New geological developments in the internal zone of Wopmay orogen, District of Mackenzie

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Abstract

The internal zone of Wopmay orogen comprises a large klippe of 2.0-2.55 Ga gneissic rocks, termed Bent gneiss, and 1.90 Ga volcanic and sedimentary cover of the Grant-Akaitcho groups. Rocks of the Grant-Akaitcho groups probably formed near the leading edge of Hottah terrane just prior to the initiation of the Calderian orogeny. The gneissic basement and its cover were tectonically interleaved along west-vergent thrusts during the earliest stages of the Calderian orogeny. They were subsequently emplaced upon Slave craton. Lineations in the klippe and the autochthon indicate that the emplacement of the klippe was oblique dextral. Final Calderian compression resulted in the formation of large northerly-trending folds.

Résumé

La zone interne de l'orogène de Wopmay comprend une large klippe de roches gneissiques de 2,0-2,55 Ga, appelée gneiss de Bent, et une couverture volcanique et sédimentaire de 1,90 Ga des groupes de Grant-Akaitcho. Les roches des groupes de Grant-Akaitcho se sont probablement formées près de la bordure frontale du terrane de Hottah juste avant que s'amorçe l'orogenèse caldérienne. Le socle gneissique et les roches sus-jacentes ont été tectoniquement interfoliés le long de chevauchements à vergence ouest durant les toutes permières étapes de l'orogenèse caldérienne. Ils ont par la suite été mis en place sur le craton des Esclaves. Selon les linéations observées dans la klippe et les roches autochtones, la mise en place de la klippe découle d'un mouvement dextre oblique. La compression caldérienne finale a provoqué la formation d'immenses plis à direction nord.

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INTRODUCTION

During the summer of 1990, two months were spent mapping rocks in the Calder River (86F) map area. The map area includes: (1) Archean rocks of Slave province; (2) rocks of Hottah terrane, interpreted as an exotic terrane that collided with the western margin of Slave craton during the Calderian orogeny (Hildebrand et. al., 1983); (3) rocks of the Akaitcho and Grant groups, formerly interpreted as part of a rift succession deposited on the western margin of Slave craton prior to the Calderian orogeny (Easton, 1980; 1981; Hoffman and Bowring, 1984; but see Bowring and Grotzinger, 1988); (4) plutons of the syn-collisional Hepburn batholith (Lalonde, 1986); and (5) rocks of Great Bear magmatic zone, a post-collisional magmatic arc (Hildebrand et. al., 1986). Previous investigations within the Calder River area are listed in Hildebrand et. al. (1987). The major aims of the project are to unravel the geological evolution of the central Great Bear magmatic zone, the medial zone (Hildebrand et. al., 1990), and the western part of the internal zone of Wopmay orogen. The purpose of this report is to summarize some of the geological results of the year's fieldwork, with particular emphasis on the stratigraphy and structure of the internal zone where nearly all of the work was concentrated. The principal results of the fieldwork are summarized below.

1. Within the medial zone, on the east limb of Eyston anticline (Fig. 1), Archean gneisses and unconformably overlying metasedimentary rocks of the Odjick Formation are exposed beneath an easterly-vergent thrust fault. We have dated rocks above the thrust in three places. In one case orthogneisses yield a U-Pb zircon age of about 2.0 Ga (Hildebrand, et. al., 1990) and the other two samples are about 2.5 Ga. The assemblage of gneisses above the thrust is termed Bent gneiss. It forms the trailing edge of a klippe (Turmoil klippe) that cores a regional syncline, known as Robb River syncline (Fig. 1), between the western limb of Exmouth anticline and Eyston anticline.

2. Within Turmoil klippe, volcanic and sedimentary rocks of the Akaitcho and Grant groups sit unconformably upon Bent gneiss. Sequences of rocks identical to those of the type Grant Group (Easton, 1981) within the medial zone were traced laterally into rocks of the Akaitcho Group, indicating that the two groups were deposited within the same basin. The basin was apparently located on the leading edge of Hottah terrane.

