Sedimentology and hydrocarbon potential of fluvial strata in the Tantalus and Aksala formations, northern Whitehorse Trough, Yukon

D.G.F. Long
Department of Earth Sciences, Laurentian University[1]

Long, D.G.F., 2005. Sedimentology and hydrocarbon potential of fluvial strata in the Tantalus and Aksala formations, northern Whitehorse Trough, Yukon. *In:* Yukon Exploration and Geology 2004, D.S. Emond, L.L. Lewis and G.D. Bradshaw (eds.), Yukon Geological Survey, p. 167-176.

ABSTRACT

Extensive conglomeratic strata in the Late Jurassic to Early Cretaceous Tantalus Formation were deposited in both shallow gravel-bed braided rivers, and deeper meandering gravel bed rivers. Overbank, marsh and swamp deposits, with potential to contain abundant terrestrial organic materials, are restricted to recessive intervals associated with small sandy and gravelly high-constructive river systems. Medium- to high-volatile bituminous and anthracitic coals in these intervals have limited potential as a source of additional gaseous hydrocarbons. Most of the conglomerates have a high fracture density, which would make them good reservoirs for coal-bed methane in settings where the Tantalus Formation lies beneath a seal of younger volcanic strata. Strata of the Late Norian Mandanna member of the Aksala formation near Takhini Hotsprings do not contain fluvial strata: laminated, bioturbated, intraclast-bearing red sandstones were deposited in an intertidal setting, and may have lost most of their organic material prior to burial.

RÉSUMÉ

D'importantes strates conglomératiques de la Formation de Tantalus datant du Jurassique tardif au Crétacé précoce se sont déposées à la fois dans des cours d'eau anostomosés peu profonds et dans des cours d'eau sinueux plus profonds, à fond de gravier. Des dépôts de débordement, de marais et de marécages, qui peuvent contenir des matières organiques terrestres abondantes, sont limités à des intervalles récessifs associés à de petits réseaux hydrographiques sableux et graveleux très constructifs. Dans ces intervalles, des charbons bitumineux et anthraciteux à teneur en matières volatiles de moyenne à élevée offrent un potentiel limité comme source supplémentaire d'hydrocarbures gazeux. La plupart des conglomérats présentent une grande densité de fractures qui en feraient de bons réservoirs pour du méthane de houille dans des milieux où la Formation de Tantalus repose sous une couche étanche formée de strates volcaniques plus récentes. Près de Takhini Hotsprings, les strates du membre Mandanna de la formation Aksala, datant du Norien tardif, ne renferment pas de strates fluviatiles : des grès rouges laminés et bioturbés à intraclastes se sont déposés dans un milieu intertidal et ont probablement perdu la majeure partie de leurs matières organiques avant leur enfouissement.

---

[1] *Sudbury Ontario, Canada P3E 2C6, dlong@laurentian.ca*

INTRODUCTION

Terrestrial hydrocarbons, which may represent a viable source for coal-bed methane, may be present at several levels within the Whitehorse Trough in the Yukon and Northern British Columbia. K.G. Osadetz (pers. comm., 2004) suggests that within the Whitehorse Trough there may be a potential for as much as 7.3 trillion cubic feet (21 billion m^3) of gas, and 0.1 billion (20 million m^3) barrels of oil. Estimates for the Yukon segment of the trough are 8.12 million barrels (1.29 million m^3) of recoverable oil and 196 billion cubic feet (5521 million m^3) of marketable gas (National Energy Board, 2001). The major source of the gas may be from fractionation of coals within the terrestrial sequences, and algae in the marine sequences, most of which are above the grade required for methane production (Hannigan et al., 1995; Hunt, 1994; Hunt and Hart, 1993; Long, 1981, 1982a,b, 1984, 1986). Terrestrial units within the sequence have potential as both sources and reservoirs of coal-bed methane, at least in parts of the Whitehorse Trough where structural or facies closure occurs. In order to properly assess this potential, it is essential to understand the sedimentology of the units, as this will allow preliminary estimates of the hydrocarbon potential, and the architecture, permeability structure and heterogeneity of potential reservoirs.

The objectives of the current study are to determine the age, depositional environments and hydrocarbon potential of both the Tantalus Formation, and the Mandanna member of the Aksala formation. This includes determination of the sedimentary architecture of fluvial facies in these units, and the relationship between the carbonate facies and contemporary vocaniclastic rocks in the Aksala formation. In addition, the provenance characteristics of the Tantalus Formation will be determined using petrographic analysis of clast types and isotopic dating of zircon populations. Ultimately this data may be used in conjunction with the vibra-seismic survey conducted across the Whitehorse Trough in 2004 as part of the Targeted Geoscience Initiative between the Yukon Geological Survey and the Geological Survey of Canada. The survey was initiated to identify potential hydrocarbon traps, reservoirs and seals in these units within the Whitehorse Trough.

