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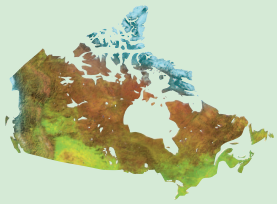

# Updates to the Cambrian basin of the northern Northwest Territories

*B.C. MacLean*

Geological Survey of Canada

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**Abstract:** A remapping of the subsurface of the mainland Northwest Territories is nearing completion with an Open File in preparation. One of the new maps provides additional detail to our understanding of a portion of the Cambrian basin and reveals the presence of a central graben system at its core. Rifting of Mackenzie Trough was preceded by uplift and occurred in two phases. The first, during deposition of the Mount Cap Formation, was most active in the south during *Glossopleura* time; the second, after a short hiatus, was during deposition of the Saline River Formation. The Good Hope depocentre is more complex than previously mapped and deepens southwestward into north Mackenzie Trough which, in turn, deepens southward into south Mackenzie Trough. A major Laramide thrust fault is revealed by seismic data to be an inverted Cambrian normal fault.

**Résumé :** Une nouvelle cartographie géologique du sous-sol de la partie continentale des Territoires du Nord-Ouest est presque terminée, et un dossier public est en préparation. Une des nouvelles cartes présente des détails supplémentaires permettant d'améliorer nos connaissances sur une partie du bassin cambrien, et révèle la présence d'un système central de grabens au cœur du bassin. Le rifting de la cuvette de Mackenzie a été précédé d'un soulèvement et s'est produit en deux phases. La première, pendant le dépôt de la Formation de Mount Cap, a été plus active dans le sud durant la période correspondant à la zone à *Glossopleura*; la seconde, après un bref hiatus, a eu lieu pendant le dépôt de la Formation de Saline River. Le dépocentre de Good Hope est plus complexe que la cartographie antérieure ne le laissait supposer, et s'approfondit vers le sud-ouest dans la partie nord de la cuvette de Mackenzie, laquelle s'approfondit à son tour vers sa partie sud. Une faille de chevauchement majeure associée à l'orogenèse du Laramide a été révélée par les données sismiques comme étant une faille normale d'âge cambrien dont le mouvement a été inversé.

## INTRODUCTION

The Cambrian basin under the northern Interior Plains in the Northwest Territories is one of considerable economic importance. It has been the scene of recent oil and gas exploration successes (Drummond, 2009; Price and Enachescu, 2009) and a newly completed assessment estimates that the basin contains about 20 per cent of the total oil volume of the interior platform and the ten largest undiscovered pools, as well as almost 20 per cent of the total gas and six of the largest ten undiscovered gas pools (Hannigan et al., in press). The most thorough and comprehensive published study of the Cambrian stratigraphy of the western mainland of the Northwest Territories available today is that of Dixon and Stasiuk (1998), a report based largely on outcrop measurements and well data. A multi-disciplinary study of the subsurface stratigraphy and structure of the mainland Northwest Territories, relying heavily on seismic-reflection data, has since been undertaken by the present author, and an Open File is being prepared that will present a series of maps and cross-sections. One of the new maps, a pseudo Cambrian isopach, duplicates a portion of one of the Dixon and Stasiuk figures. This note provides a comparison of the pre- and post-seismic maps and illustrates the contribution made by seismic-reflection data to our understanding of the basin.

## DATA

Outcrop, borehole, seismic, and potential field data were all incorporated into the new study. Information from more than 500 boreholes within the study area was largely derived from the published literature, including important summaries of the Cambrian by Dixon (1997) and Dixon and Stasiuk (1998). Ties to seismic data were enabled by use of more than 160 synthetic seismograms derived from sonic and density logs. Over 1100 seismic-reflection lines (Fig. 1), acquired by the petroleum industry and released to the public under Federal Regulations after a period of confidentiality, were interpreted on a digital workstation.

