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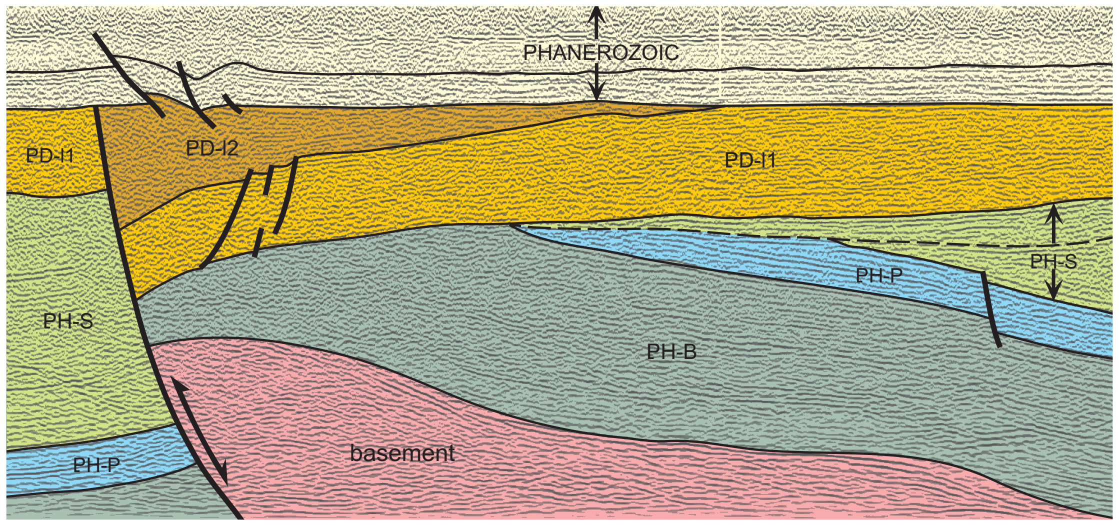
D.G. Cook and B.C. MacLean



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Cover illustration
Interpreted seismic line, 1983 Forward Resources Line FR14, showing a Forward Orogeny basement-involved compressional fault that was reactivated by later extension. See Figure 20 for full explanation.

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SUBSURFACE PROTEROZOIC STRATIGRAPHY AND TECTONICS OF THE WESTERN PLAINS OF THE NORTHWEST TERRITORIES

ABSTRACT

Reflection seismic records from the northwestern plains of the Northwest Territories reveal about 14 km of Proterozoic strata deformed to varying degrees, including spectacular large-scale faults and folds. The Proterozoic section, subdivided into four seismic assemblages representing five unconformity-bounded sequences, can be reasonably correlated with outcropping strata on Coppermine Homocline and Brock Inlier to the east and in the Cordillera to the west. Correlations are based largely on recognizing similar stratigraphic and tectonic histories. The HB Assemblage at the base of the subsurface stratigraphic column contains two unconformity-bounded sequences, the lower of which is correlated with the Bigbear and Fault River formations (of the Hornby Bay Group) on Coppermine Homocline, and with the Wernecke Supergroup in the Cordillera. The upper sequence, comprising the Basinal, Platformal, and Syntectonic units (of the HB Assemblage), is correlated with the deltaic Lady Nye Formation, platformal East River Formation, and syntectonic Kaertok and LeRoux formations, (of the Hornby Bay Group) on Coppermine Homocline, but has no known correlatives in the Cordillera. The DL Assemblage is the third sequence and is correlated with the Dismal Lakes Group on Coppermine Homocline, and the Pinguicula Group in the Cordillera. The fourth sequence, the Tweed Lake Assemblage, is correlated with the Coppermine River Group on Coppermine Homocline (a correlation supported by chemical analyses of basalts) and has no known correlative in the Cordillera. The fifth and stratigraphically highest sequence, the M/S Assemblage, is correlated with the Shaler Supergroup on Coppermine Homocline, and the Mackenzie Mountains Supergroup and Hematite Creek Group in the Cordillera (correlations that are supported by the presence of ‘Grenville-age’ detrital zircons, and macro- and microfossils).

The subsurface tectonic history includes compressional and extensional events, and parallels remarkably well the history of Coppermine Homocline. The most important compressional event, the thick-skinned, intracratonic Forward Orogeny, identified in the subsurface and on Coppermine Homocline, is probably related to the Racklan Orogeny, identified in the Wernecke Mountains of the Cordillera. Forward Orogeny basement-cored structures affected HB Assemblage and older strata and were peneplaned by regional erosion before deposition of the DL Assemblage and correlative strata. The most important extensional event postdated DL Assemblage deposition and occurred primarily as a reactivation of Forward Orogeny faults. Other structures include early extensional faults related to Basinal Unit subsidence, and late, long-wavelength folds affecting the Tweed Lake Assemblage, M/S Assemblage, and correlative strata.

Strong, discordant seismic reflections are mostly interpreted as representing intrusive sheets that are correlated with Western Channel Diabase sheets on Coppermine Homocline. Younger sheets imaged in M/S Assemblage strata are correlated with the Tsezotene sills exposed in the Mackenzie Mountains.

The Cambrian Mackenzie Trough, grabens and half-grabens developed at various times (Early Cambrian, post-Devonian/pre-Cretaceous, and post-Cretaceous), the transpressional (Laramide?) Colville Hills, and the Laramide Imperial Anticline, are all Phanerozoic elements whose development was influenced by Proterozoic history.

RÉSUMÉ

Des profils de sismique-réflexion obtenus dans les plaines du nord-ouest des Territoires du Nord-Ouest ont révélé la présence de strates protérozoïques cumulant environ 14 km d’épaisseur. Ces strates, qui ont été déformées à divers degrés, contiennent des failles et des plis à grande échelle. La coupe protérozoïque est subdivisée en quatre assemblages sismiques, qui représentent cinq séquences limitées par des discordances; elle peut raisonnablement être mise en corrélation avec des strates qui affleurent à l’est dans l’homoclinal de Coppermine et la boutonnière de Brock, et à l’ouest dans la Cordillère. Les corrélations sont en grande partie basées sur la reconnaissance de stratigraphies et d’évolutions tectoniques semblables. L’assemblage de HB, à la base de la succession stratigraphique enfouie, se compose de deux séquences limitées par des discordances. La séquence inférieure de l’assemblage de HB est mise en corrélation avec les formations de Bigbear et de Fault River (Groupe de Hornby Bay) dans l’homoclinal de Coppermine, et avec le Supergroupe de Wernecke dans la Cordillère. La séquence supérieure de l’assemblage de HB, qui se compose d’une unité de bassin, d’une unité de plate-forme et d’une unité syntectonique, est mise en corrélation avec des formations du Groupe de Hornby Bay dans l’homoclinal de Coppermine : la Formation de Lady Nye (faciès deltaïque), la Formation d’East River (faciès de plate-forme), ainsi que la succession syntectonique constituée des formations de Kaertok et de LeRoux. Cette séquence n’a pas d’équivalent connu dans la Cordillère. L’assemblage de DL, qui constitue la troisième séquence, est mis en corrélation avec le Groupe de Dismal Lakes dans l’homoclinal de Coppermine, et le Groupe de Pinguicula dans la Cordillère. La quatrième séquence, soit l’assemblage de

Tweed Lake, est mise en corrélation avec le Groupe de Coppermine River dans l’homoclinal de Coppermine (corrélation qu’appuient des résultats d’analyse chimique de basaltes), mais n’a pas d’équivalent connu dans la Cordillère. La cinquième séquence, soit l’assemblage de M/S, au sommet stratigraphique de la coupe, est mise en corrélation avec le Supergroupe de Shaler dans l’homoclinal de Coppermine, ainsi qu’avec le Supergroupe de Mackenzie Mountains et le Groupe de Hematite Creek dans la Cordillère (corrélations appuyées par la présence de zircons détritiques d’âge «grenvillien», et étayées par des macrofossiles et des microfossiles).

L’évolution tectonique des strates enfouies, qui comprend des épisodes de compression et de distension, présente un parallélisme remarquable avec celle de l’homoclinal de Coppermine. L’épisode de compression le plus important a été l’orogenèse de Forward, une déformation intracratonique qui a mis en jeu le socle. Cette orogenèse, dont les traces sont reconnues dans la succession enfouie ainsi que dans l’homoclinal de Coppermine, est probablement liée à l’orogenèse du Racklan, dont les effets ont été identifiés dans les monts Wernecke de la Cordillère. Les structures à noyau de socle de l’orogenèse de Forward ont mis en jeu l’assemblage de HB ainsi que les strates plus anciennes. Ces structures ont subi une pénéplanation due à une érosion régionale avant le dépôt de l’assemblage de DL et des strates corrélatives. Le plus important épisode de distension a suivi le dépôt de l’assemblage de DL, et s’est principalement manifesté par une réactivation des failles formées lors de l’orogenèse de Forward. Les autres structures comprennent notamment des failles de distension liées à la subsidence de l’unité de bassin de l’assemblage de HB, tôt dans l’évolution du bassin, ainsi que des plis à grande longueur d’onde qui se sont formés tard dans l’évolution du bassin et qui ont touché l’assemblage de Tweed Lake, l’assemblage de M/S et les strates corrélatives.

La plupart des réflecteurs sismiques marqués et discordants représenteraient des feuillets corrélatifs de ceux de la diabase de Western Channel dans l’homoclinal de Coppermine. Des feuillets plus récents qui sont visibles sur les profils des strates de l’assemblage de M/S sont mis en corrélation avec les filons-couches de Tsezotene, qui sont exposés dans les monts Mackenzie.

La cuvette de Mackenzie (Cambrien), les grabens et demi-grabens formés à différentes époques (Cambrien précoce, post-Dévonien/pré-Crétacé et post-Crétacé), ainsi que les collines de Colville formées par transpression (Laramide?) et l’anticlinal d’Imperial (Laramide) sont tous des éléments phanérozoïques dont la formation a été influencée par les événements du Protérozoïque.

SUMMARY

This report presents the results of a study of subsurface Proterozoic strata underlying an area encompassing almost 400 000 km^2 of northwestern Canada, bounded by the Mackenzie Mountains on the west and Coppermine Homocline on the east, and extending from 63° North latitude to the Arctic coast. The study was based primarily on seismic data originally acquired by the petroleum industry for exploration purposes and now in the public domain. Tens of thousands of line kilometres of reflection seismic data were studied and they revealed a layered Proterozoic section, up to 5 seconds thick (14 km at a 5500 m/s seismic velocity), deformed to various degrees, including spectacular large-scale faults and folds. The primary objectives were to interpret the Proterozoic stratigraphic and structural sequences portrayed in the seismic records and to correlate them, as fully as possible, with Proterozoic strata and events known from outcrops on Coppermine Homocline, Brock Inlier, and Victoria Island to the east, and in the Mackenzie and Wernecke mountains to the west.

Precambrian basement and five unconformity-bounded Proterozoic sequences, which have been deformed by a number of extensional, compressional and possibly transpressional events, have been identified. Correlations from subsurface to surface are proposed primarily on the basis of parallel geological histories, augmented by analytical data including geochemical analyses of basalts cored in two exploration wells drilled in the Tweed Lake area (Sevigny et al., 1991), gravity and aeromagnetic signatures of basalts (MacLean and Miles, 2002), geochronology of detrital zircons (Rainbird et al., 1996b; Villeneuve et al., 1998), and limited lithostratigraphic data from other exploration wells. Names that indicate correlations, but emphasize their provisional nature have been applied to subsurface units. Thus the subsurface ‘HB Assemblage’ is correlated with the surface ‘Hornby Bay Group’, and ‘DL Assemblage’ is correlated with ‘Dismal Lakes Group’. The subsurface ‘M/S Assemblage’ is correlated with the surface ‘Mackenzie Mountains and Shaler supergroups’. Basalts drilled in the Tweed Lake area are referred to as the Tweed Lake basalts and are placed within the Tweed Lake Assemblage. These are correlated with the Copper Creek Formation and the Coppermine River Group, respectively.

The HB Assemblage comprises four units. At the base of the assemblage is a discontinuous sequence of strata, assigned to the Lower Unit, which is correlated eastward with the discontinuous Bigbear and Fault River formations, the lowermost formations of the Hornby Bay Group on Coppermine Homocline, and westward with the very thick Wernecke Supergroup in the Cordillera. The ages of the Bigbear and Fault River formations fall between 1.84 Ga (the age of the underlying Wopmay basement) and 1663 Ma (the age of the Narakay volcanic complex, found higher in the column). The age of the Wernecke Supergroup is known only to be greater than 1.71 Ga. Unconformably overlying the Lower Unit is a tripartite sequence comprising the Basinal, Platformal, and Syntectonic units of the HB Assemblage, which are correlated respectively with the deltaic Lady Nye, the platformal East River, and the syntectonic Kaertok and LeRoux formations of the Hornby Bay Group. This tripartite succession has no established counterpart in the Cordillera. The only age control for this succession comes from the Kaertok Formation, which contains the Narakay volcanic complex dated at 1663 Ma. The DL Assemblage, which unconformably overlies the HB Assemblage, is correlated eastward with the Dismal Lakes Group on Coppermine Homocline and westward with the Pinguicula Group (as redefined by Thorkelson, 2000) in the Cordillera. The age of the Dismal Lakes Group is bracketed by 1663 Ma, the age of the Narakay complex, below, and 1267 Ma, the age of the Coppermine basalts above.

Following Sevigny et al. (1991), basalts encountered in the Tweed Lake wells are correlated with the basalts dated as 1267 Ma in the Coppermine River Group on the homocline. These have no known counterparts in the Cordillera.

The M/S Assemblage is correlated eastward with the Shaler Supergroup on Coppermine Homocline, Victoria Island and Brock Inlier, and westward with the Mackenzie Mountains Supergroup and the Hematite Creek Group in the Cordillera. The age of the Mackenzie/Shaler package is known to be younger than circa 1 Ga, the age of contained detrital zircons, and older than basic intrusions, which cut across it (779 Ma for those cutting the Shaler Supergroup, and 723 Ma for those intruding the Mackenzie Mountains Supergroup).

The youngest Proterozoic strata in the region pertain to the Windermere Supergroup in the Cordillera and the Natkusiak Formation basalts on Victoria Island. Windermere Supergroup equivalents have not been identified in the subsurface.

A variety of tectonic events affected the region during the greater than 1 billion years represented by the strata studied. Both compressional and extensional events have been identified, and transpressional events inferred. Inversions of pre-existent structures are common. Recognition of the remarkable parallelism of the tectonic histories of the subsurface and surface strata is a key component of our correlation rationale.

The most important tectonic event was the Forward Orogeny, a compressional, intracratonic, thick-skinned deformation somewhat comparable to that of the Rocky Mountain foreland of the United States. First recognized in the seismic records, its effects can be identified on the published maps of Coppermine Homocline of Ross and Kerans (1989). There, one phase of deformation is dated at 1663 Ma, the age of the Narakay volcanic complex that lies within the syntectonic Kaertok Formation (Bowring and Ross, 1985). Forward Orogeny structures affecting both HB Assemblage and Hornby Bay Group strata were peneplaned by prolonged erosion and subsequently overlain unconformably by DL Assemblage and Dismal Lakes Group strata. The Forward Orogeny (circa 1663 Ma) is correlated with the Racklan Orogeny (1.71 Ga – 1.59 Ga), the effects of which are recorded in the Cordillera by deformed Wernecke Supergroup strata. These strata were subsequently truncated by erosion and overlain unconformably by the Pinguicula Group (Thorkelson, 2000).

A major extensional event postdated DL Assemblage and Dismal Lakes Group deposition and was expressed primarily by inversions of Forward Orogeny faults. Other tectonic events include early extensional faulting related to subsidence during deposition of the lower portion of the Basinal Unit and late, long-wavelength folding affecting the entire Proterozoic section.

Strong, discordant, and discontinuous seismic reflections within the HB Assemblage are interpreted, in most cases, as representing intrusive sheets that are, in turn, correlated with sheets of the Western Channel Diabase that were mapped on Coppermine Homocline by Ross and Kerans (1989) and assigned an age of 1408 Ma by Wanless and Loveridge (1978) and Wanless et al. (1970). Younger sheets that have been identified on the seismic within M/S Assemblage strata adjacent to the Mackenzie Mountains have been confirmed by well control to represent the 779 Ma Tsezotene sills, which are exposed in the Mackenzie Mountains.

The development of many Phanerozoic tectonic elements and structures was influenced by the pre-existent Proterozoic framework. These elements include the Cambrian Mackenzie Trough, the transpressional (Laramide ?) Colville Hills, the Laramide Imperial Anticline, and shallow grabens and half-grabens that developed during at least three poorly understood extensional events (Early Cambrian; post-Devonian/pre-Cretaceous; and post-Cretaceous).

SOMMAIRE

Ce rapport présente les résultats d’une étude sur des strates protérozoïques enfouies qui s’étendent sur près de 400 000 km2 dans le nord-ouest du Canada, dans une région délimitée à l’ouest par les monts Mackenzie, à l’est par l’homoclinal de Coppermine, au sud par le 63e parallèle de latitude Nord, et au nord par l’océan Arctique. Cette étude s’est principalement basée sur des données sismiques qui ont été recueillies à l’origine par des sociétés pétrolières pour des fins d’exploration, mais qui ont depuis été versées dans le domaine public. L’examen de données de sismique-réflexion cumulant des dizaines de milliers de kilomètres linéaires a révélé l’existence d’une succession protérozoïque stratifiée dont l’épaisseur atteint jusqu’à cinq secondes (14 km, suivant une vitesse des ondes sismiques de 5500 m/s). La succession a été déformée à divers degrés, et renferme notamment des failles et des plis à grande échelle. Les objectifs principaux de cette étude étaient, dans un premier temps, d’interpréter les séquences stratigraphiques et la séquence structurale du Protérozoïque qui sont représentées dans les profils sismiques, et, dans un deuxième temps, de les mettre en corrélation autant que possible avec des strates et des événements protérozoïques déjà connus par des affleurements à l’est dans l’homoclinal de Coppermine, la boutonnière de Brock et l’île Victoria, et à l’ouest dans les monts Mackenzie et Wernecke.

L’examen des profils de sismique-réflexion a permis d’identifier le socle précambrien ainsi que cinq séquences protérozoïques limitées par des discordances, qui ont été déformés lors de plusieurs épisodes de distension, de compression et peut-être de transpression. Les corrélations proposées entre le sous-sol et la surface sont en majeure partie basées sur l’évolution géologique parallèle des successions, ainsi que sur des données analytiques, dont les résultats de l’analyse géochimique de basaltes carottés dans deux puits d’exploration dans la région du lac Tweed (Sevigny et al., 1991); les signatures gravimétriques et aéromagnétiques de basaltes (MacLean et Miles, 2002); les âges de zircons détritiques (Rainbird et al., 1996b, Villeneuve et al., 1998); et un nombre limité de données lithostratigraphiques recueillies dans d’autres puits d’exploration. Les unités enfouies sont désignées par des noms qui indiquent des corrélations tout en mettant l’accent sur la nature provisoire de celles-ci. Ainsi, l’«assemblage de HB » identifié en profondeur a été mis en corrélation avec le «Groupe de Hornby Bay», qui est exposé en surface, tandis que l’«assemblage de DL» a été mis en corrélation avec le «Groupe de Dismal Lakes». De même, une corrélation a été établie entre l’«assemblage de M/S» de la succession enfouie et les «supergroupes de Mackenzie Mountains et de Shaler» qui affleurent en surface. Les basaltes recoupés dans des puits de la région du lac Tweed sont appelés «basaltes de Tweed Lake» et ont été classés dans l’«assemblage de Tweed Lake». Des corrélations ont été établies entre ces basaltes et la Formation de Copper Creek, ainsi qu’entre l’assemblage de Tweed Lake et le Groupe de Coppermine River.

L’assemblage de HB comprend quatre unités. À la base, l’unité inférieure est une séquence discontinue, mise en corrélation vers l’est avec les formations discontinues de Bigbear et de Fault River, qui constituent les unités basales du Groupe de Hornby Bay dans l’homoclinal de Coppermine. Vers l’ouest, l’unité inférieure est mise en corrélation avec le Supergroupe de Wernecke, d’épaisseur considérable, qui affleure dans la Cordillère. L’âge des formations de Bigbear et de Fault River se situe entre 1,84 Ga (l’âge du socle sous-jacent, qui appartient à l’orogène de Wopmay) et 1,663 Ga (l’âge du complexe volcanique de Narakay, qui se trouve plus haut dans la succession). Quant au Supergroupe de Wernecke, on sait seulement que son âge dépasse 1,71 Ga. L’unité inférieure est recouverte en discordance par une séquence tripartite qui comprend une unité de bassin, une unité de plate-forme et une unité syntectonique que l’on attribue à l’assemblage de HB. Ces trois unités sont respectivement mises en corrélation avec les formations suivantes, qui font partie du Groupe de Hornby Bay : Lady Nye (faciès deltaïque), East River (faciès de plate-forme), Kaertok et LeRoux (unités syntectoniques). Cette séquence tripartite n’a pas d’équivalent établi dans la Cordillère. L’unique limite chronologique qu’on lui connaisse est fournie par le complexe volcanique de Narakay (1663 Ma), contenu dans la Formation de Kaertok. L’assemblage de DL, qui repose en discordance sur l’assemblage de HB, est mis en corrélation vers l’est (dans l’homoclinal de Coppermine) avec le Groupe de Dismal Lakes, et vers l’ouest (dans la Cordillère) avec le Groupe de Pinguicula (tel que redéfini par Thorkelson, 2000). L’âge du Groupe de Dismal Lakes se situe entre 1663 Ma (l’âge du complexe volcanique de Narakay sous-jacent) et 1267 Ma (l’âge des basaltes de Coppermine sus-jacents).

À l’instar de Sevigny et al. (1991), une corrélation a été établie entre les basaltes recoupés dans les puits de la région du lac Tweed et les basaltes datés à 1267 Ma qui affleurent dans le Groupe de Coppermine River, dans l’homoclinal de Coppermine. Ces basaltes n’ont aucun équivalent connu dans la Cordillère.

L’assemblage de M/S est mis en corrélation vers l’est avec le Supergroupe de Shaler dans l’homoclinal de Coppermine, l’île Victoria et la boutonnière de Brock, tandis que vers l’ouest, dans la Cordillère, il est mis en corrélation avec le Supergroupe de Mackenzie Mountains et le Groupe de Hematite Creek. On sait que l’âge des supergroupes de Mackenzie et de Shaler est inférieur à 1 Ga environ (l’âge des zircons détritiques qui y sont logés) et supérieur à celui des intrusions basiques qui les pénètrent (779 Ma, dans le cas des intrusions recoupant le Supergroupe de Shaler, et 723 Ma, dans le cas de celles qui pénètrent le Supergroupe de Mackenzie Mountains).

Les strates protérozoïques les plus récentes de la région appartiennent au Supergroupe de Windermere, dans la Cordillère, et aux basaltes de la Formation de Natkusiak, dans l’île Victoria. Aucun équivalent du Supergroupe de Windermere n’a été relevé en profondeur.

Divers événements tectoniques ont touché la région pendant la période de plus d’un milliard d’années que représentent les strates étudiées. La présente étude a permis d’identifier des épisodes de compression et de distension, et de déduire l’existence d’épisodes de transpression. Les cas d’inversions de structures préexistantes sont nombreux. Le remarquable parallélisme entre les évolutions tectoniques des successions enfouies et affleurantes est un élément-clé des corrélations établies dans cette étude.

Le plus important événement tectonique a été l’orogenèse de Forward, une déformation par compression intracratonique qui a mis en jeu le socle et qui a été quelque peu semblable à la déformation de l’avant-pays des Rocheuses, aux États-Unis. Les effets de cette orogenèse, d’abord reconnus sur des profils sismiques, sont identifiables sur les cartes de l’homoclinal de Coppermine publiées par Ross et Kerans (1989). Selon ces cartes, l’une des phases de déformation remonte à 1663 Ma, soit l’âge du complexe volcanique de Narakay, qui repose au sein de la Formation de Kaertok (unité syntectonique) (Bowring et Ross, 1985). Les structures de l’orogenèse de Forward dans les strates du Groupe de Hornby Bay et de l’assemblage de HB ont subi une pénéplanation due à une érosion prolongée, après quoi les strates déformées ont été recouvertes en discordance par l’assemblage de DL et le Groupe de Dismal Lakes. L’orogenèse de Forward (vers 1,663 Ga) est mise en corrélation avec l’orogenèse du Racklan (1,71–1,59 Ga), dont les effets sont visibles dans les strates déformées du Supergroupe de Wernecke, dans la Cordillère. Ces strates ont ensuite été arasées par l’érosion et recouvertes en discordance par le Groupe de Pinguicula (Thorkelson, 2000).

L’accumulation de l’assemblage de DL et du Groupe de Dismal Lakes a été suivie d’un important épisode de distension, qui s’est principalement manifesté par l’inversion du mouvement des failles formées durant l’orogenèse de Forward. Parmi les autres événements tectoniques, on compte la formation, tôt dans l’évolution du bassin, de failles de distension associées à la subsidence qui a accompagné l’accumulation de la partie inférieure de l’unité de bassin de l’assemblage de HB, ainsi que la formation, tard dans l’évolution du bassin, de plis à grande longueur d’onde qui ont affecté toute la succession protérozoïque.

Les réflecteurs sismiques marqués, discordants et discontinus dans l’assemblage de HB seraient pour la plupart des feuillets corrélatifs de ceux de la diabase de Western Channel, qui ont été cartographiés dans l’homoclinal de Coppermine par Ross et Kerans (1989) et datés à 1408 Ma par Wanless et Loveridge (1978) et Wanless et al. (1970). Des forages ont permis de confirmer que des feuillets plus récents, identifiés dans les profils de sismique-réflexion de la succession de l’assemblage de M/S à proximité des monts Mackenzie, représentent les filons-couches de Tsezotene, qui affleurent dans les monts Mackenzie et qui ont été datés à 779 Ma.

Le cadre tectonique établi au Protérozoïque a influencé la formation de nombre d’éléments et de structures tectoniques au Phanérozoïque. Ces éléments comprennent la cuvette de Mackenzie (Cambrien), les collines Colville (Laramide?), formées par transpression, et l’anticlinal d’Imperial (Laramide), ainsi que des grabens et demi-grabens peu profonds qui se sont formés pendant au moins trois épisodes de distension mal définis (Cambrien précoce; post-Dévonien/pré-Crétacé; et post-Crétacé).

INTRODUCTION

This report presents the findings of a study of subsurface Proterozoic strata in an area that encompasses almost 400 000 km^2 in northwestern Canada. The study area is bounded by the Mackenzie Mountains on the west and Coppermine Homocline on the east, and extends from the Arctic coast south to 63° North latitude (Fig. 1P[1]). The study is based primarily on released seismic data acquired by industry for hydrocarbon exploration and made available to the public through a succession of federal regulatory agencies, most recently the National Energy Board. These data were commonly acquired to explore the Phanerozoic section, with the sub-Cambrian unconformity providing an exploration floor for most companies. Records were nonetheless acquired to various listening times, often up to six seconds, and revealed a layered Proterozoic section, up to 5 seconds thick (14 km at 5500 m/s two-way time). This layered section is deformed to various degrees, and includes spectacular large-scale faults and folds. Our primary objectives were to interpret the Proterozoic stratigraphic and structural sequences portrayed in the seismic records and to correlate them, as fully as possible, with Proterozoic strata known from outcrop in the surrounding areas. Data from a number of disciplines were used, including surface outcrop maps, exploratory wells, and potential field maps, but the prime source of subsurface information was tens of thousands of line kilometres of reflection seismic data. Digital data provided by companies (see acknowledgments) have been reprocessed under contract. In many cases companies had not processed sections to full depth, so our processing revealed the deeper section for the first time.

Surface geology

Outcropping Proterozoic strata relevant to this study have been mapped to the west in the Mackenzie and Wernecke mountains, and to the east on Coppermine Homocline, Brock Inlier, and Victoria Island. Young et al. (1979) correlated post-Wopmay Orogeny strata across northwestern Canada in terms of three major sequences: A, B, and C. Sequence A (comprising the Wernecke Supergroup in the Cordillera and the Hornby Bay, Dismal Lakes, and Coppermine River groups on Coppermine Homocline) has proven to encompass too great a variety of subsequences and tectonic events to still be useful as a regional simplifying concept (MacLean and Cook, 2002). Sequence B as defined by Young et al. (1979) comprises the Pinguicula Group and Mackenzie Mountains Supergroup in the Cordillera, and Shaler Supergroup in the east. With some adjustments within the Pinguicula, Sequence B continues to be a useful stratigraphic concept for correlating across northwestern Canada. Sequence C, the Windermere Supergroup remains a valid entity, but apparently is not represented in the subsurface.

In Sequence A, Wernecke Supergroup in the Cordillera was correlated with the Hornby Bay, Dismal Lakes, and Coppermine River groups on Coppermine Homocline. However, that succession on the homocline is now known to comprise four unconformity-bounded sequences (Fig. 2, 3). The Hornby Bay to Coppermine River succession is cut by regional unconformities at the base of the Lady Nye Formation (Ross and Kerans, 1989), at the base of the Dismal Lakes Group (Cook and MacLean, 1995) and can be interpreted at the base of the Coppermine River Group (this paper). More damaging to the concept of Sequence A as a single stratigraphic package is the fact that Hornby Bay Group and older rocks were orogenically deformed during the Forward Orogeny (ca. 1663 Ma) and subsequently peneplaned prior to deposition of the Dismal Lakes Group (Cook and MacLean, 1995). Similarly, Wernecke Supergroup strata were affected by the Racklan Orogeny (1.71–1.59 Ga) structures, which are truncated by an unconformity at the base of the Pinguicula Group (Thorkelson, 2000). Thorkelson et al. (2001) argued that the Wernecke Supergroup can at best be correlated with only the lower part of the Hornby Bay Group and that the two successions may not correlate at all. We suggest in this report that the Wernecke Supergroup might correlate with the lowermost formations of the Hornby Bay Group, the Fault River and Bigbear formations.

The Pinguicula Group, which unconformably overlies the Racklan-deformed Wernecke Supergroup, had been considered broadly correlative with the Mackenzie Mountains Supergroup (Young et al., 1979), but has recently been subdivided (Thorkelson, 2000) into lower and upper parts separated by a major hiatus. Thorkelson (2000) correlated the lower part (Pinguicula name retained), dated as ca. 1.38 Ga, with the Dismal Lakes Group on Coppermine Homocline. The Dismal Lakes Group seems to postdate the Western Channel Diabase sheets (minimum age of 1408 Ma), but its age is essentially unclear other than the fact that it is bracketed by the underlying 1663 Ma upper Hornby Bay Group and the overlying 1267 Ma Copper Creek Formation (informally, Coppermine basalts). The Copper Creek is the lower formation of the Coppermine River Group, which apparently has no stratigraphic counterpart in the Cordillera.

The above details, combined, render “Sequence A” more or less invalid as a unifying regional correlation concept.

Sequence B comprises the Shaler Supergroup (unconformably overlying the Coppermine River Group) on Coppermine Homocline, the Mackenzie Mountains

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[1] Figures with a “P” suffix are found on the CD-ROM in the pocket accompanying this publication.

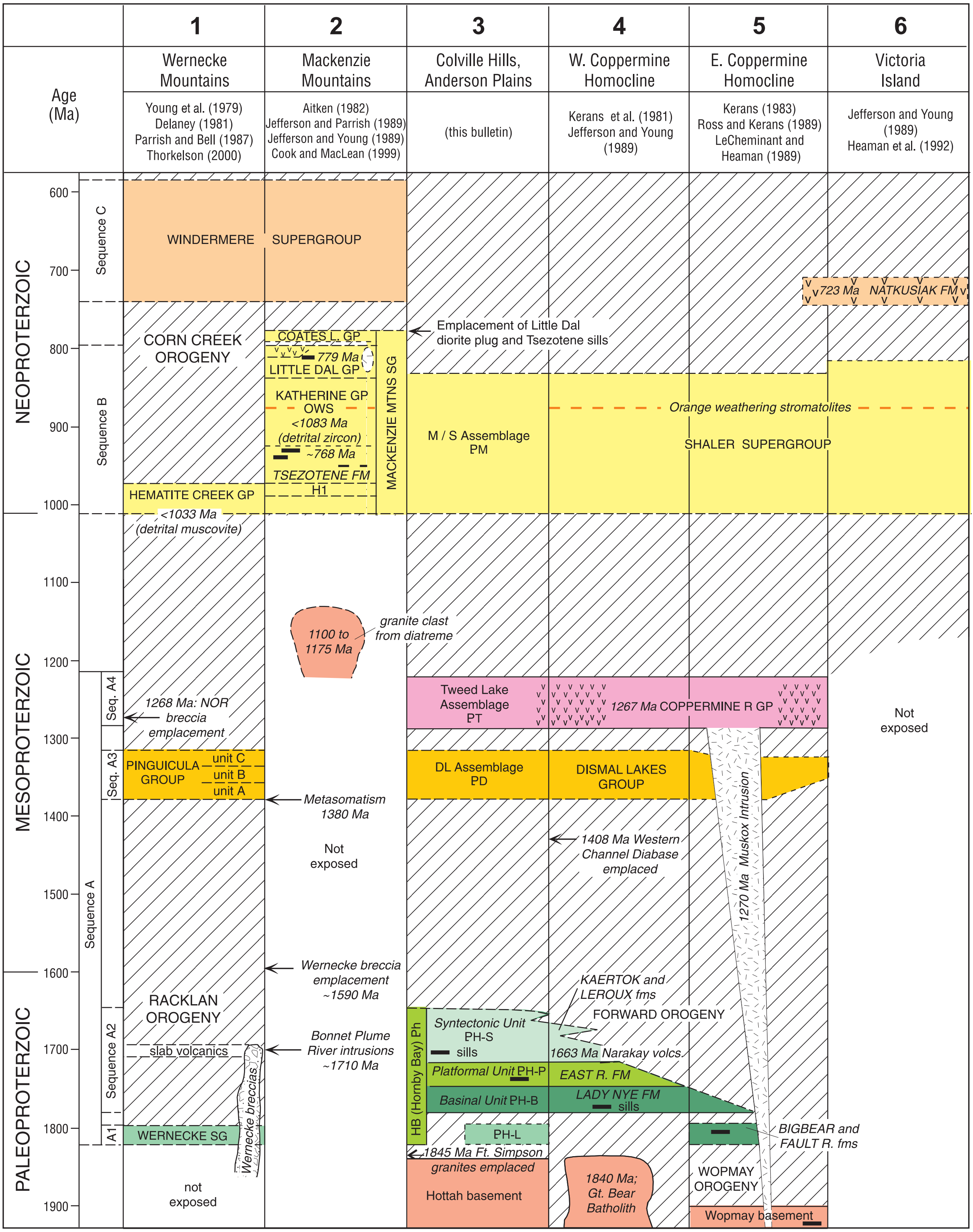


Figure 2. *Correlation chart of Proterozoic strata in northwestern Canada. Compare with the stratigraphic cross-section of Figure 3. Major sequences A, B, and C are modified from Young et al. (1979); A1 through A4, after MacLean and Cook (2002).*

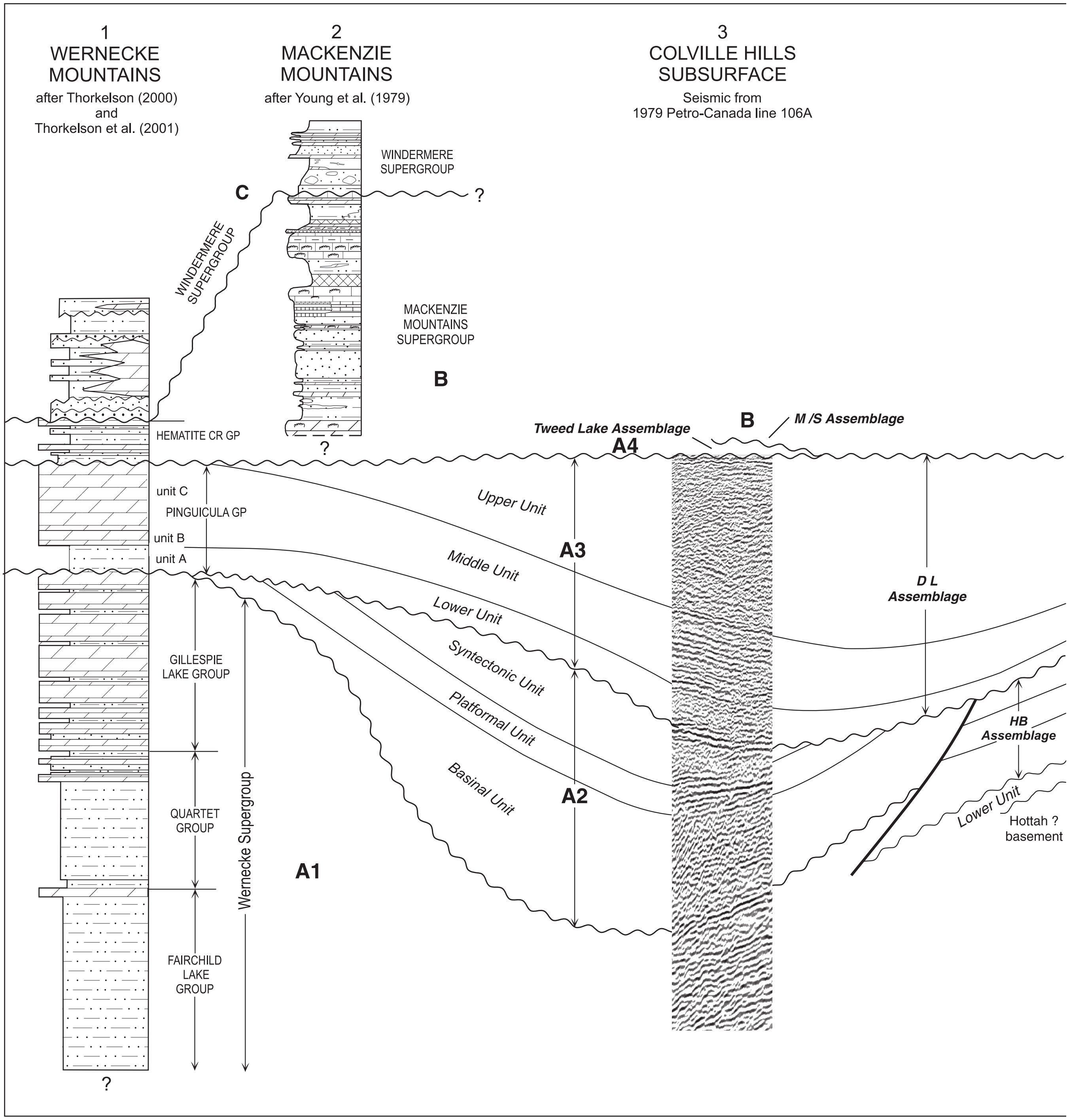


Figure 3. *Interpreted correlation of subsurface Proterozoic seismic units to outcropping formations on Coppermine Homocline and Victoria Island in the east, and the Wernecke and Mackenzie mountains in the west. Major sequences A, B, and C are modified from Young et al. (1979), A1 through A4 after MacLean and Cook (2002). See Figure 2 for ages of strata.*

Supergroup in the Mackenzie Mountains, and the Hematite Creek Group (unconformably overlying Pinguicula Group) in the Wernecke Mountains. All workers have correlated the Mackenzie Mountains Supergroup in the Cordillera with the Shaler Supergroup in the east. Sandstone units from both the Mackenzie Mountains and Shaler supergroups have yielded ‘Grenville age’ (ca. 1.0 Ga) detrital zircons (Rainbird et al., 1996a). The Mackenzie Mountains Supergroup was intruded by 779 Ma diabase dykes (LeCheminant, 1994), and the Shaler Supergroup was

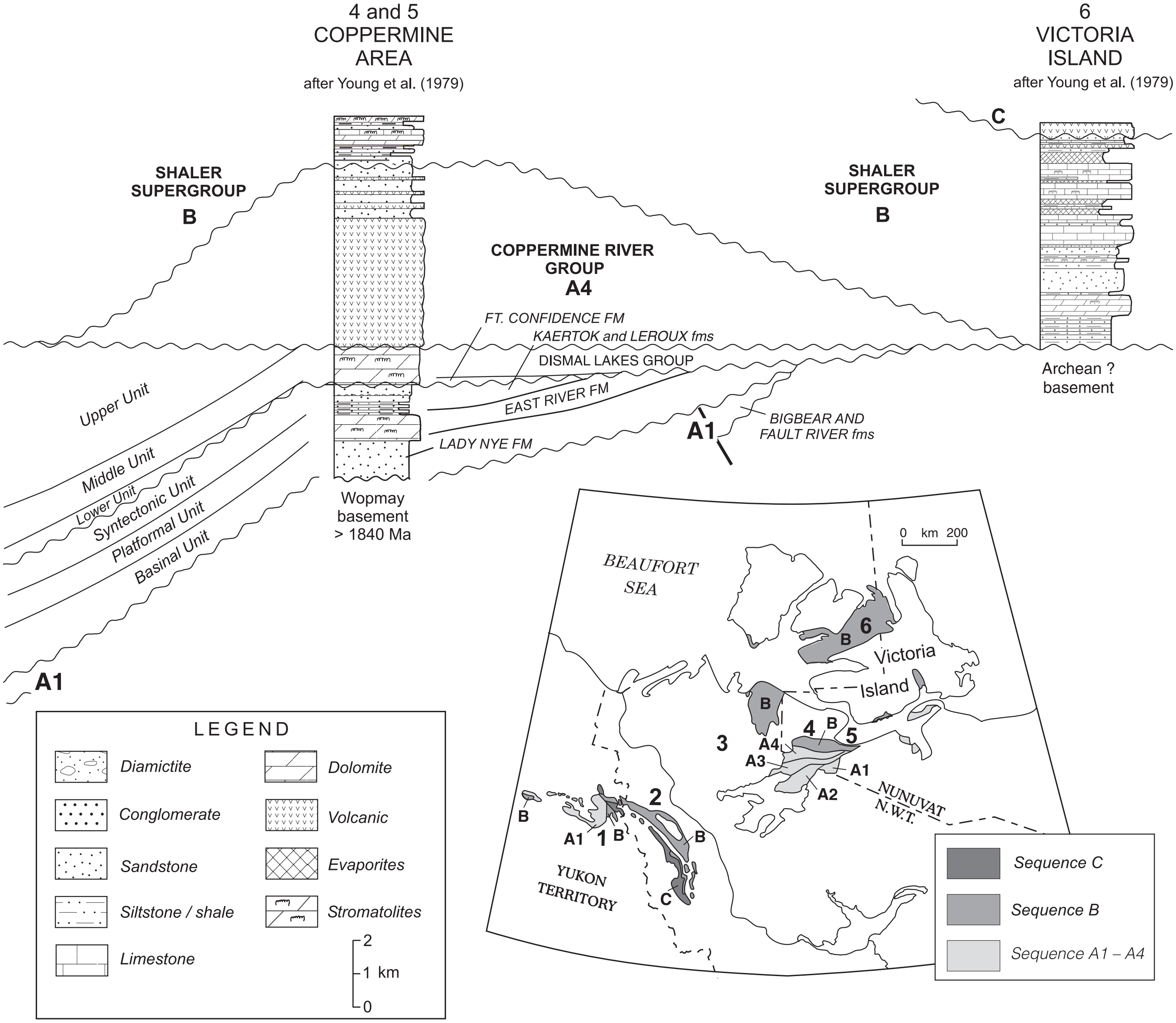


Figure 3. *Cont'd.*

intruded by 723 Ma dykes (Heaman et al., 1992). Thus the age of the package is bracketed between 1.0 Ga and 0.8 Ga. In the Wernecke Mountains Thorkelson (2000) renamed the unconformable upper part of the Pinguicula Group as the Hematite Creek Group, which he correlated with the Mackenzie Mountains and Shaler supergroups. We will present arguments in this report that the Hematite Creek Group represents only the lowermost Mackenzie Mountains Supergroup. With the exception of Thorkelson's important stratigraphic adjustment, Sequence B today is essentially as defined by Young et al. (1979).

Sequence C comprises the Windermere Supergroup in the Cordillera and correlative Natkusiak Formation basalts on Victoria Island. Windermere equivalents are nowhere identified in the subsurface units reported here.

History of subsurface research

Petersen (1974) reported Proterozoic sedimentary rocks imaged on seismic data under the Colville Hills "in the order of tens of thousands of feet", and petroleum companies have since acquired thousands of kilometres of seismic data. Data acquired prior to mid-1970 were proprietary, but since that time most seismic data have been released to the public by the appropriate federal agency (currently National Energy Board). Until the 1980s, there was little interest in the subsurface Proterozoic, with the exception of an important structural study by Davis and Willot (1978) who concluded that Laramide Colville Hills structures were the result of strike-slip movement along reactivated Precambrian faults. In a study of well samples and logs from Peel Plain, Peel Plateau, Colville Hills, and Anderson Plain regions, Aitken and Pugh (1984) assigned subcropping Proterozoic strata to the Mackenzie Mountains Supergroup. Subsequently available seismic data show the picture to be more complex (Fig. 4P). F.A. Cook (1988 a, b) interpreted a seismic data-set in the Lac Maunoir area of the Colville Hills and portrayed apparent stratigraphic repetitions as due to bedding-parallel faults. Cook envisioned about 90 km of horizontal transport on a master detachment extending some 250 km northwest to the Inuvik area. Similarly, Clark and Cook (1992) visualized a regional detachment linking the Lac Maunoir ‘structures’ to the Fort Good Hope area about 200 km to the southwest. Those interpretations were reasonable, given the small data set used. Regional seismic coverage, however, (Transects B, C, E) reveals regionally persistent seismic stratigraphic units and negates the existence of a regional shallow detachment. What had appeared to be a stack of bedding-parallel thrust plates is, instead, a continuous stratigraphic succession. Proterozoic strata are, nonetheless, offset by a variety of relatively steeply dipping faults that are listric at some level below the depth of seismic penetration (Cook, and Mayers, 1990a; b; MacLean and Cook, 1992; Cook and MacLean, 1995). Both compressional and extensional displacements occurred, and inversions of previously formed structures are common (Cook and MacLean, 1996a). Cook and MacLean (1995) named the predominant compressional event the Forward Orogeny, which they compared, in style but not scale, to thick-skinned, intracratonic belts such as the Rocky Mountain foreland of the United States and the Sierras Pampeanas of Argentina.

Seismic stratigraphy and nomenclature

In the subsurface, we have identified Precambrian basement and five unconformity-bounded Proterozoic sequences, which have been deformed by a number of extensional, compressional and possibly transpressional events. Although a few well penetrations provide a superficial understanding of the lithology of some intervals, our subsurface units are basically seismic units and must therefore be considered informal; Article 16 (c) of the North American Stratigraphic Code precludes “formalization of units known only from seismic profiles” (North American Commission on Stratigraphic Nomenclature, 1983, p. 854). Correlations from subsurface to surface are based mainly on comparisons of stratigraphic sequences and structural histories, although four types of analytical data do contribute to the correlation rationale. First, basalt encountered in the Tweed Lake wells is correlated with the Coppermine basalts on the basis of chemical similarity (Sevigny et al., 1991). Second, strata in a half-graben south of Great Bear Lake are assigned to the Tweed Lake Assemblage on the basis of gravity and aeromagnetic signatures (MacLean and Miles, 2002). Third, ‘Grenville-age’ zircons (ca. 1000 Ma) were recovered from the PCI Sammons H-55 well adjacent to the Mackenzie Mountains (Rainbird et al., 1996b) and from outcrop in Cap Mountain in the southern part of the report area (Villeneuve et al., 1998). Grenville-age detrital zircons are considered to be reliable indicators of Sequence B strata (i.e., Mackenzie Mountains and Shaler supergroups) (Rainbird et al., 1996a). Fourth, strata encountered in a diamond-drill hole located adjacent to Brock Inlier have been assigned to the Shaler Supergroup by Darnley Bay Resources. Other than those links no direct connections from the subsurface to the surface have been established, and correlations are proposed primarily on the basis of parallel geological histories, including stratigraphic and structural comparisons. Seismic-time to depth conversions are crude. For thickness calculations we applied average velocities derived from sonic logs recorded in petroleum exploration wells (Appendix C). For the Lower Unit of the HB Assemblage (which no well penetrated) we applied a relatively high velocity of 5500 m/s.

Although we find the sum of similarities compelling, we recognize the necessary limitations of correlations based on argument rather than established physical continuity. Consequently, we have given our subsurface units names that indicate our correlations, but also emphasize the provisional nature. In previous papers (MacLean and Cook, 1992; Cook and MacLean, 1995) we named the subsurface sequences ‘assemblages’ to differentiate them from the formal surface units (e.g., ‘Hornby Bay Assemblage’ instead of ‘Hornby Bay Group’). In this report we further emphasize informality and the provisional aspect of our correlations by reducing names to their initials. Thus 'HB Assemblage' is a contraction of 'Hornby Bay Assemblage', and 'DL Assemblage' is a contraction of 'Dismal Lakes Assemblage'. The subsurface 'M/S Assemblage' is a contraction of 'Mackenzie Mountains and Shaler supergroups'. We refer to basalts drilled in the Tweed Lake area as the Tweed Lake basalts and place them within the Tweed Lake Assemblage. These are correlated with the Copper Creek Formation and the Coppermine River Group, respectively.

At the bottom of the stratigraphic column is a sequence of strata that we previously identified as the 'unnamed layered unit' and considered to have no clearly established counterpart in outcrop (Cook and MacLean, 1995). We here suggest that it correlates with the Bigbear and Fault River formations, the lowermost formations of the Hornby Bay Group, and accordingly have included it as the 'Lower Unit' of the HB Assemblage. The Wernecke Supergroup in the Cordillera may correlate with these basal units.

Our HB Assemblage and DL Assemblage seismic units are best expressed in the Colville Hills and Anderson Plain (Fig. 1P). For convenience this broad area will henceforth be referred to as the Colville-Anderson area. There, units are distinctive and can be reliably recognized over great distances (e.g., Transects A, B, C, E, I, L). The stratigraphic succession and history of deformation established in the Colville-Anderson area (Cook and MacLean, 1995) provided a framework that we have extrapolated westward across Mackenzie River into Peel Plain and Peel Plateau (jointly referred to as the Peel area, hereafter). There the seismic data are older and less reliable and seismic markers representing HB and DL assemblages are carried with less confidence (e.g. Transects D, H, and western parts of B, C, E). Conversely, in the southern part of the Peel area, the M/S Assemblage imaged on seismic lines is confidently correlated with the Mackenzie Mountains Supergroup in the adjacent Mackenzie Mountains. Extrapolation of HB and DL assemblages southward into Mackenzie Plain, Franklin Mountains, Great Bear Plain, and Great Slave Plain (Mackenzie-Great Bear area, hereafter) is even less reliable because of changes in internal seismic character. Interpretation of assemblage boundaries in these regions is based primarily on identifying unconformities (Transects F, G, J, K). Extrapolation of the M/S Assemblage southward into the Mackenzie-Great Bear area is considered much more reliable.

Potential field data

Total field aeromagnetic and Bouguer gravity maps provided by the Continental Geoscience Division of the Geological Survey of Canada are reproduced here as Figures 5P and 6P, respectively. A prominent first-order positive magnetic anomaly trending north and northwest across the report area is considered to be the northward extension of the Fort Simpson anomaly (Ross, 1991; Villeneuve et al., 1991). Another prominent north-trending positive anomaly to the east corresponds to Great Bear Batholith of the Wopmay Orogen. An abrupt swing to the west in the area of Coppermine Homocline appears to mark a right-angle bend in Wopmay Orogen (Ross, 1991), but the anomaly there no doubt reflects the combined effect of Great Bear Batholith and the younger Coppermine basalts.

Proterozoic strata in the report area are variably thick, up to 5 s (14 km), and are locally cut by intrusive sheets. In spite of the presence of this huge volume of variably dense and variably magnetic material we see limited correspondence between potential field trends and Proterozoic structural and isopach trends. It has thus far been impossible to separate shallow and deep potential field effects, with two notable exceptions. The most obvious is an apparent correspondence between low aeromagnetic signature and the distribution of the M/S Assemblage in both the southern Mackenzie-Great Bear Area and the outcropping Shaler Supergroup along Coppermine Homocline (Fig. 7P). The close relationship in those areas has influenced our placing of the M/S Assemblage zero-edge in areas of poor seismic control. The second exception is a north-trending positive aeromagnetic and gravity anomaly south of Keith Arm of Great Bear Lake (Fig. 7P). That anomaly trends parallel to the Blackwater Fault, a Proterozoic normal fault, and has been modelled by MacLean and Miles (2002) as being due to an east-dipping panel of volcanic rocks, probably pertaining to the Coppermine/Tweed basalts.

A spectacular gravity anomaly (Hornal et al., 1970) and a corresponding magnetic anomaly (Riddihough and Haines, 1972; Geophysics Division, Geological Survey of Canada, 1992) lie immediately south-southeast of Darnley Bay (Fig. 5P, 6P). Known as the Darnley Bay anomaly, this feature is attributed to a large basic or ultra-basic intrusive body and is discussed on pages 14 and 15.

Phanerozoic considerations

Proterozoic structures have been instrumental in localizing the Cambrian Mackenzie Trough, the transpressional Laramide Colville Hills, the Laramide Imperial Anticline, and shallow grabens and half-grabens developed during at least three poorly understood extensional events (Early Cambrian; post-Devonian-pre-Cretaceous; and post-Cretaceous). A time-structure contour map of the sub-Cambrian unconformity surface (MacLean, 1999) (Fig. 8P) shows topography that is due to both Phanerozoic deformation and Precambrian erosional relief. These features are discussed more fully in a subsequent section.

Acknowledgments

This project could not have been adequately done if we had been unable to re-process seismic data to modern standards and to depths greater than those submitted to the Canadian government. We are indebted to the following companies, who provided digital data for reprocessing: Amoco Canada Petroleum Co. Ltd., Gulf Canada Resources Ltd., Imperial Oil Resources Ltd., Mobil Oil Canada, Petro-Canada Resources, Shell Canada Ltd., Sigma Exploration (1978) Ltd., and Unocal Canada Exploration Ltd. Pulsonic Geophysical Ltd. and Veritas Geoservices Ltd. re-processed the data under contract. P. Lawrence provided geophysical technical support. P. Neelands, D. Sargent, and M. Theuerkauf provided cartographic support. We have benefited from discussions with colleagues, particularly D. Thorkelson and G. Abbott, who have kept us current on age relationships of Wernecke and Mackenzie mountains units in the Cordillera.

BASEMENT

Seismic character of basement

A prominent reflection at the base of the HB Assemblage is considered by us to represent crystalline basement. This reflection is best expressed in the Colville-Anderson area (Transects B, C) northwest of Great Bear Lake (mainly Hottah Terrane of Ross, 1991). In the Colville-Anderson area the seismic character of basement varies from uniform to weakly layered, and locally the layering appears folded or faulted (see Transects B, C, E). Future studies may permit identification of mappable domains of common character, but at this time specific terrane signatures have not been recognized.

