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BeaufortSPAN™ East Phase IV Illuminates Deep Rift Architecture of the Canada Basin

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Summary

An infill, long-offset, seismic survey was shot in the summer of 2010 using specialized new technology for acquiring data in first-year ice-covered areas in the Canadian Beaufort Sea from Herschel Island in the south to the McClure Strait in the north, extending earlier coverage into water depths of between 500 to 2,500 m. These new seismic data confirm our observation that the Beaufort-Mackenzie margin may be subdivided into three segments, the "foldbelt" segment off Herschel Island, dominated by compressional tectonics, the "Tuk" segment off the Tuktoyaktuk Peninsula, dominated by strike-slip tectonics, and the "Banks" segment off Banks Island, dominated by extensional tectonics. The infill data and extended coverage into deeper water permit new geological observations, including from southwest to northeast: 1) recognition that the Beaufort-Mackenzie fold-belt extends in the form of foreland thrusts that terminate in subtle fault-propagation folds some 20-50 km to the north into areas previously mapped as undeformed, 2) recognition of a very deep (> 20 km) and rugose top of oceanic crust in the vicinity of the presumed extinct spreading center that is inferred from gravity data in the central Canada Basin, 3) imaging on at least six new lines of the continent-ocean boundary (COB) offshore Banks Island and recognition of a regional roll-over structural trend perhaps 200 km in strike extent that is related to an extensional break-away fault system, with hints on some lines of compressional toe thrusts some 50 km outboard and down-dip, 4) recognition of Ellesmerian deformation in Paleozoic strata underlying the McClure Strait, and 5) documentation the of coincidence between anticlinal structures cored by Paleozoic strata and two positive gravity anomalies, each on the order of tens of km in width and > 100 km in length, just landward of the COB offshore Banks Island and off the Tuktoyaktuk Peninsula.

Introduction

Infill lines and new lines in the McClure Strait - a previously seismically uncharted area - for a deep, long-offset seismic reflection survey were acquired in 2010 in the Canadian Beaufort Sea from Herschel Island to McClure Strait (the BeaufortSPAN East Phase IV survey) and are shown in black in Figure 1. The previous phases of acquisition including Phases I (purple), II (red) and III (green) are also shown in Figure 1. New seismic data acquired in 2010 in the shallow-water transition zone adjacent to the Tuktoyaktuk Peninsula

