Geoscience Canada

Structural evolution of the Cape Smith Belt from initial thrusting to basement-involved folding

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Volume 16, numéro 3, september 1989

URI : https://id.erudit.org/iderudit/geocan16_3art03

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Éditeur(s)

The Geological Association of Canada

ISSN

0315-0941 (imprimé)
1911-4850 (numérique)

Découvrir la revue

Citer cet article

Lucas, S. B. & St-Onge, M. R. (1989). Structural evolution of the Cape Smith Belt from initial thrusting to basement-involved folding. *Geoscience Canada*, *16*(3), 122–126.

Résumé de l'article

Les relations déformation-métamorphismepermettent de distinguer quatre stagesdans l'histoire structurale de la bande duCap Smith. Tout d'abord, des chevauche-ments en série (D,) se sont développés dunord vers le sud au dessus d'un décollementde base entre le socle et la couverture. Ensecond lieu, l'élévation des températuresreliée à un processus de ré-équilibrationthermique dans les nappes de chevauche-ment (épaisseur cumulée de 20 à 30 km) a permis la formation d'une zone de cisaille-ment plastique (shear zone) à la base de laceinture de chevauchement. En troisème-ment lieu, d'importants chevauchementshors-série ont remanié les chevauchementsen-série de la zone interne pendant et aprèsle maximum thermique relié à D,. Les che-vauchements hors-série se sont manifestésjusqu'aux conditions tardi-apogée ther-mique. Finalement, les nappes de che-vauchement D,, responsables de la struc-turation actuelle de la bande du Cap Smith,ont été reprises par un épisode de plisse-ment (d'axe est-ouest) du socle (D2) aucours des derniers stades de compressionnord-sud.

grateful to Tim Byrne (Brown University), Dugald Carmichael and Herb Helmstaedt (Queen's University), Paul Hoffman and Randy Parrish (Geological Survey of Canada) and Christian Picard (Mineral Exploration Research Institute in Montréal) for lively discussions on the outcrops. Christian Picard is acknowledged for a very careful review of an early version of this paper.

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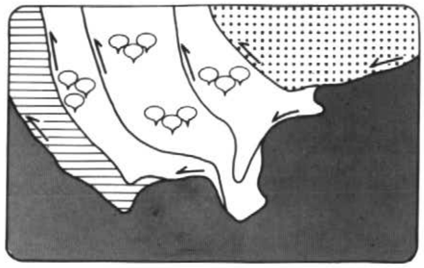

Structural evolution of the Cape Smith Belt from initial thrusting to basement-involved folding [1]

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Summary

Structures in the Cape Smith Belt record the transition during collisional deformation from (1) initial thin-skinned thrust belt growth, to (2) internal thickening of the thrust belt involving basement thrusting, and finally to (3) basement-involved, crustal-scale folding. Overprinting deformation-metamorphism relationships allow recognition of four principal stages in the history of the thrust belt. First, south-verging, regular (piggy-back)-sequence thrusts developed above a regional basal décollement which was localized at the basement-cover contact. Second, thermal equilibration of the thrust belt (20 to 30 km thick) resulted in metamorphism and the development of a ductile shear zone at its base. Third, major out-of-sequence thrust faults internally deformed the thrust belt from pre- to post-thermal peak conditions. Finally, thrust belt deformation (D_1) was followed by an episode of basement- (footwall-) involved folding (D_2) which continued to accommodate the north-south shortening.

Résumé

Les relations déformation-métamorphisme permettent de distinguer quatre stages dans l'histoire structurale de la bande du Cap Smith. Tout d'abord, des chevauchements en série (D_1) se sont développés du nord vers le sud au dessus d'un décollement de base entre le socle et la couverture. En second lieu, l'élévation des températures reliée à un processus de ré-équilibration thermique dans les nappes de chevauchement (épaisseur cumulée de 20 à 30 km) a

[1] Geological Survey of Canada Contribution No. 19189

permis la formation d'une zone de cisaillement plastique (shear zone) à la base de la ceinture de chevauchement. En troisèmement lieu, d'importants chevauchements hors-série ont remanié les chevauchements en-série de la zone interne pendant et après le maximum thermique relié à D_1. Les chevauchements hors-série se sont manifestés jusqu'aux conditions tardi-apogée thermique. Finalement, les nappes de chevauchement D_1, responsables de la structuration actuelle de la bande du Cap Smith, ont été reprises par un épisode de plissement (d'axe est-ouest) du socle (D_2) au cours des derniers stades de compression nord-sud.

