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Report of activities on the structural geology of southern Peel Plateau and Peel Plain region, Northwest Territories and Yukon

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Report of activities on the structural geology of southern Peel Plateau and Peel Plain region, Northwest Territories and Yukon

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Abstract: Peel Plateau and Peel Plain have widespread hydrocarbon potential and have been identified by industry stakeholders as a high-priority exploration region, yet the area is underexplored and its geological history remains poorly understood. The Northwest Territories Geoscience Office and collaborators initiated a multidisciplinary study in 2005, "Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain, Northwest Territories and Yukon", the focus of which is to expand geoscience knowledge in the Peel Plateau and Peel Plain. As part of this project, fieldwork reported here was conducted in 2006 in the southern Peel Plateau and Peel Plain and northern Mackenzie and Franklin mountains. Detailed structural mapping was carried out along major structures, such as the Tabasco, Deadend, and Southbound faults, as well as across the Imperial anticline.

Résumé : Le plateau de Peel et la plaine de Peel recèlent un potentiel en hydrocarbures généralisé et ont été identifiés par des intervenants de l'industrie comme une région hautement prioritaire à explorer; cette région reste cependant sous-explorée et son histoire géologique est encore mal comprise. Le Bureau géoscientifique des Territoires du Nord-Ouest et des collaborateurs ont amorcé en 2005 un projet de recherche multidisciplinaire axé sur des études géoscientifiques régionales et le potentiel en hydrocarbures du plateau de Peel et de la plaine de Peel dans les Territoires du Nord-Ouest et au Yukon. Ce projet a comme objectif d'étendre les connaissances géoscientifiques sur le plateau de Peel et la plaine de Peel. Le présent article rend compte de travaux sur le terrain réalisés dans le cadre de ce projet en 2006 dans la partie sud du plateau de Peel et de la plaine de Peel ainsi que dans la partie nord des monts Mackenzie et des monts Franklin. Des travaux de cartographie structurale détaillée ont été effectués le long des principales structures comme les failles de Tabasco, de Deadend et de Southbound, ainsi que transversalement à l'anticlinal d'Imperial.

INTRODUCTION

Peel Plateau and Peel Plain lie within the Interior Plain of the Northern Mainland Sedimentary Basin in the Northwest Territories and Yukon, between 65°N and 68°N latitude and 128°W and 136°W longitude (Fig. 1a). The region is bounded by the Mackenzie Mountains to the south, the Richardson Mountains to the west, the Mackenzie Delta to the north, and the Mackenzie River and Anderson Plain to the east. Peel Plateau, locally reaching 950 m in elevation, is an erosional remnant. Peel Plain consists of lowlands with elevations between 125–450 m. Peel Plateau and Peel Plain are underlain by Cambrian to Upper Devonian strata overlying a Proterozoic succession and are capped by a thin veneer of Albian clastic rocks.

Peel Plateau and Peel Plain have widespread hydrocarbon potential and have been identified by industry stakeholders as a high-priority exploration region, yet the area is underexplored and its geological history remains poorly understood (e.g. Pyle et al., 2006a). Insufficient stratigraphic, structural, and geochemical data preclude a comprehensive assessment. To expand geoscience knowledge of Peel Plateau and Peel Plain and stimulate exploration and industry investment, the Northwest Territories Geoscience Office (NTGO), in collaboration with the Geological Survey of Canada (GSC) and Yukon Geological Survey (YGS), initiated a multidisciplinary, four-year (2005–2009) study (Pyle et al., 2006a), "Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain, Northwest Territories and Yukon" (http://www.nwtgeoscience.ca/petroleum/PeelPlateau.html, [accessed 2006-10-03]). Thematic studies will address knowledge gaps pertaining to basin evolution, tectonic history, and petroleum potential of the area. Specifically, the geometry, kinematics, and timing of formation for key Phanerozoic regional structures will be re-examined; the influence of Proterozoic tectonism on the orientation of Phanerozoic structures will also be reassessed. Observations will be integrated with seismic data to reassess potential petroleum traps across the region (e.g. Osadetz et al., 2005).

This paper reports fieldwork conducted in 2006 along the northern front of the Mackenzie Mountains. Work was conducted in the southern Peel Plateau and Peel Plain and northern Mackenzie and Franklin mountains, through the southern half of Upper Ramparts (NTS 106 G) and Sans Sault Rapids (NTS 106 H) map areas with reconnaissance work done in the southeast corner of Snake River (NTS 106 F) map area. Detailed structural mapping was carried out along major structures, such as the Tabasco, Deadend, and Southbound faults as well as across the Imperial anticline (Fig. 1b).

