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GEOLOGY OF THE SOUTHEASTERN CHURCHILL PROVINCE: CROSSROADS LAKE AREA, WESTERN LABRADOR

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ABSTRACT

The Southeastern Churchill Province in the vicinity of Crossroads Lake comprises deformed Archean and variably deformed Paleoproterozoic meta-igneous rocks. Five units were identified in the field and these are Archean charnockite, Paleoproterozoic orthopyroxene monzodiorite, undated gabbronorite, Paleoproterozoic megacrystic charnockite of the De Pas batholith, and coronitic gabbronorite–amphibolite of uncertain age. The oldest unit is Archean migmatitic charnockite that is intensely deformed and locally contains numerous mafic layers. The orthopyroxene monzodiorite containing mafic dykes is intruded by massive megacrystic charnockite of the De Pas batholith. The latter has contemporaneous migmatitic gabbronorite associated with local shear zones. The De Pas batholith is devoid of significant deformation. A gabbronorite containing pyroxene grains having coronas of garnet and amphibole is exposed in the western half of the map area. All units except the coronitic gabbronorite are deformed by north- and northwest-striking shear zones that record right-lateral transpression. No minerals of economic interest were found in the map area.

INTRODUCTION

A two-year, 1:50 000-scale bedrock mapping project was begun during the summer of 2009 in the Crossroads Lake area of western Labrador (Figure 1). The goal of this project is to create a comprehensive bedrock map accompanied by a supporting whole-rock geochemistry, geochronology and a mineral-resource-potential database. The project is part of a joint Geo-mapping for Energy and Minerals (GEM) project conducted in concert with the Géologie Québec and the Geological Survey of Canada. The project will investigate the geology of NTS map area 23I as a possible region of interest to mineral exploration companies. A new high-resolution airborne magnetic survey has been flown in the area by the Geological Survey of Canada (Dumont, 2009a, b, c, d). The Géologie Québec is conducting complementary mapping on the Québec side of the border concurrent with the Geological Survey of Newfoundland and Labrador work. In Labrador, mapping was carried out primarily in NTS map areas 23I/14 and the northern half of 23I/11, with limited work in the adjoining map areas 23I/10 and 11 (Figure 1). Detailed geological mapping began with a two-man field crew conducting systematic traverses by foot and by boat. Limited helicopter support was used in the second half of the field season for drop-off traversing and reconnaissance.

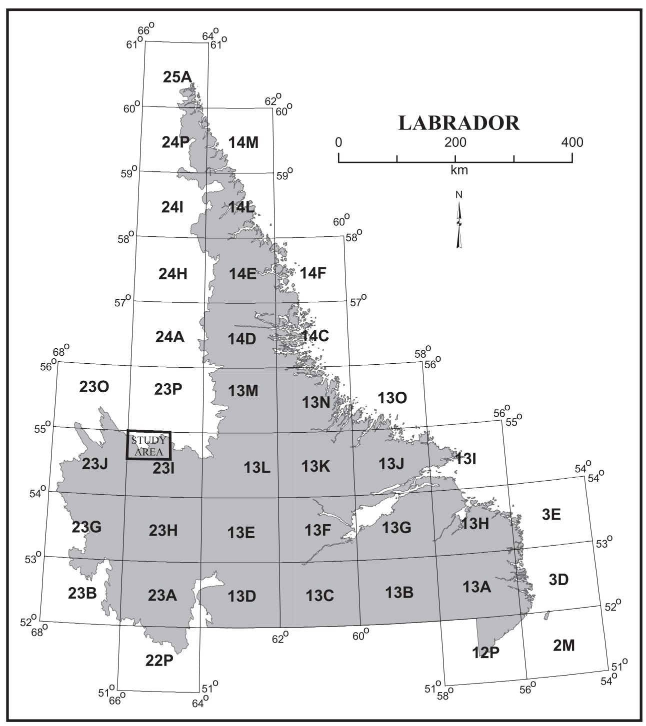


Figure 1. *Index map of Labrador showing location of Crossroads Lake study area within NTS map areas 23I/14, 15, 11, 10.*

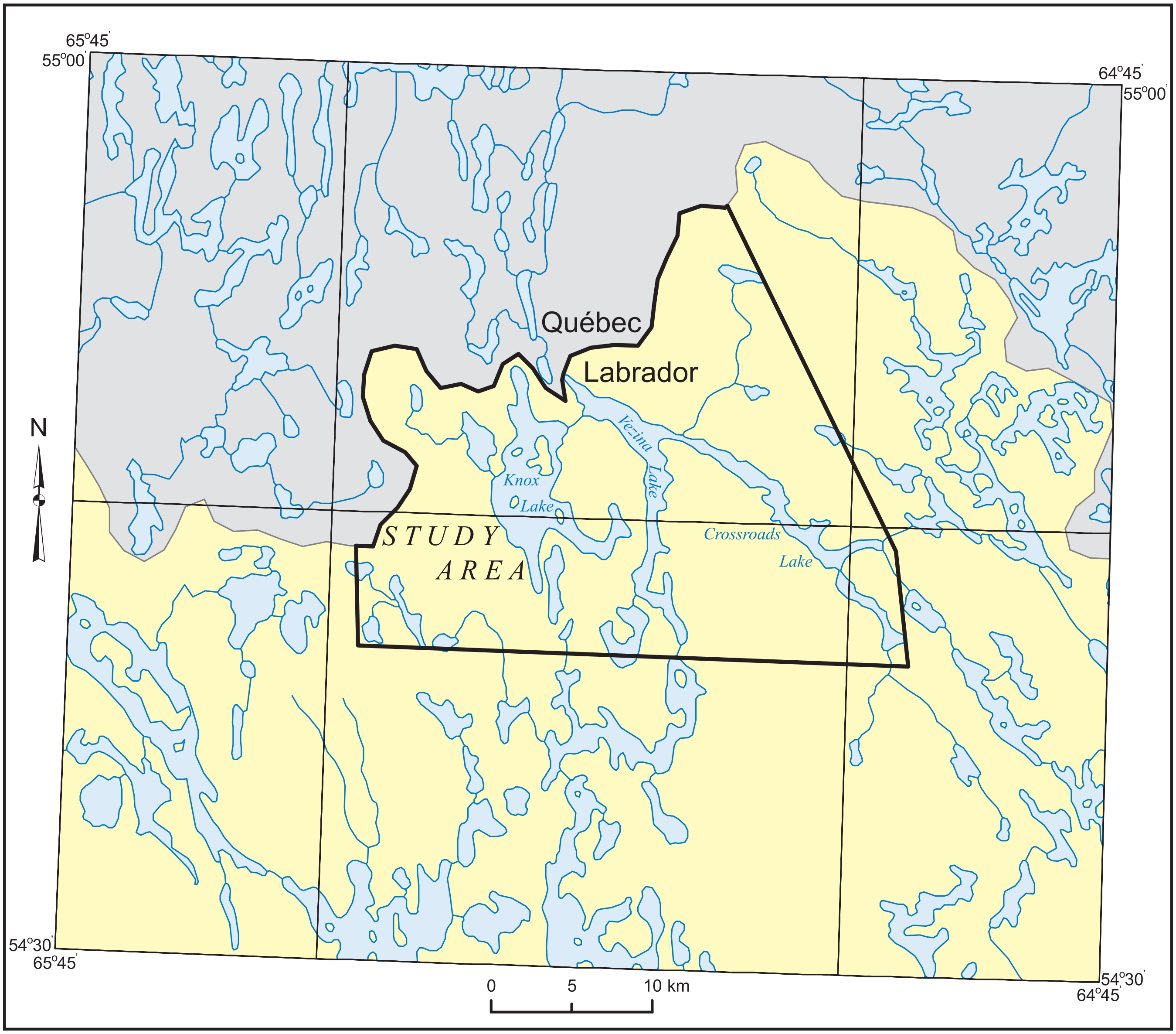


Figure 2. *Location map of the Crossroads Lake field area and major water bodies.*

