

Tectonic evolution of the Kuujuaq terrane, New Québec Orogen

Serge Perreault and Andrew Hynes
 Department of Geological Sciences
 McGill University
 3450 University Street
 Montréal, Québec H3A 2A7

Summary

The Kuujuaq terrane of the New Québec Orogen may represent a northern extension of the De Pas batholith, which is thought to be the remnant of a lower Proterozoic continental magmatic arc. Collision between the Kuujuaq terrane and the Labrador Trough to the west produced intense deformation, associated with large-scale, southwest-directed transport. The Kuujuaq batholith, thought to be a subduction-related granitoid suite, was emplaced at a late stage in the deformation. Extensive post-tectonic metamorphism involved retrogression of early granulite-facies mineral assemblages. Our interpretation is that the Kuujuaq terrane was subjected to deep and protracted burial (>40 m.y.). This is consistent with, and most easily explained by, its development within a major continental collision zone such as that between India and Asia.

Introduction

In the past ten years, features of many Early Proterozoic orogens have been explained in terms of plate-tectonic processes and continental collision (e.g. Lewry *et al.*, 1981; St-Onge *et al.*, 1989). Detailed mapping of the hinterland zones of Early Proterozoic belts shows that some consist of discrete terranes bounded by large shear zones (e.g., Korstgård *et al.*, 1987).

Interpretations of the tectonic evolution of the New Québec Orogen (Hoffman, 1988), once considered the type example of an ensialic orogen (Dimroth, 1981), have changed drastically following recent regional and more detailed mapping (Wardle and Bailey, 1981; van der Leeden *et al.*, 1990; Girard, 1990; Poirier *et al.*, 1990; Moorhead and Hynes, 1990). New geochronological data and the recognition of distinct lithotectonic terranes make it possible to reconcile the characteristics of the orogen with those

of a modern continent-continent collision zone (e.g., India with Asia). In this paper, we focus on the tectonic evolution of one such terrane, the Kuujuaq terrane, in the hinterland of the northern New Québec Orogen.

Geological setting

The Kuujuaq terrane (see Wardle *et al.*, 1990) is separated from the eastern part of the Labrador Trough, known as the Rachel zone (Wares and Goutier, 1990), by the lac Turcotte fault (Figure 1). The Rachel zone is composed of metamorphosed equivalents of the Kaniapiskau Supergroup of the Labrador Trough, which rests on Archean basement probably correlative with the Superior Province. The Kuujuaq terrane is composed of reworked Archean basement, which could have belonged either to the Superior Province or the Rae Province (Hoffman, 1988), Early Proterozoic supracrustal gneiss, and an axial belt of syntectonic felsic granitoids. The Kuujuaq terrane is divided into a western lac Gabriel domain and a northeastern lac Berthet domain by the lac Pingiajjulik fault. The lac Gabriel domain is composed mainly of quartzofeldspathic paragneiss containing minor amounts of marble, calc-silicate, amphibolite and ultramafic schist, pelitic gneiss and coarse-grained feldspathic gneiss with metaconglomerate horizons. The lac Berthet domain is composed mainly of hornblende paragneiss, amphibolite, quartz-plagioclase-biotite paragneiss, pelitic gneiss and tonalitic gneiss. Minor amounts of quartzofeldspathic paragneiss rest on an Archean basement of migmatized granitic gneiss. The quartzofeldspathic paragneiss of the lac Gabriel domain is interpreted to have formed in a platformal environment, whereas other paragneiss units are interpreted as continental-slope sediments, possibly derived from the erosion of a magmatic arc (Poirier *et al.*, 1990).

A series of granitoid intrusions, termed here the Kuujuaq batholith, was emplaced along a NW-trending line, parallel to the lac Pingiajjulik fault, within paragneiss of the lac Berthet and lac Gabriel domains (Figure 1). Granitoid compositions range from dioritic to granitic and are metaluminous, containing hornblende and/or biotite. Geochemically, they have affinities with calc-alkaline granitoids (major elements, AFM, Na₂O-K₂O-CaO diagrams) and are interpreted to be related to continental arc magmatism (Poirier *et al.*, 1990). Late to post-tectonic pegmatite and granite also intrude the rocks of the Kuujuaq terrane. The Kuujuaq batholith (1.84–1.83 Ga) shares many features with the De Pas batholith (1.84–1.83 Ga) of the central part of the New Québec Orogen (Girard, 1990; van der Leeden, 1990).