In the Peel area to the west, the basement reflection is weaker and not as reliably identified. The weakness of the 'basement' reflection may indicate that the underlying rocks are not crystalline basement. They may instead be another sedimentary succession – for example equivalents of the Wernecke Supergroup exposed in the Wernecke Mountains to the southwest. Whatever the nature of sub-HB Assemblage, a speculative small sub-Cambrian 'basement' high is interpreted in the Peel area (Fig. 4P), based on extrapolating the basement reflection beyond the northwest ends of Transects H and B. There, a southeastward-dipping basement reflection, if projected updip to the northwest, would intersect the sub-Cambrian unconformity. Mapping the extent of this 'basement' high is precluded by a lack of seismic control.

In the Mackenzie-Great Bear area to the south, seismic data at depth are of poor quality and a basement reflection can rarely be identified.

Basement subdivisions based on potential field data

Basement beneath the report area and those adjacent has been subdivided into four linear terranes (Ross, 1991; Fig. 5P, 6P, 9). From east to west they are: the well-exposed and extensively studied 1.79–2.02 Ga Great Bear magmatic zone of the Wopmay Orogen; the 1.85–2.38 Ga Hottah Terrane, also part of Wopmay Orogen; the 1.79–2.02 Ga Fort Simpson Terrane; and the Nahanni Terrane of uncertain age. Villeneuve et al. (1991) summarized relationships among the terranes. Recent geochronology (Ross et al., 2000), however, indicates that the Fort Simpson, Hottah, and Great Bear belts, despite their contrasting aeromagnetic responses across a broad region 300 km wide have a narrow range of magmatic ages (1875–1832 Ma) regardless of which terrane was sampled. Thus, the extrapolation of subsurface terranes established in the south into the northern Interior Plains (Fig. 5P, 6P, 9) on the basis of aeromagnetic anomaly distribution is no doubt oversimplified.

Furthermore, subsequently acquired potential field data also show a more complex picture. As seen in Figure 5P, the Fort Simpson magnetic high in the study area consists of a chain of culminations leading northward to the southwestern part of Great Bear Lake. From there it swings due west and then northwestward to the Mackenzie River delta area where it intersects a NE–SW-trending chain of anomalies. Thus, the Fort Simpson magnetic high, which in the south is clearly linked, tectonically and temporally, to Wopmay Orogen is seen to change character and swing westward as it extends northward. Just how far north of the Great Slave Shear Zone the label and age of 'Fort Simpson' can be justifiably carried is, we suggest, an open question. The strong anomaly in the study area is possibly an unrelated zone within the Nahanni or Nahanni/Hottah Terrane.

Little is known of the age(s) of the Nahanni Terrane. The Sm-Nd signatures of the granite from the Fort Simpson anomaly indicated to Villeneuve et al. (1991) a crustal history dating back to at least 2.45 Ga. U-Pb systematics of a granite clast from a diatreme near Coates Lake in the Mackenzie Mountains were interpreted (Jefferson and Parrish, 1989) to provide a crystallization age of 1175–1100 Ma (Fig. 2), and an inherited age of about 1.6 Ga. Jefferson and Parrish (1989) considered sedimentary clasts within the diatreme to be fragments of Mackenzie Mountains Supergroup (MMS) rocks. The apparent absence of clasts from the Wernecke Supergroup or Pinguicula Group implies that the diatreme may have sampled a structural high whereon MMS directly overlies 1.6 Ga 'basement' (approximately the age of the Narakay volcanics intruding the Hornby Bay Group on Coppermine Homocline). Alternatively 'basement' there may simply be a granitic intrusion into Wernecke and/or Pinguicula strata.

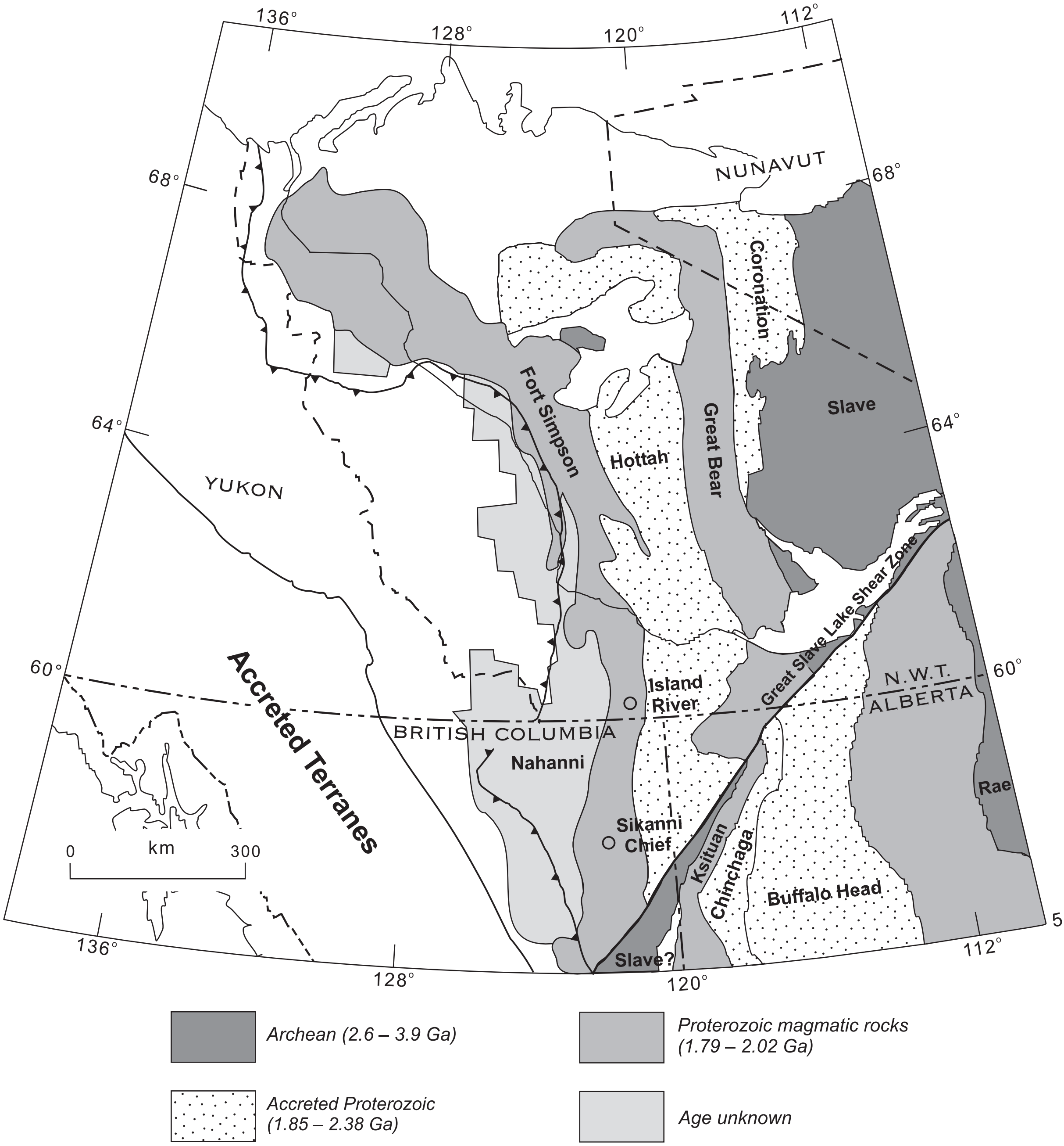


Figure 9. *Basement domains for northwestern Canada (after Ross, 1991 and Villeneuve et al., 1991). Imperial Island River and Imperial Sikanni Chief are two wells that penetrated Fort Simpson Terrane.*

Basement influence on depositional and structural patterns

There is a faint correspondence between potential field trends and some stratigraphic thickness variations. Specifically, isochron and isopach maps of the combined Basinal and Platformal units of the HB Assemblage (Fig. 10P, 11P), and of the total Proterozoic sedimentary package (Fig. 12P), have a general north-northwest trend in the southern part of the Colville-Anderson area, which changes to a northeast-southwest trend in the northwestern part. Aeromagnetic anomaly trends (Fig. 5P), and to a lesser degree gravity trends (Fig. 6P) display similar shifts from north-northwest trend to northeast-southwest trend across the Colville-Anderson area. Thus, it appears that basement structure influenced basin formation. However, we see no one-to-one correlation between basin thicks and thins and potential field highs and lows.

On a smaller scale, late Wopmay Orogeny strike-slip faults, both northeast- and northwest-trending, (see basement area of Fig. 4P) documented by Hoffman (1984) and Hoffman and St. Onge (1981) did affect the Hornby Bay Group, and are inferred by us to have affected the HB Assemblage structure and deposition. Some of these faults were reactivated during deposition of lower units of the Hornby Bay Group (Hoffman and St-Onge, 1981) and again during the Forward Orogeny (Cook and MacLean, 1995). Northeast-trending basement uplifts on Coppermine Homocline, considered here to be Forward Orogeny structures, include the Teshierpi, Fault River, and Leith Ridge faults. In a later section we will argue that northwest- and northeast-trending Forward Orogeny structures in the Colville-Anderson subsurface were also probably localized by faults related to the strike-slip faults documented by Hoffman and St Onge. If so, the family of strike-slip faults is geographically much more extensive than previously recognized. If these faults localized Forward Orogeny uplifts, it follows that they also strongly influenced deposition of the Syntectonic Unit of the HB Assemblage.

Darnley Bay anomaly

The Darnley Bay gravity anomaly (Fig. 6P, 13) was recorded by Hornal et al. (1970) at the mouth of Hornaday River adjacent to Darnley Bay. The anomaly is circular with a radius of 30 miles (48 km) and rises to +119 mgal, about 130 mgal above the regional field. Riddihough and Haines (1972) outlined a large magnetic anomaly (Fig. 5P) approximately coincident with the gravity anomaly, based on five high-level (3.5 km) magnetic profiles. A low-level (610 m) magnetic survey by the Geophysics Division of the Geological Survey of Canada (1992) provided greater detail, showing two magnetic culminations within the limits of the gravity anomaly.

All workers referenced here have inferred that the Darnley Bay gravity/magnetic anomaly is caused by a large basic or ultrabasic intrusion into Proterozoic strata, but there is no consensus as to the shape of, and depth to, the intrusion. Hornal et al. (1970) modelled an inverted cone extending 24 miles (38 km) into the crust with its top within 3 miles (4.8 km) of the surface. Stacey (1971) presented a variety of models, and found that either an inverted or upright truncated cone could produce the observed anomaly. Depending on configuration and density contrast he found that depth to the intrusion could be as shallow as 0.5 km or as deep as 10.0 km. He favoured models of an inverted truncated cone with its top at a depth of 3.1 km or an upright truncated cone with its top at 5.5 km. Riddihough and Haines (1972) found that magnetic measurements over the anomaly do not resolve the question of whether the body is an inverted or upright cone, but they concluded that the depth to the top of the magnetic portion of the body was 3 to 4 km below surface and depth to the base was 15 to 22 km below surface. One seismic line, Sigma-8, (Vye, 1972) extends onto the western flank of the anomaly but ends short of its centre. A set of bright reflections was considered by McGrath et al. (1993) to represent the top of the intrusive body at a 3 km depth and therefore constitute a constraint on their gravity model. Their model consisted of a steeply dipping, high-density body with a higher-density core. The line Sigma-8 is included in the eastern end of Transect A. In the context of our regional interpretation we construe the bright reflections as representing the Platformal Unit of our HB Assemblage rather than the top of an intrusive body.

Riddihough and Haines (1972) interpreted the intrusion to be geologically related to the Late Precambrian (723 Ma) Franklin Diabases, in part because Franklin dykes and sills outcrop in the adjacent Brock Inlier. Conversely Jefferson et al. (1994) observed that the Franklin intrusions in Brock Inlier were thin and sparse relative to those on Victoria Island, and suggested that the Brock Inlier intrusions were distant from their source and were unlikely to be related to the Darnley Bay intrusion. Consequently, they interpreted the intrusion to be a component of the much older (~1270 Ma) Mackenzie event.

The Darnley Bay anomaly is currently the target of base metal and diamond exploration by Darnley Bay Resources (2001), which at time of writing has a website <www.darnleybay.com> that contains gravity and magnetic maps of the anomaly (Fig. 13, 14). The company has carried out high-resolution gravity, magnetic, and electromagnetic ground surveys. Their interpretation at time of writing (January, 2002) was that the main intrusive source is at a depth of 3000 m with projections extending upward and outward into shallower lateral zones. Their detailed aeromagnetic data (Fig. 14) reveal north-northwest-striking linear magnetic trends crossing the anomaly, which they interpret as representing a dyke system. They note that, “at least one of the dykes crosses the main intrusive, indicating that the dykes were emplaced after the main intrusive”. These dykes are probably related to the 723 Ma Franklin event. If so, they support the conclusion of Jefferson et al. (1994) that the Darnley Bay intrusive body predates the Franklin event.

Darnley Bay Resources attempted to penetrate the intrusive body with their Drill Hole No. 1. On June 27, 2000 they reported that they had drilled through Phanerozoic rocks and encountered, at 1168 m, Proterozoic pale green mudstone and sandstone, which they assigned to the Escape Rapids Formation of the Shaler Supergroup. The drill hole was stopped at 1812 m without encountering the intrusive body. The drilling results have been incorporated into our interpretation of the eastern end of Transect A.

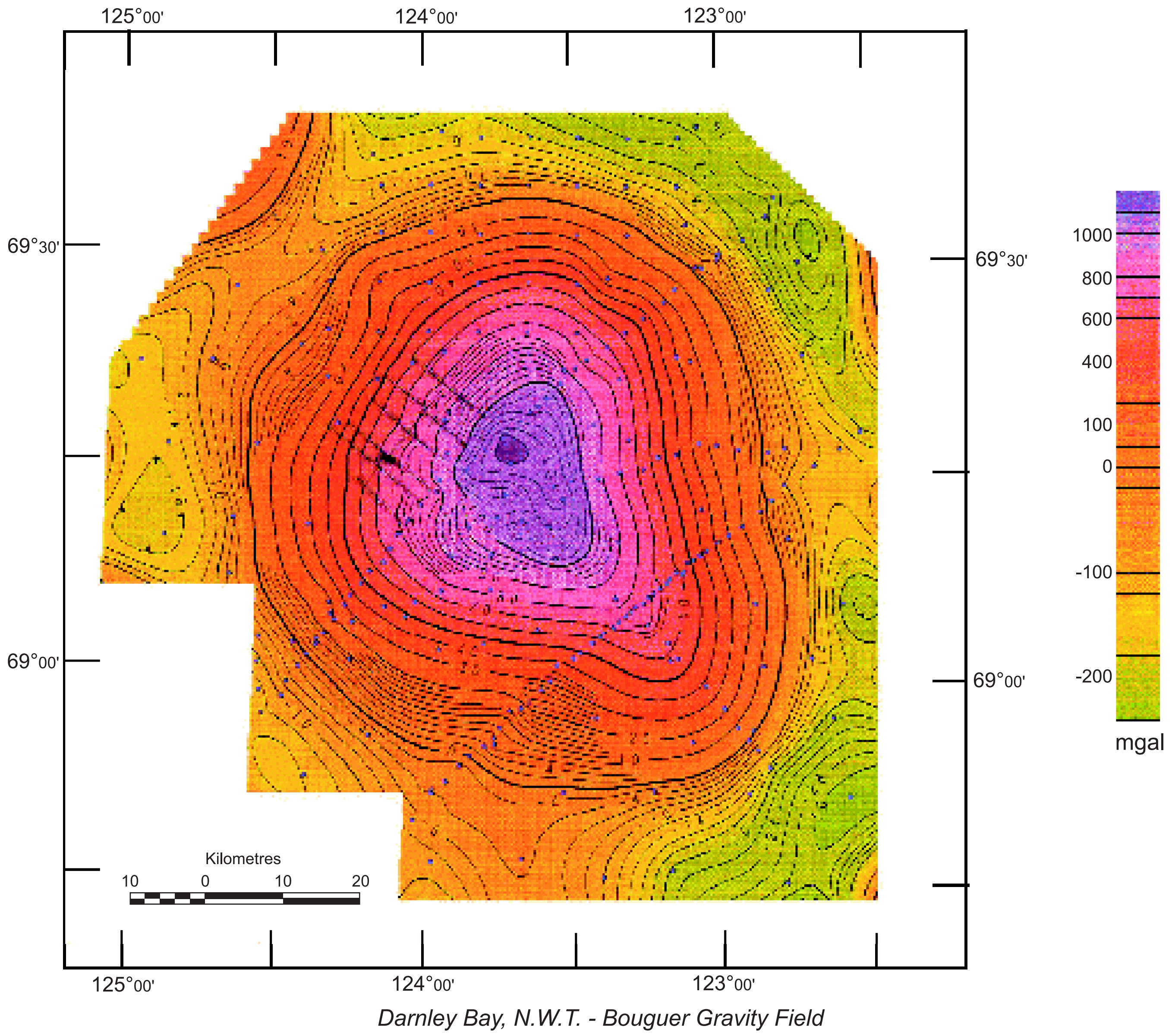


Figure 13. *High-resolution Bouguer gravity map of Darnley Bay anomaly. After Darnley Bay Resources (2000a).*

In summary, the Darnley Bay coincident gravity and magnetic anomalies are considered to represent a large mafic intrusion by all who have studied them. However, a wide range of depths to the top of the intrusion, from as little as a 0.5 km to as great as 10 km, have been modelled. It is known to be greater than 1812 m deep at the site of the Darnley Bay Resources Drill Hole No. 1. Available seismic data (Transect A, east end) suggest to us that the intrusion is not imaged on the data and that its top lies significantly below a through-going set of seismic reflections about 1.5 s below surface (2.8 km at an average seismic velocity of 5500 m/s), which we interpret to represent the Platformal Unit of the HB Assemblage.

HB ASSEMBLAGE

Overview

The HB Assemblage, the most widespread of our assemblages, occurs throughout the study area. The assemblage comprises four units and represents a redefinition of the Hornby Bay Assemblage of Cook and MacLean (1995), which comprised three units: a Basinal, a Platformal, and a Syntectonic unit. The HB Assemblage applied here includes a fourth, discontinuous, lower unit, which we previously (Cook and MacLean, 1995) called the ‘unnamed layered unit’. We here include it in the HB

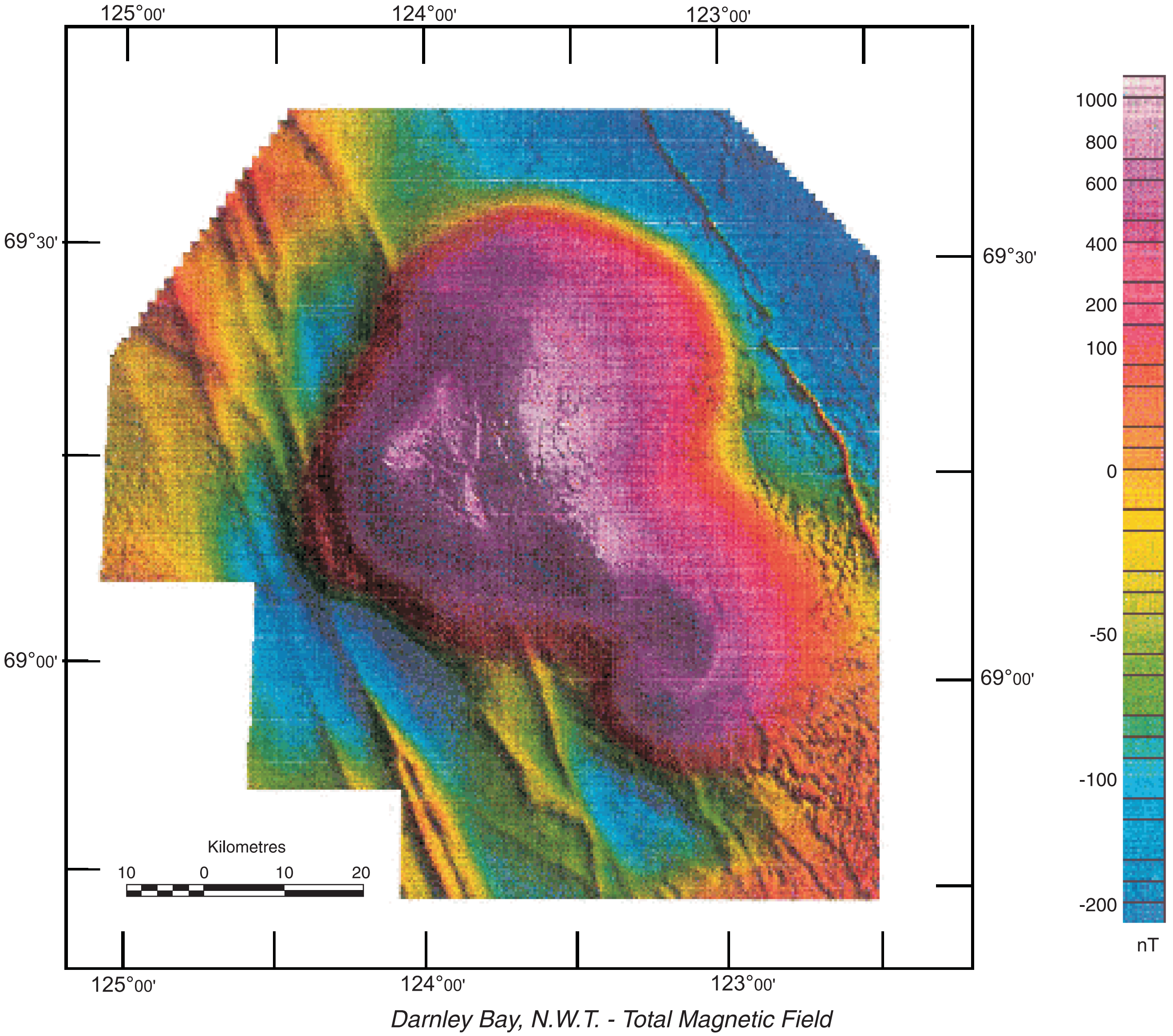


Figure 14. *High-resolution aeromagnetic map of Darnley Bay anomaly. Linear northwestward-trending anomalies are assumed to represent (diabase?) dykes that postdate the main body. After Darnley Bay Resources (2000b).*

Assemblage as the 'Lower Unit' because we now suggest a correlation with the Bigbear and Fault River formations, discontinuous lower units of the Hornby Bay Group on Coppermine Homocline. We further suggest that the Lower Unit, Bigbear, and Fault River comprise a sedimentary sequence separated from the rest of the HB Assemblage and Hornby Bay Group by a regional unconformity.

The Lower Unit is recognized only in the eastern parts of the study area (e.g., Transects C, E, K), whereas the Basinal, Platformal, and Syntectonic units occur throughout the Colville-Anderson area and have been traced westward across the Mackenzie River into the Peel area (e.g. Transect B, C, and H). There, the basement reflection is weaker and discontinuous. Subdivision of the HB Assemblage is largely dependent on successfully identifying Platformal Unit reflections. As the Platformal Unit is not as clearly defined in the Peel area as it is in the Colville-Anderson area, subdivision of the Assemblage cannot be made with the same level of confidence. To the south in the Mackenzie-Great Bear area we assign strata to the HB Assemblage but have been unable to subdivide them further. In that region, assignment to the HB Assemblage is based on the identification of a regional unconformity that we interpret as separating the underlying HB Assemblage from the overlying DL Assemblage (e.g., Transect F; south parts of

Transects J, K). A notable exception is the footwall block of Blackwater Fault, a large west-dipping normal fault, south of Keith Arm of Great Bear Lake. There, all four units of the HB Assemblage are identified (east end of Transect G).

Lower Unit

Over two areas, one about 180 x 125 km in the eastern part of the Colville-Anderson area, and the other about 125 x 25 km south of Keith Arm (Fig. 15P, 16P), basement is overlain by the Lower Unit, a variably layered interval up to 1.5 s thick (4 km at a seismic interval velocity of 5500 m/s). The unit may extend across the 250 km separating the two mapped areas but the data there are of low quality, precluding identification. In the southern part of the Colville-Anderson area, seismic data are of insufficient quality to image the base of the unit so isochrons and isopachs could not be constructed. Thus the area of occurrence of the Lower Unit there is probably larger than as shown on Figures 15P and 16P.

Westward from Lac Maunoir the Lower Unit is generally missing, although weak subhorizontal reflections at the top of ‘basement’ are imaged locally (e.g., eastern part of Transect B; also see Fig. 30). The lack of seismic definition precludes accurate documentation of the areal distribution of the unit, however its overall discontinuous nature implies a major unconformity at the base of the overlying Basinal Unit.

Eastward from the Lac Maunoir area the unit’s subsurface extent is not known, because of a lack of seismic control. In outcrop on the east flank of Coppermine Homocline the Bigbear and Fault River formations mapped by Ross and Kerans (1989), at the base of the Hornby Bay Group are considered to be equivalent to the subsurface Lower Unit (Fig. 15P, 16P).

To the north of Lac Maunoir (e.g., eastern ends of Transects C, E, L; Fig. 17, 18) the unit comprises an enigmatic succession of seismic markers that vary from undulatory to remarkably planar. Deposition of the succession is not understood and comments below are mainly descriptive, with interpretive speculation applied only to two subparallel planar reflections, and to a feature that has the characteristics of a reef. The two planar reflections appear to be superimposed across an otherwise undulatory and hummocky stratigraphic package (Transect C, L; Fig. 18). These reflections were considered by Cook and Mayers (1990b) to represent intrusive sheets, but because they are sharper and much more continuous than reflections that we attribute to intrusive sheets elsewhere in the report area, we subsequently interpreted them to be stratigraphic boundaries (Cook and MacLean, 1995). We here return to the probability that they represent sheets. Their discordant aspect, seemingly imposed on an undulatory, perhaps folded, stratigraphic package, is best illustrated on Transects C and L, east and southeast ends respectively, and in Figure 18. When the two parallel ‘sheets’ are ignored, four crude seismic-stratigraphic subunits can be identified. The individual units are variably thick, as is their aggregate thickness (Fig. 15P, 16P).

Subunit 1

The seismic character of subunit 1 is transitional to that of basement and placement of the lower boundary is somewhat subjective (e.g. Transect C). The upper boundary is in places planar (Fig. 17) and in places undulatory (Transect C, Fig. 18). Assuming an interval velocity of 5500 m/s, subunit 1 varies from about 1100 m to 2500 m in thickness.

Subunit 2

Subunit 2 varies from zero to greater than 2.2 km in thickness and contains huge hummocks or mounds. A typical mound displayed on Transect C, Line PCR 90X, is about 11 km across with relief of greater than 1 km. The origin of the mounds is unknown, but appears to be depositional rather than erosional. Subunit 2 is overlain either by subunit 3 with apparent conformity (Transect L, Line PCR 120A) or, unconformably by the Basinal Unit of the HB Assemblage (Transect C, Line PCR 90X).

Subunit 3

Subunit 3 is parallel-bedded, varies in thickness from zero to 750 m, and tends to fill topographic lows between subunit 2 hummocks. Subunit 3 is missing over the tops of some hummocks, as a result of nondeposition or erosion. In either case topography on some mounds survived pre-Basinal Unit erosion (Transect C, Line PCR 90X).

Paleoproterozoic reef?

In the area east and southeast of Lac Maunoir seismic records are shorter, show only the upper part of the Lower Unit, and subunits cannot be identified with confidence. In that area, a reef-like feature has been identified on seismic within strata that we assign to subunit 3 (Fig. 19a, b). Subunit 4 and the lower boundary of the Basinal Unit drape over a ‘mound’ of low-amplitude internal reflections. East of there, subunit 3 contains low-amplitude, parallel but discontinuous reflections such as would be expected from a shale basin seaward of a carbonate bank edge. West of the ‘reef’ the subunit’s seismic character is that of a back-reef environment in that reflections are stronger, more

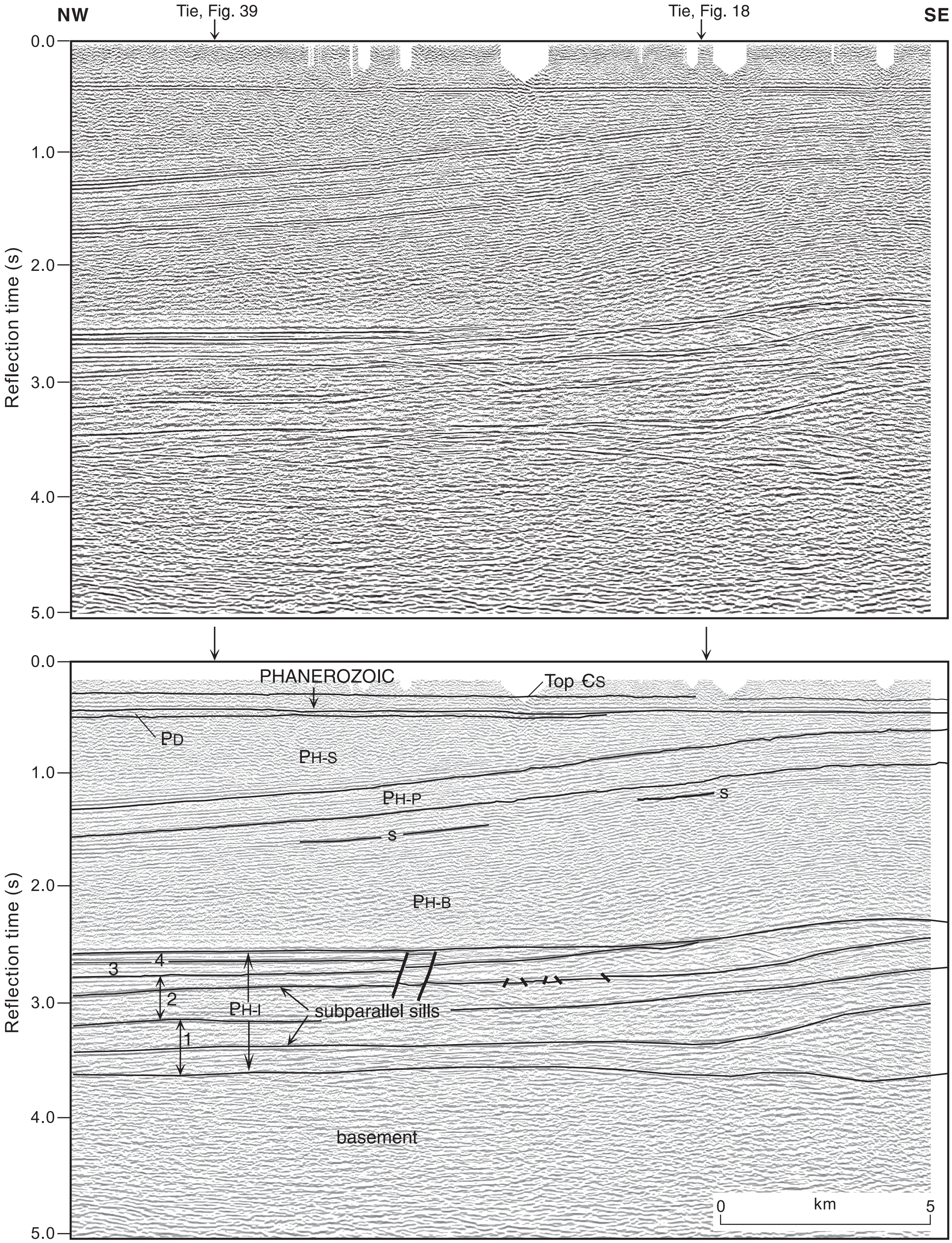


Figure 17. *1979 Petro-Canada Line 77A showing the Lower Unit of the HB Assemblage (*ⱣH-L*) to be about 1 second (2750 m) thick and divided into four variably thick subunits by strong reflections. Two strong subparallel reflections are interpreted to represent intrusive sheets (sills). Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ⱣH-l*, Lower Unit of HB Assemblage;* ⱣH-B*, Basinal Unit;* ⱣH-P*, Platformal Unit;* ⱣH-S*, Syntectonic Unit; s, intrusive sheet;* ⱣD*, DL Assemblage, undivided;* ꞒS*, Cambrian Saline River Formation.*

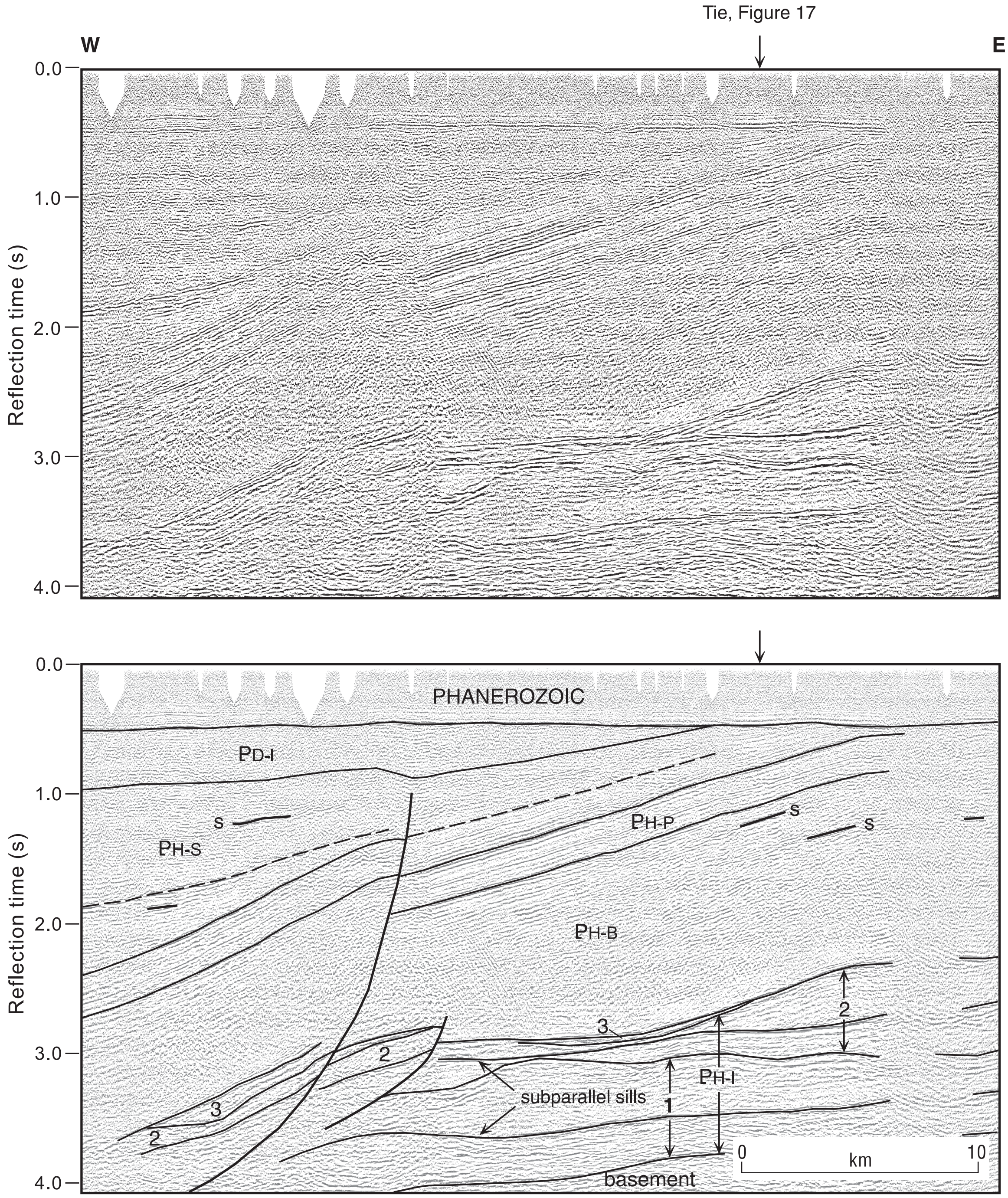


Figure 18. *1984 Petro-Canada Line 90X showing the four units of the HB Assemblage including three of the four subunits of the Lower Unit. Higher-level discontinuous sills have been intruded into progressively older strata toward the east while maintaining a more or less constant depth relative to the sub-*PD *unconformity. Two lower-level subparallel continuous reflections are also interpreted as sills, but of an earlier generation. Vertical exaggeration is approximately 1:1 at seismic velocity of 5500 m/s. See Figure 1P for location.* PH-I, *Lower Unit of HB Assemblage; 1, 2, 3, subunits of Lower Unit;* PH-B, *Basinal Unit;* PH-P, *Platformal Unit;* PH-S, *Syntectonic Unit;* PD-I, *Lower DL Assemblage; s, intrusive sheet.*

continuous and lead into, rather than over the mound. The mound itself is 270 ms thick (740 m at 5500 m/s) and rests upon a platform of subunit 2, which exhibits velocity pull-up under the mound and increases in dip eastward (and seaward). The velocity pull-up is about 27 ms suggesting that the mound's internal seismic velocity is about 10 per

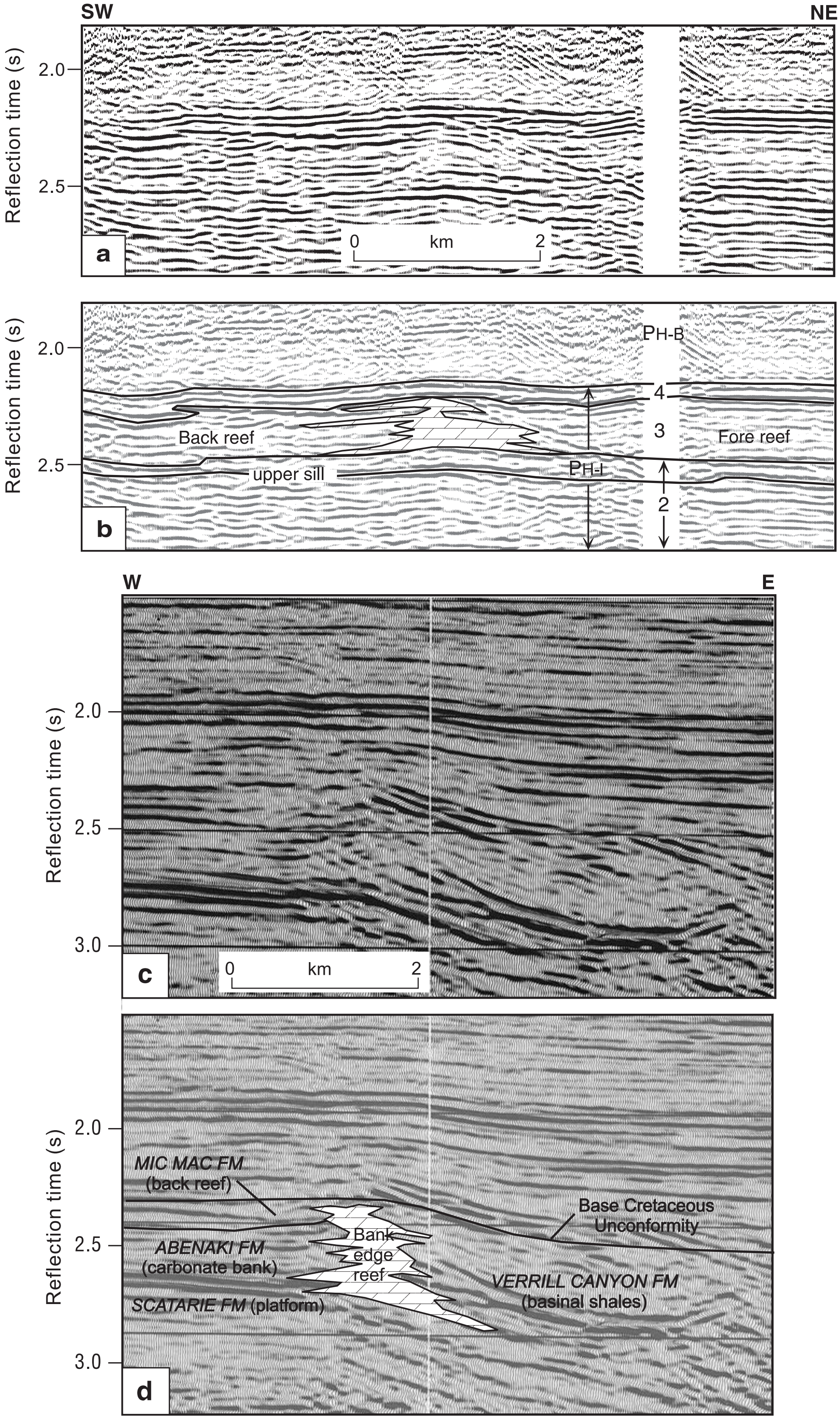


Figure 19a. *and* ***b.*** *1974 Unocal Canada Line W9 showing interpreted Proterozoic reef. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* PH-I, *Lower Unit of HB Assemblage; 2, 3, 4, subunits of Lower Unit;* PH-B, *Basinal Unit.* ***c.*** *and* ***d.*** *A portion of 1983 Shell Canada Line C-102 provides a comparison with a Jurassic age reef from the Scotian Basin, offshore Nova Scotia, Canada.*

cent higher than its host rock. The mound is capped by a zone of strong, continuous reflections, such as might be generated by thin but continuous carbonate and shale interbeds deposited over a drowned reef.

Paleoproterozoic reefs documented elsewhere in northern Canada are considerably smaller than the feature described here. Immediately to the east of the Wopmay Orogen in Kilohigok Basin, for example, stromatolite reef complexes up to 10 m in height occur within rocks of the Goulbourn Group (Campbell and Cecile, 1981). Kilohigok Basin is the foreland basin of the Wopmay Orogen (1.85 Ga) making these reefs older than the Lac Maunoir example. Delaney (1981) reports stromatolites within the Gillespie Lake Group at the top of the Wernecke Supergroup in the Wernecke Mountains. The possibility that the Wernecke Supergroup correlates approximately with the Lower Unit is discussed below.

Kerans et al. (1981) described low-relief, laterally linked, domal stromatolites and "several prominent basinwide marker beds of silicified bioherms and biostromes of compound domal stromatolites" in the East River Formation (unit 9 of Kerans et al, 1981) of the Hornby Bay Group on Coppermine Homocline. Their descriptions did not include mound height measurements but their lithofacies column shows stromatolites in the order of one metre or less.

The Lac Maunoir seismic feature has the appearance of a bank-edge reef in rocks that are dated no better than early in HB Assemblage time (1.84–1.66 Ga) (Fig. 2). Support for its interpretation as a reef is found in a remarkably similar looking seismic example from a much younger Jurassic carbonate bank edge in offshore Nova Scotia (Fig. 19c, d). There, a bank-edge 'mound' of the Baccaro Member of the Abenaki Formation (MacLean and Wade, 1993) separates the weak, discontinuous reflections from within the Verrill Canyon shale lying to seaward from a zone of strong, continuous reflections generated by back-reef environment Abenaki Formation rocks. Reflections from the Scatarie Formation platform rocks exhibit velocity pull-up under the reef and increasing dip seaward of the bank edge. Overlying beds of the Mic Mac Formation show drape over the drowned reef and bank edge.

Subunit 4

Subunit 4 is a generally thin, distinctively layered, discontinuous unit that is best displayed on Figure 17 and the southeast end of Transect L. On Transect L it thickens anomalously northwestward to at least 0.7 s (1.9 km at a seismic interval velocity of 5500 m/s). That accumulation occurs in the core of an overlying broad anticline, has uncertain internal structure, and may represent tectonic thickening. The discontinuous nature of subunit 4 is due either to nondeposition or to truncation at the overlying sub-Basinal Unit unconformity (Transect C; Fig. 17).

Lower Unit south of Keith Arm

In the area to the south of Keith Arm of Great Bear Lake, a distinctively layered interval is assigned to the Lower Unit because it underlies strata assigned to the Basinal Unit (Transect G, Line PCR 60X; Transect K, Line PCR 8416). The unit terminates abruptly westward against the west-side-down Blackwater Fault, a large-displacement normal fault (MacLean and Miles, 2002) here interpreted to be an inverted Forward Orogeny fault. The Lower Unit is imaged only in the footwall block, but is presumably present in the hanging wall but too deep to be imaged on available seismic records. The unit is about 1.5 km thick in the northern part of the Blackwater block, thickens southward to greater than 3 km and then thins abruptly to about 1 km (Fig. 16P). These thickness changes appear to be due to erosional truncation at the base of the Basinal Unit.

Correlation, age, and inferred lithology of the Lower Unit

We correlate the Lower Unit with the Bigbear and Fault River formations on Coppermine Homocline on the bases of similar stratigraphic position (overlying crystalline basement) and similar discontinuous occurrence below a regional unconformity (base of the Basinal Unit in the subsurface; base of Lady Nye Formation at surface). The age of the unit is poorly constrained and depends on the validity of that correlation. The age of the Bigbear and Fault River formations is between 1.84 Ga (that of the underlying Wopmay Orogen basement) and 1.66 Ga (that of the Narakay volcanic complex in the Kaertok Formation, which occurs higher in the Hornby Bay Group). The age of the Wernecke Supergroup in the Cordillera is greater than the 1.71 Ga Bonnet Plume River Intrusions (Thorkelson et al., 2001), and possibly falls in the range 1.66 Ga–1.84 Ga. The supergroup is clearly older than the 1.66 Ga Kaertok Formation but has been tentatively correlated with the lower parts (East River Formation and older) of the Hornby Bay Group (Cook and MacLean, 1995; Thorkelson, 2000). However, Thorkelson et al. (2001) suggested that in order for that correlation to be viable a major unconformity should exist within the group, and consequently the unconformity above the Lower Unit, in the subsurface, and above the Bigbear and Fault River formations at surface is potentially very important. Accordingly, we interpret (Fig. 2, 3) that the Wernecke Supergroup potentially correlates only with the Lower Unit of the HB Assemblage in the subsurface, and only with the Bigbear and Fault River formations of the Hornby Bay Group at surface. This treatment implies that the unconformity represents a large hiatus, and we consider that the Wernecke Supergroup and its continental counterparts comprise a separate depositional sequence. Note that the Wernecke Supergroup is known only to predate the 1.71 Ga Bonnet Plume River Intrusions. With no constraint on the maximum age the Wernecke sequence need not be correlated with any part of the Hornby Bay Group.

The Lower Unit has not been encountered in drilling. The 'correlative' Bigbear and Fault River formations comprise a variety of continental conglomerate, sandstone, and minor mudstone (Ross and Kerans, 1989). In contrast, the Lower Unit of the HB Assemblage has at least one apparent reef, implying that the unit comprises, at least in part, offshore marine equivalents of the continental Bigbear and Fault River formations. The 13 km thick Wernecke Supergroup presumably represents continental-margin rift deposits with uncertain relationships to the continental Lower Unit, and Bigbear and Fault River formations. However, lithologies in the Wernecke provide little or no insights into lithologies in the Lower Unit.

Basinal Unit

The Basinal Unit appears as a thick zone of generally weak, discontinuous reflections. It is a seismically dull zone sandwiched between a very strong basal reflection, below, and a distinctive bundle of reflections representing the overlying Platformal Unit, above (e.g., Transects A-D, L, Fig. 20). The unit fills an intracratonic basin extending over the entire Colville-Anderson and much of the Peel area. Thickness varies from 1 to 1.5 seconds (2.8 to 4.1 km at a seismic interval velocity of 5500 m/s), with the exception of a very deep northeast-southwest trough in the northwest part of the study area (Fig. 21) where thickness exceeds 7 km. Both sides of that trough are imaged on seismic lines (e.g., western end of Transect A). In the broad area southeast of that trough local, abrupt thickness variations occur partly because of basement topography and partly because of syndepositional extensional faulting.

An example of basement topography occurs at the eastern end of Transect C, (Line 90X) where a huge basement mound with topographic relief of about 0.3 s (800 m) can be seen. Similar mounds are imaged on Transect E (Lines PCR 80X and PCR 90A), and on Figure 22. Cook and MacLean (1992) attributed the feature in Figure 22 to an early phase of compressional deformation because it coincides with a large polyphase fault. Conversely the mounds exhibited on Transects C and E have no associated large fault, and we now consider these topographic highs to be huge monadnocks on the eroded basement surface.

A compelling reason for rejecting these culminations as compressional structures is the presence of extensional syndepositional growth faults, across which the Basinal Unit thickens abruptly. Syndepositional normal faults are interpreted at four localities (Fig. 21). For two of these faults (see eastern end of Transect C, Line PCR 109; also see Fig. 31) it is is apparent that syndepositional extension affected only the lower part of the unit. Stratigraphic thickening across two other faults (Fig. 23; Transect L, Line Mobil I-3) indicates syndepositional extension, but timing cannot be determined with available data. In both cases the evidence for the extensional phase was largely obscured by subsequent compressional inversion during the Forward Orogeny. The fault illustrated in Figure 23 is discussed in greater detail in Cook and MacLean (1996a) than it is here.

Distinct seismic markers locally interrupt the generally weak seismic character of the Basinal Unit (western end of Transect A) and local unconformable relationships exist within the unit (Fig. 24). These observations suggest that future studies may permit subdivision of the unit.

In the Colville-Anderson area the Basinal Unit rests unconformably on either basement or the Lower Unit of the HB Assemblage. In the Peel area the Basinal Unit is identified (Transects C, D, H), but data quality is generally poorer and seismic interpretation more subjective than in the Colville-Anderson area. We assume that the Basinal Unit in the Peel area overlies crystalline basement, but the basement reflection is weaker there and could, instead, represent a contact with sedimentary rocks such as the Wernecke Supergroup.

The upper boundary of the Basinal Unit is placed at the lowermost bright reflection of the overlying, layered Platformal Unit, except on a few large fault blocks where the DL Assemblage rests unconformably on the Basinal Unit.

Southward in the Mackenzie-Great Bear area the Basinal Unit can be identified in the vicinity of Blackwater Fault, a large west-side-down normal fault south of Keith Arm (Transect G, Line PCR 60X; Transect K, Line PCR 8416). 'Correlative' Lady Nye Formation strata outcrop about 150 km to the northeast along Leith Ridge on the southeast side of Great Bear Lake (Ross and Kerans, 1989; Fig. 4P). Over the remainder of the Mackenzie-Great Bear area HB strata are tentatively identified on the basis of unconformable relationships with the overlying DL Assemblage (Transects F, G, J, K), but data quality generally does not permit subdivision of the HB Assemblage.

Correlation, age, and inferred lithology of the Basinal Unit

We correlate the Basinal Unit with the Lady Nye Formation on Coppermine Homocline on the basis of similar stratigraphic position above a regional unconformity (Fig. 2, 3). The age of the Lady Nye Formation is poorly constrained as younger than 1.84 Ga (the age of the underlying Wopmay Orogen basement) and older than 1.66 Ga (the age of the Narakay volcanic complex which occurs higher in the Hornby Bay Group). If, as discussed under Correlation, age, and inferred lithology of the Lower Unit (p. 21) the 1.71 Ga Wernecke Supergroup correlates only with the subsurface Lower Unit and the surface Bigbear and Fault River formations, it follows that the Basinal Unit and the Lady Nye Formation have no known correlatives in the Cordillera.

No well penetrates strata that we have assigned to the Basinal Unit. The unit is assumed to contain deep-water, perhaps turbiditic, siliciclastic deposits, time-equivalents of deltaic sandstone and shale of the Lady Nye Formation outcropping on Coppermine Homocline (Fig. 2, 3).

Platformal Unit

The Platformal Unit, our most distinctive and widely recognizable seismic unit (Transects A-E; Fig. 23), comprises a parallel set of reflections 0.2 s to 0.5 s (550 m to 1400 m) thick, and conformably overlies the Basinal Unit. This relatively thin unit blankets the Colville-Anderson area, maintaining a consistent seismic character, with thickness changes apparent mostly on a regional scale. Local exceptions, where the unit thins onto paleo-structural highs (e.g., Fig. 25, 26) mark the earliest phase of uplift related to the Forward Orogeny. The Platformal Unit is our most important marker both for subdividing the HB Assemblage and for the recognition of Forward Orogeny structures. The tectonic stability implied by the continuous parallel reflections suggests a stable platformal environment, hence the name ‘Platformal Unit’. It is locally absent as a result of erosional truncation on some Forward Orogeny fault blocks (Fig. 20, 27P). Although the seismic data in the southeastern part of the Colville-Anderson area are less reliable, we interpret that erosion at the Sub-DL Assemblage unconformity has removed the Platformal Unit from the crest of a broad, northerly plunging anticline (Fig. 27P).

In the Peel area a reflective zone of appropriate thickness is considered to represent the Platformal Unit, and is our primary basis for identifying HB Assemblage strata there; data gaps preclude direct ties to the type Colville-Anderson area.

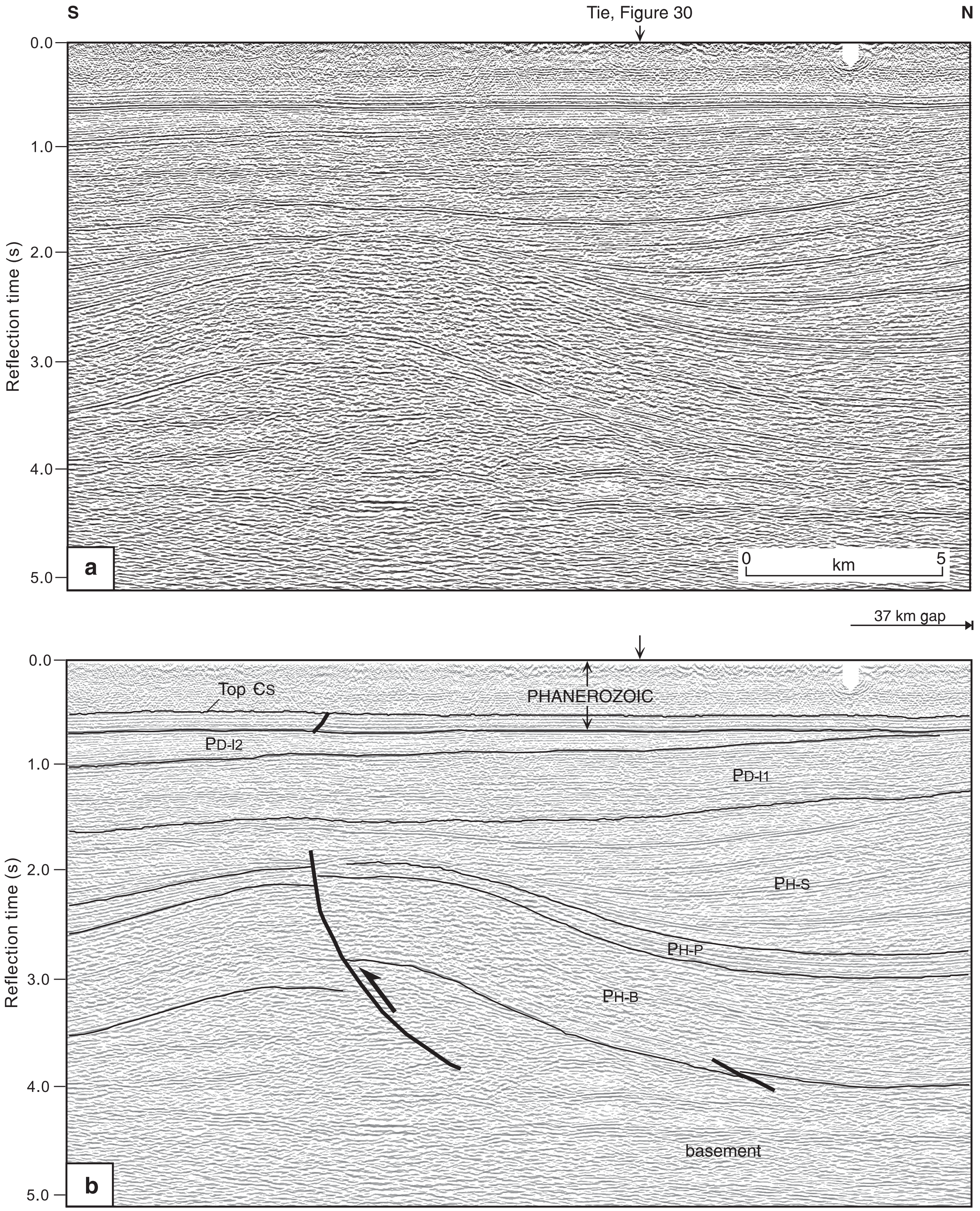
Southward in the Mackenzie-Great Bear area, as with Lower and Basinal units of the HB Assemblage, the Platformal Unit has been identified only in the vicinity of the large west-side-down Blackwater Fault south of Keith Arm (Transect G, Lines PCR 60X and PCR 8414; Transect K, Line PCR 8416). ‘Correlative’ East River Formation strata outcrop about 150 km to the east-northeast along Leith Ridge on the east side of the Great Bear basin (Ross and Kerans, 1989; Fig. 10P, 11P). Over the remainder of the Mackenzie/Great Bear area data quality does not permit subdivision of the HB Assemblage.

