

## On folds and thrusts affecting the Coppermine River Group, northwestern Canadian Shield<sup>1</sup>

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Received August 5, 1990

Revision accepted December 17, 1990

Examination of existing geological and aeromagnetic maps of the Coppermine homocline reveals two periods of deformation which affect rocks of the Coppermine River Group but predate rocks of the Rae Group. The oldest event generated easterly-trending folds and southerly-vergent thrust faults and is probably related to events along the northern margin of Laurentia. The younger event caused northerly-trending folds, possibly correlates with an east-west compressional event seen in the subsurface of the Interior Plains, and was likely a result of plate interactions along the western margin of Laurentia. Both deformational events that affect the Coppermine homocline are younger than 1267 Ma and are not correlative with the pre-1268 Ma Racklan orogeny of the northern Cordillera.

L'examen des cartes géologiques et aéromagnétiques existantes de l'homocline de Coppermine révèle deux périodes de déformation qui affectèrent les roches du Groupe de Coppermine River, mais prédatent les roches du Groupe de Rae. L'événement le plus ancien a créé des plis de direction est, et des failles de chevauchement de vergence sud, et il est probablement relié aux événements survenus le long de la marge nord du Laurentia. L'événement le plus jeune a engendré des plis de direction nord, qui peuvent être corrélés avec un événement en régime de compression est-ouest, observé en subsurface dans les Plaines de l'Intérieur; lequel résulte vraisemblablement d'interactions de plaques le long de la marge occidentale du Laurentia. Ces deux événements de déformation qui ont perturbé l'homocline de Coppermine sont plus jeunes que 1267 Ma, et ils ne sont pas corrélables avec l'orogène de Racklan de la Cordillère septentrionale.

[Traduit par la rédaction]

Can. J. Earth Sci. 28, 523-531 (1991)

### Introduction

The 1.7–0.7 Ga Proterozoic successions of the northwestern Canadian Shield and northern Cordillera are important to our understanding of the development of North America because they provide one of the few records of sedimentation, volcanism, and deformation which postdate the main amalgamation of the Laurentian supercontinent (Hoffman 1989) but predate, or are synchronous with, its breakup. Middle to Late Proterozoic successions of northwestern Canada are exposed mainly within the Coppermine homocline, the Brock inlier, the Minto inlier on Victoria Island, the Bathurst Inlet area, and in the northern Cordillera (Fig. 1).

Young *et al.* (1979) correlated and divided the successions into three sequences: A, B, and C. The oldest sequence (A) includes rocks of the Wernecke Supergroup within the Cordillera and the Hornby Bay, Dismal Lakes, and Coppermine River groups of the Coppermine homocline. In the Cordillera, rocks of the Wernecke Supergroup were metamorphosed to greenschist facies and deformed during the Racklan orogeny (Gabrielse 1967; Young *et al.* 1979). Rocks of sequence B, which in the Cordillera sit unconformably upon the deformed rocks of sequence A, include the Pinguicula Group and the Mackenzie Mountains supergroup of the Cordillera, the Shaler Group of Victoria Island, and the Rae Group of the Coppermine homocline. Rocks of unit C include rocks of the Windermere Supergroup within the Cordillera (Jefferson and Parrish 1989), the Coronation sills of the Coppermine homocline, and the Natkusiak flows and related sills on Victoria Island.

Examination of seismic reflection data from the Interior Plains, located between the Coppermine homocline and the northern Cordillera, suggests the presence of a thin-skinned, easterly-vergent, thrust-fold belt in the subsurface that affects rocks of sequence A but predates those of sequence B (Cook 1988a, 1988b). Accordingly, Cook tentatively correlated the

east-west compressional event with the Racklan orogeny of the Cordillera. More recently, Cook and Mayers (1990) examined additional seismic data through the same area, but did not recognize thrust faults of the magnitude proposed by F. A. Cook. However, they also found evidence for an east-west compressional event that deforms strata of sequence A.

Compilation of a new 1 : 500 000 scale map of northern Wopmay orogen and the Coppermine homocline focused our attention on compressional structures within the homocline that, like those beneath the Interior Plains, postdate rocks of the Coppermine River Group (upper sequence A) but predate those of the Rae Group (sequence B). Thus, Middle to Late Proterozoic deformational events are possibly more widespread than previously thought. In this paper we discuss the evidence for compressional deformation affecting rocks of the Coppermine River Group and explore the possibility that they are related to events of the Interior Plains and northern Cordillera.

### General geology

Rocks of the Coppermine homocline unconformably overlie Archean rocks of the Slave Province and 2.2–1.8 Ga. rocks of Wopmay orogen (Fig. 1). They comprise four distinct packages of supracrustal rocks separated by unconformities: the Hornby Bay Group, the Dismal Lakes Group, the Coppermine River Group, and the Rae Group, in ascending order (Baragar and Donaldson 1973).

The Hornby Bay and Dismal Lakes groups (Fig. 2) are both clastic to carbonate sequences. The Hornby Bay Group comprises coarse-grained siliciclastic sedimentary rocks deposited in fault-bounded graben, overlain by westward-thickening fluvial-peritidal deposits (Ross 1983). Volcanic and associated hypabyssal intrusive rocks in the upper part of the group have a U–Pb zircon age of  $1663 \pm 8$  Ma (Bowring and Ross 1985). The overlying Dismal Lakes Group passes upwards from siliciclastic rocks at its base to carbonates, all of which were deposited upon a northwesterly-facing fluvio-marine shelf

<sup>1</sup>Geological Survey of Canada Contribution 15190.

