Preliminary observations on stratigraphy and hydrocarbon potential of middle to Upper Cretaceous strata, Eagle Plain basin, northern Yukon

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Jackson, K., McQuilkin, M., Pedersen, P.K., Lane, L.S. and Meyer, R., 2011. Preliminary observations on stratigraphy and hydrocarbon potential of middle to Upper Cretaceous strata, Eagle Plain basin, northern Yukon. In: Yukon Exploration and Geology 2010, K.E. MacFarlane, L.H. Weston and C. Relf (eds.), Yukon Geological Survey, p. 125-134.

ABSTRACT

The Eagle Plain basin, having proven hydrocarbon potential, is a relatively underexplored intermontane basin located in northern Yukon . Previous studies of the middle Albian-Cenomanian Parkin Formation and the Turonian Fishing Branch Formation are based on broad lithostratigraphic correlations. The primary goal of the study is to refine the sequence stratigraphic framework of the middle to Upper Cretaceous succession based on sedimentological observations. New findings from this study require subdivision of the stratigraphic nomenclature by defining new informal lithological members. Facies transitions, paleoflow indicators and isopach maps indicate overall westward deepening of the basin. Large-scale, sand-prone mass transport deposits observed in the upper part of the lower Parkin shale member in western Eagle Plain indicate the presence of shelf-to-basin floor relief of at least 100 m. Recognition of significant shelf-to-basin floor topography greatly increases the potential for hydrocarbon reservoirs (gas-dominated) in stratigraphic traps associated with the shelf edge.

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INTRODUCTION

This project is part of the Geo-mapping for Energy and Minerals (GEM) program conducted by the Geological Survey of Canada in collaboration with the Yukon Geological Survey and universities. GEM is a five year program (concluding in 2013) intended to provide new public domain geoscience information to identify the energy and mineral resource potential of northern Canada.

The objective of this study is to refine the stratigraphic framework for the middle to Upper Cretaceous succession of the Eagle Plain basin by integrating seismic, outcrop, core, well log and petrographic data, and to present some initial sedimentological interpretations. A concurrent biostratigraphic study will be incorporated to publish an updated hydrocarbon resource assessment of the succession. Comparison of new data with research from adjacent basins is also a priority, as it is vital to understanding regional-scale sedimentation patterns and paleogeography in northern Yukon and Northwest Territories.

FIELD RESEARCH

Eight weeks of cumulative field work was carried out in the summers of 2009 and 2010 in the Eagle Plain area. Eagle Plain consists of low-lying, rolling topography dominated by north-trending Laramide-aged structures of the Eagle foldbelt. The study area is located roughly between latitudes of 65°N and 67°N, and longitudes of 136°W and 139°W (Fig. 1).

The middle Albian-Cenomanian Parkin Formation and the Turonian Fishing Branch Formation are the primary units investigated in this study (Fig. 2). Over one hundred field samples were collected, from which key specimens were slabbed and sectioned for petrographic analysis. Shale samples were collected to study foraminiferal assemblages and Rock-Eval pyrolysis for organic geochemistry and thermal maturity.

REGIONAL STRATIGRAPHY

The Eagle Plain basin is a relatively unexplored intermontane basin with proven hydrocarbon potential located in northern Yukon. Out of 34 exploratory wells drilled in Eagle Plain since 1957, five encountered significant hydrocarbons. Well control is largely concentrated in the southern and eastern parts of the basin, and large gaps exist in our understanding of the subsurface.

Proterozoic to Quaternary-aged strata are preserved in the sedimentary record of Eagle Plain basin. The Cretaceous succession is up to 2 km thick and underlies the majority of the study area at surface. The middle to Upper Cretaceous succession of Eagle Plain consists of two major transgressive-regressive clastic cycles of the Eagle Plain Group, as defined by Dixon (1992a). Mountjoy (1967) assigned the type section of the Eagle Plain Group to outcrops along the Fishing Branch River in the western part of Eagle Plain basin (Fig. 3).

Eagle Plain was located at the northern terminus of the Cordilleran Foreland Basin during the middle to Late Cretaceous. Provenance is interpreted to be from the encroaching Cordilleran orogen to the south, while open-marine and offshore conditions prevailed to the north (Dixon, 1992a). Extensional tectonism was dominant during the middle Cretaceous, and syndepositional faulting may have had a significant influence on the basin profile.

Existing interpretations of Cretaceous basin morphology were based on lithostratigraphic correlations and suggested deposition in a broad, low-angle shelf setting in the Cordilleran Foreland Basin (Dixon, 1992a). However, observations from this study indicate greater stratigraphic complexity than previously recognized, necessitating subdivision of the current nomenclature (Fig. 4). Several new informal stratigraphic members are defined and discussed briefly in this report.

PRELIMINARY RESULTS AND DISCUSSION

DEVELOPMENTS IN STRATIGRAPHIC FRAMEWORK

PARKIN FORMATION

The Parkin Formation is described by Dixon (1992a) as consisting of a basal transgressive sandstone member and an overlying shale member which lies unconformably on lower Albian shales of the Whitestone River Formation. It is overlain gradationally by the regressive Fishing Branch Formation. Dixon (1992a) divided the Parkin Formation into a basal sandstone member and overlying shale member; the unit is further subdivided herein, based on observations from this study.