Structural geology

The earliest Hudsonian structures observed are strong foliation and gneissic banding. The few folds that can be convincingly corre-

lated with these features are intrafolial and isoclinal. Formation of a large basement-nappe in the northern lac Berthet domain was probably synchronous with this D₁ deformation. A second phase of deformation (D₂) produced metre- to kilometre-scale NE-trending, upright or SE-overtured folds in the south, and NW-overtured folds in the north. These are overprinted by NW-trending, moderately to steeply plunging folds developed on all scales (D₃). These late folds vary in attitude from overturned to the southwest to upright, and are locally isoclinal. There is evidence for dextral motion on the lac Pingiajjulik fault synchronous with D₃, as indicated by asymmetric pressure shadows around rotated porphyroblasts and by shear folds.

Metamorphism

An early granulite-facies metamorphism (M₁) is recognized in the lac Berthet domain, but not in the lac Gabriel domain. Granulite-facies assemblages are found mainly in metabasites, which contain the subassemblage clinopyroxene-garnet-plagioclase (Figure 1: samples 3, 6 and 10) and, in one sample, orthopyroxene (sample 3). Physical conditions during M₁ are poorly constrained due to re-equilibration during subsequent metamorphism. Temperatures of 800°C to 850°C and pressures of 600 to 800 MPa have been calculated for samples 3 and 6 (Figure 2: SP87-29 and SP86-446, respectively). This metamorphism was probably associated with the formation of the D₁ basement nappe in the lac Berthet domain prior to the emplacement of the Kuujuaq batholith.

The second metamorphic event (M₂) occurred syn- to late D₃, at upper amphibolite facies. Retrogression of the M₁ assemblages in the lac Berthet domain produced hornblende-garnet assemblages at the expense of pyroxene in mafic rocks (Figure 1: samples 3, 6 and 10). In the lac Gabriel domain, mafic rocks are characterized by the assemblage garnet-hornblende-plagioclase-quartz (Figure 1: samples 1 and 4). Pelitic rocks in the lac Berthet domain contain the assemblage sillimanite-garnet-biotite-plagioclase-quartz (Figure 1: samples 2, 7 and 8) and cordierite (Figure 1: sample 5). Peak conditions were 700°–750°C and 600–800 MPa, with retrograde effects recorded at 450–550 MPa and 480°–600°C (Figure 2).

The P-T paths (Figure 2) show the cooling-unloading features typical of high-grade terranes, with minor isobaric heating occurring prior to unloading (Thompson and England, 1984). The second metamorphic event is therefore interpreted to have resulted from crustal thickening by large-scale thrusting associated with D₂ and D₃ events.

Geochronology

Igneous zircons in the Kuujuaq batholith give U-Pb ages of 1845–1833 Ma and meta-

