The Proterozoic Pinguicula Group: Stratigraphy, contact relationships and possible correlations

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ABSTRACT

The Pinguicula Group is a Proterozoic succession of clastic and carbonate rocks exposed in the Wernecke Mountains of northern Yukon. The strata were deposited with angular unconformity on the Wernecke Supergroup following the Racklan orogeny and emplacement of the Hart River sills. Two contact relationships have been resolved in the 2009 field season. The first, a 1.38 Ga dyke previously thought to crosscut unit A, has instead been recognized to crosscut the underlying Wernecke Supergroup strata. This relationship is significant because it once again places the lower age limit of the Pinguicula Group into question and may reposition the Pinguicula Group within the history of geologic events. Secondly, the previously undefined contact relationship between units B and C has been identified as a gradational contact confirming the placement of unit C within the Pinguicula Group. In addition, preliminary data collected from the western Ogilvie Mountains draws similarities between units PR1 and PR2 of the lower Fifteenmile Group and units A, B and C of the Pinguicula Group. Although preliminary results from the 2009 field season have resolved some of the unknowns surrounding the Pinguicula Group, they have also raised more questions.

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INTRODUCTION

The Proterozoic Pinguicula Group consists of clastic and carbonate rocks in the Wernecke Mountains of northern Yukon (Eisbacher, 1981). These strata were deposited with angular unconformity on the Wernecke Supergroup following contractional deformation and metamorphism during the Racklan orogeny (Eisbacher, 1978; Thorkelson, 2000). Previous work, summarized in Thorkelson *et al.* (2005), described the main characteristics of the group, but questions remained about its age, depositional environment, areal extent and relations with Proterozoic successions in adjacent inliers. Suggested correlations between the Pinguicula Group and strata in the Ogilvie Mountains (Abbott, 1997) had not been tested.

The Pinguicula Group *sensu stricto* is located in the Wernecke Mountains approximately 150 km north-northeast of Mayo along the Bonnet Plume River (map areas 106C/5, 106C/6, 106C/11, 106C/12, 106C/13 and 106C/14). Possible correlative strata are exposed in the eastern Ogilvie Mountains (map areas 116A/10 and A/11), approximately 140 km northeast of Dawson City, and in the western Ogilvie Mountains (map areas 116B/11, 116B/13 and 116B/14) approximately 90 km north of Dawson City. Field work in the summer of 2009 was carried out in the Wernecke and western Ogilvie mountains (Fig. 1).

This paper outlines field data collected in summer 2009 and preliminary interpretations of contact relationships and sedimentary environments. These data are part of a graduate degree project that aims to map and characterize the Pinguicula Group in the Wernecke Mountains and evaluate correlations with similar strata in the Ogilvie Mountains. Geochemical, isotopic and geochronological analyses will be completed on samples in the spring of 2010. Future work may include additional mapping and sampling in the Wernecke and Ogilvie mountains and related laboratory analyses. Locations given in this report by UTM coordinates are based on North American Datum (NAD) 1927.

