Field investigations of the Upper Devonian to Lower Carboniferous Tuttle Formation, eastern Richardson Mountains, Yukon

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ABSTRACT

The Upper Devonian to Lower Carboniferous Tuttle Formation was an exploration target for oil and gas in the Peel Plateau and Eagle Plain in the 1960s and 1970s. To date, seven minor gas shows have been identified in the Tuttle Formation in the Peel region. This study is part of a long-term project to investigate the sedimentology, stratigraphy and hydrocarbon potential of this unit in the Peel region.

The Tuttle Formation forms the upper part of a siliciclastic wedge that was deposited in the foreland basin of the Yukon and Ellesmerian fold belts. In the eastern Richardson Mountains, on Trail and Road rivers, it occurs as alternating packages of resistant and recessive intervals. Resistant intervals, 23 to 54 m thick, comprise five lithofacies including fining-upward sandstone, massive sandstone, siltstone, conglomerate and diamictite. Recessive intervals, 55 and 144 m thick, consist of siltstone and shale and are mostly covered.

RÉSUMÉ

La Formation de Tuttle datant du Dévonien supérieur au Carbonifère inférieur a constitué dans les années 60 et 70 une cible d'exploration à la recherche de pétrole et de gaz sur le plateau Peel et dans la plaine Eagle. Jusqu'à maintenant, on a identifié sept vindices mineurs de gaz dans la Formation de Tuttle dans la région de Peel. Cette étude s'insère dans un projet de recherche à long terme sur la sédimentologie, la stratigraphie et le potentiel en hydrocarbures des couches du Paléozoïque supérieur dans la région de Peel.

La Formation de Tuttle forme la partie supérieure d'un biseau silicoclastique déposé dans le bassin d'avant pays des zones de plissement Ellesmerienne et du Yukon. Dans la partie orientale des monts Richardson le long des rivières Trail et Road, elle prend la forme d'ensembles alternants d'intervalles récessifs et résistants. Les intervalles résistants d'une épaisseur de 23 à 54 m comprennent cinq unités lithologiques dont un grès à granodécroissance vers le haut, un grès massif, un siltstone, un conglomérat et une diamictite. Les intervalles récessifs d'une épaisseur de 55 à 144 m se composent de siltstone et de shale, et sont principalement couverts.

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INTRODUCTION

In 2006, the Yukon Geological Survey began fieldwork in the eastern Richardson Mountains as part of the "Regional Geoscience Studies & Petroleum Potential, Peel Plateau and Plain" study, known informally as 'The Peel Project'. The project is a working partnership that involves the efforts of the Geological Survey of Canada, Northwest Territories Geoscience Office, Yukon Geological Survey, and university and industry affiliates (Pyle *et al.*, 2006). It is a four-year project ending in 2009.

Upper Paleozoic strata comprising the Canol, Imperial and Tuttle formations and the overlying 'Cf' map unit (Norris, 1981b; 1982b) were studied as part of this investigation, with the Upper Devonian to Lower Carboniferous Tuttle Formation as the main focus. This paper summarizes preliminary findings of work on the Tuttle Formation to date.

LOCATION, ACCESS AND EXPOSURE

The study area is in the northeast corner of the Yukon in the eastern Richardson Mountains, on Trail River map sheet (NTS 106L; Fig. 1). During summer 2006, field studies were based out of an exploration camp on a tributary of the upper Caribou River. Access to camp was via a 30-minute helicopter ride from Eagle Plains Hotel located on the Dempster Highway. Fieldwork was helicopter-supported, as there is no infrastructure in the region.

The Paleozoic succession in the region crops out along the eastern flank of the Richardson Mountains as well as along the northern Mackenzie Mountains, allowing for surface investigation of rocks equivalent to those that are in the subsurface of the Peel Plateau and Plain.

Exposures of the Tuttle Formation and neighbouring units were mainly limited to river cuts. Sandstone bodies of the

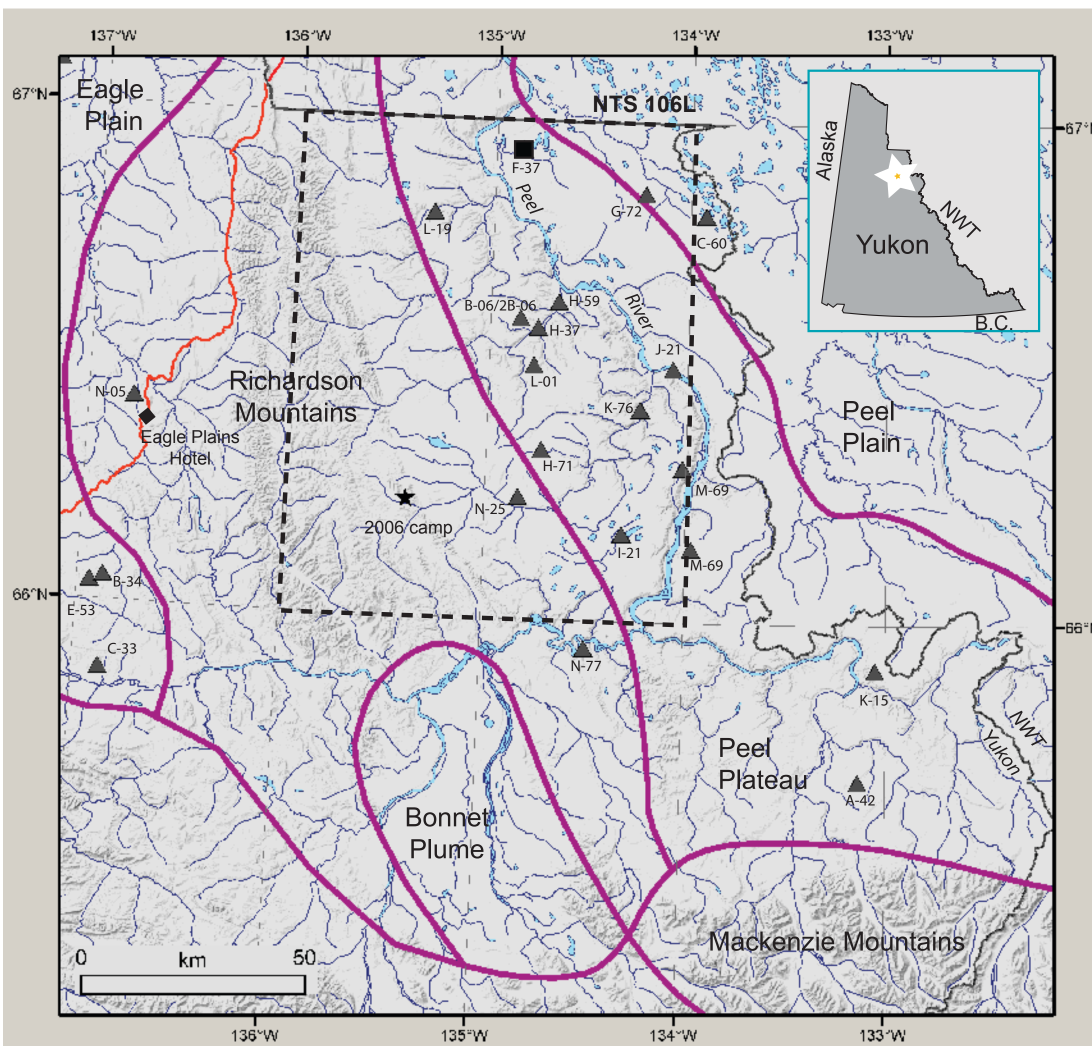

Figure 1. *Map of study area displaying well locations (triangles), summer 2006 camp (star) and Eagle Plains Hotel (diamond). NTS mapsheet 106L is highlighted with a dashed box. Tuttle Formation type section in the F-37 well is represented by a square.*

Tuttle Formation form resistant units that crop out on Trail and Road rivers, as well as along a north-trending ridge extending south of Trail River to north of Road River. A number of site visits were made in areas mapped as the Tuttle Formation by Norris (1981b), as well as recessive units that lie stratigraphically above and below, including the Canol and Imperial formations and Norris' (1981b) map units 'Dus' and 'Cf' (see Fig. 2 for locations).

PREVIOUS STUDIES

During the 1960s and 1970s, the Richardson Mountains and the neighbouring Peel Plateau and Plain were mapped at a 1:250 000 scale by the Geological Survey of Canada as part of Operation Porcupine. Bedrock maps for the Yukon portion of the Peel region include NTS map sheets 106E (Wind River) and 106F (Snake River) by Norris (1982a,b), and 106L (Trail River) and 106K (Martin House) by Norris (1981b,c). No bedrock mapping has been completed since. This mapping has contributed to an understanding of the geology on a regional scale, however our field observations indicate that some detailed remapping is required.

