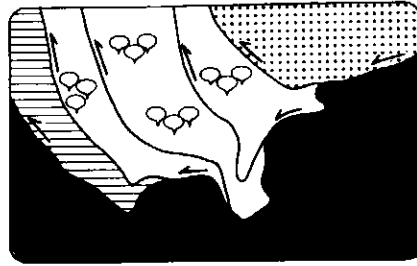


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## P-T conditions of metamorphism inferred from the metabasites of the Cape Smith Belt, northern Quebec

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### Summary

In the Cape Smith Belt, lower greenschist- to middle-amphibolite facies metabasites are exposed in an oblique cross-section displaying over 18 km of structural relief. Mapping of regional mineral isograds has documented the nature and relative timing of the thermal responses to southward directed crustal thickening. In the belt's foreland, hot-side-down metamorphism followed a stage of regular-sequence thrusting. Syn-thermal peak out-of-sequence thrusting was responsible for local inversion of the isograds in the footwall of the out-of-sequence domain. In the belt's hinterland, post-thermal peak out-of-sequence faulting produced pervasive retrogression to greenschist facies and truncation of the thermal peak isograds.

### Résumé

Dans la bande du Cap Smith, des metabasites de facies schiste vert à amphibolite moyen, affleurent en section oblique sur plus de 18 km de relief structural. Une cartographie des isogrades à l'échelle régionale a permis d'établir la séquence des événements thermiques associés à un épaississement crustal survenu dans la bande du Cap Smith. Dans l'avant-pays, un gradient métamorphique normal a suivi l'emplacement initial des nappes de charriage. Des chevauchements désordonnés, synchrones à l'apogée thermique, sont responsables d'une inversion locale des isogrades dans le domaine sous-jacent aux failles hors-séries. Dans l'arrière-pays, des failles de chevauchement tardives ont produit un métamorphisme rétrograde au facies schiste vert et un recouplement des structures thermiques progades.

### Introduction

The Cape Smith Thrust Belt trends east-west across the northern part of the Ungava Peninsula in northern Québec. The belt was developed during southward-directed thrusting of Proterozoic cover units over the underlying Archean craton of the Superior Province, during the 1900 Ma Trans-Hudson Orogen (St-Onge and Lucas, in press). A well-preserved metamorphic succession, from lower greenschist to middle amphibolite facies (Bégin *et al.*, 1988), is exposed in oblique section over more than 18 km of structural relief (Lucas, in press). Regional mineral isograds were mapped in metabasites, which constitute the principal rock type within the belt. This was followed by a detailed petrological and microprobe study of mafic mineral assemblages sampled at the various structural levels within the belt (Bégin, in prep. a and b). This paper presents the major findings of the regional metamorphic study, with an emphasis on the distinct thermal events recorded by the metabasites of the Cape Smith Belt.

### Geologic Setting

Three major tectonostratigraphic suites are recognized in the Cape Smith Belt. From south (foreland) to north (hinterland), these are: (1) the continental rift-fill clastic sediments and tholeiitic basalts of the Povungnituk Group (Francis *et al.*, 1983; Hynes and Francis, 1982; Picard, 1986, 1989); (2) the highly magnesian (komatiitic) and tholeiitic basalts of the Chukotat Group interpreted as transitional crust (Francis *et al.*, 1983; Hynes and Francis, 1982; Picard, 1986, 1989); and (3) the ophiolitic units of the Watts Group (St-Onge *et al.*, 1988). Crustal thickening of the Povungnituk Group rocks took place during early pre-thermal peak regular- (piggyback-) sequence thrusting (Lucas and St-Onge, 1989 - this issue, p. 122-126). In the hinterland, re-imbrication of the earlier thrust stack was accomplished by late out-of-sequence thrusting, active at syn- and post-thermal peak conditions (Lucas and St-Onge, 1989 - this issue, p. 122-126). The thermal consequences of these two thrusting episodes are recorded in the mafic rocks of the belt.