## OVERVIEW

Cambrian strata within the study area include the Mount Clark, Mount Cap, and Saline River formations plus the lowermost part of the predominantly Ordovician Franklin Mountain Formation (Fig. 2). Mount Clark Formation consists mainly of quartz sandstone and is a proven gas reservoir within the study area. The Cambrian succession was deposited on Proterozoic strata within a semi-enclosed, epicontinental marine basin, bordered by positive elements and open, possibly by way of Mackenzie Trough, to a continental shelf and its associated oceanic basin. The basin was subdivided into various tectonic and paleogeographic elements by Williams (1987), Pugh (1983), and Dixon and Stasiuk (1998). MacLean and Cook (1999), with the aid of seismic-reflection data, added Mackenzie Trough, a thick graben lying between Mackenzie Plain depocentre and Mahony Arch.

## 1998 MAP

Among the several maps included in Dixon and Stasiuk (1998) is one showing the thickness of the interval between the base of the Mount Clark Formation and top of the Saline River Formation (their Figure 5). The full map extended from 62° to 70° north and 116° to 132° west and encompassed the entire Cambrian basin. That portion of the map lying within the limits of the recent seismic study is reproduced in Figure 3. Although based on relatively few data points (<500 wells and <10 outcrops) irregularly distributed over almost 325 000 km$^2$, the map succeeded both in outlining the basin and revealing most of its tectonic elements. Contours, by necessity, are smooth and lacking in detail.

The western boundary of the basin is defined by the depositional onlap edge of Saline River strata on the east flank of Mackenzie Arch. Other depositional edges outline Mahony and Bulmer arches and areas of thicker strata are identified as depocentres.

### Tectonic elements

Mackenzie Arch is the name applied by Gabrielse (1970) and Aitken et al. (1973) to a northwest-trending Proterozoic to Cambrian structure that passes through the Mackenzie Mountains and merges with Mackenzie Platform under Peel Plain. It separates the Mackenzie and Selwyn basins and likely provided the restrictive barrier necessary for development of hypersaline marine conditions and precipitation of Saline River Formation evaporites.

Peel Arch (Williams, 1987) lies within the eastern portion of the Mackenzie Platform (Lenz, 1972), the Cambrian to Middle Devonian shelf platform that separated the coeval Richardson Trough from the epicontinental basin.

Bulmer Lake Arch was recognized by Meijer Drees (1974) as a north-northwest-trending paleotopographic and tectonic feature in the Bulmer Lake area.

Mahony Arch was the name applied by Pugh (1993) to a northwest-trending Cambrian high passing below Mahony Lake. It roughly parallels Mackenzie Arch and separates Good Hope Basin from Mackenzie Trough (Keele Trough of Pugh (op. cit.)).

Good Hope depocentre is the name used by Dixon and Stasiuk (1998) for Good Hope Basin, which was the name given by Pugh (1993) to a broad, shallow, Cambrian depression northeast of Mahony Arch.

The ridges and depocentres in the northern portion of the basin are much more subtle than those found further south. The Aubry depocentre is a shallow feature located west of