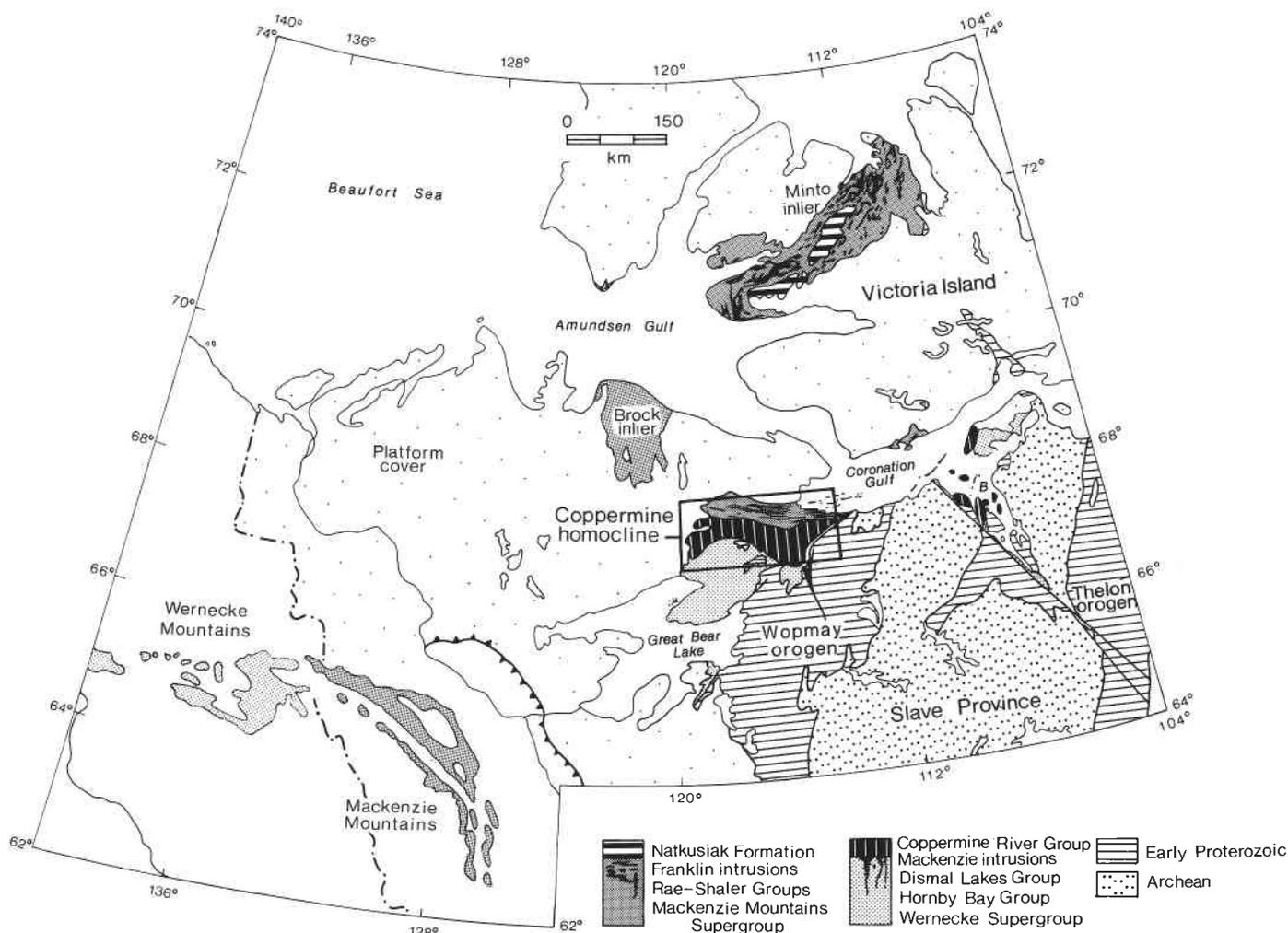


FIG. 1. Map of the northwestern Canadian Shield and northern Cordillera after Young *et al.* (1979) and Hoffman (1989), showing the distribution of the Middle-Late Proterozoic sequences. The location of Fig. 2 is outlined. B, Bathurst Inlet.

(Kerans *et al.* 1981; Kerans 1983). Well-developed karst in the upper part of the group was argued by Kerans (1983) to have developed during regional uplift consequent to emplacement of the Muskox intrusion because the karst is approximately centred over the intrusion.

Rocks of the Coppermine River Group are divided into two formations: a thick sequence of flood basalts termed the Copper Creek Formation, overlain by a mixed sequence of sandstone, siltstone, and basaltic lava flows collectively named the Husky Creek Formation (Baragar and Donaldson 1973). Lavas of the Coppermine River Group and their intrusive equivalents, the Muskox intrusion and the Mackenzie dyke swarm, constitute one of the most voluminous and widespread episodes of continental basaltic magmatism of any age (Fahrig and Jones 1969; Fahrig 1987; LeCheminant and Heaman 1989). Magmatism spanned only a few million years with the Muskox intrusion being emplaced at  $1270 \pm 4$  Ma and the Mackenzie dyke swarm at  $1267 \pm 2$  Ma (LeCheminant and Heaman 1989). Basaltic lavas of the group are not precisely dated but are compositionally similar to the intrusions and were obviously fed by them (Baragar 1969).

