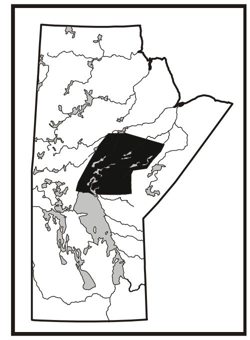
GS-22

FIELD, GEOCHEMICAL AND GEOCHRONOLOGICAL STUDIES OF PALEOPROTEROZOIC MAFIC AND ULTRAMAFIC DYKES IN THE NORTHWESTERN SUPERIOR PROVINCE (PARTS OF NTS 63I, 63J AND 63P)



by D.C. Peck, N.M. Halden[1], L.M. Heaman[2], M.T. Corkery, H.D.M. Cameron and K. Toope[2]

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SUMMARY

New field and lithogeochemical data have been collected for selected Paleoproterozoic mafic and ultramafic dykes within the northwestern part of the Superior Province in Manitoba. The dykes record important information concerning the tectonic, magmatic and metallogenetic evolution of the Superior Boundary Zone. Dykes occurring within the retrogressed part of the Pikwitonei domain and immediately to the east of the Thompson Nickel Belt show variable degrees of deformation and recrystallization during high temperature regional metamorphism. One of these dykes (Cuthbert Lake) is known to be coeval with the 1.88 Ga Molson dyke swarm. Recent U-Pb geochronological data indicate that the major period of ultramafic magmatism in both the Fox River and Thompson Nickel belts also occurred at ca. 1.88 Ga. Thereafter, high temperature metamorphism within the Superior Boundary Zone obliterated primary mineral assemblages in small and medium-sized dykes and along the margins of large dykes.

Based on petrological similarities to the deformed Molson dykes, the Archean age proposed for the abundant, deformed, mafic metaplutonic rocks in the central part of the Pikwitonei Domain should be verified with precise U-Pb geochronology. These rocks may have formed in an immature rift system concurrently with the Thompson Nickel Belt ultramafic magmatism. The age of metamorphosed sulphide-rich paragneiss intruded by both deformed and undeformed mafic and ultramafic dykes, assumed to be Archean, should also be verified. It is noteworthy that several of the deformed dykes exposed in Cuthbert and Wintering lakes contain disseminated Cu-rich magmatic sulphide mineralization.

The Paleoproterozoic dykes in the Superior Boundary Zone show a very similar range in petrology, paragenesis and major element geochemistry. However, preliminary results suggest that the trace element geochemistry of the dykes varies considerably. These differences are interpreted to reflect variations in the extent of crustal contamination or regional differences in the compositions of the mantle sources. Most of the dykes examined have geochemical affinities with low-Ti komatiite-tholeiite magmatic suites. Accordingly, the larger, layered dykes should be investigated for their potential to host magmatic Ni-Cu sulphide deposits and platinum-group element deposits.

INTRODUCTION

Work continues on a collaborative research program that will provide better constraints on the timing, metallogenetic significance and petrogenesis of Paleoproterozoic dykes in the northwestern part of the Superior Province in Manitoba. Recent, related studies of deformed Paleoproterozoic dykes in the Superior Boundary Zone within and immediately east of the Thompson Nickel Belt (TNB) (e.g., Heaman et al., 1986; Ducharme, GS-10, this volume) indicate that the main dyke event occurred at 1.88 Ga and was contemporaneous with and genetically related to the emplacement of the ultramafic sills in the TNB and the formation of komatiitic volcano-plutonic suites in both the Fox River Belt in northeastern Manitoba and the Cape Smith belt in northern Quebec.

This year, geochronological samples were collected from two of the largest known dykes (Molson Lake and Nelson River dykes), both of which are believed to be part of the 1.88 Ga Molson swarm. In addition, field observations obtained during a reconnaissance study of a deformed, mineralized composite dyke exposed on Cuthbert Lake within the Pikwitonei granulite domain suggest that high temperature metamorphism associated with the Paleoproterozoic Trans-Hudson orogenic event extends further to the east than was previously suggested. The latter brings into question the exact position and nature of the eastern boundary of the TNB.

