Pillow Basalt Ridge Facies: Detailed Mapping of Eskay Creek–Equivalent Stratigraphy in Northwestern British Columbia

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INTRODUCTION

In 2003, the British Columbia Geological Survey and the Geological Survey of Canada initiated a joint project to map lower Middle Jurassic, upper Hazelton Group rocks in the Telegraph Creek and Iskut River map areas of northwestern British Columbia. In this region, the upper Hazelton Group is host to the Eskay Creek volcanic-hosted massive sulphide (VHMS) deposit, as well as numerous showings, prospects and geochemical anomalies, making it one of the most highly prospective regions in British Columbia. The scope of the project includes regional and detailed mapping of the upper Hazelton Group, as well as geochemical and geochronological studies. Fieldwork between Kinaskan Lake and More Creek in the Telegraph Creek map area in 2003 (Alldrick *et al.*, 2004a; 2004b) extended southwards into the Iskut and Forrest Kerr areas in 2004 (Alldrick *et al.*, this volume), including Pillow Basalt Ridge. Funding is provided by the British Columbia Ministry of Energy and Mines and by the Geological Survey of Canada's Targeted Geoscience Initiative II.

This paper describes the features of the Pillow Basalt Ridge (PBR) facies, as defined in Alldrick *et al.* (this volume) in the Iskut River map area. Pillow Basalt Ridge is the prominent ridge, 12 km long by 6 km wide, between the Iskut River and Forrest Kerr Creek, north of their confluence (Fig. 1).

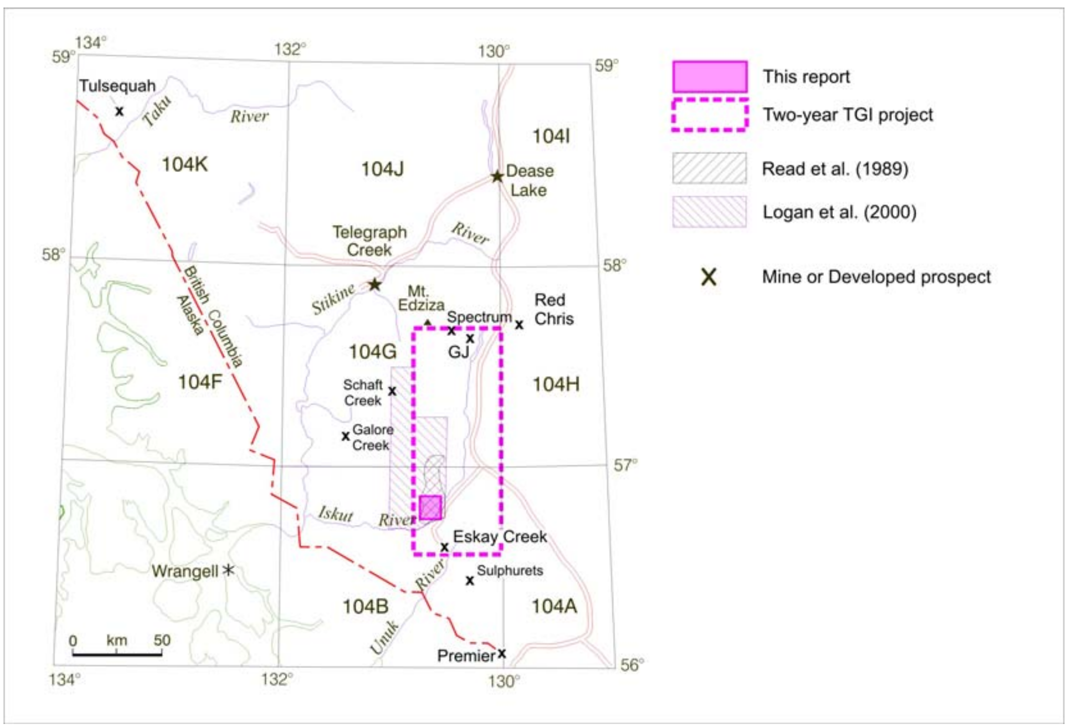

Figure 1. Location map of study area.