STRATIGRAPHY

In the study area, exposed rock units range from Neoproterozoic to Upper Cretaceous (Fig. 2). At the front of the Mackenzie Mountains, mostly Paleozoic strata are exposed; limited work was conducted in Proterozoic and Mesozoic units. The sedimentary succession is reviewed briefly here (in ascending stratigraphic order); readers are referred to Pyle et al. (2006a, b, and references therein) for a more comprehensive description.

Late Proterozoic rocks of the Katherine Group are exposed in the southernmost part of the study area. The unit is quartzite dominated; minor mudrocks and (stromatolitic) dolostone occur in recessive intervals.

Proterozoic strata are generally overlain by the Cambro-Ordovician Franklin Mountain Formation. Areas missing Cambrian strata define part of the ancient Mackenzie Arch. Aitken et al. (1982), however, recognized the Cambrian Mount Cap and Saline River formations near the east boundary of the Sans Sault Rapids map area. The Mount Cap Formation consists of sandstone, limestone, and shale; the Saline River Formation consists of bedded evaporite and redbed units. The Franklin Mountain Formation is a thick (more than 700 m in places), well bedded, pale orange-weathering dolostone. It is disconformably overlain by the Upper Ordovician–Lower Silurian Mount Kindle Formation, which consists of thick-bedded, dark brownish-grey-weathering, fossiliferous, resistant dolostone units that generally are blocky and massive. The Mount Kindle Formation is up to 400 m thick (Morrow, 1999).

In the western part of the study area west of the Arctic Red River, the Mount Kindle Formation is unconformably overlain by the late Silurian to early Devonian Peel Formation, which consists of light grey-to pale orange-weathering, argillaceous to silty dolostone. The Tatsieta Formation is transitional with the underlying Peel Formation (Morrow, 1999), and consists of light grey-weathering lime mudstone with minor silty dolostone and green shale. Its distribution seems to be associated with that of the Peel Formation, west of the Arctic Red River.

In the eastern part of the study area, the Mount Kindle Formation is overlain by the Arnica Formation. It is marked by alternating pale- and dark-brown-weathering dolostone that yields a distinctive colour banding in outcrop. This unit commonly features brecciated intervals, particularly near the facies change with the time-equivalent Bear Rock Formation (*see* below). The contact with the underlying unit is concordant, but probably unconformable (Douglas and Norris, 1961). Overlying the Arnica Formation, the Landry Formation includes resistant, thick-bedded, lime mudstone with minor shale, and weathers to pale grey with distinctive gritty texture. Combined thickness of the Arnica and Landry formations in the subsurface consistently reaches about 500 m (Morrow, 1999).

