DESCRIPTIVE NOTES

INTRODUCTION

This Half Way Hills and Whitehills Lake map is one of a group of new A-series bedrock geology maps arising from the Woodburn project, under the auspices of the Western Churchill NATMAP program. Fieldwork from 1996–2000 addressed the stratigraphic relationships, age, tectonic setting, and deformation history of supracrustal and plutonic rocks in the Churchill Province north of Baker Lake, Nunavut (Fig. 1). The geology of the Half Way Hills and Whitehills Lake map is based primarily on mapping carried out during 1997, 1999 and 2000, supplemented in the western half of the area by field observations by F.C. Taylor and I.R. Annesley in 1980, and J.R. Henderson, M.N. Henderson and L. Pryer in 1989 (Taylor, 1985; Henderson and Henderson, 1994). This new A-series map supersedes previously published preliminary Open File maps (Zaleski et al., 2001b) and Current Research papers (Zaleski et al., 2000) on the area.

Supracrustal rocks in the map area have been previously assigned to the 'Woodburn Lake group' and 'Ketyet River group'. In past usage, the two groups run into each other with no clear distinction between their constituent lithological assemblages. The informal name 'Woodburn Lake group' was originally used in 1978 for Archean volcanic rocks, including ultramafic flows, and associated sedimentary rocks north of Tehek Lake and near the Meadowbank River (Amer Lake NTS 66 H/1, Ashton, 1988) (Fig. 2). Schau (1983) applied the informal name 'Ketyet River group' to supracrustal rocks, interpreted as Archean, east of Tehek and Whitehills lakes. In the Half Way Hills area, contiguous with the western margin of Schau's map, Taylor (1985) considered all the supracrustal rocks to be Archean and likely correlative with the 'Woodburn Lake group'. Henderson and Henderson (1994) referred to supracrustal rocks from north of Tehek Lake to Whitehills Lake (Fig. 2) as 'Woodburn Lake group'. New mapping and geochronology conducted during the Woodburn project show that the Ketyet River group and the Half Way Hills area include both Archean and Proterozoic supracrustal rocks (Zaleski et al., 2001b; Davis and Zaleski, unpublished data). Archean supracrustal rocks from the Meadowbank River to Whitehills Lake can be interpreted as a stratigraphic succession to which we apply the name Woodburn group.

The Woodburn group as defined here comprises a lower volcanic succession, the Meadowbank formation, overlain by an upper succession of dominantly sedimentary rocks subdivided into the Amarulik formation and the Ukalik formation (Table 1). The Meadowbank formation is further subdivided into four assemblages comprising three dated volcanic cycles (Davis and Zaleski, 1998; unpublished data): 1) the 2.735 Ga Sanningajukuluk assemblage, 2) the 2.72 Ga Nutipilik assemblage, 3) the Qugqiilik assemblage of unknown age, and 4) the 2.71 Ga Apuqti'naaqtuq assemblage.

In the Half Way Hills and Whitehills Lake map area, the oldest cycle of the Meadowbank formation (Sanningajukuluk assemblage) overlies Mesoarchean basement (Half Way Hills basement complex), and is in fault contact with the Amarulik formation (Table 1). An additional package of quartzite and interlayered volcanic rocks, the Whitehills belt, is in fault contact with the Sanningajukuluk assemblage. On the basis of detrital zircon ages, the Whitehills quartzite was inferred to stratigraphically overlie the Meadowbank formation (Zaleski et al., 2001b). Preliminary ages of detrital zircons suggest post-2.5 Ga deposition (Pehrsson et al., 2002, 'southern association' Ketyet River group). As the Whitehills quartzite belt is considerably younger than the Amarulik and Ukalik formations and potentially correlative with Paleoproterozoic ensialic basin deposits (ibid.), it is not considered to be part of the Woodburn group. The youngest recognized unit of supracrustal rocks in the area, the Paleoproterozoic Tasirjuaq conglomerate, consists of polymictic conglomerate, wacke and slate discontinuously exposed along syn-D_2 structures (see below).

As few of the geographic features in the area have formally recognized names, two types of geographic names are shown on the map. Formal geographic names are capitalized (e.g. Whitehills Lake). Traditional Inuit names in the Inuktitut language are given in Roman orthography (e.g. Sanningajukuluk), as well as in Inuktitut syllabics.

REGIONAL GEOLOGY

The Woodburn group lies in the Rae Province (Churchill Province), north of the regional geophysical anomaly interpreted by Hoffman (1988) as a major craton-scale suture, the Snowbird tectonic zone (Fig. 1). The Woodburn group occupies a central position along a northeasterly trending zone of comparable Neoarchean supracrustal belts spanning the breadth of the Western Churchill Province. These belts have been interpreted as rift-related deposits characterized by ultramafic-mafic rocks, terrigenous sedimentary rocks, and locally recognized basement.

The Woodburn succession comprises multiple cycles of bimodal volcanic rocks, associated felsic to mafic volcaniclastic rocks and iron-formation, overlain by quartzite and wacke. It is part of a belt of deformed supracrustal rocks extending northeasterly from Schultz Lake to beyond the Meadowbank and Quoich rivers (Fig. 2). The supracrustal rocks are enclosed by a voluminous suite of 2.62–2.60 Ga granite, and intrusive relationships can be demonstrated locally (Ashton, 1988; Roddick et al., 1992; Davis and Zaleski, 1998; Zaleski, in press). Subsequent to the emplacement of Neoarchean granite, four phases of ductile deformation affected the region (Pehrsson et al., 2000; Zaleski et al., 2001a). The dominant regional trends are defined by northwest-verging, tight to isoclinal, D_2 folds and associated faults that resulted in imbrication of volcanic rocks, basement, and quartzite and greywacke panels. The duration of penetrative ductile deformation in the region is limited by the undeformed deposits and intrusions of the ca. 1.84–1.81 Ga lower Baker Lake Group (Dubawnt Supergroup) (Rainbird et al., 2002).

