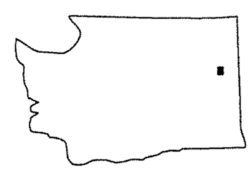
NATURAL RESOURCES

Geologic Map of the Dartford 7.5-minute Quadrangle, Spokane County, Washington

by Robert E. Derkey,
Wendy J. Gerstel,
and Robert L. Logan

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Open File Report 98-6
June 1998



Location of quadrangle

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Jennifer M. Belcher - Commissioner of Public Lands

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U.S. Geological Survey
National Cooperative Geologic Mapping Program
(Agreement Number 1434-HQ-97-AG-01809)

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SUMMARY OF THE GEOLOGY OF THE DARTFORD QUADRANGLE

Named for the community of Dartford near the southeast corner of the quadrangle and 8.5 miles north of downtown Spokane, the Dartford quadrangle is situated on Mesozoic and early Tertiary dike- to batholith-scale granitic rocks. The granitic rocks are exposed in much of the western part of the quadrangle. The Mesozoic granitic rocks are part of the Spokane dome of the Priest River metamorphic core complex, which includes high-grade metamorphic rocks. There are no outcrops of these metamorphic rocks and only limited exposures of early Tertiary granitic rocks in the quadrangle. Additional details of the core complex and related intrusive rocks can be found in Rehrig and others (1987), Armstrong and others (1987), Joseph (1990), and Harms (1982).

The early Miocene topography of the Spokane area was perhaps similar to that of the present, with exposures of the granitic and metamorphic rocks (Robinson, 1991). The climate was wet, and weathering caused extensive development of grus and saprolite. As middle Miocene lavas of the Columbia River Basalt Group covered the Columbia plateau, they blocked the ancestral Columbia and its tributary rivers, forming lakes in the Spokane area (Pardee and Bryan, 1926). Clay, silt, and sand from the adjacent hills, as well as from the highlands north and east of the area contributed to sedimentation in these lakes. These thick, middle Miocene fluvial and lacustrine deposits in the Spokane area are the Latah Formation (Pardee and Bryan, 1926; Robinson, 1991). Areas underlain by Latah have a typically rounded or rolling topography. On steeper slopes, such as the flanks of Fivemile Prairie, the Latah Formation is blanketed with colluvial and residual soils and basalt landslide and rockfall debris.

The first basalt flows of the Columbia River Basalt Group to reach the Spokane area were those of the Grande Ronde Basalt. Grande Ronde basalt crops out near the course of the Little Spokane River, commonly in complex depositional relations with the Latah Formation (Plate 1). After a hiatus of approximately 1 million years (Tolan and others, 1989), the next basalt to enter the area was the Priest Rapids Member of the Wanapum Basalt. The Grande Ronde and Priest Rapids are the only known units of the Columbia River Basalt Group in the northern part of Spokane County (Joseph, 1990; Swanson and others, 1979) and the only basalt units identified in the Dartford quadrangle. The only in-place exposures of Priest Rapids basalt found in the quadrangle cap hills or uplands above 2,180 feet elevation in the southern and eastern parts of the quadrangle.

Deep river valleys, ancestral to the present Spokane and Little Spokane Rivers, were cut by Pleistocene time (Molenaar, 1988). Then, in the Pleistocene, enormous volumes of flood water, discharged from glacial Lake Missoula east of Spokane, repeatedly raced through the area. As the flood waters rose, the volume of water greatly exceeded the capacities of the existing channels, and the floods spread across the area, stripping much of the grus and saprolite and locally depositing sediment.

Flood deposits are extensive in the Dartford quadrangle and are divided in this report into flood gravels and flood sands. Flood gravels occur mainly in the Little Spokane River channel. Flood sands were deposited as overbank sediments. The ancestral Little Spokane River channel merges with the Spokane River at or near the southern border of the Dartford quadrangle (Molenaar, 1988).

PREVIOUS GEOLOGIC MAPPING IN THE SPOKANE AREA

The Dartford quadrangle lies directly west of the Mead quadrangle, for which a geologic map was completed by Derkey in 1997. Other geologic mapping in the Spokane area consists of the Mount Spokane 15-minute quadrangle (Weissenborn and Weis, 1976) immediately east of the Mead quadrangle and the Greenacres quadrangle (Weis, 1968) southeast of the Mead quadrangle. Reconnaissance or compiled geologic maps at 1:100,000 scale or smaller include the Spokane (1:100,000-scale) quadrangle (Joseph, 1990), the west half of the 1° x 2° Spokane (1:125,000-scale) quadrangle (Griggs, 1966), and a surficial geologic map of the Washington portion of the Spokane (1:250,000-scale) quadrangle (Kiver and others, 1979). Reconnaissance and compiled geologic maps at 1:250,000-scale were completed by Griggs (1973) and Stoffel and others (1991), respectively.

In 1994, the Division of Geology and Earth Resources, completed a detailed study of Quaternary deposits that form the Spokane sole-source aquifer. That 1:50,000-scale map is available in digital form from the Spokane County Water Quality Management Program in the Public Utilities Department.

DESCRIPTION OF MAP UNITS

Quaternary Deposits

Qa **Alluvium (Holocene)**—Silt, sand, and gravel in present-day stream channels and flood plains; predominantly reworked Missoula flood deposits consisting of granitic and metasedimentary (quartzite) rock types similar to lithologic units east and northeast of the quadrangle; sparse basalt clasts probably derived from flood deposits or from adjacent highlands. In the northwestern portion of the quadrangle, alluvium consists of gravel with abundant sand and silt derived from adjacent granitic highlands, loess, and Latah Formation.