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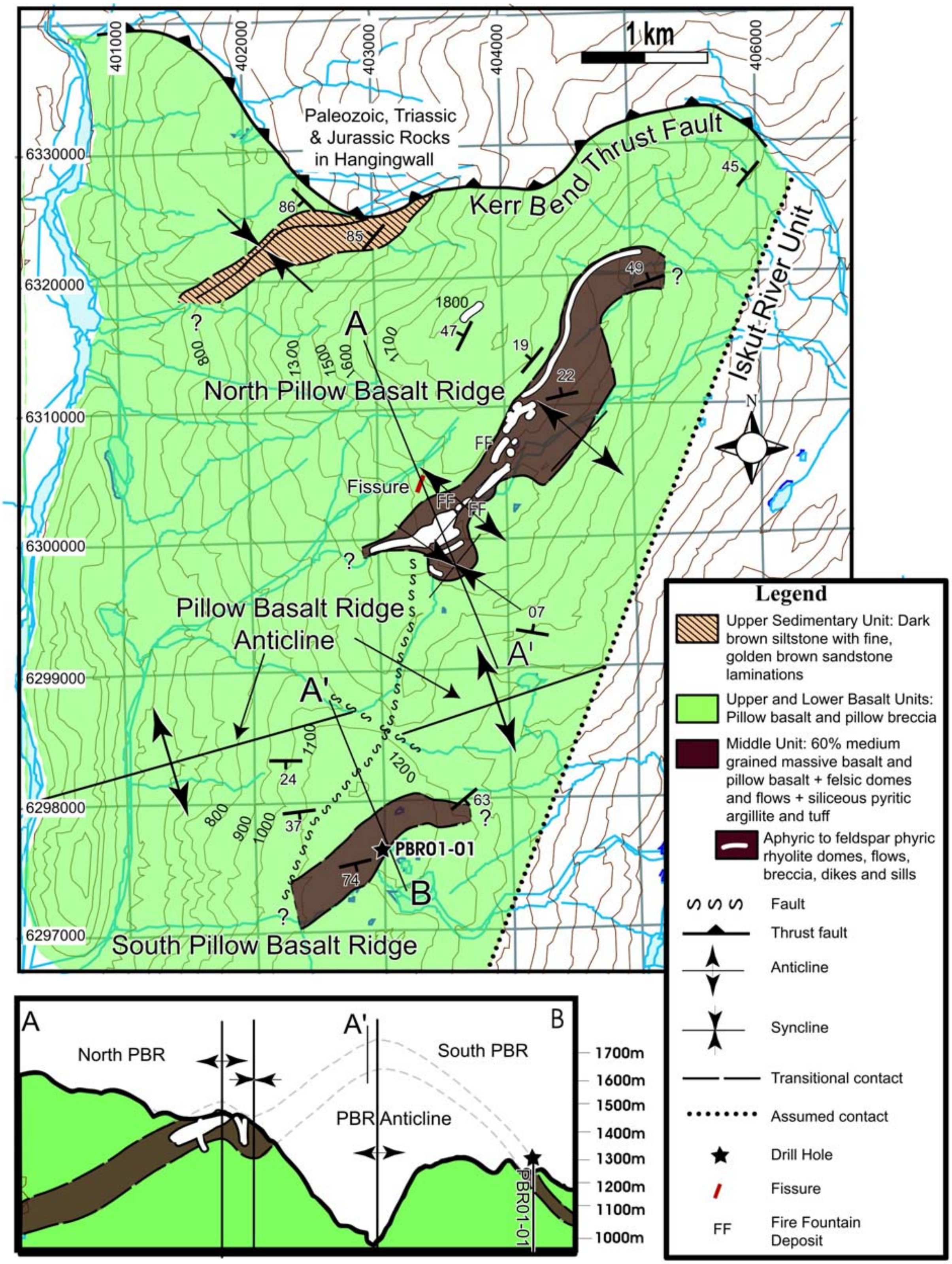

Figure 2. Geologic map and cross-section of Pillow Basalt Ridge.