3. Although the internal structure of Turmoil klippe is complex and incompletely resolved, we have identified a number of westerly-vergent thrust faults along which the basement and cover are interleaved. The faults were folded about northwesterly-trending axes (F_2) during emplacement of Turmoil klippe; subsequently refolded about northerly-trending axes (F_3) during terminal stages of Calderian shortening; and still later, broadly-folded about an east-northeast trend (F_4) by an apparently unrelated deformational event.

4. Removal of the effects of F_3 and F_4 folds reveals subhorizontal, northeasterly-trending stretching lineations within Proterozoic rocks of the autochthon of Exmouth anticline and rocks of the Turmoil klippe. The lineation was likely generated as Turmoil klippe was transported northeastward over Slave craton and suggests a dextral transpressive emplacement.

5. Some possible Hepburn plutons within the thrust stack have S_1 Calderian fabrics, and others, such as the Robb, are little-deformed. This, coupled with isotopic evidence which indicates that most Hepburn plutons were derived from west of Slave craton (Bowring and Podosek, 1989; Housh et. al., 1989), suggest that the westward-vergent thrusts, F_1, and S_1 formed prior to the emplacement of Turmoil klippe on Slave craton.

EYSTON ANTICLINE: POSSIBLE AUTOCHTHON WITHIN THE MEDIAL ZONE

St-Onge et. al. (1984) recognized that within the internal zone, Archean rocks and their autochthonous Proterozoic sedimentary cover are exposed beneath a basal décollement in a series of large-scale northerly-trending folds (Exmouth anticline, Acasta syncline, Scotstoun anticline, and Carousel anticline-Figure 1). They also argued that movement on the décollement predated the folding because the fault is folded. King (1986) and St-Onge and King (1987) argued that because the fold axes of the large-scale folds are coaxial with Calderian folds, and because the traces of mineral isograds both transect and are folded by the folds, that the folding was a late result of progressive deformation during the Calderian orogeny. Consequently, they divided the Calderian orogeny into two stages: D_1, represented by northerly-trending thrusts and related folds; and D_2, represented by the relatively large-scale basement-involved folds.

In the medial zone, on the western limb of a large anticline, Hildebrand et. al. (1990) discovered relationships similar to those exposed on the large-scale folds of western Slave craton, in that an easterly-vergent thrust fault structurally superposes high-grade gneiss on Proterozoic metasedimentary rocks which themselves sit unconformably on Archean gneiss. During the 1990 season we traced the triad another 15 km northward (Fig. 1).

The section of Proterozoic metasedimentary rocks exposed beneath the thrust fault contains quartzite, garnet amphibolite, carbonate, conglomerate, and semipelite. The presence of a 10 m interval of white quartzite suggests that the section might be correlative with the lower Odjick Formation. Overall, the lithologies are similar to those present beneath the décollement on the western side of Exmouth anticline. The metasedimentary rocks are folded about axial planes that dip easterly at 50°-70°, the same inclination as bedding, the overlying thrust fault and gneissic layering in the rocks above it. Additionally, the folds have an asymmetry suggesting easterly-directed topside-over-bottom movement.

Whereas the rocks of the structurally overlying plate are continuous eastward to Exmouth anticline (Fig. 1), the Archean and its cover may be continuous with Slave craton. If they are structurally continuous, beneath Robb River syncline, with the autochthonous core of Exmouth anticline, then Eyston anticline represents the known western limit of Slave craton.