Mineral resource considerations: Alluvial sand and gravel deposits in the Dartford quadrangle are thin and restricted to active stream channels in the Little Spokane River. Most alluvium along the river in the south-western part of the quadrangle is in the Little Spokane River Natural Area of Riverside State Park.

Qaf **Alluvial fan deposits (Holocene)**—Sand and gravel in fan-shaped deposits where drainages from hills reach the gentler terrain of the Little Spokane valley. The small fans north of the river in secs. 1–3 and 11–12, T26N, R42E, consist of pebble and cobble gravel derived from the adjacent flood deposits. The fan in secs. 8 and 17, T26N, R43E, contains very few large cobbles or boulders. The large fan south of the Little Spokane River in sec. 7, T26N, R43E, and secs. 11–12, T26N, R42E, is composed of numerous large boulders of granite and basalt derived from the hills south of the fan.

Mineral resource considerations: Alluvial fan deposits contain gravel but are of insufficient size or have been rendered inaccessible for mining due to urban expansion. There are no known borrow pits in the alluvial fans.

Qs **Sand deposits (Holocene and Pleistocene)**—Fine, subrounded to rounded (Powers, 1953), moderately well sorted, medium-gray to nearly white, frosted eolian lithic fragments and mineral grains; mostly weathers tan to brown; fresh exposures medium to light-gray, but appear speckled because of the mixture of light and dark fragments. Mappable deposits in the southeast corner of the quadrangle range from 1 to 20 ft thick. Other isolated eolian sand deposits in the quadrangle are too small to map at 1:24,000; dunes are as much as 15 ft high. Cross-bedding and the shape of the sand deposits in the Spokane area (Joseph, 1990) indicate a source to the southwest, probably from flood sediments and basalt exposed there. Sand deposits overlie Missoula flood gravels.

Mineral resource considerations: Locally referred to as the Mead sand because of its abundance in the Mead area to the east, the sand is used to make finishing concrete. Rounded sand grains tend to be more desirable for that product than angular grains of similar size derived from rock crushing operations.

Ql **Loess (Holocene and Pleistocene)**—Light- to medium-brown, unstratified, windblown silt and clay, locally including small amounts of fine sand and volcanic ash; occurs on the top of Fivemile Prairie and covers granitic rocks north of the Little Spokane River. Loess in eastern Washington commonly contains 5 percent sand, 60 percent silt, and 35 percent clay. The major clay minerals are montmorillonite and illite at a ratio of 3:1; loess also contains minor kaolinite (Hosterman, 1969). The thickness of loess in the Dartford quadrangle exceeds 2 ft only in depressions where it has washed down from the surrounding slopes. It is mapped as a separate unit only on the top of Fivemile Prairie, where the irregular loess cover is locally thin enough that plowing of fields occasionally brings basalt and rounded flood gravel clasts to the surface. In the west-central and northwestern part of the Dartford quadrangle, the reworked loess is locally 10 to 15 ft thick but is commonly less than 1 ft thick or incompletely covers the underlying granite. A dotted pattern on Plate 1 denotes the more extensive areas of loess cover.

Mineral resource considerations: Some loess is used to make bricks in the Spokane area. Because of its limited extent and limited demand, loess in the Dartford quadrangle has little mineral resource value.

Qfg **Missoula flood gravel (Pleistocene)**—Gray, yellowish gray, and light-brown, poorly to moderately well sorted, both matrix and clast supported, thick bedded to stratified mixture of boulders, cobbles, pebbles, and sand; locally contains beds and lenses of sand. Large clasts are mostly granite, gneiss, or quartzite similar to bedrock north and northeast of the area. Boulders locally compose as much as 50 percent of the material in the unit. Matrix is mostly sand with some pebbles. Thickness varies due to buried topography; where the channel is deepest, the thickness is more than 500 ft (Derkey, 1997; Molenaar, 1988). This unit occurs adjacent to the course of the Little Spokane River, which was here the main channel for floodwaters from the north. Radiocarbon dating and paleomagnetic measurements indicate that these flood deposits are of late Wisconsin and pre-late Wisconsin age (Joseph, 1990).

Mineral resource considerations: Flood deposits are the principal source of construction sand and gravel (aggregate) in Spokane County. They have a fairly low proportion of matrix sand. Sand is imported to be added to aggregate to make concrete. The more extensive gravel resources in the Little Spokane River flood channel occur just east of the quadrangle, are covered by suburban developments, or overlie the Spokane aquifer. Water-well logs indicate there are interbeds with a higher proportion of finer material. These beds may locally limit the depth of the resource, or where the fine material is at the surface, it is overburden that is in many places too thick to permit economic recovery of the gravel.

Qfs **Missoula flood sand (Pleistocene)**—Gray, yellowish gray, and light-brown, poorly to moderately well-sorted, poorly to well-bedded, subangular to subrounded (Powers, 1953), medium-fine to coarse sand with sparse pebbles, cobbles, and boulders; locally contains beds and lenses of gravel. Sparse large clasts are granite, gneiss, or quartzite similar to bedrock north and northeast of the area. These deposits occur outside of the main flood channel of the Little Spokane River and include overflow, eddy, and slack-water deposits. Water-well logs indicate this unit is rarely more than 100 ft thick; the thickest sequence is in the Half Moon Prairie area near the central and east-central part of the map area.

Mineral resource considerations: Flood sand deposits are not as well sorted as eolian sands, and grains are commonly not as rounded as windblown grains. Flood sand may serve as the sand component added to the coarser gravels of the Spokane Valley in the making of concrete.