The study area is located in western Labrador (Figure 1), 120 km east of Schefferville, Québec, 150 km north-northwest of Churchill Falls, Labrador, and 350 km north-west of Happy Valley–Goose Bay, Labrador. Access to the area is by float plane or helicopter from the communities mentioned. The physiography of the area is dominated by numerous lakes and extensive swamplands, especially in the western half of NTS map areas 23I/14 and 11. The largest lakes are Crossroads, Vezina and Knox, which are connected by smaller rivers and streams (Figure 2). The eastern half of the map area is dominated by small, isolated, (100 m) bald hills, separated by swamps. Forest cover in the field area ranges from thick spruce and alder to more open country in which trees dot a landscape of extensive caribou moss.

REGIONAL GEOLOGY

The Southeastern Churchill Province (SECP) in western Labrador is a 300-km-wide, north–south-trending and tectonically assembled group of terranes that link the Archean Superior craton of Laurentian North America, to the west, with the Archean Nain Province to the east (Figure 3). The SECP is primarily a set of Paleoproterozoic orogens consisting of reworked Archean and Paleoproterozoic intrusive rocks (*e.g.*, Wardle *et al.*, 1990; James *et al.*, 1993, 1996). The SECP is thought to be an extension of the Rae Province, which forms part of the Trans-Hudson Orogen in northern and western Canada and follows the margins of the Superior craton (*e.g.*, Hoffman, 1988, 1990).

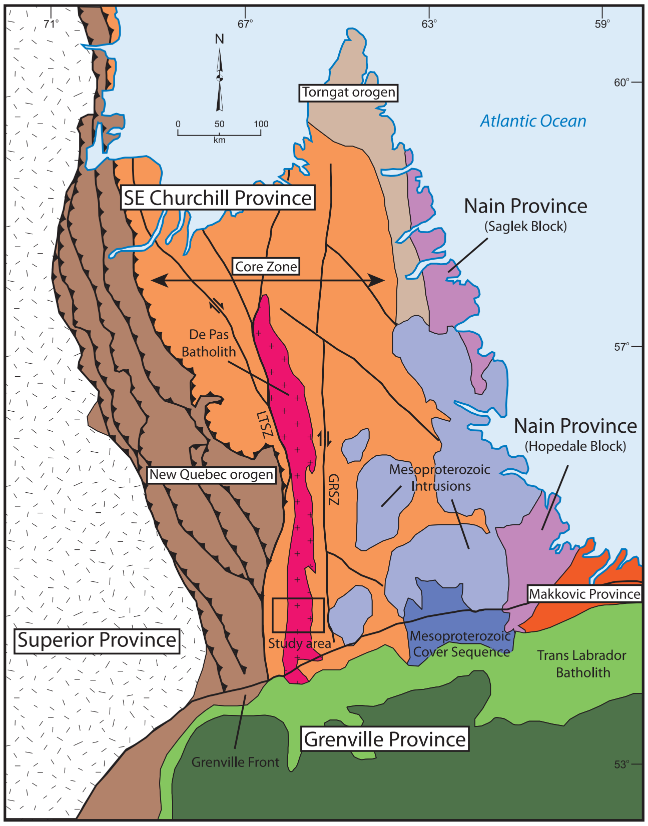


Figure 3. *Generalized geological map of Labrador and eastern Québec with major tectonic subdivisions and the location of the study area. LTSZ = Lac Tudor shear zone, GRSZ = George River shear zone. Modified from James* et al. *(1996).*

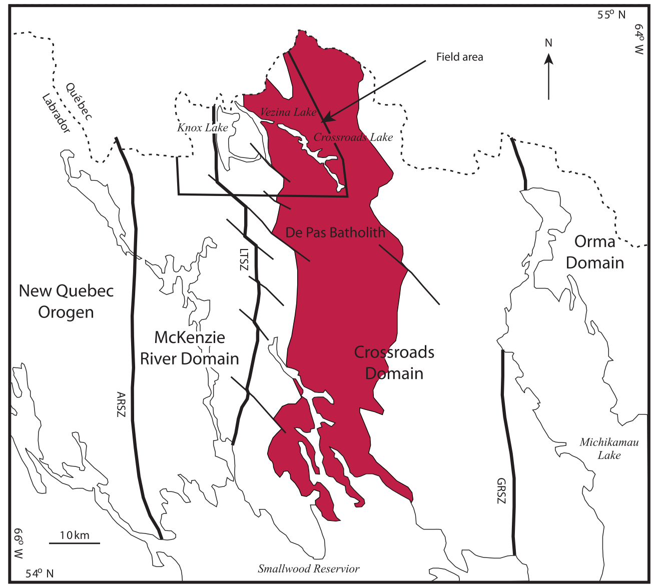


Figure 4. *Main lithotectonic subdivisions and structural features of the SECP in western Labrador. ARSZ = Ashuanipi River shear zone LTSZ = Lac Tudor shear zone, GRSZ = George River shear zone (after James* et al.*, 1996).*

The SECP is divided into 3 main tectonic divisions: the New Québec Orogen in the west, a Core Zone in the central region, and the Torngat Orogen in the east (Figure 3). The New Québec Orogen consists of a west-verging, fold-and-thrust belt that developed primarily in Paleoproterozoic sedimentary and volcanic rocks and along the eastern edge of the Superior Province (James *et al.*, 2003). The Core Zone is a composite terrane of Archean orthogneisses and Paleoproterozoic intrusive rocks including the greater than 500-km-long De Pas batholith (*e.g.*, Van der Leeden *et al.,* 1990; James and Dunning, 2000). The Torngat Orogen is a doubly verging wedge of juvenile sedimentary rocks deformed during oblique collision of the Nain Province with the Core Zone.

The Core Zone in the field area is best exposed on the north side of Smallwood Reservoir and Michikamau Lake, the locations of the most detailed mapping and data collection (James *et al.*, 1993, 1996; James and Dunning, 2000). Information gathered at Smallwood Reservoir was extrapolated 70 km north to the Crossroads Lake area where exposures are limited especially in the McKenzie River domain (western map area; Figure 4).

Mapping at 1:100 000 scale was previously carried out by James *et al.* (1993) and 1:250 000-scale mapping was completed by Wynne-Edwards (1960) and Emslie (1963).