Northwest of the Woodburn group (Fig. 2), deformed and metamorphosed Paleoproterozoic continental basin deposits of the Amer group locally preserve unconformable relationships to underlying 2.61 Ga granite (Tella et al., 1984; LeCheminant and Roddick, 1991). The Amer group has been interpreted as equivalent to the Hurwitz Group south of the Snowbird tectonic zone. Young (1984, 1988) proposed correlations of the basal quartzite and mafic volcanic rocks of the Amer group with the Kinga Formation and the Ameto Formation (Happotiyik member), respectively, of the lower Hurwitz Group. The Amer group has not been dated directly, but the lower Hurwitz Group is broadly bracketed as $> 2111 \pm 1$ Ma (Patterson and Heaman, 1991) and < 2.45 Ga (Heaman, 1994).

The volcanic assemblages of the Woodburn group have mostly been affected by greenschist-facies metamorphism. The northern and central Amarulik belt culminates at amphibolite facies with grade decreasing to both north and south (Fig. 2) (Zaleski et al., in press). Metamorphic grade increases to the east with garnet-biotite-sillimanite in pelitic wacke and sillimanite in quartzite south of Tehek Lake. Septa of supracrustal rocks extend into the high-grade terrane of the Tehek Lake plutonic complex and the Quoich River gneiss, the latter interpreted as high-grade equivalents of supracrustal rocks (Ketyet River group, Heywood and Schau, 1981; Schau et al., 1982). Similarly, Fraser (1988) considered paragneiss in the granulite terrane northeast of Woodburn Lake to be derived from Archean supracrustal protolith. The main regional metamorphism is interpreted as broadly syn-D_2 and Paleoproterozoic in age.

STRATIGRAPHY OF THE HALF WAY HILLS AND WHITEHILLS LAKE AREA

Half Way Hills basement complex

The oldest rocks in the area form a Mesoarchean basement complex that extends south of Sanningajukuluk to the Thelon River. The northeastern exposures are dominated by foliated to schistose granodiorite (unit Agd). Granodiorite samples from two locations both gave U-Pb zircon ages of 2.87 Ga (Davis and Zaleski, unpublished data). To the southwest, the basement complex includes banded mafic and felsic gneiss (unit Abg) locally cut by the foliated granodiorite (64°38.05' N, 96°17.17' W), indicating that the gneiss comprises an older (> 2.87 Ga) component of basement. The foliated granodiorite is cut by variably foliated to schistose mafic dykes, possibly representing several swarms and interpreted as feeders to overlying volcanic rocks. Comparable trace element signatures (unpublished data) suggest that a group of three subparallel dykes (64°39.15' N, 96°14.6' W) belongs to Whitehills volcanic rocks. Another dyke (64°39.1' N, 96°14.35' W) is interpreted as a feeder to Sanningajukuluk mafic rocks, but this remains to be verified. The southern and eastern contact of the basement complex to Whitehills volcanic rocks and quartzite is a fault marked by increased strain toward the contact, and a quartz-filled breccia zone (unit Pqv) developed in rocks on both sides. Along the northern and northwestern contact, basement granodiorite structurally overlies, or is in subvertical contact with mafic volcanic rocks of the Sanningajukuluk assemblage. The contact is marked by several metres of mafic schist with local low-strain lozenges preserving possible relict pillows. An enclave of low strain in a re-entrant along the western contact (64°39.40' N, 96°15.37' W), shows massive (foliated) mafic volcanic or subvolcanic rock in contact with strongly foliated granodiorite (unit Agd). The qualitative difference in strain between the mafic rock and granodiorite, and absence of a strain gradient toward the contact, suggest local preservation of a primary relationship between basement and stratigraphically overlying volcanic rocks.

Cryptic basement enclaves are likely present in the Neoarchean granite suite (unit Agt). Basement is inferred to extend south of Whitehills Lake, possibly encompassing lineated to mylonitic tonalite to granodiorite (unit Atnq) and gneissic to layered tonalite-amphibolite (unit Atng) and amphibolite (unit Aamp) south of Whitehills Lake.

WOODBURN GROUP

Meadowbank formation, Sanningajukuluk assemblage

The Sanningajukuluk assemblage extends from Kinngaaquk Tasia to the Thelon River. Its name is adopted from the traditional Inuit name for the large lake that lies across the assemblage. The assemblage is dominated by pillowed to massive mafic volcanic rocks (unit ASm), typically ophitic to subophitic to equigranular, with local plagioclase phenocrysts, and by mafic schist (unit ASms) derived from volcanic protolith. Minor komatiitic basalt (unit ASkb) (classification based on geochemical analyses, Kerswill et al., 1999) lies mainly to the north of the pillowed flows. Kerswill et al. (1999) described these as spinifex-textured flows, fine-grained massive flows, and polyhedral jointed flows, in some cases, with spinifex zones capped by flow-top breccia. The morphology of komatiitic flows indicates southward younging (J.R. Henderson, unpublished data, 1990; Kerswill et al., 1999). Pillow shapes also show dominantly southward younging (Taylor, 1985), but with local reversals (Kerswill et al., 1999) (see below).

The mafic rocks are interlayered with subordinate felsic and intermediate volcanic and volcaniclastic rocks (units ASfvc, ASfs), including quartz-porphyritic felsic volcanic rocks (unit ASfq) at the east end of Sanningajukuluk (64°41.5' N, 96°10.8' W), which gave a U-Pb zircon age of 2734 ± 2 Ma (Davis and Zaleski, unpublished data; sampling location recommended by B.A. Kjarsgaard and G.A. Jenner). Oxide-facies (unit ASif) and cherty-sulphidic iron-formation (unit ASch) are present locally in the volcanic rocks.