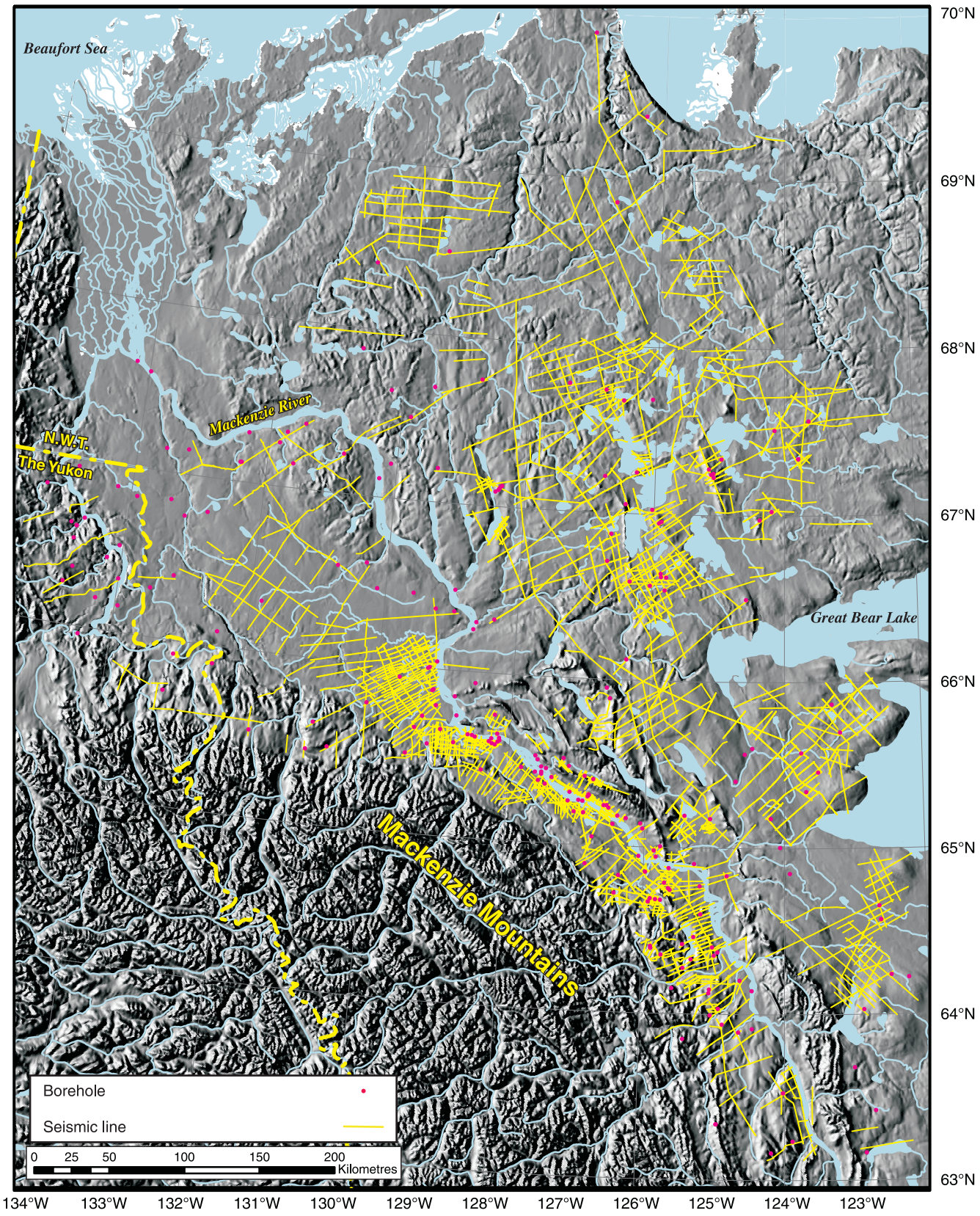


**Figure 1**. Map showing locations of petroleum industry boreholes and seismic-reflection lines plotted on a digital elevation model.

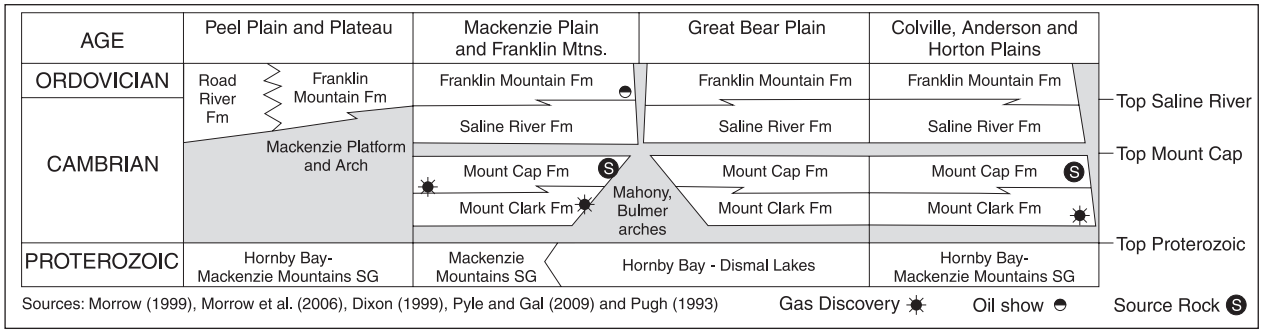


**Figure 2.** A portion of the stratigraphic column for the northern Interior Plains of the Northwest Territories showing the Cambrian through Ordovician section.