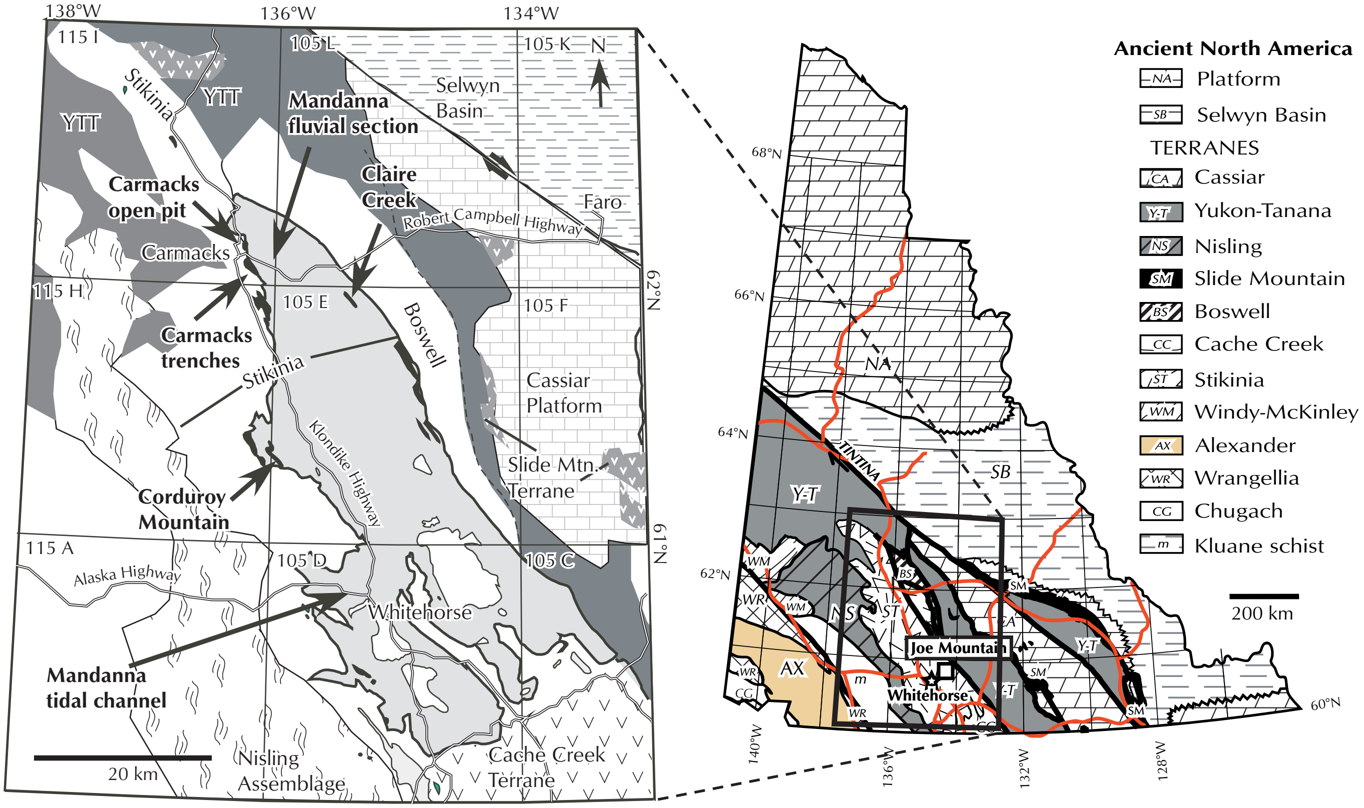

Figure 1. *Location of strata of the Laberge and Lewes River groups (light grey) and Tantalus Formation (black) in the northern Whitehorse Trough. Location of sections mentioned in text shown in bold. YTT=Yukon-Tanana Terrane. Terrane/location map at right is modified from Colpron after Wheeler and McFeely (1991).*

GEOLOGICAL BACKGROUND

Rocks of the Whitehorse Trough form part of the Intermontane belt of the Canadian Cordillera and, according to Wheeler and McFeely (1991), constitute part of the Stikine Terrane, which is bordered to the west and east by rocks of the Yukon-Tanana Terrane, and to the south by rocks of the Cache Creek Terrane (Fig. 1). The Trough has been variably interpreted as a back-arc basin (Templeman-Kluit, 1978; Monger and Price, 1979; Bultman, 1979), a fore-arc basin (Templeman-Kluit, 1979, 1980; Dickie, 1995; Johannson et al., 1997), a simple marginal basin (Eisbacher, 1981), or part of a complex of inter-arc basins (Monger et al., 1991) and small ocean basins (Souther 1991, p. 469). Metamorphic rocks in the Stikine Terrane west of the trough (included in the Late Paleozoic Takhini assemblage by Hart, 1997) are interpreted in all models as part of an older island arc system, which developed on top of the Cache Creek Terrane (Hart et al., 1995). Strata in the Cache Creek Terrane to the south and east of the trough are interpreted as remnants of a small ocean basin (Eisbacher, 1981; Souther, 1991), an oceanic plateau, or a broader ocean basin (1100 to 5500 km wide), which may represent a fragment of an ancestral Pacific Ocean basin (Templeman-Kluit, 1979; Monger and Price, 1979; Tozer, 1982; Poulton, 1982; Poulton and Aitken, 1989).

Current models (Hart, 1997) suggest that during the Triassic, deposition of volcanic and sedimentary rocks of the Lewes River Group took place in a fore-arc or inter-arc basin associated with westward subduction. The basal tholeiitic pillowed volcanic rocks (Joe Mountain Formation) may have developed along a rift, or by sea-floor volcanism associated with arc initiation in Middle Triassic (Ladinian) time; associated sediments indicate a deep-water setting. The Whitehorse Trough appears to have become a distinct basin by Upper Triassic (Carnian) time. The basin-fill begins with a thick sequence of pillow basalts and associated volcaniclastic rocks in the Povoas Formation (Templeman-Kluit, 1984; Hart, 1997). Volcaniclastic strata are more abundant in the eastern part of the basin, where they are locally calcareous. The overlying Carnian and Norian Aksala formation reflects extension of the fore-arc basin with development of carbonate reefs along the fore-arc rise (Hart, 1997).

The paleogeographic setting of the area is further complicated by the possibility that remnants of a second arc system (the northern extension of Quesnellia) may be present in the Yukon-Tanana Terrane, east of the Whitehorse Trough. Monger et al. (1982, 1991) suggest that this terrane amalgamated with Stikinia prior to Latest Triassic times, but may not have arrived at its present setting until the mid-Jurassic (Wernicke and Klepacki, 1988; Mihalynuk et al., 1994; Nelson and Friedman, 2004).

