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CHAPTER 2 - SUPRABASALT SEDIMENTS OF THE COLD CREEK SYNCLINE AREA

A. M. Tallman
J. T. Lillie
K. R. Fecht

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INTRODUCTION

This chapter describes the general stratigraphy of the sediments overlying the basalt bedrock in the Cold Creek syncline. Included is a brief discussion of their distribution, lithology, stratigraphy, and age relationships in the Pasco Basin and a more detailed discussion for the western Cold Creek syncline area across the RRL.

The study of these sediments is important to the identification and evaluation of candidate sites for a repository because: (1) Plio-Pleistocene geologic history of the Cold Creek syncline area is recorded in these sediments; (2) physical properties of these sediments, especially their lateral variations, affect the ability of seismic reflection surveys to resolve details of bedrock structure in the underlying basalt; (3) shafts constructed in the RRL will penetrate these sediments and require knowledge of their character; and (4) surface facilities constructed on or in these sediments will require information on their engineering properties.

The post-Columbia River Basalt Group sediments of the Cold Creek syncline are composed of two major units (Fig. 2-1): (1) Ringold Formation, a Miocene-Pliocene fluvial unit with some lacustrine facies; and (2) Pleistocene glaciofluvial sediments, informally termed the Hanford formation. Deposition of the Ringold Formation by ancestral streams flowing through the Pasco Basin started shortly after cessation of basalt flows. Talus and alluvium deposited on the flanks of basaltic ridges during Ringold time are also included in the Ringold Formation. The Hanford formation was deposited by catastrophic floodwaters which inundated the Pasco Basin when ice dams impounding glacial lakes failed in Montana, Idaho, northern Washington, and southern British Columbia. Minor units include the Pleistocene and Holocene talus, colluvium, alluvium, landslide debris and loess, and Holocene dune sand.

PREVIOUS WORK

Investigations of the sediments in the Cold Creek syncline area began during the 1940s during construction of the Hanford Site facilities in the 200 East and 200 West Areas and have continued since then with ongoing construction and groundwater-monitoring investigations (Newcomb and Strand, 1953; Brown, 1959; Newcomb and others, 1972; Liverman, 1975; Routson and Fecht, 1979; Tallman and others, 1979). Additional work was completed by

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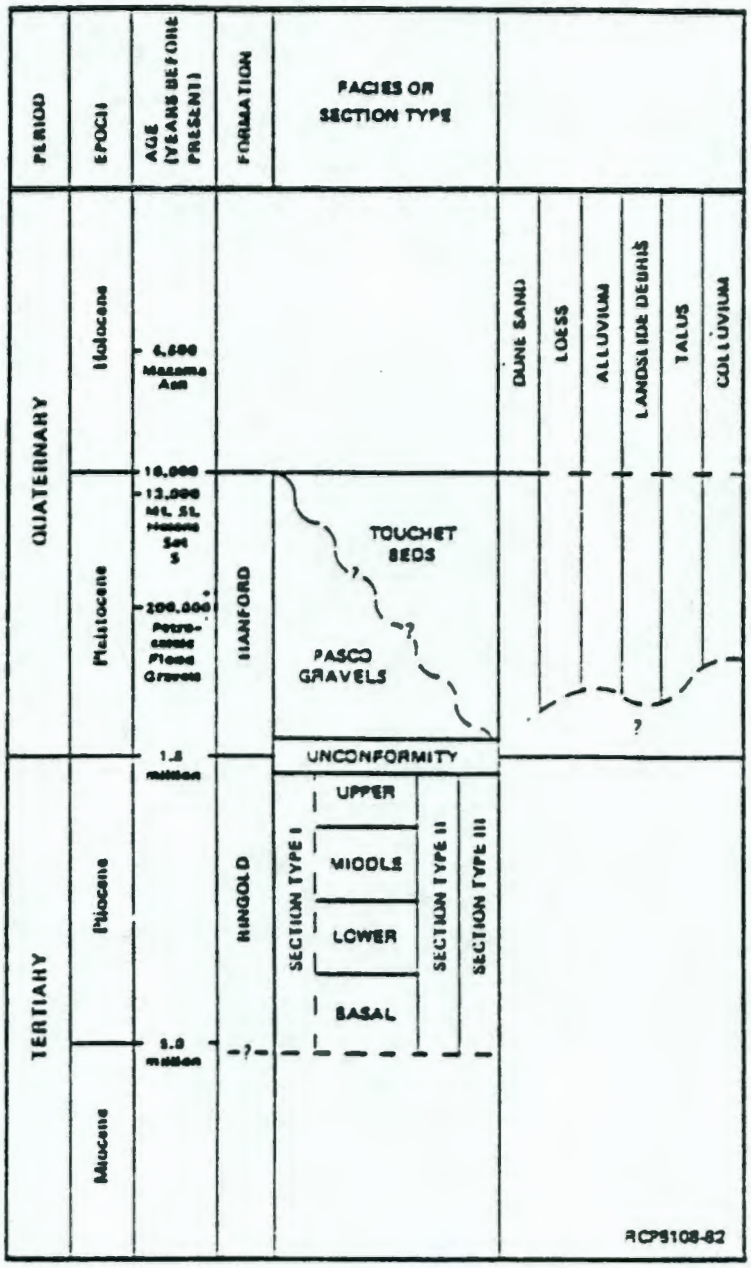

FIGURE 2-1. Sediment Stratigraphic Chart, Pasco Basin, Cold Creek Syncline.

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Washington Public Power Supply System, Inc. (WPPSS, 1977, 1981) and recently by Northwest Energy Services Company. A summary of regional and Pasco Basin post-Columbia River basalt geology is presented in Myers, Price and others (1979).

METHODOLOGY

Reconnaissance field mapping (1:62,500) of sediments in the Cold Creek syncline was completed in 1978 (Lillie and others, 1978; Myers, Price and others, 1979) and more detailed field mapping (1:24,000) is currently being done by Rockwell.

Investigations of subsurface sediments in the Cold Creek syncline utilize primarily driller's logs and samples from boreholes. These boreholes were drilled using cable-tool, mud and air rotary, and diamond-coring drilling methods (Fecht and Lillie, in press; also see Appendix A). The quality of driller's logs and sediment samples is variable and is considered in the interpretations presented in this report. Granulometric analyses and calcium carbonate ($CaCO_3$) determinations were completed on sediments from selected boreholes to aid in delineation and correlation of major facies changes within the Hanford and Ringold Formations. Geophysical logs are available for some boreholes, and some areas are covered by geophysical surveys (see Appendix B).

Paleomagnetic analyses of sediments from the Ringold Formation were completed for exposures along the Columbia River and for three core holes on the Hanford Site (Woodward-Clyde Consultants, 1978; Packer and Johnston, 1979). These data are being used to delineate time-stratigraphic units and, in conjunction with fossils, can be used for dating and correlating the Ringold Formation.

GENERAL STRATIGRAPHIC SETTING

RINGOLD FORMATION

The Ringold Formation overlies the Columbia River Basalt Group within most of the Pasco Basin, except where: (1) basalt crops out, (2) glaciofluvial Hanford formation onlaps ridges above the margin of the Ringold Formation, and (3) it has been eroded and Hanford sediments were deposited directly on basalt.

The Ringold Formation within the Pasco Basin has been divided vertically into three textural facies, generally following the divisions of Newcomb (1958): (1) lower Ringold, the "blue clay" facies consisting of silt, clay, sand, and gravel extending upward from the basalt; (2) middle Ringold, conglomerate or gravel facies; and (3) upper Ringold, clay, silt, and sand, with some minor gravel lenses (Brown, 1959). Recent work (Routson and Fecht, 1979; Tallman and others, 1979; Myers, Price and

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others, 1979; Brown, 1981) has distinguished a basal unit, the predominantly gravel facies in the bottom portion of lower Ringold, as described by Newcomb (1958) and Brown (1959).

The division of the Ringold Formation into a (1) basal, (2) lower, (3) middle, and (4) upper facies, based primarily on texture, is appropriate for much of the central Pasco Basin. On the edges of the basin, the character of the Ringold Formation differs because of derivation from local sources.

In general, three representative stratigraphic section types can be used to describe the lateral variations of the Ringold Formation in the Pasco Basin (Fig. 2-2). The central portion of the Cold Creek syncline and much of the central Pasco Basin are representative of section type I (the four facies listed above) and illustrated in DH-12 (Fig. 2-3). However, all four textural facies are not present throughout all the section type I area. Much of the upper Ringold is eroded and the lower Ringold pinches out on anticlinal ridges, and in some areas, the basal gravel unit is not present or cannot be distinguished from middle Ringold where the two are in contact. The lateral distribution is shown in Figure 2-2. A more detailed discussion of this section type is presented later in the discussion of the RRL stratigraphy.