The work by James *et al.* (1996), in the SECP of Labrador, resulted in the subdivision of the Core Zone into 3 main lithotectonic groups or domains (Figure 4). These are the McKenzie River, Crossroads and Orma domains. The McKenzie River domain consists primarily of high-grade Archean tonalite gneiss containing minor metamorphosed supracrustal rocks and gabbro and it is located primarily on the western side of the Core Zone. The tonalite gneiss has yielded a U–Pb (zircon) crystallization age of 2776 ± 5 Ma (James and Dunning, 2000). On its western side, the McKenzie River domain is separated from rocks of the New Québec Orogen by the Ashuanipi River shear zone. On its eastern side, the McKenzie River domain is separated from the Crossroads domain by the Lac Tudor shear zone (Figure 4). Both shear zones show evidence for dextral transpression and east-over-west reverse displacement (James and Dunning, 2000). The Crossroads domain consists of reworked granite–greenstone terranes, minor supracrustal rocks, and megacrystic granitoids of the 1835–1810 Ma De Pas batholith (James *et al.*, 1996). The Crossroads domain is bounded on the east and separated from the Orma domain by the transcurrent George River shear zone (Figure 4). The Orma domain consists primarily of Neoarchean orthogneisses and older supracrustal rocks. The McKenzie River and Crossroads domains have been affected by high-grade Paleoproterozoic (1820–1775 Ma) metamorphism and deforma-

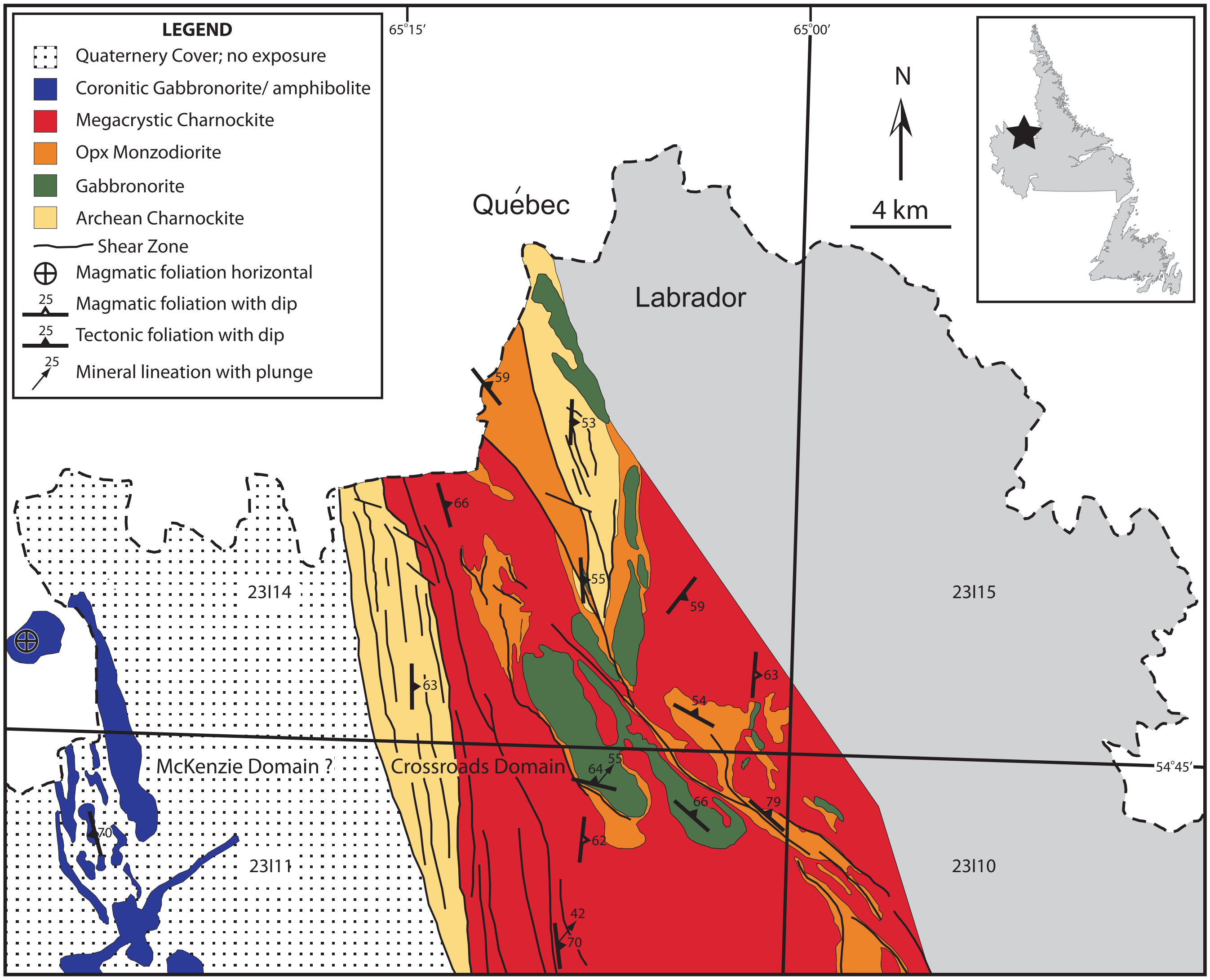


Figure 5. *Geological map of the Crossroads Lake region, western Labrador.*

tion but this thermotectonic event has not been identified in the Orma domain (James *et al.*, 2003).

GEOLOGY OF THE CROSSROADS LAKE AREA

The Crossroads Lake map area lies completely within the Core Zone of the SECP and consists of both the Crossroads and the McKenzie River domains (Figures 3, 4 and 5). There are 5 main units, namely, Archean charnockite, orthopyroxene monzodiorite, megacrystic charnockite, gabbronorite, and coronitic gabbronorite. Theses rocks are variably deformed in the north- and northwest-striking shear zones. High resolution airborne geophysics were used to interpret structures and rock type (Figure 6) where outcrop is lacking.

Archean Charnockite

Outcrops of white-grey to orange-yellow-weathering, fine- to medium-grained, quartz-rich charnockite and minor orthopyroxene-free granite are poorly exposed in the central and northern parts of the map area. These rocks were interpreted as Archean granitoids by James *et al.* (1996) based U–Pb zircon ages from the Smallwood Reservoir area. The unit is highly deformed, contains a distinctive quartz-ribbon lineation and is generally migmatitic (Plate 1A). More than one generation of leucosome may be present. Mafic layers and 'dismembered' mafic dykes locally make up a significant portion of the outcrop (Plate 1B); ultramafic rocks are rare.