Lithology, correlation, and age of the Platformal Unit

The uniform seismic character and thickness of the Platformal Unit indicates tectonic stability and implies a stable platformal carbonate environment. The seismic layering of the unit implies lithological heterogeneity such as carbonate interbedded with some contrasting lithology like shale or evaporite deposits. Only three wells penetrate strata that we assign to the Platformal Unit and each encountered dolomite or cherty dolomite with subordinate other rock types. The thicknesses penetrated (71–89 m) are not great enough to adequately test the possibility of interlayered lithologies. On the eastern flank of the broad anticline north of Smith Arm of Great Bear Lake, strata considered to represent the Platformal Unit sub-crop at the sub-Cambrian unconformity (Fig. 4P). Although poor quality seismic data in that area render the interpretation of the Platformal Unit problematic, the unit as identified was penetrated by Forward et al. Anderson C-51, and Union Imp. Stopover K-44 (Fig. 4P). In the well file for C-51 the interval penetrated is reported as 71 m thick and described as cherty dolomite with argillaceous zones in the upper part, and argillaceous cherty dolomite in the lower part. Brown oil staining was reported in a cherty zone from 940 to 943 m. In K-44 the interval penetrated is 75 m thick and comprises dolomite with some shale and chert (Pugh, 1983). Side-wall cores were sampled but were not submitted to the regulatory agency.

In the Peel area, one well, Atlantic Circle Ontaratue H-34, encountered 89 m of dolomite at the bottom of the well (Pugh 1983) in strata we consider to be Platformal Unit. The seismic unit identified there (Fig. 28) is isolated from the Colville-Anderson area by a seismic data gap along the east side of Mackenzie River.

The Platformal Unit's contact with the overlying Syntectonic Unit is marked by an abrupt change from distinct and regularly layered reflections to weaker and/or irregularly layered reflections.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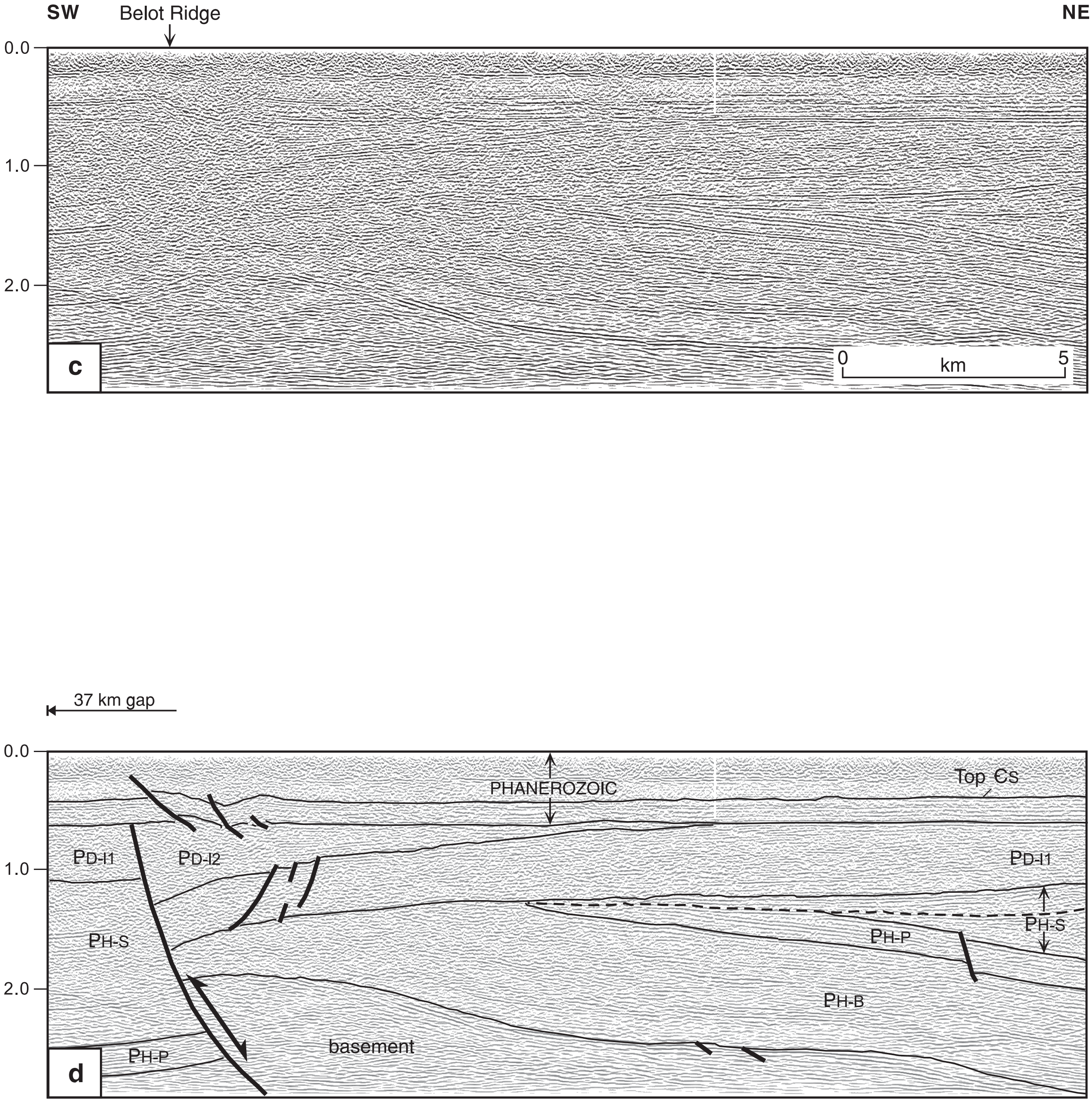


Figure 20. *1985 Petro-Canada Line 8711 and 1983 Forward Resources Line FR14 showing two Forward Orogeny structures. Unconformity-bounded seismic sequences within the* ꝐH-S *unit onlap the anticline on the left and show that they were deposited as this early-phase structure grew. The fault to the right is our 'type example' of a Forward Orogeny structure and is an example of a later phase of the Forward Orogeny. Uplift on this structure was sufficient to expose the* ꝐH-B *unit to pre-DL Assemblage erosion. The fault was reactivated by post-DL Assemblage extension. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. A pocket version of Figure 20 provides a superior display of the same lines at a larger scale. See Figure 1P for location.* ꝐH-B, *Basinal Unit of HB Assemblage;* ꝐH-P, *Platformal Unit;* ꝐH-S, *Syntectonic Unit; s, intrusive sheet;* ꝐD-I1, *Basal Member of Lower Unit of DL Assemblage;* ꝐD-I2, *Upper Member;* ꞒS, *Cambrian Saline River Formation.*

No seismic data link the subsurface to the exposures of Hornby Bay Group on Coppermine Homocline about 250 km to the east, but we correlate the Platformal Unit with the East River Formation on the homocline on the following bases: 1) they occupy similar stratigraphic positions within the HB Assemblage and Hornby Bay Group respectively, 2) East River Formation carbonate represents a platformal environment (Ross and Kerans, 1989; Kerans et al., 1981), corresponding to that interpreted for the Platformal Unit, 3) as noted above, the Platformal Unit is dolomitic where encountered by drilling, and 4) The Platformal Unit shows evidence of syntectonic deposition, (Fig. 25, 26), as does the East River Formation (Ross and Kerans, 1989). We take this tectonism, in subsurface and surface, to be the earliest manifestation of the Forward Orogeny.

The age of the Platformal Unit is considered to be that of the East River Formation, which, like that of the Lower and

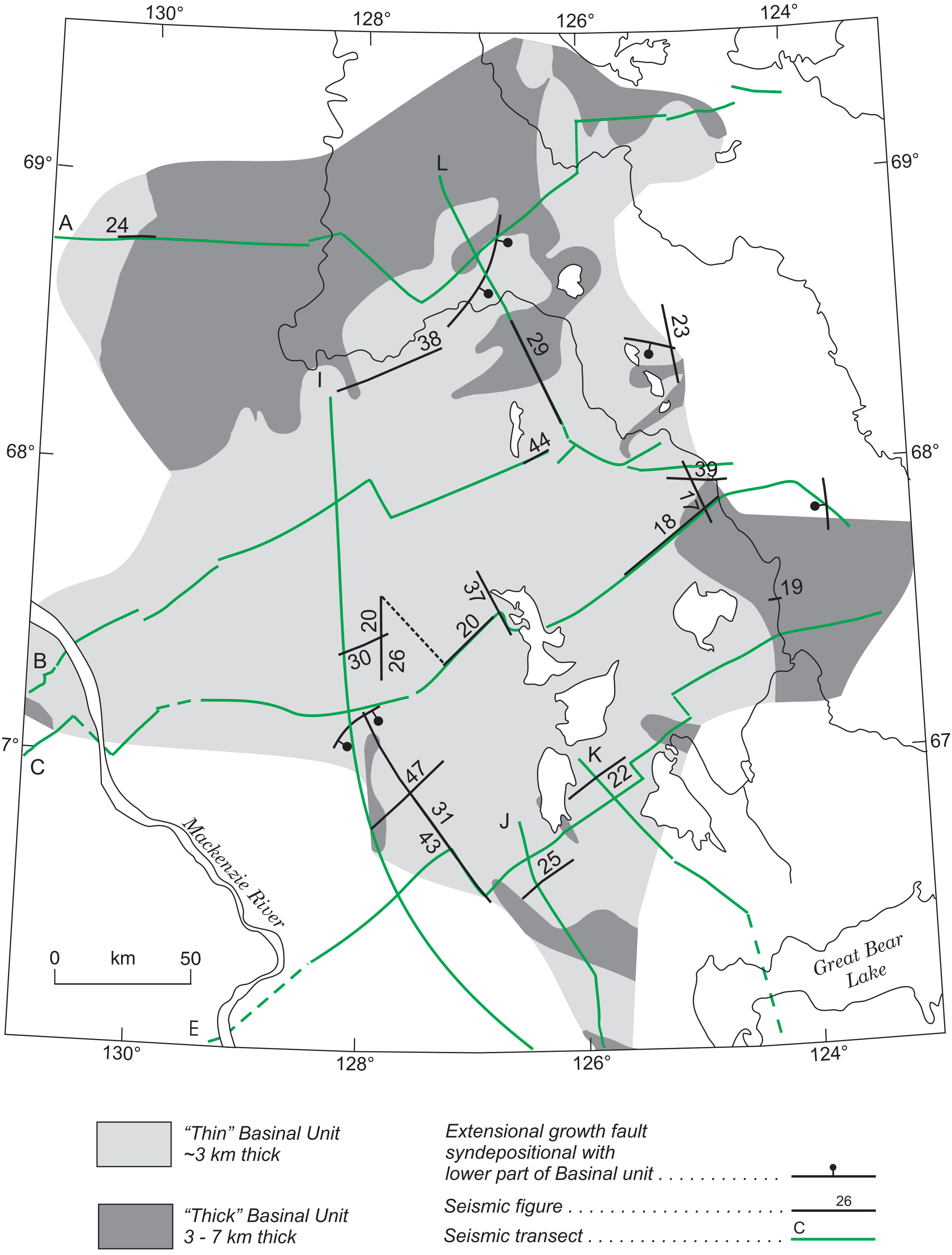


Figure 21. *Map outlining deep troughs within the Basinal Unit of the HB Assemblage.*

Basinal units, is poorly constrained as younger than 1.84 Ga (the age of the underlying Wopmay Orogen basement) and older than 1.66 Ga (the age of the Narakay volcanic complex, which occurs in the overlying Kaertok Formation).

The >1.71 Ga Wernecke Supergroup in the Cordillera was previously considered to contain equivalents of the East River and older formations of the Hornby Bay Group. However, as discussed under 'Correlation, age, and inferred lithology of the Basinal Unit', above, the East River Formation (surface) and the Platformal Unit (subsurface) are now seen to have no known correlatives in the Cordillera (Fig. 2, 3).

Syntectonic Unit

The tectonic stability generally represented by the Platformal Unit was followed by compressional uplift of basement-cored anticlines and fault blocks during the Forward Orogeny, with accompanying deposition of the Syntectonic Unit. Sedimentary wedges adjacent to large anticlines and thrust-block uplifts (Fig. 26, 29) record Syntectonic Unit deposition. The seismic character of the unit varies from distinct reflections that onlap adjacent structures (Fig. 26, 29), to weak, sub-parallel reflections in the intervening broad basins. The unit varies in thickness from zero as a result of erosion or nondeposition on structural highs (Fig. 20d, 23, 27P, 29) to 1.5 s (4.4 km) in undeformed basinal areas and in the footwalls of late structures (Fig. 20, 22).

Some depositional wedges onlap uplifted structures (Fig. 26); others form flanking aprons in both hanging wall and footwall of thrust blocks (Fig. 29). Local angular unconformities, common in the interval, represent pulses of uplift and erosion followed by renewed sedimentation. We were unable to correlate pulses in detail across the region, but two gross orogenic phases are readily apparent. For example, the wedges illustrated in Figures 20a, b, 23, 26, and 29 occupy the entire syntectonic interval, indicating that tectonism at those localities began shortly after deposition of the Platformal Unit and continued through deposition of the preserved Syntectonic section. In contrast, other faults (Fig. 20c, d, 22) moved late in the time of Syntectonic Unit deposition, and tectonism at those places postdated accumulation of thick, parallel-bedded sections of Syntectonic Unit now preserved in the footwalls.

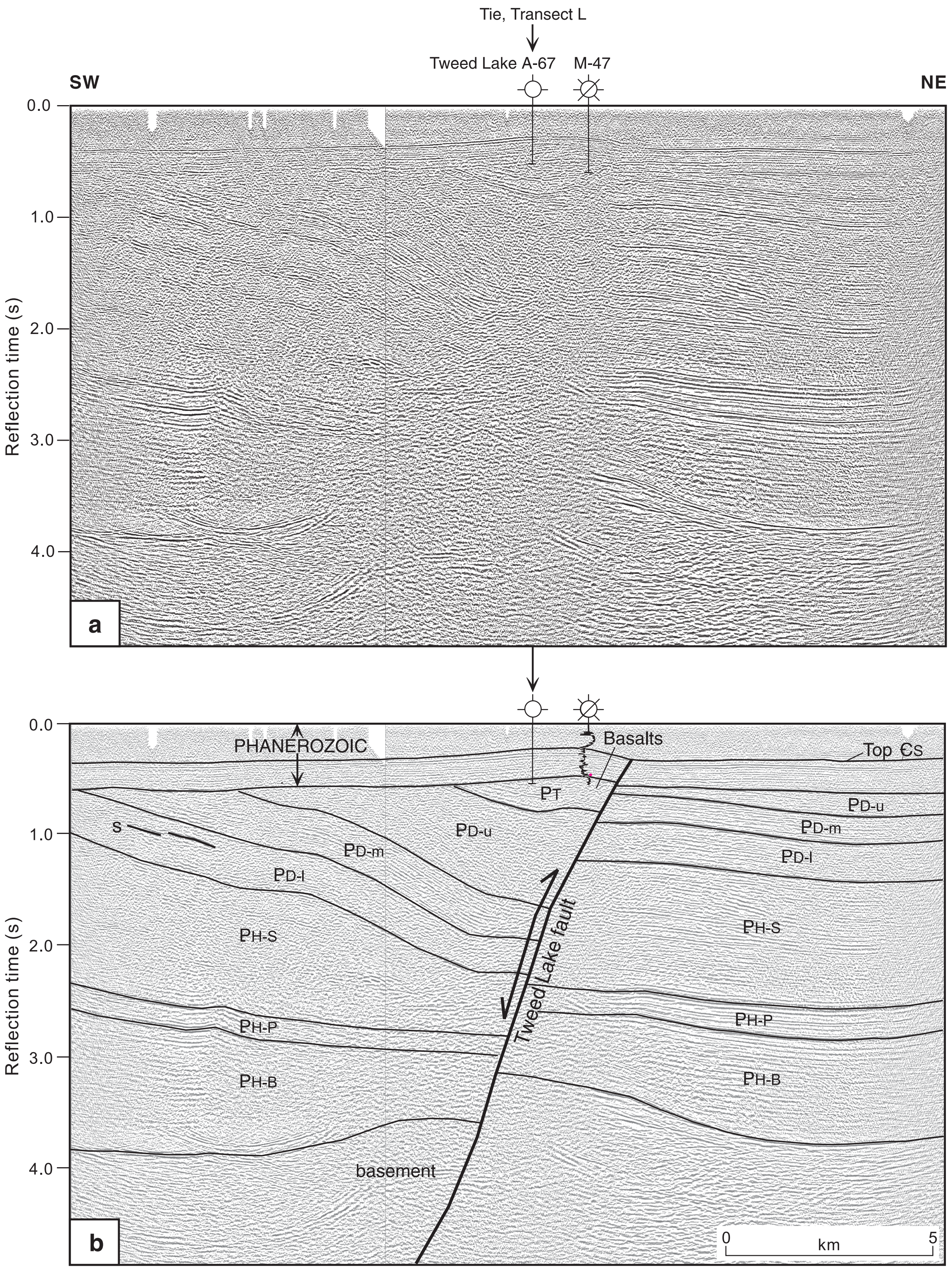
The top of the Syntectonic Unit is the unconformity at the base of the DL Assemblage. Some of the local unconformities within the Syntectonic Unit are more angular than the subsequent sub-DL unconformity and, if studied in isolation, can be mistaken for it. For example, the FR-14 structure (Fig. 20c, d) displays, within the Syntectonic Unit, an angular unconformity that was previously interpreted to be the base of the DL Assemblage (Cook and MacLean, 1992). However, the extensive network of seismic lines permits us to identify the higher surface as the regional unconformity. As will be discussed later, we find analogous relationships, displayed on geological maps of Coppermine Homocline, involving the syntectonic Kaertok and LeRoux formations and post-tectonic Fort Confidence Formation.

In the Peel area west of Mackenzie River the Syntectonic Unit is identified as strata overlying the distinctive Platformal Unit (Transects B, C, D, H) and underlying an unconformity that we identify as the sub-DL Assemblage unconformity (see Transect B). A prominent angular unconformity within the Syntectonic Unit (the dashed line in the western portions of Transects B, C, D) was initially thought to be the sub-DL Assemblage unconformity, but as such, it could not reasonably be reconciled with the sub-DL Unconformity across the Mackenzie River to the east.

In the Mackenzie-Great Bear area to the south we identify the Syntectonic Unit only adjacent to the Blackwater Fault. Elsewhere, undivided HB Assemblage is tentatively identified beneath a regional, locally angular unconformity that we consider to be the sub-DL Unconformity.

Lithology, correlation, and age of the Syntectonic Unit

We correlate the Syntectonic Unit with outcrops of syntectonic Kaertok and LeRoux formations in Coppermine Homocline (Fig. 2, 3). The Kaertok, about 500 m thick (Kerans et al., 1981), contains a variety of arenite and mudstone deposits and, interestingly, oolitic and stromatolitic dolomite (Ross and Kerans, 1989). The LeRoux Formation is mainly quartz arenite with local basal conglomeratic litharenite. If the subsurface Syntectonic Unit is composed mainly of clastic rocks, some large external source of sediment must have existed, because the Forward Orogeny uplifts, cumulatively, occupy an area too small to provide the great volume of sedimentary strata in the adjacent broad syntectonic basins; thicknesses reach 4.4 km in the southern part of the Colville-Anderson area. The presence of stromatolitic dolomite in the Kaertok Formation on Coppermine Homocline is noteworthy because exploratory drilling has encountered both siliciclastic and carbonate strata in the subsurface Syntectonic Unit. In eastern Colville-Anderson area the Forward et al. Izok D-11 well (Fig. 4P), encountered dolomite in strata that we consider to be Syntectonic Unit. West of the Colville Hills, two wells, Candel Mobil et al. Iroquois I-11, and Candel et al. Mobil Grandview L-26 (Fig. 4P) likewise encountered dolomite in Syntectonic Unit strata. Two wells, Mobil


Tie, Transect L
Tweed Lake A-67
M-47
SW
NE
0.0
1.0
2.0
3.0
4.0
Reflection time (s)
a
PHANEROZOIC
Basalts
Top Єs
PT
PD-u
PD-m
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s
PH-S
PH-P
PH-B
Tweed Lake fault
basement
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Reflection time (s)
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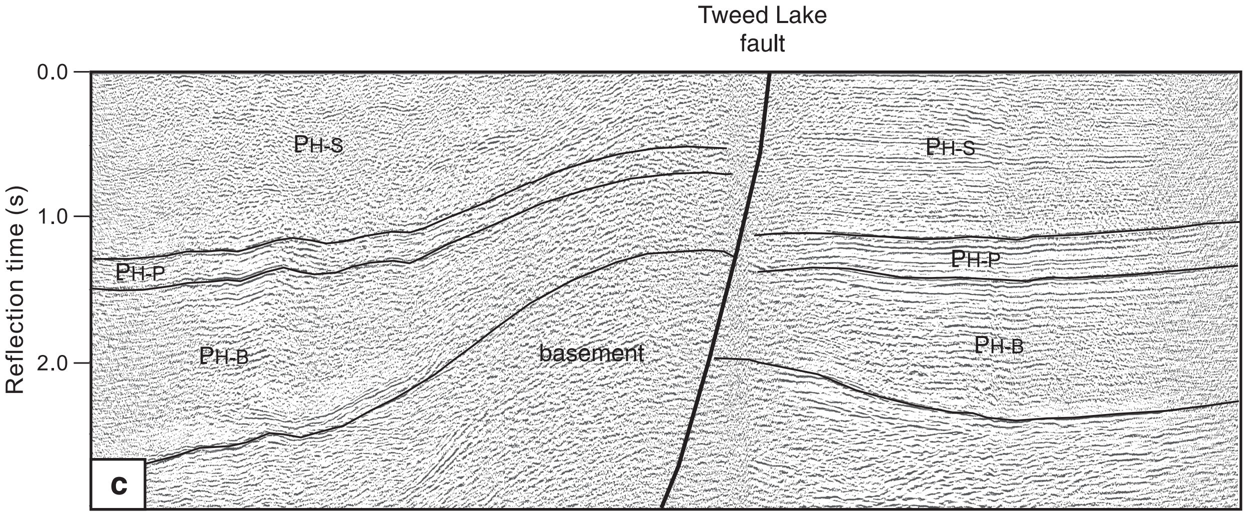


Figure 22. *1979 Petro-Canada Lines 110A and 116A. A Forward Orogeny compressional structure has undergone major post-DL Assemblage extensional inversion and later adjustment during the Laramide Orogeny. Extensional reactivation of about 1.2 s (3.2 km) vertical displacement nullified the effect of pre-DL compressional uplift (Forward Orogeny) leaving a net normal displacement of Hornby Bay units of about 1.2 km (for an alternative interpretation see Sevigny et al., 1991, Fig. 9). Gas was encountered in Tweed Lake M-47, a well drilled into an anticline that was generated by reactivation of the Proterozoic fault during Laramide deformation.* ***a.*** *Uninterpreted;* ***b.*** *interpreted.* ***c.*** *Restoration of the sub-Dismal Lakes unconformity to horizontal by shifting individual seismic traces vertically removes the effect of the extensional phase and reveals the Forward Orogeny compression with uplift of about 0.7 s (2.1 km). The curved fault is schematic. Absence of syntectonic wedges shows this to be a late-stage structure. Compare the restored structure with the FR-14 fault (Fig. 20). Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* PH-B, *Basinal Unit, HB Assemblage;* PH-P, *Platformal Unit;* PH-S, *Syntectonic Unit;* PD-l *Lower Unit, DL Assemblage;* PD-m, *Middle Unit;* PD-u, *Upper Unit;* PT, *Tweed Lake Assemblage; s, intrusive sheet;* ꞒS, *Cambrian Saline River Formation.*

Inexco NCO Sun Iroquois D-40, and Atlantic Columbian Carbon Arctic Circle Ontaratue K-04, intersected dolomite, as well as sandstone and shale. The greatest lithostratigraphic record is that of the Atlantic et al. Ontaratue H-34 well, which penetrated about 186 m of orthoquartzite, siltstone and shale, underlain by 871 m of argillite, all of which we assign to the Syntectonic Unit (Fig. 28). The orthoquartzitic upper beds were assigned to the Cambrian Mount Clark and Mount Cap formations by Pugh (1983) but the well lies considerably to the west of the Mount Clark and Mount Cap zero-edges as defined by Dixon and Stasiuk (1998) and the strata are considered to be Proterozoic (Dixon, pers. comm., 1999). The Atlantic et al. Ontaratue H-34 well bottomed in dolomite, which as noted previously, we have assigned to the Platformal Unit.

Despite the lithological heterogeneity displayed in well intersections we have thus far not identified mappable seismostratigraphic units within the Syntectonic Unit. However, a number of bright reflections in syntectonic strata flanking a large anticline in the Colville Hills area may represent fringing carbonate aprons (Fig. 20P, 30). Similar discontinuous reflections occur elsewhere in the Colville-Anderson and Peel areas. These reflections could alternatively represent sandstone; none has been tied to a well section. To complicate the interpretation, some bright reflections are discordant at a low angle to bedding (central part of Transect B) and probably represent intrusive sheets (to be discussed later).

No seismic data link subsurface units to the exposures on Coppermine Homocline about 250 km to the east, but we correlate the Syntectonic Unit with the uppermost Hornby Bay Group units (Kaertok and LeRoux formations) on Coppermine Homocline on the following bases: 1) they occur at the top of the HB Assemblage and Hornby Bay Group respectively, and 2) both the subsurface and surface units were deposited syntectonically during uplift and erosion of basement blocks. Assignment of the LeRoux to the Hornby Bay Group rather than the overlying Dismal Lakes Group is a departure from that of our previous papers (e.g. Cook and MacLean, 1995), and from that of Ross and Kerans (1989) and Kerans et al. (1981). The present assignment is actually a return to the interpretations of Baragar and Donaldson (1970, 1973). Our reasons for reassignment are because the LeRoux Formation has been

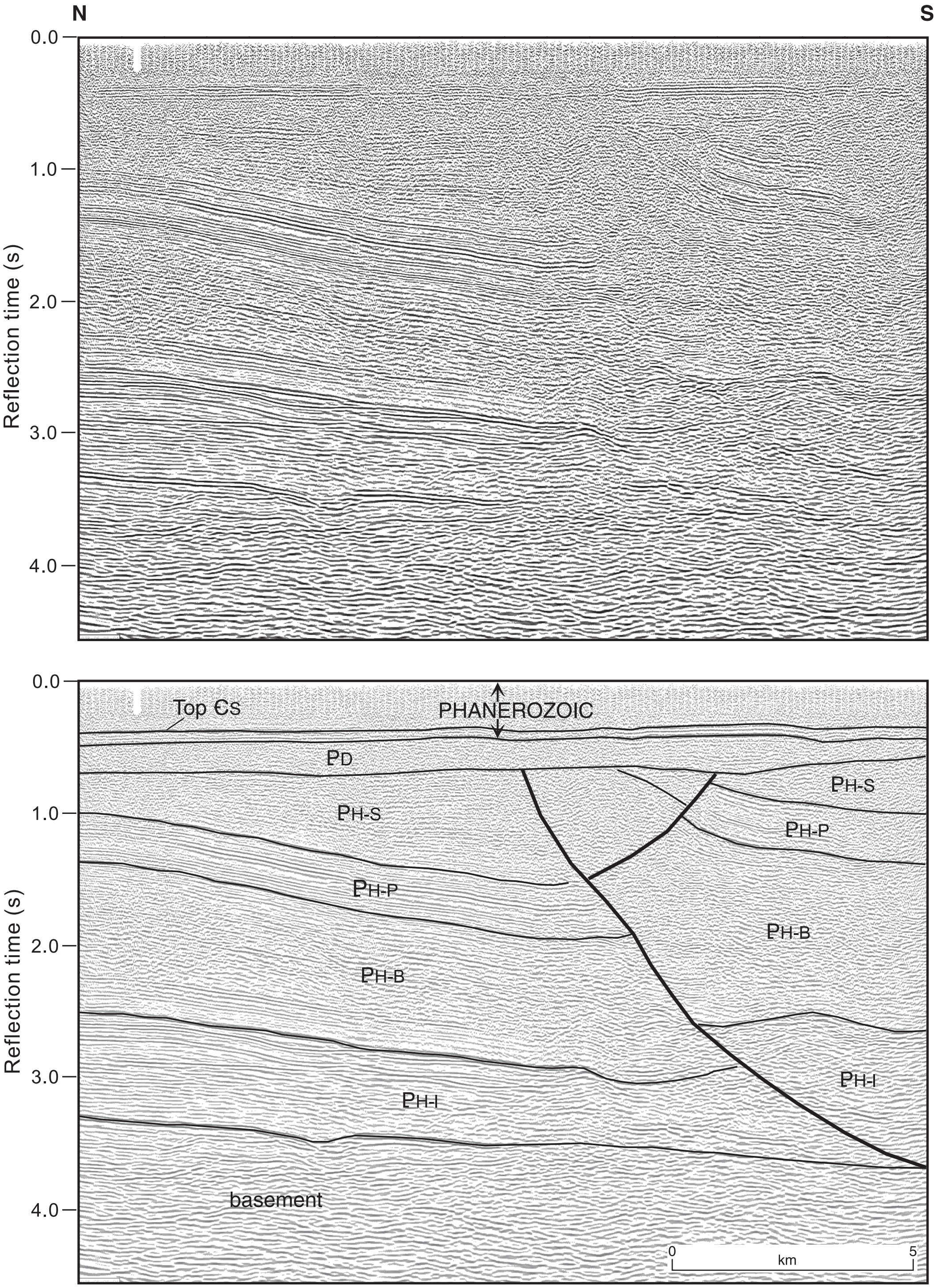


Figure 23. *1975 HBOG Line 7 provides an excellent example of the four units of the HB Assemblage, a Forward Orogeny structure and angular bedding relationships across the sub-DL Assemblage unconformity. Abrupt thickening of the Basinal Unit across the fault is interpreted as a syn-Basinal Unit half-graben that was inverted by Forward Orogeny compressional reactivation. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ⱣH-I, *Lower Unit of HB Assemblage;* ⱣH-B, *Basinal Unit;* ⱣH-P, *Platformal Unit;* ⱣH-S, *Syntectonic Unit;* ⱣD, *DL Assemblage, undivided;* ЄS, *Cambrian Saline River Formation.*

described in the literature as a syntectonic unit, and because the map of Ross and Kerans (1989) shows the LeRoux Formation to have been tilted and eroded prior to deposition of the Fort Confidence Formation, the first regionally continuous formation of the overlying Dismal Lakes Group.

Identifying the boundary between strata affected by the Forward Orogeny, and those that were not, on Coppermine Homocline, is problematical. Kerans et al. (1981) recognized that uplift and erosion of the Teshierpi Fault block were accompanied by syntectonic deposition of their Unit 10 (Kaertok Formation of Ross and Kerans, 1989), but were ambivalent about a possible syntectonic relationship between the uplift and the LeRoux Formation. On one hand they stated (op. cit., abstract, p. 157) that synchronous movement along Teshierpi Fault resulted in erosion of the upthrown block and “controlled fluvial drainage patterns of upper Hornby Bay and lower Dismal Lakes groups”, and later in their text (p. 167) that the uplift “resulted in deposition of Units 10 and 11” (i.e. the Kaertok and LeRoux formations). On the other hand they noted (p. 169) that fault movement “culminated prior to deposition of Unit 11 arenites”. We focus here on a basement-involved uplift, mapped by Ross and Kerans (1989), at the western end of Dismal Lakes, wherein the LeRoux Formation, along with underlying units, was tilted on a basement-block uplift and erosionally truncated prior to deposition of the Fort Confidence Formation (see Fig. 36 in section on Forward Orogeny, below). We interpret this tectonism on Coppermine Homocline to be a product of the Forward Orogeny, and consider both the Kaertok and the LeRoux formations to be equivalents of the subsurface Syntectonic Unit. We therefore place the LeRoux Formation within the Hornby Bay Group as did Baragar and Donaldson in 1970 and 1973. The overlying regional unconformity at the base of the Fort Confidence Formation of the Dismal Lakes Group is correlated here with the subsurface regional unconformity at the base of the DL Assemblage.

The Kaertok Formation is dated as 1663 Ma, the age of the Narakay volcanic complex, which occurs in the

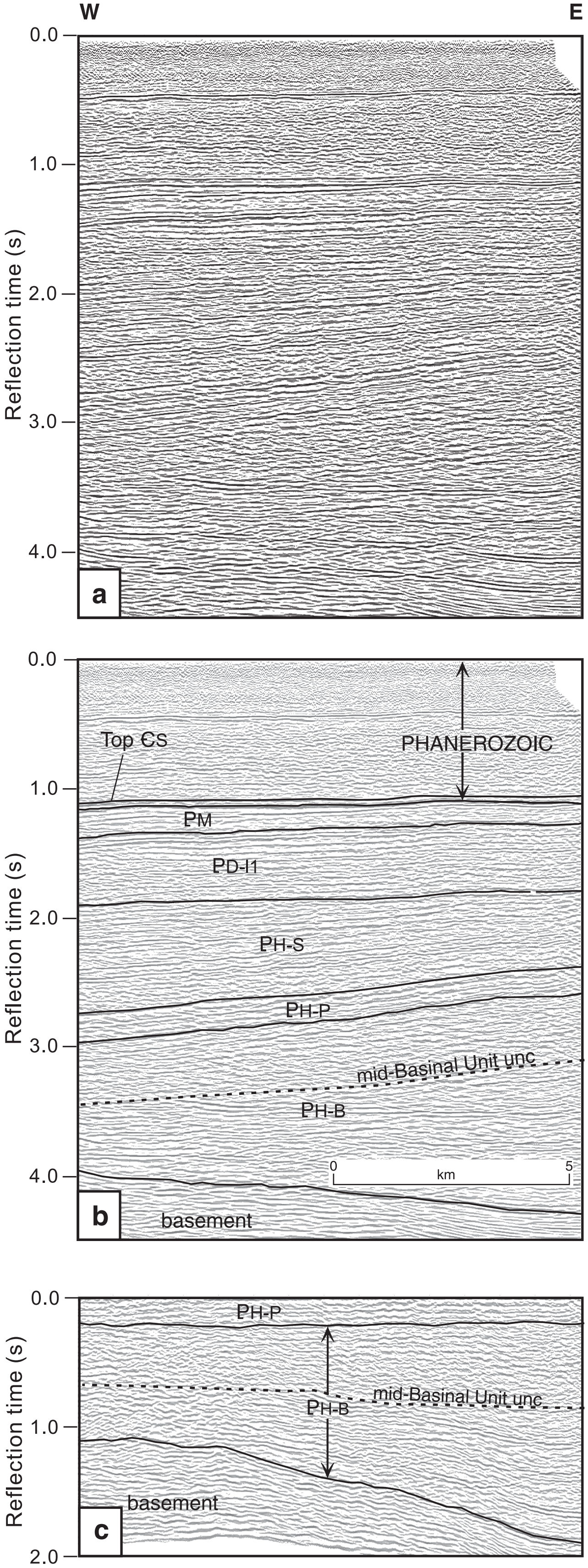


Figure 24. *1973 Shell Canada Line 1152 showing the western flank of a Basinal Unit trough and an unconformity lying about 0.5 seconds below the ⱣH-P. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ***a.*** *Uninterpreted;* ***b.*** *interpreted.* ***c.*** *The top of the Platformal Unit has been restored to horizontal by vertical shifting of seismic traces to better illustrate dramatic thickness changes and an apparent unconformity in the Basinal Unit of HB Assemblage. ⱣH-B, Basinal Unit of the HB Assemblage; ⱣH-P, Platformal Unit; ⱣH-S, Syntectonic Unit; ⱣD-I1, Basal Member of Lower DL Assemblage; ⱣM, M/S Assemblage; ЄS, Cambrian Saline River Formation.*

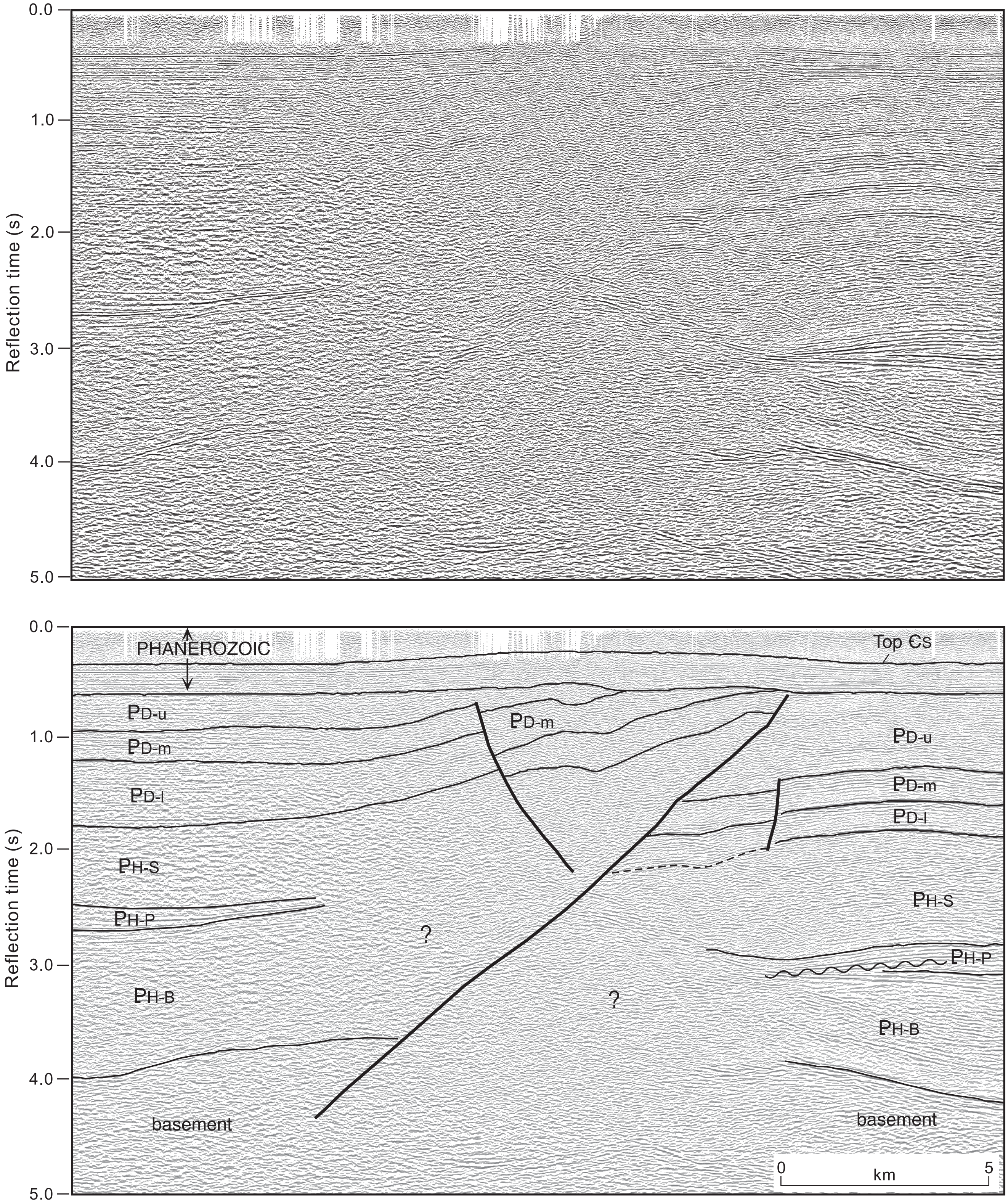


Figure 25. *1981 Petro-Canada Line 74X showing thinning of the Platformal Unit of the HB Assemblage toward the central zone of poor data and delineating a local unconformity within the unit, thus providing an example of pre-Syntectonic Unit tectonism. The large reverse fault interpreted here involves post-DL Assemblage tectonism. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ᵽH-B, *Basinal Unit of HB Assemblage;* ᵽH-P, *Platformal Unit;* ᵽH-S, *Syntectonic Unit;* ᵽD-l, *Lower Unit of DL Assemblage;* ᵽD-m, *Middle Unit;* ᵽD-u, *Upper Unit;* ꞒS, *Cambrian Saline River Formation.*

formation (Bowring and Ross, 1985). Thus if the Syntectonic Unit correlates with the Kaertok its age is better constrained than that of older HB Assemblage units. Moreover, the Syntectonic Unit unequivocally has no counterpart in the >1.71 Ga Wernecke Supergroup in the Cordillera.

Structure and tectonics related to the HB Assemblage and Hornby Bay Group

Introduction

The HB Assemblage and the Hornby Bay Group have been subjected to a variety of epeirogenic, extensional, compressional, and transpressional events. Epeirogenic uplift and concomitant erosion affected the distribution of the Lower Unit of the HB Assemblage and assumed correlatives, the Bigbear and Fault River formations, of the Hornby Bay Group. Basin subsidence and deposition of the variably thick Basinal Unit were accompanied by syndepositional normal faults, but counterparts that affected the correlative Lady Nye Formation on the Coppermine Homocline have not been found. The most important tectonic event studied was the Forward Orogeny, a compressional event that commenced during deposition of the Platformal Unit, continued throughout deposition of the Syntectonic Unit, and culminated with transpressional effects, late in the time of Syntectonic Unit deposition. Some Forward Orogeny structures are inversions of half-grabens, products of the earlier extension phase; others were themselves later negatively inverted during post-DL Assemblage extension (Cook and MacLean, 1996a).

Epeirogenic uplift

Peneplaning of the Wopmay Orogen and the Hottah Terrane was followed by deposition of the Lower Unit of the HB Assemblage, and the basal Bigbear and Fault River formations of the Hornby Bay Group. These units, themselves truncated by regional erosion, are discontinuous and unconformably overlain by younger HB/Hornby Bay strata. The Bigbear and Fault River formations are nonmarine sandstone and conglomerate units that were deposited in isolated basins on Wopmay basement of the Coppermine Homocline. In contrast, the Lower Unit of the HB Assemblage appears to represent intracontinental marine deposition in a single basin about 500 km long extending from the Horton Lake area north of Great Bear Lake to Blackwater Lake south of Great Bear Lake (Fig. 15P, 16P). The subject strata no doubt occupied greater areas initially, but regional erosion and gentle angular truncation accompanying epeirogenic uplift have reduced the area to its present remnants.

Early extension

Continental subsidence and development of a huge intracontinental basin possibly extending from Coppermine Homocline to Eagle Plain followed erosion. Into this basin were deposited the Basinal Unit (subsurface) and the deltaic Lady Nye Formation (Coppermine Homocline). Isochrons and isopachs of the basinal-platformal succession show in the northwestern part of the study area a deep sub-basin with 2-2.6 s (5.5–7 km) of strata (western end of Transect A, Fig. 10P, 11P, 21). Extensional subsidence was manifested by the development of a small number of classical half-grabens, observed in various localities. The best example (west side of Fig. 31) can be analyzed in terms of pre-rift, syn-rift, and post-rift sequences (Cook and MacLean, 1996a) and shows syntectonic deposition of the middle part of the Basinal Unit. Another example of Basinal Unit thickening abruptly across a fault can be seen on Line I-3 (Transect L). These examples suffered minor compressional inversion during the Forward Orogeny. In a third example (Fig. 23) abrupt thickening across a fault indicates an ancestral half-graben, although the half-graben aspect was obscured by complete inversion of the structure during the Forward Orogeny. A final example (east end of Transect C) again shows syntectonic deposition of the lower part of the Basinal Unit.

No counterpart to these extensional faults has been identified in the maps of Coppermine Homocline. We assume that they are local developments related to overall basin subsidence. Two of them have a northeast-southwest trend subparallel to the general trend of the depositional basin. To the west, Wernecke Supergroup strata are cut by numerous normal faults (Thorkelson and Wallace, 1998a, b, c) but the age of faulting is uncertain.

Forward Orogeny

The most important tectonic event to affect the subsurface strata examined in this study is the Forward Orogeny (Cook and MacLean, 1995). Forward Orogeny structures (Fig. 27P) are, for the most part, discontinuous thrust-fault uplifts or anticlines. They are basement-cored, and display a variety of structural trends and inconsistent vergences, similar in style to that of thick-skinned intracratonic belts such as the Rocky Mountain foreland of the U.S.A. or the Sierras Pampeanas of Argentina (Jordan and Allmendinger, 1986). In plan-view (Fig. 27P), the structures lack the parallel continuity characteristic of classic, thin-skinned fold and thrust belts such as the Canadian Rocky Mountains. Forward Orogeny structures are best documented in the Colville-Anderson area, and are interpreted to occur in the Peel area to the west and in the Mackenzie-Great Bear area to the south (specifically

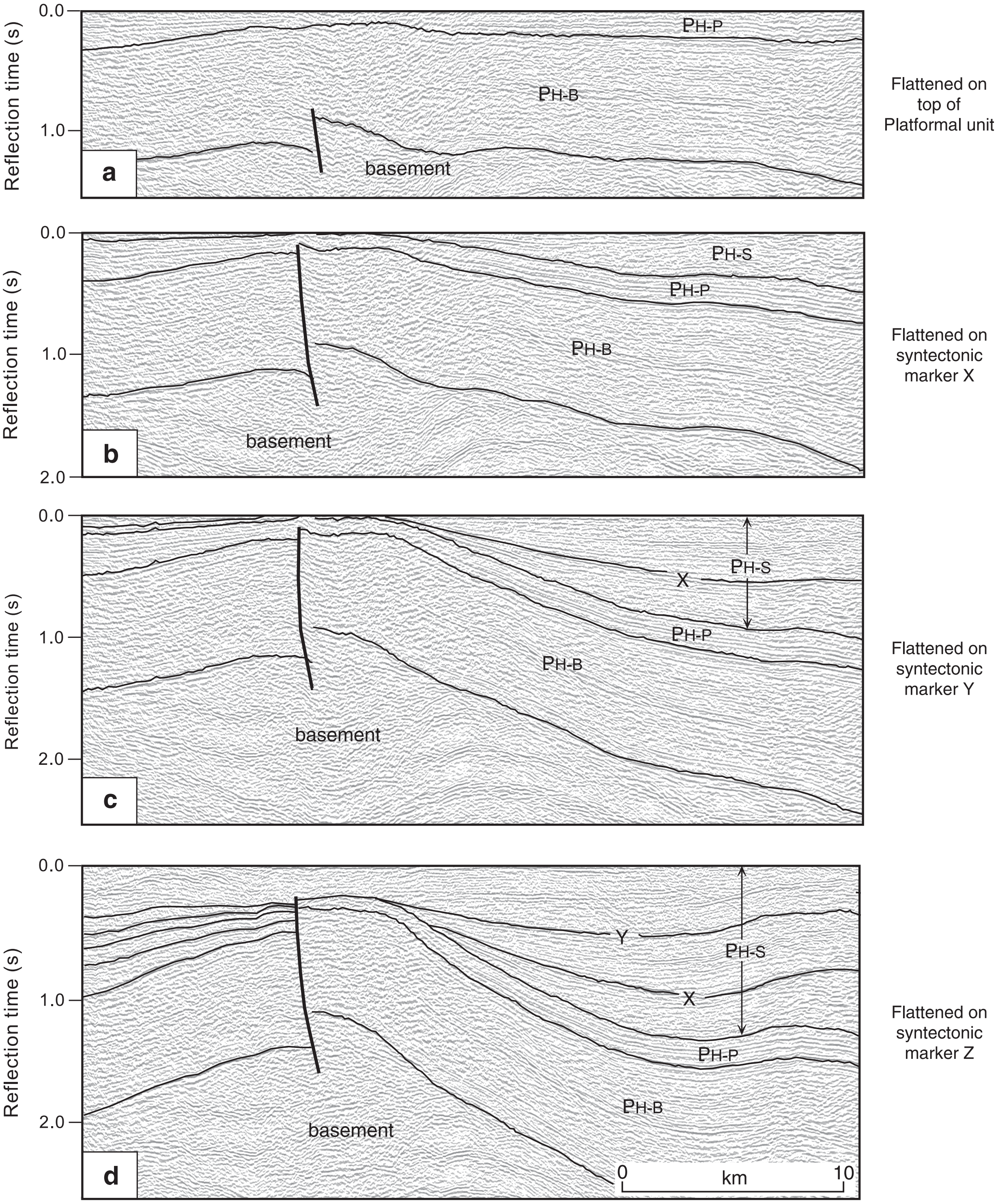
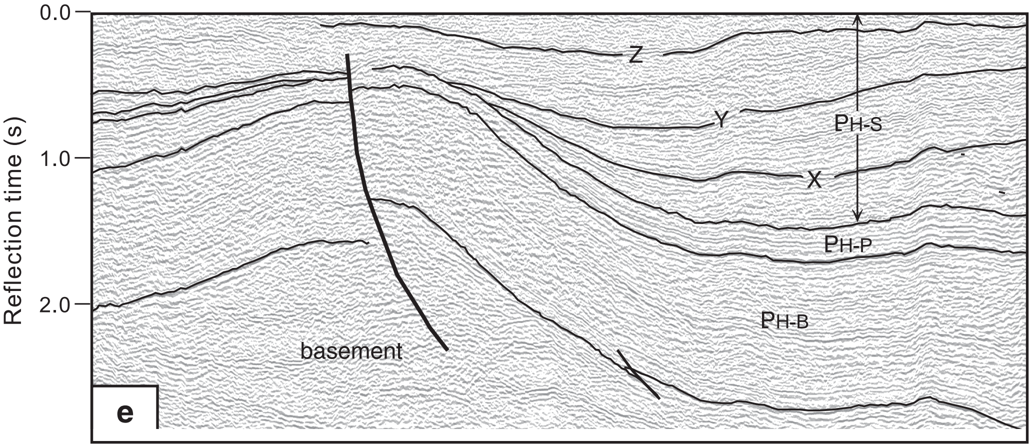
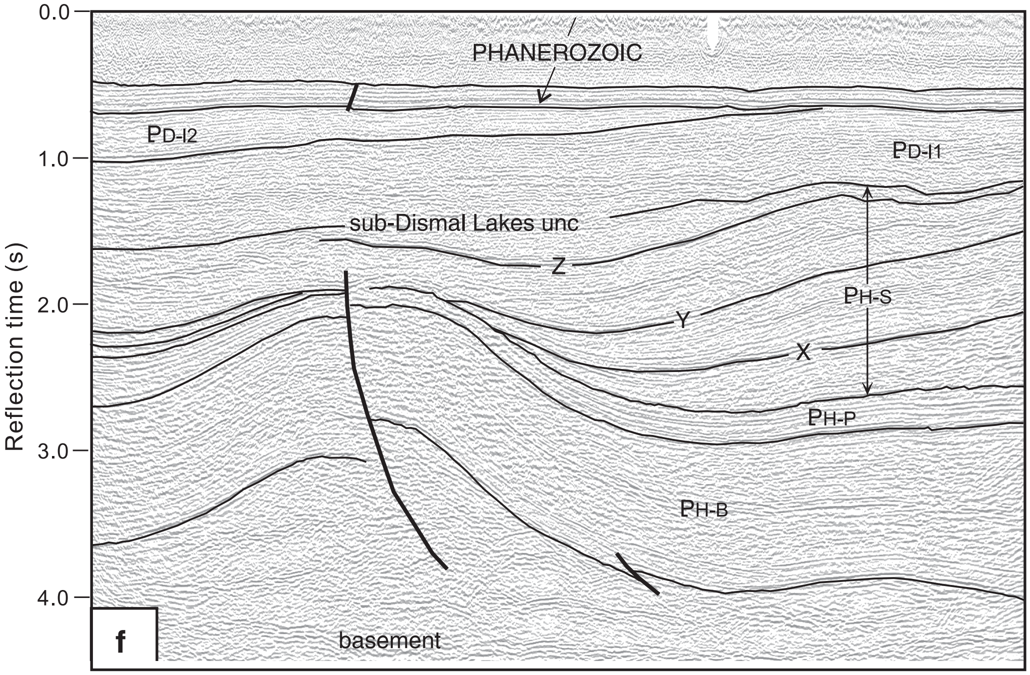


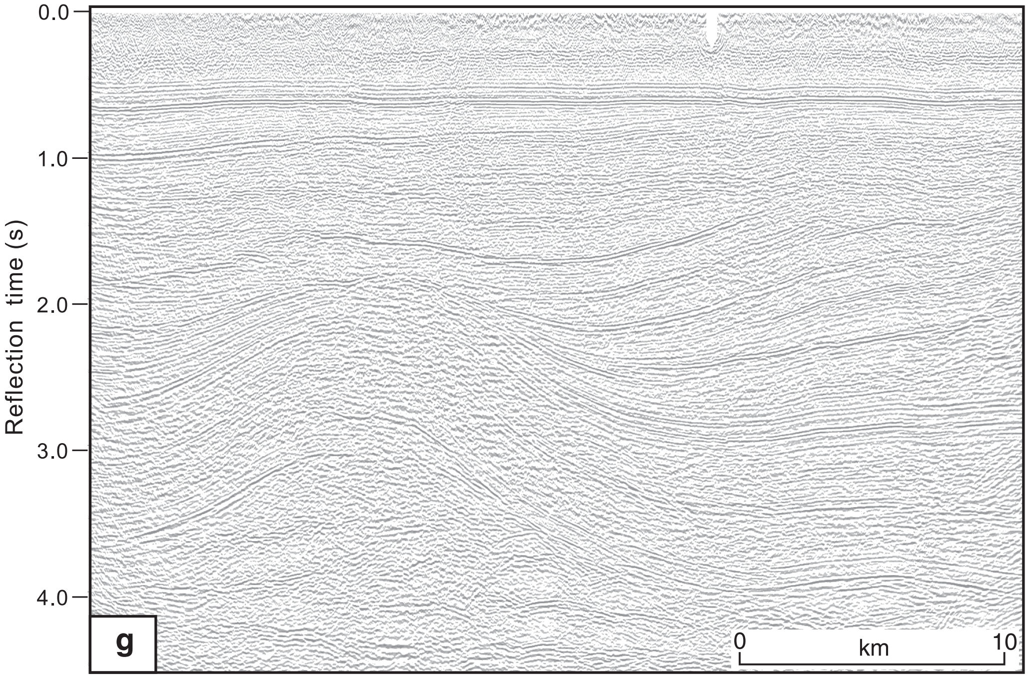
Figure 26. *1985 Petro-Canada Line 8711. Diagrams* ***a.*** *through* ***e.*** *are flattened on successively younger markers (X, Y, and Z) within the Syntectonic Unit of the HB Assemblage (ⱣH-S) to illustrate the generation through time of the large anticline. Diagram* ***f.*** *shows the present structure and* ***g.*** *displays the uninterpreted data. Vertical exaggeration is approximately 2:1 at a seismic velocity of 5500 m/s. See Figure 1P for location. ⱣH-B, Basinal Unit of HB Assemblage; ⱣH-P, Platformal Unit; ⱣH-S, Syntectonic Unit; ⱣD-I1, lower member of lower unit of Proterozoic DL Assemblage; ⱣD-I2, upper member of lower unit of Proterozoic DL Assemblage.*



Flattened on
sub-Dismal Lakes
unconformity



Interpreted
structure
section



Uninterpreted
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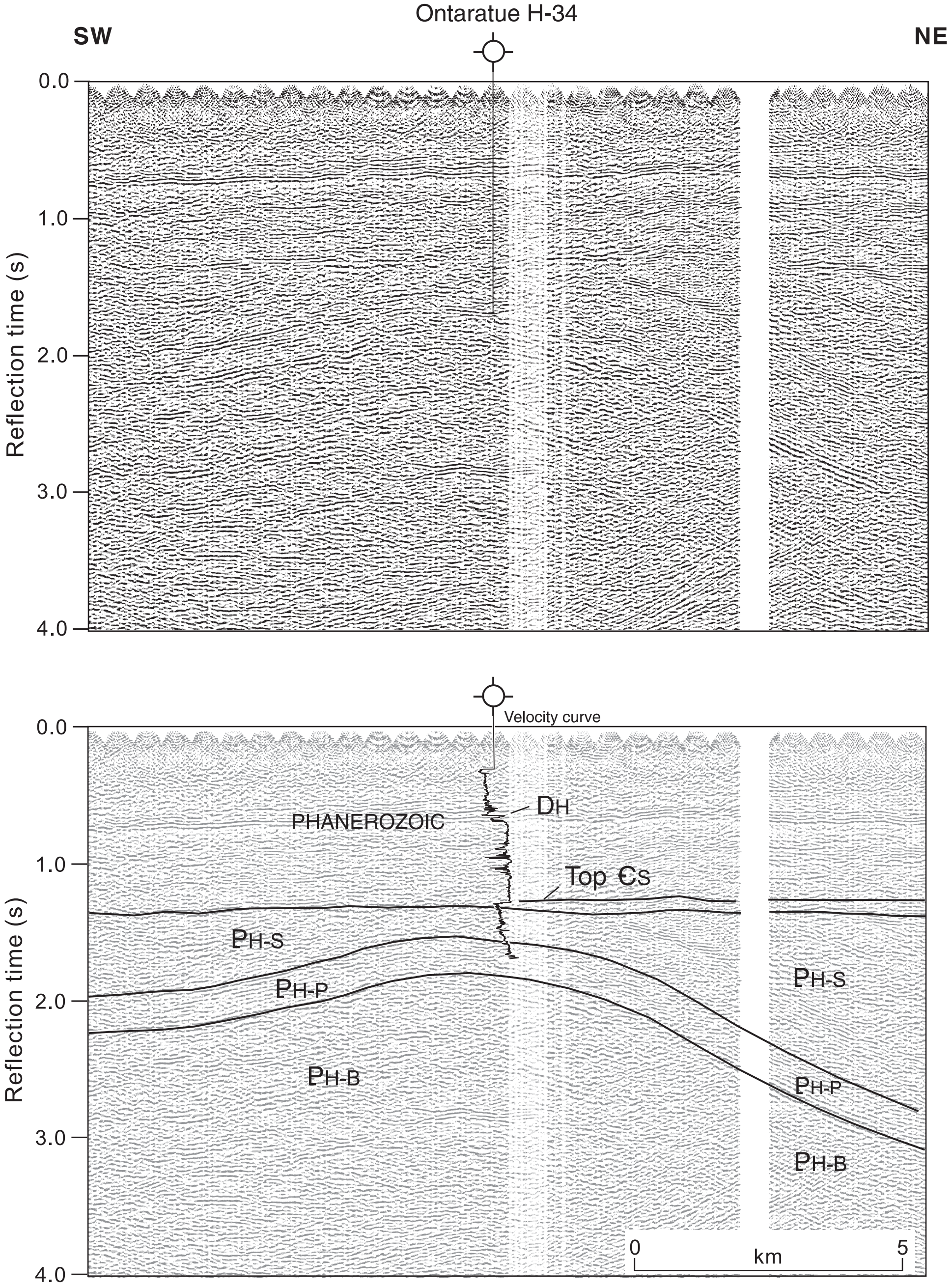

Figure 28. *1963 Petro-Canada Line 57 with velocity log from Atlantic et al. Ontaratue H-34 well. Dolomite encountered near the bottom of the well is interpreted as Platformal Unit of HB Assemblage (*PH-P*). Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* PH-B, *Basinal Unit of HB Assemblage;* PH-P, *Platformal Unit;* PH-S, *Syntectonic Unit;* ЄS, *Cambrian Saline River Formation;* DH, *Devonian Hume Formation.*

Blackwater Fault). As discussed under a separate heading, below, we identify basement uplifts mapped by Ross and Kerans (1989) on Coppermine Homocline as pertaining to this orogeny. The Racklan Orogeny identified in the Wernecke Mountains of the Cordillera is probably closely related if not the same event.