Section type II of the Ringold Formation is found north and east of Gable Mountain (Fig. 2-2) and is composed predominantly of silt, sand, and clay as represented in DH-19 (Fig. 2-3). Minor gravel lenses are present, mostly north of Gable Mountain. Sediments of this section are interpreted as floodplain overbank deposits throughout Ringold time. Erosional unconformities and paleosols are present, but there is no evidence of high-energy, main-channel, sedimentation characteristics of the middle and basal Ringold facies in the central basin.

Section type III, the fanglomerate facies (Grolier, 1965), occurs on the flanks of anticlinal ridges and includes the talus, slope wash, and side stream facies which interfinger with the central basin deposits of section types I and II (Fig. 2-2 and 2-3). This facies of the Ringold Formation is composed chiefly of basalt clasts in a matrix of quartz and feldspar or basalt sand. Locally, some openwork, angular, basalt debris is present. It is generally compacted to cemented with silica and/or $CaCO_3$. The unit is the result of mass wastage and runoff on the emerging ridges during the deposition of the other Ringold section types in the lower elevations of the Pasco Basin.

Section types I and II were deposited by a major river system which flowed through the Pasco Basin. The middle Ringold gravel of section type I is present from Sentinel Gap to the west side of Gable Mountain and throughout the central Pasco Basin to Wallula Gap, except where it is locally eroded south of the city of Pasco (Fig. 2-2). The main channel meandered across the Pasco Basin, depositing the time-transgressive middle Ringold gravels and the associated finer grained sediments. Several fluvial cycles are recognized within section type I, but have not been correlated across the basin. The fine-grained sediments of section types I

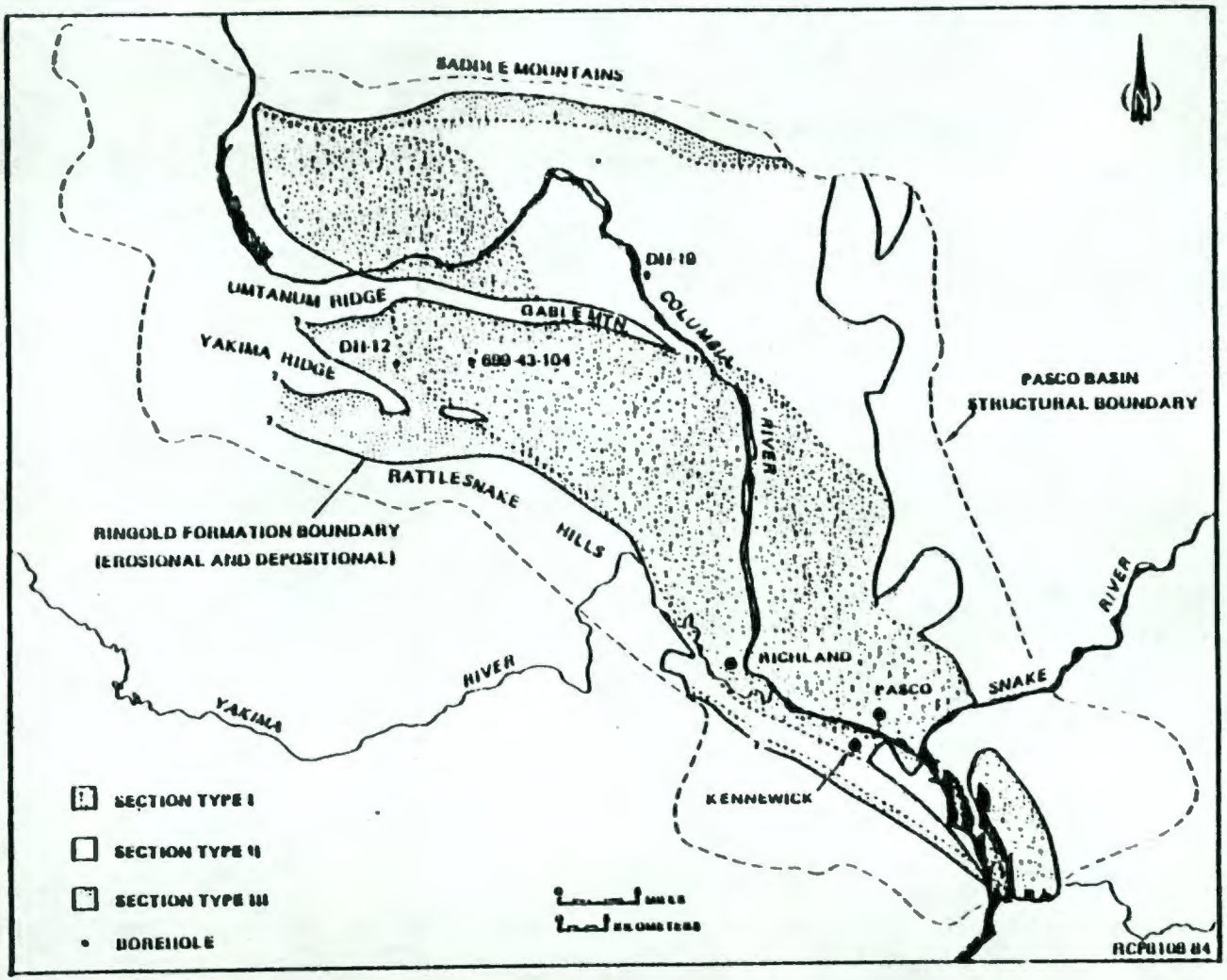

FIGURE 2-2. Distribution of Ringold Section Types.

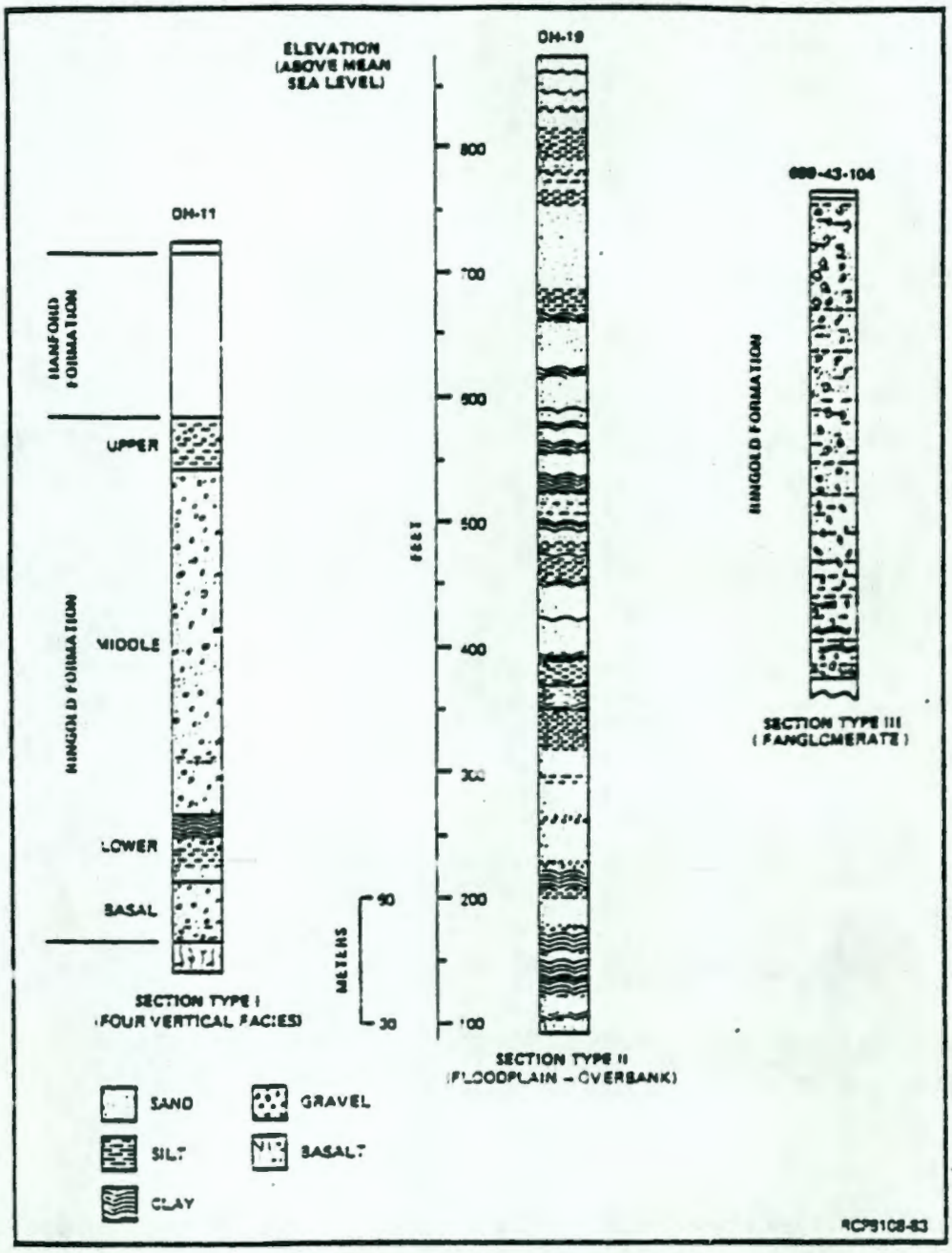

FIGURE 2-3. Ringold Section Types.