Both the northern and southern contacts of the Sanningajukuluk assemblage are northwest-verging reverse faults marked by discontinuous exposures of Paleoproterozoic Tasirjuaq conglomerate (see below). Along the northern contact, the assemblage structurally overlies younger wacke of the Amarulik formation. The contact is also marked by semicontinuous iron-formation and carbonate rocks (unit AScf) consisting of intensely carbonatized mafic-ultramafic rocks and layered to net-veined carbonate-quartz rocks, possibly derived from carbonate iron-formation. Pervasive carbonatization and discrete carbonate-altered shear zones extend into volcanic rocks south of the contact.

Amarulik formation

The Amarulik formation is named for Amarulik Lake north of the map area in the centre of the wacke belt (Zaleski et al., in press). Similar wacke extends to the southwest for nearly 100 km to south of Schultz Lake (Donaldson, 1966) (Fig. 2). The Amarulik formation in the map area mainly comprises feldspathic wacke with a large variable volcanogenic component (unit AAMwkq), tuffaceous or volcaniclastic wacke with abundant quartz and feldspar crystal clasts (unit AAMtf), and interlayered slate, mudstone and siltstone (unit AAMsl). Local mafic to intermediate volcaniclastic wacke (unit AAMmwk) contains amphibole porphyroblasts. Volcaniclastic wacke and slate are locally interbedded with silicate-facies iron-formation (unit AAMifs). The depositional age is broadly bracketed between 2.71 and > 2.61 Ga (Davis and Zaleski, unpublished data). The ages of detrital zircons indicate Mesoarchean and Neoarchean sources, including sources of similar age to the Sanningajukuluk assemblage. Several exposures of normally graded bedding in wacke north of the map area (northeast of Tasiraraujaq) indicate southward younging toward the volcanic assemblage, consistent with the interpretation that the Sanningajukuluk assemblage is in reverse fault contact with the structurally underlying Amarulik formation.

East of Tasiraraujaq and Whitehills Lake, metamorphic grade increases to amphibolite-facies and supracrustal rocks are recrystallized, in part to coarse-grained, porphyroblastic schist and gneiss. The Amarulik formation is represented by quartzite (unit AAMqz), locally with preserved clastic textures, and quartzite with abundant granitic sheets (unit AAMqzg), typically 1–5 m thick and locally conformable. The quartzite is associated with amphibole-clinopyroxene-plagioclase gneiss (unit AAMmg) with thin iron-formation interlayers, biotitic pelite (unit AAMpt) and biotite-muscovite paragneiss (unit AAMpa). West of Kinngaaquk Tasia, amphibole-clinopyroxene-plagioclase gneiss is interlayered with pelite (locally containing staurolite and garnet), biotite-hornblende schist, and thin quartzite layers. The amphibole gneiss is typically resistant to weathering and forms high ridges and hills, for example as at the landmark hill of Kinngaaquk for which Kinngaaquk Tasia is named (traditional names). Throughout the high grade area, quartzite commonly contains coarse-grained muscovite and is transitional to interlayered paragneiss containing sillimanite knots overgrown by coarse-grained muscovite and biotite. While the stratigraphic sequence is unknown, the lithological associations are similar to those of the basal section of the Amarulik formation well exposed northwest of Tehek Lake (north of the map area) (Fig. 2). There the stratigraphic succession comprises oligomictic conglomerate and quartzite, layered siliceous marble, chert and iron-formation, calc-silicate-bearing wacke with iron-formation interlayers, discontinuous quartzite lenses, and pelitic and feldspathic wacke at the top of the section (Zaleski et al., in press). Taking into account the higher metamorphic grade in the eastern Half Way Hills and Whitehills area, amphibole-clinopyroxene-plagioclase gneiss is interpreted as being derived from calc-silicate-bearing wacke protolith. The similarity to the succession northwest of Tehek Lake suggests that the quartzite and associated lithological units are strongly recrystallized basal Amarulik formation.

Whitehills quartzite belt

Clastic sedimentary rocks and subordinate volcanic rocks, referred to collectively as the 'Whitehills quartzite belt' underlie the area around Whitehills Lake and southwest to the Thelon River. Extensive exposures of white quartzite (unit APwqz) form the prominent relief north of the Half Way Hills and west of Whitehills Lake for which the belt is named. Radiometric dating shows that quartzite sampled near the Thelon River about 400 m above the granite contact (64°29.8' N, 96°27' W) contains Mesoarchean and Neoarchean detrital zircons, including zircons of similar age to the Sanningajukuluk assemblage and Half Way Hills basement granodiorite (Davis and Zaleski, unpublished data). Lithological features in common with the Paleoproterozoic Amer group, including the presence of hematitic quartzite, the paucity of pyritic conglomerate, and the presence of the volcanic rocks within the quartzite led Zaleski et al. (2001b) to consider the Whitehills belt (referred to as Kingarjuit) as of uncertain Archean or Paleoproterozoic age pending further constraints. Preliminary dates of detrital zircons suggest that deposition of pebbly feldspathic arenite postdated 2.5 Ga (Pehrsson et al., 2002).

To the north, the Whitehills belt is in fault contact with Mesoarchean basement and the Sanningajukuluk assemblage. The southern contacts are poorly exposed and both granite and quartzite are tectonized. Quartzite locally preserves clastic textures in gritty, pebbly and conglomeratic beds. Oligomictic conglomerate (unit APwqcg) and subarkose (unit APwqm) are locally present within the quartzite and around its periphery and, in some cases, adjacent to contacts with volcanic rocks. Oligomictic conglomerate is exposed along the contact with volcanic rocks in the hinge region of the F_2 synform west of Whitehills Lake (64°33' N, 96°18.5' W). The conglomerate fines from boulder-cobble conglomerate to pebbly sandstone toward the volcanic rocks. Fine-grained quartzite is typically massive to strongly cleaved, but schistose micaceous interbeds can be recognized locally. Metamorphic kyanite or sillimanite, and fuchsite are rare. Younging directions were determined based on locally preserved crossbedding and wave ripple marks.