Tertiary Sedimentary and Volcanic Rocks

Mv_{wp} **Priest Rapids Member, Wanapum Basalt, Columbia River Basalt Group (middle Miocene)**—Fine-grained, dense, dark-gray to black basalt in hand specimen; in thin section, groundmass plagioclase laths and anhedral pale-green augite, typically in approximately equal quantities, together can constitute about 90 percent of the rock, including sparse plagioclase phenocrysts; minor colorless olivine commonly less than 5 percent in groundmass; both plagioclase and olivine occur as sparse, 0.5- to 0.7-in.-long phenocrysts; matrix predominantly black to light gray-green glass and dendritic to lath-shaped opaque minerals that can make up more than 50 percent of the rock. Carbonate and green amorphous alteration products occur locally as secondary mineralization; the rock has hyalophitic texture.

The unit occurs only on Fivemile Prairie and Layton Hill and an unnamed hill to the south of Layton Hill in the northeastern part of the quadrangle. Water-well logs from Fivemile Prairie indicate the basalt is between 20 and 75 ft thick and is underlain by Latah Formation. Although the Priest Rapids Member directly overlies Grande Ronde Basalt in the Spokane area (Joseph, 1990), no such relations were found in the quadrangle. The Priest Rapids Member is between 15.3 and 14.5 m.y. old and has reversed magnetic polarity (Reidel and Fecht, 1987).

Whole-rock chemical analysis was performed on samples from the Dartford quadrangle at the Geoanalytical Laboratory at Washington State University (Appendix). Priest Rapids basalt is of the Rosalia chemical type and has higher titanium and lower magnesium and chromium contents than other flows of the Wanapum Basalt (Wright and others, 1989).

Mineral resource considerations: Priest Rapids flows generally consist of dense, hard basalt with prominent columns. However, large, well-developed basalt columns are not exposed in the Dartford quadrangle; examples can be seen near the airport west of downtown Spokane. The unit is the principal source of crushed rock used by county and state highway departments for highway surfacing, by private companies for construction aggregate, and by the railroad for fill/ballast.

Mv_{gR2} **Grande Ronde Basalt, magnetostratigraphic unit R2, Columbia River Basalt Group (middle Miocene)**—Fine-grained, dark-gray to dark greenish gray; in thin section consists of 15 to 50 percent plagioclase laths (some plagioclase as sparse phenocrysts), pale-green augite and (or) pigeonite to about 30 or 40 percent, a matrix (40–70%) of black to dark-brown glass (some of which is devitrified) and opaque minerals in dendritic to cruciform crystals; intersertal to hyalophitic texture; locally vesicular with plagioclase laths tangential to vesicle boundaries. Some vesicles contain botryoidal carbonate and red amorphous secondary minerals.

Many occurrences may be invasive. Landslides have occurred in this unit along the eastern border of the quadrangle. Basalt pillows with associated palagonite and incorporated silts between pillows are exposed in roadcuts through a linear ridge in the east-central part of the quadrangle; some pillows are more than 10 ft across. The Grande Ronde Basalt is between 15.6 and 16.5 m.y. old (Reidel and Fecht, 1987).

The Geoanalytical Laboratory at Washington State University identified our samples as Grande Ronde Basalt using whole-rock chemical analysis (Appendix). Peter Hooper (Washington State Univ. Geology Dept., written commun., 1997) identified the samples as magnetostratigraphic unit R2. Swanson and others (1979) had identified basalt in northern Spokane County including the Dartford area as N2. The R2 identification is based upon analyses of basalt. However, N2 basalt generally contains more than 4.5 percent MgO and less than 2 percent TiO_2. Our samples do not fit these criteria and instead consistently contain less than 3.5 percent MgO and fairly consistently contain greater than 2.3 percent TiO_2, which better fits the chemical signature of R2 basalt. These criteria were established by Steve Reidel, Pacific Northwest National Laboratory, (oral commun., 1998) by chemically analyzing drilling samples of R2 and N2 flows near the Keller ferry (T28N, R33E) and Lincoln (T27N, R35E). See data in the appendix for the sample locations shown on Plate 1.

Mineral resource considerations: Grande Ronde Basalt commonly displays extensive blocky jointing. Blocky jointed basalt is generally more weathered than dense basalt; nevertheless, an invasive flow of Grande Ronde Basalt is being quarried for crushed stone in the east-central portion of the Dartford quadrangle, where blocky jointing appears to be less well developed than at most other Grande Ronde exposures in the Spokane area. Poorly developed basalt columns about 2 ft in diameter, which are rare in this unit in the Spokane area, are present in the upper portions of the basalt in the quarry.

Mc_l **Latah Formation (middle Miocene)**—Light-gray to yellowish gray and light-tan, poorly indurated, finely laminated siltstone, claystone, and minor sandstone; commonly weathers brownish yellow with stains, spots, and seams of limonite; unconformably overlies granitic basement in the Dartford quadrangle; in apparent invasive contact with the younger unit Mv_{gR2}. Data from water-well logs indicate that the thickness is generally less than 500 ft, except possibly in the northeast corner of the quadrangle, where water wells do not penetrate to that depth nor do they reach granite.

The principal source mineral for the clay in the Latah Formation probably was feldspar; in the Mica area Hosterman (1969) noted kaolinite pseudomorphs after feldspars. Although plant fossils are common in the Latah Formation elsewhere (Knowlton, 1926; Berry, 1929), none were found during this study in the Dartford quadrangle. Because Latah Formation sediments are easily eroded, most exposures in the Dartford quadrangle are in ravines, roadcuts, or other excavations.

Mineral resource considerations: Spokane County is one of the largest producers of clay products in Washington (Hosterman, 1969). Almost all of the clay now being quarried is from the Latah Formation. In the Dartford quadrangle, widespread suburban residential development is likely to limit reserves of Latah Formation clay in the future.