Forward Orogeny structures are small compared to those of the U.S. Rocky Mountain foreland as described by

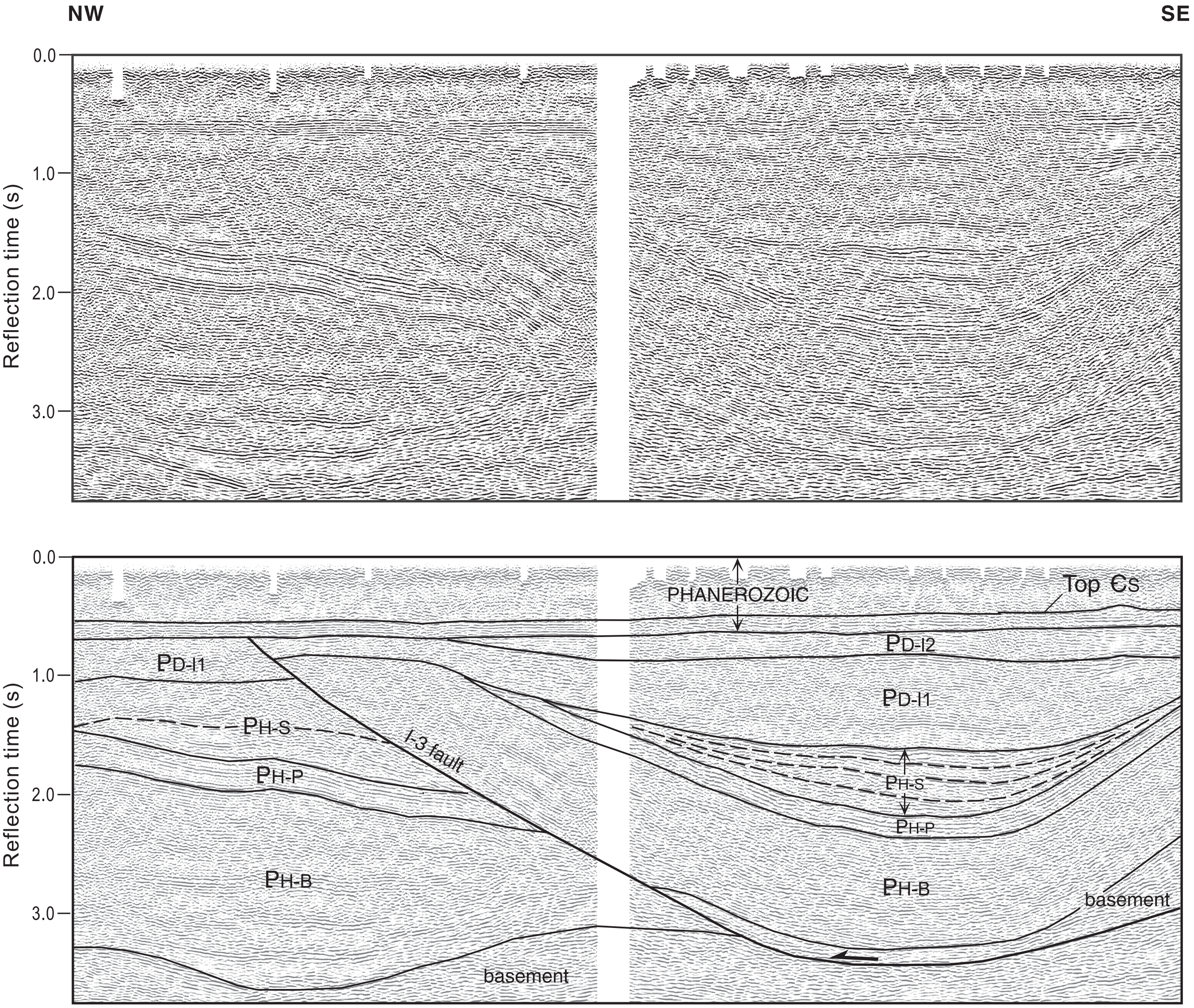

Figure 29. *1975 Mobil Line I-3 reveals syntectonic deposition with local unconformities and wedges in the footwall and hanging wall basins. The sub-DL Assemblage unconformity truncates the structure and has itself been deformed by long-wavelength folding and minor thrust displacement. Vertical exaggeration is approximately 1.5:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* PH-B, *Basinal Unit of HB Assemblage;* PH-P, *Platformal Unit;* PH-S, *Syntectonic Unit;* PD-I1, *Basal Member of Lower DL Assemblage;* PD-I2, *Upper Member of Lower DL Assemblage;* ꞒS, *Cambrian Saline River Formation.*

Rodgers in 1987, having strike lengths of 30 to 100 km compared to 75 to 300 km, and uplifts of up to 5.5 km compared to structural relief of 5 to 12 km. Trends in thickness maps of the Syntectonic Unit show regional effects of the orogeny (Fig. 32P, 33P). As in the Rocky Mountain foreland, compressional structural uplift accompanied adjacent basinal subsidence, with accumulations of up to 5 km (Fig. 33P).

The Forward Orogeny was a prolonged event that commenced during deposition of the Platformal Unit and continued through deposition of the Syntectonic Unit. Forward Orogeny structures can be divided into early and late structures. Late phase structures, developed toward the end of the time of Syntectonic Unit deposition, seem to be at least in part related to wrench displacements, and may be due to a significant shift in stress and/or strain regimes.

Early phase of Forward Orogeny

Deposition of the Basinal Unit was followed by shallower water deposition of the very uniform Platformal Unit. Over most of the region, that unit represents depositional and

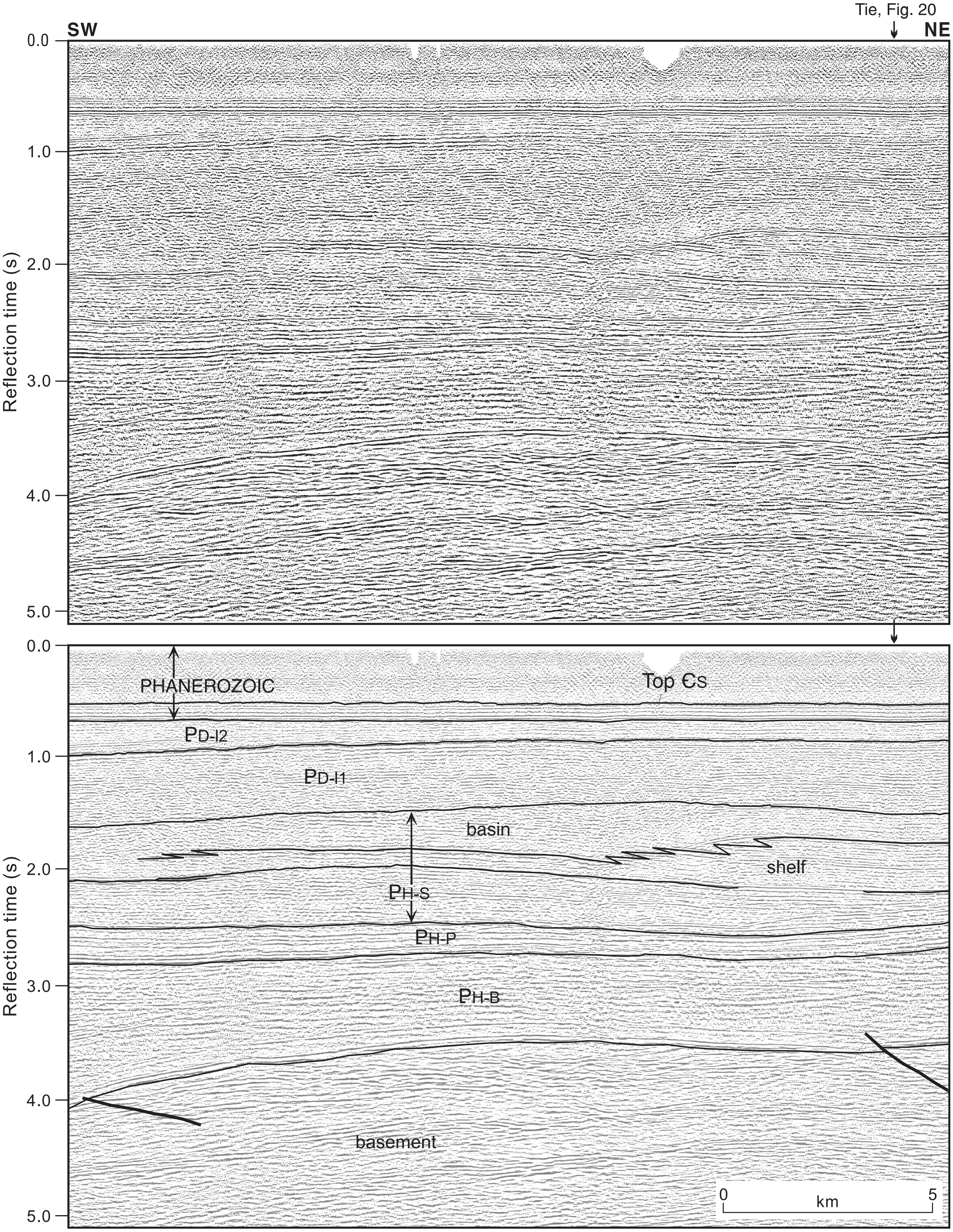

Figure 30. *1984 Petro-Canada Line 52X. A facies change from carbonate shelf to shale basin is here interpreted within the Syntectonic Unit of the HB Assemblage (ⱣH-S). Vertical exaggeration is approximately 1:1 at seismic velocity of 5500 m/s. See Figure 1P for location. ⱣH-B, Basinal Unit of HB Assemblage; ⱣH-P, Platformal Unit; ⱣH-S, Syntectonic Unit; ⱣD-I1, basal member of Lower DL Assemblage; ⱣD-I2, Upper Member of Lower DL Assemblage; ЄS, Cambrian Saline River Formation.*

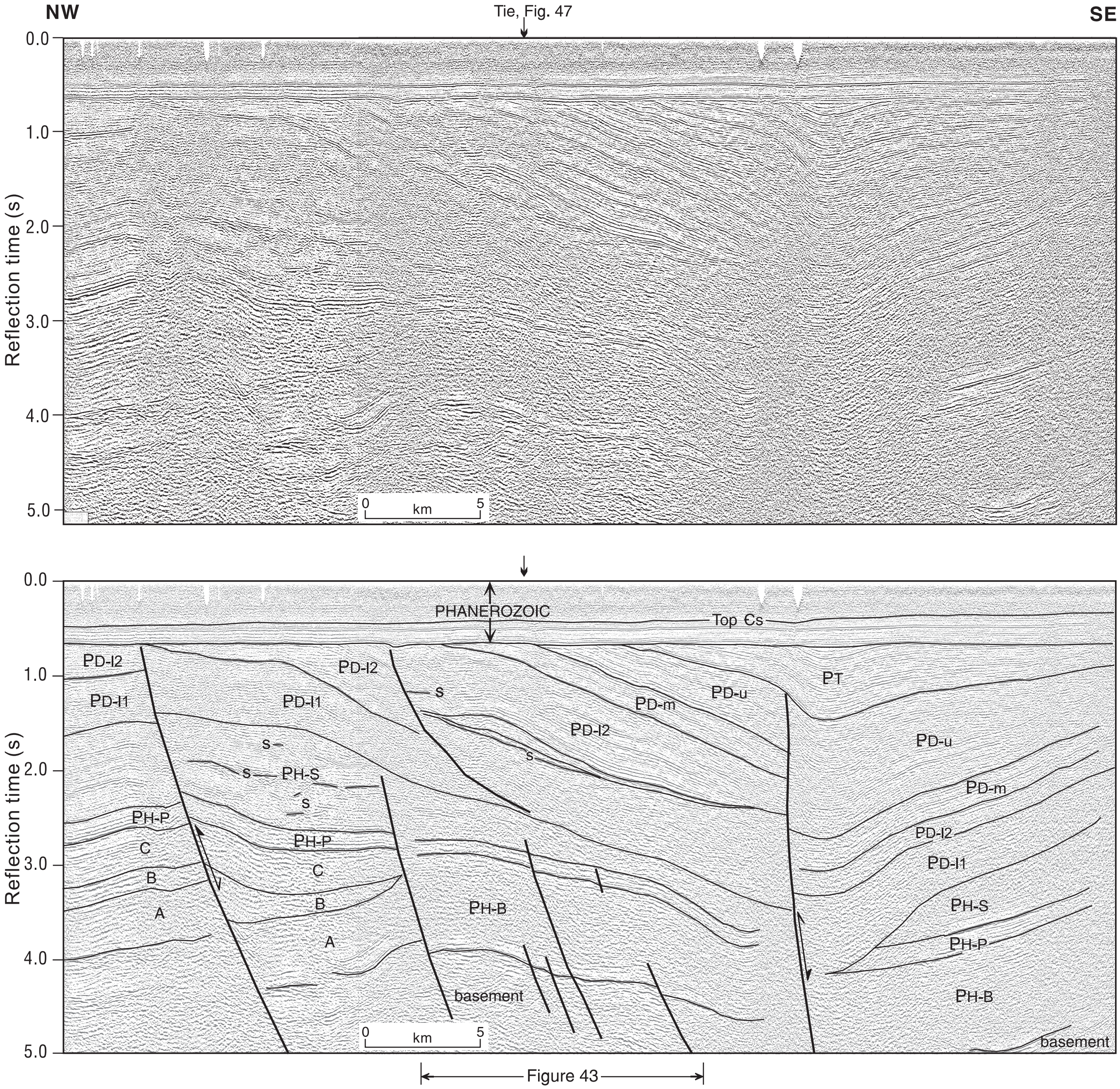

Figure 31. *1984 Petro-Canada Line 81X showing, on the west side of the figure, a syndepositional half-graben with: A – pre-rift, B – synrift, and C – post-rift sequences and, on the east side of the figure, a Forward Orogeny basement uplift reverse fault that was later inverted by major normal displacement. Extension was syndepositional with* PD-U *(Upper DL Assemblage). Note double-headed displacement arrows (solid head indicates most recent movement). Vertical exaggeration is approximately 3:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* PH-B, *Basinal Unit of HB Assemblage;* PH-P, *Platformal Unit;* PH-S, *Syntectonic Unit; s, intrusive sheet;* PD-I1, *Basal Member of Lower DL Assemblage;* PD-I2, *Upper Member of Lower DL;* PD-m, *Middle DL Assemblage;* PD-u, *Upper DL Assemblage;* PT, *Tweed Lake Assemblage;* ꞒS, *Cambrian Saline River Formation.*

tectonic stability, but locally was affected by tectonism recorded by depositional thinning onto tectonic uplifts accompanied by erosional truncation of lower beds (Fig. 25, 26). This phase of uplift marks the earliest expression of the Forward Orogeny. In our correlation rationale these early movements, affecting the Platformal Unit, correspond to early syntectonic deposition affecting the East River Formation on Coppermine Homocline. There, Ross and Kerans (1989) reported a clastic wedge in the upper part of the East River Formation, which “records the initial pulse of movement along Teshierpi Fault". In most subsurface Forward Orogeny structures, however, the first evidence of tectonism is recorded in depositional wedges and onlap sequences in the Syntectonic Unit. The orogeny continued throughout the time of deposition of the Syntectonic Unit.

Early-phase structures occur mainly across the northern part of the study area and include anticlines with onlapping unconformity-bounded sedimentary wedges in the Syntectonic Unit, and thrust faults with depositional wedges in both hanging wall and footwall. In the north-central part of the Colville-Anderson area, a series of thrust faults have dips as low as 20 degrees. From north to south the sense of vergence for these thrusts flips from southeast to northwest (Fig. 27P). The I-3 fault (Fig. 27P, 29, Transect L) is the largest in the area, with a minimum of 12 km of horizontal transport. Displacement began early, and continued through most, if not all, of the time of Syntectonic Unit deposition, as indicated by depositional wedges occupying the entire preserved Syntectonic Unit, adjacent to the structure, in both hanging wall and footwall.

Progressive growth of an early structure is illustrated in Figure 26. The reconstruction must be considered schematic because the sections are vertically exaggerated, markers X, Y, and Z cannot be correlated precisely on opposite sides of the anticline, and the flattening program restores only the vertical component of deformation. The section was first flattened using the top of the Platformal Unit as datum (Fig. 26a), and shows the unit thinning onto a structural high, thus documenting the initiation of uplift during deposition of the Platformal Unit. Subsequent reconstructions (Fig. 26b, c, d) are successively flattened on markers X, Y, Z and show the progressive development of a gently asymmetrical anticline verging to the south. Figure 26e, flattened on the sub-DL unconformity, shows the anticline in final form before deposition of the DL Assemblage. Deformation in the underlying basement is not understood. A steeply dipping, southward-verging reverse fault has been interpreted but is not well defined.

The developmental progression illustrated by Figure 26 raises the question of sediment supply. The sequences onlapping the anticline show little evidence of active erosion of the structure. Consequently, the top of the structure likely remained either below sea level or was only slightly emergent throughout its development. Since the anticline itself was never subjected to significant erosion, sediment had to be supplied externally as the anticline grew, and the flanking basins accumulated greater than 1.3 s of strata (3.8 km at a seismic interval velocity of 5800 m/s). Uplift of the anticline and subsidence and filling of the flanking basins were remarkably balanced. As noted under the discussion of lithology, both siliciclastic rocks and dolomite were encountered in wells drilled into the Syntectonic Unit elsewhere. The bold reflections used as flattening markers may represent fringing, shallow-water carbonate deposits.

Figures 20 and 26f show the present configuration of the anticline. Post-DL Assemblage tilting to the south has effectively masked the asymmetry of the structure. Taken in isolation, the sub-DL unconformity on this structure could be considered part of a continuum with the other flanking unconformities, but regional seismic correlations have shown it to be a widespread, post-tectonic hiatus that separates relatively undeformed DL Assemblage strata from rocks deformed by the Forward Orogeny. As noted above, the Syntectonic Unit probably includes strata equivalent to both the Kaertok and the LeRoux formations on Coppermine Homocline. We consider the regional unconformity at the base of the DL Assemblage to correspond to the base of the Fort Confidence Formation, a regional unconformity recognized by Baragar and Donaldson (1970), on the homocline.

Early-phase structures mainly trend northeast-southwest; for example, those in the northern part of the Colville-Anderson area, and those on Coppermine Homocline. That trend implies a general northwest-southeast orientation of the principal horizontal stress, the same general orientation as that inferred for an early phase of Racklan Orogeny in the Wernecke Mountains (Thorkelson, 2000). A notable exception is a broad northerly trending asymmetrical anticline or arch in the southeast part of the Colville Hills area (Fig. 27P). The arch is seen to be early-phase because it was erosionally truncated early during deposition of the Syntectonic Unit (Transect E).

Late phase of Forward Orogeny

In the south-central part of the study area, three large faults, the FR-14 fault, the Tweed Lake fault, and the 81X fault (Fig. 27P) developed late during deposition of the Syntectonic Unit. Each has, in its footwall, thick, parallel-layered Syntectonic strata with no evidence of depositional wedges that could have been shed from the adjacent uplift. For example, the FR-14 fault (Fig. 20c, d) postdates about 1 s (2.9 km at a seismic interval velocity of 5800 m/s) of parallel-bedded Syntectonic strata in its footwall. Deep erosion removed the almost 3 km thick Syntectonic Unit and the Platformal Unit from the crest of the uplifted block resulting in the deposition of uppermost Syntectonic Unit directly on the Platformal Unit. It presumably once overlay the Basinal Unit on the crest of the structure but has been removed by sub-DL Assemblage erosion. It is noteworthy that the pretectonic footwall strata can be directly linked on seismic records to the syntectonic beds on the flank of the early-phase anticline of line 8711 (Fig. 20a, b). The late structures tend to be more northerly trending and the faults more steeply dipping than early-phase thrusts. Although the late-phase faults are steeply dipping at upper levels (Fig. 20), they must become listric at depth, because the hanging wall block is invariably rotated relative to the sub-Dismal Lakes unconformity.

Sinistral wrench displacement

The FR-14 fault (Fig. 20, 27P, 34) is an impressive late Forward Orogeny structure, which has undergone later extensional inversion. It makes a 90-degree bend from southwest to southeast. Pre-inversion vertical offsets reach a maximum of 6.3 km on the southwest-trending segment (Fig. 34), whereas on the southeast-trending segment, the amount of offset decreases rapidly southeastward from 6.0 km to zero. In the area of zero stratigraphic offset, the fault is expressed on seismic data as a zone of poor seismic returns. The zone extends southeastward into an area of poor seismic coverage, but it is possible to interpret a second zone to the east, en echelon to the first, again with no vertical offset of markers. The second fault zone is interpreted to extend beneath Colville Lake and to bend into a south-southeast-trending, eastward-directed, (pre-inversion) thrust fault, the Tweed Lake fault (Fig. 22b).

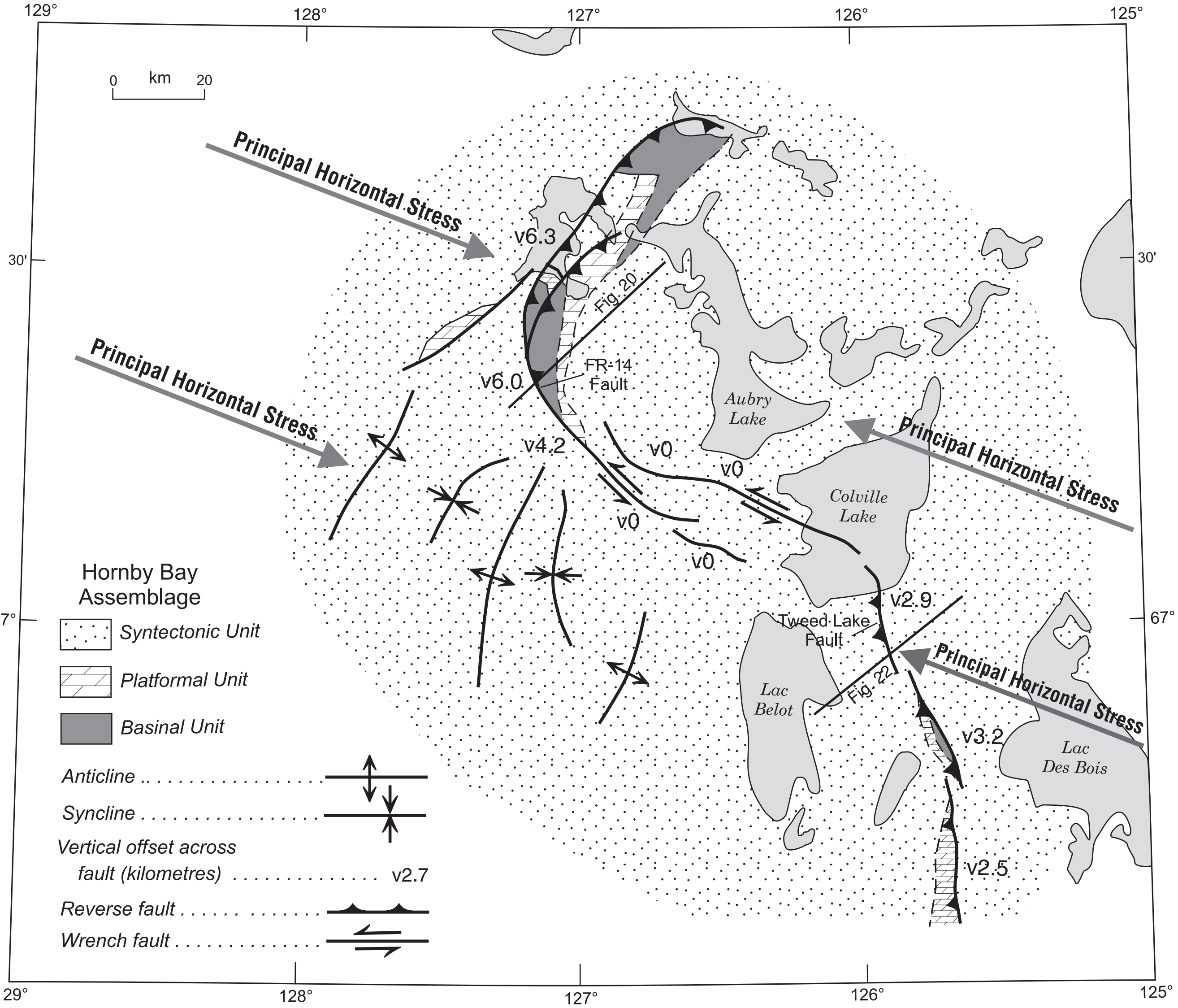

Figure 34. *Interpreted wrench fault to thrust transfer. Left-lateral strike-slip on northwest-striking faults is transferred to thrust displacement on northeast- and south-southwest-trending faults. Vertical offset across the FR-14 fault changes abruptly from zero along the interpreted strike-slip section to 6.3 km in the northeast-trending restraining bend. To the southeast, a less abrupt restraining bend has uplifts of only about 3 km. Secondary folds are compatible with strike-slip interpretation, and the wrench-thrust system indicates a west-northwest-east-southeast principal horizontal stress (after Cook and MacLean, 1995).*

We interpret the array of structures described above to comprise a sinistral wrench-fault complex with two restraining bends. Northwest-southeast-trending strike-slip displacement was converted to thrust fault and fold structural culminations on the northeast- and south-southwest-trending restraining bends, with greater uplift associated with greater deviation. A number of minor north-northeast-trending secondary folds are congruent with left-lateral displacement along the strike-slip segment of the structure (Fig. 34).

The transpressive regime expressed by this fault and fold system implies a compression direction oriented more westerly than the northwest-southeast orientation inferred for early structures in the northern portion of the Colville-Anderson area. Other late faults, for example the north-trending 81X fault (Fig. 27P), are compatible with a westerly oriented principal horizontal stress.

Not all faults have orientations compatible with the inferred stress orientations for their group. For example, a northwest-southeast-trending fault in the northeast part of the map area (Fig. 23, 27P) is an early fault, oriented subparallel to the northwest-southeast-trending stress axis inferred for early faults. Similarly, the Blackwater Fault appears to be an early fault, but has a northerly trend more typical of late faults.

Extensional inversion of Forward Orogeny faults

For a number of Forward Orogeny faults the effect of compressional displacements was obscured by later, post-DL Assemblage, extensional reactivation (see Fig. 20, 22, east end of Transect G). Although the extensional event will be discussed under the heading 'DL Assemblage', recognizing inversions is important in understanding the distribution of Forward Orogeny structures. Consequently two examples of Forward Orogeny compression masked by later extension are outlined here. In one example seismic line 116A/110A (Fig. 22) shows normal displacement greater than initial uplift, but restoration of the sub-Dismal Lakes unconformity (Fig. 22c) to horizontal removes the extensional phase, and reveals the vertical component of the Forward Orogeny deformation.

In another example more recent displacements on the Blackwater Fault were extensional, but inspection of Transect G (east end) leads to the interpretation that the fault is an inverted Forward Orogeny compressional fault. Strata that we assign to the Platformal and Syntectonic units in the down-dropped block appear to have been tilted and truncated relative to the sub-DL unconformity, indicating an ancestral Forward Orogeny structure. Convergence of markers in the Syntectonic Unit toward the ancestral high suggests that this is an early-phase Forward Orogeny structure. Subsequent extensional offsets of the DL Assemblage, Tweed Lake Assemblage, and Phanerozoic strata effectively obscure the original Forward Orogeny displacement. The interpreted structural history is parallel to that of the previous example near Tweed Lake (Fig. 22).

Forward Orogeny on Coppermine Homocline

Other Forward Orogeny structures probably exist in the subsurface to the east of the seismic grid because examples have been mapped still farther east on Coppermine Homocline. Four northeast-trending basement uplifts mapped by Ross and Kerans (1989) within or flanking the area of Hornby Bay Group exposure are similar in aspect and general trend to Forward Orogeny structures identified in the subsurface (Fig. 27P). Each postdates or is partly syndepositional with the Hornby Bay Group. One, Teshierpi Uplift, described below, is erosionally truncated by the sub-LeRoux Formation unconformity. Another to the west of Teshierpi had movement that postdated the LeRoux Formation and predated the Fort Confidence Formation of the Dismal Lakes Group. Kerans et al. (1981) and Ross and Kerans (1989) considered the tectonic regime at the end of the time of Hornby Bay deposition to be extensional, but their geological map and description of overturned beds record compression at that time. The best example (Fig. 35) has crystalline basement juxtaposed with overturned Hornby Bay Group strata, a situation that demands a compressional structure such as shown schematically in Figure 35b. Kerans et al. (1981) noted that erosion of the Teshierpi uplift began late during the time of East River Formation deposition, making this an early Forward Orogeny structure. The early phase, here, began with syntectonic deposition of upper East River Formation, continued with syntectonic deposition of the Kaertok Formation and culminated with overturned folding of the East River and Kaertok.

The LeRoux Formation lies unconformably on overturned Hornby Bay Group strata in the area of, and adjacent to, the Teshierpi Fault (Ross and Kerans, 1989) but this is not the final orogeny-closing unconformity, as the LeRoux itself was tilted and eroded on another basement uplift west of Teshierpi. On that structure the Lady Nye, East River, Kaertok, and LeRoux formations all strike into Dismal Lakes (Fig. 36) and are clearly discordant to the Fort Confidence Formation, which extends along the north shore of the lake. Thus, the main movement on Teshierpi uplift predated the LeRoux Formation, whereas basement uplift to the west postdated the LeRoux. Moreover, the LeRoux is discontinuous elsewhere on the homocline, and the Fort Confidence Formation appears to be the first Dismal Lakes Group formation to be continuous across the region. Although outcrops are sparse it appears that the regional unconformity marking the close of the Forward Orogeny

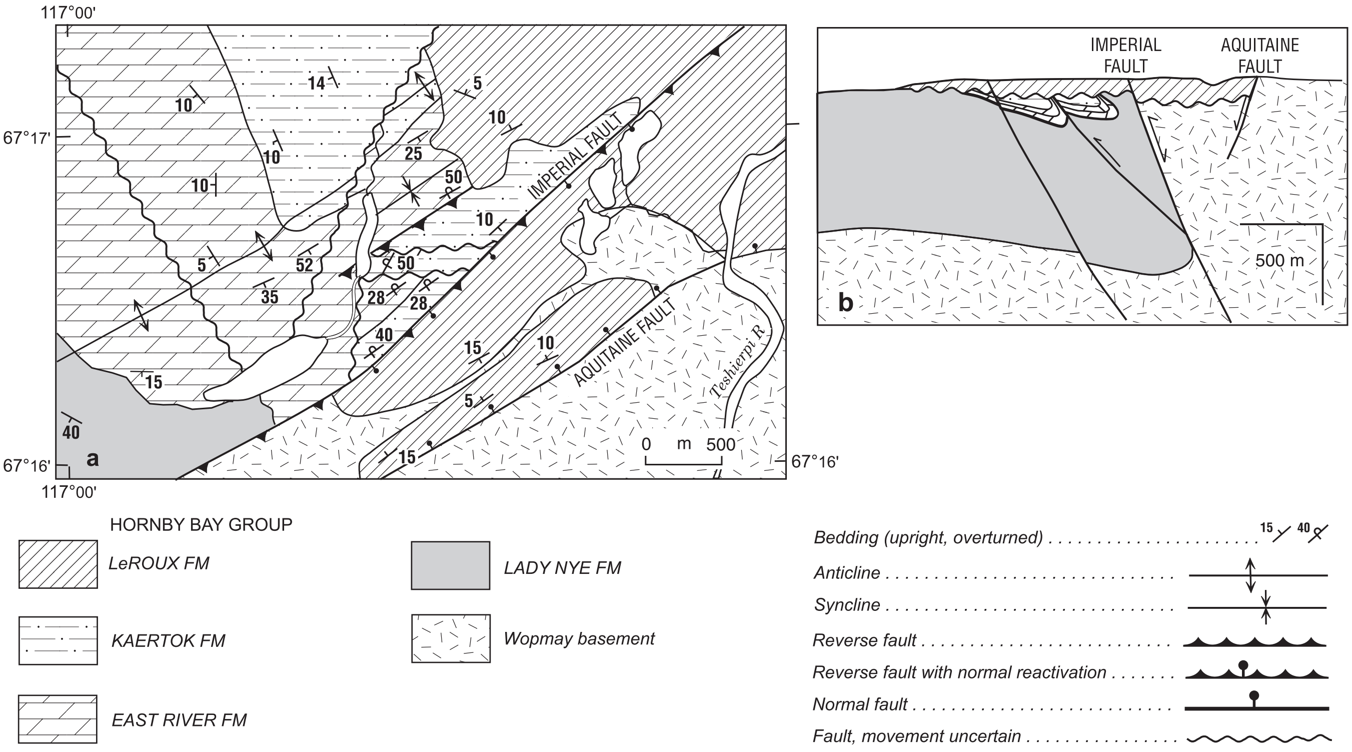

Figure 35. *Basement uplift in Coppermine Homocline, interpreted here as a compressional Forward Orogeny structure. Crystalline basement is faulted against overturned Hornby Bay Group strata; both footwall and hanging wall are unconformably overlain by gently dipping LeRoux Formation. The unconformity and LeRoux Formation are mildly offset by late extensional inversion.* ***a.*** *Geological map, simplified from Ross and Kerans (1989).* ***b.*** *Schematic cross-section based on* ***a.***

and the initiation of a new depositional cycle is at the base of the Fort Confidence Formation, not at the base of the LeRoux as we suggested in a previous publication (Cook and MacLean, 1995). The relationships are analogous to those of the subsurface wherein a number of local unconformities in the Syntectonic Unit are superceded by a through-going regional unconformity (e.g., Fig. 20). As in the subsurface, multiple movements occurred on the homocline during the East River - LeRoux syntectonic interval. In identifying the Fort Confidence Formation as being the lowermost unit of the Dismal Lakes Group, and having a regional unconformity at its base, we follow Baragar and Donaldson (1970).

Returning to the Teshierpi uplift, the sub-LeRoux unconformity truncates both the hanging wall and footwall blocks of the Imperial Fault but was offset by later, east-side-down, extensional reactivation (Fig. 35). The tectonic history of compressional uplift, erosional truncation, deposition of a younger unconformable sequence, and finally extensional reactivation is thus parallel to our interpretation of the history of some subsurface structures (Fig. 20, 22). The parallel depositional and structural histories provide a compelling argument for correlating the subsurface and surface strata.

Other apparently compressional structures mapped by Ross and Kerans (1989) on the homocline include a small, unnamed basement uplift, with adjacent overturned Hornby Bay strata, about 25 km northwest of Teshierpi uplift, and the Fault River and Leith Ridge faults. Those faults are parallel in trend to the Teshierpi uplift, and their mapped geometries imply compressional (or transpressional) origins. Both faults juxtapose uplifted crystalline basement on the east with westward-dipping Hornby Bay strata on the west. If the faults had normal offsets, the Hornby Bay beds in the western block would be expected to dip eastward into half-grabens. The westward-dipping panels strongly suggest that the most recent movement was compressional or, more likely, transpressional considering their rectilinear trends. Erosion of Dismal Lakes Group strata from the area of these faults precludes determining their ages relative to the sub-Fort Confidence unconformity, but they postdate the Hornby Bay Group and are parallel to the Teshierpi uplift, and we consider them to be co-genetic.

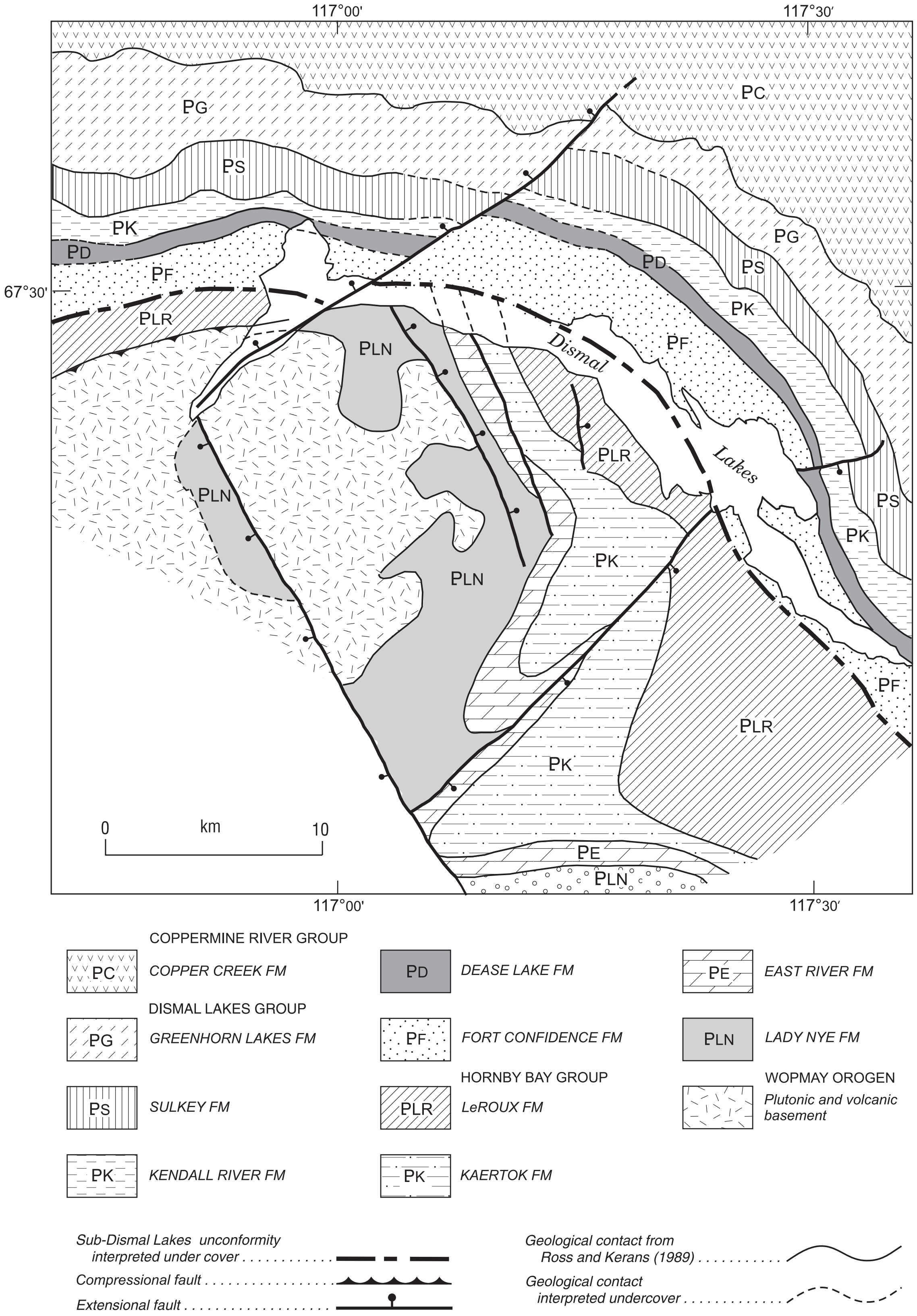

Figure 36. *Map illustrating an angular unconformity at the base of the Fort Confidence Formation of the Dismal Lakes Group. Modified from Ross and Kerans (1989); also see Figure 1 of Baragar and Donaldson (1970).*

Antecedent Wopmay faults

Wopmay Orogen is cut by a conjugate array of northeast- and northwest-trending transcurrent faults that formed during the terminal phase of shortening (Hoffman, 1984; Hoffman and St-Onge, 1981; see basement area of Fig. 27P). Some of the northeast-trending set, for example Fault River and Teshierpi faults, were reactivated during and after deposition of the Hornby Bay Group (Ross and Kerans, 1989). That is to say, the pre-existing northeast-trending basement-fault fabric localized Forward Orogeny displacements on Coppermine Homocline. Similarly, many Forward Orogeny faults in the subsurface of the Colville Hills area also trend northeastward (Fig. 27P) and a few others have the conjugate northwest trend. It seems likely that those faults were also localized by pre-existing late-Wopmay faults. If so, late Wopmay wrench-faults and possibly the Wopmay Orogen extend far to the northwest under the Colville-Anderson area.

Timing and relationship to regional tectonic events

In Dease Arm of Great Bear Lake, the 1663 Ma Narakay volcanic complex is considered to date deposition of the syntectonic Kaertok Formation (Bowring and Ross, 1985), and, therefore, also dates some phase of the Forward Orogeny. Rodgers (1987, p. 686) noted that intracratonic chains “are generally adjacent to and probably genetically related to mountain ranges that clearly developed out of geosynclines”. A collisional orogen (i.e., the deformed geosyncline of Rodgers), related to the structures described here, has not been identified.

Relationship to Racklan Orogeny

The timing and geographical extent of the Racklan Orogeny have been and continue to be debated (see Gabrielse, 1967; Eisbacher, 1978; Yeo et al., 1978; Cook, 1992). Here we accept the definition of Young et al. (1979, p. 127) who proposed that “...the term 'Racklan Orogeny' be retained for the event recorded in the Rackla River area (that is, the disturbance between the Wernecke Supergroup and the Pinguicula Group)”. Current workers in the Wernecke Mountains (Abbott, 1997; Thorkelson, 2000) also apply that definition. We previously suggested (Cook and MacLean, 1995) that Forward Orogeny tectonism could be related to the Racklan Orogeny. That suggestion is reinforced by a number of tectonic similarities:

1. Each contains dominantly northeast–southwest-trending structures implying a northwest–southeast-trending applied horizontal stress (Thorkelson, 2000; Cook and MacLean, 1995).

2. Abbott (1997) compared the two orogenies and noted that in both cases deformation occurred as large structures separated by broad areas of little or no deformation. Similarly Racklan fault geometries mapped by Thorkelson and Wallace (1998 a, b, c) are those of large, apparently deep-rooted, block faults.

3. Both orogenies include a second phase of deformation, although it is not known whether or not the second-phase kink bands in the Racklan (Thorkelson, 2000) involve a reorientation of principal stress as did the late Forward Orogeny structures.

4. New controls on the timing of the Racklan Orogeny (Fig. 2) have recently been established. Wernecke breccia dated as 1.59 Ga (Thorkelson, 2000) intrude Wernecke Supergroup strata deformed during the orogeny. Thus the Racklan Orogeny is known to be older than 1.59 Ga. The Bonnet Plume River Intrusions (ca. 1.71 Ga) intrude the Wernecke Supergroup (Thorkelson et al., 2001). The age of the Bonnet Plume relative to the Racklan Orogeny is not clear but Thorkelson et al. (2001) treated the intrusions as predating the orogeny. If so, the orogeny is younger than 1.71 Ga and older than 1.59 Ga and is potentially related to the ca. 1663 Ma Forward Orogeny.

5. Both Racklan and Forward structures were peneplaned prior to deposition of the next sedimentary cycle, the Pinguicula Group in the Werneckes, the DL Assemblage in the subsurface, and the Dismal Lakes Group on Coppermine Homocline.

Intrusive sheets into HB Assemblage

Seismic reflections, which we interpret as representing sheets intruded into the HB Assemblage, occur in two classes: an early, sharply defined set intruded into the Lower Unit; and a younger set of strong but discontinuous seismic markers, partly parallel and partly discordant to bedding, intruded into the Basinal, Platformal and Syntectonic units.

Older intrusive sheets

The older and deeper markers, previously noted under ‘Lower Unit’, appear on seismic data as two remarkably continuous subparallel reflections about 580 ms apart (1.6 km at a seismic interval velocity of 5500 m/s) within the Lower Unit of the HB Assemblage. We previously treated them as stratigraphic boundaries (Cook and MacLean, 1995), but here consider them to represent intrusive sheets because they appear to be discordant elements superimposed across an otherwise undulatory and hummocky stratigraphic package (east end of Transect C;

southeast end of Transect L; Fig. 18). In Transect C both reflections occur in a roll-over anticline within a half-graben related to early Basinal Unit extension. Thus, if they are intrusive sheets they postdate the Lower Unit and predate the early Basinal Unit extension. Having an intrusive event affecting the Lower Unit but not the Basinal Unit supports our earlier conclusion that a major hiatus separates these two sequences.

Younger intrusive sheets

The younger set of strong but discontinuous seismic markers are common in the Colville-Anderson and Peel areas, but where they are bedding-parallel their interpretation as sheets is equivocal. Reflections that most obviously represent intrusions occur in the east-central part of the Colville-Anderson area (Fig. 37, 38, and Transect B and C). There, they occur almost exclusively in the HB Assemblage and our working model is that they were emplaced prior to deposition of the DL Assemblage. One exception, to be discussed later, intrudes DL Assemblage strata and is considered to represent a still younger event.

In our best example (Fig. 37) an anticline about 10 km across is transected from one limb to the other by a persistent zone of subhorizontal bright reflections, which we interpret as intrusive sheets. The zone of intrusion is about 0.2 s thick (580 m at a seismic interval velocity of 5800 m/s), and is subparallel to the sub-DL Assemblage unconformity suggesting that emplacement occurred when the unconformity was a horizontal reference. The zone is

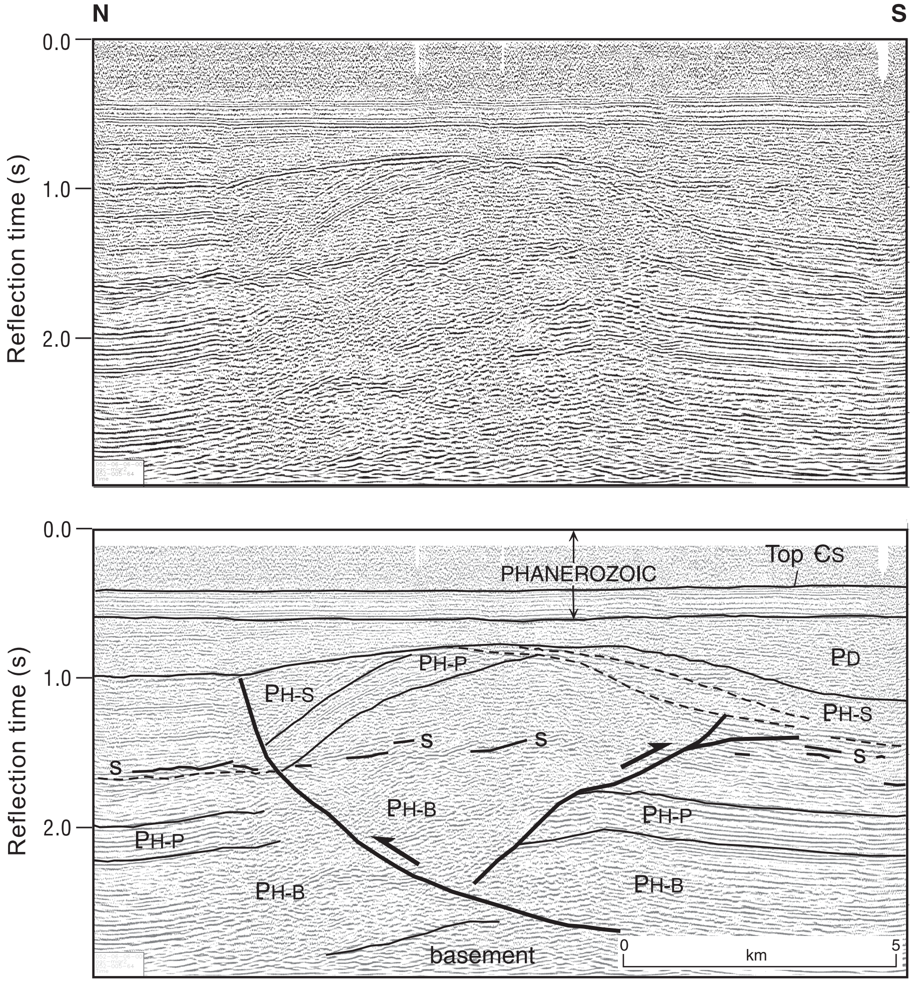

Figure 37. 1975 Amoco Canada Line 64. Subhorizontal and relatively strong reflections are interpreted as sills that crosscut, and therefore postdate a Forward Orogeny 'pop-up' structure. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location. ⱣH-B, *Basinal Unit of HB Assemblage;* ⱣH-P, *Platformal Unit;* ⱣH-S, *Syntectonic Unit; s, intrusive sheet;* ⱣD, *DL Assemblage, undivided;* ЄS, *Cambrian Saline River Formation.*

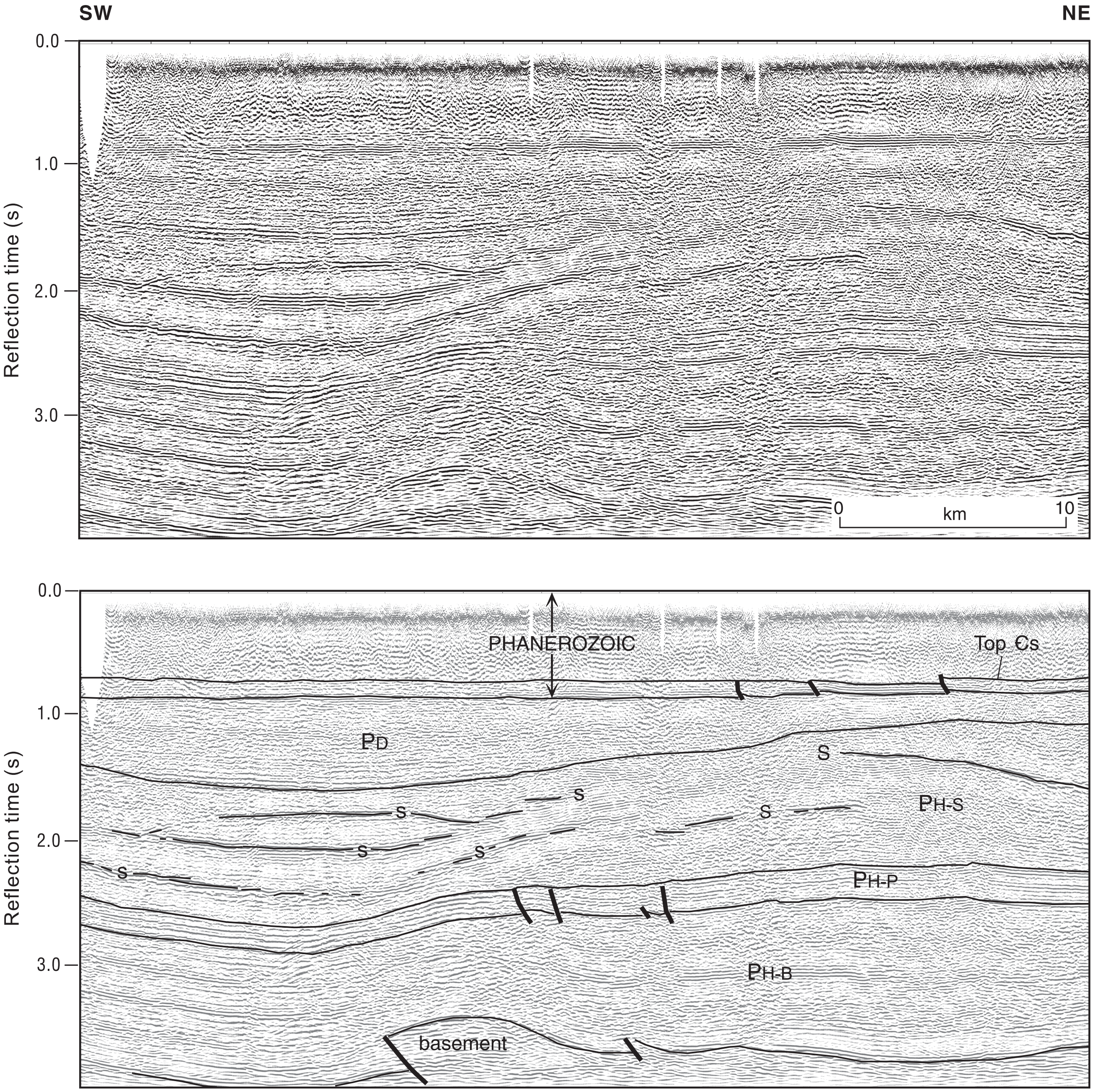

Figure 38. *1972 Sigma Explorations Line GSI-03 showing bright, discordant reflections interpreted as intrusive sheets (sills). Vertical exaggeration is approximately 2:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* PH-B*, Basinal Unit of HB Assemblage;* PH-P*, Platformal Unit;* PH-S*, Syntectonic Unit; s, intrusive sheet;* PD*, DL Assemblage, undivided;* ꞒS*, Cambrian Saline River Formation.*

about 0.6 s (1.75 km) below the unconformity, which can be taken as the minimum possible depth of emplacement at this locality. These intrusions postdate the anticline, hence postdate the Forward Orogeny. We suggest that they probably predate deposition of the DL Assemblage, but the possibility that they were emplaced at some depth below accumulated DL Assemblage strata cannot be precluded. Both the unconformity and the zone of intrusions have been subsequently arched.

