STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
Suite 965, 800 NE Oregon St., #28
Portland, Oregon 97232

OPEN-FILE REPORT O-02-02

Geology of the Surface and Subsurface of the Southern Grande Ronde Valley and Lower Catherine Creek Drainage, Union County, Oregon

A Preliminary Release

By

Mark L. Ferns, Ian P. Madin, and Vicki S. McConnell,

Oregon Department of Geology and Mineral Industries

and Jenda J. Johnson,

U.S. Geological Survey, Hawaiian Volcano Observatory

2001

WARNING

The results and conclusions of this report are necessarily based on limited geologic and geophysical data. At any given site in any map area, site-specific data could give results that differ from those shown in this report. This report cannot replace site-specific investigations. The geologic conditions of an individual site should be assessed through geotechnical or engineering geology investigation by qualified practitioners.

NOTICE

The Oregon Department of Geology and Mineral Industries is publishing this paper because the information furthers the mission of the Department. To facilitate timely distribution of the information, this report is published as received from the authors and has not been edited to our usual standards.

The geologic data and information presented in this report and the accompanying map were first produced by the Oregon Department of Geology and Mineral Industries (DOGAMI) under contract for the Grande Ronde Model Watershed Program. The original report was completed after peer reviews by geoscientists at the Oregon Water Resources Department, the U.S. Geological Survey Water Resources Division, Portland State University, and Boise State University.

DOGAMI has now been charged with producing and formally publishing a more comprehensive report describing the geology, geologic resources, and geologic history of the entire Upper Grande Ronde River Basin, including the area covered by this present report. The data released here will be used in the production of the more comprehensive study and thus eventually become available in a more formal version.

TABLE OF CONTENTS

Introduction

PURPOSE OF STUDY

Declining populations of salmon and steelhead in the Columbia Basin have led to many attempts to improve habitat in spawning streams. The Grande Ronde River (Figure 1) is one of the few remaining free-flowing tributaries of the Columbia, and Catherine Creek, a major tributary of the Grande Ronde, provides some of the best remaining upland spawning habitat in the system. Low summer flows in the lower reaches of Catherine Creek may impede spawning, and so there is considerable interest in enhancing low flows. One possible solution is to substitute groundwater in place of surface water for irrigation purposes. This requires a basic understanding of the geology of groundwater resources.

An accurate description of the surface and subsurface geology is a critical first step toward evaluating the value of such a proposal. This report, commissioned by the Grande Ronde Model Watershed Board, includes a detailed map of the surface geology, two generalized maps of subsurface geologic units, geophysical data, and geochemical data. The report also includes a descriptive interpretation of hydrogeologic characteristics of the geologic units in the valley based on well logs, geophysical data, and surface exposures.

A detailed description and analyses of the hydrogeologic characteristics of surficial and bedrock geologic units are beyond the scope of this project. The comments in the text are based largely on geologic observations and have not been quantified by direct or indirect measurements of physical hydrogeologic parameters such as

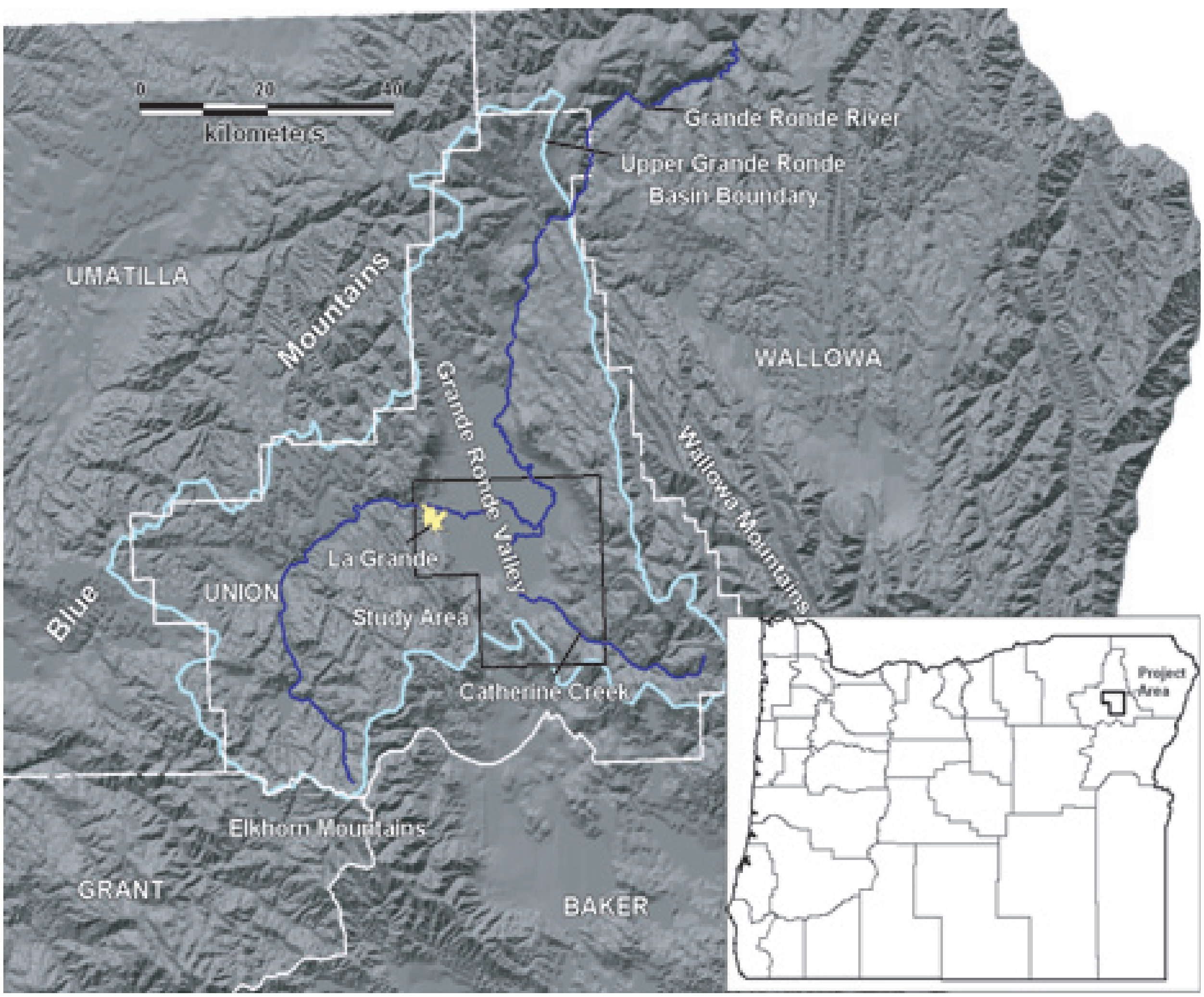

Figure 1. Location map. The study area is located in Union County in NE Oregon and covers most of the southern Grande Ronde Valley. The upper Grande Ronde basin contains important anadromous fish habitat.

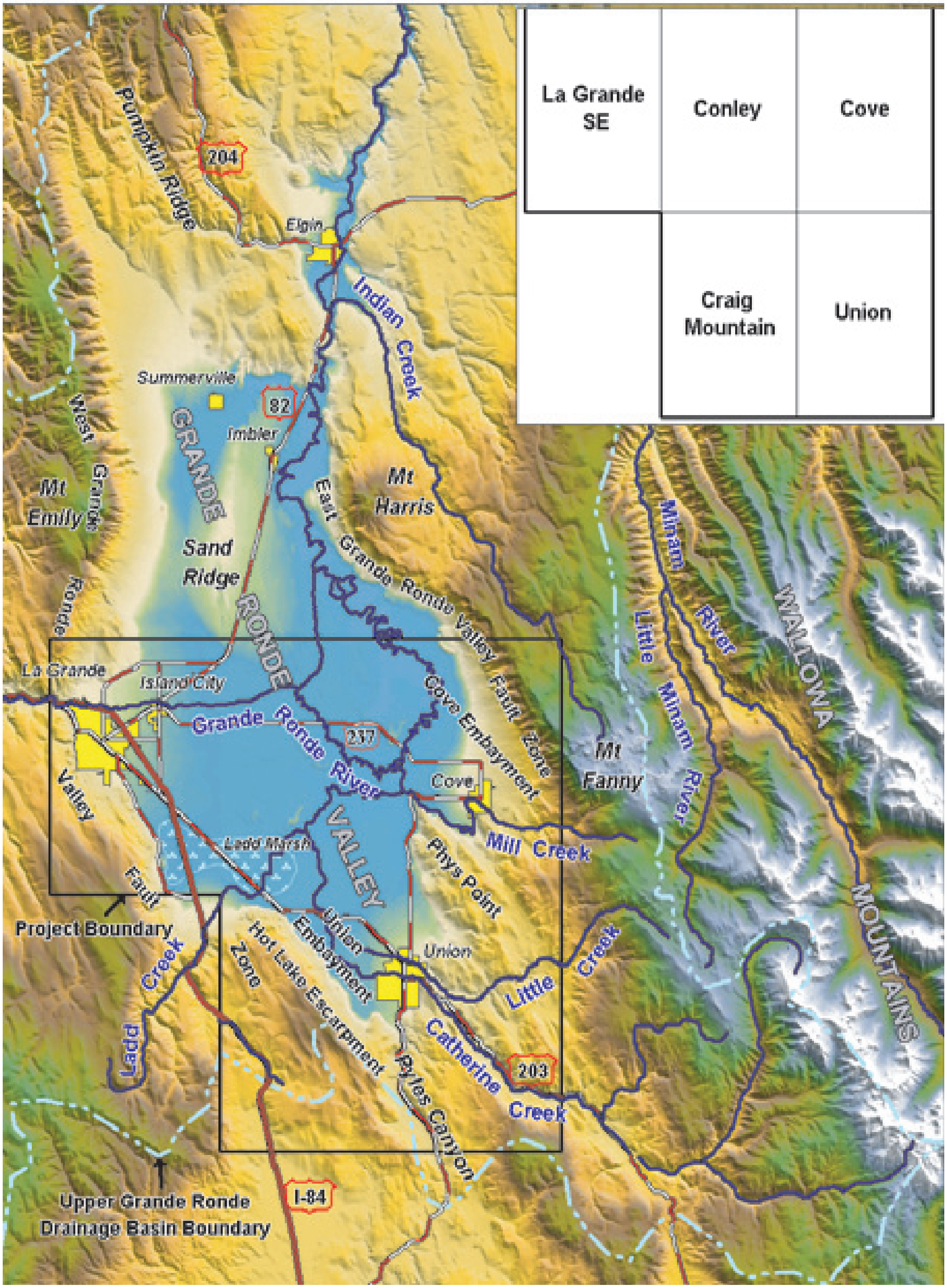

Figure 2. Major geographic features of the Grande Ronde Valley. The population centers are the cities of La Grande, Union, and Cove. The Phys Point Re?entrant and the West Grande Ronde Valley and East Grande Ronde Valley Fault Zones are structures that determine the morphology of the Grande Ronde Valley.

porosity, specific yield, and permeability. Geologic observations can be used for comparing how geologic units might transport or store water and speculating on how geologic characteristics might affect the physical makeup of an aquifer.

GEOGRAPHIC AND GEOMORPHIC SETTING

The project area is centered on the southern half of the Grande Ronde Valley and includes part of the Grande Ronde River as well as the lower Catherine Creek, Little Creek, Mill Creek, and Ladd Creek drainages (Figure 2). Catherine Creek heads (Figure 1) in the Eagle Cap Wilderness Area of the Wallowa Mountains, and flows generally west through glaciated canyons, turning north and northwest to flow through the town of Union and into the Grande Ronde Valley where it joins the Grande Ronde River downstream of La Grande (Figure 3).

The Grande Ronde River heads in the Elkhorn Mountains southwest of the valley and flows north and east through the city of La Grande, into the Grande Ronde Valley. Heavily forested uplands around the valley are administered by the Bureau of Land Management, USDA Wallowa Whitman National Forest, and individual and corporate landowners. Ladd Marsh, a large wetlands area at the southwest end of the Grande Ronde Valley, is administered by the Oregon Department of Fish and Wildlife (Figure 2).

Figure 3. City of Union looking west across the Catherine Creek fan-delta. The small diversion structure on the creek is one source of irrigation water for the southern Grande Ronde valley.

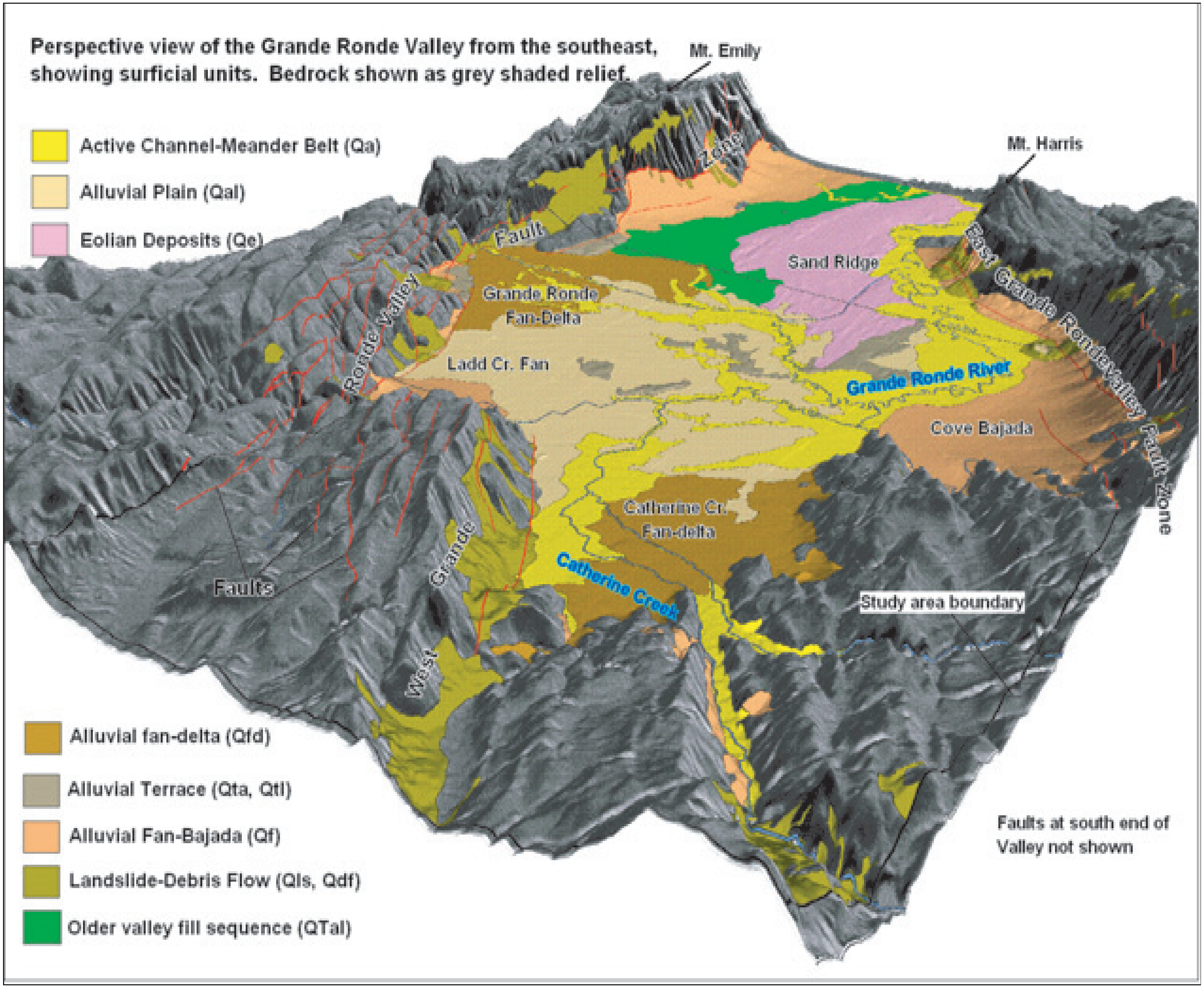

Figure 4. Perspective view of the Grande Ronde Valley from the southeast, showing geomorphic features

The 680 km^2 project area is covered by five USGS 1:24,000 scale topographic maps: La Grande SE, Cove, Union, Craig Mountain and Conley. La Grande, a city with 12,327 inhabitants, is the major population center, home to Eastern Oregon University, and county seat for Union County. Other communities in the study area are Island City (population 916), Union (population 1926) and Cove (population 594).

The Grande Ronde Valley (Figure 1) is tectonic basin situated along the east flank of the Blue Mountains. Subsidence along major fault zones (Figure 2,4) that bound the valley (East and West Grande Ronde Valley Fault Zones) began during the Late Miocene, and continues to the present. Many of the faults in the fault zones are still active and will likely produce future earthquakes (Personius, 1998; Ferns and others, in press). The valley's ragged southern margin is marked by a series of normally faulted bedrock ridges that slope north beneath the valley floor. Phys Point, a faulted upland of northwest-trending ridges, divides the southeastern margin of the Grande Ronde Valley into the Cove and Union embayments. The southwestern part of the valley includes the Ladd Marsh area, marked by marshes and ephemeral shallow lakes. The Sand Ridge, a plateau of eolian sand and silt, dominates the northern part of the valley. At the northern margin Pumpkin Ridge slopes south into the valley where it is buried under the Tertiary and Quaternary sedimentary deposits that fill the basin.

The Grande Ronde River enters the valley from the west, through a notch cut in the escarpment of the West Grande Ronde Valley Fault Zone at La Grande (Figures 4, 5). From there, the Grande Ronde River flows first eastward across an alluvial fan-delta onto a flat alluvial plain, then turns south to join Catherine Creek. The river progresses northeastward in a broad meander belt until it reaches the foot of the Cove bajada, turning north

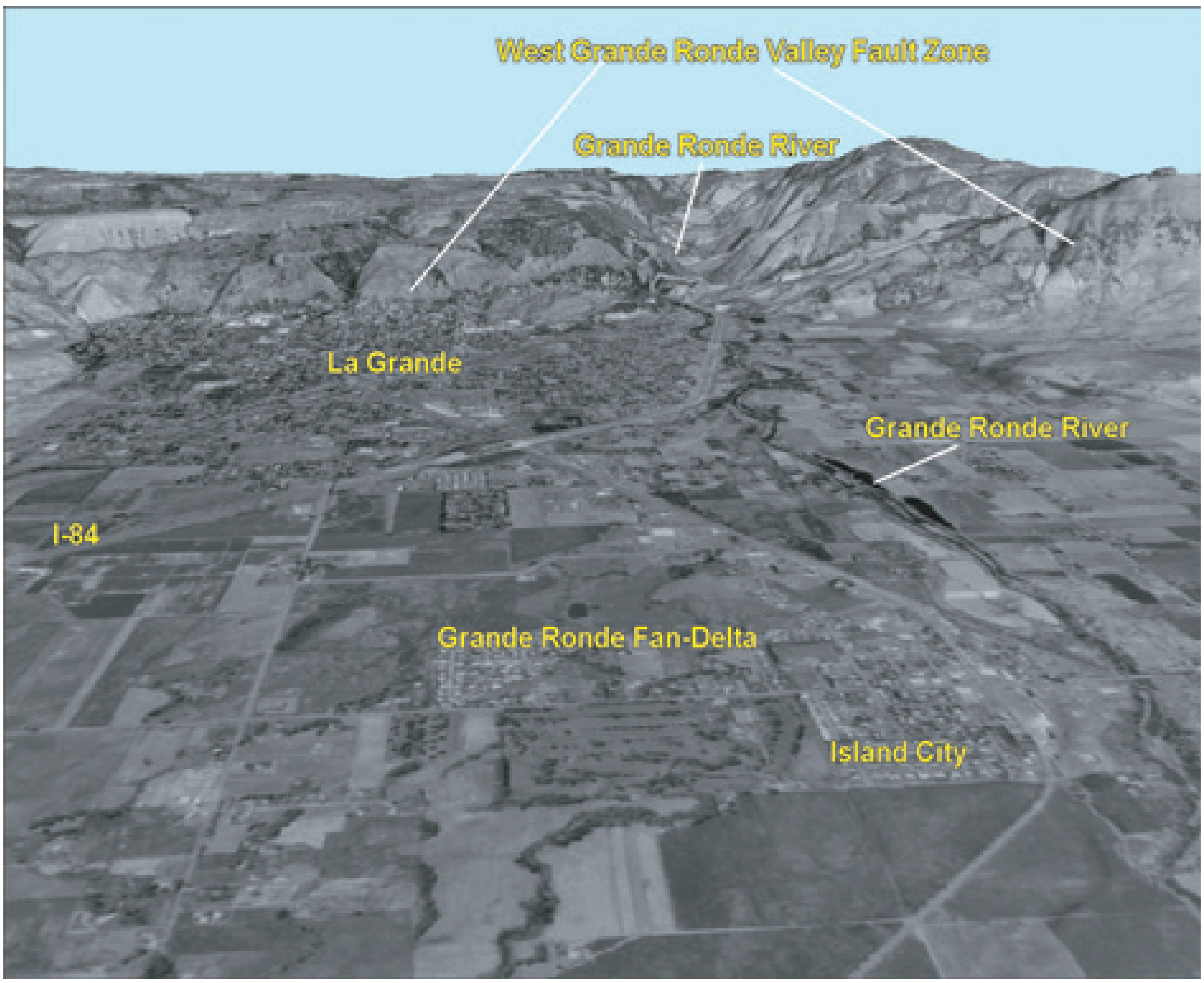

Figure 5. Perspective-orthophoto view of La Grande looking W. Broad flats in the foreground are the Grande Ronde fan-delta, escarpment at back of flats is the West Grande Ronde Valley fault zone. No vertical exaggeration.

along the East Grande Ronde Valley Fault Zone and the west flank of Mt Harris. It then swings back to the northwest skirting the east side of the Sand Ridge (Figure 4).

Catherine Creek enters the Union embayment from the southeast (Figure 4). Upstream of Union, Catherine Creek flows along a major fault scarp which bounds the southwest side of a flat-bottomed, narrow valley. At Union, Catherine Creek turns to the west as it cuts into the Catherine Creek fan-delta. The stream then turns back to the north along the west flank of the Hot Lake escarpment, eventually meandering out across the southern end of the valley onto the alluvial plain where it joins the Grande Ronde River.

The modern floor of the Grande Ronde Valley (Figure 4, Plate 1) is largely a broad, flat alluvial plain, ringed by young faults. Alluvial terrace (units Qtl, Qta), alluvial fan (unit Qf), debris flow and debris avalanche (unit Qdf), and landslide (unit Qls), deposits mantle the steep lower slopes of the surrounding highlands. Large alluvial fan-deltas (unit Qfd) form gently sloping surfaces where the Grande Ronde River and Catherine Creek enter the valley. Coalescing alluvial fans merge to form broad bajadas along the Mt Fanny-Mt. Harris and Mt Emily escarpments. The alluvial plain itself has three separate depositional environments: marshes and sporadic lakes (Qal), eolian sand (Qe), and active channels (Qa).

GEOLOGIC SETTING

The Grande Ronde Valley (Figures 1, 2 and Plate 1) is a fault-bounded structural depression within the Upper Grande Ronde Basin. The highlands around the valley expose over 1000m of middle Miocene to Pliocene volcanic rocks. In the valley these volcanic rocks have been downfaulted as much as 1000 m, and buried to depths of as much as 1000 m with Miocene, Pliocene, and Pleistocene sedimentary rocks and sediments. Active or potentially active faults along the West Grande Ronde Valley and East Grande Ronde Valley Fault Zones form the valley's margins (Gehrels, 1981; White, 1981; Simpson and others, 1993; Personius, 1998). The 60 km long West Grande Ronde Valley Fault Zone forms the western margin to the valley and contains individual faults as much as 10 km in length. Vertical offset along this zone is more than 900 m adjacent to Mt. Emily, approximately 10 km north of the study area (Ferns and Madin, 1999). The East Grande Ronde Valley Fault Zone defines the east side of the valley and extends from south of Cove to Mt Harris, just north of the study area. At Cove, there has been at least 730 m of vertical displacement across the fault zone. At the south end of the valley near Cove and Union, numerous minor faults extend from the bedrock highlands north into the valley.

METHODOLOGY AND PREVIOUS WORK

The geologic map of the project area was largely compiled from new field mapping done at a scale of 1:24,000. Interpretations were made using field data combined with air photos, orthophoto maps, agricultural soils maps (Dyksterhuis and High, 1985), SLAR (Side Looking Airborne Radar; EROS, 1990), and digital shaded relief images derived from USGS 30 m DEM (Digital Elevation Model) grids. Mapping was supplemented with numerous whole rock and trace element XRF (X-Ray Fluorescence) geochemical analyses (Appendix A, C) and limited $^{40}Ar/^{39}Ar$ radiometric age analyses.

