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Article abstract
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Deformational style in the foreland of the northern New Québec Orogen

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Summary
The northern segment of the New Québec Orogen is divided into 4 zones, based on lithostructural and deformed assemblages and deformational style. The tectonic fabric is the result of WSW-SW transport during the third deformation event, which, in the foreland, consists of two stages. A basal décollement, low-angle thrust faults and bedding-parallel sliding in the western foreland are important features of the early D2 stage. The bulk of crustal shortening occurred during the late D3 (D3y) stage, which is characterized by large-scale, high-angle out-of-sequence thrusts, and folds. The hinterland record shows more complex pre-D3 deformation, which cannot be correlated with early deformation in the foreland. The D2y out-of-sequence geometry is probably the result of syntectonic erosion of the orogenic wedge, but there is little geological evidence in the foreland supporting this premise. This apparent paradox can be explained by invoking a two-sided, double-wedge orogenic model, which links erosion and uplift in the hinterland to out-of-sequence thrusting in the foreland.

Résumé
La partie septentrionale de l'orogène du Nouveau-Québec se divise en quatre zones en fonction des assemblages lithostructuraux et de style structural. Le grain tectonique régional résulte d'un transport de ces zones vers le WSW-SW lors de la troisième phase de déformation qui comprend, dans l'avant-pays, deux phases. La phase précoce (D2x) est caractérisée par un décollement basal et des chevauchements en série dans la partie est de l'avant-pays et par des glissements parallèles aux strates dans la partie ouest. La phase tardive (D3y), surtout responsable de l'épaississement crustal, est caractérisée par un ensemble gênéralisé de grands plis et de failles de chevauchement hors série abruptes. L'arrière-pays présente des structures pré-D3 plus complexes qui ne peuvent être corréllées avec celles de l'avant-pays. L'agencement hors-série D3y provient probablement de l'érosion syn-orogénique du phénomène tectonique, mais on observe peu d'évidence de cette érosion à l'avant-pays. Cette disparité correspond peut-être au modèle de double prisms tectoniques opposés, qui relie l'érosion et le soulèvement de l'arrière-pays aux chevauchements hors série de l'avant-pays.

Introduction
Most studies of the New Québec Orogen (NQO), previously known as the Labrador Trough Orogen (Hoffman, 1988), have focused on the central (lat. 54°–57°N) and southern portions of the fold belt (e.g., Dimroth, 1978, 1981; Dimroth and Dressler, 1978; Wardle and Bailey, 1981; LeGallais and Lavoie, 1982). Until recently, little attention had been paid to the northern segment of the orogen and, with few exceptions, existing maps were lithological in nature and had escaped detailed structural interpretation.

This paper summarizes field and compilation work begun in 1986 as part of a regional metallogenic synthesis of the northern NQO funded by the Ministère de l’Énergie et des Ressources du Québec (MERQ) (Wares et al., 1988; Wares and Goutier, 1989, 1990). The project includes a 55 km by 100 km segment of the foreland of the orogen (Figure 1). Detailed mapping in selected sectors, compilation of MERQ geological maps and of data from Budkewitch (1986), Goutier (1987) and Boone (1987), and integration of Landsat TM and airborne vertical magnetic gradient data (Rheault, 1989) has permitted resolution of the stratigraphy and structure of the area.

The NQO separates the Archean Superior Province to the southwest from the Archean Proterozoic Rae Province to the northeast. The orogen comprises three NNW-trending volcano-sedimentary belts (Figure 1), defining the “Labrador Trough’, and a broad, poorly defined metamorphic-plutonic hinterland within the Rae Province. The tripartite assemblage of rocks is Early Proterozoic in age (~2145–1675 Ma; Clark and Thorpe, 1990; Machado et al., 1989) and was deformed during the Hudsonian Orogeny (~1845–1785 Ma; Machado et al., 1989; Perrault et al., 1988).

The foreland (Labrador Trough) assemblage consists of three cycles of sedimentation and/or volcanism separated by unconformities. The lower two cycles are widely interpreted as passive margin sequences thickening toward the east (Dimroth, 1981; Wardle and Bailey, 1981; LeGallais and Lavoie, 1982; Clark and Thorpe, 1990), while the upper cycle consists of a syntectonic fluvial
molasse (Chioak Formation; Hoffman, 1987). The bulk of the supracrustal assemblage in the northern NOQ is related to the second cycle of basin infilling.

