Paleoproterozoic deformation of the Racklan Orogeny, Slats Creek (106D/16) and Fairchild Lake (106C/13) map areas, Wernecke Mountains, Yukon

Marc-André Brideau, Derek J. Thorkelson[1], Laurent Godin and John R. Laughton
Simon Fraser University[2]

Brideau, M-A., Thorkelson, D.J., Godin, L. and Laughton, J.R., 2002. Paleoproterozoic deformation of the Racklan Orogeny, Slats Creek (106D/16) and Fairchild Lake (106C/13) map areas, Wernecke Mountains, Yukon. *In:* Yukon Exploration and Geology 2001, D.S. Emond, L.H. Weston and L.L. Lewis (eds.), Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 65-72.

ABSTRACT

Three events of Paleoproterozoic deformation are recognized in schist of the Fairchild Lake Group (Wernecke Supergroup) in the Wernecke Mountains. The first event produced a chloritoid ± garnet and opaque porphyroblastic, chloritoid-chlorite-muscovite-quartz schist. Pressure-temperature conditions have been estimated to lie between 3-6 kbar and 450-550°C. The second event produced a crenulation, and the third generated kink bands. All of these features are crosscut by 1.60 Ga Wernecke Breccia. These events are regarded as products of the Racklan Orogeny, a Paleoproterozoic interval of orogenesis, which favourably correlates with the Fifteenmile Orogeny in the Ogilvie Mountains of western Yukon and the Forward Orogeny in the Northwest Territories.

RÉSUMÉ

On reconnaît trois événements de déformation paléoprotérozoïque du schiste du Groupe de Fairchild Lake (Supergroupe de Wernecke), dans les monts Wernecke. Le premier événement a produit du schiste à quartz-muscovite-chlorite chloritoïde contenant des porphyroblastes de chloritoïde ± de grenat et d'un minéral opaque. On estime que les conditions de pression et température s'établissaient entre 3 et 6 kbar et entre 450 et 550°C. Le second événement a engendré une crénulation et le troisième des zones de plis en chevrons. Toutes ces déformations sont recoupées par la brèche de Wernecke datant de 1,6 milliard d'années. On estime que ces événements résultent de l'orogenèse du Racklan, qui est un intervalle paléoprotérozoïque d'orogenèse, présentant des corrélations favorables avec l'orogenèse de Fifteenmile, dans les monts Ogilvie, et avec l'orogenèse de Forward, dans les Territoires du Nord-Ouest.

[1]*dthorkel@sfu.ca*

[2]*Earth Sciences, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6*

INTRODUCTION

Proterozoic unconformities and deformational structures in pericratonic strata along the northwestern margin of ancestral North America have been recorded by several authors (Wheeler, 1954; Gabrielse, 1967; Eisbacher, 1978; Yeo et al., 1978; Kerans et al., 1981; Thompson and Roots, 1982; Mercier, 1989; Cook, 1992; Cook and MacLean, 1995; Thorkelson, 2000). In Yukon, four main periods of Paleoproterozoic to Neoproterozoic age deformation have been recognized (Eisbacher, 1978; Young et al., 1979; Abbott, 1997; Thorkelson, 2000). This paper concentrates on the oldest set of deformation features, specifically those which affected the Paleoproterozoic Wernecke Supergroup before emplacement of Wernecke Breccia at 1.60 Ga (Thorkelson et al., 2001a). These events are recorded by mesoscopic and microscopic structures in the Wernecke Supergroup and are particularly well developed in the 'Slab Mountain' area of the Wernecke Mountains, herein called the study area (Fig. 1). Thorkelson (2000) applied the name Racklan Orogeny to these events, using the term in a more specific sense than originally applied by Gabrielse (1967). The nature of Racklan Orogeny, as applied to pre-1.60 Ga events, is characterized and evaluated in this report.

SUMMARY OF FIELD RELATIONS

The study area is located in the vicinity of 'Slab Mountain' and 'Slab Ridge' (informal names), northeast of the Bonnet Plume River, at approximately Latitude 65°N and Longitude 134°W. Geologic units in the study area consist of the Fairchild Lake Group of the Wernecke Supergroup (Delaney, 1981), the Slab volcanics (Laughton et al., this volume), the 1.71 Ga Bonnet Plume River Intrusions (Thorkelson et al., 2001b), and 1.60 Ga Wernecke Breccia (Bell and Delaney, 1977; Thorkelson et al., 2001a; Hunt et al., this volume). The structures described in this report