In addition to bedrock mapping, a number of reports pertain to the study area.

Norris (1968) provided a summary of early exploration and geological work on Devonian formations of the Operation Porcupine area, including the Peel Region, up to about 1964. Norris (1985) provided a revised account of the Devonian geology of this same area from additional field work and biostratigraphic studies.

A comprehensive litho/environmental facies analysis of the Mississippian Clastic Wedge (Tuttle Formation) was made by Lutchman (1977) as a part of the Lower Mackenzie Energy Corridor Study conducted by

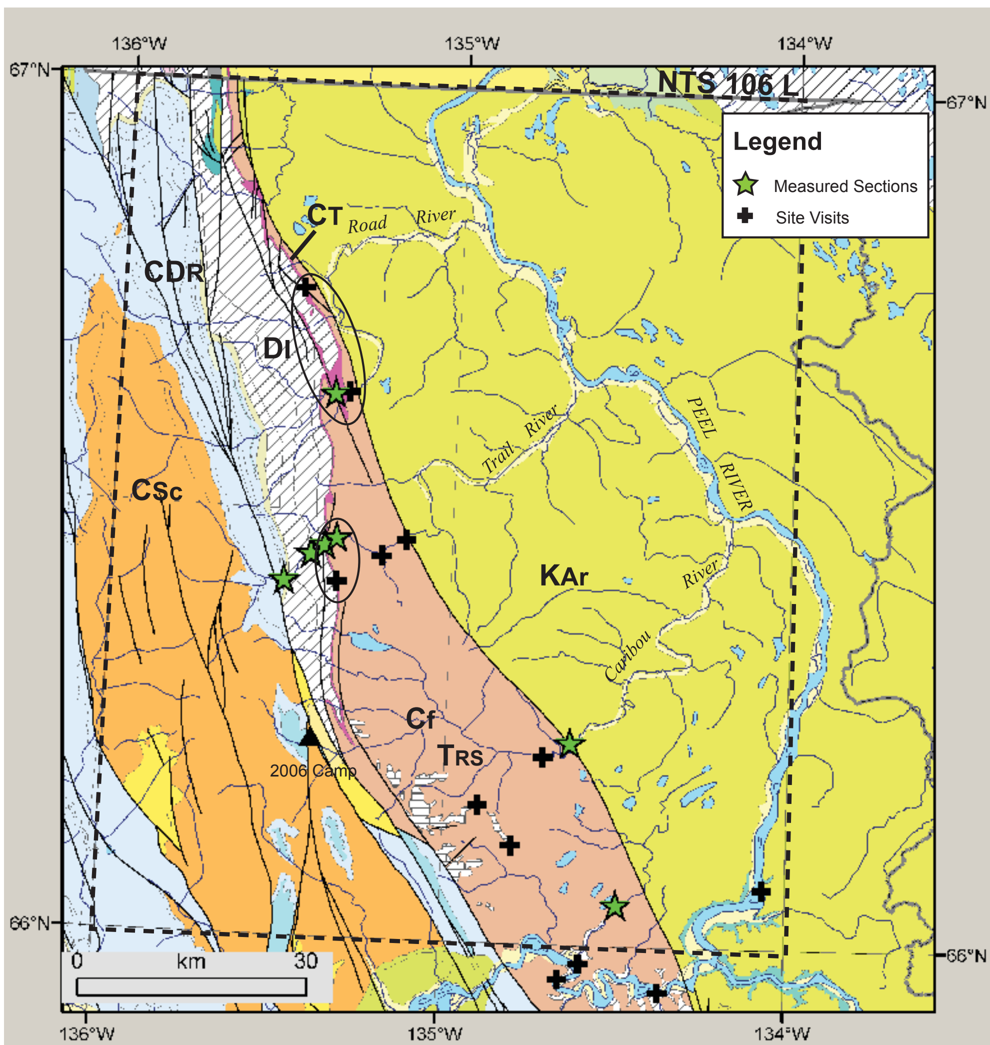

Figure 2. *Close-up map of 106L (dashed line) showing measured sections, site visits and summer 2006 camp location. Circled areas highlight Tuttle locations.*
KAr = Arctic Red Formation
Cf = Carboniferous shale
CT = Tuttle Formation
DI = Imperial Formation
CDR = Road River Formation
CSc = Slats Creek Formation.
TRS = Shublik limestone (skeletal, marine)
Geology from Norris (1981b; 1982a) and Gordey and Makepeace (2001).

Geochem Laboratories and AGAT Consultants. The study involved examination of core, cuttings and mechanical logs from available boreholes.

Pugh (1983) published a subsurface study of the Peel River map area (64° to 68° North latitude and 128° to 144° West longitude), based on regional correlation of well logs and examination of drill cuttings.

Braman and Hills (1992) reported ages of the Imperial and Tuttle formations based on miospores collected from outcrop in the eastern Richardson Mountains and Peel region.

A compilation volume of the efforts of Operation Porcupine was published in 1997 (Norris, D.K., 1997, ed.). Portions of Chapter 7 by Norris (1997) on Devonian strata and Chapter 8 by Richards *et al.* (1997) on Upper Devonian to Permian strata are pertinent to this study.

In 2000, the Government of Yukon published a petroleum resource assessment of the Peel Plateau (National Energy Board of Canada, 2000). This study was conducted by the National Energy Board on behalf of the Yukon government.

Petrel Robertson Consulting Limited (2002) completed a regional geological and geophysical assessment of the central Mackenzie Valley, Northwest Territories, and Eagle Plain, Yukon, which includes the Peel Plateau and Richardson Mountains. The data used in the assessment were derived from logs, core tests and geochemical data obtained from wells and seismic data.

Osadetz *et al.* (2005) published a petroleum resource assessment of the Peel Plateau and Plain of the Yukon Territory, which identified and used statistics to analyse eight plays in three assessment regions.

Lutchman (1977) interpreted a fluvial-deltaic model for the Tuttle Formation based on subsurface analysis. In contrast, based on outcrop observations, Hills *et al.* (1984), and Braman and Hills (1992) interpreted the Tuttle Formation to be deposited as a turbidite sequence.

EXPLORATION HISTORY

During the 1940s to 1970s, a number of oil and gas companies were actively exploring in the Peel region. Studies by these companies included photogeology, geological mapping, section measuring, drilling and seismic acquisition. A number of reports summarizing the results of these studies are available at the National Energy Board (NEB) in Calgary, Alberta.

Nineteen exploratory oil and gas wells were drilled on the Yukon side of the Peel region between 1965 and 1977 (Fig. 3). Eighteen of these wells intersected the Tuttle Formation. Various wireline geophysical logs exist for 18 of the 19 wells and are available to the public.

At least 2039 km of 2D seismic data was acquired from the Yukon Peel region between 1963 and 1976 (Oil and Gas Management Branch, 2001; Fig. 4). All 409-km of data acquired in 1976 is available in paper format from the NEB. The remainder is not publicly available.

In 1977, exploration activity in the Peel region ceased due to the Berger Commission recommendations that a ten-year moratorium be placed on pipeline construction in the Mackenzie Valley (Morrell, 1995). Renewed interest in the Peel region is expected should the proposed Mackenzie Gas Pipeline be constructed.