### Metamorphic Mineral Zones

Mapping mineral isograds in the Povungnituk Group metabasites documents a normal (hot-side-down) prograde sequence of metamorphic zones (Figure 1). The mineral zones are exposed in oblique cross-section due to post-metamorphic cross-folding of the thrust belt about north-south axes. From high structural levels in the west, to low structural levels in the east, the mineral zones are:

- (1) actinolite + albite;
- (2) hornblende + actinolite + albite;
- (3) hornblende + actinolite + oligoclase;
- (4) hornblende + oligoclase;
- and (5) garnet/clinopyroxene + hornblende + andesine. Epidote, chlorite, calcite, quartz, sphene and ilmenite are

common phases in each zone. The map pattern of the isograds clearly shows that they cross-cut the regular-sequence thrust faults, and have been folded by east-west macroscopic folds of basement and cover (Figure 1). Therefore, regional metamorphism in the southern portion of the Cape Smith Belt post-dates the early thin-skinned thrusting and predates the later thick-skinned folding. Thermal peak mineral growth outlasted the thrusting-related deformation in the Povungnituk Group metabasites. All these observations are consistent with the notion that regional metamorphism for this part of the belt is the result of the early crustal imbrication of Proterozoic cover units and upward relaxation of crustal isotherms.

The traces of the hornblende and oligoclase isograds (Figure 1) show that they are locally inverted (*i.e.*, hot-side-up). The inversion occurs in the footwall of a syn-thermal peak out-of-sequence thrust fault where pillow top directions indicate an upward-facing sequence. Therefore, the inversion is not structural and is attributed to thrusting of hot rocks over colder ones, a mechanism of heat transfer that results from out-of-sequence thrusting at syn-thermal peak conditions (see below).

In the Watts Group mafic rocks, both a prograde and a retrograde regional metamorphic event are documented. The prograde and retrograde events are associated with out-of-sequence thrusting at syn- and post-thermal peak conditions, respectively. In the northern (hinterland) portion of the belt (Figure 2), a distinct sequence of mineral isograds occurs in the metabasites. In contrast to the southern domain (Figure 1), albite is stable above the garnet isograd, in the middle amphibolite facies. This feature is typical of high-pressure metamorphic terrane, such as the Sangabawa Belt in Japan (Enami, 1981; Maruyama *et al.*, 1982). Such a higher-pressure domain can be explained in the Cape Smith Belt to be the result of out-of-sequence imbrication at syn-thermal peak conditions, exposing deeper structural levels.

A distinct thermal overprint occurs around a syn-tectonic tonalite pluton on the west side of lac Watts (Figure 2). The contact aureole is characterized by hornblende-albite and garnet-albite mineral zones. Muscovite and biotite are also present in these assemblages.

Post-thermal peak out-of-sequence thrusting produced extensive retrograde greenschist assemblages, mostly confined

to the hanging walls of the late faults (Bégin, in prep. a). Regionally, a striking feature of this deformation event is the truncation of syn-thermal peak mineral isograds by the retrograde thrusts (Figure 2). The syn-tectonic tonalite and its thermal aureole have escaped the retrogression. This is due to the fact that the tonalite is sitting at high structural levels in the retrograde thrust stack, outside any ductile shear zone (see Lucas, in press) related to the post-thermal peak thrusting.

#### Thermobarometry in Metabasites

The following calibrated methods were used to constrain P-T-XCO<sub>2</sub> conditions of regional metamorphism in the Cape Smith Belt: (1) thermodynamic modelling of mineral reactions in the KNCMASH-CO<sub>2</sub> model system (Bégin and Carmichael, 1987); (2) Plyusina's (1982) thermobarometer for hornblende-actinolite-oligoclase assemblages; (3) Graham and Powell's (1984) thermometer for garnet-hornblende-bearing rocks; (4) Kohn and Spear's (1989) barometer for garnet-hornblende-plagioclase-quartz assemblages; and (5) the compositional width of the peristerite gap at the oligoclase isograd (Maruyama *et al.*, 1982).