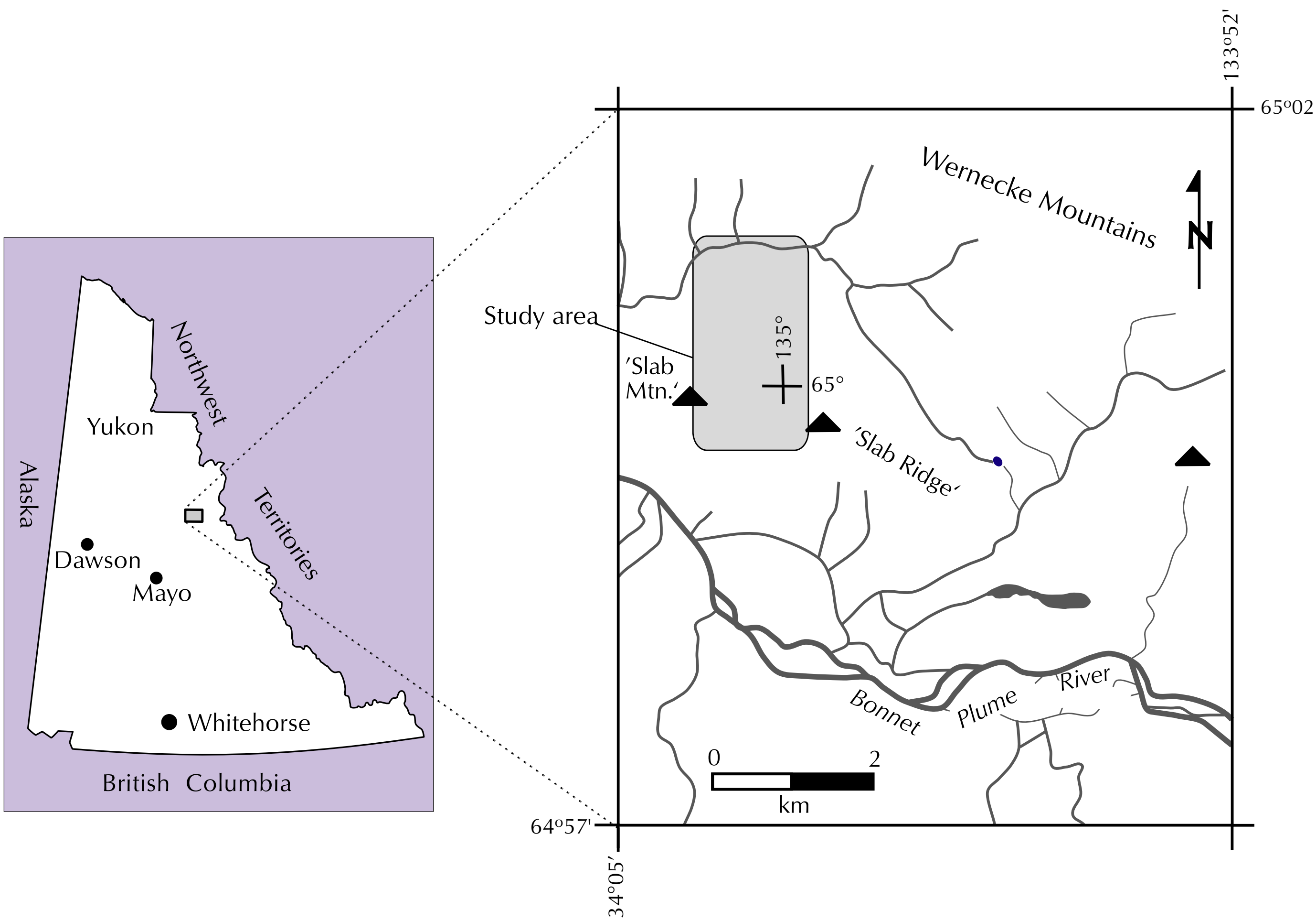

Figure 1. *Regional map displaying the location of the study area in the Wernecke Mountains.*

are best displayed in the area between Slab Mountain and Slab Ridge, where siltstone of the Fairchild Lake Group (Delaney, 1981; Thorkelson, 2000) is deformed into a northwest-striking belt of schist (Fig. 2). Original sedimentary features such as bedding and cross-laminations are commonly preserved in the sedimentary rocks that flank the schist belt. The transition from mudrock to pelitic schist typically occurs over a width of 10-30 m. Zones of Wernecke Breccia, and dykes and small stocks of the dioritic Bonnet Plume River Intrusions crosscut the schist and the sedimentary rocks (Bell and Delaney, 1977; Thorkelson et al., 2001b). The breccia zones consist mainly of clasts of siltstone, subordinate schist and diorite set in a hydrothermally precipitated matrix. The Slab volcanics occur as a megaclast in a large zone of Wernecke Breccia to the southwest of the schist belt (Laughton et al., this volume). Sedimentary bedding is moderately to steeply dipping, and the ridge is situated on the northern limb of an upright to overturned anticlinorium that closes to the south (Thorkelson, 2000). The schist belt appears to represent a region of relatively high strain, possibly developed in a region of tight parasitic folding in the anticlinorium (Thorkelson, 2000). The connection between deformational fabrics and the anticlinorium, however, has not been rigorously demonstrated.

