Geoscience Canada

The 1998 Ma Purtuniqophiolite: imbricated and metamorphosed oceanic crust in the Cape Smith Thrust Belt, northern Quebec

D. J. Scott, M. R. St-Onge, S. B. Lucas and H. Helmstaedt

Volume 16, Number 3, September 1989

URI: https://id.erudit.org/iderudit/geocan16_3art09

See table of contents

Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)
1911-4850 (digital)

Explore this journal

Cite this article

Scott, D. J., St-Onge, M. R., Lucas, S. B. & Helmstaedt, H. (1989). The 1998 Ma Purtuniqophiolite: imbricated and metamorphosed oceanic crust in the Cape Smith Thrust Belt, northern Quebec. *Geoscience Canada*, *16*(3), 144–147.

Article abstract

A sequence of rocks representing obducted oceanic crust (an ophiolite) has been identified in the Cape Smith Belt. The physical and chemical nature of this 1998 Ma ophiolite is similar to rocks from Phanerozoic ophiolites and modern oceans, implying that tectonic processes similar to those operating today were active nearly two billion years ago. At that time, northern Quebec may have been tectonically similar to the modern Red Sea.

partie granophyrique sommitale semble provenir du mélange entre le magma gabbronoritique et les sédiments selon un mécanisme comparable à celui décrit par Nadeau (1984) dans un autre filon-couche (le "No Name Sill") de la bande du Cap Smith.

L'intrusion Roméo 2. Le présence de plagioclase et d'olivine en phase cumulus dans la séquence basale évoque un liquide primitif probablement plus évolué que celui à l'origine de la séquence ultramafique de Roméo 1. De plus, elle suggère que les intrusions Roméo 1 et 2 correspondraient à deux injections magmatiques indépendantes. Les données actuellement disponibles évoquent des mécanismes de cristallisation analogues à ceux du filon-couche Roméo 1. Toutefois, la présence de globules de composition ultramafique dans la séquence gabbroïque indique l'intervention de mélanges entre une masse ultramafique semi-consolidée et le liquide résiduel de composition gabbroïque provoquant le piégeage de xénolithes ultramafiques (les globules) dans le gabbro. Cette observation est insuffisante pour conclure à l'existence de plusieurs injections magmatiques. Les résultats obtenus sur le filon-couche Roméo 1 évoquent plutôt l'influence de courants magmatiques qui auraient arraché des lambeaux de la partie supérieure de la séquence péridotitique. De tels courants magmatiques dans le système Roméo 1 pourraient également fournir une explication sur la présence de fragments sédimentaires dans la pile gabbroïque et sur les contacts abrupts observés entre les différents faciès.

Conclusion

Plusieurs observations macro- et microscopiques plaident en faveur d'une origine magmatique multiphasée pour les filons-couches Roméo 1 et 2. Cependant, les variations cryptiques de l'olivine et du clinopyroxène et l'étude comparée de la bordure figée inférieure et de la composition pondérale du filon-couche Roméo 1 montrent que cette intrusion résulte de la différenciation par des processus d'accumulation et de cristallisation *in situ* d'un seul liquide magmatique, syngénétique de la mise en place des basaltes komatiitiques à olivine du Groupe de Chukotat. Malgré l'insuffisance de données, la comparaison des filons-couches Roméo 1 et Roméo 2 indique qu'il est probable que ce dernier résulte également d'un seul cycle de différenciation mais à partir d'un liquide parent vraisemblablement plus évolué. Des résultats analogues obtenus sur le No Name Sill, intrusif à la base des basaltes du Groupe de Chukotat (Nadeau, 1984), et sur le filon-couche Delta (Desroches, 1988; Picard et Giovenazzo, sous presse) conduisent à admettre l'idée que les processus mentionés ci-dessus peuvent se généraliser (avec quelques variantes) à la plupart des filons-couches différenciés de péridotite-gabbro de la bande du Cap Smith. Les travaux en cours permettront de quantifier ce modèle et de l'appliquer pour expliquer le comportement des éléments du groupe des platinoides dans les séquences ultramafiques à mafiques.

Remerciements

Nous remercions le Ministère de l'Énergie et des Ressources du Québec (MERQ) qui a financé les travaux de terrain et de laboratoire ainsi que le Centre de Recherche Minérale à Québec (CRM) et le laboratoire de géochimie de l'Université de Montréal qui ont réalisé les analyses chimiques. Nous remercions en particulier Gilles Gauthier et Jean-Pierre Bourque (U de M) pour leur support technique. Cet article a grandement bénéficié d'une lecture critique par Stephen Lucas et Marc St-Onge (Commission géologique du Canada).