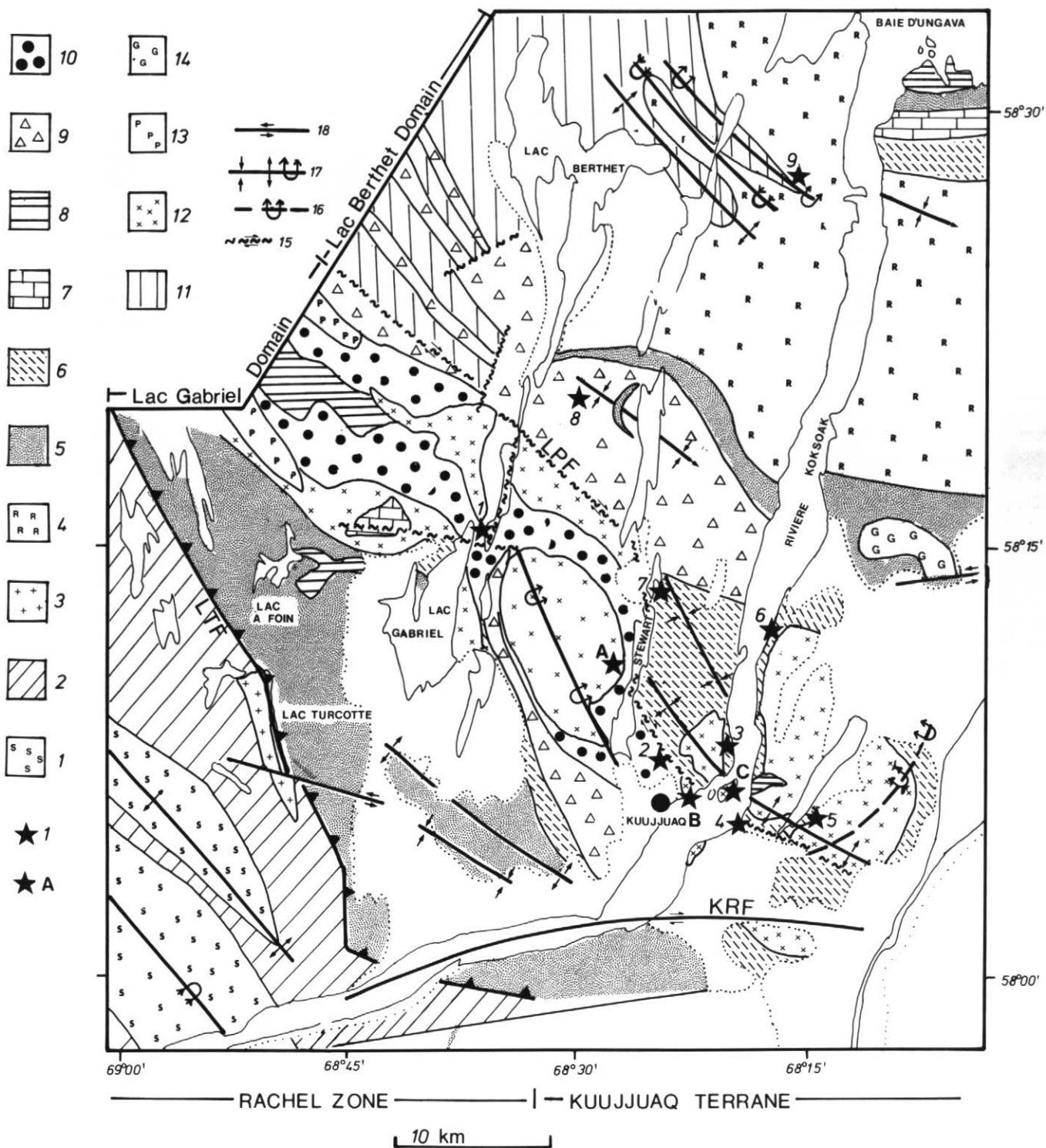


Figure 1 Map of the Kuujuaq terrane, northern part of New Québec Orogen. 1, Archean migmatite of the Superior Province; 2, metamorphosed equivalents of the Kaniapiskau Supergroup (pelitic gneiss and schist, marble, amphibolite); 3, tonalitic gneiss; 4, Archean tonalitic and granitic gneiss of the Rae Province; 5, mainly quartzofeldspathic paragneiss with minor amphibolite; 6, quartz-plagioclase-biotite paragneiss and pelitic gneiss; 7, marble and calc-silicate; 8, amphibolite; 9, mainly hornblende-bearing paragneiss with minor pelitic gneiss; 10, coarse-grained feldspathic paragneiss with metaconglomeratic horizons; 11, epiclastic amphibolite and calc-silicate; 12, tonalitic to granodioritic orthogneiss of the Kuujuaq batholith; 13, pegmatite; 14, gabbro; 15, D₂-related shear zones and faults with sense of movement; 16, D₂ folds (overturned antiform); 17, D₃ folds; synform/antiform/overturned; 18, post-D₃ faults. LPF, lac Pingiajulik fault; LTF, lac Turcotte fault; KRF, Koksoak River fault. Stars with numbers represent samples for metamorphic assemblage and P-T determinations: 1=SP86-156; 2=SP-86-319; 3=SP87-29; 4=SP86-468; 5=SP87-117; 6=SP86-446; 7=SP87-253; 8=SP87-295; 9=SP87-229. Stars with letters represent samples used in geochronology.

morphic zircons give a mean age of 1830 Ma (Figure 1: samples A and C; Machado *et al.*, 1988). Zircon and monazite extracted from a post-tectonic, post-metamorphic pegmatite near Kuujuaq yield ages of 1775 Ma (Figure 1: sample B). Emplacement of the Kuujuaq batholith therefore occurred roughly between 1845 and 1833 Ma. The granulite-facies metamorphism is interpreted to predate 1845 Ma, based on the absence of granulite-facies assemblages in the granulitoids. However, the granulitoids of the lac Gabriel domain display upper amphibolite-facies assemblages, so that the second metamorphic event may have peaked around 1830 Ma. Metamorphic conditions may have persisted for over 60 m.y.