PREVIOUS WORK

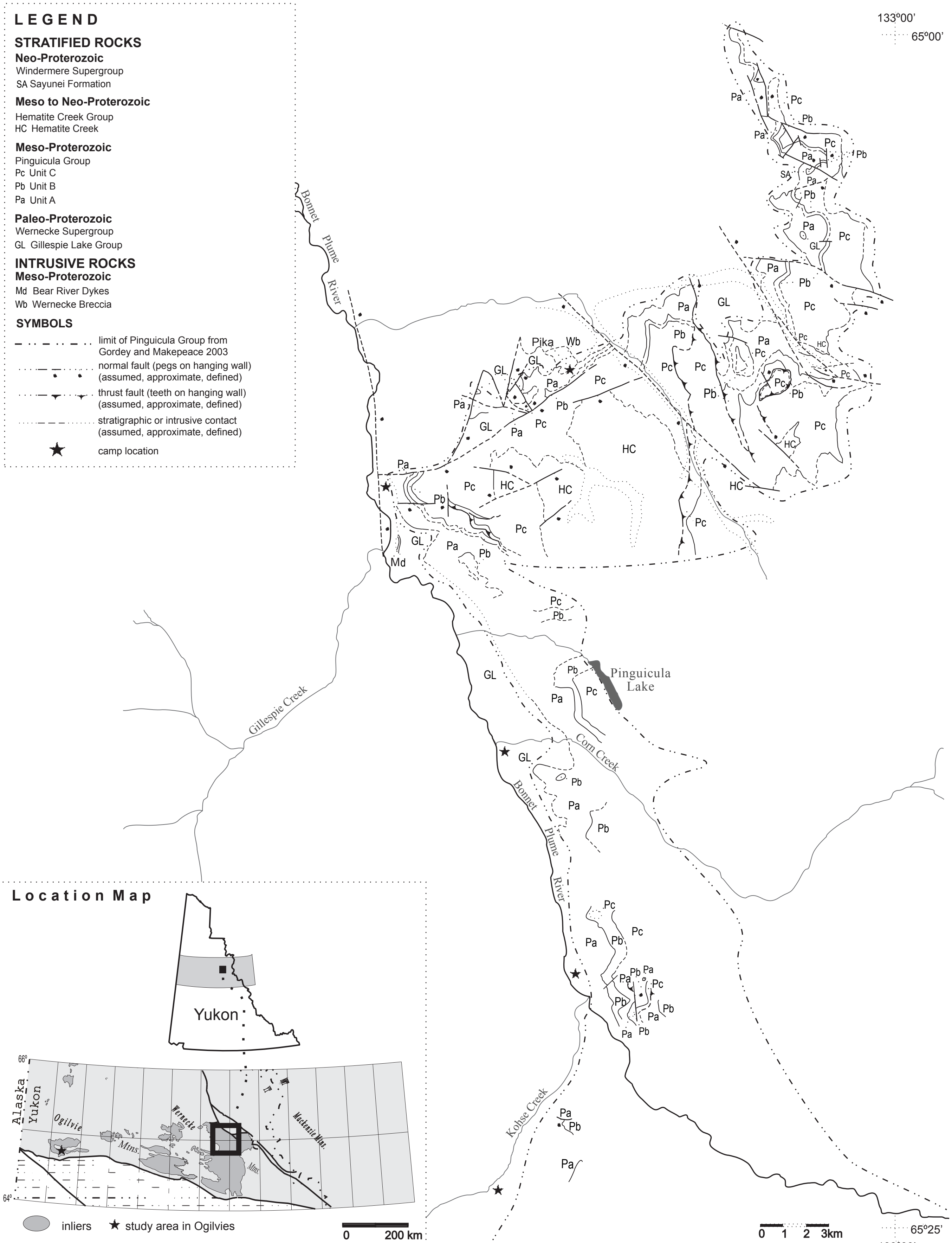
STRATIGRAPHIC NOMENCLATURE

Eisbacher (1981) defined the Pinguicula Group and divided it into six formations, termed units A through F. Subsequent work, completed by Thorkelson (2000), broke the Pinguicula Group into two successions separated by a lacuna of ~380 million years. This division was based on field data suggesting that unit A is crosscut by a *ca.* 1380 Ma dyke, whereas units D-F are younger than *ca.* 1000 Ma (the age of a detrital muscovite population from unit D). The hiatus was placed between units C and D because comparable strata in the Hart River inlier are separated by an angular unconformity (Abbott, 1997; Thorkelson *et al.,* 2005). This configuration was supported by relations in the Wernecke inlier, where zones of coarse, sparry carbonate in unit C were thought to represent karst caverns that developed during an interval of subaerial exposure (Abbott, 1997; Thorkelson, 2000). On this basis, Thorkelson (2000) kept units A through C in the Pinguicula Group and assigned units D through F to a new succession termed the Hematite Creek Group. The Hematite Creek Group was subsequently correlated with parts of the Mackenzie Mountains Supergroup (Thorkelson *et al.,* 2003). The restriction of the Pinguicula Group to units A-C of Eisbacher (1981) is followed in this report.

STRATIGRAPHIC DESCRIPTIONS, THICKNESSES AND CONTACT RELATIONSHIPS

The initial stratigraphic descriptions of the Pinguicula Group by Eisbacher (1978, 1981) were modified appreciably by Thorkelson (2000) and Thorkelson *et al.* (2005). Eisbacher (1981) described the group as a succession of “basaltic flows overlain by laminated and flasered limestone (unit A) grading into laminated dolosiltite (unit B) followed by massive dolostone (unit C), black shale with limestone laminites and stromatolites (unit D), brown laminated quartzite and red dolomitic siltstone (unit E), and finally, thinly bedded particulate limestone (unit F).” In contrast, Thorkelson *et al.* (2005) portrayed the Pinguicula Group as a succession of “basal sandstones grading into green and maroon mudstones (unit A) which are gradationally overlain by orange-weathering micritic dolostones (unit B) that are in turn overlain by grey micritic carbonate (unit C).” Thorkelson (2000) was unable to locate the volcanic flows of unit A (termed the Kohse Creek volcanics by Eisbacher, 1981) and suggested that they do not exist.

Figure 1. *(opposite page) Previously mapped extent of the Pinguicula Group in the Wernecke Mountains (Gordey and Makepeace, 2003; Thorkelson, 2000) and additional mapping completed during the 2009 field season.*


LEGEND
STRATIFIED ROCKS
Neo-Proterozoic
Windermere Supergroup
SA Sayunei Formation
Meso to Neo-Proterozoic
Hematite Creek Group
HC Hematite Creek
Meso-Proterozoic
Pinguicula Group
Pc Unit C
Pb Unit B
Pa Unit A
Paleo-Proterozoic
Wernecke Supergroup
GL Gillespie Lake Group
INTRUSIVE ROCKS
Meso-Proterozoic
Md Bear River Dykes
Wb Wernecke Breccia
SYMBOLS
limit of Pinguicula Group from Gordey and Makepeace 2003
normal fault (pegs on hanging wall) (assumed, approximate, defined)
thrust fault (teeth on hanging wall) (assumed, approximate, defined)
stratigraphic or intrusive contact (assumed, approximate, defined)
camp location
133º00'
65º00'
Bonnet Plume River
Pika
Gillespie Creek
Pinguicula Lake
Corn Creek
Kohse Creek
0 1 2 3km
65º25'
133º00'
Location Map
Yukon
Alaska
Yukon
Ogilvie Mtns.
Wernecke Mtns.
Mackenzie Mtns.
66º
64º
inliers
study area in Ogilvies
0 200 km

In the Wernecke inlier, the Pinguicula Group unconformably overlies the Gillespie Lake and Quartet groups of the Wernecke Supergroup, and zones of Wernecke Breccia (Thorkelson, 2000). Similarly, in the Hart River inlier, a succession classified as Pinguicula Group overlies the Gillespie Lake Group, as well as the Hart River sills and basalts, with angular unconformity (Abbott, 1997; Thorkelson, 2000). The angular relationship between the two successions is considered to be mainly a result of the Racklan orogeny in the Wernecke Mountains and the correlative Fifteenmile orogeny in the Ogilvie Mountains (Brideau *et al.,* 2002).

Eisbacher (1981) estimated the thickness of the Pinguicula Group (formerly units A through F) in the Wernecke inlier near Pinguicula Lake at approximately 2300 m. More recent work provided an estimated thickness of the Pinguicula Group (units A through C) of 2720 m, thickening to approximately 3520 m in the south (map areas 106C/13 and 106C/14; Thorkelson, 2000). Unit A thickens southward in map area 106C/11, and units B and C decrease in thickness in the same area (Thorkelson, 2000). A measured section in the Hart River inlier provided a thickness of 1984 m for units A and B, and an estimated thickness for unit C of 250 m (Abbott, 1997).

