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REFLECTION SEISMIC INTERPRETATION OF THE PROTEROZOIC GEOLOGY; COLVILLE HILLS REGION, NORTHWEST TERRITORIES

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ABSTRACT

Subsurface Proterozoic strata in the Colville Hills region, Northwest Territories, occur in two major sequences separated by a regional unconformity (C). The deeper sequence I, is subdivided into three sub-units, which are tentatively correlated with units mapped on Coppermine Homocline to the east. Unit Ia is correlated with Hornby Bay and/or Dismal Lakes Groups and could include crystalline rocks equivalent to those of Wopmay Orogen; unit Ib is correlated with the plateau basalts of the Copper Creek Formation; and unit Ic with the Husky Creek Formation. Sequence II is correlated with the Mackenzie Mountains supergroup, to the west, and the Rae Group, to the east. Some sub-horizontal discordant reflections are considered to be intrusive sheets. Phanerozoic formations, unconformably overlying the Proterozoic, have not been examined.

Three compressional deformational phases are inferred. Structures of the first phase include large scale block faults and smaller scale thrust faults. These distinctly different structures may represent separate orogenic events, but because both offset strata of sequence I and are truncated by unconformity C, they cannot be differentiated temporally. The large structures include one westward verging rotated block (vertical offsets of about 5 km), and an anticline about 20 km wide and 4 km high. The fault block is interpreted as underlain by a steep, curved, reverse fault which must detach at a minimum depth of 15 km. The anticline and the fault are truncated by unconformity C, but have vertical, post-unconformity reactivation of 1-1.5 km. The smaller, mainly east-verging thrusts (maximum 6 km horizontal displacement) are flatter and shallower than the larger structures. These may be related to a regional orogeny interpreted by F.A. Cook (1988) although cumulative displacements are modest compared to the 50 to 90 km of shortening interpreted by him. A second deformational phase is marked by small thrust faults which cut sequence II, and are truncated by the sub-Cambrian unconformity (marker J). Phase 1 structures were reactivated at this time. A third and final event affecting Phanerozoic and older strata resulted in the development of the structures which form the present-day Colville Hills.

INTRODUCTION

Oil industry multifold reflection seismic data released by the Canada Oil and Gas Lands Administration (COGLA) provide an important database for interpreting subsurface Precambrian stratigraphy and tectonics in the Northwest Territories. Preliminary results of a study in the region of the Colville Hills (Fig. 1) were presented by Cook and Mayers (1989). This Open File report presents a more comprehensive set of interpreted regional seismic transects (Fig. 2) and a more complete discussion than was possible in that summary.

Published subsurface studies in this region, to date, with a few notable exceptions, have concentrated on Phanerozoic strata. The focus of the present study is on the subsurface Precambrian, about which relatively little is known. Two east-west, regional, composite seismic transects, B-B' (Figs. 4, 5) and C-C' (Figs. 6, 7, 8), and three connecting north-south transects, Y-Y' (Fig. 9), Z-Z' (Fig. 10), and X-X' (Fig. 11) are interpreted. More than 750 line kilometres are represented by these five, spliced transects which are composed of twenty seismic lines (Table 1). About 30 additional lines were perused to provide supplementary ties between the transects and to local wells.

Most of the seismic data available through COGLA, were recorded using explosive sources, and digitally processed during the 1970s and early 1980s, using a variety of hardware and software combinations, and are extremely variable in quality. Many are 1200 percent CDP fold; others are 800, 600, or 400 percent, (see Table 1). Most are displayed in an unmigrated, structural stack format (with a digital processing datum of 305 m above sea level (ASL), and a datum velocity of 5500 or 6000 m/s). Format variations from these exist and have been quantitatively allowed for (Figs. 4-11).

Almost all of the seismic and well data available through COGLA in the area were collected with Paleozoic and Mesozoic beds as the prime exploration targets. Consequently seismic parameters were optimized for these zones and most seismic sections were displayed only to 3 or 4 seconds. Similarly, wells rarely penetrate more than a few tens of meters beyond the sub-Cambrian unconformity. This has hampered this interpretation of Proterozoic strata. Several lines were recorded to reflection times of 6 or 8 seconds, and the