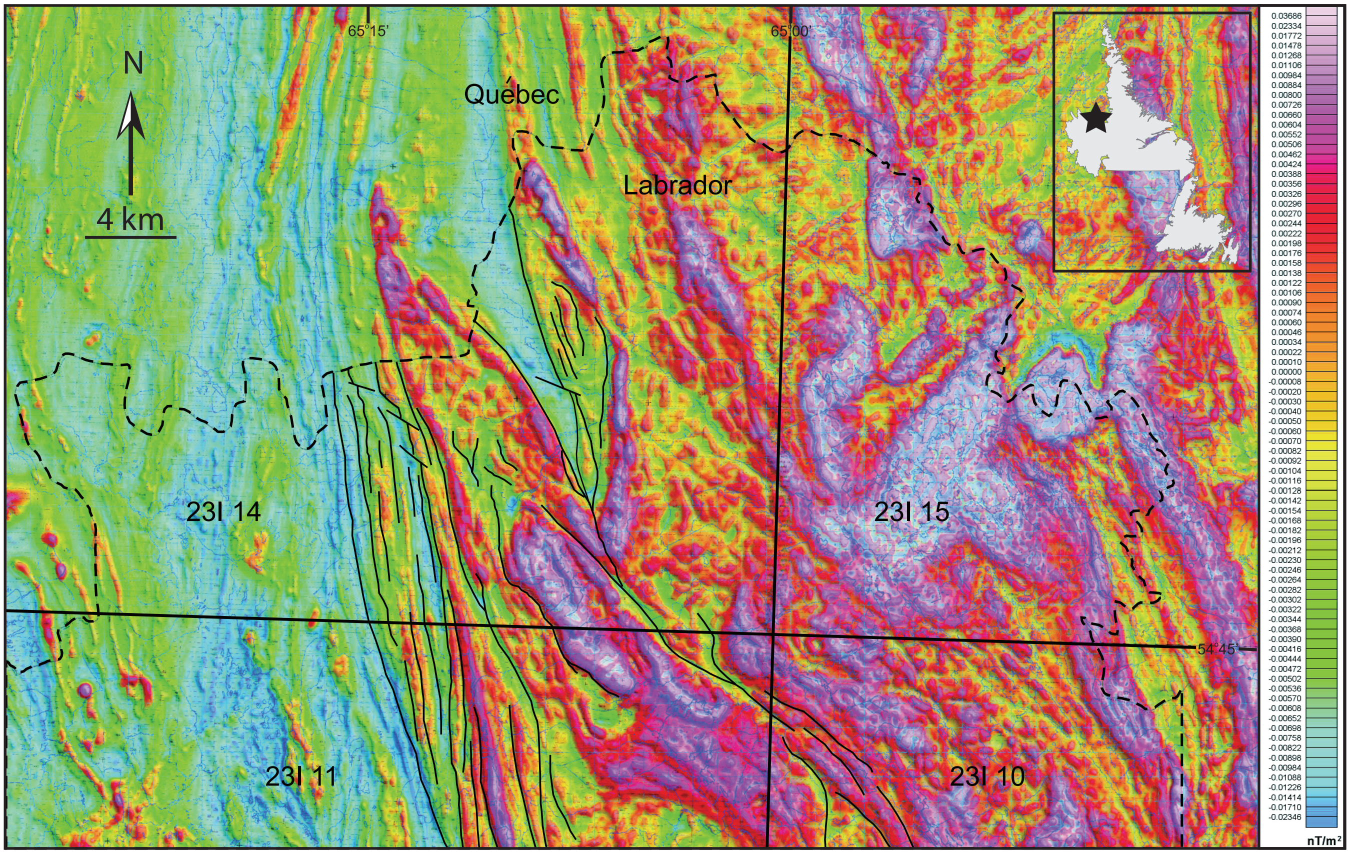


Figure 6. *Residual total magnetic field map of the Crossroads Lake area, western Labrador. Red end of spectrum – magnetic highs, blue end of spectrum – magnetic lows. Thin black lines are inferred shear zones.*

The dominant mineral assemblage of this Archean charnockite is quartz, K-feldspar, plagioclase, orthopyroxene, clinopyroxene, biotite and minor magnetite (Plate 1C, D). The mafic layers are dominated by plagioclase, amphibole and clinopyroxene.

The relationship between the Archean charnockite and the adjacent units is interpreted to be tectonic based on the 'interfingering' nature of the contacts. Outcrops of Archean charnockite alternate with orthopyroxene monzodiorite, gabbronorite, and/or younger megacrystic charnockite in the area of the contact. These zones of repeated succession may be tens to hundreds of metres wide. Individual outcrops range from a few metres to tens of metres in width.

Orthopyroxene Monzodiorite

The orthopyroxene monzodiorite unit is best exposed in, and around, the southeast end of Crossroads Lake, but is found throughout the eastern half of the map area (Figures 5, 6). The unit is typically white- to grey-weathering, fine to medium grained, and contains abundant mafic enclaves. These enclaves are typically stretched or appear to be pulled apart (Plate 2A, B) and some locally contain a gneissic fabric.

The dominant mineral assemblage of the monzodiorite is plagioclase, clinopyroxene, amphibole, orthopyroxene, K-feldspar and variable amounts of quartz. Plagioclase may be antiperthitic and/or well-twinned (Plate 2C, D) and the volume of mafic minerals is variable (from less than 1 to 20%). The foliation is defined by the orientation of mafic minerals, but where mafic minerals are lacking, the texture is granoblastic.

The age of the orthopyroxene monzodiorite is not known but enclaves of the unit have been incorporated into the Paleoproterozoic megacrystic charnockite (*see* below) and is commonly associated with shear zones and separate outcrops of gabbronorite from megacrystic charnockite. Blocks of monzodiorite are found in the charnockite. Furthermore, mafic enclaves are found only within the monzodiorite suggesting that the monzodiorite had an earlier history of mafic dyke emplacement whereas the megacrystic charnockite did not. Additionally, some blocks of monzodiorite within the megacrystic granite contain identical mafic enclaves strengthening the argument for the crystallization of the monzodiorite and the emplacement of a mafic dyke swarm prior to intrusion of the charnockite. The relation between the monzodiorite and the gabbronorite is less cer-