THREE EVENTS OF PALEOPROTEROZOIC DEFORMATION

Three distinct fabrics in the schist represent three discrete phases of deformation. The first deformational (D_1) event produced a penetrative schistosity, the second (D_2) produced crenulations, and the third (D_3) generated kink bands. All three events are interpreted to have occurred prior to 1.60 Ga, as evidenced by randomly oriented clasts of kinked schist present in the Wernecke Breccia

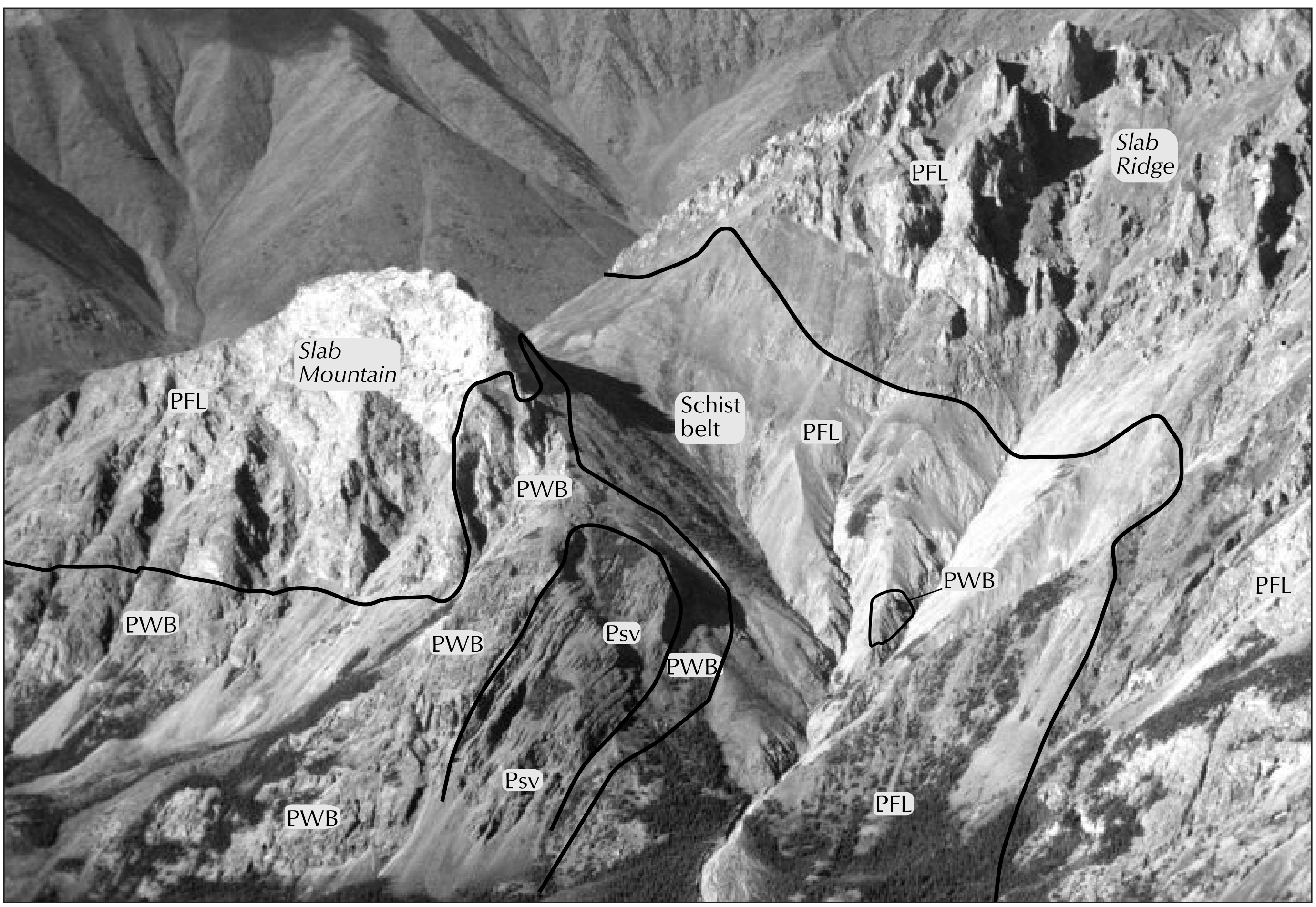

Figure 2. Study area on Slab Mountain and Slab Ridge. View to the northwest. PWB = Wernecke Breccia, PFL = Fairchild Lake Group, PSv = Slab volcanics.