While no clear evidence exists for the presence of a volcanic arc east of the Whitehorse Trough in the Triassic, local emergence of the trench-slope break may be indicated in latest Norian by local southeast-directed paleocurrents in strata of the Lewes River Group along the northeast side of the Whitehorse Trough (Wheeler, 1961) and development of asymmetric reefs (Templeman-Kluit, 1978; Reid, 1982, 1987 a,b, 1988; Reid and Templeman-Kluit, 1987; Hart, 1997). In the latest Triassic, the basin appears to have collided either with the Atlin Terrane (part of Quesnellia) or the leading edge of the North American plate.

Contraction of the remnant arc basin in the early Jurassic, related to oblique collision with the North American plate, led to uplift of adjacent arc terranes and rapid accumulation of sediment gravity flows and associated slope deposits of the Laberge Group along the western (Dickie and Hein, 1992, 1995) and eastern (Wheeler, 1961) margins of the basin, with deepwater mudstones accumulating along the basin axis (Templeman-Kluit, 1984). Continued contraction, associated with obduction of parts of the eastern arc terranes, is marked by depositional hiatuses within the basin, followed by accumulation of more feldspathic sediments in the upper part of the Laberge Group in post Middle Jurassic times (Hart, 1997; Lowey, 2004).

The Laberge Group is succeeded by up to 1.3 km of predominantly medium- and large-pebble conglomerate of the (?) Upper Jurassic, to Lower Cretaceous Tantalus Formation (Templeman-Kluit, 1980; Long, 1982a,b, 1983, 1986). Clasts in the Tantalus Formation are predominantly chert, silicified mudstone and quartz, with only minor labile lithic fragments. This suggests that much of the clastic material was derived from reworking of carbonate sequences on the leading edge of the North American plate, or from chert-rich horizons within the Cache Creek Terrane, rather than from reworking of older arc systems. Analysis of zircon assemblages and clast types within the formation may provide additional clues to the late-stage evolution of the Whitehorse Trough, and provide possible links with the evolution of the Bowser Basin in northern BC.

MANDANNA MEMBER

The Late Norian Mandanna member is the uppermost unit within the Lewes River Group (Templeman-Kluit, 1984), and lies above algal carbonates and volcaniclastic sandstones that may represent a potential marine hydrocarbon source. In the southern part of the trough, these rocks are dominated by well-bedded varicoloured siltstone, wacke, sandstone, tuff and conglomerate that conformably overlie and interfinger algal carbonates of the Hancock member. It has been suggested that the Mandanna rocks may include shallow marine, beach- and flash-flood-dominated fluvial facies (Hart, 1997). Although the carbonate reefs in the underlying Hancock member have been studied in some detail (Reid, 1981, 1982, 1986, 1987a,b; Reid and Ginsburg, 1986; Reid and Templeman-Kluit, 1987; Senowbari-Daryan and Reid, 1987; Yarnell, 2000), the exact relationships between the reefs and associated marine-reworked volcaniclastic sediments has not been documented in detail.

TANTALUS FORMATION

The Tantalus Formation contains significant coal resources at Carmacks and other locations within the trough, and may represent another potential source for coal-bed methane, as well as being a potential reservoir for conventional oil and gas. At Carmacks, the thickest coal deposits are associated with drag-folds in fine-grained overbank deposits, formed in association with high-constructive (anastomosed or single channel) stream systems, while associated conglomerates were formed predominantly in deep gravel-bed braided and meandering systems (Long, 1986). The architecture of these systems is poorly understood and needs further detailed documentation, as this may have had a direct effect on methane migration and trapping potential.

PRELIMINARY OBSERVATIONS

Due to extensive forest fires near Mandanna Lake and northwest of Carmacks, it was not possible to fly into any of the key localities in the northern Whitehorse Trough. Sections of the Mandanna member were examined south of Takhini Hotsprings, adjacent to the Alaska Highway at 60°48.922'N, 135°18.388'W, and possibly equivalent strata east of Carmacks adjacent to the Robert Campbell Highway near Eagle's Nest Bluff (Fig. 1). Parts of the Tantalus Formation were examined, and sampled at Corduroy Mountain and in the open-pit on Tantalus Butte at 62°08.532'N, 136°15.975'W, near Carmacks before the smoke became too dense to undertake detailed work.

MANDANNA MEMBER

In exposures along the Alaska Highway, south of Takhini Hotsprings, exposures of the Mandanna member are dominated by flat laminated fine- to medium-grained sandstone and siltstone, with minor massive sandstone (Fig. 2). The presence of abundant bioturbation (worm tubes – Figs. 3 and 4) in the interbedded sand-mud facies supports the interpretation of an intertidal, rather than fluvial origin. Massive to flat-laminated sandstones, with some large cobbles of mud-grade material (Fig. 5), infill broad channels with stepped margins (Figs. 2,3). Faint burrows within these sands provides evidence for an intertidal origin.