Introduction

The evolution of continental thrust belts is characterized by a complex interplay between crustal thickening mechanisms, crustal thinning mechanisms (including erosion) and metamorphic processes. Overprinting deformation and metamorphic relations have been utilized in this study to unravel the structural evolution of an ancient thrust belt: the Early Proterozoic Cape Smith Belt, located in northern Québec (St-Onge and Lucas, in press). The thrust belt's deformation history has been examined in the context of a well-established tectonostratigraphic (Hynes and Francis, 1982; St-Onge *et al.*, 1989 - this issue, p. 119-122; Picard *et al.*, in prep.), geochronologic (Parrish, 1989 - this issue, p. 126-130) and metamorphic framework (Bégin, 1989 - this issue, p. 151-154; St-Onge and Lucas, 1989 - this issue, p. 154-158). In addition, this study has employed the >18 km of structural relief present in the map area (Figure 1) to construct a down-plunge constrained cross-section of the thrust belt (Figure 2; Lucas, in press).

Development of the south-verging thrust belt occurred during northward underthrusting of the Superior Province basement and its north-facing continental margin (D_1) (Hoffman, 1985; Lucas, in press; St-Onge and Lucas, in press). Collision of the underthrust Superior Province margin with the exotic (?) Sugluk terrane (see Figure 1 in St-Onge *et al.*, 1989 - this issue, p. 119-122) is assumed to have occurred during thrust belt deformation. Folding of the thrust belt with its footwall basement (D_2) along east-west axes is interpreted to have occurred during the later stages of this collision. D_3 cross-folding (about north-northwest trending axes) and subsequent uplift and erosion are responsible for the present exposure of an oblique cross-section of the D_1-D_2 belt (Figure 1) in a doubly plunging (D_2 and D_3) synclinorium. This paper presents a summary of the D_1-D_2 deformation history of the thrust belt, and discusses the significance of major thrust belt structures in terms of mountain-building processes.

Timing of Deformation and Metamorphism in the Thrust Belt

The structural evolution of the thrust belt during D_1 and D_2 has been established through the use of cross-cutting deformation and metamorphic relations (Lucas, in press; St-Onge and Lucas, in press). It is characterized by four distinct stages (Figures 2 and 3): (1) a piggyback thrusting stage; (2) a basal shear zone deformation stage; (3) an out-of-sequence thrusting stage; and (4) a basement-involved folding stage (D_2). Thermal peak mineral isograds mapped in mafic rocks (Bégin, 1989 - this issue, p. 151-154; see also St-Onge and Lucas, 1989 - this issue, p. 154-158) clearly establish the relative timing of the four deformation stages. The isograds overprint the early D_1 thrust faults and the syn-metamorphic basal shear zone in the southern (external) part of the belt. However, isograds are truncated by syn- and post-thermal peak out-of-sequence thrusts toward the northern (internal) part. Finally, all D_1 thrust faults and thermal peak mineral isograds are folded by the D_2 structures.

Early D_1 Thrust Belt

The early D_1 thrusting stage is characterized by thin-skinned crustal thickening involving foreland-younging, piggyback-sequence (Boyer and Elliott, 1982) thrust faults (Figure 3a). These faults comprise several thrust