Tertiary Intrusive Rocks

Ei **Quartz monzonite porphyry (Eocene?)**—Pale greenish gray; contains 40 to 50 percent mostly euhedral hornblende and potassium feldspar phenocrysts that are a maximum of 1 cm long; pale greenish gray groundmass of anhedral grains of plagioclase, potassium feldspar (identified by staining), and quartz less than 0.1 mm in diameter in a 1:1:1 abundance ratio; titanite (sphene) and apatite common as accessory minerals. Contacts with adjacent biotite-muscovite granite are not exposed. The unit is exposed near a quarry in NE1/4 sec. 14, T27N, R42E. Fred Miller (U.S. Geological Survey, oral commun., 1998) considers these rocks similar to the border phase of the Silver Point quartz monzonite of Miller and Clark (1975) on the basis of hand-specimen appearance. K-Ar age estimates of the Silver Point quartz monzonite are Eocene (Miller and Engels, 1975), and thus an Eocene age is assigned to these rocks.

Mesozoic Intrusive Rocks

Ki **Biotite-muscovite granite (Cretaceous)**—Medium- to coarse-grained; light-gray in roadcuts and other fresh exposures; weathers yellow with limonitic staining; undisturbed outcrops medium-gray to medium dark gray due to lichen cover; contains medium-gray anhedral quartz (20–40%), locally as clusters of broken and annealed quartz grains, commonly as graphic intergrowths with feldspar; white potassium feldspar and white plagioclase (50–70%) in a ratio of about 2:3; potassium feldspar phenocrysts as much as 1 in. long; subhedral biotite (as much as 10%), locally forming monomineralic clusters or clustered with muscovite, rarely altered to chlorite; muscovite (0–3%) present as single euhedral crystals or clustered with other muscovite or biotite; contains accessory garnet, apatite, zircon (with metamict halos in association with biotite), epidote, and rutile; typically hypidiomorphic-granular.

Miller and Engels (1975) reported that this granite yielded discordant K-Ar ages of 48 Ma on biotite and 53 Ma on muscovite. Miller and Engels, however, demonstrated that Eocene plutons yielded consistent 45- to 51-m.y. ages. Older plutons yielded various ages over distances of 5 to 16 mi from the Eocene pluton. The loss of argon was greatest and the ages youngest adjacent to the Eocene plutons such as the Silver Point quartz monzonite. (See Discussion.)

In the granite, lighter colored pegmatite dikes, aplite dikes, and irregular-shaped intrusive phases are locally present. About 20 percent of the roadcut through Dart Hill on Highway 395 near the southeast corner of the quadrangle is pegmatite. The dikes in the largest section of this outcrop strike about N60E and dip 60 degrees NW; however, there is some variation in orientation where splays cut from one dike to another. The pegmatites typically contain very coarse crystals of cream-colored feldspar, medium-gray quartz, and silvery books of muscovite. Red garnets as much as 0.1 in. in diameter are present in the pegmatites. Aplite dikes, also with visible garnet, occur interspersed with pegmatite in some areas. Two 1- to 2-ft-wide, nearly vertical, very fine grained lamprophyre dikes crosscut all units in the Dart Hill outcrop.

Mineral resource considerations. Light-gray granite has been quarried in sec. 34, T27N, R42E, of the Dartford quadrangle by Washington Monumental and Cut Stone Co. (Moen, 1967). Granite from this quarry may have been used for roadside stone that lines the nearby Rutter Parkway.

Quartz was quarried from pegmatite in the Pacific Rock quarry in NE1/4 sec. 14, T27N, R42E. Only a single dike is now exposed there. However, the shape of the open pit suggests that there might have been multiple intersecting dikes. Mining of a similar pegmatite in biotite-muscovite granitic rocks south of Mount Spokane, about 18 mi east of the Pacific Rock quarry, produced more than 200,000 tons of silica for use in electrometallurgical plants (Weissenborn and Weis, 1976). Weissenborn and Weis (1976) described the rocks near Mount Spokane as similar to those in the Pacific Rock quarry, containing coarse-grained clusters of potassium feldspar, biotite, and some muscovite. Although no other similar occurrences of quartz are known in the Dartford quadrangle, the widespread occurrence of pegmatites suggests that similar deposits remain undiscovered.

DISCUSSION

Structure

Sparsity of good outcrops and lack of measurable features, such as fabric or bedding in geologic units, led us to show few attitudes on the accompanying geologic map (Plate 1). Exposure of fresh rock units, their contacts, and structure in the Dartford quadrangle is limited mostly to roadcuts, quarries, borrow pits, or other recent excavations. Latah Formation and surficial units, such as loess and glacial outburst flood deposits, are easily eroded, mostly flat lying, and yield only rare, poorly bedded outcrops at best. Pegmatite and other dikes are localized, and joints, although important for excavation and construction purposes, are best measured in fresh outcrops and are difficult to measure in natural outcrop where spheroidal weathering generally masks their actual orientation.

Intrusive Rocks

Miller and Engels (1975) noted four distinct periods of granitic intrusion in northeastern Washington and northern Idaho on the basis of K-Ar dating: 200+ Ma, 170 Ma, 93 to 101 Ma, and 45 to 51 Ma. Only granitic rocks from the two latest events exist in the Spokane area. The most recent intrusive event reset ages of the older plutons, including local two-mica granites. Discordant ages of coexisting mineral pairs provide evidence for the resetting, because, when heated, muscovite and biotite mica lose argon at different rates and thus yield different apparent ages. One of Miller and Engels (1975) samples (from sec. 2, T26N, R42E, in the Dartford quadrangle) gave discordant K-Ar ages of 48 Ma on biotite and 53 Ma on muscovite. Most, if not all, biotite-muscovite granitic rocks (two-mica granites) in northeastern Washington are Cretaceous or older (Fred Miller, U.S. Geological Survey, oral commun., 1998). Consequently, the biotite-muscovite granitic rocks in the Dartford quadrangle are assigned a Cretaceous age.