From the perspective of future mineral exploration for Ni-Cu-PGE deposits in the Superior Boundary Zone in Manitoba, the Molson dyke swarm requires careful scrutiny. These dykes record the timing and geochemical characteristics of the 1.88 Ga magmatic event, the tectonic environment of associated plutonism and volcanism in the main magmatic belts (TNB, Fox River) and the post-magmatic structural and metamorphic history of the Superior Boundary Zone. To date, only a limited amount of geochemical information is available for the Molson dyke swarm (e.g., Scoates and Macek, 1978). One of the objectives of the current study is to develop a regional lithogeochemical and petrological database for the Molson dykes that will complement the growing geochronological database for these rocks.

FIELD OBSERVATIONS

Scoates and Macek (1978) provide a detailed description of the field characteristics of Molson swarm dykes. Recently, reconnaissance field investigations of mafic and ultramafic Paleoproterozoic dykes that are known or believed to be part of the 1.88 Ga Molson dyke swarm have been completed in several locations within the Superior Province of Manitoba (see Fig. GS-22-1 for locations), viz.: (1) northeast-trending gabbronorite dykes in the northeastern part of the Carrot River greenstone belt (see Peck et al., 1998); (2) northeast and east-trending gabbronorite and olivine gabbronorite dykes at Cauchon Lake (see Peck et al., 1996); and, (3) a composite north-northeast trending gabbronorite-pyroxenite-peridotite dyke at Cuthbert Lake (see Peck et al., 1996 and below). This year, additional field observations were obtained for: (1) a north-northeast trending gabbronorite dyke exposed on Molson Lake; (2) a north-northeast trending gabbronorite dyke that is part of the Nelson River mafic-ultramafic dyke; and, (3) the Cuthbert Lake mafic-ultramafic dyke.

Important field characteristics common to most of these dykes include: (1) back-veining (xenomelts) of country rock-derived partial melts adjacent to the margins of larger dykes (e.g., dykes that are tens of metres thick; Fig. GS-22-2); (2) development of sedimentary-type layering structures, including size grading, truncated layering, scours and micro-rhythmic layered units in larger, mafic dykes (Fig. GS-22-3); and, (3) in the Superior Boundary Zone, a progressive increase in the intensity of deformation and the extent of metamorphic overprinting, characterized by obliteration of primary textures and mineral assemblages in smaller dykes and along the margins of larger dykes, and complete preservation of primary features in the cores of larger dykes.

PETROLOGY AND GEOCHEMISTRY

To date, the only detailed, regional petrological and geochemical investigation of the Molson dyke swarm was completed by Scoates and Macek (1978). We have launched a new investigation of the primary paragenesis, lithogeochemistry and metamorphic petrology of several suites of dykes that appear to belong to the Molson swarm. Wherever possible, precise U-Pb zircon or baddeleyite age determinations will be acquired.

Aspects of the major element geochemistry of dykes from the Cauchon Lake, Cuthbert Lake, Pipestone Lake and the northeastern part of the Carrot River greenstone belt (Fig. GS-22-1) is shown on a Jensen cation plot (Fig. GS-22-4). The dyke compositions are typical of komatiite-tholeiite suites from other rifted margin environments and may

[1] Department of Geological Sciences, University of Manitoba, 125 Dysart Road, Winnipeg, Manitoba R3T 2N2
[2] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3