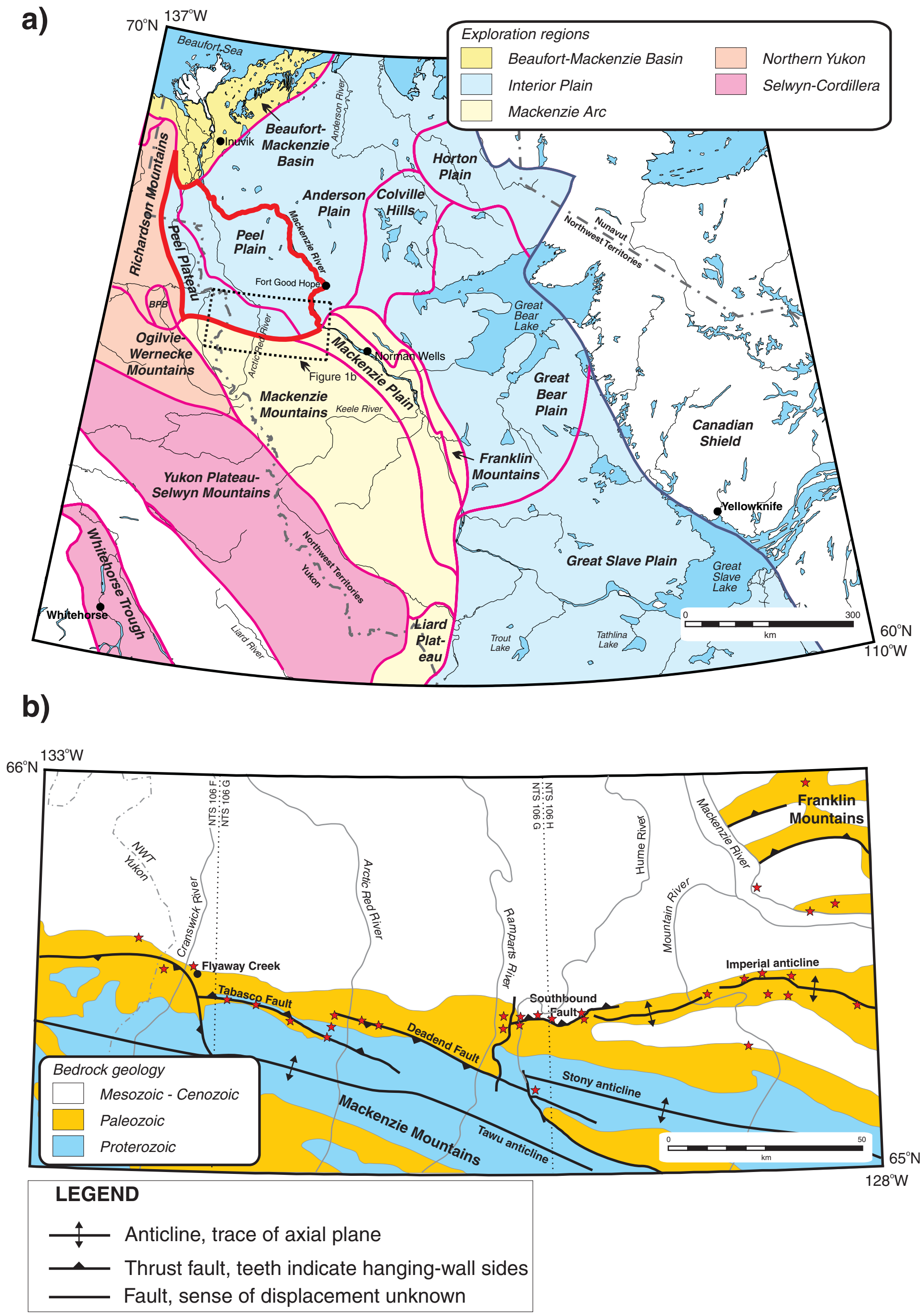


Figure 1. a) Main exploration regions of the Mackenzie River valley area. Exploration regions are subdivided into exploration areas (e.g. Great Slave and Great Bear plains) on the basis of physiographic and/or geological features. Figure shows the location of Peel Plain and Peel Plateau (thick red outline). Location of Figure 1b is shown as a dotted outline. BPB, Bonnet Plume Basin (*modified from* Morrow et al., 2006). **b)** Location map of the southern Peel Plateau and Peel Plain, and the northern Mackenzie Mountains. Figure shows major structural features discussed in text. Red stars indicate areas visited during the summer 2006 and generally include multiple stations (m*odified from* Cook and MacLean, 1999).