The first geologic map of the study area was published in 1964 as part of a water resource investigation by Hampton and Brown (1964), who recognized the presence of both a shallow gravel aquifer and a deep basalt aquifer in the valley. Walker (1973, 1979) produced 1:250,000-scale reconnaissance geologic maps of the Pendleton and Grangeville quadrangles to the northwest and northeast, respectively. Detailed, published studies are limited to an engineering geology report for the La Grande area (Schlicker and Deacon, 1971) and a tectonic study of the Grande Ronde Valley (Barrash and others, 1980); both of which contain 1:24,000 scale maps for part of the area. The valley's geothermal resource potential was briefly addressed by Brown and others (1980). Important geochemical and geochronological data can be found in unpublished studies by Gardner and others (1974), Kienle and others (1979), and a doctoral dissertation by Bailey (1990).

Subsurface geology for this study was mapped primarily using data from 525 water wells augmented by gravity anomaly maps and aeromagnetic maps (AMAX Exploration Inc, 1975), and a seismic reflection line (Liberty and Barrash, 1998). In most instances lithologies were determined from well driller's log descriptions. Well yields were also taken from well driller's logs. In a few cases cuttings samples from the wells were available for analysis. See the file, Water Well Metadata, in Appendix B for a more detailed description of criteria for interpreting water well data. Efforts to field-locate water wells resulted in 64% of the wells being located to ≤30 m, 3% were located to within 120 m, and 9% were located to within 200 m. The remaining 24% of the wells remain approximately located.

Geophysical data compiled for the project include residual magnetic intensity and Complete Bouguer gravity maps obtained from Amax Exploration Inc (Appenndix, F, G) and a reflection seismic profile (See Appendix D) generated by the Center for Geophysical Investigation of the Shallow Subsurface (CGISS) at Boise State University.

Geologic Unit Descriptions

SURFICIAL UNITS

The distribution of surficial geologic units and associated landforms is shown on Plate 1 and Figure 4. The following sections are a complete geologic description of the individual units. The discussion further focuses on the geomorphic processes that control the location in space and time of individual landforms in the Grande Ronde Valley and provides a geologic perspective regarding their usefulness for groundwater potential.

Valley Floor Units

Many valley floor units are described in terms of the deposits they include and the landforms they produce. In many instances, deposits associated with a prticular landform are relatively thin and young, and both the deposit and landform may be rapidly removed or altered by rapid depositional and erosional processes. In other instances, very thick or old deposits that were associated with a particular landform occur, but are overlain by younger deposits and landforms either of different or similar origins. This may lead to confusion in some cases. For instance, Unit QTal is a thick, old deposit of predominantly alluvial-plain facies sediments, and underlies much of the valley. In some places modern alluvial plain deposits overlie QTal, in other area perhaps fan-delta deposits. Similarly, the fan-delta deposits associated with the modern fan-delta surfaces typically overlie substantial thicknesses of older fan-delta facies deposits, yet may overlie QTal deposits in other areas. The surface geologic map indicates what kind of deposits and or landforms are present at the surface now, the subsurface maps try to give some sense of the distribution of the various sediment facies at depth.

Qa Channel alluvium (Holocene and late Pleistocene)

The unit is comprised of moderately to well sorted gravel, sand, and silt deposited in active or recently active stream channels and on adjoining flood plains of the Grande Ronde River, Mill Creek, Catherine Creek, and Little Creek. The deposit also includes sand, silt, and clay deposits in abandoned distributary channels and sloughs on the Grande Ronde River fan. The deposits typically fine downstream as they extend from the steep bedrock canyons into the flat valley floor.

The modern course of the Grande Ronde River is incising into the Grande Ronde fan-delta surface, forming a braided channel of mixed gravel bars and point sandbars. Sloughs and loess- and soil-filled lowlands mark older incisions into the fan-delta. These deposits are being constantly reworked by the river, and are probably only 5-10 m thick. The shape and gradient of the stream change markedly at the alluvial plain – fan-delta interface; shifting from a braided morphology on the fan to a pronounced meandering morphology on the plain (Plate 1, Figure 2). This corresponds with a rapid decrease in grain size in the channel deposits, from gravel and sand to clay and mud and a widening of the channel deposits as the stream shifts course in a meander belt up to 2.5 km wide. The pronounced braided morphology on the fan surface may have resulted from increased gradient after the construction of the State Ditch. Begin here.

For several kilometers upstream of Union, Catherine Creek flows northwestward along a flat-floored, northwest-trending linear valley (Plate 1, Figure 2). The flat valley floor is underlain by a thick accumulation of glacial outwash gravel deposited by Catherine and Little Creeks.

The Catherine Creek channel is confined to the southwest side of the valley, along a fault line scarp that separates an andesite escarpment from a thick apron of glacial outwash gravel (Figure 6). At Union, Catherine Creek is currently incising into the Catherine Creek fan surface. Stream morphology changes from a narrow braided channel on the fan surface to a broader, somewhat meandering morphology where Catherine Creek flows onto the alluvial plain.

Above Cove, Mill Creek flows westward out of a narrow canyon that is partially clogged with glacial outwash deposits (Figure 7). At Cove, the stream turns to the southwest, forming a broad fan-delta.

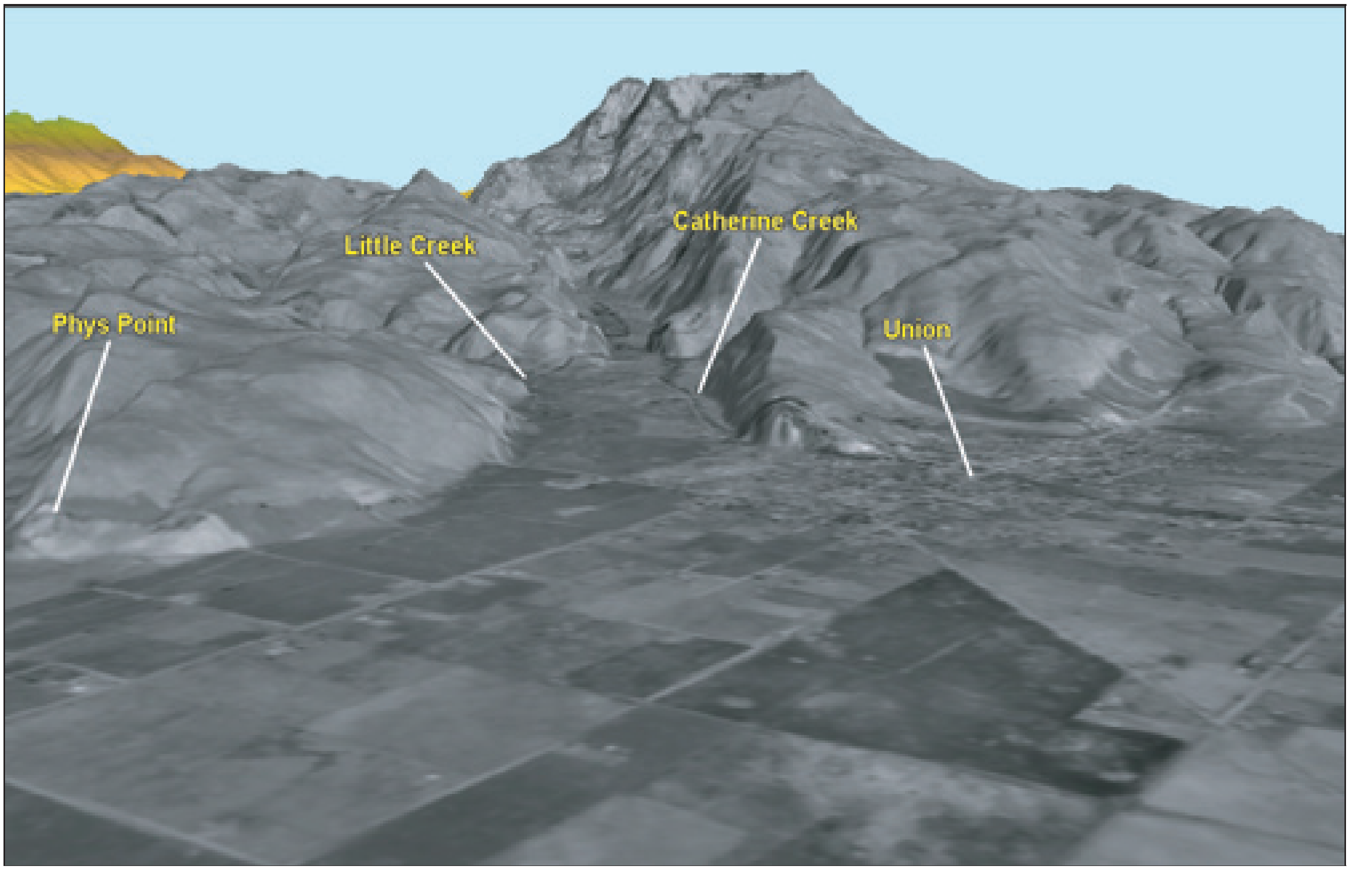

Figure 6. Perspective view looking SE up Catherine Creek.The broad valley upstream of Union is filled by glacial outwash gravels that now form the alluvial channels of Little Creek and Catherine Creek. Little Creek enters the valley and flows along the northern margin of the gravel-filled plain while Catherine Creek flows in a channel cut along the foot of the faulted escarpment on the southern margin of the plain.

Hydrogeologic characteristics

Lithologic data indicate the location and connectivity of permeable, water-bearing gravel channels within the Grande Ronde River fan-delta unit are generally random and unpredictable and the potential as an aquifer is variable (Figure 8). The channels are shallow surficial deposits that are directly connected to the modern Grande Ronde River. Thus any shallow wells in the abandoned channels are almost assuredly hydrologically connected to the modern stream, an undesirable and legally restricted situation.

Modern and abandoned channels on Catherine and Mill Creeks are also shallow surficial deposits that are directly connected to the modern drainages (Figure 9). Although the abandoned channels would have a high permeability and connectivity their location is not well constrained and the fact they are hydrologically connected to the modern stream renders them unacceptable groundwater reservoirs.

Qal Alluvial plain deposits (Holocene? and late Pleistocene)

The Grande Ronde Valley alluvial plain deposits are associated with marshlands, shallow lakes, and low terraces scoured by wind (Plate 1). Depositional and erosional processes here are dominated by fluctuating stream flows resulting from changing climatic conditions. The unit consists chiefly of fine sediments that range

Figure 7. The Mill Creek fan consists largely of coarse boulders deposited as glacial outwash. Modern Mill Creek is cutting a channel into the fan, exposing boulders as large as 0.7 m in diameter.

from predominately sandy clay to fine gravelly clay and sand. There are also minor lenses of pebbly, coarse- to medium-grained sand and organic and diatomite-rich clays. It is indicative of marsh, low-energy fluvial, and shallow lake conditions at time of deposition.

Alluvial plain-lacustrine geomorphic features include meandering stream channels, marshes, and shallow lakes. Shallow lake and marsh deposits that extend north from Hot Lake dominate the southwest end of the valley (Plate 1, Figure 2). Ladd Marsh is the remnant of an extensive area of marsh and shallow lake deposits that covered more than 52 km^2 of the valley floor prior to construction of the State Ditch (Figure 10). Water well logs indicate that the alluvial plain deposits at Ladd Marsh are about 15 m thick.

Hydrogeologic characteristics

The thin, fine-grained silt and clay deposits in the alluvial plain would have a very low permeability and capacity for storing groundwater.

Qfd Fluviatile fan and fan-delta deposits (Holocene and Pleistocene)

Alluvial fan-deltas have formed where the perennial streams, the Grande Ronde River, Ladd Creek, Mill Creek, and Catherine Creek, enter the valley resulting in subaerial delta plain deposits of stratified gravel, sand, and silt. The depositional and erosional processes are dominated by fluctuating stream flows, gradients, and sediment supply that, in turn, respond to either climatic or tectonic processes. Climatic processes will increase/decrease stream flows and sediment loads while tectonic processes will increase/decrease stream gradients. Fan-delta deposits are locally overlain by overbank silt and fine sand deposits and cut by Qa channels.

The Grande Ronde River has formed a large (50 km^2) fan-delta along the west margin of the valley at La Grande, fed from the 1800 km^2 drainage basin of the upper Grande Ronde River west of the Grande Ronde Valley. The fan surface decreases in elevation 30 m over a distance of about 8 km from the point at which the Grande Ronde River crosses the West Grande Ronde Fault Zone and enters the valley. The Grande Ronde River fan-delta deposits include gravel, sand, and silt that grade laterally into silty sand and silt alluvial plain deposits in the basin (see Plates 1, 2; Figure 4 for the approximate boundary of the deposits). At La Grande, the margin of the modern fan-delta can be traced southeast along the late Quaternary terrace riser that runs southeast through La Grande. Based on well logs and limited well cuttings, Grande Ronde fan-delta gravel deposits appear to be relatively free of clay. Most clasts are composed of basalt, most likely eroded from the Grande Ronde Basalt. Fan-delta gravel beneath the modern fan-delta surface is as much as 165 m thick and has been the most important near-surface aquifer in the Grande Ronde Valley. These deposits most likely represent shifting boundaries between the fan-delta and alluvial plain facies (Figure 8). The La Grande Municipal Well (UNIO-50520), drilled in 1999, penetrated a thick section of generally well-sorted volcanic gravel (Figure 13) (see the section "Valley Fill Sediments" for description of the well stratigraphy). Plate 2 shows contours on the bottom of the Grande Ronde fan-delta, which provide a rough estimate of the thickness of the unit at any point. Plate 3b shows the general distribution of the fan-delta deposits at various depths.

A large, 34 km^2 fan-delta has formed at the mouths of Catherine Creek and Little Creek at Union, in the south end of the valley (Plate 1). The drainage basin upstream of the fan extends over an area of about 390 km^2. The fan-delta surface decreases in elevation 34 m over a distance of 14 km from the point where Catherine Creek enters the valley. To the north, the fan-delta merges with the alluvial plain (see Plate 2 for the approximate limits). Like the Grande Ronde fan-delta deposits, the gravel is probably composed predominately of volcanic

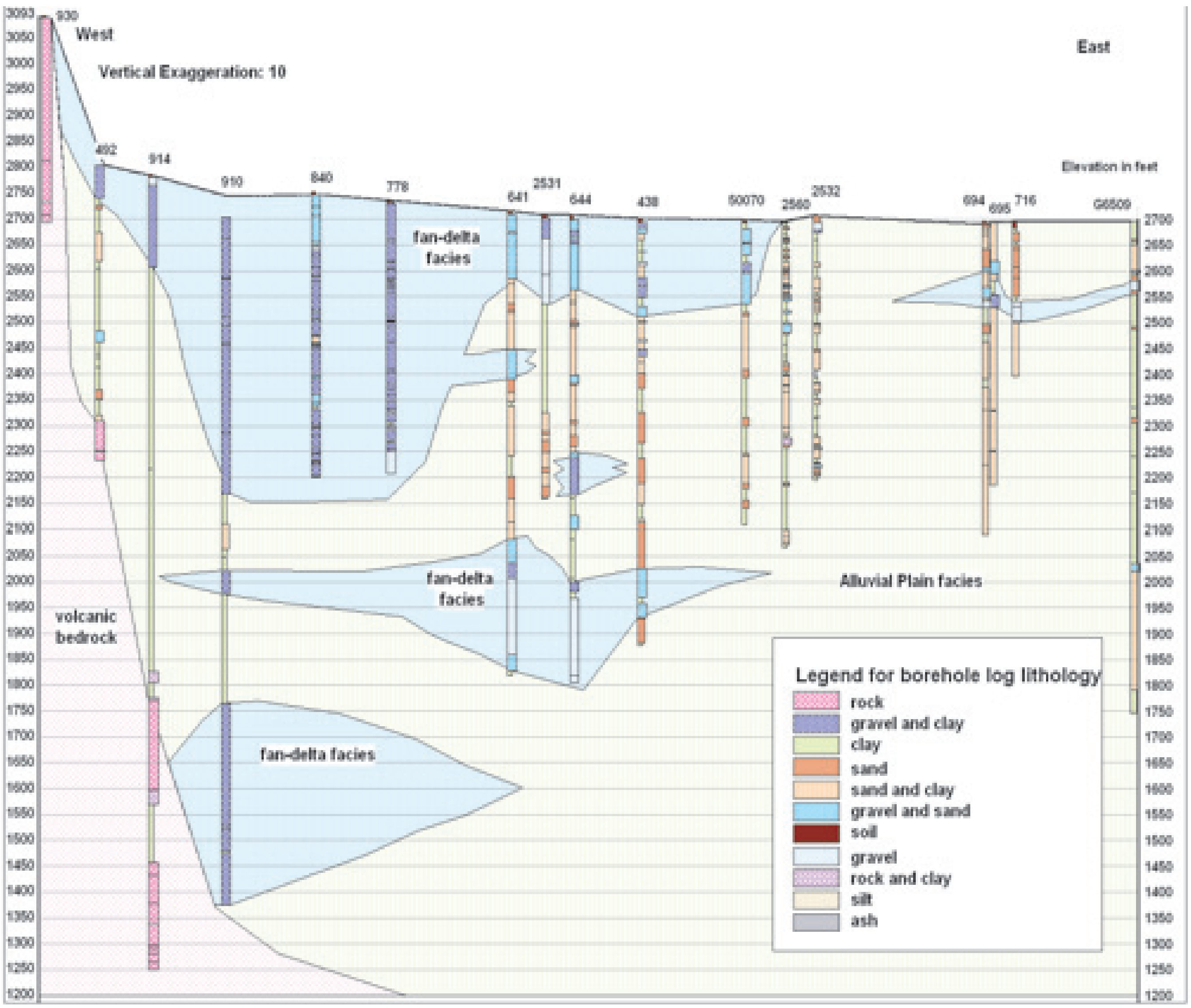

Figure 8.. Schematic facies diagram across the Grande Ronde fan?delta. Borehole (water well) logs are from a rough west-east transect extending from the west edge of La Grande to about Conley Lake.

rocks. Based on well logs interpretations, the Catherine Creek fan-delta deposits appear to contain a relatively higher proportion of clay and silt than the Grande Ronde fan-delta. Gravel that underlies the modern fan-delta surface has a maximum thickness of 150 m (Plate 2). At Union, the unit is at least 90 m thick and has historically been an important source of groundwater for the City of Union. Plate 3b shows the general distribution of the fan-delta deposits at various depths. The basin beneath the Catherine Creek fan-delta is not subsiding as rapidly as the west side of the valley, resulting in less of a structural trap where the stream enters the valley. For much of its extent, the Catherine Creek fan-delta appears to lie directly on bedrock, unlike the La Grande fan-delta, which overlies older alluvial plain deposits.

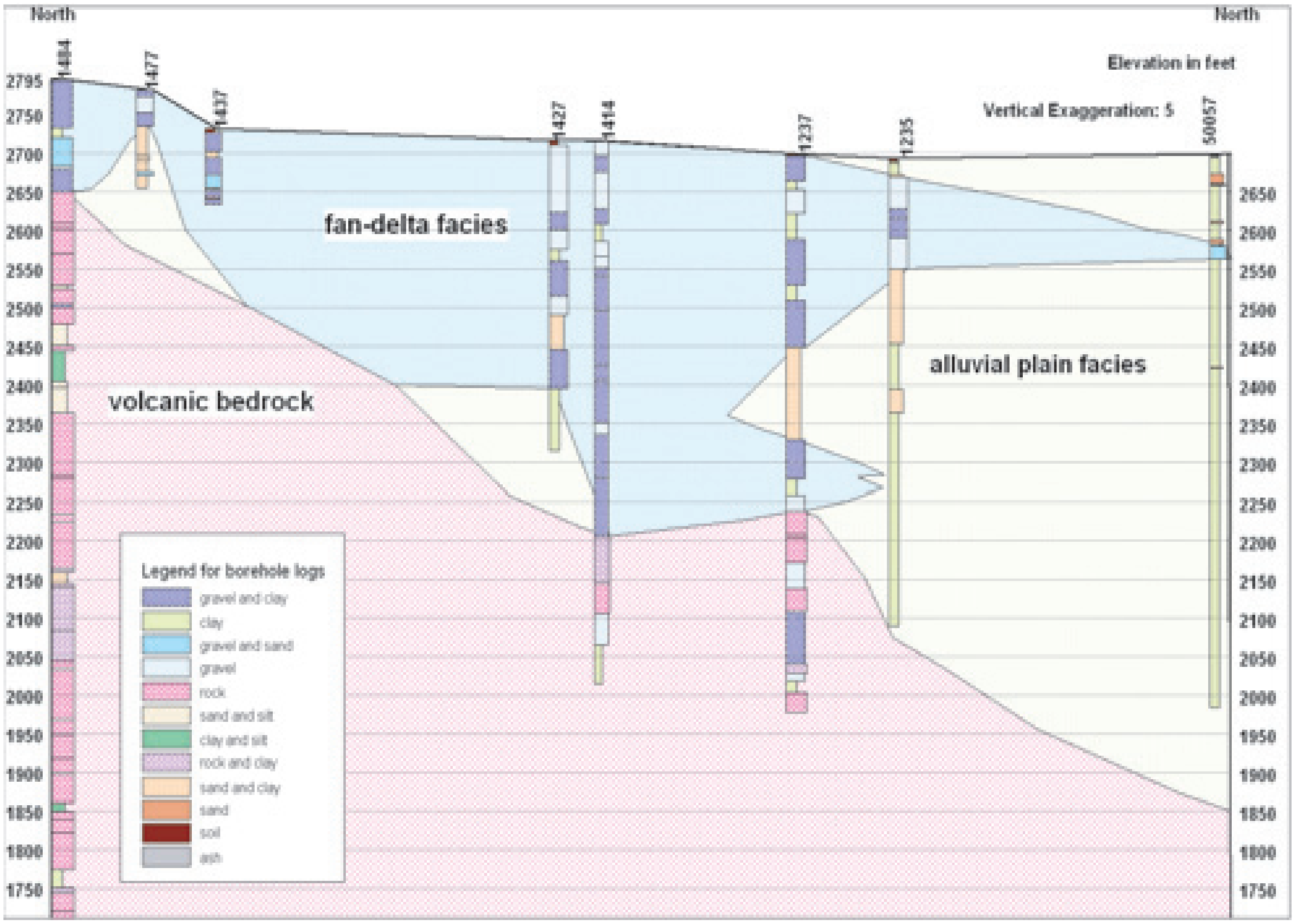

Figure 9. Schematic facies diagram across the Catherine Creek fan?delta. Borehole (water well) logs are from a rough north-south transect extending from Union to about 0.5 km west of Phys Point.

The Catherine Creek fan-delta sequence may have a larger proportion of clay- or silt-rich layers than does the Grande Ronde fan-delta. The highlands upstream of Union have been heavily glaciated and a comparably large amount of fine glacial flour was likely washed down onto the fan-delta by high-flow glacial meltwater and deposited as relatively impermeable horizons and channel-fills. Linear channels of clean, coarse gravel would be expected to form during low flow cycles.

The Catherine Creek knickpoint may have migrated laterally over time. Southeast shallowing of the volcanic basement (Plates 1,2) and the trends of modern and abandoned channels on the modern fan surface indicate progressive northwestward tilting along the Union embayment over time. As with the Grande Ronde fan-delta, the uphill part of the Catherine Creek fan-delta is likely to be more poorly sorted and contain a greater proportion of debris flow deposits; while the distal margins should become finer grained where the delta merges with the alluvial plain.

A 5 km^2 alluvial fan has formed at the mouth of Ladd Creek, at the southwestern end of the valley (Plate 1, Figure 4). The fan surface decreases in elevation 45 m in 3 km, downstream of a 100 km^2 drainage basin. Ladd

Creek splits into several channels on the fan surface, forming a classic birds foot distributary channel pattern. Well logs indicate that the fan is composed largely of gravel with interlayers of clay (Figure 11). The unit interfingers with unit Qal in the upper part of the Ladd Creek fan.

A 10 km^2 fan has formed where Mill Creek enters Cove, at the southeastern end of the valley (Plate 1, Figure 4). The fan surface decreases in elevation 65 m in 4 km, downstream of a 34 km^2 drainage basin that has been heavily glaciated (McConnell and others, in press). Well logs indicate that the upper edge of the Mill Creek fan delta is composed largely of intermixed coarse gravels and clay while the distal margin is made up of interbedded sand and gravel.

