Atlin TGI, Part VI: Early to Middle Jurassic Sedimentation, Deformation and a Preliminary Assessment of Hydrocarbon Potential, Central Whitehorse Trough and Northern Cache Creek Terrane

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KEYWORDS: *Cache Creek terrane, Laberge Group, Sinwa Formation, Nakina, Tulsequah, regional geology, forearc basin, accretionary complex, hydrocarbon potential, organic maturation.*

INTRODUCTION

The Whitehorse Trough is an Early to Middle Jurassic marine basin, which extends from southern Yukon to Dease Lake in British Columbia. It flanks oceanic crustal rocks to the east, including thick platformal carbonate and argillaceous chert successions of the northern Cache Creek terrane (Figure 1). Early studies recognised the low metamorphic grade of these sedimentary rocks (*e.g.* Monger, 1975) and their potential to host hydrocarbon accumulations (*e.g.* Gilmore, 1985; Hannigan *et al.*, 1995; National Energy Board, 2001). However, early assessments were based on data from samples collected in southern Yukon (Gilmore, 1985; National Energy Board, 2001); these data indicate that the Whitehorse Trough in the Yukon is gas-prone. It is not known if potential hydrocarbon traps were filled and preserved, as none have been drilled. Structural complexity and metamorphic grade decreases in the British Columbia portion of the Trough. On the basis of flat-lying Eocene volcanic rocks, no widespread deformation post-dates Early Eocene time (Mihalynuk, 1999). Indeed, undeformed Middle Jurassic plutons cut all major fabrics within the Whitehorse Trough in BC. Deformation is therefore constrained in age to between about 172 and 170 Ma - the age of youngest deformed strata and oldest cross-cutting plutons (*e.g.* Mihalynuk *et al.*, 1999). Such a simple deformational history limits the possibility of hydrocarbon escape subsequent to generation, during successive deformational events. An uncomplicated history also simplifies thermal maturation modeling. Previous assessments in BC were based on extrapolation from the Yukon portion of the Trough.

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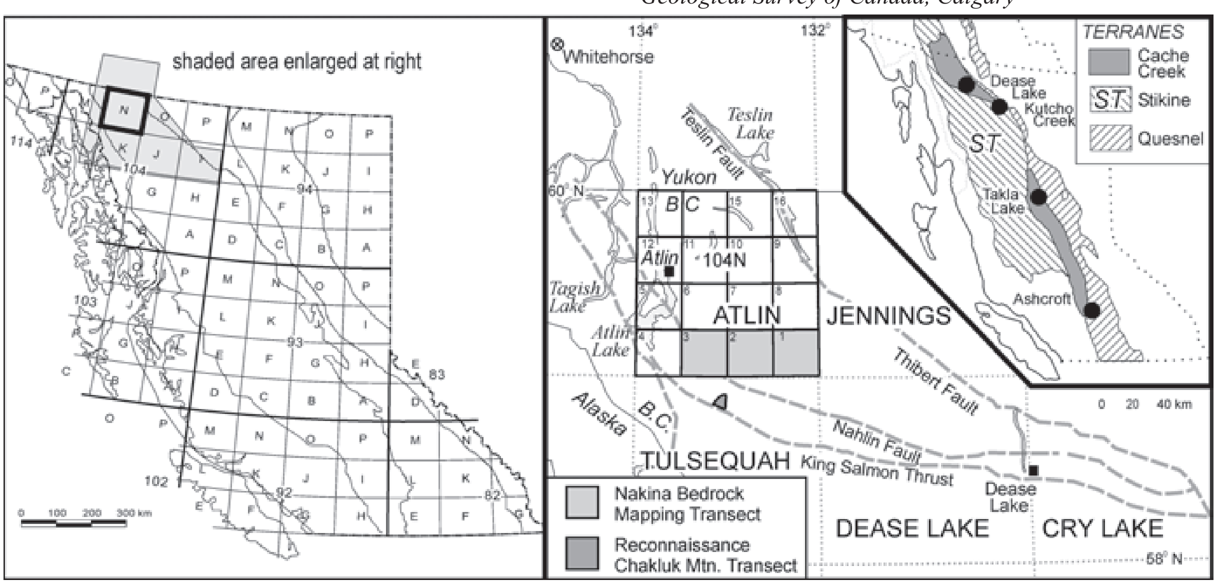

Figure 1. General location map of north-western British Columbia showing the Atlin Targeted Geoscience Initiative study area (1:250 000 sheet 104N), the Nakina regional mapping project area (1:50 000 sheets 104N/1, 2, 3), and the reconnaissance Chakluk Transect area (within 104K/14).