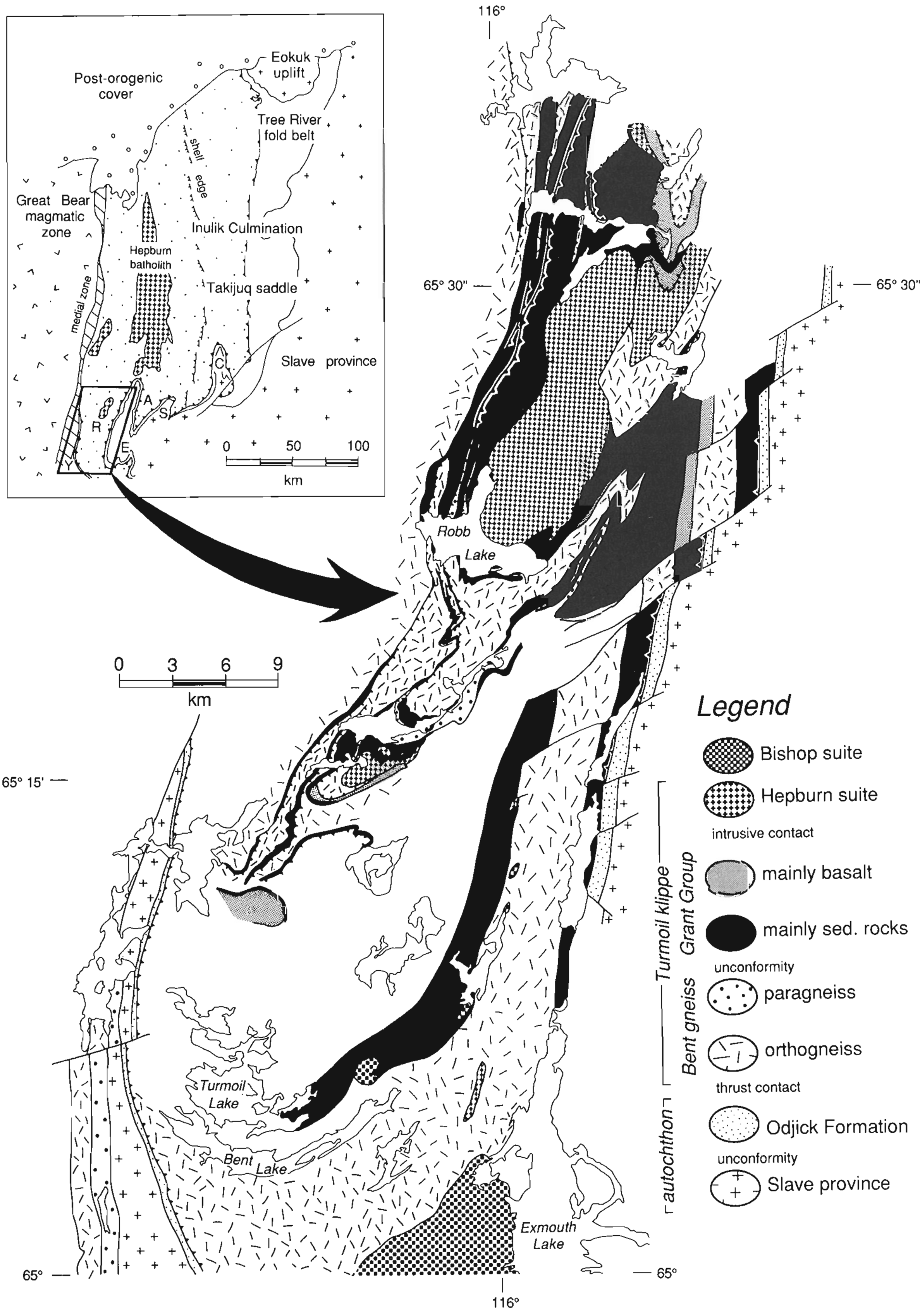

Figure 1. Geological map of the southeastern Calder River map area. Inset map after Hoffman et. al. (1988) showing location of map and regional geology. A = Acasta syncline; E = Exmouth anticline; C = Carousel anticline; S = Scotstoun anticline; Y = Eyston anticline; R = Robb River syncline.