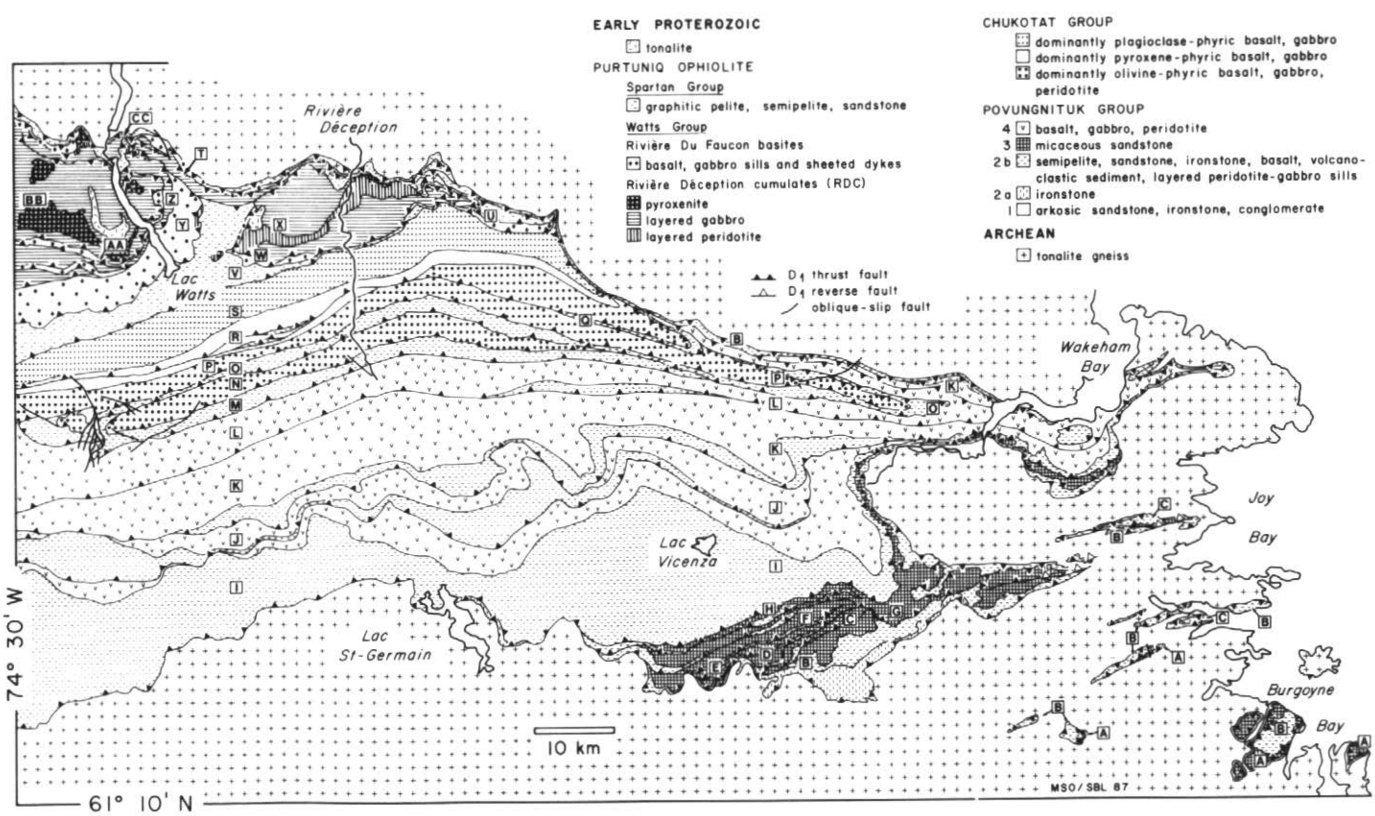

Figure 1 *Regional geological compilation map of the eastern portion of the Cape Smith Belt. Thrust faults are named after the boxed letter in their hanging wall. Numbers 1 to 4 refer to Formations in the Povungnituk Group.*

