Preliminary lithostratigraphy of the Laberge Group (Jurassic), south-central Yukon: Implications concerning the petroleum potential of the Whitehorse Trough

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ABSTRACT

The Whitehorse Trough, a Mesozoic sedimentary basin in south-central Yukon that has potential for gas and oil, consists of the Lewes River Group (Triassic), the Laberge Group (Jurassic), and the Tantalus Formation (Jura-Cretaceous). The Laberge Group in the Carmacks (115I) and Laberge (105E) map areas is subdivided into four informal lithostratigraphic units: the Richthofen, Tanglefoot, Conglomerate and Nordenskiold formations. The Richthofen formation, distinguished by siltstone to very fine sandstone and mudstone couplets, is exposed in the southern part of the Laberge map area where it rests unconformably to conformably on the Lewes River Group and is unconformably and/or conformably overlain by the Tanglefoot formation. The Tanglefoot formation, distinguished by coal-bearing, interbedded sandstone and mudstone, is exposed in the northern part of the Laberge map area and the southern part of the Carmacks map area where it rests unconformably on the Lewes River Group, and is overlain by the Tantalus Formation. The Conglomerate (conglomerate) and Nordenskiold (dacite tuff) formations occur as minor units within the Tanglefoot formation. The Richthofen-Tanglefoot formation unconformity and/or conformity is a potential petroleum play in the central Whitehorse Trough, whereas the Lewes River Group-Tanglefoot formation unconformity is a potential petroleum play in the northern Whitehorse Trough.

RÉSUMÉ

La cuvette de Whitehorse, bassin sédimentaire mésozoïque du centre-sud du Yukon ayant un potentiel en gaz et pétrole, se compose du Groupe de Lewes River (Trias), du Groupe de Laberge (Jurassique) et de la Formation de Tantalus (Jurassique-Crétacé). Dans les zones cartographiques de Carmacks (115I) et de Laberge (105E), le Groupe de Laberge est subdivisé en quatre unités lithostratigraphiques informelles : les formations de Richthofen, Tanglefoot, Conglomerate et Nordenskiold. La formation de Richthofen, qui se distingue par un siltstone passant à des couplets de grès très fin et de mudstone, est exposée dans la partie sud de la région cartographique de Laberge où elle repose en discordance sur le Groupe de Lewes River et est surmontée en discordance ou concordance par la formation de Tanglefoot. Cette dernière, qui se distingue par un grès et un mudstone interstratifiés houillers, est exposée dans le nord de la zone cartographique de Laberge et dans le sud de la zone cartographique de Carmacks où elle repose en discordance sur la Groupe de Lewes River et sous la Formation de Tantalus. Les formations de Conglomerate (conglomérat) et de Nordenskiold (tuf dacitique) forment des unités de moindre importance dans la formation de Tanglefoot. La discordance ou la concordance de la formation de Richthofen-Tanglefoot représente une zone pétrolière possible dans le centre de la cuvette de Whitehorse tandis que la discordance de Groupe de Lewes River – formation de Tanglefoot représente une zone pétrolière possible dans le nord de la cuvette de Whitehorse.

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INTRODUCTION

The Whitehorse Trough is a Mesozoic sedimentary basin that extends from just north of Carmacks, 650 km southward to Whitehorse and into northern British Columbia (Fig. 1). It is interpreted to have originated in Middle to Late Triassic time as a forearc basin, with the ancient North American margin on the east and the volcano-plutonic Stikinia arc on the west, undergoing oblique convergence (Tempelman-Kluit, 1979). The National Energy Board (2001) describes the Whitehorse Trough as an immature, mainly gas-prone basin in which potential source rocks (i.e., Triassic carbonates and Jurassic mudstones), reservoirs (i.e., Jurassic sandstones), seals (i.e., Jurassic mudstones) and traps (i.e., anticlines) have been identified. Koch (1973) estimates that 25 to 116 billion cubic metres (0.9 to 4.1 trillion cubic feet) of gas, and possibly some oil, occur within the basin. However, petroleum exploration is hampered by a poor understanding of the stratigraphy. Hence, the Yukon Geological Survey initiated a long-term study of the stratigraphy of the Whitehorse Trough, the aim of which is to better assess the hydrocarbon potential of this frontier basin. This report summarizes some of the results from the first field season of this study.