TURMOIL KLIPPE

Structurally overlying the Proterozoic metasedimentary rocks of Eyston anticline are gneissic rocks previously interpreted, on the basis of 2.0 Ga U-Pb zircon ages, to be part of Hottah terrane (Hildebrand et. al., 1990); however, preliminary geochronological results on samples collected in 1990 indicate that parts of the complex have U-Pb zircon ages around 2.5 Ga. The rocks occupy the core of Robb River syncline (Fig. 1) and, as they are structurally isolated from the main part of Hottah terrane, constitute a klippe, here termed Turmoil klippe after outcrops in the Turmoil Lake area (Fig. 1). The gneisses within Turmoil klippe are named Bent gneiss after superb outcrops in the Bent Lake area (Fig. 1). Overall, basement and cover units as mapped during 1990 do not correspond to those of St-Onge et. al. (in press)

Bent gneiss comprises mainly tonalitic orthogneiss with subordinate amounts of granitic to dioritic orthogneiss, paragneiss, and amphibolite. The tonalitic gneisses are equigranular to plagioclase-porphyroclastic, biotite-bearing rocks. They appear to be intruded by a variety of porphyritic and even-grained, but gneissic, biotite and hornblende-biotite granitoid rocks ranging from diorite to granite. In general, the granitic rocks are porphyritic and the dioritic rocks more even-grained. Metasedimentary rocks occur mainly as metre to ten-metre-wide enclaves in the tonalitic gneiss. Amphibolite occurs as lozenges within the gneisses and probably represents torn-apart mafic dykes, although in some cases there are so many lozenges and blobs of amphibolite that magma mingling is a possibility. Additionally, there are large coarse grained meta-gabbroic sills, some of which are unconformably overlain by sedimentary rocks of Grant Group. The sills are heterogeneously strained with 0.5-2.0 cm wide zones of high strain.

Supracrustal rocks

Easton (personal communication, 1982) thought that within the Hepburn Lake map area, rocks of Akaitcho Group sat unconformably on granitic basement. The granites were subsequently dated (Bowring, 1984) to be about 2.51 Ga and King et. al. (1987) subsequently confirmed the unconformable relationship. During the 1990 field season we discovered that rocks of Akaitcho and Grant groups sit unconformably on Bent gneiss (Fig. 2). This is a major result of the summer's work because it further defines the type and age of basement to these interesting, but problematic, rocks. It is clear from Nd and Pb isotopes (Bowring and Podosek, 1989; Housh et. al., 1989) and dating of ash-beds within Kilohigok basin (Bowring and Grotzinger, 1988) that rocks of the two groups are exotic with respect to Coronation margin.

Rocks of Akaitcho Group were mapped in the northern and eastern part of the area, where they are continuous with those of the type area (Easton, 1980) and a distinctive sequence of rocks, termed Grant Group (Easton, 1981), was mapped in the southern and western part of the internal zone. However, rocks of the two groups are present within the same thrust slices and are lateral facies equivalents. For simplicity we use the term Grant Group to refer to the 1.90 Ga (Bowring, 1984) cover sequence that sits unconformably on Bent gneiss.

Grant Group

The unconformity with Bent gneiss is well-exposed in numerous places. In the southern part of the area a few metres of pyritic semipelite typically sit directly on Bent gneiss or are separated from it by 10-15 cm of grus. Relief on the unconformity is typically less than 1 m. Deformation precludes any accurate estimate of thicknesses for stratigraphic units and top determinations are very sparse. However, abundant outcrops of the basal unconformity allowed us to determine local facing directions. Overlying the semipelite are 3-20 m of grey to buff weathering carbonate. The carbonate preserves tight reclined folds which are difficult to see in other lithologies. In general, the folds are asymmetric with a sense of topside-over-bottom movement to the west. Above the carbonate are pillow basalts or medium-grained psammites. The metabasalts are mostly aphyric and typically strongly deformed, although nearly pristine pillows occur in a few places. The metabasalts are intruded by abundant metagabbroic sills.