Although many of the flat-laminated sandstones in the Mandanna member may be of intertidal origin, this does not preclude the existence of fluvial strata in the northern parts of the Whitehorse Trough. Strata that appear to be structurally and stratigraphically above the Hancock member in exposures immediately to the east of Eagle's Nest (adjacent to the Robert Campbell Highway: Fig 1) are thought to be a coarser grained facies of the Mandanna member. These strata contain evidence of deposition in perennial sand-bed rivers and meandering gravel-bed rivers, with stable channels, well developed levees and extensive overbank mud and sand deposits

Figure 2. *Part of a tidal channel deposit in the Mandanna member, in exposures along north side of the Alaska Highway.*

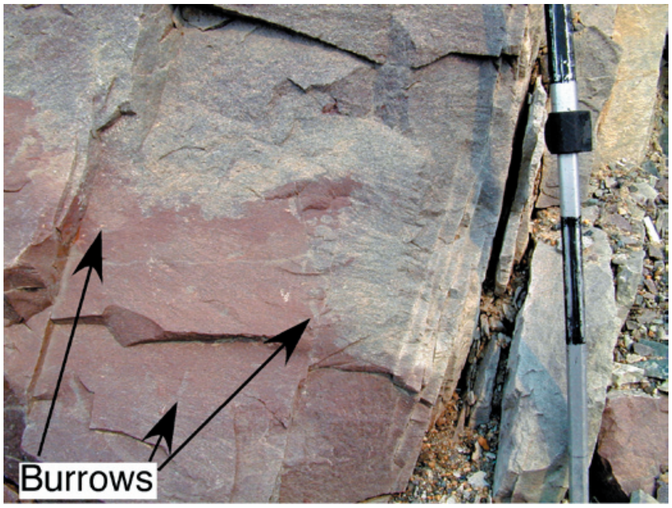

Figure 3. *Bioturbation in the stepped bank of the tidal channel in Figure 1. Mandanna member, Alaska Highway. Scale divisions 10 cm.*

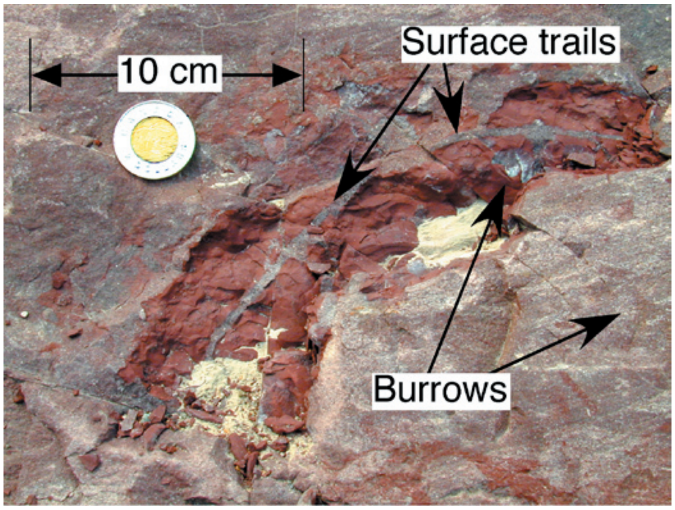

Figure 4. *Bedding plane view of mud flaser, with sand-filled surface trails and burrows. Mandanna member, Alaska Highway.*

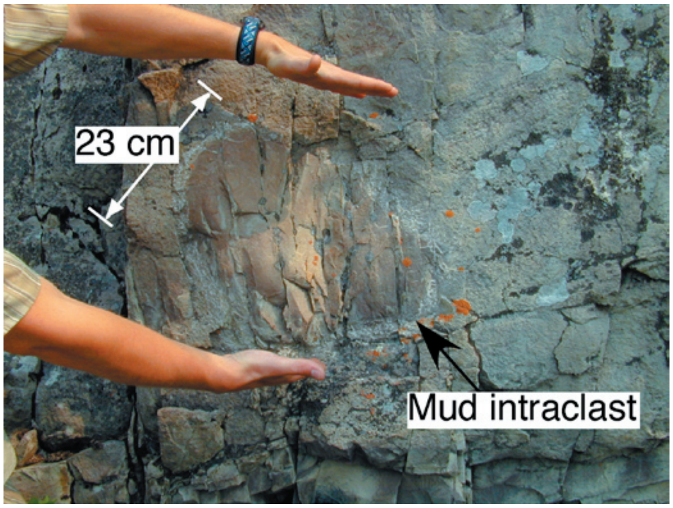

Figure 5. *Large rounded clast of intraformational mudstone in massive sandstone fill of tidal channel shown in Figure 1.*

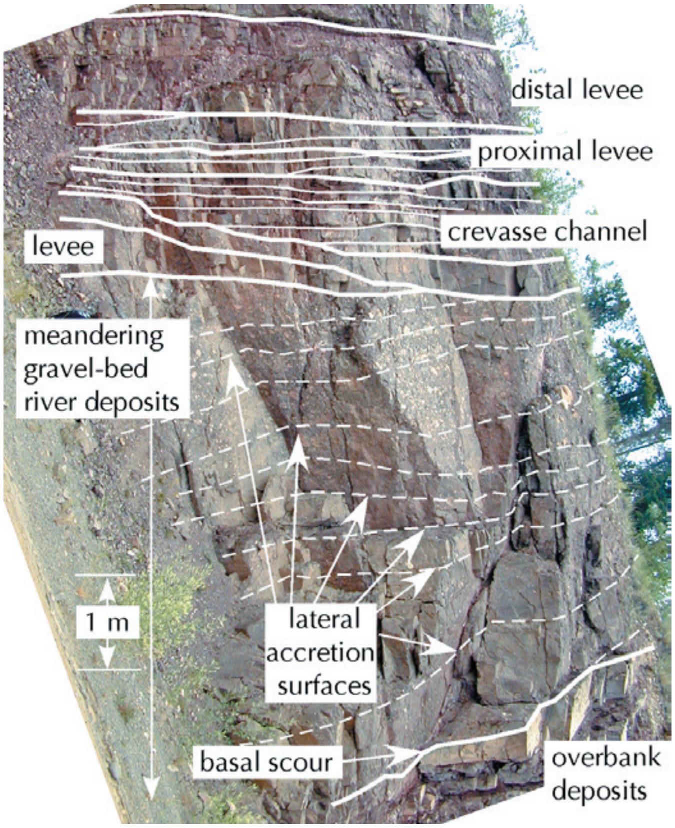

Figure 6. *Part of an exposed section of the Mandanna member, on north side of the Robert Campbell Highway, east of Eagle's Nest Bluff. The photograph has been rotated to show well developed lateral accretion surfaces within moderately poorly sorted conglomerates, interpreted here as deposits of a gravel-bed meandering river system.*