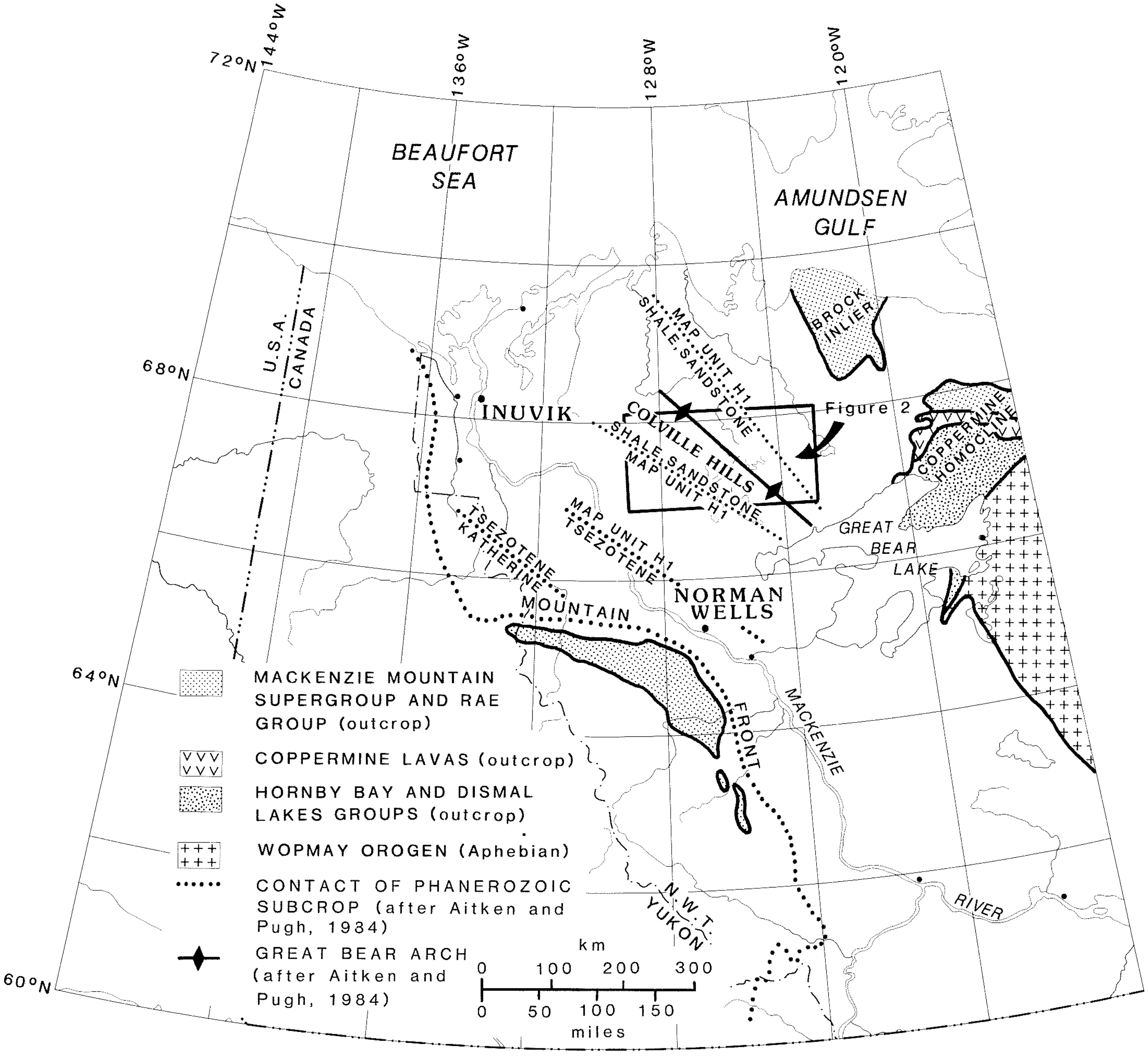

Figure 1. Location map, showing the project area (Fig. 2), key geological elements, and potential correlation of strata from the Cordillera to Coppermine Homocline.

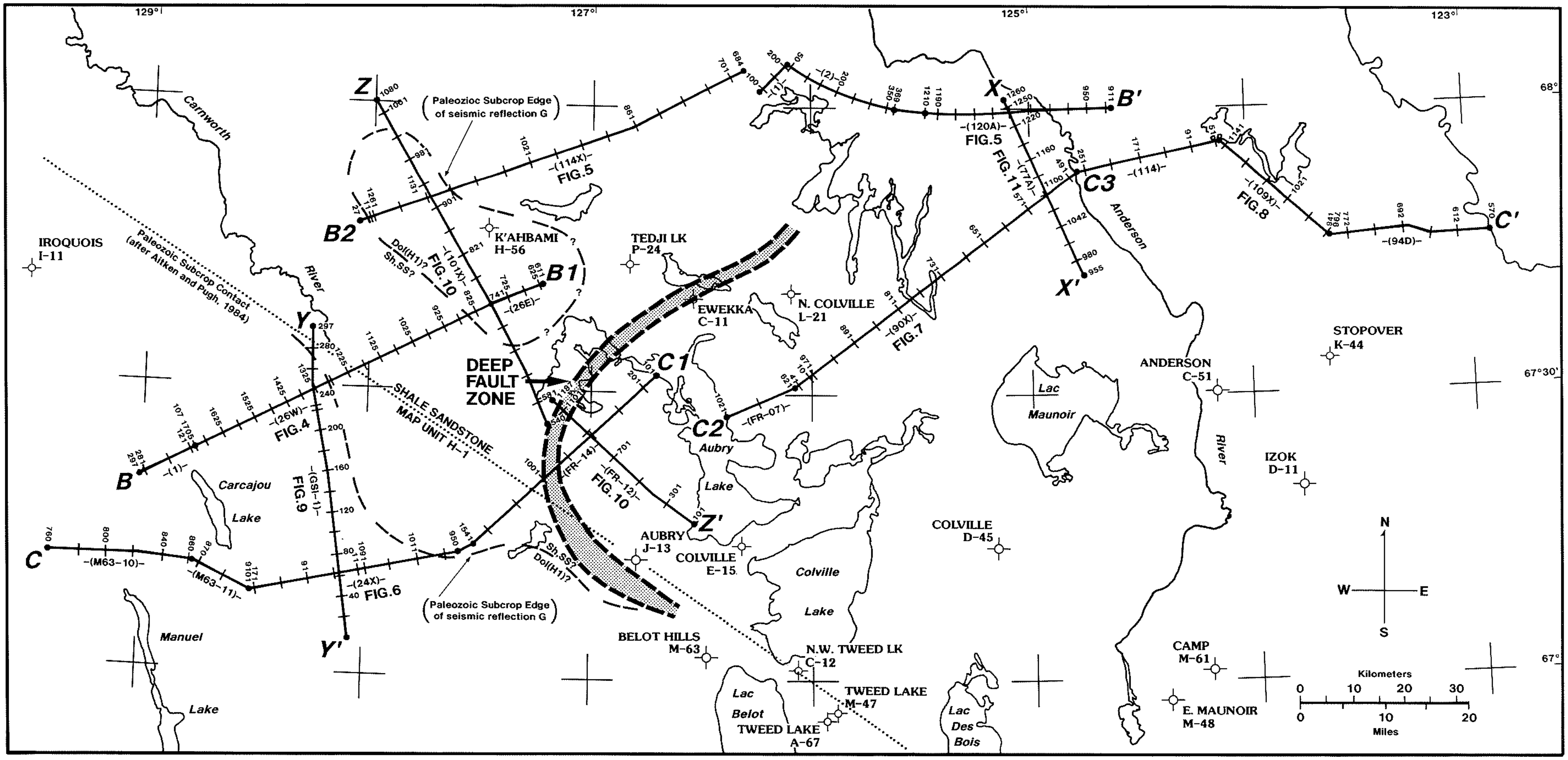

Figure 2. Project area, showing: wells penetrating the sub-Cambrian; seismic transects B-B', C-C', X-X', Y-Y', and Z-Z'; the zero-edge of Marker G; and a deep fault zone.