The Rae Group, comprising sandstones, shales, and carbonates, caps the sequence and is profusely intruded by

gabbroic sheets known as the Coronation Sills (Baragar and Donaldson 1973; Campbell 1983). One of the Coronation Sills and three of their presumed correlatives, which cut the Shaler Group on Victoria Island, were recently dated as  $723 \pm 3$  Ma (Heaman *et al.* 1990).

The uppermost units of the Coppermine homocline are Paleozoic sedimentary rocks. They were originally considered to be part of the Rae Group but were found to be fossiliferous by Dixon (1979) and Campbell (1983).

#### Coppermine River Group

The Coppermine River Group comprises 2–3.5 km of tholeiitic plateau basalts, collectively termed the Copper Creek Formation, and an overlying succession of red-coloured sandstones with intercalated basaltic lava flows, termed the Husky Creek Formation (Baragar and Donaldson 1973). The Copper Creek Formation is mostly a monotonous succession of up to 150 basalt flows which ranging in thickness from 4 to 300 m. Individual flows were traced for at least 16 km along strike, but they may be more extensive. Rare pillowed flows and pyroclastic rocks occur in the lower part of the formation.

The chemistry of the basalts was documented by Baragar (1969) and Dostal *et al.* (1983). Overall, the basalts are typical

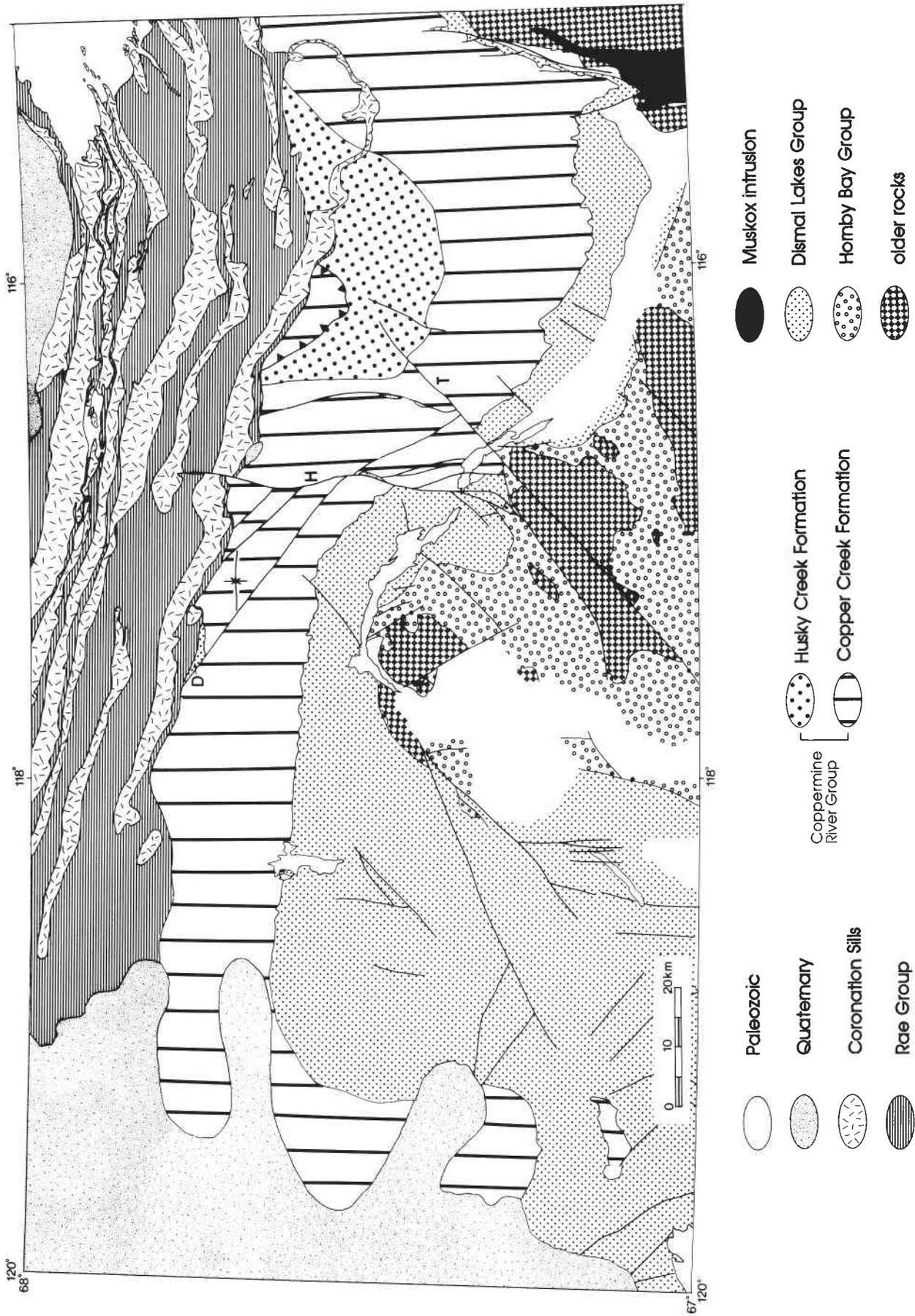


FIG. 2. Geological sketch map of the Coppermine homocline modified from Baragar and Donaldson (1973) and Ross and Kerans (1990). T, Teshierpi Fault; H, Herb Dixon Fault; D, southward-dipping Dismal Lakes Group.

continental tholeiites with low Ni, Cr, and Mg/Fe, suggesting that they were fractionated prior to eruption. They contain relatively high abundances of incompatible elements and have geochemical signatures indicative of contamination by continental crust. Furthermore, the lavas show regular mineralogical and chemical variations with stratigraphic level. For example, SiO<sub>2</sub>, Cr, Ni, and MgO decrease and FeO, TiO<sub>2</sub>, Fe-Ti oxides, and K<sub>2</sub>O increase upwards through the section. This relationship, the overall compositional similarity, and the spatial and temporal proximity of lavas to the Muskox intrusion were used to suggest that the intrusion was a crustal reservoir in which the magmas were stored prior to eruption (Dostal *et al.* 1983).

