NAIN-CHURCHILL PROVINCE BOUNDARY: A PRELIMINARY REPORT ON A CROSS-SECTION THROUGH THE HUDSONIAN FRONT IN THE SAGLEK FIORD AREA, NORTHERN LABRADOR

by

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ABSTRACT

The lower Proterozoic Ramah Group occurs as a north trending fold belt between Nachvak and Hebron Fiords in northern Labrador.

This paper presents the results of an investigation of deformation and metamorphism of the Ramah Group and adjacent gneisses in the area between Saglek Fiord and Lake Kiki.

The Ramah Group overlies the junction between the Nain and Churchill Provinces. The Churchill Province, to the west, comprises chiefly Archean rocks reworked, together with Ramah Groups rocks, during the Hudsonian orogeny, whereas Archean gneisses of the Nain Province, to the east, are only slightly affected by the Hudsonian orogeny. Prior to the Hudsonian orogeny, the Archean basement was intruded by a lower Proterozoic east-west trending dike swarm.

The original Hudsonian metamorphic zonation has been significantly telescoped along a system of west-dipping thrust faults that can be recognized in the Churchill as well as the Nain Province. In the Ramah Group, Hudsonian metamorphism varies from lower greenschist to amphibolite facies assemblages. In the Nain Province, Hudsonian effects are recognizable immediately east of the Ramah Group, and occur as retrogression of gneisses and greenschist to lower amphibolite facies metamorphism of lower Proterozoic dikes.

During the Hudsonian orogeny, movements along north-south trending sinistral shear zones caused significant rotation of lower Proterozoic dikes in the Churchill Province. Easterly directed thrusting evidenced by numerous west-dipping mylonite and pseudotachylyte zones succeeded the transcurrent movements and brought granulite over amphibolite facies rocks.

The dominant Hudsonian structures in the Saglek Fiord region are north-northwest trending west-dipping planar fabrics and gently north-northwest plunging mineral lineations. Orthopyroxene with this orientation shows that granulite facies conditions in places accompanied Hudsonian deformation. Significant telescoping of the metamorphic zonation indicates that phases of Hudsonian deformation postdate the peak of metamorphism.

A regional tectonic model is suggested. This is in accord with the pattern of late Archean-Proterozoic deformation in eastern Labrador as well as in southern Greenland.

INTRODUCTION

This report presents some preliminary results of field work across the Nain-Churchill Province boundary in the Saglek area. Work was carried out in two areas (Figure 1): the northern area around Lake Kiki provided information about the Ramah Group and the reworked Archean gneisses immediately west of the Ramah Group, and the southern area, along Saglek Fiord, gave insights into the section through the Ramah Group and gneisses on both sides.

The study aims at establishing the north-south and east-west gradients of Hudsonian metamorphism and deformation as monitored by rocks of the Ramah Group and the adjacent gneisses.

GEOLOGICAL SETTING

The Lower Proterozoic Group is predominantly of sedimentary origin (Morgan, 1975; Knight and Morgan, 1981) and occurs as a north trending fold belt between Nachvak and Hebron Fiords in northern Labrador (Figure 1).

Along its eastern margin, the Ramah Group is in unconformable contact with Archean gneisses of the Nain Province; these gneisses have had a long and complex pre-Ramah history (e.g. Morgan, 1975; Bridgwater et al., 1975; Collerson et al.,

