 4. Plan View of Three-Dimensional Finite Element Network for Pasco Basin.

grid appears to be too large in vicinity of RRL for stable solutions involving large head differences – grid is probably adequate for steady-state analysis

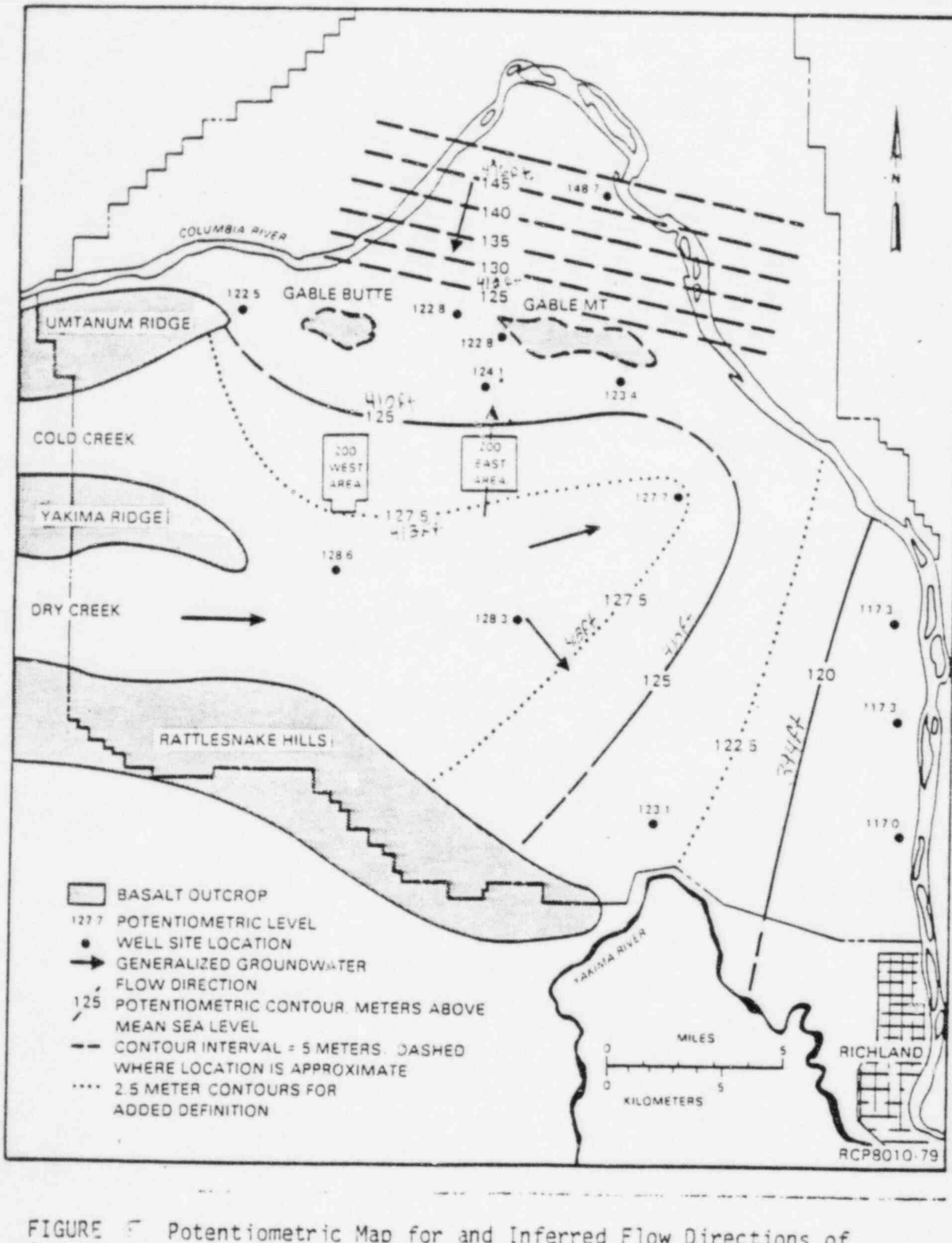

FIGURE 5 Potentiometric Map for and Inferred Flow Directions of Groundwater within the Mabton Interbed beneath the Hanford Site.

Fluxes:

No information on model-calculated fluxes was provided.

Travel Times

No travel times were reported. However, Figures 6 and 7 reveal significantly different flow directions from the location of a hypothetical repository. For anisotropy ratios of 10^{-2} to 10^{-3} (Figure 6), the inferred direction of flow is to the north/northeast toward the Columbia River. As revealed in Figure 7, anisotropy ratios of 10^{-4} to 10^{-5} produce a flow toward the north, then vertically upward. This latter path would probably result in longer travel times to the accessible environment (that is, a given distance from the repository) because of the additional time spent in low permeability dense flow interiors.