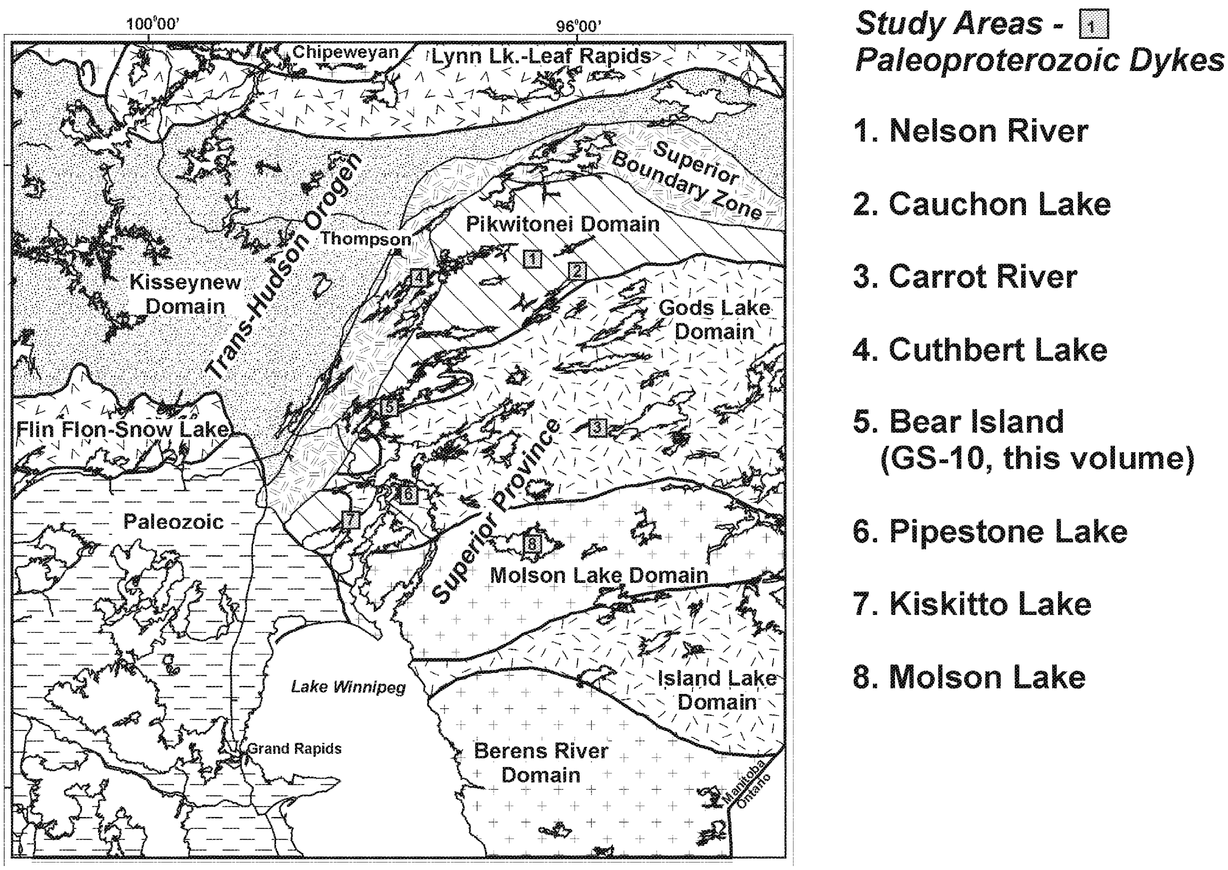

Figure GS-22-1: Location of study areas and 1999 geochronological sample sites, including the Bear Island dyke (Ducharme, GS-10, this voulme).

be related to a similar, primitive parent magma by fractional crystallization of olivine, pyroxene and, lastly, plagioclase. The trace element systematics of representative samples of the same suite of dykes is illustrated in Figure GS-22-5. Whereas the Cuthbert Lake and Pipestone Lake dykes display very little deviation from mantle-like trace element geochemical compositions, the dykes from the Cauchon Lake, Carrot River and Kiskitto Lake areas display significant enrichment in the most incompatible trace elements (e.g., Th, U, La) and are depleted in selected high-field strength elements (Nb, Zr, Ti) relative to the primitive mantle standard values (Fig. GS-22-5). A possible explanation for these trends is that local geochemical heterogeneities existed in the mantle source underlying the Superior craton during the Paleoproterozoic. Alternatively, the mantle source for all of the Molson dykes was relatively uniform in composition, and the parental magmas experienced different degrees of interaction with incompatible element-enriched and Zr-Nb-Ti-depleted Archean continental crust. We plan to carry out additional trace element analyses and limited Sm-Nd isotopic analyses in order to test these alternative hypotheses.