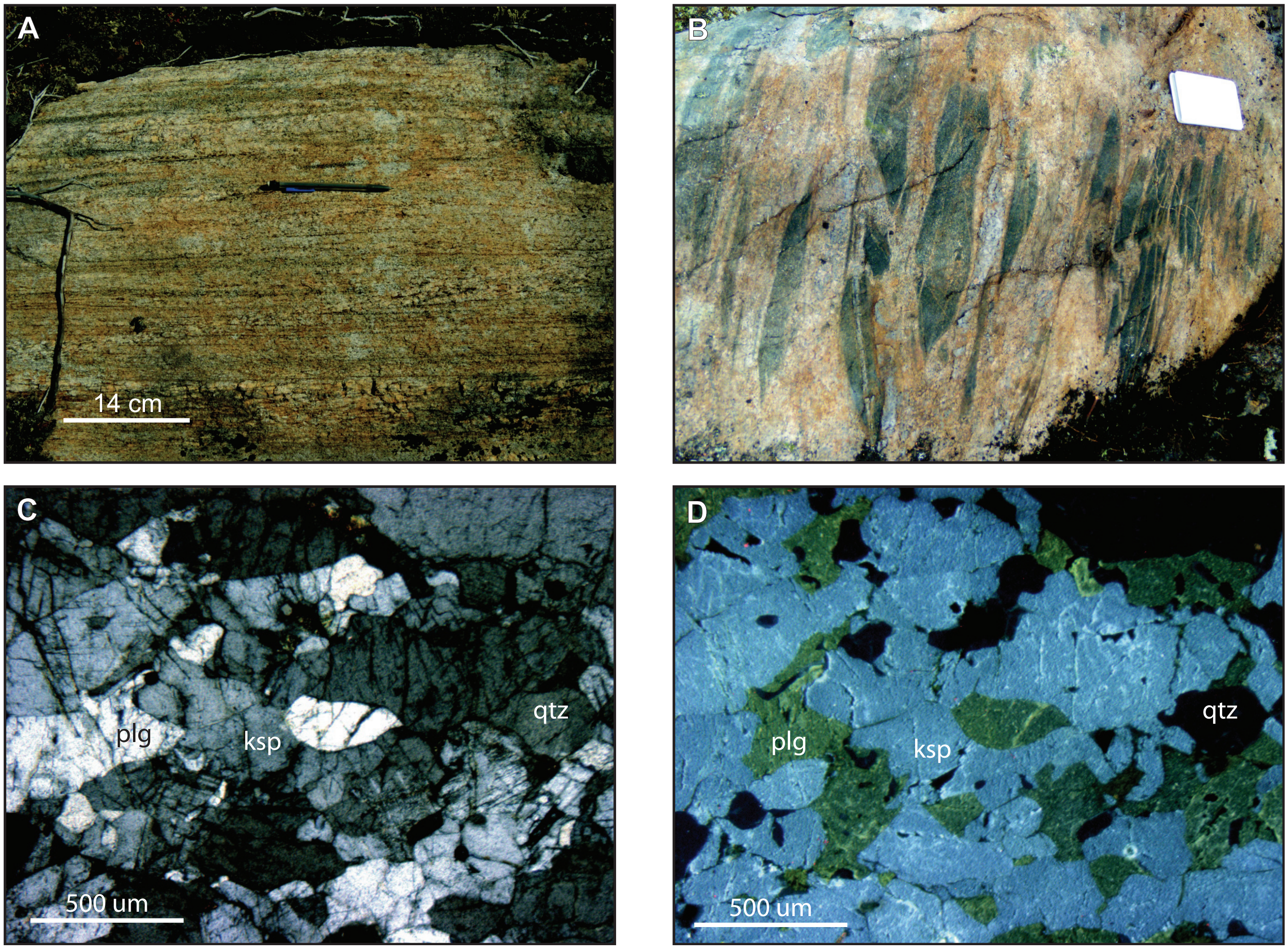


Plate 1. *Archean charnockite: A) Typical appearance of Archean charnockite in outcrop. Intense recrystallization is typical. B) Sheared mafic layers make up 50% of the outcrop in parts of this unit. C) Cross-polarized light photomicrograph and D) cathodoluminescence image of a thin section of Archean charnockite. plg = plagioclase; ksp = potassium feldspar; qtz = quartz.*

tain. Despite the monzodiorite and gabbronorite commonly being found in close proximity, no exposed contacts were seen. However, if the gabbronorite is contemporaneous with the megacrystic charnockite, as suggested below, then the gabbronorite must be younger than the monzodiorite.

Paleoproterozoic Megacrystic Charnockite

Megacrystic charnockite of the De Pas batholith is the dominant rock type in the Crossroads Lake area and forms small "bald" hills with numerous outcrops. The megacrystic charnockite locally grades into megacrystic orthopyroxene-free granodiorite and granite. The charnockite is an orange- to pink-weathering rock and contains ubiquitous perthite megacrysts (Plate 3A, B). The dominant mineral assemblage is quartz, perthite, magnetite, orthopyroxene and/or amphibole and minor plagioclase, biotite and clinopyroxene. The proportion of perthite megacrysts in the rock ranges from 30% down to a few randomly scattered crystals. These megacrysts are locally up to 5 cm in length (Plate 3A, B) and are typically perthitic (Plate 3C, D). Igneous layering may be present in the form of alternating perthite megacryst-rich and perthite megacryst-poor, but plagioclase-rich layers.

The mafic mineral content of the megacrystic charnockite is typically 5 to 10% but may locally exceed 20% whereas the granite associated with the charnockite locally contains less than 1% mafic minerals. Early formed mafic minerals are magnetite and orthopyroxene, the latter commonly rimmed by amphibole and biotite. Small inclusions of magnetite are found within the orthopyroxene and as disseminated grains throughout the rock. Amphibole replacement of the orthopyroxene may be nearly complete in some crystals, with only tiny remnants of orthopyroxene remaining. Clinopyroxene is typically present in small quantities, but increases in abundance near the contacts of the gab-

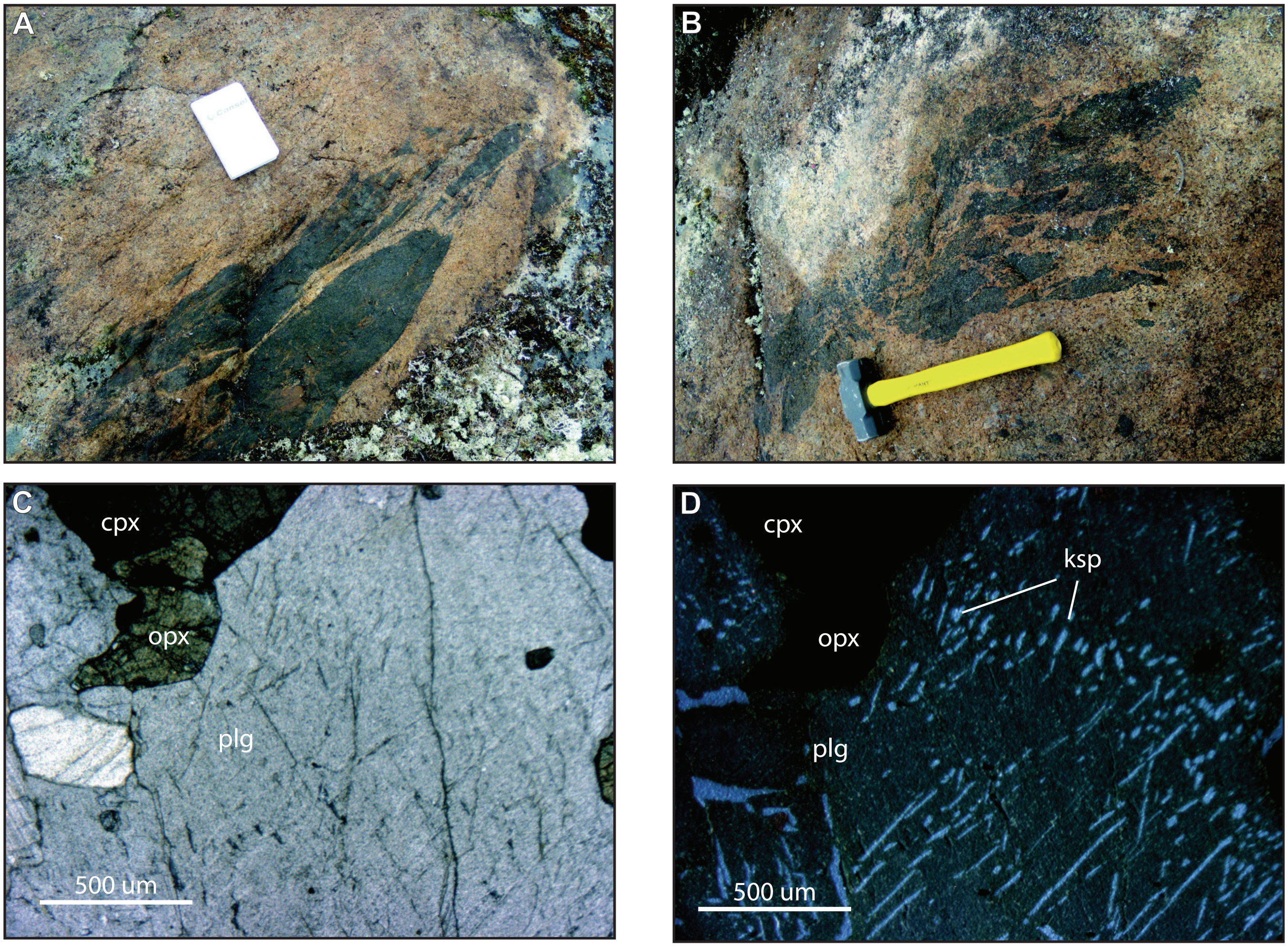


Plate 2. *A, B) Typical fine- to medium-grained orthopyroxene monzodiorite containing amphibolite enclaves. C) Cross-polarized light photomicrograph of orthopyroxene monzodiorite. D) Same sample as in Plate 2C, but in color cathodoluminescence, illustrating the antiperthitic character of plagioclase. plg = plagioclase; ksp = potassium feldspar; opx = orthopyroxene; cpx = clinopyroxene.*

bronorite. Mafic enclaves or pyroxene-rich pods are found locally in the charnockite.