Significance to Licensing

If the assumption was made that these model results represent the "true" hydrologic conditions of the Pasco Basin, then the indicated longer travel time would aid the DOE in meeting the 1000 years ground-water travel time of 10CRF60.

EVALUATION:

- Conceptual Model

  The most important aspects of a steady-state model are the boundary conditions and the choice of layering. Unfortunately, very little information was provided about the boundary conditions and the discussion of layering is internally inconsistent. Below is a discussion of each of these important aspects of the conceptual model.

  - Boundary Conditions

  - Bottom

    There is no explicit description of the ~~of the~~ bottom boundary. I assume, however, that it has been treated as a no-flow boundary. The exact nature of this boundary has not been determined as there is an extreme paucity of data in any unit below the Wanapum Basalts. There is a possibility that the Pasco Basin is a discharge area for regional flow in the flood

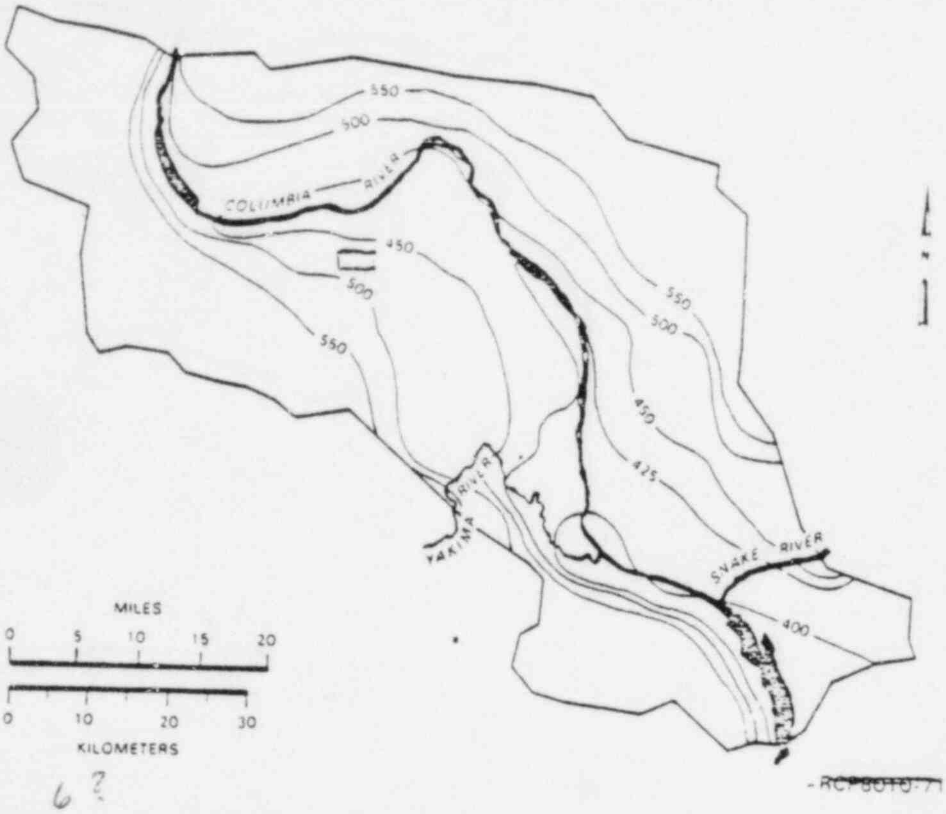

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FIGURE Model-Calculated Heads, Top of Wanapum Basalt K_z/K_x from 10^{-2} to 10^{-3}.

▭ - approximate location of hypothetical repository.

