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Dynamics of the tectonic assembly of northeast Laurentia ingeon 18 (1.9-1.8 Ga)

Paul F. Hoffman

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Article abstract

A tectonic model is proposed, based on the Cenozoic evolution of Southeast Asia, in which the southeast arm of the Rae Province rotated clockwise in response to collision alindentation of the Superior Province. A dextralpull-apart basin characterized by mafic sill-sediment complexes formed along the leading edge of the rotating block. Relics of this basin, analogous to the Andaman Sea basin of Southeast Asia, were subsequently thrust onto the Superior Province margin where they occur as allocations in the Labrador Trough.A wedge-shaped ancestral Baffin basin, analogous to the South China Sea, opened simultaneously in the wake of the rotating block.The margins of this basin are delineated bythe Foxe-Rlnkian and Dorset fold belts; their convergence and disappearance westward reflect the primary shape of the basin. North-west-dipping subduction beneath the mouth of the basin accommodated convergence of the Burwell and Nain provinces from the southeast and gave rise to the Cumberland batholith. Docking of the Burwell and Nain provinces caused compressional collapse ofthe ancestral Baffin basin and sinistral transpression of the Torngat Orogen, respectively.The model is well constrained by existing U-Pb geochronological data and makes predictions which can be tested by additional data.

The eastern Churchill Province is a unique and superb example of a two-sided, Early Proterozoic orogen that is exposed in complete coastal cross-section. With sufficient commitment, there is, therefore, no reason why these challenges cannot be overcome in the years ahead.

Acknowledgements

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[Note: bold references in the text are listed in the caption to Figure 2.]

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"The eastern Churchill Province, Torngat and New Quebec orogens"

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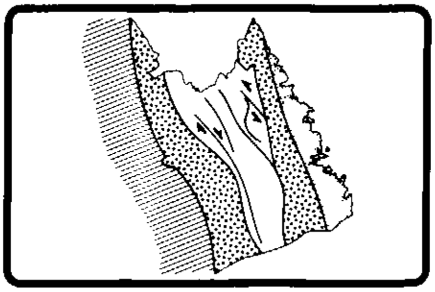
R.J. Wardle
Geological Survey Branch
Newfoundland Department of
Mines and Energy
P.O. Box 8700
St. John's, Newfoundland A1B 4J6



Dynamics of the tectonic assembly of northeast Laurentia in geon 18 (1.9–1.8 Ga)

Paul F. Hoffman
Continental Geoscience Division
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

Summary

A tectonic model is proposed, based on the Cenozoic evolution of Southeast Asia, in which the southeast arm of the Rae Province rotated clockwise in response to collisional indentation of the Superior Province. A dextral pull-apart basin characterized by mafic sill-sediment complexes formed along the leading edge of the rotating block. Relics of this basin, analogous to the Andaman Sea basin of Southeast Asia, were subsequently thrust onto the Superior Province margin where they occur as allochthons in the Labrador Trough. A wedge-shaped ancestral Baffin basin, analogous to the South China Sea, opened simultaneously in the wake of the rotating block. The margins of this basin are delineated by the Foxe–Rinkian and Dorset fold belts; their convergence and disappearance westward reflect the primary shape of the basin. Northwest-dipping subduction beneath the mouth of the basin accommodated convergence of the Burwell and Nain provinces from the southeast and gave rise to the Cumberland batholith. Docking of the Burwell and Nain provinces caused compressional collapse of the ancestral Baffin basin and sinistral transpression of the Torngat Orogen, respectively. The model is well constrained by existing U-Pb geochronological data and makes predictions which can be tested by additional data.