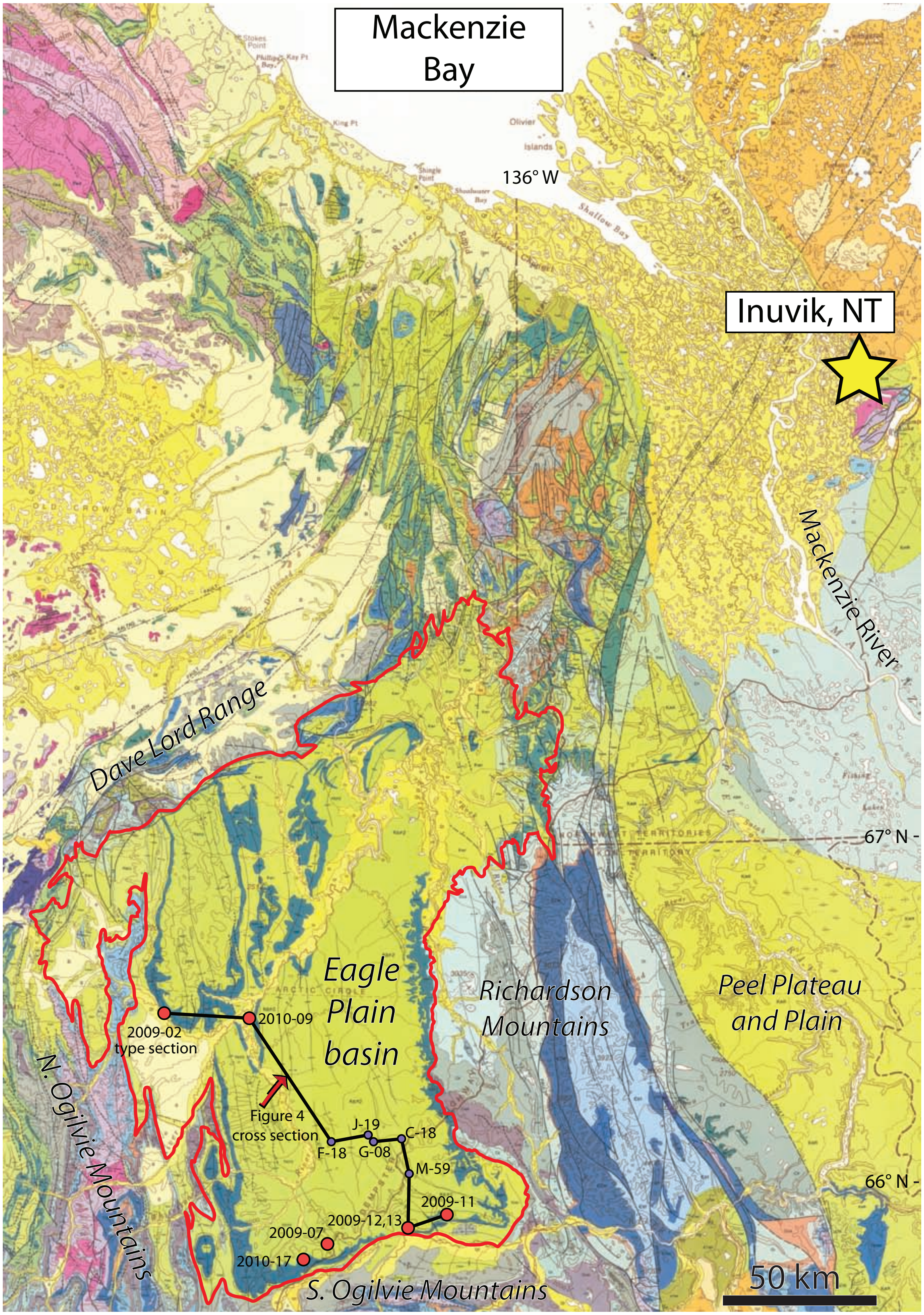

Figure 1. *Geological map of northern Yukon Territory and adjacent Northwest Territories indicating location of the Eagle Plain basin (outlined in red) and major geomorphological elements. Cretaceous bedrock (green and blue-green on map) underlies the majority of Eagle Plain at surface. (Modified from Norris, 1984)*