We report here on the first results of a preliminary hydrocarbon assessment of the BC portion of the Whitehorse Trough and the adjacent Cache Creek terrane that was conducted as a partnership between the New Ventures Branch of the BC Ministry of Energy and Mines, and the Atlin Targeted Geoscience Initiative (TGI). The Atlin TGI is a joint Geological Survey of Canada – BC Geological Survey project aimed at providing mineral exploration incentive through provision of an enhanced geoscience database for the Atlin area (mapsheet 104N; Lowe and Mihalynuk, 2002). A component is a 1:50,000 map transect across the southern part of the sheet 104N/1, 2 & 3 in 2001 and 2002 (Figure 1). This ~90km long transect spans the Cache Creek-Whitehorse Trough contact, providing an opportunity to sample and evaluate hydrocarbon potential as part of the mapping program. Initial observations from mapping within the Cache Creek terrane are reported in Mihalynuk *et al.* (2002; 2003, this volume). A preliminary report on the geology of the Whitehorse Trough, which constitutes the southwestern portion of mapsheet 104N/3, is presented in this paper (Figure 1). In addition, a reconnaissance transect of the southwestern side of the Whitehorse Trough, near the Taku River, was mapped and sampled in order to provide continuity of hydrocarbon assessment across the Trough (Figure 1). In this report, stratigraphic and structural observations are combined with petrographic analyses, programmed pyrolysis data and conodont alteration indices (CAI's) in order to provide a preliminary assessment of hydrocarbon potential in the central Whitehorse Trough and northern Cache Creek terrane.

GEOLOGICAL BACKGROUND

The Cache Creek terrane is a belt of oceanic rocks that occupies a central position within the accreted terranes of the northern Cordillera (Coney *et al.*, 1980). Fossil data suggest an age range from Mississippian through to Lower Jurassic for these rocks (Monger, 1975; Cordey *et al.*, 1991; Orchard, 1991). The terrane is characterised by tectonically imbricated slices of chert, argillite, volcaniclastic rocks, carbonate and wacke, as well as ultramafics, gabbro and basalt. These lithologies represent two distinctive lithotectonic elements: a Middle Triassic to Lower Jurassic, subduction-related accretionary complex, and a dismembered oceanic basement assemblage (Terry, 1977; Monger *et al.*, 1982; Ash, 1994; Mihalynuk, 1999). Preliminary geochemical investigations of Upper Permian (Devine, 2002) igneous rocks associated with the Nahlin ultramafic body indicate that they were produced in a primitive island-arc setting (English *et al.*, 2002). The Cache Creek terrane also includes a Permo-Triassic island-arc assemblage, the Kutcho Assemblage (Childe and Thompson, 1997), which lies to the SW of the Nahlin Fault and forms basement to the Lower Jurassic Laberge Group in the Dease Lake/Cry Lake area (Thorstad and Gabrielse, 1986; Gabrielse, 1998; Figure 1). The northern Cache Creek terrane (N of 58^0) was emplaced over the Stikine terrane and Laberge Group during the closure of an ocean basin in the Middle Jurassic (Thorstad and Gabrielse, 1986; Mihalynuk, 1999).

The Whitehorse Trough is a ~500 km long, early Mesozoic marine basin, which extends from southern Yukon to Dease Lake in British Columbia. Lower – Middle Jurassic sediments of the Trough are known as the Laberge Group. In BC, the Trough is bounded by the Nahlin Fault to the east and by the King Salmon Thrust to the southwest, although south of the King Salmon Thrust, conglomeratic facies onlap onto the Upper Triassic volcanic and carbonate rocks of the Stikine terrane (*e.g.* Souther, 1971; Figure 1). The Laberge sediments range in age from Lower Sinemurian to Middle Bajocian, and are believed to represent submarine-fan deposition in an arc-marginal setting (*e.g.* Tempelman-Kluit, 1979; Dickie and Hein, 1995; Hart *et al.*, 1995; Johannson *et al.*, 1997). The sediments are deposited on the Stuhini Group throughout much of the length of the Whitehorse Trough in British Columbia (*e.g.* Monger *et al.*, 1991), and overlie the equivalent strata – Lewes River Group – in the Yukon (*e.g.* Wheeler, 1961). However, further south in the Dease Lake area, the Laberge sediments overlie the Kutcho Assemblage of the Cache Creek terrane (*e.g.* Thorstad and Gabrielse, 1986; Gabrielse, 1998).