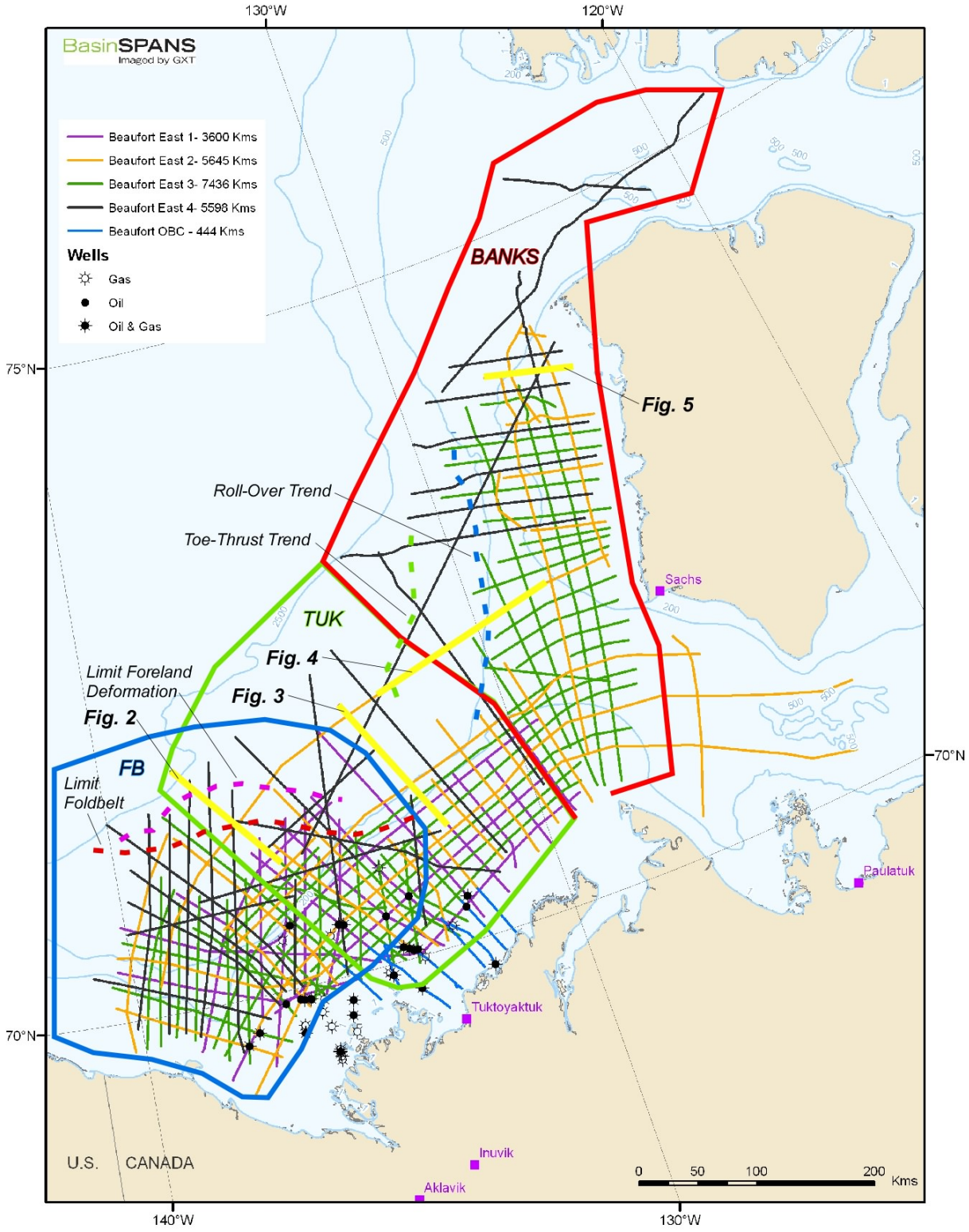

Figure 1: The BeaufortSPAN East seismic survey (Phase I in purple, II in yellow, III in green and IV in black). OBC lines acquired in 2010 are shown in blue. Also shown are the locations of three tectonically-defined segments (FB = Foldbelt, TUK = Tuktoyaktuk, and BANKS = Banks Island) and tectonic elements recognized herein, and seismic illustrations (Figures 2-5).

(shown in blue in Figure 1) are still in early phases of processing and it is premature to comment on them, except that it is anticipated that they will help to correlate structures mapped in the offshore (Phases I-III), with structures such as the Taglu and Eskimo Lakes Fault Zones and the Kugmallit Trough that have been mapped in detail onshore. The Phase IV seismic lines provide a general infill to the existing seismic program and have reduced the average spacing of dip lines of 4 – 9 km in the Beaufort Foldbelt and of 6 - 14 km off Banks Island. The infill data have also confirmed the key interpretational insight, gained from the first three phases, i.e. that the Canadian Beaufort Sea margin is segmented into three distinct tectonic domains that are defined by their orientation and structural style, and may be characterized as 1) an E-W-trending "foldbelt" segment in the vicinity of Herschel Island that is dominated by compressional structures, 2) a NE-trending "Tuk" segment in the vicinity of the Tuktoyaktuk Peninsula that is dominated by wrench structures, and the "Banks" segment off Banks Island that is characterized by typical passive-margin structures. A comprehensive report of these findings is found in Helwig et al (2010). The new findings come from seismic coverage that extends into deeper water than the previous data, from 500 to 2,500 m, which allow the observation of many features not previously imaged, and these are discussed in the section on "Interpretation", below. Furthermore, due to the typically extreme ice conditions in the Beaufort-Mackenzie area there has been sparse modern-day seismic acquisition and very little was previously known about the deeper parts of the basin.

Data Acquisition and Processing

Acquisition of seismic data in the area has historically been hampered by ice coverage. Although the 2010 acquisition season was not particularly ice-free the difficulties with ice were diminished by utilizing a proprietary streamer and deployment technology to acquire data below the pack ice. In addition, an icebreaker was used to clear first-year ice for the primary acquisition vessel. As a result, data could be acquired in a relatively regular grid (Figure 1) even in areas that were not ice-free at the time of acquisition.