Introduction

Key to the tectonic assembly of northeast Laurentia in geon 18 (1.9–1.8 Ga, Hofmann, 1990) is the tangle of orogenic belts that welds the Superior, Rae, Burwell and Nain provinces (Figure 1). The Trans-Hudson Orogen has long been viewed as a collision zone between the Superior and Churchill (Hearne, Rae and Burwell) provinces (Wilson, 1968), and the other orogenic belts may also represent collision zones between adjacent Archean provinces (Hoffman, 1990). Extending the Superior–Churchill collisional indentation-extrusion model of Gibb (1983), the configuration and tectonic history of northeast Laurentia can be compared with the Cenozoic evolution of Southeast Asia. The comparison sheds light on particular aspects of the regional tectonics that were previously enigmatic: (1) the apparent syn-collisional (1.88 Ga) age of mafic volcanism and related sill complexes in allochthons of the Labrador Trough (New Québec Orogen), (2) the westward pinch-out of the Foxe fold belt and Baffin Orogen, (3) the significance of the Cumberland batholith of Baffin Island, and (4) the conflicting components of strike-slip in the New Québec (dextral) and Torngat (sinistral) orogens. The dynamic tectonic model proposed here makes geochronological predictions against which it can be tested.

India–Eurasia indentation-extrusion tectonics and resultant extensional basins

Gibb (1983) proposed that Hudsonian (1.9–1.8 Ga) orogenesis resulted from collisional indentation of a relatively rigid Superior continent into a rigid-plastic Churchill continent that had been softened as a thermal consequence of northwest-dipping subduction of intervening oceanic lithosphere. He drew analogy with the Cenozoic India–Eurasia collision, where some 2500 km of north-south intracontinental convergence has been taken up by a combination of crustal thickening by folding and thrusting, and east-west extension by normal and conjugate strike-slip faulting. Plasticine experiments suggest that progressive indentation of India led to piecemeal southeastward extrusion and clockwise rotation of Southeast Asia (Peltzer and Tapponnier, 1988). Extrusion is directed eastward rather than westward because eastern Asia represents a "free face" due to the subductability of oceanic lithosphere in the western Pacific and northeastern Indian oceans. Although the magnitude of lateral extrusion has been questioned (Dewey *et al.*, 1989), the inferred clockwise Cenozoic rotation of southeast Asia is supported paleomagnetically (Chen and Courtillot, 1989).

An important feature of the Cenozoic tectonic evolution of Southeast Asia is the formation of extensional basins contemporaneous with the indentation-extrusion process ("mismatch basins" of Peltzer and Tapponnier, 1988). Along the inner edge of the rotating block, dextral-oblique extension (Figure 2, basin A) occurred in the Andaman Sea. The basin is situated above the east-dipping slab of the Indian plate and is being rapidly infilled with sediments carried south-ward by the Irrawaddy River. The Andaman Sea basin is structurally analogous to the Guaymas basin of the Gulf of California, although it differs from the Guaymas basin in regional tectonic setting and in its location above a dipping (but horizontally moving) slab. The Guaymas basin is notable for basaltic sill-sediment complexes, which are thought to be a product of (oblique) sea-floor spreading under the influence of high sedimentation rates (Einsele, 1986). Basaltic sill-sediment complexes may also occur in the Andaman Sea basin. As rotation of Southeast Asia continues, the Andaman Sea basin and its fringing accretionary prism are being thrust westward toward India. To the east, a wedge-shaped Cenozoic extensional basin in the South China Sea formed in the wake of the rotating block (Figure 2, basin B).