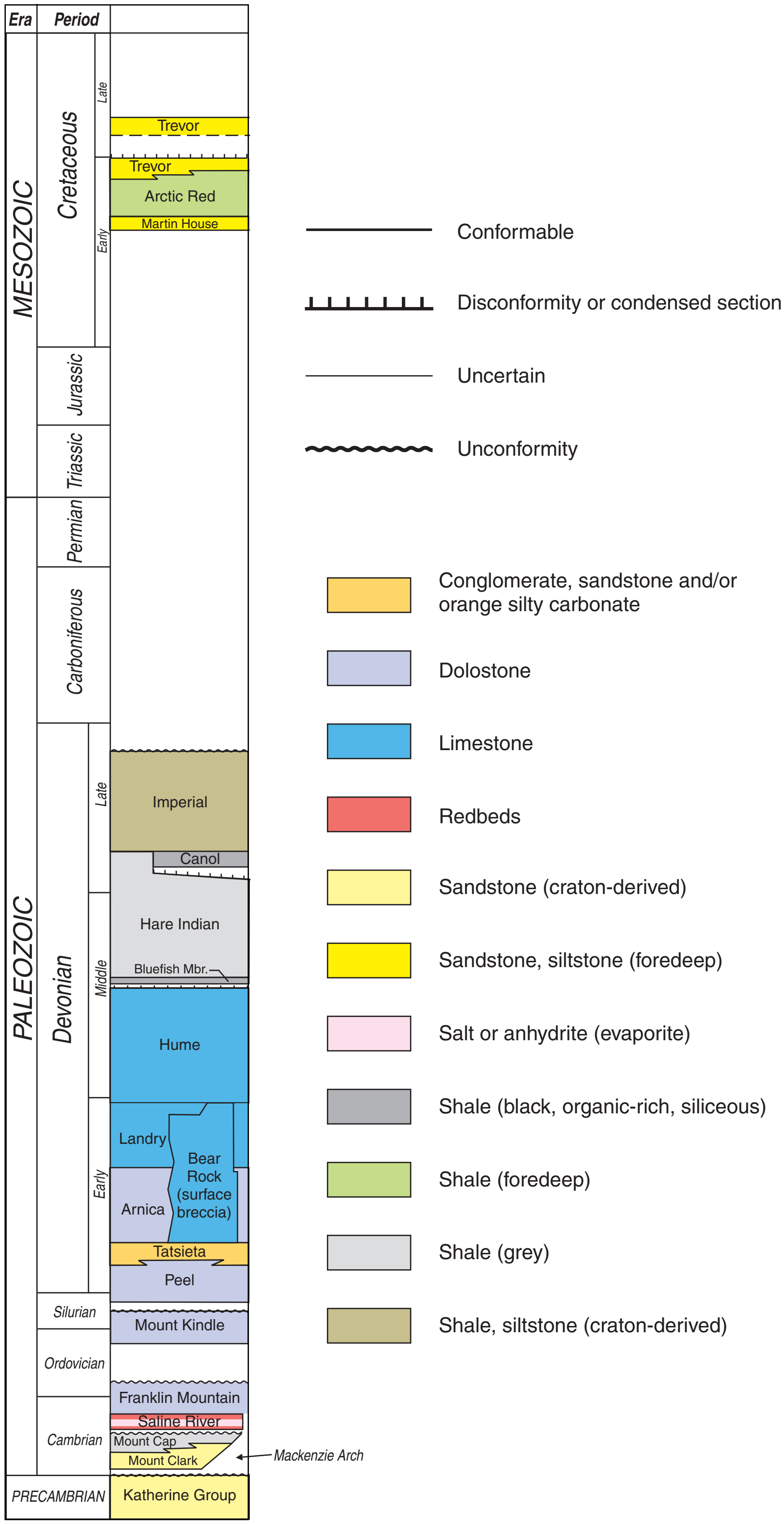


Figure 2. Schematic stratigraphic section for the southern Peel Plateau and Peel Plain and northern Mackenzie and Franklin mountains (*modified from* Morrow et al., 2006).

The Bear Rock Formation is a distinctive limestone and dolostone breccia that occurs only at surface or in the shallow subsurface, and was interpreted as a product of near-surface dissolution of evaporitic intervals (Morrow, 1991). It seems to be restricted to the Sans Sault Rapids map area (Aitken et al., 1982).

The Hume Formation is a distinctive, thick-bedded, resistant, dark grey fossiliferous and argillaceous limestone with minor calcareous shale interbeds. Its thickness is in excess of 200 m (Morrow, 1999). A recessive interval of the Hare Indian Formation shale overlies the Hume Formation. The lower interval (Bluefish Member) is a distinctive black to brown-black, bituminous, locally calcareous shale with paper-thin parting and abundant Tentaculites; the upper member consists of grey-green shale with variable siltstone and argillaceous limestone intervals. The Hare Indian Formation is up to 189 m thick (Muir, 1988).

The Ramparts Formation limestone overlies, and is partly equivalent to, the Hare Indian Formation (Aitken et al., 1982). It consists of well bedded, brown to brownish-grey-weathering platformal limestone and pale grey- to pale brown-weathering, thick-bedded, reefal limestone. It is conformable on underlying Hare Indian Formation, and its thickness in the subsurface is close to 400 m (Pugh, 1983).

The Canol Formation is organic-rich, resistant, black siliceous cherty shale that weathers a distinctive sulphur-yellow and bluish dark grey. Due to the presence of chert, the unit is resistant and a regional cliff-former. The Canol Formation averages 80 m in thickness, but is up to 150 m in places. Its lower contact is generally abrupt and concordant (Pyle et al., 2006a).

The Imperial Formation conformably overlies the Canol Formation. It is a thick (more than 1900 m regionally) succession of grey and greenish-grey, locally calcareous marine shale, siltstone, and sandstone; siltstone is the dominant lithology.

Cretaceous siliciclastic rocks include marine sandstone, shale, and mudstone, and sandstone and interbedded mudstone of the Martin House, Arctic Red, and Trevor formations, respectively.

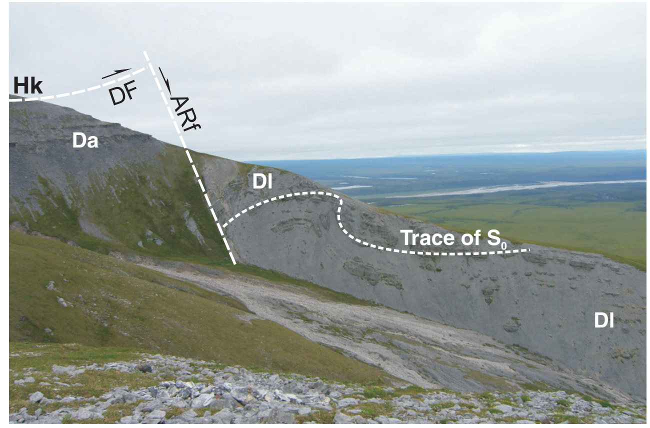


Figure 3. Field photograph of the Deadend Fault (DF) in the vicinity of the Arctic Red River (in background). The photograph shows the trace of the informal 'Arctic Red fault' (ARf). The dotted line corresponds to a bedding form line. Da = Arnica Formation, Dl = Landry Formation, Hk = Katherine Group. View to the west. Field of view is approximately 300 m.