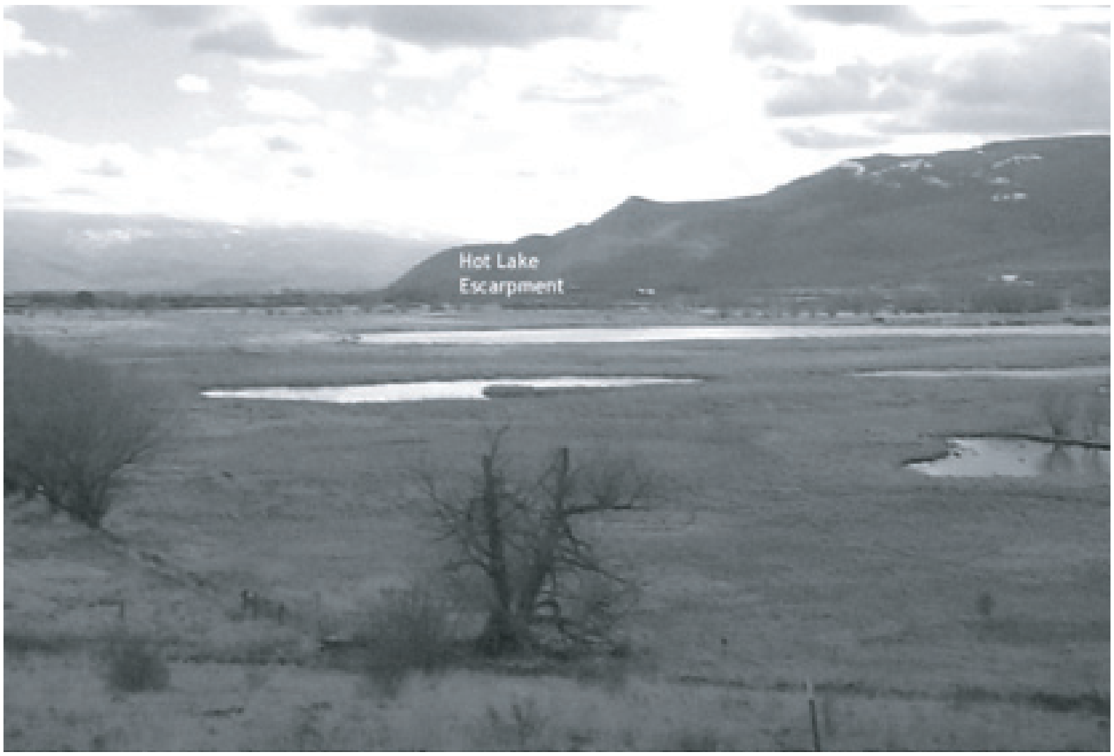

Figure 10. Ladd Marsh typifies the modern alluvial plain, which is dominated by marsh and shallow lacustrine deposits. The alluvial plain is ringed by alluvial fan delta, alluvial fan, landslide and debris flow deposits that conceal potentially active faults. The Grande Ronde Valley's most pronounced geothermal feature, Hot Lake, is fed by springs issuing from faults south of Ladd Marsh.

Hydrogeologic characteristics

The Grande Ronde fan-delta is a relatively good to very good aquifer. Driller's logs and samples indicate that the fan-delta facies is generally composed of well-sorted medium-to coarse-grained gravel. Wells drilled into the distal edges of the Grande Ronde fan-delta yield as much as 2475 gpm (e.g., UNIO-50520).

Repeated valley-side-down movement along the West Grande Ronde Valley Fault Zone has apparently kept the knickpoint of the Grande Ronde River in place, resulting in considerable accumulation of well-sorted gravel (as much as 200 m) in a structural trap. Although the Grande Ronde fan-delta appears to be mostly well-sorted fan-delta facies gravel and sand, it is likely that debris flow-deposited clay-rich gravel is interbedded in the fan-delta (especially in the upstream part). Based on well data for facies distributions in the fan-delta it is reasonable to assume the gravel becomes finer-grained and is more frequently interbedded with sand and silt lenses near the outer edges of the fan. Linear, coarse gravel filled channels can also be expected.

Lithologic information and water well data suggest that the Catherine Creek fan-delta has relatively high permeability. The surface of the fan is mantled by well-sorted gravel; and most likely similar gravel is present in the subsurface. Residential wells at Union, where the unit is at least 90 m thick, typically yield 10-20 gpm. Irrigation wells drilled in the distal edge of the Catherine Creek fan delta, e.g., UNIO-2526 and UNIO-50057 reportedly yield 500-950 gpm.

Lithologic data and inferences from the depositional environment at Ladd Creek suggest the unit would have moderate permeability. The upslope part of the fan is expected to be more poorly sorted and is underlain by volcanic basement rocks at relatively shallow depths. Well logs (Plate 2) indicate that the Ladd Canyon alluvial fan merges with the Grande Ronde fan-delta beneath Ladd Marsh. Here the distal edge of the fan likely contains well-sorted, permeable gravel channels developed during earlier erosional cycles (Figure 11). One irrigation well (UNIO-50005) has a reported yield of 1040 gpm.

Water well data and geologic interpretations suggest that the Mill Creek fan has relatively low permeability. The proximal end of the fan at Cove appears to contain interbedded clays and poorly-sorted clayey gravels with limited permeability.

Figure 11. The fan-delta deposits are major aggregate sources in the valley. Here poorly imbricated Ladd Creek fan?delta gravels are exposed in a gravel pit wall. Ladd Creek fan gravels are made up of Tertiary volcanic cobbles and do not contain mica. The Grande Ronde and Catherine Creek fan?deltas contain mica and pre-Tertiary rock clasts. The composition of the pre-Tertiary clasts are excellent provenance indicators; Grande Ronde gravels include blue chert of the Elkhorn Ridge Argillite while Catherine Creek gravels contain distinctive green metavolcanic clasts.

Qe Eolian sand and loess (Holocene and late Pleistocene)

Sand Ridge is a geomorphic feature shaped by wind that stands a maximum of 20 m above the surrounding alluvial plain in the north central valley (Figure 4). The modern surface is a broad, rolling plain marked by windblown deposits of medium-to fine-grained sand and loess and locally blanketed by extensive soils. Beneath the soil, Sand Ridge is chiefly composed of medium- to- fine-grained sand. Volcanic basement crops out along the ridge to the north (Ferns and Madin, 1999). The geomorphology is characterized by a low rolling hummocky topography reflecting old north-trending longitudinal dunes.

Hydrogeologic characteristics

Although the eolian sand deposits on Sand Ridge are expected to have relatively high permeability and porosity, the unit is thin and has limited storage capacity. The portion of this geomorphic feature that stands above the regional groundwater table is likely unsaturated.

Qtl La Grande terrace deposits (Pleistocene)

Small fluvial terraces that stand 5-30 m above the modern Grande Ronde Valley floor are found near La Grande (Plate 1, Figure 4). The most extensive terrace extends south and east from La Grande along Foothill Road and is covered by landslide deposits at the north and south ends. Another well-developed terrace occurs just north of La Grande, along Mt. Glenn Road. At La Grande, erosional remnants of a fringing, east-sloping surface that stands 20-30 m above the modern valley floor form the basis for this unit. The surface is mantled by alluvial fans that form at the mouths of Deal and Mill Creeks. The terrace itself is made up largely of gravel and sand.

Van Tassell (1999) reports a radiocarbon age of 15,280±180 B.P. from a mammoth tooth recovered in loess soils atop the terrace gravel from the Eastern Oregon University campus. The terrace probably represents an older fan-delta surface formed during the end of the Bull Lake (Middle Wisconsin) glaciation.

Hydrogeologic characteristics

The terrace gravel at La Grande is thin, and according to driller's logs, rests on impermeable shallow clays that act to form either locally perched aquifers or mounding due to impedance of downward migration of groundwater. The terrace gravel has a high relative permeability and porosity, but since the terrace surface stands above the regional groundwater table, it is not likely to be in direct contact with the larger Grande Ronde fan-delta aquifer. Typical domestic wells such as UNIO-1088 report yields of 30 gpm.

Qta Airport terrace deposits (Pleistocene)

Smaller terrace remnants occur in the center of the valley east of the La Grande airport (Plate 1). The terraces are composed largely of unconsolidated to poorly consolidated bench deposits of gravel, coarse pebbly sand, and medium- to fine-grained sand. These are possibly overbank-levee or channel-fill flood deposits that mark the high stand of the modern valley floor contemporaneous with the deposition of the La Grande terraces. The terraces form sinuous sand and fine gravel-capped ridges that stand 5-12 m above the modern valley floor.

Hydrogeologic characteristics

These clean sands and gravels are expected to have relatively high permeability and porosity, but since they are thin and stand above the regional groundwater table the upper part of the unit is likely unsaturated.

Valley Margin Units

Qf Alluvial fan deposits (Holocene and Pleistocene)

This unit includes the Cove bajada, the geomorphic feature formed by large coalescing fans along the eastern side of the Grande Ronde Valley, and the much smaller alluvial fans that have formed at the mouths of small, steep-sided canyons on the west side of the valley. Alluvial fan deposits typically grade down slope from the canyon mouths from coarse grained boulder gravels to fine to medium graded gravel, sand, and silt deposits on the valley floor.

A series of coalescing alluvial fans forms a moderately westward-dipping bajada surface covering more than 52 km^2 and extending north from Cove for more than 16 km along the Mt Fanny escarpment (Figure 12) (Plate 1, Figure 4). Fan surfaces drop more than 90 m in 14 km along the west face of Mt Fanny. Debris flow avalanche and landslide deposits marked by a mixture of large dacite and andesite, and to a lesser extent, basalt boulders and fine clay locally mantle the bajada surface along the range front. At Cove, the alluvial fan deposits are intercalated with reworked glacial outwash deposits from the Mill Creek and tributaries drainage (McConnell and others, in prep).

Figure 12. The Cove bajada is formed by coalescing fans along the East Grande Ronde Valley Fault Zone. The upper, steeper slope of the bajada is marked by coarse boulder debris flows while the gentler lower slope merges with the flat alluvial plain.

Several small alluvial fans lie directly on the La Grande terrace at the mouths of minor streams draining the hills to the west (Plate 1, Figure 4). Coalescing fan surfaces at the mouths of Mill and Deal Creek cover less than 1.5 km^2 and decrease in elevation about 75 m in less than 1.5 km. Their combined drainage basin covers about 8 km^2. At La Grande, the unit includes very coarse block breccias with andesite blocks as much as 1 m in diameter that were deposited by rock falls and small debris avalanches. The upper slopes include unstable colluvial wedges of intermixed soil and rock that mantle fault contacts. Locally the unit is found in fault contact with bedrock units.

Hydrogeologic characteristics

The Cove bajada is comprised of poorly sorted breccias and gravels that contain varying amounts of clay. Domestic water wells drilled to date on this surface generally have low yields (typically 5-15 gpm). Although well-sorted, permeable gravel channels developed during previous erosional cycles may lie beneath the distal edges of the bajada, where it merges with the alluvial plain, irrigation wells drilled to date have not found significant amounts of water in the bajada.

The uplands display geomorphic evidence of glaciation, therefore a relatively greater amount of glacial flour is expected to have been available for deposition during high-flow cycles than observed in the Grande Ronde fan-delta, resulting in relatively impermeable gravel deposits. Pore clogging by glacial flour and clays may lower overall permeability and lateral connectivity of the entire unit decreasing its water bearing potential.

Most of the material in alluvial fans elsewhere in the project area are poorly stratified debris flow deposits that contain relatively high amounts of clay. These thin fan deposits are presumed to have a very low permeability.

Qls Landslide deposits (Holocene and Pleistocene)

Landslide deposits cover much of the west margin of the Grande Ronde Valley. The deposits are typically unconsolidated, chaotically mixed masses of rock and soil. Landforms are typified by sloping hummocky surfaces marked by closed depressions, springs and wet seeps, scarps, cracks and crevices. Individual landslide deposits are often traceable upslope to landslide scarps or slip surfaces. In the map area, landslides typically originate along contacts between coherent lava flows and overlying or underlying tuffaceous units. The unit includes extremely large composite landslides along Catherine Creek. These composite slides commonly consist of individual slides of different ages that form coalescing masses. Older slides are commonly mantled by loess and ash deposits.

Qdf Debris avalanche and debris flow deposits (Holocene and Pleistocene)

Debris flow and debris avalanche deposits are made up of chaotically intermixed blocks of rock and soil are disconnected from the landslide scarp or failure zone. They typically form lobate masses on alluvial fans downslope of the range front.

Hydrogeologic characteristics

The permeability of the landslide and debris flow deposits is variable depending on the relative activity of the landslide. Active landslides are commonly marked by surface springs and indicate the presence of low-permeability zones that impede downward movement of groundwater. Older landslide deposits that contain high proportions of intermixed soil and clay can be expected to be relatively low permeability throughout.

Qu Undifferentiated surficial deposits (Holocene? and Pleistocene)

The unit includes channel, flood plain and alluvial fan, debris flow, and talus deposits that have been deposited in and along small tributary streams onto bedrock units in the uplands bordering the Grande Ronde Valley. These deposits are generally poorly sorted deposits of gravel, sand, and silt with intermixed ash and loess. Holocene and late Pleistocene ages are based on the reported presence of 6,700 year BP Mazama and 10,700 year BP Glacier Peak ashes (Cochran, 1988). Cochran (1988) has documented a complex cycle depositional stratigraphy with as many as five alluvial-aggradation/surface-erosion episodes in Ladd Canyon over the last 11,000 years.

Hydrogeologic characteristics

These units are generally thin, poorly-sorted deposits that lie directly on bedrock and are in direct communication with modern streams.

Qg Glacial deposits (Late and Middle Pleistocene)

This unit includes unconsolidated, poorly stratified coarse gravel, fine silt, sand, and loess deposits of glacial drift near Mt Fanny and includes till at the distal edge of an extensive ice cap that formerly extended over much of the Mt Fanny area (McConnell and others, in press). Unit is composted mostly of large blocks and boulders of Glass Hill Volcanics.

Hydrogeologic characteristics

The poorly sorted characteristic of glacial drift deposits lowers the permeability and porosity of these deposits. The unit has a low potential as an aquifer.

BEDROCK UNITS

Bedrock units in the upper Grande Ronde Basin include relatively young sedimentary and volcanic rocks deposited in the Grande Ronde Valley before the Holocene as well as older volcanic, sedimentary, and metamorphic rocks that predate the formation of the valley. This report focuses on the three youngest units encountered in water wells drilled into the valley: 1) A valley-fill unit (QTal) that consists largely of medium- to fine-grained sedimentary rocks including fine-grained tuffaceous siltstone and sandstone, diatomite, and volcanic ash. QTal was deposited between about 8 Ma and 10 ka. 2) Basalt, andesite, and dacite lava flows informally named the Glass Hill Volcanic Group. These calc-alkaline flows are part of the Powder River Volcanic Field and are chemically distinct from the underlying tholeiitic lavas. Unit ages range from 14.5 to 9.0 Ma. 3) The Grande Ronde Basalt, which is the most voluminous formation in the Columbia River Basalt Group. The age of the Grande Ronde Basalt ranges from 16.5 to 15.6 Ma (Baksi, 1989).

Valley Fill Sediments

Water well cuttings are the only direct source of detailed information for the valley-fill sequence (QTal) and underlying volcanic units buried within the Grande Ronde Valley. Well cuttings from four newly drilled wells (Figure 13), the Bingaman well (UNIO-50684); the Terry Trailers well (UNIO-50452); the Wright well (UNIO-50450), and the new La Grande municipal well (UNIO-50520) were used to construct stratigraphic diagrams for the valley-fill sequence (QTal). The QTal stratigraphy in these wells is briefly described below, more detailed stratigraphic descriptions are included in Appendix E.

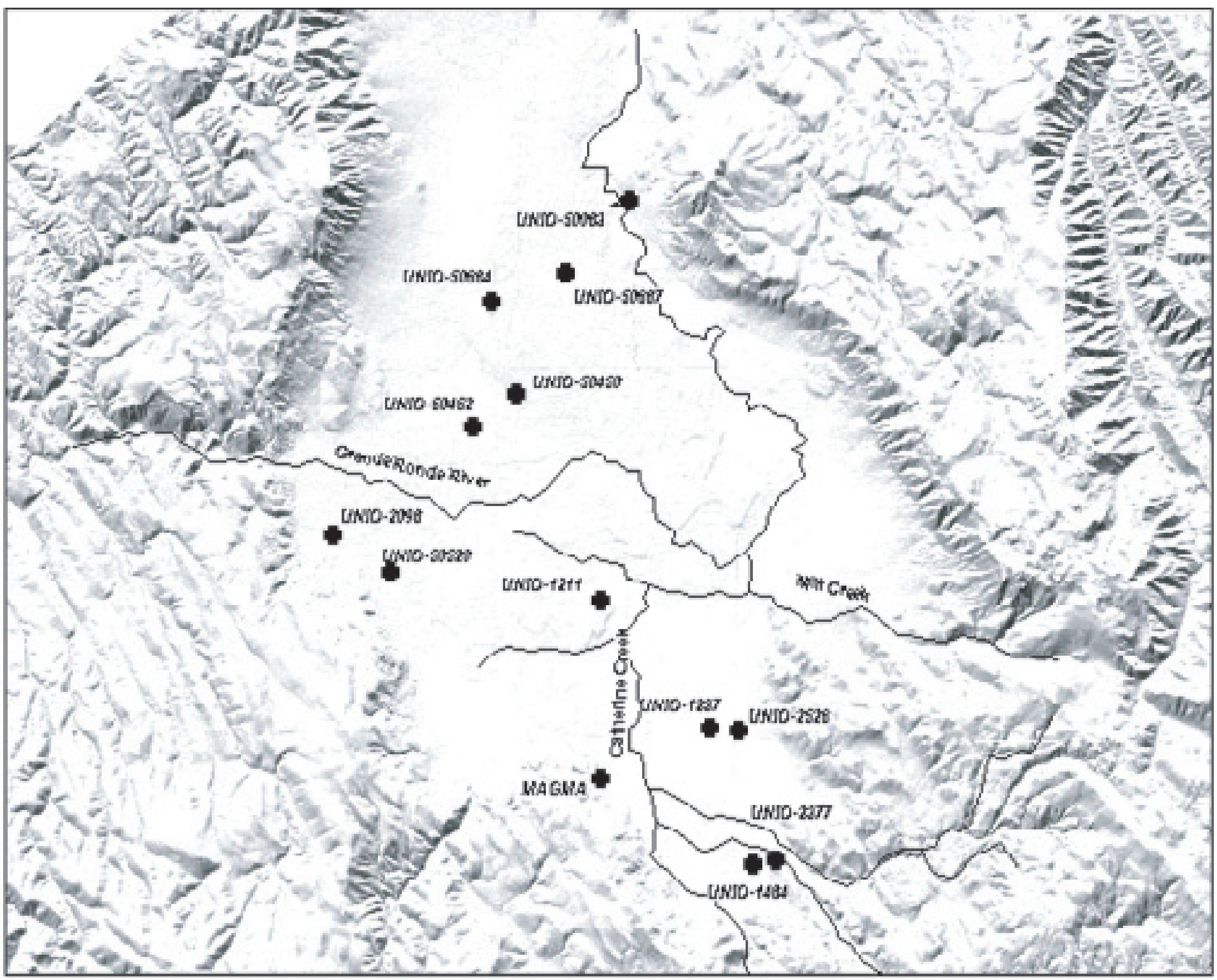

Figure 13. Shaded relief map showing location of important wells referenced in this report. Lithologic logs and location data for all wells are included in Appendix B.

QTal Stratigraphy

Because of the relatively thin lithologic layers, in some cases 30 to 60 cm, and the frequency of sample collection (~each 1.3 m) the thickness of various intervals recorded is uncertain, though the overall percentages of sediment types are probably reliable. It is also important to note that sediments scientifically described as "gravel", which includes all particles larger than 2mm in diameter, would very likely be described as coarse sand on a well driller's log.

The Bingaman well (UNIO-50684) (Figure 14), collared at an elevation of about 844 m in the wind blown sand deposits on Sand Ridge, penetrates more than 564 m of primarily alluvial plain facies sandy silt and clay before entering the underlying Glass Hill volcanic sequence (Van Tassell, 1999). QTal coarsens upward from an 85 m-thick basal section dominated by organic-rich clays and silts into a 270 m-thick middle section comprised of sandy silt interbedded with thin seams of fine gravel and sand. Individual gravel-bearing zones in the middle section are less than 3 m-thick and make up 18% of the section. The upper 210 m of section is composed chiefly of sandy silt, with seams of gravel and sand less than 3 m-thick at depths of 45 and 102 m. About 5% of the upper 210 m is composed of gravel-bearing zones. Most of the gravel particles were less than 25 mm in diameter. Glass shards from a water lain volcanic ash located near the base of the middle section at 472 m depth yielded a $^{40}Ar/^{39}Ar$ radiometric date of 7.5±0.11 million years (Van Tassel and others, 2000).

The Terry Trailers well (UNIO-50452), collared at an elevation of approximately 824 m in the Grande Ronde fan-delta, penetrates 205 m of silt, sand, and fine gravel (Van Tassell, 1999; Cunico and Sorenson, 1998 (In Appendix E)). The lower 75 m of section is fine-grained with less than 30% gravel-bearing zones. This section may mark fluctuations between fan-delta and alluvial plain depositional environments. Nearly 60% of the upper 130 m of section is gravel bearing. A 6 m-thick gravel layer was encountered at 90 m depth intercalated within in a 20 m thick gravel-bearing zone. Glass shards from a water lain volcanic ash at 110 m depth (Van Tassell, 1999) yielded a $^{40}Ar/^{39}Ar$ radiometric date of 3.1±0.3 million years (Table 3).

The Wright well (UNIO-50450), collared at an elevation of 835 m in the valley-fill sequence, penetrates 225 m of silt, sand, and fine gravel (Cunico and Sorenson, 1998 (In Appendix E)). The lower 110 m of section contains over 70% gravel bearing zones. The upper 115 m of section coarsens upward with less than 20% of the lower 50 m gravel bearing and nearly 40% of the upper 65 m of section gravel bearing. This well location appears to be in the alluvial plain facies, but close to the boundary with the fan-delta facies.

The new La Grande municipal well (UNIO-50520), collared at an elevation of 842 m penetrates 165 m of gravel, sand, and clay of the Grande Ronde fan-delta. The lower 42 m of section consists of interbedded clay, sand, and gravel, with gravel-bearing zones making up about 40% of the section. Over 90% of the upper 125 m of section is made up of gravel bearing zones.

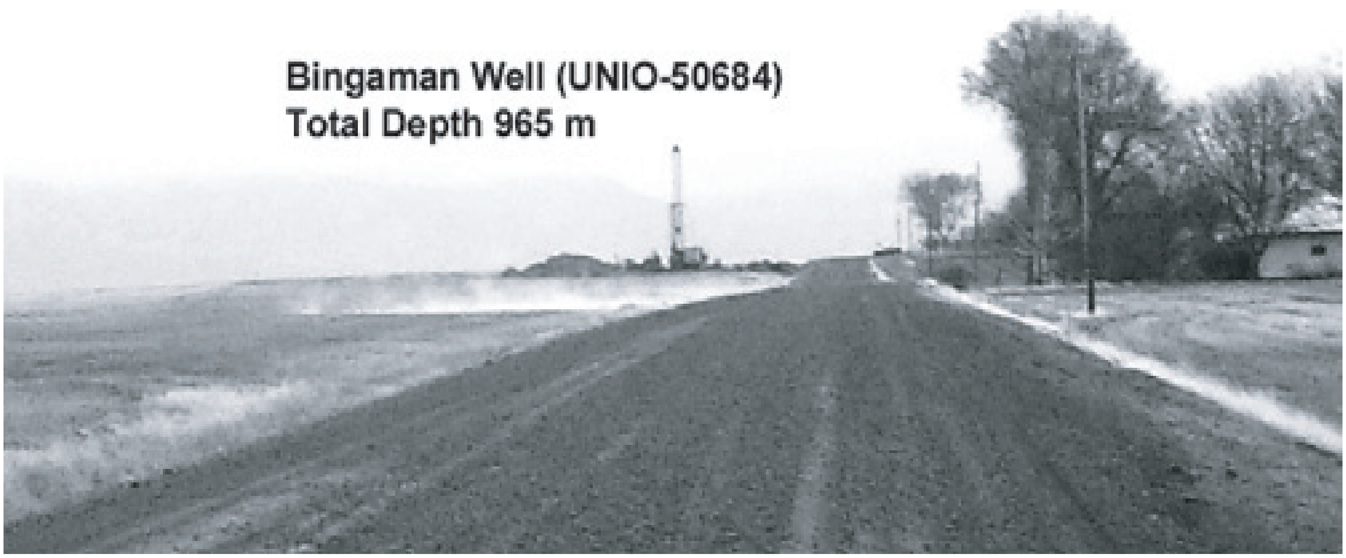

Figure 14 The UNIO-50684 well, shown here, penetrated 965 m of section before completion in 1999. The well reportedly yielded 1,700 gpm of 38o C water upon completion, note pond of steaming runoff water in foreground. Cuttings from this well have been a valuable source of scientific data.