The Husky Creek Formation comprises about 1 km of cross-bedded sandstone, siltstone, basaltic lavas, and minor mud-chip conglomerate. The basaltic lavas occur mainly in the upper part of the exposed sequence and are compositionally similar to those of the lower Copper Creek Formation. The sedimentary rocks are compositionally and texturally immature, with 10–30% hematite grains. Desiccation features are common (Campbell 1983). Limited paleocurrent data (Campbell 1983) suggest that rocks of the formation were deposited in a south-westerly-trending valley.

### Structure

The Coppermine homocline is generally considered to be a simple tilted block, as its name implies. However, this is not the case, as there are faults and folds of many ages (Baragar and Donaldson 1973; Ross and Kerans 1990). In this paper we consider only structures that postdate rocks of the Coppermine River Group and predate rocks of the Rae Group. Our discussion relies on recompilation of existing geological maps, reexamination of field notes, and analysis of aeromagnetic maps of the region. Aeromagnetic maps (Fig. 3) are particularly useful because lavas of the Copper Creek Formation, except for the stratigraphically lowest flows, which contain lesser amounts of Fe-Ti oxides relative to those at higher stratigraphic levels (Baragar 1969; Baragar and Robertson 1973; Dostal *et al.* 1983), have a high magnetic intensity, whereas rocks of the Husky Creek Formation and Hornby Bay and Dismal Lakes groups have relatively low magnetic intensities. At first glance it might appear that rocks of the Hornby Bay and Dismal Lakes groups have a reasonably high magnetic intensity; however, the broad northwesterly-trending high in that area is a continuation of the aeromagnetic high related to the Great Bear magmatic zone of Wopmay orogen, rocks of which peek through the Hornby Bay Group. Furthermore, the thin magnetically low strip between the magnetic highs of the Great Bear magmatic zone and the Copper Creek Formation is known to coincide with outcrops of the Dismal Lakes Group. North of the Coppermine River Group, younger cover rocks appear to have little effect on the aeromagnetic signatures, except to diffuse gradients slightly. Thus, we are able to extrapolate for some distance beneath the younger cover.

Although it has long been recognized that rocks of the Coppermine homocline are broadly folded, little regional significance was given to the deformation (Baragar and Donaldson 1973; Dostal *et al.* 1983;). Our reexamination of the existing maps prompted us to reevaluate two sets of folds and one group of faults that are temporally bounded by the Coppermine River and Rae groups. The two sets of folds that affect rocks of the Coppermine River Group are orthogonal to one another: the older is easterly trending and the younger northerly

trending. The faults appear to postdate the earlier folds but predate the younger folds.

### Easterly-trending folds

The easterly-trending folds are broad open structures with wavelengths of about 80 km and little, if any, plunge. The most northerly of the older easterly-trending fold set is an open syncline with limb dips generally between 5° and 10°. It is difficult to discern, as its axis and northern limb are, for the most part, covered by rocks of the Rae Group. However, the axial trace and the lower contact of the lavas on the northern limb are exposed in one fault block (Fig. 2). Although only a short portion of the northern contact is exposed, it can be inferred beneath the younger cover west of the fault block because the inflection point between the aeromagnetic high, characteristic of the lavas, and the aeromagnetic low, characteristic of the older sedimentary units, closely approximates the position of the contact between them. The syncline is strongly asymmetrical, with about 1–1.5 km of section on the northern limb and about 3 km present on the southern. The disparity in thicknesses might be explained by (1) southward-directed thrusting of rocks of the Dismal Lakes Group over rocks of the Copper Creek Group, (2) southward tilting and erosion after deposition, (3) the filling of an already existing basin that deepened to the south, or (4) eruption into a basin that was actively subsiding.

The thrust model is unlikely because the contacts between lavas of the Copper Creek Formation and sedimentary rocks of the Dismal Lakes Group are exposed on both limbs of the fold and there is no evidence that they are anything but depositional. If lavas stratigraphically above the contact on the north limb of the fold are lower lavas, as they seemed to be on visual inspection in the field, then progressive northward onlap, which should place stratigraphically higher lavas at the contact, is unlikely. Consequently, model 2, in which the thickness variations were generated by uplift and erosion in the north with consequent erosion of the upper part of the lava plateau, appears to be the most likely alternative. In fact, the abundant hematite grains of the Husky Creek Formation may have been derived from the underlying lavas. However, we cannot rule out the possibility that at least some of the thickness variation is due to nondeposition at some time during the formation of the lava plateau. A useful test would be to collect and analyze samples of the lavas on the north limb of the syncline, because in all other sections examined there are systematic compositional variations with time.