STRUCTURAL GEOLOGY

The study area marks a profound change in structural style from linear, narrow ridges and shallow detachment faults in the northern Franklin Mountains, to broad (more than 30 km wide), flat-topped anticlines with intervening narrow synclines, and deeper and more pervasive contractional structures in the northern Mackenzie Mountains (Maps 1452A and 1453A of Aitken et al. (1982)). More than 60 stations were studied to examine the structural style of Peel Plateau and Peel Plain area, and fieldwork focused on major Laramide Orogen contractional structures and older Proterozoic features (Fig. 1a); structural studies will be complemented by forthcoming geophysical interpretations. The following summarizes the features of five structures examined during fieldwork in 2006.

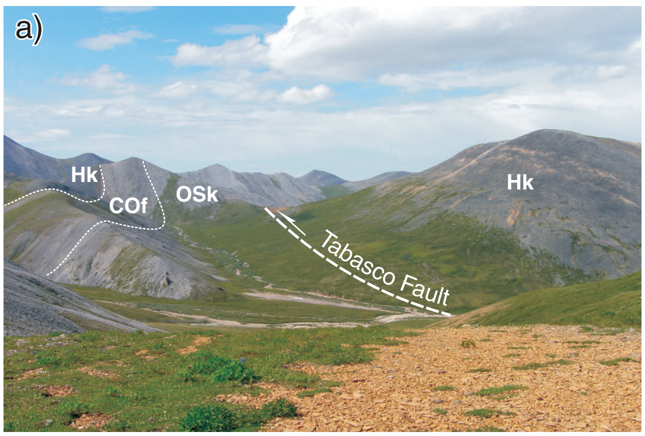
Deadend Fault

The Deadend Fault defines the front of the Mackenzie Mountains in the Arctic Red River area (Aitken et al., 1982), and can be mapped from west of the Arctic Red River to east of the Ramparts River (Fig. 1b). It is a north-verging thrust, which juxtaposes Proterozoic strata in the hanging wall against Paleozoic carbonate. It is well exposed in the Arctic Red River area, where it brings Katherine Group quartzite over the Arnica Formation (Fig. 3). A few stations overlapping the fault were studied (Fig. 1b). Here, a previously unrecognized fault was mapped; the 'Arctic Red fault' (informal term, this study) is a steep, north-side-down normal fault, which brings limestone of the Landry Formation against the Arnica Formation (Fig. 3). Stratigraphic offset across the fault suggests a minimum throw of 200 m. Crosscutting relationships of fracture sets in the vicinity of the fault suggest the 'Arctic Red fault' is late with respect to the Deadend Fault; additional work is needed to test this interpretation and to map the extent of the fault.

Tabasco Fault

The Tabasco Fault is a north-northeast-dipping thrust fault exposed on the northern flank of the Tawu anticline (Fig. 1b, 4a). Along most of its length (~70 km), it juxtaposes Proterozoic units in its hanging wall against Lower Paleozoic carbonate units in the footwall. Four stations were mapped along the structure (Fig. 1b). In outcrop, the Tabasco Fault is generally covered by rubble or vegetation

(Fig. 4a), but is well exposed locally (Fig. 4b). At one locality, the fault zone is 5 m wide and marked by steeply dipping (about 60º) discrete fault planes, abundant fault breccia, and slickensides. The Tabasco Fault is one of the few southwest- (or south-) verging structures exposed in the northern Mackenzie Mountains, and was interpreted as a major backthrust, akin to the Triangle zone of the southern Alberta foothills (Vann et al., 1986). This interpretation, however, is not well constrained and requires further investigation; alternative interpretations such as basement-involved faulting or inversion of pre-existing extensional structures also need to be considered.



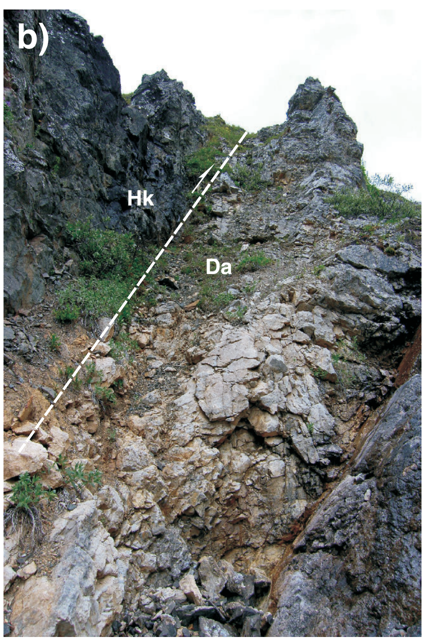


Figure 4. a) Field photograph of the Tabasco Fault. Fine dotted lines highlight stratigraphic contacts. Hk = Katherine Group, COf = Franklin Mountain Formation, OSk = Mount Kindle Formation. View to the northwest, field of view is approximately 400 m. **b)** Outcrop photograph of the Tabasco fault zone. Da = Arnica Formation, Hk = Katherine Group. View to the east. Horizontal field of view is approximately 5 m.