AGE CONSTRAINTS AND DETRITAL ZIRCON PROVENANCE

The age of the Pinguicula Group was considered by Thorkelson *et al.* (2005) to be approximately 1380 Ma. In the Wernecke inlier, Thorkelson (2000) documented a dioritic intrusion crosscutting black shale identified as unit A. Igneous zircons from the diorite were dated at approximately 1380 Ma, and the diorite was assigned to the Hart River sills of Abbott (1997). As a result, the deposition of the base of the Pinguicula Group was constrained between 1380 Ma and 1590 Ma (the age of the underlying Wernecke Breccia in other locations; Thorkelson, 2000; Thorkelson *et al.,* 2005). New data that bear on this contact relationship will be discussed later in this paper. The Bear River dykes may constrain the end of deposition of the Pinguicula Group at more than 1270 Ma (Thorkelson, 2000).

In the eastern Ogilvie Mountains, strata that Abbott (1997) correlated with unit A of the Pinguicula Group overlie the Hart River sills and Hart River basalts. This relation contrasts with the interpretation that the Hart River sills crosscut unit A in the Wernecke Mountains, and suggests that the Pinguicula Group was deposited after emplacement of the Hart River volcanics, and is therefore younger than 1380 Ma. To account for the contrasting pre- and post-1380 Ma timing relations, Thorkelson *et al.* (2005) considered that "basin formation and magmatism were broadly concurrent and locally diachronous."

Detrital zircon ages for basal sandstone of Pinguicula Group unit A provide an indication of sandstone provenance. Using thermal ionization mass spectrometry (TIMS), U-Pb analyses plotted in two distinct clusters, with the youngest detrital zircon age plotting at 1841 Ma (Thorkelson *et al.,* 2005). The detrital ages reflect the ages of the source region and not the time of Pinguicula Group deposition. Detrital zircons probably originated from the Wernecke Supergroup or directly from Laurentian crystalline rocks (Thorkelson *et al.,* 2005).

CORRELATIVE STRATA IN ADJACENT MOUNTAIN RANGES AND SEQUENCE A, B, C CLASSIFICATION

Work completed in the late 1970s correlated units A through F of the Pinguicula Group, with the upper part of the Mackenzie Mountains Supergroup (Eisbacher, 1978; Young *et al.,* 1979). More recent work has led to correlation of units D through F (Hematite Creek Group of Thorkelson, (2000)) with the Mackenzie Mountains Supergroup (Thorkelson *et al.,* 2005; Fig. 2). Pinguicula Group units A through C have been correlated with the Dismal Lakes Group of the Coppermine Homocline (MacLean and Cook, 2004) and with units PR1 through PR4 in the lower Fifteenmile Group in the Ogilvie Mountains. Units A and B have been correlated with unit H1 in the Mackenzie Mountains (Rainbird *et al.,* 1996; Thorkelson *et al.,* 2005).

Young *et al.* (1979) divided the Proterozoic stratigraphy of northwestern Canada into unconformity-bounded Sequences A, B and C. The sequences were defined on the basis of ages and orogenic events with "Sequence A encompassing the oldest rocks in the Cordillera, Sequence B intermediate age rocks and Sequence C the youngest Proterozoic rocks" (Young *et al.,* 1979). The Pinguicula Group was originally classified as Sequence B and separated from the Wernecke Supergroup (Sequence A) by age and the Racklan orogeny. Based on ages obtained from the Hart River sills by Thorkelson *et al.* (2005), which were more closely aligned with the Wernecke Supergroup than the overlying Mackenzie Mountains Supergroup strata of Sequence B, the Pinguicula Group has since been moved from Sequence B to Sequence A. MacLean and Cook (2004) further subdivided Sequence A based on the analysis of