Joseph (1990) mapped two granitic units, a biotite-bearing intrusive rock of Tertiary–Cretaceous age south of the Little Spokane River and the Cretaceous muscovite-biotite-bearing intrusive rock north of the Little Spokane River in the Dartford quadrangle. Despite the similarity of granitic rocks north and south of the river, Joseph believed that the rocks south of the river were not deformed and suggested they could be of Eocene age. Although muscovite is sparse in many of the exposures south of the river, locally these rock contain muscovite and thus are here combined into one unit.

Basalt

Two basalt units are known in the Dartford quadrangle, Grande Ronde and Priest Rapids (Swanson and others, 1979). By geochemical analyses, the Grande Ronde unit was identified as R2, rather than as N2, as reported by Swanson and others (1979). The Priest Rapids basalt is stratigraphically above the Latah Formation and Grande Ronde basalt. Priest Rapids basalt caps Latah Formation on Fivemile Prairie, Layton Hill, and the hill one mile south of Layton Hill in the Dartford quadrangle. The basalt on Fivemile Prairie is overlain in part by Quaternary sediments.

Geochemistry (Appendix) indicates that some basalt blocks or lag boulders found along the flanks of Fivemile Prairie are erosional remnants of Priest Rapids landslide blocks.

Invasive Basalt

Lavas of the Columbia River Basalt Group were deposited widely over the Columbia plateau, typically as subaerial flows; however, there were lengthy time breaks between eruptions. During these breaks, lakes formed in depressions or where the existing rivers were blocked by flows, and lacustrine sediments were deposited. When the next basalt flow entered these lakes, pillow basalts with extensive palagonite (altered volcanic glass) formed. Roadcuts through the northeast-trending basalt ridge in sec. 17, T27N, R43E, on Hatch Road expose basalt pillows.

Elsewhere, basalt apparently flowed over saturated and (or) poorly consolidated, relatively less dense lacustrine sediments. There, the weight of the basalt could not be supported by the sediments, and the basalt was able to shoulder them aside. Stoffel (1984), in his study of the Grande Ronde lignite field of southeastern Washington, noted that lava flows "burrowed into sediments as they overrode them." Schmincke (1964) described other examples of basalt apparently injected into sediments on the Columbia Plateau. Byerly and Swanson (1978) reached a similar conclusion for basalts in sediments in the Wenatchee–Ellensburg area.

In the Dartford quadrangle, we observed altered Latah silts and a basalt apophysis into the overlying silt along the upper contact of unit Mv_{gR2}, evidence for invasion or intrusion of the Latah by the basalt. Robinson (1991) noted that, elsewhere in the Spokane area, the upper and lower contacts of the Latah Formation with basalt were altered. Also, unit Mv_{gR2} consists of extensive subaerial flows in the Columbia Plateau and has no local source (Reidel and others, 1989). Consequently, we use the term invasive rather than intrusive for these occurrences of Grande Ronde Basalt in the Dartford quadrangle; however, exposures were insufficient to prove that all Grande Ronde in the map area is invasive.

A thick flow of invasive basalt is exposed in the quarry of Acme Materials Co. north of Farwell School in the southeastern part of the quadrangle (sec. 4, T26N, R43E). Geochemical analysis of two samples of basalt from the quarry (16T and 16B, Appendix) identify it as Grande Ronde. Blocky jointing typical of Grande Ronde basalt in the Spokane area is not extensive in this quarry. The upper 20 feet of the basalt consists of crude columns as much as 2 feet across. The columnar jointing is less well developed than in Priest Rapids basalt exposed near the Spokane airport, but it is better developed than in other local occurrences of Grande Ronde. Relief at the upper contact of the basalt with Latah Formation is between 20 and 30 feet in the small area of the exposed flow in the quarry.

Vesicles are locally abundant in the upper portions of the basalt in the Farwell quarry. They are unusual because they have coalesced to form irregular holes several inches across. The largest, non-coalesced vesicles are about 1 inch across and about ½ inch high (ratio of length to height 2:1). Their large size could be the result of the overlying sediment and upper chilled margin trapping gasses at the top of the invasive basalt. Closer to the upper contact, where the lava cooled more rapidly, the vesicles are smaller and more numerous. The length to height ratio also decreases as the diameter drops below ¼ inch within 2 or 3 feet of the contact. Botryoidal carbonate minerals, tentatively identified as siderite, partially fill many of the vesicles.

Landslide Deposits

Priest Rapids basalt caps bluffs, such as Fivemile Prairie, and is underlain by Latah Formation in the Dartford quadrangle. Landslides occurred along the edges of the bluffs above the Little Spokane River Valley where the weak Latah Formation could not support the overlying basalt. Most of the landslides probably occurred during the Pleistocene, when wave action on lakes or flood waters undercut the basalt and rapid draw-down of the lakes increased pore pressures, weakening the contact between the basalt and the Latah. Latah Formation involved in the landslide has been removed by erosion, leaving lag deposits of rounded basalt boulders as much as 25 feet high. Invasive basalt described by Stoffel (1984) and Schmincke (1964, 1967) as forming tongues and lobate masses conceivably could be mistaken for lag boulders.