The overlying Iskut River Unit crops out in the lowlands to the east and south, however the entire northern 9 km of the ridge is composed of PBR facies rocks. To the west, the Forrest Kerr fault juxtaposes the PBR facies against Paleozoic rocks. To the north, the Kerr Bend fault thrusts Paleozoic, Triassic and Jurassic units over PBR facies strata.

GEOLOGICAL SETTING

Pillow Basalt Ridge is located within the Stikine Terrane in northwestern British Columbia. In the Iskut River and Telegraph Creek map areas, the Stikine Terrane is composed of three major pre-accretionary units and two younger, syn- and post-accretionary units (Alldrick *et al.*, 2004a). The main stratigraphic components are 1) metavolcanic and metasedimentary Stikine Assemblage of Devonian to Permian age, 2) island-arc volcanic rocks of the Late Triassic Stuhini Group, 3) Early to Middle Jurassic island-arc volcanic and sedimentary rocks of the Hazelton Group, 4) Middle Jurassic to Cretaceous Bowser Lake Group, which is a sedimentary overlap assemblage that overlies the eastern margin of the Stikine Terrane units, and 5) upper Miocene to Holocene Mount Edziza volcanic complex.

The Pillow Basalt Ridge facies is considered to be of lower Middle Jurassic age and is assigned to the uppermost Hazelton Group (Read *et al.*, 1989; Logan *et al.*, 1994). Previous mapping of PBR identified its major bounding structures and the PBR anticline (Read *et al.*, 1989; Logan *et al.*, 1990). Read *et al.* (1989) depicted PBR as consisting entirely of pillow basalt. Logan *et al.* (1990; 1997) identified five narrow sedimentary intervals within the pillow basalt, which they depicted as discontinuous sedimentary lenses.

In the Telegraph Creek map area to the north, the uppermost Hazelton Group is interpreted to have been deposited in a subaqueous volcano-sedimentary environment, typical of rift settings (Alldrick *et al.*, 2004a). The exact temporal and structural relationship of the Pillow Basalt Ridge facies to rift segments in the Telegraph Creek area is uncertain. The PBR facies is closely affiliated, both spatially and stratigraphically, with the hangingwall sequence of pillow basalts at the Eskay Creek mine. Mapping of the central and southern portion of PBR by Homestake Mining Company (Vaskovic and Huggins, 1998) identified a zone approximately 300 m wide, which contains siliceous argillite beds up to 4 m thick, interbedded with pillow basalt. Homestake collared a diamond-drill hole (PBR01-01) in this zone, at what was then mapped as the crest of the PBR anticline (Fig. 2). The hole penetrated 1419 m of mainly basalt, with minor intervals of mudstone. In 2003, Roca Mines re-entered the hole, drilling to 1770 m without penetrating through the basalt or intersecting the Eskay equivalent contact mudstones and rhyolites that were hoped to underlie PBR.

STRATIGRAPHY

In 2004, 1:20,000-scale mapping of Pillow Basalt Ridge defined new stratigraphy and refined previously described structures (Fig. 2). The Pillow Basalt Ridge facies is divided into four units: the Lower and Upper Pillow Basalt units are separated by a Middle Unit and overlying the Upper Pillow Basalt Unit are distinctive sedimentary rocks of the Upper Sedimentary Unit. The Middle Unit varies in thickness from 130 to 200 m and contains bimodal volcanics and horizons of siliceous argillites and tuffs (Fig. 3).

Lower and Upper Pillow Basalt Units

The Lower Pillow Basalt Unit is at least 1000 m thick and the Upper Unit is at least 850 m thick. Together they form a volcanic pile which accounts for over 90% of the PBR facies. Both pillow basalt units are composed of two main variants: pillow basalts and pillow basalt breccias with transitional intervals of intact pillows in a breccia matrix. The volcanic pile is made up of many flows that interfinger and onlap one another. Individual flows are 5 to 30 m thick and are defined on a broad scale by different textures and weathering characteristics. There are a great variety of pillow forms, which range in size from 15 cm to 1.5 m in diameter (Fig. 4 and 5). Pillow geometries range from spheres to flattened lobes; most pillows display tail and drape geometry.