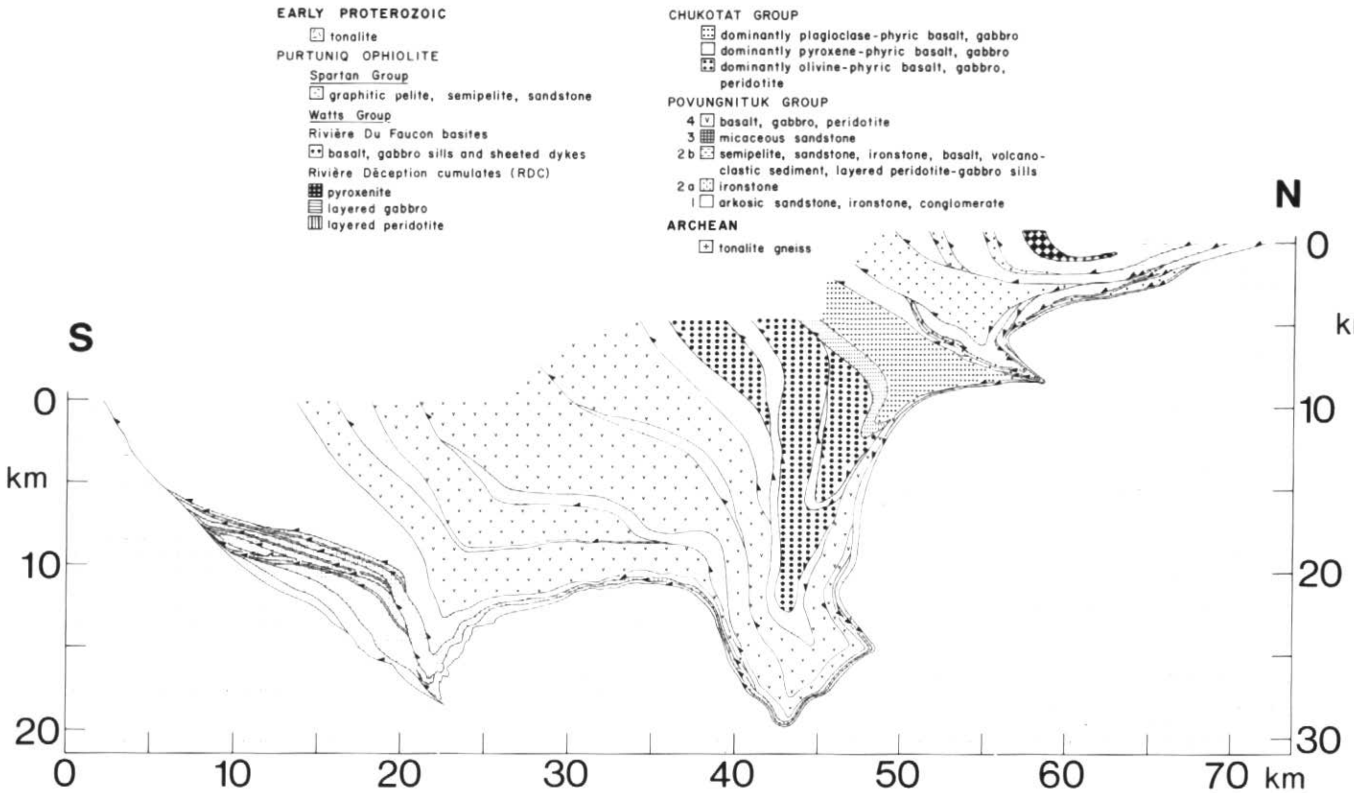

Figure 2 *Down-plunge constrained geological cross-section of the eastern portion of the Cape Smith Belt. The cross-section illustrates the D_1 thrust belt following D_2 folding (east-west axes), but prior to D_3 folding (north-south axes). See Lucas (in press) for a discussion of the method used to prepare the cross-section.*