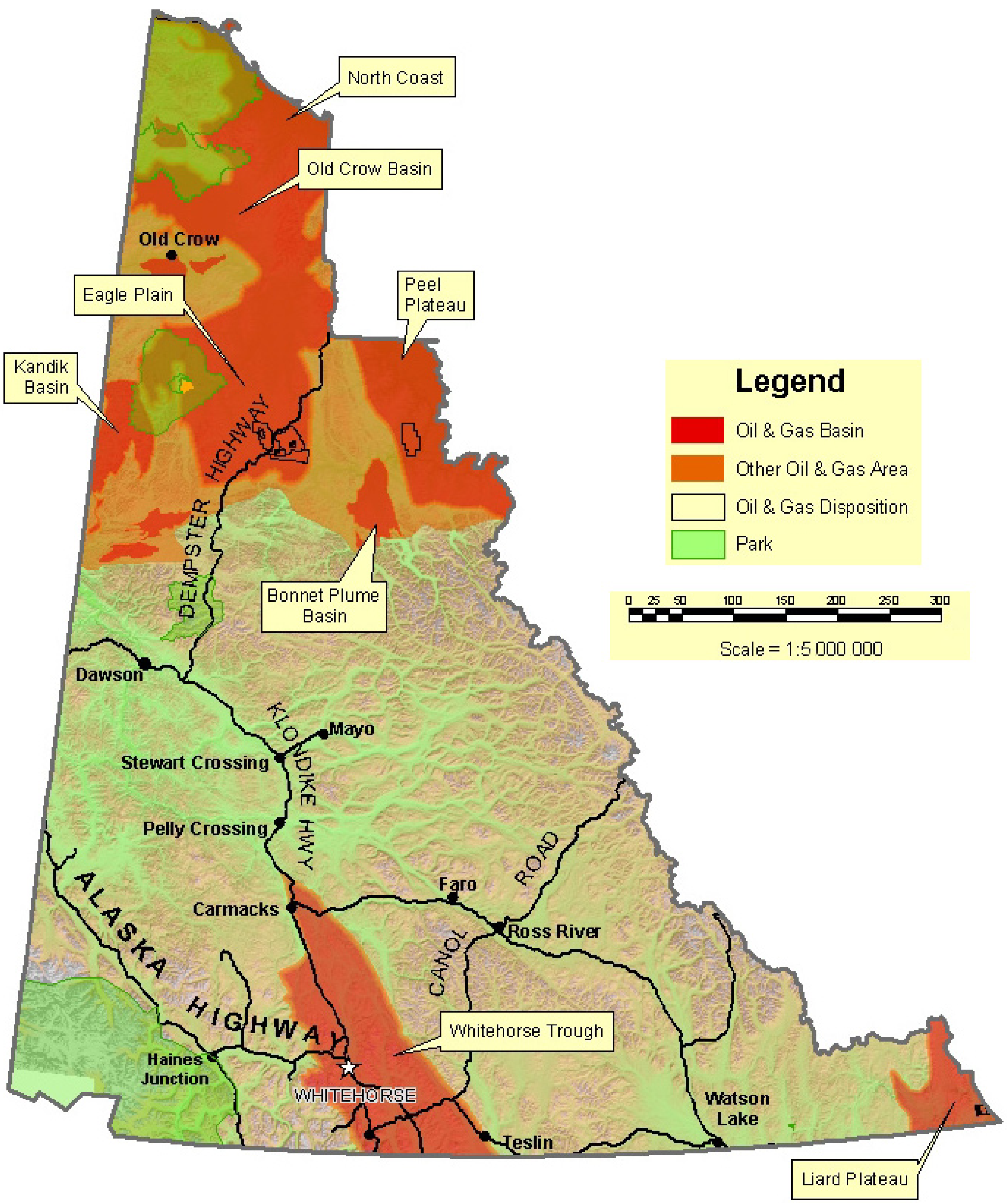


__Figure 1.__ Oil and gas basins in the Yukon showing the location of the Whitehorse Trough (Energy, Mines and Resources, August, 2002).

PROBLEMS, PURPOSE AND PREVIOUS WORK

Wheeler (1961) proposed the name ‘Whitehorse trough’ and recognized three main stratigraphic units: 1) Triassic volcanic, volcaniclastic, siliciclastic and carbonate rocks of the Lewes River Group; 2) Jurassic siliciclastic rocks of the Laberge Group; and 3) Jura-Cretaceous siliciclastic rocks of the Tantalus Formation. Laberge strata were originally described by Cairnes (1910) in the Lewes and Nordenskiold coal district (Fig. 2); and Lees (1934), working in the Laberge map area, and Bostock (1936) working in the Carmacks map area, adopted this nomenclature. Bostock and Lees (1938) subsequently described the Nordenskiold unit as a lithostratigraphic unit, as did Wheeler (1961) for the Laberge unit. Souther (1971), working in the Tulsequah map area northern British Columbia, subdivided the Laberge Group into the relatively coarser-grained Takwahoni Formation and the relatively finer-grained Inklin Formation; and Tempelman-Kluit (1984), working in the Carmacks and Laberge map areas, subdivided the Laberge Group (from oldest to youngest) into the ‘Richthofen Formation’, ‘Conglomerate Formation’, ‘Nordenskiold Dacite’ and ‘Tanglefoot Formation’. According to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983), the formations proposed by Tempelman-Kluit (1984) should be considered informal units and the term ‘formation’ not capitalized. This report follows the guidelines of the Code. In addition, the term ‘Nordenskiold formation’ proposed by Bostock and Lees (1938) is a more proper lithostratigraphic name than ‘Nordenskiold Dacite’ proposed by Templeman-Kluit (1984); hence this report uses Nordenskiold formation. The purpose of this paper is to properly define the units of the Laberge Group in the Carmacks (115I) and Laberge (105E) map areas of south-central Yukon as lithostratigraphic units.