Basalt is mainly aphanitic, with medium to dark green fresh surfaces and orange-brown weathered surfaces. Most pillow rims are thin and have textures similar to the pillow centres. However, in some layers, pillow rims are glassy and moderately thick (up to 4 cm). These basalts have a black vitreous appearance and the pillows are often surrounded by a hyaloclastite matrix. Rarely PBR basalts have a porphyritic texture; plagioclase phenocrysts range up to 8 mm long. Variolites (spherical, white weathering, devitrification features typically 1 to 3 mm in diameter) and chlorite-filled vesicles are present in approximately 25% of PBR basalts.

A number of fire fountain deposits were identified in both the lower and upper basalt units (Fig. 2). Fire fountain deposits are characterized by irregular-shaped fluidal clasts in a matrix of blocky and curviplanar fragments (Simpson and McPhie, 2001) and are interpreted to be the result of proximal submarine volcanism, deposited within 10 m of a fissure or vent. Simpson and Nelson (2004) identified these deposits in upper Hazelton Group rift segments to the north.

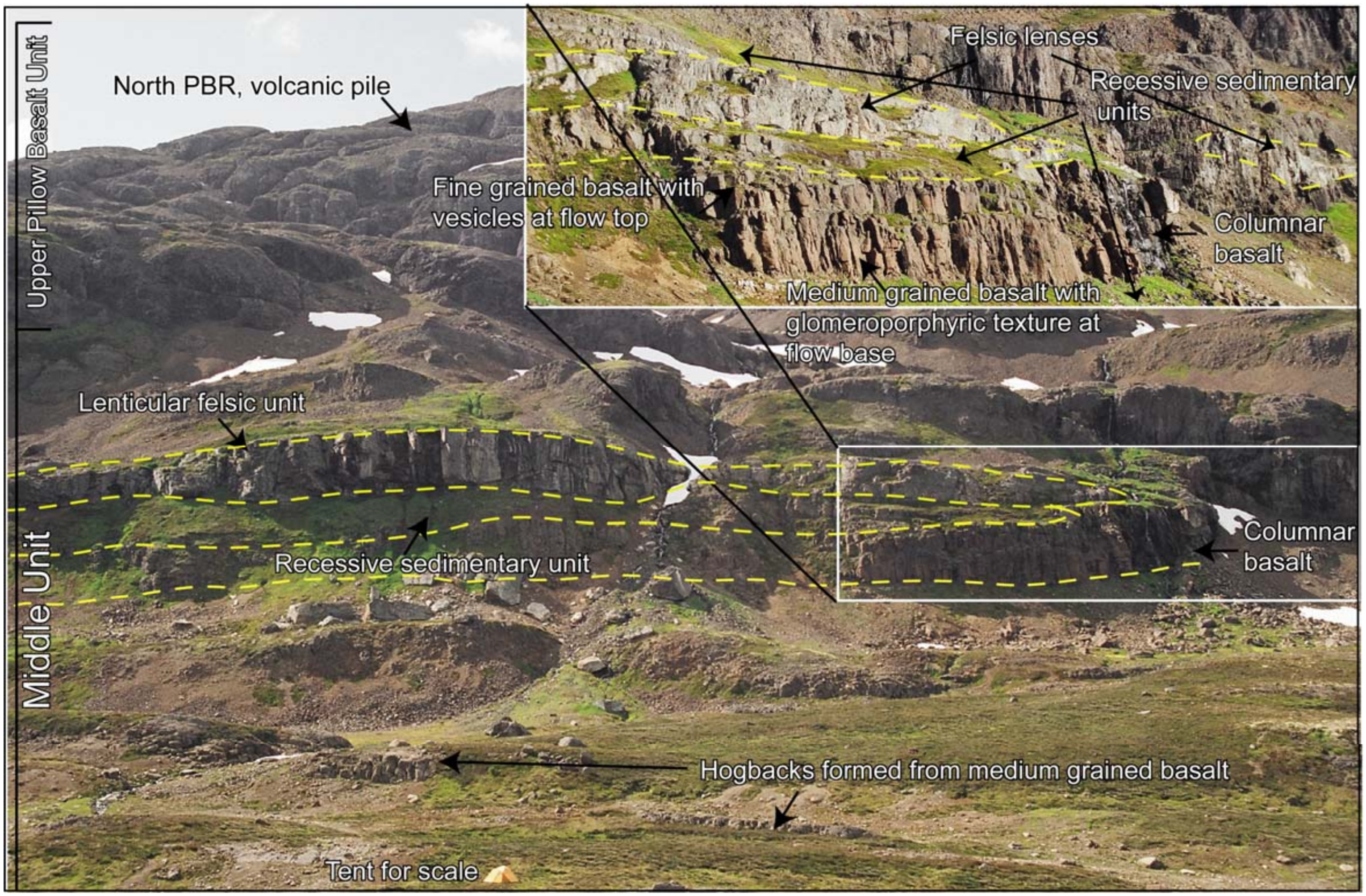

Figure 3. Northern Pillow Basalt Ridge, looking west at the Middle Unit and Upper Pillow Basalt Unit.

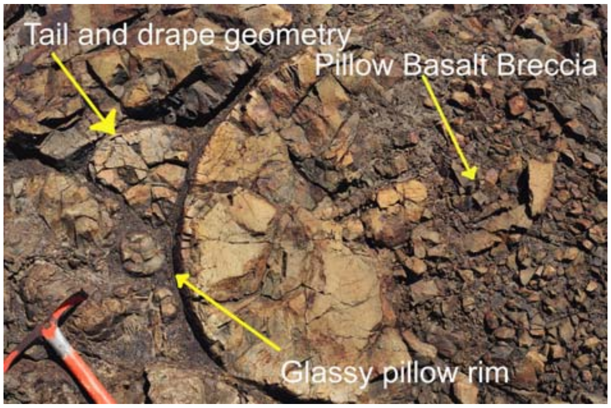

Figure 4. Typical well-developed basalt pillows.