QTal Lacustrine and fluvial sediments (Pleistocene, Pliocene, and Miocene)

This unit consists mainly of fine silt and clay, but locally includes sand, fine gravel, diatomite, ash and tuff. The unit includes all facies of the sedimentary rocks in the core of the Grande Ronde Valley that underlie the surficial units and overlie the volcanic bedrock. Driller's logs indicate that the unit is typically as much as 300 m thick, thickening to 600-900 m in the central part of the valley. The boundary between the top of the valley-fill sequence and overlying surficial units is arbitrarily placed at the end of the last major glacial maximum, the Pinedale advance; about 10,000 years BP. The lower part of the unit is late Miocene in age, based on a waterlain ash recovered from the Bingaman well (Table 3). Well logs from throughout the valley indicate that the valley-fill sequence stratigraphy changes both laterally and vertically from alluvial fan to fan-delta to alluvial plain facies (Figures 8, 9, Plate 2). Contacts between surficial geologic units described in the previous section and the underlying valley-fill sediments are generally poorly defined. Contacts are most ill-defined where coarse surficial deposits overlie and grade downward into coarse valley-fill facies and fine-grained surficial deposits overlie and grade downward into fine-grained valley-fill facies. Contacts are well-defined in other places, such as the west edge of the Grande Ronde fan-delta at La Grande, where coarse-grained surficial deposits unconformably overlie fine-grained valley-fill sediments exposed in tilted fault blocks. Within the valley-fill sequence, there are large bodies of gravel that extend beneath the modern La Grande and Catherine Creek fan-deltas. The approximate boundaries of these buried gravel bodies at 793 m, 731 m, and 671 m elevations, as interpreted from driller's logs, are shown in Plate 2.

Lateral and vertical facies changes in the valley-fill sequence record shifting of alluvial fan, fan-delta, and alluvial plain depositional settings over time. Lateral shifts in depositional settings occurs in response to both tectonic and climatic changes over the 9 Ma history of the Grande Ronde Valley. In general, in areas marginal to the older fan-delta deposits shown in Plate 2, the valley-fill sequence is composed mostly of silt and silty sand that is similar to the modern alluvial plain sediments. Although individual wells typically encounter isolated well-sorted sand and gravel layers within this sequence, the Conley Lake area is the only place where a well-sorted sand and gravel layer can be correlated from well to well. The Conley Lake lens (Plate 2) is a body of sand and gravel 15-30 m thick that extends roughly south and west from Conley Lake. The Conley Lake gravel may mark a buried paleochannel of the Grande Ronde River.

Hydrogeologic characteristics

The hydrogeologic characteristics of the valley-fill sequence vary widely due to vertical and lateral facies changes. Permeability will vary according to which sedimentary facies are encountered. Highest permeabilities occur in clean and well-sorted gravel and sand bodies along the distal edge of the fan-deltas and in and along buried stream channels. Cleaner sands, such as the Conley Lake lens (Plates 2, 3) form small productive aquifers. The 142 m- deep UNIO-1211 irrigation well reportedly yields 2,000 gpm from the Conley Lake lens. Buried alluvial fan-delta deposits are generally more productive than buried alluvial fan and alluvial plain deposits. As mapped, most of the areas designated as QTal at the surface or at depth are expected to be predominantly alluvial plain facies, and have relatively low permeability.

Volcanic Bedrock

Samples of the volcanic section from the Bingaman well (UNIO-50684), the geothermal exploration well drilled by Magma Energy near Hot Lake, a La Grande municipal well (UNIO-2098), two Union municpal wells (UNIO-1484 and UNIO-2377), an Imbler municipal well (UNIO-208), and irrigation wells at Alicel (UNIO-50687) and the foot of Mt Harris (UNIO-50083) have been geochemically analyzed and are also briefly described below (Figure 13). Dr. Marvin Beeson of Portland State University provided whole rock and trace element data for wells MB91LG (UNIO-2098), MB91IM (UNIO-208), and MB92UN (UNIO-2377) previously used in Reidel and others (1996). Data for the Magma well are from Barrash and others (1980). Complete analyses for these wells are included in Appendix C.

Volcanic Stratigraphy

The volcanic stratigraphic sections shown on Plate 3a are based on geochemical analyses presented in Appendix C. The 510 m-thick section of Grande Ronde Basalt at Mt Emily is the most complete section of

Grande Ronde Basalt lavas, encompassing 90 m of N2 (all Fiddlers Hell); 160 m of R2, 190 m of N1, before entering 60 m into the top of the R1 magnetostratigraphic unit. Fiddlers Hell flows have been identified at the top of the Grande Ronde Basalt in all of the analyzed water wells. The unit however does not occur on the east side of the valley (Figure 15).

Lower Glass Hill Volcanic Group olivine basalt flows are widespread and present in every well and section. This unit thins to the northwest, from 137 m at Union to 25 m at Mt Emily. Middle Glass Hill lavas are more restricted; disappearing between Alicel (UNIO-50687) and Imbler (UNIO-208) (Figure 16). Upper Glass Hill Volcanic group lavas are unevenly distributed; flows in the Alicel (UNIO-50687) and Bingaman (UNIO-50684) wells are also quite variable but there are thick sections at MB91LG (Unio-1006) and Harris, apparently related to proximity to eruptive centers.

Powder River Volcanic Field (Pliocene and Miocene)

All Pliocene to middle Miocene calc-alkaline and alkaline lava flows between Baker City and Elgin are part of the Powder River Volcanic Field of Bailey (1990) and Hooper and Swanson (1990). In this region, the Powder River Volcanic Field includes all lavas that post-date and are chemically distinct from Grande Ronde flood basalt volcanism (Ferns and others, in press). As such, the Powder River Volcanic Field includes lavas ranging in age from 14.3 to 3.1 Ma (late Pliocene - middle Miocene). Although no lava flows younger than 9 Ma have been found within the Grande Ronde Valley, small lava flows as young as 3.2 Ma (Table 3) have been

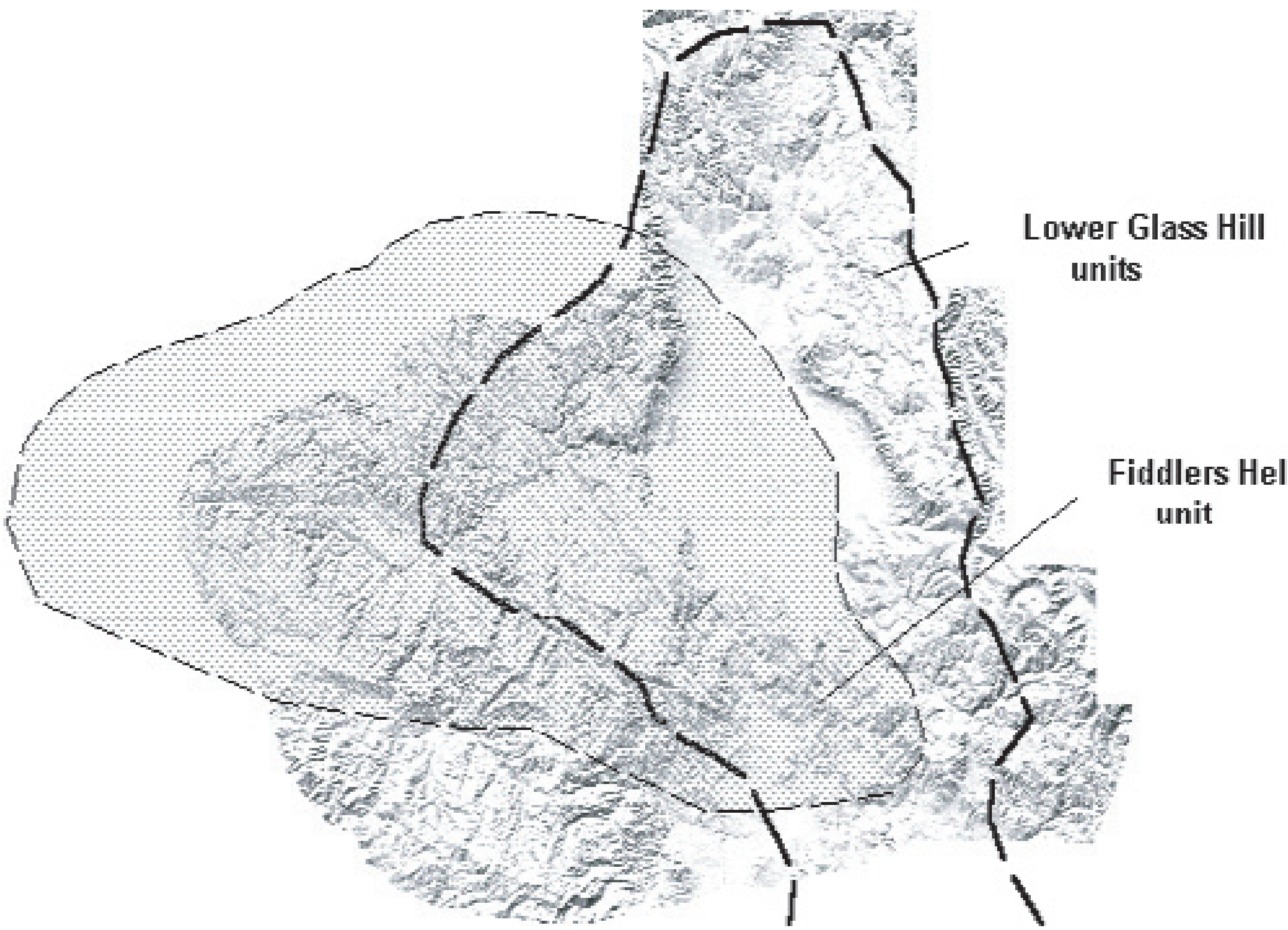

Figure 15. Shaded relief map showing the mapped distribution of the uppermost Grande Ronde Basalt unit (Fiddlers Hell) and lowermost Powder River Volcanic unit (lower Glass Hill olivine basalt). The Fiddlers Hell flows extend to the east and do not appear to have been influenced by north trending paleodrainages. The olivine basalt flows form a north-northwest trending belt of exposures that may indicate the initial development of north-trending structures. Dashed line indicates the outline of the Grande Ronde Valley.

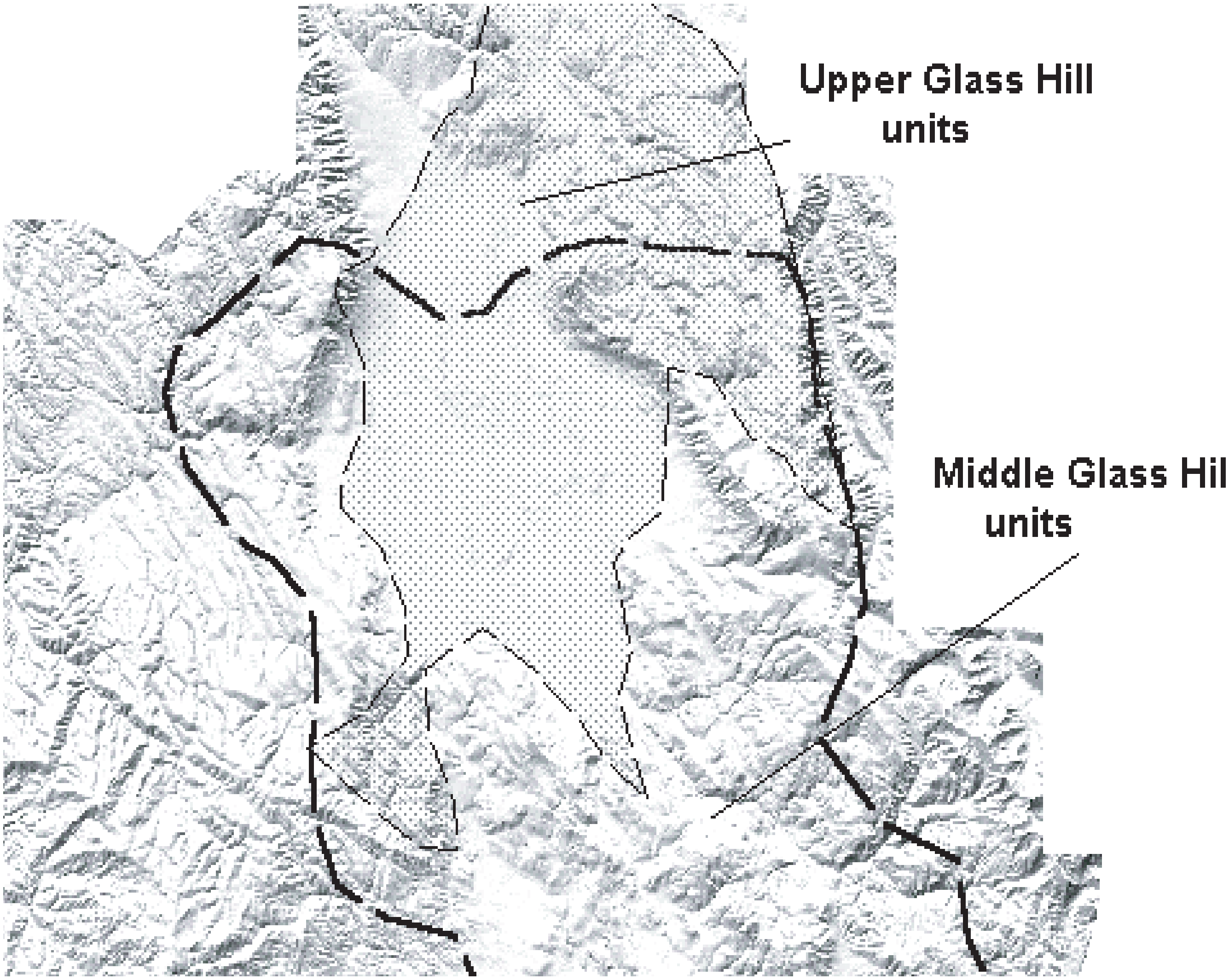

Figure 16. Shaded relief map showing mapped distribution of middle and upper Glass Hill flows. Middle Glass Hill flows, which include thick, areally extensive andesite and dacite lava flows, do not extend north of Mt Harris. Upper Glass Hill flows, which tend to be associated with small volcanoes, form a much smaller exposure belt that is roughly coincident with the modern Grande Ronde Valley. Small upper Glass Hill volcanos and vents may be buried in the valley.

identified in the nearby highlands (Ferns and others, in press). All lava flows exposed in the map area and sampled from water wells above the Grande Ronde Basalt are members of the Glass Hill Volcanic Group of Ferns and others (in press), a 300 m thick sequence of calc-alkaline and alkaline lava flows with eruption ages between 14.3 and 9 Ma (after Barrash and others, 1983). For this report, the Glass Hill Volcanic Group is separated into three stratigraphic packages, based in part on their relative hydrogeologic characteristics: 1) An upper, low volume and compositionally variable sequence of lava flows, 2) A middle sequence of thick dacite and high silica andesite flows that cover larger areas, and 3) Numerous thin olivine basalt flows that occur at the base of the sequence and generally cover very large areas.

Upper Glass Hill units

The upper sequence includes lava flows, cinder cones, small shield volcanos, and small stratovolcanos. The upper sequence includes basanite, basaltic andesite, andesite, and dacite lava flows. Larger individual volcanoes, such as Mt Harris, form small stratovolcanos as much as 425 m high that are flanked by lava flows erupted from neighboring vents (Ferns and others, in press). Upper sequence lavas are generally fine-grained with visible pheonocrysts of plagioclase, hornblende, or olivine. Variability in both thickness and lateral extent, combined with presence of interbedded sediments indicate the flows may have filled ancient channels and valleys. In general, individual flows did not appear to have traveled very far from their eruptive vents. Individual upper sequence lava flows generally do not appear in more than one well, indicating that these flows are limited in size. The only definite geochemical correlation between outcrop samples and water well samples occurs at Union, where a 30 m thick flow in the UNIO-1471 well correlates with the basaltic andesite of Ramo Flat. This flow is separated from middle Glass Hill sequence lavas by 88 m of sediment and appears to have flowed northward from the small eroded cinder cones exposed at Ramo Flat. Upper Glass Hill units that have been mapped in the exposed uplands include:

Tpgab Basanite (middle or late Miocene)

The youngest lava flow exposed in the project area is a glassy, dark-gray to black massive olivine-phyric lava flow that has limited exposure near Phys Point and High Valley. The rock is typically jet black on fresh surfaces, breaks with conchoidal fractures, and is phonolitic. It contains abundant clear, yellow colored olivine crystals as much as 1 mm in diameter. In thin section, it is characterized by 8 – 10 percent euhedral olivine crystals -often with enclosed FeTi oxides-, 6-7 percent euhedral blocky FeTi oxides as much as 0.7 mm in diameter all set in a microcrystalline groundmass of intersertal to intergranular plagioclase, FeTi oxides, anhedral nepheline, and clinopyroxene. This distinctive lava has unusually low silica contents (about 45 wt percent SiO_2) that places it in the basanite composition field (Figure 17a). East of High Valley, the unit is only about 2 m thick and covers an area of about 0.11 km^2 atop a hill east of High Valley. The lava is interpreted as the distal edge to a much larger basanite flow that crops out above the Minam River to the east (McConnell and others, in press). . The 2 m-thick outcrop lies above a more than 150 m thick section of massive andesite and dacite lava flows (Tpgad) and is the youngest lava exposed in the study area.

Tpgbr Basaltic Andesite of Ramo Flat (Middle or Late Miocene age)

Light to medium gray fine- to very-fine-grained porphyritic basaltic-andesite lava flows associated with the cinder cones of Ramo Flat (Tpgbc). Unit consists of thin lava flows generally less than 3 m thick that mantle the southern flanks of the cones. Individual flows are of limited aerial extent, generally covering less than 0.4 km^2. Hand samples are typically fine-grained, reddish in color, and highly vesicular. In thin section, characterized by 1 – 2 percent plagioclase phenocrysts as much as 4 mm in length, 1 –2 percent altered olivine crystals as much as 1 mm in diameter set in a fine-grained pilotaxitic groundmass of plagioclase, orthopyroxyne, clinopyroxene and Fe - Ti oxides. Multiple flows exposed to the southwest of the north cinder cone form a section nearly 50 m thick that may have filled a topographic depression. The thick series of flows southwest of the north cinder cone is over 60 m thick and may also have filled a topographic depression. Lava of that cone is very fine grained with phenocrysts of plagioclase, to 4 mm long,1-2 percent; iddingsitized olivine, 0.5-1 mm across; and a fine-grained pilotaxitic groundmass of plagioclase, orthopyroxene, Fe-Ti oxides, and clinopyroxene. Characterized chemically by moderate silica (55 – 56 wt percent SiO_2) and high alumina (more than 17 wt percent Al_2O_3). Compositionally similar flows overlie andesite lavas in the Union municipal water wells (see Appendix C)

Tpgrc Cinder Cones of Ramo Flat (Middle or Late Miocene)

Unit consists of a complex of small vents made up of poorly to moderately well-bedded, brick-red to reddish-gray scoria and lithic lapilli as much as 10 cm in length. The volcanic ejecta forms three prominent cinder cones along the Ramo Flat Road southeast of Union. Volcanic ejecta also includes angular boulder and spindle-shaped volcanic bombs as much as 80 cm in length. The three cinder cones are aligned parallel to the local NW-trending fault system. The northern cone forms a 60 m high mound that is breached by a massive, 10 m high basaltic andesite dike (Figure 18). breached by a large basaltic andesite dike. Red cinders and scoria are exposed in the rock pit on the flank of dike. Chemically similar flows at the top of the Glass Hill sequence in the Union municipal well may have come from this vent.

The central cone has a gentle profile and is capped by discontinuous lava flows of plagioclase-phyric basaltic andesite (Tgba). In hand sample, the scoria is high vesicular, glassy, and aphyric to sparsely porphyritic. The cinder deposits are chiefly highly vesicular glassy aphyric to sparsely porphyritic. Chemically indistinguisable from overlying and flanking Tgba lava flows.

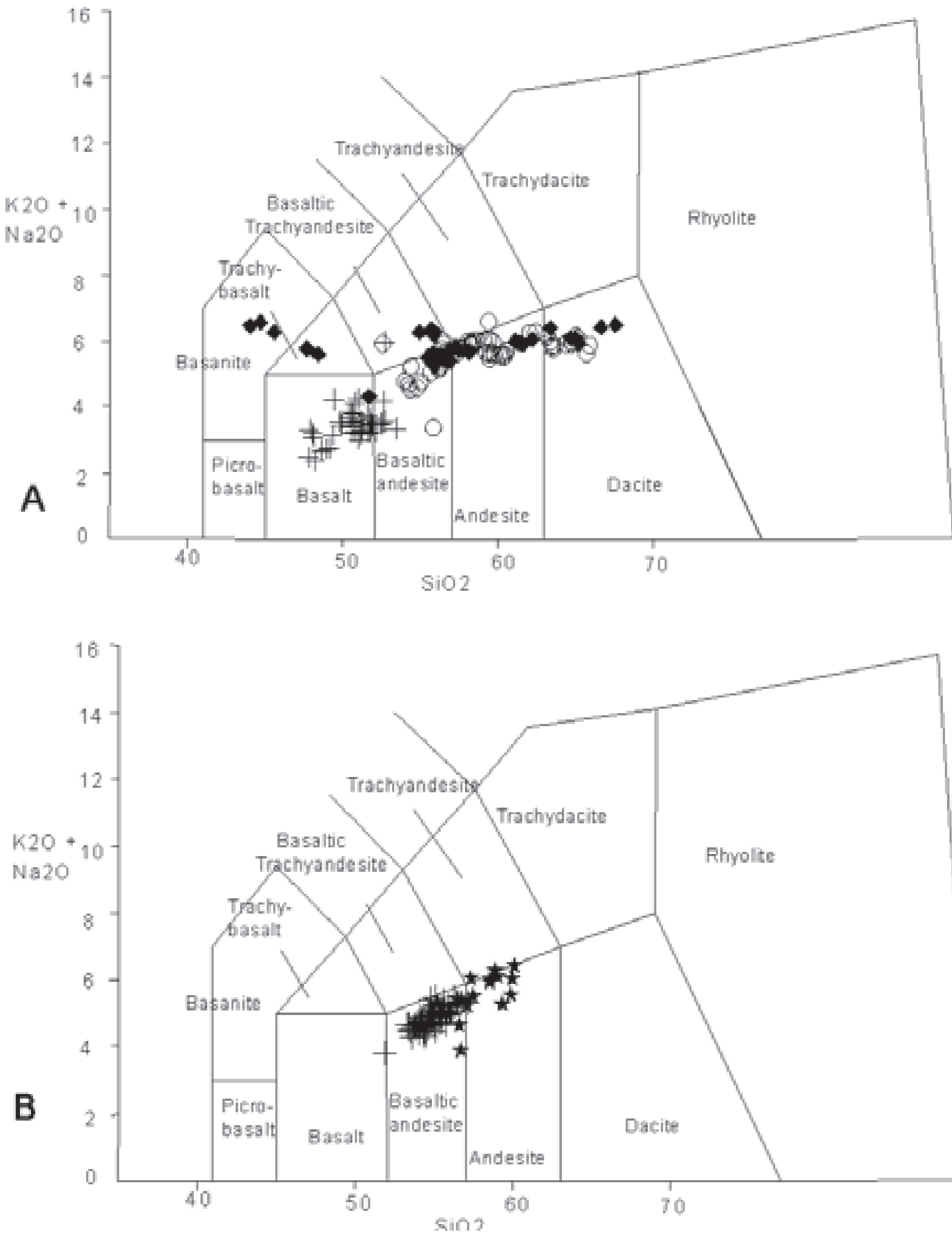

Figure 17. a). TAS (total alkalis vs silica) plot of Powder River Volcanic Field units (Le Maitre and others, 1989). Upper Glass Hill lavas=filled diamonds; middle Glass Hill lava =open circles; lower Glass Hill units=crosses. Complete analyses are included in Appendix C. This plot shows an apparent change over time toward more alkali-rich mafic lavas, with eruption of basanite, trachybasalt, and trachy basaltic andesite in the Upper Glass Hill.

b). TAS (total alkalis vs silica) plot of Grande Ronde Basalt=crosses, Fiddlers Hell=filled stars. Grande Ronde Basalt analyses form a tight cluster in the basaltic andesite field; while Fiddlers Hell analyses form a looser cluster ranging from basaltic andesite to andesite.

Figure 18. The small knob shown here is a deeply eroded Ramo Flat cinder cone that has been breached by a large basaltic andesite dike. Red cinders and scoria are exposed in the rock pit on the flank of dike. Chemically similar flows at the top of the Glass Hill sequence in the Union municipal well may have come from this vent.