Références

Desroches, V., 1988, Méthode de détermination du liquide parent des intrusions différenciées: Exemple du filon-couche Delta 3, Nouveau Québec: Projet de fin d'études, Département de Géologie de l'Université de Montréal, Montréal, Québec, 41 p.

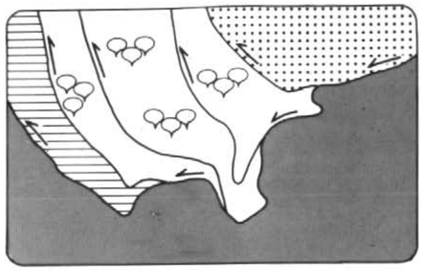
Irvine, T.N., 1982, Terminology for layered intrusions: Journal of Petrology, v. 23, p. 127-162.

Marsh, B.D., 1988, Crystal capture, sorting, and retention in convection magma: Geological Society of America Bulletin, v. 100, p. 1720-1737.

Nadeau, S., 1984, La pétrologie, la géochimie et le rôle de la contamination dans l'évolution magmatique du Sill No-Name, Cap-Smith, Baie de Wakeham, Nouveau Québec: Thèse Maîtrise, Université de Montréal, 115 p.

Picard, C. and Giovenazzo, D., in press, Pétrographie, Géochimie et Gîtologie des roches plutoniques ultramafiques et mafiques protérozoïques de la partie centrale de la Fosse de l'Ungava: implications sur la distribution des éléments du groupe des platinoïdes: Ministère de l'Énergie et des Ressources du Québec.

St-Onge, M.R., Lucas, S.B., Scott, D.J. and Bégin, N.J., 1987, Tectono-stratigraphy and structure of the lac Watts-lac Cross-Rivière Déception area, central Cape Smith Belt, northern Québec: Geological Survey of Canada, Paper 87-1A, p. 619-632.



The 1998 Ma Purtuniq ophiolite: imbricated and metamorphosed oceanic crust in the Cape Smith Thrust Belt, northern Quebec

D.J. Scott
Department of Geological Sciences
Queen's University
Kingston, Ontario K7L 3N6

M.R. St-Onge
Geological Survey of Canada
588 Booth Street
Ottawa, Ontario K1A 0E4

S.B. Lucas
Geological Survey of Canada
588 Booth Street
Ottawa, Ontario K1A 0E4

H. Helmstaedt
Department of Geological Sciences
Queen's University
Kingston, Ontario K7L 3N6

Summary

A sequence of rocks representing obducted oceanic crust (an ophiolite) has been identified in the Cape Smith Belt. The physical and chemical nature of this 1998 Ma ophiolite is similar to rocks from Phanerozoic ophiolites and modern oceans, implying that tectonic processes similar to those operating today were active nearly two billion years ago. At that time, northern Quebec may have been tectonically similar to the modern Red Sea.

Résumé

Une séquence de roches caractérisant une croûte océanique obductée (une ophiolite) a été identifée dans la bande du Cap Smith. Les aspects physiques et chimiques de cette ophiolite datée à 1998 Ma sont semblables à ceux des ophiolites phanérozoïque et des océans modernes. L'implication est que les processus tectoniques modernes sont semblables à ceux qui étaient actifs il y a deux milliards d'années. A ce temps là, le nord du Québec était peut-être similaire à la mer Rouge actuelle.

Introduction

The presence of obducted oceanic crust (an ophiolite) in Phanerozoic orogenic belts is generally taken as strong evidence in favour of plate tectonics. The apparent lack of preserved ophiolites in older mountain belts has been used as an argument against such processes. The recognition of all of the classical ophiolitic crustal rock types (*e.g.*, layered mafic- and ultramafic cumulates, "sheeted" mafic dykes, pillowed volcanics, and deep-water sediments) in two billion year-old rocks from the Cape Smith Belt, northern Quebec, is compelling evidence in favour of modern-style plate tectonic processes having been operational in the early Proterozoic. The example of old oceanic crust from northern Quebec may provide an analogue for the origin of some Archean "greenstone" belts.