Previous reports discussing the stratigraphy of the Laberge Group in the Carmacks (115I) and Laberge (105E) map areas include Cairnes (1910), Lees (1934), Bostock (1936), Bostock and Lees (1938), Tempelman-Kluit (1974, 1975, 1978, 1980, 1984), Lowey and Hills (1988), Dickie (1989), Dickie and Hein (1988, 1992, 1995), and Allen (2000). Campbell (1967) briefly mentioned the stratigraphy of the Laberge Group in the Glenlyon (105L) map area. Previous

N Carmacks	Laberge	Whitehorse	Tulsequah S
--------- (Cairnes, 1910) -------------- Laberge series Nordenskiold dacites			
	(Lees, 1934) Laberge series Nordenskiold dacites		
(Bostock, 1936) Laberge series			
--------- (Bostock and Lees, 1938) --------- Nordenskiold formation Laberge series			
		(Wheeler, 1961) Laberge group	
			(Souther, 1971) Laberge Group Takwahoni Formation Inklin Formation
--------- (Tempelman-Kluit, 1984) ----- Laberge Group Tanglefoot Formation Conglomerate Formation Nordenskiold Dacite Richthofen Formation			

Figure 2. *History of stratigraphic nomenclature of the Laberge Group.*

reports discussing the stratigraphy of the Laberge Group in the Whitehorse (105D) map area include Cockfield and Bell (1926, 1944), Wheeler (1961), Dickie (1990), Dickie and Hein (1988, 1992, 1995), Hart and Pelletier (1989), Hart and Radloff (1990), Hart and Brent (1993), Hart and Hunt (1994, 1995), and Hart (1997), whereas Palfy and Hart (1995), Clapham (2000), and Clapham et al. (2002) discuss the biostratigraphy. Previous reports discussing the lithostratigraphy of the Laberge Group in northern British Columbia include Souther (1971), Bultman (1979) and Mihalynuk (1999), whereas Smith et al. (1988), Johannson (1993, 1994) and Johannson et al. (1997) discuss the biostratigraphy. In addition, the Yukon Geological Survey has an unpublished manuscript by D.J. Tempelman-Kluit describing the geology of the Carmacks and Laberge map areas, including the stratigraphy of the Laberge Group, made available from the Geological Survey of Canada.

SUSPECT STRATIGRAPHY

The stratigraphy of the Laberge Group is suspect because published reports (e.g., Hart, 1997; Mihalynuk, 1999; Tempelman-Kluit, 1978, 1984) refer to the formations comprising it as map, lithostratigraphic, and/or chronostratigraphic units. Tempelman-Kluit (1978) expressed difficulty in distinguishing the Lewes Group from the Laberge Group and apparently mapped 'individual conglomerate, sandstone, shale and limestone bodies by composition and texture'. Hart (1997, p. 23) used nomenclature for classes of stratigraphic units that is no longer accepted, and confused 'time-rock' (i.e., lithostratigraphic) and time-stratigraphic (i.e., chronostratigraphic) units. He stated "formations and members created by Tempelman-Kluit (1984) are largely facies-representative, and not time-stratigraphic units"(p. 23), and that formations and members "cross time-stratigraphic horizons and make the use of rock-stratigraphic units impractical"(p. 40). Mihalynuk (1999) described the Takwahoni and Inklin formations as lithostratigraphic units and then defined the units by age.

Furthermore, the current distribution of the mapped strata comprising the Laberge Group in the Yukon may partly be due to confusion over what these units are and to misidentified units; the thickness of the units is based mostly on calculations from a map and not from measured sections (e.g., Hart, 1997; Wheeler, 1961); and the age of the units is not the simple 'layer cake' geology as commonly portrayed. According to the North American Commission on Stratigraphic Nomenclature (1983, Article 22) a "lithostratigraphic unit is a defined body of sedimentary, extrusive igneous, metasedimentary, or metavolcanic strata distinguished and delimited on the basis of lithic characteristics and stratigraphic position." Furthermore, lithostratigraphic units are not defined on the basis of age, inferred geologic history, depositional environment or fossil zones; they generally cut across time horizons (i.e., they are diachronous), and any particular formation may be a different age in a different area (Schoch, 1989). Lithostratigraphic units are important because several mineral deposits, such as placer gold and base metal sedimentary exhalative (SEDEX) deposits, and of course hydrocarbon deposits, are commonly facies controlled, particularly in siliciclastic sedimentary rocks. Hence, in the search for petroleum, lithostratigraphic units such as sandstone are of interest because they may be potential reservoirs for oil and gas.

REVISED STRATIGRAPHY

LITHIC CHARACTERISTICS

Richthofen formation

No type section, or stratotype, for the Richthofen formation has been described, but Tempelman-Kluit suggested that the type area is the west shore of Lake Laberge (Fig. 3). The Richthofen formation is described as 'silty shale' (Fig. 4) and apparently all mappable shale, regardless of stratigraphic position was included in this unit (Tempelman-Kluit, 1984). However, rocks exposed in

Figure 3. *Type area for the Richthofen formation, west shore of Lake Labege (view looking north).*

Figure 4. *Typical exposure of the Richthofen formation along Lake Laberge (rock hammer, circled, for scale).*

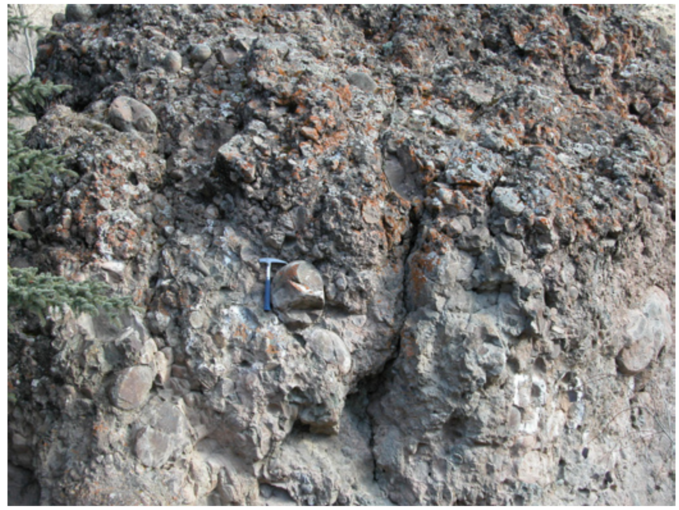


Figure 6. *Typical exposure of the Conglomerate formation at Conglomerate Mountain (rock hammer for scale).*

the type area are more properly described as a succession of graded siltstone to very fine-grained sandstone and mudstone couplets, or thin-bedded turbidites. Also occurring in the Richthofen formation and associated with these couplets are conglomerate, pebbly sandstone, sandstone, volcaniclastic rocks, pelagic fauna and relatively deep-water trace fossils such as *Zoophycos*. Lithologically then, the Richthofen formation is distinguished by siltstone-sandstone and mudstone couplets.