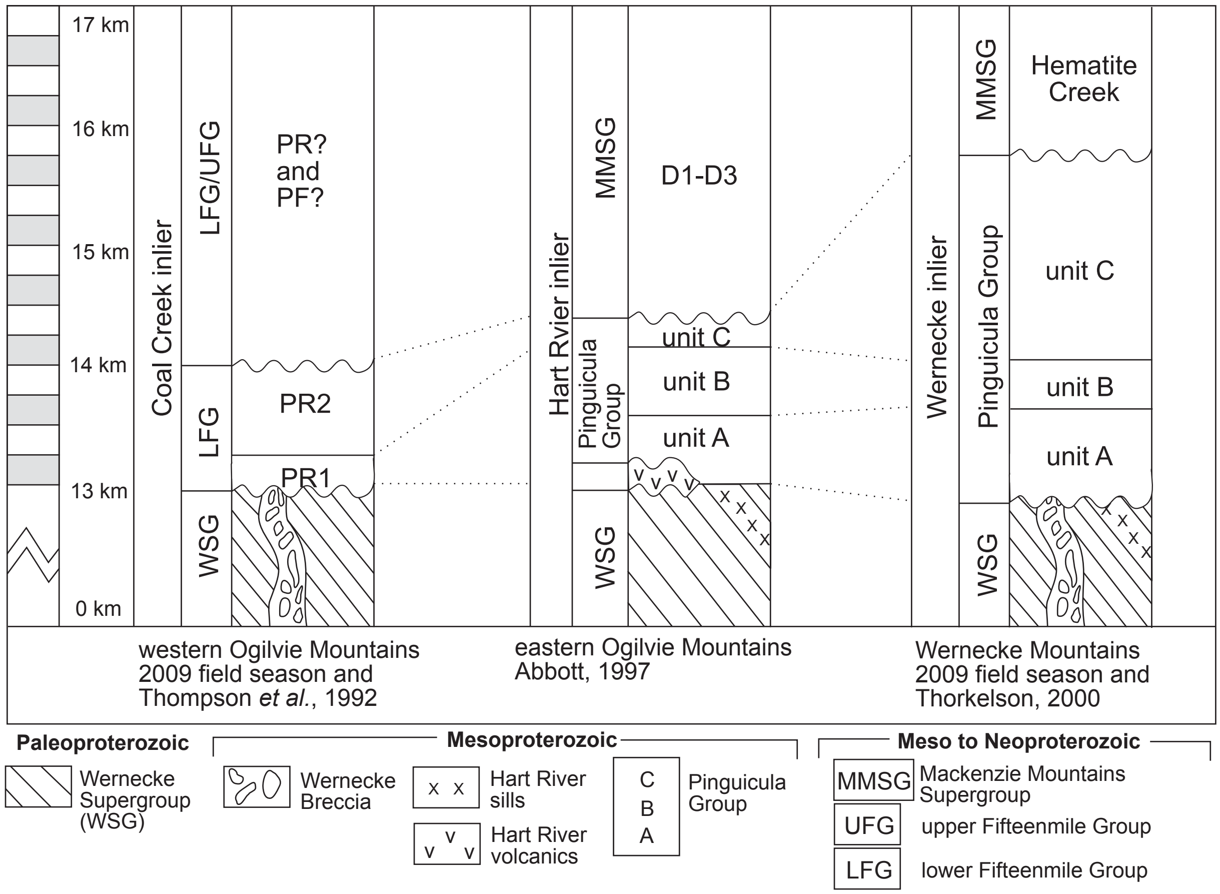


Figure 2. *Strata correlative with Meso to Neoproterozoic Pinguicula units A, B and C in the eastern and western Ogilvie Mountains (Hart River and Coal Creek inliers; modified from Abbott, 1997).*

reflection seismic data from across the western Northwest Territories, resulting in four units: A1, A2, A3 and A4. The oldest unit, A1, includes the Wernecke Supergroup, whereas the Pinguicula Group has been placed in unit A3 (MacLean and Cook, 2004). There are no strata equivalent to unit A2 in the Wernecke Mountains (MacLean and Cook, 2004), although the work of Furlanetto *et al*. (2009) implies that the Wernecke Supergroup is younger than previously thought, and may be part of Sequence A2.

DEPOSITIONAL ENVIRONMENTS

An interval of crustal stability, after deposition of the Wernecke Supergroup and contractional deformation of the Racklan orogeny, was followed by extension and emplacement of the Hart River sills (Thorkelson *et al.*, 2005). The Hart River sills likely represent an episode of rifting and crustal extension that in turn led to subsidence that allowed the deposition of the Pinguicula Group.

The Pinguicula Group was thought to have been deposited during a time of basin development with a "progression from a mid to deep-water shale basin (unit A), to a mid-water carbonate shelf (unit B), to a subtidal or intertidal carbonate bank (unit C)" (Thorkelson, 2000). Based on the thickness of the units, the basin was interpreted to deepen to the south (Thorkelson, 2000). Although the broader significance of Pinguicula basin formation has not been fully evaluated, it may reflect the separation of Laurentia from another continent (Thorkelson *et al.,* 2005).

2009 FIELD WORK

In the summer of 2009, five locations in the Wernecke Mountains (Fig. 1) and three locations in the Ogilvie Mountains were studied. The objectives of the field work were to measure stratigraphic thicknesses at selected locations, examine contact relationships, collect samples for U-Pb geochronology, isotope and geochemical analyses, and record detailed lithologic descriptions. While in the Wernecke Mountains, camps were located at the Pika MINFILE occurrence (Yukon MINFILE, 106C 071) and several locations along the eastern side of the Bonnet Plume River and Kohse Creek. Camps in the Ogilvie Mountains were located near the headwaters of Fifteenmile Creek and Coal Creek.

Stratigraphic sections were measured at two locations in the Pinguicula Group in the Wernecke Mountains previously documented by Thorkelson (2000). A section through units A and B was measured near the Pika occurrence (UTM 573349E, 7190628N). A second section was measured farther south, adjacent to the Bonnet Plume River (UTM 563956E, 7185104N), and included units B and C.

STRATIGRAPHY

Unit A

Unit A of the Pinguicula Group unconformably overlies the Gillespie Lake and Quartet groups and the Wernecke Breccia of the Wernecke Supergroup. At its base, Pinguicula A is lithologically variable, consisting of mudstone, sandstone and conglomerate. Conglomerate and sandstone form layers and lenses in the mudstone, and are locally present at the base of the succession.

Conglomerate clasts range from granule to boulder-sized (~50 cm in diameter) and are well-rounded to subrounded. Diverse clast types include yellow siltstone, green and black mudstone and distinctly red clasts with local specular hematite. The red clasts are prevalent in conglomerate overlying the Wernecke Breccia (*e.g.*, Pika occurrence) and appear to be derived from it. Some conglomerate layers are well-sorted and matrix-supported, with clasts in a matrix of well-sorted, subangular granules and coarse quartz sand. In other areas, the conglomerate is well to moderately well sorted and the matrix is composed of subrounded, fine to medium quartz sand with specular hematite and pyrite altering to limonite.

Sandstone is orange to black-weathering, grey to white, and fine to medium-grained. It is massive to thin-bedded (1-2 cm) and laminated in some areas. The grains are well sorted, well rounded and consist of approximately 90% quartz. Adjacent to the Bonnet Plume River (UTM 573352E, 7167986N), the sandstone beds (approximately 10 cm thick) are interbedded with conglomerate and contain traces of pyrite that is locally weathered to limonite. Sandstone bed thicknesses at the Pika occurrence are 3 cm to 9 m (massive) and 18 m (laminated).