(Thorkelson, 2000). Clasts of tightly folded siltstone are also present in the breccia of the study area. The folds are decimetre- to metre-scale and are truncated at the margins of the clasts, indicating that they formed prior to breccia development. The folding probably occurred during either the first or second events of deformation recorded in the schist. Younger events of folding and faulting (Mesoproterozoic to Tertiary) have been identified in the Wernecke Mountains (Green, 1972; Eisbacher, 1978; Thorkelson, 2000) and some are likely to have affected the study area. Although younger structural features have not been directly identified, the authors expect the Paleoproterozoic fabrics to be affected by younger events and stereonet analysis to be complicated by the resulting faults and folds.

D_1 STRUCTURES

In the study area, the oldest structural feature is a fine-grained schistosity in metapelitic rocks of the Fairchild Lake Group. The schist is typically greenish grey and consists of chloritoid porphyroblasts (0.5-3 mm; Fig. 3) set in a penetrative continuous schistosity (S_1), outlined by fine-grained chlorite, muscovite, quartz and opaques. The stereogram in Figure 4 illustrates the distribution of poles to schistosity in the study area. The poles define a broad great circle, interpreted as a consequence of folding about a hinge line plunging gently (~10°) to the northwest. Rotated opaques (1-2 mm), probably magnetite, were observed in hand sample. In thin section, well developed sigma and phi pressure shadows were found around porphyroblasts of chloritoid and opaques (Fig. 3).

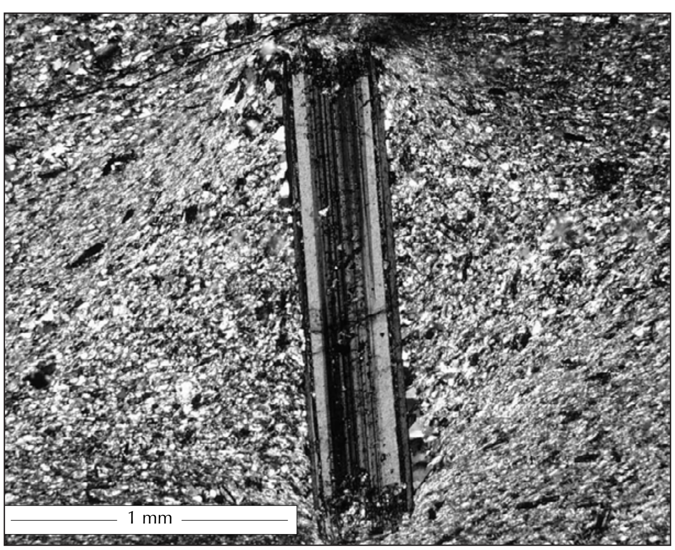

Figure 3. Photomicrograph (in cross-polarized light) of chloritoid porphyroblast with pressure shadows.

Compositional layering is highlighted by alternating light coloured (muscovite and quartz-rich) and dark coloured (chlorite and chloritoid-rich) bands, 1-10 cm wide. These layers are commonly oriented at a high angle to the schistosity and appear to represent deformed and possibly transposed sedimentary beds and laminae. Garnet porphyroblasts occur along with chloritoid porphyroblasts in another belt of schist approximately 3 km east of the study area.

D_2 STRUCTURES

In many localities within the study area, the S_1 schistosity has been deformed (D_2) into tight asymmetric crenulations (L_2). The crenulations, which have a typical wavelength of 1-2 mm and an amplitude of < 1 mm, are principally defined by deformed quartz, muscovite, chlorite and opaque grains. No new minerals grew during the crenulation-forming event. The limbs of the crenulations are locally highly attenuated, resulting in a crenulation cleavage (S_2). The distribution of crenulation lineations in Figure 5 indicates a dominant northwest- to southeast-trending, shallowly plunging orientation. This orientation is similar to that of the fold axis calculated from the poles to S_1 schistosity (Fig. 4) suggesting that