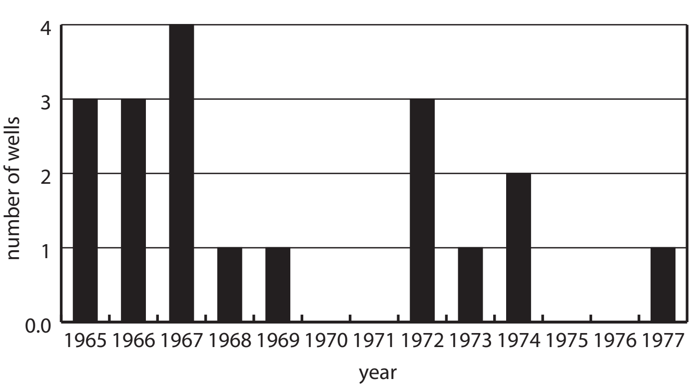

Figure 3. *History of exploratory wells drilled in the Peel Region, Yukon (Government of Canada, 1980).*

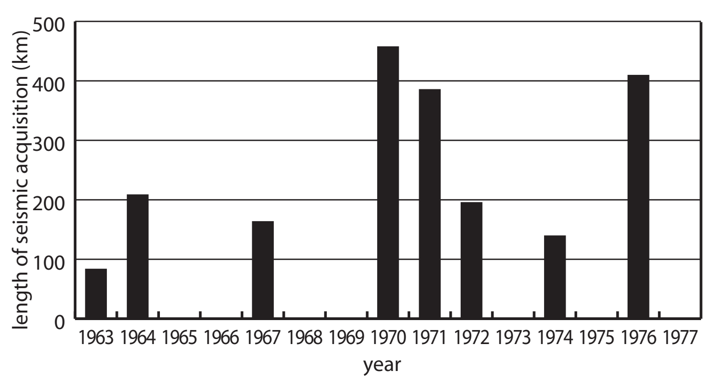

Figure 4. *History of 2D seismic acquisition in the Peel Region, Yukon (Oil and Gas Management Branch, 2001).*

GEOLOGICAL SETTING AND STRATIGRAPHIC FRAMEWORK

The Peel Plateau and Plain in the Yukon is underlain by a westerly thickening wedge of Phanerozoic sedimentary rock (up to 4.5 km thick), that unconformably overlies a poorly understood Proterozoic succession (Osadetz *et al.*, 2005). Phanerozoic strata in the region can be divided into three main depositional systems (Fig. 5): 1) Cambrian to Upper Devonian carbonates and shales of the Mackenzie Peel Shelf and Richardson Trough (Morrow, 1999); 2) an Upper Devonian to Carboniferous clastic

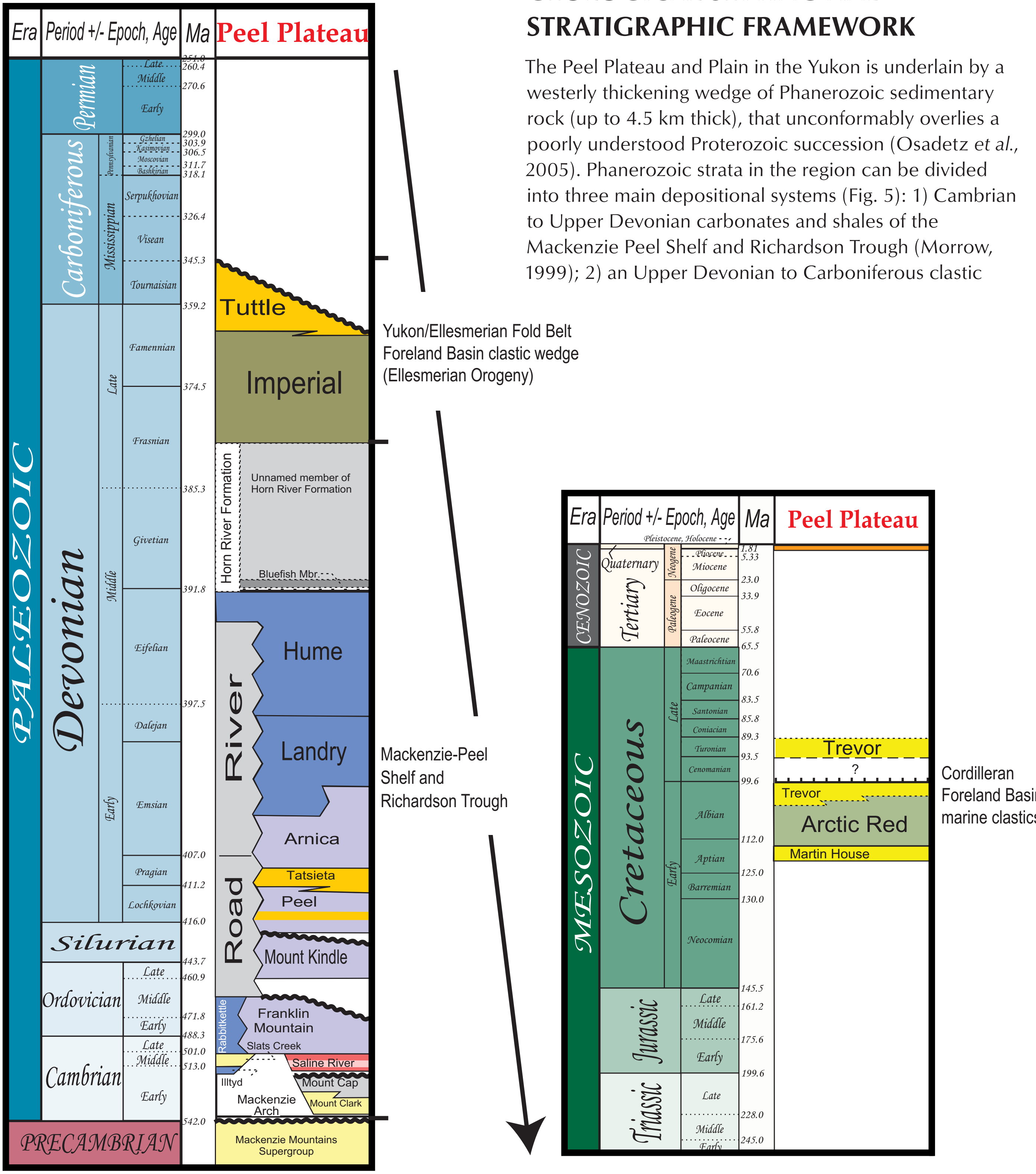

Figure 5. *Stratigraphic column for the Peel Plateau (from Morrow et al., 2006) highlighting the three main depositional systems of the Phanerozoic. Note that the column for the Richardson Mountains is similar except that this Cretaceous section has been removed by erosion.*

wedge that was deposited in a foreland basin of the Yukon and Ellesmerian fold belts associated with the Frasnian to Tournaisian Ellesmerian Orogeny (Richards *et al.* 1997); and 3) Cretaceous marine shelf deposits that were deposited in the foreland basin of the Cordilleran Orogen (Dixon, 1992).

The southern Richardson Mountains border the Peel Plateau to the west. The mountain ranges trend north and are an expression of the Richardson Anticlinorium, which is a broad, north-plunging structure bounded to the east by the Trevor Fault and to the west by Deception Fault (Norris, 1985). The Anticlinorium is a structural inversion of the Richardson Trough that occurred during the Laramide Orogeny (Osadetz *et al.*, 2005). The stratigraphy for the Richardson Mountains is correlative to the Peel Plateau and Plain, with the exception that most of the Cretaceous section has been removed by erosion.

The Upper Devonian to Carboniferous clastic wedge represents synorogenic deposition in the foreland of the Yukon and Ellesmerian fold belts (Richards *et al.*, 1997). The Ellesmerian Orogeny created a complex depositional setting across northern Yukon and the Northwest Territories with sedimentation derived from the west and north (Gordey, 1988). The clastic wedge consists of a thick (up to 1909 m, according to Richards *et al.* 1997) package of shale and siltstone, with lesser sandstone and limestone, comprising the Frasnian to Famennian Imperial Formation, and the overlying Famennian to Tournaisian Tuttle Formation (up to 1420 m, according to Pugh, 1983; see description below). Upper Devonian to Upper Mississippian Ford Lake Shale (Brabb, 1969) is the basinal equivalent to the Tuttle Formation and occurs further south and west of the Peel region (Pugh, 1983).

TUTTLE FORMATION

The Tuttle Formation has been described by many authors in the past, including Norris (1968, 1985, 1997), Lutchman (1977), Pugh (1983), Braman and Hills (1992) and Richards *et al.* (1997). Our definition of the Tuttle Formation follows Pugh (1983): he proposed the name Tuttle Formation for an alternating succession of coarse- to fine-grained clastic rocks overlying the Imperial Formation and unconformably overlain by Mesozoic strata in an area flanking the eastern, northern and western Richardson Mountains.