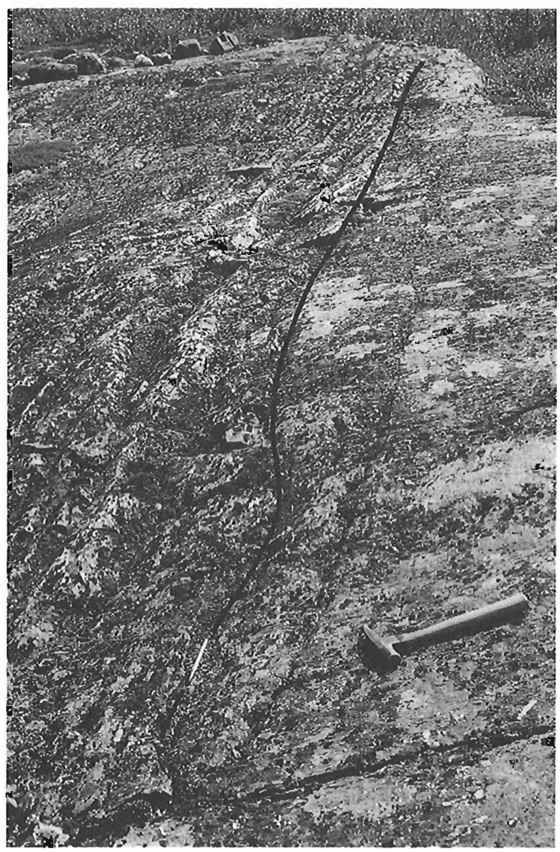

Figure 2. Photograph showing well-bedded sedimentary rocks of the Grant Group sitting unconformably on Bent gneiss south of Robb Lake. Hammer handle lies in the plane of foliation within Bent gneiss. Trace of unconformity shown by black line.

The psammites range from quartzite to arkose and are exposed in only one thrust slice. They are well-bedded rocks with bed thicknesses ranging from 15 cm to 1 m.

Farther north, the sections are different in that they contain greater percentages of sedimentary and siliceous volcanic rocks. Immediately above an unconformity of little relief is a thick fining-upward section of sandstone. Typically the sandstone is overlain by rhyolitic or basaltic lava flows. The entire sequence is intruded by gabbroic sills and siliceous porphyries. The gabbroic sills are coarse grained rocks that typically form high-standing ridges.

Locally, such as within a thin strip along the western side of Exmouth anticline (Fig. 1), possible rocks of Grant Group are more metamorphosed than elsewhere. Sillimanite porphyroblasts and/or granitic melt pods are common. As the contact with Bent gneiss was not exposed we were unable to be sure that rocks within the strip are cover but northeast of Robb Lake metasedimentary rocks of the Grant Group can be traced to higher grades toward the northeast. Accordingly, we tentatively include rocks of the strip within Grant Group.

STRUCTURE

The oldest post-depositional structures seen in the internal zone are brittle-ductile thrusts within Turmoil klippe. The thrust-sheets are thin, very continuous along strike, and contain both crystalline basement and cover. Locally, ramps (Fig. 3) with higher cut-off angles occur. The thrust faults truncate penetrative fabrics in the basement (Fig. 2) and have no apparent associated mineral lineation. Reclined, tight to isoclinal folds (F_1) of bedding and a sub-horizontal axial-planar foliation (S_1) are particularly well-developed in the supracrustal rocks. Many of the F_1 folds are outcrop-scale and are distinctly asymmetrical, with an asymmetry suggesting topside-over-bottom movement to the west. Thus, we infer a westward vergence for the thrust faults. The occurrence of thin thrust sheets containing both crystalline basement and cover is interesting but by no means unique, for such structures are known from the Scandinavian Caledonides (Björklund, 1985) and the Cape Smith belt (Lucas, 1989).