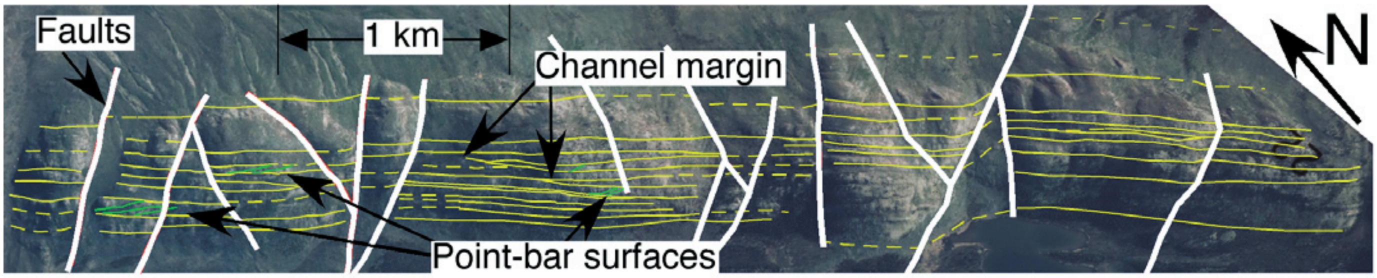

Figure 7. *Annotated air-photograph of conglomerate exposures along Corduroy Mountain shows that some of the gravel-bed systems can be traced along strike for more than 5 km. A few channels pinch out laterally, and large-scale foresets, representing lateral accretion surfaces of gravel-bed meandering rivers, can be seen locally.*

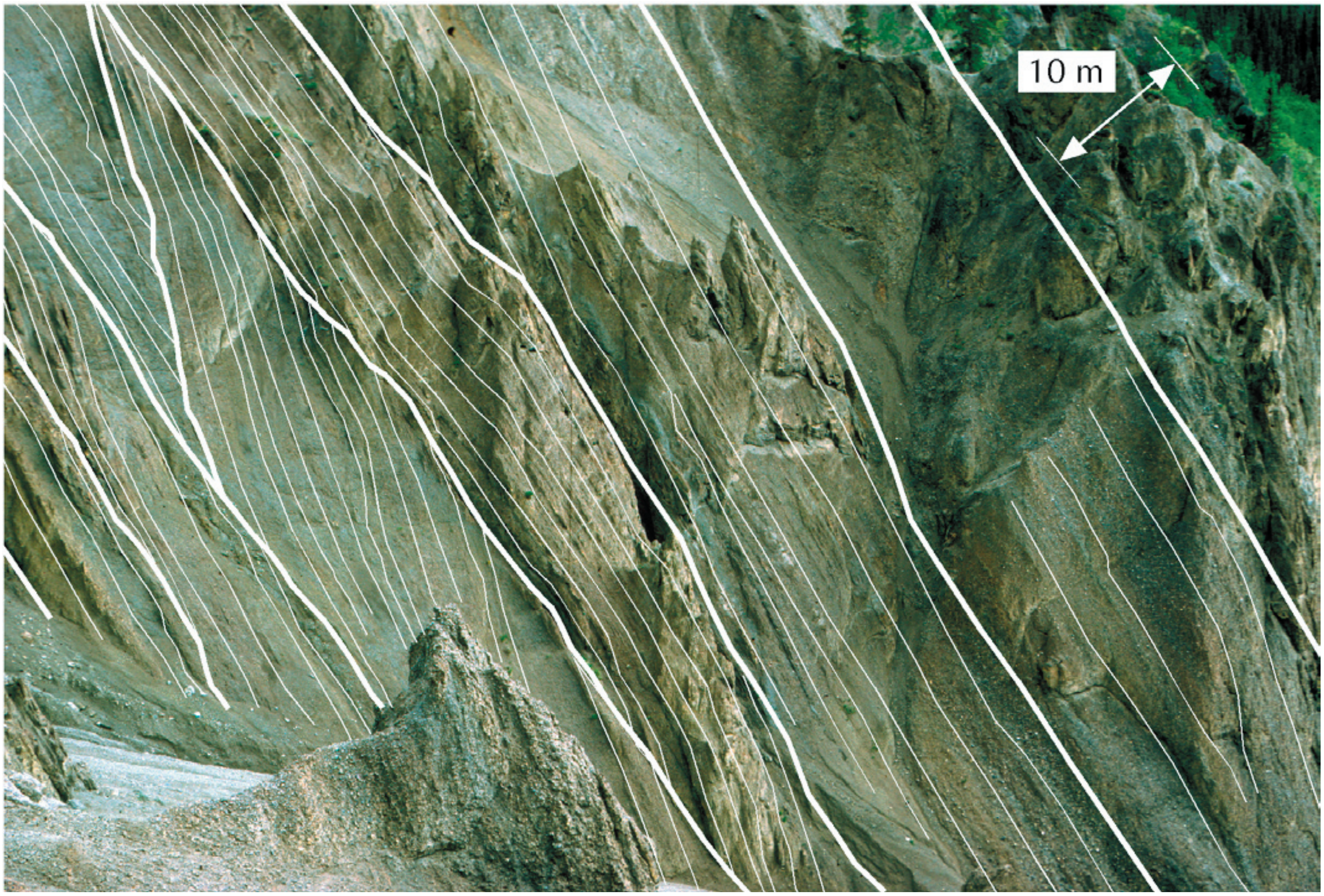

Figure 8. *Large-scale inclined sets in conglomerates of the Tantalus Formation at Claire Creek indicates that at least part of the formation was deposited in meandering gravel-bed rivers, with little evidence for preservation of overbank sediments. Thick lines indicate channel beds and margins; thin lines outline lateral accretion surfaces.*

(Fig. 6). There is no evidence for deposition under flash-flood conditions, although the rivers may have been highly seasonal.