TABLE I
Seismic Lines Comprising the Transects

TRANSECT (length, km)	SUB-TRANSECT (length, km)	C.O.G.L.A. FILE No (line No.) (line length, km)	CDP FOLD %
B-B' (240)	B-B1, Fig. 4 (86)	005-06-06-00044 (1) (12.7)	1200
		815-06-06-00003 (26W) (65.0)	600
		815-06-06-00003 (26E) 52.5	600
	B2-B', Fig.5 (154)	9229-P28-1E (114X) (79.2)	1200
		038-06-06-00047 (1) (16.4)	600
		038-06-06-00047 (2) (24.7)	600
		246-06-05-00108 (120A) (35.9)	1200
C-C' (310)	C-C1, Fig. 6 (135)	246-06-04/05-00114 (63-10) (28.3)	400
		246-06-04/05-00114 (63-11) (34.4)	400
		9229-P28-1E (24X) (43.1)	1200
		9229-F9-2E (FR-14) (47.8)	1200

TABLE I (continued)
Seismic Lines Comprising the Transects

TRANSECT (length, km)	SUB-TRANSECT (length, km)	C.O.G.L.A. FILE No (line No.) (line length, km)	CDP FOLD %
	C2-C3, Fig. 7 (85)	9229-F9-2E (FR-07) (30.7)	1200
		9229-P28-1E (90X) (74.0)	1200
	C3-C', Fig. 8 (90)	9229-P28-1E (114) (107.8)	1200
		9229-P28-1E (109X) (33.2)	1200
		9229-P28-1E (94D) (29.7)	1200
X-X' (37)	Fig. 11	246-06-06-00108 (77A) (36.9)	1200
Y-Y' (60)	Fig. 9	246-06-04/05-00114 (GSI-1) (58.6)	800
Z-Z' (103)	Fig. 10	9229-P28-1E (101X) (71.4)	1200
		9229-F9-2E (FR-12) (36.1)	1200

interpretation presented here may be improved in the future by reprocessing and redisplaying to their full extent, some of those data. We have interpreted the data as they are available from COGLA, and have not attempted to obtain copies of the original magnetic tapes from industry, in order to digitally reprocess and redisplay the lines in a longer and more uniform structural and migrated format.

Interval seismic velocities for stratigraphic units are taken from either the released acoustic logs or check shot surveys of the local wells (Vp) or, in the case of the deeper, undrilled zones, estimated (where data quality is adequate) by the Dix Equation (Dix, 1955) from the seismic processing, RMS velocities (Vd). These have been used to estimate the depths and thicknesses of the subsurface units [e.g. the depth scales shown on the seismic sections, Fig. 4-11, relative to the regional seismic datum of 305 m ASL have been built from these interval velocities and times by the cumulative "layer cake method"]. Those thicknesses and the interval velocities themselves were used to support tentative correlations with exposed sequences to the west and east. Within the study area a coherent stratigraphic and structural rationale is possible, however, cursory inspection of other seismic lines indicates that significantly greater structural complexity occurs to the south and southwest.

Precambrian strata lie below the regional sub-Cambrian unconformity (marker J, Figs. 4-11). On most sections, this unconformity is easily identified as the lowermost of a distinctive set of parallel seismic reflections, that truncates reflections representing the underlying Precambrian strata throughout the area. The Precambrian has been subdivided into two seismic sequences separated by a major unconformity (marker C). Sequence I, lying below unconformity C, is locally faulted and folded and has been affected by three, possibly four, phases of deformation. Some structures in that sequence are truncated by, and therefore predate, unconformity C; others were reactivated later to affect sequence II. Sequence II, above unconformity C, is mildly deformed by two phases of deformation. Phanerozoic rocks, mainly Cambrian to Devonian, unconformably overlie Precambrian strata, and have been affected by one phase of deformation, that which generated the isolated ridges of the Colville Hills (see Cook and Aitken, 1971; Davis and Willott, 1978).

F. A. Cook (1988a, b) analysed a number of seismic lines (one of which, 120A, is reproduced in Fig. 5) from east of Colville Hills. He interpreted Precambrian, flat thrust faults on the basis of reflection discontinuities and apparent structural repetition of layered strata. Cook considered these thrusts to represent an east verging, Proterozoic, thin-skinned thrust and fold belt, which he linked, via a regional, sub-horizontal detachment, to Proterozoic thrusting documented in the Inuvik area some 300 km to the northwest (F. A. Cook et al., 1987). In the present study, we recognize the need for some lesser measure of horizontal shortening, but we do not recognize Cook's specific thrust faults. Shortening, in our view is accomplished partly on broad folds and steeply-dipping reverse faults (the detachment level for which, must be deep in crystalline basement, at a minimum of 15 km below surface) and partly on moderate-displacement low-angle thrust faults with uncertain relationships to the steeper deeply-rooted structures.