The Cape Smith Thrust Belt preserves the imbricated and southward-tranported remnants of: (1) a *ca.* 1960 Ma (Parrish, 1989 - this issue, p. 126-130) north-facing continental rift margin (Povungnituk Group); (2) younger (*ca.* 1920 Ma; Parrish, 1989 - this issue, p. 126-130) transitional- to MORB-like volcanics (Chukotat Group, Hynes and Franciś, 1982; Picard, 1986, 1989); and (3) an older 1998 Ma (Parrish, 1989 - this issue, p. 126-130) obducted ophiolite (Watts Group) (see St-Onge *et al.*, 1989 - this issue, p. 119-122). The tectonically dismembered Purtuniq ophiolite (Figure 1) has been metamorphosed up to mid-amphibolite-facies, with a variable greenschist-facies retrograde overprint. The principal igneous stratigraphic components (Watts Group), from bottom to top, are: (1) ultramafic and mafic cumulates; and (2) sheeted mafic dykes passing upward in a continuous sequence into dominantly pillowed mafic flows and thin sills. This presumed stratigraphic order has been inverted by tectonic imbrication, such that the cumulate thrust sheets presently overlie sheets containing the dykes and flows (Figure 1).

The Spartan Group (Figure 1) is a sequence of sediments that are structurally sandwiched between the Watts and Chukotat Groups. It is characterized by deep-water graphitic pelites coarsening upward into semi-pelites with sandstone turbidites, and eventually into distal fan deposits (St-Onge and Lucas, in press). The origin of the sediments remains enigmatic. However, within the study area (Figure 1), the sediments do not appear to contain lithic fragments of volcanic origin, as might be expected had an exposed volcanic arc been active during Spartan Group sedimentation.

Flows and dykes

The flows of the Watts Group in the study area (Figure 1) are tholeiitic, with chondrite-normalized rare earth element (REE) patterns that are flat at 10 × chondritic abundance. This REE pattern resembles that of modern N-MORB (Scott *et al.*, 1988). The interpretation of the basalts as oceanic is supported by their Nd isotopic compositions (Hegner and Bevier, 1989 - this issue, p. 148-151). The sequence is dominantly pillowed, although thicker massive flows and thin sills are also present. Interflow sediment is only rarely observed. The facing direction of the pillows indicates that the sequence is upright.

The associated sheeted dykes (Figure 2a) occur at the base of the principal mafic thrust sheet. They are most extensively developed, and were sampled exclusively at a locality approximately 5 km due east of lac Watts. Individual dykes are 20-50 cm wide. Half-dykes, showing only one chilled margin,