Tpgh Hornblende Andesite (Middle or Late Miocene)

Light- to medium gray hornblende-phyric andesite. Unit includes lava flows and a spectacular 400 m long dike that forms an 8 m high rib (locally known as "The Wall") on the north wall of Warm Creek canyon. Unit also includes a 30 m-thick sill that has intruded into the lower part of the Glass Hill Volcanic Group north of Mt Fanny. In hand sample, it is characterized by 2 to 10 percent hornblende crystals as much as 1 cm in length. In thin section, characterized by seriate hornblende phenocrysts set in an aphanitic groundmass. Chemically and petrographically similar to flows associated with the Mount Harris volcano to the north which has yielded a $^{40}Ar/^{39}Ar$ plateau age of 11.86 ± 0.12 Ma (Ferns and others, in prep.).

Hydrogeologic characteristics of upper Glass Hill units

As would be expected, the hydrogeologic characteristics of the upper Glass Hill sequence are variable due to changes in lithology over short distances. Where the section is made up of thick impermeable dacite and andesite flows, as in the Alicel Well (UNIO-50687) overall permeability is low. Where the section is made up of overlapping, relatively thin basaltic andesite and andesite flows that are separated by well-developed flow breccias the permeability is likely to be higher and the capacity to store water increased . The BING-98 well, (UNIO-50684) reportedly produced artesian flow of approximately 25 gpm from interbedded andesite lava flows.

Middle Glass Hill units

The middle Glass Hill sequence is defined by generally flat-lying thick dacite and high silica andesite lava flows that coalesce to form a discontinuous sheet across the southern part of the Grande Ronde Valley. Individual lava flows are as much as 140 m thick and are generally fine-grained and aphyric. Mapped units include:

Tpgd Undifferentiated Andesite and Dacite (middle Miocene)

Thick, laterally continuous flows of light- to medium-gray platy aphyric to sparsely porphyritic stony andesite and dacite lavas (Figure 19). The unit is comprised of massive, commonly platy, lava flows as much as 90 m thick that form a stacked section more than 180 m thick. In hand sample, the rocks appear as light gray, generally aphyric lava characterized by millimeter to centimeter scale parallel partings.

In thin section, they typically contain disseminated microphenocrysts of Fe-Ti oxides, and/or clinopyroxene set in a very fine grained pilotaxitic groundmass of plagioclase, clinopyroxene, orthopyroxene, and FeTi oxides. Chemically they range from andesite to dacite with 56.9 - 65.9 wt percent SiO_2 and approximately 17 wt percent Al_2O_3 (Table 2). Unit is composed of lava flows that likely erupted from widely separated vents located to the south of the map area. A possible vent recognized in the map area is marked by a N50W-trending columnar jointed 6 m-high, 4.5 m-wide dacite dike that intrudes platy andesite/dacite on a high ridge north of Deer Creek (E 1/2 Sec 24, T3S, R40E). $^{40}Ar/^{39}Ar$ total fusion ages obtained from two related lavas south of the study area yielded dates of 13.0±0.1 and 13.1±0.2 Ma (Bailey, 1990). The flow at the top of Mt Fanny, just west of Cove, yielded a $^{40}Ar/^{39}Ar$ age of 11.8±0.09 Ma (McConnell and others, in prep.). Basal flows lie directly on lower Glass Hill sequence olivine basalt flows.

Figure 19. Middle Glass Hill flows include large dacite and andesite flows as much as 150 m thick that cover up to 100 km2. Dacites are commonly platy and are often marked by steeply dipping, narrowly spaced joints that weather to distinctive angular chips.

Tpga Andesite and basaltic andesite (Middle Miocene)

Flow-on-flow sequence of platy-jointed, glassy aphyric basaltic andesite and andesite flows exposed south of La Grande. Unit includes black, glassy lavas and light- to medium-gray finely-crystalline lavas. In thin section, the rocks are characterized by pyroxene and plagioclase microphenocrysts set in a very fine-grained pilotaxitic groundmass. Chemical compositions (Table 2) include low and medium potassium andesite (56.4 - 61.8 wt percent SiO_2, 15.8 - 17.8 wt percent Al_2O_3, 1.2 - 2.7 wt percent K_2O). Individual flows are as much as 45 m thick. Unit thickness ranges from 65 m at Ladd Canyon to 120 m at La Grande (based on drill cuttings). The unit is equivalent to the glassy basalt unit of Barrash and others (1980). Basal flows lie directly on lower Glass Hill sequence olivine basalt flows.

Tpgde Dacite of Mt Emily (Middle Miocene)

Platy gray aphyric dacite lava flow that is as much as 140 m thick and covers as much as 90 km^2 . Unit well-exposed near the summit of Mt. Emily where it consists of a single lava flow marked by a coarse, matrix-supported basal breccia with vitrophyre blocks and an upper massive, locally vesicular flow top. In thin section, the unit is characterized by pyroxene and plagioclase microphenocrysts set in a very fine-grained pilotaxitic groundmass. Chemically the dacites are medium potassium (62.7 - 66.6 wt percent SiO_2, 16.4 - 16.7 wt percent Al_2O_3, 1.5 - 2.4 wt percent K_2O). Middle Miocene age is based on a $^{40}Ar/^{39}Ar$ age of 13.38±0.24 Ma (Ferns and Madin, 1999). The Mt Emily flow lies directly on lower Glass Hill sequence olivine basalt flows.

Hydrogeologic characteristics of middle Glass Hill units

Middle Glass Hill sequence flows appear to have generally low permeabilities. No significant water-bearing zones have been encountered in the middle Glass Hill sequence in any of the deep wells drilled in the valley. Although individual flows extend over large distances, they form thick, massive units that have little apparent porosity. The only basal flow breccia noted was a vitrophyre breccia at the base of the Mt Emily dacite.

Lower Glass Hill units

The lower sequence is composed of crystal-rich, diktytaxitic olivine basalt flows. Individual lava flows 1 to 12 m thick overlie one another to form a section as much as 180 m thick. The lower sequence includes basal sediments that in places are interbedded with silicic lithic ash-flow tuff. The olivine basalt flows and underlying sediments form a 100 – 150 m-thick blanket that extends across the southern part of the valley. The lower sequence thins to the north, from 167 m at Union (UNIO-1471) and 157 m at La Grande (UNIO-2098, Plate 3) to 105 m at Imbler (UNIO-208). Mapped units include:

Tpgb Olivine Basalt (Middle Miocene)

The unit is a flow-on-flow sequence of vesicular, holocrystalline olivine basalt flows that are generally gray or light gray in color and weather to distinctive compact rounded boulders in a grussy soil (Figure 20). Flows are commonly characterized by a diktytaxitic texture where olivine phenocrysts as much as 3 mm in diameter are set in an open-textured groundmass of coarse feldspar laths. Unit locally includes more compact olivine-phyric gray glassy lavas. Individual lava flows are typically 5 to 17 m thick. Unit apparently thins to the north, from 167 m below Union to 105 m below Imbler. Flow compositions range from 47 – 53 wt percent SiO_2 and 15.2 - 17.3 wt percent Al_2O_3 (Table 2). Locally separated from underlying Grande Ronde Basalt by thin layer of tuffaceous sediments, ashflow tuff, or cobble gravels. Where overlain by units Tpgd or Tpga, the unit often forms large landslides. Lowermost flows have reversely polarized thermal remnant magnetism while uppermost flows are of normal polarity. Middle Miocene age based on whole rock $^{40}Ar/^{39}Ar$ ages of 13.3±0.8; 13.7±0.1, and 14.4±0.2 Ma for similar olivine basalt flows to the south and east (Bailey, 1990). Equivalent to the diktytaxitic basalt unit of Barrash and others (1980).

Tml Sedimentary rocks of La Grande (Middle Miocene)

Mainly indurated tuffaceous siltstone, mudstone, and fine-grained sandstone with local thin diatomite beds. Also includes lithic rhyolitic welded ash-flow tuff, air-fall tuff and coarse tuffaceous conglomerate, and mudflow breccia. Thickest exposures are found north of La Grande; where 40 m of sediments were penetrated in UNIO-2098. Unit thins to the east, where it rarely exceeds one meter in thickness and in many places is missing entirely. Color varies from yellowish-white to pale orange and moderate reddish brown where baked by overlying lava flows. Where it is overlain by Glass Hill olivine basalt and dacite flows it commonly forms a landslide slip surface.

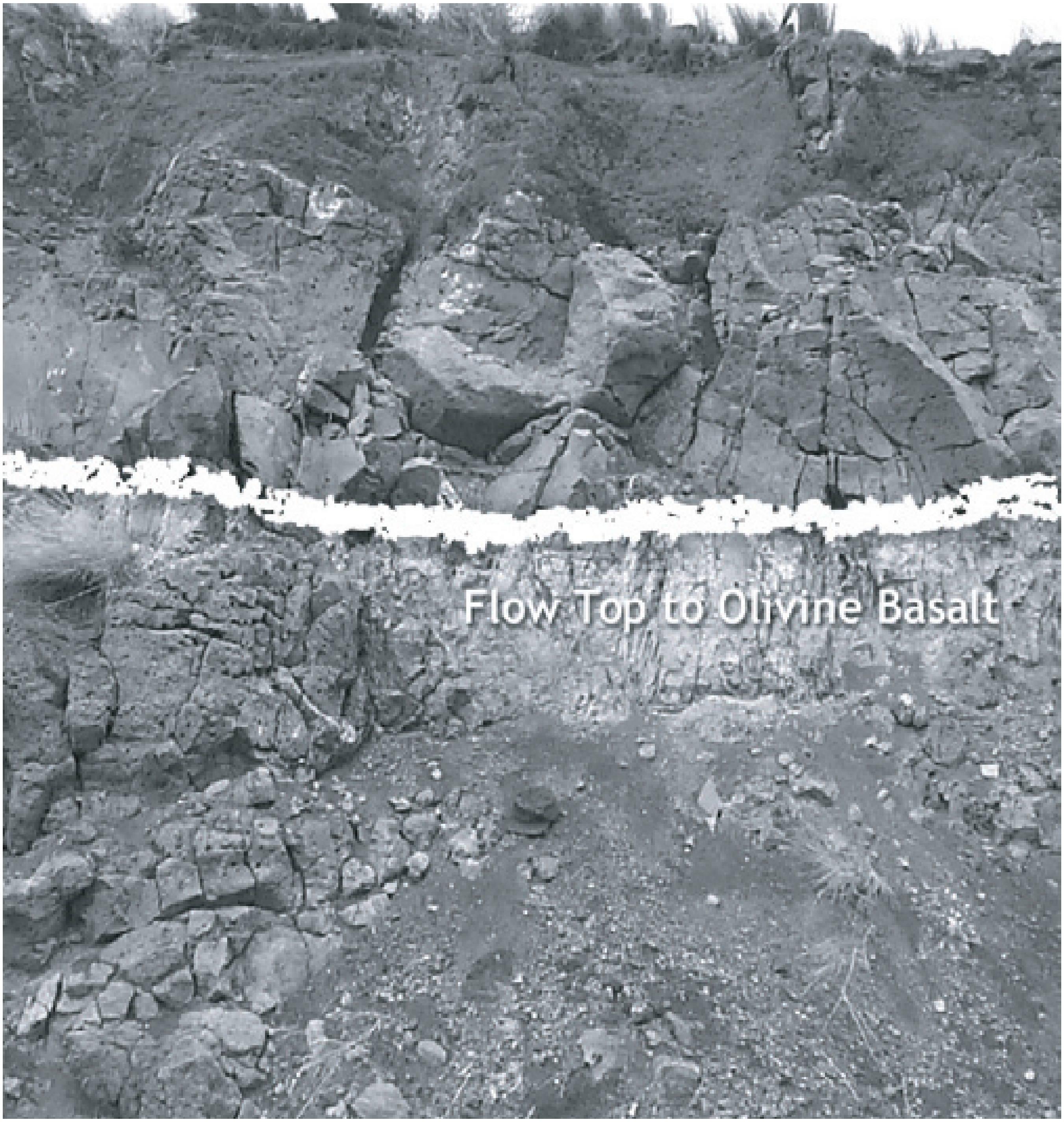

Figure 20. Lower Glass Hills flows are dominated by olivine basalt flows that form extensive sheets that are highly uneven in thickness. Flow bases are often marked by red soils that may be baked paleosols. The base of the Lower Glass Hill olivine basalt flows is often marked by poorly exposed tuffaceous sediments that form barriers to downward movement of water. The contact is often marked by springs and landslides.

Hydrogeologic characteristics of lower Glass Hill units

Although no significant flows of water have been reported from the lower Glass Hill sequence, individual olivine basalt flow are expected to have relatively high permeability and porosity. The tuffaceous sedimentary unit at the base of the lower Glass Hill sequence may locally act to block vertical movement of water. The lower contact is often marked by springs, wet seeps, and landslides in the uplands.

Columbia River Basalt Group

The most voluminous volcanic deposits found in the study area are the lavas of the Columbia River Basalt Group. The Grande Ronde Basalt is the only Columbia River Basalt Group formation exposed in outcrop and encountered in deep wells in the valley (Reidel and others, 1996; Ferns and Madin, 1999). Individual flows are typically about 30 m thick, but range between 3 and 90 m in thickness. Regionally, the Grande Ronde Basalt includes at least 120 laterally extensive individual lava flows (Reidel and others, 1989) that cover a total area of nearly 18,000 km^2 from northern Idaho to the Pacific Ocean. Locally, Grande Ronde Basalt lava flows are best exposed below Mt Harris on the east side of the Grande Ronde Valley, and along the west side of the valley above La Grande. The interiors of individual flows are generally massive basalt with well-developed internal blocky joints. Contacts between individual flows are often marked by interflow zones made up of the vesicular flow top of the bottom flow, a thin ancient soil zone, and the rubbly basal flow breccia of the overlying flow. All Grande Ronde Basalt flows are similar in appearance, being fine-grained, aphyric rocks that are blackish-gray to bluish-gray in color. They are also grossly similar in whole rock chemistry, having high TiO_2, low Al_2O_3, and high Fe/Mg ratios (see Reidel and others, 1989; Hooper and Swanson, 1990; and Swanson and others, 1981) that are quite distinctive from the overlying Glass Hill Volcanic Group flows (Table 2, Figure 21). Units within

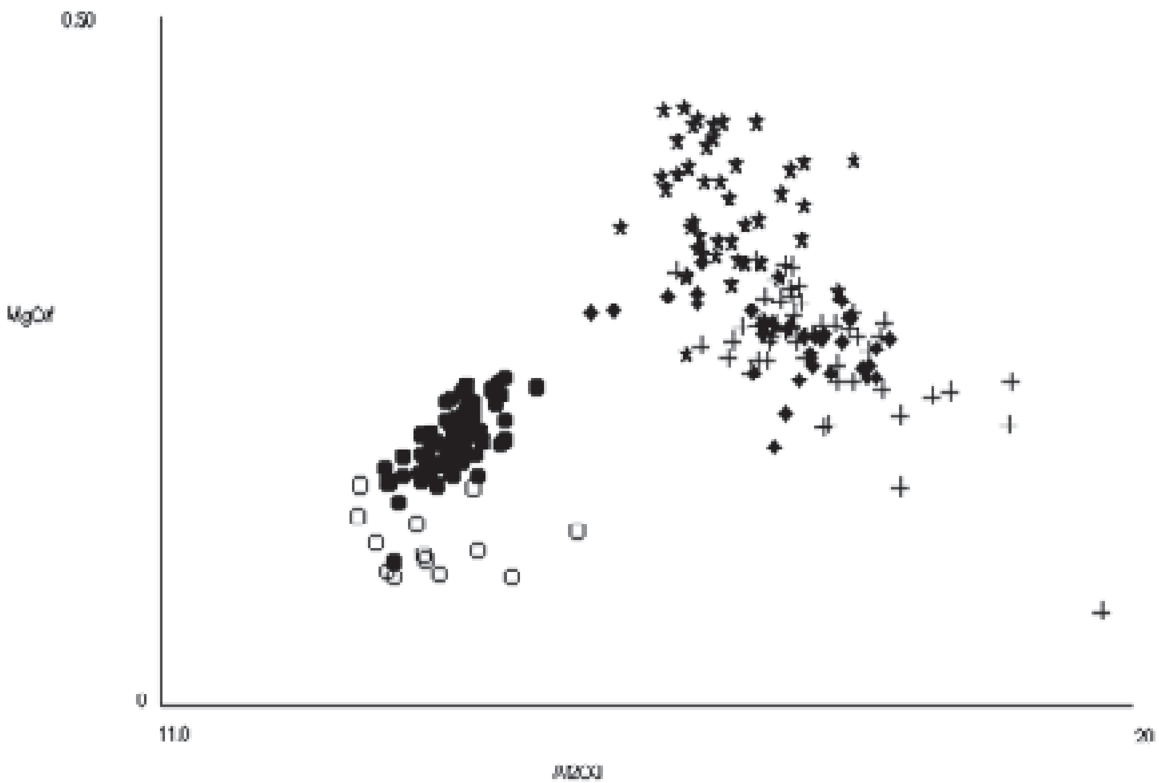

Figure 21. Al2O3 versus MgO# diagram. This plot illustrates some of the major chemical differences between the Powder River Volcanic Field and the Grande Ronde Basalt. Fiddlers Hell = open circles; other Grande Ronde Basalt = filled circles; lower Glass Hill lavas = filled stars, middle Glass Hill lavas = crosses, upper Glass Hill lavas = filled diamonds. The MgO# is a measure of the ratio of iron to magnesium in the rock and is used as a geochemical indicator of the origin of the parent magma. The MgO# equals MgO/(MgO + FeO*). Generally speaking, more "evolved" magmas contain relatively higher amounts of iron and thus have lower MgO#'s.

Figure 22. Grande Ronde Basalt flows are typically thick flows with massive, variably-jointed cores. Productive aquifers occur where basal flow breccias contain enough void spaces to form highly permeable zones. Outcrop here is cut by small east-side down faults that form part of the West Grande Ronde Valley Fault Zone. Such faults may act to retard lateral movement of water by juxtaposing impermeable flow interiors with permeable flow breccias.

the Grande Ronde Basalt are separated on the basis of magnetic polarity and subtle differences in major element geochemistry. Regionally, the Grande Ronde Basalt is divided into four mappable units on basis of magnetic polarity; basal unit R1 (first reversed package), then N1, R2, and finally N2 (second normal package). In the Grande Ronde Valley area, uppermost N2 flows are mapped separately because of their distinctive geochemistry. These high silica flows with very high Fe/Mg rations form the Fiddlers Hell unit (Figure 21, Plate 3a) and crop out at the top of the Grande Ronde Basalt along the west margin of the Grande Ronde Valley. Fiddlers Hell flows are also found on Catherine Creek and at the top of the Grande Ronde Basalt section in the La Grande and Union municipal wells, but are absent from the eastern margin of the valley north of Cove.

Over 455 m of Grande Ronde Basalt flows are exposed on the east flank of Mt Emily (Ferns and Madin, 1999) along the Emily traverse (Plate 3a). Here about 60 m of Fiddlers Hell flows lie directly atop Grande Ronde R2 flows. The Fiddlers Hell is missing from the 80 m of Grande Ronde N2 flows that are exposed on the east side of the valley north of Cove. Mapped Columbia River Basalt units include:

Tcgu Grande Ronde Basalt – undifferentiated (Middle and Lower Miocene)

The Grande Ronde Basalt is a flow-on-flow sequence of bluish-black, aphyric to sparsely plagioclase phyric lava flows. The unit includes both holocrystalline and glassy lavas that weather to form steep slopes consisting orange-brown, angular blocks (Figure 22). Fresh hand samples are generally aphyric and range from bluish gray to black in color. Differential weathering between flow tops and interior of flows results in a distinctive cliff and bench topography.

Permeable flow tops and basal breccias are marked by tree bands and impermeable, less easily erodable flow centers form grass-covered benches. Easily distinguished from overlying Glass Hill volcanics on the basis of low alumina contents (generally less than 14.5 wt percent Al_2O_3). Separated, where possible, into two magnetostratigraphic units (N2 and R2) on the basis of magnetic polarity as measured in the field by a fluxgate magnetometer. The compositionally distinct higher silica ferroandesites (more than 57 wt percent SiO_2) that locally mark the top of the N2 unit have also been separately mapped where possible (Table 2).

Tcgf Ferroandesite of Fiddlers Hell (Middle Miocene).

Chemically distinctive, high silica tholeiitic lava flows at the top of the N_2 magnetostratigraphic unit are a separate geochemical unit in the Grande Ronde Basalt (Ferns and others, 2001). Unit consists of at least five separate flows that are dark gray to gray and bluish-gray, aphyric to sparsely plagioclase-phyric glassy lavas. Uppermost flows are glassy and sparsely plagioclase-phyric. Individual lava flows are thin, less than 15 m, with conspicuous vesicular flow tops and basal flow breccias. Lower flows are glassy to holocrystalline and typified by intergranular textures in thin section. Commonly contain as much as 5 percent plagioclase and clinopyroxene phenocrysts. Compositions range from 56.3 - 62.3 wt percent SiO_2, 12.8 - 15.1 wt percent Al_2O_3, and 1.7 - 3.0 wt percent K_2O. Chemically different from Grande Ronde Basalt N2 magnetostratigraphic member on the basis of conspicuously higher abundances of SiO_2, K_2O, TiO_2, and P_2O_5 (Figure 17b).
Although the unit usually directly overlies other N2 Grande Ronde magnetostratigraphic unit flows, in places, such as the east flank of Mt Emily, lies directly on R2 Grande Ronde flows. One vent complex may be exposed on Catherine Creek, where a prominent 30-m-high remnant core of a layered spattered cone sits directly above pre-Tertiary rocks. The cone, which pinches out laterally, is composed chiefly of 10-50-cm-thick discontinuous layers of welded spatter that dip steeply beneath the overlying units. Based on geochemical analyses of water well cuttings, the unit also underlies the southern part of the Grande Ronde Valley, but is absent north of Alicel. Although a majority of Fiddlers Hell flows display normal polarity magnetism, the uppermost flow north of Indian Rock consistently displays reversed polarity. Unit includes flows previously mapped as ferroandesite of Indian Rock (Ferns and Madin, 1999) and ferroandesite of Tucker Flat (Madin, 1998; Ferns and Madin, 1999). Middle Miocene age based on a whole rock $^{40}Ar/^{39}Ar$ age determination of 15.54±0.01 (Madin, 1998).

Tcgn$_2$ N2 magnetostratigraphic unit (middle Miocene)

Flow-on-flow sequence of fine-grained, generally holocrystalline lava flows of the Grande Ronde basalts. Includes Winter Water, Ortley, Armstrong Canyon, and Sentinal Bluffs chemical type flows as defined by Reidel and others (1989). Overlies R2 magnetostratigraphic unit. Age of the N2 unit lies between 15.5 and 15.7±0.3 Ma (Baksi, 1989). Chemically distinctive, high silica tholeiitic lava flows that locally cap the N2 magnetostratigraphic unit are mapped separately as the ferroandesite of Fiddlers Hell.

Tcgr$_2$ R2 magnetostratigraphic unit (Middle Miocene)

Flow-on-flow sequence of aphyric to sparsely plagioclase-phyric lava flows that includes Grouse Creek and Wapshilla Ridge chemical type flows as defined by Reidel and others (1989). Overlies N1 magnetostratigraphic unit and is overlain by the N2 magnetostratigraphic unit. Age of the R_2 unit lies between 15.7±0.3 and 15.9±0.2 Ma (Baksi, 1989).

Tcgv Mafic cinder and scoria deposits (Miocene)

Unit consists of widely scattered accumulations of clast-supported lapilli breccias and welded spatter deposits. The orange breccias consist chiefly of dark-gray finely vesiculated lapilli 0.5 to 3 cm in diameter set in a matrix of orange and black glass shards. At least 5 m of well lithified cinders are exposed below olivine basalt flows on the east side of Phys Point (NW 1/4 Sec. 19, T3S, R40E). Less than 2 km southeast ,a similar cinder deposit that is possibly continuous with the above, is intruded by a 12-m-high remnant dike spire (NE 1/4 Sec 29, T3S, R40E). A separate cinder deposit is exposed in a fault scarp above Catherine Creek (NE 1/4 Sec. 4, T5S, R40E).

Hydrogeologic characteristics of the Grande Ronde Basalt

The Grande Ronde Basalt is the most extensive aquifer in the valley, in places providing artesian flows of more than 2,000 gpm. In the project area, the aquifer is tapped only by municipal wells at La Grande and Union. The City of Imbler and about a half-dozen irrigation wells produce from the Grande Ronde Basalt in the northern part of the valley outside the study area. Overall, the flow-on-flow constructional morphology of the Grande Ronde Basalt formation makes it an excellent water-bearing formation when confined as in the Grande Ronde Valley. Although the massive central portion of an individual flow is relatively impermeable, the contact zone between the flows is permeable and porous, and the number of flows is numerous. The proportion of flow breccias and overall permeability is expected to increase where numerous, relatively thin flows overlie one another. Limited groundwater circulation through an individual flow can be expected where the flow's interior is marked by through-going joint sets. The unit has its greatest capability to sustain production where interflow zones are well connected, however, long-term production may not be possible from interflow zones that are isolated or poorly connected. Any one particular well may be drawing from a large rechargeable aquifer of interconnected interflow breccias or be "mining" water from a discrete interflow zone. Water wells drilled into the unit to date have penetrated only the upper 180 m of Grande Ronde Basalt.