TANTALUS FORMATION

The Tantalus Formation contains significant coal resources at Carmacks and other locations within the Trough (Fig. 1), and may represent another potential source for coal-bed methane. At Carmacks, the thickest coal deposits are associated with drag-folds in fine-grained overbank deposits, formed in association with high-constructive (anastomosed and single channel) streams, whereas associated conglomerates were formed predominantly in deep-gravel-bed braided and meandering systems (Long, 1986).

Initial studies in the Braeburn-Kynocks area at Corduroy Mountain (Figs. 1, 7) suggest that it may be possible to determine the width and depth of some of the meandering gravel-bed systems. Exposures at Claire Creek indicate that stream depths may have been in excess of 12 m (Fig. 8).

Examination of measured sections taken in 1978 (D. Long, unpublished) reveal significant erosional intervals within the Tantalus Formation, and the development of an incised valley system with a relief in excess of 200 m. There is also significant erosion at the contact with underlying coal-bearing strata of the Tanglefoot Formation, at least in the area around Carmacks (Fig. 9).

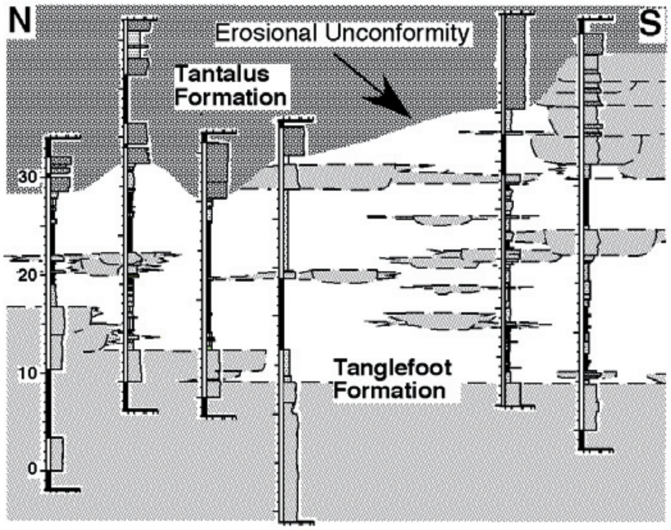

Figure 9. *Correlation of strata in the upper part of the Tanglefoot Formation, exposed in trenches south of the Yukon River at Carmacks, indicates that there is a stepped erosion surface at the base of the Tantalus Formation. Scale in metres.*

HYDROCARBON POTENTIAL

Initial studies of the Mandanna member suggests that it has little potential as a source of hydrocarbons, as there is little evidence for transported organic material. The presence of muddy intervals in the fluvial strata in the northern part of the Whitehorse Trough may provide local seals for stratigraphic traps for hydrocarbons migrating from stratigraphically lower members of the Aksala formation.

The presence of thick coal seams in the Tantalus Formation near Carmacks indicates that there is some potential for in-situ gasification to produce coal-bed methane. Other, fine-grained parts of the formation may also contain high concentrations of organic matter, and so, may have limited potential as a source of conventional oil and gas. The formation is dominated by porous conglomerates and minor sandstones, and is highly fractured in almost all locations. This would make it a good reservoir rock in situations where structural traps exist, but leaves little potential for stratigraphic traps of the type envisaged by the National Energy Board (2001) in their analysis of the hydrocarbon potential of the Whitehorse Trough. These models typically show lenses of coarse-porous facies encapsulated in fine-grained material: a situation which is clearly not evident in the Tantalus Formation, where fines represent less than 5% of the sequence.

Given the complex structural history of the area, the most significant risks for both structural and stratigraphic traps is seal integrity. No oil stains have been encountered in the >150 thin sections of the Tantalus Formation examined to date, suggesting that liquid hydrocarbons were never abundant.

FUTURE WORK

Field work in 2005 will concentrate on determining the character of fluvial strata in the Mandanna member of the Aksala formation, and in the Tantalus Formation. In addition, the study will be expanded to include marine strata of the Hancock and Casca members of the Aksala formation, in order to determine if these are potential sources of liquid or gaseous hydrocarbons. Representative samples will be collected and examined for hydrocarbon content, type and grade using vitrinite reflectance and RockEval analysis.

Architectural elements and discontinuity surfaces in the Tantalus Formation will be traced along strike in order to determine the potential width/depth ratios of individual channel systems. This type of information is required to determine interconnectivity and lateral heterogeneity of potential reservoirs (c.f., Jordan and Pryor, 1992) and the tectonostratigraphic history of the basin.

Analysis of zircon assemblages from three large samples collected from the Tantalus Formation in 2004 will be used to determine if there were significant changes in provenance during deposition of the formation. Petrographic and geochemical investigation of clast types (predominantly chert) within the formation may provide additional clues to the late stage evolution of the Whitehorse Trough, and provide possible links with the evolution of the Bowser Basin in northern B.C.

ACKNOWLEDGEMENTS

I thank the Yukon Geological Survey, Laurentian University Research Fund and the NSERC Discovery Grants program for funding parts of this study. I thank Jeremie Caza for his able assistance in the field, and Grant Lowey for continuing discussions on the sedimentology and hydrocarbon potential of the Whitehorse Trough. I thank Steve Piercey and Grant Lowey for critically reviewing an earlier version of this paper.

REFERENCES

Bultman, T.R., 1979. Geology and tectonic history of the Whitehorse trough west of Atlin, British Columbia. Unpublished PhD thesis, Yale University, New Haven, Connecticut, 284 p.

