Field notes on the Upper Devonian Imperial Formation (NTS map sheet 106L), Tetlit Creek, east Richardson Mountains, Yukon

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ABSTRACT

Although the Upper Devonian Imperial Formation is widespread across northern Yukon and Northwest Territories, its geology is poorly understood in northern Yukon. The Imperial Formation is well exposed in outcrop along the eastern flank of the Richardson Mountains, notably on Tetlit Creek and Trail River (NTS map sheet 106L). During the summer of 2008, detailed partial stratigraphic sections were measured on Tetlit Creek to record lithologic variation within the formation. In addition, samples were collected to establish the age of the strata and its source rock potential by means of palynological, geochemical and vitrinite reflectance analyses.

In the east Richardson Mountains, Imperial Formation strata can be informally subdivided into two parts. The lower is predominantly mudstone and siltstone while the upper part comprises sandstone and fine-grained siliciclastic rocks. Palynological analyses for this region have established that the Imperial Formation is late Frasnian to Famennian in age. Accompanying thermal alteration indices (T.A.I.), as well as vitrinite reflectance data, suggest that the strata are overmature with respect to hydrocarbon generation. Based on Rock Eval/TOC results from surface, most of the organic matter present within the strata are not favourable for source rock potential.

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INTRODUCTION

Fine-grained siliciclastic rocks and sandstone successions characterize Upper Paleozoic and Cretaceous strata of the Richardson anticlinorium and adjacent Peel Plateau and Eagle Plain regions. The Imperial Formation is a thick sequence of predominantly mudstone and shale in its basal portion with an increase in sandstone higher in the succession. Although in outcrop there does not appear to be abundant organic-rich strata, the Imperial Formation is potentially an important source rock attaining a thickness of up to 1909 m on the east flank of the northern Richardson Mountains (A.W. Norris, 1997). Osadetz *et al.* (2005) suggest that the slope and shelf sandstone of the Imperial Formation may represent significant opportunities for the structural entrapment of petroleum. Little is known about the Imperial Formation including its hydrocarbon source rock potential and thermal maturity in the study area, which includes the eastern Richardson Mountains and adjacent Peel Plateau. To more fully document the character, age, hydrocarbon source rock potential and related thermal maturity of the Imperial Formation, detailed studies were undertaken. Stratigraphic sections were measured and samples collected with the results presented herein.

STUDY AREA AND LOCATION

Upper Devonian Imperial Formation exposures occur along both the western and eastern flanks of the Richardson Mountains and extend to the west under Eagle Plain and east under Peel Plateau and Plain. This paper focuses on Imperial Formation strata along the eastern flank of the Richardson Mountains that are continuously exposed over tens of kilometres on Tetlit Creek (NTS map sheets 106L/11 and 12), a tributary of the Road River, northeast Yukon (Fig. 1). Strata dip slightly to the east (010° to 020°) over much of the area. Parts of exposures were easily accessible via gravel bars along the Tetlit Creek, however deep rushing waters of Tetlit Creek often prohibited closer examination of the outcrop.

PREVIOUS WORK

A summary of Imperial Formation nomenclature and previous work is outlined in publications by Pugh (1983), A.W. Norris (1985; 1997) and Hadlari *et al.* (2009). Previous geological work on Tetlit Creek is limited to 1:250 000-scale bedrock mapping of the Trail River map sheet (NTS 106L) as part of Operation Porcupine (Norris, 1981b). During this mapping exercise, Norris separated the Imperial Formation into two parts including a lower part comprising “shale, dark grey, rusty-weathering; siltstone, dark grey” and an upper part comprising “sandstone, fine-grained, lithic, dark grey; siltstone, dark grey” (Norris, 1981a; b). The author has used these two designations in this paper.

A regional summary addressing the hydrocarbon potential of the Imperial Formation in the Peel Plateau is a petroleum resource assessment of the Peel Plateau and Plain by Osadetz *et al.* (2005), in which the Imperial Formation is identified as contributing to three conceptual natural gas plays, however little data were available for this assessment. Recommendations made by Osadetz *et al.* (2005) were followed up in the collaborative Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain, Northwest Territories and Yukon project (“Peel Project”) by GSC, Northwest Territories Geoscience Office and the Yukon Geological Survey. Data collected and compiled on the Imperial Formation as part of this project are presented in Allen and Fraser (2008) as well as Chapters 7 and 10 of Pyle and Jones (2009). Supplementary follow-up work, including results of Rock-Eval/total organic carbon (TOC) analyses for all Yukon’s exploration oil and gas wells, is presented in Allen *et al.* (2008).

METHODOLOGY

Objectives of this study include outlining and integrating stratigraphy, as well as palynological and source rock geochemical information acquired through both reconnaissance and detailed sampling of Imperial Formation sections. Data originate from four well-exposed stratigraphic sections, ranging from 20 to 450 m thick, measured on Tetlit Creek, Yukon (NTS map sheets 106L/11 and 12; Fig. 2). The results presented here stem from field research conducted in 2008 and follow-up analysis. This research involved measuring, describing and sampling partial sections of the Imperial Formation in detail to document its occurrence, sedimentology and variability in this region, and to assess its source rock potential. This included documenting the abundance of sandstone and its relationship to adjacent fine-grained strata. Mudstone, siltstone and shale were analysed for source rock potential including quality and quantity of organic matter, as well as thermal maturity.

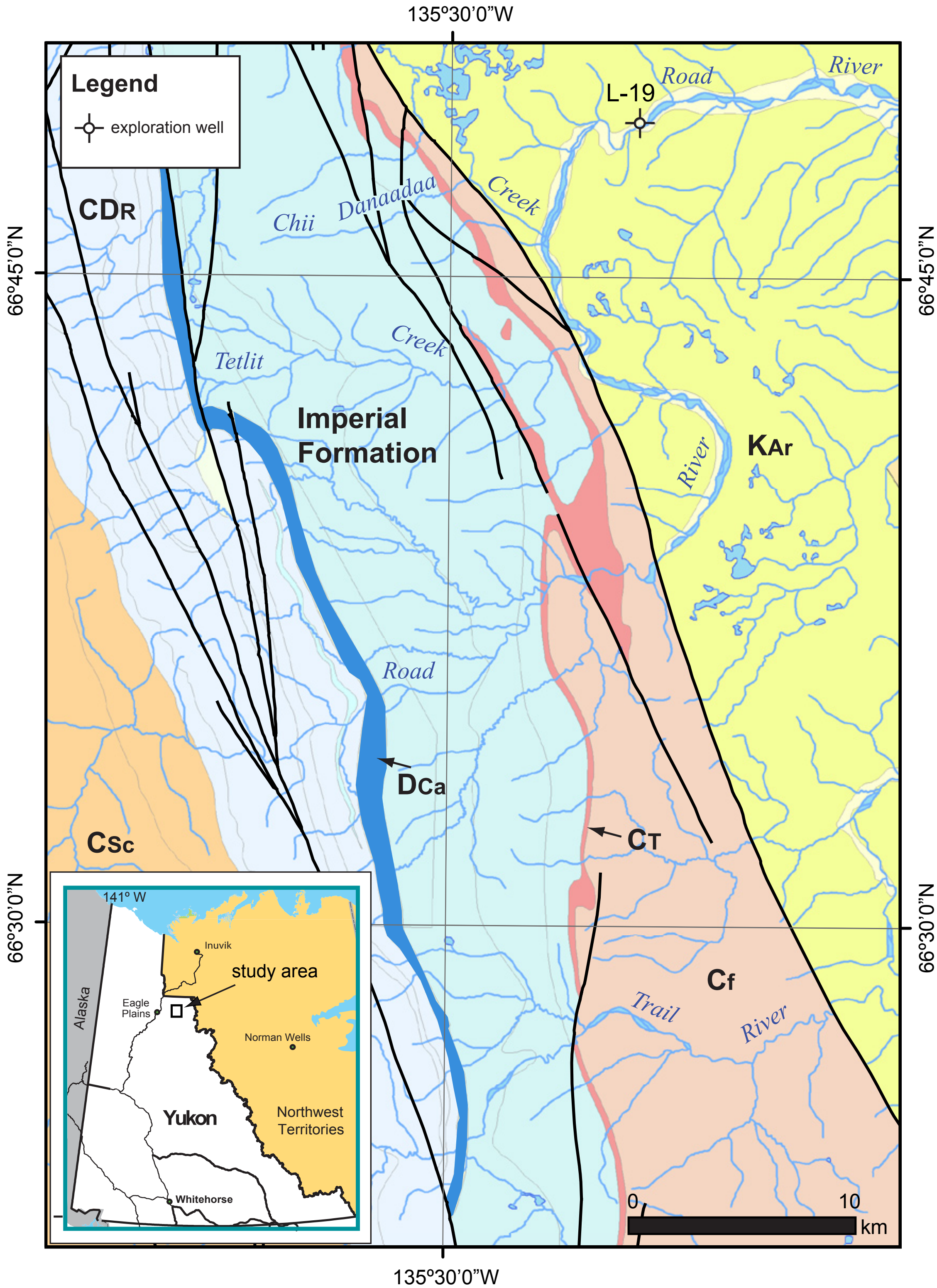

Figure 1. Location map including Tetlit Creek, Road River, Trail River and borehole Peel River Y.T. L-19.
KAr = Lower Cretaceous Arctic Red Formation, Cf = Upper Devonian Ford Lake Shale, CT = Upper Devonian Tuttle Formation,
DCa = Upper Devonian Canol Formation, CDR = Cambrian to Devonian Road River Group,
CSc = Cambrian Slats Creek Formation. Geology from Gordey and Makepeace (2001).