TYPE SECTION

The type section for the Tuttle Formation is the Pacific Peel Y.T. F-37 borehole which was drilled in 1972 in the Peel region of the Yukon (Fig. 6). In this well, the Tuttle Formation occurs between depths of 106.7 and 980.2 m from the surface and is 873.5 m in total thickness. At this

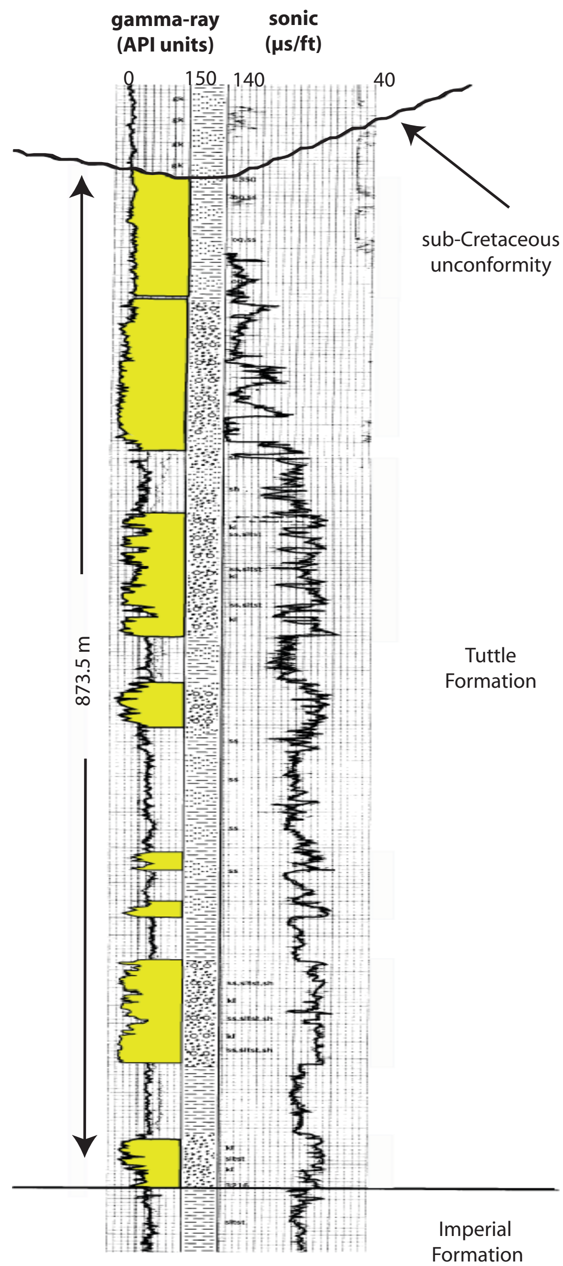

Figure 6. *Gamma-ray and sonic curves for the Tuttle Formation type section interval (106.7 to 980.2 m) in the Pacific Peel Y.T. F-37 borehole (see location on Fig. 1). Shaded areas represent coarser grained intervals (after Pugh, 1983).*

location, the Tuttle Formation overlies shale of the Upper Devonian Imperial Formation, and is eroded above by the sub-Cretaceous unconformity. Cretaceous marine siliciclastic rocks lie above the unconformity.

Pugh (1983) described the Tuttle Formation type-section as chert conglomerate, very poorly sorted quartz and chert sandstone, siltstone and shale. The conglomerate is predominantly multicoloured chert, including white, buff, grey, yellow, orange and pale green clasts. Most of the sandstone and shale beds are micaceous, with sandstone also containing kaolinite pore-filling cement. The top 100 m of the formation contains orthoquartzite beds. Pugh's (1983) definition of the Tuttle Formation includes the interval between the Imperial Formation and the overlying Mesozoic strata, including the map units 'Dus' and 'Cf' of Norris (1981b).

DISTRIBUTION

The Tuttle Formation is found at surface on the western and eastern flanks of the Richardson Mountains (northwestern circle area in Fig. 7). Norris (1982a,b) mapped a Carboniferous sandstone and shale, designated map unit 'MO', along the northern front of the Mackenzie Mountains on NTS map sheets 106E (Wind River) and 106F (Snake River) (southern circled area in Fig. 7). In the Yukon digital geology compilation map by Gordey and Makepeace (2001), the Tuttle Formation and map unit 'MO' were combined into the lower Carboniferous Tuttle Formation (i.e., map unit 'lCT'). Further field investigations are required to confirm this correlation. Surface exposures of the Tuttle Formation and map unit 'MO' are limited almost exclusively to the Yukon Territory.

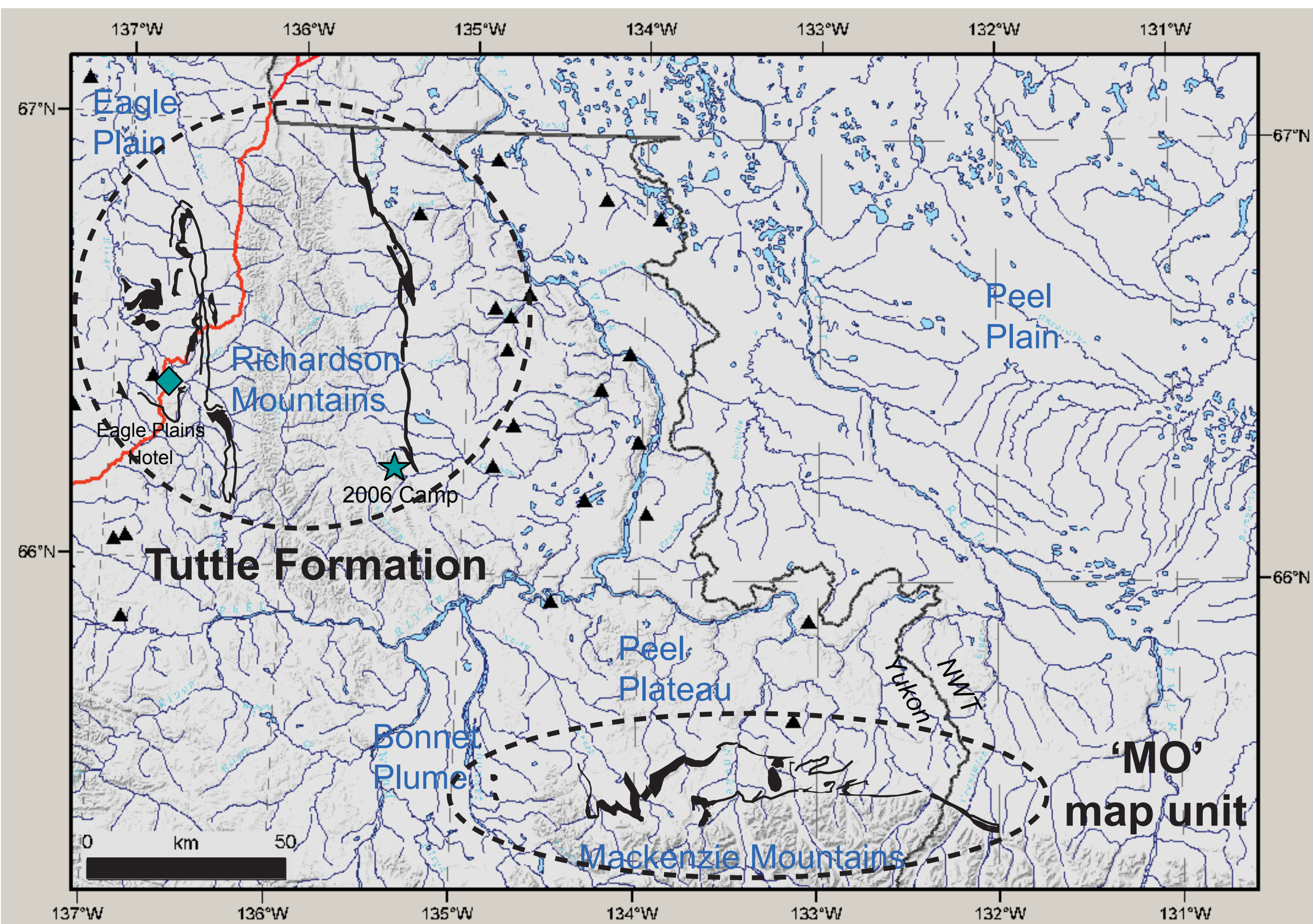

Figure 7. *Surface expression (black polygons) of the Tuttle Formation and map unit 'MO' of Norris (1981a,b; 1982 a,b). Triangles represent Yukon well locations.*

In the Peel region, the Tuttle Formation is intersected in eighteen Yukon and nine Northwest Territories boreholes. Figure 8 displays an isopach map of the Tuttle Formation in the Peel region, based on Pugh (1983), showing the range in thickness from 0 m at the western and eastern erosional edges to 1198.7 m in borehole H-37.