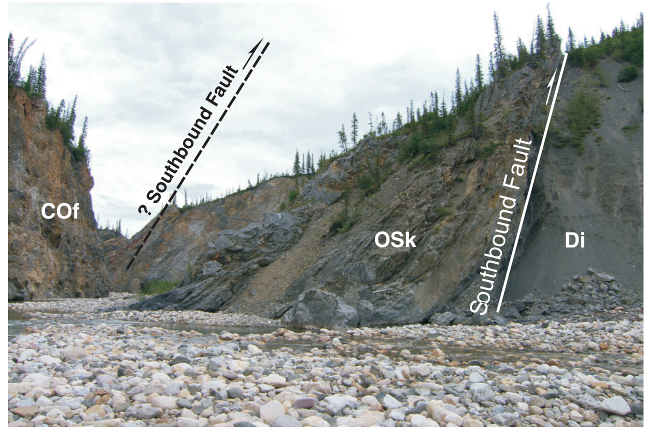


Figure 5. Field photograph of the Southbound Fault. The photograph shows a horse of the Mount Kindle Formation within the fault zone. The northernmost fault (dashed line) is assumed and probably represents a splay of the Southbound Fault. COf = Franklin Mountain Formation, OSk = Mount Kindle Formation, Di = Imperial Formation. View to the east. Horizontal field of view is approximately 15 m.

Southbound Fault

The Southbound Fault is located in a structurally complex area where structures of the Franklin Mountains meet those of the Mackenzie Mountains (Fig 1b; Map 1453A of Aitken et al. (1982)). It is a south-verging, high-angle fault (at surface) exposed on the southern flank of Southbound Ridge; it commonly juxtaposes the Franklin Mountain Formation above the Imperial Formation. Several stations were studied on Southbound Ridge and along Hume River (Fig. 1b). At one locality (65º22.476'N, 129º51.273'W), an approximately 6 m thick horse of fossiliferous Mount Kindle Formation carbonate was found within the fault zone (Fig. 5). Map relationships surrounding the Southbound Fault suggest it is a reverse fault; however, asymmetric structures at outcrop scale suggest the last motion on the fault was normal, likely the result of relaxation postdating Laramide Orogen. Similar to the Tabasco Fault, the Southbound Fault is a south-verging structure, and could potentially represent a back thrust, or alternatively, an inverted normal fault, but additional work is required to test these models.

Imperial anticline

The Imperial anticline, located between the Mackenzie and Franklin mountains, is an arcuate, northwest- to west-trending regional feature, which mimics the regional curvature of the Franklin Mountains. Within the study area, the anticline extends as far west as the Mountain River (Fig. 1b). It is an asymmetric anticline, with a shallow-dipping south limb and a steep-dipping north limb (Fig. 6). The geometry of the Imperial anticline is commonly delineated by resistant limestone of the Ramparts Formation. Several traverses were mapped across both limbs of the anticline (Fig. 1b); much of the Imperial anticline is, however,

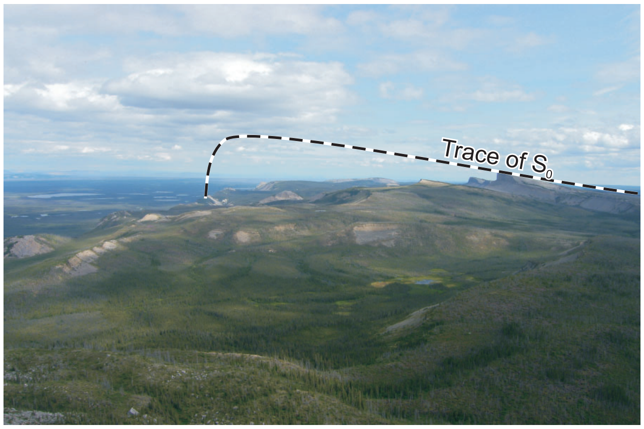


Figure 6. Panoramic photograph of the Imperial anticline in the vicinity of Stratigrapher Cliffs. Direction of view (to the east-northeast) is approximately parallel to the axis of the anticline. The dashed line corresponds to a bedding form line. The anticline is marked by a gently dipping south limb and subvertical north limb. Field of view is approximately 4 km.

overlain by vegetation (e.g. Fig. 6). Cook and MacLean (1999) interpreted the Imperial anticline as a fault-bend fold overlying a bedding-parallel thrust ramp and hypothesized that thrusting was facilitated by the presence, at shallow levels, of the Saline River Formation evaporite; the present authors' observations support this interpretation. It has important petroleum potential implications, as the proposed geometry allows for possible structural traps involving the siliciclastic intervals underlying the Saline River Formation (i.e. Cambrian Mount Clark and Mount Cap formations). The Mount Clark Formation is a known reservoir in the Colville Hills area, approximately 200 km to the northeast of Peel Plain.