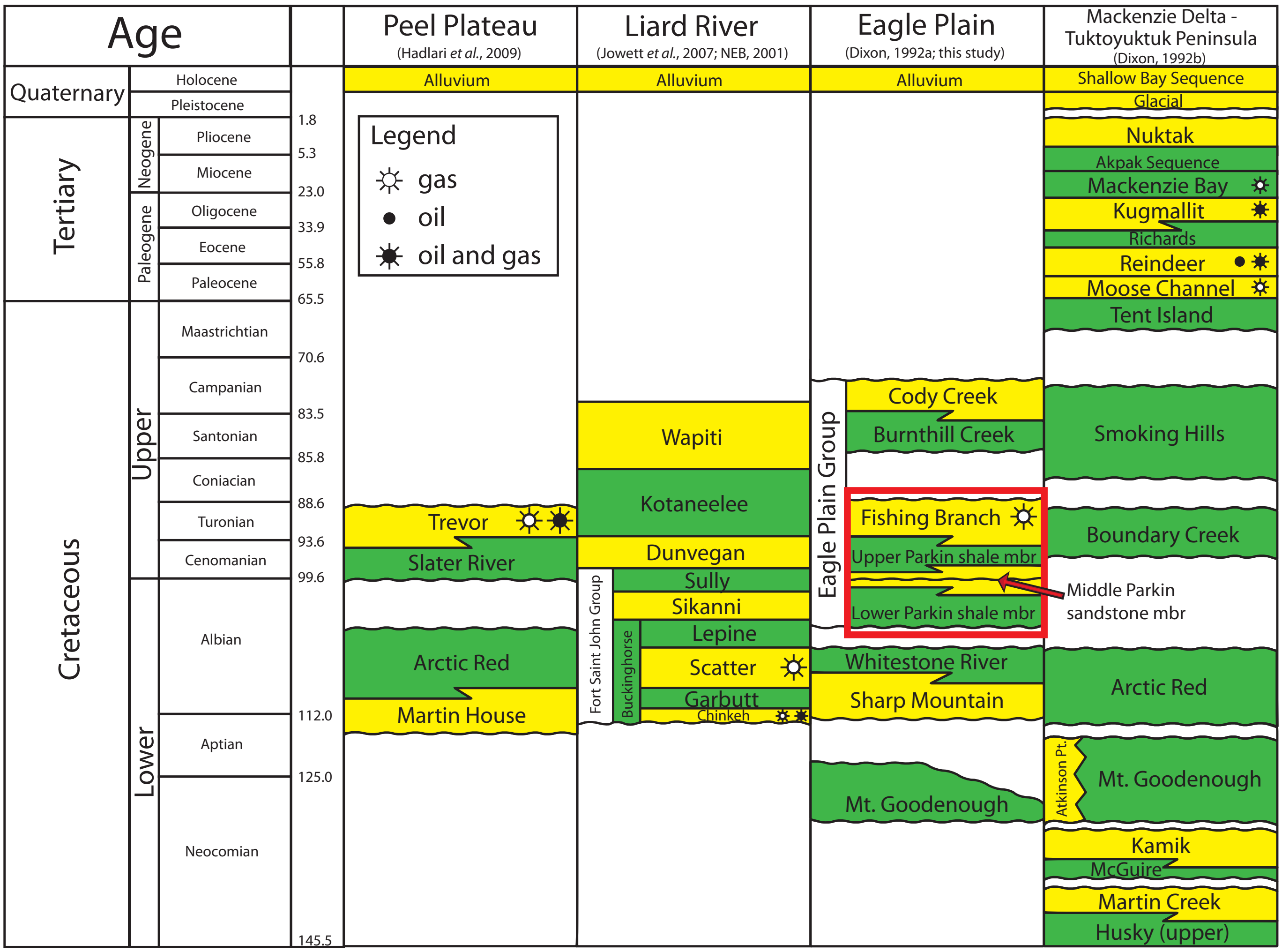

Figure 2. *Cretaceous to recent stratigraphy of Eagle Plain area and other basins of northern Canada. Red box outlines the units investigated in this study.*

Basal Parkin sandstone member

The basal Parkin sandstone member is a transgressive unit consisting of coarse-grained fluvial and fine to medium-grained shoreface sandstones (Fig. 5). The basal sandstone member exhibits porosities of up to 22% in core from the North Parkin D-61 well. It is overlain abruptly at a major flooding surface by the newly defined lower Parkin shale member.

Prior to this study the basal Parkin sandstone member was documented only in the subsurface; however, several sections of the unit were measured in this study along a 20-km outcrop belt in southern Eagle Plain (Stations 2009-11, 2009-12, 2009-13; see Figure 1). A westward change in facies from a fluvial to a marine environment is apparent along the exposures. Interfingering of the marine and non-marine facies suggests an eastward stepwise transgression, although the true shoreline orientation is not known.

Ammonites collected from the basal sandstone member at Station 2010-12 have been dated as middle Albian (Haggart, 2010), indicating that the basal Parkin sandstone is older than the Cenomanian age suggested by Dixon (1992a).

New unit: Lower Parkin shale member

The lower Parkin shale member is a siltstone and shale-dominated succession overlying the basal Parkin sandstone member at a major flooding surface. It is separated from the newly defined upper Parkin shale member by the middle Parkin sandstone member in southern Eagle Plain and equivalent sand-prone mass transport deposits identified from outcrop in the western part of the study area.