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and II were deposited as lateral equivalents of the main-stream facies. After the deposition of the upper Ringold of section type I and before the deposition of the Hanford formation, there was a major period of fluvial incision and as much as 150 m of Ringold sediments were eroded across the central portion of the Pasco Basin. The nature of these missing sediments is not known, but the lateral equivalent, the upper Ringold of the White Bluffs, is a fine facies similar to the sand and silt of section type II. Erosional remnants of the upper Ringold are present in the west-central part of the basin. These fine-grained sediments are either the floodplain overbank equivalents of a now eroded channel deposit, or they represent a low-energy, fluvial-lacustrine environment throughout the basin for all of upper Ringold time.

HANFORD FORMATION

The Pasco Basin was inundated by multiple Pleistocene floods when ice dams failed along the glacier margin in northern Montana, Idaho, Washington, and southern British Columbia (Bretz, 1923, 1925; Baker, 1973). An estimated 2,000 km^3 of water from Glacial Lake Missoula surged across eastern Washington (Pardee, 1942), deeply scouring basalt and aggrading thick sequences of subfluvially deposited sediments. The floodwaters were diverted into numerous anastomosing channels which debouched into the Pasco Basin (Baker, 1973; Baker and Nummedal, 1978). Water was temporarily impounded behind the underfit water gap at Wallula, with the resultant temporary lake reaching an elevation of ~365 m in the Pasco Basin.

The sediments deposited in the Pasco Basin during these flood events are informally referred to as the Hanford formation. The Hanford formation is divided into two textural facies: (1) Pasco Gravels (Brown, 1975) and (2) Touchet Beds (Flint, 1938). The Pasco Gravels (Fig. 2-4) range in texture from boulders to fine sand and represent varied energy environments during flooding. The Touchet Beds (Fig. 2-5) are made up of rhythmically bedded, fine-grained sediments deposited in low-energy, slackwater environments.

Floodwaters entered the Pasco Basin by three routes: (1) through Sentinel Gap, (2) across the northeastern flanks of the Pasco Basin in several well-developed coulees, and (3) down the Snake River (Fig. 2-6). The texture of the Hanford formation varies throughout the Pasco Basin. In general, the Pasco Gravels are coarsest immediately south of Sentinel Gap and south of the Gable Mountain-Gable Butte constriction, where coarse debris was deposited when the floodwaters spread out into the Pasco Basin and deposited a swath of gravels to Wallula Gap. Coarse gravels are also present in the southern Pasco Basin, where floodwaters entered the basin via the Snake River (Brown, 1981; Lindberg and Brown, 1981). The Touchet Beds are generally restricted to higher elevations on the flanks of ridges and up tributary valleys of the Pasco Basin away from the higher energy, main-channel flow.

The number of Pleistocene floods in eastern Washington and the Pasco Basin is not known. Stratigraphic evidence for as many as 12 floods is reported in the Spokane area by Stradling and others (1980). In work done

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FIGURE 2-4. Pasco Gravels, Reference Repository Location.

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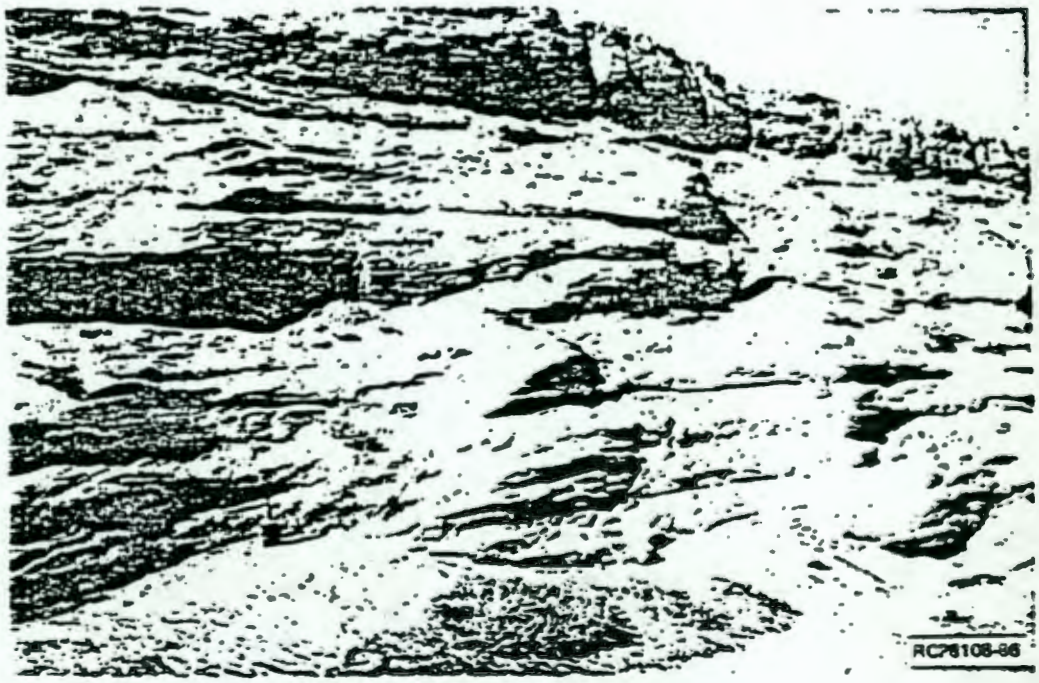

FIGURE 2-5. Touchet Beds, Pasco Basin.

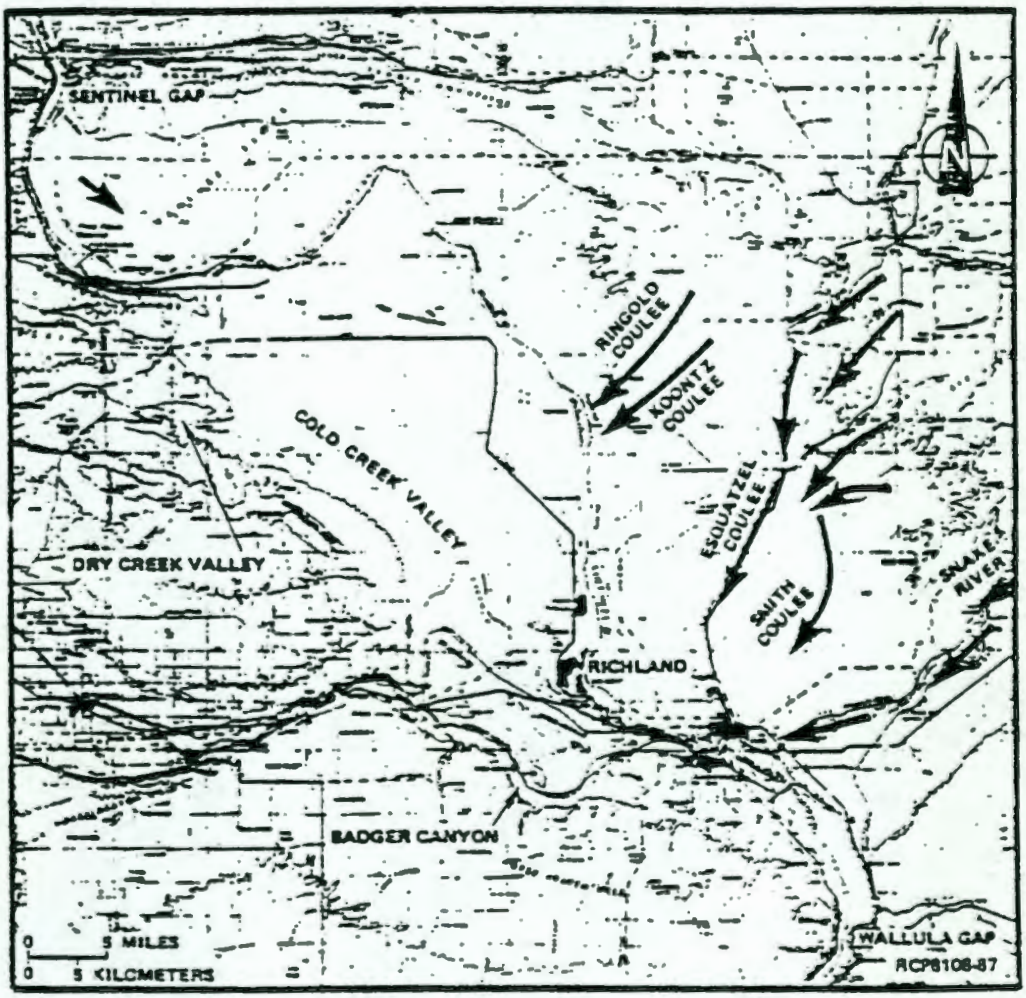

FIGURE 2-6. Floodwater Routes into the Pasco Basin.

for Rockwell, L. G. Hansen reported stratigraphic evidence for at least seven floods in the Columbia River Valley in the northwestern Columbia Plateau. The Touchet Beds in the Walla Walla Valley are interpreted to represent "about 40" individual floods (Waitt, 1980) based on the assumption that each major sedimentary cycle represents one flood. Bjornstad (1980) concluded that these cycles represented energy pulses in one major flood, but he did find evidence for at least two separate floods. Within the Pasco Basin, multiple, graded sequences of Pasco Gravels and Touchet Beds have been observed in boreholes and outcrop. Whether each sequence represents an individual flood or merely changes in the environment during deposition is not known.