MEASURED SECTIONS

Stratigraphic section 08TLA-TET-01 records lithologies of the top 50 m of the Upper Devonian Canol Formation as well as the basal 400 m of the Imperial Formation (Fig. 3). Two concise stratigraphic sections, 08TLA-TET-02 and 08TLA-TET-04 (each approximately 20 m thick), were measured in the upper part of the Imperial Formation and demonstrate the difference in the percentage of sandstone compared to the lower member (Figs. 4, 5). A fourth section, 08TLA-TET-09, of the Tuttle Formation on Tetlit Creek is included for comparison purposes (Fig. 6). This Tuttle section was previously published in Allen *et al.* (2009).

SAMPLES

A variety of analyses were conducted on samples collected from the Imperial Formation. Seventeen samples were submitted to the Palynology Laboratory of the Geological Survey of Canada (GSC), Calgary to provide new constraints on age and thermal maturation. Thirty-four samples were submitted to the Organic Geochemistry Laboratory of the GSC, Calgary to assess hydrocarbon source rock potential and provide new

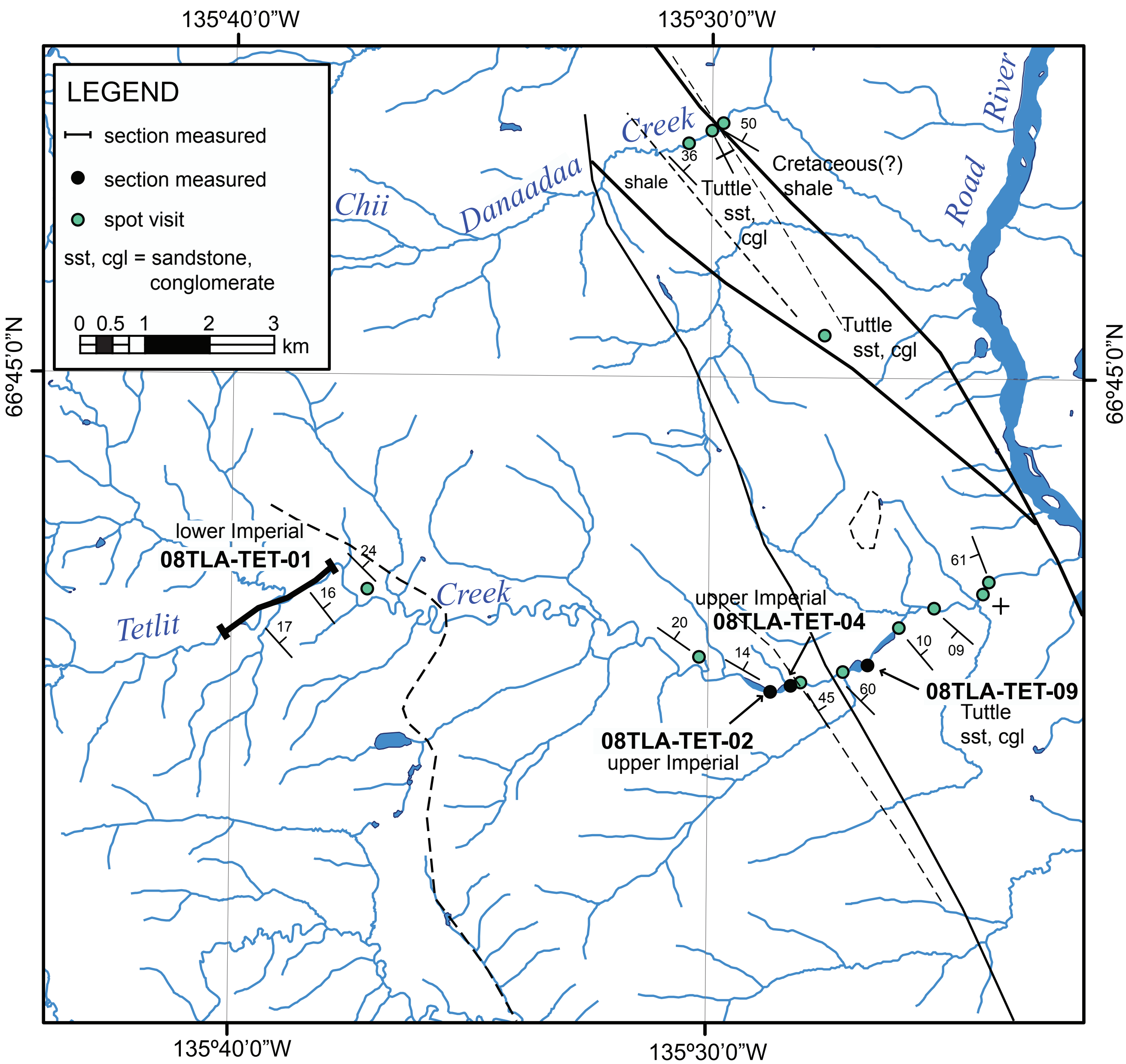

Figure 2. *Map illustrating location of measured sections on Tetlit Creek.*

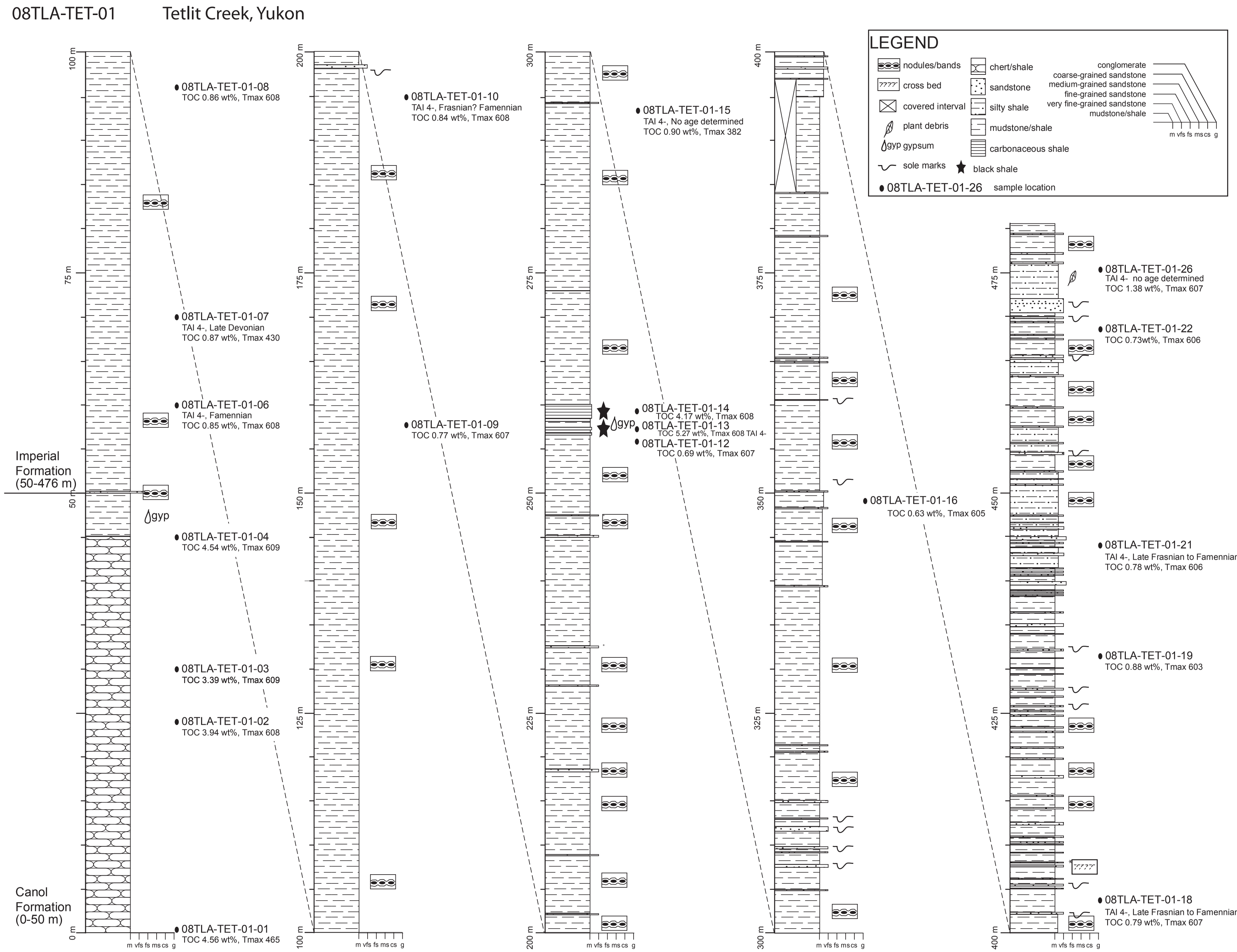

Figure 3. *Measured section 08TLA-TET-01 of Canol Formation and lower Imperial Formation on Tetlit Creek, starting at UTM 470501, 7399711 (NAD83, Zone 8). The entire section was measured on the north side of Tetlit Creek (NTS map sheet 106L/12) over approximately a 2 km distance.*