Pugh (1983) interpreted a maximum thickness of over 1250 and 1420 m for the Tuttle Formation on the east and west sides of the Richardson Mountain Anticlinorium, respectively. Norris (1985) suggests the depocentre of the Tuttle Formation was within what is now the Richardson Anticlinorium, before it was uplifted and Tuttle strata subsequently removed by erosion.

AGE

The Tuttle Formation on Trail and Road rivers has been assigned an early-middle Famennian to early Tournaisian age based on miospores (Hills *et al.*, 1984; Braman and Hills, 1992). Within the Tuttle Formation on Trail River, there is a change from possible middle Famennian miospores to latest Famennian or early Tournaisian miospores, suggesting that there may be a hiatus in the Formation (Braman and Hills, 1992). Parts of the section are missing, however, and in other parts the spores are highly carbonized making age determinations uncertain through this interval (Braman and Hills, 1992).

FIELD WORK AND PRELIMINARY FINDINGS

The 2006 field season involved an initial reconnaissance study of the distribution and accessibility of potential stratigraphic sections of the Tuttle Formation. Once exposures were identified, sections were measured and

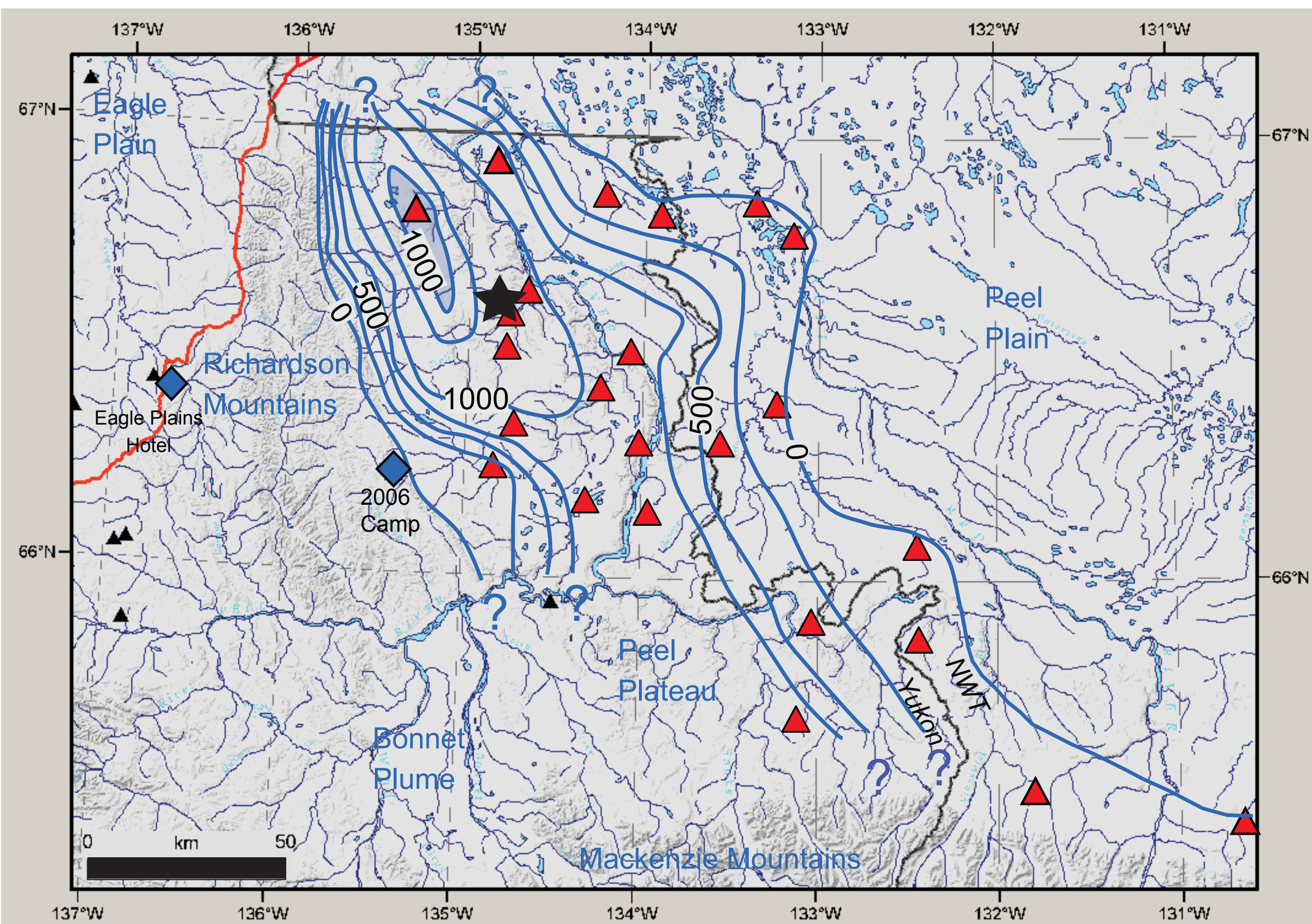

Figure 8. *Subsurface distribution of the Tuttle Formation in the Peel region. Contours represent thickness of Tuttle Formation in metres based on well data (after Pugh, 1983). Borehole H-37 (star) has the thickest Tuttle section in the Peel region at 1198.7 m. Dark grey triangles represent Peel region wells that intersect the Tuttle Formation.*

sampled to obtain data for use in future resource assessments. Samples were collected for porosity and permeability analysis for reservoir potential; Rock-Eval pyrolysis, total organic carbon, and hydrocarbon extraction analyses for source rock potential and thermal maturation determination; microfossils (i.e., spores and foraminifera) for dating; and thin sections for lithology and rock fabric. Most of the samples are still undergoing lab analysis.

Detailed sections of the Tuttle Formation were measured on the Trail and Road rivers. In addition, two visits to exposures of Tuttle Formation were made. Section and visit locations can be found on Figure 2.

MEASURED SECTIONS

The first impression of the Tuttle Formation in the field is its alternating resistant and recessive nature in outcrop. Resistant 'ribs' of dominantly sandstone, with lesser amounts of conglomerate and siltstone, alternate with recessive, covered units that are interpreted as siltstone and shale. In this paper, siltstone is applied to fine-grained clastic rocks composed primarily of silt-size grains and tends to be flaggy; shale is applied to rocks that exhibit fissility and are made up of clay-size material; while mudstone is applied to fine-grained rocks that are made up of silt- and clay-size material and lack fissility.

A total of 300 m of the Tuttle Formation was measured, but no complete section was observed in the field. Detailed sections were measured on both Trail and Road rivers, and for most of the sections, sedimentary structures were difficult to distinguish due to inaccessibility, lichen, cementation and mud cover.

The best exposed section of Upper Paleozoic strata was the Trail River section (Fig. 9). This section provided individual bed thicknesses, grain-size distribution, and sedimentary structures associated with the sandstone and shale of the Tuttle Formation and adjacent units. A total of 225 m of strata were measured (Fig. 10), which consisted of 81 m of resistant sandstone, with an intervening covered interval measuring 144 m. It was unclear in the field whether this section represented the base of the Tuttle Formation: the unit below the first sandstone rib consisted predominantly of shale, with lesser sandstone and siltstone. This is possibly the map unit 'Dus' of Norris (1981b). Norris (1981b) assigned strata above the Tuttle Formation to map unit 'Cf' (i.e., Carboniferous shale) on Trail River. However, we suggest that the Tuttle Formation may extend eastward to the Trevor Fault. This interpretation would be consistent with the findings of Braman and Hills (1992).