Mafic to intermediate volcanic rocks (unit APwmi) of the Whitehills belt are at least in part interbedded with quartzite, locally with 'dirty' feldspathic quartzite or conglomeratic units along the contact. The volcanic rocks are remarkably homogeneous and massive, characterized by sparse to abundant plagioclase megacrysts in an ophitic to subophitic matrix. The megacrysts distinguish the volcanic rocks from those of the Sanningajukuluk assemblage, especially southeast of Sanningajukuluk where both volcanic suites occur together. The distinction is supported by geochemical analyses, which indicate a calc-alkaline signature for Whitehills rocks, in contrast to komatiitic and tholeiitic signatures for Sanningajukuluk rocks (Kerswill et al., 1999). Near the northern margin of the Whitehills belt, plagioclase megacrystic volcanic rocks are interlayered with quartzite. In one location (64°39.95' N, 96°8.63' W), dark quartzite in contact with volcanic rocks apparently contains detritus derived from the local volcanic substrate. North of Qaamiutaq and southeast of Sanningajukuluk, discontinuous volcanic rocks are apparently linked by a recessively weathering unit of subarkose or feldspathic quartzite, suggesting possible facies transitions.

In the higher grade domain east of Whitehills Lake, fine-grained homogeneous amphibolite and associated quartzite were interpreted as being equivalent to volcanic rocks and quartzite of the Whitehills belt. Black sulphidic pelite (unit APwpt) and minor associated paragneiss (unit APwpa) are tentatively included with the Whitehills belt, an interpretation supported by the presence of sulphidic pelite associated with quartzite and volcanic rocks on the southwestern and southern shores of Whitehills Lake. East of Whitehills Lake, quartzite to the south of sulphidic pelite contains numerous silicate-sulphide iron-formations (unit APwif) and gossans, atypical of the main Whitehills belt. Isolated zones of quartzite, pelite and paragneiss interleaved with tonalite (units Atng, Atnq) and granite (unit Agt) in the tectonized domain south of Whitehills Lake are tentatively considered to belong to the Whitehills belt.

Tasirjuaq conglomerate

Tasirjuak conglomerate as defined here comprises polymictic conglomerate (unit PTcg) and interbedded slate (unit PTsl) and wacke (unit PTwk) in discontinuous exposures in three narrow zones, localized along D_2 structures. Tasirjuaq conglomerate is present along the faulted contacts of the Sanningajukuluk assemblage with Amarulik wacke to the north and Whitehills quartzite to the south, and in the faulted hinge region of the F_2 synform through Whitehills Lake. The Tasirjuaq conglomerate is named for the traditional Inuit name for Whitehills Lake.

Polymictic conglomerate on the northern shore of Whitehills Lake was originally interpreted as lying at the stratigraphic base of the Whitehills quartzite (Taylor, 1985; Zaleski et al., 2001b). We now reinterpret the stratigraphic relationships in the light of new data that show that the conglomerate is Paleoproterozoic in age. Deposition of the Tasirjuaq conglomerate is bracketed to > 1.835 Ga, based on its involvement in D_2 deformation, and < 2.0 Ga based on the youngest detrital zircon in a sample collected near the northern shore of Whitehills Lake (64°38.95'N, 96°1.2' W) (Davis and Zaleski, unpublished data). We interpret it to overlie the Whitehills quartzite belt (Table 1). The contact with quartzite lies in a wide valley with no exposure. However, an area of intermittent outcrops (64°36.96' N, 96°9.16' W,) shows a transition from quartzite, to flaggy greywacke with minor pebbles in a few beds, to greywacke with pebbly-granular beds, to coarse polymictic conglomerate with pebbly-granular interbeds.

Clasts in the conglomerate include granite, syenite, quartzite and quartz-feldspar porphyry, intraformational wacke and conglomerate, and local amphibolite, laminated dolostone, mafic and felsic volcanic rocks, and chert. On Whitehills Lake near the geochronology sampling locality, several beds, 2–4 m thick, are dominated by syenite clasts, several centimetres to 1.5 m in size, in a matrix largely composed of finer syenitic detritus. The clasts show brecciation and dense fractures not evident in the matrix. Taylor (1985) reported massive to brecciated syenite overlain by syenite-clast conglomerate, which he interpreted as an unconformity developed on top of syenite. In contrast, we did not see evidence of in situ regolith or syenite, and the distribution of syenite boulders in several beds implies transport and deposition. The large size of the boulders and the presence of intact, internally brecciated clasts does suggest a proximal source.

PLUTONIC ROCKS

Plutonic rocks in the area are dominated by medium- to coarse-grained granite interpreted as belonging to the Neoarchean granite suite (unit Agt) dated to the north at 2.62–2.60 Ga. The granite varies from equigranular to porphyritic, commonly with microcline megacrysts or augen up to 5 cm in length. South of Whitehills Lake, granite is strongly sheared to mylonitic, and mafic minerals are typically replaced by retrograde chlorite. East of Kingaaquk Tasia, semiconformable granitic sheets in supracrustal rocks increase in abundance.

South of Sanningajukuluk, basement granodiorite, Whitehills quartzite and the quartz breccia that marks the faulted contact between them are all intruded by granodiorite (unit APgd). The granodiorite itself is strongly foliated, fractured and hematized. Several other isolated occurrences of granodiorite, including minor intrusions and dykes in Whitehills quartzite, are grouped with the same unit.