Pre-Tertiary Units

Older basement rocks are exposed near the Catherine Creek State Park. These are metamorphic and intrusive rocks that very well indurated and make very limited aquifers. Mapped units include:

KJi Intrusive rock (Late Jurassic or Early Cretaceous)

Massive, vertically jointed outcrops of an intrusive complex is exposed along Catherine Creek south of the Catherine Creek State Park. The bulk of the intrusion is a gray, fine- to medium-grained altered diorite made up of 60 modal percent plagioclase and 15 – 20 modal percent chlorite. The intrusive is cut by small, poorly exposed pink potassium feldspar and quartz bearing pegmatites. Tentatively considered to be an outlier of the much larger Wallowa Batholith to the east.

JTrs Calcareous argillite (Late Triassic or Jurassic)

Massive dark gray to black, fine grained calcareous argillite and dirty limestone. Unit includes highly contorted, hydrothermally altered, brecciated bluish-gray metamorphic limestone exposed in a fresh landslide scar south of Catherine Creek. The breccia is permeated with yellow to ochre-colored iron staining. Along the contact with the KJi intrusive north of Catherine Creek, the unit includes actinolite-rich limestone hornfels that spheroidally weathers to form a pebbly soil. On basis of lithologic similarities, tentatively correlated with the Hurwal Formation of Late Triassic - Early Jurassic age (Smith and Allen, 1941; Beaulieu, 1972).

STRUCTURE

The modern Grande Ronde Valley is a graben that is bounded on the east and west by major fault zones (Figure 23). The graben is best described as a pull-apart basin (Gehrels, 1981; White, 1980) and forms part of the Olympic Wallowa Lineament (Mann and Meyer, 1993). The basin floor, as defined by the top of the Powder River Volcanic Field, is a faulted and tilted surface that plunges to depths of more than 600 m below the valley floor. The west and east sides of the valley are bounded by major through-going fault zones that form prominent bounding escarpments, abruptly separating the valley fill sequence from the volcanic basement. The southern margin of the valley is defined by an irregularly-shaped, north-sloping uplands that plunges beneath the valley fill sequence.

The steep, west margin of the valley is marked by the 60 km long West Grande Ronde Valley Fault Zone. The West Grande Ronde Valley Fault Zone is a 3 km wide band of mainly down-to-the-east, subparallel faults that separate the valley floor from the rolling highlands to the west. Within the zone, individual faults with vertical offsets as much as 700 m can be traced for as far as 10 km. West Grande Ronde Valley Fault Zone shows up as a strong aeromagnetic gradient that is defined by closely-spaced contours (Figure 24). Subtle topographic features, including linear range fronts, low linear escarpments on alluvial fans and terraces, faceted spurs, and “Z”-shaped topographic inflections along bedrock-alluvial fan contacts (Simpson and others, 1993;

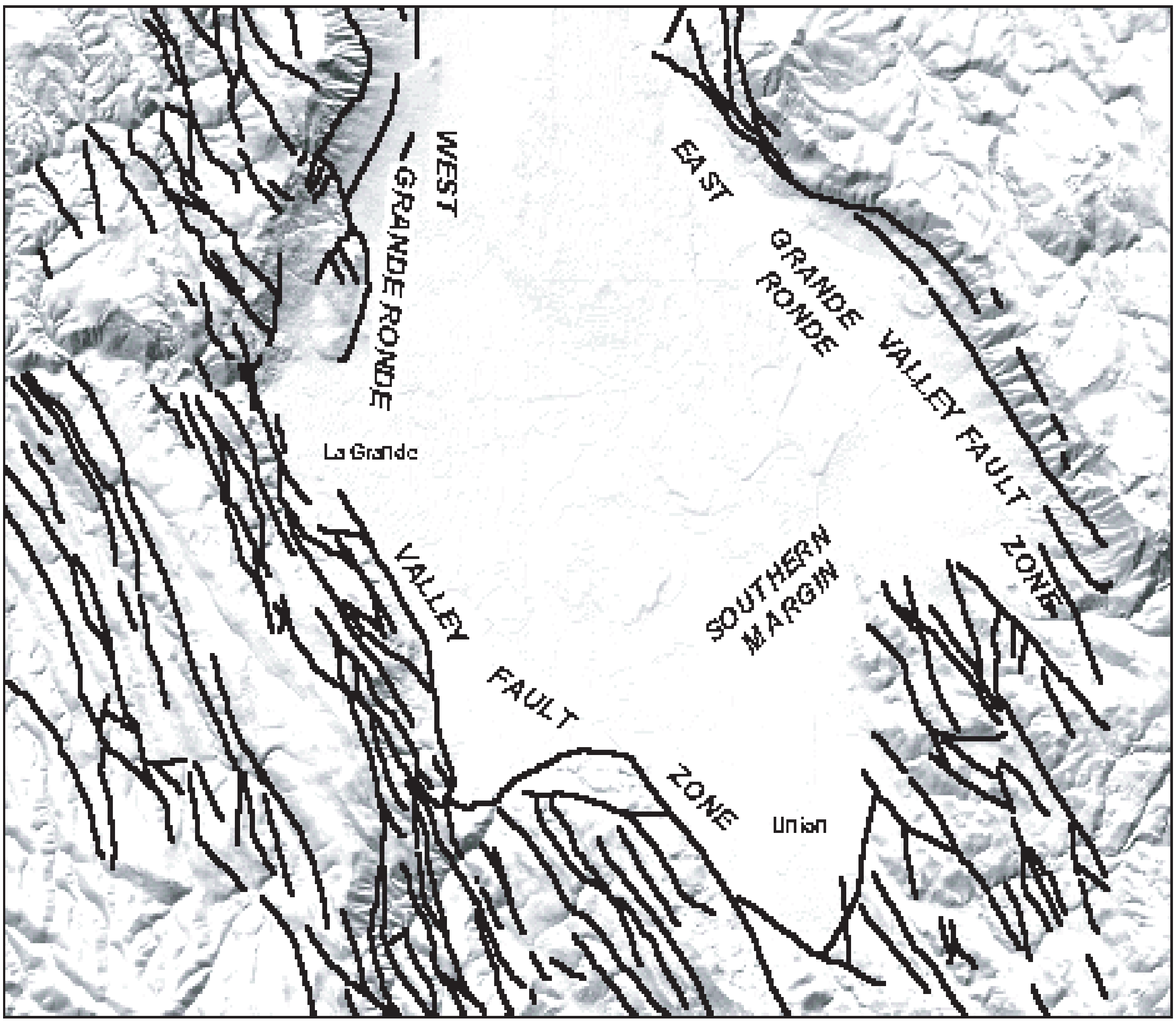

Figure 23. Shaded relief map showing major fault zones in the southern part of the Grande Ronde Valley.

Personius, 1998; Ferns and Madin, 1999) indicate that surface ruptures along the West Grande Ronde Valley Fault Zone are Late Quaternary and possibly Holocene in age. The southern part of the West Grande Ronde Valley Fault Zone is made up by subparallel fault strands that bound rotated blocks of volcanic rocks that dip into the valley. One fault segment (Taylor Creek fault of Gehrels, 1981) crosses into the valley floor south of La Grande beneath Ladd Marsh, trending toward Hot Lake and the western margin of the Union embayment.

The southern margin of the Grande Ronde Valley is marked by the topographically subdued, northward

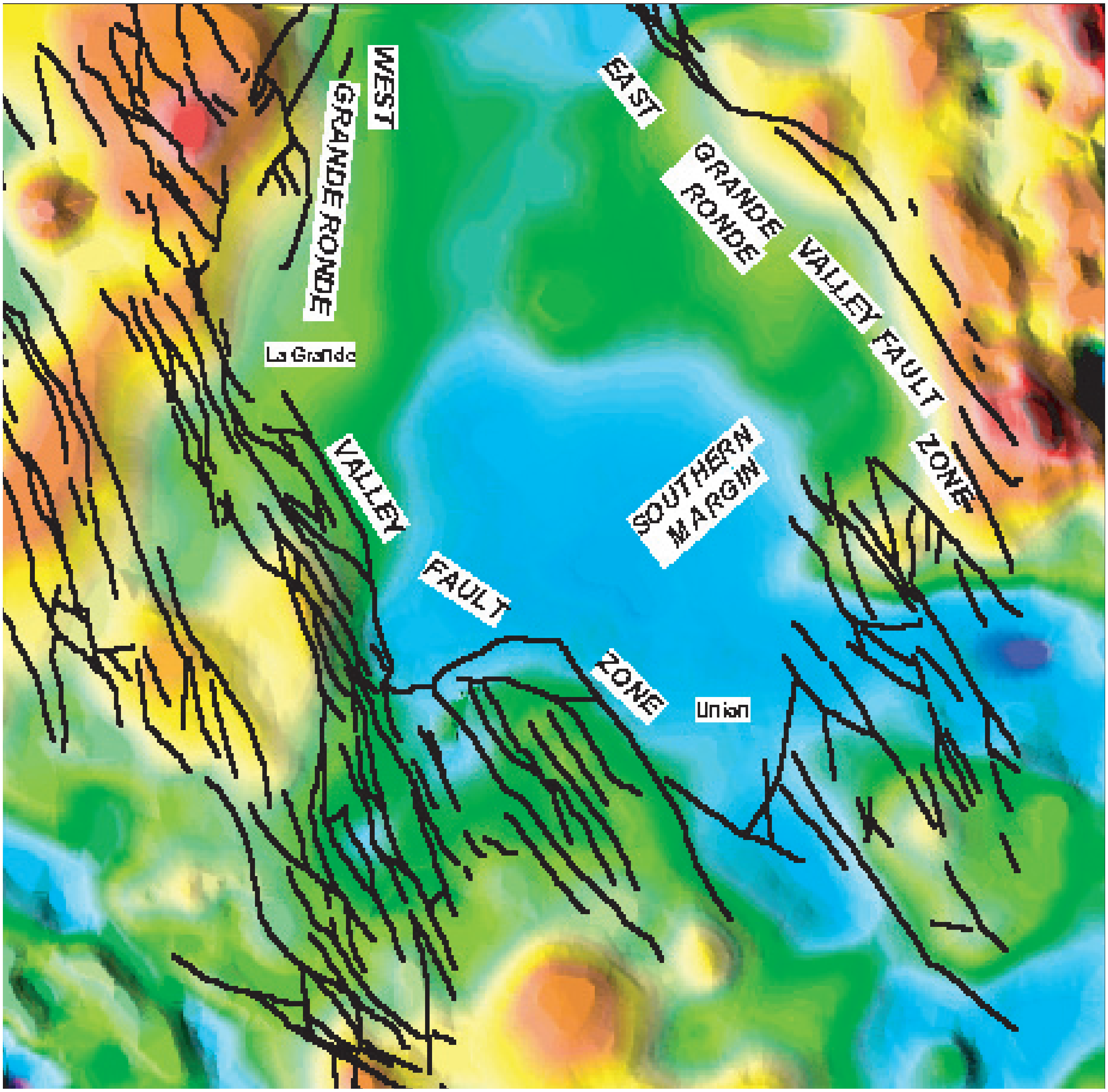

Figure 24. Plan view of the major fault zones superimposed on an aeromagnetic contour map. Red, orange, and yellow colors denote areas with relatively high magnetic signatures. Blues mark relative magnetic lows. Some magnetic features are associated with mapped geologic structures; note that East and West Grande Ronde Valley Fault Zones coincide with sharp magnetic gradients. Bulls?eye shaped magnetic highs may mark the vent areas for middle Glass Hill dacite and andesite flows; note in particular the strong high in the northwest corner of the figure. Other magnetic features, such as the pronounced magnetic low in the southeast corner of the figure do not coincide with any exposed geologic feature.

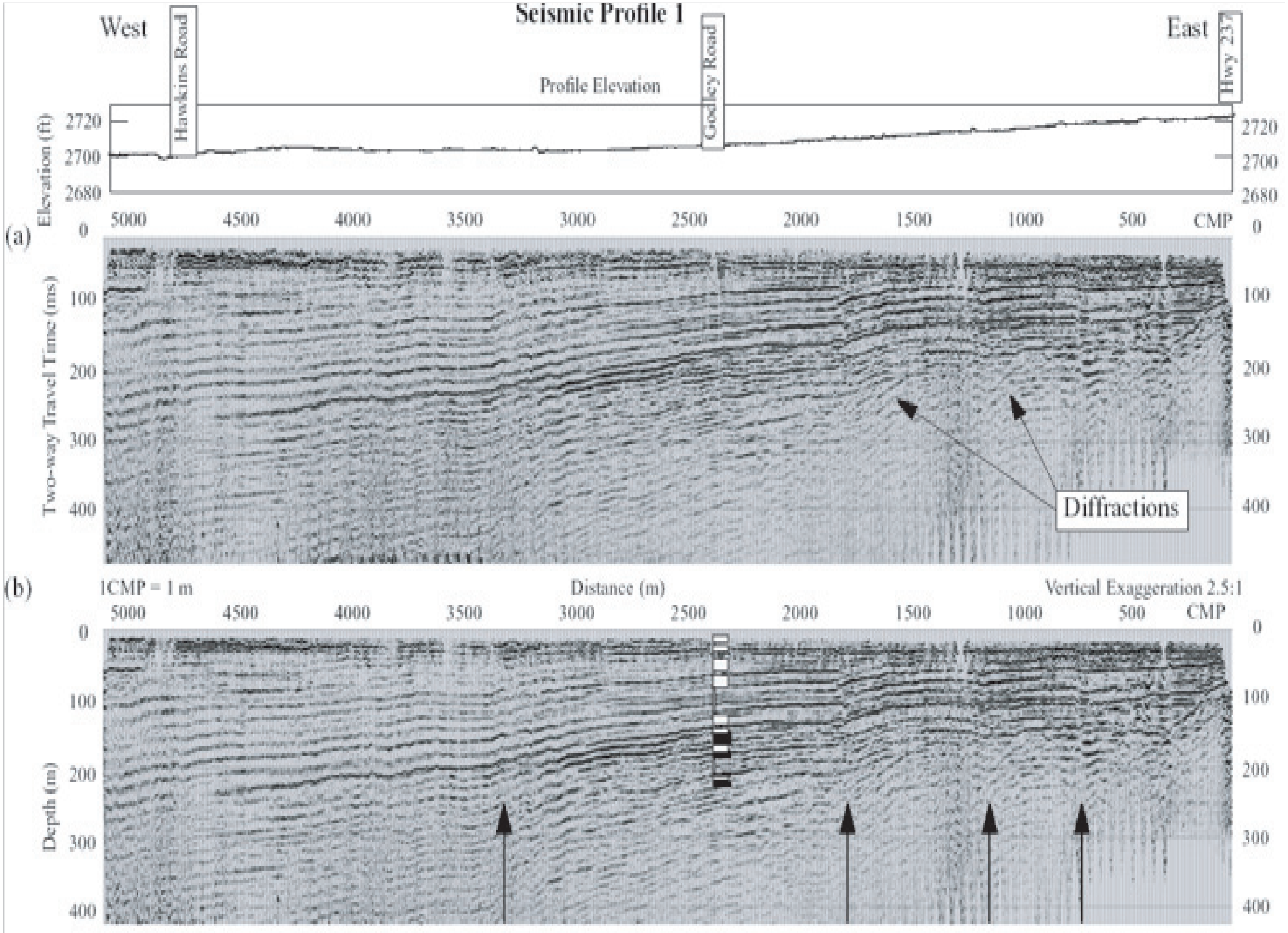

Figure 25. Seismic profile from Liberty and Barrash (1998) (see Appendix D for entire report). The Little Creek Fault is projected along the line at CMP 1840.

plunging, faulted uplands that separates the Union and Cove embayments. The uplands extend southward from Phys Point and includes High Valley. The uplands are cut by numerous north- to northwest-trending faults with as much as 200 m of vertical displacement. At Union, the volcanic uplands dip to the west- northwest beneath the Catherine Creek alluvial fan-delta. The basin floor north of Union imaged in the seismic line (Figure 25) forms a westward tilted surface that drops to more than 300 m below land surface east of Hot Lake. Northeast of Union, the alluvial fan delta surface is dropped down to the east along the 1 km long scarp that marks the northern extension of the Little Creek Fault (White, 1981). A prominent break occurs in the seismic profile where the Little Creek Fault projects across the seismic line to the north, apparently offsetting the top of the volcanic basement by about 25 m (Figure 25). Additional near vertical breaks in the seismic profile correspond to unnamed faults that project into the valley from the uplands to the south. The seismic profile and water well data indicate that in this area the volcanic basement is broken up into a series of west-dipping blocks.

A series of northwest trending, down-to-the-east faults link Phys Point with the west side of High Valley. Lower Glass Hill Volcanic Group flows are exposed at the base of the escarpment on the east side of Phys Point. The east side of High Valley is bounded by a scissors fault along which the sense of displacement switches from down-to-the-east at High Valley to down-to-the-west east of Phys Point. This area is marked by a positive magnetic anomaly (Figure 24).

The East Grande Ronde Valley Fault Zone runs along the foot of the 760 m high escarpment that forms the east wall of the Grande Ronde Valley. The upthrown escarpment dips to the north-northeast, forming a topographic ramp that swings to the west and dives beneath the Mt Harris volcano to the north. The East Grande Ronde Valley Fault Zone abruptly separates Grande Ronde Basalt flows exposed in the steep sloping escarpment from the more gently sloping Cove bajada. The zone consists of several large displacement, long-strike-length en echelon faults that can be traced for as much as 20 km. The East Grande Ronde Valley Fault Zone is about 1 km in width and is offset on the south by the east-west trending Mill Creek fault (White, 1981). Trace of the East Grande Ronde Valley Fault Zone shows up as a strong aeromagnetic gradient (Figure 24). The driller's log for the UNIO-715 well indicates about 200 m of sedimentary fill above the upper Glass Hill Volcanic Group at the foot of the escarpment north of Cove, indicating at least 1,000 m of cumulative down-to-the-west vertical displacement across the East Grande Ronde Valley Fault Zone.

The deepest part of the study area (Plate 2) is marked by a broad gravity low that is slightly offset from a broad magnetic low. Both the gravity and magnetic patterns support a geologic model wherein the valley's volcanic basement rocks deepen to the northwest. The seismic profile also indicates that the valley-fill/volcanic basement contact deepens to the west and may deepen to the north (Liberty and Barrash, 1998; Appendix F,G).

GEOLOGIC HISTORY

The Grande Ronde Valley is situated in a region of complex geology near the edge of the North American craton in northeast Oregon (Figure 26). The valley is believed to be underlain by 200-300 Ma accreted allochthonous terranes, fragments of oceanic and island arc crust that were sutured together in the Late Jurassic, about 160 Ma(Brooks and Vallier, 1978; Brooks, 1979; Dickinson, 1979; Silberling and others, 1984). Limey sedimentary rocks and volcanic rocks of one island arc fragment, the Wallowa Terrane, are exposed along upper Catherine Creek while fine-grained siliceous sedimentary rocks of an oceanic fragment, the Baker Terrane, are exposed along the upper Grande Ronde River.

At about 145 Ma, large intrusions formed during the tectonic collision between the terranes and the ancestral west margin of the North American continent (Brooks, 1979). Older terrane strata were progressively disrupted and then metamorphosed as a complex series of granitic stocks and small batholiths were emplaced along and adjacent to terrane boundaries over about a 25 Ma time span (Vallier, 1995; Johnson and others, 1995). The crystalline core of the largest intrusive complex, the Wallowa Batholith, now forms the heart of the Wallowa Mountains at the headwaters of the Catherine Creek drainage.

At about 100 Ma, the intrusive complexes and suspect terranes began to be uplifted and eroded, as the Blue Mountains region emerged as part of the North American continental landmass. Old shorelines are marked by ocean beach sands that lie directly on eroded intrusive rock between La Grande and John Day (Brown and Thayer, 1966; Brooks and others, 1984). Uplift continued over the next 20 or 30 million years apparently shifting the coastline westward as between 5 and 15 km of overlying rocks were stripped by erosion from above the plutonic complexes (Ferns and others, in press). During the Paleocene and Eocene, at about 60 Ma, river systems draining the continental interior deposited a thick sequence of river and deltaic sediments (Fisk, 1986). Coarse quartzite-boulder-filled channels cut into the Wallowa Batholith further east are all that remain of a large, westward-flowing river and delta system (Cisneros, 1999).

Tertiary volcanism near La Grande began about 28 Ma when dacite and rhyolite lavas and tuffs erupted from the Tower Mountain caldera, a large silicic volcanic center on the headwaters of the Grande Ronde River (Ferns and others, in press). Columbia River Basalt flood lavas, now exposed in the escarpments along the east and west side of the Grand Ronde Valley, erupted over a short period of time beginning about 17 Ma(Tolan and others, 1989; Baksi, 1989). The first flood lavas, the Imnaha Basalt, erupted onto an irregular surface and buried deeply eroded canyons cut into older basement rocks (Hooper and Swanson, 1990). Younger Grande Ronde flood basalts apparently flowed into the La Grande area from vents located further to the east and northeast (Hooper and Swanson, 1990). Grande Ronde Basalt volcanism culminated at about 15.5 Ma with eruption of highly evolved high-silica ferroandesite lavas (Ferns and Madin, 1999; Ferns and others, in press). Local interactions between flows and water may be evidence for the beginning development of structural basins atop the Grande Ronde Basalt surface (Ferns and others, in press).

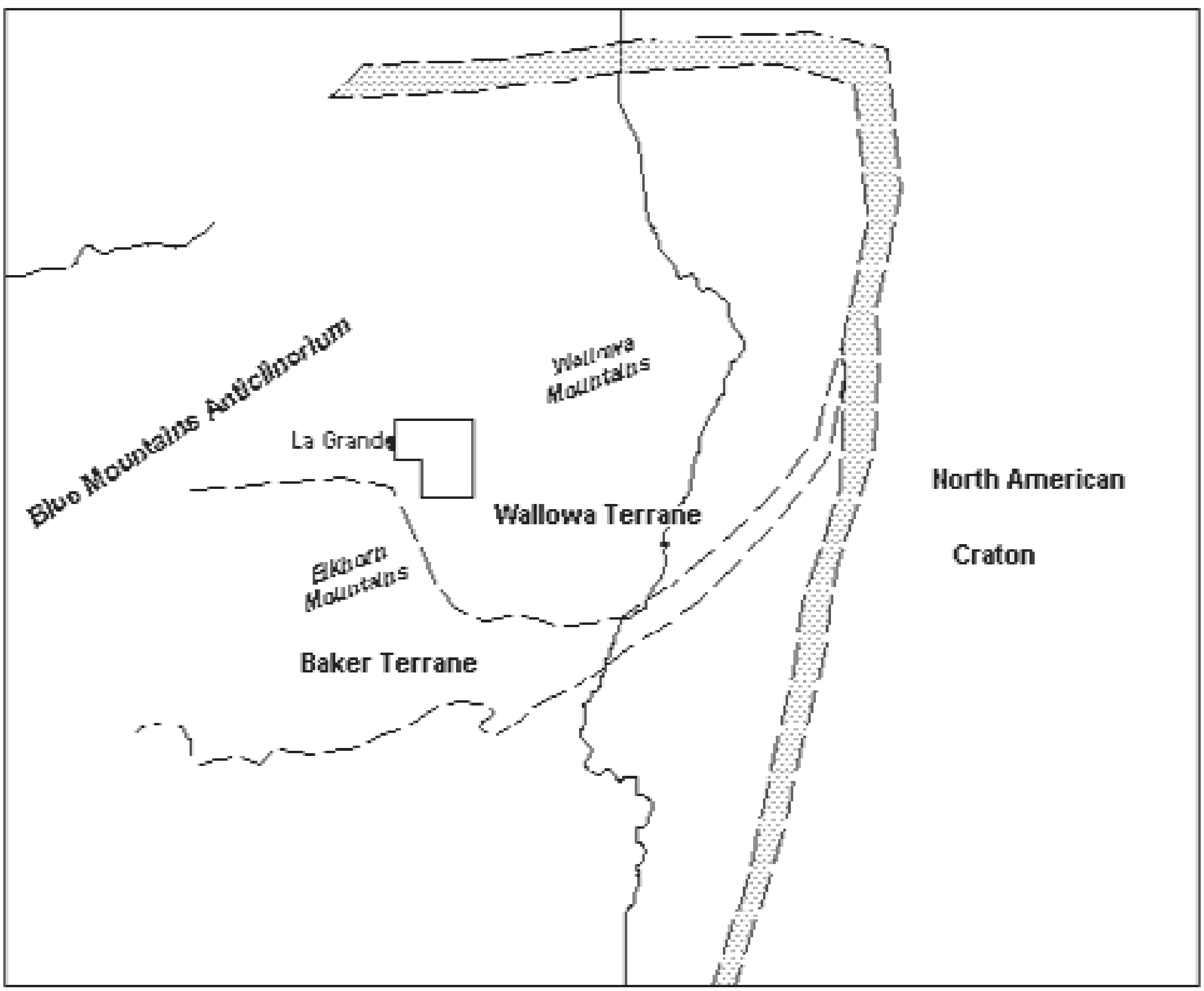

Figure 26. Sketch map showing the relative position of the North American craton and the accreted terranes of northeast Oregon. The craton's margin is crudely defined by a sharp increase in Sr isotope ratios of post-accretion intrusions.