Acquisition parameters included a 25 m shot interval, 12.5 m group interval and maximum offset of 9000 m. The record length was 18 sec, and the data were processed to pre-stack time (PSTM) images of 16 sec and pre-stack depth (PSDM) images of 40 km record length. Pre-stack depth migrated (PSDM) seismic lines are used for the interpretation which was tested iteratively against gravity and magnetic modeling.

Interpretation

Five figures illustrate the new observations. They are final PSDM images from previous phases of data acquisition. Many of the new observations were originally noted in the prior vintages, but it is only with the new acquisition that the regional extent of these features could be documented. Figure 2 is from the Foldbelt segment and shows the extent of subtle foreland structuring approximately 40 km to the north of the previously-recognized limit of foldbelt deformation (Lane, 1998). Fault-propagation folds at the termination of blind thrusts are seen on several new lines. This observation was anticipated from prior seismic vintages. Figure 3 is from the "TUK" segment dominated by wrench-style structures and shows previously-recognized oceanic fracture zones that traverse this central segment of the Beaufort margin. This illustrates the rugosity of the oceanic crust but does not fully illustrate the oceanic spreading ridge which is seen on the new lines though their current state of processing is at present immature. Figure 4 is from the "BANKS" segment and shows a regional roll-over structure and a related toe-thrust system. Figure 5 illustrates an anticline developed in Paleozoic strata that coincides with the axis of a gravity anomaly that has a width > 20 km and a strike length > 100 km. A similar relationship is observed along the TUK segment to the south. Both structures may be shown on the basis of the new data to track consistently along gravity anomalies that have a width > 20 km and a strike length > 100 km.