In another example (Fig. 38) a number of bright reflections occur in Syntectonic Unit strata. Most are bedding parallel (sills) but some are discordant to bedding (dykes). The zone of ‘intrusion’ is about 0.6 s (1.75 km) thick, which may imply that emplacement occurred over a protracted period of time, but the length of time or even the relative ages of upper and lower levels cannot be determined with available data.

A third example of reflections that we consider to represent intrusive sheets occurs on a number of Petro-Canada lines, acquired in the area north of Maunoir Lake, one of which is shown in Figure 39. There, westward-dipping HB Assemblage strata are cut by a set of bright, somewhat ragged, reflections that we interpret as representing intrusive sheets. The most prominent reflection cuts at a low angle across Basinal Unit strata. Although dipping westward, the intrusive body nonetheless cuts upsection westward toward the Platformal Unit. A similar

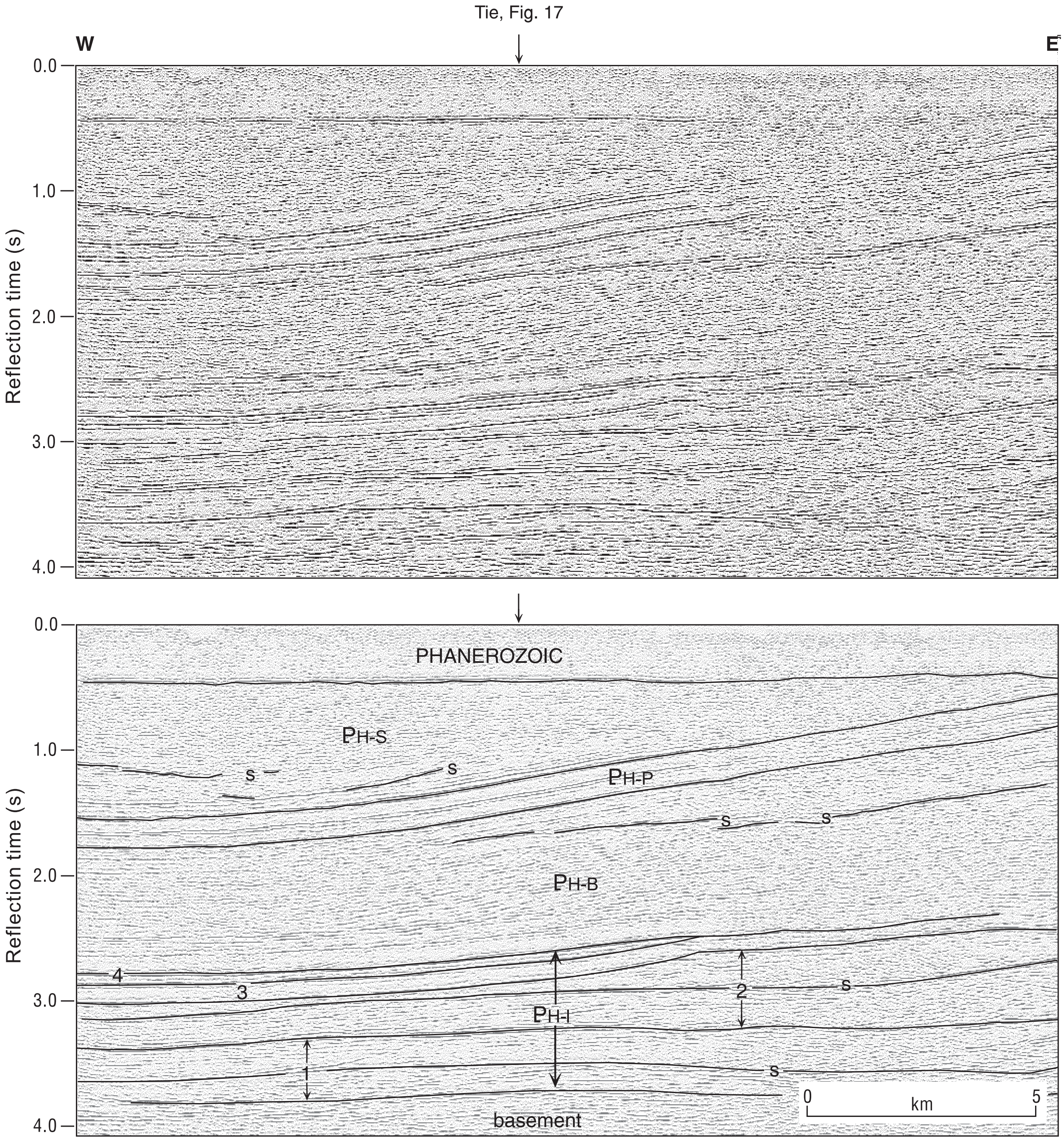

Figure 39. *Petro-Canada Line 116 showing subunits of the Lower Unit of the HB Assemblage. Two subparallel continuous reflections are interpreted as intrusive sheets intruded discordantly across the Lower Unit. Higher level discontinuous reflections are interpreted as a younger generation of sheets. They occur in progressively older strata toward the east. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* PH-I, *Lower Unit of HB Assemblage; 1, 2, 3, 4, subunits of Lower Unit;* PH-B, *Basinal Unit of HB Assemblage;* PH-P, *Platformal Unit;* PH-S, *Syntectonic Unit; s, intrusive sheet.*

but less extensive reflection is observed upsection and westward in the Syntectonic Unit. On this line the higher and lower sheets overlap and could be linked by a dyke, too steeply dipping to be imaged by the seismic method. Adjacent lines, however, show that the upper and lower sheets overlap in only a very small area, and so we suspect that the lower and upper reflections represent separate, although related, events.

All of the sheets discussed above are believed to be related parts of a complex of subhorizontal intrusions, which regionally cuts stratigraphically downsection from west to east across a west-dipping homocline (Transect C). That homocline is interpreted as the west-dipping limb of a broad anticlinal arch (none of our seismic data extend eastward far enough to image the east limb). In the axial area of the ‘arch’ the sheet reflections become bedding parallel (Transect C). The arch was uplifted and truncated by pre-DL Assemblage erosion, and was uplifted again such that DL Assemblage strata were tilted and eroded at the sub-Cambrian unconformity.

Correlation of sheets

The younger set of seismically imaged sheets probably correlates with the Western Channel Diabase sheets, which outcrop about 100 km to the east on Coppermine Homocline (Bowring and Ross, 1985; Ross and Kerans, 1989). The Western Channel Diabases have been dated as about 1400 Ma by K-Ar (Wanless et al., 1970) and Rb-Sr (Wanless and Loveridge, 1978). The age must be considered a minimum considering the dating methods, thus the age of the intrusions is bracketed between 1663 Ma and 1400 Ma. Individual sheets of Western Channel Diabase, as mapped, are much less extensive than those in the subsurface, but correlation is indicated by similarities of stratigraphic hosts, similar changes in level of stratigraphic emplacement, and similar postorogenic timing of emplacement.

On the homocline the Western Channel Diabase sheets are intruded into Hornby Bay Group and older rocks, with a progressive change in the level of emplacement occurring across the map area of Ross and Kerans (1989). The diabase intrudes East River Formation strata at its westernmost exposure at Dease Arm of Great Bear Lake, intrudes progressively older Hornby Bay Group strata eastward, and in its easternmost occurrences intrudes Wopmay basement. This progressive change in stratigraphic level across about 100 km mimics, in nature and scale, the changes in emplacement level displayed by subsurface reflections. The Western Channel intrusions mapped by Ross and Kerans (1989) appear to be postorogenic at three localities. First, the westernmost sheet crosses a dipping panel of Lady Nye and East Fork formations (Basinal and Platformal unit equivalents respectively). Next, two small sheets occur near Fault River on opposite sides of the Fault River Fault. On the west side, diabase intrudes Fault River Formation (lowermost Hornby Bay), whereas on the east side a sheet intrudes Wopmay basement. The proximity of these intrusions suggests that they may be erosional remnants of a single intrusion or, at minimum, represent a single intrusive phase. If so, the intrusive event postdates displacement on the fault. Finally, a Western Channel sheet at Leith Ridge Fault is shown by Ross and Kerans (1989) and Hildebrand et al. (1983) to cut Wopmay basement on the east side of the fault, and Hornby Bay Group on the west, and must, therefore, postdate the fault. As discussed above, we consider the Fault River and Leith Ridge faults to be Forward Orogeny structures. Thus the Western Channel Diabase appears to postdate the Forward Orogeny, as do the intrusive sheets imaged in the subsurface.

The intrusive sheets are not seen in the DL Assemblage or Dismal Lakes Group in the subsurface or surface, respectively. On a regional scale in the subsurface both the sheets and the sub-DL unconformity cut downsection from west to east. Similarly in outcrop on the homocline both the Western Channel intrusions and the sub-Dismal Lakes unconformity cut downsection from west to east. We conclude that the sheets were emplaced as subhorizontal intrusions with the pre-Dismal Lakes erosional surface as the horizontal reference. Variations in depth below the unconformity are assumed to be due to post-emplacement erosion at the unconformity, and if so, the intrusive sheets are older than the DL Assemblage (Dismal Lakes Group). Relationships envisioned are shown schematically in Figure 40. In summary, discordant reflections are interpreted as representing intrusive sheets, which correlate with Western Channel Diabase sheets and are younger than the 1663 Ma Forward Orogeny, older than 1400 Ma, and apparently older than the DL Assemblage and Dismal Lakes Group.

DL ASSEMBLAGE

Overview

The DL Assemblage is preserved in a structural basin that has been eroded to zero thickness on both its east and west flanks (Fig. 4P, 41P, 42P), and consequently there is no physical continuity to presumed correlatives in the Dismal Lake Group on Coppermine Homocline to the east, nor to the Pinguicula Group in the Wernecke Mountains to the west. The assemblage is defined in the Colville-Anderson area where it is subdivided into Lower, Middle, and Upper units, and the Lower unit is, itself, subdivided into basal and upper members. In the Colville-Anderson area the assemblage comprises a stratigraphic wedge that thickens from erosional zero in the east to a maximum of about 7 km in the south-central part of the area (Fig. 42P). Thickness

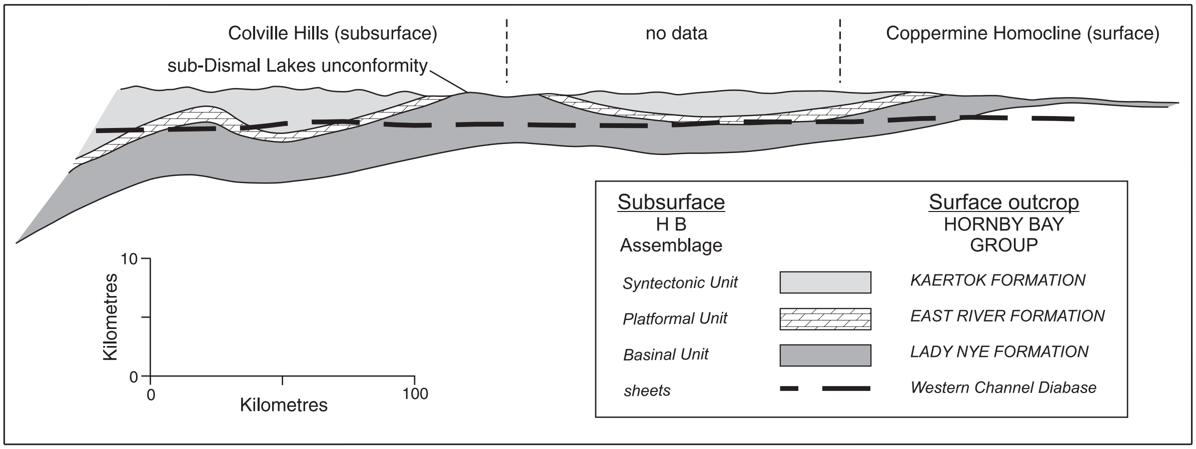

Figure 40. *Schematic diagram illustrating subhorizontal intrusive sheets cutting across regional structure. 'Sheets' imaged on seismic are interpreted as correlating with Western Channel Diabase mapped by Ross and Kerans (1989) on Coppermine Homocline. Scales are approximate only.*

changes are due partly to stratigraphic thickening westward, particularly in the Lower DL Assemblage, and partly to erosional truncation at subsequent unconformities. The Lower DL is identified throughout the Colville-Anderson area, whereas the Middle and Upper DL Assemblage are restricted to the south-central part of that area (Fig. 4P). The Middle and Upper units are missing as a result of pre-Cambrian erosion over the northern regions of the Colville-Anderson area. On seismic records, the basal unconformity ranges from angular and reflective (Fig. 20, 29), through angular but not reflective (Fig. 30 western side), to paraconformable (Fig. 30 eastern side). Where angular, but not reflective, it is placed at the boundary between dipping reflections below and subhorizontal reflections above. Where the unconformity is paraconformable the seismic network has permitted extrapolation from controlled areas.

The assemblage is interpreted to be present westward across the Mackenzie River in the Peel area, where it is identified primarily on the basis of an unconformity expressed in a large half-graben outlier in Grandview Hills area (Fig. 4P, west end of Transect B, and north end of Transect H). The strata in the outlier cannot be tied to the DL Assemblage east of the river, but they can reasonably be projected over an intervening arch (Transect B). About 1.29 s (3.5 km) of DL Assemblage are preserved in the outlier but the assemblage is undivided because of generally poorer quality data and loss of seismic markers.

Southward into the Mackenzie-Great Bear area the DL Assemblage is similarly identified on the basis of an underlying unconformity. The Middle DL is locally recognized but the seismic data are generally of poor quality and subdivisions are not carried on Figure 4P, nor on Transects F, G, nor the southeast parts of Transects J, and K. In the southeastern part of the Mackenzie-Great Bear area, near Blackwater Lake, strata that we assign to the DL Assemblage are represented by a distinctively layered seismic sequence (e.g., eastern ends of Transects F and G, southeastern ends of Transects J and K). No sub-sequences are obvious.

The Lower, Middle, and Upper parts of the DL Assemblage of the Colville-Anderson area are described in greater detail below.

Lower DL Assemblage

The Lower DL Assemblage is seismically dull except for a distinctive, strong reflection or reflection couplet that permits local subdivision into Basal and Upper members (e.g. Transect C, Fig. 20, 30). The marker presumably represents a lithological change. It is identified over most of the south-central part of the Colville-Anderson area, but is lost in the eastern part, perhaps because of facies changes (Transect E) and, consequently, the Lower DL is undivided there (Fig. 4P). In one small area the reflection or couplet changes to a bundle of reflections 0.27 s thick (750 m at 5400 m/s) (Fig. 43), representing an anomalous stratigraphic accumulation, perhaps a carbonate buildup.

The Basal Member of the Lower DL is variable in thickness and tends to thin across ancestral Forward Orogeny structures, and to thicken into adjacent ancestral basins (Fig. 20d, 29). Part of that variation appears to be a result of infilling of post-Forward Orogeny topography. For example, thinning across the FR-14 fault block of about 200 ms (as displayed in Fig. 20c, d) implies topographic relief of at least 550 m, assuming a seismic interval velocity of 5400 m/s. On other structures, seismic reflections in the variable basal unit are continuous across the uplift and are

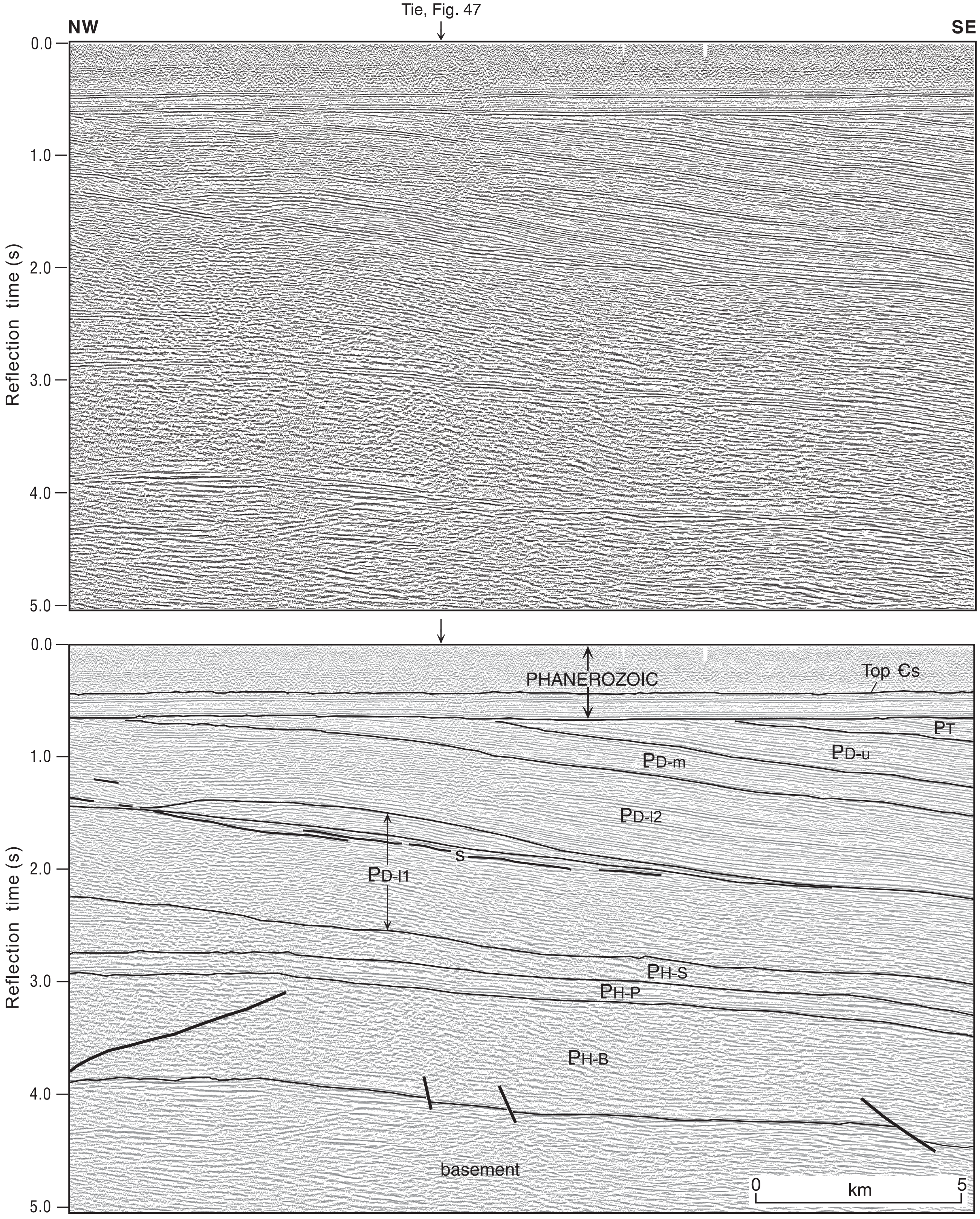

Figure 43. *1984 Petro-Canada Line 81X. The top of* ⱣD-I1 *is marked by an anomalous bundle of reflections possibly representing a carbonate buildup. A planar reflection, transverse to bedding, is interpreted as an intrusive sheet. See also Figures 31 and 47. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ⱣH-B, *Basinal Unit of HB Assemblage;* ⱣH-P, *Platformal Unit;* ⱣH-S, *Syntectonic Unit; s, intrusive sheet;* ⱣD-I1, *Basal Member of Lower DL Assemblage;* ⱣD-I2, *Upper Member of Lower DL;* ⱣD-m, *Middle DL Assemblage;* ⱣD-u, *Upper DL Assemblage;* ⱣT, *Tweed Lake Assemblage;* ЄS, *Cambrian Saline River Formation.*

tilted or bowed on the flanks of the uplift (e.g., Fig. 29; Transect B, lines HBOG 1, 2, 3). The tilting seems too severe to be attributable to differential compaction, and syndepositional reactivation of some Forward Orogeny structures is implied.

Across the northernmost part of the area there is a strong reflection (western part of Transect A) that we consider to represent the top of the Basal Member, although we have been unable to tie it with seismic links to the marker established in the south. The Basal Member, thus defined, thins from west to east (west end of Transect A) from 300 ms to 120 ms (1600 m to 650 m, assuming a seismic interval velocity of 5400 m/s), and similarly thins from 450 ms in the south (see Transect B) to 120 ms in the north (1350 m to 650 m). We attribute those thickness changes to topography-filling sedimentation. In the south-central part of the Colville-Anderson area the Basal Member thins eastward and the marker dividing the Lower DL Assemblage is eventually lost (perhaps because of a facies change in the Lower DL (Transect E) or perhaps poor data quality). The Basal Member can be carried along Transect E only to the tie with Transect J and may be overstepped by the Upper Member in a manner illustrated in Figure 44. Deposition of the Basal Member seems to have eliminated post-Forward Orogeny topography.

Inferred lithology, correlation, and age of the Lower DL Assemblage

Eight wells penetrate the Basal Member of the Lower DL Assemblage. Four of those, I-11, H-56, J-13, and M-63 (Fig. 4P) encountered dolomite in the upper part. The other four, K-23, C-11, L-21, and E-15 encountered sandstone and shale in the lower part. The change from siliciclastic rocks at the base to carbonate deposits at the top is not marked by any strong seismic reflection, suggesting a transitional rather than an abrupt lithological boundary. Conversely, the sharply defined reflection separating the Basal Member from the upper implies an abrupt change upward from dolomite to some other lithofacies such as shale. This suggestion has not been tested by drilling, but the prograding character of reflections within the upper package on the flank of a late structure (Fig. 44) is consistent with interpretation of the Upper Member of the Lower DL Assemblage as a siliciclastic succession.

We correlate the sub-DL Assemblage unconformity with an unconformity at the base of the Fort Confidence Formation on Coppermine Homocline, and in a general way we correlate the Lower DL Assemblage with the siliciclastic Fort Confidence Formation of Ross and Kerans (1989). Stratigraphic relationships are portrayed schematically in Figure 45. Whereas the Basal Member of the Lower DL Assemblage appears to contain a clastic to carbonate cycle, the Fort Confidence is entirely siliciclastic, representing a mixed marine and deltaic environment. The Basal Member of the Lower DL is probably overstepped by the Upper Member and, therefore, has no correlatives on the homocline. If so, post-Forward Orogeny rifting and subsidence of the Dismal Lakes basin began in the west and expanded eastward into the homocline area.

Thorkelson (2000) redefined the Pinguicula Group in the Wernecke Mountains of the Cordillera to comprise only the lower three units A, B, C of Eisbacher (1978, 1981). Thorkelson correlated the redefined Pinguicula with the Dismal Lakes Group on Coppermine Homocline, and accordingly we correlate it with the DL Assemblage (Fig. 45). Unit A comprises a siliciclastic succession of shale and siltstone with basal sandstone and conglomerate and varies in thickness from 600 to 1400 m. It probably correlates with part or all of our variably thick Lower DL Assemblage (Fig. 45).

Our understanding of the age of the DL Assemblage derives from our understanding of the age of the Dismal Lakes Group on Coppermine Homocline, an age that is constrained no more precisely than younger than the Western Channel Diabase and the 1663 Ma Narakay volcanics in the underlying Hornby Bay Group and older than the overlying 1267 Ma Coppermine basalts. If the 1400 Ma age for the Western Channel Diabase represents a crystallization rather than a reset age, then the age of the Dismal Lakes Group probably falls between 1400 Ma and 1267 Ma. The onlapping relationships interpreted for the DL/Dismal Lakes entity imply that the Basal Member of the Lower DL Assemblage is older than any part of the Dismal Lakes Group.

Middle DL Assemblage

The Middle DL Assemblage is a distinctively layered unit (Transect E, Fig. 22) about 0.33 s thick (900 m at a seismic interval velocity of 5400 m/s) that extends across the southern part of the Colville-Anderson area. It is missing to the north as a result of erosional truncation at the sub-M/S Assemblage or sub-Cambrian unconformities. It is best identified in the Tweed Lake area (Fig. 22) and is the principal marker for carrying DL Assemblage stratigraphy westward into a large, southward-plunging syncline in the south-central part of the area (Transect E). Its identification at the eastern end of Transect E is less reliable because there, its seismic expression is weaker and the seismic data are of poorer quality.

Inferred lithology, correlation, and age of the Middle DL Assemblage

One well, M-61, in the eastern part of the report area, encountered dolomite in strata that we assign to the Middle

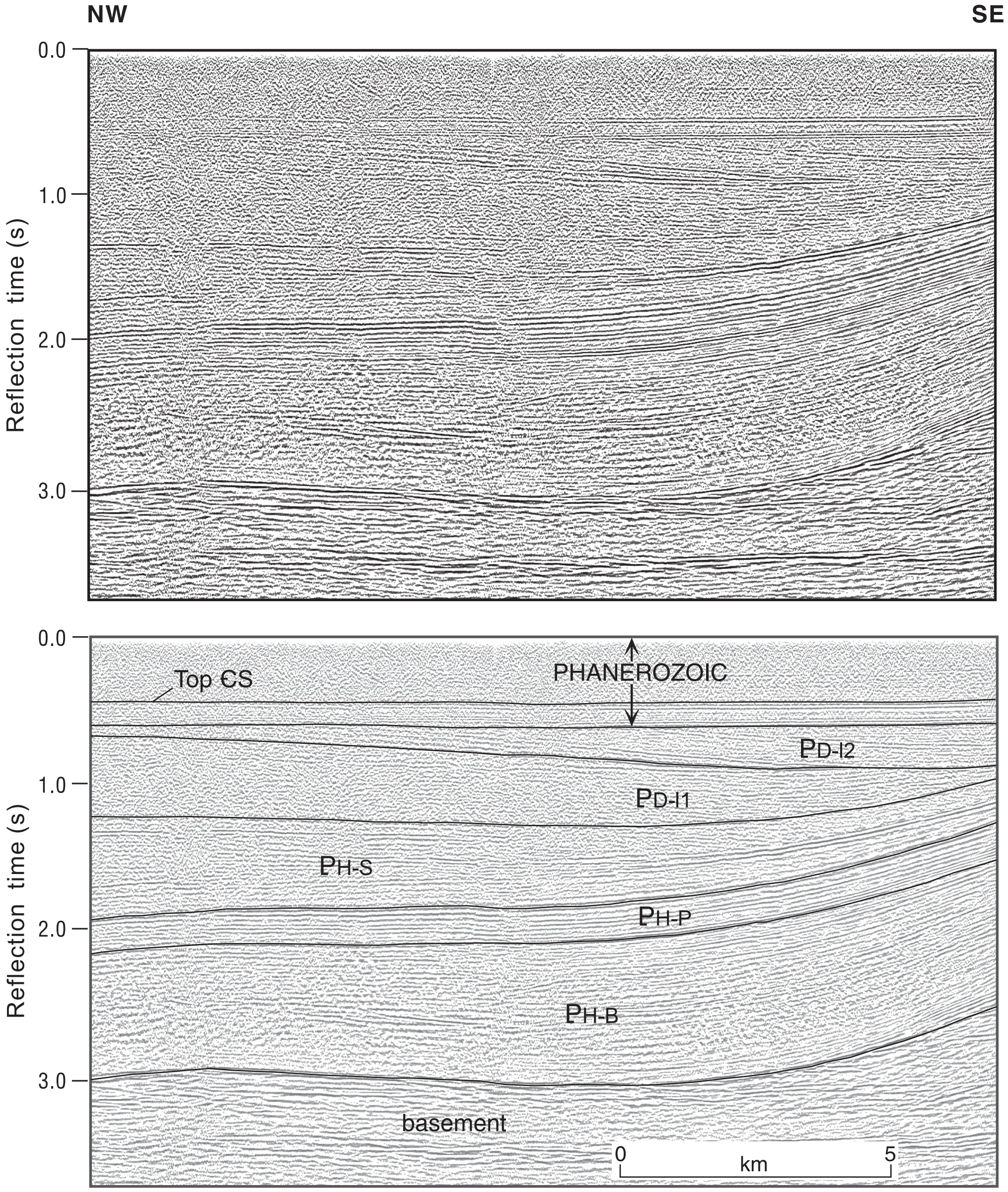

Figure 44. *1984 Petro-Canada Line 114X. Onlap of seismic markers in DL Assemblage onto a Forward Orogeny high imply reactivation during deposition of the Lower DL Assemblage. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ⱣH-B, *Basinal Unit of HB Assemblage;* ⱣH-P, *Platformal Unit;* ⱣH-S, *Syntectonic Unit;* ⱣD-I1, *Basal Member of Lower DL Assemblage;* ⱣD-I2, *Upper Member of Lower DL Assemblage;* ЄS, *Cambrian Saline River Formation.*

DL Assemblage. It is in an area of poor-quality seismic data and the stratigraphic assignment is admittedly subjective. The more or less uniform thickness of about 0.35 s (1 km) for the middle unit suggests a stable environment, and the seismic layering probably represents interbedded rock types, possibly carbonate and shale.

We correlate the seismically layered Middle DL Assemblage with the platformal sequence comprising the Dease Lake, Sulky Lake, and Greenhorn Lakes formations on the homocline (Fig. 45). That mainly dolomitic succession has a variety of subsidiary mudstone and sandstone units (Ross and Kerans, 1989) that might provide a varied seismic response such as that of the Middle DL Assemblage.

In the Wernecke Mountains of the Cordillera, Thorkelson (2000) correlated a redefined Pinguicula Group with the Dismal Lakes Group on Coppermine Homocline, and we, accordingly, correlate it with the DL Assemblage (Fig. 45).

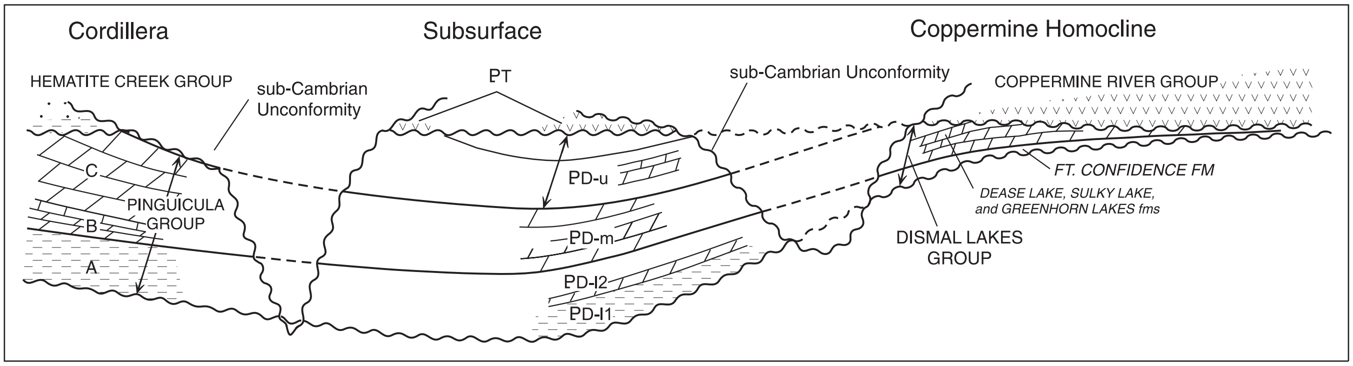

Figure 45. *Schematic chart showing proposed correlation of subsurface DL Assemblage with surface Dismal Lakes Group (Coppermine Homocline) and Pinguicula Group (Wernecke Mountains). Scales are variable but this section spans about 750 km and DL Assemblage thickness can exceed 7 km.* PD-l1, *Basal Member of Lower DL Assemblage;* PD-l2, *Upper Member of Lower DL Assemblage;* PD-m, *Middle DL Assemblage;* PD-u, *Upper DL Assemblage;* PT, *Tweed Lake Assemblage; A, B, C, Pinguicula subdivisions from Thorkelson (2000).*

Thorkelson's Unit B comprises laminated limestone and dolomite up to 320 m thick, and Unit C comprises thin- to thick-bedded or massive limestone and dolomite up to 1800 m thick. Units B and C, combined, may correlate approximately with the 'platformal carbonates' of the Middle DL Assemblage and accordingly with the carbonate succession comprising the Dease Lake, Sulky Lake, and Greenhorn Lakes formations of the Dismal Lakes Group on Coppermine Homocline (Fig. 45).

The age of the Middle DL Assemblage, like that of the entire DL Assemblage, is constrained no more precisely than younger than the 1663 Ma Narakay volcanics in the underlying Hornby Bay Group and older than the overlying 1267 Ma Coppermine basalts, but could be bracketed between the 1400 Ma age for the Western Channel Diabases and 1267 Ma.

Upper DL Assemblage

The Upper DL Assemblage is a seismically dull unit that, like the underlying Middle DL, occurs only in the southern part of the Colville-Anderson area (Fig. 4P). Its thickness is variable because it has been erosionally truncated at unconformities at the base of the overlying Tweed Lake Assemblage or Cambrian strata. Seismic expression and thickness variations are best illustrated in the central part of Transect E, where abrupt thickness changes across two large, normal faults or half-grabens can be viewed. One, in the Tweed Lake area, is westward dipping; the other, about 30 km to the west, is eastward dipping. The Upper DL Assemblage is about 1.5 s (4 km) thick in the eastern half graben and thins eastward across the fault to only about 0.33s (900 m) in the footwall block. An east-to-west change of similar magnitude occurs across the western fault. These abrupt thickness changes occur below an unconformity at the base of the overlying Tweed Lake Assemblage. That the Upper DL strata in the down-dropped blocks are in part syntectonic graben fill is a possibility that cannot be precluded with presently available data.

Inferred lithology, correlation, and age of Upper DL Assemblage

Four wells penetrated the Upper DL Assemblage (Fig. 4P). They are widespread and the intersections cannot be placed in relative stratigraphic positions, so no conclusion can be drawn regarding lithostratigraphic sequence. Three of the wells were drilled east of Tweed Lake where only the lower part of the Upper DL Assemblage is preserved. D-45, north of Lac Des Bois, encountered sandstone and shale, and M-47, east of Lac Des Bois, encountered shale. A-40, southeast of Lac Des Bois, encountered dolomite. That well lies close to the M/S Assemblage zero-edge (Fig. 4P), which because of equivocal seismic data cannot be precisely placed (Fig. 46). Thus, dolomite encountered there could represent M/S Assemblage, but that possibility is considered unlikely because no basal dolomite is reported at the base of the Shaler Supergroup on the Coppermine Homocline (Rainbird et al., 1996a). The fourth well, N-37, encountered dolomite; the well was drilled in an area of poor seismic records, but seems to have penetrated somewhat higher in the Upper DL Assemblage.

In our correlation scheme (Fig. 45) we interpret that the Upper DL Assemblage has no counterparts in either the Dismal Lakes Group on Coppermine Homocline to the east, or in the Pinguicula Group in the Wernecke Mountains of the Cordillera. We assume that equivalent strata were removed from both areas by pre-Coppermine River Group erosion in the east, and by pre-Hematite Creek Group erosion in the west.

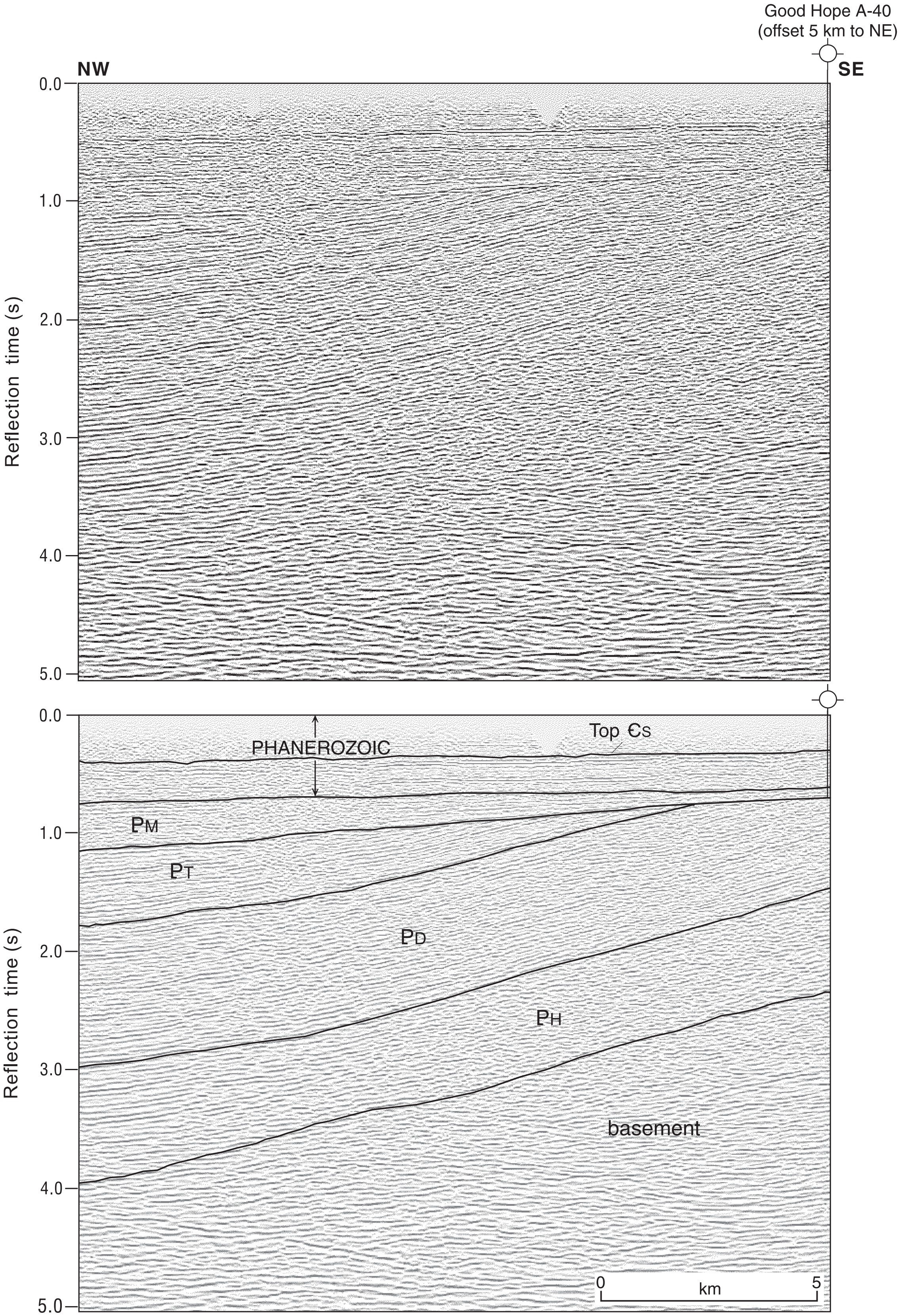

Figure 46. *1982 Petro-Canada Line 70X showing a wedge of M/S Assemblage unconformably overlying strata assigned to the Tweed Lake and DL assemblages and overlain by Phanerozoic strata. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ⱣH, *HB Assemblage undivided;* ⱣD, *DL Assemblage undivided;* ⱣT, *Tweed Lake Assemblage;* ⱣM, *M/S Assemblage;* ЄS, *Cambrian Saline River Formation.*

The age of the Upper DL Assemblage, like the other units in the assemblage, is considered to be bracketed between 1663 Ma and 1267 Ma, but could be bracketed between 1400 Ma and 1267 Ma. As correlated, the Upper DL is younger than any preserved Dismal Lakes Group strata on the homocline or Pinguicula Group strata in the Wernecke Mountains.

Structure and tectonics related to the DL Assemblage and Dismal Lakes Group

The DL Assemblage and the Dismal Lakes Group are offset by normal faults that predate the overlying Tweed Lake and Coppermine basalts. DL Assemblage strata are offset by widespread major normal faults that tend to occur as negative inversions of steeply dipping Forward Orogeny faults. Five subsurface examples are illustrated. In the best example (Fig. 22), normal displacement of about 1.2 s (3.2 km at a seismic interval velocity of 5400 m/s) is great enough to nullify the effect of compression and to mask the Forward Orogeny thrust block. Flattening the sub-DL unconformity (restoring it to horizontal) reveals the Forward Orogeny uplift of 0.7 s (2 km at 5800 m/s).

In another subsurface example, one of mild inversion (Fig. 20c, d), extensional offset was much less than the earlier compressional displacement, and the ancestral Forward Orogeny uplift remained as a high-angle thrust block. A third example is found in the Peel area (west end of Transect B) where a Forward Orogeny-uplifted block, truncated by pre-DL erosion, was subsequently negatively inverted by post-DL normal fault displacement.

A fourth example, Blackwater Fault (east end of Transect G), exhibits normal dip-separation of about 3.1 s (8.4 km), which juxtaposes DL and Tweed Lake strata in the hanging wall with clearly imaged HB Assemblage in the footwall or uplifted block. As discussed under ‘HB Assemblage’, Syntectonic Unit strata in the western, hanging-wall block appear to be truncated by the sub-DL unconformity as a result of erosional truncation of an ancestral Forward Orogeny fault block. A fifth example of negative inversion is illustrated later in Figure 57, which shows the sub-DL unconformity truncating a relatively small Forward Orogeny structure and offset by later normal displacement.

A surface example of negative inversion is found on a geological map of Coppermine Homocline (Ross and Kerans, 1989). There, the east-side-up, compressional, Teshierpi Uplift was truncated by erosion such that LeRoux Formation strata unconformably overlie crystalline basement in the eastern uplifted block, and overturned Hornby Bay Group in the western footwall. However the unconformity was itself offset by postorogenic east-side-down mild inversion. The parallel structural histories of this and the noted subsurface structures are an important part of the rationale for correlating from the subsurface to outcropping strata (Cook and MacLean, 1995).

Extensional displacements discussed here predate the Coppermine and Tweed Lake basalts and are considered to postdate the entire DL Assemblage and Dismal Lakes Group. However, thickening of the Upper DL Assemblage into pre-basalt sedimentary wedges (central part of Transect E) may represent syntectonic half-graben fill.

DL and Dismal Lakes strata are also affected by compressional deformation, but this phase of deformation can be interpreted as postdating the overlying basalts and will be discussed below.

Intrusive sheet into DL Assemblage

A strong discordant reflection cutting DL Assemblage strata, imaged on two orthogonal seismic lines (marker ‘s’ on Fig. 43 and 47) in the south-central part of the Colville-Anderson area (Fig. 48) probably represents an intrusive sheet unrelated to, and younger than, those discussed under HB Assemblage. In detail there appears to be a set of closely spaced reflections, which probably represent a complex of closely spaced sheets, but for simplicity they will be discussed as a single package. Because the package is recorded on two orthogonal lines its approximate geographic limits and three-dimensional geometry can be outlined. The sheet forms a broad, asymmetrical arch crossing the sub-Dismal Lakes unconformity and cutting across a broad syncline (Fig. 47). In contrast, on an orthogonal line (Fig. 43) the sheet appears rectilinear, and dips to the southeast across DL Assemblage strata. Smaller sheets related to it may reach as high as the sub-Cambrian unconformity but both the northwest and southeast extremities of the sheet are essentially preserved. From the forgoing the sheet can be described as crudely circular in plan, about 30 km across, gently warped about a southeast-plunging axis (Fig. 48), and postdating a long-wavelength fold.

Given the strength and sharpness of this reflection it is surprising that no others have been noted that might represent this younger intrusive activity. If sheets of this age occur below the sub-DL unconformity they will, of course, be indistinguishable from those of the older Western Channel Diabase set.

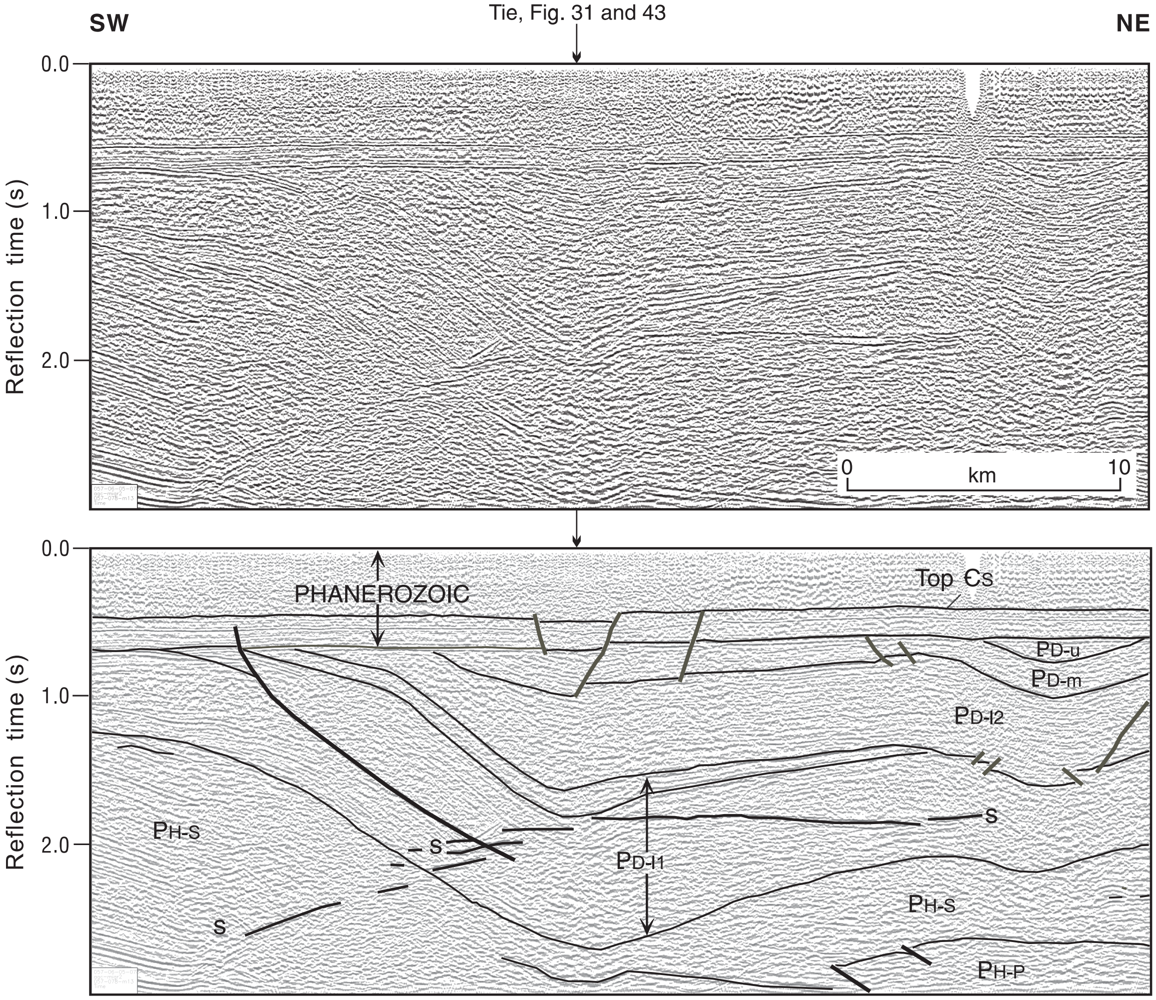

Figure 47. *1971 Mobil Oil Canada Line 63-13. Discordant reflections are interpreted as intrusive sheets that were emplaced into folded HB and DL assemblages. See also Figures 31 and 43. Vertical exaggeration is approximately 2:1 at a seismic velocity of 5500 m/s. See Figure 1P for location. s, intrusive sheet;* ꝐH-P, *Platformal Unit of HB Assemblage;* ꝐH-S, *Syntectonic Unit;* ꝐD-l1, *Basal Member of Lower DL Assemblage;* ꝐD-l2, *Upper Member of Lower DL Assemblage;* ꝐD-m, *Middle DL Assemblage;* ꝐD-u, *Upper DL Assemblage;* ЄS, *Cambrian Saline River Formation.*

Correlation of intrusive sheet

The intrusive sheet described intrudes the DL Assemblage and also postdates long-wavelength folds that regionally postdate the Tweed Lake and Coppermine basalts. Potentially correlative events are the 778 Ma 'Tsezotene' sills intruded into the Mackenzie Mountains Supergroup (MMS) in the Cordillera, or the extensive 723 Ma Franklin sills intruded into the Rae Group on Coppermine Homocline and Brock Inlier. Proximity is no help, because the sheet in question is more or less equidistant from the Mackenzie Mountains and Coppermine Homocline. The question of why the sheet is emplaced into deeper DL Assemblage rather than younger hosts is unresolved.

TWEED LAKE ASSEMBLAGE

Overview

Strata assigned to the Tweed Lake Assemblage occur in two synclinal outliers in the Colville Hills area and another half-graben outlier in the hanging wall block of Blackwater Fault south of Keith Arm of Great Bear Lake (Fig. 4P). A fourth small patch of Tweed Lake Assemblage lies between the two synclinal outliers. The assemblage is named for basalts (informally the Tweed Lake basalts) encountered in four wells in the Tweed Lake area. The closely adjacent Tweed Lake M-47 and A-67, and Nogha 0-47 were drilled in the eastern synclinal outlier. The fourth well, Bele 0-35,

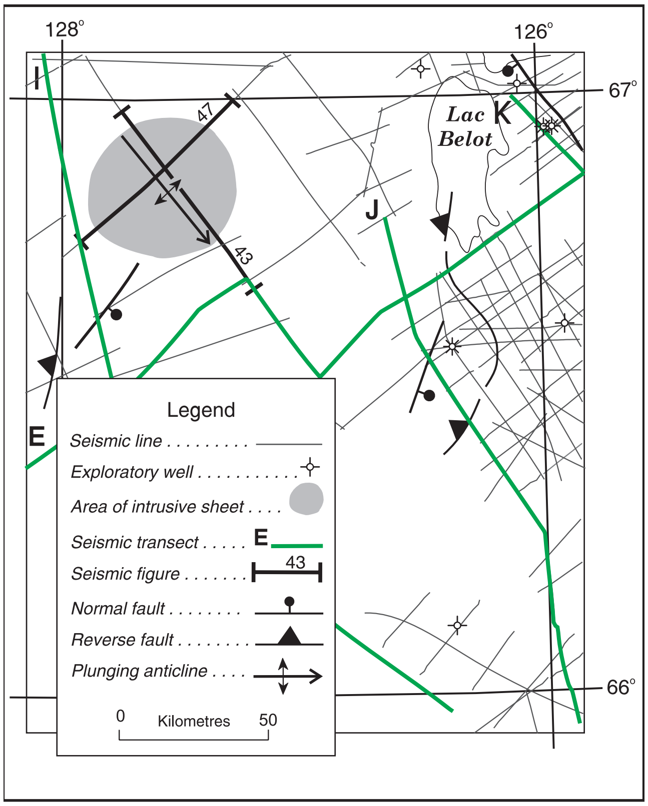

Figure 48. *Map showing the extent of a discordant reflection interpreted as an intrusive sheet intruded into DL Assemblage strata (see Fig. 43, 47).*

encountered basalt in the small patch noted above. In the Tweed Lake area the assemblage is up to 800 ms (2 km) thick (Fig. 49P, 50P). It has a seismically layered basal interval of unknown composition about 140 ms thick (380 m at a seismic interval velocity of 5400 m/s) overlain by a seismically dull interval of about the same thickness (Fig. 22). The wells, Tweed Lake A-67 and M-47, encountered basalt in the dull interval. Strata in the synclinal outlier 30 km to the west have a distinctly layered seismic expression, and have not been penetrated by any exploration well. In spite of the different seismic expression that outlier is assigned to the Tweed Lake Assemblage because it is structurally similar to the calibrated Tweed Lake outlier. Both outliers occur as north-trending, doubly plunging synclines and both are cut by normal faults more or less axial to the synclines. Basal strata in both unconformably overlie Upper DL Assemblage beds.

In the Blackwater Fault half-graben (Fig. 51), south of Keith Arm, an east-dipping wedge up to 3.5 km thick overlying DL Assemblage (Fig. 50P) is assigned to the Tweed Lake Assemblage on the basis of gravity and magnetic signatures (MacLean and Miles, 2002) as discussed below. The seismic expression there shows layered basal and dull upper intervals.