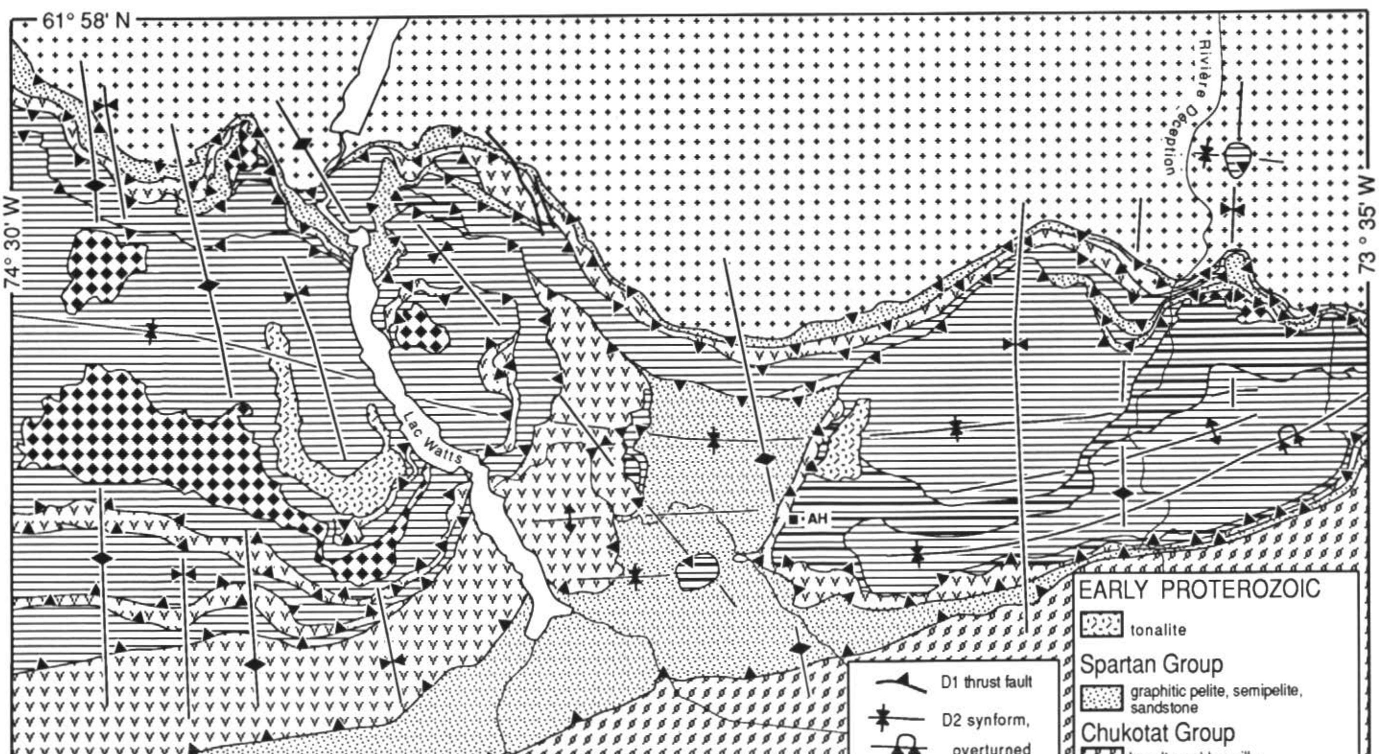


Figure 1 *Simplified geological map of the eastern portion of the Purtuniq ophiolite, Cape Smith Belt, northern Quebec.* ***AH****, former Asbestos Hill mine at Purtuniq. (Modified from St-Onge* et al.*, 1988).*

are present, but do not make up a large proportion of the population. The dykes are tholeiitic, and have been subdivided into two distinct populations on the basis of their trace element content. One population is characterized by flat, chondrite-normalized REE patterns that are 10 × chondrite; these are interpreted as being chemically similar to N-MORB. The other population shows a relatively strong enrichment in light REE (LREE) (La_N/Lu_N up to 20) and other incompatible trace elements, and resemble E-type MORBs. In addition, the two populations are also recognized as having distinct Nd isotopic signatures (see Hegner and Bevier, 1989 - this issue, p. 148-151). Field relations at the above locality indicate that the two populations occur in roughly equal proportions and intrude each other, suggesting that emplacement of the two populations was coeval. Similar compositional variations between demonstrably coeval dykes have been documented in sheeted dyke swarms in Phanerozoic ophiolites (J. Malpas, pers. comm., 1989, *e.g.*, Troodos, Cyprus, Baragar *et al.*, 1987).

The stratigraphic transition from the sheeted dyke complex into the overlying volcanic sequence occurs over a thickness of approximately 150-200 metres. Thin, fine-grained massive flows or thin sills directly overlie the zone of 100% dykes, and are themselves cut by individual dykes of similar composition and orientation as the underlying sheeted dykes. A gradual transition occurs passing stratigraphically upward from dykes to massive flows cut by dykes, and finally to pillowed flows. Overall, the proportion of dykes decreases up-section until they are virtually absent in the pillowed flows. The total preserved stratigraphic thickness of dykes and overlying flows is approximately 3000 metres. This mafic sequence (south end of lac Watts, Figure 1) is thrust-bound at top and bottom. As a result, the stratigraphic contacts with either the overlying sediments or underlying crustal cumulates are not observed.

Mafic and ultramafic crustal cumulates

Ultramafic cumulates occur as (1) decimetre- to kilometre-scale stratigraphic bodies within the mafic cumulates; or (2) thrust-bound lozenges at the base of mafic cumulate thrust sheets. Preserved relict layering is defined by variations in abundance of olivine and clinopyroxene. Modal grading in the layers and textures observed in thin-section suggest a cumulate origin for these rocks. Individual layers range in thickness from millimetres to tens of metres, with the lateral extent of layers ranging from metres to tens of metres, depending on layer thickness (Figure 2b).