Above the basal strata, unit A consists of a succession of laminated mudstone. The mudstone is commonly cleaved, locally exhibiting pencil cleavage and in a few localities

Figure 3. *Centimetre-scale green-maroon mottling in mudstone of unit A at the Pika MINFILE occurrence (UTM 573381E, 7190576N).*

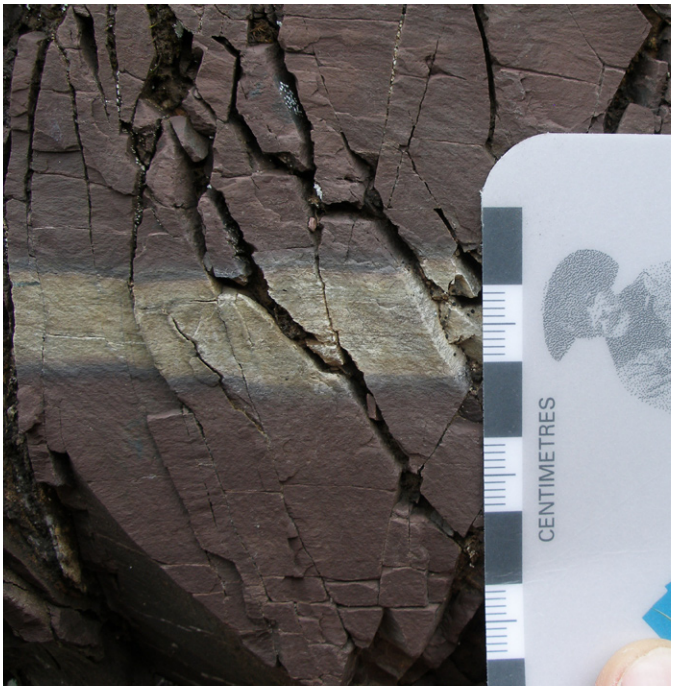


Figure 4. *Possible ash beds in mudstone of unit A at the Pika occurrence (UTM 573343E, 7190633N). These centimetre-scale beds are less indurated than overlying and underlying beds.*

Figure 5. *Unit B yellow/orange-weathering, maroon to green dolomudstone (UTM 573524E, 7190577N).*

the cleavage is crenulated (UTM 572959E, 7169440N). Near the Pika occurrence, the mudstone is dominantly maroon with green and grey interlayers. Although the maroon and green colours are broadly stratiform, some layers display both colours in a mottled pattern (Fig. 3). The mottling may be the product of diagenetic overprinting because it is independent of primary lamination. Toward the contact with unit B, the mudstone alternates between maroon and green, before changing to a slightly darker grey/black colour, and then returning to maroon just below the contact with unit B. In the southern part of map sheet 106C/14, the mudstone is grey to black and locally displays limonitic staining on fracture surfaces, interpreted as oxidation of diagenetic pyrite.

Upsection, toward the contact with unit B, unit A typically becomes slightly calcareous and contains calcareous nodules. The nodules are tabular to lenticular and typically deflect sedimentary laminae, forming a pinch-and-swell structure. Nodules are approximately 1-9 cm thick and tend to be concentrated in certain layers.

Possible tephra layers are present in laminated mudstone near the base of unit A, near the Pika occurrence. These light grey, slightly recessive layers are 0.1-5.5 cm thick (Fig. 4). Several samples were taken to determine their age and composition.

Unit B

Unit B gradationally overlies the increasingly calcareous mudstone beds of unit A and is dominated by yellow/orange-weathering, maroon to green dolomudstone (Fig. 5). At the base of unit B, a massive, quartz-silty carbonate grades into green to maroon, laminated dolomudstone. As with unit A, unit B alternates in colour between green and maroon. The boundary between units A and B is placed at the base of the yellow/orange-weathering dolomudstone of unit B.

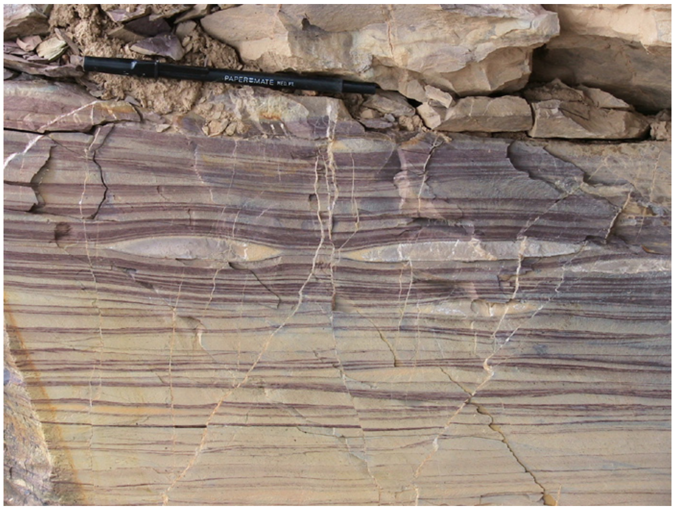


Figure 6. *Carbonate lenses (approximately 2 cm thick and 10 cm long) in unit B at the Pika occurrence (UTM 573524E, 7190577N).*

Figure 7. *Carbonate lenses (approximately 3 cm thick and 10 cm long) that have undergone soft sediment deformation in unit B (UTM 564074E, 7185389N).*

Features characteristic of unit B include carbonate nodules, flat-pebble conglomerate and possibly thin carbonate beds. Most of the nodules are in maroon, quartz-silty dolostone and are 2-5 cm thick and 5-10 cm long. Some are lenticular, whereas others are ellipsoidal (Figs. 6, 7). Others are tabular, with an approximate thickness of 1-5 cm and appear bedlike. The nodules, intraclasts and possible beds are grey-green on fresh surfaces, medium-grey on weathered surfaces and weather recessively relative to the host rock.