Locally, three sedimentary sequences identified in boreholes in the Pasco Basin (Brown, 1981) are interpreted to be three separate flood events. In an excavation in the south-central basin, three main sequences of Hanford sediment are interpreted to represent multiple flood events in the late Pleistocene (Wisconsinan, ~80,000 to 10,000 yr before present). Older gravels in Badger Coulee contain a petrocalcic horizon and are interpreted as pre-Wisconsinan flood sediments. More detailed analysis of borehole samples and exposures is needed to refine the flood history of the Pasco Basin.

Clastic dikes (Fig. 2-7) commonly occur in the Touchet Beds and Pasco Gravels. They are also found in the Ringold and Ellensburg Formations and in basalt. The dikes are generally vertical- to irregular-dipping fissure fillings in the host sediments that are filled with clay-to-gravel sediments. The mechanism for the formation of the clastic dikes is not known, but they have been interpreted not to be related to permafrost, desiccation, or seismic activity (Black, 1979). Most dikes observed appear to be filled from above and display intricate fluvial bedding with evidence for multiple, filling events. The mechanism for opening of the fissure may be related to loading and dewatering during Pleistocene catastrophic flooding (Black, 1979; Baker 1973).

SURFICIAL DEPOSITS

Relatively minor amounts of alluvium, dune sand, loess, talus, colluvium, and landslide debris occur in the Pasco Basin. Most of these deposits are Holocene, but some may be as old as the Pleistocene (Lillie and others, 1978; Myers, Price and others, 1979).

Alluvium occurs in the floodplains of the Yakima and Columbia Rivers and in the Cold Creek and Dry Creek Valleys. Alluvium below the elevation of major Pleistocene catastrophic flooding is Holocene, but ranges from Pleistocene to present above flood level. Some Pleistocene alluvium may be overlain by the Hanford formation.

Dune sand is present throughout much of the Pasco Basin and consists of medium- to fine-grained sand with minor amounts of silt. Active dunes are present in the central Pasco Basin and to the north and east along the

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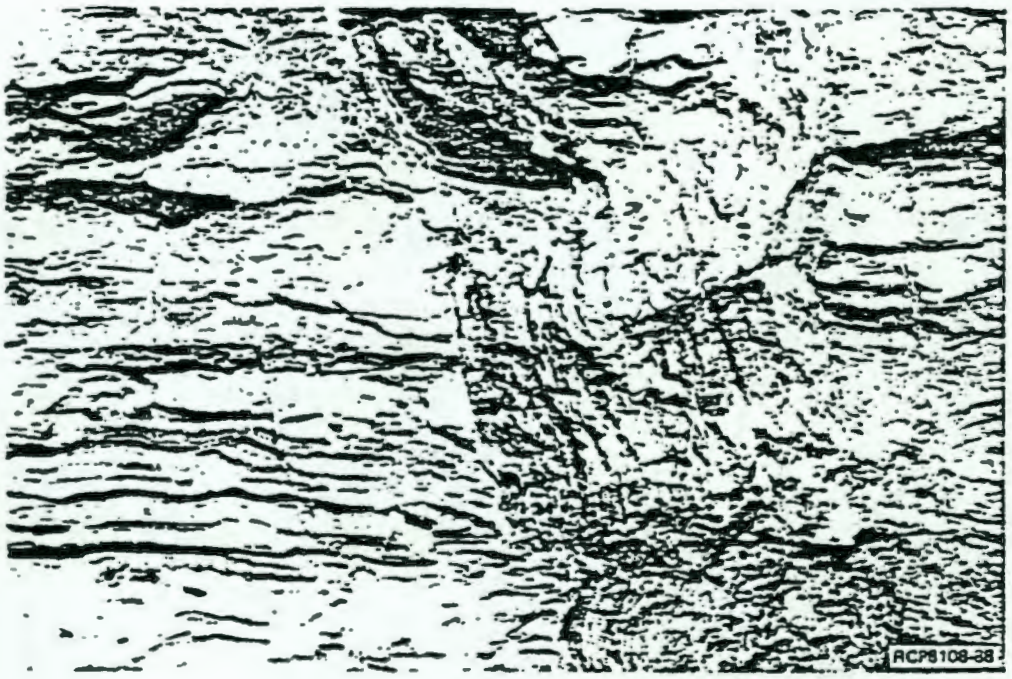

FIGURE 2-7. Clastic Dike in Touchet Beds, Pasco Basin.

Columbia River. Stabilized, longitudinal dunes occur in the south-central portion of the Pasco Basin. Dune sand is chiefly reworked Hanford sediments.

Talus and colluvium are present on ridge flanks. These deposits are primarily Holocene, but are in part Pleistocene at elevations above flood level. Basalt landslide debris is present along anticlinal ridges. Large, partly eroded landslides and landslide complexes are probably Pleistocene or older. Landslides in the Ringold Formation along the White Bluffs are predominantly Holocene; however, some large landslide complexes are overlain by the Pleistocene Hanford formation. Active landsliding on the White Bluffs chiefly is related to increased irrigation on top of the White Bluffs as well as undercutting by the Columbia River.

STRATIGRAPHY OF THE REFERENCE REPOSITORY LOCATION

The Ringold and Hanford formations overlie the Columbia River Basalt Group in the RRL area (Fig. 2-8 and 2-9). Dune sand veneers the Hanford formation in parts of the area.

RINGOLD FORMATION

The Ringold Formation within the RRL is composed of the basal, lower, middle, and upper units (section type I), with some interfingering of the fanglomerate and side-stream facies (section type III) in the western part of the area (Fig. 2-2 and 2-3).

Basal Ringold

The basal Ringold unit overlies the Elephant Mountain Member of the Saddle Mountains Basalt in the RRL and is chiefly a silty, sandy gravel to a gravelly sand that varies in thickness from 0 to >45 m (Fig. 2-8 and 2-9). The bedding structure is not known from available borehole data. Clasts are predominantly basalt, but include quartzite, granitic rocks, metamorphic rocks, and other lithologies from outside the Pasco Basin. The sand fraction is primarily quartz and feldspar. The exotic lithologies indicate a through drainage in the Pasco Basin during deposition of the basal Ringold. The dominance of basalt reflects the influence of the side-stream and fanglomerate debris of section type III and proximity to basalt highs. The unit is commonly well cemented with silica and/or calcite. It is generally thicker in the deepest part of the Cold Creek syncline in the RRL area and is folded with the basalt, suggesting that this unit was deposited during deformation of the Cold Creek syncline (Fig. 2-10). Previous work on the northern flank of the Cold Creek syncline suggested that the unit was generally the same thickness throughout (Routson and Fecht, 1979; Tallman and others, 1979) and that most deformation occurred after deposition.