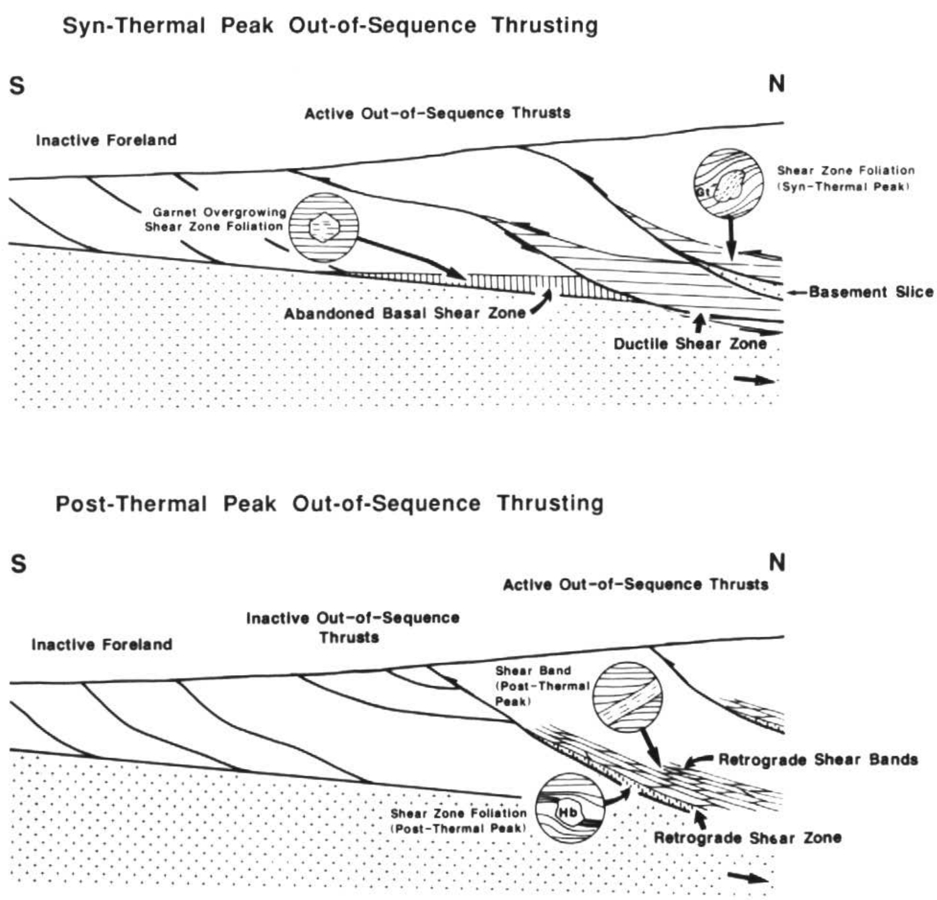

Figure 3 ***(right)*** *Schematic representation of the structural evolution of the thrust belt during D_1. The figure illustrates the basic geometry, kinematics and deformation-metamorphism relationships associated with the evolution of the thrust belt.*

see Vol 16, #4
p 212 for Fig 3(a to d)

systems which ramp up from a basal décollement in the southern and eastern (more external) portions of the Cape Smith Belt (Figures 1 and 2). They are responsible for the incorporation of 0.5-7 km thick sheets of rift and transitional crust units into the thrust belt (Povungnituk and Chukotat Groups, Figure 1).

A regional basal décollement separates the D_1-deformed Early Proterozoic rocks from the Archean basement throughout essentially all of the eastern part of the Cape Smith Belt (Figure 1). However, the décollement is above the basement-cover contact in a series of outliers in the Burgoyne Bay area (Figure 1). These outliers contain up to 30 m of autochthonous Proterozoic cover (Formation 1, Figure 1) and mark the location of a major ramp in the décollement's trajectory. The minimum hinterland (northern) margin displacement on the décollement is estimated to be in the order of 100 km (Lucas, in press). This is consistent with the observation that the footwall basement in the mapped area shows no evidence for crustal stretching or rift volcanism (St-Onge and Lucas, in press).

The early D_1 thrust faults are characterized by a north-to-south movement direction and minimum displacements that range up to 10-15 km. The transport direction is suggested by (1) the consistent stacking of more distal rift facies units on more proximal units (St-Onge *et al.*, 1989 - this issue, p. 119-122); and (2) the generally east-trending and north-dipping geometry of thrust ramps (Figures 1 and 2). Several lines of evidence indicate that the system of early D_1 thrust faults developed in a piggyback fashion (Boyer and Elliott, 1982). First, fault-bend folds (Suppe, 1983) associated with ramps in structurally lower (more southerly) thrusts deform older hanging wall (more northerly) thrusts. Second, overlying thrusts were deformed during syn-metamorphic movement along the underlying basal décollement (Lucas, in press).

Basal Shear Zone

A south-verging ductile shear zone (termed basal shear zone) has been mapped immediately adjacent to the basal décollement in the southern and eastern parts of the Cape Smith Belt (Figure 3b; see Figure 1 in Lucas and St-Onge, 1989 - this issue, p. 158-163). It contains < 1-5 km of well-foliated, highly strained thrust belt rocks, and < 1-3 m of the Archean gneissic basement immediately below the basal décollement. The shear zone cross-cuts early D_1 thrust faults and thus postdates their movement. This is further supported by the observation that metamorphic minerals overgrow early D_1 fault zone foliations above the shear zone, but are deformed during growth within the shear zone. However, the basal shear zone foliation is consistently overgrown by the highest grade phases, indicating that movement along the shear zone ceased at thermal peak conditions.