A southwest-trending mineral lineation (L_2) is well-developed in allochthonous and autochthonous cover rocks along the west side of Exmouth anticline. It plunges 30°-60° on steeply-dipping to vertical bedding and cleavage planes. Where, bedding and/or cleavage dip eastward, such as on the western limb of Robb River syncline, the lineation trends and plunges southeast. The brittle thrusts and S_1 are tightly to isoclinally folded (F_2) about axes that trend northeast and plunge moderately, perpendicular to L_2 (Fig. 3). A well-developed crenulation cleavage (S_2), axial planar to F_2, is present in mica-rich units.

The temporal relationship between L_2 and F_2 was not satisfactorily resolved in the field but as the two linear elements are at a high angle to one another it is likely that the two were generated by the same deformational event. Furthermore, as L_2 are clearly folded by F_3 folds and plot on a great circle (Fig. 4), they must have been dispersed from a discrete cluster by the F_3 folds. This indicates that they were not refolded by F_2, supporting the argument that F_2 and L_2 were generated during the same deformational event. When the effects of F_3 folds are removed the lineation is subhorizontal and northeasterly-trending on the autochthon of Exmouth anticline; therefore, the original orientation of the cluster was probably the same. This suggests that emplacement of Turmoil klippe onto Slave province was likely dextral oblique.

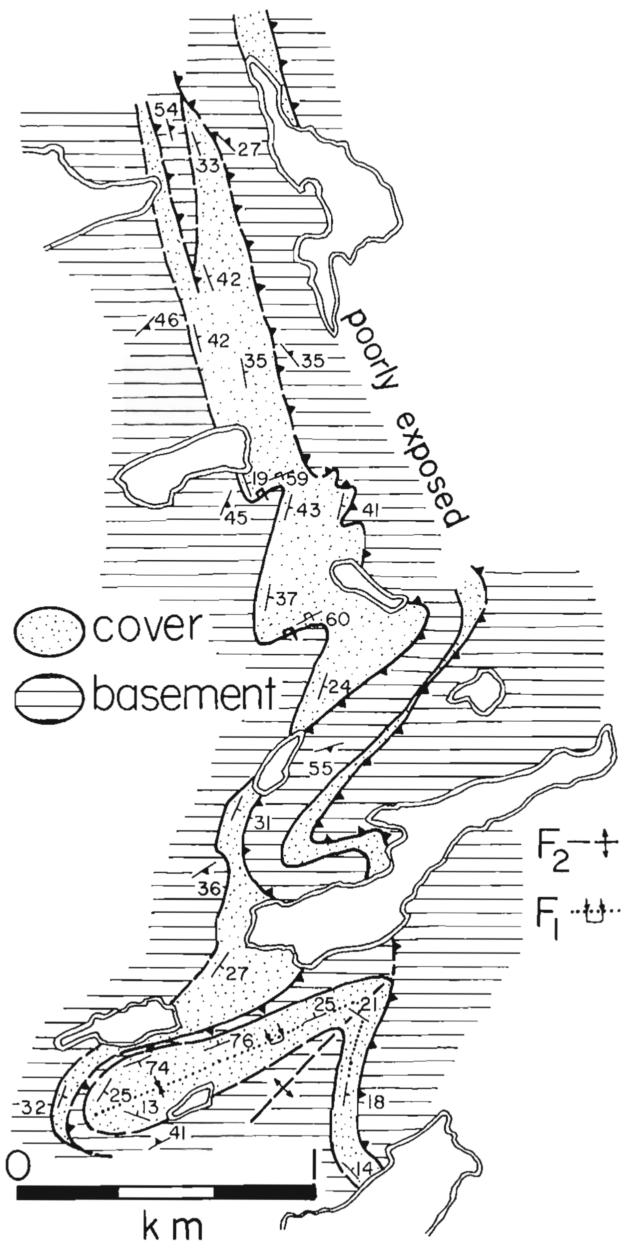

Figure 3. Detailed geological map showing geology south of west end of Robb Lake. Note the thin imbricate thrust sheets involving Bent gneiss and Grant Group cover. One F_1 and one F_2 fold axis are indicated.