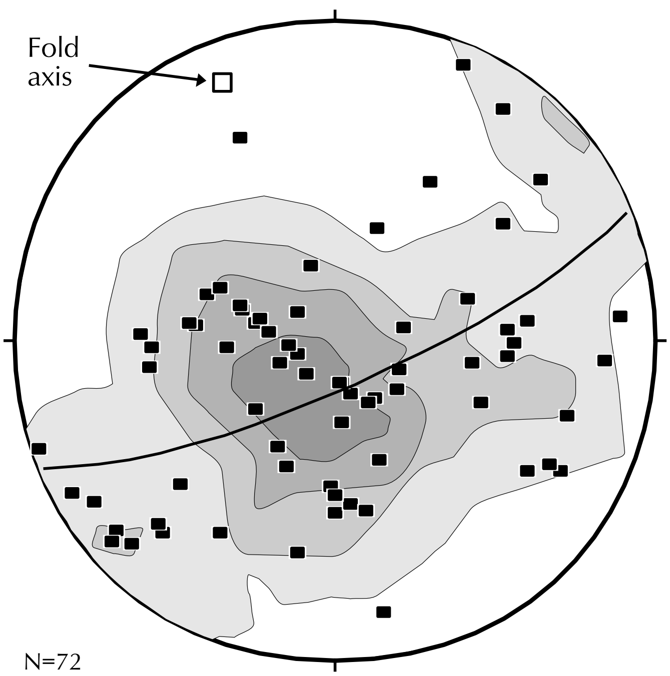

***Figure 4.** Stereogram of poles to schistosity. The orientations of the schistosity appear to be controlled by folding about an axis plunging 12° toward 336°. Great circle and fold axis represent a computer-generated best fit.*

crenulation development and folding S_1 belong to the same phase of deformation (D_2).

D_3 STRUCTURES

Kink bands are abundant in the schist, either as groups of parallel bands or in conjugate, intersecting sets. The kinks affect the orientation of both the main schistosity and the crenulations, and are therefore assigned to a third phase of deformation. The width of most of the bands ranges from 2 to 20 mm. Although the kink bands are mainly restricted to the schist, a small proportion also occurs in sedimentary rock beyond the boundaries of the schist belt. As with the crenulations, the kinks are not associated with new mineral growth. Preliminary stereonet analysis of the kink bands did not reveal any dominant trend in distribution.

METAMORPHIC CONDITIONS

Metamorphism during schist development (D_1) is characterized as lower- to middle-greenschist grade, based on an equilibrium mineral assemblage of chlorite, muscovite, chloritoid and quartz.

This assemblage indicates a maximum temperature of 550°C, according to mineral stabilities in the KFMASH (K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O) system shown on AFM (Al_2O_3-FeO-MgO) projections from Bucher and Frey (1994) for metapelites (Fig. 6). The presence of garnet as well as chloritoid porphyroblasts approximately 3 km east of the study area was used to constrain the minimum temperature of metamorphism. Garnet has a high variability in temperature of first appearance in metapelites (Bucher and Frey, 1994). This temperature is controlled by the presence of manganese and calcium. In the presence of these elements, the temperature of first appearance is approximately 450°C (Bucher and Frey, 1994; Fig. 6). Pressure of formation is poorly constrained by the mineral assemblage. Pressure was estimated to be 3-6 kbar by assuming geothermal gradients range from 25-30°C/km, which are typical of continental environments (Hall, 1996; Raymond, 1995). This pressure corresponds to depths ranging from 15-22 km, based on pelitic rock densities of 2250-2700 kg/m^3. This depth estimate is somewhat greater than the expected minimum 7.4 km to 12.9 km depth range of the Fairchild Lake Group that would have existed if the Fairchild Lake Group were overlain only by the younger strata of the Wernecke Supergroup (i.e., the 3.4-km-thick Quartet Group and the >4-km-thick Gillespie Lake Group; Delaney, 1981; Thorkelson, 2000). The absence of new mineral growth during D_2 (asymmetric crenulation of the schistosity), and D_3 (kink-band formation), suggests that metamorphic conditions did not change appreciably from the end of D_1

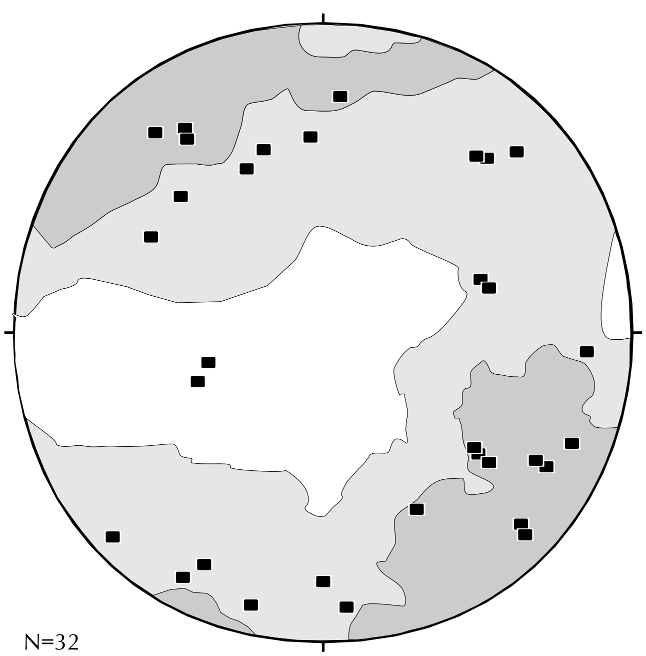

Figure 5. Stereogram of the crenulation lineation measurements. The lineations preferentially trend northwest and southeast.