Two texturally distinct olivine populations are recognized in the ultramafic cumulates. Relict igneous grains range from Fo92 to Fo80. This population appears to record variations in magma composition, and shows a first-order correlation toward decreasing Fo content passing stratigraphically upward in the sequence. The second population consists of neoblastic metamorphic olivines (Fo96 to Fo99) which are restricted in occurrence to areas of highest metamorphic grade. The extremely Mg-rich nature of this population suggests that some alteration (serpentinization?) may have taken place prior to metamorphism. Chromium-rich spinels, with iron-rich metamorphic overgrowths, are commonly preserved in olivine-rich layers despite almost complete serpentinization of the host rock. Analysis of preserved primary clinopyroxene grains indicates that it is diopside, with Cr_2O_3 content ranging from 0.5 to 1.5 wt.%. The compositions of the primary igneous phases are comparable to those reported for the Bay of Islands complex of western Newfoundland (Smith and Elthon, 1988), which is generally accepted as having formed in a mid-ocean ridge-type setting (Pearce *et al.*, 1984).

Layered mafic rocks (Figure 2c) are volumetrically the most extensive unit in the ophiolite (Figure 1). The compositional layering in the mafic cumulates varies from centimetre- to metre-scale, and is defined by modal variations of primary clinopyroxene and plagioclase between clinopyroxenite and anorthosite end-members. Overall, gabbroic compositions are the most common, although anorthositic gabbros can locally form laterally extensive stratigraphic bodies. Where observed, the stratigraphic transition from ultramafic- to mafic cumulates occurs gradationally, over an approximately 100 metre thick interval. The cumulate nature of the mafic rocks is suggested by the gradual stratigraphic transition from the ultramafic cumulates (*e.g.*, southern synformal structure, in the vicinity of rivière Déception, Figure 1). The plagioclase-clinopyroxene modal layering and fine-scale textures observed in less deformed examples are best explained by cumulus crystallization. The crystallization sequence, inferred from the gross cumulate stratigraphy, is olivine + spinel > clinopyroxene > plagioclase. Orthopyroxene is not observed in the cumulate sequence. Its absence argues against an island arc tectonic setting for the ophiolite (Pearce *et al.*, 1984).

An extensive body of non-layered clinopyroxenite is found on the west side of lac Watts (see Figure 1). The presence of layered gabbro xenoliths at the margins of the clinopyroxenite body suggests that it is intrusive. Its strongly LREE-depleted nature distinguishes it chemically from conformable clinopyroxenite bodies which constitute layers in the cumulate sequences.

Rare earth element analyses indicate that the layered cumulates vary from LREE-depleted to slightly LREE-enriched. However, samples from within any one thrust sheet are either LREE-depleted or enriched. This suggests the possibility that the products of at least two magma chambers, each reflecting a chemically different source, are now tectonically juxtaposed. The two populations have distinct Nd-isotopic compositions (Hegner and Bevier, 1989 - this issue, p. 148-151), and may correlate directly with the two observed dyke populations.

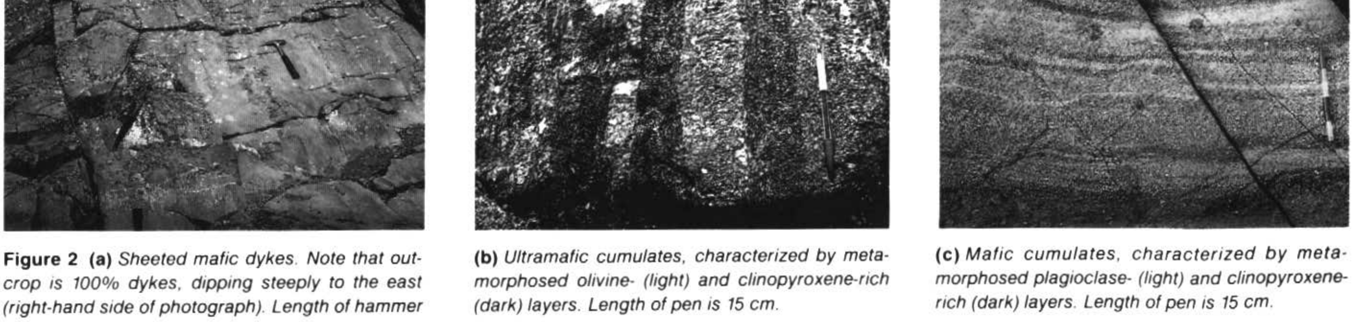


Figure 2 **(a)** *Sheeted mafic dykes. Note that outcrop is 100% dykes, dipping steeply to the east (right-hand side of photograph). Length of hammer is 34 cm.*