Lithology, correlation, and age of Tweed Lake Assemblage

As noted above, wells drilled into the Tweed Lake Assemblage encountered basalt in a seismically characterless interval, but the assemblage is represented by distinct seismic layering elsewhere. The Tweed Lake area may be a distal part of the Coppermine plateau basalts and the well-layered Tweed Lake Assemblage to the west may be made up largely of sedimentary strata, correlative with the Coppermine River Group. Folding of the western doubly plunging syncline was, at least in part, syndepositional, as indicated by stratigraphic thinning onto the flanks of the syncline (Fig. 31). In summary, we have no information on rock types in the interval other than that basalt is present. The subsurface strata have been truncated by pre-M/S Assemblage and pre-Cambrian erosion, so original depositional thicknesses cannot be determined. If the Coppermine basalts on the homocline were deposited at or near the depocentre, basalt could be expected to thin toward the Tweed Lake area and beyond.

We consider the age of the Tweed Lake basalts to be the same as that of the Copper Creek Formation basalts on Coppermine Homocline. LeCheminant and Heaman (1989) considered the Copper Creek basalts to be coeval with the Mackenzie dyke swarm which they dated as 1267 Ma.

A variety of information and arguments for correlating the Tweed Lake Assemblage with the Coppermine River Group, and for correlating outlier to outlier, follow.

Regional unconformity

In the subsurface a significant unconformity at the base of the Tweed Lake Assemblage is required because large, normal-fault structures are truncated at the base of the assemblage (Transect E). On Coppermine Homocline a corresponding unconformity at the base of the Coppermine basalts, largely unnoted in the geological literature, is manifested on the geological maps of Ross and Kerans (1989) and Baragar and Donaldson (1973). In particular, a west-side-down normal fault near the west end of Dismal Lakes (Fig. 36) has significant offset of Dismal Lakes Group strata and only minor offset of the lowermost Copper Creek Formation indicating that most of the fault displacement occurred prior to deposition of the basalts. At the top of the Dismal Lakes Group, the upper member of the Greenhorn Lakes Formation is thinner in the upthrown block (Fig. 36) implying pre-basalt erosion. Further evidence for pre-basalt erosion is found in the disappearance eastward of first the upper and then the entire Greenhorn Lakes Formation (Unit 16 of Baragar and Donaldson, 1973).

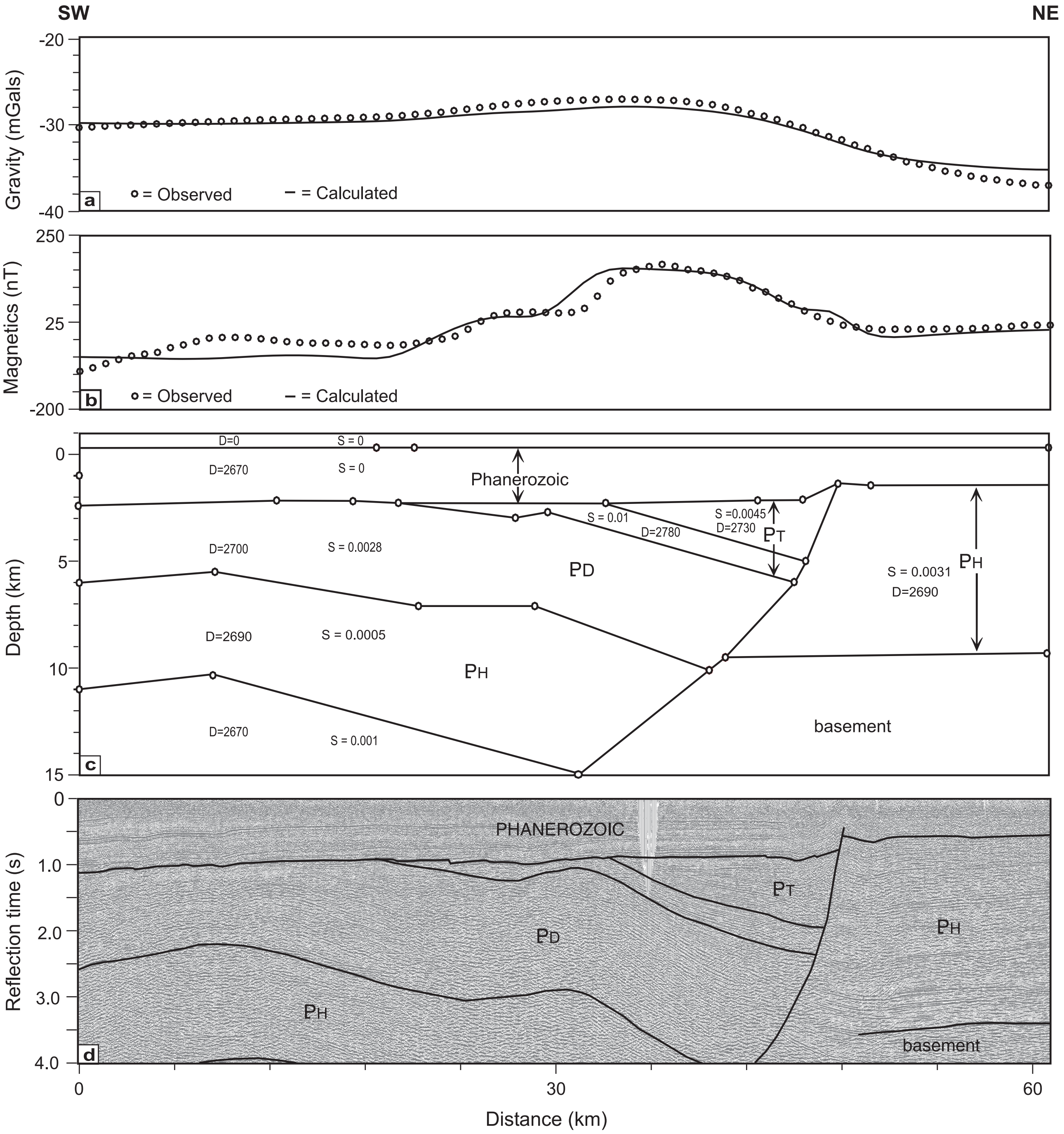

***Figure 51.** Magnetic and gravity models of the Blackwater Fault half-graben fill. **a.** Observed and modeled Bouguer Gravity response; **b.** Observed and modeled Total Field Magnetic response; **c.** Density and Magnetic Susceptibility model (depth scale in km); **d.** portion of Petro-Canada seismic line 60X with interpretation. This is a composite figure summarizing MacLean and Miles (2002).* ⱣH*, HB Assemblage, undivided;* ⱣD*, DL Assemblage, undivided;* ⱣT*, Tweed Lake Assemblage.*

Chemistry of the Tweed Lake basalts

Sevigny et al. (1991) analyzed basalts from the Petro Canada – Canterra Tweed Lake M-47 well and concluded (p. 184) that they, "have geochemical characteristics, including of major, trace, and rare earth elements, that are similar to those of the most enriched Coppermine lavas but significantly different from those of the younger Proterozoic volcanics, such as the Natkusiak basalts", and (p. 190), that "These data thus show that the geochemical signatures of the M-47 and Coppermine basalts are nearly identical and allow correlation of these units with some confidence". This composition-based correlation of Tweed Lake basalts to Coppermine basalts supports our subsurface to surface correlation rationale.

Magnetic and gravity signatures

Strata in the Blackwater Fault half-graben south of Keith Arm of Great Bear Lake are correlated, on the basis of gravity and magnetic signatures, with the Copper Creek and Husky formations of the Coppermine River Group (MacLean and Miles, 2002). Thicknesses of about 2 km in the Tweed Lake area and about 3.5 km in the Blackwater half-graben compare favourably with 4.2 km reported for the Coppermine River Group (Baragar and Donaldson, 1973).

On Coppermine Homocline the Copper Creek Formation has a high magnetic intensity except for the lowermost flows that contain lesser amounts of Fe-Ti oxides relative to those at higher stratigraphic levels (Hildebrand and Baragar, 1991). In the two major outliers in the Colville Hills area the Tweed Lake basalts have no obvious correspondence between magnetic signature and basalt distribution, perhaps because the amount of basalt is relatively small, or perhaps any basalt that is present represents the low-magnetic lower beds of the Copper Creek Formation.

On the other hand, strong magnetic and gravity signatures for the Blackwater Fault half-graben south of Keith Arm led MacLean and Miles (2002) to interpret the presence of Tweed Lake Assemblage in the half-graben (Fig. 51). Both the Bouguer Gravity and Total Field Magnetic anomalies have been modelled by MacLean and Miles (2002) and are attributed to an eastward-dipping sequence of Tweed Lake Assemblage about 3.5 km thick. Were it not for the potential field signatures these strata could as well have been assigned to the younger M/S Assemblage.

Structure and tectonics related to the Tweed Lake Assemblage and Coppermine River Group

Introduction

In the subsurface, normal faults and long-wavelength folds affect the Tweed Lake Assemblage. The relationship of the faults to the folds is not clear, but both may be manifestations of one extensional event. South of Great Bear Lake, Tweed Lake Assemblage strata are offset by a single large-displacement normal fault. At the surface on Coppermine Homocline the Coppermine basalts are similarly deformed by normal faults and a long-wavelength fold, and appear to be involved in a spectacular set of folds near Dease Arm of Great Bear Lake.

Subsurface structures

Tweed Lake Assemblage strata in the Colville Hills area occur mainly in two doubly plunging synclines (Fig. 4P) within which the unconformable base of the assemblage truncates large-displacement normal faults that offset DL Assemblage and older strata (Transect E, central part). Subsequently, the Tweed Lake strata were themselves offset by modest reactivation of those faults. The reactivated faults occur more or less axially to the synclines (Fig. 4P). Folding of the western syncline was, at least in part, syndepositional, as indicated by stratigraphic thinning onto the flanks of the syncline (Fig. 31). A third doubly plunging syncline, cored by Upper DL Assemblage strata, occurs further west (Fig. 4P). Thus there are three synclinal depressions separated by anticlinal highs. We assume that all structures of this series postdate the Tweed Lake Assemblage even though the level of erosion of the westernmost depression is such that no Tweed Lake is preserved. These large folds have wavelengths of 70 to 80 km, but are, nonetheless, shallow structures having small amplitudes (relative to wavelengths) of 2.5 to 3 km. The succession of synclinal depressions and anticlinal highs results in a complex map pattern that is poorly understood but may be an interference effect caused by two generations of folding. Note that a younger, less prominent, anticline-syncline pair about 70 km west of Aubry Lake trends northwest-southeast and appears to postdate the M/S Assemblage.

Evidence regarding crustal dynamics, whether extensional or compressional, is equivocal. The synclines have more or less axial normal faults suggesting that the sags and the faults are dynamically related and result from a single extensional event. Conversely the anticline separating the two eastern synclines is disrupted by a thrust fault (Transect E; line PCR 90A, Fig. 25), which implies a compressional origin for the long-wavelength folds. The timing of the thrust relative to the Tweed Lake basalts cannot be determined but the dilemma can be resolved if the synclines were initially extensional basins, later accentuated by post M/S Assemblage compression.

To the southeast, south of Great Bear Lake, the Blackwater Fault is a large normal fault that offsets Tweed Lake Assemblage (Fig. 4P; Transect G, east end). No Tweed Lake strata are preserved in the uplifted footwall block, but a minimum post-Tweed Lake displacement of 1.8 s (~5 km) is recorded. Aggregate displacement of about 3.1 sec (about 8.4 km at a seismic interval velocity of 5400 m/s) is recorded by offset of the Platformal Unit of the HB Assemblage. As noted in the discussion of the Forward Orogeny we interpret the Blackwater Fault normal offsets to be as a result of reactivation of an ancestral Forward Orogeny fault.

Surface structures on Coppermine Homocline

The post-Tweed Lake extensional structures have apparent counterparts on Coppermine Homocline, where numerous normal faults offset both the Dismal Lakes and Coppermine River groups. The most noticeable are the Herb Dixon and Teshierpi faults in the vicinity of Dismal Lakes (Baragar and Donaldson, 1973) (Fig. 49P, 50P). A smaller-displacement fault, discussed earlier, near the west end of Dismal Lakes (Fig. 36; Ross and Kerans, 1989; Baragar and Donaldson, 1973) like those in the Tweed lake area, exhibits both pre- and post-basalt displacements.

Strata of the Coppermine River Group were buckled into a long-wavelength fold, a prominent north-trending syncline (Fig. 4P) mapped by Baragar and Donaldson (1973) having a crest-to-trough half-wavelength of about 100 km, considerably greater than the typical half-wavelengths in the subsurface. The origin of the syncline, whether compressional or extensional, is equivocal. It may represent sag due to localized crustal extension as expressed by normal faults. Hildebrand and Baragar (1991), however, interpreted the Coppermine River Group to have been deformed during two compressional phases: an early phase that generated east-trending folds and thrusts, and a later one that caused the north-trending syncline. We have not recognized the earlier phase in the subsurface.

North of Dease Arm of Great Bear Lake, map patterns (Ross and Kerans, 1989) are dominated by asymmetrical, discontinuous, eastward-plunging, en echelon folds that affect at least the section including Dease Lake to Greenhorn Lakes formations. Although outcrops are sparse in the critical area it seems that Coppermine basalts must also be affected by this fold phase. Steeply dipping and overturned bedding dips indicate a northward vergence for the fold set. Ross and Kerans (1989) also described strata-bound folds in the incompetent Dd3 unit of the Dease Lake Formation, which they suggest were a result of northward translation on a normal fault detachment. Alternatively, the northward vergence of those folds and their proximity to Dease Arm suggest a genetic relationship to the Dease Arm folds. The relationship, if any, of this remarkable fold set to the somewhat obscure subsurface compressional post-Tweed Lake structures is unknown, other than that the timing is potentially the same.

M/S ASSEMBLAGE

Overview

The youngest subsurface Proterozoic sequence, the M/S Assemblage, is considered to be the subsurface equivalent of both the Mackenzie Mountains Supergroup (MMS) in the Cordillera and the Shaler Supergroup on Victoria Island, Brock Inlier and Coppermine Homocline. The distribution and thickness of strata that we assign to the assemblage is shown on Figures 4P, 52P, and 53P. In the northeast, adjacent to Brock Inlier (Transect A, east end), a finely layered seismic interval, about 0.2 s thick (530 m at a seismic interval velocity of 5300 m/s), in angular discordance with underlying seismic markers, is interpreted to represent the M/S Assemblage, an assignment that is supported by a mineral exploration hole drilled by Darnley Bay Resources Ltd. In the northwest part of the map area, a wedge of parallel-bedded strata with a maximum thickness of about 0.4 s (1.1 km at a seismic interval velocity of 5300 m/s), unconformably overlies DL Assemblage and is unconformably overlain by Lower Cambrian units (Transect A). A single, dominant reflection lies about 0.17 s (450 m) above the base. An apparent paleotopographic high, with M/S Assemblage missing, between the northwest and northeast occurrences (Fig. 4P) is suspect because seismic data quality there is poor (Transect A). Future data acquisitions may show the assemblage to occur more or less continuously, or as outliers, across that area.

In the southwestern part of the map area, M/S Assemblage strata are identified in an arcuate belt extending from Peel Plateau, adjacent to the Mackenzie Mountains, up the Mackenzie River valley to Cap Mountain. Underlying Imperial Anticline in Peel Plateau, M/S Assemblage is imaged on seismic records (Fig. 54) as a wedge of well-layered strata with some strong internal reflections, floored by an unconformity, and thickening southward toward the Mackenzie Mountains. Thickening of the wedge southward is mostly due to differential erosion at the sub-Cambrian unconformity and to duplication by a thrust fault (Fig. 54–56), but in the lowermost beds depositional thickening is apparent. For example, Figure 54 shows a lower interval, bounded by the basal unconformity below and a strong reflection above, that thickens southward from 0.34 s (0.9 km) to 0.55 s (1.46 km).

From Imperial Anticline, M/S Assemblage strata can be carried, on seismic records, up the west side of Mackenzie River valley to the area across the river from the settlement of Tulita. The seismic character there resembles that of the lower part of the assemblage at Imperial Anticline, although available seismic data are commonly too shallow to image the unconformable base. East of the river, near Tulita, strata assigned to M/S Assemblage occur in a large syncline, about 60 km across, with 2.1 s (5.6 km) of section (Transects F, G, M). The assemblage there is a layered succession with two bold markers 0.35 to 0.4 sec (0.9 km to 1.1 km) apart. The base of the section is an unconformity that truncates underlying strata. The unconformity is perhaps best illustrated in Transect F, line PCR 77X/44X. Variable data quality precludes carrying the bold reflections from section to section, but where they are present stratigraphic thickening, comparable to that seen at Imperial

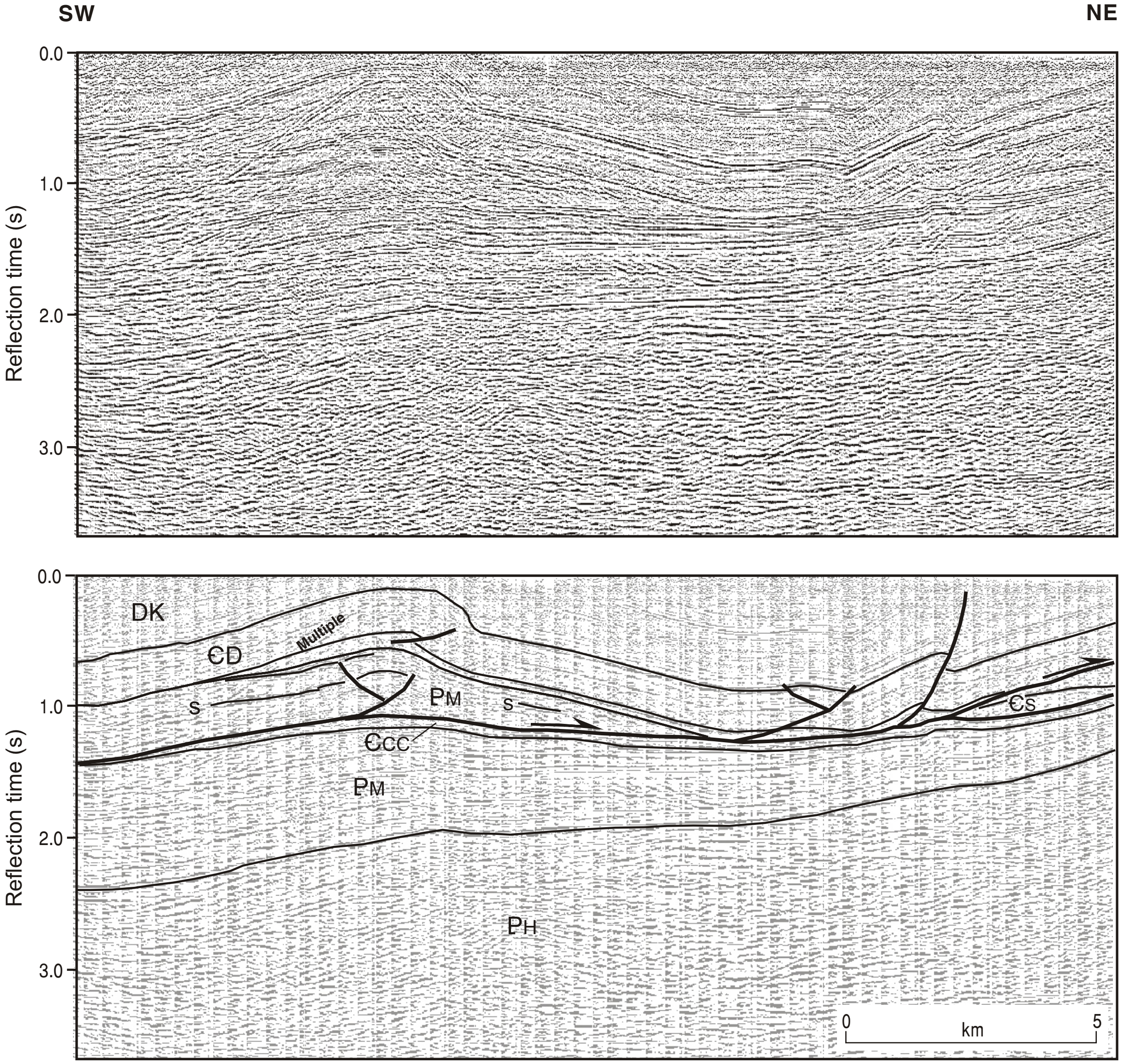

Figure 54. *1982 Petro-Canada Line 105. Overthrust interpretation is based on model shown in Figure 56. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* PH, *HB Assemblage undivided;* PM, *Mackenzie Mountains Supergroup; s, sill;* ЄCC, *Lower and Middle Cambrian Mount Clark and Mount Cap formations;* ЄS, *Cambrian Saline River Formation;* ЄD, *Cambrian to Devonian carbonates;* DK, *Devonian and Cretaceous clastic deposits (includes Middle Devonian limestone).*

Anticline, can be measured in a basal interval bounded by the unconformable base and the lowermost bold reflection (Transect F, line PCR 77X/44X; Transect G, west end; Transect M, east end). In Transect G a basal interval ranges from 0.6 s (1.6 km) to 0.8 s (2 km); in Transect F from 0.16 s (0.4 km) to 0.29 s (0.77 km); and in Transect M from 0.8 s (2 km) to 0.95 s (2.5 km). Data gaps preclude tying strata in the syncline to M/S Assemblage west of the river, but the synclinal beds can be reasonably carried south (Fig. 52P, 53P) to the area of Cap Mountain, where Proterozoic strata equivalent to M/S Assemblage occur in outcrop (Villeneuve et al., 1998).

Strata that we assign to the M/S Assemblage extend up Mackenzie River valley, and correspond closely to an aeromagnetic low (Fig. 7P). The correspondence along the east side of the McConnell range is so striking that we have used the aeromagnetic trends to constrain our interpretation of the east-west-trending MMS zero edge north and northeast of Norman Wells where seismic data are poor or nonexistent. In the southern part of the area, within the aeromagnetic low, is a magnetic high that runs parallel to the MMS zero edge. The high appears to be related to the McConnell fault block, but the link is problematical because it extends eastward beyond the surface trace of the fault.

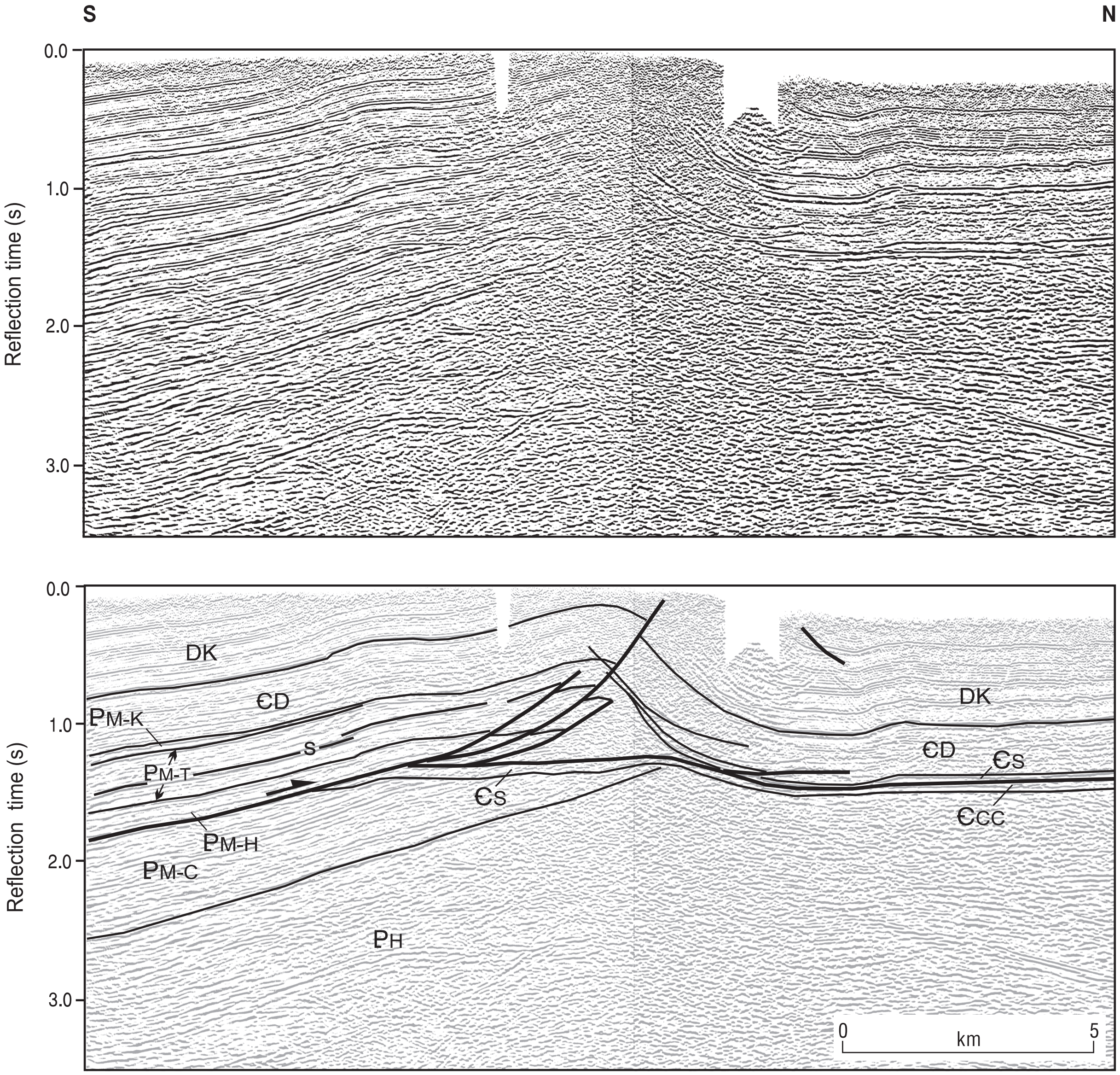

Figure 55. *1982 Petro-Canada Line 45A. Overthrust interpretation is based on model shown in Figure 56. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ⱣH, *HB Assemblage undivided;* ⱣM-C, *lower part of Mackenzie Mountains Supergroup (Hematite Creek Group);* ⱣM-H, *H1 dolomite;* ⱣM-T, *Tsezotene Fm; s, sill;* ⱣM-K, *Katherine Group;* ЄCC, *Lower and Middle Cambrian Mount Clark and Mount Cap formations;* ЄS, *Cambrian Saline River Formation;* ЄD, *Cambrian to Devonian carbonates;* DK, *Devonian and Cretaceous clastic deposits (includes Middle Devonian limestone).*

Two important, small outliers of M/S Assemblage occur in the central part of the map area (Fig. 4P). The larger outlier, lying immediately north of the west end of Great Bear Lake, is represented on seismic as a finely layered interval > 0.6 s (>1.6 km) thick. There, strata are assigned to the M/S Assemblage because they unconformably overlie strata assigned to the Tweed Lake Assemblage (Transect K and Fig. 46) and are unconformably overlain by Lower Cambrian beds. The remaining, still smaller, outlier comprises a thin, unconformable interval only about 0.1 s thick (260 m) wedged between DL Assemblage beneath, and Cambrian strata above. It may correlate with the Tweed Lake Assemblage but as it has an east-west structural trend, discordant to that of the Tweed Lake Assemblage outliers, we assign it to the M/S Assemblage.

Correlation of the Mackenzie Mountains Supergroup with the Shaler Supergroup

Young et al. (1979), basing their correlations mainly on stratigraphic similarities, correlated the Mackenzie

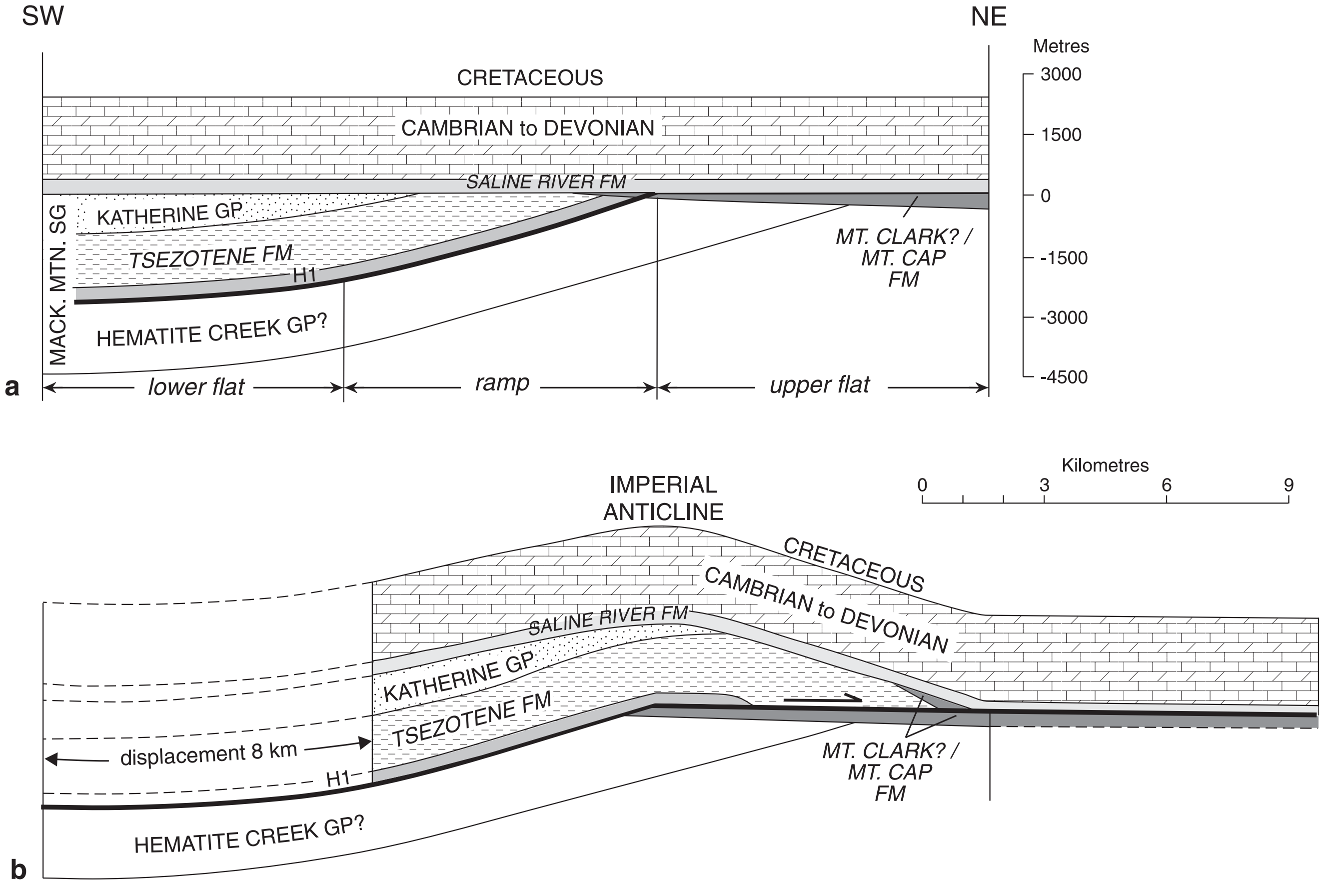

Figure 56. *Schematic interpretation of a fault-bend fold wherein the lower flat, ramp, and upper flat are all bedding parallel (after Cook and MacLean, 1999).* ***a.*** *Pre-thrust geometry. A bedding-parallel fault in flexed Mackenzie Mountains Supergroup strata intersects the sub-Cambrian unconformity and diverts into flat-lying Cambrian Saline River Formation salt beds.* ***b.*** *Post-thrust geometry after displacement of about 8 km. Compare with seismic sections in Figures 54 and 55.*

Mountains Supergroup in Mackenzie Mountains with the Shaler Supergroup in Brock Inlier, Coppermine Homocline and Minto Inlier. Subsequent studies (e.g., Aitken, 1982; Jefferson and Young, 1989) supported, and more recent analytical work corroborated, with minor modification, that initial correlation. The age of the Mackenzie and Shaler supergroups is constrained by three types of age control data: detrital zircons, diabase intrusions, and microfossils.

Shaler Supergroup and Mackenzie Mountains Supergroup strata both yield Grenville-age (ca. 1000 Ma) detrital zircons (Rainbird et al., 1996a; Rainbird et al., 1997), and are therefore known to be younger than 1000 Ma. Rainbird et al. (1997) interpreted a trans-continental drainage system that transported detritus from the Grenville Orogen to the northwestern shores of the continent as it stood at that time. That drainage system apparently was disrupted at the close of MMS-Shaler deposition, because Grenville-age zircons are not found in the younger Windermere Supergroup. Consequently, in addition to constraining the earliest possible age, the presence of Grenville-age detrital zircons serves as a direct correlation indicator for MMS-Shaler strata.

The youngest possible age of the MMS and Shaler Supergroup is constrained by the 779 Ma Tsezotene sills (LeCheminant, 1994) that intrude the Mackenzie Mountains Supergroup and the 723 Ma Franklin intrusions (Heaman et al., 1992) that intrude the Shaler Supergroup. This combination of detrital zircons and diabase intrusions constrains the age of the MMS as between 1000 and 779 Ma and that of the Shaler Supergroup as between 1000 and 723 Ma.

The correlation of the Mackenzie Mountain Supergroup with the Shaler Supergroup was further reinforced by the discovery of carbonaceous megafossils including Chuaria and Tawuia in the Wynniat Formation of the Shaler Supergroup on Victoria Island (Hofmann and Rainbird, 1994). The Little Dal Group of the MMS is the only other locale in North America in which Tawuia has been found (Hofmann and Aitken, 1979). Palynological control derives from the discovery of the distinctive acritarch Trachyhystrichosphaera from the Shaler Supergroup on Victoria Island (N.N. Butterfield, pers. comm., 1998). Trachyhystrichosphaera occurs worldwide in ca. 1000–700 Ma rocks and appears to be an excellent index fossil for the MMS-Shaler interval (Butterfield et al., 1994).

In the Wernecke Mountains Eisbacher (1978, 1981) subdivided the Pinguicula Group into six subunits, and Young et al. (1979) correlated the group with the Mackenzie Mountains and Shaler supergroups. Thorkelson (2000) subdivided the Pinguicula into two groups on the basis of an intra-group unconformity, and retained the lower units A, B, and C in the Pinguicula Group. He did not recognize Eisbacher's Units C, D, E, but placed equivalent strata in a new group, the Hematite Creek Group, which he correlated with the Mackenzie Mountains Supergroup. Although the Hematite Creek Group can be considered part of the Mackenzie Mountains Supergroup on the basis of extracted 'Grenville' age detrital zircons (ca. 1033 Ma) (Thorkelson, 2000), we note that no one-to-one correlations can be made. This is not surprising considering that the Hematite Creek Group, overlying an unconformity, consists of the lowermost strata of the supergroup, whereas the base of the MMS is not exposed. The absence of recognizable MMS units in the Hematite Creek Group implies that the entire group is older than the H1 dolomite, the oldest exposed MMS unit (Aitken et al., 1982).

In Eagle Plain west of Richardson Mountains and west of our study area, a cursory examination of seismic stratigraphy with L. Lane of the Geological Survey of Canada (Calgary) leads us to the conclusion that sub-Cambrian Proterozoic strata there probably pertain to the HB Assemblage, which leads to the further conclusion that the Mackenzie Mountains and Shaler supergroups are nowhere continuous with each other today.

Lithology, correlation, and age of the M/S Assemblage

Adjacent to Brock Inlier

Strata imaged in the northeast near Darnley Bay are assigned to the M/S Assemblage because of proximity to exposed Shaler Supergroup in Brock Inlier. That assignment is essentially corroborated by a mineral exploration hole DBR-01 drilled by Darnley Bay Resources Ltd. in June, 2000. The drill hole passed through the sub-Cambrian unconformity at about 1168 m depth. Mudstone and sandstone, extending from that level to the drillhole's total depth of 1812 m, were assigned by company geologists to the Escape Rapids Formation of the Shaler Supergroup (Darnley Bay Resources, 2001). This calibration of the sub-Cambrian unconformity and the presence of Shaler Supergroup was important for interpreting somewhat equivocal seismic data on the east end of Transect A.

Northwest part of map area

The parallel-bedded wedge in the northwest part of the report area (Fig. 4P, 52P, 53P, 57, and Transect A) could be either Tweed Lake Assemblage or M/S Assemblage based on its unconformable relationship with the underlying DL Assemblage. The interval is too thin (1 km) to permit reliable comparison of seismic character with other Tweed Lake or M/S occurrences. We assign these strata to the M/S rather than the Tweed Lake Assemblage because 1) they are potentially more or less continuous with the M/S strata near Darnley Bay, and 2) they probably extend northward to Tuktoyaktuk Peninsula where Proterozoic sandstone, siltstone, and dolomite described by Wielans (1992) in wells on the peninsula are considered to represent Mackenzie Mountains Supergroup. Another important consideration in assigning the strata to the M/S Assemblage is that they were unaffected by reactivation of post-DL Assemblage normal faults (e.g. Fig. 57; Transect A, Line Shell 224), whereas the Tweed Lake Assemblage elsewhere was offset, as discussed earlier (Fig. 22, Transect G).

Imperial Anticline, Peel Plateau

Lithology and correlation of M/S Assemblage in the southern Peel area west of Norman Wells and adjacent to Mackenzie Mountains are constrained by the Sammons H-55 well, drilled on the crest of Imperial Anticline (Fig. 58). The uppermost Proterozoic strata in H-55 are reliably correlated with the outcropping Tsezotene Formation of the Mackenzie Mountains Supergroup in the adjacent Mackenzie Mountains. In order to understand the stratigraphy it is necessary to understand a Laramide bedding-parallel thrust fault. The fault and its implications have been described in detail (Cook and MacLean, 1999) and are only summarized here.

Imperial Anticline, lying between the Mackenzie and Franklin mountains, is a fault-bend fold generated by displacement on an unusual thrust fault for which the lower flat, ramp, and upper flat are each bedding parallel as shown schematically in Figure 56. The gently folded, overall southward-dipping wedge of M/S Assemblage strata is truncated by the (originally subhorizontal) sub-Cambrian unconformity (Fig. 56a). M/S Assemblage beds were parallel to the unconformity in the south and flexed upward to be truncated at 10 to 20° in the north. The geometry of the thrust was dictated by the pre-existing flexure and unconformity configuration (Fig. 56a). The fault remained bedding parallel as it progressed from horizontal Proterozoic beds (the lower flat) to dipping Proterozoic

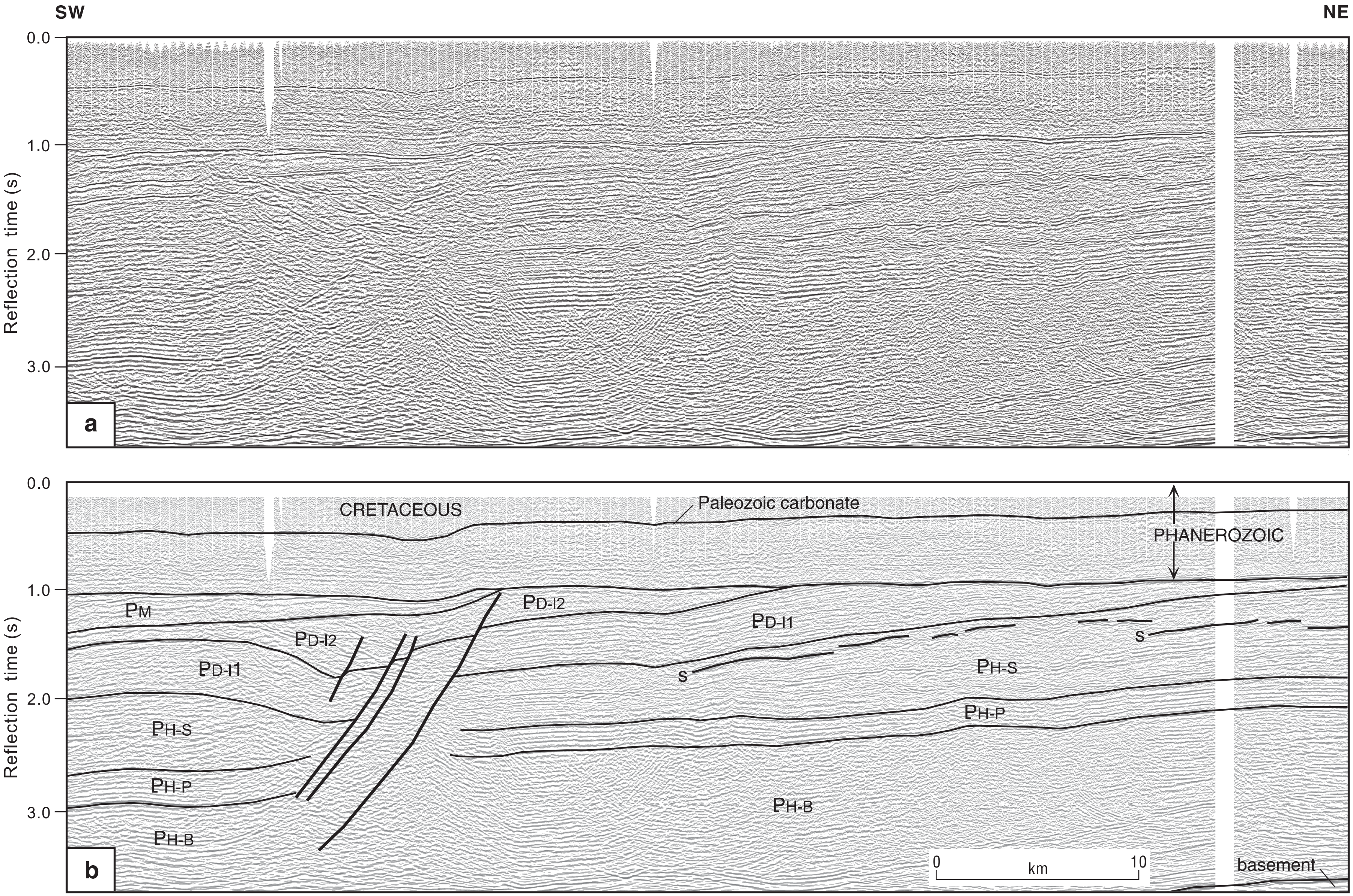

Figure 57. *1972 Pan Canadian Line 4. A wedge of M/S Assemblage strata unconformably truncates the DL Assemblage in a half-graben that resulted from extensional inversion of a Forward Orogeny reverse fault. Post-Cretaceous extensional sag was localized by the Proterozoic fault zone. Vertical exaggeration is approximately 2:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ⱣH-B, *Basinal Unit of HB Assemblage;* ⱣH-P, *Platformal Unit;* ⱣH-S, *Syntectonic Unit; s, intrusive sheet;* ⱣD-I1, *Basal Member of Lower Unit of DL Assemblage;* ⱣD-I2, *Upper Member of Lower Unit;* ⱣM *- M/S Assemblage.*

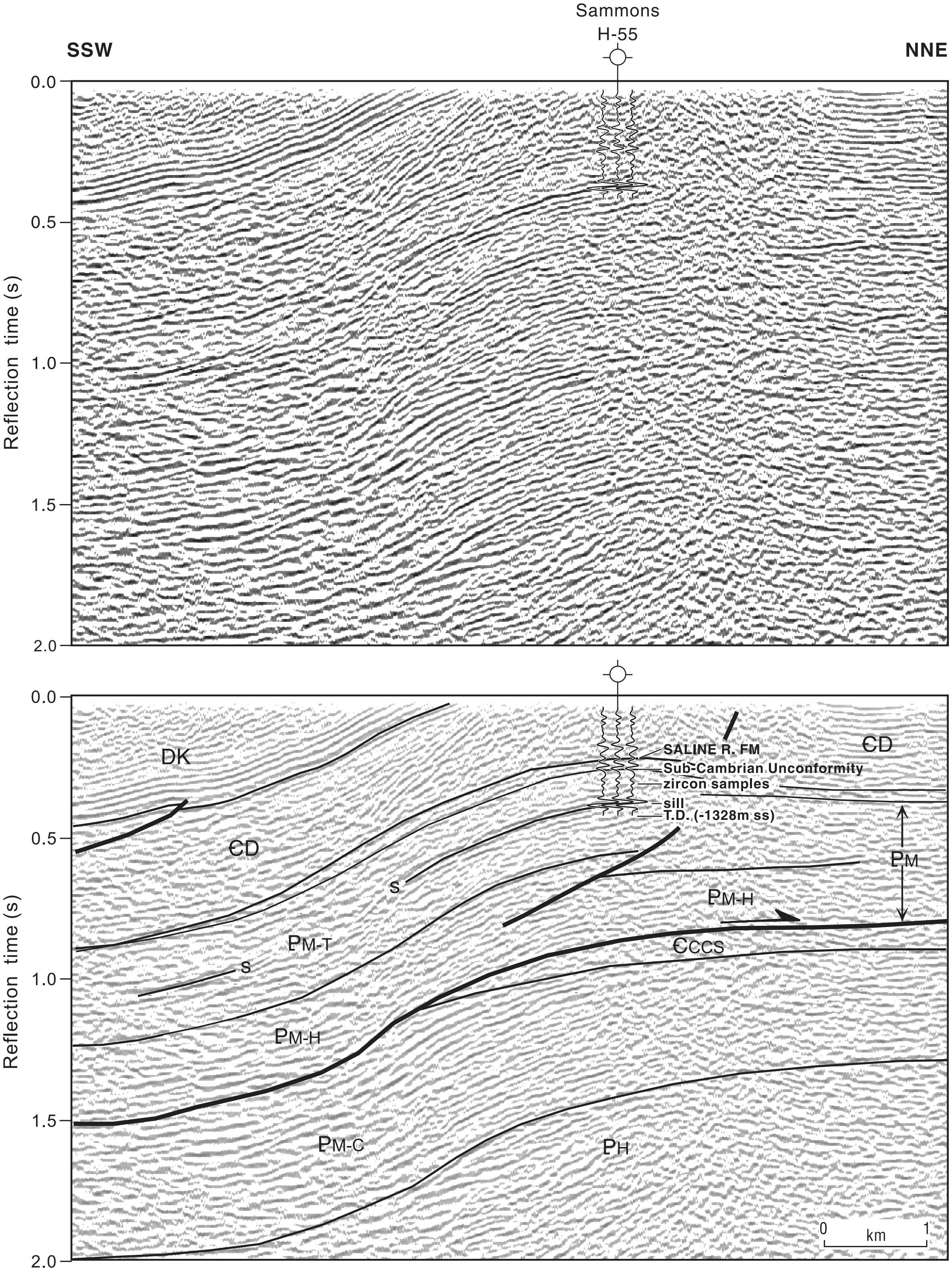

***Figure 58.** 1985 Sigma Explorations Line 6A overlain with synthetic seismic traces generated from the Sammons H-55 sonic log. See text for discussion. Vertical exaggeration is approximately 1:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* ᏢH, *HB Assemblage undivided;* ᏢM-C, *lower part of Mackenzie Mountains Supergroup (Hematite Creek Group);* ᏢM-H, *H1 dolomite;* ᏢM-T, *Tsezotene Fm;* ᏢM, *Mackenzie Mountains Supergroup undivided*; *s, sill;* ЄCCS, *Lower and Middle Cambrian undivided;* ЄD, *Cambrian to Devonian carbonates;* DK, *Devonian and Cretaceous clastic deposits (includes Middle Devonian limestone).*

beds (the ramp) to intersect the sub-Cambrian unconformity. At that point it crossed a few metres of basal Cambrian siliciclastic strata and was diverted into flat-lying Saline River Formation salt (the upper flat). The fault-bend fold (Imperial Anticline) was caused by the forward displacement of the wedge of Proterozoic strata across this deflection zone (Fig. 56b). The sub-Cambrian unconformity and a few metres of basal Cambrian beds in the footwall of the overthrust are imaged on a number of lines (Cook and MacLean, 1999), two of which are reproduced here (Fig. 54, 55).

A single well (Petro-Canada Inc. Sammons H-55), drilled on Imperial Anticline (Fig. 58), passed through Cambrian Saline River Formation shale into a 407 m thick sequence of Proterozoic siltstone and shale with interbeds of quartzitic sandstone and dolomite. Wissner (1986) assigned the interval to the Tsezotene Formation and that correlation is supported by the presence of a mafic igneous sill (Canadian Stratigraphic Services Ltd., 1988) because, in the closely adjacent Mackenzie Mountains, sills are observed only in the Tsezotene Formation. A solid tie can be made between a high velocity (>6000 m/s) sill logged in the well and a bright seismic reflection (Fig. 58). Rainbird et al. (1996b) considered the uppermost part of the drilled interval to be Katherine Group on the basis of quartz arenite lithology and an assemblage of 'Grenville' age (ca. 1,000 Ma) detrital zircons obtained from drill core. Recent work, however, (Villeneuve et al., 1998) indicates that 'Grenville' age detrital zircons are a correlation indicator for Mackenzie Mountains Supergroup in general, but are not reliable as an indicator specifically of the Katherine Group. Considering that the quartz arenite core, from which the zircons were extracted, is only 3 m thick, and considering that no formational break is obvious on the seismic record, we follow Wissner and assign the entire drilled Proterozoic interval to the Tsezotene Formation.

Aitken et al. (1982) reported a thickness of greater than 749 m for the Tsezotene in the adjacent Mackenzie Mountains. Applying an average velocity of 5000 m/s for Proterozoic beds, as derived from the Sammons H-55 velocity log (see Appendix C), a 750 m interval of Tsezotene would be expected to be 0.3 s thick. The H1 dolomite/Tsezotene contact is not particularly reflective in Figure 58 so we place it at a weak marker about 0.3 s down from the sub-Cambrian unconformity. Unit H1 and the Katherine Group are much more readily interpreted in Figure 55. There, we consider that H1 is represented by a distinctive set of reflections in the hanging wall of the thrust and that the base of the Katherine Group is imaged as a single sharp reflection truncated by the sub-Cambrian unconformity on the left side of the figure. In this interpretation the intervening sill-bearing Tsezotene is the predicted 0.3 s thick. All of these considerations lead to the conclusion that the important glide zone must occur under (or possibly within) the H1 dolomite.

The interval underlying the detachment thickens southward, so measured thicknesses vary depending on what part of the regional wedge is imaged on a given seismic line. For example in Figure 54 the maximum sub-thrust interval is 0.92 s (2.3 km) whereas the maximum thickness recorded in Figure 55 is 0.6 s (1.5 km). If our formational picks are approximately correct, then at least 2.3 km underlying the detachment are older than H1, the oldest exposed unit in the Mackenzie Mountains. These sub-detachment layers no doubt correlate, at least in part, with the Hematite Creek Group reported by Thorkelson (2000) in the Wernecke Mountains, 300 km to the west-southwest. Both sections are basal to the MMS succession and both are apparently older than the H1 dolomite unit. The Hematite Creek Group comprises a diverse succession of shallow-water carbonate and clastic rocks up to 1050 m thick (Thorkelson, 2000). Thorkelson's description of the group may be summarized as consisting of intercalated shale, dolomite, siltstone and quartz arenite. Dolomite constitutes about 50% of the lower succession whereas quartz arenite becomes increasingly important upward, occurring as layers up to 200 m thick near the top, where it predominates. The bold reflection about 0.5 s (1.25 km) above the base of the seismic section at Imperial Anticline (Fig. 54) section might be attributed to the same or a similar thick quartz arenite layer, and the 1050 m thick Hematite Creek could correlate with the lowermost unit on the seismic section. That suggestion is admittedly hazardous given the thickness variations documented in that seismic interval.

Cranswick A-22, a well to the west of Sammons H-55 (Fig. 4P), encountered Proterozoic quartz arenite which, with no other control, we assign to the Katherine Group.

Looking to the Shaler Supergroup in the east, the H1 carbonate has been correlated with the Mikkelsen Island Formation on Coppermine Homocline (Rainbird et al., 1996a). The sub-H1 seismic stratigraphy would then correlate with sub-Mikkelsen sandstone, shale, and siltstone of the Escape Rapids Formation on Coppermine Homocline and Minto uplift.

Mackenzie-Great Bear area (south to latitude 63°)

No well penetrates the M/S Assemblage strata in the large syncline that extends more or less up the Mackenzie River valley from near Tulita to at least latitude 63° (Fig. 52P, 53P). Data quality has precluded subdivision of the interval even though the great thickness of M/S Assemblage preserved (2.1 sec, 5.6 km at 5300 m/s) may represent the entire Mackenzie Mountains Supergroup as known from surface studies in the Cordillera. The syncline extends southward to Cap Mountain (Fig. 52P, 53P) where strata in the syncline are calibrated as M/S Assemblage by an outcropping Proterozoic section in the hanging wall of Cap Fault.

Douglas and Norris (1974) mapped four Proterozoic map units in Cap Mountain and Aitken et al. (1973) described them in detail. The section, about 1.8 km thick, comprises a generally shallow-water succession of fine-grained siliciclastic rocks with some dolomite in the lower part, and some quartzose sandstone in all units but more abundant in the uppermost. Shallow-water indicators (mudcracks, crosslaminae, and ripple marks) occur in all units, although sedimentary overfolds indicate slope deposits at one level in Unit 3, as do scour and fill and load casts in the upper part of Unit 4 (Lone Land Formation). Aitken et al. (1973) reported a 90 ft. (27.4 m) thick orthoquartzitic sandstone at the base of the Lone Land Formation. Quartzitic sandstone such as this could potentially generate a strong seismic response and might account for the bold reflections seen on seismic records from the area to the west and northwest of Cap Mountain.

The Cap Mountain succession was considered by Aitken and Pugh (1984) to correlate with the Hornby Bay Group on Coppermine Homocline, but can now be reliably placed in the much younger M/S Assemblage because Grenville-age detrital zircons have been extracted from the lowermost two units and Chuaria, a carbonaceous megafossil, has been recovered from the uppermost unit (Villeneuve et al., 1998). Chuaria was previously reported from the Mackenzie Mountains and Shaler supergroups (Hofmann and Rainbird, 1994). The Laramide-age Cap Fault disrupts the synclinal trough (Transect G) but the presence of M/S Assemblage strata east of the fault is confirmed by the presence of the distinctive acanthomorphic acritarch Trachyhystrichosphaera identified by Butterfield from Proterozoic strata in the Blackwater Lake G-52 well (Samuelssen and Butterfield, 2001). Trachyhystrichosphaera occurs worldwide in ca. 1000–700 Ma rocks including the Shaler Supergroup (Butterfield and Rainbird, 1998). Specific formations of the known MMS, exposed in the Mackenzie Mountains, were not recognized by Aitken et al. (1973) in the 1800 m thick Cap Mountain section. Although the base is not exposed, we suggest that the section represents some part of the 2.3 km of seismic stratigraphy recorded at Imperial Anticline.

If the Cap Mountain section correlates with the basal strata at Imperial Anticline it follows that it correlates with the Hematite Creek Group in the Wernecke Mountains. The two outcropping successions are not strikingly similar. The Cap Mountain section is dominantly siliciclastic with some dolomite beds in Unit 1 and with quartzose sandstone becoming more important in Units 3 and 4, whereas the Hematite Creek Group is about 50 % dolomite with siliciclastic interbeds in the lower part, changing upward to dominantly orthoquartzite in the upper part. A common characteristic is that shallow-water indicators, such as mudcracks, ripple marks, and crosslaminae, are common in both successions.