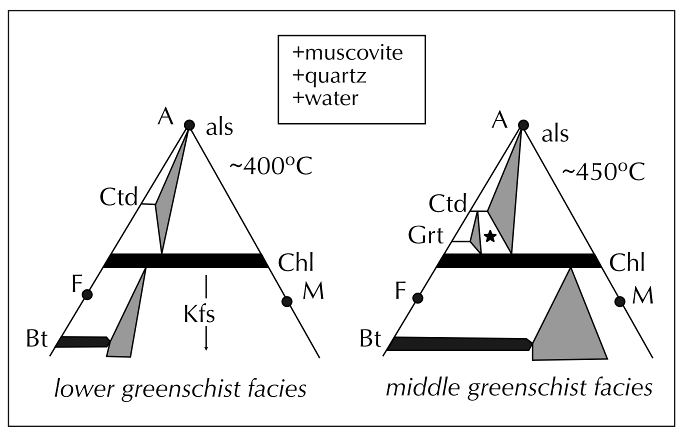

Figure 6. Mineral assemblages in the KFMASH (K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O) system shown on AFM projections. At 400°C chloritoid is stable and at 450°C chloritoid and garnet are stable. Star represents inferred composition of schist in study area. A = Al_2O_3, F = FeO, M = MgO, als = aluminium silicates, Bt = biotite, Chl = chlorite, Ctd = chloritoid, Grt = garnet, Kfs = K-feldspar (modified from Bucher and Frey, 1994).

(schistosity formation) to the end of D_3 (kink-band formation).

RACKLAN OROGENY: DEFINITION AND RECOMMENDED USAGE

The three events of Paleoproterozoic deformation recorded in the study area are herein regarded as products of the Racklan Orogeny. However, the term Racklan Orogeny has been used to describe more than one unconformity in the Yukon and in the subsurface of the Northwest Territories, and therefore requires clarification. The term Racklan Orogeny was originally applied by Gabrielse (1967) to describe an angular unconformity between 'Purcell-like' strata and the Rapitan Group in the North Rackla River area of Yukon, approximately 60 km south of the study area. The foundation for this description was an angular unconformity between rocks of uncertain affinity previously recorded by Wheeler (1954), and other rocks of uncertain affinity. Subsequently, Eisbacher (1978), Young et al. (1979) and Wheeler and McFeely (1991) recognized that the unconformity noted by Wheeler (1954) actually separated the Wernecke Supergroup from the Pinguicula Group and that the unconformity was well exposed throughout much of the Wernecke Mountains. The lower part of the Pinguicula Group hosts the 1.38 Ga Hart River sills (Blusson, 1974; Abbott et al., 1997; Thorkelson, 2000), constraining the age of the Racklan Orogeny to >1.38 Ga.

Thorkelson (2000) provided evidence that the Racklan Orogeny occurred prior to 1.60 Ga. The evidence lies in the abundance of deformational features in the Wernecke Supergroup (described herein) that are crosscut by Wernecke Breccia (1.60 Ga), and the paucity of deformational features younger than the breccia (and older than the Pinguicula Group). Furthermore, the earliest phase of pre-1.60 Ga deformation, which produced schistosity in the Wernecke Supergroup, has been tentatively linked to large-scale folding (Thorkelson, 2000), and is therefore a plausible cause of the angular unconformity beneath the Pinguicula Group. Similarly, the second and third pre-breccia events that yielded crenulations and kink bands in the study area may have been concurrent with the formation of larger structures that could have deformed the Wernecke strata into folds or tilted panels. These relations infer that the three deformation events described in this report appropriately account for the Racklan discordance, and that Racklan Orogeny is favourably restricted to pre-1.60 Ga.