The tectonic fabric in the megacrystic charnockite is generally weak to non-existent (Plate 3A). Where the rock still contains an igneous texture, a primary foliation is defined by the alignment of feldspar megacrysts. In shear zones, the megacrystic charnockite has been completely recrystallized into K-feldspar augen gneiss (Plate 3B). Deformed mafic dykes are common in, and around, these shear zones.

The megacrystic charnockite has intrusive and tectonic contacts with the orthopyroxene monzodiorite unit and gabbronorite unit (Plates 3E and F). The monzodiorite may be tectonically juxtaposed with the megacrystic charnockite or may be separated from the megacrystic charnockite by small, 3- to 4-m-wide shear zones. The gabbronorite shows evidence of being contemporaneous with the megacrystic charnockite because in some instances angular blocks of gabbronorite appear in the megacrystic charnockite whereas other blocks have more diffuse edges and contain inclusions of perthite megacrysts.

Gabbronorite

Gabbronorite is poorly exposed throughout the eastern half of the map area. However, outcrops of gabbronorite can be correlated with the high magnetic anomalies in the aeromagnetic survey and this geophysical signature has been used to extrapolate the extent of the unit (Figures 5, 6). The gabbronorite displays variable textures that range from massif and equigranular to migmatitic (Plate 4A, B). The unit typically is mesocratic but leucocratic variants occur local-

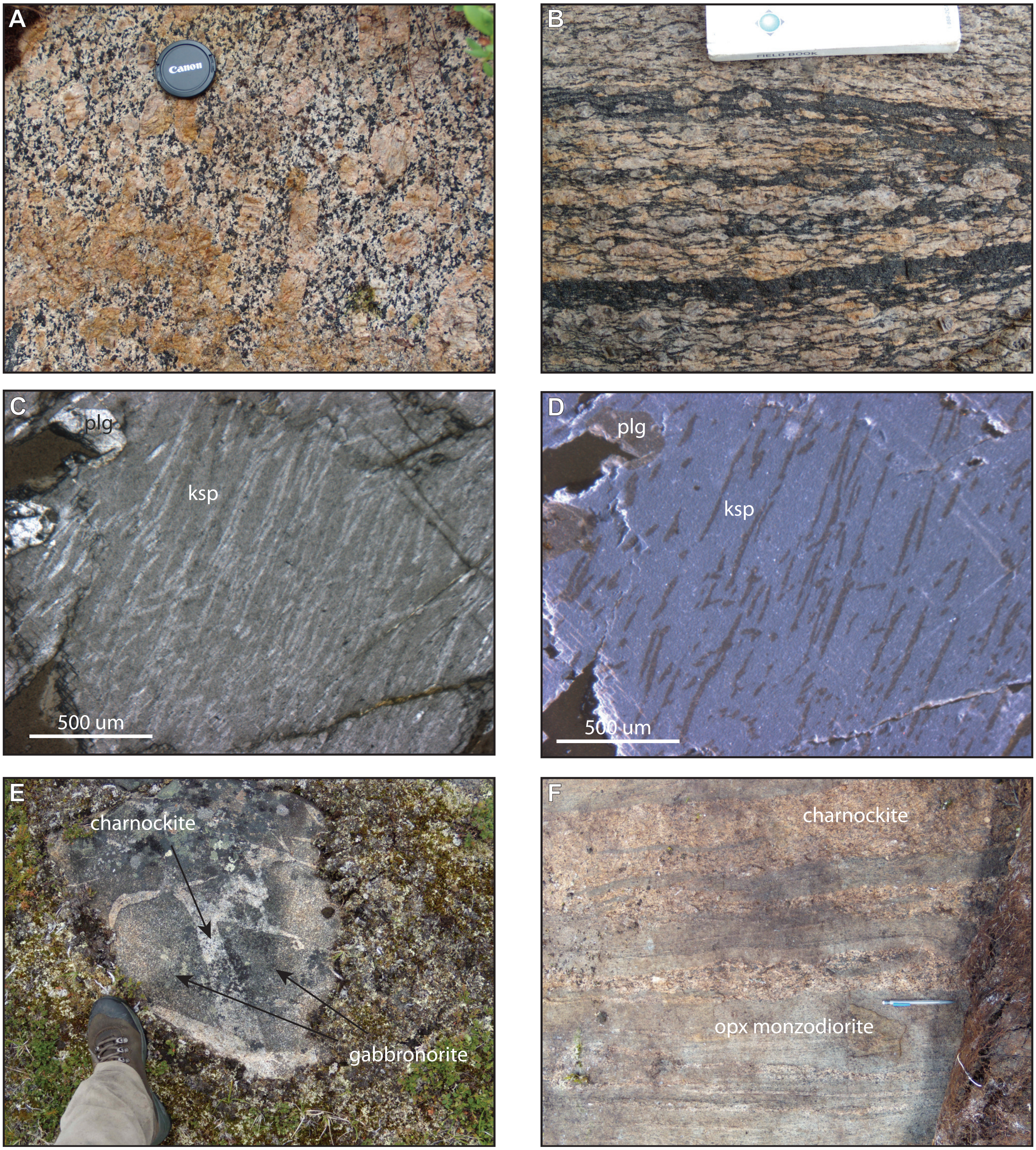


Plate 3. *Megacrystic charnockite of the De Pas batholith. A) Typical massive megacrystic charnockite. Undeformed charnockite makes up the majority of outcrops of the De Pas batholith in the Crossroads Lake area. B) Intensely deformed megacrystic charnockite and bifurcated mafic dyke (dark layers). Outcrop is located near the contact of the megacrystic charnockite and Archean granite. C) Cross-polarized light photomicrograph of a typical feldspar crystal. D) Cathodoluminescence image of the same feldspar as in "c". Plates 3E and 3F illustrate the intrusive relationships of the megacrystic charnockite and the gabbronorite and orthopyroxene monzodiorite units. plg = plagioclase; ksp = potassium feldspar.*