GEOCHRONOLOGY

Recent U-Pb geochronological data obtained for the Paleoproterozoic mafic and ultramafic dykes in the northwestern part of the Superior Province in Manitoba (Heaman et al., 1986; Heaman and Corkery, 1996; Peck and Heaman, 1998) indicate that there are at least 2 principal age groupings, viz., ca. 1.88 Ga Molson dyke swarm (Scoates

Figure GS-22-2: Contact between a chilled margin of a segment of the Nelson River mafic-ultramafic dyke (upper right) and older, Archean gneisses (bottom left), showing discontinuous veins of intermediate composition (upper right) emanating from a granodiorite melt zone that formed in the thermal aureole of the dyke.

Figure GS-22-3: Centimetre scale modal layering (micro-rhythmic layering), including truncated layering, involving variations in plagioclase:pyroxene modal proportions in a layered mafic dyke occurring immediately to the south of the Fox River Belt.

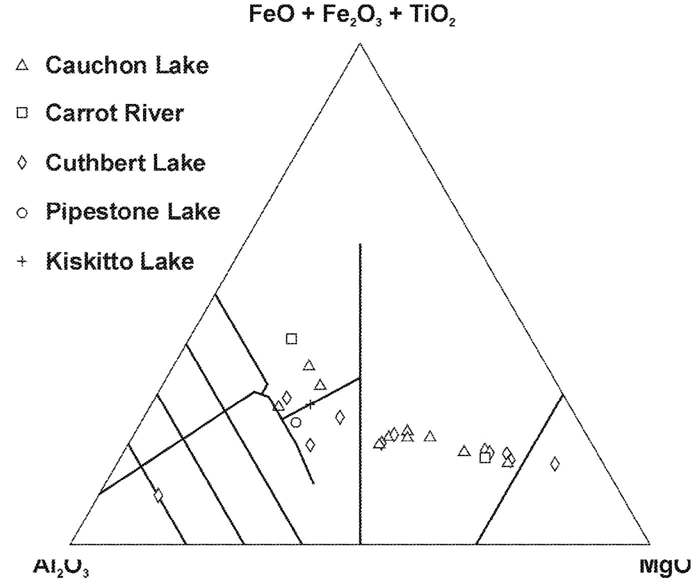

Figure GS-22-4: Jensen cation diagram (Jensen, 1976) for selected Molson dyke suites from the Superior Province, northern Manitoba. The data are unpublished.

and Macek, 1978) and ca. 2.1 Ga dykes (Split Lake block; Heaman and Corkery, 1996; Fig. GS-22-1). The first precise U-Pb age determination (1.880 Ga) for a mineralized ultramafic intrusion in the TNB (Setting Lake area; L. Hulbert, Geological Survey of Canada, written communication, August, 1999) clearly demonstrates that the Molson dyke swarm was, at least in part, coeval with ultramafic magmatism in the TNB and, likely, part of a major ca. 1.88 Ga magmatic episode that affected most of the northern margin of the Superior Province. Contemporaneous, 1.88 Ga magmatism produced komatiite-basalt volcanic sequences and layered mafic and ultramafic intrusions in the TNB and Fox River Belt in Manitoba, the Cape Smith belt and Labrador Trough in Quebec, and picritic magmatism in the Pechenga district, northeastern Russia (Green and Melezhik, 1999).

This year, geochronological sampling was done on the southeastern margin of a large gabbroic dyke on Molson Lake and within a gabbroic dyke exposed along the western shoreline of the Nelson River to the north of Cauchon Lake (Fig. GS-22-1). In both cases, two or more samples were collected from different parts of the dyke. Sampling targeted