Supracrustal rocks in the eastern map area are sheeted and intruded by weakly foliated to massive monzodiorite to syenite (units Pmdsy, Pmd, Psy), which commonly shows patchy and nebulous textures indicating hybridization and magma mingling. Tectonic fabrics in monzodiorite are locally developed immediately adjacent to contacts. In the supracrustal rocks, sillimanite knots are overgrown by coarse-grained retrograde muscovite and biotite. Fabrics in the monzodiorite-syenite suite and in supracrustal rocks are cut by massive unfoliated granite (unit PHgt), considered to be part of the Paleoproterozoic Hudson granite suite (Peterson et al., 2002). East of Kinngaaquk Tasia, dispersed supracrustal septa included in massive granite tend to have conformable curviplanar attitudes suggesting that little or no rotation occurred during intrusion. Hudson granite dykes cutting the Amarulik formation north of the map area have been dated at 1835 ± 1 Ma (Roddick et al., 1992). Lamprophyre and syenite dykes (unit PMlm), and more plug-like intrusions exposed on islands in Whitehills Lake belong to the Martell intrusions (Taylor, 1985), the subvolcanic equivalent of the 1.84–1.81 Ga, Christopher Island Formation (Dubawnt Supergroup) (Rainbird et al., 2002). Both dykes and stocks are massive, and the latter show locally developed intrusion breccias with rounded to angular quartzite clasts and mantled corroded quartz grains in a lamprophyre matrix. Chilled margins were observed locally on lamprophyre contacts (Taylor, 1985; this study). Several east-northeasterly trending diabase dykes (unit Pdb) in the northern map area are likely equivalent to post-Hudsonian dykes that cut the Pitz Formation (Dubawnt Supergroup) in the Aberdeen Lake area 100 km to the west (A.N. LeCheminant, pers. comm., 1999).

STRUCTURAL INTERPRETATION

Four main phases of ductile deformation (D_1-D_4) are recognized on the basis of fabric orientations and overprinting relationships, relationships between fabrics and metamorphic mineral parageneses, correlations to macroscopic structures, and interpretation of the map pattern. Each of the main deformation events produced macroscopic folds and related fabrics. The dominant fabrics in the area are S_1 and S_2 mineral schistosities with easterly to northerly trends. S_1 is typically parallel to bedding (S_0), and locally S_1 and S_0 define mesoscopic F_2 folds. S_2 is commonly a composite fabric comprising transposed S_1 or, locally, a differentiated crenulation cleavage. S_3 and S_4 are typically crenulation cleavages associated with mesoscopic and macroscopic F_3 and F_4 folds that trend westerly and southerly, respectively. West and north of Whitehills Lake, low-grade phyllosilicate minerals and amphiboles define S_1 and S_2 schistosities, which are crenulated by S_3 and S_4 fabrics. East of Whitehills Lake and Tasiraraujuq, composite S_1/S_2 defined by medium- and high-grade minerals are increasingly transposed to form composite S_3 or S_4 fabrics. S_3 and S_4 fabrics are partly defined by coarse-grained, recrystallized muscovite and biotite that overgrow higher grade parageneses.

The oldest tectonic fabrics recognized comprise locally preserved gneissic and mylonitic layering in basement rocks cut by 2.87 Ga granodiorite. These fabrics predate basement granodiorite (unit Agd) and deposition of Neoarchean supracrustal rocks, and they are omitted from the D_1-D_4 structural scheme discussed here. The granodiorite (unit Agd) contains a schistosity which is generally conformable with the dominantly northeasterly trending, southerly dipping foliation in adjacent younger supracrustal rocks. Strain in the granodiorite increases toward the southern contact with quartz breccia (fault zone) and the Whitehills belt. A strong, down-dip to moderately oblique, stretching lineation plunging toward the southeast could be related to early movement on the fault.

An F_2 antiformal fold trace is interpreted to extend through basement rocks into the Sanningajukuluk assemblage from the Thelon River to south of Sanningajukuluk, and several additional F_2 traces are suggested in the volcanic rocks by attitudes of bedding and schistosity, and by implied or observed changes in younging direction. Between Sanningajukuluk and Tasiraraujaq, the attitudes of pillowed flows define an F_2 fold hinge, and changes in facing direction on the dominant S_2 foliation (J.R. Henderson, unpublished data, 1989) suggest the presence of a refolded F_1 fold (64°42.5' N, 95°59' W). (Kerswill et al., 1999) also reported probable F_1 isoclinal closures in intraflow sedimentary rocks, and noted that the volcanic succession ('northern volcanic belt' of Kerswill et al., 1999) may be thickened by fold repetition.

The major northeasterly trending fold that deforms the Whitehills quartzite belt was recognized by Taylor (1985) who considered it to be an overturned, northwesterly verging syncline. Henderson and Henderson (1994) reinterpreted the fold as an F_2 synform that deforms a schistosity subparallel to layering. Both authors placed the axial surface trace within the volcanic unit (APwmi) north of Whitehills Lake. Our work shows that Whitehills volcanic rocks and subarkose interlayered with quartzite define an F_2 synform-antiform pair. Parasitic S-shaped folds, defined by the volcanic rocks along the northern limb of the F_2 synform, indicate that the axial surface trace of the synform passes through Whitehills Lake. Quartzite exposures in the southwest, in the hinge region of the synform, show dominantly inward younging away from the outer margin that is consistent with an upward facing fold. Changes in younging direction and local overturned bedding 5 km east of the Thelon River (64°34.19' N, 96°22.03' W) are accounted for by mesoscopic chevron folds, parasitic to the macroscopic F_2 synform. North of Qaamiutaq and south of Sanningajukuluk, northward younging toward the Sanningajukuluk assemblage is consistent with the presence of an F_2 antiform. Layer-parallel S_1 schistosity is well preserved locally in the Whitehills quartzite, indicating that D_1 deformation postdated deposition and is likely to be Paleoproterozoic in age.