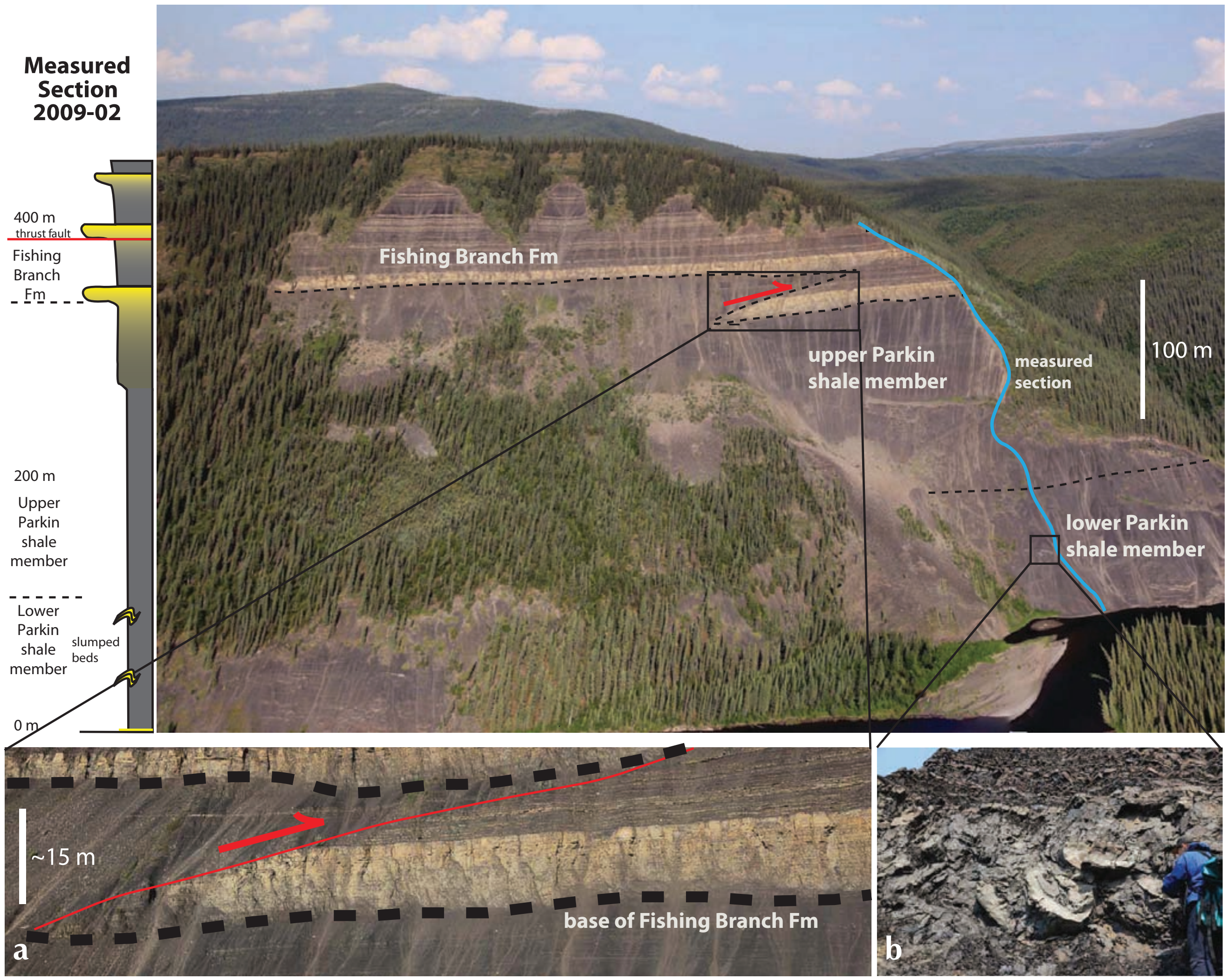

Figure 3. *Measured section at Eagle Plain Group type section (Station 2009-02, 7W 586947 7374123). Insets:* ***(a)*** *thrust fault offsetting the lowest upward coarsening sandstone cycle of the Fishing Branch Formation;* ***(b)*** *convoluted sand-prone unit in the lower Parkin Formation shale member interpreted as slump deposits;*

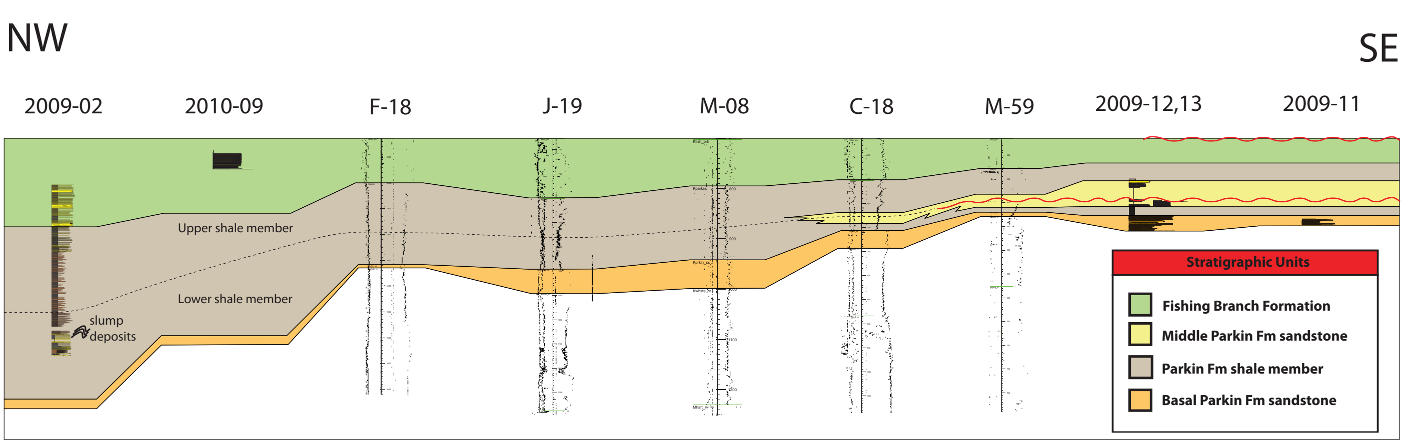

Figure 4. *Cross section with correlation of outcrop and well data from the Parkin and Fishing Branch transgressive-regressive formations cycle showing updated stratigraphic framework. Transect is shown in Figure 1.*

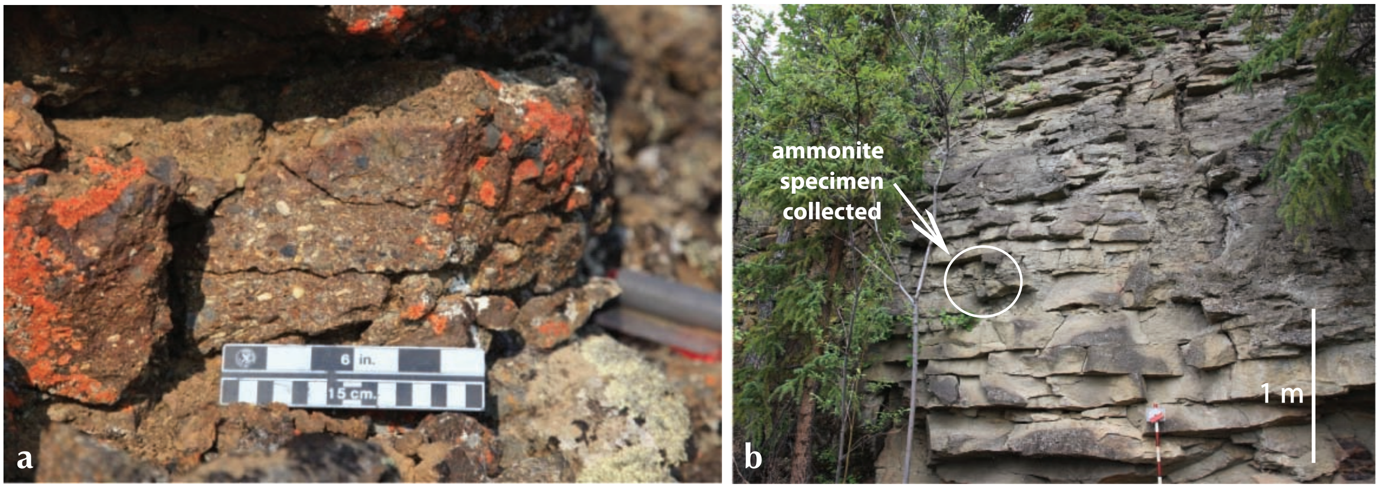

Figure 5. *Outcrops of the lower Parkin Formation sandstone member in southern Eagle Plain:* ***(a)*** *Coarse-grained fluvial sandstones and channel base conglomerates with black and white chert pebbles (Station 2009-11, UTM 8W 412908 7309651);* ***(b)*** *medium and coarse-grained shoreface sandstones (Station 2009-12, UTM 8W 401623 7305779). Ammonite specimen is identified as Middle Albian-aged Cleogastroplites aberrans (Haggart, 2010).*