The flat-pebble conglomerate in unit B, above the Bonnet Plume River (UTM 564074E, 7185389N), consists of light grey or white dolostone clasts in maroon, quartz-silty dolostone. The conglomerate forms layers up to 2 m thick. Clasts range from <1 cm to 9 cm long and are approximately 1-2 cm thick (Fig. 8). Some of the pebbles appear to have undergone soft sediment deformation whereas others have maintained their tabular morphology. In one location (UTM 564074E, 7185389N), a section rich in flat-pebble conglomerate overlies 1 m carbonate beds and underlies pyrite-rich dolomudstone.

Figure 8. *Metre-scale beds of flat-pebble conglomerate that have undergone soft sediment deformation in unit B above the Bonnet Plume River (UTM 563956E, 7185104N). Clasts are 1-9 cm long and 1-2 cm thick.*

Unit C

Unit C is dominated by craggy and dark to medium-grey weathering, layered to massive grey dolostone. At the Bonnet Plume River section (UTM 563956E, 7185104N) the unit gradationally overlies unit B as the weathered colour grades from yellow to grey over an interval of approximately 7 m. The lower part of unit C consists of carbonate layers, some of which contain shaly partings, interbedded with laminated grey siltstone. Most of the beds are 1-60 cm thick, but some are more massive, with thicknesses >60 cm. The dolostone in the lower part of unit C is typically fetid (on fresh surface), contains stylolites, and has pervasive carbonate veins.

Figure 9. *Zebra dolostone of Unit C above the Bonnet Plume River (UTM 564124E, 7185044N).*

Zebra dolostone (Fig. 9) becomes conspicuous several metres above the stylolites. White dolospar 'stripes' in darker primary dolostone define the texture. In separate horizons, chert nodules and brecciated dolostone with void-filling dolospar cement (Fig. 10) are also present.

The contact between units B and C was previously not well understood and thought to be unconformable (Thorkelson, 2000). Recent work in the area has shown that yellow-weathering dolostone of unit B grades upward to a grey-weathering, fetid dolostone of unit C.

Figure 10. *Pervasive, late brecciation in thin-bedded dolostone; breccia interstices are filled with coarsely crystalline dolospar.*

IGNEOUS INTRUSIONS

Diorite dykes crosscutting units A, B and C

Three diorite dykes that crosscut the Pinguicula Group were sampled. The first is an east-trending dyke hosted by units A, B and C at UTM 576862E, 7161598N. The second, a northwest-trending dyke, and the third, a northeast-trending dyke, crosscut unit A adjacent to Kohse Creek (UTM 572676E, 7150368N and UTM 572865E, 7150726N). Geochronological analyses will be undertaken to determine the minimum ages of the units cut by the dykes.

Re-evaluation of Hart River sills in unit A

The age of the Pinguicula Group in the Bonnet Plume River area was previously constrained by a relationship that is now called into question. The minimum age of the basal Pinguicula Group was provided by a dioritic Hart River sill, dated at 1380 Ma, that intrudes black siltstone (Thorkelson *et al.,* 2005). The siltstone was regarded by Thorkelson (2000) and Thorkelson *et al.* (2005) as part of unit A. Re-examination of this locality on either side of a small tributary of the Bonnet Plume River (UTM 574258E, 7159882N) has confirmed that diorite intrudes siltstone, but the siltstone does not appear to belong to unit A. The siltstone differs in detail from nearby black, laminated, sandy siltstone that clearly belongs to unit A (exposed up-section across a short covered interval) that is not crosscut by the diorite. The siltstone hosting the diorite is now considered to belong to either the Gillespie Lake Group or the Quartet Group of the Wernecke Supergroup, and to be unconformably overlain by unit A.

Differences between the graphitic siltstone intruded by the Hart River sills and the siltstone of unit A leading to this reclassification are as follows: the bedding is thicker in graphitic siltstone, as compared to unit A laminated siltstone; fracturing is widely spaced in the graphitic siltstone compared to more closely spaced fracturing in unit A; red weathering and pyrolusite pervade the graphitic siltstone, whereas unit A has neither red weathering nor pyrolusite staining; the orientation of bedding in the graphitic siltstone and unit A are dissimilar (strike differing by as much as 100° and dip 26°); crenulations are present in the graphitic siltstone but absent in unit A at that locality; and unit A is clearly not graphitic or as strongly indurated. For these reasons, the diorite dyke is tentatively considered to crosscut strata of the Wernecke Supergroup, rather than unit A. This hypothesis will be tested using geochemistry and isotopes.

This new crosscutting relationship resolves complications identified by Thorkelson *et al.* (2005) regarding discrepancies between the position of the Hart River sills in the Wernecke inlier. Because the Hart River sills have not been shown to crosscut unit A in the Wernecke inlier, locally diachronous basin formation and synchronous magmatism are not required.

SAMPLING

Sampling was undertaken for further characterization of the Pinguicula Group. Forty-two samples were collected in the Wernecke Mountains for petrographic, geochemical and/or isotopic analyses, and sixteen samples were collected for geochronological analysis (Fig. 11).

Detrital zircons will be extracted from sandstone for U-Pb geochronology. In addition, clasts from conglomerates will be sorted into lithologic groups and, where possible, dated using U-Pb zircon geochronology. This may provide insight into the possibility that strata were deposited, or that a terrane was obducted, between the time of Wernecke Supergroup deposition (<1640 Ma; Furlanetto *et al.,* 2009) and formation of the Pinguicula basin.

DEPOSITIONAL ENVIRONMENTS AND POST-DEPOSITIONAL TEXTURE FORMATION

The Pinguicula Group represents basinal to platformal sedimentation (Thorkelson, 2000). Deposition began after uplift and erosion of the Wernecke Supergroup. Following an interval of extension associated with the emplacement of the Hart River sills, subsidence and/or sea-level rise resulted in the deposition of deep-ocean sediment characteristic of unit A. The basin appears to have deepened to the south (map area 106C/11) where unit A becomes thicker and darker.