Fluviatile sands and gravels, and thin discontinuous lenses of rhyolitic lithic ash-flow tuff were then deposited in local structural basins (Ferns and others, in press). The ash-flow and sedimentary units were subsequently buried by diktytaxitic olivine basalt flows, which began erupting at about 14. Ma (Bailey, 1990). Deep water wells in the Grande Ronde Valley indicate that successive basalt eruptions filled a north-northwest-trending ancestral Grande Ronde Valley with as much as 150 m of olivine basalt. On the margin of the valley, the olivine basalt flows extend laterally over an area of some 580 km^2, thinning to the north and the west. At about 13.3 Ma, basaltic andesite, andesite, and dacite lavas began erupting from vents located within or along the margins of the modern Grande Ronde Valley (Ferns and Madin, 1999; Ferns and others, in press). N35W trending fault zones within and marginal to Grande Ronde Valley apparently developed in conjunction with this volcanism, as a northwest trending belt of small basaltic andesite vents have been identified on the south end of the Grande Ronde Valley (Gardner and others, 1974).

Between 13 and 7 Ma, geologic processes in the La Grande quadrangle were dominated by deformation and erosion. By 13 Ma, the northern end of the Blue Mountain anticlinorium had been uplifted enough to form a topographic barrier to the westward flow of basaltic lavas of the Saddle Mountain Formation of the Columbia River Flood Basalt flows (Hooper and Swanson, 1990). By 8 Ma, the Grande Ronde Valley was actively subsiding, forming a major, possibly fault-bounded, catch basin for air fall tuffs and fine-grained silts and allowing the formation of fan deltas and alluvial fans along the developing walls of the valley. At about 7 Ma, small trachybasalt, trachy basaltic andesite, and trachyandesite flows erupted on the highlands to the west of the Grande Ronde Valley (Kienle and others, 1979).

Major uplift and deformation may have waned by the middle Pliocene at about 3.2 Ma when a small high silica andesite of Tamarack Mountain erupted along the south end of the Hilgard fault zone and unconformably overrode an older faulted and tilted surface of Grande Ronde Formation and Powder River Volcanic Field lavas (Ferns and others, in press). Volcanism apparently concluded with the eruption of a high silica andesite cinder cone at Jones Butte immediately north of the Grande Ronde Valley at approximately 2 Ma (Fiebelkorn and others, 1983; Ferns and others, in press).

The depositional history of the Grande Ronde Valley during the late Pleistocene and early Quaternary was dominated by at least three episodes of alpine glaciation in the adjacent highlands of both the Elkhorn Mountains and the Wallowa Mountains (Bentley, 1974). Both the Grande Ronde River and Catherine Creek carried glacial outwash material into the Grande Ronde Valley, producing terrace and fan deposits as braided streams flowed across the valley.

Intense agricultural and ranching activity has altered the natural drainage patterns of both the Grande Ronde River and Catherine Creek in the last century. Historically surface water has been used for both activities and numerous irrigation ditches and drainage canals have been constructed to control the flow of water including the State Ditch, a 13 km drainage canal that bypasses about 64 km of the old meander channel of the Grande Ronde River (Plate 1) (Hampton and Brown, 1964).

DISCUSSION

The more permeable geologic units that make the best aquifers in the Grande Ronde Valley occur at two levels. Relatively shallow alluvial aquifers include 1) well-sorted gravel and sand deposits that extend beneath the Grande Ronde and Catherine Creek fan deltas and 2) well-sorted channel sand and gravel deposits such as the Conley Lake lens, that are buried beneath the alluvial plain. The shallow aquifers are generally cold-water and require pumping. . Deep volcanic aquifers include 1) locally restricted zones in permeable upper sequence lavas and 2) the Grande Ronde Basalt. These are generally warmer water systems that may provide artesian flow.

The capacity of each of these aquifers will be influenced by subsurface geologic conditions. The most productive wells (including the La Grande municipal wells) in the gravel aquifer are located where lenses of coarse, well-sorted gravel overlap to form a thick, continuous sequence (Plate 2). Examining the geologic factors controlling the deposition of these units and influencing the distribution of permeability can aid in the understanding of the distribution of productive zones in the subsurface. The longterm storage capacity of the shallow aquifers will depend in part upon the vertical and lateral continuity of the cleaner sand and gravel lenses. Rapid, lateral and vertical facies changes may result from increased or decreased stream flows and shifting of stream courses brought on by tectonic movement or climatic fluctuations. In a study of Ladd Creek, Cochran (1988) showed that, over the last 10,000 years, 1) sediment deposition was the dominant process during the transition from warm-dry to cool-moist conditions, 2) flood plains are most stable during cool-moist conditions, and 3) down-cutting and erosion dominates during the transition from cool-moist to warm-dry conditions. Even though it is presently unclear how the Grande Ronde Valley responded to the dramatic climate fluctuations during the pre-Holocene glaciations (Van Tassell, 1997, 1999), wells penetrating gravels at shallow depths (793 m elevation) beneath the modern alluvial plain show the fan deltas to have been more extensive than they are today (Plate 3b). Wells penetrating gravels at slightly deeper levels (732 m elevation) outline less extensivefan deltas (Plate 3b). Based on the 2.6$\pm$0.5 Ma ash recovered from 716 m elevation in UNIO-50452, these deposits would predate the glacial activity.

POSSIBLE EFFECTS OF FAULTS

Lateral continuity of the cleaner sands and gravels in the shallow cold water aquifers may be affected by juxtaposing of permeable and impermeable units along faults. The West Grande Ronde Valley Fault Zone likely influences the hydrologic characteristics of the Grande Ronde River fan-delta. Logs of wells located in downtown La Grande (Plate 2) indicate that about 120 m of interbedded alluvial fan and fan-delta deposits overlie 180-310 m of finer grained alluvial plain sediments. Alluvial fan and fan-delta sections here are unexpectedly thin, considering that to the east, the new La Grande municipal well (Figure 8) was still in fan-delta deposits at a final depth of 165 m. Since active or potentially active faults have been identified in La Grande (Personius, 1998; Ferns and others, in press), the unexpected eastward thickening of the fan-delta deposits can be best explained by down-to-the-east movement along buried faults.

The Catherine Creek fan-delta is also cut by faults. The Little Creek Fault (White, 1981) and other faults cutting the fan-delta sequence in the Union embayment are clearly imaged in the South Grande Ronde Valley seismic line (Liberty and Barrash, 1998).

Long-term storage capacity for the deep volcanic aquifers will in large part be dependent upon how well the highly permeable interflow zones are connected to one another. Faults can affect groundwater movement in several ways. 1) They can act as open conduits that allow upwelling of artesian water to the surface. Hot springs at Hot Lake and Cove most likely mark such zones. 2) Faults can impede flow of groundwater by acting as an impermeable barrier to lateral flow, effectively “ponding” groundwater behind the upgradient part of the fault. 3) Flows can also partition an aquifer by juxtaposing permeable and impermeable units.

The West Grande Ronde Valley Fault Zone likely influences the overall hydrologic characteristics of the Grande Ronde Basalt artesian aquifer at La Grande. Active or potentially active faults at La Grande (Personius, 1998; Ferns and Madin, 1999; Ferns and others, in press) indicate that this a tectonically active area where the buried Grande Ronde Basalt artesian aquifer may be partitioned into relatively small, poorly interconnected blocks. Similar partitioning may occur in the Catherine Creek and Mill Creek fan deltas. The Little Creek Fault (White, 1981) and other faults in the Union embayment clearly show sizeable offsets in the buried volcanic section.

POSSIBLE EFFECTS OF HYDROTHERMAL ALTERATION

Hydrothermal alteration can produce a marked reduction in a geologic unit’s permeability. Mineralogical changes include conversion of volcanic glass to clay and zeolite minerals and filling of open spaces by new minerals. Deep well cuttings from the Bingaman (UNIO-50684) and Alicel wells (UNIO-50687) have quartz- and/or zeolite-filled vesicles and veinlets, unidentified green minerals (probably chlorite or celadonite) and, at the Alicel well, pyrite-coated joint surfaces. As waters from these wells reportedly range from 35-42^{o} C, they might be better described as low temperature geothermal fluids. Water temperatures elsewhere in the aquifer range from 20-21^{o}C in the municipal wells at La Grande and Union to 79^{o}C at Hot Lake (Oregon Department of Geology and Mineral Industries, 1994). Alteration minerals in these wells indicate that net permeability in the Grande Ronde Basalt may decrease with depth due to clogging by hydrothermal minerals.

POTENTIAL FOR CONCEALED AQUIFERS IN THE VALLEY-FILL SEQUENCE

Wells at La Grande tap valley-fill fan-delta facies sediments beneath the modern Grande Ronde fan-delta. Well logs indicate that a shallow (approximately 790 m elevation) gravel mass extends east beneath the surficial alluvial plain sediments beyond the edge of the modern day Grande Ronde fan. Fan-delta facies thicken to more than 165 m at the depocenter (Plate 2). Limited well log data suggest that fan-delta facies gravel interfingers with finer-grained alluvial plain facies sediments; making it possible that additional gravel-rich zones might occur at greater depths marginal to the modern fan (Figure 8).

Several wells near Conley Lake produce moderate amounts of water out of gravel and sand lenses at 60-90 m depths. These may be sand levee deposits similar to the surficial Airport terraces. Although similar lenses may be concealed elsewhere beneath the alluvial plain, they are not likely to constitute a major aquifer as they appear to be small and discontinuous .

THE GRANDE RONDE BASALT AQUIFER

A significant volume (as much as 2,000 gpm) of water is produced from irrigation and municipal wells that penetrate into the Grande Ronde Basalt. In nearly every instance, these wells penetrated as much as 300 m of impermeable Glass Hill Volcanic Group before tapping the Grande Ronde Basalt aquifer. As the more productive wells (more than 1,000 gpm) penetrate more than 120 m of Grande Ronde Basalt, the depth to the productive part of the Grande Ronde Basalt aquifer is probably more than 730 m deep, and possibly considerably more, in the northern part of the project area. North of the project area, two wells near Alicel, the recently drilled Cuthbert well (UNIO-50763) and the older LeRoux well (Hampton and Brown, 1964) failed to reach the top of the Glass Hill Volcanic Group at depths of more than 610 m. The Bingaman well (UNIO-50684), located just to the north, reached the top of the upper Glass Hill Volcanic Group sequence at a depth of 580 m.

Structure contours on Plate 2 portray the elevation of the top of the Glass Hill Volcanic Group sequence. This unit is projected to underlie valley-fill sequence sediments at about 210 m below land surface in an area that extends from the confluence of Catherine Creek and the Grande Ronde River south to the city of Union. The Glass Hill Volcanic Group sequence is also projected to under lie valley-fill sequence sediments at similar depths beneath Cove. However expected depths to the productive Grande Ronde Basalt aquifer beneath the Glass Hill Volcanic Group are likely as much as 640 m in both areas.

CONCLUSIONS

Wells that intersect fan-delta facies sediments or the Grande Ronde Basalt yield high-volume flows. Although we can estimate how much of the valley is underlain at relatively shallow depths (150 m) by fan-delta facies sediments, we cannot forecast the amount of water they can yield on a sustainable basis. About 18% of the valley is projected to be underlain by fan-delta facies sediments at the 730 m elevation (Plate 3b); decreasing to less than 5% at the 670 m elevation. Data from deeper wells do not exist to draw deeper level contours, but geologic considerations suggest that if there are fan-delta sediments at greater depths they will underlie the surficial fans.

As the Grande Ronde Basalt is projected to underlie the entire valley, a potentially large, but deep, ground-water resource exists. A major question is “How deep?” Based on the interpretative structural contour maps (Plates 2, 3), we project that about 70% of the valley is underlain by volcanic basement rocks at depths less than 305 m. Geochemical analyses of recovered well samples and interpretation of well logs indicate that highly productive wells generally need to penetrate through 305 m of Glass Hill Volcanic Group lavas to a depth of at least 120 m into the upper part of the Grande Ronde Basalt. Thus we can predict that, for about 60% of the valley, wells would need to be drilled more than 610 m deep before producing significant flows from the deep aquifer.

The seismic refraction line study (Liberty and Barrash 1998) shows faults that may form vertical barriers to lateral flow and limit lateral connectivity within the Grande Ronde Basalt aquifer. Hydrothermal alteration minerals in cuttings from the Alicel (UNIO-50687) and Bingaman (UNIO-50684) wells indicate fluid temperatures were high enough for mineralization of hydrothermal clays and zeolites that have the capability to severely reduce permeability in the fault zones. Although it is possible that the entire Grande Ronde Basalt sequence (presumably more than 305 m thick in the valley) retains sufficient open pore space to be a highly productive aquifer, a prudent assessment must consider potential clogging effects of low temperature hydrothermal alteration. Combination of hydrothermal alteration minerals and high water temperatures (32^{o}C) indicate that the overall porosity and permeability of the Grande Ronde Basalt is reduced at depths greater than 760 m.

It is also important to note that in other locations of similar geomorphology to the Grande Ronde Valley where there is significant ground-water production from the Grande Ronde Basalt there are associated water level declines and well interference, increasingly expensive well operation, and deterioration of well performance (Davies-Smith and others, 1988). Even though the aquifer has great potential for instantaneous production rates, the low vertical permeability severely limits recharge.

RECOMMENDATIONS

Although the geologic framework of the Grande Ronde Valley is now well defined, there is insufficient hydrologic data to determine whether the ground-water resource is suitable to use for irrigation in place of surface water. Such a question requires a detailed hydrologic study which would assess both surface and groundwater budgets for the entire upper Grande Ronde Basin, the rates and distribution of both ground-water recharge and discharge, and the subsurface distribution of hydraulic head. Although the fan-delta aquifers and the deep Grande Ronde Basalt aquifer may yield enough water for short-term irrigation offsets; long-term solutions require utilization at a sustainable rate that does not result in long-term water-level declines or impacts to existing water users, both surface water and ground-water.

Several geologic issues that may impact the groundwater resource remain to be addressed. Deeper fan-delta facies aquifers may be buried at greater depths beneath the La Grande and Catherine Creek fan-deltas as well as the Cove fan. Well-defined geophysical surveys combined with deep stratigraphic test wells should provide sufficient data to more accurately define the true boundaries of the fan-delta facies aquifers. Important fan-delta facies hydrogeologic characteristics such as hydraulic conductivity and storage coefficients need to be determined by a detailed hydrogeologic study. Monitoring wells and pump test data can provide important data for such a study.

The question as to whether impermeable vertical fault zones divide the Grande Ronde Basalt into semi- discrete partitions might be addressed by continuous monitoring of municipal wells at Union and La Grande. As the two deep Union municipal wells are clearly separated by faults, a close look at any pump or aquifer characterization tests that might have been conducted during their construction may yield important clues.

Questions as to how the aquifers are recharged cannot be answered with existing data. Detailed water geochemistry and temperature studies of the deep Grande Ronde Basalt aquifer may reveal chemical and temperature gradients that point to the recharge zones. Mapping chemical ratios in aquifers is one proven method for locating recharge zones and fingerprinting water sources (e.g. Caldwell and Truini, 1997).

ACKNOWLEDGMENTS

This report was funded by the Oregon Watershed Enhancement Board (originally Governor's Watershed Enhancement Board), the Oregon Water Resources Department, and the Oregon Department of Geology and Mineral Industries.

Our understanding of the volcanic evolution of the Grande Ronde region benefited greatly from interactions with Steve Reidel (Richland, Washington), Marvin Beeson (Portland State University), and Peter Hooper (Washington State University). Special thanks go to Jay Van Tassell (Eastern Oregon University) and Michelle Cunico, Oscar Sorenson and Curt Peterson (Portland State University) whose time-consuming work on sediment samples from newly drilled water wells provided us with important information and insights on the stratigraphic and structural evolution of the Grande Ronde Valley. We acknowledge the effort of Ian Betteridge (University of Oregon) in locating the many water wells in the Grande Ronde Valley that were used for this study.

We would especially like to thank the numerous local landowners who graciously allowed us access to important outcrops along the valley margin and pointed out well locations. La Grande's resident deep water well driller, Waldo Lowe, supplied us with a rich bounty of meticulously collected samples from deep wells drilled for Mr. R. Bingaman, and Mr. M. DeLint, who are to be commended for their perseverance in the face of adversity.

Most importantly, we would like to thank the Grande Ronde Model Watershed Board whose interest and financial support for this project provided the impetus for a larger geologic mapping program that encompasses the entire upper Grande Ronde Basin. We would like to think that the data collected during this phase of the study will lead to a much-improved understanding of all of the geologic factors that have shaped the upper Grande Ronde Basin.

Table 1. Important water wells used as data sources

Well ID	Name	Total depth (m)	Yield (gpm)	Aquifer	T (°C)	Well Owner	Longitude	Latitude
UNIO-50684	Bingaman	956	1700	Grande Ronde Basalt	38	Greg Bingaman	45.399038	-118.005443
UNIO-50452	Terry Trailers	218	1850	Grande Ronde River fan delta	13	Homer Case	45.355802	-118.014063
UNIO-50083	IM-1	773	700	Grande Ronde Basalt	33	Russell Bingaman	45.434754	-117.933580
UNIO-208	City of Imbler	471	2500	Grande Ronde Basalt	26	City of Imbler	45.461100	-117.962572
UNIO-50687	Alicel	934	1000	Grande Ronde Basalt	40	Creston Shaw et al	45.409336	-117.966818
UNIO-1484	98UNION	393	1500	Grande Ronde Basalt	22	City of Union	45.207240	-117.866024
UNIO-2377	MB92UN	514	1922	Grande Ronde Basalt	21	City of Union	45.208291	-117.854455
UNIO-50520	La Grande Municipal	168	2475	Grande Ronde River fan delta	12	City of La Grande	45.305747	-118.055874
UNIO-50450	Wright Well	219	200	Alluvial plain	13	Donald Wright	45.367217	-117.991771
UNIO-2098	MB91LG	742	2600	Grande Ronde Basalt	23	City of La Grande	45.318332	-118.085564
UNIO-1237	UNIO-1237	219	1800	upper Glass Hill?	17	W.C. Farms	45.253724	-117.889516
UNIO-1211	UNIO-1211	142	2000	Conley Lens	14	Stone Machinery CO.	45.296764	-117.946617
UNIO-2526	UNIO-2526	64	650	Catherine Creek fan delta	nd	Norman Svaty	45.253171	-117.873946
n.d.	Magma	832	—	—	—	—	45.235500	-117.945000

Table 2. Representative samples of whole rock and trace element geochemistry

QUADRANGLE	Union	Cove	Union	Union	Cove	La Grande	La Grande	Union
FIELD_ID	97CC36	97CC70a	97CC144	97CC143	97CC18	MB91LG	MB91LG	MB92UN
LAB	WSU	WSU	WSU	WSU	WSU	Hanford	Hanford	Hanford
FORMATION	Glass Hill	Glass Hill	Glass Hill	Glass Hill	Glass Hill	Glass Hill	Grande Ronde	Grande Ronde
MEMBER	Upper	Upper	Upper	Middle	Middle	Lower	Fiddlers Hell	–
MAP_UNIT	Tpgh	Tpgba	Tpgbr	Tpgd	Tpga	Tpgob	Tcgf	Tcg
LITHOLOGY	Hornblende andesite	Basanite	Basaltic andesite	Dacite	Andesite	Basalt	Ferro-andesite	Ferro-andesite
SiO_2	58.05	44.07	55.47	65.91	62.06	50.98	58.85	56.22
Al_2O_3	17.04	15.18	17.00	16.45	16.38	15.78	13.10	13.64
TiO_2	1.20	3.03	1.62	0.63	1.01	1.15	1.96	2.54
FeO	7.07	14.84	8.57	4.31	5.49	8.86	11.90	11.00
MnO	0.11	0.20	0.14	0.07	0.09	0.17	0.23	0.22
CaO	6.92	8.37	7.26	4.94	5.60	9.73	4.67	6.79
MgO	3.36	7.77	3.71	1.77	2.71	8.57	1.58	3.14
K_2O	1.36	0.99	1.38	1.94	1.83	0.55	2.35	2.29
Na_2O	4.35	5.48	4.15	3.94	4.42	2.88	3.99	3.20
P_2O_5	0.53	0.35	0.70	0.29	0.41	0.34	0.77	0.38
Ni	55.00	63.00	32.00	15.00	43.00	171.00	0.00	2.00
Cr	75.00	79.00	65.00	35.00	64.00	412.00	0.00	18.00
Sc	15.00	22.00	22.00	12.00	18.00	30.00	30.00	34.00
V	161.00	343.00	187.00	82.00	122.00	242.00	60.00	314.00
Ba	521.00	341.00	622.00	630.00	711.00	331.00	878.00	826.00
Rb	15.00	3.00	15.00	28.00	24.00	6.00	69.00	60.00
Sr	991.00	800.00	778.00	576.00	899.00	394.00	301.00	316.00
Zr	157.00	71.00	182.00	165.00	170.00	100.00	243.00	190.00
Y	19.00	15.00	23.00	17.00	18.00	22.00	55.00	38.00
Nb	14.60	3.70	24.80	10.10	12.80	8.50	21.80	14.80
Ga	24.00	21.00	20.00	19.00	20.00	13.00	26.00	20.00
Cu	38.00	128.00	2.00	13.00	24.00	64.00	0.00	8.00
Zn	101.00	111.00	123.00	73.00	79.00	86.00	151.00	121.00
Pb	6.00	7.00	5.00	7.00	5.00	2.00	9.00	5.00
La	30.00	9.00	22.00	9.00	38.00	0.00	53.00	14.00
Ce	51.00	25.00	40.00	46.00	55.00	32.00	62.00	53.00
Th	4.00	2.00	3.00	1.00	0.00	0.00	6.00	7.00
Au	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3. $^{40}Ar/^{39}Ar$ ages of volcanic rocks and ashes

Sample ID	Rock Type	Age (Ma)
Terry-356	Rhyolite Ash	3.1±0.30
Bing-1553	Rhyolite Ash	7.5±0.11
99LG-59	Dacite Lava	11.9±0.12
98-MAD-105	Andesite Lava	3.2±0.15

REFERENCES

AMAX Exploration, Inc., 1975, Residual magnetic intensity map and complete Bouguer and terrain corrected gravity map, Denver Co.

Bailey, D.E., 1990, Geochemistry and Petrogenesis of Miocene volcanic rocks in the Powder River volcanic field, northeastern Oregon: Pullman, WA, Washington State University doctoral dissertation, 341 p.

Baksi, A.K., 1989, Reevaluation of the timing and duration of extrusion of the Imnaha, Picture Gorge, and Grande Ronde Basalts, Columbia River Basalt Group, in Reidel, S.P. and Hooper, P. R., Volcanism and tectonism in the Columbia River Flood-Basalt Province: Geological Society of America Special Paper 239, p. 105-111.

Barrash, W., Bond, J.G., Kauffman, J.D., and Venkatakrishnan, R., 1980, Geology of the La Grande area, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 6, 67 p., 4 maps, 1:24,000 scale.

Beaulieu, J.D., 1972, Geologic formations of eastern Oregon (east of longitude 121o30'): Oregon Department of Geology and Mineral Industries Bulletin No. 73, 80 p.

Bentley, E.B., 1974, The glacial morphology of eastern Oregon uplands: Eugene, Oregon, University of Oregon doctoral dissertation, 250 p.

Brooks, H.C., 1979, Plate Tectonics and the Geologic History of the Blue Mountains: Oregon Department of Geology and Mineral Industries Oregon Geology, v. 41, no. 5, p. 71-80.

Brooks, H.C., and Vallier, T.L., 1978, Mesozoic rocks and tectonic evolution of eastern Oregon and western Idaho, in Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States (Pacific Coast Paleogeography Symposium 2, Sacramento, Calif.): Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 133-146.