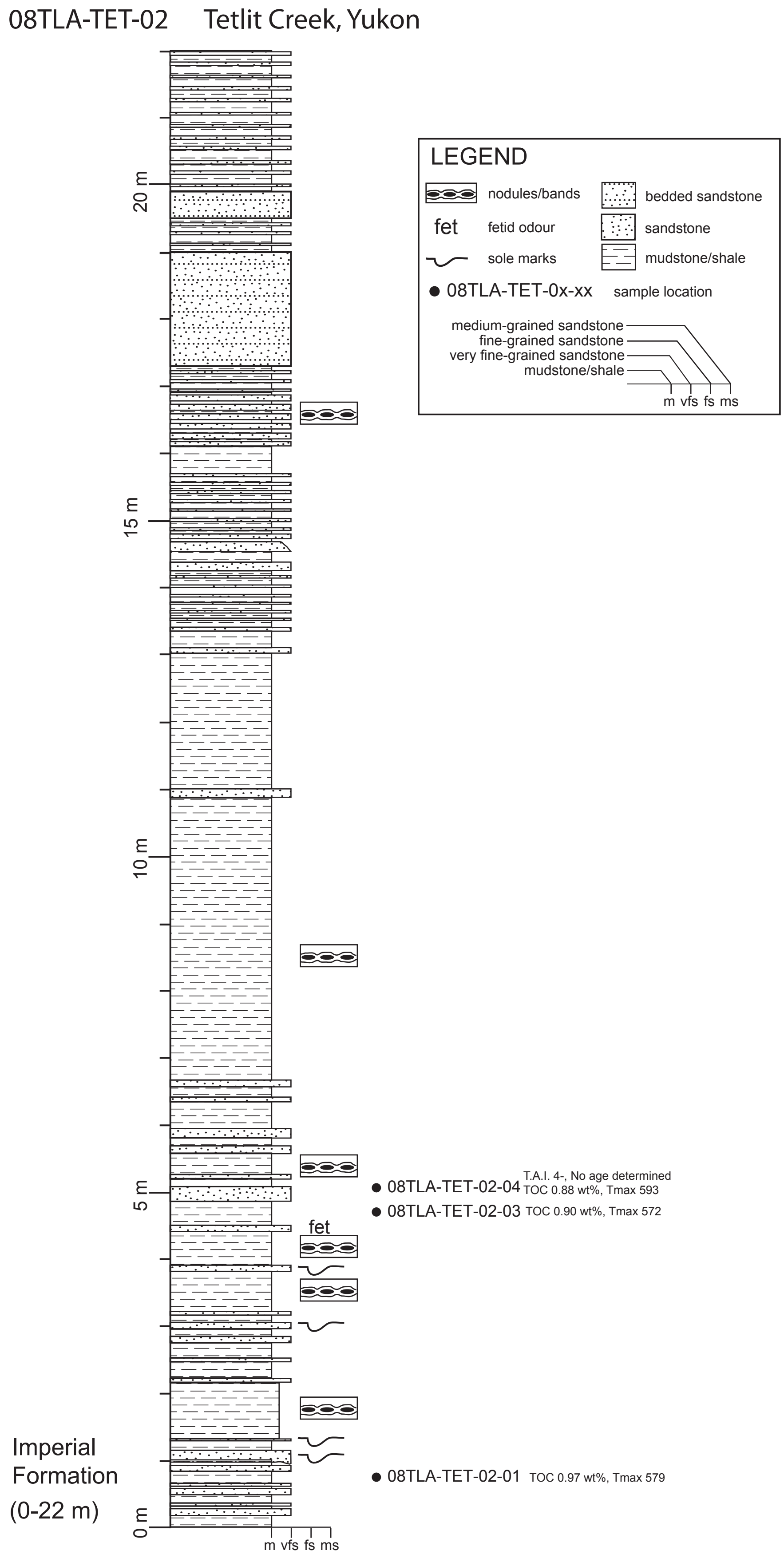

Figure 4. *Measured section 08TLA-TET-02 of upper Imperial Formation on Tetlit Creek, starting at UTM 478859, 7398783 (NAD83, Zone 8). The entire section occurs on the south side of Tetlit Creek (NTS map sheet 106L/11), approximately 7 km downstream from section 08TLA-TET-01.*

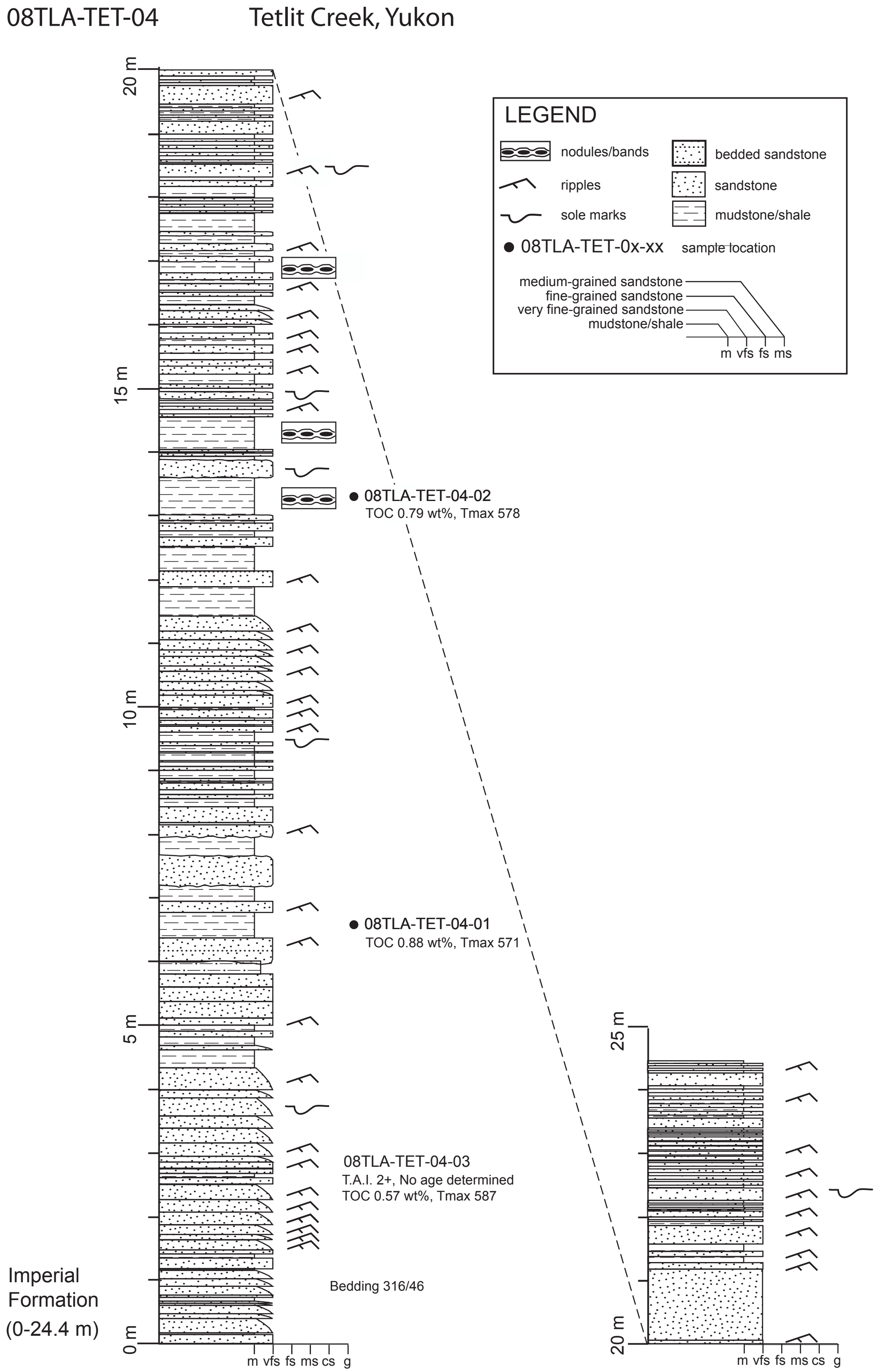

Figure 5. *Measured section 08TLA-TET-04 of upper Imperial Formation on Tetlit Creek, starting at UTM 479213, 7398847 (NAD83, Zone 8). The entire section was measured on the south side of Tetlit Creek (NTS map sheet 106L/11), approximately 335 m east of section 08TLA-TET-02.*