Flat-pebble conglomerate such as that in unit B is common in Proterozoic carbonate rocks. Another distinctive characteristic of the Pinguicula Group is the abundance of zebra textures. Zebra textures and stylolites form in deep subsurface environments where limestone is replaced by Mg-metasomatism at temperatures of up to 200°C (Merino *et al.,* 2006; Wallace *et al.,* 1994). This information suggests that zebra textures in unit C probably developed at depth, which is in contrast to interpretations made by Thorkelson (2000), who described zebra-textured clasts in an intraclast conglomerate in unit C and suggested that they formed "at or near the sediment surface, shortly after micritic deposition and prior to lithification."

		limestone/dolostone	siltstone/mudstone	sandstone	conglomerate	intrusive diorite
PINGUICULA GROUP	unit C	● KM09-8-2-1 ● KM09-8-1-5 ● KM09-8-1-4 ● KM09-8-1-3 ● KM09-8-1-2				
	unit B	● KM09-8-1-1 ● KM09-7-2-2 ● KM09-7-2-1 ● KM09-3-2-5 ● KM09-3-2-3 ● KM09-3-2-2 ● KM09-3-2-1	◆ KM09-3-2-6			⬟ KM09-11-1-1
	unit A		◆ KM09-2-7-1 ◆ KM09-2-6-2 ◆ KM09-2-6-1 ◆ KM09-2-5-1 ◆ KM09-2-4-2 ◆ KM09-2-4-1 ◆ KM09-2-1-1 ◆ KM09-1-3-2 ★ KM09-1-3-1* ◆ KM09-12-4-1 ◆ KM09-12-3-1 ◆ KM09-12-2-1 ◆ KM09-11-2-1 ◆ KM09-10-4-1 ◆ KM09-3-1-1 ★ KM09-2-9-1* ◆ KM09-2-8-1	★ KM09-12-2-2 ★ KM09-10-3-1 ★ KM09-4-1-2 ★ KM09-1-4-2 ★ KM09-1-4-1	★ KM09-10-3-7 ★ KM09-10-3-3 ★ KM09-10-3-2 ★ KM09-10-3-6 ★ KM09-4-1-1	⬟ KM09-11-6-2 ⬟ KM09-11-6-1 ⬟ KM09-11-7-3 ⬟ KM09-10-6-1

● C, O and Sr isotopes ◆ Nd isotopes ★ U-Pb dating, detrital zircon ⬟ U-Pb dating, zircon *possibly ash

Figure 11. *Summary of samples collected from units A, B and C of the Pinguicula Group in the Wernecke Mountains. For anticipated analyses for each sample refer to symbol legend.*

FIFTEENMILE GROUP IN OGILVIE MOUNTAINS

Work completed in the Fifteenmile Group in the Ogilvie Mountains focused on three locations previously mapped by Thompson *et al.* (1992). Traverses were completed along Fifteenmile Creek (UTM 579128E, 7183747N) to examine PR1 and PR2, and at the northern reaches of Coal Creek (UTM 552687E, 7186821N and UTM 549468E, 7188402N) to characterize PR3 through PR5. Field work at these locations focused on sampling, detailed rock descriptions and contact relationships. This information will be used to clarify the possible relationship between the Pinguicula and lower Fifteenmile groups.

Stratigraphy

Descriptions of the lower Fifteenmile Group, from the western Ogilvie Mountains, provided by Thompson *et al.* (1992) are as follows: PR1 comprises shale and silty dolostone with common dolostone olistoliths; PR2 is a medium to thick-bedded dolomitic mudstone, dolostone breccia, and massive, medium-crystalline dolostone; PR3 is a recessive-weathering, grey, medium-bedded dolostone with mudstone interbeds; PR4 is a brecciated, medium-grey oolitic packstone, with rare stromatolites; and PR5 comprises shale, pebbly mudstone, gritty mudstone, stromatolitic limestone and quartz sandstone.

Thompson *et al.* (1992) mapped the Wernecke Breccia as crosscutting siltstone (PR1 and locally PR5) of the lower Fifteenmile Group near Fifteenmile Creek (UTM 577590E, 7180979N). More recent field work, however, determined that the Wernecke Breccia underlies unit PR1 and is bleached and stained with malachite. Such features record an episode of subaerial exposure (Thorkelson, 2000) between deposition of the Wernecke Breccia and deposition of the lower Fifteenmile Group, and suggest that the Fifteenmile Group is younger than the Wernecke Breccia. Field investigation in 2009 confirmed this relationship: units PR1 and PR5 are not bleached and have not been affected by the emplacement of Wernecke Breccia.

The following observations of the lower Fifteenmile Group were made while traversing three sections in the 2009 field season. Unit PR1 comprises grey- and orange-weathering, black mudstone, with pencil cleavage, interbedded with grey to brown, very fine to coarse, silty sandstone beds approximately 10 cm thick. The clastic rocks are overlain by an orange-weathering, silty dolostone with bedding 1-5 cm thick. The light-grey-weathering dolostone of unit PR2 is bedded (layers 4-50 cm thick) and alternates between laminated beds and massive beds crosscut by an intense white veining with no distinct orientation. A second set of pink veins crosscuts both beds. Stylolites separate the beds and the rock is fetid. Another notable feature of unit PR2 is flat-pebble conglomerate with planar clasts 1-10 cm long. Unit PR3 comprises stromatolitic dolostone with stromatolites approximately 10 cm across and 30 cm high at the top of the unit, but 1-2 m in diameter lower in the unit. Subtle pink carbonate veins are present throughout the unit. Chert nodules and buff weathering are characteristic of unit PR4 dolostone. Unit PR5 is largely as described by Thompson *et al.* (1992), with the exception of desiccation cracks in the shale.

Sampling

Sixteen samples were collected for geochemical and isotopic analyses and six samples were collected for geochronological analysis. Two of the six samples collected for geochronological analyses are from fine-grained, green, diorite dykes (2-12 m wide): one crosscutting PR2 and another crosscutting PR5. Analytical results will be compared with those from the Pinguicula Group.