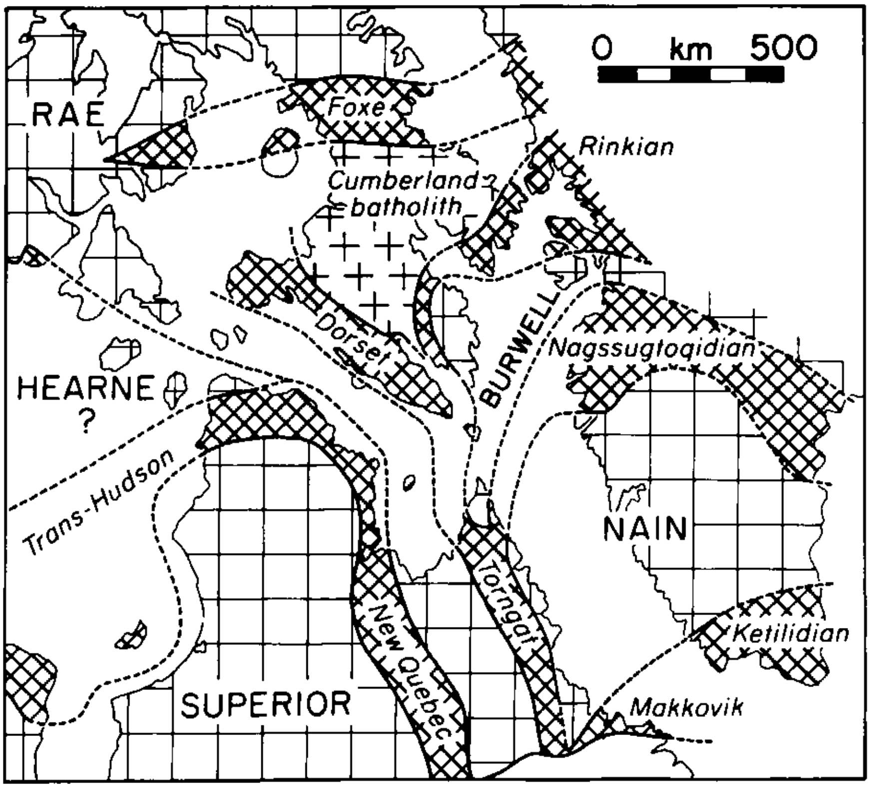


Figure 1 *Pre-drift reconstruction of northeast Laurentia showing inferred relations between Archean provinces and orogenic belts of geon 18.*

Dynamic model for tectonic assembly of northeast Laurentia

The proposed model is illustrated by four "snapshots" at 20 m.y. intervals (Figure 3). Consequent to indentation of the Superior Province, the southeast arm of the Rae Province rotated clockwise by analogy with Southeast Asia. Dextral-oblique extension along its inner margin produced new oceanic crust (analogous to the Andaman Sea) that was ultimately thrust onto the northeast margin of the Superior Province (Labrador Trough). In the wake of the rotating arm of the Rae Province, a wedge-shaped basin (analogous to the South China Sea, but possibly floored by extended continental crust) opened in the area of the Baffin Orogen. The deformed southern and northern margins of this basin are represented by the Dorset and Foxe fold belts, respectively. Northwest-dipping subduction beneath the Rae Province, including the ancestral Baffin basin, is postulated to account for generation of the Cumberland batholith and to accommodate convergence of the Burwell and Nain provinces from the southeast (Grocott and Pulvertaft, 1990). The batholith extends eastward into the Rinkian belt (Proven batholith) of West Greenland and perhaps southward into the Torngat Orogen (west of the Tasiuyak paragneiss) of Labrador (Bertrand *et al.*, 1990). Granitic magmatism was most intense near

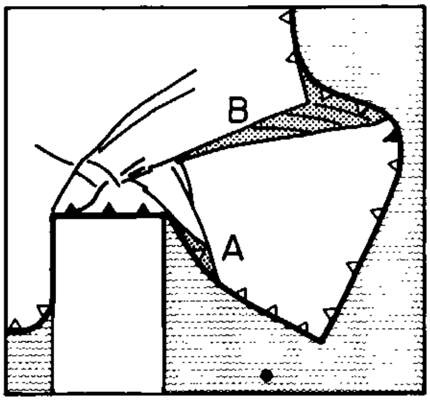


Figure 2 *Extensional basins (A and B) formed during asymmetric lateral extrusion, based on plasticine experiment from Peltzer and Tapponnier (1988). Dot indicates finite rotation pole.*

the postulated axis of the ancestral Baffin basin (Jackson *et al.*, 1990), perhaps reflecting the high heat flow associated with the newly opened basin and the thermal blanketing effect of its sedimentary fill. In Southeast Asia, the closest analogy to the Cumberland batholith is the Louzon arc of the northern Philippines, which is a product of diachronous east- and west-dipping subduction at the east margin of the South China Sea basin. Finally, docking of the Nain and Burwell provinces caused sinistral transpression of the Torngat Orogen and compressional collapse of the ancestral Baffin basin, respectively. The Nagssugtoqidian Orogen of West Greenland is a northwest-dipping suture zone between the Nain and Burwell provinces (Kalsbeek *et al.*, 1987), but regional geochronological constraints are as yet insufficient to specify whether the Burwell and Nain provinces docked successively or together.