Figure 5. Pillows from the Upper Pillow Basalt Unit directly above the Middle Unit, that range up to 1.5 m in diameter.

In the Upper Pillow Basalt Unit, a crack and fill feature was identified. A 20 m wide fissure cuts 65 m vertically down through a massive pillow basalt layer. This gap is completely infilled with a dense basalt breccia. On the fissure's margins the basalt breccia drapes over intact pillows of the fissure wall.

Although the Upper and Lower Basalt units strongly resemble each other, the following features set them apart: 1) fire fountain deposits, as well as pillows with the largest diameters, are concentrated in the Upper Pillow Basalt Unit immediately above the Middle Unit, 2) in northern PBR, the Upper Pillow Basalt Unit has higher proportions of thick glassy rims and hyaloclastite matrix (Fig. 4); 3) in the northwestern portion of PBR, just below the Upper Sedimentary Unit, a breccia in the Upper Pillow Basalt Unit consists of angular basalt clasts supported in a blue-grey limestone matrix.

Middle Unit - Bimodal Igneous and Sedimentary Zone

The Middle Unit is exposed on both limbs of the PBR anticline (Fig. 2). Pillow basalts in the Middle Unit are interlayered with other lithologies that represent a distinct depositional and volcanic regime different from that seen on the majority of PBR. The thickness of the Middle Unit varies, partly controlled by the paleotopography of the top of the Lower Pillow Basalt Unit.