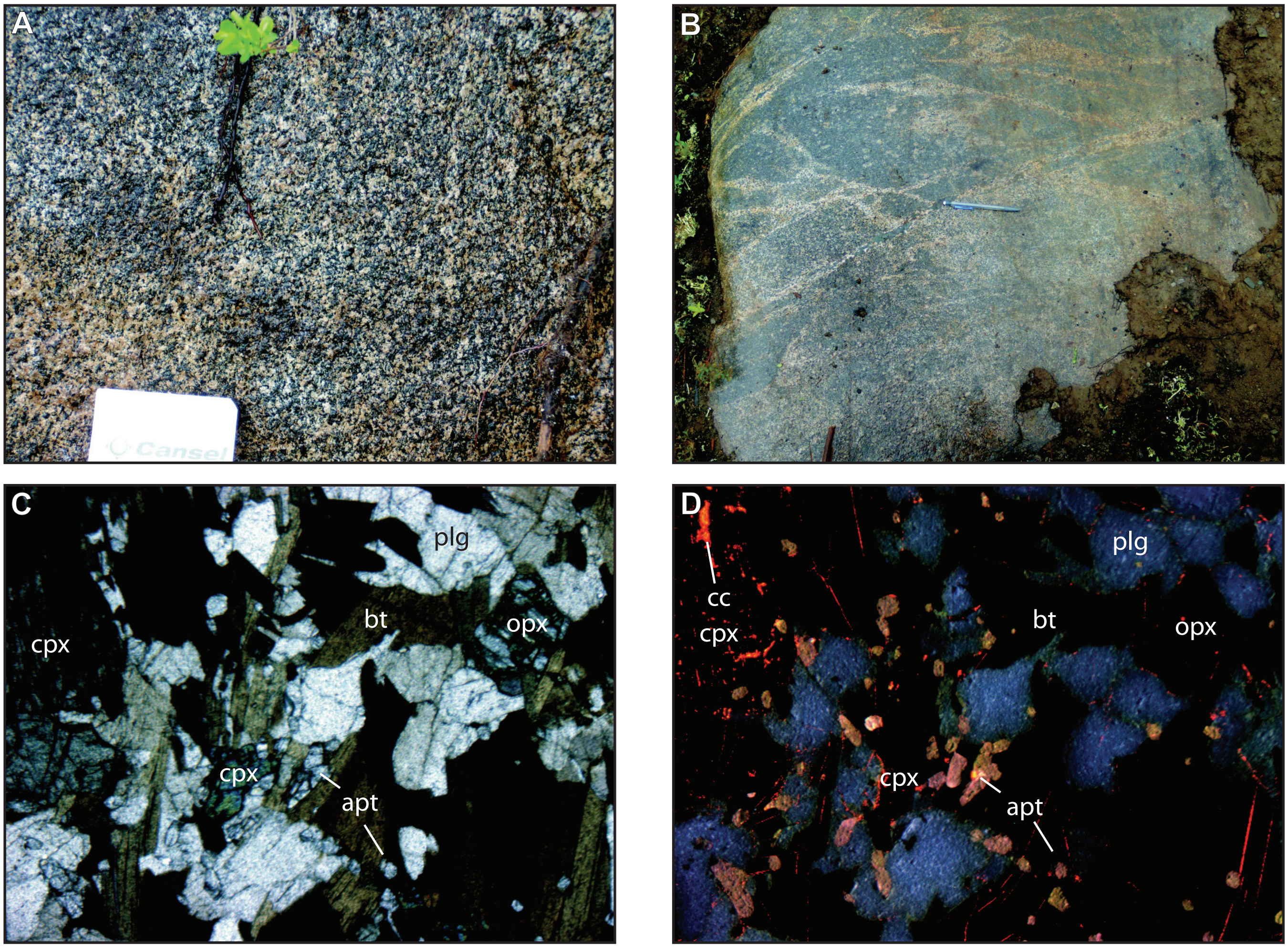


Plate 4. *Gabbronorite: A) Outcrop of massive gabbronorite. B) Outcrop of migmatitic gabbronorite. C) Cross-polarized light photomicrograph of gabbronorite. D) Cathodoluminescence view of the same image as in 4c. plg = plagioclase; cpx = clinopyroxene; apt = apatite; bt = biotite; cc = calcite; opx = orthopyroxene.*

ly. Distinguishing gabbronorite from the more mafic-rich variety of the orthopyroxene monzodiorite is difficult in the field.

The mineral assemblage is plagioclase, clinopyroxene, orthopyroxene, biotite and amphibole with minor apatite, K-feldspar and quartz (Plates 4C, D). In migmatitic varieties (Plate 4B), leucosomes contain the same assemblage as the non-migmatitic unit but contain less biotite and amphibole. The ubiquitous presence of apatite and biotite suggests that the original magma was rich in volatiles.

Outcrops of gabbronorite, as discerned from high aeromagnetic signatures, show that the gabbronorite bodies parallel major shear zones in the area (Figures 5, 6). These bodies are elongated in the direction of shearing along both north- and northeast-striking shear zones.

Coronitic Gabbronorite–Amphibolite

Gabbronorite and amphibolite form small hills that rise sharply out of the surrounding wetlands in the western half of the map area (Figure 5; Plate 5A) and are seemingly the only rock types exposed in the area. The gabbronorite is variably deformed, having nearly pristine igneous texture and a subhorizontal foliation, whereas the amphibolite has been wholly recrystallized and contains a steeply dipping foliation. The relationship between the amphibolite and the gabbronorite is unclear. Both rock types have a high magnetic signature and both occur in the western part of NTS map area 23I/14 (Figures 5, 6) suggesting that the two rock types have a connection, although they are mineralogically quite different. The coronitic gabbronorite consists of plagioclase, orthopyroxene, and clinopyroxene. Coronas of green amphibole typically separate clinopyroxene and pla-

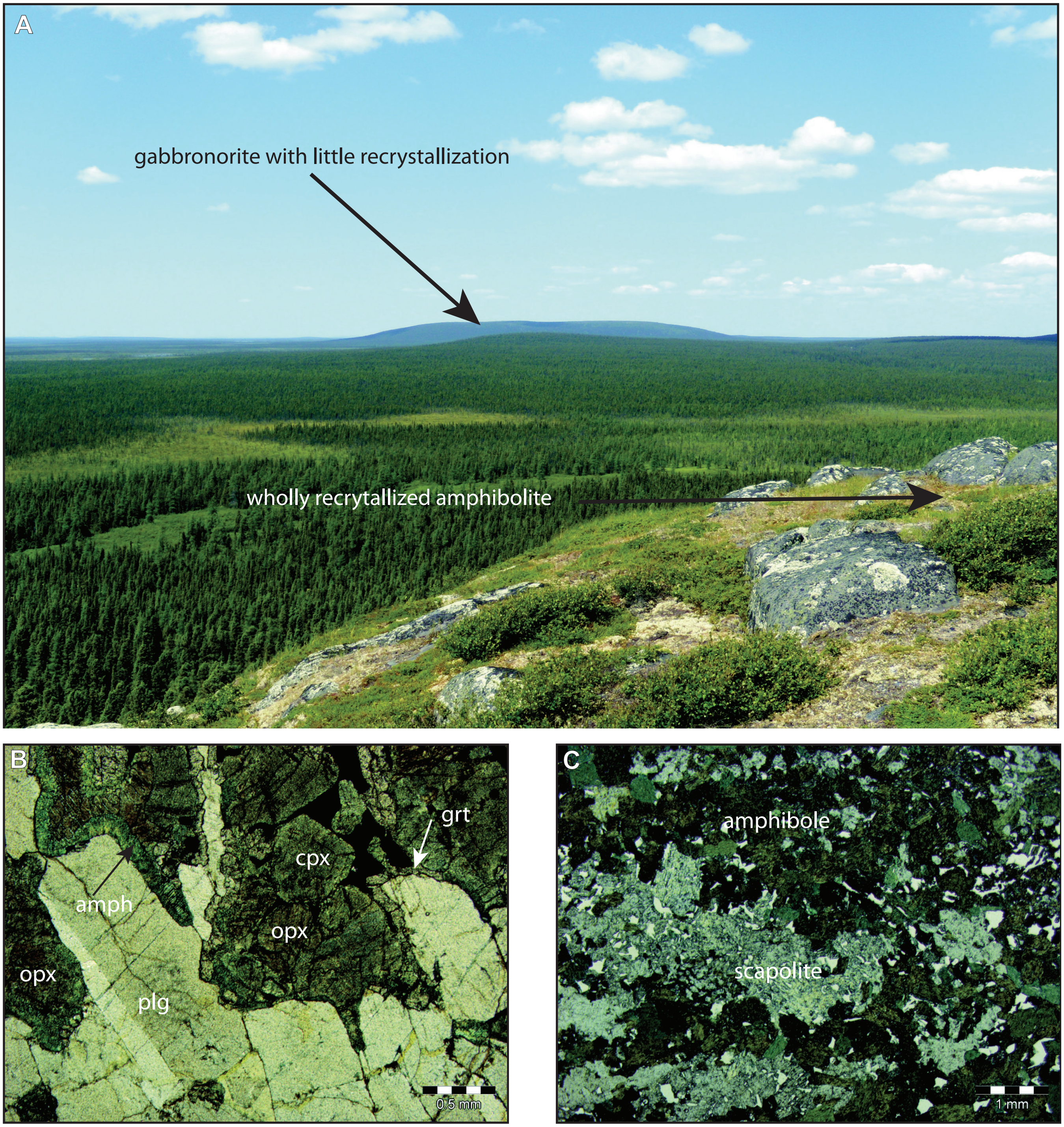
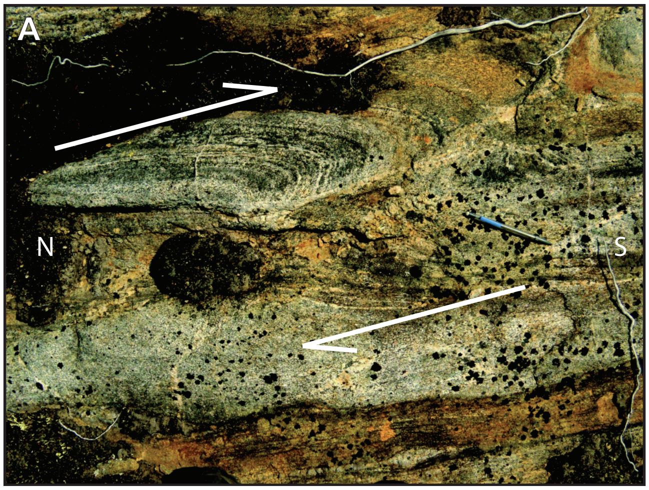