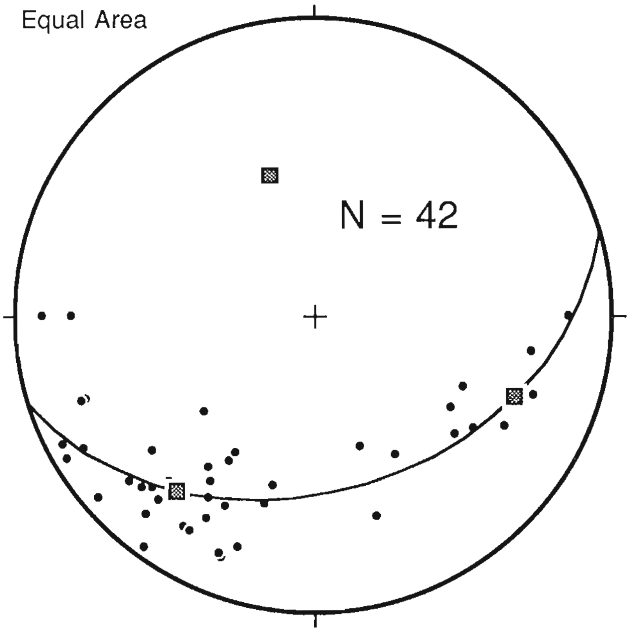

Figure 4. Equal area lower hemisphere stereonet plot of L_2 lineations collected from Robb River syncline.

All of the above structures are folded by northerly-trending folds (F_3) that involve Archean basement of the autochthon. They are thick-skinned folds interpreted to have been generated during the latest stages of the Calderian orogeny (King, 1986; Hoffman et. al., 1988). Examples include Exmouth anticline and Robb River syncline. They have wavelengths of 10-30 km and amplitudes of 10-15 km. The lower hemisphere plot of L_2 (Figure 4), collected from Robb River syncline north of the west-southwest trending axis of even younger F_4 folds, clearly plot on a great circle, indicating that F_3 folds are similar in their geometrical form (Ramsay, 1967). This makes any estimate of the amount of shortening impossible as constant bed length cannot be assumed. The indicated axis for the F_3 fold is steeper and more westerly than expected from the trend of contacts. This is probably because the lineations used for the plot were collected on the northern limb of an F_4 anticline that plunges westerly, thus, slightly rotating and steepening the axis. Counterclockwise rotation by right-lateral faults of the area could also account for the rotation, but would not cause the steepening of the axis.

HEPBURN INTRUSIVE SUITE

We mapped several plutons that are possibly members of Hepburn intrusive suite (Lalonde, 1986) and they range from strongly deformed to non-deformed. The most deformed, and probably the oldest, plutons are protomylonitic megacrystic granites containing potassium feldspar phenocrysts 5 to 10 cm long. Biotite is the sole ferromagnesian mineral. At least one of the deformed granitic plutons appears to intrude Bent gneiss, but the pluton is not dated.

A large pluton located on the north side of Robb Lake is a non-deformed to slightly-foliated biotite granite. It also contains 5-10 cm long potassium feldspar phenocrysts and is notable because it intrudes deformed Hepburn plutons, Bent gneiss with a folded Calderian S_1 fabric, and rocks of Grant Group. Because isotopic data indicate that the magmas for Hepburn intrusive suite were generated through interaction of mantle-derived basalt with crustal melts derived from isotopically homogeneous crust in the age range 2.0-2.4 Ga, not the isotopically heterogeneous Archean of Slave craton (Bowring and Podosek, 1989; Housh et. al., 1989), and because no member of the suite is known to intrude autochthonous rocks of Slave craton despite careful mapping (St-Onge et. al., 1984), it is generally assumed that the plutons were emplaced outboard of the western edge of Slave craton and transported on top of it. Accordingly, the westward-vergent thrusts, F_1, and S_1 formed prior to the intrusion of the Robb pluton, and were subsequently transported onto Slave craton, as was the Robb pluton, within Turmoil allochthon.