**Lithotectonic subdivisions**

We have divided the northern segment of the NOQ into 4 zones (Figure 1), based on lithostratigraphy and deformatonal style (Wares et al., 1989). From west to east, these are the Chioak and Baby zones (foreland), and the Rachel and Kuujjuaq zones (hinterland).

The **Chioak zone**, an autochthonous-parautochthonous belt resting unconformably on the Superior craton, is composed of a shallow water shelf sequence (Ferriman Subgroup) that is unconformably overlain by turbidites (Menihk Formation) and by syntectonic, immature continental clastic sediments (Chioak Formation; Figure 2). The **Baby zone**, a central, strongly folded and thrust-faulted belt, comprises a rift-related volcano-sedimentary sequence, i.e., the Abner dolomite, the Baby turbidites and iron formation and the Hellancourt tholeiitic basalt (Figure 2). This sequence is intruded by abundant tholeiitic gabbro sills. Meta-argillite and quartzite that are devoid of gabbro sills (Thévenot Formation) overlie the Hellancourt Formation and possibly represent syntectonic foredeep sediments. The **Rachel zone** marks the western edge of the hinterland. It is composed of an amphibolite-grade, thrust-imbricated package of Baby zone rocks, uncorrelated metasedimentary rocks, and Archean basement (Moorhead and Hynes, 1990; Poirier et al., 1990). The **Kuujjuaq zone** is composed of reworked Archean basement, amphibolite- to granulite-facies Early Proterozoic metasedimentary and metavolcanic rocks, syntectonic intrusions of continental arc affinity, and minor post-kinematic dykes. This zone may represent the root of a continental arc terrane (Machado et al., 1989; Perreault and Hynes, 1990; Poirier et al., 1990).

Three major faults separate the zones described above. The low-angle Garigue thrust separates the Chioak and Baby zones and represents the basal decollement of the latter (Budkewitz, 1986; Clark and Thorpe, 1990). The Rachel fault separates the Baby and Rachel zones; it is a high-angle reverse fault (Moorhead and Hynes, 1990) that may also record a significant dextral strike-slip displacement (Goulet, 1987). The Turcotte fault separates the Rachel and Kuujjuaq zones (Perreault and Hynes, 1990).

The **Baby zone** is subdivided into three domains characterized by similar lithological assemblages but varying styles of deformation (Figures 3 and 4). From west to east, the amplitude and wavelength of folds increase, their interlimb angles decrease, and metamorphic grade increases from lower to upper greenschist. Folds plunge 0–30° (average 15°) to the SSE. The western portion (**Mélozès domain**) consists of thrust-imbricated Abner dolomite and Baby turbidites. Hellancourt basalt and tholeiitic gabbro sills are absent from this domain. Folds are isolinal, overturned to recumbent near thrust faults, open and upright within allochthons, and are west-vergent with wavelengths rarely exceeding one kilometre. Deformation of the central volcano-sedimentary portion (**Gerido domain**) is characterized by imbricated synclines and duplexes and low-to-high-angle reverse faults with dips increasing toward the east. Synclines are tight and overturned to the west; they have 2–4 km wavelengths, amplitudes reaching 3 km and are generally subhorizontal, extending over tens of kilometres. The eastern portion (**Thévenot domain**) is characterized by the same lithologies as in the Gerido domain. There are fewer high-angle reverse faults, as this domain is dominated by large-scale,
tight to open, inclined to upright anticlines and synclines. The folds have wavelengths of 6-12 km and amplitudes as high as 6 km.

**Sequence of deformation**

At least four phases of deformation are recognized in the northern QNO. The two earliest phases of deformation are best recorded in the Rachel zone (Moorehead and Hynes, 1990) where they correspond to the development of a basal décollement (D1) and NW transport of basement-cored Pennine-style nappes (D2). The third deformational event encompasses the main stage of compression and is characterized by a SW to WSW transport direction. In the Baby zone, this event is preserved as two increments of deformation, i.e., the D3 (early) and D4 (late) stages. Only D3 is observed in the Rachel zone. In the foreland, D3 was formerly referred to as D1 (Goulet, 1987; Wares and Goulet, 1989), but the nomenclature was modified (Wares and Goulet, 1990) in an attempt to establish internal consistency with hinterland deformation. Furthermore, although D3 deforms D2 structures, the foreland deformation is probably the result of continuous strain since the stages are coaxial and there is no evidence of temporally discrete events.