(b) *Ultramafic cumulates, characterized by metamorphosed olivine- (light) and clinopyroxene-rich (dark) layers. Length of pen is 15 cm.*

(c) *Mafic cumulates, characterized by metamorphosed plagioclase- (light) and clinopyroxene-rich (dark) layers. Length of pen is 15 cm.*

Primary igneous textures, such as compositionally graded layering, are generally better preserved in the ultramafic cumulates than in the mafic cumulates. In addition, ultramafic cumulates commonly show cleavages cross-cutting primary layering. Conversely, the mafic cumulates tend to have a transposed, (tectonic) compositional layering that appears to preserve primary variations in mineralogy. Preserved bedding-cleavage relationships and folds in ultramafic cumulates suggest that early, obduction-related deformation may have occurred prior to the late thrusting, penetrative bulk shear deformation and amphibolite-grade metamorphism that is recorded in the mafic cumulates.

Tectonic Interpretation

The older age of the ophiolite (1998 Ma) with respect to the rift sequence (*ca.* 1960 Ma) precludes its interpretation as part of a south-to-north progression from rift to oceanic crust. Two possible explanations for the older ophiolite age are: (1) it may have developed in a separate basin, outboard from the rift margin, or (2) it may be an along-strike equivalent segment to the younger rift margin sequence that has been subsequently juxtaposed against a younger portion of the margin by transpression. In the first scenario, the two basins must be separated by some form of crust. If the Chukotat Group is part of the younger basin, only the Spartan Group sediments separate the two basins at present. However, depositional basement to these sediments is not observed. In the second scenario, a paleotectonic setting such as the modern Red Sea rift is suggested. There, within a single basin, continental rifting and mid-ocean ridge spreading are occurring coevally over an along-strike distance of several hundreds of kilometres (Cochran and Martinez, 1988). In the Red Sea, the earliest truly oceanic rocks are approximately 5 million years ***older*** than the youngest continental rifting. If the oldest oceanic rocks were subsequently juxtaposed against the youngest rift deposits as a result of transpressive deformation, then a structural sequence with the same relative age relationships as observed in the Cape Smith Belt would be produced.

Evidence of subduction-related magmatism is not present in the eastern portion of the ophiolite. The Watts Group flows are clearly similar to N-MORB. They are not enriched in large-ion lithophile elements, as would be expected for an island arc setting. The observed paucity of plagiogranitic/dioritic intrusions is consistent with a non-subduction-related origin for the Purtuniq ophiolite. The relatively distal nature of the preserved sedimentary rocks in the lac Watts area supports a quiet-basin origin for the sequence. The Watts Group is best interpreted as crust produced at an oceanic spreading ridge for several reasons: (1) field relations, such as the stratigraphic transition from sheeted dykes to pillow basalts, and the inferred stratigraphic association of the basalts with the mafic-ultramafic cumulates; and (2) the chemistry of the magmatic units. It is not possible here to distinguish between a restricted, back-arc setting or a larger, oceanic setting on the basis of chemistry (Hawkins, 1980). Concomitant SM-Nd isotopic studies on the magmatic units of the ophiolite (Hegner and Bevier, 1989 - this issue, p. 148-151) support this interpretation, in that the isotopic data suggests that the time-intergrated source for the basalts is highly depleted (*i.e.*, an asthenospheric source).

As a mafic-dominated thrust belt that is not significantly modified by late faulting and granitoid intrusions, the well-exposed Cape Smith Belt may provide an analogue for some Archean greenstone belts. Amongst the "greenstones" of the belt, an allochthonous rift-to-oceanic sequence and an exotic ophiolite suite have been distinguished on the basis of field relations and geochemical aspects (St-Onge *et al.*, 1987; Picard *et al.*, in prep.; St-Onge and Lucas, in press). Based on field relations and chemistry, the preserved ophiolite section is indistinguishable from the crustal portions of many Phanerozoic ophiolites. This suggests that processes of oceanic crust formation operating in the early Proterozoic were similar to those in the Phanerozoic. Detailed comparisons of the Cape Smith Belt mafic rocks and younger ophiolites with Archean greenstone belts may further our understanding of the processes associated with mafic magmatism through Earth history.