Other studies of the Proterozoic in the region deal mainly with surface exposures in the Mackenzie Mountains to the west and Brock Inlier and Coppermine Homocline to the east (Fig. 1). Williams (l986) provided an outline of the general lithostratigraphy in the subsurface of Mackenzie River corridor and discussed possible links to outcrops to the west, and to the east. Aitken and Pugh (1984) correlated subsurface Proterozoic strata of the Colville Hills region with the informal Mackenzie Mountains supergroup, which has been extensively studied by Aitken (e.g., 1982; Aitken et al., 1978a, b). Aitken (1982) has also tentatively correlated the Mackenzie Mountains supergroup with strata of the Shaler Group exposed in Brock Inlier to the east (Fig. 1). Similarly, Young et al. (1979) correlated the lower part of the Mackenzie Mountains supergroup with the Rae Group in Coppermine Homocline, northeast and east of Great Bear Lake. There, Precambrian rocks mapped by Baragar and Donaldson (1973a, b), and Ross and Kerans (in press), occur in four gross packages. The oldest is composed of the highly deformed sedimentary, volcanic and intrusive rocks of the Lower Proterozoic Wopmay Orogen. These are unconformably overlain by the fluvial to shallow marine sandstones, conglomerates, shales and dolomites of the Hornby Bay Group, which has been assigned (by U-Pb zircon dating) a minimum depositional age of 1663 Ma (Bowring and Ross, 1985). These strata are unconformably overlain in turn by another fluvial to shallow marine sequence comprising the Dismal Lakes Group (mainly dolomite in the upper part and siliciclastic rocks in the lower part). There, a major regional paleokarst unconformity occurs near the top of the Dismal Lakes Group. In the Coppermine Homocline up to 80 m of shallow marine dolostone separate the karst surface from the overlying plateau basalts of the Coppermine River Group. The Coppermine River Group has been mapped over almost 300 km and consists of the lower, Copper Creek Formation of about 150 primarily subaerial basaltic flows of nearly constant thickness over large areas. The upper, Husky Creek Formation, consists of up to 1.2 km of red fluvial sandstones and a few basalt flows, recording declining volcanic activity. The youngest Proterozoic sequence, the Rae Group, comprising various clastic, carbonate, and minor gypsum beds, unconformably covers all of the other packages.

The regional subsurface unconformity interpreted and illustrated herein (marker C, Figs. 4 to 11) presumably is equivalent to one or more of the unconformities noted above, most likely that underlying the Rae Group. Seismic sequence II, accordingly, is correlated with some, or all, of the Mackenzie Mountains supergroup, the Rae Group, and the Shaler Group. Two of the three seismic units below the subsurface unconformity are correlated, in downward succession, unit Ic with the Husky Creek Formation, and unit Ib with the Copper Creek Formation. A third basal unit is believed to represent the Dismal Lakes Group and/or the Hornby Bay Group, but may include strata equivalent to formations in the highly deformed Wopmay Orogen (Fig. 3).

Our correlations of seismic sequences with exposed sequences in the region are in general agreement with those of F. A. Cook (1988a) with important differences regarding the placement of the sub-Rae Group unconformity, and the identification of major thrust fault repeats.

SEISMIC STRATIGRAPHY

Proterozoic sequence I

The lower seismic sequence is divided into three sub-units, Ia, Ib, and Ic (Figs. 3-11). In the western part of the study area the subdivisions of unit I are difficult to trace due to the combined affect of increased structural complexity and changing seismic character. On transect C-C' the change coincides with a large, westward-directed fault at about shot-point (sp) 1001 on line FR-14, (Fig. 6). On transect B-B' the change occurs at a zone of structural complexity at about sp 945 on line 114X (Fig. 5). On transect Z-Z' (Fig. 10) the change occurs northward, across the same large fault noted above on transect C-C'.

Unit Ia

Unit Ia typically is characterized by indistinct, hummocky, wispy seismic patterns. The top of unit Ia is a strong reflection (marker A, Fig. 4-11) that can be carried with confidence over the eastern portion of the study area, and is the most consistent seismic marker in the Proterozoic sequences . To the west few distinct, continuous reflections are identifiable in unit Ia, whereas to the east a number of problematical reflections occur (Fig. 8, and eastern parts of Fig. 5 and 7). Two prominent reflections S1 and S2 tend to be sub-horizontal and parallel to each other, but discordant to marker A, the top of unit Ia. A third, weaker reflection, S3, lies between but is non-parallel to S1 and S2. In line 120A, Figure 5, other reflections, including marker AA, lie immediately beneath and parallel to marker A. These various markers were interpreted by F.A. Cook (1988b, Fig. 4) to represent strata repeated by a major sub-horizontal thrust fault. We cannot accept his marker-by-marker correlations, and accordingly do not accept his thrust fault. Some of the complex relationships, as will be discussed later under STRUCTURE, can be interpreted as due to small-displacement thrust faults, which account for thickening in the overlying unit Ib, but do not explain the discordant reflections S1-S3. These may represent intrusive sheets as discussed later. Dix Interval Velocities calculated for unit Ia are generally high and vary between 6500 and 7500 m/sec. similar to those characteristic of buried dolomite, but at these depths (greater than 2.5 sec, or 8 km) the seismic processing velocities from which these were calculated are often unreliable.

Correlation of unit Ia: It will be argued below that unit Ib correlates with the plateau basalts of the Copper Creek Formation on Coppermine Homocline (coevally dated with the Muskox intrusion and Mackenzie dyke swarm, using U-Pb methods, as about 1267 Ma, by LeCheminant and Heaman, 1989). If so, the high-velocity unit Ia could represent dolomites of the Dismal Lakes Group which underlies the Copper Creek Formation in outcrop on Coppermine Homocline. Unit Ia, however, is much thicker than known thicknesses of the Dismal Lakes Group. Therefore the group may thicken dramatically westward, as the Hornby Bay Group is known to do southwestward [one of the Hornby Bay units has a tenfold thickness increase across