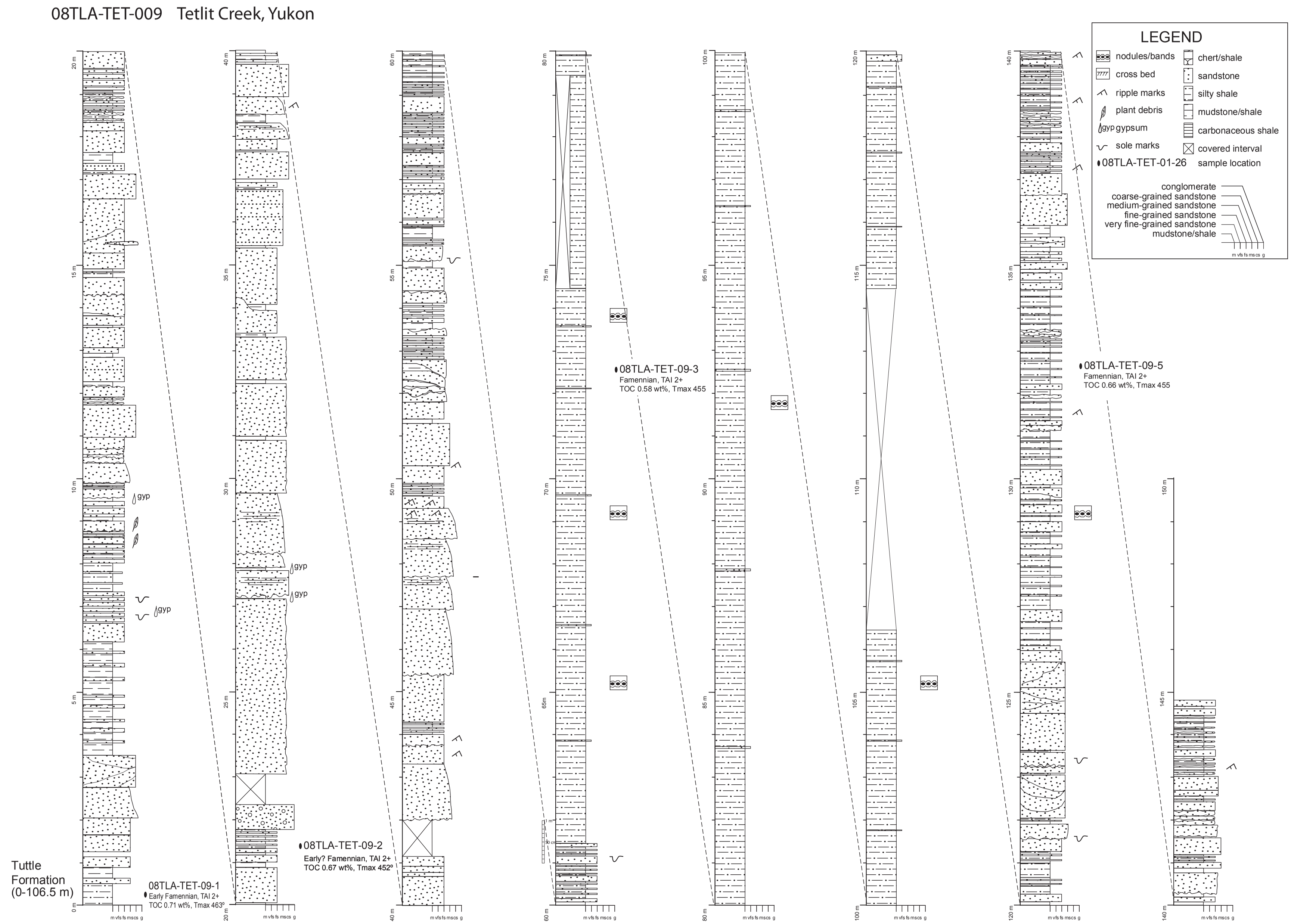

Figure 6. *Measured section 08TLA-TET-09 of Tuttle Formation on Tetlit Creek, starting at UTM 480401, 7399167 (NAD83, Zone 8). The entire section was measured on the south side of Tetlit Creek (NTS map sheet 106L/11), approximately 1.2 km down stream from section 08TLA-TET-04. This section was previously published in Allen et al. (2009) and is included here for quick reference.*

information on organic matter quantity, type and thermal maturity. These rock samples were pyrolyzed using Rock-Eval 6/TOC at the Organic Geochemistry Labs on a Delsi Rock-Eval 6 unit equipped with a total organic carbon (TOC) content analysis module. Peters (1986) provides a summary of interpretive guidelines for Rock-Eval data. Rock-Eval/TOC results of three mudstone samples collected on Tetlit Creek in 2007 as part of reconnaissance work during the multi-agency "Peel Project" are included here as well. Two Imperial Formation samples were submitted to the Organic Geochemistry and Organic petrology Laboratory of the GSC, Calgary to determine thermal maturity using vitrinite reflectance.

STRATIGRAPHY

Paleozoic strata, ranging from Cambrian to Early Carboniferous, flank the Richardson Mountains and underlie large areas in the Eagle Plain basin and Peel Plateau and Plain. The Imperial Formation records deposition of a clastic wedge into a foreland basin of Yukon and Ellesmerian fold belts associated with uplift during the Frasnian to Tournaisian Ellesmerian Orogeny (Pugh, 1983; Richards *et al.*, 1997). Basinal mudstone and shale with turbiditic sandstone characterize the Late Devonian Imperial Formation in this region (Braman and Hills, 1992). The Imperial Formation is conformably underlain by the black, marine shale and chert of the Upper Devonian Canol Formation and in turn, overlain conformably by Upper Devonian to Early Carboniferous Tuttle Formation or unconformably by Cretaceous strata (Fig. 7).

CANOL FORMATION

The Upper Devonian Canol Formation (Bassett, 1961) is a marine unit characterized by black chert and siliceous shale coated in a light yellow to pale green weathering patina. Beds are predominantly hard, platy, planar and up to 10 cm thick (Fig. 8). Due to the resistant nature of the

Figure 8. *Close-up of Canol Formation, Tetlit Creek. Scale card is 9 cm long.*

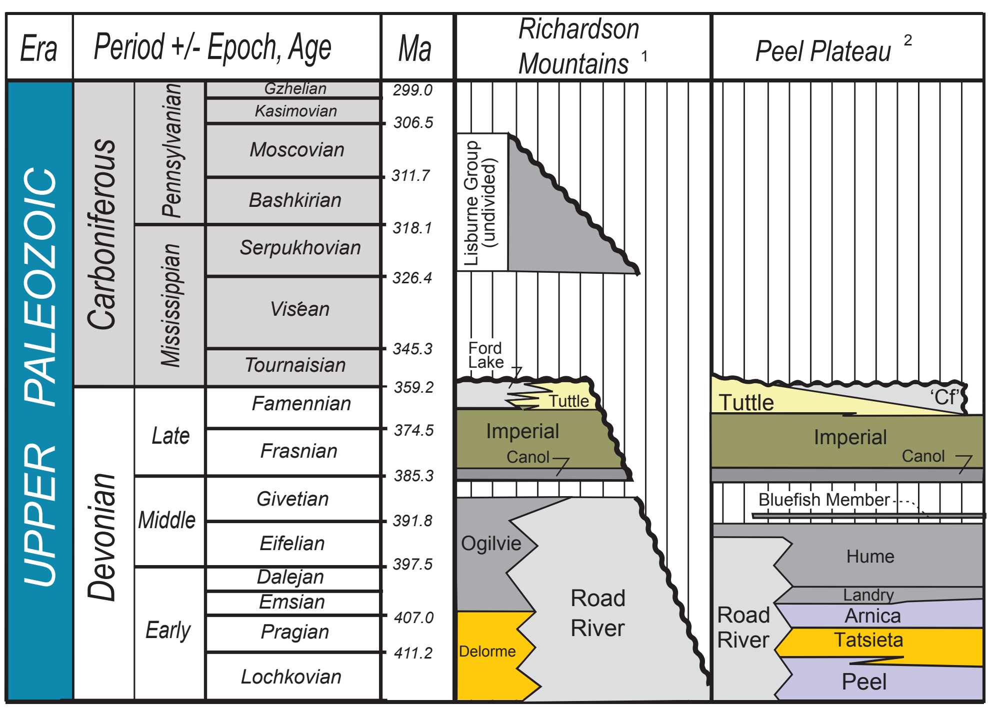

Figure 7. *Stratigraphic correlation chart of Upper Paleozoic strata illustrating the stratigraphic position of the Imperial Formation in the Richardson Mountains and Peel Plateau. The stratigraphic position for the Imperial Formation, Tuttle Formation and Ford Lake Shale (and equivalent 'Cf') has been modified based on new palynological data (Utting, 2008; 2009). [1]Modified from Morrow et al. (2006), [2]modified from Pigage (2007). Time scale after Gradstein et al. (2004).*

Figure 9. *Photo of Canol and Imperial formations as noted on Tetlit Creek. Note the resistant nature of the Canol shale and chert in the foreground versus the recessive weathering of the Imperial Formation mudstone.*

strata, the Canol Formation forms narrow canyons. On Tetlit Creek, the Canol Formation forms a canyon with rushing water that is partly inaccessible except in its upper part, which is included in section 08TLA-TET-01 (Fig. 3). Mineralization is common in the Canol Formation in the form of small, scattered pyrite nodules (up to 25 cm across) and stringers (noted by author in 2007 in exposures on Road River). Water pooling at the base of the formation is generally bright orange or rusty due to its high iron content.

The base of the Imperial Formation is partially exposed adjacent to the Upper Devonian Canol Formation on Tetlit Creek (Fig. 9). The contact between the Canol and Imperial formations, although sharp, appears to be conformable (A.W. Norris, 1997). Palynomorphs indicate a late Givetian or more probably an early Frasnian age as identified by D.C. McGregor from the Canol Formation on Trail River (Norris, 1985).

IMPERIAL FORMATION

The Imperial Formation, originally defined by Hume and Link (1945) and later modified by Bassett (1961), applies to the sequence of Upper Devonian marine to marginal marine clastic rocks and minor interbedded limestone that overlie the Canol Formation and unconformably underlie Cretaceous strata throughout a large part of the Mackenzie River area (Norris, 1985). A.W. Norris (1968) measured approximately 1816.6 m of Imperial Formation on Trail River, which included Tuttle equivalent strata in the top 134.1 m (Norris, 1985).

The Imperial Formation has been informally subdivided into lower and upper parts, originally designated by Tassonyi (1969), later modified by Norris (1981a; b) and then Pugh (1983) who separated the conglomerate, conglomeratic sandstone and shale out of the upper Imperial Formation and assigned them to the Tuttle Formation. The usage in this paper follows Norris (1981a, b) where the lower part includes "shale, dark grey, rusty-weathering; siltstone, dark grey" and the upper part "sandstone, fine-grained, lithic, dark grey; siltstone, dark grey".

Lower Imperial Formation

In the study area, rocks assigned to the lower member crop out mainly along Tetlit Creek, Trail River and Road River (Fig. 1). The lower member consists predominantly of non-fissile mudstone, siltstone and shale (Fig. 10). Rusty weathered nodules and continuous bands of clay and siltstone ironstone are common in the lower part of the Imperial Formation (Fig. 11). The lower part of the Imperial Formation contains little to no sandstone. The sandstone that is present is very fine grained and occurs in beds averaging 10 to 20 cm thick. On both Trail River (Allen and Fraser, field notes, 2006) and Tetlit Creek, thin organic-rich, black shale intervals were identified (Fig. 12).