Acknowledgements

Normand Bégin (Queen's University) is warmly thanked for contributions during the three summers of field work. Numerous ideas presented here were developed during discussions with Stephen Edwards and John Malpas during an extended visit to Memorial University of Newfoundland (MUN) by the first author. Edwards is thanked for comments on an earlier version of the manuscript. The input of MUN's ICP-MS team is greatly appreciated. Christian Picard is thanked for a helpful review.

References

Baragar, W.R.A., Lambert, M.B., Baglow, N. and Gibson, I., 1987, Sheeted dykes of the Troodos ophiolite, Cyprus, *in* Halls, H.C. and Fahrig, W.F., eds., Mafic Dyke Swarms: Geological Association of Canada, Special Paper 34, p. 257-272.

Cochran, J.R. and Martinez, F., 1988, Evidence from the northern Red Sea on the transition from continental to oceanic rifting: Tectonophysics, v. 153, p. 25-53.

Hawkins, J.W., Jr., 1980, Petrology of back-arc basins and island arcs: Their possible role in the origin of ophiolites: *in* Panayioutou, A., ed., Proceedings of the International Ophiolite Symposium, Cyprus, 1979, p. 244-254.

Hegner, E. and Bevier, M.L., 1989, Geochemical constraints on the origin of mafic rocks from the Cape Smith belt: Geoscience Canada, v. 16, p. 148-151.

Hynes, A. and Francis, D.M., 1982, A transect of the early Proterozoic Cape Smith Foldbelt, New Quebec: Tectonophysics, v. 62, p. 251-278.

Parrish, R.R., 1989, U-Pb geochronology of the Cape Smith Belt and Sugluk block, northern Québec: Geoscience Canada, v. 16, p. 126-130.

Pearce, J.A., Lippard, S.J. and Roberts, S., 1984, Characteristics and tectonic significance of supra-subduction zone ophiolites, *in* Kokelaar, B.P. and Howells, M.R., eds., Marginal Basin Geology: Geological Society of London, Special Publication 16, p. 77-94.

Picard, C., 1986, Lithogéochimie de la partie centrale de la Fosse de l'Ungava, *in* Lamothe, D., Gagnon, R. and Clark, T., eds., Exploration en Ungava, données récentes sur la géologie et la gîtologie: Ministère de l'Énergie et des Ressources du Québec, DV 86-16, p. 57-72.

Picard, C., 1989, Pétrologie et volcanologie des roches volcanique de la partie centrale de la Fosse de l'Ungava: Ministère de l'Énergie et des Ressources du Québec, ET 87-07, 88 p.

Picard, C., Lamothe, D., Piboule, M. and Oliver, R., in prep., Magmatic and geotectonic evolution of a Proterozoic oceanic basin system: The Cape Smith Thrust-Fold Belt (New Québec): submitted to Precambrian Research.

Scott, D.J., St-Onge, M.R., Lucas, S.B. and Helmstaedt, H., 1988, The 1999 Ma Purtuniq Ophiolite: Imbricated oceanic crust obliquely exposed in the Cape Smith Thrust-Fold Belt, northern Quebec, Canada: Geological Society of America, Abstracts with Program, v. 20, p. A158.

Smith, S.E. and Elthon, D., 1988, Mineral compositions of plutonic rocks from the Lewis Hills massif, Bay of Islands complex: Journal of Geophysical Research, v. 93, p. 3450-3468.

St-Onge, M.R. and Lucas, S.B., in press, Evolution of the Cape Smith Belt, early Proterozoic continental underthrusting, ophiolite obduction and thick-skinned folding, *in* Lewry, J.F. and Stauffer, M.E., eds., The Early Proterozoic Trans-Hudson Orogen: Lithotectonic Correlations and Evolution: Geological Association of Canada, Special Paper, in press.

St-Onge, M.R., Lucas, S.B., Scott, D.H. and Bégin, N.J., 1988, Geology, eastern portion of the Cape Smith Belt, parts of the Wakeham Bay, Cratère du Nouveau Quebec, and Nuflik Lakes map areas, northern Quebec: Geological Survey of Canada, Open File 1730, 16 maps, 1:50,000 scale.

St-Onge, M.R., Lucas, S.B., Scott, D.J. and Bégin, N.J., 1989, Evidence for the development of oceanic crust and for continental rifting in the tectonostratigraphy of the early Proterozoic Cape Smith Belt: Geoscience Canada, v. 16, p. 119-122.