The Middle Unit is a bimodal igneous and sedimentary zone predominately composed of mafic volcanic rocks interbedded with clastic sedimentary lithologies and felsic volcanic rocks. Overall, 60% of rock exposures in the zone are mafic, but in particular intervals, felsic and sedimentary rocks are the dominant rock types. On cliff exposures, flows of medium-grained, massive basalt form 5 to 25 m thick, orange-brown weathering, vertical faces, with metre-scale columnar joints (Fig. 3). Felsic units form 0.5 to 10 m thick, pale weathering, vertical, resistant cliff faces. Sedimentary intervals are typically 1 to 6 m thick, rusty weathering and recessive. A 30 m thick section of the bimodal igneous and sedimentary rock suite also occurs as a discontinuous band within the Upper Pillow Basalt Unit (Fig. 2).

Mafic Rock of the Middle Unit

Where the Middle Unit crops out on southern PBR, all mafic layers are pillow basalts. On northern PBR, the majority of mafic rock is medium-grained, non-pillowed basalt, which forms massive, columnar-jointed, outcrops. However, pillow basalt is also present. The presence of vesicles and absence of upper chill margins, indicate that the medium-grained massive basalt layers are extrusive flows. They exhibit gradational stratification with the coarsest texture at the bottom of each flow and a vesicular, finer grained texture near the flow tops. The medium-grained basalt commonly contains radiating plagioclase microlites, and locally displays a distinctive glomeroporphyric texture with feldspars up to 2.5 mm long. Lewis *et al.* (2001) describe a similar texture in the hangingwall basalts of the Eskay Creek mine.

Sedimentary Rock of the Middle Unit

Sedimentary layers are discontinuous and onlap both felsic and mafic flows. Their upper contacts with igneous flows are sometimes peperitic, and in one location several beds are entrained and folded within a felsic flow. Sedimentary rocks of the Middle Unit are medium bedded (5 to 25 cm thick) and can be internally laminated or graded. Some beds have an undulating base, grading and flat upper contacts, which are typical of beds deposited by density currents in a deep basin (Bouma 1962). The most common rock types are interbedded dark brown to black siliceous argillites and light-coloured felsic tuffs (Fig. 6), known as "pyjama beds" (Anderson, 1993). Light-coloured felsic tuff layers are generally more abundant near the tops of sedimentary intervals. Other sedimentary lithologies include light green intermediate to mafic tuff, dark blue-grey massive siltstone, and thin graphite-rich mudstone beds. Beds are typically siliceous; some are highly siliceous with a conchoidal fracture. Most beds contain a distinct felsic volcanic component of potassium feldspar and quartz. Disseminated pyrite crystals, less than 1 mm in size, can constitute up to 10% of the rock volume. Rarely, 1 to 3 mm thick pyrite laminations are preserved. About 20% of the black argillite beds have spherical, white weathering prehnite rosettes up to 1 cm in diameter. These have also been identified in other upper Hazelton Group rocks, including the Contact Mudstones in the Eskay Creek mine area (Ettlinger, 2001) and in the mudstones of the Four Corners complex in the Forgold facies (Alldrick *et al.*, this volume).

Figure 6. Siliceous dark argillites and light felsic tuffs of the Middle Unit.

Felsic Rock of the Middle Unit

Intrusive and extrusive felsic rocks are an important part of the Middle Unit on northern PBR. Intrusive bodies include dikes, sills and cryptodomes; extrusive bodies include flows, domes and breccias. Felsic flows are typically autobrecciated, white to light grey, and locally display flowbanding. Some flows are peperitic, incorporating up to 30% sedimentary clasts and matrix. The felsic rock is aphanitic, locally spherulitic, has a semi-translucent dove-grey fresh surface, and often contains pyrite. Most felsic rocks have fine (less than 1 mm) potassium feldspar phenocrysts, and rarely quartz and plagioclase microphenocrysts, in a groundmass of potassium feldspar and quartz. Some quartz microphenocrysts are partly resorbed, and they occur in aggregates with potassium feldspar. Flow facies are highly variable and change rapidly between massive flows, autobrecciated flows, and breccias and conglomerates. Some felsic breccias are polymictic with sedimentary clasts and a variety of distinct felsic clasts. At least one flow has a thickness of 10 m or more over a strike length of 3 km; other felsic bodies form lenticular exposures that are less than 10 m across.