The basal shear zone is recognized at outcrop-scale by a well-developed foliation and, in general, a stretching lineation (Lucas, in press). These fabrics are developed in all thrust belt lithologies except the interiors of competent (*e.g.*, ultramafic) sills. Primary layering is generally completely transposed into the shear zone's tectonic foliation, which parallels the basement-cover contact. Detailed microstructural study (Lucas, in prep.) has shown that mylonites were produced in the shear zone from thrust belt lithologies and from footwall gneisses as a result of grain-size reduction by dislocation creep mechanisms.

The basal shear zone contains a suite of kinematic indicators which document a top-to-the-south sense of movement. Stretching lineations are well developed in the shear zone and appear to record an approximately north-to-south ductile shear flow direction. The kinematic indicators that were used include (1) C/S fabrics (Berthé *et al.*, 1979); (2) shear band foliations (Platt and Vissers, 1980); (3) porphyroblasts recording syn-growth rotation in the inclusion trails; and (4) asymmetric folds of the shear zone fabric showing various states of fold axis rotation into the shear direction. In general, kinematic observations consistently indicated a south-directed sense of shear.

Out-of-Sequence Thrust Faults

An increase in the complexity of D_1 structures toward the hinterland (northern) margin of the belt resulted from re-imbrication of the internal part of the thrust belt and emplacement of footwall (Archean basement) thrust slices into the belt (Figures 3c,d). Re-imbrication occurred along out-of-sequence thrust faults which cut through the previously assembled thrust belt (*i.e.*, in the hanging walls of pre-existing thrusts). Two distinct systems of out-of-sequence thrusts occur in the belt (Figures 3c,d): (1) syn-thermal peak and (2) post-thermal peak. A relative age progression between the two systems of out-of-sequence faults is observed, with the youngest thrust faults in the preserved belt being structurally the highest, and the most northerly (hinterlandward; Figure 2).

Ductile shear zones developed adjacent to both the syn- and post-thermal peak out-of-sequence faults in order to accommodate fault movement (see Lucas and St-Onge, 1989 - this issue, p. 158-163). A southward sense of displacement is recorded by a suite of kinematic indicators in these ductile shear zones. These kinematic indicators include (1) shear bands, (2) C/S fabrics, (3) back-rotated boudins, and (4) rotated syn-deformation porphyroblasts. The top-to-the-south sense of movement on the out-of-sequence thrusts, parallel to that recorded by the older regular-sequence thrusts, indicates that the belt maintained a relatively constant transport direction throughout its deformation history.

Displacement estimates for the syn-thermal peak system are on the order of 50-100 km, while those for the post-thermal peak system indicate at least 50 km of movement. The minimum displacement estimates are based on measurements of fault length parallel to the movement direction (*i.e.*, in the cross-section, Figure 2), given that no hanging wall and footwall cut-offs can be matched. The displacement estimates are of the same order of magnitude as that inferred for the regular-sequence basal décollement, and indicate that out-of-sequence thrusts are responsible for significant crustal shortening (Lucas, in press).

D_2 Basement-Involved Folding

Map-scale D_2 folds deform the thrust belt, its footwall basement and the thermal peak mineral isograds. These folds are west-trending, and are approximately coaxial with the commonly observed outcrop-scale D_2 minor folds. The D_2 map-scale folds appear to be localized in two principal settings: (1) major viscosity interfaces, such as the basement-cover contact; or (2) where adequate mechanical layering is present, such as mafic-ultramafic sills in sediments. At the level of the basal décollement in the lac St-Germain-Wakeham Bay area (Figure 1), the D_2 map-scale folds produce a striking "W-shaped" geometry. The geometry of these folds is best observed in the cross-section (Figure 2). The folds have relatively high amplitude to wavelength ratio (20 km/30 km), and a profile characterized by two cuspate synclinal keels separated by a lobate median antiform. A minimum strike length of 150 km of the "W-shaped" D_2 profile is suggested by gravity data from a detailed survey (Feininger *et al.*, 1985) conducted 10 km west of the area shown on Figure 1.

Discussion

The geometric development of the early D_1 thrust belt was guided by the structure and stratigraphy of the underthrust rifted continental margin (Figure 3a; see Lucas, in press). In contrast, however, the development of the basal shear zone (Figure 3b) was largely influenced by the structure of the early D_1 fault system (a wedge of sediments lying between volcanic-dominated thrust sheets and footwall basement gneisses (Figure 2)). The relatively weak siliciclastic sediments sandwiched betwen stronger basalts and gneisses accommodated the bulk of the strain associated with displacement along the basal décollement during metamorphism (see Lucas and St-Onge, 1989 - this issue, p. 158-163).