CACHE CREEK TERRANE

The geology of the Cache Creek terrane in the Nakina area is described in Mihalynuk *et al.* (2002; 2003, this volume), and will not be discussed in detail here. Within this region, speculative hydrocarbon plays have focused on the Mississippian – Permian carbonates of the Horsefeed Formation (Hannigan *et al.*, 1995). These carbonate sequences were deposited upon volcanic pediments within the Cache Creek ocean basin (Monger, 1977; English *et al.*, 2002), and were subsequently incorporated into the Cache Creek subduction complex during closure of an ocean. A potential gas source within the Horsefeed Formation is provided by shallow water back-reef algal laminites and dark, fetid argillaceous limestones (*e.g.* National Energy Board, 2001). However, a lack of maturation data has previously precluded a rigorous assessment of the hydrocarbon potential of this region.

LABERGE GROUP

Laberge Group strata are well exposed in the mountains west of the Sloko River in 104N/3. Estimates of total stratigraphic thickness are difficult to determine due to thrust fault repetition and the absence of biogeochronological constraints. Basal units have been observed during this study at one location north of Mount Headman, and uppermost units have not been identified.

Laberge Group lithologies within the Nakina area include greywacke, sandstone, siltstone, argillite and minor conglomerate. The dominant lithology is blue-grey to green-grey medium-grained massive wacke with subordinate interbedded argillites (Photo 1). Greywacke beds are 1-2 m thick, while subordinate argillaceous intervals reach 20 cm in thickness. Interbedded siltstone and sandstone couplets display a characteristic banded appearance, and commonly weather an orange-brown colour (Photo 2). Couplet intervals reach 200 m in thickness, although they

Photo 1. Laberge Group strata exposed NE of Paradise Peak. The succession is dominated by well-bedded greywacke with subordinate argillaceous interbeds. A brick-red columnar jointed sill of the Sloko Group here intrudes Laberge Group strata.

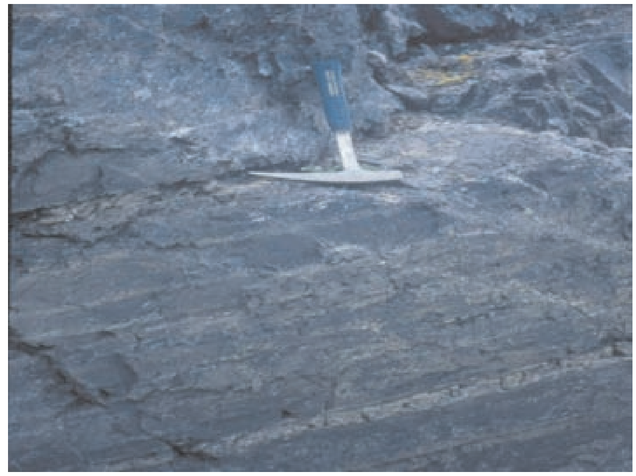

Photo 2. Dark grey siltstone and pale brown sandstone couplets exposed south of the Nakonake River. These lithologies are interpreted to dominate the lowermost strata of the Laberge Group in this region. The hammer lies on a contact with overlying greywacke.

are commonly minor (~ 1 m) components of greywacke dominated successions. Conglomerates are a minor constituent of the Laberge Group in this region and are laterally discontinuous reflecting deposition in channels (Photo 3). These conglomerates are matrix-supported and reach 10 m in thickness.

STRATIGRAPHY ALONG THE CHAKLUK TRANSECT

A transect with continuous exposure extends from Mount Headman to Chakluk Mountain, herein referred to as the Chakluk Transect (Figures 1 and 2). The oldest strata on the Chakluk Transect are the Upper Triassic carbonates of the Sinwa Formation (Figure 3). These carbonates are composed of fine-grained, medium brownish-grey limestone, commonly with a bioclastic component of gastropods and bryozoans. No bedding was discernible.