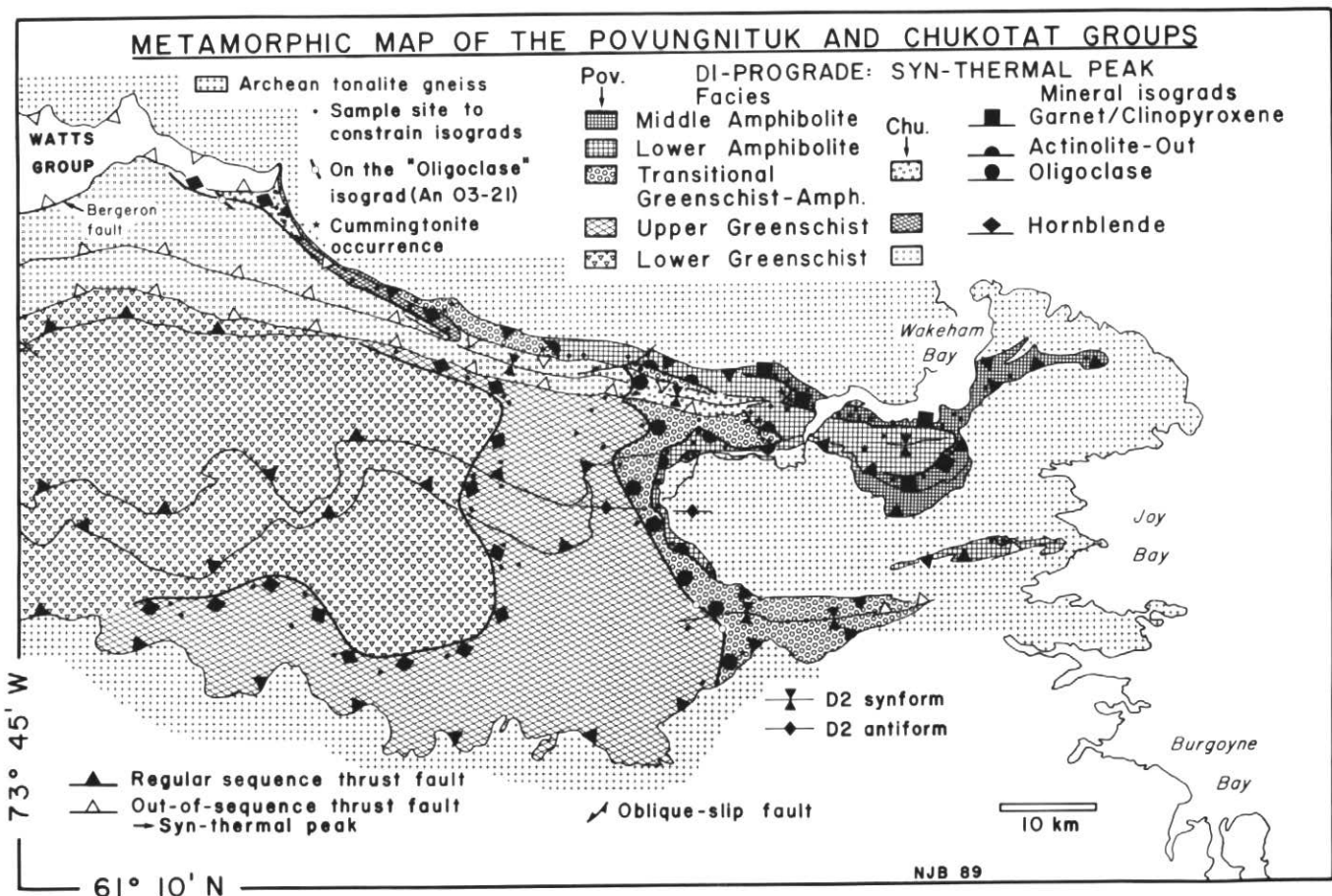


Figure 1 Metamorphic map of the Povungnituk Group (Pov.) and Chukotat Group (Chu.) mafic rocks, in the eastern portion of the Cape Smith Belt. Ornaments on the isograds are on the high-grade side.

Post-thrusting P-T estimates for the regular-sequence thrusting domain display a south-to-north increase in pressure and temperature ranging from 4.8 to 8.2 kb and 460°-625°C (Bégin, in prep. c). These results are consistent with a southward-tapering wedge geometry for the thrust belt. Metamorphic XCO<sub>2</sub> values are relatively constant (mean of 0.1) for the entire study area.

In the out-of-sequence hinterland, garnet-hornblende assemblages in layered metagabbros record higher pressures (8-10 kb) for similar temperatures (550°-620°C), when compared with pressures calculated for the southern regular-sequence domain. Closure of the peristerite gap in this temperature range corroborates the higher pressure determinations for the northern domain (Bégin, in prep. a and c). Along the northern margin, a few samples with syn-kinematic garnet porphyroblasts yield lower thermal peak estimates (500°-560°C and 7-8 kb, Bégin, in prep. c), suggesting that uplift and erosion in the northern domain is in part related to movement along the prograde out-of-sequence thrust faults (Bégin, in prep. c; St-Onge and Lucas, in press). Retrograde metamorphism associated with

post-thermal peak out-of-sequence thrusting produced overprinting greenschist assemblages, at conditions ranging from 4.9 to 6.1 kb and from 475° to 490°C.