Aubry Lake. It is separated from the Horton depocentre by a northwest-trending low-amplitude feature named Maunoir Ridge by Dixon and Stasiuk (1998). Dixon and Stasiuk (op. cit.) suggested that Maunoir Ridge might be related to a large scale antiform within the underlying Proterozoic strata shown in Figure 4 of Cook and MacLean (1992).

## 2011 MAP

### Construction

To construct the new map (Fig. 4), seismic lines were converted into digital format, loaded into a workstation, and shifted to a common datum of 305 m (1000 feet) a.s.l. They were then tied to borehole data, using synthetic seismograms where available. Depths at which horizons had been penetrated by the boreholes (well picks) were obtained from GSC Calgary's Sample and Analysis Management System (SAMS) database. Most of the SAMS picks for the Cambrian section were those of Dixon (1997). As the seismic grid was being interpreted, there were occasions when the seismic pick at a borehole location disagreed with the SAMS entry. When such an occasion arose the author was fortunate in being able to discuss the problem with J. Dixon of GSC Calgary, who was most helpful. Sometimes the well pick was revised and the database updated, sometimes the seismic correlation was changed.

Reflection time picks for every shotpoint were then exported from the workstation and, after format editing in MS Word® and Excel®, imported into Esri™ ArcMap™. Faults were copied manually from the seismic displays into ArcMap. Contouring of the data produced a series of 'seismic time structure maps' and 'seismic time thickness maps'. Conversion of the maps from units of reflection time to metres required an estimate of the velocity field for each horizon: that is, a map of the velocity at which the seismic wave pulse travelled through the overlying rock strata. A spreadsheet was built containing the well picks and their corresponding seismic-reflection times. Well picks were adjusted to match the seismic datum and velocities were then calculated at each well using the formula [(depth * 2)/ reflection time]. When contouring the velocity values, care was taken to shape the contours between well control points such that regional depth and thickness trends were honoured. Grids of the time and velocity fields were calculated within ArcMap and used to calculate a depth grid using the formula [velocity * (reflection time / 2)]. The resulting rough contours needed considerable editing, particularly across faults where limitations in the software's gridding algorithm had created spurious anomalies. Contours were trimmed so as not to extend into areas without seismic control.

The topic of depth conversion will be explored more thoroughly in the Open File, but it is important to note here that calculation of a velocity field over a wide area using a limited number of well penetrations as data points (32 in this case), and the use of machine gridding, necessarily limit the reliability of the depth map in the areas between control points. However, the map is more than sufficient to identify regional trends and individual features at the scale produced here.

### Insights from map

The addition of seismic-reflection data to existing well and outcrop data has led to a new map of the Saline River Formation to Proterozoic (base of Mount Clark) interval (Fig. 4). Irregularities in the areal distribution of data (Fig. 1) constrained map detail in some areas, as did variations in the clarity of the seismic sections.

The new map confirms overall basin configuration and features identified by earlier workers, but provides considerably more detail, including fault information, and adds a new graben to the list of known tectonic elements.

Beginning in the west, irregularities in the depositional onlap edge reveal old indentations and promontories on Mackenzie Arch. An opening to the northwest beyond the data grid suggests a paleo-low or saddle in the surrounding high ground. The existence of Maunoir Ridge and its flanking shallow depocentres are confirmed, but the shapes and positions of these elements are altered. Good Hope depocentre is shown to be more complex than previously