Figure 10. *View of section 08TLA-TET-01 of the Imperial Formation on north side of Tetlit Creek, Yukon. Here the Imperial Formation is largely grey shale and mudstone. Rusty weathered fracture surfaces give the outcrop an overall reddish hue. The thin resistant bands (<10 cm thick) are nodular layers of ironstone. Person circled for scale.*

Figure 11. *Close-up of lower Imperial Formation (08TLA-TET-01). The presence of clay ironstone nodules and nodular bands are ubiquitous in this unit. Pencil circled for scale.*

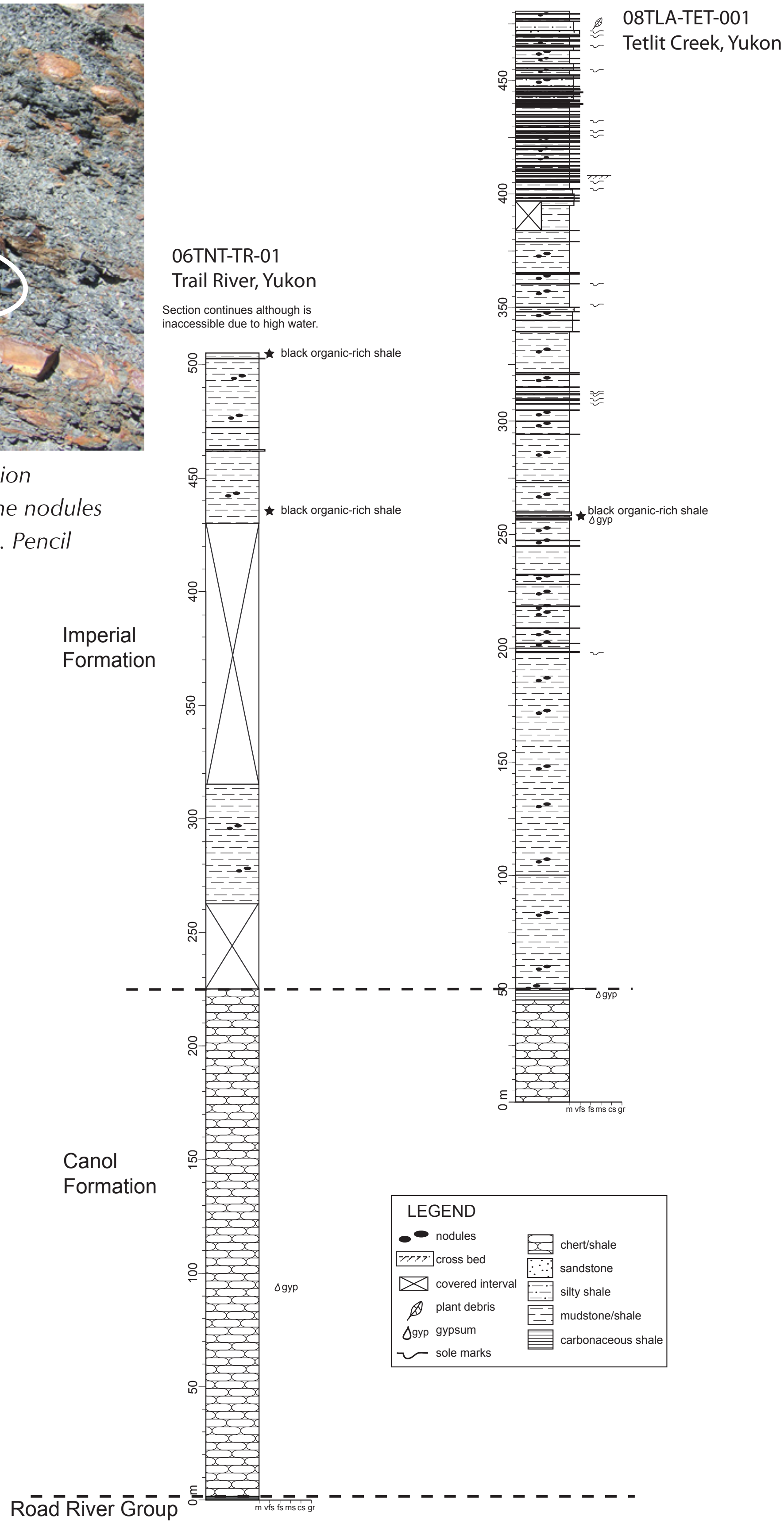

Figure 12. *Correlation of Canol and lower Imperial formations on Trail River and Tetlit Creek. The Trail River section is approximately 14.5 km due south-southeast of the Tetlit Creek section. Note the occurrence of organic-rich shale at approximately the same stratigraphic level in both sections. The location of the Canol/Imperial contact on Trail River is estimated.*

Mudstone

The dominant lithology in the lower member of the Imperial Formation is a combination of mudstone, shale and less commonly, siltstone. The lithology lacks fissility and commonly breaks into small irregular blocks or shards (≤1 cm across; Fig. 13). The mudstone and shale are medium dark grey to dark grey on the fresh surface and rusty weathered on their fracture surfaces, giving the outcrop an overall reddish or purplish hue. Locally, white to yellow popcorn-like precipitate coats the mudstone and sandstone.

Figure 13. *Close-up of lower Imperial Formation on Tetlit Creek, Yukon. The unit is predominantly dark grey shale and mudstone that breaks into small irregular blocks or shards as shown here.*

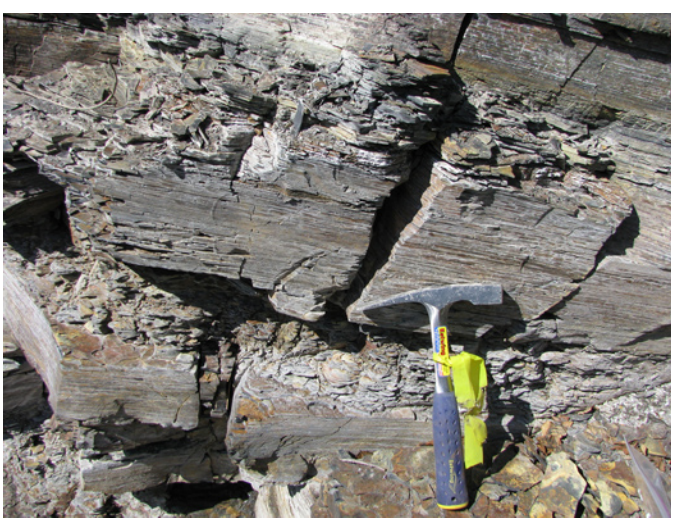

Figure 14. *Close-up of black, organic-rich shale of the lower Imperial Formation. Hammer for scale is 28 cm long.*

Nodules and laterally continuous to discontinuous bands of medium to dark grey clay and siltstone ironstone are ubiquitous throughout the lower part of the Imperial Formation. The individual nodules occur as various shapes, generally 2 to 4 cm thick, but may be up to 10 cm thick, in discrete discontinuous layers that can be traced along bedding. Faint laminae are commonly visible in these layers. These resistant and very well-indurated ironstone bands form continuous marker beds that are useful to follow when measuring sections in mudstone-dominated sections.

Black, organic-rich shale

Within the lower Imperial Formation (section 08TLA-TET-01), four bands of fissile, black, organic-rich shale were recorded over a 3.7-m interval within grey mudstone (Fig. 14). These beds are 30, 25, 35 and 165 cm thick and occur approximately 200 m above the base of the Imperial Formation. Their contacts are abrupt with the underlying and overlying mudstone. From afar, these bands may be easily mistaken with sandstone intervals due to their brown rusty weathering and resistant nature (Fig. 15).

Thin-bedded sandstone

Sandstone in the lower Imperial Formation weathers yellowish grey and is dark grey on the fresh surface. The sandstone is very fine grained, quartz-rich with lesser chert and finely micaceous. Some sandstone beds show a fining upward with an abrupt massive base, grading up into parallel laminated sandstone and siltstone, passing

Figure 15. *Outcrop of black, organic-rich shale interval, approximately 200 m above the base of the Imperial Formation on Tetlit Creek. This interval is 165 cm thick.*

upward into mudstone. The basal contacts of the sandstone beds are typically abrupt with underlying units, and are planar to undulating with local scours apparent with up to 3 cm of relief. Tool and flute marks were also observed and measurable. Plant impressions on top of sandstone beds were observed, though are not common. Utting (2009) identified abundant woody and coaly fragments in samples of both the lower and upper Imperial Formation mudstone.

The sandstone forms continuous resistant ledges within the more recessive mudstone and siltstone of the formation, notably above 350 m stratigraphic thickness. The sandstone beds range in thickness from 3 cm to 55 cm but are generally 10 to 20 cm thick. The thickest sandstone package noted was 170 cm thick at approximately 420 m above the base of the Imperial Formation (08TLA-TET-01). This sandstone, comprises two large beds separated by 10 cm of shale, is fine grained, dark grey and has a scoured base with flute marks as well as coalified plant debris. The upper part of this sandstone package is parallel laminated and fines upward into siltstone.

Upper Imperial Formation

Concise stratigraphic sections (08TLA-TET-02 and 08TLA-TET-04) were measured of the upper Imperial Formation (Figs. 4, 5). In these sections, it is apparent that sandstone is much more common than in the lower Imperial Formation, with sandstone comprising more than 50 percent of the strata. Mudstone and siltstone intervals, 1 to 50 cm thick, are interstratified with sandstone intervals of similar thickness.