Two major northeasterly trending, syn-D_2 low-angle reverse faults dissect the map area. The contact between the Whitehills belt and basement is a silicified fault zone that is partly localized on F_2 fold limbs, but also apparently truncates macroscopic fold traces at a low angle (64°38' N 96°16' W). The fault coincides with one of several northwest-directed thrust faults and splays inferred by Taylor (1985) on both margins of, and within, the quartzite. An unconformable relationship is implied between the Whitehills belt and basement by detrital zircon of basement age in the quartzite. However, any observed contacts are strongly tectonized. The poorly constrained position of the transition from K-feldspar-chlorite parageneses to biotite-muscovite parageneses (see below) is permissive of the metamorphic transition being partly coincident with the faulted contact. The presence of higher grade parageneses in the stratigraphically higher units of the faulted hangingwall is consistent with a reverse component to displacement. Local foliation fish and mica microfabrics in the basal subarkose also suggest south-side-up movement toward the northwest.

A second fault juxtaposes the Sanningajukuluk assemblage (Meadowbank formation) with the younger Amarulik formation along a southerly dipping structural contact. The fault is nearly conformable to the Sanningajukuluk assemblage in that it closely follows units of iron-formation and carbonate rocks. The low-angle geometry and reverse sense of movement are consistent with a thrust fault. Tasirjuaq conglomerate is present discontinuously along the contact suggesting synkinematic deposition contemporaneous with faulting. The conglomerate contains fabrics consistent with D_2 deformation.

Shallowly to moderately plunging, macroscopic F_3 folds and related fabrics trend westerly across the area. South of Sanningajukuluk, F_3 folds deform reverse faults and F_2 folds, producing fold interference patterns. S_3 crenulation cleavage and mesoscopic and macroscopic F_3 folds overprint major F_2 folds and related fabrics between the Thelon River and Whitehills Lake. Shallowly plunging F_3 folds are interpreted as extending into the higher grade area east of Whitehills Lake. Northerly trending upright F_4 folds (F_3 of Henderson and Henderson, 1994) also deform F_2 folds, most prominently the antiform-synform pair in the Whitehills belt north of Whitehills Lake. East of Tasiraraujak and Kinngaaquk Tasia, fold interference (dominantly F_3 and F_4) combined with shallow dips and topographic relief imparts a complex map pattern. The area south and southeast of Whitehills Lake is characterized by east-west trending, straight, structural trends, partly defined by tectonized contacts, that appear discordant to polyphase fold traces to the north. High-strain fabrics in the area are defined by porphyroclastic feldspar typically wrapped by fine-grained muscovite, epidote, and calcite, with minor biotite and, in some cases chlorite, indicating a structural domain dominated by retrograde shearing.

METAMORPHISM

Metamorphic grade varies across the area from low in the northwest to high in the east. In the west, mafic rocks contain greenschist-facies parageneses of amphibole-chlorite-epidote-plagioclase, and iron-formation near the Meadowbank River contains stilpnomelane (64°35.86' N, 96°28.38' W). A biotite-in transition recognized in felsic volcanic, plutonic and sedimentary rocks subdivides the low-grade area. The exact position of the transition is poorly constrained, but from the Thelon River to Qaamiutaq, K-feldspar-chlorite-white mica parageneses lie to the northwest in the Amarulik formation, Sanningajukuluk assemblage, Tasirjuaq conglomerate and Half Way Hills basement complex, and biotite-muscovite parageneses lie to the southeast in the Whitehills belt. Although the position of the metamorphic transition close to the northern faulted contact of the Whitehills belt for much of its length may reflect south-side-up movement, the observed parageneses do not require large displacements. In the vicinity of Tasiraraujaq, the biotite in transition crosses both of the reverse faults that dissect the map area.

It is interesting to note that the chlorite-K-feldspar parageneses observed from the Thelon River to Tasiraraujaq represent the lowest grades of metamorphism observed in the entire Woodburn project mapping area. The coexistence of chlorite-K-feldspar implies temperatures of less than 300–400°C, the likely temperature range of the first prograde appearance of biotite + muscovite (Spear, 1993). Although D_2 faults are present throughout the project area, exposures of fault-controlled Tasirjuaq conglomerate were observed only in the area of lowest metamorphic grade, suggesting that its preservation may be a result of the higher structural level of exposure. Tasirjuaq conglomerate on Whitehills Lake generally contains biotite-muscovite assemblages, and its structural setting is somewhat different as it occupies the hinge region of an F_2 synform. The conglomerate shows development of S_2axial planar schistosity, but without being obviously folded by F_2 folds. The presence of chlorite in syenite clasts in the northeastern exposures suggests the possibility of lower metamorphic grade in the core of the upward-facing F_2 synform.

In the southwestern map area, local chloritoid-bearing parageneses in the Whitehills belt are consistent with the biotite-in transition. However, an isolated occurrence of staurolite-andalusite 3 km east of the Thelon River indicates the transition to amphibolite-facies at low pressure below that of the aluminosilicate triple-point, and temperatures in excess of ca. 460°C (Spear, 1993 and references therein).