D3 in the foreland is characterized by a penetrative schistosity, isoclinal folds and shear folds that are limited to pelitic sedimentary units, except near the eastern limit of the Baby zone where folding involved the more competent gabbroic sills. In the Mélèzes domain, these folds are limited to high-strain zones adjacent to thrust faults. D3 folds trend NW to NWW and are overturned to the SW. D3 thrust faults are mostly bedding-parallel in the Gerido and Thévenet domains, as indicated by a paucity of stratigraphic repetition within younger (D4) thrust slices and by a conspicuous D3 shear zone located at the base of the Hellan Court Formation. In the Mélèzes domain, where sills are absent, low-angle D3 thrust faults imbricate the sedimentary sequence. The D3 Garigue fault (basal décollement) thrusts Abner dolomite over the shelf sequence.

The main tectonic fabric of the orogen is the result of D2. This event is recorded in all four zones. In the Chiaoak zone, it generated NW-trending, upright, open folds, whereas in the Baby and Rachel zones, it produced NW- to NNW-trending, open to tight, large-scale, upright to overturned folds with axial planar crenulation cleavages. D2 faults, such as the bedding-parallel thrusts at the base of the Hellan Court Formation and the Garigue fault, are folded by D3 structures. D3 high-angle reverse faults are abundant, truncate D2 folds, and are limited to the Gerido and Thévenet domains, except south of the Mélèzes River, where they extend into the Mélèzes domain. The Robelin and Archiac faults are D3 structures that separate the Mélèzes and Gerido and Gerido and Thévenet domains, respectively (Figures 3 and 4).

D4 is observed in the Chiaoak and Baby zones; it resulted in NE-trending upright open folds that created local dome and basin patterns with D3 folds.

The chronology of faulting is complex, as illustrated in an oblique structural cross-section (unbalanced down- and up-plunge projections) across the foreland (Figure 4). In the Mélèzes domain, D3 faults apparently form an in-sequence imbricate fan (Boyer and Elliott, 1982), as suggested by regular, repeated imbrication of Abner dolomite over Baby turbidites and the fact that westerly faults do not truncate underlying faults to the east. The spacing and dip of faults increase toward the Gerido domain. D3 faults are truncated by the Robelin fault, which represents the westernmost D3 fault (D3 basal décollement) in the northern half of this area. In the Gerido and Thévenet domains, D3 faults form a consistent trailing fan of break-back thrusts younging toward the hinterland, i.e., the entire D3 fault system is out-of-sequence. The structures in lower (westerly) thrust slices are consistently truncated by faults at the base of the upper slices and, in some cases, the upper slices consist of stratigraphically higher lithologies than the lower ones (e.g., Robelin fault). In Figure 4, it was assumed that the Robelin fault does not truncate the Garigue fault, although the true structural relationship between these faults is presently unknown. Out-of-sequence thrusts that truncate older décollements have been documented in many fold-thrust belts, including the Cape Smith Belt to the northwest (Lucas, 1989). At the eastern margin of the foreland, all D3 faults and folds are truncated by the Rachel fault, which may be syn-D3 or a late-tectonic feature.

**Discussion**

In the Baby zone, both D3 and D4 reflect transport toward the WSW-SW, slightly oblique to the trend of the orogen. In the Rachel zone, however, D3 reflects transport to the NW and D4 reflects transport to the SW. Whether D3 in the Rachel zone reflects a true compression direction or local transport caused by a major lateral ramp structure is uncertain (Moorehead and Hynes, 1990). If the latter case is correct, early compression in the hinterland may have been toward the SW, in which case D3 and D4 would likely be coeval with D3 in the foreland. However, the relations between the early stages of deformation in the Baby and Rachel zones remain speculative, since there is presently no convincing way to correlate the early deformations between these zones.

The out-of-sequence D3 event is related to the bulk of crustal shortening, given the associated degree of imbrication and juxtaposition of domains. We estimate the degree of shortening related to D3 at 78% in the Gerido domain and 50% in the Thévenet domain, based on deconvolution of the Hellan Court basalt. This is equivalent to a minimum 80 km southwestward displacement of the basalt at the eastern margin of the foreland, ignoring the D3 displacement. These estimates are similar to the minimum 64% shortening calculated by Boone (1987) along a cross-section in the same area.