Conglomerate formation

No stratotype for the Conglomerate formation has been described but Tempelman-Kluit indicated the type area is

Figure 5. *Type area for the Conglomerate formation, Conglomerate Mountain north of Lake Laberge.*

Conglomerate Mountain north of Lake Laberge (Fig. 5). The Conglomerate formation is described as framework- to matrix-supported conglomerate (Fig. 6), and apparently all mappable conglomerate, regardless of stratigraphic position, was included in this unit (Tempelman-Kluit, 1984). Also occurring in the Conglomerate formation are pebbly sandstone and sandstone. Lithologically though, the Conglomerate formation cannot be distinguished by conglomerate because this rock type also occurs in other formations. Therefore, the stratigraphic position of conglomerate must be determined before it can be assigned to a formation.

Nordenskiold formation

No stratotype for the Nordenskiold formation has been described, but Tempelman-Kluit suggested that the type area is the valley of the Nordenskiold River near Montague Mountain and Conglomerate Mountain north of Lake Laberge (Fig. 7). The Nordenskiold formation is described as massive dacite tuff (Fig. 8), and apparently all tuff was included in this unit (Tempelman-Kluit, 1984). Also occurring in the Nordenskiold formation are well preserved crystal tuffs. Lithologically though, the Nordenskiold formation cannot be distinguished by tuff because this rock type also occurs in other formations. Therefore, the stratigraphic position of tuff must be determined before it can be assigned to a formation.

Figure 7. *Type area for the Nordenskiold formation, valley of the Nordenskiold River near Montague Mountain and Conglomerate Mountain north of Lake Laberge.*

Figure 9. *Type area for the Tanglefoot formation, Tanglefoot Mountain (on left foreground) north of Lake Laberge and east of Chain Lakes.*

Figure 8. *Typical exposure of the Nordenskiold formation at Montague Mountain.*

Figure 10. *Typical exposure of the Tanglefoot formation, Robert Campbell Highway east of Carmacks (Jacob's staff is 1.5 m long).*

Tanglefoot formation

No stratotype for the Tanglefoot formation has been described but Tempelman-Kluit suggested the type area is Tanglefoot Mountain, north of Lake Laberge and just west of Chain Lakes (Fig. 9). The Tanglefoot formation is described as arkose and feldspathic sandstone (Fig. 10), and apparently all mappable sandstone regardless of stratigraphic position was included in this unit (Tempelman-Kluit, 1984). However, based on this study, the Tanglefoot formation is characterized by interbedded sandstone and mudstone. Also occurring in the Tanglefoot formation and associated with the interbedded sandstone and mudstone are conglomerate, pebbly sandstone, volcaniclastic rocks, coal, abundant terrestrial plant fossils and marginal marine fossils. Lithologically then, the Tanglefoot formation is distinguished by coal-bearing interbedded sandstone and mudstone.

DISTRIBUTION

Five Finger Rapids

Tempelman-Kluit (1984) mapped a thin band of Richthofen formation and Conglomerate formation at Five Finger Rapids, 20 km north of Carmacks (Fig. 11). However, the shale mapped as 'Richthofen formation' is a carbonaceous sequence of mudstone with carbonate concretions (Fig. 12), and not the siltstone-sandstone and mudstone couplets characteristic of the Richthofen formation; whereas the conglomerate mapped as the 'Conglomerate formation' is a sequence of coal-bearing conglomerate, pebbly sandstone, sandstone and mudstone (Fig. 13). In addition, immediately up-river from Five Finger Rapids is the historic Five Finger coal mine, in

Figure 12. *Tanglefoot formation mudstone at Five Finger Rapids incorrectly mapped as 'Richthofen formation' (carbonate concretions on right side of photograph are approximately 20 cm in diameter).*

Figure 11. *Part of the geologic map for the Carmacks map area (from Tempelman-Kluit, 1984).*