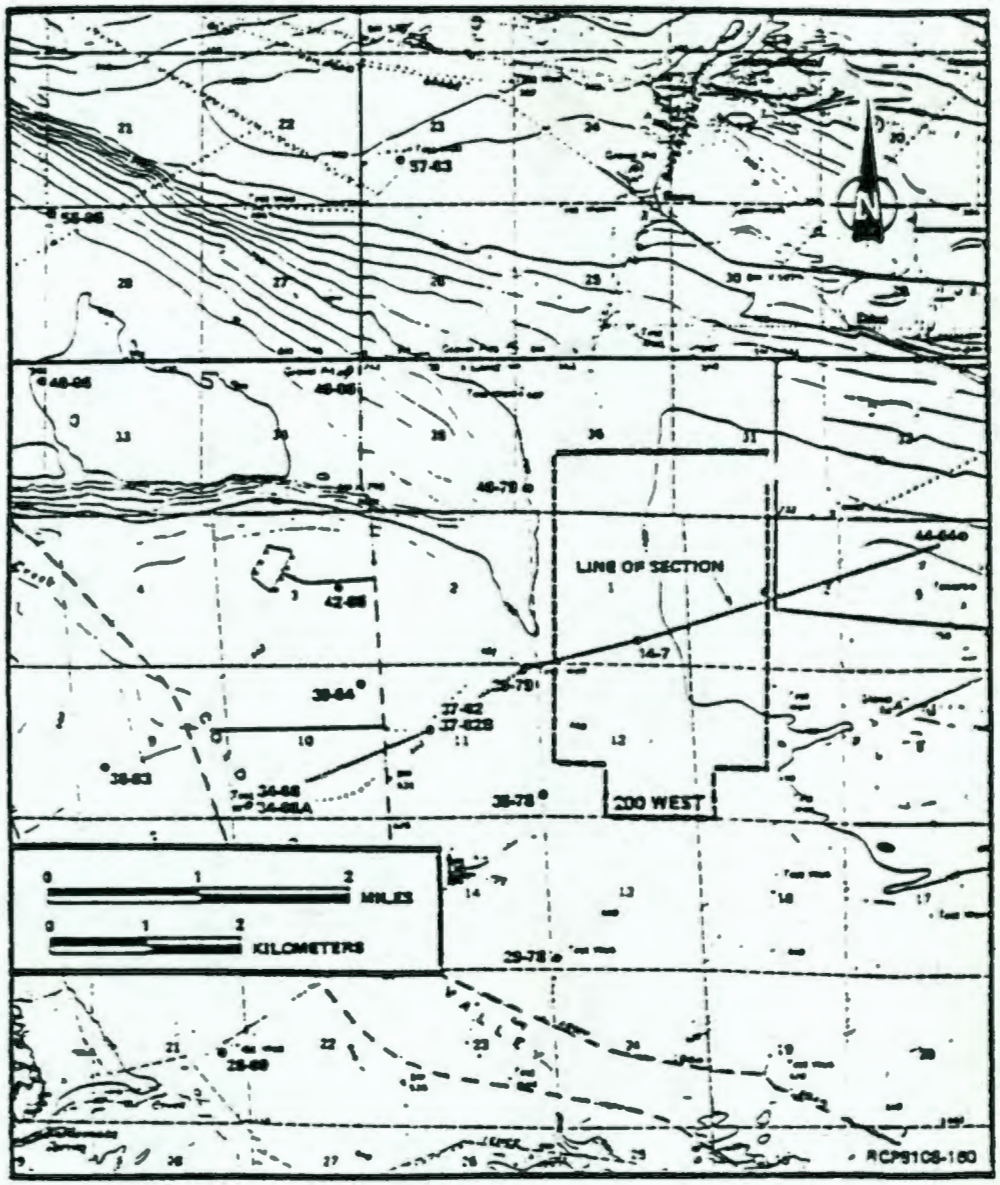

FIGURE 2-8. Index to Location of Fence Diagram Wells and Cross Sections.

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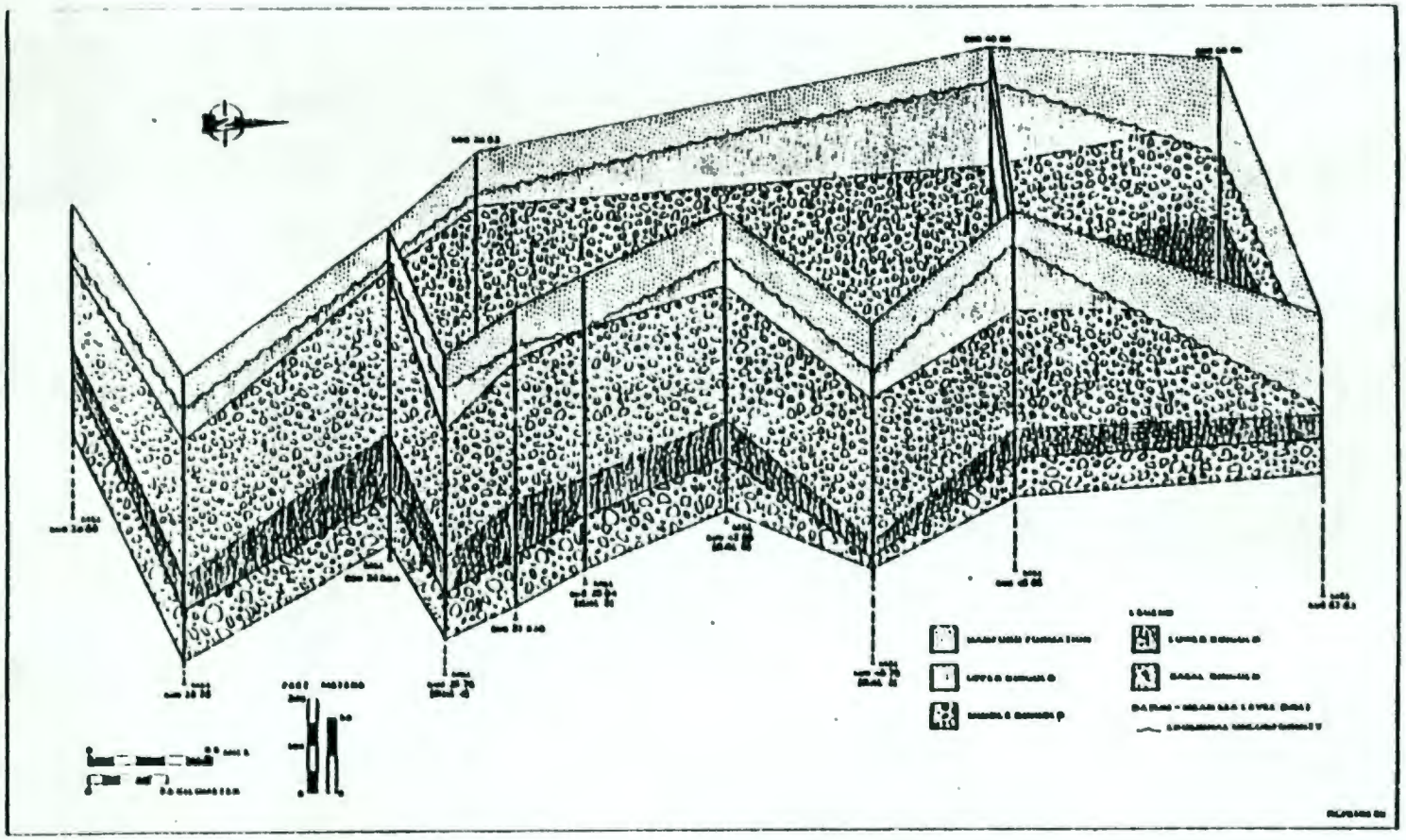

FIGURE 2-9. Fence Diagram, Reference Repository Location.