Sandstone

Sandstone in the upper Imperial Formation is very fine grained, moderately to poorly sorted and quartz-rich. It weathers from moderate reddish brown to yellowish grey and is medium dark grey to dark grey on the fresh surface. In hand specimen, the sandstone appears to be similar in composition to the lower Imperial Formation. The sandstone is well indurated with little to no apparent porosity. Allen and Fraser (2008) reported negligible porosity and permeability for the Imperial Formation based on standard porosity and permeability procedures by AGAT Laboratories, and on thin section analyses of representative samples of the formation collected from Trail River. The sandstone beds are variable in thickness, ranging from 2 to 54 cm thick and averaging 12 to 20 cm. The sandstone beds are generally tabular and ledge-forming amongst the finer grained siliciclastic rocks in which they occur (Fig. 16). Individual bed thicknesses commonly vary laterally, giving sandstone beds a lensoidal appearance. The bases of the beds are sharp (Fig. 17) and commonly undulating, due to scouring into underlying fines by as much as 15 cm. Bases of sandstone beds commonly exhibit flute and/or tool marks indicating flow directions. The tops of the sandstone beds are either in sharp contact with overlying mudstone or demonstrate a fining-upward succession in which the sandstone grades

Figure 16. *Typical exposure of the upper Imperial Formation on Tetlit Creek characterized by sandstone beds (5 to 10 cm thick) separated by mudstone and shale intervals of similar thickness.*

Figure 17. *Close-up of sandstone in upper Imperial Formation on Tetlit Creek showing abrupt undulating basal contact over shale and visible sole marks. Circled pencil for scale.*

Figure 18. *Thick sandstone and conglomerate beds of Tuttle Formation exposed on south side of Tetlit Creek. Person circled for scale.*

up into siltstone and finally mudstone. The top parts of these graded beds are often rippled or parallel laminated.

Higher in the stratigraphic succession, the relative abundance of sandstone to mudrock continues to increase. The percentage of sandstone, individual bed thickness and grain size gradually increases up section, presumably grading into the Tuttle Formation. Approximately 850 m due east of section 08TLA-TET-04, the sandstone is light grey, medium to coarse grained, poorly sorted, rich in quartz and multi-coloured chert grains (white, green, black, grey) with a white chalky infill between the grains. This lithology is very similar to the Tuttle Formation observed on Trail and Road rivers (Fraser and Allen, 2007).

Along the Richardson Mountains, the top of the Imperial Formation is marked by the occurrence of either the sandstone and/or conglomerate or silty shale of the Tuttle Formation or the Dus map unit of Norris (1981b) and A.W. Norris (1997). In the northern part of the Trail River map sheet, Norris (1981b) mapped Upper Jurassic to Lower Cretaceous North Branch Formation on top of the Imperial Formation, with the unconformable contact representing the sub-Cretaceous unconformity.

TUTTLE FORMATION

Norris (1981a; b) mapped the Upper Devonian to Lower Carboniferous sandstone and conglomerate of the Peel and Eagle Plain region as the Tuttle Formation, which was later formally designated by Pugh (1983). The sandstone in this unit is lithologically distinct from the Imperial Formation due to its bed thickness (Fig. 18), light grey colouring, coarser grain size, poor sorting, abundance of visible quartz and multi-coloured (grey, green, black and white) chert grains within a kaolin-filled matrix (Fig. 19). The conglomerate in this unit ranges from granule to pebble conglomerate and tends to be more commonly observed in the northern part of the Trail River map sheet (106L; Fraser and Allen, 2007). The Tuttle Formation is resistant and crops out in the drainages making it a good marker unit. Figure 6 illustrates the Tuttle Formation section measured on Tetlit Creek (08TLA-TET-09).

The contact between the Imperial and Tuttle formations appears to be gradational but diachronous and likely intertongues (Pugh, 1983). Pugh (1983) states that the base of the Tuttle Formation can be distinguished from the underlying Imperial Formation by the first occurrence of conglomerate, silicified beds or brownish-black shale. On Tetlit Creek, there is a break in exposure between the Imperial Formation and the Tuttle Formation and therefore the contact relationship has not been included in a measured section. This may be related to the recessive nature of fine-grained packages in the Imperial, or to the north-trending fault mapped by Norris (1981b).

PALYNOLOGY AND PROBABLE AGE

Fossils were uncommon in the components of the Imperial Formation examined for this study, with the exception of scattered coalified plant debris and palynomorphs. Pollen and spores identified from the Imperial Formation on Tetlit Creek sections have been

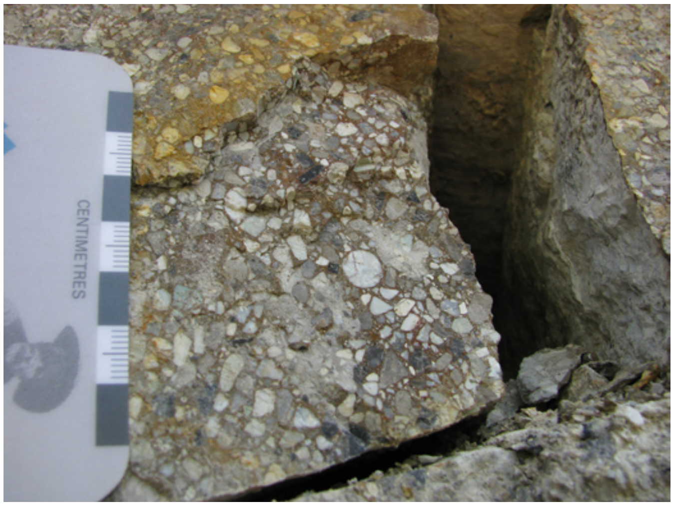

Figure 19. *Close-up of Tuttle Formation chert granule to pebble conglomerate, Tetlit Creek.*

assigned a Frasnian to Famennian (Late Devonian) age (Utting, 2008; 2009). This age range is consistent with palynomorphs identified in Imperial Formation on Trail River, also assigned to Frasnian to early Famennian(?) (14.5 km to the south; Utting, 2007). In 6 of 13 samples submitted from Tetlit Creek, the preservation of spores was too poor for identification and thus, no age was determined.

In 3 of 6 samples from correlative Imperial Formation strata on Trail River, spores are common but preservation is very poor due to sulphide pseudomorphs and high thermal maturity (Utting, 2007). The high thermal maturity in some samples has resulted in a large number of specimens being too dark to be confidently identified. Exceptions include species of *Hystricosporites* and *Ancyrospora* that have a distinctive ornament of grapnel tipped spines that are recognizable even on specimens that are black (Utting, 2007).

Recent palynological studies of Tuttle Formation strata on Trail River indicate that the formation is late Frasnian to Strunian (lastest Famennian) in age (Utting, 2007; 2008). Palynomorphs identified from the six samples collected from Tuttle Formation strata on Tetlit Creek are assigned an early to late Famennian age (Utting, 2008; 2009; Table 1), which is consistent with the results from Trail River.

Table 1. *Summary of palynological data including probable age and thermal alteration index (T.A.I.) for the Imperial and Tuttle formations.*

					NAD83, Zone 8		
Sample	**GSC C-Nos.**	**Probable age**	**Formation**	**T.A.I.**	**UTME**	**UTMN**	**Reference**
08TLA-TET-01-06	532919	Famennian, Late Devonian	Imperial	4-	470627	7399851	Utting, 2009
08TLA-TET-01-07	532920	Late Devonian	Imperial	4-	470654	7399864	Utting, 2009
08TLA-TET-01-10	532921	Frasnian(?), Famennian, Late Devonian	Imperial	4-	471144	7400102	Utting, 2009
08TLA-TET-01-13	481986	none	Imperial	4-	471356	7400236	Utting, 2009
08TLA-TET-01-15	532922	none	Imperial	4-	471555	7400282	Utting, 2009
08TLA-TET-01-18	532923	late Frasnian to Famennian, Late Devonian	Imperial	4-	471933	7400370	Utting, 2009
08TLA-TET-01-21	532924	late Frasnian to Famennian, Late Devonian	Imperial	4-	472097	7400445	Utting, 2009
08TLA-TET-01-26	532925	not determined	Imperial	4-	472162	7400584	Utting, 2009
07TNT-TET-22A	*473141*	*Devonian*	*Imperial*	*4-*	*477777*	*7399240*	*Utting, 2008*
07TNT-TET-23A	*473142*	*Famennian(?), Late Devonian*	*Imperial*	*4-*	*472740*	*7400219*	*Utting, 2008*
08TLA-TET-02-04	532926	not determined	Imperial	4	478836	7398794	Utting, 2009
08TLA-TET-04-03	532927	not determined	Imperial	2	479213	7398847	Utting, 2009
08TLA-TET-06-03	532928	not determined	Imperial	4-	479913	7399032	Utting, 2009
08TLA-TET-09-01	532929	early Famennian, Late Devonian	Tuttle	2+	480401	7399167	Utting, 2009
08TLA-TET-09-02	532930	early(?) Famennian, Late Devonian	Tuttle	2+	480471	7399267	Utting, 2009
08TLA-TET-09-03	532931	Famennian, Late Devonian	Tuttle	2+	480499	7399314	Utting, 2009
08TLA-TET-09-05	532932	Famennian, Late Devonian	Tuttle	2+	480534	7399371	Utting, 2009
07TNT-TET-21A	473139	Late Devonian	Tuttle	2	482352	7400500	Utting, 2008
07TNT-TET-21B	*473140*	*late(?) Famennian, Late Devonian*	*Tuttle*	*2*	*482286*	*7400408*	*Utting, 2008*

Italics previously published in Allen and Fraser (2008).