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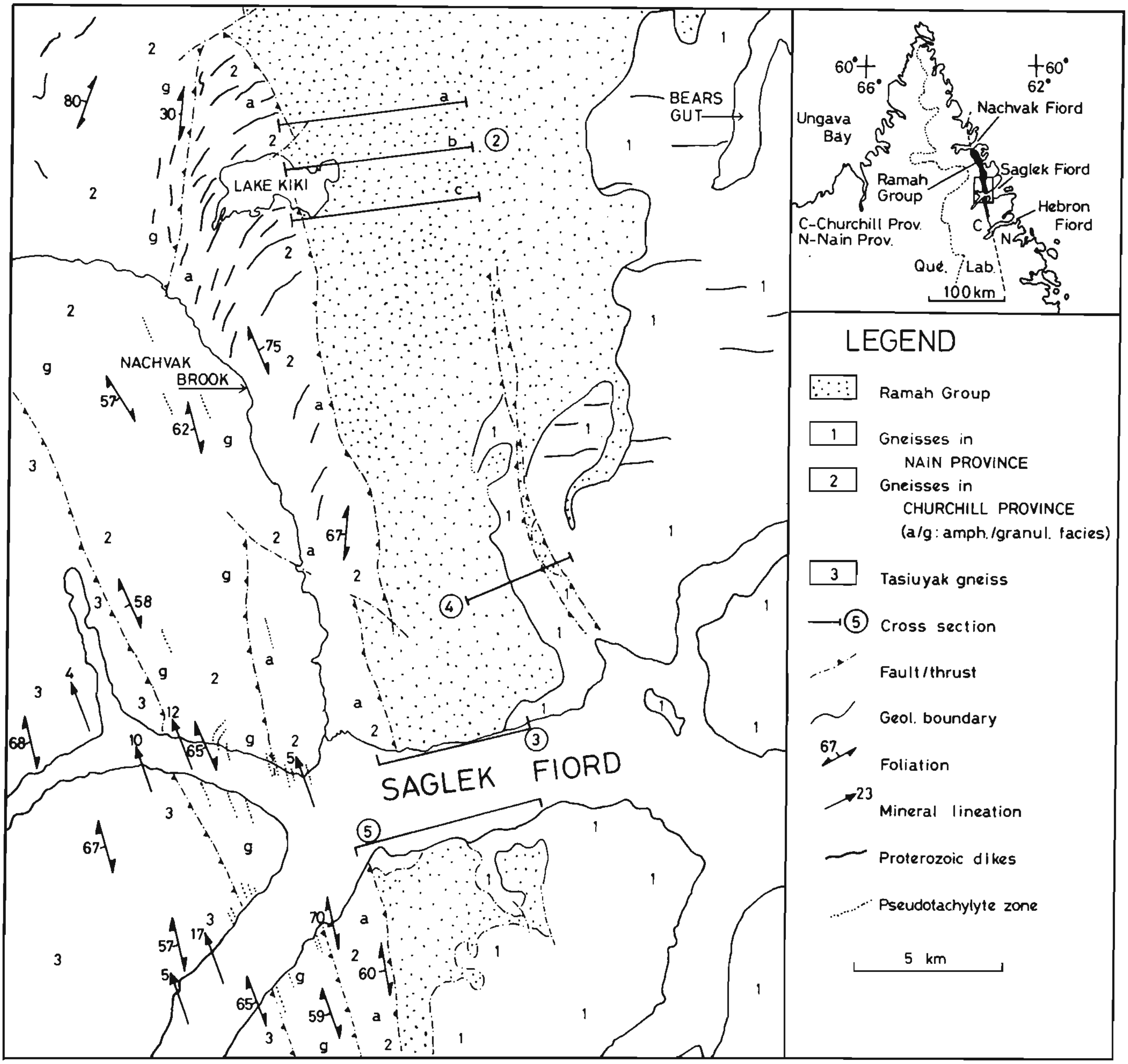

Figure 1: *Index map to the study area with generalized geology. Dikes, pseudotachylytes, etc. are mainly indicated where studied. Numbers refer to Figure number of cross-sections. Incorporates data from Morgan (1975, 1978) and Ryan et al. (1983).*

1976; Collerson and Bridgwater, 1979; Ryan et al., 1983, 1984).

Gneisses west of the Ramah Group belong to the Churchill Province, and are in tectonic contact with the Lower Proterozoic metasediments. Churchill Province gneisses are chiefly Archean rocks overprinted and reworked during the Hudsonian orogeny. The Ramah Group was variably deformed and metamorphosed during the Hudsonian, and increasing metamorphism and structural complexity have been reported from east to west and from north to south (Morgan, 1975; Ryan et al., 1983, 1984; Mengel, 1984).

DESCRIPTION OF ROCK UNITS

Nain Province, east of the Ramah Group

The Archean basement comprises a complex unit predominantly composed of banded quartzofeldspathic gneisses of tonalitic to granodioritic composition, and includes remnants of two supracrustal sequences and a number of discrete plutonic units. The grade of metamorphism is upper amphibolite to granulite facies. The basement gneisses are intruded by a predominantly east-west trending Early Proterozoic dike swarm dated at 2300-2400 Ma (Fahrig, 1970; Taylor, 1974). During the Hudsonian Orogeny, the dikes in the westernmost part of the Nain Province were converted to amphibolites, but discordances are preserved.

The unconformity at the base of the Ramah Group is marked by a regolith (average thickness 1-8 m, maximum 12 m; Knight and Morgan, 1981). In the regolith feldspars from the Archean gneisses are thoroughly altered to greenish gray clay minerals, whereas quartz, although slightly bleached, is otherwise unaltered. Structures in the regolith perfectly outline the original gneissic layering.

Where the Ramah/basement contact has not been reactivated by thrusting, the main cleavage in the Ramah rocks can be traced without interruption into the regolith. However, thrusting has obliterated the regolith in many places (e.g. south of Saglek Fiord; Morgan, 1975; Ryan et al., 1983; Mengel, 1984).