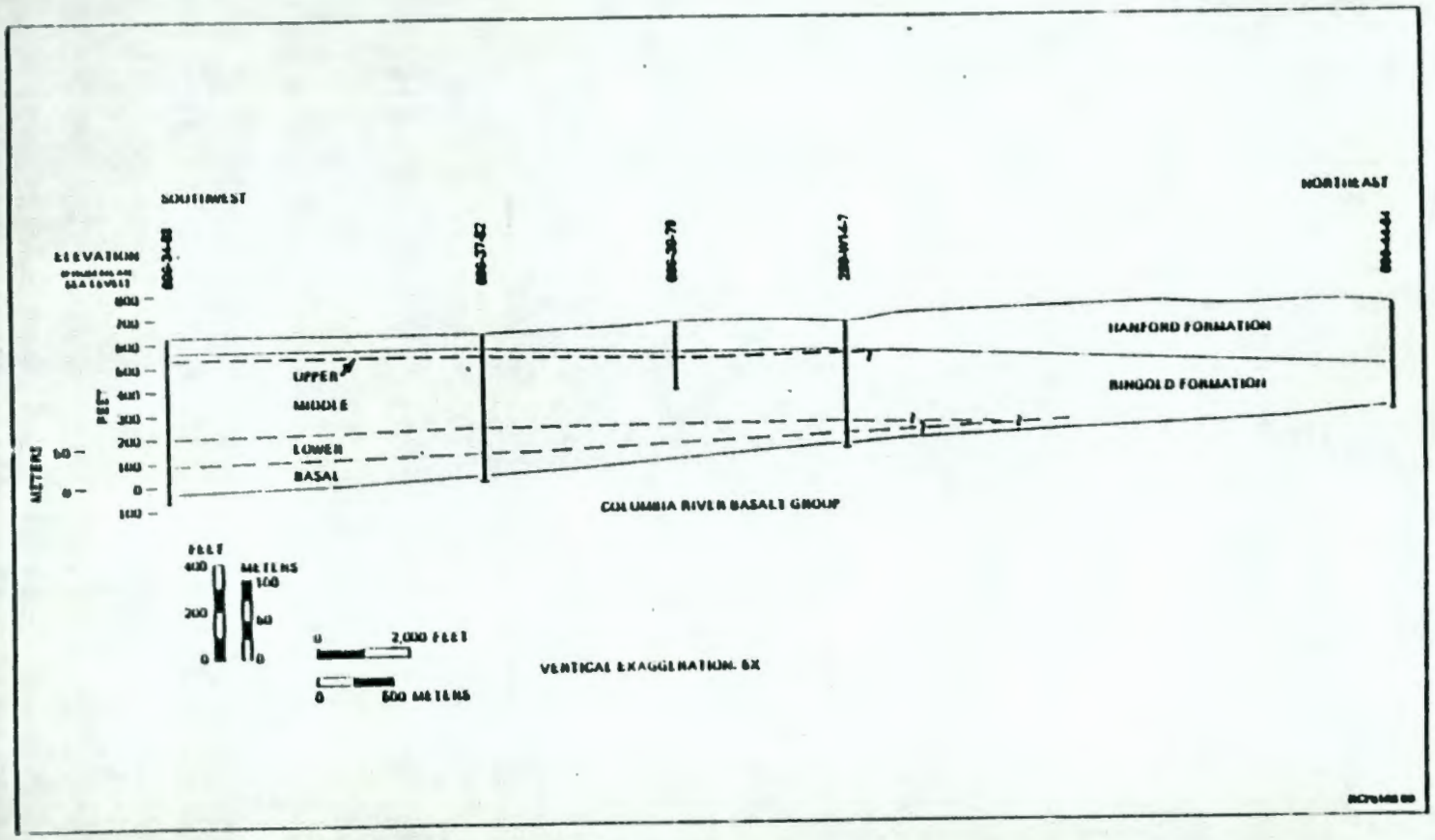

FIGURE 2-10. Structure Cross Section, Reference Repository Location.

The nature of the contact between the basal Ringold and the basalt is not fully understood, but it is assumed that regional drainage was the dominant influence on sediment deposition in the Pasco Basin very soon after the deposition of the last basalt flow (Ice Harbor Member) in the southern Pasco Basin. In the RRL, the Ringold overlies the Elephant Mountain Member, but the sediments differ from the tuffaceous Levey interbed between the Ice Harbor and Elephant Mountain Members in the southern part of the Pasco Basin (Chapter 3). It is, therefore, assumed that most deposition of the highly basaltic Ringold gravels occurred after deposition of the Ice Harbor Member. Upon continued deformation, the main channels were confined primarily to synclinal areas with local slope wash off the synclinal limbs. The unit includes gravel deposited in high-energy, main-channel environments and associated fine sediments from floodplain and local lacustrine environments.

Lower Ringold

A sand, silt, and clay facies with some gravel stringers overlies the basal Ringold gravels throughout the RRL area (Fig. 2-8 and 2-9). This represents a low-energy, fluvial unit with some lacustrine facies; the unit varies in thickness from 5 to 35 m. The unit is thickest in the deepest parts of the syncline, generally thin updip, and pinches out on anticlinal ridges (Fig. 2-10). Fining, upward, sedimentary cycles are observed in grab samples from wells, but the low well density precludes correlating these cycles between wells. In core, the silt-clay fraction is finely laminated to massive (Fig. 2-11).

The sand and silt are composed of quartz, feldspar, and mica with lithic fragments of Columbia River basalt and rocks from outside the Pasco Basin. The sediments are generally compacted with variable induration.

The thinning of the lower Ringold unit on the flanks of the Cold Creek syncline indicates that the unit was deposited during or after deformation of the Cold Creek syncline (Fig. 2-10). During lower Ringold time, the RRL area, as well as most of the Cold Creek syncline, was a region of low-energy deposition. Floodplain deposits are dominant, with some relatively thick sequences of lacustrine deposits. Minor gravel horizons indicate that there was periodic, minor, channel deposition throughout the region. The contact between the basal and lower units is generally gradational, indicating a general decrease in fluvial energy. It is not known whether this low-energy environment is representative of the entire Pasco Basin, with subsequent erosion of the lower Ringold sediments on the anticlinal highs, or is only present in the synclinal areas with coeval, major, channel deposition outside major synclinal areas.

Middle Ringold

The middle gravel facies overlies the lower Ringold and is present throughout the RRL (Fig. 2-9 and 2-10). It consists of pebble-to-cobble gravel with a matrix of sand, silt, and some clay. The unit is up to

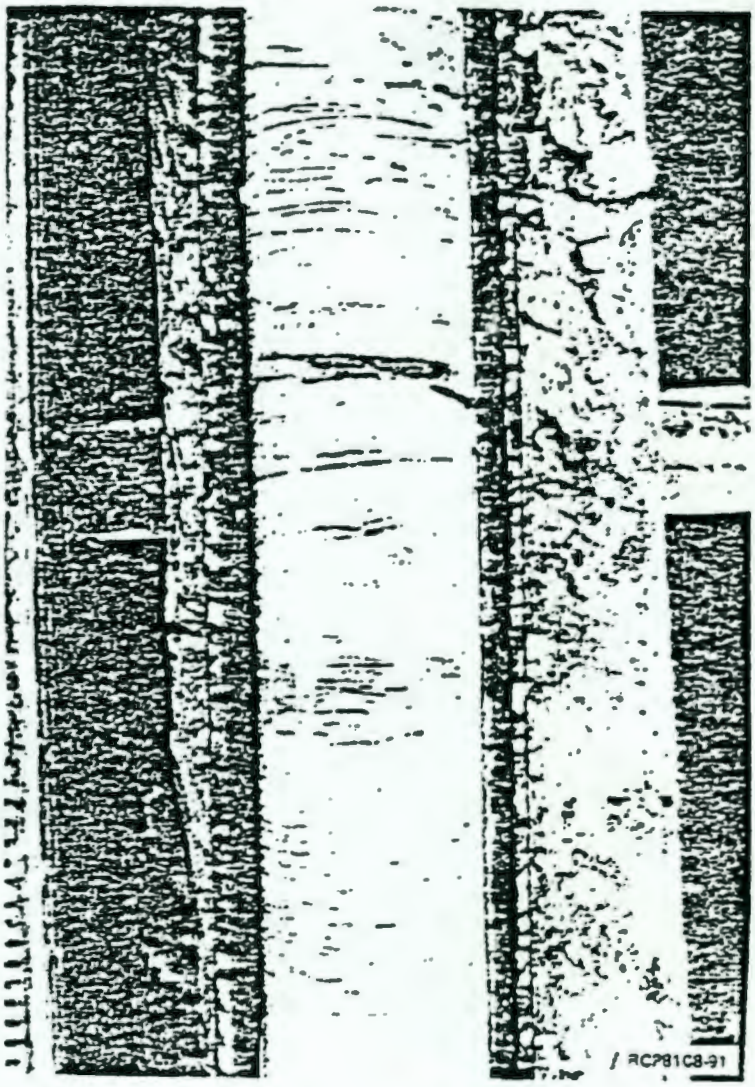

FIGURE 2-17. Lower Ringold Sediments, Borehole CH-19.

100 m thick in the RRL and contains horizons of sand and silt. The gravel is composed of basalt and quartzite with metamorphic, granitic, and porphyritic-volcanic rocks. The sand fraction is predominantly quartz and feldspar, with mica and basalt commonly a significant constituent. The silt and clay fraction is quartz, feldspar, and smectite. The conglomerate observed in cores from the 200 West Area and exposed at the White Bluffs, 30 km east of the RRL, has a massive appearance with minor imbrication of clasts. Cross bedding is common in the sand lenses from cores and at the White Bluffs exposure (Fig. 2-12).

Induration varies from essentially no cementation to well cemented by $CaCO_3$ and/or silica (SiO_2). Much of the well-indurated conglomerate facies is matrix supported (Fig. 2-13).

Openwork, uncemented gravel is occasionally found in core. Limited data within the RRL do not reveal deformation of the middle Ringold (Fig. 2-10), but a general, arcuate, concave, upward contact with the upper Ringold throughout much of the Cold Creek syncline suggests there has been some deformation of the middle Ringold. The variations in thickness are generally related to channels of middle Ringold into the lower Ringold and erosion of the middle Ringold by post-Ringold fluvial activity, primarily Pleistocene flood channels.

The contact with the lower Ringold is generally sharp, indicating an abrupt change in fluvial energy environment. The conglomerate was deposited in a high-energy environment and the particle roundness and exotic lithologies suggest transport over considerable distance. The Ringold Formation has long been considered to be of Columbia River drainage origin (Merriam and Buwalda, 1917). The presence of modern Snake River lithologies indicates an influence of the present Snake River drainage (Tallman and others, 1979; Brown, 1981). Recent studies indicate that lithologies of the modern Clearwater and Salmon River drainages are present in the middle Ringold in the southeastern Pasco Basin (Richman, 1981; Webster and others, in press). This facies is interpreted as main-channel deposition, undoubtedly recording multiple erosional unconformities and sedimentary cycles.