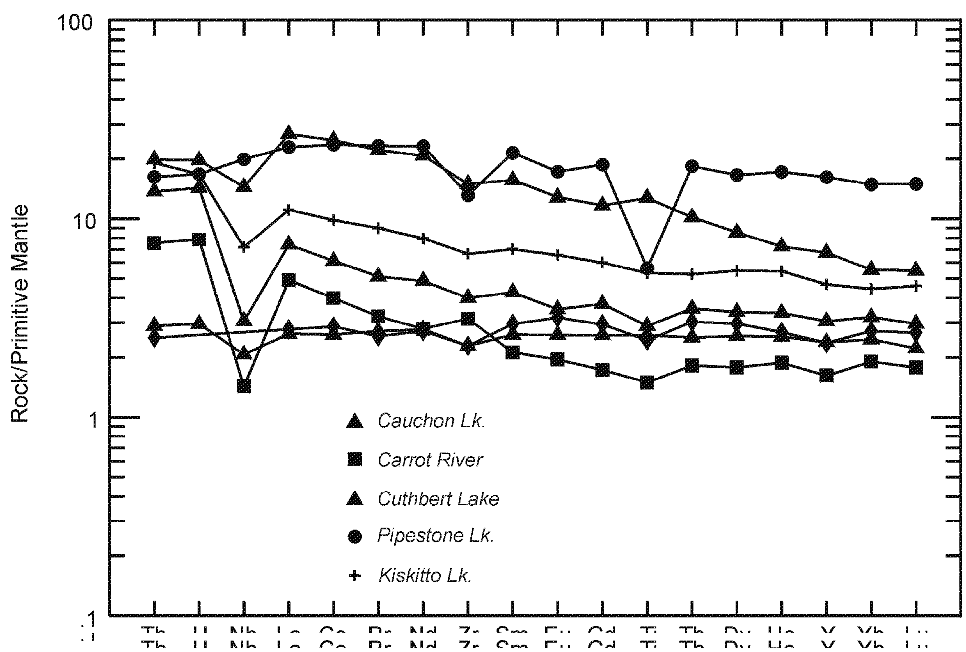

Figure GS-22-5: Primitive-mantle-normalized multielement plots for selected, representative samples of Molson dykes from the Cauchon Lake, Cuthbert Lake, Pipestone Lake, Kiskitto Lake and Carrot River areas. Mantle normalization values are from McDonough and Sun (1995). The data are unpublished.

coarse-grained to pegmatitic, commonly varitextured feldspathic pods that are commonly developed in large Molson dykes (Fig. GS-22-6). These pods are interpreted to represent the crystallization of evolved, residual magma that is strongly enriched in compatible trace elements, including zirconium. This approach proved very successful in obtaining primary zircons from other Molson dykes. On a cautionary note, leucosome material occurring in some of the Proterozoic dykes immediately adjacent to or within the Thompson Nickel Belt appears to be of metamorphic origin (partial melts associated with granulite facies metamorphism). In addition, many of the larger Molson dykes contain granitic "back veins" and xenomelts derived from partial melting of the country rock along the dyke margins. These xenomelts may contain zircons inherited from the country rock.

A single geochronological sample was collected from a metamorphosed but relatively undeformed layered mafic dyke occurring immediately to the south of the Fox River Belt. The dyke strikes ca. 080° and is sub-vertical. Layering in this dyke comprises diffuse, micro-rhythmic modal layering (Fig. GS-22-3), truncated tops of inclined sets of modal layers (similar to cross-bedding in sedimentary rocks) and decametre - to metre-scale planar modal layering. The dyke intrudes both Archean tonalitic migmatitic gneisses and massive and foliated granodiorite.

METALLOGENETIC SIGNIFICANCE

Recent investigations of deformed metagabbro and metapyroxenite bodies in the Wintering Lake and Cuthbert Lake areas, both of which occur in the Superior Boundary Zone, suggests that these rocks and their locally significant Cu-rich disseminated to massive sulphide occurrences may be deformed equivalents of the Molson dyke swarm and not part of a Late Archean plutonic suite, as previously believed (e.g., Hubregtse, 1978). This suggestion is based on field observations from the Cuthbert Lake area. Low water levels in 1999 provided excellent exposure of the Cuthbert Lake area mafic and ultramafic dykes. Reconnaissance mapping conducted in the southwestern part of Cuthbert Lake indicates that the extent of the dyke is far greater than shown on existing geological maps for the area (Hubregtse, 1978). In addition, the dyke is a composite body comprising sub-parallel, sub-vertical dykes that range from <1 m to tens of metres in thickness. Rock types observed in the Cuthbert Lake dyke include quartz diorite, leucogabbronorite, gabbronorite, olivine gabbronorite, pyroxenite and peridotite. The many sub-parallel dykes are commonly connected by narrow, fine-grained gabbroic apophyses that are oblique to the strike of the main dykes. An unexpected feature of many of the larger dykes is that they commonly have deformed and metamorphosed margins. It appears that only the ultramafic cores of the largest dykes, exposed on islands in the central part of the lake, have not been significantly affected by metamorphism and deformation. Furthermore, the amphibolite facies metamorphic mineral assemblages present in the deformed parts of the Cuthbert Lake composite dyke are similar to those developed in the ortho- and paragneisses that constitute the Archean basement in this area. This suggests that a high temperature metamorphism affected the area following emplacement of the Cuthbert Lake dyke. As a consequence, the presence of amphibolite facies metamorphic mineral assemblages in the basement gneisses and, most importantly, in deformed garnetiferous sulphidic iron formations that are locally intruded by the Cuthbert Lake dyke, is not sufficient evidence of an Archean age. The large amount of amphibolite facies paragneiss and associated metagabbro and metapyroxenite that occurs in the Wintering Lake - Partridge Crop Lake - Cuthbert Lake region should be re-examined with the intent of obtaining precise age information and structural and metamorphic data.