Churchill Province, west of Ramah Group

Gneisses of the Churchill Province are comparable to those of the Nain Province, but have experienced additional metamorphism and deformation during the Hudsonian orogeny. Archean structures dominate gneisses immediately west of the Ramah Group, but farther west the north-northwest oriented 'Hudsonian trend' gradually obliterates all earlier fabrics. South of Saglek Fiord, however, all gneisses west of the Ramah Group have strong Hudsonian fabrics, and the gradual transition observed farther north is not seen. Gneisses west of the Ramah Group (marked 2a on Figure 1) underwent Hudsonian amphibolite facies metamorphism, but still contain relics of earlier (Archean) granulite-facies assemblages. Hudsonian amphibolite-facies gneisses are separated from Hudsonian granulite-facies gneisses further west (2g on Figure 1) by a major north-northwest trending west-dipping thrust fault (e.g. just west of Lake Kiki, Figure 1).

North-south trending, west-dipping mylonite zones and networks of pseudotachylyte veins occur throughout the gneisses in the traversed part of the Churchill Province. Along the north shore of Saglek Fiord, the pseudotachylyte/ mylonite zone separating granulite from amphibolite facies gneisses is at least 100 m thick, and zones of comparable thickness and orientation occur further west towards and within unit 3 (the Tasiuyak gneiss, see Figure 1). Similar zones occur south of Saglek Fiord (B. Ryan, personal communication), and are shown on Figure 1.

Tasiuyak gneiss

The Tasiuyak gneiss, named by Wardle (1983), is a pervasively lineated quartzofeldspathic garnet-biotite (± sillimanite, ± graphite) gneiss with highly attenuated quartz stringers, locally seen to be folded in millimetre-scale isoclinal folds. Pre-, syn-, and postkinematic garnet occur, and cordierite has been observed locally in hand specimen. The Tasiuyak gneiss contains layers, in some places isoclinally folded, of rusty metasediments and garnet-bearing mafic and ultramafic granulites (Wardle, 1983, 1984; Ryan et al., 1983, 1984).

Leucosomes, which define the prominent linear microstructures in the rock, are tonalitic to granodioritic in composition. The origin of the unit is somewhat enigmatic; Wardle (1983) considers it to be a diatexite, perhaps combined with thorough leucogranite injection, of an aluminous Archean sedimentary protolith. Ryan et al. (1983, 1984) suggest a similar origin, and report evidence of Tasiuyak gneiss intruding neighboring rocks in support of extensive anatexis within the unit.

Ramah Group

The lower four of the six formations constituting the Ramah Group (Morgan, 1975; Knight and Morgan, 1981) are represented in the mapped areas. Immediately overlying the regolith, the Rowsell Harbour Formation comprises quartzites and minor pelites and dolostones. The Reddick Bight Formation contains characteristic fine grained laminites as well as quartzites, pelites and minor dolostone. These two formations represent shallow shelf sedimentation, whereas black graphitic and pyritiferous shales of the overlying Nullataktok Formation are interpreted to indicate rapid subsidence with subsequent deep-water sedimentation. In the area north-east of Lake Kiki, dolomitic rocks of the Warspite Formation occur. The members of this formation are deepwater fan deposits derived from a silicic/carbonate shelf environment.

The lower three formations of the Ramah Group are intruded by diabase sills.

STRUCTURE

Preliminary cross-sections have been constructed in what are considered to be key areas in order to demonstrate the important elements of the structural geology of the Hudsonian front (Figures 2, 3, 4, and 5).

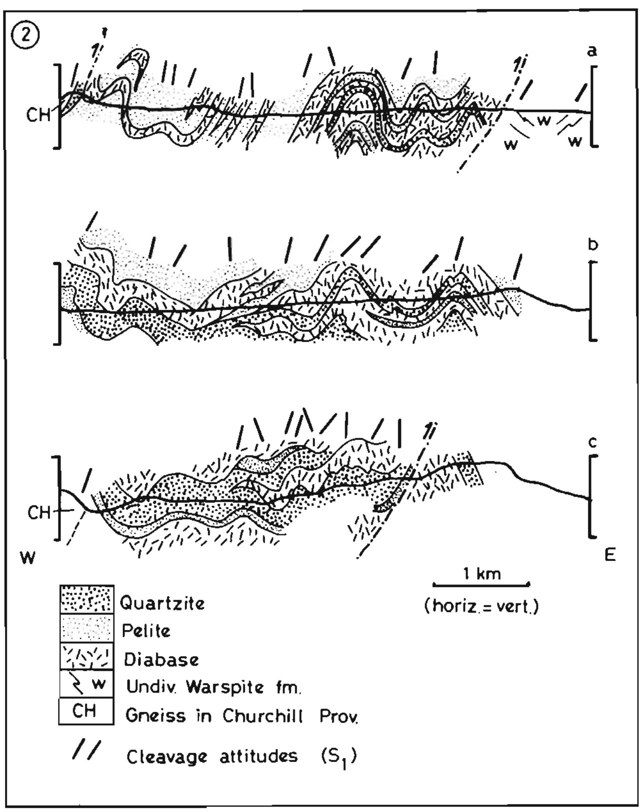

Figure 2: *Cross-sections in Ramah Group east of Lake Kiki. For location of sections, see Figure 1.*