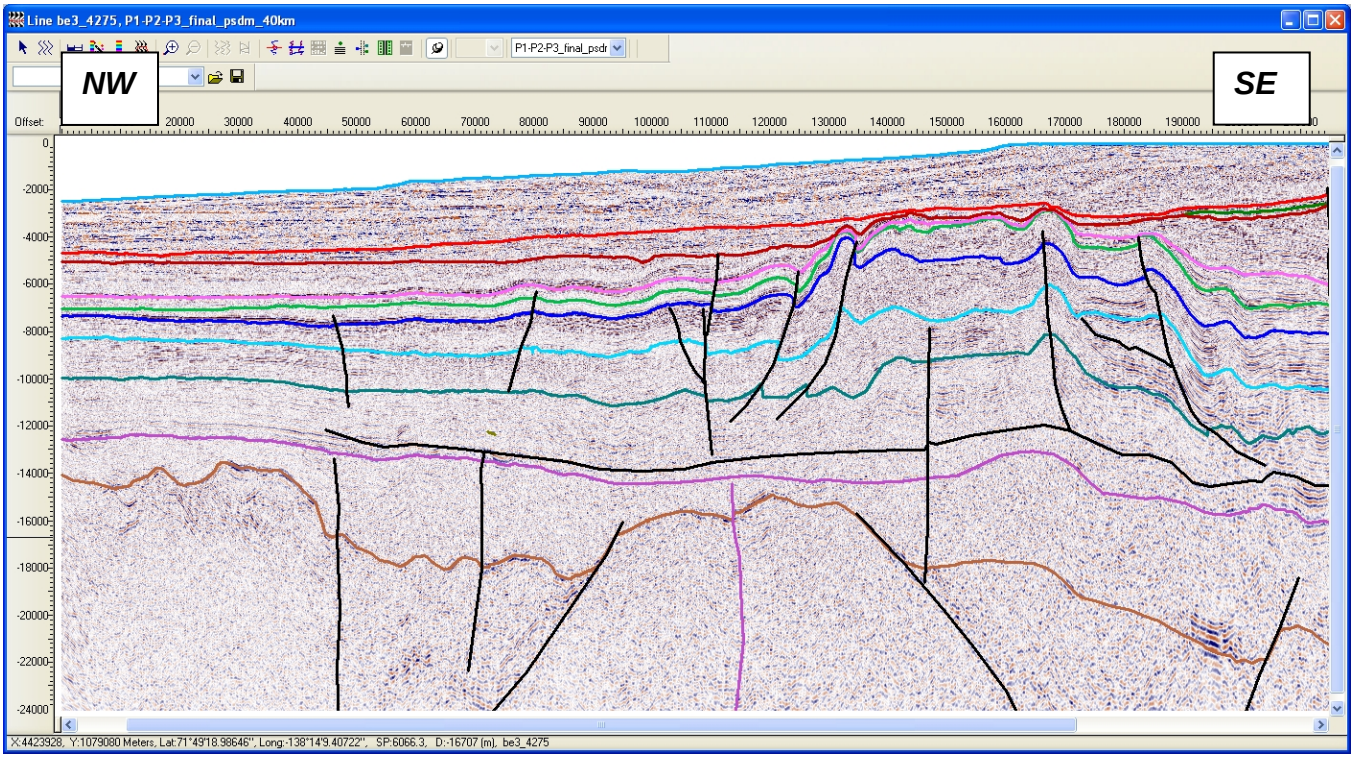

Figure 2: Foreland-style fault-propagation folds extending 20-50 km to the north of the limit of foldbelt deformation previously-mapped by Lane (1998).

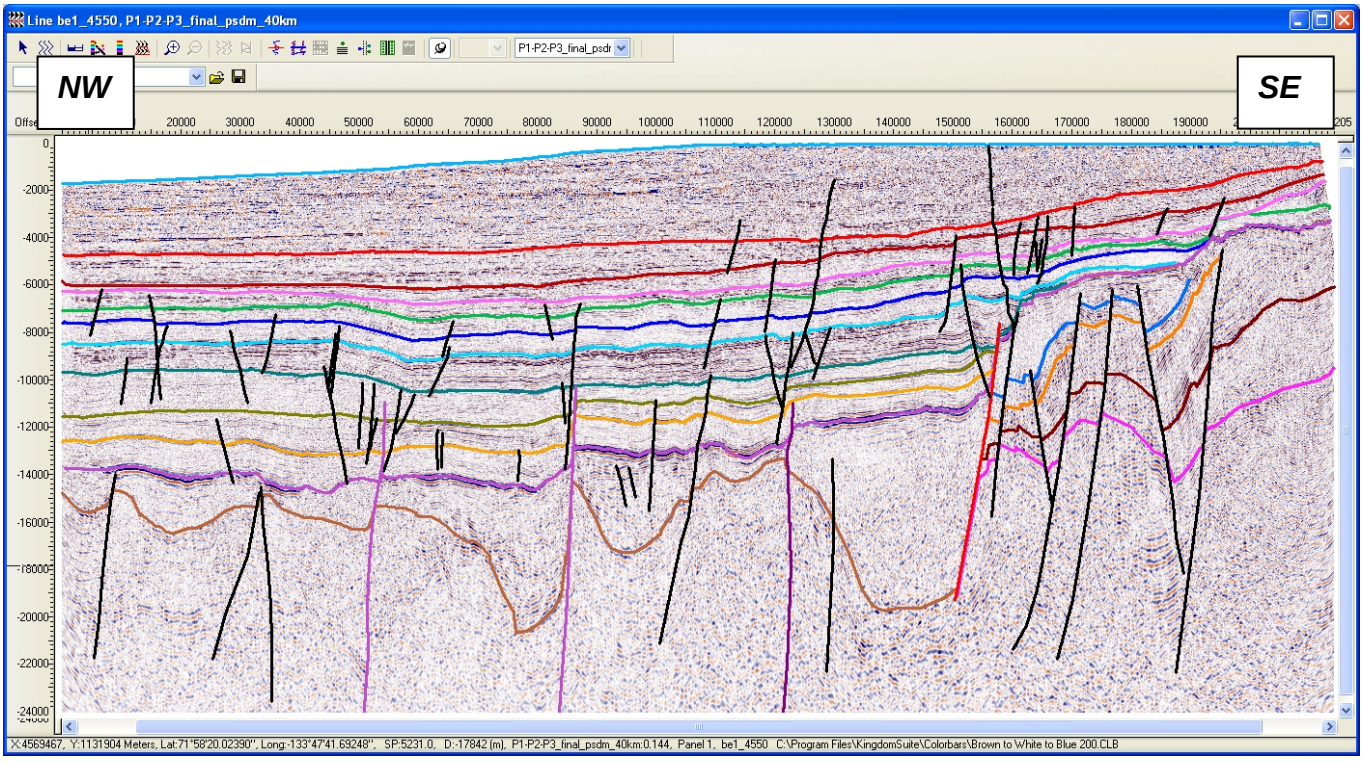

Figure 3: Rugose oceanic crust with oceanic transform faults along the “TUK” segment of the Beaufort-Mackenzie margin that is dominated by wrench structures.