The Sinwa Formation is overlain disconformably by the Laberge Group (Souther, 1971), the contact was not exposed along the Chakluk Transect. The basal unit of the Laberge Group is a coarsening-upward sequence that is approximately 1000 m thick (Figure 3). The sequence grades from beds of siltstone and argillite to rhythmically bedded couplets of siltstone and sandstones, and finally up into beds of massive greenish greywacke.

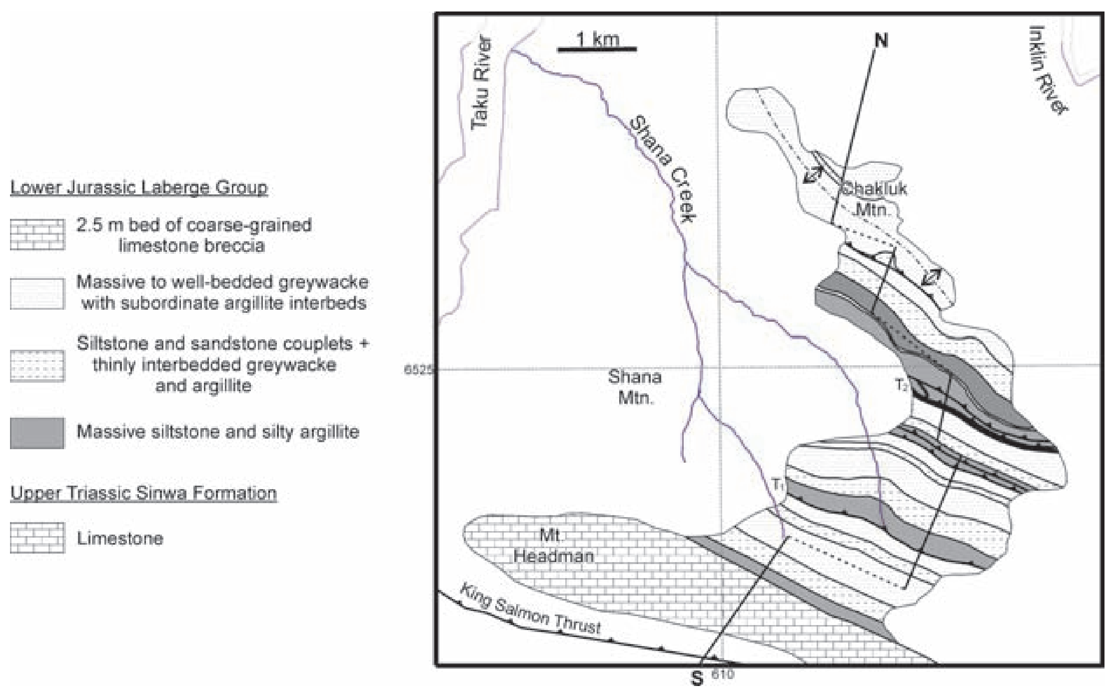

Figure 2. Generalised geologic map of the Chakluk Transect area.

Photo 3. Matrix-supported conglomerate exposed SE of Paradise Peak. Well-rounded granitoid clasts reach 30 cm in size at this locality.

Overlying the wacke is a succession of fine-grained siltstone with subordinate greywacke (Figure 3). These strata include a single, 2.5 metre marker bed of limestone breccia containing bioclasts of crinoid ossicles and bivalves (Photo 4). This bed becomes laminated toward its top. This fine-grained sequence grades upwards into coarser-grained facies, with a predominance of medium-grained greenish greywacke around Chakluk Mountain. This succession of 1 m greywacke beds and subordinate argillite is at least 350 m thick.

Slatey cleavage is commonly developed along the transect, and in one outcrop, folded, fine-grained metasediments display a phyllitic sheen (Photo 5).