Lake Kiki cross-section: Figure 2 shows three cross-sections in the Ramah Group east of Lake Kiki. Folds are generally open, and fold axes are everywhere gently (10-30°) north to north-northwest plunging with axial planes slightly overturned to the east. S_0 is a compositional or laminar bedding, and S_1 is a slaty to phyllitic cleavage in pelitic rocks and a coarser fracture cleavage in quartz-rich rocks and diabase sills. S_0-S_1 relationships are generally well preserved, and only rarely is S_0 obliterated.

Younging criteria (cross-bedding) indicate that all units are the right way up. These cross-sections show, as also noted by Morgan (1975), the radial fanning of cleavage where the more competent diabase sills are involved in folding. Locally, the effects of a later deformation episode (D_2 - more or less coaxial with D_1) can be seen as minor crenulations of S_1. Preliminary observations suggest that D_2 is better developed in the western part of the Ramah Group. The transgressive nature and frequent wedging-out of the diabase sills is also evident from the cross-sections. These characteristics, combined with shallow-plunging fold axes and gently rolling topography, give a complex outcrop pattern in map view. Towards the western contact, folds in the Ramah Group become more overturned to the east, and more asymmetrical (Figure 2, sections a and b). This is probably caused by Churchill gneisses being thrust eastwards over Ramah Group rocks.

Northern side of Saglek Fiord cross-section: This section (Figure 3), along the north shore of Saglek Fiord, represents a superbly exposed cut through both the Ramah Group and the stratigraphically underlying gneisses. Ramah Group rocks are gently folded in open folds and face upward everywhere. East-directed thrusting is evident in several places. In the central part of the section adjacent east- and west-dipping thrusts (backthrusts) combine to form a prominent 'pop-up' structure. In the eastern part, the boundary between the Ramah Group and the gneisses of the Nain Province is gently dipping and represented by a well-preserved regolith.

In the west, however, the boundary between the Ramah Group and the gneisses of the Churchill Province is vertical to steeply east-dipping, and the regolith is not observed. The orientation of this boundary could have resulted from folding related to east-directed thrusting, or could be the site of a reverse fault with limited displacement. The latter suggestion is favored because the corresponding contact south of Saglek Fiord is a back-thrust, based on observations of asymmetric folds and truncated structures (see below).

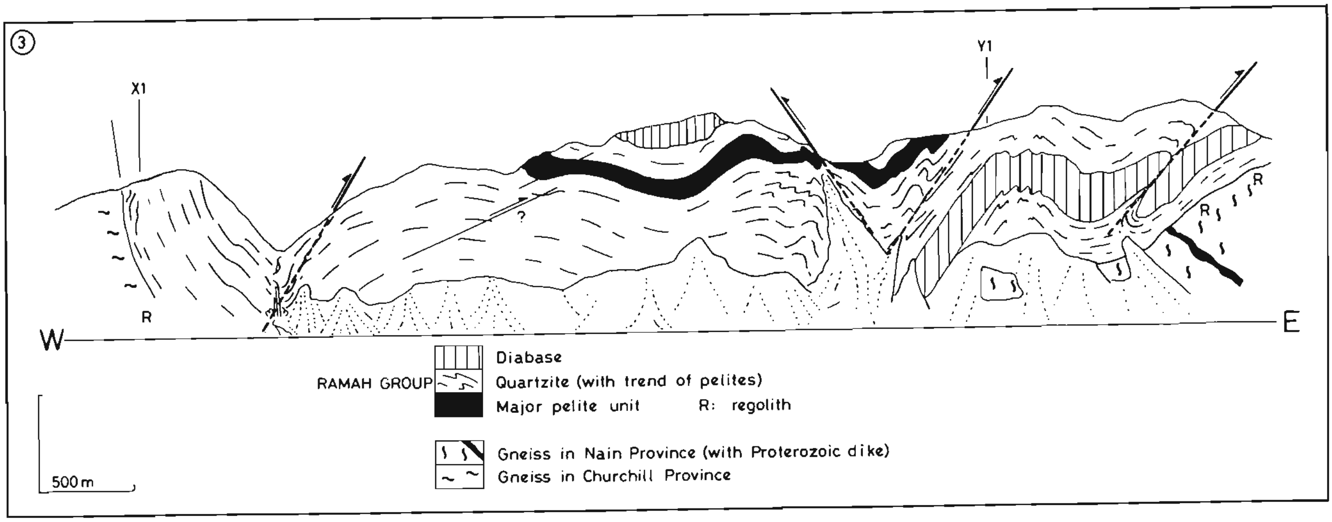

Figure 3: *Schematic cross/cliff-section in Ramah Group and adjacent gneisses along the north shore of Saglek Fiord, based on observations from the fiord and visits to accessible outcrops. Scale approximate. X1 and Y1 are reference points for comparison with Figure 5.*