The section measured on Road River is 108 m thick, and consists of 53 m of resistant sandstone and a covered interval of 55 m. The strata are structurally complex and

Figure 9. *Sandstone interval of the Tuttle Formation exposed on Trail River (location within circled area on Trail River, Fig. 2). Stratigraphic thickness measured is 55 m. Top of section is to the right. Rock hammer (30 cm long) circled for scale.*

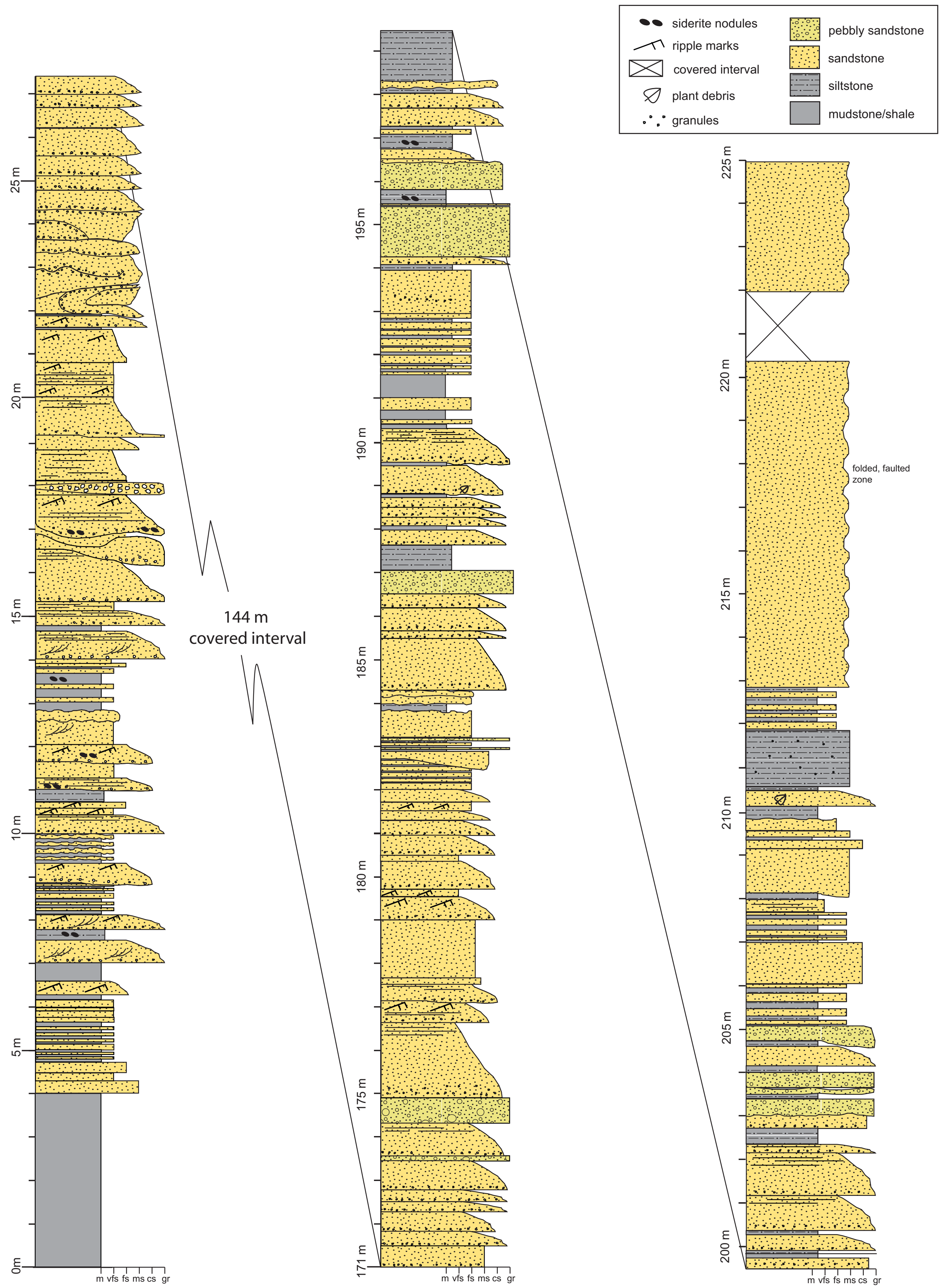

Figure 10. *Measured stratigraphic section on Trail River.*

an upper contact could not be determined. An additional 57 m of shale, with lesser amounts of sandstone and siltstone, was also measured below the Tuttle Formation, and tentatively assigned to the Imperial Formation.

SITE VISITS

Two visits to other Tuttle Formation exposures were made in the study area. The first was on a north-trending ridge south of Trail River (Fig. 2). At this location, the Tuttle Formation was exposed on surface and no fresh rock faces were observed due to lichen cover. Sandstone and conglomerate samples were taken for thin-section analysis and porosity and permeability determinations.

The second visit was to a large, steep exposure of the Tuttle Formation on a north-trending ridge north of Road River (Fig. 2). At this location approximately 8-10 m of conglomerate and lesser sandstone were exposed. A sample of conglomerate from the topmost 3 m of the exposure was obtained for thin section, and porosity and permeability determinations.

Figure 11. *Fining-upward sandstone on Trail River. Note the gradual fining up from granule-rich sandstone at the base to medium sandstone at the top. Granules are predominantly chert. Parallel laminae to large-scale planar crossbeds are evident in the sandstone. Hammer is 30 cm long.*

SEDIMENTOLOGY

The Tuttle Formation, as observed in outcrop along the eastern flank of the Richardson Mountains, consists of alternating packages of coarse-grained clastic rocks including medium- to very coarse-grained sandstone and conglomerate, with finer grained intervals of siltstone and shale that are largely covered. The sections measured on Trail and Road rivers indicate the coarse-grained packages range from 23 to 54 m thick, while the largely covered finer grained intervals range from 55 to 144 m thick.

Field investigations of the coarse-grained Tuttle Formation on Trail and Road rivers revealed five lithofacies that could readily be identified, including fining-upward sandstone, massive sandstone, siltstone, conglomerate and diamictite. These units are described in order of abundance observed in the field.

Fining-upward sandstone

Fining-upward sandstone is the most common lithofacies observed within measured sections of the Tuttle Formation (Fig. 11). The sandstone is light olive-grey to medium-grey on the fresh surface and weathers medium grey, dark yellowish orange or light brown. Individual fining-upward beds average 60 cm thick, with 100 cm being the thickest observed bed. The base of each bed is commonly marked by scours (up to 25 cm deep) and exhibits sole marks and/or load casts. Fining-upward beds tend to be stacked on top of one another and are locally separated by siltstone intervals less than 10 cm thick.

Fining-upward beds consist of coarse- to very coarse-grained sandstone with, or without, granules and pebbles at the base, grading to medium- to very fine-grained sandstone at the top. At the base, the sandstone is poorly sorted, containing up to 20% subangular to subrounded very coarse sandstone, granules or pebbles (less than 1.7 cm in diameter). The larger grains consist of varicoloured chert (i.e., grey, black, yellow, green), tripolitic chert (white) and quartz (smoky grey). The matrix consists of finer grained chert and quartz sandstone, which is generally more rounded than the larger grains. This basal zone is massive or cross-bedded. The top portion of the fining-upward beds are lithologically similar to the base, and are either massive, or parallel laminated. In the fine- to very fine-grained sandstone at the top, ripples were observed in laminations and beds 2 mm to 3 cm thick.

Commonly observed in this lithologic unit was a fine-grained, white chalky mineral precipitated in pore spaces. This mineral has been identified in previous work as kaolinite (Lutchman, 1977; Pugh, 1983). Fossilized plant debris occur as millimetre-size plant fragments on bedding planes, or as randomly oriented tree fragments. No *in situ* plant remains were identified.

Massive sandstone

The second most common lithofacies noted within measured sections of the Tuttle Formation is massive sandstone. The sandstone is light to medium grey and weathers dusky yellow, moderate brown, light olive-grey and greyish-orange. Beds range from 30 to 450 cm thick and have abrupt lower contacts. The sandstone is typically resistant, well indurated and blocky, but locally is friable and fractured.

The sandstone is poorly sorted and ranges from fine sand to granules (Fig. 12). Coarse sand to granule-sized grains comprise 5 to 25% of the overall rock texture. Larger grains are predominantly tripolitic chert (white) with lesser quartz (smoky grey). The chert grains are subangular to rounded, and contain a variety of internal structures including laminae and circular fragments (possibly radiolarian fossils), or are structureless. The matrix of the finer grained sandstone is chert- and quartz-rich. The sandstone on Road River has a greater proportion of quartz in the matrix than that on Trail River, resulting in a more indurated rock. Quartz overgrowths and fused-grain boundaries were observed in thin section. Other material includes 3% carbonaceous material, mud clasts up to 10 cm across, and white chalky pore filling interpreted as kaolinite.

Carbonized tree fragments, millimetre-size plant debris, and grey mudchips are common in this lithofacies, notably at the base of beds. Millimetre-sized carbonaceous material was concentrated along parallel laminae in the top portion of some beds. Siderite nodules and continuous bands were also observed locally.

Siltstone

Poorly exposed, recessive intervals of siltstone were noted between some of the sandstone beds described above. These intervals are typically less than 10 cm thick, but can be up to 50 cm thick. This lithofacies is dominated by siltstone with lesser mudstone and is dark grey to black, with rusty weathering. Thin laminae and beds of sandstone up to 3 cm thick were also observed in this unit. The sandstone is very fine-grained and quartz-rich with beds 1 to 10 cm thick, giving the unit a striped appearance (Fig. 13).