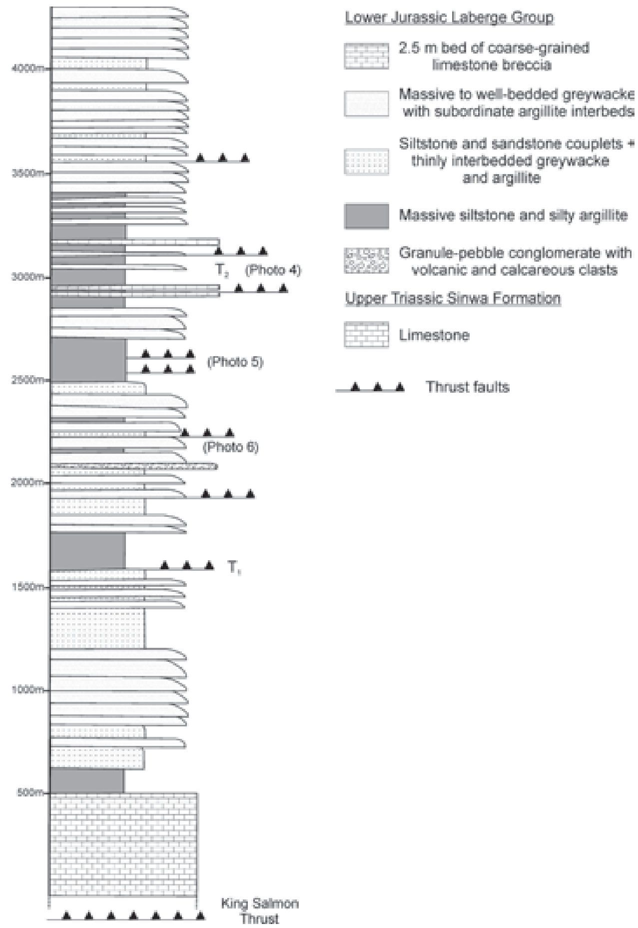

Figure 3. Stylised stratigraphic column for the Chakluk Transect.

STRATIGRAPHY IN NAKINA MAP-AREA

Stratigraphic correlation within the Laberge Group is hampered by frequent lateral facies changes and a lack of marker horizons and macrofossils. Nevertheless, a tentative stratigraphic column is presented in Figure 4. This stratigraphic column includes a complete section from SW to NE. The degree of structural repetition remains unconstrained.

Southwest of thrust fault T_3 (Figure 5), the lowermost strata in the core of anticline A_1 comprise couplets of 10-30 mm, fine-grained sandstones grading into ~ 10-30 mm of darker siltstone layers (Photo 2). These intervals reach 200 m in thickness, and weather a characteristic orange-tan colour, possibly as a consequence of pervasive dolomitisation of the matrix. These strata grade upwards into a succession dominated by massive blue-grey wacke interleaved with 1-5 m thick intervals of sandstone and siltstone couplets. The stratigraphically highest strata south of thrust fault T_3 are dominated by a monotonous succession of medium-grained blue-grey to green-grey epidote-bearing wacke and occasional ~ 100 m intervals of dark grey siltstone. Sparse tabular to lensoid bodies of matrix-supported cobble conglomerate contain clasts dominated by

Photo 4. 2.5m bed of limestone breccia exposed on the ridges south of Chakluk Mountain. This carbonate unit has been truncated and repeated by a series of NW trending thrust faults.

limestone, volcanic and felsic intrusive lithologies (Figure 4). Sinwa Formation and the Stuhini Group are probable sources. Granitic clasts may signal exhumation of plutonic roots of the Stuhini arc.

Photo 5. Folded metasediments display a phyllitic sheen at some localities south of Chakluk Mountain. Elsewhere, Laberge Group strata do not display any signs of significant thermal metamorphism.

Strata interpreted as the lowest stratigraphic levels in the hanging wall of thrust fault T_3 are lithologically similar to those in the footwall. Once again, the succession is dominated by ubiquitous blue-grey to green-grey wacke interleaved with intervals of sandstone and siltstone couplets and subordinate cobble conglomerate. The lack of marker horizons hinders estimation of structural repetition. These wacke dominated successions pass into finer grained facies dominated by interbedded argillite and greywacke (1 m thick on average). This sequence is at least 300 m in thickness.