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Upper Ringold

The upper Ringold unit is present in parts of the RRL as an erosional remnant overlying the conglomerate facies (Fig. 2-9 and 2-10). The unit is composed of well-sorted sand and silt with minor amounts of clay. Thin horizons of pebble gravel are common. The sand and silt fraction is primarily quartz and feldspar, with locally large amounts of mica and basalt. Quartz, smectite, and mica make up the clay fraction. Caliche horizons are common and usually are present on the upper erosional surface where the unit is moderately to well cemented. The unit generally appears to grade from the silty-sandy-gravel of the middle Ringold facies. The upper surface is erosional throughout the RRL (Fig. 2-9).

FIGURE 2-12. Cross-Bedded Sand Lens of Middle Ringold, White Bluffs.

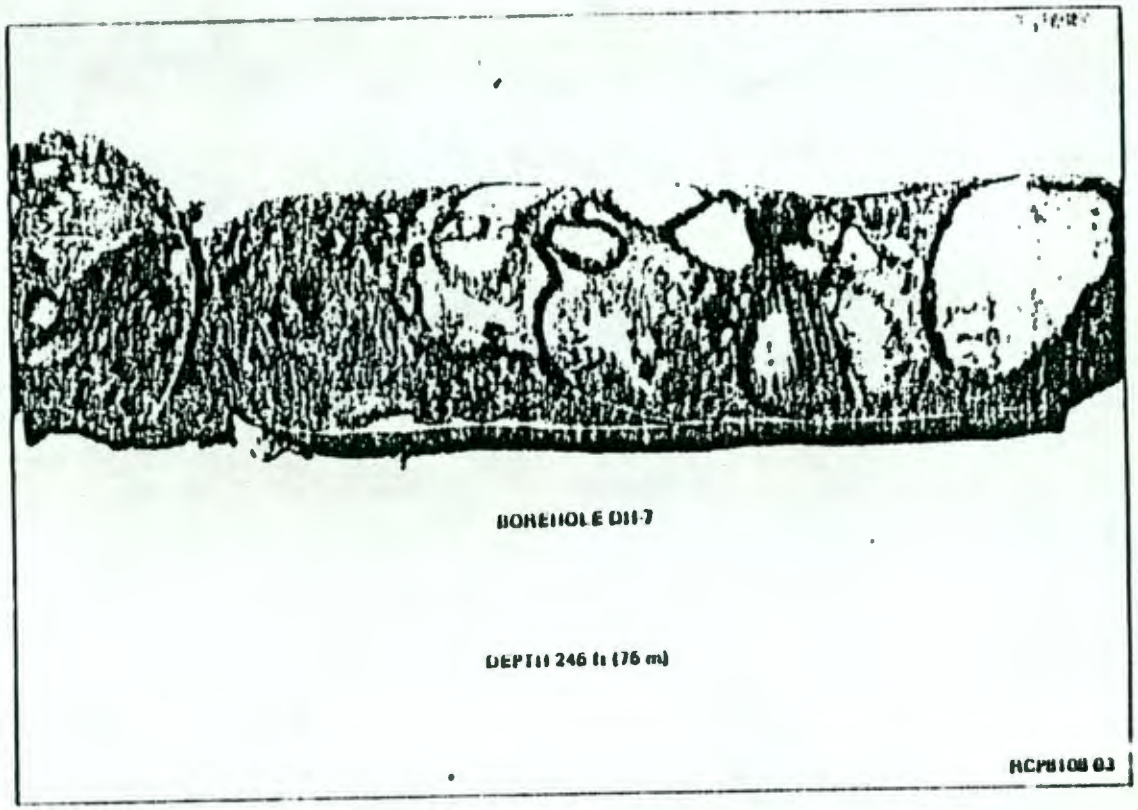

FIGURE 2-13. Matrix-Supported Clast of Middle Ringold, Borehole DII-7.

Core samples outside the RRL show alternating sand, silt, and clay horizons similar to those observed in the White Bluffs (Fig. 2-14). Only the lowermost part of the upper Ringold section found at the White Bluffs is present in the RRL. It represents a low-energy, fluvial environment with some lacustrine facies, probably a floodplain of a major fluvial system. Pebble gravels indicate small channels or perhaps extensive sheet-wash periodically inundated the area, and paleosols represent extended periods of subaerial exposure. Sediments interpreted to be loess overlie the fluvial sequence and are included in the upper Ringold unit.

Erosion removed an unknown amount of the upper Ringold in the RRL; that which remained was buried by the sediments of the Quaternary Hanford formation. The timing of loess deposition relative to the major erosion of the upper section of this unit is not known. If the major erosion of the upper Ringold occurred before the deposition of the loess, as suggested by the caliche horizon below the loess, the loess unit may be considerably younger than the underlying fluvial sediments. The extensive caliche horizon on most of the upper erosional surface of the upper Ringold unit, be it loess or fluvial sediments, suggests that the surface existed for some time prior to deposition of the glaciofluvial Hanford formation. It also suggests that very little erosion took place during Pleistocene flooding in this area of the Pasco Basin as it was generally protected in the lee of the Umtanum Ridge-Gable Mountain structure.

HANFORD FORMATION

The Hanford formation, chiefly the Pasco Gravels, overlies the Ringold Formation throughout the RRL (Fig. 2-9 and 2-10). The sediments are made up of gravel to sand and represent relatively high-energy, subfluvial deposition during Pleistocene flooding. A thin sequence of Touchet Beds is present at or near the surface mainly to the west of the RRL.

The surface of the subfluvial bars is commonly armored with a lag gravel, resulting from the winnowing of fine sediments during waning stages of flooding. This has been further accentuated by eolian deflation during the Holocene.

Clastic dikes occur within the RRL. The surface expression of these dikes is polygonal-patterned ground with polygons up to tens of meters across.

Bergmounds are very common up the Cold Creek Valley and on the flanks of Rattlesnake Mountain (Fecht and Tallman, 1978). These relatively unique landforms resulted from the grounding of large, glacial icebergs on the surface of the Hanford formation, thus protecting the underlying sediments from erosion during draining of the floodwaters.

Pasco Gravels

The Pasco Gravels range from boulders to fine-grained sand and display varied bedforms (Routson and others, 1979). The best exposures of the

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FIGURE 2-14. Laminated Upper Ringold Sediments, White Bluffs.

Pasco Gravels are in excavations for waste facilities east of the RRL. Massively bedded, horizontally bedded (often with fine laminations), cross-bedded, and graded-bed sequences have been observed in these excavations. Pasco Gravels are poorly exposed in the RRL, except for one, small, gravel pit in the northern part where the gravels are cross bedded (Fig. 2-4). Bedding present elsewhere in the Cold Creek syncline is assumed present in the RRL.

The gravel generally consists of <50% basalt, with some intrusive, igneous, metamorphic, and sedimentary rocks. Source areas for the non-basaltic rocks are the glaciated terrain to the north. Most of the sand is arkosic, with some horizons containing a relatively high basalt content. Mt. St. Helens Set S ash is locally present in the finer facies of the Pasco Gravels.

The Pasco Gravels are not generally indurated, but some horizons are moderately to well cemented with $CaCO_3$. These horizons are sometimes difficult to differentiate from the Ringold Formation in boreholes.

Two coarse- to fine-graded sequences are recognized in boreholes from the RRL. In areas where the Pasco Gravels form or fill channels in the Ringold Formation, as many as four, graded sequences are present. It is not known if these sequences represent separate floods or energy variations in the depositional environment during a single flood. Current interpretation honors two discrete floods and is based on borehole data, which include driller's logs (lithology, texture, and penetration rate), geophysical logs, and stratigraphic position relative to sediments known to represent multiple floods in the south-central Pasco Basin. Both graded sequences generally are composed of a relatively thin basal unit, consisting of poorly sorted silty-sandy-gravel with clasts ranging from pebbles to >30-cm boulders. This grades upward to a better sorted, silty-sandy, cobble-gravel unit overlain by sand and silt. The lower, graded sequence often has a calcic horizon on the upper surface, resulting in a slower drilling rate, and appears to be denser on geophysical logs.

Touchet Beds

The Touchet Beds are composed of rhythmically bedded silt to fine sand with stringers of coarse sand and gravel. A discrete horizon of Mt. St. Helens Set S ash is common.

Relatively minor, isolated exposures of Touchet Beds are present in the RRL. Touchet Beds in Cold and Dry Creek Valleys occur in generally protected areas distal to the main flood channel(s).

AGE RELATIONSHIPS

The age of the sediments overlying the Columbia River Basalt Group in the Pasco Basin is extremely important in the determination of deformation

rates. The Ringold and Hanford formations record deformation which may have taken place since the last basalt flow entered the Pasco Basin. To establish deformation rates, it is necessary to determine as precisely as possible the absolute age of the sediments. The methods used and results to date are discussed for both the Ringold and Hanford formations.