Additional research will also be required to: (1) determine if all of the mafic-ultramafic intrusions in the Cuthbert Lake - Wintering Lake region are rift-related and part of the 1.88 Ga extensional magmatic episodes that formed the TNB and the Molson dyke swarm; and (2) determine if the numerous Cu-Ni (+/-PGE) sulphide showings in metagabbro and metapyroxenite on Wintering Lake, Partridge Crop Lake and Cuthbert Lake developed during the Archean or the Paleoproterozoic.

With respect to item (2), the most relevant field observation obtained to date is that many of the Cu-Ni sulphide showings in these lakes occur within metagabbroic intrusions emplaced into metamorphosed sulphide facies iron formation. If both the metagabbro bodies and the sulphide facies iron formations are determined to be Paleoproterozoic in age (e.g., the mineralized, deformed metagabbros at Cuthbert Lake are believed to be part of the 1.883 Ga Cuthbert Lake dyke; Heaman et al., 1986), then the rifting, sedimentation and magmatism that characterize the TNB may have extended well to the east of its interpreted eastern boundary (e.g., McRitchie, 1995).

Most of the largest Paleoproterozoic dykes in the Superior boundary zone (e.g., Cuthbert Lake, Molson Lake and Nelson River dykes) display evidence of igneous layering features that are interpreted to have formed in dilatant structures within the dyke. Here, magma flow that in most parts of the dyke was vertical and driven by buoyancy, was dominated by thermal and density-driven convection cells. In these areas, the dykes probably behaved in much the same manner as a sill and could have developed ore deposits similar to those seen in layered mafic-ultramafic intrusions. Many of the world's major magmatic Ni-Cu sulphide deposits and PGE deposits occur in NeoArchean and Paleoproterozoic layered intrusions (ca. 2.7 to 1.9 Ga) that developed in continental margin rift systems and share many geochemical and petrological features with the large, layered Paleoproterozoic dykes described here. Accordingly, we recommend that the dykes be explored for magmatic Ni, Cu and PGE deposits, particularly where they intrude S-rich paragneiss. These paragneisses potentially represent a major source of external sulphur believed to be critical to the development of magmatic sulphide deposits.

ONGOING RESEARCH

Future investigations will focus on building a regional field, petrological and lithogeochemical database for the Molson dykes. This information, combined with new geochronological data, will aid in developing a regional tectonic and metallogenic model for the eastern part