**Conclusions**

Mapping of mineral isograds in the Cape Smith Belt has led to the recognition of four distinct thermal events: (1) thermal relaxation of isotherms following regular-sequence thrusting; (2) local thermal inversion of the hornblende and oligoclase isograds and syn-kinematic high-grade mineral growth in the hinterland, during out-of-sequence thrusting; (3) emplacement of a tonalite pluton in the hinterland resulting in local contact metamorphism; and (4) extensive retrogression to greenschist conditions in the hinterland as a result of further out-of-sequence thrusting.

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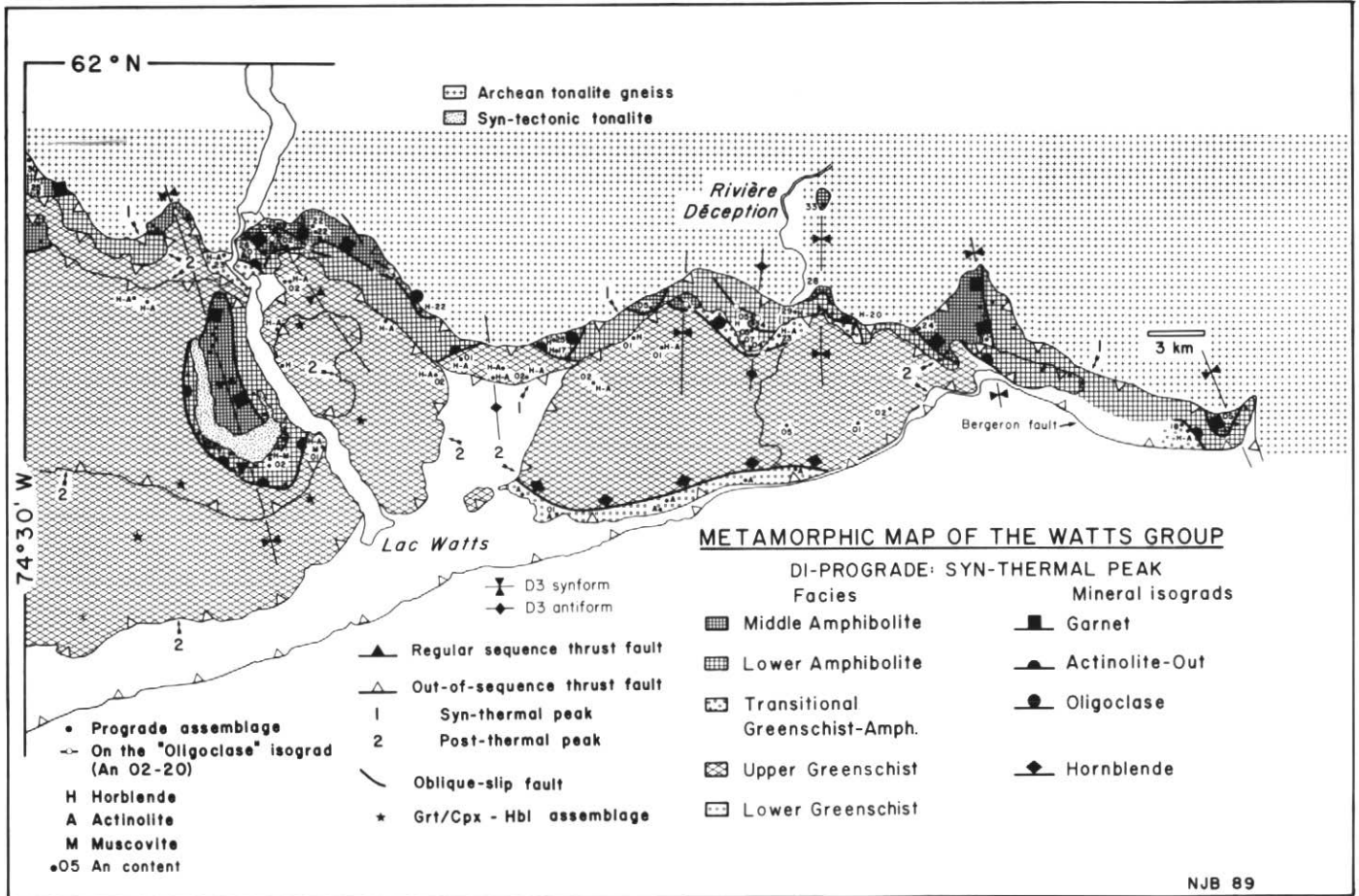
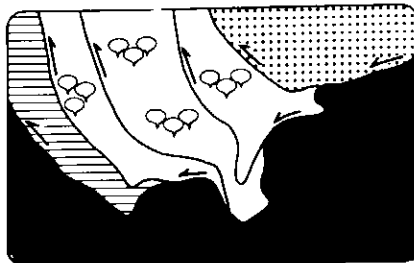


Figure 2 Metamorphic map for the Watts Group mafic rocks. Grt, garnet; Cpx, clinopyroxene; Hbl, hornblende.