Conglomerate

The coarsest lithofacies observed was a matrix-supported, small-pebble conglomerate (Fig. 14). In the literature, conglomerate is described as one of the more abundant facies within the Tuttle Formation, however on Trail and Road rivers, it is a subordinate unit.

In measured sections, conglomerate beds normally did not exceed 60 cm in thickness. An exception is the north-trending ridge north of Road River, where conglomerate 8 to 10 m thick was exposed.

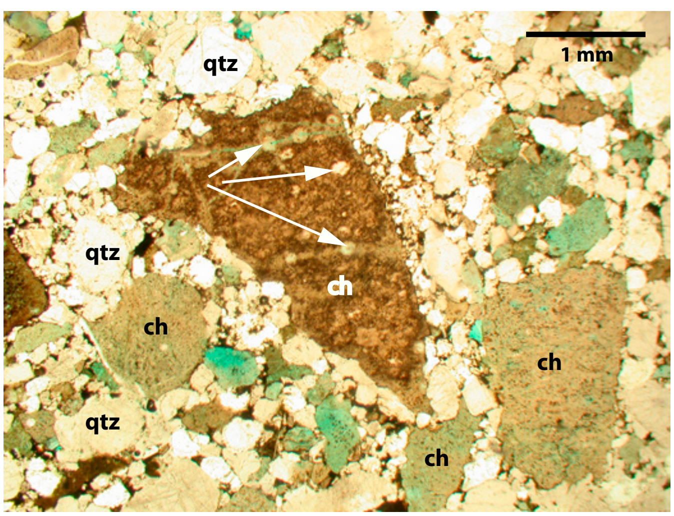

Figure 12. *Thin section of massive sandstone. Note the poor sorting and the larger chert (ch) and quartz (qtz) grains in a predominantly quartz matrix. There are possible radiolarian fossils in the chert clast in the middle of the figure (arrows).*

Figure 13. *Siltstone. Note the striped appearance enhanced by the alternating beds of light grey very fine-grained sandstone and dark grey siltstone.*

Figure 14. *Chert-pebble conglomerate from Trail River. Note the abundance of chert clasts. Chert in this sample is varicoloured including white, grey, black, yellow, and light green.*

Figure 15. *Diamictite on Road River consisting of rounded clasts within a blocky finer grained matrix. This lithology is very distinctive in the sections due to its dark colour and structureless appearance.*

On Trail and Road rivers, the conglomerate is typically matrix-supported with clasts averaging 1 cm across, although cobbles were observed locally. Conglomerate beds are lensoidal and are either massive or normally graded. Pebbles are subangular to rounded and are predominantly varicoloured chert (i.e., white, medium to light grey, light yellowish-grey, black, greyish-pink, bluish-grey, light and dark green and grey banded varieties) and quartz (white and smoky grey). Clasts are spherical. The matrix is composed of poorly sorted chert and quartz grains of variable sand sizes. Weathered surfaces are rusty.

Diamictite

Diamictite is the least abundant lithofacies observed and was only found on Road River. It is medium dark grey on the fresh surface and weathers blackish-red to greyish-red. This lithofacies appears dirty in contrast to neighbouring units and is extremely friable.

Diamictite consists of a disorganized mixture of mudstone, siltstone or very fine-grained sandstone supporting clasts of coarse sandstone, granules, pebbles and cobbles (up to 10 cm across). Clasts comprise up to 20% of the composition and are subrounded to round (Fig. 15). No internal sedimentary structures were observed, and the bases were scoop- or lobate-shaped. Beds vary in thicknesses from 85 to 220 cm. Disseminated carbonaceous plant debris is present locally.

POROSITY AND PERMEABILITY

Thirty Tuttle samples were submitted to AGAT Laboratories, Core Services Division in Calgary for analysis of porosity and permeability using standard procedures of AGAT Laboratories.[1] Out of the samples submitted, 28 were analysed using 38.1- to 25.4-mm (1.5- to 1.0-inch) plugs, with 2 samples insufficient for this type of analysis (i.e., plugs could not be made). A fracture in another sample produced permeability errors and is not reported here. All samples submitted were hand samples collected from the field and were chosen to represent a wide range of grain sizes from various Tuttle Formation outcrops.

Note that outcrop-based predictions of subsurface reservoir quality has certain limitations, including differences in diagenetic history and pore system evolution between surface and subsurface samples and the fact that recent outcrop diagenesis (leaching, cementation, sediment infill, etc.) may enhance or destroy porosity and permeability that occurs in the subsurface (Tobin, 1997). Hence, the results from this analysis will be used as an approximation of subsurface reservoir quality in a frontier region with otherwise sparse subsurface data.

[1]*AGAT Laboratories, 2006. Final Core Analysis Report, Outcrop Samples Miscellaneous Locations. Prepared for Yukon Geological Survey, 16 p.*

Figure 16 is a cross-plot of porosity (percent) versus permeability (millidarcies). Samples were divided into five classes based on grain size, including fine, medium and coarse sandstone, granule to pebble conglomerate, and a poorly sorted fine sandstone to granule conglomerate. The figure also displays reservoir porosity and permeability classes defined by Levorsen (2001).

Porosity ranged from 1.6% in coarse-grained sandstone to 18.6% in medium-grained sandstone. Permeability ranged from 0 to 13.7 mD in coarse-grained sandstone. Based on these surface samples, the best prospects for reservoir rock are medium-grained sandstone, followed by coarse-grained sandstone and then the poorly sorted fine sandstone to granule conglomerate.

The granule- to pebble-conglomerate has the poorest reservoir characteristics of samples analysed. Exceptions to these results are observations at a large conglomerate outcrop in the northern part of the study area. Vugs measuring up to approximately 15 cm in diameter were observed (Fig. 17). Two samples from this outcrop were submitted for porosity/permeability analyses. The first had poor to fair reservoir characteristics, and the second was unsuitable for testing because it was too friable to make a plug. We expect this second sample would have fair to good reservoir characteristics as it appeared porous in hand specimen.

Figure 17. *Vuggy conglomerate indicating high porosity at a Tuttle exposure north of Road River. Notebook is 18 cm long.*

HYDROCARBON OCCURRENCES

The Tuttle Formation has historically been an exploration target in both the Peel region and Eagle Plain. In the Peel, minor gas has been detected in six Yukon wells and in one Northwest Territories well (Table 1 and Fig. 18).

In Eagle Plain, gas has been detected in the Tuttle Formation in six wells. Four have had minor gas shows, and two wells, the Western Minerals Chance #1 L-08 (UWI 300L086610137300) and the Mobil Oil Birch Y.T. B-34 (UWI 300B346610136405), have estimated reserves of 57 x 10^6 and 81 x 10^6 m^3(2 and 3 billion cubic feet (BCF)), respectively (National Energy Board of Canada, 2000).

No record of oil shows exist in the literature, however a sample of bitumen-stained sandstone found in what is believed to be Tuttle Formation on Trail River is currently undergoing analysis as part of this study.

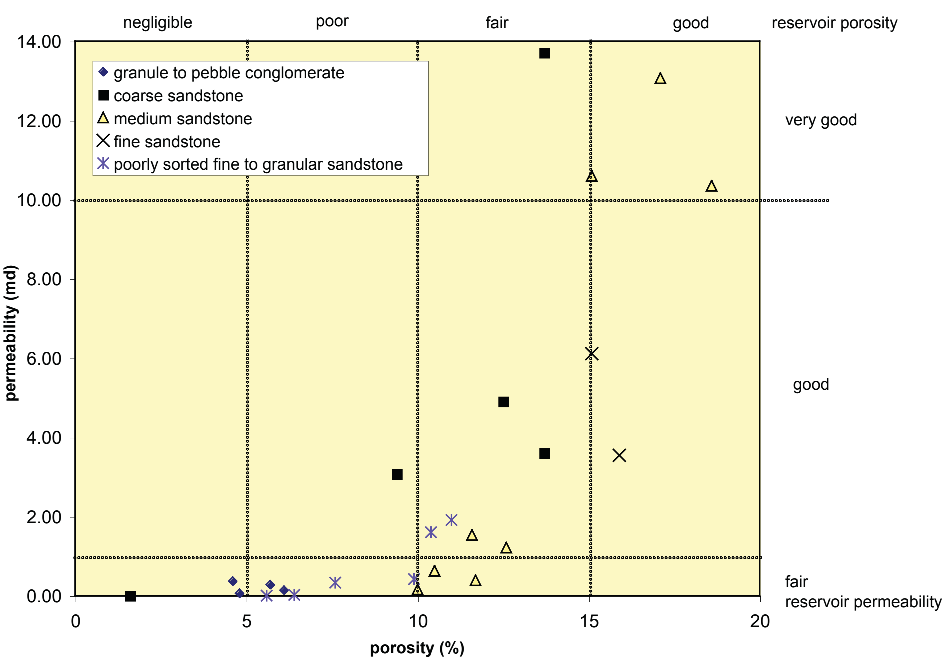

Figure 16. *Porosity/permeability cross-plot for 25 Tuttle surface samples. Samples were classified into five groups (granule to pebble conglomerate, coarse sandstone, medium sandstone, fine sandstone, and poorly sorted fine to granular sandstone) based on predominant grain size.*