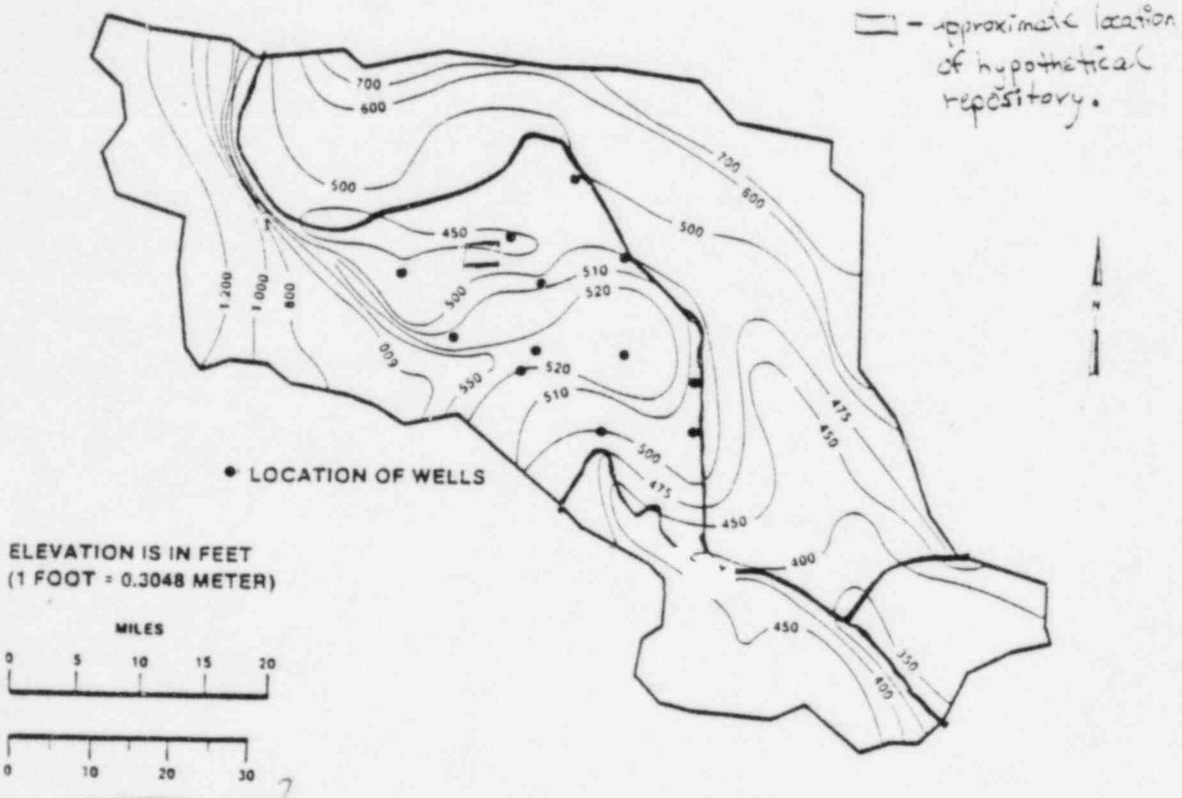

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FIGURE Model-Calculated Heads, Top of Wanapum Basalt K_z/K_x from 10^{-4} to 10^{-5}.

basalts. If this is the case, then treating this boundary as impermeable could produce unrealistically vertical gradients, and exaggerated travel times.

- Top and Lateral Boundaries

The treatment of these boundaries is not described by the authors. My guess is that It must be assumed that these boundaries they were treated as a constant hydraulic head boundaries with heads being equal to the water-table elevation for the top boundary and equal to heads measured from wells near completed in the appropriate units for the lateral boundaries. This would be consistent with other modeling studies of the Pasco Basin. However, the document seems to make contradictory statements with regards to the lateral boundaries. On page III-51, the authors state that the boundary conditions may need adjustment but appear to be in the proper range. This statement suggests that the boundaries were treated as constant heads. However, on Figures 6 and 7 (this report) the model-calculated heads are different at the boundary for the two cases. This would not be possible if the boundaries were constant heads. In a steady-state simulation, these held potentials will dominate the model results. The adequacy of employing these conditions depends on the data needed to support them in terms of their input value and measures of the resulting output. That is, a head valve is needed at every computational point along the boundary. If hydraulic head data are scarce, as they are for most basalts within the Pasco Basin, then a large uncertainty is introduced by interpolating or extrapolating valves to the boundary. In addition, these input head valves along with the input hydraulic conductivities result in a model-calculated flux across the boundaries. Unfortunately, no information on the real flux exists thereby eliminating the possibility of cross-checking the accuracy of the boundary conditions.

In summary, the lack of a description of the type and possible values of flux or head assigned to the model makes the evaluation of the boundary conditions impossible. Also, because the boundary conditions dominate

steady state simulations, the ability to evaluate the overall modeling effort is severly limited.

-Hydrostratigraphic Units

Several questions arise in evaluating the hydrostratigraphic units simulated in this study: 1) Which units were simulated?, 2) How were the units chosen?, and 3) How are model results affected by this choice?

Shown in Figure 1 are the five layers the authors state have been simulated. However, in their "SUMMARY OF RESULT," they indicate that four layers were simulated. One possible resolution of this descrepancy is that the top layer was held as a constant-head boundary. If this were true, then the model would have five layers of which only the lower four were being simulated. However only three layers are mentioned. This could mean that the three basalts were simulated and the top layer was held as constant heads.

Due to the complexity of the flood basalts, no unique set of hydrostratigraphic units exists. In addition, even if every zone of different hydraulic properties could be identified and characterized sufficient computer recources do not exist to simulate all of them. The units that were chosen were on the basis of changes in the geochemistry and hydraulic heads with depth. These may or may not be indicators of distinct hydrostratigraphic units. However because some lumping of smaller units will always be necessary, a more important question is what affect the choice of units has on model results. Of course the obvious effect is to lose detail of the hydraulic-head distribution. Perhaps less notable is the incorrect travel path that would be predicted by a grid which is less detailed than reality. In addition, any comparison of model results to measured values requires some interpolation or lumping procedure for the measured parameters. This introduces additional uncertainty into model calibration.