Large-scale mass transport complexes involving packages of sediments up to 100 m thick are observed in outcrop at the top of the lower Parkin shale member in western Eagle Plain (Station 2009-02), indicating a shelf-to-basin floor relief of at least 100 m (Fig. 6). Mass transport processes of this magnitude occur due to oversteepening and failure of shelf-edge clinoforms (Fig. 7); examples of these deposits are well-documented in both ancient and modern analogues around the world (*e.g.*, Armitage *et al.*, 2009; Gee *et al.*, 2006). The intensely convoluted slump deposits are dominated by interbeds of very fine grained sandstones and siltstone, and are interpreted as the distal expression of the same regression which deposited the middle Parkin sandstone member. Limited paleoflow data from tool marks and current ripples in the overlying undeformed bedding indicate westward-directed paleocurrents in this part of the basin.

Overall westward-thickening trends observed in Cretaceous isopachs also reflect conditions with increasing accommodation space and subsidence to the west (Fig. 8).

New unit: Middle Parkin sandstone member

In outcrop in southern Eagle Plain (Station 2010-13), hummocky sandstones and a chert-rich pebble conglomerate layer are overlain by an upward-coarsening cycle of at least 15 m of clean quartz-rich shoreface sandstones (Fig. 9). The conglomerate lag marks a newly recognized intraformational sequence boundary; the middle Parkin sandstone member is interpreted to be stratigraphically equivalent to the sand-prone mass transport deposits in western Eagle Plain. Well log responses indicating coarse-grained facies in the middle of the Parkin Formation in wells Blackie No. 1 M-59 and East Chance C-18 become more subdued to the north, suggesting a southern source for coarser grained sediments to the south of the Eagle Plain basin. The middle sandstone member is overlain abruptly by the upper Parkin shale member.

New unit: Upper Parkin shale member

The upper shale member of the Parkin Formation is dominated by interbedded shales and siltstone and is gradationally overlain by the Fishing Branch Formation. The upper contact of the upper Parkin shale member is taken at the base of the lowest sandstone bed, above which the succession consists of at least 30% sandstone and is dominated by thicker, more prominent sandstone beds (Dixon, 1992a).

FISHING BRANCH FORMATION

The Fishing Branch Formation is described by Dixon (1992a) as an overall upward-shallowing fine to medium-grained marine sandstone unit consisting of stacked coarsening upward cycles, individually up to 30 m thick.

At the Eagle Plain Group type section (Station 2009-02; see Figures 1 and 3) in western Eagle Plain, two upward-coarsening cycles capped by flooding surfaces represent the lowest parasequences of the Fishing Branch Formation. The sand-rich units consist of interbedded very fine to fine-grained sandstone and siltstone with unidirectional current