A certain amount of backthrusting is also considered necessary to explain the fanning of cleavage observed in the Ramah Group. S_1 dips eastward in the western part of Figure 3 and westward in the eastern part. East of Figure 3 (see also Figure 4a), the fan swings back to an easterly dip. Backthrusting is also thought to be responsible for this local fanning (see discussion below).

Figure 3 also demonstrates the different rheological behaviour during deformation of competent diabase sills as opposed to less competent pelites. Diabase responds to compressive stress by large scale open folding and faulting, whereas pelites become more highly contorted and thoroughly folded in smaller scale open to tight folds, and locally exhibit considerable thickening in axial zones. The style of folding is thus dominantly controlled by the more competent units.

Easterly Ramah Group cross-section: The nature of the eastern margin of the Ramah Group is further exemplified in Figure 4 which is a cross-section about 5 km north of Figure 3 (see Figure 1 for location). Here, the Ramah/basement boundary does not mark a zone of dislocation and the steeply west-dipping cleavage in Ramah Group rocks penetrates into the underlying regolith. The boundary between gneisses and the 'outliers' of Ramah Group rocks to the east is not exposed, but considering field observations, the present distribution of rock units can be explained in two ways: in figure 4b, the configuration is interpreted in terms of a folded thrust-surface, and in Figure 4c as a series of synclinal 'pockets' preserved between two thrusts and a backthrust. At present, several observations favor the latter model:

(a) The prominent fanning of the cleavage is more likely related to the various thrusts than to a single fold phase.

(b) If folding of a thrust-surface was involved, one would expect to find evidence of fabrics related to the thrusting as well as to the subsequent folding. However, this is not the case and, instead, very simple S_0-S_1 relationships and a well-preserved regolith are preserved.

(c) Extensions of what appear to be the faults/thrusts suggested in Figure 4a have been observed both north (10-15 km) and south (2-3 km) of the section (Morgan, 1978).

(d) Possible thrusts occur to the east in Archean gneisses in the Nain Province (B. Ryan, A. Nutman; personal communication).