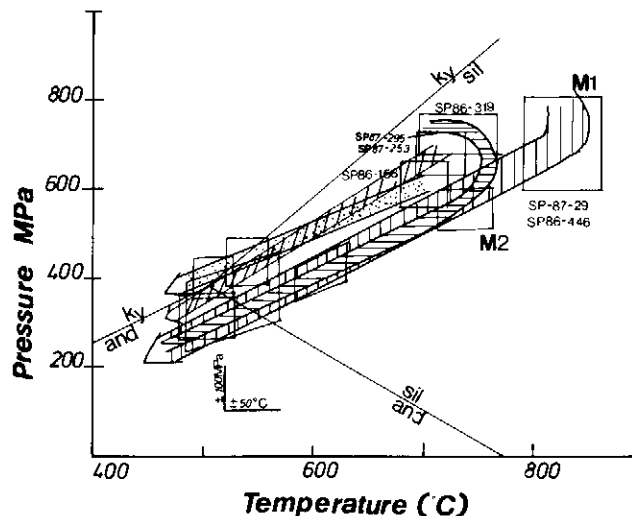
The apparent longevity of the metamorphism, and the low slopes of the retrograde P-T paths (Figure 2), are indicative of an uplift rate of only 0.2 cm per m.y. accompanied by a cooling rate of about 5°C per m.y. The long residence time at moderate to high temperatures required by the data may be responsible for the unusually widespread retrogression in the lac Berthet domain

Discussion

The Kuujuaq batholith is most simply interpreted as the result of subduction beneath the Kuujuaq terrane. The polarity of this subduction depends on whether the basement observed in the lac Gabriel domain is part of the Superior Province. In this model, the subduction probably occurred from the east, in which case the lac Turcotte fault is of only local significance and the lac Pingiajulik fault is a major boundary. If the basement rocks belong to the Rae Province, subduction probably occurred from the west, in which case the lac Turcotte fault is a major boundary and the lac Pingiajulik fault is a less important, late structure. In the western part of the lac Gabriel domain, aeromagnetic signatures similar to those of the basement to the Rachel zone provide some support for the first model.

A noteworthy feature of the Kuujuaq terrane is that it appears to have experienced substantial structural thickening prior to emplacement of demonstrable magmatic arc-related rocks. This, combined with the evidence for protracted crustal thickening, makes it difficult to explain the characteristics of the region without the development of a major continental collision zone. In the Himalayan orogenic belt, continental collision and associated crustal thickening began more than 50 m.y. ago and is still in progress (Coward *et al.*, 1986; Chamberlain *et al.*, 1989). Using the Himalayan collision as a modern analogue, much of the late- to post-tectonic strike-slip motion observed on faults in the Kuujuaq region may reflect fragmentation of the Superior Province plate in response to indentation by another continent such as the Rae Province (Hoffman, 1990; *cf.* Molnar and Tapponnier, 1975).

Figure 2 Pressure-temperature diagram for the Kuujuaq terrane. Boxes represent clusters of well-constrained P-T points for: single grains, cores of matrix grains, cores of grains in mutual contact, rims of grains in mutual contact; all from samples of amphibolite and pelitic gneiss. M₁ and M₂ refer to the first and second metamorphic events, respectively. SP86-446 and SP87-29, pyroxene-bearing amphibolite; SP86-156, garnet amphibolite; SP86-319, SP87-253 and SP87-295, pelitic gneiss.



Acknowledgements

This paper forms part of the first author's Ph.D. thesis. Discussions with J. Moorhead and R. Wares are greatly appreciated. Field work was funded through grants from the McGill Centre for Northern Studies (SP), FCAR and Natural Sciences and Engineering Research Council (AH). The manuscript benefitted greatly from the comments of G. Poirier, R. Wardle and two anonymous reviewers.