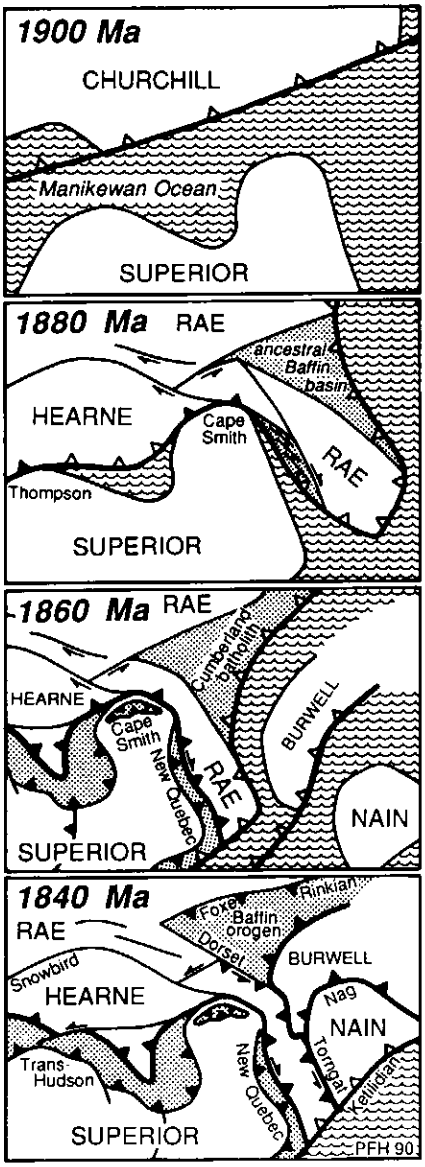


Figure 3 *Tectonic model for evolution of northeast Laurentia in geon 18.*

Timing constraints and predictions

The initial collision between the northern promontories of the Superior Province and the Churchill hinterland (Rae and Hearne provinces) occurred shortly before 1.88 Ga (all ages cited are based on U-Pb chronology). This follows from the observation that thrusting both predates and postdates tonalite plutons of that age in the Cape Smith Belt (St-Onge and Lucas, 1990; Parrish, 1989) and mafic (Molson) dykes of the same age in the Thompson belt (Bleeker, 1990; Heaman *et al.*, 1986). The maximum age limit for thrusting in the Cape Smith Belt is 1.92 Ga (Parrish, 1989). The minimum age of 1.88 Ga for the onset of collisional indentation is crucial to the model.

New Québec Orogen. The foreland thrust belt (Labrador Trough) of the New Québec Orogen preserves the telescoped northeastern margin of the Superior Province and allochthons accreted to the southwestern edge of the Rae Province (Wardle *et al.*, 1990). Strain is partitioned across the belt between southwest-directed thrusting toward the Superior Province (foreland) and dextral strike-slip in the Rae Province (hinterland). Parautochthonous volcanism (Castignon Lake complex) coeval with the shelf to foredeep transition (Sokoman ironstone) provides an age of 1.88 Ga (Chevé and Machado, 1988) for the onset of thrusting onto the foreland. More far-travelled allochthons (Baby–Howse zone) contain spectacular gabbro sill-sediment complexes (Figure 4). The sills are syn-collisional (1.88–1.87 Ga, N. Machado and R. Parrish, unpublished data) and therefore cannot be related to initial rifting of the Superior margin, which occurred at or before 2.14 Ga (Wardle *et al.*, 1990). Hoffman (1987) proposed that the gabbro sills represent foredeep magmatism in front of the active thrust belt; however, magmatism in an Andaman Sea-type basin behind the active thrust belt (Figure 5) represents an alternative interpretation. In the latter case, the mafic rocks should have the geochemical signatures of "supra-subduction zone ophiolites" (Pearce *et al.*, 1984), although they would lack the stratigraphic organization of ophiolites (Einsele, 1986).