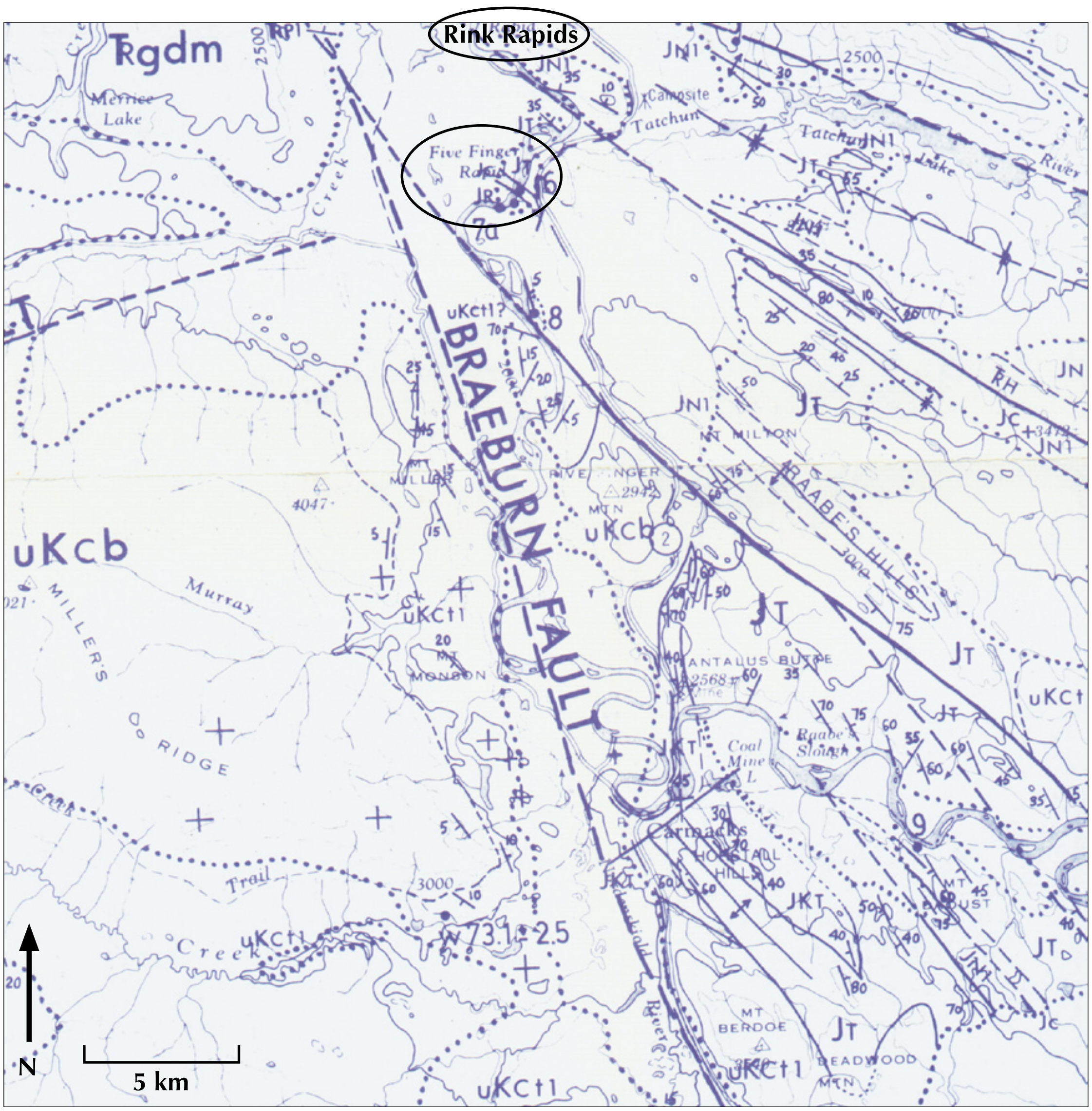


Figure 13. Tanglefoot formation conglomerate at Five Finger Rapids incorrectly mapped as 'Conglomerate formation'.

which coal was extracted from strata of the Laberge Group (Hunt, 1984; Deklerk, 2002). Hence, the entire section exposed at Five Finger Rapids belongs to the Tanglefoot formation.

Rink Rapids

The Nordenskiold formation was mapped by Tempelman-Kluit (1984) as outcropping along the Yukon River near Rink Rapids, 25 km north of Carmacks (Fig. 11). However, the tuff mapped as 'Nordenskiold Dacite' is a sequence of interbedded sandstone and mudstone (Fig. 14). Although several of the sandstone beds appear tuffaceous, carbonaceous laminae and terrestrial plant fossils are locally present. Therefore, this carbonaceous section of interbedded sandstone and mudstone is part of the Tanglefoot formation.

Figure 14. Tanglefoot formation interbedded sandstone and mudstone at Rink Rapids incorrectly mapped as the 'Nordenskiold (Dacite) formation' (rock hammer for scale).

Figure 15. Tanglefoot formation interbedded conglomerate and sandstone near Eagle's Nest Bluff incorrectly mapped as the 'Conglomerate formation' (Jacob's staff is 1.5 m long).

Eagle's Nest Bluff

Tempelman-Kluit suggested that a section of conglomerate and sandstone unconformably overlying carbonates of the Lewes River Group near Eagle's Nest Bluff, 20 km east of Carmacks, are part of the Conglomerate formation. However, these rocks consist of a sequence of conglomerate, pebbly sandstone, sandstone and mudstone (Fig. 15). In addition, several of the lowermost sandstone beds are tuffaceous, terrestrial plant fossils and coal seams are present up section, the rocks display a consistent dip to the west, and they are mapped by Tempelman-Kluit (1984) as the Tanglefoot formation in the Carmacks map area (115I). Therefore, the section exposed near Eagle's Nest Bluff represents the basal part of the Tanglefoot formation.