Numerical Implementation

Except for the finite-element grid, no details of numerical implementation are provided in the document.

Model Calibration

The only calibration that was performed involved adjusting the ratio of vertical to horizontal hydraulic conductivity for the three basalt layers. The resulting hydraulic-head surface for the top of the Wanapum was then subjectively compared to the same measured surface. All simulations resulted in heads that are significantly higher than the measured values, in some places at least 100ft. However the authors believe the simulations with lower ratios of vertical to horizontal conductivities produced a "relative pattern" of hydraulic heads that more closely resembles the measured heads.

Evaluation of the model calibration:

1) Insufficient data, in terms of input parameters, boundary conditions, and data used for model comparison are provided to allow for a complete evaluation of the model calibration.

2) The fact that all model calculations produce heads that are too high is indicative of a systematic plan in which either the model set up or the model parameters are invalid. If the top and lateral boundaries of the model are held at constant hydraulic heads which were interpolated from measured valves, then the most likely cause of the high heads is that the model hydraulic conductivities are too low. If the top boundary is a recharge condition, then the amount of assumed recharge could be too large.

3) Assuming that: a) the shape of the potentiometric surface presented in figure 5 is accurate; b) the model boundary conditions are held potentials with values being close to the "real" values; and c) the shape of the model-predicted potentiometric surface

would not change as a more accurate calibration is achieved; then the fact that lower conductivity ratios produce a more realistic pattern of hydraulic heads indicates that the lower units are controlled more by the shape of the basin and perhaps a more regional flow system than by the Columbia River.

4) The authors of the report under review believe that if the Cold Creek barrier were included in the model the overall calibration would improve. This is unlikely as heads in all regions, even far to the south, are too high.

5) Even though the lower hydraulic conductivity ratios appear to produce more realistic patterns of hydraulic heads, the absolute values of heads for the higher ratios are closer to the measured valves.

Sensitivity Analysis: None performed

Model Results.

The fact that this model has not been calibrated combined with the lack of information on boundary conditions makes any results from this model highly suspect. At best, the significance of this study is to parameterize the vertical to horizontal hydraulic conductivity ratios. However, even these results are not reliable given the inability of the model to produce accurate hydraulic heads in any region.

Lewiston Morning Tribune/Wednesday, July 31, 1985 **B**

Nuclear waste

Gardner's mail runs against Hanford site

By David Ammons
of the Associated Press

OLYMPIA – Washington Gov. Booth Gardner, vowing to oppose a highly radioactive nuclear waste repository at Hanford unless there is public support, said Tuesday his mail is running 2 to 1 against the project.

The federal government, the sponsor of the first national repository, must get its act together and begin a major education effort if it is to expect Washington or any other state to take the politically volatile wastes, the governor told a news conference.

Gardner said he will make those same comments at a congressional hearing in Washington, D.C., on Thursday.

He said he will also be lobbying for passage of legislation allowing Washington, South Carolina and Nevada to phase down the volume of out-of-region low-level nuclear wastes they accept.

The governor said the state's relations with the U.S. Department of Energy are improving, but that the government still needs to do better.

The agency has agreed to allow Washington to monitor the site testing at Hanford and has provided Oregon with funds to study transportation of nuclear wastes to the site, he said.

But he said the government has denied extensions to the state for comment on site studies, ignored other suggestions, and has not resolved the state's concern over long-term storage of defense wastes at Hanford.

Gardner said he has made it clear to the government that Washington would accept the site only if it is proved extremely safe, is shown to be the safest of the three nominated sites, and if state residents are willing to take it.

The first two elements are the subject of government tests.

As for the third, Gardner said his mail is running 2 to 1 against becoming the host state, and that it will take an education effort and a perception of a responsive federal government to turn that around.

"The bottom line is public confidence, and that means in my language that they almost have to bend over backwards to show appearance of cooperation and fairness," Gardner said. "There's probably some distance they have to travel before that equation is completed."

The final site won't be picked before 1991, he said. Polling and other public opinion gathering will be done before the state has to decide whether to acquiesce or to veto, he said. Congress can override a state veto.

Gardner said the federal legislation on low-level nuclear wastes "seems to be moving" through Congress. Under existing law, the three states with disposal sites could cut off out-of-region shipments on Jan. 1, 1986.

Legislation backed by the three governors and Rep. Morris Udall, D-Ariz., would allow the states to phase down the volumes over a six-year period. At the end of that time, all states would be expected to participate in regional waste sites.

Currently, Washington is accepting over half the nation's low-level wastes, which come mostly from medical and research facilities and the nuclear industry.