These strata grade upwards into a series of coarsening upwards cycles (Figure 4). They are 25 m in thickness; there are thinly interbedded sandstone and siltstone at the base, with sandstone beds becoming thicker (up to 1-2 m) and more massive towards the top. At least 5 cycles are counted, although the number of cycles varies along strike. Above these cycles, significant intervals of siltstone and sandstone couplets are conspicuous by their absence, as once again the stratigraphy becomes dominated by a monotonous succession of medium-grey to green-grey wacke and rare ~100 m intervals of dark grey siltstone. Fine-grained argillaceous interbeds within the greywacke are commonly rich in woody fragments and plant-detritus.

The uppermost part of the stratigraphy within the Nakina area consists of sets of light grey-tan coloured wacke and sandstones that overlie a silty shale interval (Figure 4). One of these sets (~ 50-100 m) is mainly coarse sandstone and granule conglomerates containing up to 3% vitreous orange garnet (1-5 mm) and sparse, unusually fresh olivine grains. As is typical of other wacke units, a high percentage of the grains are derived from fine to medium grained hornblende-feldspar porphyry. This unit has a magnetic susceptibility of > $20x10^{-3}$ SI, and consequently shows up as an anomaly on the aeromagnetic map of the Atlin area. This has allowed extrapolation of this unit into areas of poor exposure.

One of the structurally highest units within the Laberge Group may also be one of the stratigraphically youngest. It

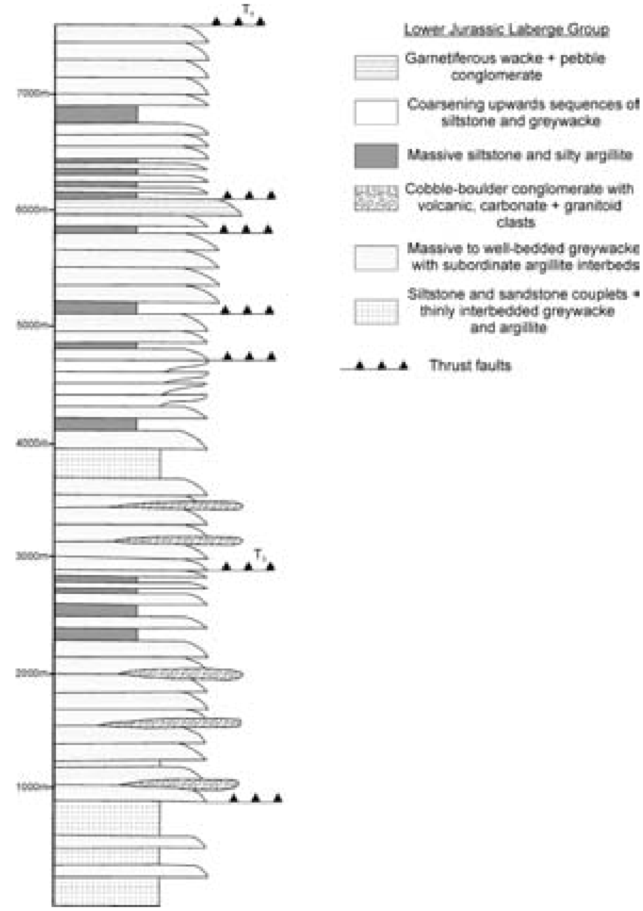

Figure 4. Stylised stratigraphic column for the Nakina area. T_3 and T_4 correspond to thrust faults on Figure 5.

occurs along the Sloko River below the confluence with the Nakonake (Figure 5). Petrographic analysis of a sample reveals a single grain of very fine-grained dark blue to tan-violet pleochroic crystals that may be blueschist. If correct, this unit may record the influx of Cache Creek detritus in the Whitehorse Trough.

STRUCTURE OF THE LABERGE GROUP

Laberge sediments overlie the Upper Triassic Sinwa Formation (Souther, 1971) or are carried in the hanging wall of the crustal-scale King Salmon Thrust together with the Sinwa Formation, and are thrust over the more proximal facies of the Laberge Group to the south (Takwahoni Formation; Figure 1). Subsidiary thrust faults in the Chakluk and Nakina areas mimic the orientation and vergence of this major structure (Figures 6 and 7 respectively). Average dips of 40^0-60^0 suggest syn-to-post deformational steepening of these thrust faults. Displacement on thrust faults is difficult to constrain due to a lack of marker horizons and age-control.