Two small felsic volcanic centres were delineated within the Middle Unit on northern PBR. These show rapid thickening into roughly dome-shaped exposures. These two felsic complexes are composed of massive, mainly unbrecciated, felsic rock which is intruded by both felsic and mafic dikes. The contacts between the felsic and mafic dikes, and between the dikes and the surrounding dome, are highly irregular and curviplanar, indicating intrusion into semi-solid bodies. A network of feeder dikes and sills underlies each dome. The domes are surrounded by sedimentary rocks. Large wedges of sedimentary rock up to 4 m thick were incorporated into the magma as giant xenoliths. Bedding attitudes in the sedimentary strata adjacent to the domes depart from the normal PBR structural grain, indicating that they may be controlled locally by the paleoslope of the domes, or deformed by the mafic and felsic dikes.

Upper Sedimentary Unit

The Upper Sedimentary Unit overlies the Upper Pillow Basalt Unit at the northwestern edge of Pillow Basalt Ridge. Here, a syncline developed in the immediate footwall of the Kerr Bend fault exposes the depositional contact between the two units. The Upper Sedimentary Unit is composed of dark grey siltstone with golden brown sandstone laminations. The sedimentary strata interfinger with pillow basalts and in places form the matrix in pillow breccia. This intimate association with the volcanic rocks indicates that the sedimentary rocks are part of the upper Hazelton Group, rather than Bowser Lake Group as suggested in Read *et al.* (1989).

STRUCTURE

Pillow Basalt Ridge is structurally bounded to the north by the Kerr Bend thrust fault, and to the west by the Forrest Kerr fault. As described in the accompanying regional description of Alldrick *et al.*

(this volume), these may be original basin-bounding faults. Although the present Kerr Bend fault places older strata over PBR, and was therefore active following PBR deposition, there is evidence that it was also a controlling structure for a horst of Paleozoic and Triassic rock that was uplifted during PBR deposition.

Alldrick *et al.* (this volume) propose that two stress regimes controlled the major structures on PBR. An early extensional regime is responsible for the northeasterly orientation of the felsic eruptive centres, dikes, fissures, fissure eruptions and fire fountain deposits preserved in Pillow Basalt Ridge. These extensional features are syn-rift.

A later compressional stress regime is responsible for folding which produced the PBR anticline, a broad regional fold that affects all of PBR. The PBR anticline trends 060°, and has been offset by an inferred east-southeast–trending fault that occupies the deep valley separating northern and southern PBR (Fig. 2). Minor folds trending north-northeast to northeast within the Middle Unit are probably related to this folding event. This small-scale buckling of the Middle Unit helped accommodate the space requirements of the fold in the thicker, more rigid, pillow basalt units.

The later compressional regime is related to a sinistral shear couple that straddles PBR (Alldrick *et al.*, this volume). Shearing on the eastern side of PBR is responsible for the northern deflection of PBR strata as it trends towards the Iskut River. This shearing also accommodated deposition of the overlying Iskut River Unit. In contrast to the high energy deposits of the Iskut River Unit, the syncline at the northwestern edge of PBR exposes conformable, fine-grained distal sedimentary rocks that were deposited in a relatively quiescent part of the basin.

FACIES INTERPRETATION

Pillow Basalt Ridge represents a major rift segment where more than 2 km of pillow basalt filled a subsiding subaqueous basin. The total thickness of the PBR facies remains unknown, as does the type of rock that lies beneath it. Alldrick *et al.* (this volume) suggest that basal Middle Jurassic deposits of coarse clastic rock interfingered with medium-grained basalt and felsic rock that are exposed in the hangingwall of the Kerr Bend fault, may also underlie the PBR facies.