Table 1. *Historical gas shows in the Tuttle Formation in the Peel region (Government of Canada, 1980; Indian and Northern Affairs, 1966a and 1966b).*

Well name and unique well identifier (UWI)	Drill stem test (DST) depth	Recoveries
Shell Peel River Y.T. **B-06** (UWI300B066640134450)	DST #2 312.4-430.4 m (1025-1412 ft)	18.3 m (60 ft) mud; 18.3 m (60 ft) mud-cut water; gas to surface in 30 seconds; too small too measure
Shell Peel River Y.T. **B-06A** (UWI302B066640134450)	DST #1 798.3-866.9 m (2619-2844 ft)	789.4 m (2590 ft) partly gasified water; gas to surface in 45 minutes
McD GCO Northup Taylor Lake Y.T. **K-15** (UWI300K156600133000)	DST #1 729.4-737.0 m (2393-2418 ft)	30.5 m (100 ft) water-cut mud; 121.9 m (400 ft) mud-cut gassy fresh water
Shell Peel River Y.T. **M-69** (UWI300M696610133450)	DST #4 1742.8-1799.8 m (5718-5905 ft)	94 m (310 ft) mud; gas to surface too small to measure
Shell Peel River Y.T. **I-21** (UWI300I216620134150)	DST #2 767.5-888.8 m (2518-2916 ft)	418.5 m (1373 ft) fresh water, slightly gasified
Shell Canada Peel River Y.T. **L-01** (UWI300L016640134450)	DST #2 1338.7-1394.2 m (4392-4574 ft)	91.4 m (300 ft) water-cut mud; 182.9 m (600 ft) mud-cut water; 640 m (2100 ft) slightly gasified water
Arco Shell Sainville River **D-08** (UWI300D08662013330)	DST #5 898.6-907.7 m (2948-2978 ft)	gas to surface in 25 minutes; too small to measure

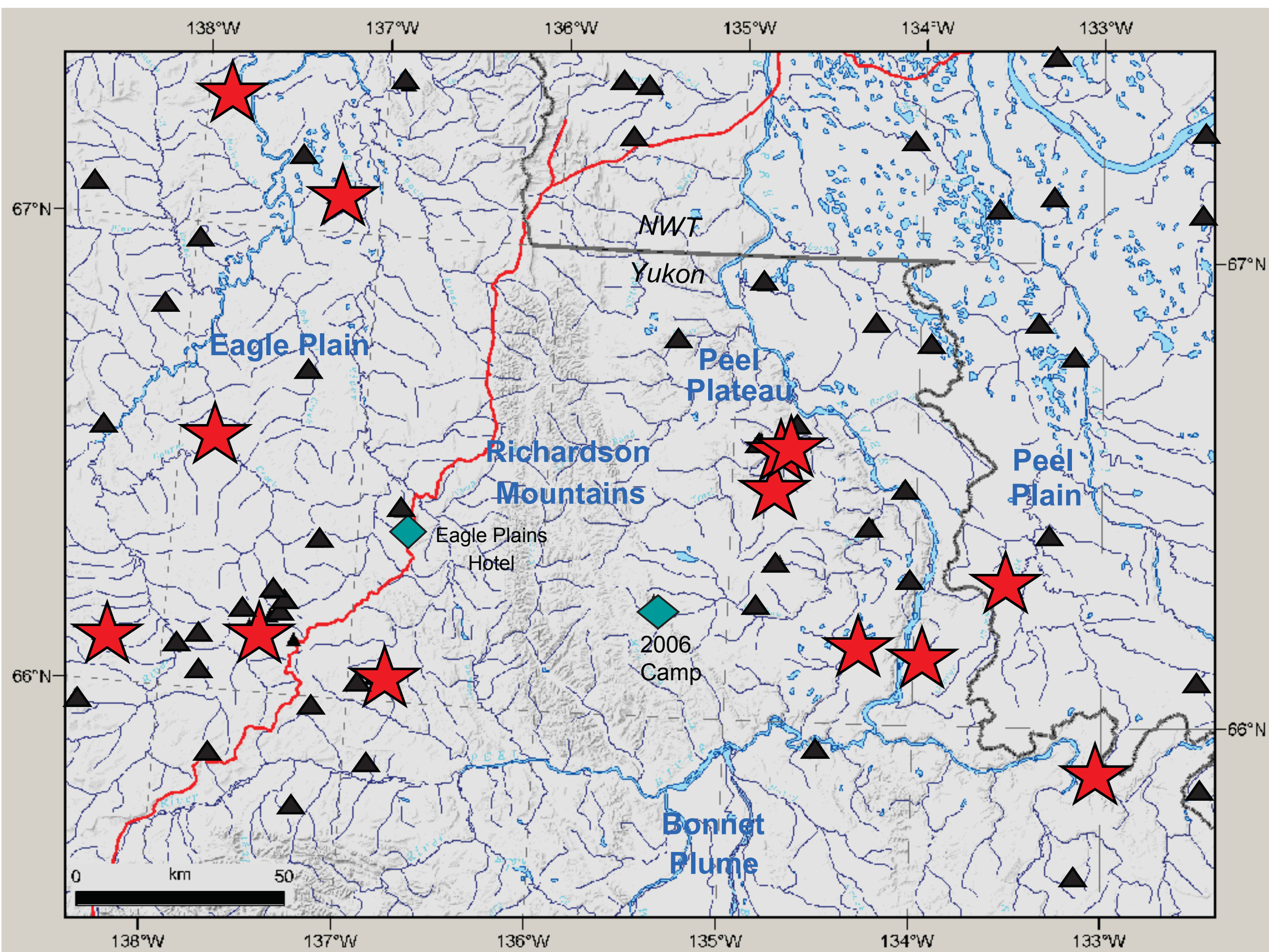

Figure 18. *Map highlighting wells which have had gas shows (stars) in the Tuttle Formation in the Peel region (Government of Canada, 1980; Indian and Northern Affairs, 1966a,b) and Eagle Plain (National Energy Board of Canada, 2000; Osadetz et al., 2005a). Triangles indicate other wells in vicinity.*

CONCLUSIONS

The Tuttle Formation on the eastern flank of the Richardson Mountains was investigated as part of the four-year, multi-partner "Regional Geoscience Studies & Petroleum Potential, Peel Plateau and Plain" project. Field studies in 2006 in NTS map sheet 106L (Trail River) identified the Upper Devonian to Lower Carboniferous Tuttle Formation as alternating resistant and recessive intervals. Resistant intervals comprise chert- and quartz-rich sandstone, with lesser conglomerate and siltstone. Intervening poorly exposed, recessive intervals consist predominantly of siltstone and shale.

Exposed resistant sections of the Tuttle Formation on Trail and Road rivers are divided into five lithofacies, including fining-upward sandstone, massive sandstone with lesser siltstone, conglomerate and diamictite. In our map area we found only limited exposure of conglomerate. However, the distribution of conglomerate is reported as variable in the map area (Pugh, 1983; Norris, 1985).

Based on surface-sample analyses of porosity and permeability, the best prospects for reservoir rock are medium-grained sandstone, followed by coarse-grained sandstone, and then poorly sorted fine sandstone to granule conglomerate. Noticeable vuggy porosity was observed in Tuttle conglomerates on a ridge north of Road River. Minor gas shows have been found in the Tuttle Formation in the Peel region in six Yukon wells and in one NWT well. These gas shows, along with gas shows and combined reserve estimates of 138 x 10^6 (5 BCF) in the Tuttle Formation in Eagle Plain, show a promising future for the Tuttle Formation as a reservoir unit, and warrant further investigation.

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