EONOTHEM	ERATHEM	SYSTEM	AGE (Ma)	FRONT RANGES, MACKENZIE MOUNTAINS (Williams, 1989)		COLVILLE HILLS–SEISMIC SEQUENCES (Cook and Mayers, 1990)			COPPERMINE HOMOCLINE (Baragar and Donaldson, 1973; Bowring and Ross, 1985; Heaman and Rainbird, 1990; Hoffman and Bowring, 1984; LeCheminant and Heaman, 1989)	
				Formation	Lithology (Thickness, km)	Formation/ Sequences	Velocity, m/s (Thickness, km)	Structural Events	Formation (Age, Ma)	Lithology (Thickness, km)
PHANEROZOIC	CENOZOIC	QUATERNARY	65		Sand, clay, till	Post Cambrian Not Studied	Vp=2100	Phase 3: small scale Laramide folding and faulting		
	MESOZOIC	CRETACEOUS	135		Ss, sh		Vp=3000			
	PALEOZOIC	DEVONIAN	410	*IMPERIAL* *CANOL* *RAMPARTS* *HARE INDIAN* *HUME* *BEAR ROCK*	Sh, ss Sh Lst Sh Lst Anhydrite, dol		Vp=5100 Vp=5100 Vp=6000 Vp=5100 Vp=6000 Vp=6400			
		SILURIAN–U. ORDOVICIAN		*MT. KINDLE*	Dol		Vp=6400			
		LOWER ORDOVICIAN	510	*FRANKLIN MTN.*	Dol		Vp=6400 (Saline River Reflector)			
		CAMBRIAN	570	*SALINE RIVER* *MOUNT CAP* *MOUNT CLARK*	Sh, evaporite Sh Ss	*SALINE RIVER* *MOUNT CAP* *MOUNT CLARK*	Vp=4600 Vp=4600 Vp=4800 (Reflection J)		Unnamed Units	Dol Ss, slst
PROTEROZOIC	UPPER PROTER.		770 1000	MACKENZIE MTN. SUPER GROUP KATHERINE GP. TSEZOTENE Unit H1 Unnamed	Quartzite (1.9) Slst (1.2) Dol (0.4) Sh, ss	sequence II	Vd=4500–6000 (0.5–3.0) (Reflection C)	Phase 2: thrust faulting, regional reactivation of phase 1	Coronation Sills (723)	Gabbro, diabase
									RAE GP.	Dol, ss, sh, mds (1.2)
	MIDDLE PROTEROZOIC					sequence Ic	Vd=6500 (0.0–1.7) (Reflection B)	Phase 1: large scale faulting and folding and smaller scale thrust faulting	COPPER-MINE RIVER GROUP (1267) *HUSKY CREEK*	Ss, slst, basalt (1.2)
						sequence Ib	Vd=6000–6500 (3.0–3.5) (Reflection A)		*COPPER CREEK*	plateau basalt, ss (3.0)
			1600			sequence Ia	Vd=6500–7500 (Thickness unknown)		DISMAL LAKES GROUP	Dol, ss, sh, mds, (1.1)
	LOWER PROTEROZOIC								HORNBY BAY GROUP (>1663)	Ss, dol, sh, cgl (2.0)
			2500						Deformed rocks of Wopmay Orogen (> 1840)	Sedimentary, volcanic, metamorphic, and igneous rocks

Figure 3. Correlation chart showing the interpreted relationships between the seismic sequences and sequence boundaries in the report area and exposed rocks in the Mackenzie Mountains (west) and the Coppermine Homocline (east). Vp-measured P Wave Velocity; Vd-calculated Dix Interval Velocity.

400 km from Coppermine Homocline to Cap Mountain to the southwest (G.M.Ross, pers. comm., 1989)]. Conversely, unit Ia could include rocks equivalent to one or both of the Hornby Bay Group and complexly deformed rocks of the Wopmay Orogen. Because we cannot identify a reflection that might represent crystalline basement, our unit Ia is undivided and corresponds to F.A. Cook's (1988a) sequences I and II combined.

Unit Ib

Unit Ib is an interval of fairly constant thickness (1.0 - 1.2 sec.) characterized by a weak or semi-transparent pattern of parallel reflections. Based on its relatively uniform Dix seismic velocity of 6 to 6.5 km/sec. this unit is calculated to be 3 to 3.5 km thick over most of the study area. However, near the east side of the area, on lines 120A (Fig. 5) and 90X (Fig.7) the unit thickens eastward abruptly from 3 to 4 km over a distance of about 27 km. This may be depositional, but it appears more likely to be due to structural duplication on two or more thrust faults. One of these, as interpreted on line 120A (Fig. 5), has a horizontal displacement of 5 or 6 kilometres. A second such fault with one or two kilometres of shortening is identifiable on a number of short lines that are sub-parallel to line 120A. Both faults have been carried southward on transect X-X', line 77A (Fig. 11) into line 90X (Fig. 7) and interpreted there to explain the sudden thickening of unit Ib. These faults are of modest displacement relative to those interpreted by F.A. Cook (1988a, b) in the same general area. The upper contact with unit Ic is transitional into a zone of strong parallel seismic markers, and the boundary is selected as the lowest, consistently strong reflection (marker B, Figs. 4-11). This reflection is readily identified on B2-B' east of about sp 945 of line 114X (Fig. 5), and on transect C-C1, east of about sp 900 of line FR-14, (Fig. 6). West of those points, it is less reliably identified, due to structural complexities, and changing seismic character of the units.

Correlation of unit Ib: Unit Ib corresponds generally with F.A. Cook's seismic sequence III, and is correlated with the Copper Creek Formation composed largely of plateau basalts (Fig. 3). Its relatively uniform seismically calculated thickness of about 3 km, Dix interval velocity of 6.0 to 6.5 km/sec., and uniform reflection character, compare favourably with a measured thickness (Baragar and Donaldson, 1971) of 3 km for the Copper Creek Formation and expected velocities of 4 to 6.5 km/sec. for volcanic rocks. This correlation implies that the Coppermine basalts extend westward, with little thinning, into the subsurface for at least 300 km, and would more than double their known lateral extent and volume. This correlation supports Davis and Willot (1978) who attributed magnetic anomalies, coincident with Colville Hills structures, to the folded or faulted involvement of Coppermine basalts in these structures.

Unit Ic

Seismic unit Ic is a zone of strong parallel reflections, which varies in thickness from zero to 1.2 seconds (zero to 3.5 km) because of truncation by an overlying regional unconformity (marker C, Figs. 4-11). The truncation is best seen in the hanging wall of a large, tilted fault block shown in Figures 6 and 10 (lines FR-14 and FR-12). The unit is tentatively identified west of the fault, some 4-5 km deeper, as indicated. In this interpretation the unit thickens dramatically across the fault because of greater preservation in the footwall block and erosional truncation in the hanging wall block.

Correlation of unit Ic: If unit Ib, discussed above, correlates with the Copper Creek Formation, it follows that the overlying, multilayered unit Ic correlates with the interbedded clastic and volcanic rocks of the Husky Creek Formation in Coppermine Homocline. Unit Ic corresponds in a general way with F.A. Cook's (1988a, Fig. 3) seismic reflection sequence IV, with the exception that reflections at the base of unit Ic, in line 120A, Figure 5, were interpreted by Cook (1988a, b) to be a thrust repetition of reflections above and below our marker A (compare his Figs. 4, 1988a and b, with our Fig. 5). That interpretation is, in our view, precluded by the regional extent of units Ib and Ic presented here (Figs. 5 and 7).