REGIONAL CORRELATION

The Racklan orogenic events in the Wernecke Mountains appear to correlate with two other intervals of Paleoproterozoic deformation: the Forward Orogeny in the Northwest Territories (a correlation proposed by Cook and MacLean, 1995), and the Fifteenmile Orogeny in the Ogilvie Mountains of western Yukon (Mercier, 1989). The Forward Orogeny records deformation concurrent with eruption of the Narakay volcanics at ca. 1.66 Ga (Bowring and Ross, 1985; Cook and MacLean, 1995), and is consistent with a pre-1.60 Ga age for the Racklan Orogeny in the Wernecke Mountains (Thorkelson et al., 1998). The Fifteenmile Orogeny is inferred from unconformable relations between the Wernecke Supergroup and the Fifteenmile Group, which has been correlated, in part, with the Pinguicula Group (Abbott, 1997). Taken together, these orogenic events appear to belong to an interval of widespread regional tectonism, which occurred prior to deposition of the Pinguicula Group and correlative strata. Regional thin-skinned deformation extending from Yukon to the Northwest Territories, largely recognized in seismic reflection profiles, was referred to as Racklan Orogeny by Cook (1992). However, some of the deformation considered by Cook (1992) occurred after deposition of the Pinguicula Group and cannot be part of the Racklan Orogeny as used by Thorkelson (2000) and in this report. Additional work is required to clarify the timing, nature and correlation of the unconformities observed in the subsurface.

CONCLUSIONS

1. Three discrete events of pre-1.60 Ga deformation are recorded in the schist of the Fairchild Lake Group of the Wernecke Supergroup. The first event (D_1) produced a schistosity at lower- to middle-greenschist grades. The D_2 and D_3 events produced crenulations and kink bands, respectively. The D_1 schistosity appears to have been folded about a northwest-trending axis, possibly during D_2 or D_3.
2. The metamorphic conditions present during D_1 are estimated to be between 450-550°C and 3-6 kbar, corresponding to a depth of ~15-22 km. Following D_1, the mineral assemblage remained unchanged, implying that peak metamorphic conditions developed during D_1.

3. The deformation and metamorphism observed in the study area are regarded as products of Racklan Orogeny. This interval of orogenesis, as originally recognized, occurred between deposition of the Wernecke Supergroup and the Pinguicula Group. Relations described in this report suggest that most, if not all, of the Racklan orogenic activity occurred prior to 1.60 Ga, the age of Wernecke Breccia emplacement. The Racklan Orogeny, as used in this report, is considered equivalent to the Fifteenmile Orogeny of western Yukon, and the Forward Orogeny of the Northwest Territories.

ACKNOWLEDGEMENTS

This research was supported by an NSERC undergraduate student research awarded to Marc-André Brideau, a Lithoprobe grant to Derek Thorkelson, a Northern Studies Training Program grant to John Laughton, and the Yukon Geology Program. Newmont Mines Limited permitted access to unpublished maps and reports. Dan Marshall provided information on metamorphic rocks. Florine Lawrance provided helpful comments on earlier drafts of the manuscript.

REFERENCES

Abbott, G., 1997. Geology of the Upper Hart River Area, Eastern Ogilvie Mountains, Yukon Territory (116A/10, 116 A/11). Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Bulletin 9, 92 p.

Abbott, G., Thorkelson, D., Creaser, R., Bevier, M.L. and Mortensen, J., 1997. New correlations among Proterozoic successions and intrusive breccias in the Ogilvie and Wernecke mountains, Yukon. *In:* Lithoprobe Report No. 56, p. 188-197.

Bell, R.T. and Delaney, G.D., 1977. Geology of some uranium occurrences in Yukon Territory. *In:* Report on Activities, Part A, Geological Survey of Canada, Paper 77-1A, p. 33-37.

Blusson, S.L., 1974. Geology of the Nadaleen River, Lansing, Niddery Lake, Bonnet Plume Lake, and Mount Eduni map areas, Yukon Territory. Geological Survey of Canada, Open File 205, 1:250 000 scale.

Bowring, S.A. and Ross, G.M., 1985. Geochronology of the Narakay Volcanic Complex: Implications for the age of the Coppermine Homocline and Mackenzie igneous events. Canadian Journal of Earth Sciences, vol. 22, p. 774-781.

Bucher, K. and Frey, M., 1994. Petrogenesis of Metamorphic Rocks, 6th Edition. Complete Revision of Winkler's Textbook. Springer-Verlag, New York, 434 p.

Cook, D.G. and MacLean, B.C., 1995. The intracratonic Paleoproterozoic Forward Orogeny, and implication for regional correlation, Northwest Territories, Canada. Canadian Journal of Earth Sciences, vol. 32, p. 1991-2008.

Cook, F.A., 1992. Racklan Orogen. Canadian Journal of Earth Sciences, vol. 29, p. 2490-2496.

Delaney, G.D., 1981. The mid-Proterozoic Wernecke Supergroup, Wernecke Mountains, Yukon Territory. *In:* Proterozoic Basins of Canada, F.H.A. Campbell (ed.), Geological Survey of Canada, Paper 81-10, 23 p.