The Middle Unit records an interruption in the volcanic and depositional events that characterize the thick Upper and Lower Pillow Basalt units on PBR. The presence of fine-grained felsic turbidites in this interval suggest that there was a period of significant length during which the extrusion of mafic lava was suppressed. If, rather than erupting, mafic magma accumulated at depth, it could have provided sufficient heat to cause crustal-level partial melting. Hart *et al.* (2004) link the partial assent of mantle in rift environments to the generation of felsic magmas and the convective hydrothermal systems that are necessary for the formation of VHMS deposits. The reduced amount of mafic eruptions in the Middle Unit may also have allowed time for crystallization to occur in the magma chamber. When this magma next extruded it produced the coarser grained basalt that is characteristic of the Middle Unit on PBR. This sequence of events may also have generated other upper Hazelton bimodal volcanic sequences where massive basalt with a similar coarse texture is observed.

The felsic domes and cryptodomes of the PBR Middle Unit are too small to have produced the adjacent felsic flows and breccias. At least one felsic centre, now either buried or eroded, must have been significantly larger than those currently exposed on PBR.

Sparse paleo-direction indicators, including branching pillows, lava tubes, and the orientation of sedimentary layers entrained into lava flows, show a pattern of southerly flow. This suggests that the main eruptive centre was located on northern PBR or even farther to the north. The relatively thin (150 m thick) interval of PBR equivalent strata in the hangingwall of the Eskay Creek mine probably represents the fringe of this volcanic accumulation.

The differences between the Middle Unit exposures on northern and southern PBR are also consistent with north-south, proximal-to-distal progression. The Middle Unit on northern PBR is thicker than on southern PBR. It contains significant amounts of felsic and medium-grained mafic volcanics. The thinner Middle Unit on southern PBR contains only pillow basalts with sedimentary intervals; it does not contain any of the more viscous volcanic rocks that characterize the northern exposures.

Farther to the north, in the Forgold facies (Alldrick *et al.*, this volume), a larger felsic centre, the Four Corners complex, is present. If the Forgold facies was initially part of the same rift segment as the PBR facies, this may represent further northward thickening of the Middle Unit.

The suite of rock types that comprise the Middle Unit of PBR is not restricted to the Middle Unit. A narrow, discontinuous zone that repeats the Middle Unit's rock suite is also present within the Upper Pillow Basalt Unit. Variations of this rock suite were also observed in the Four Corners complex of the Forgold facies, and in the Sixpack Range (Alldrick *et al.*, this volume). This suggests that the events that led to the suppression of mafic volcanism, the deposition of sediments, generation of felsic volcanism, and the production of coarser grained massive basalt, were repeated several times throughout the history of the rift. Each of these intervals may represent favourable stratigraphy for the formation and preservation of VHMS mineralization.

CONCLUSIONS

Detailed mapping of Pillow Basalt Ridge in the Iskut River map area has defined four map units: a Lower Pillow Basalt Unit; a Middle Unit which consists of bimodal volcanic rocks and intercalated clastic sedimentary strata; an Upper Pillow Basalt Unit; and the overlying siltstones of the Upper Sedimentary Unit. The PBR facies is interpreted to have been deposited in an extensional submarine setting where basin subsidence kept pace with the accumulation of at least a 2 km thickness of volcanic and sedimentary rocks.

The Middle Unit represents a time interval when there were decreased mafic eruptions, but a sustained presence of a large mafic magma chamber. Heat from the mafic magma chamber generated felsic magmas from partial melting of the crust, and could potentially have driven VHMS mineralizing systems.

The presence of bimodal volcanism, fire fountain deposits, and pyritic sedimentary and felsic horizons are all indications that the Middle Unit of PBR may be favourable strata for the presence of VHMS style mineralization. The presence of bimodal igneous and sedimentary rock suites in the Middle Unit, elsewhere on PBR, and in other rift facies (the Forgold and Sixpack facies; Alldrick *et al.*, this volume), indicates that otherwise less prospective pillow basalt sequences do contain strata that is favourable to VHMS formation and preservation.

Strata underlying PBR at depth also represent an attractive exploration target. The new interpretation of the location and orientation of the PBR anticline presented in this article should facilitate future exploration of this blind strata.

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