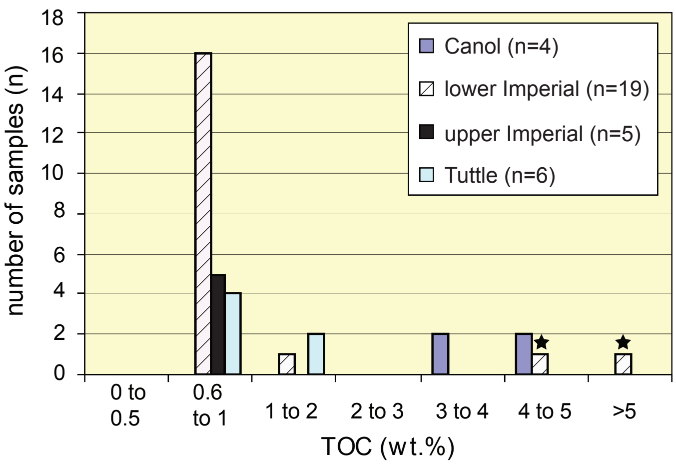

Figure 20. *Histogram summarizing total organic carbon (TOC), expressed in weight percent (wt%), from samples collected during this study of the Canol, Imperial and Tuttle formations. Note that the two black, organic-rich shale samples (stars) had TOC values similar to the Canol Formation.*

SOURCE ROCK POTENTIAL

Thirty-four samples collected from Tetlit Creek were analysed for source rock determination using Rock-Eval pyrolysis/TOC analysis. These analyses provide implications for source rock distribution and quality, thermal maturation and hydrocarbon potential. Table 2 summarizes Rock-Eval/TOC results. Figure 20 illustrates the distribution of the number of samples by formation, and the corresponding weight percent (wt%) of total organic carbon (TOC). TOC values for the Imperial Formation on Tetlit Creek range from 0.57 to 1.38 wt%, with the exception of two samples collected from black, organic-rich shale intervals (25 and 165 cm thick) which measured 5.27 and 4.17 wt%, respectively. With the exception of these two black shale intervals, TOC values suggest that the Imperial Formation is generally not a favourable source rock. These TOC values are consistent with values reported for Imperial Formation strata in Peel Plateau subsurface (*i.e.*, boreholes C-60, G-72, F-37, H-71 and H-37), which generally have TOC values <1 wt%. Subsurface S2 values, however, measure >0.2 mg HC/g rock suggesting thermal maturities are within the "oil window"(Allen *et al.*, 2008).

The Canol and Imperial formation samples are all overmature and the original kerogen type cannot reliably be determined from geochemical data. The type of organic matter in the Canol Formation could not be determined using the pseudo-van Krevelen diagram due to high thermal maturities which result in values plotting too low to be meaningful (Peters, 1986). Plotting the Imperial Formation hydrogen and oxygen indices on a pseudo-van Krevelen diagram (Fig. 21a) suggests that types III (gas-prone) and IV (inert or dry-gas prone) kerogen are present in the rocks. Type IV kerogen can originate from other kerogen types that were reworked or oxidized (Peters *et al.*, 2005). Outcrop samples commonly show depletion in S1 and S2 due to weathering (Peters, 1986). Caution should be used with samples that have S2 values below 0.2 mg HC/g rock, as they are unreliable due to the broad nature of their S2 peak (Peters, 1986). Rock-Eval and TOC results from outcrop suggest that the Imperial Formation has little to no hydrocarbon-generating potential. This is misleading due to the very low S2 values and related high thermal maturities which can make source rocks appear less like a source rock (Dembicki, 2009). Results for the Tuttle Formation plot along the base of the type II and III kerogen evolutionary pathways suggesting the organic matter is likely gas-prone.

Thermal maturity levels of stratigraphic successions can be estimated using T_{max} values derived from Rock-Eval pyrolysis, thermal alteration indices and vitrinite reflectance. Most samples analysed from the Canol and Imperial formations have very low S2 values, less than 0.2 mg HC/g rock, and are therefore unreliable predictors of thermal maturity and production index (S1/(S1+S2)). T.A.I. corresponds to maturity-induced colour changes noted in miospores under the microscope in transmitted light (Staplin, 1969). T.A.I. values estimated by Utting (2008; 2009) also indicate that the Imperial Formation is thermally mature (Tables 1, 2). Vitrinite reflectance (%Ro_R), a key measurement used to access petroleum source rocks, was performed on selected samples. Collectively, the high thermal maturity values imply that, at surface, the Canol and Imperial formations are thermally overmature. This is consistent with results for the Imperial Formation on Trail River, reported in Allen and Fraser (2008) and by Norris (1985) who reported that D.C. McGregor determined that all of the unoxidized spores from the Imperial Formation on Trail River are dark brown to black indicating severe thermal maturation.

Table 2. *Summary of Rock-Eval/TOC outcrop data, as well as thermal maturity indicators, thermal alteration index (T.A.I.) and vitrinite reflectance (%Ro_R) (OGOPet Lab, 2009; Coal Maceral and Vitrinite Reflectance) from Tetlit Creek. Parameters measured and derived from Rock-Eval pyrolysis include TOC = total organic carbon as percent weight of whole rock; S1 = mg hydrocarbons per gram of rock; S2 = mg hydrocarbons/g rock; S3 = mg CO_2/ g rock; PI = Production Index (S1/S1+S2); HI = Hydrogen Index (100 x (S2/TOC)); OI = Oxygen Index (100 x (S3/TOC)); T_{max} = maximum temperature (°C) at top of S2 peak. Note where S2 values are less than 0.2 mg HC/g rock, the PI and T_{max} values are unreliable (values in italics). T.A.I. 3+/4- and T.A.I. 4 - indicate strata are overmature or within the dry gas zone, while T.A.I. 2 and T.A.I. 2+ correspond to the "oil window" (Utting et al., 1989). *Organic-rich, black shale of lower Imperial Formation.*

											NAD83, Zone 8		
Sample	TOC	S1	S2	S3	PI	HI	OI	T_{max} (°C)	T.A.I.	VR %Ro_R	UTME	UTMN	Formation
08TLA-TET-01-1	4.56	0.02	0.05	0.32	0.24	1	7	465			470502	7399710	Canol
08TLA-TET-01-2	3.94	0.01	0.02	0.32	0.35	1	8	608			470541	7399760	Canol
08TLA-TET-01-3	3.39	0.01	0.04	1.65	0.20	1	49	609			470577	7399768	Canol
08TLA-TET-01-4	4.54	0.01	0.03	0.64	0.19	1	14	609			470611	7399814	Canol
08TLA-TET-01-6	0.85	0.01	0.04	0.18	0.12	5	21	608	4-		470627	7399851	lower Imperial
08TLA-TET-01-7	0.87	0.01	0.04	0.28	0.12	5	32	430	4-		470654	7399864	lower Imperial
08TLA-TET-01-8	0.86	0.00	0.03	0.19	0.13	3	22	608			470852	7399826	lower Imperial
08TLA-TET-01-9	0.77	0.01	0.03	0.48	0.17	4	62	607			470981	7399934	lower Imperial
08TLA-TET-01-10	0.84	0.00	0.02	0.54	0.21	2	64	608	4-		471144	7400102	lower Imperial
08TLA-TET-01-12	0.69	0.00	0.03	0.27	0.12	4	39	607			471356	7400236	lower Imperial
*08TLA-TET-01-13	5.27	0.01	0.04	0.65	0.26	1	12	608	4-	2.27	471356	7400236	lower Imperial
*08TLA-TET-01-14	4.17	0.01	0.04	0.53	0.20	1	13	608			471356	7400236	lower Imperial
08TLA-TET-01-15	0.90	0.03	0.09	0.27	0.23	10	30	382	4-		471555	7400282	lower Imperial
08TLA-TET-01-16	0.63	0.01	0.05	0.21	0.13	8	33	605			471768	7400272	lower Imperial
08TLA-TET-01-18	0.79	0.00	0.03	1.27	0.10	4	161	607	4-		471933	7400370	lower Imperial
08TLA-TET-01-19	0.88	0.01	0.05	0.82	0.11	6	93	603			472015	7400465	lower Imperial
08TLA-TET-01-21	0.78	0.01	0.05	0.21	0.13	6	27	606	4-		472097	7400445	lower Imperial
08TLA-TET-01-22	0.73	0.00	0.03	0.20	0.11	4	27	606			472160	7400544	lower Imperial
08TLA-TET-01-26	1.38	0.01	0.03	0.80	0.18	2	58	607	4-	2.36	472162	7400584	lower Imperial
07TNT-TET-23A	0.57	0.00	0.02	0.23	0.12	4	40	605	4-		472740	7400219	lower Imperial
08TLA-TET-02-1	0.97	0.00	0.10	0.28	0.04	10	29	579			478900	7398756	lower Imperial
08TLA-TET-02-3	0.90	0.00	0.09	0.21	0.04	10	23	572			478836	7398794	lower Imperial
08TLA-TET-02-4	0.88	0.01	0.07	0.41	0.07	8	47	593	4		478836	7398794	lower Imperial
07TNT-TET-22A	0.86	0.01	0.10	0.17	0.06	12	20	581	4-		477777	7399240	upper Imperial
08TLA-TET-04-1	0.88	0.01	0.12	0.36	0.05	14	41	571			479213	7398847	upper Imperial
08TLA-TET-04-2	0.79	0.01	0.09	0.43	0.06	11	54	578			479213	7398847	upper Imperial
08TLA-TET-04-3	0.57	0.01	0.10	0.15	0.06	18	26	547	2		479213	7398847	upper Imperial
08TLA-TET-06-3	0.69	0.01	0.21	0.16	0.06	30	23	484	4-		479913	7399032	upper Imperial
08TLA-TET-09-1	0.71	0.03	0.27	0.24	0.11	38	34	463	2+		480401	7399167	Tuttle
08TLA-TET-09-2	0.67	0.01	0.29	0.41	0.04	43	61	452	2+		480471	7399267	Tuttle
08TLA-TET-09-3	0.58	0.03	0.19	0.13	0.13	33	22	455	2+		480499	7399314	Tuttle
08TLA-TET-09-5	0.66	0.01	0.32	0.34	0.04	48	52	455	2+		480534	7399371	Tuttle
07TNT-TET-21A	1.31	0.06	1.21	0.20	0.05	92	15	437	2		482352	7400500	Tuttle
07TNT-TET-21B	1.29	0.04	1.29	0.18	0.03	100	14	447	2		482286	7400408	Tuttle