Two outliers in Colville-Anderson area

No well penetrates either of the outliers noted above. As each contains only the basal M/S Assemblage the outliers should correlate in a general way with the Escape Rapids Formation (sandstone, shale, and siltstone) on Coppermine Homocline, the Hematite Creek Group (dolomite, shale, siltstone, and sandstone) in Wernecke Mountains (Fig. 2), and the Cap Mountain section (shale, siltstone, dolomite, sandstone).

Structure and tectonics related to the M/S Assemblage

The Mackenzie and Shaler supergroups, with their strong lithostratigraphic correspondence, represent remarkable stability across northwestern Canada. Some authors (e.g. Jefferson and Young, 1989; Rainbird, et al., 1996a) have considered that a continental promontory (Great Bear Arch) in the Colville-Anderson area separated Amundsen Basin from Mackenzie Basin. However the presence of two outliers, considered here to represent correlatives of the Mackenzie and Shaler supergroups, implies that the succession was deposited across the intervening area, even though it is mostly missing today as a result of post-MMS pre-Cambrian erosion. The time available for erosional stripping was about 235 million years (from 779 Ma to 544 Ma), the same period available for deposition of the Windermere rift sequence.

The M/S Assemblage, and Mackenzie Mountains and Shaler supergroups have been deformed by Precambrian long-wavelength folds with half-wavelengths ranging from 35 to 80 km and amplitudes up to 5 km. In the Mackenzie Mountains Williams (1986) identified a broad northwest-southeast-trending Precambrian fold on published surface maps. In the subsurface, the north- to northwest-trending syncline in the southern part of the study area (Fig. 4P, 52P, 53P), has a half-wavelength of about 60 km and an amplitude of about 5 km. Stratigraphic thickness changes in the lower part of the succession suggest that deposition was at least in part syntectonic. In Brock Inlier in the northeast part of the map area (Fig. 4P) outcropping Shaler Supergroup strata are deformed into a northwest-trending anticline-syncline pair (Okulitch, 2000) with a half-wavelength of about 35 km. The largest known fold affecting strata of this age is mapped in Minto Uplift on Victoria Island (Christie et al., 1963; Okulitch, 2000). There, the Holman Island Syncline has a half-wavelength of about 80 km and trends northeasterly, in sharp contrast to the generally northwesterly trend of the other noted structures.

We suggest that intracontinental buckling at the scale observed is probably due to crustal extension rather than compression. The syntectonic deposition, noted in at least the lower parts of the succession, also suggests that the deformation was a result of synclinal sag rather than anticlinal uplift. The contrasting trends of Holman Syncline on Victoria Island and the folds in Brock Inlier are perhaps more easily explained as being the result of local extension rather than compression. Evidence is meager, however, for normal faults accompanying these 'extensional' folds. A family of small Precambrian normal faults, offsetting the M/S Assemblage, is recorded in the southern part of the area (Transect J, Line PCR 56X). Elsewhere, normal faults that cut the M/S Assemblage also offset Cambrian strata.

Intrusive sheets into M/S Assemblage

Diabase sheets intrude both the Shaler Supergroup (Franklin diabases) and the Mackenzie Mountains Supergroup (Tsezotene sills). The Sammons H-55 well confirmed the presence of sills within M/S Assemblage strata under Imperial Anticline. It follows that M/S Assemblage strata elsewhere probably also contain intrusive sheets. Strong reflections in the large syncline underlying the Mackenzie River valley (Transect F) are candidates but the great lateral extent of individual markers suggests that they are unlikely representatives of sills. The intrusive sheet, discussed earlier (Fig. 47), that intrudes DL Assemblage in the Colville Hills area is a potential candidate. It postdates long-wavelength folding of the Tweed Lake basalts, but its age relative to folding of the M/S Assemblage is not known. If it were a Tsezotene or Franklin sill its emplacement into much older strata would suggest that the M/S Assemblage had been mostly removed from the Colville-Anderson area before sill emplacement.

PROTEROZOIC INFLUENCE ON PHANEROZOIC GEOLOGY

Overview

The Proterozoic structural and stratigraphic framework influenced Paleozoic and Mesozoic depositional and deformational events in a variety of ways. Discussed under separate headings below are: Lower and Middle Cambrian paleotopography and depositional basins, in part influenced by Precambrian structure; Laramide transpressional (?) anticlines and faulted anticlines in the Colville Hills, in part localized by reactivation of polyphase Proterozoic basement-block faults; and little-known, but widespread, Phanerozoic shallow grabens and half-grabens, largely localized by reactivation of large post-DL Assemblage and/or post-Tweed Lake Assemblage half-grabens.

A fourth example of Proterozoic influence is Imperial Anticline, a fault-bend fold west of Norman Wells, the geometry of which was dictated by Precambrian structural geometry. The anticline and its Proterozoic controls were discussed under the heading 'Imperial Anticline Area' and will not be revisited here.

Early–Middle Cambrian basin framework

The depositional limits of the Lower Cambrian Mount Clark, Middle Cambrian Mount Cap, and Upper (?) Cambrian Saline River formations define a Cambrian intracratonic basin bounded on the west by Mackenzie Arch, a northwest-trending paleotopographic high (Fig. 59). The eastern flank of the arch is outlined by the zero-edge of the Lower–Middle Cambrian Mount Clark and Mount Cap formations. The arch is documented in outcrop in the northern Mackenzie Mountains (Aitken et al., 1973; Aitken and Cook, 1974), and in exploration wells beneath Peel Plateau and Plain (Dixon and Stasiuk, 1998). As it plunges northward from the Mackenzie Mountains into the Peel area it crosses the M/S Assemblage zero edge into a region characterized mainly by HB Assemblage strata and Forward Orogeny structures. Thus Mackenzie Arch crosses, at a high angle, earlier stratigraphic and structural trends and prominent aeromagnetic trends, and appears not to have been controlled by any ancestral Proterozoic feature.

In contrast, the southern part of the Lower–Middle Cambrian basin is broken into Mackenzie Trough, and Mahony/Bulmer Arch, which appear to have been strongly influenced by antecedent structure (Transect M). Mackenzie Trough is a locus of thick Cambrian siliciclastic and evaporitic accumulation, the axis of which closely corresponds to the axis of the broad syncline of M/S Assemblage (Fig. 4P, Fig. 52P). Mahony/Bulmer Arch comprises the eastern flank of Mackenzie Trough and corresponds approximately with the zero-edge of M/S Assemblage on the eastern flank of the Proterozoic syncline. The M/S Assemblage syncline and Mackenzie Trough are early elements of the Keele Tectonic Zone (KTZ), which was a tectonically active zone of intermittent subsidence and uplift throughout the Phanerozoic (MacLean, 1999; MacLean and Cook, 1999).

On a much smaller scale, Precambrian topography has locally controlled deposition of quartzose sandstone of the basal Cambrian Mount Clark Formation (Old Fort Island Formation in the southeastern part of the report area). Topographic control is best documented along the eastern edge of Paleozoic exposures south of Great Bear Lake. Balkwill (1971) mapped and described the Cambrian Old Fort Island Formation as occurring discontinuously in paleodepressions between knobs and ridges in the

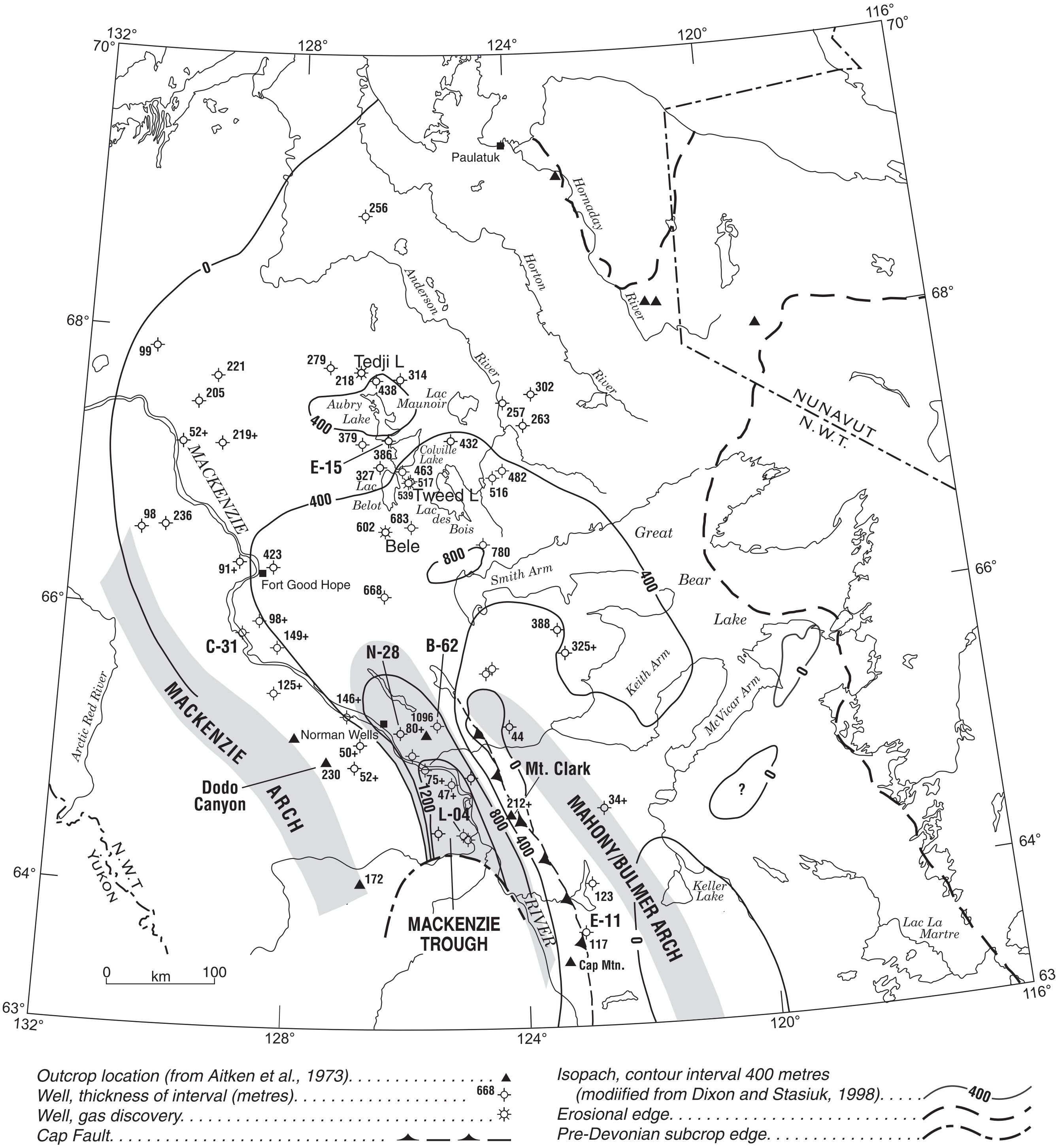

Figure 59. *Cambrian tectonic elements and isopach map of Mount Clark to Saline River interval.*

Precambrian erosional surface. A subsurface example (Fig. 60) shows unidentified basal Cambrian beds infilling Precambrian topography in an area east of the McConnell Range.

Colville Hills

Phanerozoic structures northwest of Great Bear Lake comprise surface anticlines and faulted anticlines of the Colville Hills (Cook and Aitken, 1971), and subsurface anticlines and synclines farther to the north under Anderson

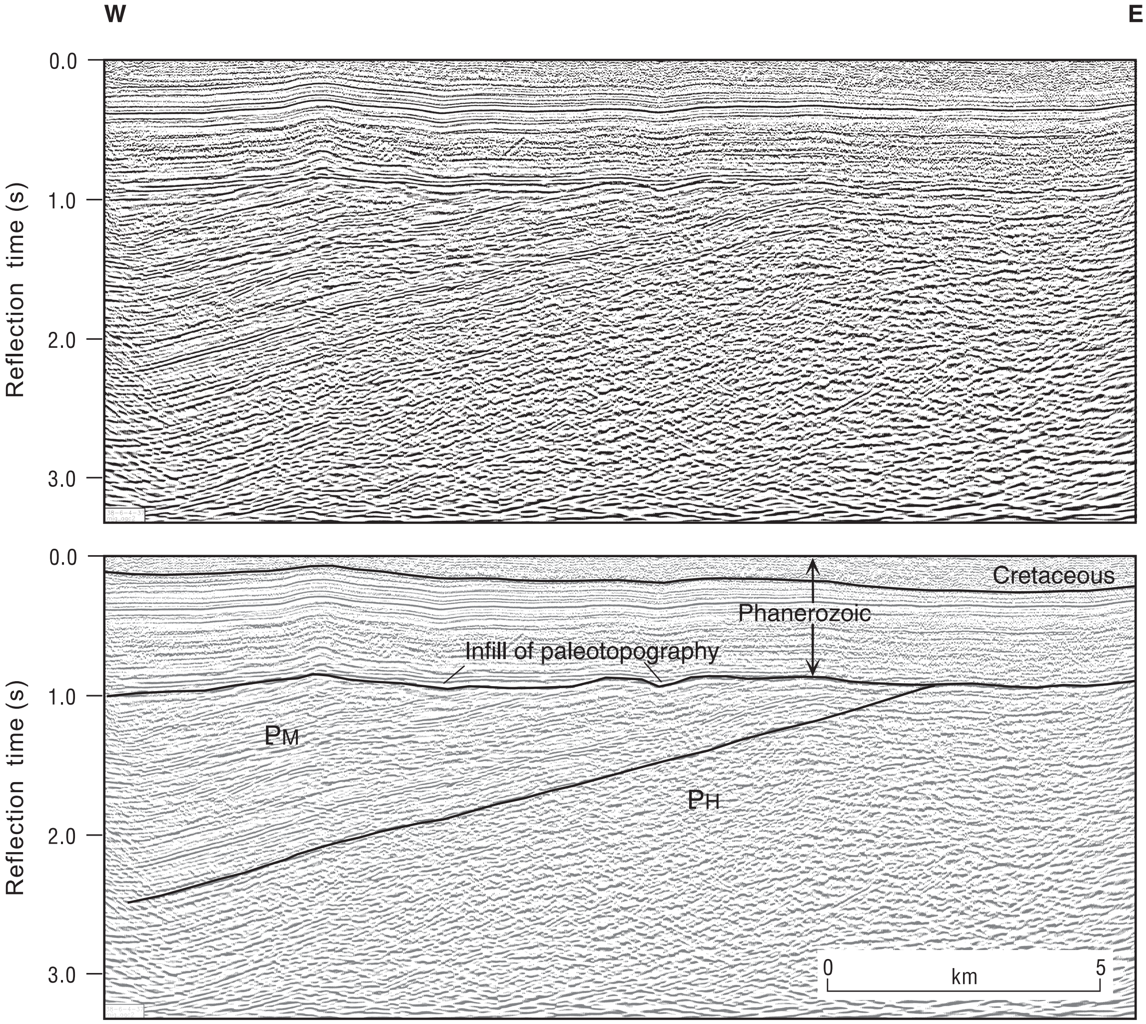

Figure 60. *1973 Hudsons' Bay Oil and Gas Line 4. Thickness variations in basal Phanerozoic (Cambrian) strata are attributed to paleotopographic fill. Vertical exaggeration approximately 2:1 at a seismic velocity of 5500 m/s. See Figure 1P for location.* PH, *HB Assemblage;* PM, *M/S Assemblage.*

Plain (MacLean and Cook, 1992). The structures are sinuous and trend northerly, with two notable exceptions, Colville Ridge and the subsurface Sadene Anticline (Fig. 61). Northwest-trending Phanerozoic faults in Brock Inlier may belong to the 'Colville Hills' family of structures. Also Cap Fault, underlying the McConnell Range, 200 km to the south, has affinities with Colville Hills structures.

The timing of development of the Colville Hills faulted anticlines is not well constrained. Their development is generally assumed to be related to the Laramide (Late Cretaceous–Early Tertiary) tectonism that formed the Mackenzie and Franklin mountains. In fact, their age is known no more precisely than that they postdate the tilted Early Cretaceous (Aptian–Albian) sandstone found on the flanks of some Colville Hills structures. The Colville Hills were considered by Cook and Aitken (1971) to be linked to the Laramide northern Franklin Mountains via a detachment in evaporitic strata of the Cambrian Saline River Formation. Subsequent studies (Davis and Willott, 1978; MacLean and Cook, 1992) negated that notion by showing that Proterozoic rocks are involved in the structures. Furthermore, there is no apparent detachment linking Colville Hills and Franklin Mountains at any level within the depth of seismic observation (Transects C, E). Some Colville Hills structures were clearly localized by reactivation of pre-existing Proterozoic structures, whereas Proterozoic antecedents are obscure for others, and not apparent at all for the subsurface northern population (Fig. 61). Indeed, the northern family of Phanerozoic structures, with the exception of Sadene Anticline, occurs at a high angle to underlying Proterozoic faults.

Examples of obvious Proterozoic fault control include Belot Ridge (Fig. 20) and the gas-bearing Tweed Lake

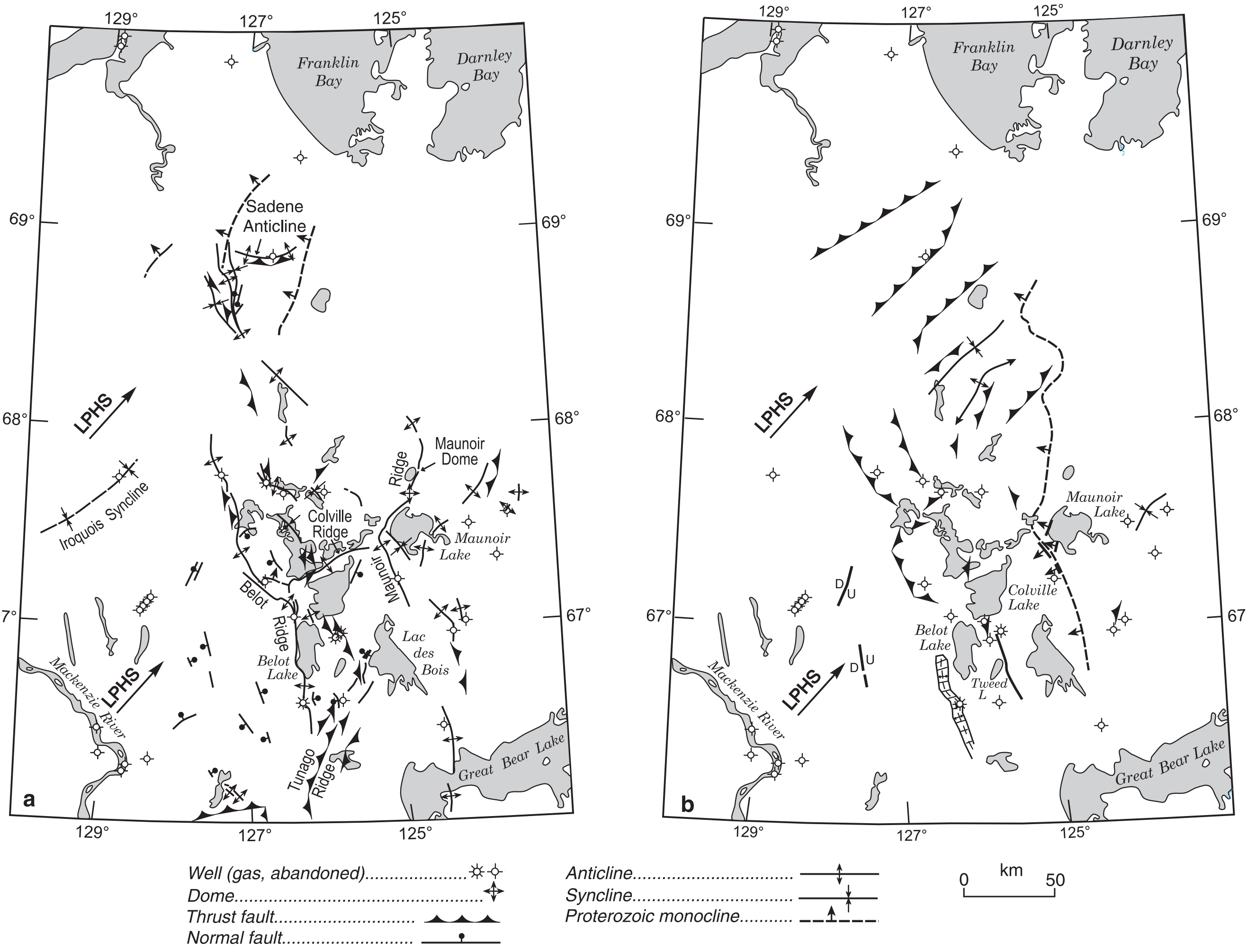

Figure 61. *A comparison of Phanerozoic structural trends with Proterozoic trends in the Colville Hills region.* ***a.*** *Major Phanerozoic trends (compare with Fig. 61b).* ***b.*** *Proterozoic trends. Belot Ridge and, to a lesser degree, Maunoir Ridge overlie ancestral features. LPHS, Laramide Principal Horizontal Stress (after MacLean and Cook, 1992).*

Anticline (Fig. 22). In both cases the structural history includes Forward Orogeny compressive deformation, post-DL Assemblage extensional inversion, and post- or syn-Cretaceous compressional (or transpressional) inversion (Cook and MacLean, 1996a). If the Proterozoic faults had been directly reactivated as thrusts, the Phanerozoic structures would have broad wavelengths on the same scale as the older structures, which is clearly not the case (e.g., Fig. 20). Accordingly, we suggest that these relatively small, thrust-faulted anticlines represent upper-level adjustments in response to ‘Laramide’ transpressional reactivation of the earlier faults.

The relationship between Proterozoic structure and the Phanerozoic Maunoir Ridge, one of the largest Colville Hills anticlines, is more tenuous. An ancestral Proterozoic fault is weakly expressed on equivocal seismic (MacLean and Cook, 1992; their Fig. 9), and the ridge follows a prominent homoclinal panel of HB Assemblage strata. A cross-sectional view of the homoclinal panel can be seen in Transect E (Line Unocal W7) and the mapped trace is illustrated in Figure 61.

We consider the compressive stress vector applied to the continental crust under Colville Hills during the Cordilleran Laramide Orogeny to have been directed generally northeast (Fig. 61), more or less orthogonal to the Mackenzie Mountains arc. Present-day in-situ (residual?) stresses (Gough et al., 1983; Zoback et al., 1991) support this suggestion. Given a northeast-southwest stress vector, the north-northwest-south-southeast-trending Proterozoic faults would have been favourably oriented for right-lateral shear (Fig. 61b) and preferentially reactivated. The strike-slip reactivation proposed here is supported by the presence, in Mackenzie Mountains, of north-northwest-striking Precambrian faults that were reactivated with right-lateral strike-slip due to northeastward-directed Laramide compression (Aitken and Cook, 1974). It is noteworthy that all Phanerozoic structures, except Sadene Anticline and Colville Ridge, have orientations favourable for right-lateral displacement under northeast-southwest compression, and right-lateral effects are implied by en echelon patterns at the north end of Belot Ridge (Aitken and Cook, 1970). Moreover, Maunoir Dome occurs at a kink in an otherwise north-northeast-trending set of ridges that comprise a northeast extension of Maunoir Ridge. If there were dextral displacements along that ridge-set the kink would be a compressive zone and the dome a predictable structural culmination.

In the Colville Hills area MacLean and Cook (1992) attributed a few northeast-striking normal faults to extension perpendicular to the compression vector, compatible with the proposed right-lateral shear system. Although that analysis may be valid for some faults, they may, instead, pertain to a post-Cretaceous extensional event discussed in the following section.

'Colville Hills' faults in Brock Inlier

In Brock Inlier in the northeast part of the report area a set of steeply dipping faults, trending north-northwest, offset Proterozoic and Paleozoic strata (Cook and Aitken, 1969; Jones et al., 1992) (Fig. 4P). One, in the Bluenose Lake area, offsets Ordovician Franklin Mountain Formation strata and the faults can be dated no more precisely than post-Ordovician. However, the north-northwest trend and the fact that they root in Proterozoic strata suggest that they are part of the post-Lower Cretaceous 'Colville Hills' family.

McConnell Range as a 'Colville Hills' structure

The McConnell Range, in the south-central part of the report area, is geomorphologically a Franklin Mountains range, but in terms of tectonic affinity it could be considered a 'Colville Hills' structure. Like the Colville structures it is underlain by a steeply dipping compressional fault, the Cap Fault, rooted in Proterozoic strata (Transect G). Also like the Colville structures, there is no apparent detachment within the depth of seismic observation linking it to the adjacent Mackenzie Mountains. Evidence for a dextral strike-slip component of displacement provides a third element of comparison. A component of strike-slip is indicated by structural culminations at Cap Mountain and Mount Clark. Cap Mountain is situated at a deflection in the range that would be a restraining bend given a dextral strike-slip component (Fig. 62). The asymmetrical Cap Mountain with its thick section of Proterozoic strata is underlain by a fault that trends north and curves abruptly to the west at the north end of the mountain. We suggest that the longitudinally asymmetrical structure can be attributed to a component of dextral displacement on that curved fault. Mount Clark, a doubly plunging anticline (Cook and Aitken, 1977), is less convincingly due to dextral displacements, but it too occurs at an apparent restraining bend in Cap Fault. Other evidence for a dextral component of displacement is found in right-lateral en echelon folds mapped by Douglas (1974) and Douglas and Norris (1974) on the west side of the McConnell Range (Fig. 62). Right-lateral en echelon folds are also mapped by Douglas and Norris (1974) at the north end of Willow Ridge Anticline, a small structure to the east of the southern part of McConnell Range (Fig. 62).

The similarities between McConnell Range and Colville Hills structures suggest that McConnell was probably localized by an underlying Forward Orogeny fault. Such a fault would be parallel to, but much longer than the Forward Orogeny component interpreted for the Blackwater Lake fault to the east, and much longer and straighter than any Forward Orogeny fault documented in the Colville Hills. The hypothesis that McConnell Range and Cap Fault are due to reactivation of an ancestral Forward Orogeny fault cannot be tested with available seismic data.

Colville Hills discussion

A widespread family of northerly trending structures extends from McConnell Range in the south, through the Colville Hills to Brock Inlier in the northeast. Certain members of the family were localized by rejuvenation of ancestral Proterozoic Forward Orogeny faults. Rejuvenation could be related to the Late Cretaceous–Tertiary (Laramide) deformation of the Cordillera, but the age cannot be established any more precisely than post-Lower Cretaceous, nor can a detachment connection to the Cordillera be demonstrated. Subsurface Phanerozoic structures in the Anderson Plains area north of the Colville Hills (Fig. 61a) are problematical because most strike at a high angle to documented Proterozoic faults, and therefore cannot be attributed to reactivation of known Proterozoic faults. Nor do they appear to be detached above any shallow décollement surface. A possible rationalization of these structures is that they may be due to 'Laramide' vertical or near vertical strike-slip faults which, having little or no dip-slip offsets, would be essentially invisible to reflection seismic methods.

Three Colville Hills structures are gas-bearing reservoirs, the gas being trapped in porous Lower Cambrian sandstone of the Mount Clark Formation (Meding, 1994).

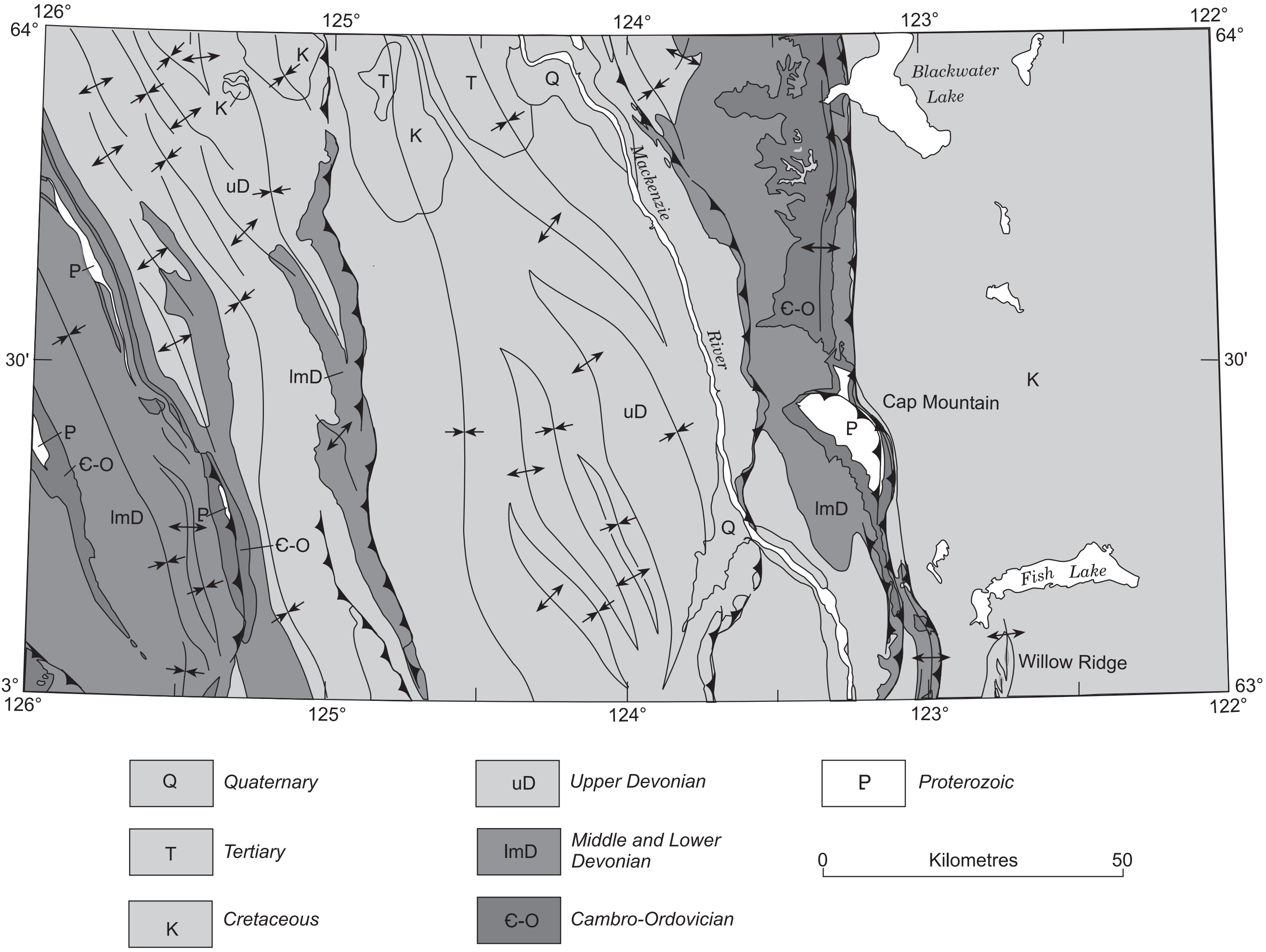

Figure 62. *En-echelon folds in the Mackenzie River valley as evidence of right-lateral strain. From Douglas (1974) and Douglas and Norris (1974).*

Extensional faults

Extension, expressed by the presence of half grabens, grabens, and monoclinal flexures of various Phanerozoic ages, is recorded on a number of seismic lines and is more common than is generally recognized in the published literature. Some normal faults may be a local consequence of right-lateral transpression along Colville Hills structures (MacLean and Cook, 1992). Most, however, have no obvious connection to Laramide features, have orientations incompatible with the inferred Colville Hills transpressional system, and are probably simply manifestations of basin subsidence. Although important to our understanding of the tectonics of the region, Phanerozoic extensional features have not been analyzed in detail as part of this study. They are discussed here because many resulted from reactivation of Proterozoic faults. We restrict our comments here to structures that can be seen on our regional transects. The distribution of extensional faults known to involve Phanerozoic strata is shown in Figure 63P.

The oldest Phanerozoic faults noted are Early–Middle Cambrian. On the basis of normal faults of that age, seen elsewhere, we interpret a set of down-to-basin faults on the west flank of the Cambrian Mackenzie Trough (Transect M). In the northwestern region of the report area a multi-phase normal fault is imaged on Transect A (Line Shell 224). Strata assigned to the DL Assemblage thicken abruptly eastward into a pre-M/S Assemblage half-graben. Later reactivation offset M/S to Devonian strata whereas Cretaceous strata remain unfaulted, indicating that extension occurred post-Devonian but pre-Cretaceous. Weakly developed, east-dipping antithetic faults form the west side of an asymmetrical graben.

Perhaps the best-defined Phanerozoic extension was a reactivation of Blackwater Fault south of Great Bear Lake. Transect K records a large graben bounded by Blackwater Fault on the east and a conjugate east-side-down fault on the west, and a number of related monoclinal flexures. Transect G shows Paleozoic strata downdropped to the west across Blackwater Fault and an anticline-sycline pair immediately above the fault. We suggest that the fold pair is a result of later (Laramide?) transpression.

TECTONIC AND CORRELATION SUMMARY

Tectonic and structural discussion and correlation arguments, presented earlier for each stratigraphic unit, are summarized here to provide a more continuous overview of the tectonic, stratigraphic, and intrusive history, and to recapitulate the overall rationale for correlating seismic with surface units. Our conclusions are drawn from various lines of evidence. For more detailed data and arguments on which the conclusions were based we refer the reader to the pertinent preceding sections.

Despite having few well penetrations and no seismic ties to outcropping Proterozoic rocks, a variety of stratigraphic, structural, chemical, and geochronological considerations were brought to bear on our correlation rationale. Five, unconformity-bounded, subsurface sequences are correlated with sequences exposed on Coppermine Homocline to the east and in the Cordillera to the west (Fig. 2, 3). The five subsurface sequences are nowhere seen in a single seismic section, and since entire sequences have locally been removed by erosion it is not always clear, in the absence of other considerations, which sequences are present at a given locale. However, the subsurface sequences were subjected to deformational and epeirogenic events, which to a remarkable degree are paralleled by events recorded in geological reports and maps of Coppermine Homocline and to a lesser degree of the Cordillera. The parallelism of tectonic and stratigraphic histories provides the principle evidence for our largely uncalibrated correlation scheme. Available chemical analyses of basalts, geochronology of detrital zircons, and limited biochronology support the rationale.

Late Wopmay Orogeny transcurrent faults

The first tectonic event with relevance to this study is a terminal, compressional, Wopmay Orogeny episode during which the Wopmay Orogen was segmented by a remarkable set of northeast- and northwest-trending transcurrent faults that postdate the youngest-dated (1.84 Ga) Great Bear Pluton (Hoffman and Bowring, 1984). The peneplaned Wopmay Orogen forms the basement of the Coppermine Homocline succession. The transcurrent faults are significant to this study because some of them were reactivated during younger deformations on Coppermine Homocline, and we suggest that parallel-trending faults in the subsurface to the west (Fig. 27P, 32P, 33P) were also a result of reactivation of members of this fault set. If so the conjugate transverse faults lie under a much broader region than had been previously appreciated, and the compressive deformation that caused them affected the Hottah Terrane in addition to the Wopmay Orogen, or alternatively the Wopmay Orogen extends much farther to the northwest than previously thought.

HB Assemblage and Hornby Bay Group

Peneplaning of the Hottah and Wopmay basements was followed by deposition of the HB Assemblage and the correlative Hornby Bay Group. Four assemblage subdivisions and an internal unconformity have potential counterparts in the Hornby Bay Group on the homocline. We correlate the discontinuous basal Lower Unit of the HB Assemblage with fluviatile sandstone and conglomerate of the discontinuous Bigbear and Fault River formations of the Hornby Bay Group. Each is truncated by a regional unconformity and together comprise our lowermost sequence. In the subsurface the unconformity occurs at the base of our Basinal Unit (which overlies either basement or the truncated Lower Unit), and on the homocline the unconformity occurs at the base of the deltaic Lady Nye Formation (which overlies either Wopmay basement or Fault River/Bigbear formations).

Wernecke Supergroup, and Fault River and Bigbear formations

The intra-group, intra-assemblage unconformity is significant. We suggest that the subsurface Lower Unit and the surface Bigbear and Fault River formations, combined, comprise a separate depositional sequence unrelated to the Hornby Bay Group proper, a conclusion that has important implications for correlating the Wernecke Supergroup in the Cordillera. The age of this newly considered sequence is constrained by 1663 Ma Narakay volcanics in the Hornby Bay section above and 1.84 Ga Wopmay basement below, and potentially corresponds with the >1.71 Ga age of the Wernecke Supergroup. Although possibly the same approximate age, there is presumably no genetic connection between the 13 km thick, continental margin Wernecke succession and the intra-continental fluvial deposits of the Bigbear and Fault River formations. There is, of course, no older-limit constraint on the age of the Wernecke Supergroup and it could be entirely older than any of the post-Wopmay strata of Coppermine Homocline or of our subsurface units.

Post-unconformity tripartite sequences

Above the unconformity, in the subsurface, three HB Assemblage seismic stratigraphic units, the Basinal, Platformal, and Syntectonic units, have counterparts in the Hornby Bay Group. They are the deltaic Lady Nye Formation, the platformal East River Formation, and the syntectonic Kaertok and LeRoux formations (Fig. 2, 3). The onset of continental subsidence and marine encroachment is marked by deposition of the deeper-water Basinal Unit and the deltaic Lady Nye formation. In the subsurface, subsidence was accompanied locally by the development of syndepositional normal faults, which have no obvious counterparts on Coppermine Homocline. Basin filling and the accumulation of up to 6 km of basinal sediments was followed by deposition of the remarkably persistent and seismically consistent dolomitic Platformal Unit, which we correlate with platformal carbonate of the East River Formation on the homocline. Both of these platformal units bear the sedimentary record of an initial pulse of the Forward Orogeny, a Wyoming-style, intra-continental, basement-block-uplift orogeny. Erosion of uplifted blocks and simultaneous deposition resulted in accumulation, in the subsurface, of the Syntectonic Unit, which we correlate with the syntectonic Kaertok and LeRoux formations on the homocline. The orogeny proceeded in two main phases, with the early phase punctuated by multiple pulses. The syntectonic Kaertok Formation contains the 1663 Ma Narakay volcanic complex (Bowring and Ross, 1985). Dating the Kaertok also dates an early pulse of the orogeny.

In the Wernecke Mountains the Racklan Orogeny postdated deposition of the Wernecke Supergroup and preceded 1595 Ma Wernecke brecciation, and is thus potentially related to the ca. 1663 Ma Forward Orogeny. Conversely the Racklan could be much older because its timing relative to the 1.71 Ga Bonnet Plume River Intrusions is uncertain (Thorkelson et al., 2001).

As noted above, the Wernecke Supergroup in the Cordillera may correlate with the subsurface Lower Unit and the surface Bigbear and Fault River formations. With that exception, the HB Assemblage and Hornby Bay Group have no other apparent correlatives in the northern Cordillera.

The HB Assemblage is cut by discordant reflections interpreted as intrusive sheets that probably correlate with the Western Channel Diabase sheets intruded into Hornby Bay Group and Wopmay basement on the homocline. The sheets postdate the Forward Orogeny in both subsurface and surface. The Western Channel sheets have been dated as about 1400 Ma (Wanless et al., 1970; Wanless and Loveridge, 1978), a minimum age considering the dating methods.

DL Assemblage and Dismal Lakes Group

Forward Orogeny basement-cored uplifts were peneplaned by continental regional erosion. Renewed continental subsidence saw the sea encroaching from the west and deposition of the subsurface DL Assemblage and the surface Dismal Lakes Group. We previously correlated the DL Assemblage (Cook and MacLean, 1995) with the Dismal Lakes Group as mapped by Ross and Kerans (1989) on Coppermine Homocline (including the LeRoux Formation). We now consider the LeRoux Formation to be syntectonic and have reassigned it to the Hornby Bay Group as originally placed by Baragar and Donaldson, (1970, their map-unit 11; 1973, their map-unit 13). Accordingly, the Fort Confidence Formation is here considered to be the lowermost formation of the Dismal Lakes Group, and we correlate the sub-Fort Confidence unconformity with our seismically defined sub-DL unconformity.

On Coppermine Homocline the Dismal Lakes Group thickens progressively from a near feather-edge in the east to about 1.1 km in the west (Baragar and Donaldson, 1973; Kerans et al., 1981; Ross and Kerans, 1989). In the subsurface the DL Assemblage also thickens westward from an erosional zero-edge to at least 7 km in the central part of the study area. The surface and subsurface strata are separated by a broad, north-trending Precambrian arch (Fig. 4P). Prior to pre-Cambrian erosion the strata would have comprised a single erosional wedge beneath the sub-Coppermine River Group unconformity (Fig. 45). On the homocline the succession is an onlapping sequence with successively younger units forming the basal formation eastward (Baragar and Donaldson, 1973; Ross and Kerans, 1989). A similar depositional pattern is observed in the Lower DL Assemblage, which thins from west to east; the Basal Member probably wedges to zero before reaching the outcrop belt. We correlate the Upper Member of the Lower DL, believed to be a siliciclastic unit, with the siliciclastic Fort Confidence Formation (Fig. 45).

We consider the seismically layered Middle DL Assemblage to comprise a mixed carbonate and clastic succession that we suggest correlates with the platformal succession on the homocline, consisting of the Dease Lake, Kendall River, Sulky, and Greenhorn Lakes formations. That mainly dolomitic succession has a variety of subsidiary mudstones and sandstones (Ross and Kerans, 1989) that might provide a varied seismic response such as that of the Middle DL Assemblage.

The subsurface Upper DL Assemblage appears to have no counterpart on the homocline; equivalent strata are missing, perhaps as a result of nondeposition, but more likely because of regional erosion prior to deposition of the subsequent major sequence, the Coppermine River Group.

An extensional tectonic phase, manifested mainly as negative inversion of Forward Orogeny thrust faults, generated normal fault offsets of Dismal Lakes/DL strata and preceded deposition of Tweed Lake and Coppermine River Group basalts. Extensional reactivation is most apparent on seismic sections (Fig. 20d, 22), but similar effects can be found on geological maps of Coppermine Homocline (Fig. 35). Extension probably postdated DL Assemblage deposition, but the possibility of syntectonic thickening of the Upper DL Assemblage into half-grabens cannot be precluded with the available data.

The parallel histories of compressional uplift, peneplaning, deposition, and negative inversion comprise a compelling element in our rationale for correlating the HB and DL assemblages with the Hornby Bay and Dismal Lakes groups, respectively. The age of the Dismal Lakes/DL package is bracketed by the supposedly 1400 Ma Western Channel Diabase and the overlying 1267 Ma Coppermine basalts.

The DL Assemblage is cut by one enigmatic ‘intrusive sheet’ that might be related to 1267 Ma Dykes of the Mackenzie Dyke Swarm. We suggest that it is more likely related to the much younger (723 Ma) Franklin diabase sheets that intrude the Shaler Supergroup or the (779 Ma) Tsezotene sheets that intrude the Mackenzie Mountains Supergroup.

DL Assemblage and Pinguicula Group

Thorkelson (2000) subdivided the Pinguicula Group in the Wernecke Mountains into a lower package, for which he retained the name Pinguicula, and an upper package, which he named the Hematite Creek Group. He correlated the redefined Pinguicula, comprising Units A, B, and C, with the Dismal Lakes Group on Coppermine Homocline, and accordingly we correlate it with the DL Assemblage (Fig. 45). Unit A comprises a siliciclastic succession of shale and siltstone with basal sandstone and conglomerate and varies in thickness from 600 m to 1400 m. It probably correlates with part or all of our variably thick Lower DL Assemblage (Fig. 45).

Thorkelson’s Unit B comprises laminated limestone and dolomite up to 320 m thick and Unit C comprises thin- to thick-bedded or massive limestone and dolomite up to 1800 m thick. Units B and C, combined, may correlate approximately with the ‘platformal carbonates’ of the Middle DL Assemblage and accordingly with the carbonate succession comprising the Dease Lake, Sulky Lake, and Greenhorn Lakes formations of the Dismal Lakes Group on Coppermine Homocline (Fig. 45). In this rationale, equivalents of the Upper DL Assemblage are missing in the Wernecke Mountains as a result of pre-Hematite Creek Group erosion.

Tweed Lake Assemblage and Coppermine River Group

Deposition and extension of the Dismal Lakes/DL stratigraphic package were followed by regional uplift and erosional truncation prior to deposition of the basalt-bearing Tweed Lake Assemblage in the subsurface, and the Copper Creek Formation (Coppermine basalts) on the homocline. Sevigny et al. (1991) correlated the Tweed Lake basalts with the Coppermine basalts on the basis of chemical similarity, thus providing an important anchor point in correlating from subsurface to surface. Pre-basalt erosional truncation of underlying units is most apparent in the subsurface (e.g., Transect E). On the homocline, more subtle evidence for pre-basalt erosion is found on geological maps of Ross and Kerans (1989) and Baragar and Donaldson (1973), which show local truncation of normal faults and of Dismal Lakes Group formations at the base of the Coppermine basalts (Fig. 36).

Subsurface and surface basalts were offset by normal faults in an extensional phase, commonly manifested as modest reactivation of the earlier post-Dismal Lakes faults (Fig. 22, Transect E, Fig. 36). On the homocline a number of extensional faults offset the Copper Creek Formation (Ross and Kerans, 1989; Baragar and Donaldson, 1973), the most obvious being a conjugate pair, the Herb Dixon and Teshierpi faults, in the vicinity of Teshierpi Mountain. The basalt-bearing sequences in both surface and subsurface are folded into broad, long-wavelength folds the nature of which, whether compressional or extensional, is not understood. On one hand the preserved folds are synclines that could represent extensional sags, and they and the normal faults could be manifestations of one extensional event. Conversely, in the subsurface, anticlinal areas have small-scale thrusts (e.g., Transect E) that imply that the long-wavelength folding was compressional. The basalts are missing from the crests of the anticlines so their age relative to the small faults cannot be determined. On Coppermine Homocline post-basalt compressional effects are expressed as a remarkable chain of en echelon, tight to overturned, north-verging folds north and northeast of Dease Arm of Great Bear Lake (Ross and Kerans, 1989). They affect Dismal Lakes Group formations, and appear to also affect poorly exposed basalt of the Copper Creek Formation. The relationship of those folds to the long-wavelength fold noted above is not known, nor is the age relative to the Shaler Supergroup known. In summary the basalts of both subsurface and surface are affected by both extension and compression. Because the extension appears to have been at least partly syndepositional, we conclude that the compressional phase was younger.

Hildebrand and Baragar (1991) interpreted two compressional phases that affected the Coppermine basalts, an early one that generated easterly trending folds and thrusts, and a later one that caused a northerly trending, long-wavelength fold. We have not recognized the earlier phase in the subsurface.

M/S Assemblage, and Mackenzie Mountains and Shaler supergroups

Young et al. (1979) correlated the Mackenzie Mountains Supergroup in the Cordillera and the (recently defined) Shaler Supergroup in Coppermine Homocline, Victoria Island, and Brock Inlier. That insightful correlation has been largely confirmed by later stratigraphic and analytical studies including the documentation of 'Grenville-age' detrital zircons in both supergroups (Rainbird et al. 1997), the geochronology of diabase intrusions (LeCheminant, 1994; Heaman et al., 1992), and paleontology (Butterfield and Rainbird, 1998; Hoffman and Rainbird, 1994; Samuelson and Butterfield, 2001).

Strata assigned to the M/S Assemblage along the western side of the report area are reliably correlated with the Mackenzie Mountains Supergroup based on 1) proximity to exposed MMS, 2) the presence, in the H-55 well and the Cap Mountain section, of 'Grenville' age detrital zircons, 3) a mafic sill, encountered in the H-55 well, a counterpart of Tsezotene sills outcropping in the adjacent Mackenzies, and 4) a seismic stratigraphy, calibrated in part by the H-55 well, that can be related to the known MMS in Mackenzie Mountains. At least 2.3 km of strata in the lower part of the M/S Assemblage can be reasonably correlated with the Hematite Creek Group in the Wernecke Mountains. Neither the lower 2.3 km nor the Hematite Creek Group outcrops in the Mackenzie Mountains.

M/S Assemblage strata drilled near Darnley Bay, in the northeastern part of the study area, are correlated, by Darnley Bay Resources, with the Escape Rapids, the basal formation of the Shaler Supergroup. Two outliers in the Colville-Anderson and Peel areas assigned to the M/S Assemblage are important because they establish depositional continuity of the MMS and Shaler supergroups across the Colville Hills area.

The Shaler and Mackenzie Mountains supergroups are intruded by diabase dykes and intrusive sheets. Seismic data from the Imperial Anticline area adjacent to the Mackenzie Mountains show a number of bright, bedding-parallel reflections that we interpret as intrusive sheets, an interpretation that is confirmed by intersection in the H-55 well.

The Mackenzie Mountains Supergroup, the M/S Assemblage, and the Shaler Supergroup have all been folded into long-wavelength folds. The mechanics of forming intracratonic broad folds is not understood, but their presence is a final element in support of our correlation scheme.

ECONOMIC POTENTIAL

Economic potential is discussed in three categories: hydrocarbon possibilities in Proterozoic strata; hydrocarbons, actual and possible, in Phanerozoic structures having links to Proterozoic structures; and mineral potential of Proterozoic rocks.

Hydrocarbon possibilities in Proterozoic units

Sedimentary Proterozoic strata under the report area are up to 14 km thick, and enormous structures are present. If suitable conditions exist, large hydrocarbon reservoirs could be present. Because well penetrations are sparse we have little information on the possible presence of porous units and potential source beds. Macauley (1987) reported on the organic geochemistry of 'Cambrian–Proterozoic' sediments in the Colville Hills area. He considered the total organic carbon in Proterozoic rocks to be too low to be of major source interest, and considered thermal maturation to be beyond the oil generation window and greater than that of the overlying Cambrian. Snowdon and Williams (1986) assessed the thermal maturation and petroleum source potential of Cambrian and Proterozoic samples from 17 wells between 60 and 68° North latitude. With very few exceptions Proterozoic samples were found to have total organic carbon contents of less than 0.4 %. They suggest (op. cit., p. 6) that probably the most significant result of their survey is the indication that a 75 m thick Proterozoic shale section in Mobil Belot Hills M-63 contained up to 1.4% organic carbon at a maturity level beyond the oil window but within the gas generation phase. The strata, hard, black, grey or greenish shale, slightly dolomitic, with very fine-grained pyrite, had been considered by Aitken and Pugh (1984) to correlate with Unit P1 of the Shaler Group outcropping on Brock Inlier (Cook and Aitken, 1969). We here consider the interval to fall in the much older (1663 Ma to 1267 Ma) DL Assemblage.

A thick (6 km) sequence of M/S Assemblage, the youngest Proterozoic strata in the report area, occurs along the Mackenzie River valley. In the correlative Mackenzie Mountains Supergroup in the adjacent Cordillera, Aitken (1981) reported giant stromatolitic reefs up to 300 m high, with thick mantles of boulder-sized talus on their flanks, occurring in the 'Basinal assemblage' of the Little Dal Group. Elsewhere in the Basinal assemblage isolated, small, stromatolitic bioherms and extensive biostromes occur. Turner (1999) analyzed the growth dynamics, framework composition, and microstructure of selected Little Dal reefs.

Turner et al. (2000) discussed five stages of reef growth and noted that the Little Dal reefs record a major inflection point in the development of reefal ecosystems and are the earliest known representatives of ‘modern’-style reef growth. We are not aware of any data on either porosities of the carbonate facies, total organic carbon, or hydrocarbon maturity for the encasing deep-water rhythmite lithofacies. In the subsurface in a synclinal trough under Mackenzie River Valley (Transects F, G, and M), the M/S Assemblage attains thicknesses great enough to contain strata equivalent to the Little Dal Group, but we have not identified seismic features that might be considered reefs or carbonate bank edges.

We have interpreted other, much older, carbonate bank and reef features in seismic records of the lowermost unit of the HB Assemblage. They occur at depths of about 2.25 s (6 km). Similar ‘reefs’ could occur at much shallower depths in the eastern part of the study area, untested by seismic exploration. The interpreted age for these strata (between 1.84 Ga and 1.66 Ga) renders them unlikely exploration targets.

In summary, the possibility of economic hydrocarbons in Proterozoic strata underlying the report area is low, but should not be completely discounted. If porous strata and source beds could be found, significant volumes of hydrocarbons could occur in the huge structures that are present. Our current knowledge of hydrocarbon maturity indicates that any hydrocarbon discovery in Proterozoic rocks would likely be gas.

Phanerozoic geology influenced by Proterozoic elements

Basal Cambrian sandstone

The main exploration play in the Colville Hills has been the basal Cambrian sandstone of the Mount Clark Formation. Three gas pools, Tedji Lake, Tweed Lake, and Bele (Fig. 59) have been discovered. Tweed Lake gas has a peculiar composition (mainly methane and nitrogen) and includes some condensate (Bever and MacIlreath, 1992). Reservoir data are summarized by Medding (1994) who showed Initial Established Reserves as follows: Tedji Lake, 1045 M m^3 (37 bcf), Tweed Lake, 4883 M m^3 (173 bcf), and Bele, 2969 M m^3 (105 bcf). Bever and MacIlreath (1992) reported 112 bcf in Tweed Lake.

The Tweed Lake pool occurs in an anticline that developed by Laramide transpressional (?) reactivation of a Proterozoic fault (Fig. 22). Tedji Lake and Bele discoveries also seem to occur above Proterozoic structures although, because of poor seismic quality, the relationship is not as clear-cut as it is with Tweed Lake. Other wells drilled on Colville Hills structures were dry. Tweed and Tedji are relatively small domes with little or no surface expression, whereas Bele occurs on Belot Ridge, a classic Colville Hills ridge. The Mount Clark sandstone thins onto the Tedji Lake structure (Meding, 1994) indicating that the Laramide structure coincided in part, at least, with Early Cambrian topography. Locally, particularly in the southeastern part of the report area, basal Cambrian strata are discontinuous, filling in paleodepressions on the Precambrian erosional surface (Fig. 60; also Balkwill, 1971). Thinning of the basal sandstone onto paleotopographic highs and draping due to differential compaction may have created hydrocarbon-trapping conditions.

Cook and MacLean (1996b, 1999) described Imperial Anticline west of Norman Wells as a high risk, basal Cambrian, sub-thrust play. The area of sub-thrust Lower–Middle Cambrian strata is 5 to 12 km wide by at least 50 km strike length. The play is high risk because it is difficult to prove either structural closure on the footwall or the presence of Mount Clark reservoir sandstone that far west.

Up to 0.75 s (1500 m at a seismic interval velocity of 4000 m/s) of Lower and Middle Cambrian strata are seismically imaged in Mackenzie Trough underlying the Mackenzie River valley in the southwestern part of the report area (Transect M). These strata have been penetrated by very few wells. K’Alo B-62 penetrated the entire Lower–Middle Cambrian section and logs recorded there provided the seismic interval velocity. Highly indurated quartz arenites at the bottom of the well are considered to be basal Cambrian Mount Clark Formation. The lack of porosity is not encouraging.

MacLean (1999) presented seismic time structure contours on the sub-Cambrian unconformity, but did not differentiate between structural closures and paleotopographic highs.

For a discussion of source rocks, potential reservoirs, and thermal maturity of the Cambrian sandstone the reader is referred to Dixon and Stasiuk (1998).