Flyaway Creek

Reconnaissance work was conducted at Flyaway Creek, approximately 8 km east of the Cranswick River (Fig. 1b, 7). The structurally complex area surrounding the Cranswick River is of interest because it features several generations of faulting (GSC maps 1452A, Aitken et al. (1982); and 1529A, Norris (1982)). Mapping along Flyaway Creek recorded several moderately to steeply dipping, south-verging thrust faults (Fig. 8a), as well as abundant bedding-parallel, reverse slip planes. In several places, the faults repeat portions of the stratigraphic succession (Fig. 7).

The southernmost fault places limestone of the Hume Formation above black shale of the Bluefish Member (Hare Indian Formation). Here, the immediate hanging wall is marked by tight upright folds, suggested by the variable facing direction (Fig. 8b).

To the north, several fault splays place more competent, siliceous intervals of the Canol Formation above less competent, thin (less than 50 m thick) horizons of the Imperial Formation; incompetent fissile shale at the base of the Canol Formation seems to have provided a detachment

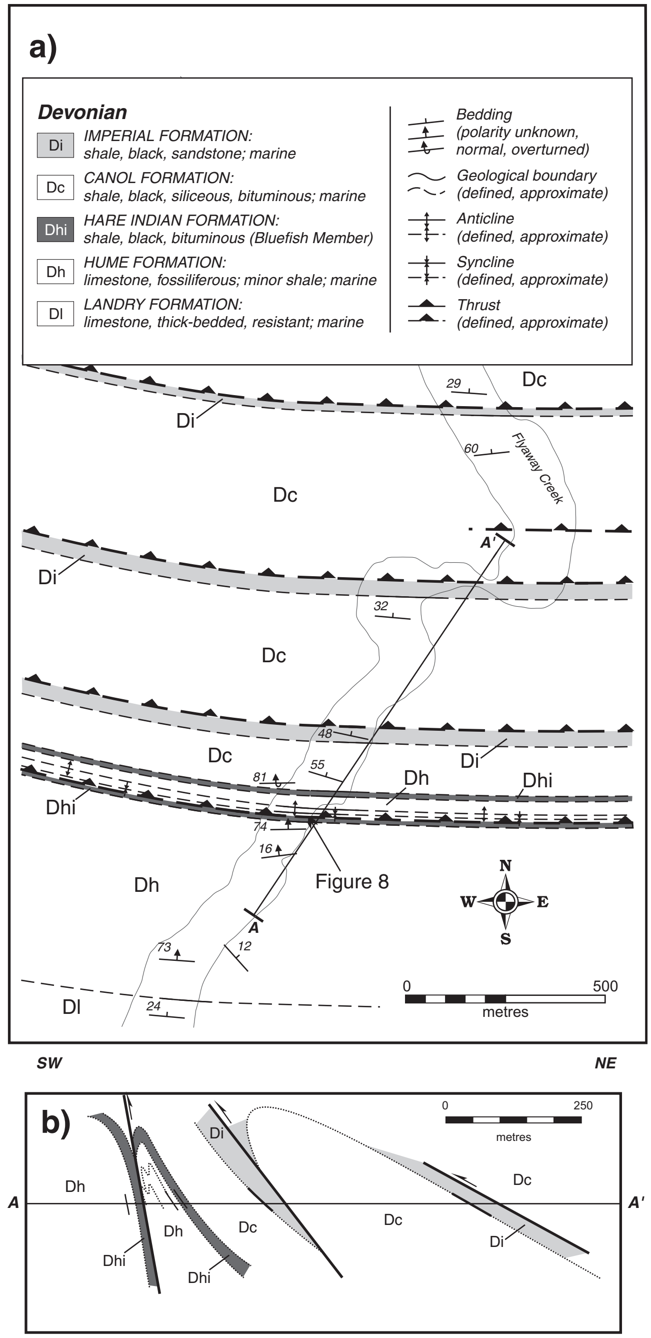


Figure 7. a) Geological map of a section of Flyaway Creek (*see* Fig. 1b for location). Figure shows the location of Figure 8. **b)** Diagrammatic cross-section showing relationships across the faults mapped along Flyaway Creek. *See* Figure 7a for location of section.

surface for these faults. Displacement along the faults is difficult to estimate as they are mostly bedding parallel. Although more detailed investigation is required to evaluate the regional significance of these structures, fieldwork suggests that a structurally thickened succession (>250 m) of organic-rich Canol Formation shale is present here, and potentially elsewhere in the subsurface of southern Peel Plateau and Peel Plain.