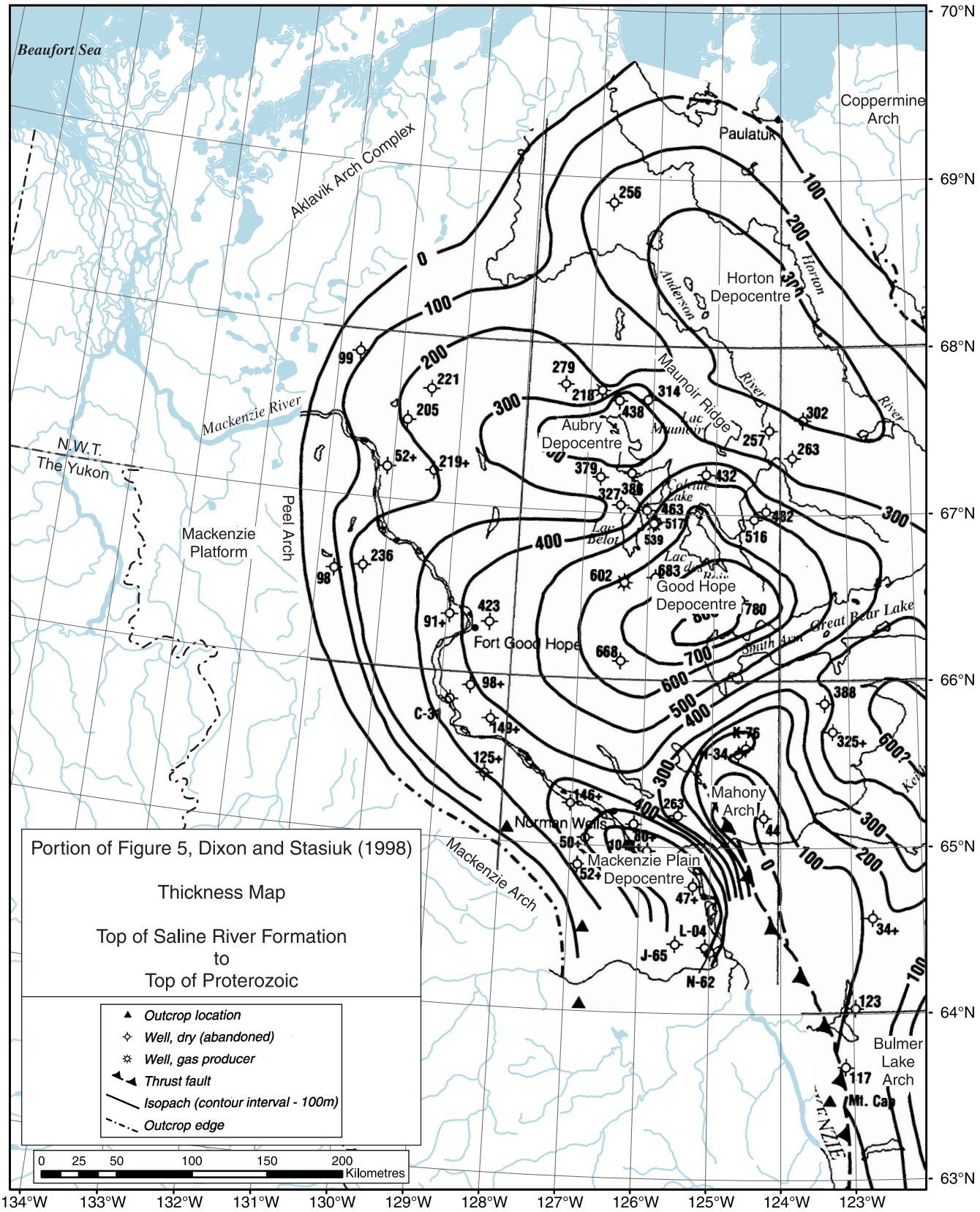


**Figure 3.** A portion of a 1988 vintage map of the thickness of the top of the Saline River Formation to the top of the Proterozoic, based largely on borehole and outcrop data. The zero contour outlines the areal extent of the late Cambrian basin. *From* Figure 5 of Dixon and Stasiuk (1998).