On the flanks of Fivemile Prairie in the Dartford quadrangle, lag boulders of Priest Rapids basalt (samples D-92 and D-93) are adjacent to invasive Grande Ronde basalt (samples D-43 and D-78). Because the boulders are a different basalt unit, we interpret the lag boulders as remnants of landslides and not part of an invasive Priest Rapids flow. On the geologic map (Plate 1), the pattern of dashed lines indicates areas where surface morphology suggests landslide activity. Within these patterned areas, boulders (knockers) of basalt are commonly intermixed with Latah Formation. Tongues and lobes of invasive basalt and scouring by Pleistocene floods could also account for some of the morphology.

Flood Channels and Aquifers

Boese and Buchanan (1996) note that, in addition to the Spokane aquifer (flood gravels), there are several different aquifers in the Little Spokane River basin and adjacent highlands. They include (1) granitic rocks of the crystalline basement, (2) lower sand and gravel deposits in the Latah Formation and in Pleistocene deposits, (3) upper (surficial) sand and gravel deposits, (4) landslide deposits, and (5) Grande Ronde and Priest Rapids basalt aquifers.

The Spokane aquifer, composed of Pleistocene gravel, occupies the ancestral valley of the Spokane River. Characterized as an unconfined aquifer, it consists of coarse sand, gravel, cobbles, and boulders deposited during several catastrophic glacial outburst floods. The aquifer is the only significant source of good-quality drinking water in the Spokane Valley (Molenaar, 1988). The ancestral Spokane River flowed northward from the modern Spokane Valley east of downtown Spokane, turned northward beneath the community of Hillyard northeast of downtown Spokane, and continued around the north end of Fivemile Prairie in the Dartford quadrangle (Molenaar, 1988).

This channel is filled with more than 500 feet (DNR, unpub. data, 1993) of flood gravel and glacial outwash material (Molenaar, 1988).

Outburst floods also traveled down the valley of the present Little Spokane River; however, based on the geologic mapping and water-well logs in the Mead and Dartford quadrangles, coarse gravels are less extensive and flood sands are more extensive than in the Spokane River valley. Coarse gravels in the Little Spokane River flood channel are separated by interbeds of finer sediments that limit ground-water movement between aquifers (Boese and Buchanan, 1996). Some of the fine sediments are probably lakebed deposits that accumulated in glacial Lake Columbia (Kiver and others, 1991); others may be glacial outwash or finer grained flood deposits.

Gravel in the east-central and northeast parts of the Dartford quadrangle was deposited in a stratigraphically higher or upper ancestral flood channel that closely follows the present course of the Little Spokane River. This gravel constitutes the surficial aquifer (Boese and Buchanan, 1996). A second deeper channel, with its floor more than 500 feet below the surface, was identified by a seismic reflection profile along Colbert Road in the Mead quadrangle, about 2 miles east of the present channel of the river (Palmer and Derkey, 1996; Derkey, 1997). This probably is the deepest part of the ancestral Little Spokane River channel locally; similar depths have been found in the ancestral Spokane River channel. Aquifers in this lower channel would be lower Pleistocene deposits of Boese and Buchanan (1996).

The course of the ancestral Little Spokane River from the Colbert Road seismic line channel to where it joins the ancestral Spokane River channel is uncertain. Derkey (1997) suggested that the ancestral channel turned south and west from Colbert Road and extended beneath the present westward course of the Little Spokane River. This now seems unlikely because granitic bedrock is exposed in the modern channel of the river at Dartford. A more probable path for the ancestral Little Spokane River channel in the southeast corner of the Dartford quadrangle is southward from Colbert Road beneath Highway 2 to join the ancestral Spokane River channel of the Hillyard trough somewhere near the Y intersection of Highways 2 and 395 just south of the Dartford quadrangle. Because few wells penetrate deep enough to reach it, the deeper channel would appear to be a relatively untested aquifer.

Perched Aquifers

In recent years, extensive suburban development (two or three homes per acre) in the southern portion of the Dartford quadrangle and hobby farm development (10 acres or smaller) in the northern portion have caused problems. Issues facing homeowners and officials in this rapidly growing area north of Spokane include establishing and protecting a reliable source of drinking water, managing wastewater, and preventing hazards that may result from terrain modifications during development. Recently, modification or elimination of drainages has overfilled shallow, perched aquifers and increased flow from springs associated with Latah Formation, invasive basalt, or mass-wasting/landslide deposits. Clearing the vegetation (which consumes ground water) from homesites, injecting stormwater through dry wells, and adding water from septic systems and lawns have also contributed to exceeding the capacity of perched aquifers on Fivemile Prairie at the southern margin of the quadrangle and in the adjacent Mead quadrangle. Basement and surface flooding has resulted. Preliminary observations in the Dartford quadrangle indicate that perched aquifers form where the soil, alluvium, and flood sediment cover is thin on impermeable units such as Latah Formation or where clay and silt are abundant at the surface.

Loess

Loess mantles most areas of southeastern Washington. In northern Spokane County, it is most common on low hills and plateaus where erosion by water has been minimal. Although loess is locally as thick as 75 feet in Spokane County (Hosterman, 1969), it rarely exceeds 2 feet in the Dartford quadrangle; except in depressions where loess has washed down from the surrounding slopes. In the northwest portion of the quadrangle, deep gullying of the loess by streams threatens some local roads, wastes productive soils, and delivers sediment to downstream areas.