North of the syncline there is no evidence on available aeromagnetic maps for any rocks with the high magnetic intensities of the lavas (Fig. 3). This suggests that there are no lavas preserved north of the syncline. The magnetic data are compatible with that area being underlain by rocks such as occur within either the Dismal Lakes or Hornby Bay groups. Whether this is due to complete erosion of the lavas in that area prior to folding or the result of folding and later faulting is unclear.

### Thrust faults

Several faults cut rocks of the Coppermine River Group but do not appear to displace rocks of the Rae Group. The most interesting of these is a large U-shaped fault located about 60 km northwest of the Muskox intrusion (Fig. 2). The fault has a pronounced magnetic signature and can therefore be traced for considerable distances beneath the overlying Rae Group (Fig.

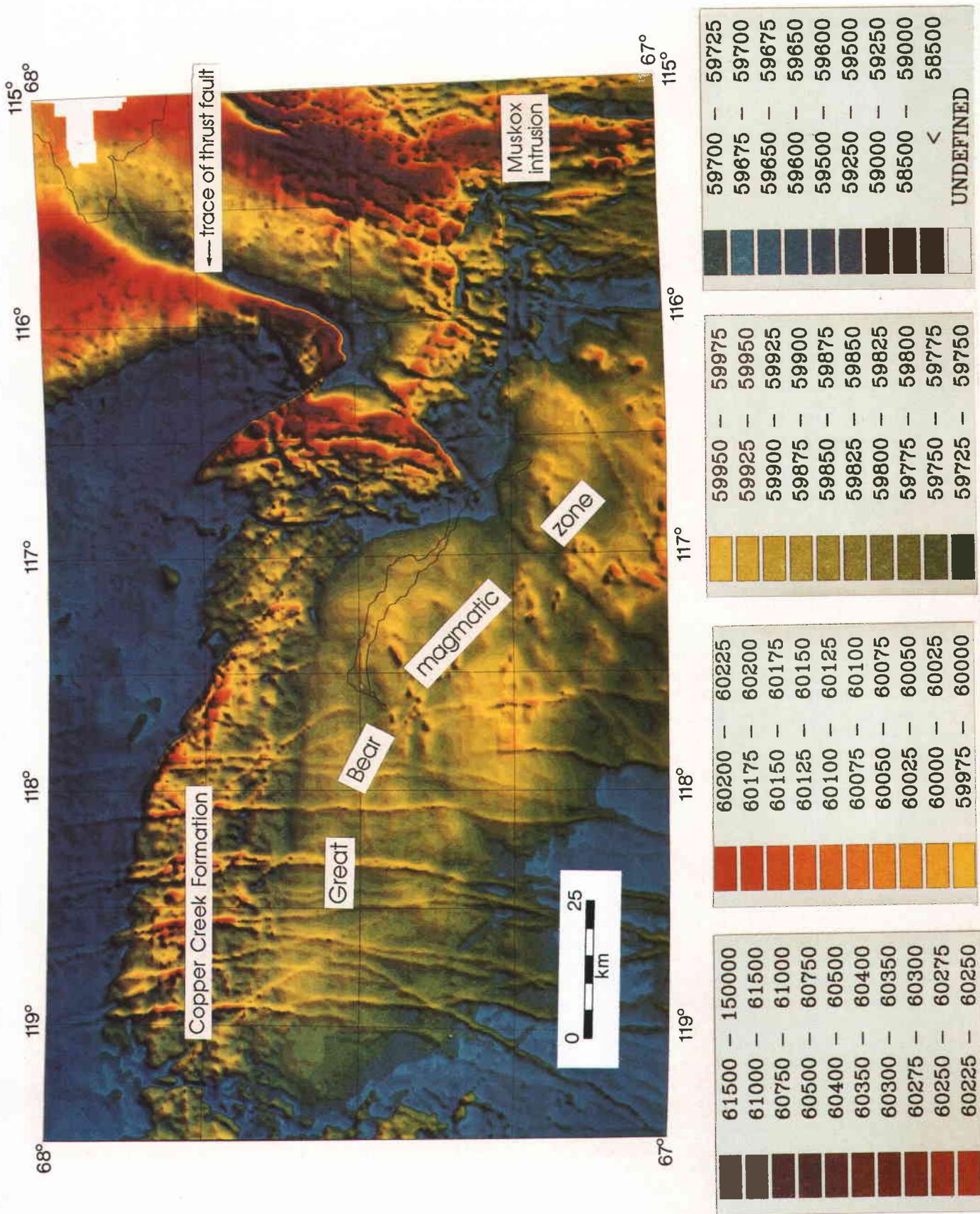


FIG. 3. Aeromagnetic map of the region of the Coppermine homocline. Produced by the Geophysical Data Centre, Geological Survey of Canada.