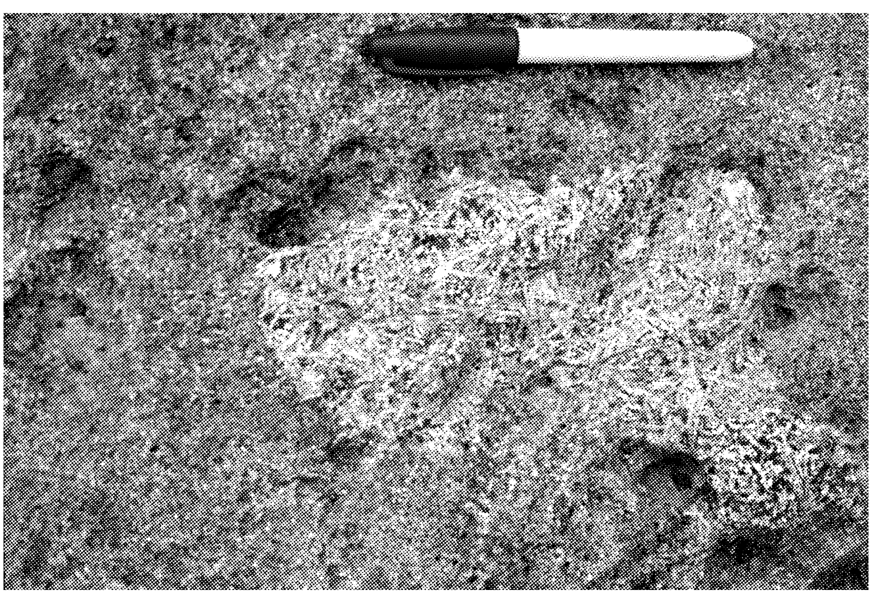

Figure GS-22-6: Coarse-grained, acicular plagioclase in a feldspathic "pod" developed in gabbronorite, Nelson River dyke. Petrologically and morphologically similar "pods" are known to contain primary zircons in other Paleoproterozoic dykes in the Superior Province of Manitoba.

of the Superior Boundary Zone. This database will also help to establish the geological relationships between the Molson dykes and the major Superior Boundary Zone magmatic belts (Thompson, Fox River). We recommend that additional detailed mapping accompanied by U-Pb geochronology should be conducted in and adjacent to Cuthbert, Partridge Crop and Wintering lakes, in order to determine whether these areas contain rift basin sedimentary rocks and ultramafic-mafic intrusions that are coeval with the TNB.

REFERENCES

Green, A.H. and Melezhik, V.A. 1999: Geology of the Pechenga Ore Deposits - A review with comments on ore forming processes; *in* Keays, R.R., Lesher, C.M., Lightfoot, P.C. and Farrow, C.E.G. (eds.), Dynamic processes in magmatic ore deposits and their application in mineral exploration, Geological Association of Canada, Short Course Volume 13, p. 287-328.

Heaman, L.M. and Corkery, M.T., 1996: Proterozoic tectonic evolution of the eastern Trans-Hudson margin: Preliminary U-Pb results from the Split Lake block, Manitoba; Geological Association of Canada, Program with Abstracts, v. 21, p. A43.

Heaman, L.M., Machado, N., Krogh, T.E., and Weber, W. 1986: U-Pb zircon ages for the Molson dyke swarm and the Fox River sill: Constraints for Early Proterozoic crustal evolution in northeastern Manitoba, Canada; Contributions to Mineralogy and Petrology, v. 94, p. 82-89.

Hubregtse, J.J.M.W. 1978: Sipiwesk Lake - Wintering Lake - Landing Lake area; *in* Manitoba Energy and Mines, Minerals Division, Report of Field Activities, 1978, p. 54-62.

Jensen, L.S. 1976: A new cation plot for classifying subalkalic volcanic rocks; Ontario Department of Mines, Miscellaneous Paper 66.

McDonough, W.F. and Sun, S.S. 1995: The composition of the earth; Chemical Geology, v. 120, p. 223-253.

McRitchie, W.D. 1995: Mineral development potential in Manitoba - nickel in the southwest extension of the Thompson Nickel Belt; Manitoba Energy and Mines, Economic Geology Report ER95-2, 29 p.

Peck, D.C. and Heaman, L.M. 1998: Geochemical characteristics and preliminary U-Pb zircon age of Proterozoic mafic dykes from the eastern part of the Carrot River greenstone belt (parts of NTS 63I/16); *in* Report of Activities, 1998, Manitoba Energy and Mines, Geological Services, p.135-143.

Peck, D.C., Cameron, H.D.M., Layton-Matthews, D., and Bishop, A. 1996: Geological investigations of anorthosite, gabbro and pyroxenite occurrences in the Pikwitonei granulite domain and the Cross Lake region; *in* Manitoba Energy and Mines, Minerals Division, Report of Field Activities, 1996, p. 85-90.

Scoates, R.F.J. and Macek, J.J. 1978: Molson dyke swarm; Manitoba Department of Energy and Mines, Mineral Resources Division, Geological Paper 87-1, 53 p.