West of Kinngaaquk Tasia, kyanite in Whitehills quartzite is interpreted as being derived from pyrophyllite decomposition, constraining temperatures to ca. 400°–500°C and pressures to ca. 2.7–3.6 kb (Spear, 1993 and references therein). A greenschist- to amphibolite-facies transition is defined by the change from kyanite and chloritoid in quartzite, to sillimanite- and staurolite-bearing parageneses in metasedimentary rocks to the east, suggesting temperatures in excess of ca. 550°C. Parageneses in metabasites change from greenschist-facies to hornblende-clinopyroxene-plagioclase consistent with amphibolite-facies. Polyphase metamorphism and structural telescoping may have played a role in the distribution of parageneses. For example, two instances of isolated high-grade parageneses (garnet-clinopyroxene in metabasite, and K-feldspar-sillimanite in paragneiss) have been noted near the greenschist-amphibolite transition. The position of the southern extension of the transition is poorly constrained, but biotite-aluminosilicate parageneses continue east of Whitehills Lake. At the southeastern end of Kinngaaquk Tasia, relict andalusite porphyroblasts are overgrown by sillimanite and a transition from andalusite-biotite to sillimanite-biotite-bearing parageneses can be traced to the southeast in pelitic rocks. If the aluminosilicate-bearing pelitic parageneses represent a prograde sequence, then they also suggest relatively low-pressure metamorphic conditions (< 3–4 kb).

In low-grade rocks, micas and chlorite define S_1 schistosity and S_2 foliation or crenulation cleavage, and are kinked and crenulated by F_3 and F_4 microfolds. In medium- to high-grade rocks east of Whitehills Lake, amphibole porphyroblasts in metabasite define a strong lineation and S_2 mineral schistosity. In pelitic rocks with two aluminosilicate minerals, relict andalusite porphyroblasts are overgrown by sillimanite knots that define the dominant schistosity. Sillimanite is crenulated by F_3 and F_4 microfolds and overgrown by coarse, randomly oriented or weakly kinked biotite and muscovite plates. This suggests that the main regional metamorphism is broadly syn-D_2 and, hence, bracketed to < 2.0 Ga by the syntectonic Tasirjuak conglomerate, which contains D_2 fabrics, and > 1.835 Ga based on the age of Hudson granite dykes that cut fabrics in the Amarulik wacke to the north (Roddick et al., 1992). Medium-to high-grade rocks involved in F_3 and F_4 folds east of Whitehills Lake are extensively intruded by massive granite (unit PHgt), considered to be correlative to the Hudson granite dykes. Although the granite east of Whitehills Lake has not been dated, this correlation implies that the minimum age bracket of 1.835 Ga for D_2 deformation may also apply to D_3 and D_4 deformation. Numerous massive lamprophyre intrusions (unit PMlm) apparently cut across D_3 and D_4 structures, for example in the hinge region of the F_4 fold through Whitehills Lake. This relationship supports a minimum age bracket of 1.81 Ga for D_3 and D_4 deformation, based on the age of a syenite intrusion that cuts ultrapotassic rocks of the lower Baker Lake Group (Rainbird et al., 2002).

ECONOMIC GEOLOGY

The map area encompasses 22 known gold, base metal and polymetallic mineral occurrences, 21 of which lie in the Sanningajukuluk volcanic assemblage or in adjacent Amarulik wacke (Table 2) (Kerswill et al., 1999; Zaleski et al., 2001b). A single base metal occurrence (no. 1) and numerous gossans are present in sulphidic pelite, quartzite and iron-formation southeast of Whitehills Lake. Several features of vein-hosted mineral occurrences in the Sanningajukuluk assemblage led Kerswill et al.(1999) to conclude that gold and base metal mineralization were linked to synvolcanic rather than late tectonic processes. These features included evidence of deformation and metamorphism, and metal endowment comprising Au with strongly anomalous Ag, Pb and/or Zn, in addition to locally anomalous concentrations of one or more of Mo, W, Bi, Sb and As.

ACKNOWLEDGMENTS

The Woodburn Project was initiated by Jack and Mariette Henderson to follow up on previous reconnaissance mapping. Although Jack was not able to return to the field himself, he was a continuing source of support and inspiration until he passed away in 1997. The results of the Woodburn Project are dedicated to his memory.

Wouter Bleeker, Bill Davis, Alan Donaldson, Norm Duke, Erika Greiner, George Jenner, John Kerswill, Bruce Kjarsgaard, Rob L'Heureux, Rob Rainbird and Lori Wilkinson contributed to the mapping and interpretation of the Half Way Hills and Whitehills Lake area map. Bill Davis derived the U-Pb ages. The field program operated out of the Meadowbank camp of Cumberland Resources Ltd., and Brian Alexander, Roger March and other Cumberland employees are gratefully acknowledged for their co-operation and logistical help during the field season. Subhas Tella and Karen Fallas reviewed the map and manuscript, and their comments greatly improved the final version.

REFERENCES

Ashton, K.E.
1988: Precambrian geology of the southeastern Amer Lake area (66H/1), near Baker Lake, N.W.T.; Ph.D. Thesis, Queen's University, Kingston, Ontario, 335 p.

Davis, W.J. and Zaleski, E.
1998: Geochronological investigations of the Woodburn Lake group, Western Churchill Province: preliminary results; *in* Radiogenic Age and Isotopic Studies: Report 11; Geological Survey of Canada, Current Research 1998-F, p. 89–97.

Donaldson, J.A.
1966: Geology, Schultz Lake, District of Keewatin; Geological Survey of Canada, Preliminary Map 7-1966, scale 1:253 440.

Fraser, J.A.
1988: Geology of the Woodburn Lake map area, District of Keewatin; Geological Survey of Canada, Paper 87-11, 12 p.

Heaman, L.M.
1994: 2.45 Ga global mafic magmatism; Earth's oldest superplume?; *in* Abstracts of the Eighth international conference on Geochronology, cosmochronology, and isotope geology; U.S. Geological Survey Circular, p. 132.

Henderson, J.R. and Henderson, M.N.
1994: Geology of the Whitehills-Tehek Lakes area, District of Keewatin, Northwest Territories, Geological Survey of Canada, Open File 2923, scale 1:100 000.

Heywood, W.W. and Schau, M.
1981: Geology of the Baker Lake region, District of Keewatin; *in* Current Research, Part A; Geological Survey of Canada, Paper 81-1A, p. 259–264.