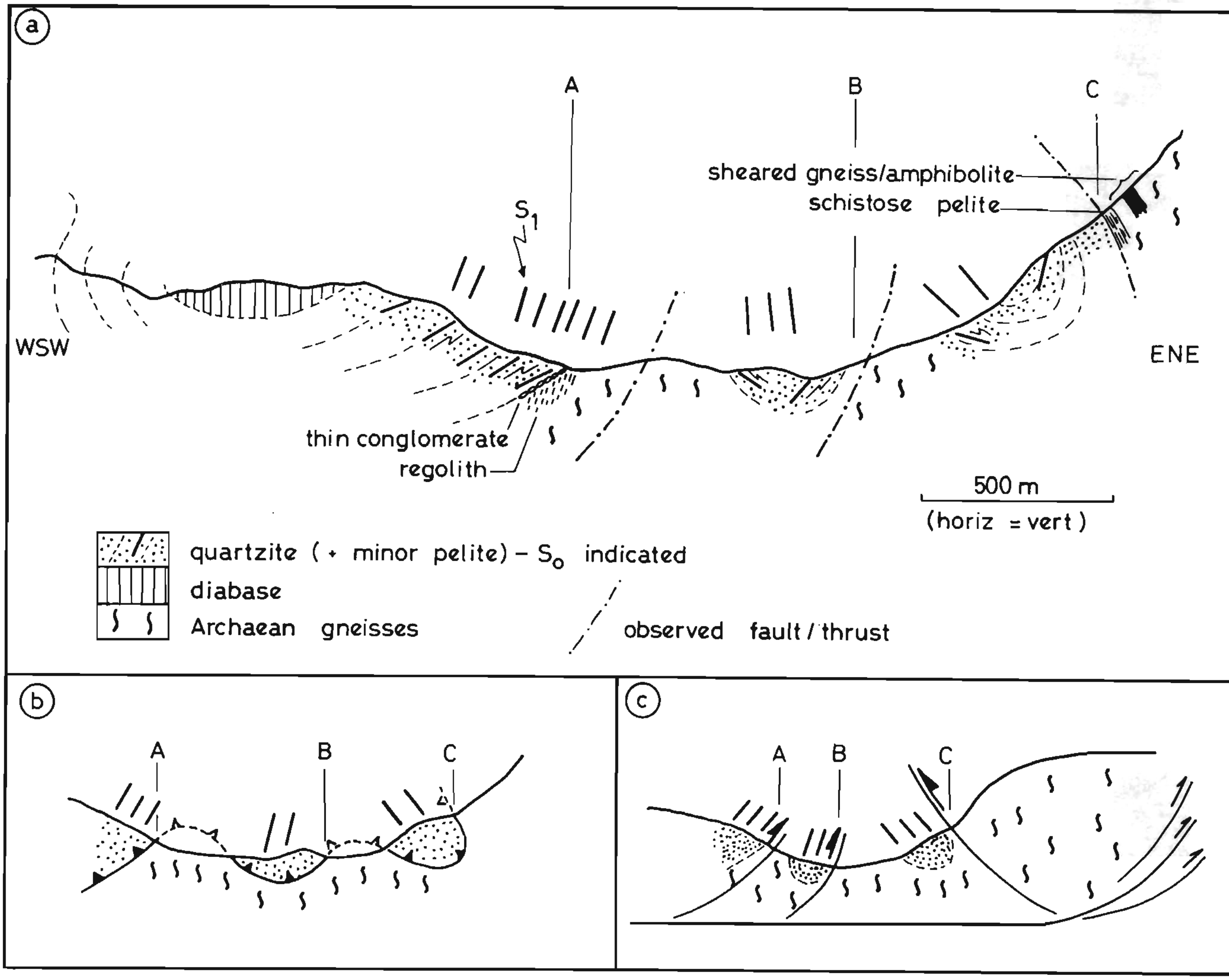

Figure 4: *(4a): Cross-section in the eastern Ramah Group and underlying Archean gneisses.*
(4b): Schematic interpretation of (4a) in terms of a folded thrust-surface.
(4c): Schematic interpretation of (4a) in terms of a combination of thrusts and backthrusts.
(because A, B and C occur in all 3 figures) A, B, and C are reference points.

South side of Saglek Fiord cross-section: The section along the south shore of Saglek Fiord (Figure 5) shows a slightly different pattern from that on the north shore. In this section, only a few east-directed, west-dipping thrusts are seen, whereas backthrusts of the opposite sense are more common.

Assuming a generally compressive tectonic regime created by east-directed forces, these backthrusts probably formed in response to large stress build-ups in the gneisses east of the Ramah Group. A number of less conspicuous west-dipping thrusts with minor displacements may well occur in the Ramah Group, as indicated by mapping further south of Saglek Fiord (Mengel, 1984), and these may together account for significant shortening.

The westernmost thrust fault is not fully understood at present. The distribution of rock units indicates a normal fault with 'west-side-down' movement, but asymmetric folds suggest the opposite sense of movement, which would be compatible with east-directed thrusting. Normal faulting, on the other hand, should be associated with extension in an east-west direction, for which no evidence has been encountered yet. Alternatively, the Ramah Group rocks