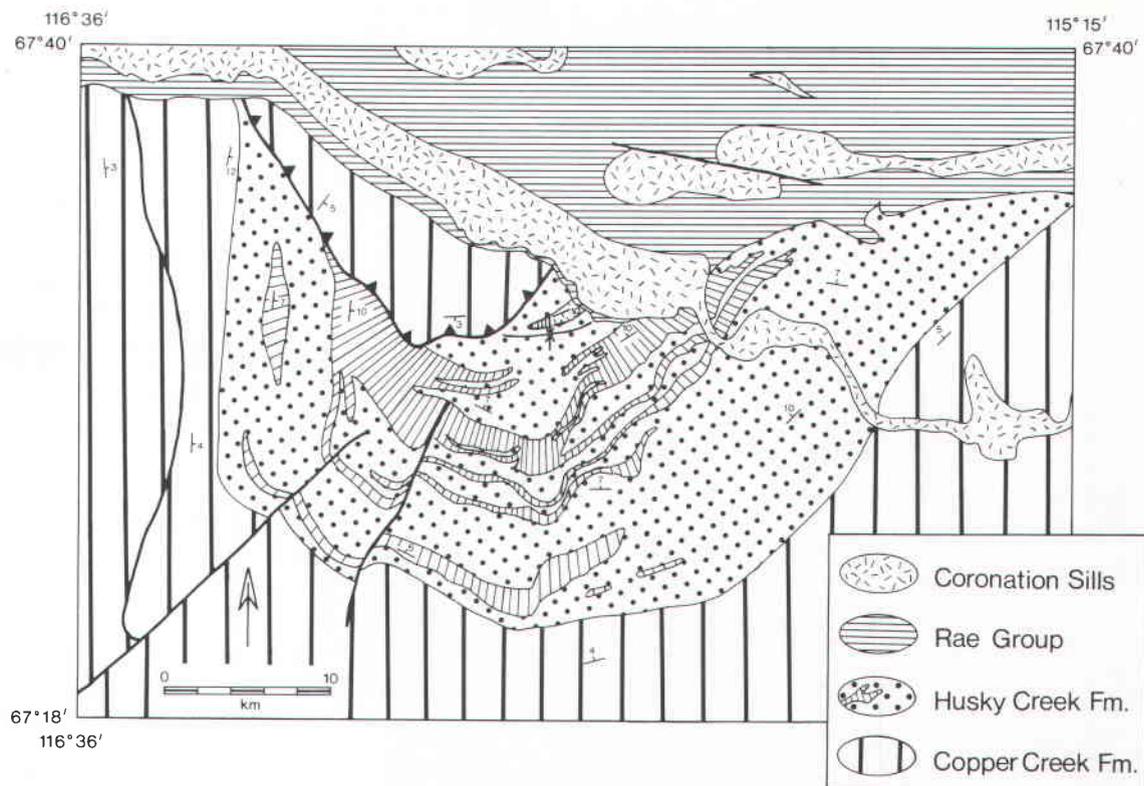


FIG. 4. Detailed geological map of the area surrounding the proposed thrust fault. Modified from Baragar and Donaldson (1973).

3). It places lavas of the Copper Creek Formation on top of rocks of the younger Husky Creek Formation. On the basis of paleomagnetic evidence, Baragar and Robertson (1973) demonstrated that lavas north of the fault were rotated about  $28^\circ$  counterclockwise relative to those south of the fault and interpreted the fault to be the result of buckling due to magma withdrawal. However, on recently published aeromagnetic maps the fault can be traced well to the north beneath rocks of the Rae Group, which makes a reinterpretation necessary. Because the fault trace is concave northward, as is bedding south of the fault, and because it places older rocks upon younger rocks, we interpret it as a thrust fault.

Rocks in the lower plate generally dip gently northward except just beneath the fault itself where they form an easterly-trending footwall syncline (Fig. 4) with southerly dips on the northern limb up to  $40^\circ$ . Basalts in the upper plate dip gently south to southeasterly. In the west, the fault clearly cuts downsection northwestward, as demonstrated by the truncated strikes and the cutoffs of bedding within rocks of the Husky Creek Formation. On its southern and eastern limbs it appears to be concordant with the strike of bedding in the Husky Creek Formation. This suggests a southerly to easterly direction of movement.

As stated above, the thrust fault is interpreted to correspond to an obvious steep gradient in the aeromagnetic pattern of the region (Fig. 3) and can be traced northward for many kilometres beneath the younger cover. Within the buried portion of the thrust sheet there is another aeromagnetic gradient, low to the north and west, high to the south and east. The high corresponds to middle and upper lavas of the Copper Creek Formation. The low could represent rocks of the Husky Creek Formation, Rae, Dismal Lakes, and Hornby Bay groups, as well as the lower-

most flows of the Copper Creek Formation, which are all typified by relatively low magnetic intensities. Because dips in the thrust plate are southward, the region of low magnetic intensity probably represents rocks of the lower Copper Creek Formation and the stratigraphically subjacent Dismal Lakes and Hornby Bay groups.

The minimum stratigraphic displacement on the fault can be estimated by using the systematic chemical variations within the lavas. Figure 5 shows trends measured in samples collected from six sections of the basalts. It also shows the total variation and mean for samples collected from the thrust sheet. The lavas of the thrust sheet most closely resemble those from the upper third of the main lava plateau. Thus, there could be a kilometre of vertical movement on the fault.

If we assume southerly vergence, that the lavas came from the upper third of the pile, and that the inflection in the magnetic pattern within the thrust sheet represents the basal contact of the lavas as to the west, then by projecting this contact eastward there is a minimum of 45 km of horizontal movement on the fault, based on the distance between the contact within the thrust sheet and the projected contact. If the vergence on the fault is easterly, then the minimum amount of horizontal movement is in excess of 160 km, for to the west there is continuous exposure of the lavas for that distance and no evidence of a footwall cutoff. Because 160 km is a large amount of movement for a thrust fault in subgreenschist-facies rocks, we favour a generally southward vergence for the fault. Thus, 45 km is probably a more realistic estimate of the horizontal displacement.