Hoffman, P.F.
1988: United plates of America, the birth of a craton: early Proterozoic assembly and growth of Laurentia; Annual Reviews of Earth and Planetary Sciences, v. 16, p. 543–603.

Kerswill, J.A., Kjarsgaard, B.A., Bretzlaff, R., Jenner, G.A., and Samaras, C.
1999: Metallogeny and geology of the Half Way Hills area, central Churchill Province, Northwest Territories (Nunavut); *in* Current Research 1999-C; Geological Survey of Canada, p. 29–41.

Kretz, R.
1983: Symbols for rock-forming minerals; American Mineralogist, v. 68, p. 277–279.

LeCheminant, A.N. and Roddick, J.C.
1991: U-Pb zircon evidence for widespread 2.6 Ga felsic magmatism in the central District of Keewatin, N.W.T.; *in* Radiogenic Age and Isotopic Studies: Report 4; Geological Survey of Canada, Paper 90-2, p. 91–99.

Patterson, J.G.
1985: A preliminary geological compilation map of the northeastern Barren Grounds, parts of the Districts of Keewatin and Franklin ; Geological Survey of Canada, Open File 1138, scale 1:1 000 000.

Patterson, J.G. and Heaman, L.M.
1991: New geochronologic limits on the depositional age of the Hurwitz Group, Trans-Hudson hinterland, Canada; Geology, v. 19, p. 1137–1140.

Pehrsson, S.J., Jenner, G., and Kjarsgaard, B.A.
2002: The Ketyet River group: correlation with Paleoproterozoic supracrustal sequences of the northeastern Rae and implications for Proterozoic orogenesis in the western Churchill Province; GAC-MAC Joint Annual Meeting, Abstracts Volume 27, p. 90.

Pehrsson, S.J., Wilkinson, L., Zaleski, E., Kerswill, J., and Alexander, B.
2000: Structural geometry of the Meadowbank deposit area, Woodburn Lake group – implications for genesis of a major gold deposit in the Western Churchill Province; Geocanada 2000, The Millennium Geoscience Summit, CD-ROM Abstract no. 829, 4 p.

Peterson, T.D., van Breemen, O., Sandeman, H., and Cousens, B.
2002: Proterozoic (1.85–1.75 Ga) igneous suites of the Western Churchill Province: granitoid and ultrapotassic magmatism in a reworked Archean hinterland; Precambrian Research v. 119, p. 73–100.

Rainbird, R.H., Davis, W.J., Stern, R.A., Hadlari, T., and Donaldson, J.A.
2002: Integrated geochronology of the late Paleoproterozoic Baker Lake Group (Dubawnt Supergroup), Baker Lake basin; GAC-MAC Joint Annual Meeting, Abstracts Volume 27, p. 95.

Roddick, J.C., Henderson, J.R., and Chapman, H.J.
1992: U-Pb ages from the Archean Whitehills-Tehek lakes supracrustal belt, Churchill Province, District of Keewatin, Northwest Territories; *in* Radiogenic Age and Isotopic Studies: Report 6; Geological Survey of Canada, Paper 92-2, p. 31–40.

Schau, M.
1983: Baker Lake map sheet (56D); Geological Survey of Canada, Open File 883, scale 1:125 000.

Schau, M., Tremblay, F., and Christopher, A.
1982: Geology of Baker Lake map area, District of Keewatin: a progress report; *in* Current Research, Part A; Geological Survey of Canada, Paper 82-1A, p. 143–150.

Spear, F.S.
1993: Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths; Mineralogical Society of America, Washington, D.C., U.S.A., 799 p.

Taylor, F.C.
1985: Precambrian geology of the Half Way Hills area, District of Keewatin; Geological Survey of Canada, Memoir 415, 19 p.

Tella, S., Thompson, D.L., and James, D.T.
1984: Geology of parts of the Deep Rose Lake and Pelly Lake map areas, District of Keewatin; *in* Current Research, Part A; Geological Survey of Canada, Paper 84-1A, p. 313–322.

Young, G.M.
1984: Proterozoic plate tectonics in Canada with emphasis on evidence for a late Proterozoic rifting event; Precambrian Research, v. 25, p. 233–256.
1988: Proterozoic plate tectonics, glaciation and iron-formations; Sedimentary Geology, v. 58, p. 127–144.

Zaleski, E.
in press: Geology, Meadowbank River area, Nunavut; Geological Survey of Canada, Map 2068A, scale 1:50 000.

Zaleski, E., Davis, W.J., and Sandeman, H.A.
2001a: Continental extension, mantle magmas and basement/cover relationships; *in* 4th International Archaean Symposium 2001, Extended Abstracts, Cassidy, K.F., Dunphy, J.M., van Kranendonk, M.J. (ed.), AGSO - Geoscience Australia, Record 2001/37, p. 374–376.

Zaleski, E., Pehrsson, S., and Wilkinson, L.
in press: Geology, Amarulik and Tehek Lakes area, Nunavut; Geological Survey of Canada, Map 2070A, scale 1:50 000.

Zaleski, E., Pehrsson, S.J., Davis, W.J., Greiner, E., L'Heureux, R., Duke, N., and Kerswill, J.A.
2001b: Geology, Half Way Hills to Whitehills Lake area, Nunavut; Geological Survey of Canada, Open File 3697, scale 1:50 000.

Zaleski, E., Pehrsson, S., Duke, N., Davis, W.J., L'Heureux, R., Greiner, E., and Kerswill, J.A.
2000: Quartzite sequences and their relationships, Woodburn Lake group, western Churchill Province, Nunavut; Geological Survey of Canada, Current Research 2000-C7, 10 p. (online; www.nrcan.gc.ca/gsc/ bookstore)