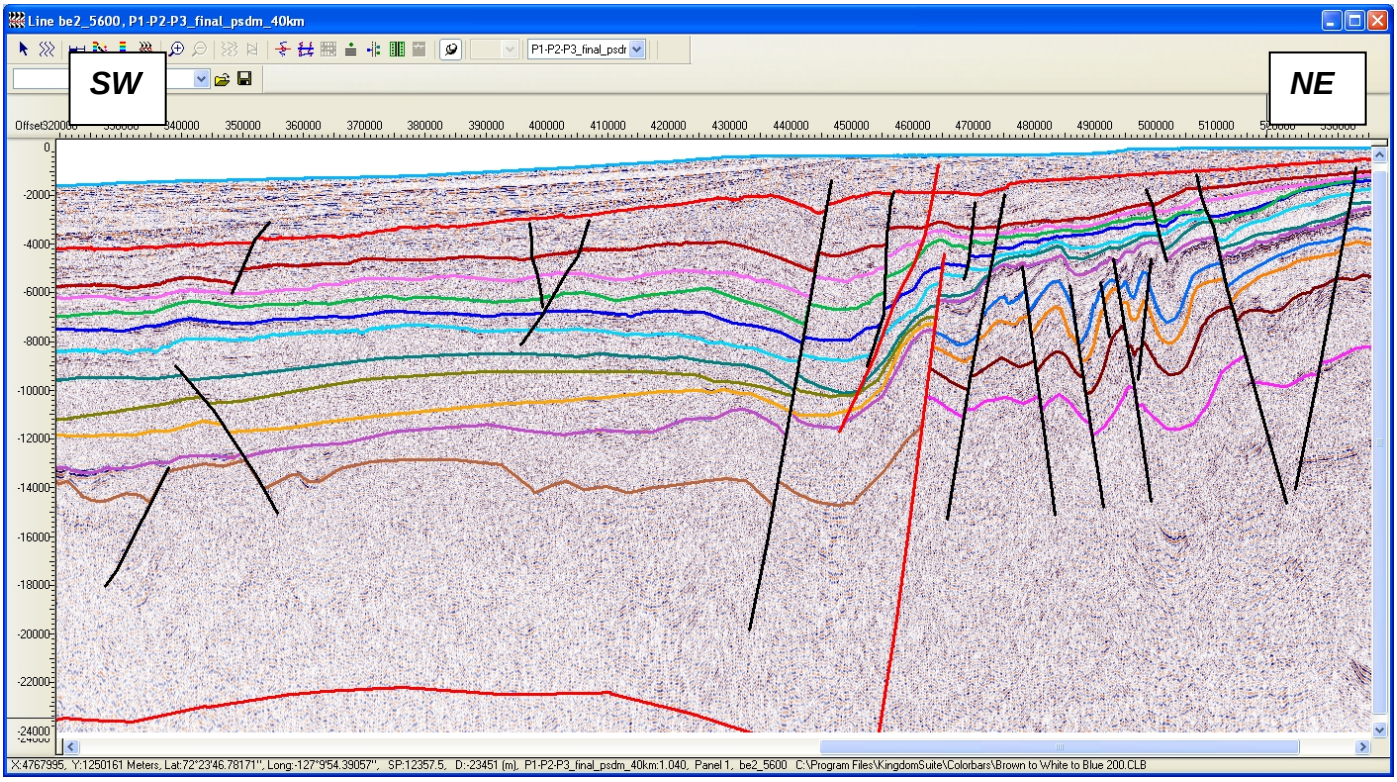

Figure 4: Break-away normal fault and linked toe-thrust along the “BANKS” segment of the Beaufort-Mackenzie margin which is dominated by typical passive-margin structures. The roll-over and toe-thrust structures appear to be of regional extent.