As in the case of the Cape Smith Belt (Lucas, 1989), out-of-sequence thrusting in the northern QNO seems to be the dominant mechanism responsible for crustal thickening, although the causes for such deformational style are not clear. Widespread out-of-sequence high-angle thrusting in the foreland of an orogen is thought to be a consequence of maintaining critical taper during

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**Figure 2** Stratigraphy of the foreland (Chiaoak and Baby zones) of the northern New Québec Orogen, modified from Clark and Thorpe (1990). **Koksoak Group** is an informal name and includes the Abner Baby-Hellan Court formations (Wares and Goulet, 1990). The Knob Lake and Koksoak groups are part of the second cycle sequence, with the possible exception of the Abner dolomite. The Chiaoak Formation is synorogenic and is related to the third cycle.
Figure 3. Geological map of a segment of the foreland of the northern New Québec Orogen. The autochthonous/parautochthonous Chioak zone was deformed by $D_3$ and $D_4$, and the allochthonous Baby zone (Koksoak Group) was deformed by $D_3$, $D_4$, and $D_5$. Most large-scale structures are the result of $D_3$. 

[Diagram showing geological features and legend]
growth of the orogenic wedge, which invariably thins due to erosion and in-
sequence forward thrust propagation (Davis et al., 1983; Morley, 1988). If
erosion of the wedge is the principal cause of the D₂ out-of-sequence geo-
metry, and one assumes the critical taper model of Davis et al. (1993)
where a single uniform wedge faces the undisturbed craton, one would ex-
pect a high rate of uplift prior to and during D₂, as well as the deposi-
tion of wedge-derived syntectonic fore-
deep sediments in the foreland. There
is no evidence, however, for rapid up-
lift of the foreland assemblage, as it
displays all the characteristics of up-
per crustal material. Furthermore, the
presence of wedge-derived foredeep
sequences in the foreland has yet to be
convincingly demonstrated. Hoff-
man (1987) interpreted the entire sec-
ond-cycle sequence of the northern
NQO as a foredeep assemblage, but
this is difficult to reconcile in view of
the abundant tholeiitic magmatism
and the fact that the youngest volca-
nic unit (Hélinecourt Formation) is >25
m.y. older than D₂ (Machado et al.,
1989). With the possible exception of
the Thévenet Formation, we also in-
terpret the second-cycle sequence as
a passive margin sequence (cf. Le-
Gallais and Lavole, 1982; Clark and

The absence of syntectonic ero-
sional features in the foreland can be
reconciled by invoking a two-sided
orogen (Koons, 1990), in which or-
ogenic geometry is controlled by two
mechanically coupled wedges, i.e., a
steep inboard wedge facing the in-
dentor and a shallow outboard wedge
facing the undisturbed craton. In such
a scenario, the orogen perturbs pre-
vailing winds and erosion concentrates at the toe of the inboard wedge
down to the indentor, resulting in syn-
tectonic sediment deposition on the indentor and uplift concentrated be-
low the inboard wedge. Applying such
a model to the NQO, erosion and uplift
would have been focussed in the
Rachel zone, and syntectonic wedge
sediments deposited (but not neces-
sarily preserved) east of the Kuujuaq
zone. Perreault et al. (1988) con-
cluded that post-D₂, rapid differential
uplift of the Rachel zone juxtaposed the hinterland against the foreland along the Rachel fault. Perreault and
Hynes (1990) have also demonstrated
that the Kuujuaq zone experienced
deep late-tectonic burial, supporting
the idea that the out-of-sequence geo-
metry of the foreland may result from
the erosion of a two-wedge orogen on
the slope facing the indentor.
Conclusions

D$_2$ shortening in the foreland was accommodated by in-sequence "piggyback" thrusting and local isoclinal folding in the Mélièzes domain, and by isoclinal folding and bedding-parallel gliding (with little imbrication) in the Gerido and Thévenet domains. A thin-skinned tectonic model is applicable to deformation in the foreland, and the style of deformation of the D$_2$ stage is such that out-of-sequence reverse faults in the Gerido and Thévenet domains form a trailing imbricate fan that youngs toward the hinterland. Deformation in the hinterland was more complex, with involvement of the basement early in the tectonic history. Early hinterland deformation cannot presently be correlated with early deformation in the foreland.

The out-of-sequence geometry of the D$_2$ stage of deformation is ubiquitous in the area studied and is the principal mechanism responsible for crustal thickening. In the New Québec Orogen and in other orogens where this is observed, rapid erosion of crustal material on the indentor (Rae Province) side of the inboard wedge may account for the absence of syntectonic, wedge-derived sediments in the foreland. Further investigations are required to establish the applicability, across the orogen, of the geometry observed in the north and the relative timing and coupling of events in the foreland and hinterland.

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