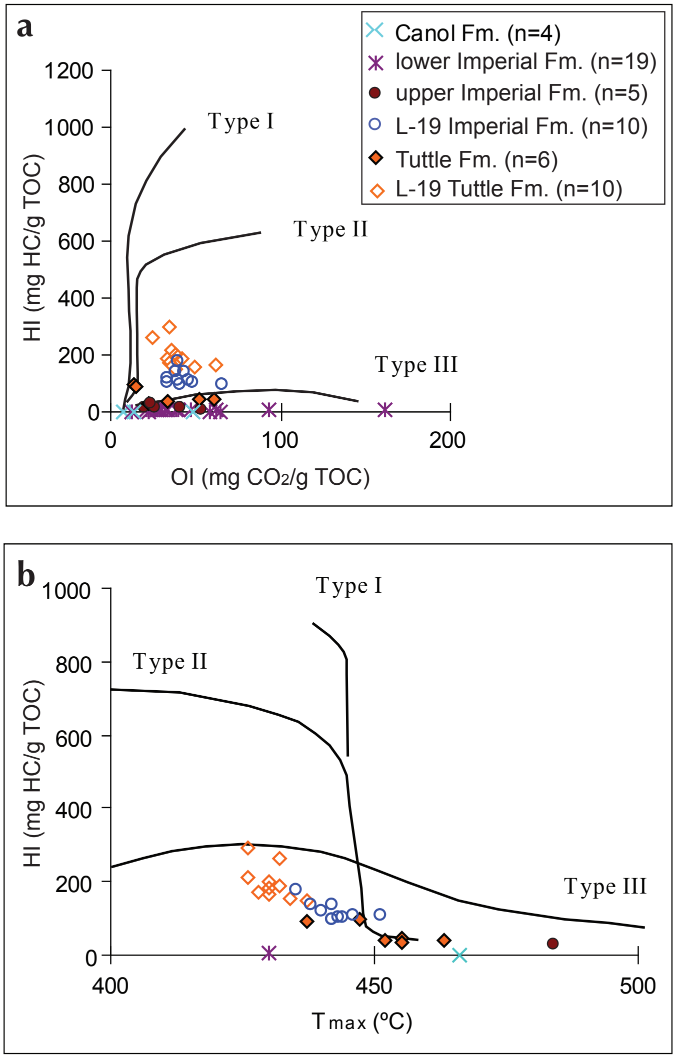

Figure 21. *Cross plots of Rock-Eval and TOC data; n= number of samples. (a) Oxygen indices (OI) and hydrogen indices (HI) plotted on a pseudo van Krevelen diagram. Due to low S2 values and very high thermal maturities, most values plot too low on the diagram to be meaningful (Peters, 1986). Imperial samples plot along the type III evolutionary pathway, while Tuttle samples plot on both the type II and III. Borehole L-19 data from Allen et al. (2008). (b) The T_{max} versus HI cross plot indicates that the Tuttle Formation contains types II and III kerogen. Due to the unreliable T_{max} data for most of the dataset, most values from surface samples do not plot on this cross plot. Borehole L-19 data from Allen et al. (2008).*

Borehole Peel River Y.T. L-19 (U.W.I. 300L196650135150) is the closest oil and gas exploration well to Tetlit Creek that penetrated the Imperial Formation. In this well, T_{max} values for the Imperial Formation range from 435° to 451°C (Table 3), showing a gradual increase in maturity with increasing depth (Allen *et al.*, 2008). These thermal maturity results for L-19 and for exploration wells to the east (*e.g.*, C-60, F-37, G-72, H-37 and I-21) indicate that Imperial Formation strata are within the "oil window" (Allen *et al.*, 2008). These results show a discrepancy from outcrop sample results that typically indicate that Imperial strata are overmature with respect to hydrocarbon generation. Organic matter within the Imperial Formation subsurface comprises type II, oil- and gas-prone kerogen, and type III, gas-prone kerogen (Allen *et al.*, 2008; Figure 21). A possible explanation for the discrepancy in the thermal maturation between the surface and subsurface may be proximity to the Richardson Mountains and related structural histories that resulted in higher thermal maturity levels for outcrop samples.

CONCLUSIONS

The lower part of the Imperial Formation is distinct from the upper part, most notably in the abundance of sandstone. The lower Imperial Formation is predominantly non-fissile mudstone and shale with lesser siltstone and sandstone. Rusty weathered clay ironstone bands and nodules are very common in the lower Imperial Formation. Thin, organic-rich, black shale intervals with high TOC values were documented in the lower Imperial Formation on Tetlit Creek. Similar shale documented on Trail River occurs at approximately the same stratigraphic level. The geographic extent and thickness of this organic-rich shale interval is uncertain.

The upper Imperial Formation contains at least 50% sandstone. The sandstone is very fine grained, well indurated, with no visible porosity. The abundance of sandstone beds, bed thickness and grain size increases up section, until it grades into the Tuttle Formation. The sandstones are characterized by their very fine grain size and sharp basal contacts that commonly exhibit sole marks. Fossils are uncommon although some coalified plant debris was observed. Other sedimentary structures noted associated with the sandstone beds include graded beds, parallel- to cross-laminae and scours.

Palynology results indicate that the Imperial Formation is Frasnian to Famennian (Late Devonian) in age. Associated T.A.I. values indicate that the Imperial Formation strata are overmature with respect to hydrocarbon generation at surface. Due to high thermal maturities, spore and pollen identification was prohibitive in some samples. Corresponding vitrinite reflectance values also indicate high thermal maturation for the strata.

Rock-Eval/TOC pyrolysis results indicate that kerogen within the Imperial Formation strata are possibly type III or terrestrially-derived organic matter (gas-prone). TOC values suggest that the Imperial Formation has overall low total organic carbon contents (0.57 to 1.38 wt%), with the exception of thin organic-rich, black shale intervals noted in the lower Imperial Formation (4.17 and 5.27 wt%). Combined Rock-Eval/TOC results from surface suggest that the Imperial Formation is not a favourable source rock. Rock-Eval/TOC results from subsurface samples east of the Richardson Mountains indicate that the Imperial Formation strata are within the "oil window" and contain types II and III kerogen (oil- to gas-prone) indicating much better prospects of being a suitable petroleum source rock.

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Table 3. *Summary of Rock-Eval/TOC data for borehole Peel River Y.T. L-19 (U.W.I. 300L196650135150), previously published in Allen et al. (2008). Location of well is UTM 486115E, 7410232N, Zone 8, NAD83.*

Sample depth from (F)	Sample depth from (F)	TOC (wt%)	S1 (mg HC/g rock)	S2 (mg HC/g rock)	S3 (mg CO_2/g rock)	Production index (S1/(S1+S2))	Hydrogen index (mg HC/ g TOC)	Oxygen index (mg CO_2/g rock)	T_{max} (°C)	Formation
160	190	2.94	0.36	6.23	1.07	0.05	212	36	426	Tuttle
510	540	1.50	0.36	4.40	0.52	0.08	293	35	426	Tuttle
810	840	0.83	0.22	1.42	0.29	0.13	171	35	428	Tuttle
1400	1440	1.33	0.49	3.49	0.33	0.12	262	25	432	Tuttle
1680	1720	0.75	0.29	1.37	0.25	0.18	183	33	430	Tuttle
2010	2040	0.67	0.26	1.26	0.28	0.17	188	42	432	Tuttle
2350	2380	0.72	0.31	1.45	0.27	0.18	201	38	430	Tuttle
2660	2690	0.74	0.25	1.21	0.46	0.17	164	62	430	Tuttle
2970	3000	0.66	0.23	0.97	0.26	0.19	147	39	437	Tuttle
3200	3230	0.54	0.18	0.85	0.27	0.18	157	50	434	Tuttle
3440	3470	0.58	0.28	1.02	0.23	0.22	176	40	435	Imperial
3750	3780	0.55	0.16	0.76	0.24	0.18	138	44	438	Imperial
4100	4130	0.62	0.21	0.86	0.24	0.19	139	39	442	Imperial
4380	4410	0.86	0.29	1.04	0.28	0.22	121	33	440	Imperial
4710	4740	0.64	0.14	0.65	0.31	0.18	102	48	443	Imperial
5010	5040	0.65	0.18	0.67	0.22	0.21	103	34	444	Imperial
5330	5360	0.65	0.17	0.63	0.43	0.21	97	66	442	Imperial
5670	5700	0.66	0.23	0.66	0.27	0.26	100	41	442	Imperial
5980	6010	0.67	0.22	0.73	0.31	0.23	109	46	446	Imperial
6280	6310	0.65	0.20	0.71	0.26	0.22	109	40	451	Imperial

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