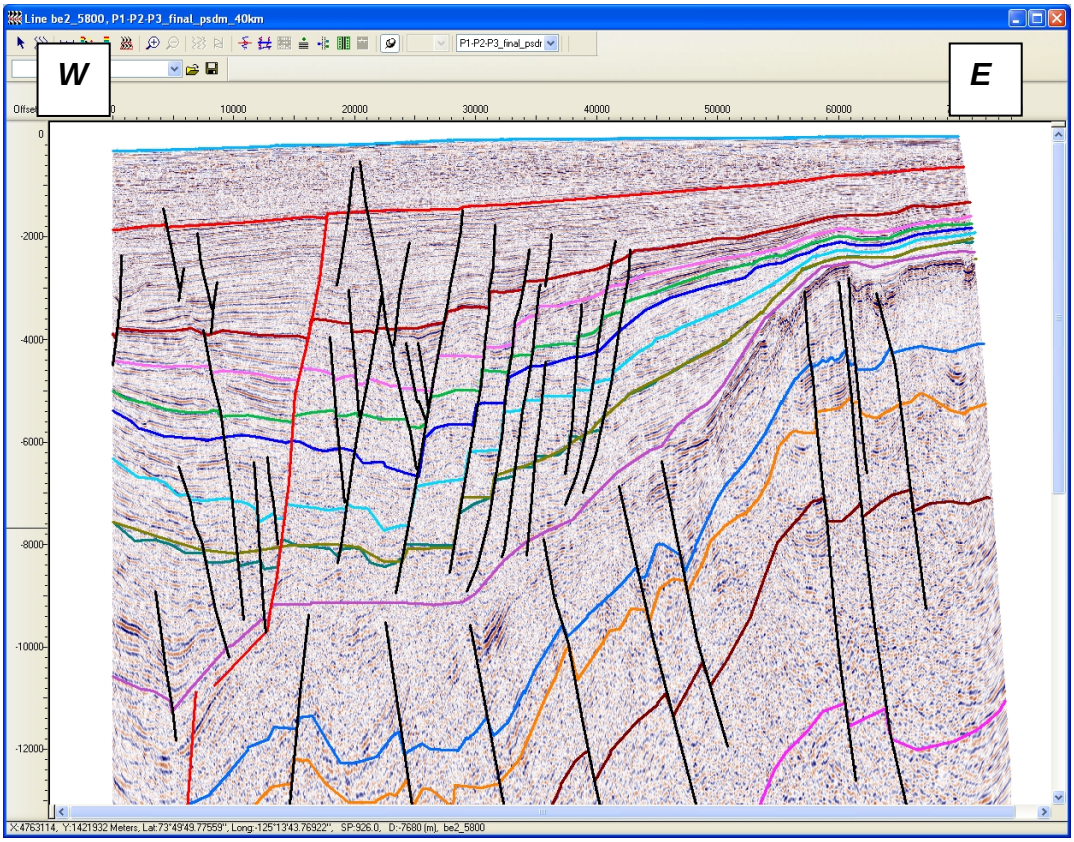

Figure 5: Anticlinal structure developed in Paleozoic strata that coincide with a regionally-extensive gravity anomaly.

We have observed a high-amplitude reflection in the vicinity of the McClure Strait that correlates with the top of the Paleozoic section, probably the top of Devonian carbonates, on seismic lines along the northern margin of Banks Island. The new lines are still in the early phases of processing but show clear evidence of folding and faulting beneath this unconformity consistent with Ellesmerian deformation in this area as reported by Harrison and Brent (2005). We look forward to the final processing of these lines with great anticipation.

Conclusions

The new seismic data confirm earlier interpretations and add significant new observations about the deeper parts of the basin. The documentation of subtle structures to the north of the foldbelt in parts of the basin previously described as "undeformed" and the recognition of typical passive margin structures offshore Banks Island are not unexpected. But the imaging of relict sea-floor spreading ridges and graben structures in the oceanic crust at depths > 20 km are new and exciting observations. The imaging of the deformed Paleozoic strata in the McClure Strait is still a work in progress but reference to data from previous phases provides reason for optimism that some details may be resolved. The most significant findings, from an economic perspective, may be the recognition that two rather large gravity anomalies along the Banks and Tuk margins may be the expression of Paleozoic-cored anticlinal structures that may be prospective for hydrocarbons, or that may provide a positive structural drape above which hydrocarbon traps may have formed in younger sediments.

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