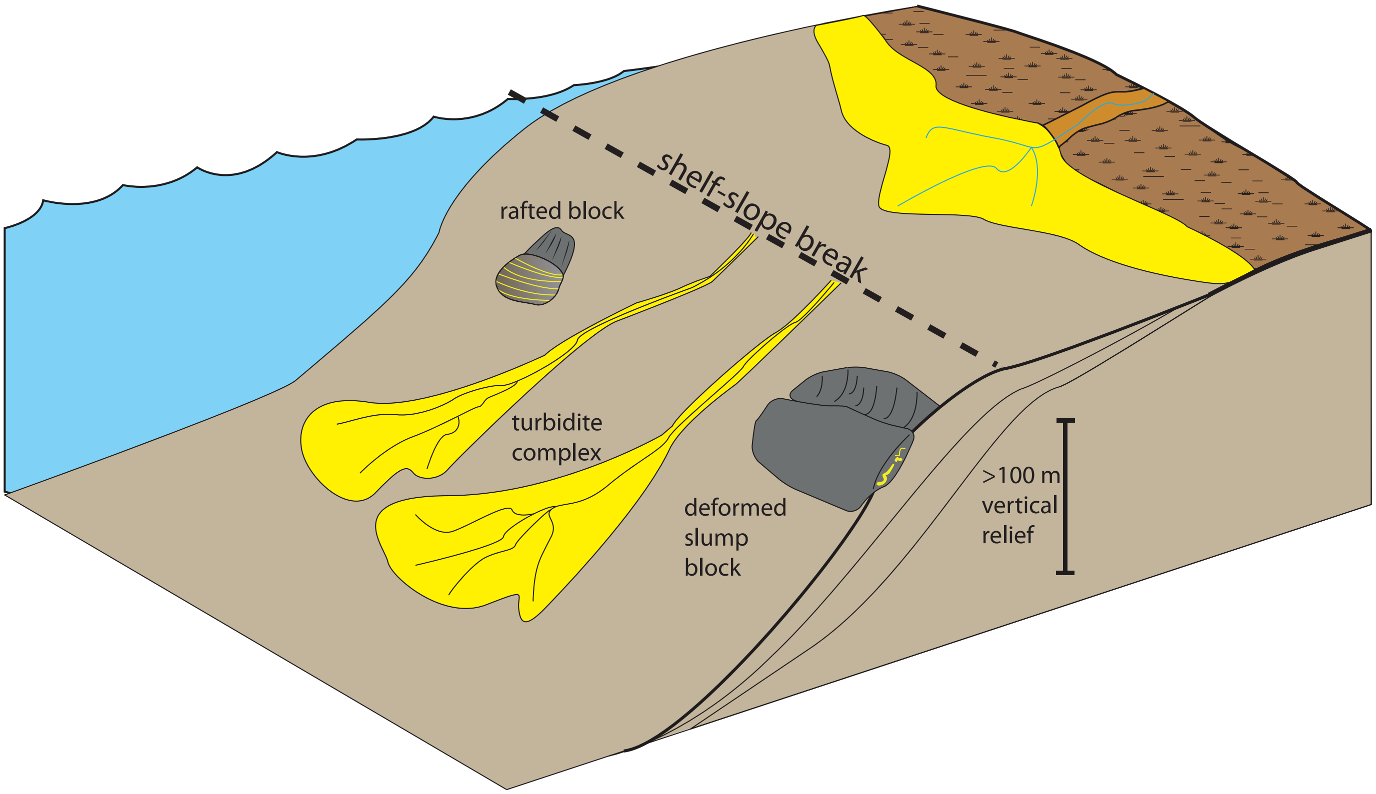

Figure 6. *Block diagram depiction of slope failure and mass wasting processes that occur as a result of increased accommodation and changing depositional parameters at the shelf-slope break. Diagram is vertically exaggerated; a slope angle of 1-2 degrees is sufficient for mass transport processes to occur.*

ripples and tabular beds, interpreted as being deposited in the prodelta of a fluvial-dominated delta. Towards the east, at Station 2010-09, the Fishing Branch cycles are thicker, coarser grained, sandier and show a *Teichichnus* and *Planolites*-dominated ichnofabric; this outcrop is interpreted to represent a more proximal deltaic setting *i.e.*, the delta front.

Outcrops of the Fishing Branch Formation in southern Eagle Plain (*e.g.*, Station 2009-07) are generally shalier and sandstone beds are dominated by storm-generated bedforms including large hummocks. This change in facies suggests a transition to a more distal storm-dominated environment in the south, possibly in the windward side of a deltaic complex.

New unit: Fishing Branch fluvial sandstone member

In southern Eagle Plain (*e.g.*, Stations 2009-07, 2010-23), medium to coarse-grained cross-bedded sandstones with channel lag conglomerates and abundant clay clasts overlie interbedded fine hummocky sandstones and shales. This previously undocumented fluvial unit represents an unconformity and period of sea level lowstand capping the Fishing Branch Formation, and is unconformably overlain by marine shales of the Santonian Burnthill Creek Formation.

PETROLEUM SYSTEMS AND IMPLICATIONS FOR HYDROCARBON POTENTIAL

Eagle Plain has recognized petroleum potential, and the most significant hydrocarbon occurrences are found in structures in the Chance and Birch fields in the southern part of the basin. Mesozoic source rocks in Eagle Plain are dominated by Type III gas-prone kerogen (Link *et al.*, 1989). Potential source rocks in the lower Albian Whitestone River Formation are largely immature in the southern part of Eagle Plain becoming increasingly mature towards the northwest as the Cretaceous succession thickens (Dixon, 1992a). Biogenic activity may also contribute to gas generation.

The Cretaceous strata were commonly considered a secondary target to deeper Paleozoic reservoirs; however, the sandstone of the Fishing Branch Formation flowed 3300 Mcf of gas per day on a production test at the