Phanerozoic extension

Extensional grabens and half-grabens, discussed earlier, were localized by extensional reactivation of Proterozoic faults (Transect K, Fig. 51). These structures have not been adequately studied. There may be roll-over anticlines or other culminations related to those features that could have hydrocarbon trapping potential.

Economic minerals

Jefferson et al. (1994) provided a mineral resource assessment of the Franklin igneous events of Arctic Canada. They assigned a low-to-moderate rating to the region around Brock Inlier, with the exception of the Darnley Bay gravity and magnetic anomaly, to which they assigned a moderate-to-high rating. Darnley Bay Resources, in anticipation of discovering a major base-metal deposit related to a large basic or ultra-basic intrusive body, drilled a diamond-drill hole to 1812 m, which bottomed in Shaler Supergroup strata without encountering the intrusion. To the northwest of the gravity and magnetic anomaly they drilled a number of short, approximately 200 m, diamond-exploration holes, most of which encountered kimberlite emplaced into Ordovician cherty dolomite. On their website <www.darnleybay.com> they reported recovering micro-diamonds from kimberlite. The Darnley Bay anomaly is discussed in more detail elsewhere in this report.

The prospect of other types of mineral deposits occurring in subsurface Proterozoic rocks at economic depths is small, but for interest we outline here some prominent mineral occurrences in outcropping strata. A Proterozoic Mississippi Valley-type zinc-lead deposit occurs at Gayna River in breccia zones within the Grainstone Formation of the Little Dal Group, Mackenzie Mountains Supergroup (Hewton, 1982; Aitken, 1988). The mineralization occurs in the vicinity of Little Dal reefs. Hewton (1982) described the deposits in detail, noting that individual zones range up to over 1 million tonnes with grades up to 10% combined zinc-lead, and estimated possible reserves to be in excess of 50 million tonnes of greater than 5% combined zinc-lead. Equivalent subsurface strata may occur in the core of the large syncline of M/S Assemblage underlying the Cambrian Mackenzie Trough, but are at depths of at least 2.2 s (4.4 km at an average seismic velocity of 4000 m/s for the Phanerozoic section).

Stratiform occurrences of disseminated copper sulphides occur in the Coates Lake Group (overlying the Mackenzie Mountains Supergroup) in the Mackenzie Mountains (Jefferson, 1978; Jefferson and Ruelle, 1986), however we do not consider that any of our subsurface units correlate with these strata. Aitken et al. (1973) reported copper mineralization, as malachite, occurring throughout a 3500-foot interval (1060 m) in the Proterozoic section at Cap Mountain. We presently consider the Cap Mountain section to occur very low in the M/S Assemblage and therefore conclude that this mineralization is unrelated to that in the Coates Lake Group.

REFERENCES

Abbott, G.
1997: Geology of the upper Hart River area, eastern Ogilvie Mountains, Yukon Territory (116A/10, 116A/11); Exploration and Geological Services Division, Yukon Region Bulletin 9, Indian and Northern Affairs.

Aitken, J.D.
1981: Stratigraphy and sedimentology of the Upper Proterozoic Little Dal Group, Mackenzie Mountains, Northwest Territories; in Proterozoic Basins of Canada, (ed.) F.H.A. Campbell; Geological Survey of Canada Paper 81-10, p. 47-71.

1982: Precambrian of the Mackenzie Fold-Belt — a stratigraphic and tectonic overview; in Precambrian Sulphide Deposits, (ed.) H.S. Robinson Memorial Volume, R.W. Hutchinson, C.D. Spence and J.M. Franklin; Geological Association of Canada Special Paper 25, p. 149–161.

1988: Giant "algal" reefs, Middle/Upper Proterozoic Little Dal Group (>770, <1200 Ma), Mackenzie Mountains, N.W.T., Canada; in Reefs, Canada and Adjacent Areas, (ed.) H.H.J. Geldsetzer, N.P. James, and G.E. Tebbutt; Canadian Society of Petroleum Geologists Memoir 13, p. 13–23.

Aitken, J.D. and Cook, D.G.
1970: Geology, Colville Lake and Coppermine, District of Mackenzie; Geological Survey of Canada Map 12-1970, scale 1:500 000.

1974: Carcajou Canyon map-area, District of Mackenzie, Northwest Territories; Geological Survey of Canada Paper 74-13, 28 p.

Aitken, J.D. and Pugh, D.C.
1984: The Fort Norman and Leith Ridge structures: Major, buried, Precambrian features underlying Franklin Mountains and Great Bear and Mackenzie Plains; Bulletin of Canadian Petroleum Geology, v. 32, p. 139–146.

Aitken, J.D., Cook, D.G., and Yorath, C.J.
1982: Upper Ramparts River (106 G) and Sans Sault Rapids (106 H) map areas, District of Mackenzie; Geological Survey of Canada Memoir 388, 48 p.

Aitken J.D., Macqueen, R.W., and Foscolos, A.E.
1973: A Proterozoic sedimentary succession with traces of copper mineralization, Cap Mountain, southern Franklin Mountains, District of Mackenzie (95 O); in Current Research, Part A, Geological Survey of Canada Paper 73-1A, p. 243–246.

Balkwill, H.R.
1971: Reconnaissance Geology, southern Great Bear Plain, District of Mackenzie; Geological Survey of Canada, Paper 71-11, 47 p.

Baragar, W.R.A. and Donaldson, J.A.
1970: Coppermine and Dismal Lakes map-areas, District of Mackenzie (86 O and N); in Report of Activities, Part A; Geological Survey of Canada, Paper 70-1A, p. 120–124.

1973: Coppermine and Dismal Lakes map-areas; Geological Survey of Canada, Paper 71-39, 20 p., 2 maps.

Bever, J.M. and McIlreath, I.A.
1992: The Early Cambrian Tweed Lake gas field and related gas occurrences, Northwest Territories, Canada; American Association of Petroleum Geologists, 1992 Annual Convention, Official Program, p. 8–9.

Bostock, H.S.
1967: Physiographic regions of Canada; Geological Survey of Canada, Map 1254A, scale 1:5,000,000.

Bowring, S.A. and Ross, G.M.
1985: Geochronology of the Narakay volcanic complex: Implications for the age of the Coppermine homocline and Mackenzie igneous events; Canadian Journal of Earth Sciences, v. 22, p. 774–781.

Butterfield, N.J. and Rainbird, R.H.
1998: Diverse organic-walled fossils, including “possible dinoflagellates”, from the early Neoproterozoic of Arctic Canada; Geology, v. 26, p. 963–966.

Butterfield, N.J., Knoll, A.H., and Swett, K
1994: Paleobiology of the Neoproterozoic Svanbergfjellet Formation, Spitsbergen; Fossils and Strata, v. 34, 84 p.

Campbell, F.H.A. and Cecile, M.P.
1981: Evolution of the Early Proterozoic Kilohigok Basin, Bathurst Inlet-Victoria Island, Northwest Territories; in Proterozoic Basins of Canada, (ed.) F.H.A. Campbell; Geological Survey of Canada, Paper 81-10, p. 103–131.

Canadian Stratigraphic Services Ltd.
1988: PCI Sammons H-55, N 65o 24’ 28”, W 128o 24’ 45”, Northwest Territories – Canada; Canadian Stratigraphic Services Ltd., Log NWT-711.

Christie, R.L., Fyles, J.G., Thorsteinsson, R., and Tozer, E.T.
1963: Geology, Banks, Victoria, and Stephansson islands, District of Franklin; Geological Survey of Canada, Map 1135A, scale 1:1,000,000.

Clarke, E.A. and Cook, F.A.
1992: Crustal scale ramp in a Middle Proterozoic orogen, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 29, p. 142–157.

Cook, D.G. and Aitken, J.D.
1969: Geology, Erly Lake, District of Mackenzie; Geological Survey of Canada Map 5-1969, Scale 1;250,000.

1971: Geology, Colville Lake map-area and part of Coppermine Map-area, Northwest Territories; Geological Survey of Canada Paper 70-12, 42 p.

1977: Geological Maps of Blackwater Lake (96B) and Fort Norman (96C), District of Mackenzie; Geological Survey of Canada, Open File Report 402.

Cook, D.G. and MacLean, B.C.
1992: Proterozoic thick-skinned intracratonic deformation, Colville Hills region, Northwest Territories, Canada; Geology v. 20, p. 67–70.

1995: The intra-cratonic Paleoproterozoic Forward Orogeny, and implications for regional correlations, Northwest Territories, Canada. Canadian Journal of Earth Sciences, v. 32, p. 1991–2008.

1996a: Mid-continent tectonic inversions, Northwest Territories, Canada; Journal of Structural Geology, v. 18, p. 791-802.

1996b: The Imperial Anticline overthrust, a high risk basal Cambrian play; in Program and Abstracts, Pools ’96, Oil and gas pools of the western Canada sedimentary basin, Canadian Society of Petroleum Geologists Conference, 1996.

1999: The Imperial Anticline, a fault-bend fold above a bedding-parallel thrust ramp, Northwest Territories, Canada; Journal of Structural Geology, v. 21, p. 215–228.

Cook, D.G. and Mayers, I.R.
1990a: Precambrian structure and stratigraphy based on seismic interpretation, Colville Hills region, Northwest Territories; in Current Research, Part C; Geological Survey of Canada, Paper 90-1C, p. 339–348.

1990b: Reflection seismic interpretation of the Proterozoic geology, Colville Hills region, Northwest Territories; Geological Survey of Canada, Open File 2254.

Cook, F.A.
1988a: Proterozoic thin-skinned thrust and fold belt beneath the Interior Platform in northwest Canada; Geological Society of America, Bulletin, v. 100, p. 877–-890.

1988b: Middle Proterozoic compressional orogen in northwestern Canada; Journal of Geophysical Research, v. 93, p. 8985–9005.

1992: Racklan Orogen; Canadian Journal of Earth Sciences, v. 29, p. 2490–2496.

Darnley Bay Resources Ltd.
2000a: Bouguer gravity field, Darnley Bay, N.W.T.; http://darnleybay.com/bouger_gravity_field.htm

2000b: Total magnetic field, Darnley Bay, N.W.T.; http://darnleybay.com/magnetic_field.htm

2001: Darnley Bay Resources website http://darnleybay.com

Davis, J.W. and Willott, R.
1978: Structural geology of the Colville Hills; Bulletin of Canadian Petroleum Geology, v. 26, p. 105–122.

Delaney, G.D.
1981: The mid-Proterozoic Wernecke Supergroup, Wernecke Mountains, Yukon Territory; in Proterozoic Basins of Canada, (ed.) F.H.A. Campbell; Geological Survey of Canada Paper 81-10, p. 1–23.

Dixon, J. and Stasiuk, L.D.
1998: Stratigraphy and hydrocarbon potential of Cambrian strata, Northern Interior Plains Northwest Territories; Bulletin of Canadian Petroleum Geology, v. 46, p. 445–470.

Douglas, R.J.W.
1974: Geology, Dahadinni River, District of Mackenzie; Geological Survey of Canada, Map 1374A, 1: 250,000.

Douglas, R.J.W. and Norris, D.K.
1974: Geology, Wrigley, District of Mackenzie; Geological Survey of Canada, Map 1373A, 1: 250 000.

Eisbacher, G.H.

1978: Two major Proterozoic unconformities, northern Cordillera; in Current Research, Part A; Geological Survey of Canada, Paper 78-1A, p. 53–58.

1981: Sedimentary tectonics and glacial record in the Windermere Supergroup, Mackenzie Mountains, northwest Canada; Geological Survey of Canada, Paper 80-27, 40 p.

Gabrielse, H.

1967: Tectonic evolution of the northern Canadian cordillera; Canadian Journal of Earth Sciences, v. 4, p. 271–298.

Geophysics Division, Geological Survey of Canada

1992: Magnetics – total field, Darnley Bay; aeromagnetic total field map 1:250,000 scale; Geological Survey of Canada, Open File 2517.

Gough, D.I., Fordjor, C.K., and Bell, J.S.B.

1983: A stress province boundary and tractions on the North American plate; Nature, v. 305, p. 619–621.

Heaman, L.M., LeCheminant, A.N., and Rainbird, R.H.

1992: Nature and timing of Franklin igneous events, Canada: Implications for a Late Proterozoic mantle plume and the break-up of Laurentia; Earth and Planetary Science Letters, v. 109, p. 117–131.

Hewton, R.S.

1982: Gayna River: A Proterozoic Mississippi Valley-type zinc-lead deposit; in Precambrian Sulphide Deposits, H.S. Robinson Memorial Volume, (ed.) R.W. Hutchinson, C.D. Spence, and J.M. Franklin; Geological Association of Canada Special Paper 25, p. 667–700.

Hildebrand, R.S. and Baragar, W.R.A.

1991: On folds and thrusts affecting the Coppermine River Group, northwestern Canadian Shield; Canadian Journal of Earth Sciences, v. 28, p. 523–531.

Hildebrand, R.S., Bowring, S.A., Steer, M.E., and Van Schmus, W.R.

1983: Geology and U-Pb geochronology of parts of the Leith Peninsula and Rivière Grandin map areas, District of Mackenzie; in Current Research, Part A; Geological Survey of Canada, Paper 83-1A, p. 329–342.

Hoffman, P.F.

1984: Geology, Northern Internides of Wopmay Orogen, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1576A, scale 1:250 000.

Hoffman, P.F. and Bowring, S.A.

1984: Short-lived 1.9 Ga continental margin and its destruction, Wopmay Orogen, Northwest Canada; Geology, v. 12, p. 68–72.

Hoffman, P.F. and St-Onge, M.R.

1981: Contemporaneous thrusting and conjugate transcurrent faulting during the second collision in Wopmay Orogen: Implications for the subsurface structure of post-orogenic outliers; in Current Research, Part A; Geological Survey of Canada, Paper 81-1A, p. 251–257.

Hofmann, H.J. and Aitken, J.D.

1979: Precambrian biota from the Little Dal Group, Mackenzie Mountains, northwestern Canada; Canadian Journal of Earth Sciences, v. 16, p. 150–166.

Hofmann, H.J. and Rainbird, R.H.

1994: Carbonaceous megafossils from Neoproterozoic Shaler Supergroup of Arctic Canada; Palaeontology, v. 37, Part 4, p. 721–731.

Hornal, R.W., Sobczak, L.W., Burke, W.E.F., and Stephens, L.E.

1970: Preliminary results of gravity surveys over the Mackenzie basin and Beaufort Sea with maps; Gravity Map Series of the Earth Physics Branch, Canada Department of Energy Mines and Resources, 12 p, 3 maps.

Jefferson, C.W.

1978: Stratigraphy and sedimentology, Upper Proterozoic Redstone Copper Belt, Mackenzie Mountains, N.W.T. - A preliminary report; in Mineral Industry Report 1975, Indian and Northern Affairs, EGS 1978-5, p. 157–169.

Jefferson, C.W. and Parrish, R.R.

1989: Late Proterozoic stratigraphy, U-Pb zircon ages, and rift tectonics, Mackenzie Mountains, northwestern Canada; Canadian Journal of Earth Sciences, v. 26, p. 1784–1801.

Jefferson, C.W. and Ruelle, J.C.

1986: The Late Proterozoic Redstone Copper Belt, Mackenzie Mountains Northwest Territories; in Mineral Deposits of Northern Cordillera, (ed.) J.A. Morin; Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 154–168.

Jefferson, C.W. and Young, G.M.

1989: Late Proterozoic orange-weathering stromatolite biostrome Mackenzie Mountains and western Arctic Canada; in Reefs, Canada and adjacent areas, (ed.) H.H.J. Geldsetzer, N.P. James, and Tebbutt, G.E.; Canadian Society of Petroleum Geologists, Memoir 13, p. 72–80.

Jefferson, C.W., Hulbert, L.J., Rainbird, R.H., Hall, G.E.M., Gregoire, D.C., and Grinenko, L.I.

1994: Mineral resource assessment of the Neoproterozoic Franklin Igneous Events of Arctic Canada: Comparison with the Permo-Triassic Noril'sk-Talnakh Ni-Cu-PGE deposits of Russia; Geological Survey of Canada, Open File 2789.

Jones, T.A., Jefferson, C.W., and Morrell, G.R.

1992: Assessment of mineral and energy resource potential in the Brock Inlier – Bluenose Lake area, N.W.T.; Geological Survey of Canada, Open File 2434,

Jordan, T.E. and Allmendinger, R.W.

1986: The Sierras Pampeanas of Argentina: A modern analogue of Rocky Mountain foreland deformation; American Journal of Science, v. 286, p. 737–764.

Kerans, C.

1983: Timing of emplacement of the Muskox intrusion: constraints from Coppermine Homocline cover strata; Canadian Journal of Earth Sciences, v. 20, p. 673–683.

Kerans, C., Ross, G.M., Donaldson, J.A., and Geldsetzer, H.J.

1981: Tectonism and depositional history of the Helikian Hornby Bay and Dismal Lakes Groups, District of Mackenzie; in Proterozoic Basins of Canada, (ed.) F.H.A. Campbell; Geological Survey of Canada, Paper 81-10, p. 157–182.

LeCheminant, A.N.

1994: (Abstract) 779 Ma mafic magmatism in the northwestern Canadian Shield and northern Cordillera: a new regional time marker; in Abstracts of the Eighth International Conference on

Geochronology, Cosmochronology and Isotope Geology; U.S. Geological Survey Circular 1107, p. 187.

LeCheminant, A.N. and Heaman, L.M.
1989: Mackenzie igneous events, Canada: Middle Proterozoic hotspot magmatism associated with ocean opening; Earth and Planetary Science Letters, v. 96, p. 38–48.

Macauley, G.
1987: Organic geochemistry of some Cambrian-Proterozoic sediments, Colville Hills, Northwest Territories; Geological Survey of Canada, Open File 1498.

MacLean, B.C.
1999: Sub-Cambrian unconformity sub-crop and seismic time structure map, western plains, Northwest Territories, Canada; Geological Survey of Canada, Open File 2998.

MacLean, B.C. and Cook D.G.
1992: The influence of Proterozoic structures on the development of Laramide age structures, Northwest Territories, Canada; Bulletin of Canadian Petroleum Geology, v. 40, p. 207–221.

1999: Salt tectonism in the Fort Norman area, Northwest Territories, Canada; Bulletin of Canadian Petroleum Geology; v. 47, p. 104–135.

2002: Sequence A today; in Abstracts Volume 27, Geological Association of Canada Conference 2002, p. 71.

MacLean, B.C. and Miles, W.
2002: Potential field modelling of a Proterozoic half-graben near Blackwater Lake, Northwest Territories, Canada, and its implications for the Fort Simpson anomaly; Canadian Journal of Earth Sciences, v. 39, p. 169–187.

MacLean, B.C. and Wade, J.A.
1993: East coast basin atlas series: seismic markers and stratigraphic picks in Scotian Basin wells; Atlantic Geoscience Centre, Geological Survey of Canada, 276 p.

McGrath, P.H., Broome, H.J., and Klein, J.
1993: New models for the Darnley Bay, N.W.T., gravity anomaly (abstract); in Program with Abstracts; Geological Survey of Canada, Forum 1993, p. 15.

Meding, M.G.
1994: Analysis of selected Northwest Territories hydrocarbon pool data; Energy Mines and Petroleum Resources, Government of the Northwest Territories.

North American Commission on Stratigraphic Nomenclature
1983: North American stratigraphic code; American Association of Petroleum Geologists Bulletin, v. 67, p. 841–875.

Okulitch, A.V. (comp.)
2000: Geology, Horton River, Northwest Territories – Nunavut; Geological Survey of Canada, Map NR-9/10/11/12-G, scale 1:1 000 000, Open File 3845 (National Earth Science Series, Geological Atlas).

Parrish, R.R. and Bell, R.T.
1987: Age of the NOR breccia pipe, Wernecke Supergroup, Yukon Territory; in Radiogenic and iostope studies; Report 1; Geological Survey of Canada, Paper 87-2, p. 39–42.

Petersen, E.V.
1974: Promising new play gaining momentum in the Great Bear Lake area of NWT; in Oilweek, November 25, 1974, p. 14–15.

Pugh, D.C.
1983: Pre-Mesozoic geology in the subsurface of Peel River map area, Yukon Territory and District of Mackenzie; Geological Survey of Canada, Memoir 401, 61 p.

Rainbird, R. H., Jefferson, C.W., and Young, G.M.
1996a: The early Neoproterozoic sedimentary Succession B of northwestern Laurentia: Correlations and paleogeographic significance; Geological Society of America, Bulletin v. 108, p. 454–470.

Rainbird, R.H., Villeneuve, M.E., Cook, D.G., and MacLean, B.C.
1996b: Detrital zircons from two wells in the Northwest Territories: implications for the correlation and provenance of Proterozoic subsurface strata; in Current Research, Part B, Geological Survey of Canada Paper 1996-B, p. 29–38.

Rainbird, R.H., McNicoll, R.J., Theriault, R.J., Heaman, L.M., Abbott, J.G., Long, J.G.F., and Thorkelson, D.J.
1997: Pan-continental river system draining Grenville Orogen recorded by U-Pb and Sm-Nd geochronology of Neoproterozoic quartzarenites and mudrocks, northwestern Canada; Journal of Geology, v. 105, p. 1–17.

Riddihough, R.P. and Haines, G.V.
1972: Magnetic measurements over Darnley Bay, N.W.T.; Canadian Journal of Earth Sciences, v. 9, p. 972–978.

Rodgers, J.
1987: Chains of basement uplifts within cratons marginal to orogenic belts; American Journal of Science, v. 287, p. 661–692.

Ross, G.M.
1991: Precambrian basement in the Canadian Cordillera: an introduction; Canadian Journal of Earth Sciences, v. 28, p. 1133–1139.

Ross, G.M. and Kerans, C.
1989: Geology, Hornby Bay and Dismal Lakes groups, Coppermine Homocline, District of Mackenzie, Northwest Territories; Geological Survey of Canada Map 1663A, scale 1:250 000.

Ross, G.M., Annell, H.C., and Hamilton, M.A.
2000: Lithology and U-Pb geochronology of shallow basement along the SNORCLE Line, southwest Northwest Territories: a preliminary report; in Lithoprobe Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) and Cordilleran Tectonics Workshop, Lithoprobe Report No. 72.

Samuelsson, J. and Butterfield, N.J.
2001: Neoproterozoic fossils from the Franklin Mountains, northwestern Canada: stratigraphic, paleoenvironmental, and paleobiological implications; Precambrian Research, v. 107, p. 235–251.

Sevigny, J.H., Cook, F.A., and Clark, E.A.
1991: Geochemical signature and seismic stratigraphic setting of Coppermine basalts drilled beneath the Anderson Plains in northwest Canada; Canadian Journal of Earth Sciences, v. 28, p. 184–194.

Snowdon, L.R. and Williams, G.K.
1986: Thermal maturation and petroleum source potential of some Cambrian and Proterozoic rocks in the Mackenzie Corridor; Geological Survey of Canada, Open File 1367, 14 p.

Stacey, R.A.
1971: Interpretation of the gravity anomaly at Darnley Bay, N.W.T.; Canadian Journal of Earth Sciences, v. 8, p. 1037–1042.

St-Onge, M.R., King, J.E., and LaLonde, A.E.
1991: Geology, east-central Wopmay Orogen, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1754A, scale 1:125 000.

Thorkelson, D.J.
2000: Geology and mineral occurrences of the Slats Creek, Fairchild Lake and "Dolores Creek" areas, Wernecke Mountains, Yukon Territory (106D/16, 106C/13, 106C/14); Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, Bulletin 10.

Thorkelson, D.J. and Wallace, C.A.
1998a: Geological Map of Slats Creek area, Wernecke Mountains, Yukon, NTS 106D/16; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs, Canada, Geoscience Map 1998-9.

1998b: Geological Map of Fairchild Lake area, Wernecke Mountains, Yukon, NTS 106C/13; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs, Canada, Geoscience Map 1998-10.

1998c: Geological Map of “Dolores Creek” area, Wernecke Mountains, Yukon, NTS 106C/14; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs, Canada, Geoscience Map 1998-11.

Thorkelson, D.J., Mortensen J.K., Creaser, R.A., Davidson, G.J., and Abbot, J.G.
2001: Early Proterozoic magmatism in Yukon, Canada: constraints on the evolution of northwestern Laurentia; Canadian Journal of Earth Sciences, v. 38, p. 1479–1494.

Turner, E.C.
1999: Growth dynamics, framework composition, and microstructure of giant early Neoproterozoic calcimicrobial reefs, Little Dal Group, Mackenzie Mountains, N.W.T.; Ph.D. Thesis, Queen’s University, Kingston, Ontario, Canada. 276 p.

Turner, E.C., Narbonne, G.M., and James, N.P.
2000: Framework composition of early Neoproterozoic calcimicrobial reefs and associated microbialites, Mackenzie Mountains, N.W.T., Canada; in Carbonate Sedimentation and Diagenesis in the Evolving Precambrian world, (ed.) J.P. Grotzinger and N.P. James; Special Publication 67, Society for Sedimentary Geology (SEPM). Tulsa, OK, United States, p.179–205.

Villeneuve, M.E., Theriault, R.J., and Ross, G.M.
1991: U-Pb ages and Sm-Nd signature of two subsurface granites from the Fort Simpson magnetic high, Northwest Canada; Canadian Journal of Earth Sciences, v. 28, p. 1003–1008.

Villeneuve, M.E., Butterfield, N.J., Cook D.G., and MacLean, B.C.
1998: Age of the Cap Mountain (Northwest Territories) Proterozoic section, sequence B, based on detrital zircon ages; in Current Research, Part F, Radiogenic Age and Isotopic Studies: Report 11; Geological Survey of Canada, Paper 1998-F, p. 117–127.

Vye, R.J.
1972: Interpretation of Darnley Bay area seismic data, NTS 97 C/1, C/8; Indian and Northern Affairs assessment report No. 19684; unpublished assessment report, R.J. Kirker Resources.

Wanless, R.K. and Loveridge, W.D.
1978: Rb-Sr isotope age studies, report 2 (Canadian Shield); Geological Survey of Canada, Paper 77–14.

Wanless, R.K., Stevens, R.D., LaChance, G.R., and DeLabio, R.N.
1970: Age determinations and geological studies, K-Ar isotope ages, report 9; Geological Survey of Canada, Paper 69-2A.

Wielans, J.B.W.
1992: The pre-Mesozoic stratigraphy and structure of Tuktoyaktuk Peninsula; Geological Survey of Canada, Paper 90-22, 90 p.

Williams, G.K.
1986: Proterozoic, Mackenzie Corridor; Geological Survey of Canada, Open File 1273.

Wissner, U.
1986: A new look at the Imperial Anticlinorium, Mackenzie Plain, Northwest Territories: Program and Abstracts, Canadian Society of Petroleum Geologists 1986 Convention, p. 97.

Yeo, G.M., Delaney, G.D., and Jefferson, C.W.
1978: Two major Proterozoic unconformities, northern Cordillera: Discussion; in Current Research, Part B; Geological Survey of Canada, Paper 78-1B, p. 225–230.

Young, G.M., Jefferson, C.W., Delaney, G.D., and Yeo, G.M.
1979: Middle and Upper Proterozoic evolution of the northern Canadian Cordillera and Shield; Geology, v. 7, p. 125–128.

Zoback, M.L., Zoback, M.D., Adams, J., Bell, J.S.B., Suter, M., Suarez, G., Jacob, K., Estabrook, C., and Magee, M.
1991: Stress map of North America, Scale 1:5 000 000, Continental-Scale Map 005; Geological Society of America.

Appendix A
Proterozoic Well Control

Unique well identifier (UWI)	Short name	Well name	Spud date	Total depth (m)	KB (m)	Surface latitude	Surface longitude
300F726320120150	Cartridge F-72	Imperial Cartridge F-72	26-Feb-60	688.2	435.6	63.188611	120.484444
300C356350120300	Lac Tache C-35	Imperial Lac Tache C-35	23-Feb-60	524.0	309.1	63.737500	120.612500
300E116350123000	Blackwater E-11	Union Japex Blackwater E-11	22-Feb-72	2170.2	504.4	63.672222	123.058333
300G526410122450	Blackwater L. G-52	Shell Blackwater Lake G-52	09-Feb-64	1981.2	370.0	64.022222	122.920000
300D616520124000	Wolverine Cr. D-61	Sinclair Wolverine Creek D-61	01-Dec-68	1931.8	310.0	65.170556	124.214444
300B626520125150	K'Alo B-62	PCI K'Alo B-62	24-Jan-86	1985.0	112.2	65.184067	125.451350
300I746530124300	Mahony L. I-74	Sinclair Mahony Lake I-74	24-Mar-69	1883.7	310.3	65.393333	124.725000
300H556530128150	Sammons H-55	PCI Sammons H-55	14-Mar-84	1710.0	379.7	65.407653	128.412561
300K766540124150	Whitefish River K-76	Sinclair Whitefish River K-76	30-Jan-69	1606.9	241.4	65.592222	124.487778
300H346540124300	W. Whitefish R. H-34	ARCO West Whitefish River H-34	14-Mar-72	1654.5	230.7	65.556667	124.595833
300G226600123150	Losh Lake G-22	BP et al. Losh Lake G-22	15-Mar-75	1225.3	293.2	65.858056	123.326389
300N376610126150	Tunago N-37	EXCO et al. Tunago N-37	12-Jan-85	1626.0	236.1	66.113869	126.366611
302N376610126150	Tunago 2N-37	EXCO et al. Tunago 2N-37	12-Jan-85	1626.0	236.0	66.113867	126.366611
300N396620128150	Ontadek Lake N-39	Mobil Inc NCO Sun Ontadek L. N-39	13-Apr-70	1798.3	97.2	66.312583	128.360750
300A406630124300	Good Hope A-40	Union Decalta Good Hope A-40	15-Dec-74	1592.6	443.8	66.486111	124.597778
300H346630132000	Ontaratue H-34	Atlantic et al. Ontaratue H-34	20-Dec-63	4075.2	141.7	66.389583	132.097639
300O476640125450	Nogha O-47	PCI Canterra Nogha O-47	10-Jan-86	1416.0	353.7	66.614494	125.888575
300O356640126150	Bele O-35	PCI Canterra Bele O-35	14-Feb-86	1384.0	397.1	66.582817	126.358919
300L266640130150	Grandview L-26	Candel et al. Mobil Grandview L-26	09-Mar-72	2395.7	164.9	66.592222	130.339167
300K046640130450	Ontaratue K-04	Atlantic et al. Ontaratue K-04	14-Nov-64	2728.0	103.6	66.560417	130.769528
300M486700124150	East Maunoir M-48	Union IOL East Maunoir M-48	21-Jan-74	862.6	382.8	66.965000	124.400000
300M476700125450	Tweed Lake M-47	PCI et al. Tweed Lake M-47	11-Jan-85	1420.0	435.3	66.946419	125.902617
300A676700125450	Tweed Lake A-67	PCI Canterra Tweed Lake A-67	13-Nov-85	1347.0	396.0	66.936556	126.938578
300M616710124000	Camp M-61	Forward et al. Camp M-61	03-Jan-84	1145.0	330.5	67.015511	124.216889
300C126710126000	NW Tweed L. C-12	PCI et al. N.W. Tweed Lake C-12	25-Feb-86	1365.0	296.1	67.017178	126.050953
300M636710126150	Belot Hills M-63	Mobil Belot Hills M-63	31-Jan-72	1283.5	461.8	67.045833	126.462500
300D456720125000	Colville D-45	Union Mobil Colville D-45	29-Mar-73	1173.5	639.8	67.235714	125.155797
300E156720126150	Colville E-15	Mobil Colville E-15	18-Apr-70	1827.6	386.8	67.238389	126.307111
300J136720126450	Aubrey J-13	Forward et al. Aubrey J-13	18-Mar-84	1330.0	337.8	67.210419	126.792969
300D116730123450	Izok D-11	Forward et al. Izok D-11	15-Feb-83	900.0	299.0	67.335419	123.808589
300D406730129450	Iroquois D-40	Mobil Inexco NCO Sun Iroquois D-40	14-Mar-71	2590.8	216.4	67.485556	129.872222
300K446740123300	Stopover K-44	Union Imp Stopover K-44	15-Feb-75	942.4	367.0	67.558611	123.642222
300C516740124000	Anderson C-51	Forward et al. Anderson C-51	06-Apr-83	1010.0	300.0	67.502081	124.175781
300L216750126000	North Colville L-21	Pex Fina North Colville L-21	27-Jan-78	1195.1	338.0	67.676944	125.093611
300C116750126300	Ewekka C-11	Forward et al. Ewekka C-11	15-Feb-84	1340.0	360.4	67.667306	126.547722
300K246750126450	Tedji Lake K-24	Ashland et al. Tedji Lake K-24	13-Mar-74	1213.1	346.9	67.727222	126.832222
300H566750127150	K'Ahbami H-56	PCI Westcoast K'Ahbami H-56	05-Mar-85	1605.0	304.9	67.757747	127.413725
300I116750129300	Iroquois I-11	Candel Mobil et al. Iroquois I-11	25-Apr-72	2121.7	127.4	67.677778	129.534722
300A736800130300	Tenlen A-73	CDR Tenlen A-73	01-Feb-71	2593.8	139.6	67.868750	130.722656
300D026900126450	Sadene D-02	Mobil Gulf Sadene D-02	08-Mar-77	1857.8	236.8	68.850278	126.787500
300M336950131450	Atkinson M-33	IOE Atkinson M-33	01-May-70	1928.5	12.8	69.713333	131.911944

Appendix B
Seismic database

NEB file	Date	Operator	Area	Minimum latitude	Maximum latitude	Minimum longitude	Maximum longitude
7-6-5-1	1945	Imperial Oil / Esso	Norman Wells	65.00	65.00	126.00	129.00
554-10-6-5	1958	Pentland and Allen	Peel Plateau	66.00	66.00	132.00	132.00
554-10-6-7	1958	Pentland and Allen	Peel Plateau	67.00	67.00	134.00	134.00
554-10-6-8	1958	Pentland and Allen	Peel Plateau	67.00	67.00	134.00	134.00
331-9-5-1	1959	Hunt Oil	Mackenzie River	64.00	64.00	124.00	124.00
554-10-6-10	1959	Pentland and Allen	Peel Plateau	65.00	65.00	128.00	128.00
58-9-7-2	1960	Texaco	Nicholson Penn. / Anderson R.	68.00	68.00	129.00	129.00
246-6-6-7	1960	Richfield Oil Corp.	Grandview Hills / Arctic Red R.	67.00	67.00	130.00	130.00
246-6-6-12	1960	Petro-Canada	Peel Plateau	66.00	67.00	128.00	133.00
331-9-7-20	1960	Hunt Oil	Liverpool Bay	69.00	69.00	130.00	130.00
19-6-6-9	1960	Western Decalta	Rond Lake	67.00	67.00	128.33	128.33
246-6-6-84	1960	ARCO (Petro-Canada)	Grandview Hills	66.00	68.00	129.00	132.00
76-6-2-3	1961	Great Plains	Taylor Lake	66.00	66.00	133.00	133.00
352-6-7-21	1961	Canada Southern Pet.	Canot Lake	67.25	68.00	128.25	129.75
246-9-6-80	1961	ARCO (Petro-Canada)	Mackenzie River	66.33	67.50	132.00	131.25
246-7-6-13	1961	Petro-Canada	Glacier	65.00	66.70	124.50	126.20
246-8-6-13	1961	Petro-Canada	Glacier	66.00	66.83	128.00	132.25
246-8-6-14	1961	Petro-Canada	Glacier	66.00	66.83	128.00	132.25
246-6-6-18	1961	ARCO (Petro-Canada)	Circle River	66.50	66.50	130.17	130.17
37-6-5-42	1962	Shell Oil Co.	Wrigley / Redstone	63.33	64.83	124.33	126.25
7-6-5-41	1963	Imperial Oil / Esso	Norman Wells	65.00	66.00	128.00	130.00
17-6-5-17	1963	Texaco	Mackenzie River	65.00	66.00	128.00	129.00
17-6-5-18	1963	Texaco	Mackenzie River	65.17	65.33	127.25	127.50
246-6-6-15	1963	ARCO	Glacier	65.00	67.00	128.00	133.00
37-6-6-47	1963	Shell Canada Ltd.	Peel Plateau	66.00	67.35	132.50	135.83
7-9-6-52	1964	Imperial Oil	Peel Plateau	67.00	68.00	132.00	134.00
37-6-6-59	1964/65	Shell Oil Co.	Peel Plateau	65.00	67.00	132.00	135.00
19-6-5-22	1965	Western Decalta	Norman Wells	65.00	65.33	126.25	127.00
246-6-6-29	1965	ARCO	Glacier Area	65.00	67.00	128.00	133.00
1-6-5-21	1966	Amerada	Fort Norman	64.67	65.00	126.00	126.75
1-6-5-22	1966	Amerada	Fort Norman	64.67	65.00	126.00	126.75
1-6-5-24	1966	Amerada	Fort Norman	64.67	65.00	126.00	126.75
17-6-5-23	1966	Texaco	Mountain River	65.00	66.00	129.00	130.00
17-6-5-24	1966	Texaco	Carcajou River	65.33	65.67	127.50	128.50
45-6-6-51	1967	Chevron	Peel Plateau	66.67	67.00	135.00	135.75
7-6-6-68	1967	Esso Resources	Peel Plateau	66.10	67.30	132.70	135.50
41-6-5-10	1968	Sinclair	Fort Norman	65.00	65.75	124.00	125.00
45-6-6-56	1968	Chevron	Peel Plateau	67.33	67.55	132.27	133.50
45-6-4-58	1968	Chevron	Great Slave Plain	66.25	68.00	128.00	130.00
632-6-2-11	1968	J. R. McDermott	Taylor Lake	65.83	61.17	132.00	134.00
632-6-6-12	1968	J. R. McDermott	Norman / Peel Plateau	65.00	66.00	127.00	129.00
216-6-5-18	1969	Banff Oil Ltd.	Oscar Cr. / Raider Is.	65.00	65.00	127.00	127.00
2-6-7-41	1969	Gulf Oil	MacKenzie Delta	68.50	68.50	133.50	133.50
2-6-6-42	1969	Gulf Oil	Peel River	66.00	66.67	134.25	135.75
2-6-6-43	1969	Gulf Oil	Peel Plateau	66.35	66.35	132.00	132.00
17-6-5-32	1969	Texaco	Hoosier Ridge / Norman Wells	65.00	65.67	126.75	128.50
17-6-5-33	1969	Texaco	Fort Norman	64.00	64.25	124.50	127.50
17-6-5-38	1969	Texaco	Hume River	65.00	66.00	139.00	130.00
216-6-5-8	1969	Banff Oil	Norman Wells	65.00	66.00	126.00	128.00
216-6-5-9	1969	Banff Oil	Brackett Lake	64.50	65.33	124.50	125.50
57-6-5-55	1969	Mobil	Canol / Norman Wells	64.50	65.25	127.50	129.00
37-6-7-98	1969	Shell Canada Ltd.	MacKenzie Delta	68.00	68.50	129.50	131.25
45-6-5-74	1969	Chevron	Mountain R. / Fort Good Hope	65.33	66.17	129.00	130.25
57-6-5-78	1969	Mobil	Mackenzie Plains	64.80	67.10	126.20	128.00
28-6-6-49	1969	Union / Guaranty Trust	Peel Plateau	66.00	67.50	124.00	127.00

NEB file	Date	Operator	Area	Minimum latitude	Maximum latitude	Minimum longitude	Maximum longitude
583-1-6-9	1969	Union / Guaranty Trust	Peel Plateau	66.00	67.50	124.00	127.00
2-6-4-44	1970	Gulf Oil	Great Slave Plain	69.00	69.00	135.00	135.00
216-9-7-17	1970	Banff Oil	Grandview Hills	66.75	67.50	130.00	130.50
216-6-5-18	1970	Banff Oil	Oscar Creek	65.25	65.55	126.25	127.50
57-6-6-79	1970	Mobil	Fort Good Hope	65.25	66.00	129.00	131.50
60-6-5-91	1970	Amoco	Cranswick River	65.00	66.00	131.00	134.00
37-6-6-97	1970	Shell Canada Ltd.	Peel River	66.00	67.00	133.00	135.00
37-6-6-108	1970	Shell Canada Ltd.	Glacier Area	66.00	68.00	130.00	134.00
632-6-6-13	1970	J. R. McDermott	Norman / Peel Plat.	65.00	66.00	127.00	130.00
632-6-7-14	1970	J. R. McDermott	Inuvik Area	67.83	68.17	132.50	133.00
551-6-6-4	1970	Kerr McGee	Fort McPherson	66.00	68.00	134.00	135.25
667-6-7-47	1971	Pacific Petroleums	Arctic Red River	65.00	66.00	130.00	132.00
60-6-5-148	1971	Amoco	Redstone Area	64.10	64.30	124.50	124.70
2-6-7-54	1971	Gulf Oil	Mackenzie Delta	68.50	69.00	133.00	133.75
19-6-5-45	1971	Western Decalta	Birch Island	64.17	64.67	124.00	125.00
57-6-5-64	1971	Mobil	Great Bear Plain	65.00	65.75	127.50	132.00
57-6-6-66	1971	Mobil	Rond Lake / Peel Plat.	66.50	67.50	125.00	130.00
57-6-6-67	1971	Mobil	Nomac Area / Peel Plat.	67.25	67.83	129.00	131.00
58-6-7-15	1971	Texaco	Anderson Plains	68.25	68.50	129.25	130.10
60-6-6-109	1971	Amoco	Cranswick River	65.00	66.00	131.00	134.00
60-6-6-110	1971	Amoco	Canyon Area	65.00	66.00	132.00	134.00
37-6-6-109	1971	Shell Canada Ltd.	Peel River	67.50	68.00	134.50	135.50
54-6-6-49	1971	Sun Oil	Grandview Hills Area	66.00	68.00	131.00	132.00
820-6-5-1	1971	Candex	Little Bear River	64.00	65.00	125.00	127.00
673-6-5-6	1971	Aquitaine	Brackett Lake	64.50	65.33	124.50	125.50
750-1-5-12	1971	Canadian Reserve	Ft. Norman, Wrigley	63.25	65.00	123.50	124.75
667-6-6-33	1972	Pacific Petroleums Ltd.	Martin House / Peel Plat.	66.67	66.67	132.75	132.75
5-6-6-26	1972	Dome	Peel Plateau	65.83	66.00	132.00	132.90
7-6-4-121	1972	Imperial Oil	Wrigley	63.17	63.67	124.00	125.00
19-6-6-32	1972	Western Decalta	Grandview Hills	66.17	67.33	130.25	132.25
60-6-5-115	1972	Amoco	Cloverleaf	64.00	64.00	124.00	126.00
60-6-6-145	1972	Amoco	Carcajou Ridge	66.00	66.00	128.00	129.00
28-6-6-51	1972	Union	Colville Lake	67.50	67.67	125.35	125.75
54-6-6-21	1972	A.I.O.G.	Grandview	66.00	68.00	130.00	132.00
821-6-5-9	1972	CanDel	Fort Norman	64.00	65.00	124.00	126.00
821-6-6-15	1972	CanDel Oil	Peel Plateau	66.00	67.00	128.00	130.00
673-6-5-53	1972	Aquitaine	Brackett Lake	64.50	65.33	124.50	125.50
690-6-6-9	1972	PetroFina	Colville Lake	67.00	68.00	125.00	127.00
7-6-6-169	1972	Esso Resources	Colville Lake	66.50	67.50	124.00	125.00
7-6-6-169	1973	Esso Resources	Great Bear L. / Colville L.	66.00	68.00	124.00	126.00
19-6-6-52	1973	Western Decalta	Norman Wells	65.17	65.25	126.67	126.75
1-6-5-32	1973	Amerada	Mirror Lake	64.00	65.00	126.00	127.00
2-6-7-70	1973	Gulf Oil	Darnley Bay	69.25	69.25	124.50	124.50
2-6-6-71	1973	Gulf Oil	Ramparts	65.67	66.00	130.50	132.00
2-6-7-72	1973	Gulf Oil	Horton River	69.25	69.25	127.25	127.25
19-6-4-33	1973	Western Decalta	Redstone Area	63.50	64.25	124.00	124.50
19-6-5-34	1973	Western Decalta	Norman Wells	65.00	65.33	126.00	126.75
19-6-5-35	1973	Western Decalta	Norman Wells	65.00	65.33	126.00	126.75
19-6-5-36	1973	Western Decalta	Norman Wells	65.00	66.00	126.00	127.00
19-6-5-37	1973	Western Decalta	Dahadinni	63.83	64.00	124.25	124.50
19-6-5-38	1973	Western Decalta	Keele S. / Great Bear Pl.	64.00	64.17	124.75	125.25
19-6-4-39	1973	Western Decalta	Wrigley / Great Slave Pl.	63.17	63.67	123.75	124.15
19-6-6-47	1973	Western Decalta	Tree River	67.17	61.50	132.00	133.00
63-6-6-20	1973	Murphy Oil	Tree River	67.08	67.08	132.40	132.40
62-6-5-35	1973	Canada Cities Service	Little Bear	67.50	65.00	125.50	126.25
28-6-7-52	1973	Union	Mackenzie Delta	68.33	68.67	129.50	131.25
37-6-7-123	1973	Shell Canada Ltd.	Mackenzie Delta	68.00	69.00	128.00	130.00
38-6-4-37	1973	H.B.O.G.	Willow Lake	63.00	63.50	122.50	123.50
38-6-7-40	1973	H.B.O.G.	Mackenzie Delta	67.00	68.00	134.00	135.00

NEB file	Date	Operator	Area	Minimum latitude	Maximum latitude	Minimum longitude	Maximum longitude
815-6-6-5	1973	Ashland	Colville Lake	66.83	68.00	125.00	127.25
821-6-6-16	1973	CanDel Oil	Peel Plateau	66.75	67.55	128.75	129.50
690-6-6-11	1973	PetroFina	Colville Lake	67.00	68.00	126.00	126.00
699-6-6-10	1973	Inexco Oil Co.	Peel Plateau	66.00	66.17	132.25	132.50
507-6-5-1	1973	Trans-Prairie	Carcajou River	65.35	65.75	128.00	129.00
531-7-4-1	1973	A. Brenner	Mackenzie River	64.17	64.33	124.00	126.00
531-7-7-3	1973	A. Brenner	Parry Peninsula	69.67	69.83	124.75	124.75
690-6-6-12	1973	Petro-Fina	Colville Lake	67.00	68.00	125.00	127.00
17-6-6-61	1974	Texaco	Peel Plateau	65.83	66.50	132.00	133.17
58-10-6-18	1974	Texaco	Peel Plateau	65.83	66.50	132.00	133.17
2-6-2-97	1974	Gulf	Satah River	66.00	67.00	134.00	135.00
76-6-6-30	1974	Great Plain	Chick L. / Kelly L.	65.00	67.00	125.00	130.00
57-6-5-84	1974	Mobil	Great Bear Plain	67.83	68.83	123.75	125.00
28-6-6-54	1974	Union	Peel Plateau	66.25	66.75	124.33	125.75
673-6-5-69	1974	Aquitaine	Great Bear Pl., Brackett L.	64.75	65.25	124.50	125.30
19-6-6-51	1974	Western Decalta	Tree River	67.17	67.50	131.75	132.75
58-6-5-17	1975	Texaco	Kelly L. / Thurton L.	65.00	66.00	126.00	127.00
7-6-5-175	1975	Esso Resources	Mackenzie Plain	65.00	66.00	127.00	130.00
5-6-6-44	1975	Dome	Rond Lake	65.83	66.67	128.00	127.00
57-6-6-86	1975	Mobil	Tadenet Area	67.00	69.00	125.00	130.00
746-6-5-1	1975	Mesa Petroleum Co.	Great Bear Lake	65.17	65.33	123.25	123.50
38-6-6-47	1975	Hudsons Bay Oil and Gas	Horton River	68.00	69.25	124.75	126.25
52-6-6-5	1975	Ashland	Colville Lake	67.00	68.00	125.00	127.00
58-8-5-19	1975	Texaco	Kelly L. / Thurton L.	65.50	66.00	126.00	127.00
690-6-7-14	1976	PetroFina	Carnwath River	67.00	68.00	128.00	130.00
57-6-7-100	1976	Mobil	Tadenet Lake	68.50	69.00	126.00	127.50
7-6-5-328	1978	Esso/ IMPERIAL	Norman Wells	65.25	68.30	126.25	127.00
19-6-5-56	1979	Western Decalta	Norman Wells	65.15	65.30	126.75	127.25
7-9-5-370	1979	Esso Resources	Norman Wells	65.00	65.60	126.00	127.00
7-9-5-356	1979	Esso Resources	Norman Wells	65.00	66.00	126.00	128.00
7-6-5-362	1980	Esso Resources	Norman Wells	65.00	65.50	126.00	128.00
7-9-5-367	1980	Esso Resources	Norman Wells	65.00	65.60	126.00	127.00
7-6-5-377	1981	Esso Resources	Norman Wells	65.00	66.00	126.00	128.00
246-6-5-108	1982	Petro-Canada	Anderson Plains	66.33	68.00	124.50	126.50
246-6-6-110	1982	Petro-Canada	Tweed Lake	65.33	67.50	124.50	128.00
7-6-5-367	1982	Esso Resources	Fort Norman	64.00	65.00	125.00	127.00
7-9-5-367	1982	Esso Resources	Fort Norman	64.00	65.00	125.00	127.00
246-6-5-114	1983	Petro-Canada	Lac- a- Jacques	65.83	68.17	126.50	128.50
9229-F9-2E	1983	Forward Resources	Tedji Lake	66.50	68.00	125.00	128.00
9229-N9-3E	1983	NSM Resources	Little Bear	64.67	65.10	125.50	127.00
9229-T21-1E	1983	Texaco	Norman Wells	65.00	66.00	127.00	129.00
246-6-4-112	1983	Petro-Canada	Carcajou	65.00	66.00	127.00	129.00
246-6-6-113	1983	Petro-Canada	Tweed Lake	64.00	67.00	124.00	129.00
246-6-5-115	1983	Petro-Canada	Sammons Creek	64.00	66.00	125.00	130.00
9229-N9-6E	1983	NSM Resources	Little Bear	64.67	65.10	125.50	127.00
9229-F9-5E	1984	Forward Resources	Rond Lake	65.67	67.33	124.00	129.00
9229-F9-7E	1984	Forward Resources	Tedji Lake	66.50	68.00	125.00	128.00
9229-J1-2E	1984	Esso Resources	Fort Norman	64.00	65.00	124.00	126.00
9229-C4-1DA	1985	Chevron	Fort Good Hope	66.33	66.50	128.75	129.75
9229-P28-2E	1985	Petro-Canada	Blackwater Lake	64.00	64.83	121.50	124.25
9229-P28-3E	1985	Petro-Canada	Mahoney Lake	65.50	66.50	125.00	127.50
9229-S40-1P	1985	Sigma	MacKenzie Basin	63.50	65.00	127.00	131.00
9229-A31-1E	1985	Texaco	Norman Wells	65.17	64.67	127.25	128.50
9229-C55-1DA	1986	Canterra	Norman Wells	66.25	66.25	130.25	130.25
9229-P28-4E	1986	Petro-Canada	Lac- a- Jacques	67.25	68.00	126.00	128.00
9229-P28-5E	1986	Petro-Canada	Blackwater Lake	64.00	66.17	121.50	124.75
9229-P28-7E	1986	Petro-Canada	Tweed Lake	66.17	67.17	125.25	126.75
9229-P28-10E	1986	Petro-Canada	Brackett lake	65.00	65.33	125.00	125.75

NEB file	Date	Operator	Area	Minimum latitude	Maximum latitude	Minimum longitude	Maximum longitude
9229-P28-11DA	1986	Petro-Canada	Mountain River	65.33	66.33	128.25	131.00
9229-P28-12E	1986	Petro-Canada	Tweed L. / Colville L.	66.00	68.17	125.00	127.00
9229-P28-13E	1986	Petro-Canada	Tweed L. / Colville L.	66.00	68.17	125.00	127.00
9229-J1-4E	1986	Esso Resources	Campbell Lake	67.00	67.00	134.00	134.00
9229-J1-2E	1986	Lithoprobe	Beaufort Sea	68.16	69.50	132.75	135.00
	1986	Lithoprobe	Mackenzie Delta	68.10	69.25	133.00	135.00
	1986	Lithoprobe	NWT	68.10	69.25	133.00	135.00
937-C55-2E	1987	Canterra	Mackenzie Valley	65.00	67.00	125.00	130.00
9229-C90-1E	1987	Conoco	Little Bear	64.00	65.00	125.00	126.00
9229-P28-18E	1988	Petro-Canada	Hoosier Ridge	65.33	65.50	127.17	127.50
9229-C4-2E	1988	Chevron	Fort Good Hope	65.00	66.00	128.00	129.00
9229-C55-1E	1988	Canterra	Fort Good Hope	66.33	66.83	126.50	121.10
9229-C4-3E	1988	Chevron	Fort Good Hope	65.00	67.00	128.00	131.00
9229-C4-4E	1988	Chevron	Fort Good Hope	65.00	67.00	128.00	131.00
9229-C4-5E	1988	Chevron	Fort Good Hope	65.00	67.00	128.00	131.00
9229-C4-7E	1989	Chevron	Fort Good Hope	65.00	67.00	128.00	130.00
9229-C4-8E	1989	Chevron	Fort Good Hope	65.00	66.00	128.00	130.00
9229-M3-1E	1989	Mobil	Fort Good Hope	65.00	66.00	129.00	130.00
9229-A4-1E	1990	Amoco	Peel Plateau	65.75	66.25	130.00	131.25
9229-C4-1E	1990	Chevron	Hume River	66.00	66.00	129.00	129.00
9229-C4-10E	1992	Chevron	Fort Norman	64.00	65.00	124.00	126.00
9229-J1-6E	1992	Esso Resources	Norman Wells	65.25	65.33	123.75	123.85

Appendix C
Seismic interval velocities of Proterozoic units as derived from exploration well sonic logs

Proterozoic unit	Well	Interval vel. ft./s	Interval vel. m/s	Average vel. for unit m/s
M/S Assemblage	Sammons	16400	4999	
	Blackwater G-52	18000	5486	
	Blackwater I-54	16000	4877	
	Blackwater E-11	18000	5486	
	Caribou N-25	18000	5486	5267
Tweed Lake Assemblage	Tweed A-67	17224	5250	
	Nogha	18045	5500	
	Tweed M-47			
	Bele			5375
DL Assemblage	Sadene D-2	17000	5182	
	K'Ahbami	20669	6300	
	Tedji K-24	16000	4877	
	Ewekka C-11	16404	5000	
	N. Colville L-21	15500	4724	
	Tenlen A-73	23000	7010	
	Colville E-15			
	Belot Hills M-63	19000	5791	
	Belot Hills M-63	13000	3962	
	Camp M-61	21325	6500	
	Aubry J-13	21325	6500	
	Colville D-45	14000	4267	
	E. Maunoir M-48			
	Ontadek L. N-39			
	Tunago N-37	15092	4600	
	Good Hope A-40			
	N. Tweed C-12	21325	6500	5087
Syntectonic Unit of HB Assemblage	Izok D-11	19685	6000	
	Iroquois I-11	22000	6706	
	Iroquois D-40	16000	4877	
	Grandview L-26			
	Ontaratue K-4	16000	4877	
	Ontaratue H-34	22000	6706	5833