Joe and 'Fossil' creeks

Tempelman-Kluit (1984) mapped sandstone and shale exposed along Joe and 'Fossil' creeks, 25 km northwest of the north end of Lake Laberge as the Richthofen formation (Fig. 16), and Allen (2000) also mapped the rocks along Joe Creek as the Richthofen formation. However, rocks exposed along these creeks consist of a succession of interbedded sandstone and mudstone that

Figure 16. *Part of the geologic map for the Laberge map area (from Tempelman-Kluit, 1984).*

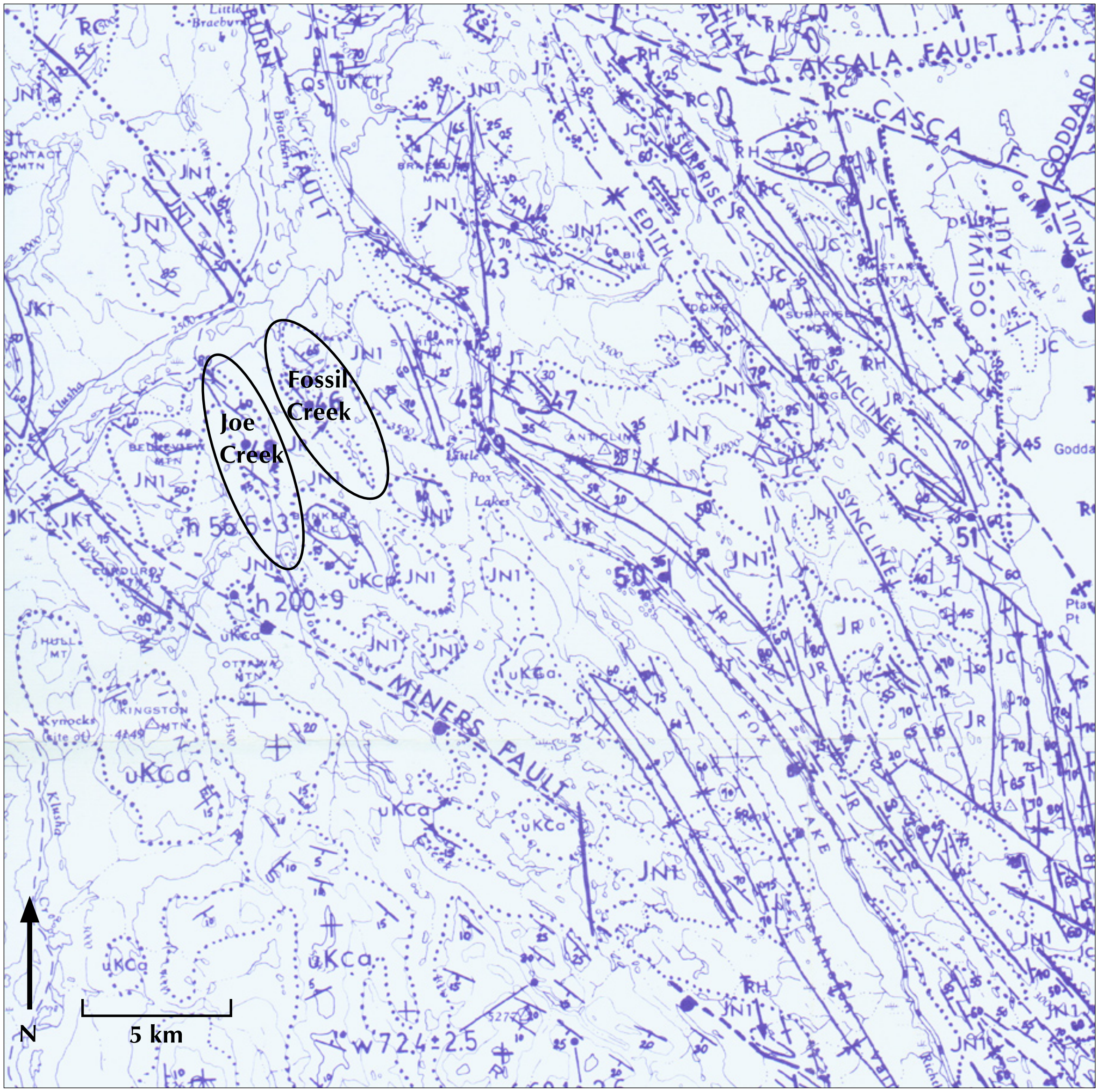


Figure 17. *Tanglefoot formation interbedded sandstone and mudstone at Joe Creek, incorrectly mapped as 'Richthofen formation' (sandstone beds are up to 1 m thick).*

contain thin coal seams and abundant terrestrial plant fossils (Fig. 17). Hence, these rocks belong to the Tanglefoot formation and not the Richthofen formation.

Therefore, either the Richthofen formation was completely removed by erosion in the northern part of the Laberge map area and the Carmacks map area, which seems unlikely, or the Richthofen formation was not deposited in this area, which is a more plausible interpretation. Also, most of the conglomerate now assigned to the Conglomerate formation and most of the tuff now assigned to the Nordenskiold formation can be reassigned to other formations (i.e., the Richthofen and Tanglefoot formations).

THICKNESS

Most of the stratal architecture of the Whitehorse Trough, including the Laberge Group, is based on Hart and Radloff (1996) and Hart (1997). However, the thicknesses they present are mainly estimates or calculations from a map and not from measured stratigraphic sections. Even the original work by Wheeler (1961) on the Whitehorse Trough is based on calculations from a map, and although this provides an initial framework, measured stratigraphic sections are required to properly determine the stratigraphy of the Laberge Group.

Although some sections have been measured, their location is poorly recorded, they may be 'composite' sections, or they may have been measured incorrectly. The section locations in Dickie (1989) are only to the nearest degree and several are erroneous (i.e., latitude and longitude coordinates do not correspond to NTS map numbers); and section 3 in Dickie (1989) was apparently measured from the base to the top of Conglomerate Mountain, but bedding consistently dips southward and so a properly measured section section would go from north to south across the mountain front.