Proterozoic sequence II

Sequence I is separated from sequence II by a regional unconformity (marker C, Figs. 4-11) which is locally angular, truncating structures affecting sequence I (e.g., Fig. 6, line FR-14, sp 401-1001). It is nonetheless difficult to trace with precision across the entire region because it does not everywhere correspond to an observable velocity/density contrast, and over large areas it is paraconformable. Indeed, in the eastern part of the area (e.g. Fig. 7) apparent truncation of underlying sequence I strata could be attributed to depositional wedging. The obvious truncation noted further west, however, seems to require the existence of a regional unconformity.

Sequence II has an indistinct seismic character, with a few strong, internal, reflections. In the western part of the study area a single strong reflection (marker G) occurs about 0.8 seconds above the base of the sequence. (Figs. 4-6, 9, 10). It has been truncated by erosion at the sub-Cambrian unconformity (marker J) but is preserved in a westward dipping homocline and in a synclinal outlier, both of which are outlined by the erosional zero-edge (Fig. 2). Broad facies changes in sequence II are indicated by the disappearance eastward of marker G (Figs. 5 and 7), and the appearance eastward of a lower reflection (marker D, Fig. 7). Overall, sequence II strata occur in a broadly undulating, westward dipping, homoclinal wedge that thins eastward to zero thickness due to erosion at the sub-Cambrian unconformity. This interpretation negates the existence of the broad anticlinal Great Bear Arch suggested by Aitken and Pugh (see Fig. 1).

Markers E and F on Figure 6 are problematical in that they cut upsection eastward across sequence II. Either of these might be interpreted to represent the regional unconformity C. In each such interpretation, strata lying east of the reflector would comprise an additional unit(s) in sequence I. Such interpretations have not been followed here because we have been unable to identify equivalent reflections "E" or "F" on transect B-B' to the north, nor on any of the tie-lines. Reflections E and F might represent eastward directed thrust faults. If so, they must be listric into an unseen detachment surface above reflection C, because underlying reflections are not displaced.

Correlation of sequence II: Sequence II probably correlates with the Mackenzie Mountains supergroup to the west, and with the Shaler and Rae groups to the east. Strata immediately underlying the sub-Cambrian unconformity have been identified as various formations of the informal Mackenzie Mountain supergroup in a number of wells in the region. Wissner (l986) identified the Tsezotene Formation in the PCI Sammons H-55 well, which is situated on Imperial Anticline west of the Mackenzie River. Aitken and Pugh (1984) correlated Precambrian rocks encountered in fifteen wells in the greater Anderson Plains area with formations of the Mackenzie Mountains supergroup. Their contact between "map-unit H1" and "unnamed shale and sandstone" probably corresponds to our marker G (Figs. 4,-

6, 9, 10) in the western part of the study area (compare their generalized trace for that contact with the zero-edge of marker G, Fig. 2).

The thickness of sequence II varies from a maximum of 3-4 km to zero. Because the lowermost unnamed shale and sandstone of Aitken and Pugh (1984) in the subsurface is virtually unseen in the Mackenzie Mountains, and because of apparent facies changes eastward, no direct thickness comparisons can be made with measured thicknesses in the Mackenzies. Katherine Group and older units of the Mackenzie Mountains supergroup vary from l.6 to 3.5 km in thickness (Aitken, et al., 1973). This supergroup has been correlated in a general way with the Rae Group exposed in Coppermine Homocline, the Shaler Group on Victoria Island and with unnamed units on Brock Inlier (Young et al., 1979; Aitken, 1982). Accordingly, sequence II also is correlated eastward with the Rae and Shaler groups. A major unconformity at the base of the Rae Group (Baragar and Donaldson, 1973a, b), analogous to our unconformity C, supports that conclusion. It is noteworthy that the sub-Rae Group unconformity, as mapped by Baragar and Donaldson, appears paraconformable over part of its surface trace, but elsewhere cuts rapidly downsection. Our unconformity C, seems to be significantly lower than the sub-Rae Group unconformity indicated by F.A. Cook (1988a, Fig. 3), and probably occurs near the base of his reflection sequence V.

Alternative General Correlations

The regional unconformity C, identified here, could correlate with the contact between the Dismal Lakes and Hornby Bay Groups on Coppermine Homocline. That contact is unconformable in places and conformable in others (Ross and Kerans, 1989). In that rationale, unit Ia would represent crystalline basement probably equivalent to Wopmay orogen; units Ib and Ic would represent Hornby Bay Group; and unit II would represent Dismal Lakes Group and younger rocks including basalts of the Coppermine River Group.

Support for such an interpretation may be found in the occurrence of basalts encountered in three wells south of the study area (PCI Canterra Nogha O-47, PCI Canterra Bele O-35, and PCI et al Tweed Lake M-47). Current studies by D. G. Cook and B. C. MacLean indicate that those basalts occur very high in the Proterozoic succession. If future studies establish that they correlate with the Coppermine River Group, the stratigraphic units defined in this report will require major reassignment. In particular, the laterally extensive sequence II, (here correlated with Rae Group and Mackenzie Mountain supergroup) would be older than the Coppermine basalts.

Conversely, those basalts may correlate in a general way with basalts noted near the top of the Mackenzie Mountain supergroup to the west (Aitken, 1982). That case would support the correlations suggested here (Fig. 3), particularly that of sequence II representing Mackenzie Mountain supergroup.

Intrusive Sheets

A number of seismic reflections are interpreted as representing intrusive sheets. One of these, marker H (see line 120A, Fig. 5, and 90X, Fig. 7) cuts discordantly across seismic sequence Ib. Three other markers S1, S2, and S3 cut discordantly across unit Ia (Figs. 5, 7, and 8). These are sub-horizontal or gently east dipping, and were interpreted by Cook (1988a, b) as representing stratigraphic layering in the footwall of the lower, of two large-displacement thrust faults. An alternative interpretation, offered here, is that these sub-horizontal reflections represent intrusive sheets.