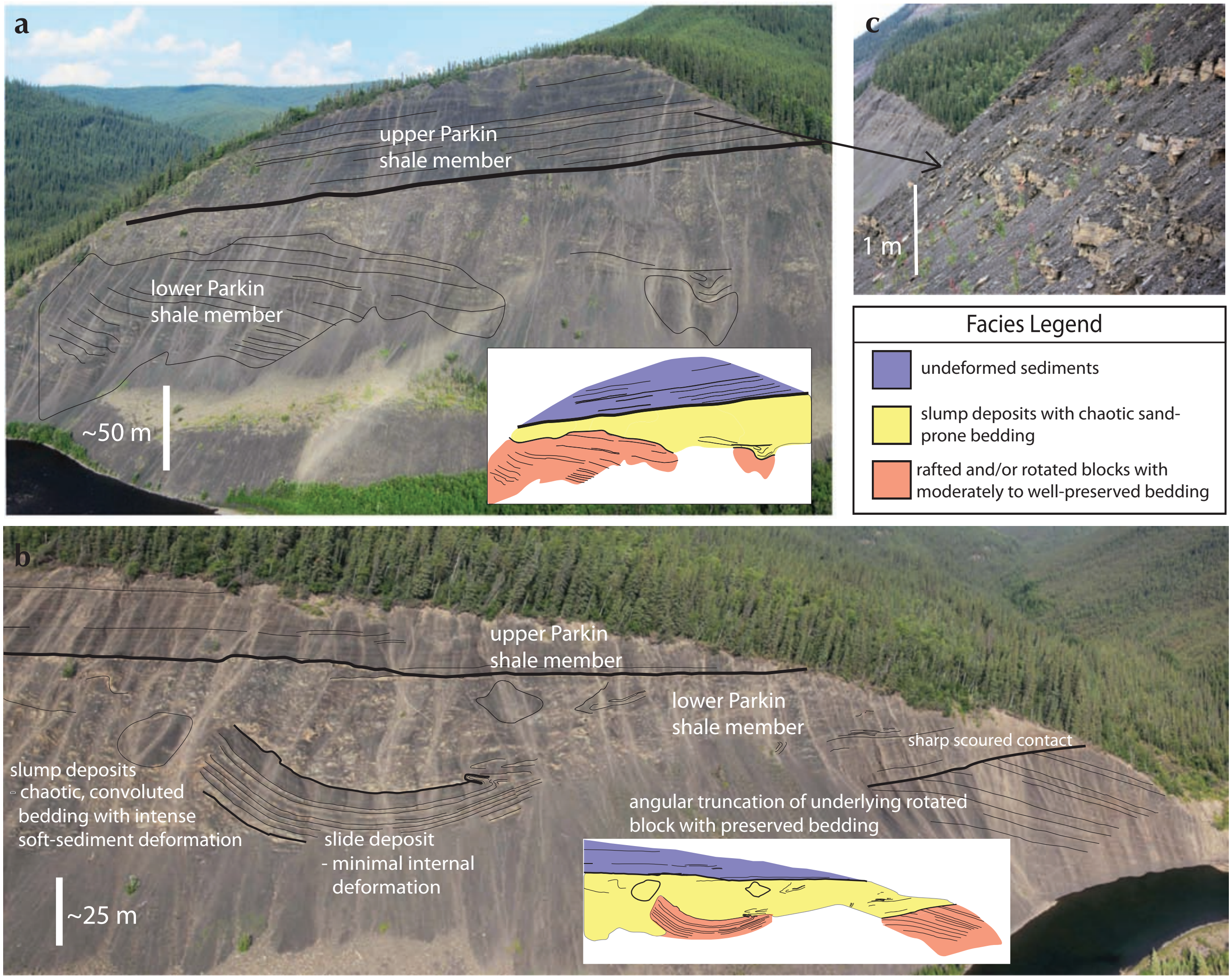

***Figure 7. (a)** and **(b)** Outcrops along Fishing Branch River (south of Station 2009-02) exhibiting very large (>100m in scale) mass transport complexes with convoluted sand-prone bedding. Select beds are traced to show varying degrees of soft sediment deformation. Insets show line drawing of bedding and colours indicate facies. **(c)** Photograph of undeformed bedding of the upper Parkin shale member which overlies the slump deposits with overlying sandstones.*

Chance G-08 well, and oil and gas-cut mud was recovered at several other wells. A recent petroleum assessment (Osadetz *et al.*, 2005) estimated 349 Bcf of natural gas and 108 MMbbls of oil in Cretaceous reservoirs.

Recognition of the presence of a shelf-slope break in the Cretaceous basin adds potential for large new hydrocarbon plays in stratigraphic traps. Sand-prone slump deposits in the upper Parkin shale member indicate transport of sandy sediments across the shelf and deposition at the shelf edge, resulting in oversteepening and failure of shelf edge clinoforms. Increased subsidence and accommodation at the shelf-edge allows potential space for the accumulation of thick sandstone bodies.

The mass transport deposits may represent the distal expression of a shelf-margin delta complex located farther landward at the shelf edge. Shelf-margin delta complexes are often associated with slope failures due to oversteepening of the delta front along the shelf edge. There is also potential for a turbidite fan complex basinward of the slope break by sandy gravity-driven flows. Very large oil and gas fields have been discovered within shelf-margin delta and turbidite fan sandstones around the world. Such high-yield reservoirs in stratigraphic traps could easily have been overlooked in northwest Eagle Plain where well control is sparse.