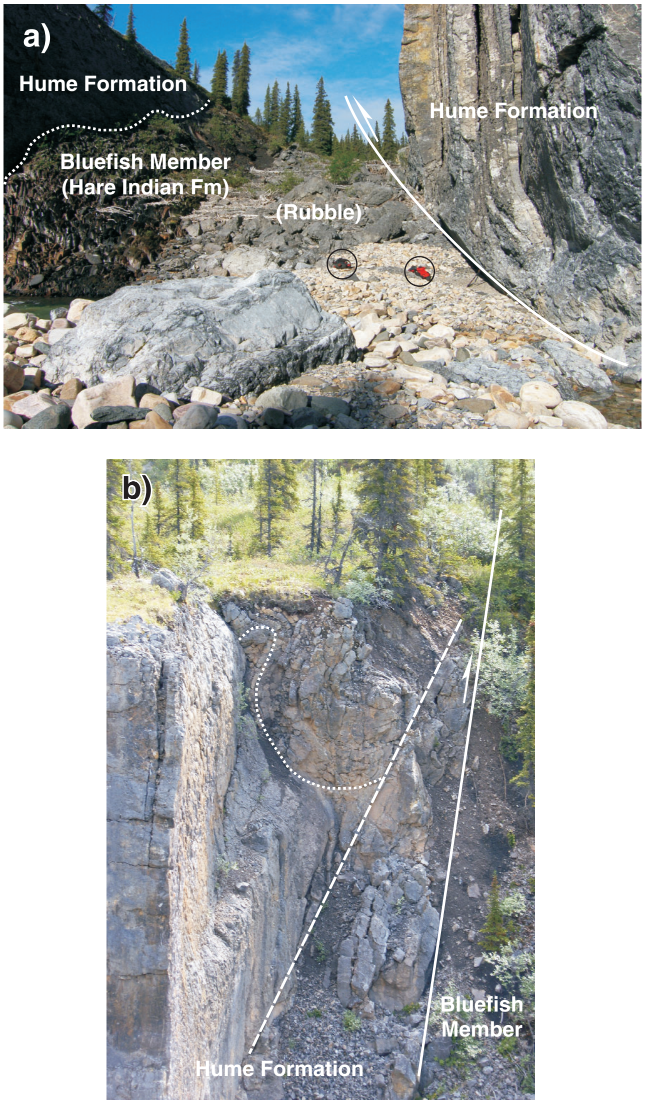


Figure 8. Outcrop photographs of the main fault zone at Flyaway Creek. *See* Figure 7 for approximate location of photographs. **a)** Main thrust fault at Flyaway Creek. Solid line shows the fault plane. The dotted line highlights the approximate contact between the Hume Formation (in the shade) and black shale of the Bluefish Member. The interval between the black shale and the Hume Formation in the immediate hanging wall of fault is rubble. Backpacks (circled) in the foreground for scale. Photograph is looking west from the creek. **b)** Fault zone at Flyaway Creek showing tight folding within the fault zone. Solid line is main fault plane; dashed line is a splay of the main fault. Dotted line highlights the bedding form line and does not correspond to a stratigraphic contact. View to east; horizontal field of view is approximately 6 m.

ONGOING AND FUTURE WORK

Ongoing work focuses on re-examining existing seismic data in light of recent fieldwork. Specifically, structures such as the Imperial anticline will be reassessed for potential structural traps. Cook and MacLean (1999) suggested the existence of a detachment in Cambrian strata, creating potential traps in the core of the anticline; additional work is warranted to test the existence of this geometry elsewhere or along the structure, and to document the effect of detachment in other structures, such as in the northern Franklin Mountains.

Fieldwork in the Upper Ramparts (NTS 106 G) and Snake River (NTS 106 F) map areas will resume in the summer of 2007. Mapping will be focused around major possibly Proterozoic structures that are exposed in the northern Mackenzie Mountains (e.g. Grand Forks Fault, Aitken et al. (1982)) in order to study their influence on the evolution of younger Laramide structures. Fieldwork will also examine the change of structural trends at the junction of the Mackenzie Mountains and Richardson Mountains to the west. Major structural features in the Richardson Mountains are dominantly south-trending faults ("Richardson Fault Array", e.g. Norris (1997)), in contrast to northwest- to west-trending contractional structures in the Mackenzie Mountains.

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