Diabase sills intrude the Mackenzie Mountains supergroup to the west, and the Shaler, Rae, Coppermine, Dismal Lakes and Hornby Bay groups to the east. Consequently, they are to be expected in the Precambrian rocks imaged on these sections. If reflections S1-S3 (Figs. 5, 7, and 11) do represent intrusive sheets, the intrusions cross-cut, and therefore postdate, the tilted panel of sequences I and II, would be younger than sequence II, and may have been emplaced in the same general period as diabase dikes and sills mapped by Cook and Aitken (1969), intruding strata equivalent to the Shaler Group on Brock Inlier, and to the Coronation Sills (604-718 Ma) which cut the Rae Group on Coppermine Homocline (Baragar and Donaldson, 1973).

Phanerozoic Strata

Phanerozoic strata in the study area include those of Cambrian, Ordovician, Silurian, Devonian, and Cretaceous ages. The Phanerozoic is easily identified on most seismic lines because the lower part of the section, comprising sandstones, shales, and evaporites of the Mount Clark, Mount Cap, and Saline River formations, is expressed as a distinct band of parallel reflections. The base of that band, (marker J) moreover, commonly truncates reflections from the underlying Proterozoic beds.

STRUCTURE

The region has been subjected to three, possibly four, phases of compressional deformation. The first (1a and 1b) affected strata of sequence I; phase 2 affected strata up to and including sequence II, and reactivated phase 1a and 1b structures; and the third and youngest affected all strata in the region including the Phanerozoic.

Phase 1

Phase 1 structures affect sequence I strata, and are truncated by unconformity C. They occur as two distinct sets: a) large structures that must extend to depths of at least 15 km, and b) smaller thrust faults that may detach at much shallower levels. Because they have significantly different characters they may represent separate periods of deformation. Thus, even though they cannot be differentiated temporally, they are described separately below as phases 1a and 1b

Phase 1a:

Phase 1a is represented, in the lines interpreted here, as a large fault, with vertical offset of about 5 km, and one anticline 20 km across and 4 km high. The fault occurs as a broad zone of disruption of seismic markers, and is westward directed. It is well displayed on Figures 6 and 10, and because those figures are perpendicular to each other the structure is known to strike about north-south from line FR-14 (Fig. 6) to line FR-12 (Fig. 10). Through cursory examination of a number of adjacent lines the fault zone has been traced as a curvilinear zone at least 100 km long (Fig. 2). As all of sequence I is nowhere visible on both sides of the fault, which largely coincides with a zone of poor record, correlation across it is difficult. However, we have concluded that marker B can be identified on both sides of the fault, and from this and general considerations of the overall structure, a number of conclusions can be drawn. Firstly, the upthrown eastern block is a large tilted or rotated mass with a minimum structural relief of 5 km, as measured on the A and B markers. Rotation of the hanging wall block implies that it is underlain by a curved, eastward dipping thrust fault as interpreted in Figure 6. Secondly, the strata imaged in the western, footwall block, terminate abruptly at the fault zone and do not project beneath the hanging wall block. The structure appears, therefore, to be a deeply rooted, curved reverse fault. Tentative correlations across the fault zone imply vertical offset of at least 5 km and require that any detachment surface, relative to this deformation, be at a minimum depth of 15 km. In gross geometry the structure seems to be analogous to the intra-cratonic, crustal-scale, Laramide uplifts of the Rocky Mountain foreland of mid-western U.S.A. (e.g., Matthews, 1978). Considering its geometry and its northwestward sense of transport, the fault appears to be incompatible with a regional, "thin-skinned", eastward directed thrust belt interpreted by F.A. Cook (1988a, b) in the eastern part of our study area.

A large anticline in the northern part of the area (Fig. 5) is 20 km across and 4 km high, and because of its size is considered to be a phase 1a structure.

It is noteworthy that sequence I strata in the anticline, and in the hangingwall of the fault, are truncated by the regional unconformity C, yet the unconformity is bowed upwards over the structures by 1 or 2 km (vertical) of post-unconformity reactivation.

Phase 1b:
Sequence I is also cut by smaller-scale thrust faults, mostly eastward verging (for example see Figs. 7 and 10). These faults are flatter and although these too must have a detachment level in or below unit Ia, seem to require a shallower detachment surface than the large fault described above. Available data do not permit a temporal separation, and phase 1b structures could have developed contemporaneously with, earlier than, or later than phase 1a structures.

F.A. Cook (1988a, b, Figs. 4) interpreted thrust faults, cutting sequence I strata in this region, with 50 to 90 km of shortening above a regional detachment surface occurring about 1 km below the top of our unit Ia. We recognize compressive deformation of the same general age as that indicated by F.A. Cook, but do not recognize his specific thrust faults, nor the same magnitude of shortening. Line 120 A in Figure 5 was also interpreted by F. A. Cook (1988b, Fig. 4). His upper thrust, there, was based on the interpretation that reflections in our unit Ic were a thrust-repetition of reflections above and below the top of our unit Ia, an interpretation that we do not accept considering the regional distribution of units Ia, Ib, and Ic. Cook's lower thrust provided a rationalization for problematical reflections (S1, S2, and S3) discussed above under unit Ia. If his interpretation were applied to our markers, then S2 (Fig. 5) in a footwall plate would correlate with a weakly defined marker in unit Ib in a hangingwall plate. Similarly marker S3 in the footwall would correlate with marker A in the hangingwall. We do not accept these correlations, and offer the alternative suggestion that the problematical reflections, S1, S2, and S3, represent intrusive sheets, in which case no major thrust fault is required. Further studies will no doubt resolve the identities of these markers.