Eisbacher, G.H., 1978. Two major Proterozoic unconformities, northern Cordillera. *In:* Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 53-58.

Gabrielse, H., 1967. Tectonic evolution of the northern Canadian Cordillera. Canadian Journal of Earth Sciences, vol. 4, p. 271-298.

Green, L.H., 1972. Geology of Nash Creek, Larsen Creek, and Dawson Creek map-areas, Yukon Territory. Geological Survey of Canada, Memoir 364, 157 p.

Hall, A., 1996. Igneous Petrology, Second Edition. Longman Group Limited, New York, 568 p.

Hunt, J.A., Laughton, J.R., Brideau, M-A., Thorkelson, D.J., Baker T. and Brookes M., 2002 (this volume). New mapping around the Slab iron oxide-copper-gold occurrence, Wernecke Mountains (parts of NTS 106C/13, 106D/16, 106E/1 and 106F/4), Yukon. *In:* Yukon Exploration and Geology 2001, D.S. Emond, L.H. Weston and L.L. Lewis (eds.), Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 125-138.

Kerans, C., Ross, G.M., Donaldson, J.A. and Geldsetzer, H.J., 1981. Tectonism and depositional history of the Helikian Hornby Bay and Dismal Lakes Groups, District of Mackenzie. *In:* Proterozoic Basins of Canada, F.H.A. Campbell (ed.), Geological Survey of Canada, Paper 81-10, p. 157-182.

Laughton, J.R., Thorkelson, D.T., Brideau, M-A. and Hunt, J.A., 2002 (this volume). Paleoproterozoic volcanism and plutonism in the Wernecke Mountains, Yukon. *In:* Yukon Exploration and Geology 2001, D.S. Emond, L.H. Weston and L.L. Lewis (eds.), Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 139-145.

Mercier, E., 1989. Evénements tectoniques d'origine compressive dans le Proterozoique du nord de la Cordillère canadienne (montagnes Ogilvie, Yukon). Canadian Journal of Earth Sciences, vol. 26, p. 199-205.

Raymond, L.A., 1995. Petrology: The Study of Igneous, Metamorphic and Sedimentary Rocks. McGraw-Hill Higher Education, New York, 742 p.

Thompson, R.I. and Roots, C.F., 1982. Ogilvie Mountains Projects, Yukon: Part A: A new regional mapping program. Scientific and Technical Notes. *In:* Current Research, Part A, Geological Survey of Canada, Paper 82-1A, p. 403-414.

Thorkelson, D.J., 2000. Geology and mineral occurrences of the Slats Creek, Fairchild Lake and "Dolores Creek" areas, Wernecke Mountains, Yukon Territory (106D/16, 106C/13, 106C/14). Exploration and Geological Division, Yukon Region, Indian and Northern Affairs Canada, Bulletin 10, 73 p.

Thorkelson, D.J., Abbott, J.G., Mortensen, J.K., Creaser, R.A. and Villeneuve, M.E., 1998. Proterozoic sedimentation, magmatism, metasomatism and deformation in the Wernecke and Ogilvie Mountains, Yukon. *In:* Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (March 6-8), Simon Fraser University, F. Cook and P. Erdmer (comps.), 1998, Lithoprobe Report No. 64, p. 110-119.

Thorkelson, D.J., Mortensen, J.K., Davidson, G.J., Creaser, R.A., Perez, W.A. and Abbott, J.G., 2001a. Early Mesoproterozoic intrusive breccias in Yukon, Canada: The role of hydrothermal systems in reconstructions of North America and Australia. Precambrian Research, vol. 111, p. 31-55.

Thorkelson, D.J., Mortensen, J.K., Creaser, R.A., Davidson, G.J. and Abbott, J.G., 2001b. Early Proterozoic magmatism in Yukon, Canada: Constraints on the evolution of northwestern Laurentia. Canadian Journal of Earth Sciences, vol. 38, p. 1479-1494.

Yeo, G.M., Delaney, G.D. and Jefferson, C.W., 1978. Two major Proterozoic unconformities, Northern Cordillera: Discussion. *In:* Current Research, Part B, Geological Survey of Canada, Paper 18-1B, p. 225-230.

Young, G.M., Jefferson, C.W., Delaney, G.D. and Yeo, G.M., 1979. Middle and late Proterozoic evolution of the northern Canadian Cordillera and Shield. Geology, vol. 7, p. 125-128.

Wheeler, J.O., 1954. A geological reconnaissance of the Northern Selwyn Mountains region, Yukon and Northwest Territories. Geological Survey of Canada, Paper 53-7, 42 p.

Wheeler, J.O. and McFeely, P. (comps.), 1991. Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America. Geological Survey of Canada, Map 1712A, 1:2 000 000 scale.