ACKNOWLEDGMENTS

This quadrangle map was produced in cooperation with the U.S. Geological Survey National Cooperative Geologic Mapping Program (Agreement Number 1434-HQ-97-AG-01809). We thank Ryan Jakubowski for volunteering as a field assistant during the summer of 1997. Also, field visits with Keith Stoffel, Tom Frost, Gene Kiver, and Dale Stradling were greatly appreciated; their insights and additions were most helpful. Fred Miller provided insights into the geology of the granitic units in the quadrangle. Keith Ikerd did the electronic drafting, and Jari Roloff provided the layout expertise for this report. We also wish to thank the Washington Department of Ecology for providing the logs of the water wells shown in Plate 1.

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Appendix: Geochemical analyses for units of the Columbia River Basalt Group in and near the Dartford quadrangle

A total of 26 samples were analyzed by x-ray fluorescence methods and assigned to basalt units. Four samples from the adjacent Mead quadrangle and one from the adjacent Spokane Northwest quadrangle were also analyzed. Analyses were performed by the Geoanalytical Laboratory, Department of Geology, Washington State University, Pullman, WA 99164-2812. A description of the updated analytical methods, precision, and accuracy of the process is given in Johnson and others, in press. Total Fe is reported as FeO. Sample locations are shown on Plate 1.

Whole-rock, non-normalized, major element analyses of samples determined to be Grande Ronde Basalt, magnetostratigraphic unit R2 (reported as percent)

Sample no.	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	KO_2	NaO_2	P_2O_5	Total
D6	55.29	13.66	2.459	11.75	0.266	7.06	2.97	1.8	3.12	0.453	98.83
D10	55.51	13.54	2.428	12.11	0.267	7.11	3.25	1.92	3.1	0.438	99.67
D14	56.07	13.53	2.203	11.03	0.211	6.87	3.25	1.99	3.19	0.395	98.74
D16B	56.04	13.43	2.132	11.28	0.193	6.89	3.23	1.95	3.14	0.402	98.69
D16T	56.08	13.75	2.154	11.04	0.191	6.68	3.22	2.03	3.2	0.405	98.75
D17	55.15	13.38	2.418	12.72	0.249	6.79	2.89	1.85	3.27	0.447	99.16
D19	54.28	13.27	2.431	11.81	0.261	7.04	2.83	1.9	3.12	0.482	97.42
D36	54.89	13.31	2.371	11.95	0.207	7.03	3.31	1.89	3.16	0.414	98.53
D42	55.22	13.29	2.433	11.91	0.247	6.98	3.01	1.84	3.26	0.455	98.65
D43	57.01	13.72	2.243	10.98	0.194	6.92	3.46	1.8	3.35	0.396	100.07
D46	54.98	13.31	2.358	12.36	0.223	6.95	3.25	1.91	3.13	0.424	98.9
D53	55.06	13.31	2.307	12.02	0.199	6.87	3.33	1.88	3.23	0.412	98.62
D78	55.62	13.4	2.336	11.56	0.196	6.87	3.29	1.73	3.11	0.402	98.51
D79	56.2	13.57	2.265	11.22	0.212	6.92	3.39	1.83	3.19	0.414	99.21
D80	55.79	13.4	2.129	11.56	0.21	6.79	3.16	1.89	3.17	0.394	98.49
D95	55.51	13.5	2.381	11.32	0.201	6.89	3.1	1.76	3.16	0.454	98.28

Whole-rock, non-normalized, major element analyses of samples determined to be Priest Rapids Member, Rosalia chemical unit, Wanapum Basalt (reported as percent)

Sample no.	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	KO_2	NaO_2	P_2O_5	Total
D15	50.53	13.02	3.642	14.14	0.239	8.46	4.52	1.28	2.63	0.792	99.25
D20	51.06	13.03	3.691	14.1	0.226	8.73	3.87	1.27	2.73	0.803	99.51
D47	50.56	12.83	3.662	14.5	0.232	8.59	4.3	1.35	2.74	0.796	99.56
D92	50.03	12.72	3.64	13.73	0.237	8.55	4.18	1.34	2.61	0.801	97.84
D93	49.65	12.75	3.675	14.31	0.24	8.5	4.15	1.28	2.58	0.8	97.94
M115	50.08	12.75	3.629	14.12	0.251	8.52	4.5	1.34	2.65	0.789	98.63
M1001	50.64	12.87	3.64	14.41	0.225	8.57	4.31	1.32	2.73	0.791	99.51
M1002	50.07	12.79	3.666	13.82	0.228	8.6	4.02	1.28	2.63	0.781	97.89
M1003	49.67	12.8	3.658	14.05	0.232	8.53	4.14	1.28	2.59	0.786	97.74
SNW1001	50.33	12.84	3.669	13.62	0.226	8.65	4.45	1.31	2.66	0.787	98.54

Whole-rock, normalized, major element analysis of samples determined to be Grande Ronde Basalt, magnetostratigraphic unit R2 (reported as percent)