Phase 2

A number of minor thrust faults, both east and west verging, offset markers in sequence II, and are truncated by the sub-Cambrian unconformity (marker J). Some of these appear to be listric into some detachment level within sequence II (e.g. at sp 830 to 850, line M63-10, Fig. 6). Others root at deeper levels and offset the regional unconformity C (e.g. at sp 781 to 931, line 101X, Fig. 10) Some of these faults, for example those on Figure 10 show greater offset of markers below the unconformity than of those above, indicating reactivation of earlier-formed 1b structures. The large, phase 1a structures also experienced reactivation at this time, because unconformity C is bowed into broad anticlines over the 1a structures. For example the large 1a fault structure illustrated in Fig. 6 has about 5 km of vertical uplift, of which about 2 km is a consequence of post-unconformity deformation. Similar reactivation is recorded by the tilting of unconformity C over the large anticline (see lines 1 and 2, Fig. 5).

Phase 2 thrust faults are interpreted to account for abrupt thickening of unit Ib in the eastern part of the area (Figs. 5, 7, and 11). These faults are inferred to have developed during phase 2 because unconformity C is tilted with other strata as a consequence of displacements on them. These are best displayed on Figure 5, where the thickening of unit Ib can be attributed primarily to a thrust fault with stratigraphic offset of about 6 km. The locus of the fault is defined by the footwall cutoffs of marker AA, and a parallel, higher, reflection couplet which abruptly diverges westward from parallelism with marker A. Marker A is difficult to identify in the footwall presumably because there is no velocity/density contrast across the thrust, in the zone where it coincides with the top of unit Ia. A second thrust fault, east of the first, can be identified on a number of short lines (not shown) south of line 120A, Figure 5. Both of these faults are carried southward on line 77A (Fig. 11) and projected into line 90X of Figure 7. The seismic records of transect C3-C' are of very poor quality, but permit extension of the faults eastward where they appear to offset marker B at the top of unit Ib. Unit Ib returns to normal stratigraphic thickness in the footwall of the easternmost fault.

The phase 2 structures are important, because they represent a little known orogenic event affecting strata correlative with the Mackenzie Mountain supergroup. Precambrian faulting of strata of this age has previously been interpreted on Brock inlier to the east (Yorath and Cook, 1981).

Phase 3

Phase 3 thrust faults offset Proterozoic and Phanerozoic strata (e.g. line FR-14, sp 901-1001, Fig. 6). That structure is local and must be listric, becoming bedding-parallel at a very shallow depth. Other faults cutting the Phanerozoic affect much larger blocks and must root deeper in the section (e.g. sp 1030, Fig. 11). Faults that disrupt the Phanerozoic commonly occur above a zone of disruption in the Precambrian, and have probably been localized by the presence of older structures. The details of any such relationship have not as yet been established. Structures generated during phase 3 are expressed at surface as the isolated ranges of the Colville Hills.

CONCLUSIONS

Seismic interpretation across a 30 000 km2 region of the Colville Hills indicates that:

1. The Proterozoic rocks in the northern part of the Colville Hills region can be subdivided into two major sequences (I and II) separated by a locally angular, locally paraconformable unconformity (marker C) that appears to correlate with that mapped at the Coppermine River Group - Rae Group boundary in the Coppermine Homocline to the east.
2. Sequence I is subdivided into three units, Ia, Ib, and Ic. Unit Ia is correlated with the Dismal Lakes Group, but may include rocks equivalent to the Hornby Bay Group and/or highly deformed rock units of the Wopmay Orogen. Sequence Ib is correlated with the plateau basalts of the Copper Creek Formation, and unit Ic is correlated with fluvial sandstones and occasional basalt flows of the Husky Creek Formation.
3. Sequence II unconformably overlies sequence I and is correlated, to the west, with the Mackenzie Mountains supergroup, and to the east, with the Rae and Shaler groups. Marker G may correspond to a contact interpreted by Aitken and Pugh (1984) subdividing

sequence II into shales and sandstones below and dolomites of map-unit H1 above.

4. In alternative correlations unit Ia could represent crystalline basement; units Ib and Ic could represent Hornby Bay Group; and unit II could represent Dismal Lakes Group and younger rocks including basalts of the Coppermine River Group. This or some similar correlation scheme will be required if basalts, which occur very high in the Proterozoic succession in three wells south of the study area, are shown to correlate with the Coppermine basalts.
5. The shallower, sub-Cambrian unconformity that has been mapped in outcrop and penetrated by exploration wells is readily detected on the seismic profiles (reflection J).
6. Proterozoic rocks have been deformed by three, possibly four phases of compression directed roughly east-west. The earliest of these (phase 1) postdates strata interpreted to correlate with the Husky Creek Formation, and affected only sequence I strata. The most significant early structure is a large rotated, or tilted, fault block interpreted as being underlain by a steeply dipping, curved reverse fault which extends to at least 15 km below surface (phase 1a). Gross geometry of the structure seems to be analogous to, although at a smaller-scale than, that of intracratonic, crustal scale uplifts typical of Wyoming. Smaller scale, shallower angle, thrust faults also post-date Husky Creek Formation strata and pre-date unconformity C. They may result from a separate phase of deformation (phase 1b) from that which produced the large rotated blocks of phase 1a. Although deformation of this general age in this region has been previously interpreted by F.A.Cook (1988a, b) we do not recognize his two large displacement, sub-horizontal thrust faults. Resolution of the lower of his faults is dependant on the identification of a number of strong, sub-horizontal reflections that are considered here to be post-orogenic igneous intrusions, but which were thought by F.A. Cook to be pre-orogenic footwall strata.
7. If the above-noted reflections S1 and S2 represent intrusive sheets, they are younger than sequence II strata, and probably are related to the Coronation Sills emplaced on Coppermine Homocline.
8. A second compressional deformation, phase 2, was less intense, and postdates strata correlated with the Mackenzie Mountains supergroup and the Rae Group. It affected both sequences I and II. Compressive deformation of this age in northwestern Canada has previously been only weakly documented.

9. The third, and last, compressional deformation (phase 3) was post-Early Cretaceous, and is probably related to the Tertiary Laramide orogenic development of the Mackenzie and Franklin Mountains to the southwest. Displacements during this phase of deformation, which resulted in the development of the Colville Hills, were relatively small and were probably localized by underlying earlier structures.

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