Baffin Orogen. The Baffin Orogen comprises the Cumberland batholith and its flanking fold belts (Figure 1). The Foxe–Rinkian fold belt tapers westward across Melville Peninsula and disappears between convergent Archean terrains (Henderson, 1984). To the east, the belt comprises a lower platformal facies (carbonate, quartzite, pelite) overlain by a basinal turbiditic flysch facies. An assemblage of mafic-ultramafic flows, sills, epiclastic and chemical rocks is locally abundant at the bottom of the basinal facies (Henderson *et al.*, 1989). The Dorset fold belt and the Cumberland batholith disappear westward beneath the Paleozoic cover of the Foxe Basin. The stratigraphic similarity and apparent correlation of the Foxe–Rinkian and Dorset belts imply a common basin (Jackson and Taylor, 1972; Grocott and Pulvertaft, 1990). The model proposed here provides that the westward taper of the orogen relates to the wedge-shape of the original basin (ancestral Baffin basin of Figure 3). Its shape is a consequence of the rotation of the southeast arm of the Rae Province in response to indentation of the Superior Province. A falsifiable prediction of the model is that the onset of extension and rapid subsidence (*i.e.*, deposition of the turbidite-pelite sequence and associated igneous rocks) would have occurred at about 1.88 Ga, coeval with collisional indentation.

Cumberland batholith. The enormous Cumberland (charnockite-enderbite-granite) batholith of Baffin Island (Figure 1) intruded rocks of the ancestral Baffin basin around 1.86–1.85 Ga (Jackson *et al.*, 1990). The coeval Proven batholith (Rb-Sr age 1.86 Ga) in the Rinkian belt of West Greenland is interpreted as a magmatic arc generated in response to north-dipping subduction that accommodated convergence in the Nagssugtoqidian belt to the south (Grocott and Pulvertaft, 1990). Alternatively, the subduction zone may have been located northwest of the Burwell Province, implying that the Tasiuyak paragneiss (Van Kranendonk and Ermanovics, 1990), which extends north from the Torngat Orogen across Hudson Strait and southeastern Baffin Island (Hoffman, 1990), delineates a suture zone between the Rae Province and both the Nain and Burwell provinces (Figure 3). The area of the proposed suture zone on Baffin Island (Frobisher Bay and Hall Peninsula) is part of a huge (130,000 km^2) well-exposed area last mapped in a single field season 25 years ago (Blackadar, 1967).

According to the model proposed here, the batholith was emplaced soon after the ancestral Baffin basin opened. As the lithosphere would still have been relatively thin and hot, the timing may account for the remarkable volume of crustal melt produced in the axial part of the basin and the extensive upper crustal granulite-facies metamorphism (Jackson and Morgan, 1978; Cortemiglia *et al.*, 1985). However, the extent to which the metamorphic history of the basin relates to plutonism as distinct from subsequent collisional deformation remains to be determined.

Torngat Orogen. The Torngat Orogen is a sinistral-oblique collision zone between the Rae and Nain provinces (Van Kranendonk and Ermanovics, 1990). Preliminary results indicate that the Abloviak shear zone (Torngat Orogen) was active in the interval 1.86–1.83 Ga (Bertrand *et al.*, 1990), but it is not clear whether this was the time of collision, or of shearing related to sinistral-oblique subduction (*cf.* Fitch, 1972) prior to collision. In the proposed model (Figure 3), the collision in the New Québec Orogen predates that in the Torngat Orogen. As the onset of collision predates the peak of metamorphism by time intervals that vary be-

Figure 4 *Satellite view of gabbro sill-sediment complex in central Labrador Trough (NASA photo S17-47-58 with permission). Sills underlie highlands dusted white with early winter snow. Dark V-shaped area is Romanet horst, which exposes parautochthonous shelf strata (Pistolet Subgroup) structurally below sill-sediment allochthon. Field of view (looking WSW) is 60 km wide in middleground.*