Sample no.	N-SiO_2	N-Al_2O_3	N-TiO_2	N-FeO*	N-MnO	N-CaO	N-MgO	N-KO_2	N-NaO_2	N-P_2O_5
D6	55.95	13.82	2.488	11.89	0.269	7.14	3.01	1.82	3.16	0.458
D10	55.69	13.58	2.436	12.15	0.268	7.13	3.26	1.93	3.11	0.439
D14	56.79	13.7	2.231	11.17	0.214	6.96	3.29	2.02	3.23	0.4
D16B	56.79	13.61	2.16	11.43	0.196	6.98	3.27	1.98	3.18	0.407
D16T	56.79	13.92	2.181	11.18	0.193	6.76	3.26	2.06	3.24	0.41
D17	55.61	13.49	2.438	12.83	0.251	6.85	2.91	1.87	3.3	0.451
D19	55.72	13.62	2.495	12.12	0.268	7.23	2.9	1.95	3.2	0.495
D36	55.71	13.51	2.406	12.13	0.21	7.13	3.36	1.92	3.21	0.42
D42	55.98	13.47	2.466	12.07	0.25	7.08	3.05	1.87	3.3	0.461
D43	56.97	13.71	2.241	10.97	0.194	6.91	3.46	1.8	3.35	0.396
D46	55.59	13.46	2.384	12.5	0.225	7.03	3.29	1.93	3.16	0.429
D53	55.83	13.5	2.339	12.19	0.202	6.97	3.38	1.91	3.28	0.418
D78	56.46	13.6	2.371	11.73	0.199	6.97	3.34	1.76	3.16	0.408
D79	56.65	13.68	2.283	11.31	0.214	6.98	3.42	1.84	3.22	0.417
D80	56.64	13.61	2.162	11.74	0.213	6.89	3.21	1.92	3.22	0.4
D95	56.48	13.74	2.423	11.52	0.205	7.01	3.15	1.79	3.22	0.462

Whole-rock, normalized, major element analyses of samples determined to be Priest Rapids Member, Rosalia chemical unit, Wanapum Basalt (reported as percent)

Sample no.	N-SiO_2	N-Al_2O_3	N-TiO_2	N-FeO*	N-MnO	N-CaO	N-MgO	N-K_2O	N-Na_2O	N-P_2O_5
D15	50.91	13.12	3.67	14.25	0.241	8.52	4.55	1.29	2.65	0.80
D20	51.31	13.09	3.71	14.17	0.227	8.77	3.89	1.28	2.74	0.80
D47	50.78	12.89	3.68	14.56	0.233	8.63	4.32	1.36	2.75	0.80
D92	51.14	13	3.72	14.03	0.242	8.74	4.27	1.37	2.67	0.82
D93	50.7	13.02	3.75	14.61	0.245	8.68	4.24	1.31	2.63	0.82
M115	50.78	12.93	3.68	14.32	0.254	8.64	4.56	1.36	2.69	0.80
M1001	50.89	12.93	3.66	14.48	0.226	8.61	4.33	1.33	2.74	0.79
M1002	51.15	13.07	3.75	14.12	0.233	8.79	4.11	1.31	2.69	0.80
M1003	50.82	13.1	3.74	14.38	0.237	8.73	4.24	1.31	2.65	0.80
SNW1001	51.07	13.03	3.72	13.82	0.229	8.78	4.52	1.33	2.7	0.80

Whole-rock, trace element analyses of samples determined to be Grande Ronde Basalt, magnetostratigraphic unit R2 (reported in ppm)

Sample	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th
D6	0	18	30	377	891	44	329	179	39	15.1	21	4	132	6	25	59	9
D10	0	17	28	362	895	42	334	180	38	13.8	23	5	132	8	25	56	6
D14	0	18	29	316	818	48	329	185	37	15.1	24	5	126	3	25	59	9
D16B	0	13	24	309	824	48	328	184	36	14.7	24	5	123	9	22	41	7
D16T	0	17	24	298	867	52	353	189	37	15.3	24	6	129	9	12	44	10
D17	0	14	29	370	957	45	350	185	38	14.9	23	9	135	10	10	54	7
D19	0	18	32	360	1086	47	341	185	39	14.5	19	2	138	6	27	51	7
D36	0	12	26	356	695	45	325	178	38	13.3	21	8	126	10	18	60	6
D42	0	13	28	345	916	45	327	188	40	14.8	20	11	133	7	27	49	7
D43	0	15	27	314	708	47	327	185	37	13.2	23	8	124	8	22	51	8
D46	0	14	26	335	759	44	326	180	38	14.1	23	5	133	3	18	49	8
D53	0	14	26	326	681	48	324	185	37	14.4	24	4	132	11	27	47	7
D78	0	14	22	337	736	46	331	183	38	14.3	23	8	127	7	20	45	6
D79	0	15	29	319	792	46	328	182	37	14.2	20	4	126	6	30	54	9
D80	0	18	28	292	851	50	331	186	36	14.8	23	4	121	12	13	63	5
D95	0	13	31	341	820	47	349	185	38	16.4	24	5	129	10	24	60	10

Whole-rock, trace element analyses of samples determined to be Priest Rapids Member, Rosalia chemical unit, Wanapum Basalt (reported in ppm)

Sample	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th
D15	3	32	33	456	553	29	280	207	49	19.8	25	16	154	6	17	74	4
D20	5	33	33	442	536	31	296	214	52	20.6	27	18	154	2	24	73	4
D47	5	26	35	444	552	33	289	213	50	19.8	22	17	151	6	18	68	5
D92	7	30	32	463	546	31	288	210	50	19.2	19	17	151	7	32	67	7
D93	8	27	36	453	586	28	292	209	51	20.5	22	15	157	5	16	58	6
M115	6	31	33	454	538	30	284	206	49	18.7	22	13	154	6	25	71	8
M1001	4	28	33	448	543	31	292	212	51	18.9	21	15	157	8	19	68	6
M1002	4	29	36	455	568	32	293	210	51	20.1	21	17	157	3	20	71	6
M1003	4	26	41	450	574	29	290	209	52	19.4	21	12	159	9	23	85	5
SNW1001	7	27	30	461	530	29	289	206	49	19.4	25	15	151	3	22	67	5

Latitude and longitude of samples from the Mead (M) and Spokane NW (SNW) quadrangles

Sample no.	Latitude	Longitude
M115	47.752944	117.351981
M1001	47.808831	117.269572
M1002	47.801869	117.303736
M1003	47.793572	117.277017
SNW1001	47.733803	117.430092