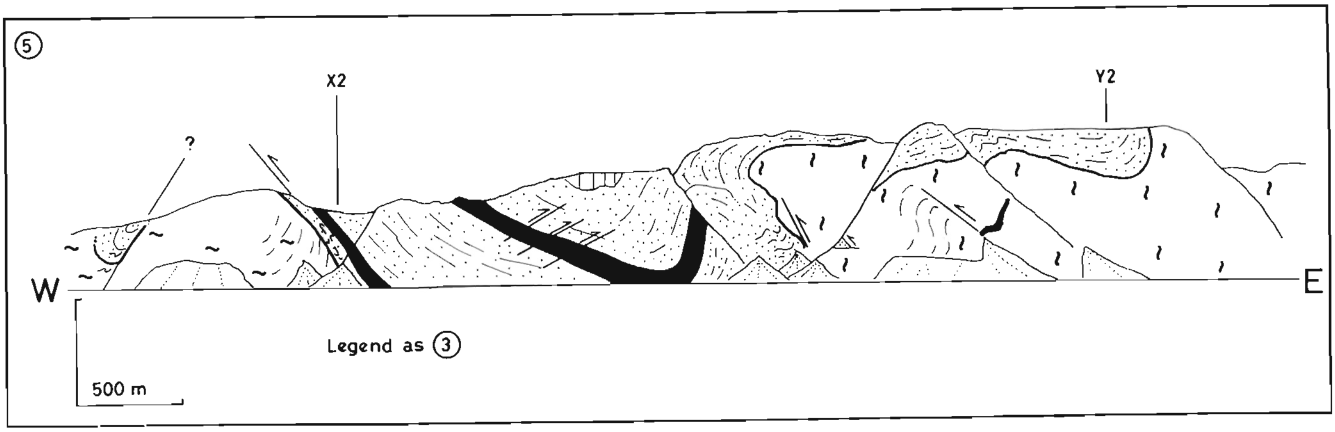

Figure 5: *Schematic cross/cliff-section of Ramah Group and adjacent gneisses along south shore of Saglek Fiord. East and west have been inverted for ease of comparison with other sections. Based on observations from the fiord and visits to outcrops along the shore. Section drawn from photographs, so in the eastern third the perspective is slightly distorted. What looks like a major basement-cored west-verging fold is a generally west-dipping Ramah/basement boundary. Scale approximate. Legend as Figure 3. X2 and Y2 are reference points for comparison with Figure 3.*

could constitute a synclinal 'pocket' between two thrusts, similar to the configuration shown in Figure 4.

Structural continuity from south to north

The reference points X1 and Y1 in Figure 3 have been extrapolated across Saglek Fiord (X2 and Y2 in Figure 5) along lines parallel to the axial surfaces of large scale folds in the Ramah Group. It is obvious that the distribution of thrusts, backthrusts, anticlines and synclines varies along the length of the Ramah Group. If, furthermore, Figures 3 and 5 are compared with Figure 2, the picture of north-south variations becomes even more evident.

An important consequence of the configuration of thrusts and backthrusts in the above cross-sections is that the entire Ramah Group must be underlain by a basal thrust. Such a thrust, probably located in the basement, is the only way the shortening evidenced by the thrusts seen at the surface, can be geometrically accommodated. The north-south variations are thus a reflection of where and how thrusts cut up-section from the basal thrust (i.e. distribution of ramps in the basement) and of the amount of stress build-up in the gneisses (space problem) giving rise to backthrusting. The amount of displacement on the observed thrusts in the Ramah Group is probably not large, as shown for example by the high degree of lithological continuity. Taking 30% as the shortening necessary for the initiation of cleavage formation, the amount of postdepositional shortening of the Ramah Group must be in the order of 30-50%.

In the gneisses, on the other side, the amount of displacement is harder to assess. The thrust bringing granulite-facies gneisses over amphibolite-facies gneisses could be the site of considerable dislocation.

Structure west of the Ramah Group

The gneisses in the Churchill Province have been examined in detail along sections immediately west of the Ramah Group (1-2 km north of Figure 3). Archean structures are generally overprinted by north to north-northwest trending moderately west-dipping Hudsonian planar fabrics, or are truncated by similarly oriented mylonite zones, shear zones, and brittle/ductile fault zones. Small scale folds have a constant vergence, all indicating easterly directed tectonic transport. Characteristic of these shear zones is a reddish color of the tonalitic/granodioritic gneisses. Proterozoic dikes are converted to amphibolites, and display brittle faulting (dextral offset, looking north) parallel to the shear zones. Towards the Churchill/Ramah contact, Archean linear fabrics change from northwest to southwest plunging, probably reflecting rotation into parallelism with the direction of tectonic transport combined with the brittle conjugate folds mentioned above, suggest that uplift accompanied later stages of Hudsonian deformation. The mineralogy of these later brittle zones indicates greenschist facies conditions, thus suggesting that the kinematic phase postdates the main Hudsonian metamorphism.

Planar and linear fabrics of gneisses in the Churchill Province (especially in units 2g and 3 in Figure 1) are uniform, and are attributed to Hudsonian tectonism. Mineral lineations are everywhere gently north-northwest plunging, and the observation of othopyroxene grains aligned parallel to this direction indicates that granulite facies conditions in places accompanied Hudsonian tectonism. The stability of orthopyroxene by definition indicates granulite facies conditions, but temperature, pressure and fluid activity may have varied siginificantly from Archean to Proterozoic granulite facies metamorphism. The prominent 'Hudsonian trend' is believed to be related to transcurrent movements along the Hudsonian front. The (re)orientation of the Proterozoic dikes provide information on the timing and sense of movement (see below).

PROTEROZOIC DIKES

In the Nain Province, the Proterozoic dike swarm is generally east-west trending (e.g. Morgan, 1975, 1978; Ryan et al., 1983, 1984). Figure 1 shows selected dikes east and west of the Ramah Group. Immediately east of the Ramah Group, the dikes have been affected by Hudsonian metamorphism and deformation, and are converted to amphibolites with a variably developed schistosity. West of the Ramah Group, dikes have a stronger Hudsonian overprint. Within the amphibolite facies gneisses (unit 2a in Figure 1), the dikes are amphibolites and they are rotated into (near) parallelism with the gneissic foliation. Further west in granulite facies gneisses (unit 2g in Figure 1), the dikes are garnet-two pyroxene-bearing mafic granulites.