DISCUSSION

A first order problem that arises from the field work and preliminary U-Pb zircon dating is the significance of the circa 2.5 Ga rocks within Bent gneiss. There are now a large number of U-Pb zircon ages in the internal zone that are between 2.5 and 2.58 Ga (Bowring, 1984; unpublished data). They form a discrete cluster of ages that is younger than most known rocks of Slave province (Hoffman, 1989). As they are overlain by rocks dated at 1.90 Ga they were unlikely to have been in contact with Slave craton at that time for passive margin rocks of Coronation Supergroup were being deposited then. It is interesting that west of the medial zone, Hottah terrane comprises mostly rocks in the age range 2.0-1.9 Ga with no rocks as old as 2.5 Ga, whereas Turmoil klippe may be dominated by rocks about 2.5 Ga and contain few rocks in the age range 2.0-1.9 Ga. The obvious question is whether rocks of Turmoil klippe are part of Hottah terrane, were once part of Slave craton, or represent something entirely different such as a composite terrane. Whatever their ultimate origin, it is likely that rocks of Turmoil klippe were not in contact with Coronation margin between 1.967-1.90 Ga and probably were part of Hottah terrane during the Calderian orogeny.

Given that rocks of Grant Group are not products of initial rifting on Slave craton, what is their tectonic setting? We know that the upper parts of the sequence erupted just prior to the Calderian orogeny at about 1.90 Ga, but do not know the age of initiation of magmatism or sedimentation. Since the sequence constitutes the easternmost parts of Hottah plate, and is not compositionally like an arc sequence, it is reasonable to assume that it was deposited trenchward of any arc on that plate. If so, rocks of Grant Group were deposited near the leading edge of Hottah terrane. Since forearc regions are generally considered to be regions of low heat flow, a mechanism is needed to account for the magmatism, not only of Grant Group, but also of Hepburn intrusive suite (Hoffman et. al., 1988), which starts as Grant magmatism wanes (Bowring, 1984). Two modern analogues exist. Ridge subduction (DeLong and Fox, 1977), particularly in a small basin such as in the Woodlark Basin, where subduction of the Woodlark spreading ridge beneath the New Georgian forearc causes abundant magmatism, yet just precedes collision of the Australia-India plate with the Solomon arc (Perfit et. al., 1987; Johnson et. al., 1987). In fact, many cases of forearc magmatism generated by ridge subduction are known and include cases in Japan (Miyake, 1985; Hibbard and Karig, 1990), the Aleutians (Hill et. al., 1981), and Chile (Forsyth and Nelson, 1985).

The second analogue generates its magmatism by asthenospheric upwelling concomitant with roll-back of the lower plate such as in the Marianas, Japan and New Zealand. Asthenospheric upwelling may drive the roll-back (Tatsumi et. al., 1989) or be a passive response to roll-back induced by subduction of progressively older, hence denser, oceanic lithosphere. Whatever mechanism is invoked to generate the Grant-Hepburn magmatism it apparently occurred near the leading edge of Hottah terrane just prior to the start of the Calderian orogeny.

EVOLUTION

The overall evolution of the internal zone of Wopmay orogen is as follows.

1. Eruption and deposition of Grant Group on Bent gneiss. Based on distribution and comparison of chemical analyses the most likely tectonic setting was a former forearc region. The intense magmatism and subsidence in a normally cold forearc region may have been caused by ridge subduction as in the Woodlark Basin and/or aesthenospheric upwelling due to slab roll-back as in the Marianas.

2. Intrusion of earliest plutons of Hepburn intrusive suite, coeval with westerly-vergent thrusting involving Bent gneiss and rocks of Grant Group. Formation of F_1 and S_1. The thrusts may have formed as back thrusts related to ramping of Turmoil allochthon over Slave cratonic margin.

4. Northeastward transport of Turmoil klippe onto Slave craton. Formation of F_2 folds and L_2 lineation.

5. Formation of F_3 folds during terminal phase of Calderian orogeny.

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