RINGOLD FORMATION

The Ringold Formation was assigned a Pliocene age by Gustafson (1973, 1978) based on vertebrate fossils. Caliche from the surface of the Ringold Formation at White Bluffs was dated using thorium/uranium methods at >500,000 yr before present, or beyond the limits of the method. Attempts to date Ringold ash horizons using fission-track methods have proved unsuccessful because of the lack of heavy minerals and large shards suitable for dating. The major emphasis in dating has been on the determination of the paleomagnetic stratigraphies and relating these to paleontologic data.

The upper Ringold at the White Bluffs contains microtine rodent fossils, 3.7 to 4.8 million years old (Repenning, in press). A Hemphillian (>4.8 million years old) rhinoceros was identified by Gustafson (1978) in the middle Ringold of the White Bluffs just above river level. This indicates that the predominantly reversed magnetic section of the White Bluffs (Packer and Johnston, 1979) represents the Gilbert Reversed Epoch, or 3.4 to 5.25 mybp.

The upper part of the Ringold Formation in the RRL is interpreted to be stratigraphically equivalent to the White Bluffs section. The erosional remnant of the upper Ringold in the RRL is, therefore, >3.7 million years and the middle Ringold is >4.8 million years. The underlying Elephant Mountain Member (10.5 million years) limits the maximum age of the Ringold Formation in the RRL. However, in the southern part of the Pasco Basin, the Ice Harbor Member (8.5 million years) and the Levey interbed are stratigraphically above the Elephant Mountain Member. Based on stratigraphic position, the basal Ringold in the Pasco Basin is interpreted to be post-Ice Harbor Member (8.5 million years) in age. Therefore, the Ringold Formation in the RRL is concluded to be >3.7 and <8.5 million years old.

HANFORD FORMATION

The number and age of Pleistocene floods that inundated the Pasco Basin is not known, but at least three events have been dated using ^{14}C and thorium/uranium methods and the Mt. St. Helens Set S ash horizon.

Pre-Wisconsinan Flood Deposits

Gravels cemented with $CaCO_3$ and assumed to be of Pleistocene flood origin are present in Badger Canyon. Three thorium/uranium age dates on the caliche from the petrocalcic horizons in these gravels yielded ages of

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200,000 (+250,000 -70,000), 220,000 (+380,000 -70,000), and >210,000 yr (Tallman and others, 1978). These gravels may be correlative to flood gravels in the Cheney-Palouse channeled scabland tract north of the Pasco Basin (Patton and Baker, 1978; Baker and Nummedal, 1978). The Cheney-Palouse gravels are interpreted to be pre-Bull Lake in age (155,000 to 130,000 yr old) (Pierce and others, 1976). Gravels of this age range have not been identified in the RRL boreholes to date, but ~8 km northwest of the RRL is an isolated outcrop of gravels which have similar field characteristics as the Badger Canyon gravels and may be correlative.

Wisconsinan Flood Deposits

The oldest ^{14}C date on the Hanford formation is in a normal-graded sequence containing clastic dikes located in the south-central part of the Pasco Basin. This sequence was eroded during a later flood that truncated the clastic dikes and deposited a later flood sequence. Wood fragments from the truncated clastic dike were dated at >32,000 radiocarbon years before present. The upper limit of the age is not known, but wood samples from flood gravels near Wanapum Dam were dated at 32,700 ± 900 radiocarbon years before present (Fryxell, 1965). These may represent the same flood.

The last major Pleistocene scabland flood occurred ~13,000 yr ago, based on the occurrence of Mt. St. Helens Set S ash within the flood deposits and ^{14}C dates on organic sediments above and below Mt. St. Helens Set S ash near the source (Mullineaux and others, 1977). Mt. St. Helens Set S ash is present throughout the Pasco Basin, commonly occurring in the Touchet Beds, but also present in the Pasco Gravels. In Cold Creek and Dry Creek Valleys, Mt. St. Helens Set S ash is present in Touchet sediments under bergmounds (Fecht and Tallman, 1978).

Wood from a clastic dike in a flood bar southeast of Gable Mountain was dated at 18,705 (+1,515 -1,275) radiocarbon years. These sediments are stratigraphically related to the most recent, major, flood deposits and the current interpretation is that the wood was redeposited from older material. Another factor to support this conclusion is that evidence from radiocarbon dates in southern British Columbia indicate that the last major Wisconsinan advance in the northern United States began after 17,500 to 18,000 radiocarbon years before present (Clague and others, 1980). This makes an 18,705 (+1,515 -1,275) radiocarbon years flood in the Pasco Basin highly unlikely, if not impossible.

In summary, there are three, dated, flood sequences in the Pasco Basin: (1) a pre-Wisconsinan flood or floods with a well-developed calcic cement, (2) a Wisconsinan event >32,000 radiocarbon years before present, and (3) a late Wisconsinan flood(s) associated with Mt. St. Helens Set S ash ~13,000 radiocarbon years before present (Fig. 2-1).

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SUMMARY AND CONCLUSIONS

The post-Columbia River Basalt Group sediments of the Cold Creek syncline are composed of two major units: (1) Ringold Formation, a Miocene-Pliocene fluvial unit with some lacustrine facies; and (2) Pleistocene glaciofluvial sediments, informally termed the Hanford formation. Deposition of the Ringold Formation by ancestral streams flowing through the Pasco Basin started shortly after cessation of basalt flows. The Hanford formation was deposited by catastrophic floodwaters which inundated the Pasco Basin when glacial ice dams failed in Montana, Idaho, northern Washington, and southern British Columbia. Minor units include the Pleistocene and Holocene talus, colluvium, alluvium and loess, landslide debris, and Holocene dune sands.

The Ringold Formation overlies the Columbia River Basalt Group within most of the Pasco Basin. The division of the Ringold Formation into a basal, lower, middle, and upper facies, based primarily on texture, is appropriate for much of the central Pasco Basin. The predominant texture of each of these four facies is as follows: (1) basal--silty, sandy gravel to a gravelly sand; (2) lower--sand, silt, and clay; (3) middle--pebble-to-cobble gravel with a sand, silt, and clay matrix; and (4) upper--sand and silt.

In general, three representative stratigraphic sections can be used to describe the lateral variations of the Ringold Formation in the Pasco Basin. The central portion of the Cold Creek syncline and much of the central Pasco Basin are of representative section type I, the four vertical facies listed above. Section type II of the Ringold Formation north and east of Gable Mountain is composed predominantly of silt, sand, and clay. This section is interpreted to represent floodplain overbank sedimentation throughout Ringold time.

Section type III is the fanglomerate facies on the flanks of anticlinal ridges and includes the talus, slope wash, and side-stream facies which interfinger with the central basin deposits of section types I and II. This facies of the Ringold Formation is chiefly composed of basalt clasts with a matrix of quartz and feldspar or basalt sand. The unit is the result of mass wastage and runoff on the emerging ridges during the deposition of other Ringold section types in the lower elevations of the Pasco Basin. Section types I and II were deposited by a major river system which flowed through the Pasco Basin.

The sediments deposited in the Pasco Basin during catastrophic flood events are informally referred to as the Hanford formation. The Hanford formation is divided into two textural facies: (1) Pasco Gravels and (2) Touchet Beds. The Pasco Gravels range in texture from boulders to fine sand, representing varied energy environments during flooding. The Touchet Beds are made up of rhythmically bedded, fine-grained sediments deposited in low-energy, slackwater environments.

The number of Pleistocene floods in eastern Washington and the Pasco Basin is unknown. Within the Pasco Basin, multiple, graded sequences of Pasco Gravels and Touchet Beds have been observed in boreholes and outcrops. Whether each sequence represents an individual flood or merely changes in the energy environment during deposition is not known. Locally, three sedimentary sequences have been identified in the Pasco Basin boreholes and are interpreted to be three separate flood events.

The Ringold and Hanford formations record the deformation which has taken place since the last basalt flow entered the Pasco Basin. In order to establish deformation rates, it is necessary to determine, as precisely as possible, the absolute age of these sediments.

The major emphasis for age determination of the Ringold Formation has been on the determination of the paleomagnetic stratigraphy, and using paleontologic data, assigning age ranges to the formation. Fossils from the upper Ringold Formation indicate an age of 3.7 to 4.8 million years and that the predominantly reversed magnetic section represents the Gilbert Reversed Epoch. The basal Ringold is interpreted to be mainly post-Ice Harbor in age. Based on these assumptions, the Ringold Formation in the RRL is interpreted to be >3.4, but <8.5 million years old.

The number and age of Pleistocene floods to inundate the Pasco Basin are not known, but at least three events have been dated. These three flood sequences in the Pasco Basin are: (1) a pre-Wisconsinan flood or floods, (2) a Wisconsinan event >32,000 radiocarbon years before present, and (3) a late Wisconsinan flood(s) associated with Mt. St. Helens Set S ash ~13,000 radiocarbon years before present.

Reference

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