The evolution from basal décollement to basal shear zone represents a transition from discontinuous strain along a narrow fault zone to continuous ductile strain in a broad shear zone. Basal shear zone deformation is interpreted to have initiated at the basement-cover contact (décollement) and expanded into the thrust belt and its underlying footwall basement. The basal shear zone became inactive at syn-thermal peak conditions after it was overridden by out-of-sequence thrust faults. Its demise is attributed to (1) strain hardening of the shear zone during prograde metamorphism resulting from the emplacement of the out-of-sequence thrust stack; and (2) decrease in the shear zone strain rate as a result of the development of major (overlying) out-of-sequence décollements (Lucas, in press).

D_2 basement-involved folding is interpreted to be the final stage of deformation associated with the collisional orogeny which was responsible for D_1 deformation. The P-T estimates for D_2 (St-Onge and Lucas, in press) suggest that folding of the underthrust basement and the thrust belt followed relatively shortly after D_1. In total, an evolution is observed in the nature of basement-involvement during the D_1-D_2 collisional orogeny. Initially, crustal shortening during D_1 was accomplished by the development of the thrust belt and by bulk underthrusting of the Superior Province basement (Figures 3a,b). Next, slices of underthrust basement were accreted to the thrust belt along out-of-sequence thrusts (Figure 3c) relatively late in the D_1 thrusting episode (see Lucas, in press). Finally, the footwall basement and thrust belt deformed together by folding in order to accomplish crustal shortening during D_2.

Acknowledgements

Dave Scott and Normand Bégin (both at Queen's University, Kingston) are gratefully acknowledged for their assistance both with mapping in eastern Cape Smith Belt (1985-87) and with discussions on the structural history of the belt. Tim Byrne (Brown University) is acknowledged for many beneficial discussions and comments on the ideas presented in this paper. Christian Picard (Mineral Exploration Research Institute in Montréal) is thanked for a helpful review.

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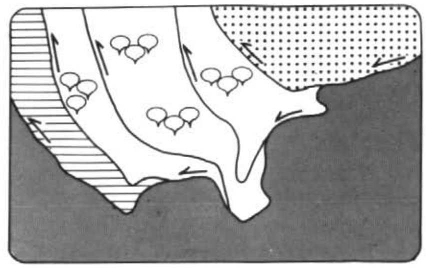

U-Pb geochronology of the Cape Smith Belt and Sugluk block, northern Quebec [1]

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Summary

The Cape Smith Belt is a multiply-deformed thrust belt containing metamorphosed basaltic volcanic, mafic intrusive, and sedimentary rocks. It lies south of the Kovik antiform and the Sugluk block; together, these constitute the Ungava segment of the Trans-Hudson Orogen. U-Pb dating of representative units reveals that Archean rocks of the Superior craton which underlie the belt are *ca.* 2780-2880 Ma old, and that the oldest rocks in the belt proper are those of the Purtuniq ophiolite at 1998 ± 2 Ma. The belt evolved between *ca.* 2000 Ma (oceanic crust generation) and about 1830 Ma, the age of the later part of the belt's south-directed structural translation and subsequent thick-skinned deformation. The Povungnituk Group (the structurally lowest assemblage of sedimentary and volcanic rocks) was deposited *ca.* 1960 Ma, and being younger than the ophiolite, cannot be the rift assemblage which led to creation of oceanic crust of the Purtuniq ophiolite. Ages of intrusions and sedimentary rocks within the Sugluk block are as young as 1830 Ma, and they were metamorphosed and deformed at granulite facies at 1830-1820 Ma, prior to a period of slow cooling.

Résumé

La bande du Cap Smith est une ceinture de chevauchement qui est caractérisée par une tectonique polyphasée et qui comprend des basaltes, intrusions mafiques et sédiments métamorphosés. La ceinture se trouve au sud de l'antiforme Kovik et du bloc de Sugluk; cet ensemble constitue le segment Ungava de l'orogène Trans-Hudsonienne. La datation

[1] Geological Survey of Canada Contribution No. 18989