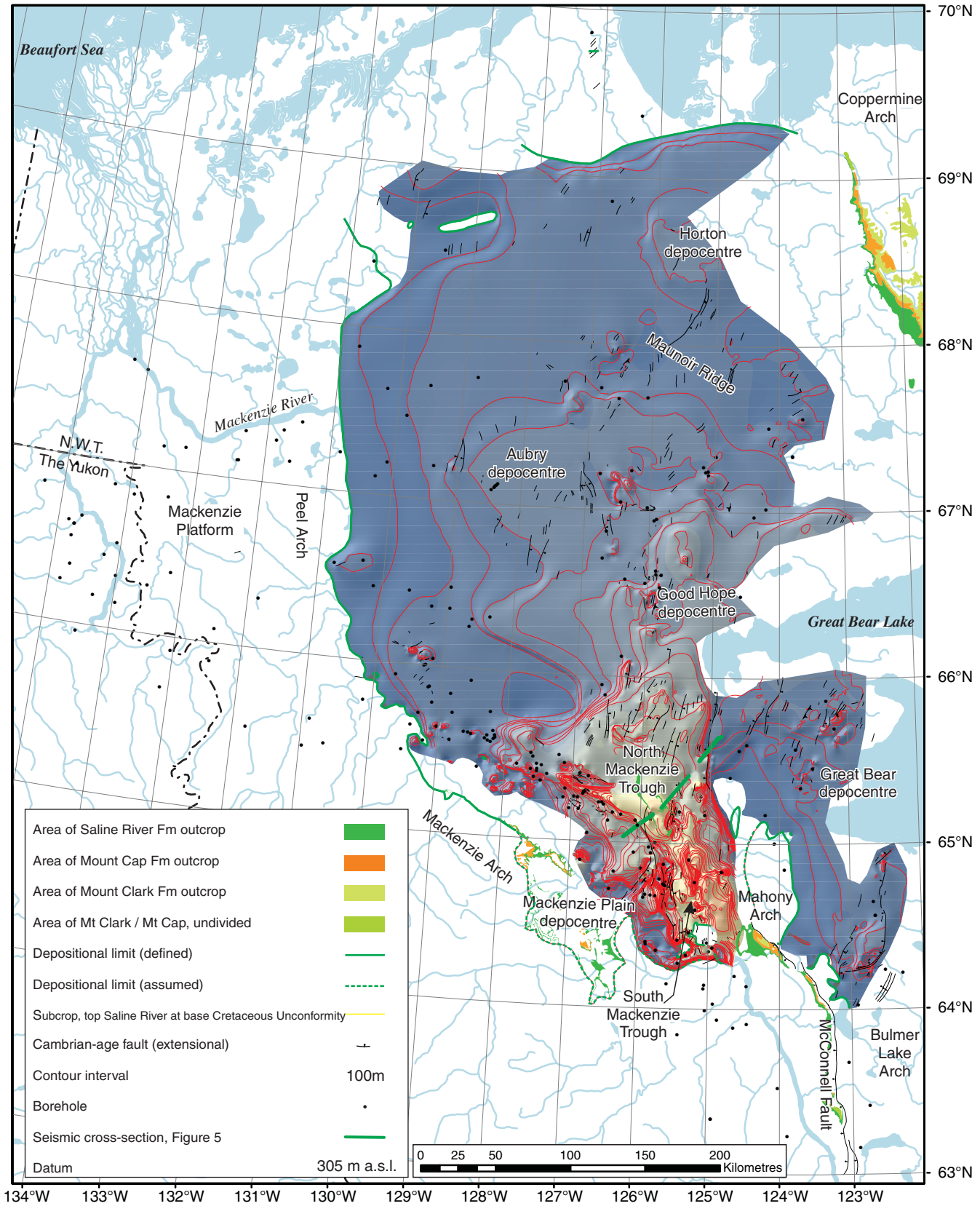


**Figure 4.** Map showing the thickness of the interval between the top of the Saline River Formation to the top of the Proterozoic as derived from outcrop, borehole, and seismic-reflection data. The depositional edges of Saline River Formation outline the areal extent of the late Cambrian basin; thickness trends provide an estimate of its vertical dimension.