Several other possible thrust faults occur to the west of the one described above. They are northwesterly trending, cut the easterly-trending fold discussed above, and predate deposition of rocks of the Rae Group. They are cut by a northerly-trending

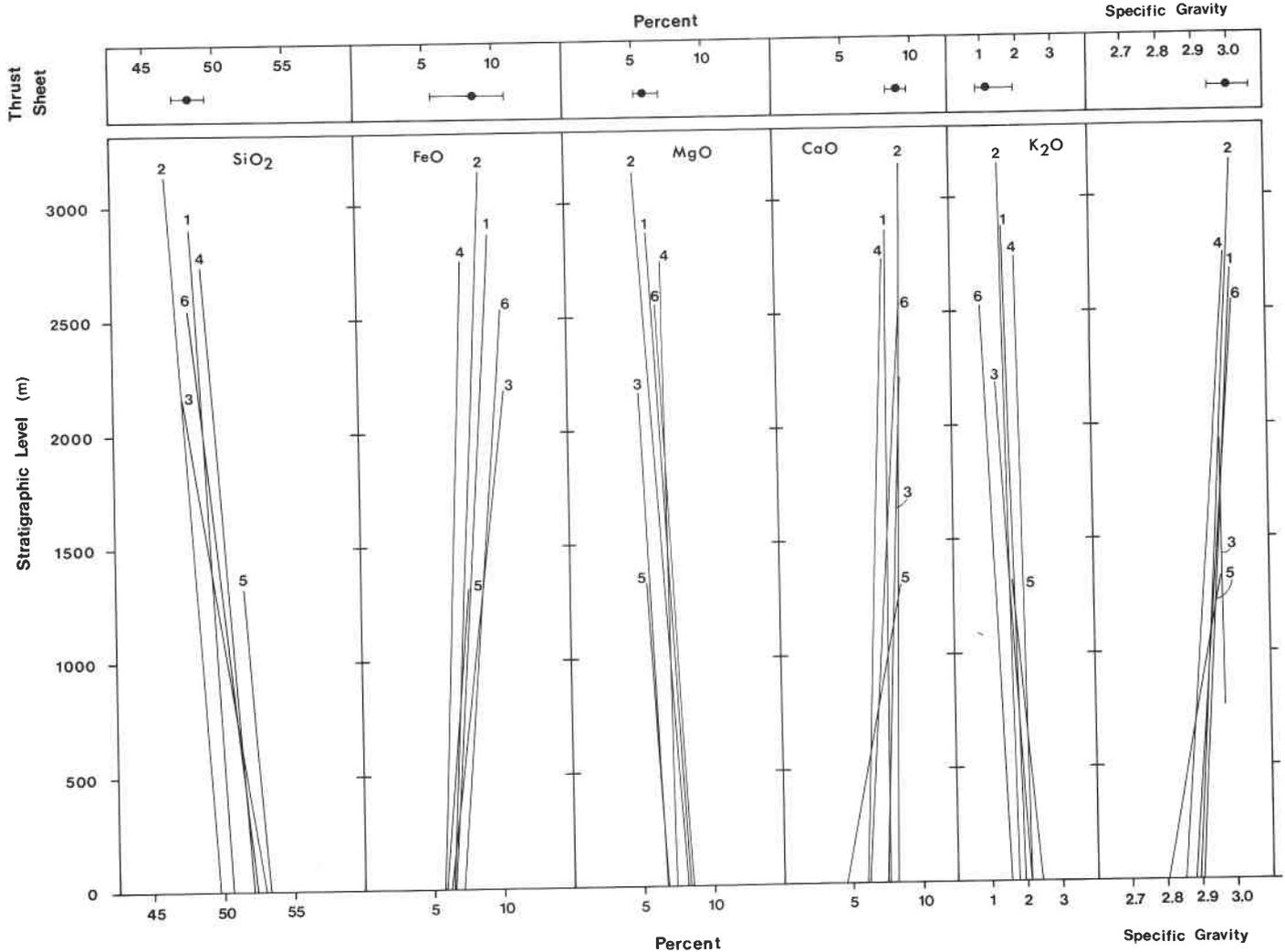


FIG. 5. Trends vs. stratigraphic height in autochthonous lavas of the Copper Creek Formation compared with the mean and total variation of samples collected within the thrust sheet. The lines numbered 1–6 are regression lines through sets of analyses corresponding to numbered sections of Baragar (1969) and Dostal *et al.* (1983).

normal fault, the Herb Dixon fault, which was possibly active during the Phanerozoic, as evidenced by small remnants of Cambrian quartzites (Baragar and Donaldson 1973) along its eastern side (Fig. 2). East of the Herb Dixon fault are several faults that could be continuations of the faults on the western side. The faults east of the Herb Dixon fault parallel bedding in the lavas but were not recognized farther east than the Teshierpi Fault (Fig. 2). Examination of air photographs further to the east indicates several semiconcordant truncations within the lava pile, but whether they represent continuations of the faults, reflect paleotopography, or are related to synvolcanic erosion awaits further fieldwork.

#### Northerly-trending folds

The second set of folds is difficult to discern but comprises broad, shallowly plunging, open folds with wavelengths of about 160 km, limb dips of less than 5°, and north-northwesterly trends. Within the axial zones of the folds a steeply dipping cleavage is locally developed (Baragar and Donaldson 1973). Overall, the folds control the first-order outcrop pattern of the Hornby Bay, Dismal Lakes, and Coppermine River groups and appear to fold the thrust fault but predate rocks of the Rae Group.