The thrust fault separating the granulite-facies gneisses from the amphibolite-facies gneisses also records changes in the style of dike deformation. Within the amphibolite-facies block, the dikes are systematically rotated anticlockwise from east-west to north-south orientation as one moves west from the Churchill/Ramah contact (Figure 1). In the granulite facies block, on the other hand, the dikes appear less strongly deformed and reoriented, and discordances are frequently observed. This, together with the prominent subhorizontal lineation of the 'Hudsonian trend', suggests that early sinistral transcurrent movements occurred along the Hudsonian Front, and these were succeeded by thrusting and easterly transport of granulite-facies rocks that were less affected by the earlier transcurrent movements.

METAMORPHISM

Based on field observations, the metamorphic grade in Ramah Group rocks varies only slightly (greenschist to lower amphibolite facies) in the areas studied. Generally, biotite is not present, and quartz and carbonate coexist stably. Chloritoid, sometimes with kyanite, appears in rocks of appropriate composition in both western and eastern parts of the Ramah Group. Higher grade kyanite-bearing schists occur along the western margin. Lithological discontinuities suggest that these units are thrust slices brought up from slightly deeper levels.

West of the Ramah Group, Hudsonian metamorphism increases. Amphibolite facies overprinted Archean granulite-facies assemblages in unit 2a (Figure 1) and further west (unit 2g) granulite-facies conditions prevailed. Thorough syntectonic recrystallization obliterated evidence of the pre-Hudsonian (Archean) mineral assemblages in unit 2g, but considering the overall similarities between the units 2a and 2g, 2g was probably also affected by granulite facies metamorphism in the Archean.

The distance between Hudsonian granulite-facies assemblages in the west and greenschist-facies rocks in the east is less than 8 km (see Figure 1). Movement on the observed thrusts and mylonite zones must have caused substantial telescoping of the original Hudsonian metamorphic zonation. A similar shortening was observed south of Saglek Fiord (Mengel, 1984).

Orthopyroxenes oriented parallel to the Hudsonian linear trend show that granulite-facies conditions accompanied Hudsonian strike-slip deformation, and the telescoped metamorphic zonation suggests that phases of the east-directed thrusting clearly postdated peak metamorphism in the reworked basement.

DISCUSSION

Observations of transcurrent movements and thrusting in the Churchill Province are in excellent agreement with the indentation model of Watterson (1978) to explain the large scale tectonic features of Proterozoic mobile belts of Greenland. This model (Figure 6) explains the distribution of deformation across the Archean/Protero-zoic boundary in Greenland in terms of a rigid 'indenter' pressing north across southern Greenland. As a result, north-south to northeast-southwest trending sinistral shear zones, as well as southeast-directed thrusting, will occur in western Greenland and areas immediately west thereof (e.g. northeastern Labrador).

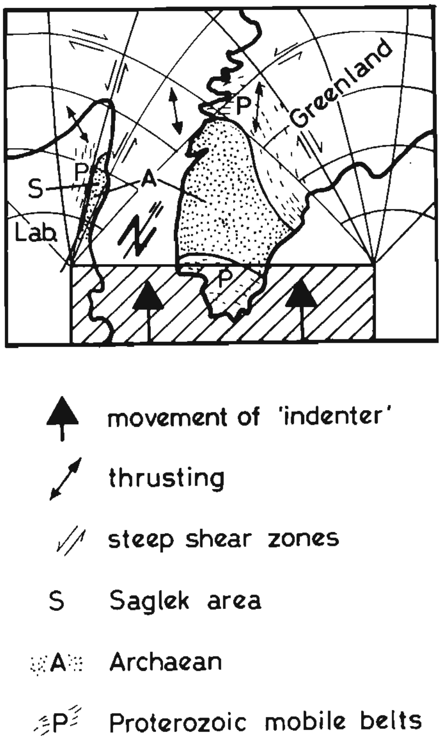

Figure 6: *Indentation model of Watterson (1978) to explain Late Archean-Proterozoic deformation in Greenland. The indenter sets up a large scale stress-system (thin lines) that is predicted to form shear zones and thrusts (arrows indicate sense of shear and direction of thrusting). Location of Labrador with respect to Greenland from Collerson et al. (1976).*

The suggested sinistral transcurrent shear and the east-directed thrusting in the Saglek Fiord area are in accord with the above model, and can be interpreted in terms of collision-type tectonics succeeding the intracratonic deposition of the Ramah Group.

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