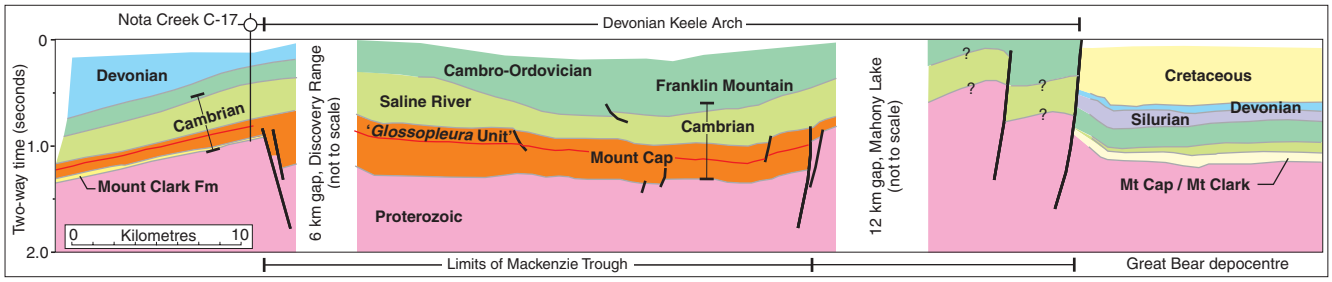


**Figure 5.** A section across Mackenzie Trough based on an interpretation of Ranger Oil Line F02 (Ranger Oil Ltd., report filed with the National Energy Board under Program ID 5553763, 1996), Devon Line 72695 (Devon ARL Corporation, report filed with the National Energy Board under Program ID 5553578, 2001) and British Petroleum Line 2 (British Petroleum Exploration Canada Ltd, report filed with the National Energy Board under Program ID 5550662, 1975). Thickening of 'sub-*Glossopleura* Unit' strata into the graben is evidence of an early onset of rifting. Datum is 305 m (1000 feet) a.s.l. *See* Figure 4 for location.

mapped and to not extend beyond 127° west but rather to deepen southwestward into north Mackenzie Trough, which, in turn, deepens southward into south Mackenzie Trough.

Mackenzie Trough is the name assigned by MacLean and Cook (1999) to an Early and Middle Cambrian fault-bound graben located between the Mackenzie and Mahony arches. It is the site of anomalously thick Mount Cap and Saline River strata and is in part coexistent with the later developed Keele Arch. MacLean and Cook (op, cit.) proposed the descriptive term Keele Tectonic Zone in acknowledgment of its long tectonic history of multiple structural inversions.

Seismic-reflection data across the trough (Fig. 5) reveal important features and information regarding its development over time. The thinning of the basal Mount Clark Formation on the west flank of the structure is evidence that the graben may have been preceded by a broad uplift. The '*Glossopleura* Unit' was correlated from the Shell Keele River L-04 well where MacLean and Cook (1999) described it as corresponding to *Glossopleura*-bearing shales (Fritz, 1970). Rifting during Mount Cap deposition produced a full graben and was most active before '*Glossopleura* Unit' time. Extension and subsidence were renewed during deposition of Saline River Formation with the graben expanding eastward, possibly as a half graben. The graben complex continued to collect thick sediment through at least some of Franklin Mountain Formation deposition. The absence of post-Franklin Mountain Formation strata is a product of inversion of the graben during pre-Devonian time to form a segment of Keele Arch. The easternmost fault was a normal fault during Saline River deposition but inverted during the Laramide Orogeny to become the east bounding fault of the informally named 'St Charles Range'.

An approximately 50 km wide zone of thicker Cambrian strata runs northward from the south end of Mackenzie Trough where it is thickest (Fig. 4), then northeastward through the north Mackenzie Trough, northward into Good Hope depocentre, and then northwestward into the east Aubry depocentre. Work is underway to test if this represents a central rift system related to the break-up of Rodinia.

In the area lying east of Mackenzie Trough, the outline of Mahony Arch has been enlarged, Bulmer Lake Arch and Good Hope depocentre confirmed, and a large normal-fault complex discovered north of Bulmer Lake Arch. West of this feature, an irregular depositional edge reveals either a new, unnamed high, or a northern spur to Bulmer Lake Arch.

## SUMMARY

Seismic data, when supported by a consistent set of well and outcrop control data, is a powerful tool in advancing our subsurface knowledge. In this case it has confirmed the broad outlines of our earlier understanding of the Cambrian basin (Dixon and Stasiuk, 1998) and has added significant detail and new insights into the tectonic and stratigraphic evolution of an economically important package of rock.

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