Correlations with Pinguicula Group

Correlations between the Pinguicula Group and the lower Fifteenmile Group are based on stratigraphic similarity to the two lower units of the lower Fifteenmile Group, and on similar contact relationships with the underlying Wernecke Supergroup. In contrast to the descriptions of Thompson *et al.* (1992), unit PR1 of the lower Fifteenmile Group unconformably overlies the Wernecke Breccia. This relationship is analogous to that in the Wernecke Mountains, where unit A of the Pinguicula Group unconformably overlies bleached Wernecke Breccia at the Pika occurrence. In addition, unit PR1 and units A and B of the Pinguicula Group have similar stratigraphic characteristics, including sandstones overlain by black and green siltstone and orange-weathering dolostone. Similarities can also be drawn between unit PR2 and Pinguicula Group unit C, which are both grey-weathering dolostones. The presence of stromatolites in unit PR3 but not in the Pinguicula Group makes such a correlation less plausible: unit PR3 is better equated with the Hematite Creek Group. Units PR4 and PR5 are dissimilar to the Pinguicula Group, but contain abundant shallow-water features such as ripple marks and mudcrack casts, and are favourably correlated with strata of the Hematite Creek Group.

MINERALIZATION

Three styles of mineralization were identified during the field work. Two of the styles involve Cu enrichment and one involves Pb and possibly Ag enrichment. All may be worth consideration in mineral exploration programs.

One style of Cu enrichment is present in units that underlie the Pinguicula Group (Wernecke Supergroup and Wernecke Breccia), within a few metres of the sub-Pinguicula unconformity. This phenomenon was noted at three localities: two in the Ogilvie Mountains and one in the Wernecke Mountains. In the Wernecke Mountains, the Pika occurrence (UTM 572861E, 7191172N) was originally described by Thorkelson (2000) as supergene oxide mineralization within Wernecke Breccia and adjacent strata of the Wernecke Supergroup. The mineralization is expressed as malachite staining on fracture surfaces in bleached and crumbly rock that apparently formed during subaerial weathering, leaching and supergene mineralization prior to deposition of the Pinguicula Group.

In the Ogilvie Mountains, this style of mineralization is present beneath units PR1 and PR5 (UTM 552687E, 7186821N and UTM 549570E, 7188381N respectively) of the lower Fifteenmile Group (Thompson *et al.,* 1992). Beneath both units, underlying zones of Wernecke Breccia are bleached and fractured, and host local fracture-fillings of malachite. The prevalence of malachite-staining beneath the Pinguicula and lower Fifteenmile groups indicates that supergene enrichment of Wernecke Breccia-related Cu-mineralization is widespread in the Proterozoic inliers and locally augments pre-existing hypogene mineralization; such secondary enrichment may add economic value to underlying zones of Wernecke Breccia.

The second style of Cu mineralization is in unit A of the Pinguicula Group and is most prominent at a locality overlooking the Bonnet Plume River near the southeast corner of map area 106C/13 (UTM 563803E, 7184575N). The mineralization consists of malachite-staining on platy siltstone and nodules (0.5-2 cm diameter) of pyrite altered to limonite, with additional malachite-staining surrounding individual nodules.

The Pb and possibly Ag mineralization is in a set of veins that crosscut the Pinguicula Group 8 km south and 2 km west of the confluence of the Bonnet Plume River and Kohse Creek (approximate UTM 572779E, 7150112N). The veins are approximately 2 m wide, highly weathered, and their original constituents have been largely converted to earthy encrustations and fracture-fillings of limonite, possibly anglesite and other minerals or mineraloids. Remnants of galena within the weathered vein material were noted in one of the veins. At depth, these veins probably contain greater abundances of the original vein minerals. Possible Ag mineralization in these veins is suggested by the presence of galena- and silver-bearing veins in the region (*e.g.*, Yukon MINFILE, 106C 001, Kohse prospect).

CONCLUSIONS

Contacts between units A, B and C of the Pinguicula Group are gradational. The gradational contact between units A and B was previously suggested, but the nature of the contact between units B and C was not well understood. Firm documentation of a gradational contact between units B and C confirms that all units of the Pinguicula Group belong to a single, conformable succession.

The age of the Pinguicula Group may not be as old as previously considered by Thorkelson *et al.* (2005). A 1380 Ma dyke, previously thought to crosscut Pinguicula unit A, is now regarded as crosscutting only the Wernecke Supergroup. The contact relationship between the Pinguicula Group and the Hart River sills is now comparable to the relationship in the eastern Ogilvies documented by Abbott (1997), which shows the Pinguicula Group unconformably overlying the Hart River sills and possibly related volcanic strata. Elimination of the crosscutting relationship between the 1380 Ma intrusion and the Pinguicula Group means that the latter could be nearly as young as the overlying Hematite Creek Group, and may be more appropriately placed in Sequence B of Young *et al.* (1979), rather than Sequence A. Forthcoming age determinations on detrital minerals and crosscutting dykes may further constrain the age and affinity of the Pinguicula Group.

Correlations between the Pinguicula Group and strata in the adjacent western Ogilvie Mountains were revisited. At this stage, correlations between PR1 and PR2 of the lower Fifteenmile Group with units A, B and C of the Pinguicula Group seem most favourable. Additional work involving comparison of isotopic signatures and detrital mineral populations will serve to test this hypothesis.

Cu, Pb and possibly Ag mineral enrichments were identified in both the Wernecke and western Ogilvie mountains. Two styles of Cu enrichment were identified: one in the underlying Wernecke Supergroup and one in unit A of the Pinguicula Group. Lead, and possibly Ag enrichments, are present east of Kohse Creek, near the Kohse occurrence, in a series of veins that crosscut what is thought to be unit A of the Pinguicula Group.

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