Plate 5. *A) Intrusions of gabbronorite stand in relief against the surrounding wetlands. Rocks on hill in the distance are little deformed whereas the hill in the foreground is underlain by wholly recrystallized rocks. B) Photomicrograph of undeformed gabbronorite. C) Photomicrograph of recrystallized gabbronorite converted to amphibolite. plg = plagioclase; cpx = clinopyroxene; opx = orthopyroxene; grt = garnet; amph = amphibole*

gioclase, and garnet forms coronas between opaque minerals and plagioclase (Plate 5B). Other fine-grained, unidentified intergrowths are present between orthopyroxene and plagioclase. The amphibolite, on the other hand, consists primarily of amphibole, scapolite, calcite and quartz indicative of significant alteration (Plate 5C). Ilmenite is partly replaced by rutile, and remnants of plagioclase are present. This mineral assemblage indicates that the rock has under-



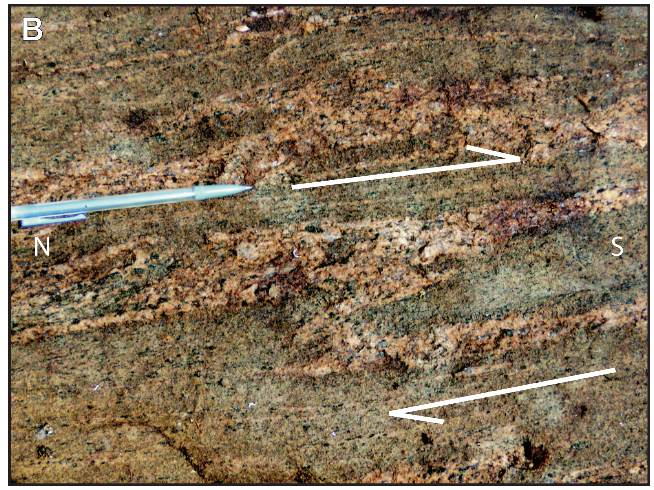


Plate 6. *Kinematic indicators indicative of right-lateral transpression. A) Sheared mafic layer in Archean charnockite. B) "Z" fold in mixed younger megacrystic charnockite (orange) and orthopyroxene monzodiorite (grey).*

gone near complete recrystallization, and very little remains of the original mineral assemblage. The coronitic gabbronorite must, at least, postdate deformation as it shows minimal evidence for deformation.

The lack of outcrop precludes determination of the relationship between the gabbronorite–amphibolite unit and the other units in the map area. The coronitic gabbronorite in the western part of the map area is texturally and mineralogically distinct from the gabbronorite farther east and the two are unlikely related. Previous work by James *et al.* (1993), around the Smallwood Reservoir, 80 km to the south, indicates that the vast wetland areas surrounding isolated outcrops of gabbronorite and amphibolite may be underlain by tonalite gneiss of the McKenzie River domain of James *et al.* (1996).

Dykes

Dykes of uncertain origin and age occur throughout the map area. Dykes are dominantly granitic pegmatite but rare, fine-grained mafic dykes having the same orientation are also present. These dykes are typically east-striking, range in width from a few centimetres to 50 cm, and crosscut all previous mentioned rocks with the exception of the coronitic gabbronorite and amphibolite.

STRUCTURE

The Crossroads Lake map area is dominated by north-striking, east-dipping shear zones with a subset of northwest-striking shear zones (Figures 5, 6). The orientation of Crossroads Lake is controlled by one of the northwest-striking shear zones. Both sets of shear zones appear to be contemporaneous, and they may coalesce, anastomose or splay. The shear zones are most commonly concentrated in the Archean charnockite or orthopyroxene monzodiorite units especially along the western edge of the De Pas batholith (Figures 5, 6). Intrusions of gabbronorite are in close proximity to the shear zones and mimic the structural trend. The De Pas megacrystic charnockite lacks the penetrative fabric of the Archean charnockite and orthopyroxene monzodiorite, and typically shows only weak primary alignment of feldspar crystals. However, locally along shear zones, the megacrystic charnockite contains augen feldspars and is intensely deformed (Plate 3B).

Foliations in the map area are north striking except near northwest-striking shear zones and all are east dipping. The dominant mineral lineation (where present) plunges to the northeast regardless of the lineation being associated with north-striking shear zones or northwest-striking shear zones, but the lineations do not provide a sense of the direction of shear. Other kinematic indicators such as deformed mafic or migmatite layers record right-lateral transpression (Plate 6A, B). Right-lateral transpression is supported by the orientation and anastomosing nature of the shear zones as they are interpreted from the airborne geophysics (Figure 6).

SUMMARY AND DISCUSSION

Rocks of the Crossroads Lake comprise variably deformed and exposed meta-igneous rocks. Rock units in the field area are Archean charnockite and granite, orthopyroxene monzodiorite of unknown age, gabbronorite, megacrystic charnockite, and coronitic gabbronorite and amphibolite. All rock units are deformed by north- and northwest-striking shear zones and are crosscut by east–west-striking dykes except the coronitic gabbronorite.

Previous mapping by James *et al.* (1993, 1996) indicated large offsets on northwest-striking shear zones and that they crosscut the north-striking shear zones. Long north-west-orientated lineaments, reflected as topographic features such as valleys and rivers, were interpreted as surface manifestations of these shear zones. However, the north-west-striking shear zones show little effect in the geophysical signature of the north-trending shear zones (Figure 5, 6). The 'stepping-out' nature of large exposures of the De Pas batholith, as previously mapped, can be attributed to the coalescing of north- and northwest-striking shear zones and a repeated switch between transpressional and translational shearing during oblique convergence.

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