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## Tectonic controls on the thermal evolution of the Cape Smith Thrust Belt<sup>1</sup>

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### Summary

Re-imbrication of the internal part of the Cape Smith Thrust Belt has resulted in the development of two distinct structural-metamorphic domains. In a southern (regular-sequence thrusting) domain, thermal peak metamorphism occurred after deformation, while in a northern (out-of-sequence thrusting) domain, it occurred during deformation (*i.e.*, re-imbrication). The interactions of tectonic and thermal processes have been studied using three methods: (1) qualitative evaluation of the timing between mineral growth and deformation; (2) analytical P-T paths from growth-zoned garnets; and (3) numerical modelling of vertical heat conduction. Analytical P-T paths suggest that uplift in the regular-sequence domain resulted primarily from erosion and isostatic unloading. In contrast, P-T paths in the out-of-sequence domain indicate that the northern portion of the thrust belt experienced faster unroofing relative to the regular-sequence domain. This has been attributed to both ramping of the out-of-sequence thrusts at deeper structural levels and possibly to extensional faulting at higher structural levels. Field and thin-section observations on the timing of metamorphism coupled with numerical modelling suggests that the thermal peak metamorphism documented in the regular-sequence domain is a consequence of the emplacement of the out-of-sequence thrust stack.

### Résumé

La ré-imbrication de la partie interne de la bande du Cap Smith divise cette dernière en deux domaines métamorpho-structuraux distincts. Dans un domaine sud, caractérisé par des chevauchements en-série, le méta-

morphisme suit la déformation. Par contre, dans un domaine nord, caractérisé par des chevauchements hors-série, le métamorphisme est synchrone avec la déformation (*i.e.*, la ré-imbrication). L'étude de l'interaction des processus tectoniques et thermiques dans la bande du Cap Smith a fait l'objet de trois approches différentes: (1) une évaluation qualitative de la croissance des minéraux métamorphiques et de la déformation; (2) la détermination des trajectoires P-T à partir de grenats zonés; et (3) la modélisation numérique de la conduction verticale de chaleur. Les trajectoires P-T suggèrent que le soulèvement tectonique de la zone de chevauchement en-série résulte vraisemblablement de l'érosion et d'un soulèvement isostatique. Dans le domaine hors-série les trajectoires P-T indiquent cette zone a subi des taux plus importants de soulèvement tectonique et d'érosion. Il est postulé que ces taux sont dus à la présence de rampes de failles hors-série aux niveaux structuraux inférieurs et que peut-être le soulèvement a été facilité par le jeu de failles normales aux niveaux structuraux supérieurs. Les observations pétrologiques de terrain et en lame mince ainsi que la modélisation numérique indiquent que le paroxysme métamorphique dans le domaine en-série correspond à la mise en place des chevauchements hors-séries.

### Introduction

Regional metamorphism in orogenic belts is a consequence of the often complex interplay of tectonic and thermal processes (*e.g.*, Spear *et al.*, 1984; Oxburgh *et al.*, 1987). Integrating structural, petrological and thermal studies therefore provides a means of constraining the tectonic evolution of young (*e.g.*, Selverstone, 1985, 1988) and old (*e.g.*, St-Onge and King, 1987) mountain belts. In the Cape Smith Belt of Early Proterozoic age, analytical P-T paths and observations on the timing of regional metamorphism and deformation were combined with the results of numerical modelling of vertical heat conduction. This has permitted evaluating the role of large-scale deformation structures in the thermal history of the thrust belt.

The tectonothermal evolution of the Cape Smith Belt is characterized by an interaction between (1) thrusting, (2) uplift and erosion, and (3) thermal equilibration of thickened crust. The south-verging thrust belt developed ca. 1920 to 1880 Ma (Parrish, 1989 - this issue, p. 126-130) during the Trans-Hudson Orogen in response to underthrusting of the northern Superior Province margin and obduction of an ophiolite from the overriding plate. Further thrust belt deformation occurred along out-of-sequence thrusts (Lucas, in press) between ca. 1880 and ca. 1840 Ma (Parrish, 1989 - this issue, p. 126-130). The deformation history of the thrust belt can be divided into three principal stages (Lucas and St-Onge, 1989a - this

<sup>1</sup> Geological Survey of Canada Contribution No. 18889