REVISED AGE

Figure 18 is a plot of fossil ages for formations in the Laberge Group in the Carmacks and Laberge map areas based on Tempelman-Kluit (1984), showing a 'layer-cake' geology with the Richthofen formation ranging from Hettangian to Pliensbachian in age, the Conglomerate and Nordenskiold formations ranging from Sinemurian to Toarcian in age, and the Tanglefoot formation ranging from Toarcian to Bajocian in age. Figure 19 is a revised plot of the same fossil ages based on reassigning misidentified units to other formations. Note that the Richthofen and Tanglefoot formations span almost the same age — since these formations represent the same basin fill, and possibly, at least in part, a facies change — whereas the Conglomerate and Nordenskiold formations are now restricted in age.

IMPLICATIONS

The revised stratigraphic architecture of the Whitehorse Trough for the Carmacks and Laberge map areas is shown in Figure 20. Note that in the southern part of the Laberge map area, the Richthofen formation rests unconformably and/or conformably on the Lewes River Group, and it in turn is overlain unconformably and/or conformably by the Tanglefoot formation. In contrast, in the northern part of the Laberge map area and in the southern part of the Carmacks map area, the Tanglefoot formation rests unconformably on the Lewes River Group, and the Conglomerate and Nordenskiold formations occur as minor units — perhaps best described as members — within the Tanglefoot formation. Hence, this diagram shows the stratigraphic position of the formations of the Laberge Group, which can be used to delimit these lithostratigraphic units in the Carmacks and Laberge map areas. This revised lithostratigraphy has important implications in the search for gas and oil in the Whitehorse Trough.

An important process in the exploration for gas and oil is the definition of the 'play' and the mapping of its 'fairway'. A play is a group of related petroleum prospects or pools having similar geologic conditions of source rock, reservoir, seal and trap, and the fairway is the geographic distribution of these geologic controls (Allen and Allen, 1990; White, 1988). Although further work is required before play-fairway maps can be constructed for the Whitehorse Trough, the National Energy Board (2001) described eight conceptual plays (i.e., three gas with minor oil, and five solely gas). However, one of these plays (i.e., the Conglomerate-Richthofen stratigraphic conceptual gas and oil play) is based on the assumption that the Richthofen formation and Conglomerate formation interfinger, but this contact relationship probably does not occur in the Carmacks and Laberge map areas; and a second play (i.e., the Hancock-Conglomerate structural conceptual gas and oil play) only briefly mentions the Tanglefoot formation as a possible reservoir.

Based on the revised lithostratigraphy presented in this report, two new conceptual plays are possible.

Figure 18. *Plot of fossil ages for the Laberge Group in the Carmacks and Laberge map areas (from Tempelman-Kluit, 1984; Jurassic time scale from Palfy et al., 2000).*

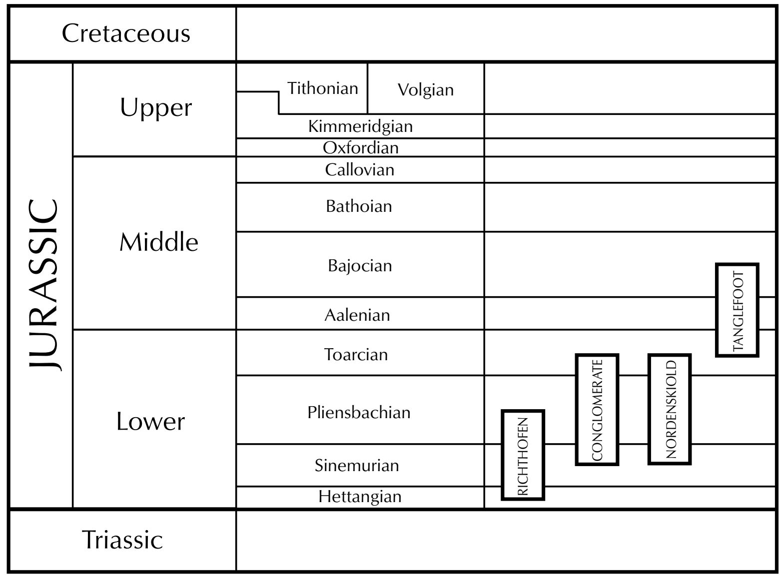


Figure 19. *Revised plot of fossil ages based on reassigning misidentified units to other formations (age chart from Palfy et al., 2000).*