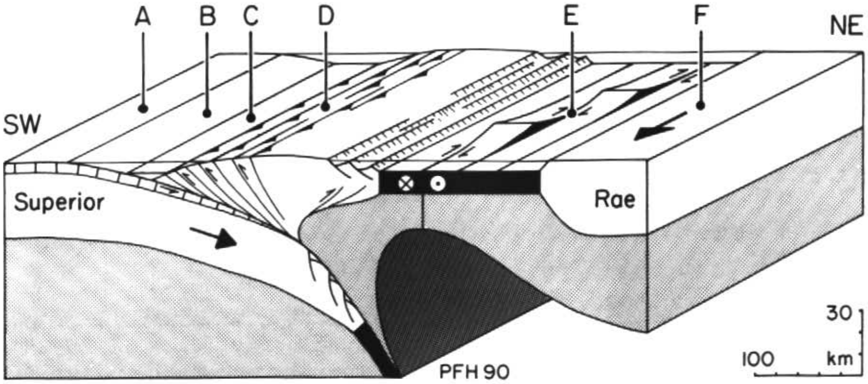


Figure 5 *Lithospheric model of the New Québec Orogen (Labrador Trough) at 1.88 Ga.*
***Zone A**, emergent flexural forebulge (sub-Wishart unconformity and Fleming Silcrete); **Zone B**, subaqueous foredeep outer ramp (Wishart Quartzite, Ruth Shale, Sokoman Ironstone and Castignon Lake alkalic volcanism); **Zone C**, foredeep axial turbidites (Menihek flysch); **Zone D**, foreland thrust-fold belt; **Zone E**, Andaman Sea-type dextral-oblique extensional basin floored by mafic sill-sediment complexes (Montagnais sills), and possibly also the site of Doublet Group volcanism and Laporte Group sedimentation; **Zone F**, hinterland. Zone E may have been thrust onto Zone D during subsequent shortening. The model predicts that mafic igneous rocks of Zone E are derived from a mantle source enriched in slab-derived components.*

tween orogens, it is best estimated by dating foredeep magmatism (Hoffman, 1987). As foredeep magmatism in the New Québec Orogen occurred at 1.88 Ga (Chevé and Machado, 1988), the model may be tested by dating gabbro sills in the Torngat Orogen which are cut by thrusts, but intrude foredeep sediments of the Ramah Group (Hoffman, 1987).

The proposed model does not specify whether the Burwell and Nain provinces were conjoined prior to their collision with the Rae Province or docked successively. The Nagssugtoqidian Orogen of West Greenland is a northwest-dipping suture zone between the Burwell(?) and Nain provinces that records 70 m.y. of subduction prior to collision at about 1.85 Ga (Kalsbeek *et al.*, 1987). Given that the Cumberland batholith is 1.86–1.85 Ga and plutonism in the Torngat Orogen is 1.86–1.83 Ga, the indication is that collisions involving the Rae, Burwell and Nain provinces were nearly simultaneous. After the Burwell and Nain provinces docked, plate convergence jumped to the Ketilidian Orogen at the southern margin of the Nain Province (Kalsbeek and Taylor, 1985).

Conclusions

A testable model is proposed to account for the complicated tectonic configuration and dynamic assembly of northeast Laurentia. The model follows concepts of indentation-extrusion tectonics derived from the Cenozoic evolution of Southeast Asia; it affirms and extends the Superior–Churchill indentation model of Gibb (1983). It provides possible explanations for syn-collisional mafic magmatism in the Labrador Trough, the westward disappearance of the Foxe fold belt on Melville Peninsula, the location and magnitude of the Cumberland batholith on Baffin Island, and the conflicting kinematics of the New Québec and Torngat Orogens. A key test of the model is that inception of basinal sedimentation and associated magmatism in the Foxe–Rinkian belt should be about 1.88 Ga. Another test is that collision-related foredeep magmatism should be younger in the Torngat Orogen than in the New Québec Orogen (*i.e.*, younger than 1.88 Ga). The area of southern Baffin Island between Hudson Strait and Cumberland Sound (within a 200 km radius of the logistical centre at Iqaluit) is identified as perhaps the least adequately known key region in the entire Canadian shield. New geochronological data for the Torngat and Baffin orogens reinforce the epochal importance of geon 18 (1.9–1.8 Ga) for the assembly of Laurentia.

Acknowledgements

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