Dickie, J.R., 1995. Conglomeratic fan deltas and submarine fans of the Jurassic Laberge Group, Whitehorse Trough, Yukon Territory, Canada; fore-arc sedimentation and unroofing of a volcanic island arc complex. Sedimentary Geology, vol. 98 (1-4), p. 263-292.

Dickie, J.R. and Hein, F.J., 1992. A Pliensbachian submarine slope and conglomerate gully-fill succession; Richthofen to Conglomerate formation transition (Laberge Group), Brute Mountain, Yukon. Yukon Geology 1992, p. 71-86.

Dickie, J.R. and Hein, F.J., 1995. Conglomeratic fan deltas and submarine fans of the Jurassic Laberge Group, Whitehorse Trough, Yukon Territory, Canada: fore-arc sedimentation and unroofing of a volcanic island complex. Sedimentary Geology, vol. 98, p. 263-292.

Eisbacher, G.H., 1981. Late Mesozoic-Paleogene Bowser Basin molasse and cordilleran tectonics. *In:* Sedimentation and tectonics in alluvial basins. A.D. Miall (ed.), Geological Association of Canada, Special Paper 23, p. 125-151.

Hannigan, P., Lee, P.J., Osadetz, K.G., Dietrich, J.R. and Olsen-Heise, K., 1995. Oil and Gas Resource Potential of the Bowser-Whitehorse Area of British Columbia. Geological Survey of Canada, Geofile 2001-5, March 1995.

Hart, C.J.R., Dickie, J.R., Ghosh, D.K. and Armstrong, R.L., 1995. Provenance constraints for Whitehorse Trough conglomerate; U-Pb zircon dates and initial Sr ratios of granitic clasts in Jurassic Laberge Group, Yukon Territory. *In:* Jurassic magmatism and tectonics of the North American Cordillera, D.M. Miller and C. Busby (eds.), Geological Society of America, Special Paper 299, p. 47-63.

Hart, C.J.R., 1997. A transect across Northern Stikinia: geology of the northern Whitehorse Map area, southern Yukon Territory (105D/13-16). Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Bulletin 8, 112 p.

Hunt, J.A., 1994. Yukon coal inventory 1994. Report prepared for Energy and Minerals Branch, Economic Development, Yukon Territorial Government, 169 p.

Hunt, J.A. and Hart, C.J., 1993. Thermal maturation and hydrocarbon source rock potential of Tantalus Formation coals in the Whitehorse area, Yukon Territory. *In:* Yukon Exploration and Geology 1993, Exploration and Geosciences Division, Yukon Region, Indian and Northern Affairs Canada, p. 67-77.

Johannson, G.G., Smith, P.L. and Gordey, S.P., 1997. Early Jurassic evolution of the northern Stikinian arc; evidence from the Laberge Group, northwestern British Columbia. Canadian Journal of Earth Sciences, vol. 34, no. 7, p. 1030-1057.

Jordan, D.W. and Pryor, W.A., 1992. Hierarchical levels of heterogeneity in a Mississippi River meander belt and application to reservoir systems. AAPG Bulletin, October, 1992, vol. 76, no. 10, p. 1601-1624.

Long, D.G.F., 1981. Coal deposits. *In:* An assessment of mineral and fuel resource potential of Yukon Territory. W.D. Sinclair, D.C. Findlay, W.H. Pool and K.M. Dawson (eds.), Geological Survey of Canada, Interim Report, August, 1981.

Long, D.G.F., 1982a. Quesnel coalfield, Whitehorse Trough, Big Salmon coalfield, Ross River coalfield, Dawson coalfield, Amphitheater coalfield, Watson Lake coalfield, South Nahanni - Mattson coalfield, Moose Channel coalfield. *In:* World Coalfields, Tectonics, Rijks Geologische Dienst, the Netherlands, I.G.C.P., 166, p. CANADA 14, 27, 28, 29, 30, 31, 32, 33, 35.

Long, D.G.F., 1982b. Depositional framework of coal deposits in forearc basin and molasse sequences of the Whitehorse Trough, Yukon Territory, Canada. International Association of Sedimentologists, Eleventh International Congress on Sedimentology, McMaster University, Hamilton, Ontario, Canada, August 22-27, 1982, Abstracts of Papers, p. 36.

Long, D.G.F., 1983. Depositional setting of coal deposits in the Whitehorse Trough, Yukon Territory, Canada. Canadian Society of Petroleum Geologists, The Mesozoic of Middle North America, Program and Abstracts, p. 57

Long, D.G.F., 1984. Carmacks-Braeburn-Whitehorse coalfield, Big Salmon coalfield, Ross River coalfield, Dawson coalfield, Amphitheater coalfield, Watson Lake coalfield, South Nahanni-Mattson coalfield. *In:* World Coalfields, Tectonics, Rijks Geologische Dienst, the Netherlands, I.G.C.P., 166, p. CANADA 27T-33T.

Long, D.G.F. 1986. Coal in Yukon. *In:* Mineral deposits of the northern Cordillera, J.D. Morin (ed.), Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 311-318.

Lowey, G.W., 2004. Preliminary lithostratigraphy of the Laberge Group (Jurassic), south-central Yukon: implications concerning the petroleum potential of the Whitehorse Trough. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 129-142.

Mihalynuk, M.G., Nelson, J. and Diakow, L.J., 1994. The Cache Creek Terrane entrapment; oroclinal paradox within the Canadian Cordillera. Tectonics, vol. 13, no. 3, p. 575-595.

Monger, J.W.H. and Price, R.A. 1979. Geodynamic evolution of the Canadian Cordillera, progress and problems. Canadian Journal of Earth Sciences, vol. 16, p. 770-791.