References

- Chamberlain, C.P., Zeitler, P.K. and Jan, M.Q., 1989, The dynamics of the suture between the Kohistan island arc and the Indian plate in the Himalaya of Pakistan: *Journal of Metamorphic Geology*, v. 7, p. 135-149.
- Coward, M.P., Windley, B.F., Broughton, R.D., Luff, I.W., Petterson, M.G., Pudsey, C.J., Rex, D.C. and Asif, M., 1986, Collision tectonics in the NW Himalayas, in Coward, M.P. and Ries, A.C., eds., *Collision Tectonics*: Geological Society of London, Special Publication No. 26, p. 203-19.
- Dimroth, E., 1981, Labrador Geosyncline: a type example of early Proterozoic orogenic reactivation, in Kröner, A., ed., *Precambrian Plate Tectonics*, Elsevier, Amsterdam, p. 331-352.
- Girard, R., 1990, Les cisaillements latéraux dans l'arrière-pays des orogènes du Nouveau-Québec et de Torngat: une revue: *Geoscience Canada*, v. 17, p. 301-304.
- Hoffman, P.F., 1988, United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Proto-Laurentia: *Annual Reviews of Earth and Planetary Sciences*, v. 16, p. 543-603.
- Hoffman, P.F., 1990, Dynamics of the tectonics assembly of northeast Laurentia in geon 18 (1.9-1.8 Ga): *Geoscience Canada*, v. 17, p. 222-226.
- Korstgård, J., Ryan, B. and Wardle, R., 1987, The boundary between Proterozoic and Archaean crustal blocks in central West Greenland and northern Labrador, in Park, R.G. and Tarney, J., eds., *Evolution of the Lewisian and Comparable Precambrian High-Grade Terrains*: Geological Society of London, Special Publication No. 27, p. 247-259.
- Lewry, J.F., Stauffer, M.R. and Fumerton, S., 1981, A cordilleran type batholith belt in the Churchill Province in northern Saskatchewan: *Precambrian Research*, v. 14, p. 277-313.
- Machado, N., Perreault, S. and Hynes, A., 1988, Timing of continental collision in the northern Labrador Trough, Québec: evidence from U-Pb geochronology: *Geological Association of Canada - Mineralogical Association of Canada, Program with Abstracts*, v. 13, p. A76.
- Molnar, P. and Tapponnier, P., 1975, Cenozoic tectonics of Asia: *Science*, v. 189, p. 419-426.
- Moorhead, J. and Hynes, A., 1990, Nappes in the internal zone of the northern Labrador Trough: Evidence for major, early NW-vergent basement transport: *Geoscience Canada*, v. 17, p. 241-244.
- Poirier, G., Perreault, S. and Hynes, A., 1990, Nature of the eastern boundary of the Labrador Trough near Kuujuaq, Québec, in Lewry, J.F. and Stauffer, M.R., eds., *The Early Proterozoic Trans-Hudson Orogen of North America*: Geological Association of Canada, Special Paper 37, p. 397-412.
- 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 tectono-stratigraphy of the Early Proterozoic Cape Smith Belt: *Geoscience Canada*, v. 16, p. 119-126.
- Thompson, A.B. and England, P.C., 1984, Pressure-temperature-time paths of regional metamorphism. II: their influence and interpretation using mineral assemblages in metamorphic rocks: *Journal of Petrology*, v. 25, p. 929-955.
- van der Leeden, J., Bélanger, M., Danis, D., Girard, R. and Martelain, J., 1990, Lithotectonic domains in the high-grade terrain east of the Labrador Trough (Québec), in Lewry, J.F. and Stauffer M.R., eds., *The Early Proterozoic Trans-Hudson Orogen of North America*: Geological Association of Canada, Special Paper 37, p. 371-386.
- Wardle, R.J. and Bailey, D.G., 1981, Early Proterozoic sequences in Labrador, in Campbell, F.H.A., ed., *Proterozoic Basins of Canada*: Geological Survey of Canada, Paper 81-10, p. 331-358 (supplement).
- Wardle, R.J., Ryan, B. and Ermanovics, I., 1990, The Eastern Churchill Province, Torngat and New Québec Orogens: An overview: *Geoscience Canada*, v. 17, p. 217-222.
- Wares, R.P. and Goutier, J., 1990, Deformational style in the foreland of the northern New Québec Orogen: *Geoscience Canada*, v. 17, p. 244-249.