#### Relationship of faulting to folding

Although the vergence of the major thrust fault is not well constrained, it is most likely southerly as discussed above. If correct, then it resulted from north-south compression, as did the first set of folds, however, as it cuts the axial traces of the folds it must be younger. In many thrust-fold belts the earlier formed folds are cut by younger thrust faults as contraction continues. Therefore, it is reasonable that the folds and thrust are part of the same progressive deformational event. In fact, the proposed uplift and erosion of the northern part of the lava plateau prior to folding, the folding, and the thrusting are all compatible with a single progressive north-south compressional event. In this model the deformational front migrated south with time. The northerly-trending folds are orthogonal to the earlier deformation and are likely related to a completely different event.

#### Age and correlation of deformation

The time of deformation and the orientation of structures within the Coppermine homocline, the Wernecke-Mackenzie mountains, and beneath the Interior Plains are critical to tectonic interpretations of the northwestern Canadian Shield. The maximum age of deformation within the Coppermine homocline

is constrained by the age of the Mackenzie dyke swarm, dated at  $1267 \pm 2$  Ma (LeCheminant and Heaman 1989), and the upper limit by the Coronation Sills, dated at  $723 \pm 3$  Ma (Heaman *et al.* 1990). Within the Wernecke–Mackenzie mountains the minimum age of deformation is determined by a  $^{207}\text{Pb}/^{235}\text{U}$  monazite age of 1268 Ma (Parrish and Bell 1987) from breccias that crosscut cleavage in rocks of the Wernecke Supergroup (Thompson and Roots 1982). Furthermore, the breccias cut another group of rocks, known informally as the ‘‘Fifteenmile group,’’ that have no cleavage and sit unconformably upon rocks of the Wernecke Supergroup (C. Roots, personal communication, 1990). Thus, as pointed out by Hoffman (1989), there is a problem relating the deformation within the Coppermine homocline to the Racklan orogeny because the orogeny is apparently older than magmatism associated with the Coppermine River Group. One could appeal to uncertainties in the U–Pb interpretations or diachronous deformation and argue that as such the data are inconclusive, but the simplest interpretation of the data is that the Racklan orogeny is older than events in the Coppermine homocline. Furthermore, because the breccias and the lavas are approximately the same age it is possible that they are part of the same magmatic event, as hypothesized by Peterson and LeCheminant (1989).

McMechan and Price (1982) suggested that the Racklan orogeny was the same event as the East Kootenay orogeny, which affects rocks of the Belt–Purcell Supergroup in the southern Cordillera. If their correlation is right, then the age of the Racklan orogeny must be older than 1365–1370 Ma, based on U–Pb zircon ages of the Hellroaring Creek stock (J. K. Mortensen, personal communication, 1989), which cuts deformed and metamorphosed rocks of the Belt–Purcell Supergroup. In this model, the deformation that affects the Coppermine homocline cannot be related to the Racklan orogeny, and because structures beneath the Interior Plains are also interpreted to postdate rocks of the Coppermine River Group (Cook 1988a, 1988b), the deformation there would also be younger than the Racklan orogeny. Whatever the relationship of the Racklan to the East Kootenay, when taken at face value the radiometric ages indicate that the deformational events of the Interior Plains and Coppermine homocline postdate the Racklan orogeny.

Although it is likely that the deformation beneath the Interior Plains – Coppermine homocline areas is significantly younger than the Racklan orogeny of the Cordillera, it is probable that at least one of the deformations in the Coppermine homocline is correlative with that which produced the compressional structures beneath the Interior Plains, because the deformation in both areas postdates deposition of the Coppermine River Group and predates the deposition of the Rae Group. Whereas structures beneath the Interior Plains are northerly trending (Cook 1988a, 1988b), it is unlikely that the early deformational event that affected rocks of the Coppermine River Group is of the same age and origin. It was probably generated by an event to the north, perhaps along the northern margin of Laurentia. However, trends of the second set of folds in the Coppermine homocline are northerly, as are the trends of structures beneath the Interior Plains (Cook 1988a, 1988b; Cook and Mayers 1990) and could have been generated by the same event. Since the deformation appears less intense in the Coppermine homocline than to the west, and since it indicates east–west contraction, it seems reasonable to link the deformation in both areas to an event that occurred along the western margin of Laurentia.

## Conclusions

- (1) Within the Coppermine homocline two discrete sets of compressional structures that affect rocks of the Coppermine River Group but predate rocks of the Rae Group are recognized.
- (2) The older set of structures includes easterly-trending folds and southerly-vergent thrust faults. The younger set comprises broad, open northerly-trending folds.
- (3) Both deformational events probably postdate the Racklan orogeny of the northern Cordillera.
- (4) The older easterly-trending structures were probably generated by events to the north, perhaps at the northern margin of Laurentia. Deformation may have progressed southward with early uplift and erosion of the lava plateau, followed by folding and finally, thrusting.
- (5) The younger northerly-trending structures of the Coppermine homocline and those beneath the Interior Plains are likely correlative. They were probably generated by an event along the western margin of Laurentia.

## Acknowledgments

We would like to thank G. Lemieux and R. Kelly for photography, J. Janveau and P. McGrath for obtaining the shaded relief aeromagnetic data, and Dianne Paul for cheerfully drafting the figures. Discussions with D. Cook, A. N. LeCheminant, P. F. Hoffman, J. Mortensen, R. Parrish, R. Rainbird, and C. Roots were beneficial. F. A. Cook, D. G. Cook, P. F. Hoffman, and A. N. LeCheminant critically reviewed the manuscript.

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