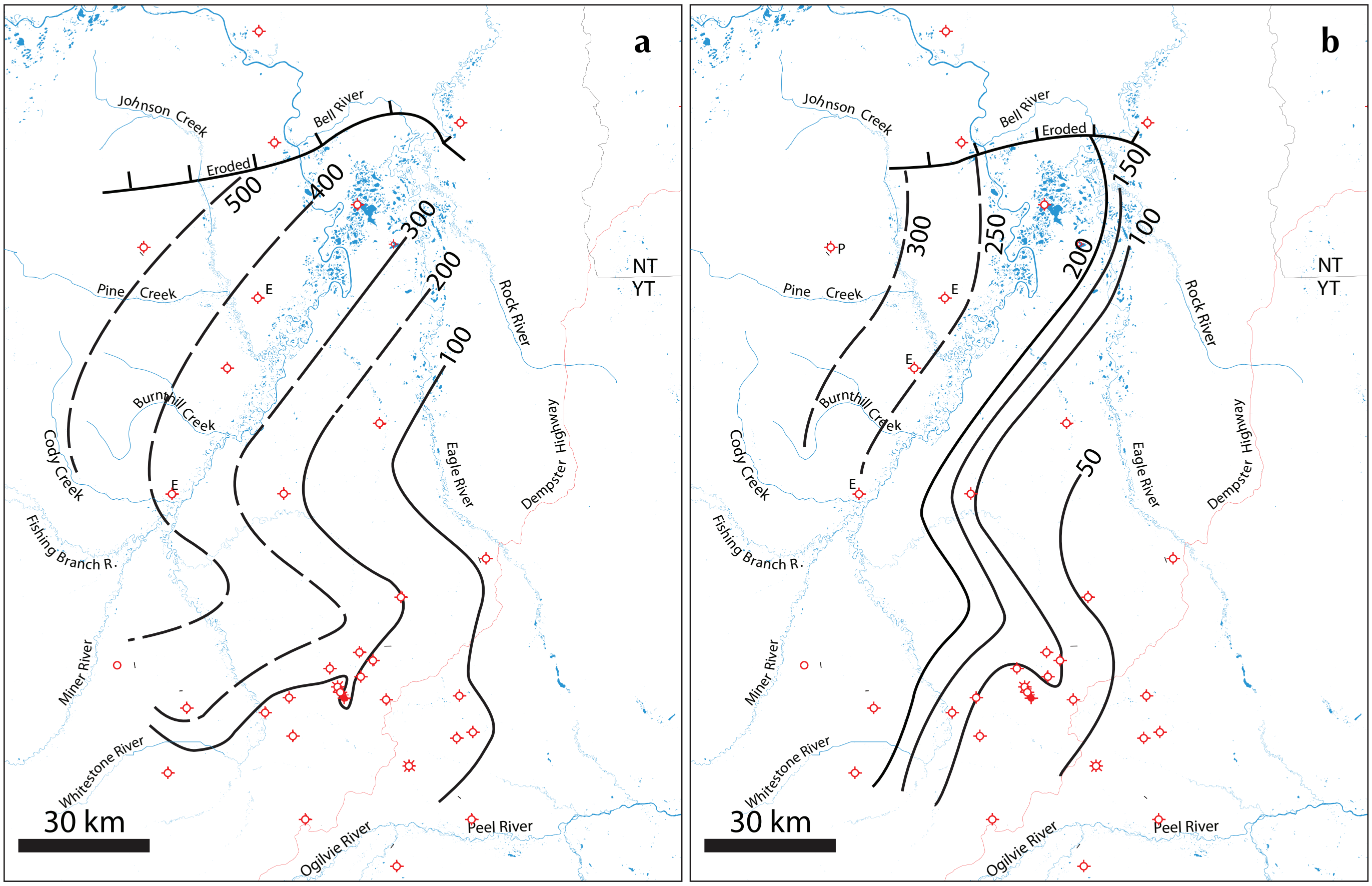

Figure 8. Isopach maps of ***(a)*** Parkin Formation and ***(b)*** Fishing Branch Formation, demonstrating overall trend of thickening sediments basinward to the west; P, partial section; E, eroded (after Dixon, 1992a; base-map from geoSCOUT Systems).

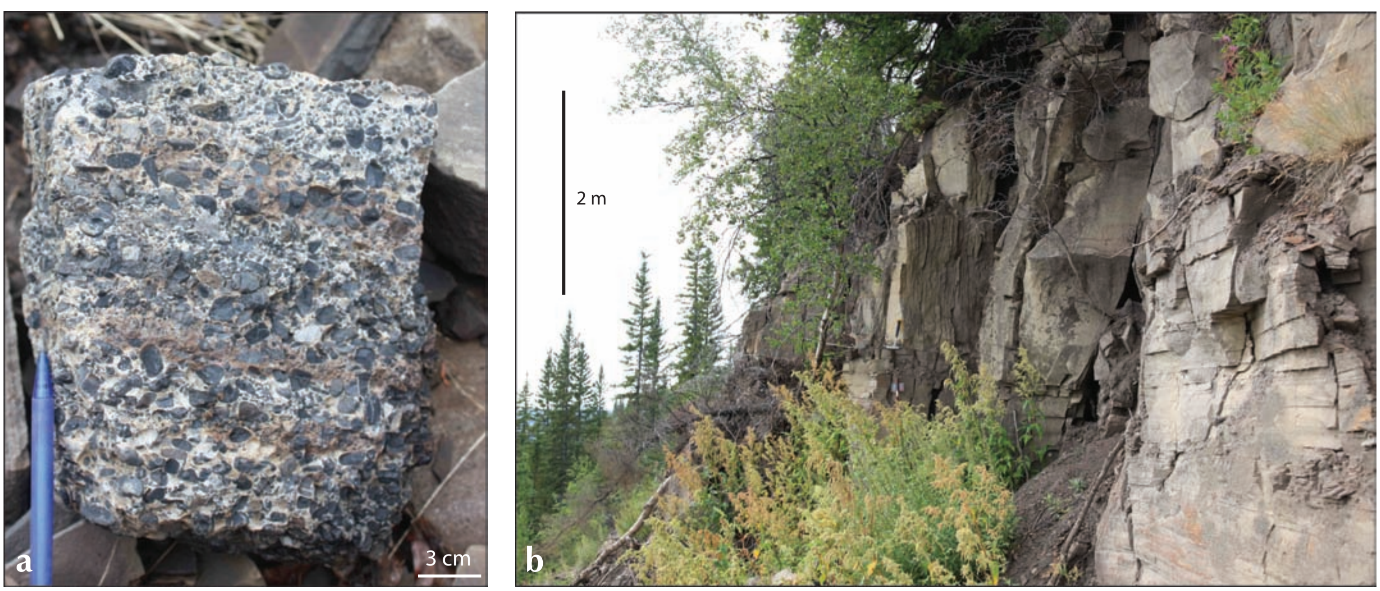

Figure 9. Outcrops of middle Parkin Formation sandstone member at Station 2009-13, UTM 8W 400748 7306350. The unit consists of ***(a)*** Chert pebble-rich transgressive lag, which is overlain by ***(b)*** at least 5 m of fine to medium-grained shoreface sandstones.

SUMMARY

The stratigraphic complexity of the Parkin and Fishing Branch formations is undoubtedly greater than the scope of prior studies of the succession, and thus further investigation is required. Subdivision of the stratigraphic nomenclature is required to reflect previously unrecognized intraformational unconformities. Thus far the following important observations are highlighted: 1) facies trends, paleoflow indicators, and isopachs suggest a broadly westward-deepening basin; 2) southeastern Eagle Plain received periodic input of coarse-grained sediment; and 3) mass transport deposits in western Eagle Plain indicate the presence of a significant shelf-to-basin floor relief (>100 m), which boosts the potential for stratigraphically confined play types associated with the shelf edge.

ACKNOWLEDGEMENTS

Thanks to the Geological Survey of Canada, Natural Resources Canada, and Yukon Geological Survey for financial support and use of their research facilities, and to geoLOGIC Systems Ltd. for contributing software licenses and subsurface data to the University of Calgary. Thanks to Jim Dixon for his review and input. Additionally, we appreciate the permission and participation of the Vuntut Gwitchin First Nations in undertaking this project.

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