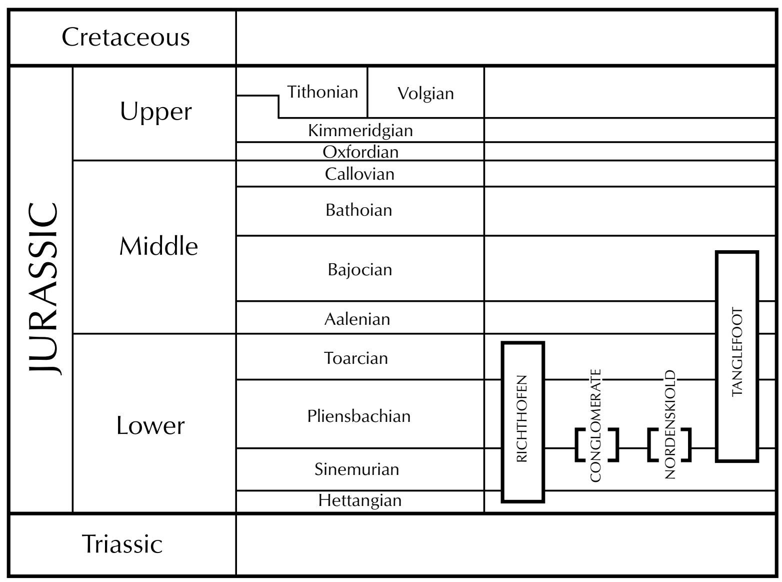
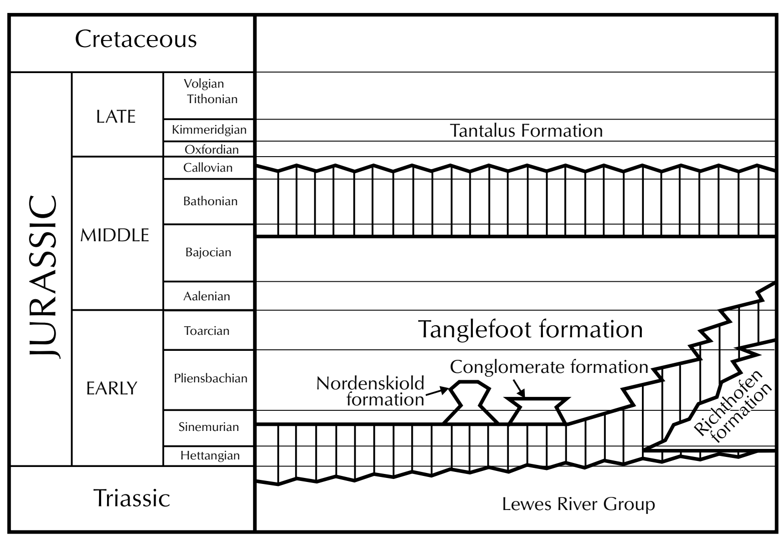


Figure 20. *Revised lithostratigraphy of the Laberge Group in the Carmacks and Laberge map areas (age chart from Palfy et al., 2000). Vertical bars indicate a period of non-deposition.*



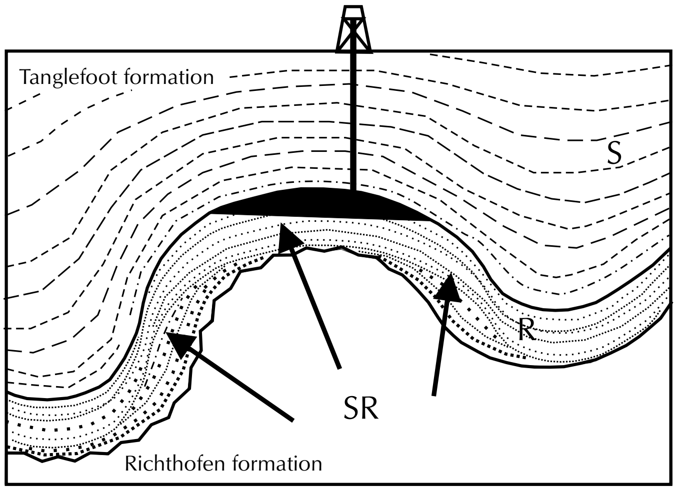


Figure 21. *Conceptual petroleum play #1, southern part of the map areas (R=reservoir, S=seal, SR=source rock).*

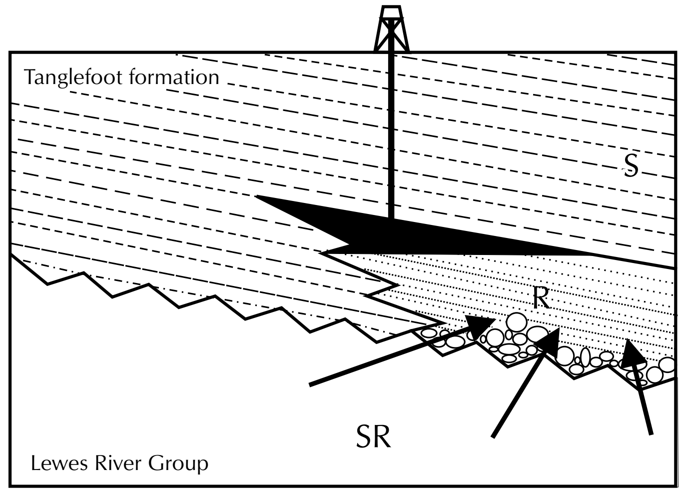


Figure 22. *Conceptual petroleum play #2, northern part of the map areas (R=reservoir, S=seal, SR=source rock).*

Figure 21 is a conceptual petroleum play developed for the Richthofen formation-Tanglefoot formation unconformity and/or facies change. This play requires the primary migration of petroleum from source rocks of Richthofen formation siltstone-sandstone and mudstone couplets, and accumulation in reservoirs of Tanglefoot formation sandstone. Regional topseals (or cap rock) of Tanglefoot formation mudstone would prevent further migration of petroleum with trapping in structural anticlines. The play is restricted to the southern part of the Laberge map area. Figure 22 is a conceptual petroleum play developed for the Lewes River Group-Tanglefoot formation unconformity, assuming that the Richthofen formation was not deposited in the northern part of the map areas. This play requires the primary migration of petroleum from source rocks of Lewes River Group carbonates, and accumulation in reservoirs of Tanglefoot formation sandstone. Regional topseals of Tanglefoot formation mudstones would prevent further migration of petroleum with stratigraphic trapping in pinchouts. The play is restricted to the northern part of the Laberge map area and the southern part of the Carmacks map area (i.e., the northernmost part of the Whitehorse Trough).

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