Monger, J.W.H., Price, R.A. and Tempelman-Kluit, D.J., 1982. Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera. Geology, vol. 10, p. 70-75.

Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Harms, T., Struik, L.C., Campbell, R.B., Dodds, G.E., Gehrels, G.E. and O'Brien, J., 1991. Part B. Cordilleran terranes. *In:* Upper Devonian to Middle Jurassic assemblages, Chapter 8 of Geology of the Cordilleran Orogen in Canada, H. Gabrielse and C. Yorath (eds.), Geological Survey of Canada, Geology of Canada, vol. 4, p. 281-327.

National Energy Board, 2001. Petroleum Resource assessment of the Whitehorse Trough, Yukon Territory, Canada. Oil and Gas Branch, Department of Economic Development, Government of the Yukon, 59 p.

Nelson, J. and Friedman, R., 2004. Superimposed Quesnel (late Paleozoic-Jurassic) and Yukon-Tanana (Devonian-Mississippian) arc assemblages, Cassiar Mountains, northern British Columbia: filed, U-Pb, and igneous petrochemical evidence. Canadian Journal of Earth Sciences, vol. 41, no. 10, p. 1201-1235.

Poulton, T.P., 1982. Paleogeographic and tectonic implications of Lower and Middle Jurassic facies patterns in northern Yukon Territory and adjacent Northwest Territories. *In:* Arctic Geology and Geophysics. A.F. Embry and H.R. Balkwill (eds.), Canadian Society of Petroleum Geologists, Memoir 8, p. 13-27.

Poulton, T.P. and Aitken, J.D., 1989. The Lower Jurassic phosphorites of southeastern British Columbia and terrane accretion to western North America. Canadian Journal of Earth Sciences, vol. 26, p. 1612-1616.

Reid, R.P., 1981. Report of field work on the Upper Triassic reef complex of Lime Peak, Laberge map-area, Yukon. *In:* Yukon geology and exploration 1979-80, Exploration and Geological Sciences Division, Yukon Region, Indian and Northern Affairs Canada, p. 110-114.

Reid, P., 1982. Lime Peak; an Upper Triassic reef complex in Yukon. AAPG Bulletin, vol. 66, no 5, p. 621-622.

Reid, R.P., 1986. Discovery of Triassic phylloid algae; possible links with the Paleozoic. Canadian Journal of Earth Sciences, vol. 23, no. 12, p. 2068-2071.

Reid, R.P., 1987a. Nonskeletal peloidal precipitates in Upper Triassic reefs, Yukon Territory (Canada). Journal of Sedimentary Petrology, vol. 57, no. 5, p. 893-900.

Reid, R.P., 1987b. The co-variation of lithology and geometry in Triassic reefal limestones at Lime Peak, Yukon. *In:* Yukon Exploration and Geology 1981, Department of Indian and Northern Affairs, Yukon Region, Exploration and Geological Services Division, p. 58-61.

Reid, R.P., 1988. Lime Peak reef complex, Norian age, Yukon. *In:* Reefs; Canada and adjacent areas, H.J. Helmut, N.J. Geldsetzer and G.E. Tebbutt (eds.), Canadian Society of Petroleum Geologists, Memoir 13, p. 758-765

Reid, R.P. and Ginsburg, R.N., 1986. The role of framework in Upper Triassic patch reefs in the Yukon. Palaios, vol. 1, no. 6, p. 590-600.

Reid, R.P. and Tempelman-Kluit, D.J., 1987. Upper Triassic Tethyan-type reefs in the Yukon. Bulletin of Canadian Petroleum Geology, vol. 35, no. 3, p. 316-332.

Senowbari-Daryan, B. and Reid, R.P., 1987. Upper Triassic sponges (Sphinctozoa) from southern Yukon, Stikinia Terrane. Canadian Journal of Earth Sciences, vol. 24, no. 5, p. 882-902.

Souther, J.G., 1991. Volcanic regimes, Chapter 14. *In:* Geology of the Cordilleran Orogen in Canada, H. Gabrielse and C. Yorath (eds.), Geological Survey of Canada, Geology of Canada, vol. 4, p. 457-490.

Templeman-Kluit, D.J., 1978. Laberge (106E) map area, Yukon. Geological Survey of Canada, Open File Report 578, 1:250 000 scale.

Templeman-Kluit, D.J., 1979. Transported cataclasite, ophiolite and granodiorite in Yukon: evidence of arc-continent collision. Geological Survey of Canada, Paper 79-14, 27 p.

Templeman-Kluit, D.J., 1980. Highlights of field-work in the Laberge and Carmacks map areas, Yukon Territory. *In:* Current Research, part A. Geological Survey of Canada, Paper 80-1A, p. 357-362.

Templeman-Kluit, D.J., 1984. Geology, Laberge (105E) and Carmacks (105I), Yukon Territory, Geological Survey of Canada, Open File Report 1101, 1:250 000 scale .

Tozer, E.T., 1982. Marine Triassic faunas of North America: their significance for assessing plate and terraine movements. Geologishe Rundschau, vol. 71, p. 1077-1104.

Wernicke, B. and Klepacki, D.W., 1988. Escape hypothesis for the Stikine block. Geology, vol. 16, p. 416-464.

Wheeler, J.O., 1961. Whitehorse map-area, Yukon Territory, 105D. Geological Survey of Canada, Memoir 312, 156 p.

Wheeler, J.O. and McFeeley, P., 1991. Tectonic Assemblage Map of the Canadian Cordillera. Geological Survey of Canada, Map 1712A, 1:1 000 000 scale.

Yarnell, J.M., 2000. Paleontology of two North American Triassic reef faunas; implications for terrane paleogeography. Unpublished MSc thesis, University of Montana, Missoula, Montana, 141 p.