Brooks, H.C., Ferns, M.L., and Avery, D.G., 1984, Geology and gold deposits map of the southwest corner of the Bates quadrangle, Grant County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-35, scale 1:24,000.

Brown, C.E., and Thayer, T.P., 1966, Geologic Map of the Canyon City Quadrangle, northeastern Oregon: U.S. Geological Survey Miscellaneous Investigations Map I-447, scale 1:250,000.

Brown, D.E., Black, G.L., and McLean, G.D., 1980, Preliminary Geology and Geothermal Resource Potential of the Craig Mountain - Cove area, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-80-0468 p., 1 map

Caldwell, R.R. and Truini, M., Ground-Water and Water-Chemistry Data for the Upper Deschutes Basin, Oregon: U.S. Geological Survey Open File Report 97-197, 77 p.

Cisneros, G., 1999, Reconstruction of Late Cretaceous - early Tertiary quartzite-bearing fluvial sediments, Elkhorn Mountains, northeastern Oregon: in Mendelson, C.V., and Mankiewicz, C., ed., Twelfth Keck Research Symposium in Geology Proceedings; Carleton College, Northfield, Minnesota; p. 291-298.

Cochran, B.D., 1988, Significance of Holocene alluvial cycles in the Pacific Northwest Interior: Moscow, Idaho, University of Idaho doctoral dissertation, 255 p.

Cunico, M. and Sorenson, O., 1998, A Sediment analysis for potential groundwater resources in the La Grande Basin: Portland State University Student Project for Oregon Dept. of Geology and Mineral Industries, p. 20.

Davis?Smith, A., Bolke, E.L., and Collins,C.A., 1988, Geohydrology and digital simulation of the ground?water flow system in the Umatilla Plateau and Horse Heaven Hills area, Oregon and Washington: U.S. Geological Survey Water?Resources Investigation Report 87-4268, 72 p.

Dickenson, W.R., 1979, Mesozoic fore-arc basin in central Oregon: Geology, v.7, p. 166-170.

Dyksterhuis, E.L. and High, C.T., 1985, Soil Survey of Union County area, Oregon: U.S. Department of Agriculture, Soil Conservation Service, 194 p.

EROS (1990) U.S. Geological Survey Side-Looking Airborne Radar (SLAR) Ritzville, WA., Walla Walla, WA., Pendleton, OR, Mariposa CA, and Las Vegas NV 1o x 2o quadrangles: EROS Data Center, U.S. Geological Survey.

Ferns, M.L. and Madin, I.P, 1999, Geology and Mineral Resources of the Summerville quadrangle, Union County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-111, scale 1:24,000.

Ferns, M.L., Madin, I.P., and Taubeneck, W.H., In Press, Geology of the La Grande 30' x 60' Quadrangle, Baker, Grant, Umatilla, and Union Counties, Oregon. Oregon Department of Geology and Mineral Industries RMS-1, scale 1:100,000.

Ferns, M.L., McConnell, V.S., Van Tassell, J., and Madin, I.P., In Preparation, Geology of the Imbler quadrangle, Union County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series, GMS-11x, scale 1:24,000.

Fiebelkorn, R.B., Walker, G.W., MacLeod, N.S., McKee, E.H., and Smith, J.G., 1983, Index to K-Ar determinations for the State of Oregon: Isochron/West, no. 37, p. 3-60.

Fisk, L.H., 1986, Stratigraphy, age and petroleum potential of Cretaceous and Paleogene rocks in north-central Oregon: Ann Arbor Michigan, Michigan State University doctoral dissertation, 63 p.

Gardner, M.C., Knox, R.D., and Koenig, J.B., 1974, Geology of the La Grande-Baker area, Oregon: report for Amax Exploration Inc., 49 p.

Gehrels, G.E., 1981, The geology of the western half of the La Grande Basin, northeastern Oregon: Los Angeles CA; University of Southern California masters thesis, 97 p.

Geraghty, E., 1999, Glaciation of the Elkhorn Mountains, northeastern Oregon: in Mendelson, C.V., and Mankiewicz, C., ed., Twelfth Keck Research Symposium in Geology Proceedings; Carleton College, Northfield, Minnesota, p. 283-286.

Hampton, E.R., and Brown, S.G., 1964, Geology and ground-water resources of the Upper Grande Ronde River Basin, Union County, Oregon: U.S. Geological Survey Water-Supply Paper 1597, 99 p.

Hooper, P.R., Johnson, D.M., and Conrey, R.M., 1993, Major- and trace-element analyses of rocks and minerals by automated X-ray spectrometry: Washington State University Geology Department Open-File Report, 36 p.

Hooper., P.R., and Swanson, D.A., 1990, The Columbia River Basalt Group of the Blue Mountains Province, in Walker, G.W., ed., Geology of the Blue Mountains region of Oregon, Idaho, and Washington: Cenozoic Geology: U.S. Geological Survey Professional Paper 1437, p. 63-99.

Johnson, K.S., Walton, C., Barnes, C. G., and Kistler, R. W., 1995, Time-dependent geochemical variations of Jurassic and Cretaceous plutons in the Blue Mountains, northeastern Oregon: Geological Society of America, annual meeting, Abstracts with Programs, v. 27, p. 435.

Kienle, C.F..Jr., Hamill, M.L., and Clayton, D.N., 1979, Geological Reconnaissance of the Wallula Gap Washington - Blue Mountains - La Grande, Oregon region: Shannon and Wilson Inc, report prepared for the Washingon Public Power Supply System, Contract No. 44013, C.O. No 38, p. 58.

Kuno, H., 1968, Differentiation of basalt magmas, in Hess, H.H., and Poldevaart, Arie., eds., Basalts-The Poldevaart treatise on rocks of basaltic composition: New York, John Wile, v. 2, p. 624 - 688.

Le Maitre, R.W., Bateman, Pl., Dudek, A., Keller, J., Lameyre Le Bas, M.J., Sabine, P.A., Schmid, R., Sorensen, H., Streckeisen, A., Wooley, A.R., and Zanettine, B., 1989, A classification of igneous rocks and glossary of terms, Blackwell, Oxford

Liberty, L. M., and Barrash, W., 1998, Southern Grande Ronde Valley Seismic Project - Phase II: Reflection Seismic Results: Report prepared for the Oregon Department of Geology and Mineral Industries: Boise State University, Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Technical Report BSU CGISS 98-05, 10 p.

McConnell, V.S., Betteridge, I.A.P., in review., Geology of the Mt. Fanny and Little Catherine Creek Quadrangles, Union County, Oregon: Oregon Dept. of Geology and Mineral Industries, GMS-XX.

McConnell, V.S., Hydrothermal history of the Long Valley caldera, California: Life after Collapse: Fairbanks, Alaska; University of Alaska Fairbanks Phd dissertation, 238 p.

Oregon Department of Geology and Mineral Industries, 1994, Digital Data and Selected Texts from Low-Temperature Geothermal Database for Oregon; Low-Temperature Geothermal Resources and Technology Transfer, Oregon --Phase I Final Report: Oregon Department of Geology and Mineral Industries Open-File Report O-94-09, 625 kb in 5 files; .xls and .asc file formats.

Personius, S.F., 1998, Surficial geology and neotectonics of selected areas of western Idaho and northeastern Oregon: U.S Geological Survey Open-File Report 98-771, 26 p.

Reidel, S.P., Beeson, M.H., Tolan, T.L., and Lindsey, K.A., 1996, The age of La Grande basin (LGB), northeast Oregon: New evidence for middle Miocene deformation and basin formation [abs.]: Geological Society of America Abstracts with Programs, v. 28, no. 5, p. 104.

Reidel, S.P., Tolan, T.L, Hooper, P.R., Beeson, M.H., Fecht, K.R., Bentley, R.D., and Anderson, J.L., 1989, The Grande Ronde Basalt, Columbia River Basalt Group; Stratigraphic descriptions and correlations in Washington, Oregon, and Idaho, in Reidel, S.P. and Hooper, P. R., Volcanism and tectonism in the Columbia River Flood-Basalt Province: Geological Society of America Special Paper 239, p. 21-53.

Schlicker, H.J. and Deacon, R.J., 1971, Engineering geology of the La Grande area, Union County, 16 p, 1 map, scale 1:24,000.

Silberling, N.J., Jones, D.L., Blake, M.C., Jr., and Howell, D.G., 1984, Lithotectonic terrane map of the western conterminous United States, in Silberling, N.J. and Jones, D.L., eds., Lithotectonic terrane maps of the North American Cordillera: U.S. Geological Survey Open-File Report 84-523, 43 p.

Simpson, G.D., Hemphill-Haley, M.A., Wong, I.G., Bott, J.D.J., Silva, W.J., and Lettis, W.R., 1993, Seismotectonic evaluation, Unity Dam, Burnt River Project -Thief Valley Dam, Baker Project, Northeastern Oregon: Final report prepared for U.S. Bureau of Reclamation by William Lettis & Associates and Woodward-Clyde Federal Services, 167 p.

Smith, W.D. and Allen, J.E., 1941, Geology and physiography of the northern Wallowa Mountains, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 12, 65 p.

Swanson, D.A., Anderson, J.L., Camp, V.E., Hooper, P.R., Taubeneck, W.H., and Wright, T.L., 1981, Reconnaissance geologic map of the Columbia River Basalt Group, northern Oregon and western Idaho: U.S. Geological Survey Open-File Report 81-797, 33 p, 5 map sheets, scale 1:250,000.

Tolan, T.L., Reidel, S.P., Beeson, M.H., Anderson, J.L., Fecht, K.R., and Swanson. D.A.,1989, Revisions to the estimates of the areal extent and volume of the Columbia River Basalt Group,. in Reidel, S.P. and Hooper, P. R., Volcanism and tectonism in the Columbia River Flood-Basalt Province: Geological Society of America Special Paper 239, p. 1-20.

Vallier, T.L., 1995, Petrology of pre-Tertiary igneous rocks in the Blue Mountains Region of Oregon, Idaho, and Washington: Implications the geologic evolution of a complex island arc: in Vallier, T.L. and Brooks, H.C., eds., Geology of the Blue Mountains Region of Oregon, Idaho, and Washington; Petrology and Tectonic Evolution of Pre-Tertiary Rocks of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1438, p. 125 - 209.

Van Tassel, J., Ferns, M.L, and McConnell, V.S., 2000, Neogene sediment accumulation and subsidence rates, La Grande Basin, northeast Oregon: Geological Society of America Program with Abstracts, Cordilleran Meeting, v. 32, p. A73-A74.

Van Tassell, J., 1997, Cyclostratigraphy of the Grande Ronde graben, NE Oregon (abstract): Geological Society of America Abstracts with Programs, Cordilleran section, p. 71.

Van Tassell, J., 1999, Sedimentary record of Pleistocene glaciations and precipitation from the La Grande Basin, northeast Oregon: Geological Society of America Abstracts with Programs, v. 31, p.A-368.

Walker, G.W., 1973, Reconnaissance geologic map of the Pendleton quadrangle, Oregon and Washington: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-727, scale 1:250,000.

Walker, G.W., 1979, Reconnaissance geologic map of the Oregon part of the Grangeville quadrangle, Baker, Union, Umatilla, and Wallowa counties, Oregon: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-1116, scale 1:250,000

White, R.R., 1981, Structural geology of the eastern half of the La Grande Basin, northeastern Oregon: Los Angeles CA; University of Southern California masters thesis, 133 p.

APPENDIX A

ANALYTICAL METHODS

Geochemical analyses of 235 rock chip and water well cutting samples are included in the attached geochemical database. The geochemical database includes samples analyzed by 3 different laboratories. The 151 samples collected by Oregon Department of Geology and Mineral Industries staff were trimmed and submitted to either the Washington State University GeoAnalytical Laboratory (WSU) at Pullman Washington or the X-Ray Analytical Laboratories (XRAL) at Toronto, Canada. Both laboratories use glass beads fused with lithium tetraborate. The Washington State University GeoAnalytical Laboratory's uses an automatic Rigaku 3370 spectrometer. Each element analysis is fully corrected for line interference and matrix effects. See Hooper and others (1993) for a more complete description of Washington State University GeoAnalytical Laboratory analytical methods. XRAL uses a Siemens SRS 3000 sequential X-Ray fluoursence spectrometer which reportedly gives instrumental precision on most elements of about 0.5%. Results from both labs have been normalized on a volatile-free basis and recalculated with total iron expressed as FeO. The database also includes analyses Dr. Marvin Beeson of Portland State University of 84 water well samples that were analyzed at Hanford.

Age determinations for ash samples from the Terry Trailers and Bingaman wells were performed by the Geochronology Lab, Geophysical Institute, University of Alaska Fairbanks. Ages were derived using by laser ablation stepwise $^{40}Ar/^{39}Ar$ age determinations hand picked, washed glass shards. Samples were irradiated for 2 MW hours at the McMaster University Nuclear Reactor, Ontario, Canada. Irradiated samples were subsequently fused with a coherent 6W Ar-ion laser and argon isotopic rations measured on a VG3600 mass spectrometer at the University of Alaska Geochronology Laboratory. See McConnell (1995) for more details.

(Hooper, P.R., Johnson, D.M., and Conrey, R.M., 1993, Major- and trace-element analyses of rocks and minerals by automated X-ray spectrometry: Washington State University Geology Department Open-File Report, 36 p.)

(McConnell, V.S., Hydrothermal history of the Long Valley caldera, California: Life after Collapse: Fairbanks, Alaska; University of Alaska Fairbanks Phd dissertation, 238 p.)

APPENDIX B

Methodology used in picking and locating water wells

Water well locations were first plotted using the Oregon Department of Water Resources GRID (Groundwater Resource Information) database; which plotted all wells at section , quareter section or quarter-quarter section centroids. A plot of all wells deeper than 100 ft was next superimposed on geo-referenced raster images of USGS 7 1/2 topographic maps (USGS DRG's). Well locations were adjusted to match more detailed locations described on actual water well logs. Wells with street addresses were located within appropriate city blocks atop an overlay of MapInfo StreetInfo files (proprietary enhanced TIGER files with address coding). Wells with bearing and distance data were plotted from raster image section corners.

Important deep wells were field located by direct contact with the well owners or -in some cases- direct visual confirmation. Locations of important new wells were plotted on appropriate topographic maps during field visits as they were being drilled.

Well logs as MapInfo files, "Well_Logs....," in **folder Appendix B**.

APPENDIX C

Oregon Department of Geology and Mineral Industries
Information for Metadata report

1. Title of publication/data set?

Surface and Subsurface Geology of the Southern Grande Ronde Valley and lower Catherine Creek Drainage,
Union County, Oregon,

Formal author(s) of the published work

Mark L. Ferns, Ian P. Madin, and Vicki S. McConnell Oregon Department of Geology and Mineral Industries, and Jenda J. Johnson U.S Geological Survey, Hawaiian Volcano Observatory

-Cooperators, collaborators, funding agencies, and other contributors who deserve mention
Grande Ronde Model Watershed Program, Oregon Water Resources Department

Summary (provide an abstract):

This report provides detailed 1:24,000 scale geologic mapping of the lower Catherin Creek area and sothern Grande Ronde Valley based on new filed work and geochemical studies. The report focuses on the geologic characteristics that influence the movement of groundwater. The map includes subsurface data based on waer wells and geophysical data, and includes a rough three dimensional model of the main geologic units beneath the southern Grande Ronde Valley floor.

4. Why was the data set created? what are the potential uses?

5. Does the data set describe conditions during a particular time period?
(provide timeframe)

6. How was the data set created? Briefly describe methodology, procedures

7. How accurate are elements in the data set? (Note: 1:24,000 base map accuracy is ±40 feet, 1:100,000 accuracy is ±166.67 feet) Provide accuracy figure/estimate and explanation

Information regarding limitations of the data:

-what uses are the data <u>not</u> intended for?

APPENDIX D

Southern Grande Ronde Valley Seismic Project — Phase II: Reflection Seismic Results, 10 pages.

Contained in separate PDF file : Seismic Reflection.pdf

See **folder Appendix D**

APPENDIX E

A Sediment Analysis for Potential Groundwater Resources in the La Grande Basin

Michelle Cunico , *Portland State University*
Oscar Sorensen, *Portland State University*

Abstract

Drill core logs were constructed from chippings obtained from two wells in the LaGrande basin. Drill core data was also compiled onto spreadsheets to assist in assembling stratigraphic columns of the two wells. These spreadsheets contain percentages of cement blocks, framework grains, and free matrix, as well as HCL test results. The Wright well and well #598 are located about 1.5 Km apart and display no similarities between cores upon preliminary investigation. There were also no significant patterns found down-core when comparing the chippings in each individual well. Sediments were analyzed from 5 feet below the surface to 734 feet below the surface on the Wright well, and from 85 feet below the surface to 720 feet below the surface on well #598. The color of each sediment was also classified using Munsell color charts.

The LaGrande basin lies between the Blue Mountains and the Wallowa Mountains in Northeastern Oregon. This basin contains many alluvial fans and two active streams which are all contributors to the basin's sedimentary environment. The Grande Rhonde river is the largest stream in the basin and is believed to be the key source of sediments in the location of the wells. Catherine Creek, a much smaller stream, is believed to have been a minor contributor of sediment in the past and is the likely source of the granitic minerals periodically found in the Wright well. The Wright well also contains many samples which appear to be paleosols, whereas well #598 displayed no such soils.

The importance of further study on the basin and its well drillings is described in an attempt to further understand the sediments and the systems at work. It is also required that additional testing be done; radiocarbon dating, diatom identification, and cement tests should be completed on samples that have already been selected.

Introduction

The sediment analysis of two drill cores was undertaken by Portland State University for the Department of Geology and Mineral Industries in Portland Oregon to aid in the determination of potential groundwater resources in the LaGrande basin to be used for agricultural purposes. An initial investigation of IO samples was analyzed from a subset of the first drill core (see G316 Student Study of LaGrande Drill Project Samples). It was determined from these results that the entire core should be examined to obtain more information. The entirety of the first drill core (Wright) contained 108 samples with depth ranging from 5-734 feet. This drill site was located in the Grande Ronde valley found in the Conley quadrangle with location UTM Nad zone 11 422334, 502389. The second drill site (#598) was located approximately 1.5 KM away from Wright and contained 122 samples ranging in depth from 85-720 feet. This drill site location is also in the Grande Ronde valley found in the LaGrande SE quadrangle with location UTM Nad zone 11 420676, 5022761. The two drill sites are situated North of the Grande Ronde River at an elevation of approximately 2710 feet.

The emphasis was to gain information on the two drill cores so that they could be correlated and independently examined. Analytical tools such as color, grain size, cement, induration, stratigraphic data, and strip charts were used to describe the physical characteristics of the subsurface sediments to determine their likely influence on groundwater flow.

Geology

The La Grande study area lies includes the Grande Ronde valley in which flows the Grande Ronde river. The Grande Ronde valley is surrounded by the Tertiary Columbia River Basalt group and includes various andesite intrusions. It is situated between the Blue Mountains on the west and the Wallowa mountains on the east. Catherine Creek which originates in the Wallowa mountains and is a small tributary of the Grande Ronde, is believed to transport sediment from the granitic Wallowa mountains into the basin. The valley is characterized by basalt bedrock that is overlain with alluvial and lacustrine deposits. The majority of this sediment is thought to consist of Pleistocene age lake deposits (Hampton and Brown, 1964). Included in the sediments is the presence of modem ash deposits thought to originate from Quaternary Cascade volcanism (Barrash et al, 1980). The Grande Ronde Valley contains a few surficial mounds that exhibit both east to west and north to south trends. These are believed to be erosional remnants of stream terraces. This would provide evidence for past migration of the Grande Ronde River.

Methodology

The drill cores were separated into zip-loc storage bags so that the clay fraction would not be compromised through poor handling. Many of the sediments in the Wright well were received wet and were dried in a convection oven to obtain accurate color results. The color of each sample was determined using the Munsell color chart. More than one sample was analyzed at a time so that comparisons could be made.

The sediments were analyzed using visual techniques and were placed into a tray for sifting and separation. The use of grain size cards, a binocular scope, and hand lens were used to determine the percentages of cemented blocks over and under I cm, the percentages of framework grains over 2mm (gravel) and under 2mm (sand), and the percentage of free matrix in the sample. This data was then compiled onto a spreadsheet which was used to assemble stratigraphic columns. These stratigraphic columns were assembled on Macdraw, a Macintosh drafting program. The cemented blocks were loosely indurated (grains break free with pressure applied by the finger), and were classified based on the grain size within the cemented block. The cemented blocks were also tested with HCL to identify calcareous cement.

Drill logs were made to visually analyze the sediments so that comparisons could be made between the two different well cores. This was done by gluing representative sediments from each sample onto sixteen I 0”x 3 1 “ sheets of railroad paper. Information regarding each sample was documented adjacent to the sediment sample on each sheet. The sheets were then divided into equal sized boxes so that the two drill cores could be compared side by side. This would be important in determining any correlation between the two wells. A petrographic scope was used occasionally in order to identify possible ash layers in the drill cores.

Results

There was a wide range in the color of the sediments obtained from the LaGrande wells as seen in figure 1. The color of the samples ranged from light-yellowish brown to dark-gray. There were several samples that were deep-red to brown indicating oxidation. Some of the sediments analyzed also displayed dark-gray to black coloring which indicates the presence of organic matter.

The sediments received from well #598 and the Wright well in LaGrande were visually inspected to determine the percentages of cemented blocks, framework grains, and free matrix. Figure 2 contains several spreadsheets regarding the results of this analysis. The cemented blocks were separated into two size categories; over I cm and under I cm. The framework grains were separated regarding grain size as well; over 2mm (gravel) and under 2mm (sand). The mean of each size classification is also given in figure 2. Several of the cemented blocks were loosely indurated upon close inspection. All of the cemented blocks were also tested with low concentration HCL. The results of this test can be found in the last column of figure 2. The figure also indicates if any samples are absent of cement.

Stratigraphic columns were assembled (figure 3) for each well to assist in finding a pattern down core of each well and to aid in finding any correlation between the two cores. Upon inspection of these stratigraphic columns, it was found that the Wright well displayed a slight pattern of increasing grain size from 13-23 feet and then decreases in size again from 2340 feet. This pattern creates a mirror image on the stratigraphic column. Another pattern was also found further down core starting at 417 feet and ending at 467 feet. This sequence appears to alternate between slightly-gravely-mud and mud. There were no other patterns identified down core in the Wright well or well #598. There was also no correlation found between the Wright well and well #598.

Strip charts were assembled for each well investigated. These were used in conjunction with the stratigraphic columns to assist in comparing the two drill cores. Again, there was no correlation found between the Wright well and well #598. There were several ash layers identified in each sample which would assist in correlating the two wells if further information is desired.

Discussion

A complete analysis of the sediments provided us with some important information but there may still be some vital information that can be obtained. In the work done by Barrash et others (1980), they described the sediments as being mostly Pleistocene lake deposits. The high percentage of cemented blocks in the samples and the degree of induration support this statement. There is also some samples from both wells, particularly #598, that contained enough wood to be radiocarbon dated to provide evidence to this conclusion. Since many of these sediments are believed to be lake deposits it may be beneficial to conduct diatom samples on some of the more muddy samples to also obtain a possible age date. Samples were selected every 100 feet for future testing.

The grain size analysis showed a distinct pattern in the Wright core after 477 feet down core. The samples arrived wet and there appeared to be fluctuations within the stratigraphic colunm between more gravel sized sediments interbedded between more silt sized sediments. The samples with the higher percentage of gravel sized sediments were also much more inundated. However, there were no samples from #598 well that appeared to be wet although the handling of the samples before they were sent is unknown and they may have had the opportunity to dry. There was also no comparable pattern down core, or distinct correlation between the two cores. However, these cores only represent a fraction of the depth of the sediment in the basin, and the analysis of the full cores down to bedrock could be useful. It may also be helpful to compare the Wright core to previous drills that have been done in the area. A previous study by Baxter et al (1978) to determine geothermal resources, published well data in the area some of which are in close proximity to the LaGrande sites. It might also prove beneficial to make some grain mounts and/or thin sections to 2et a closer look at the texture of the sediments and the mineralogy. Finally, XRD could be used to determine the existence of ash in the samples that were presumed to be ash layers.

Conclusion

The two drill cores (Wright and #598) in the La Grande basin were analyzed using tools such as color, grain size, stratigraphic data, and strip charts to examine the characteristics of the subsurface sediments. This data did not provide evidence of individual down core patterns nor correlation between the two cores. However, much more analysis could be done such as full core testing to bedrock, XRD, diatom testing, thin sections, cement tests, and radiocarbon dating.

APPENDIX F

Total Field Contours

See MapInfo files in **folder Appendix F**.

APPENDIX G

Bouguer Anomaly Contours

See MapInfo files in **folder Appendix G**.