Laberge Group sediments predominantly dip to the northeast. Locally, bedding does flatten to horizontal or

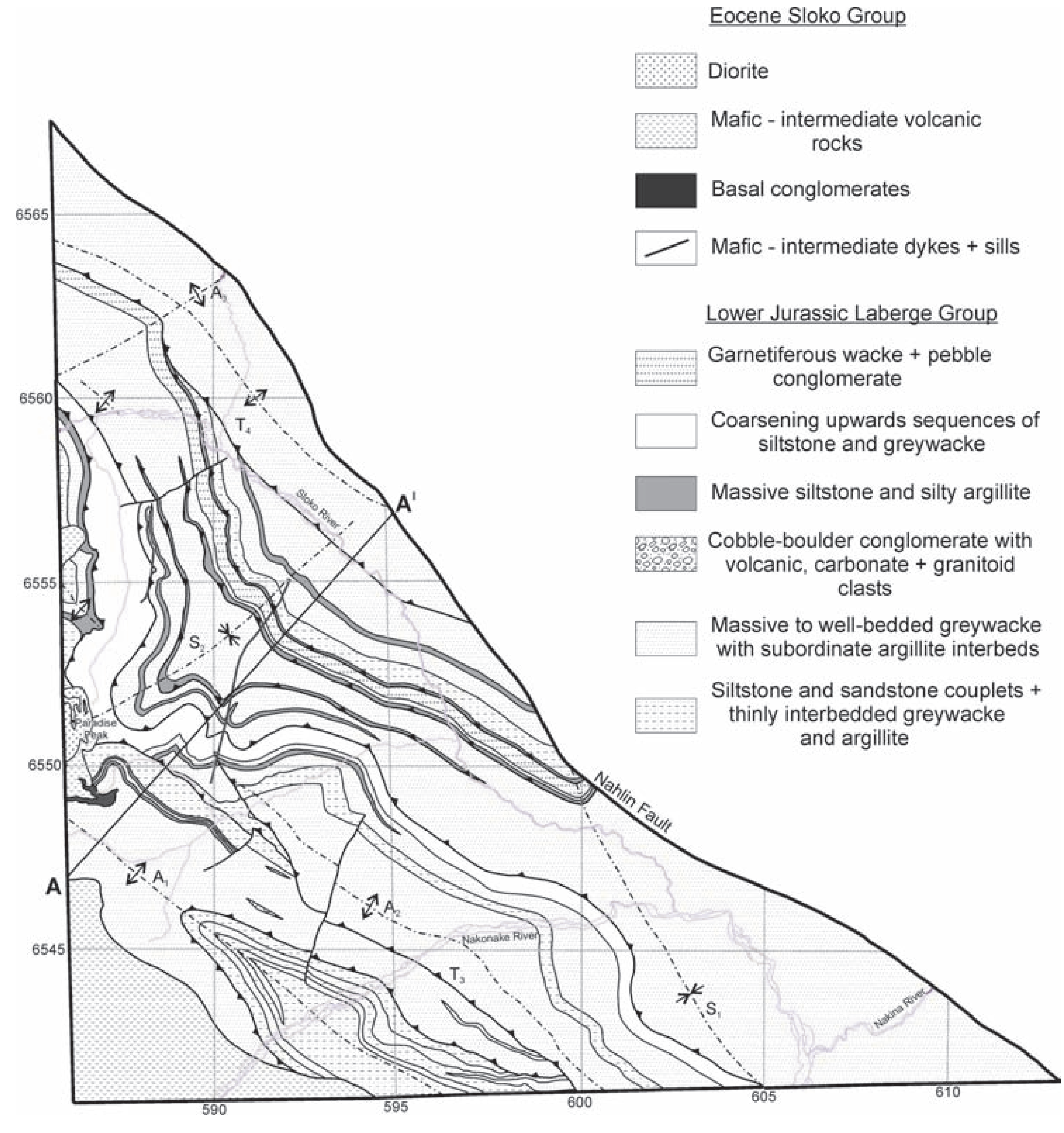

Figure 5. Generalised geologic map of the Nakina area, NTS 104N/3 with a 5km UTM grid superimposed.

even SW-dipping, commonly forming the western limb of antiforms interpreted as occurring above hanging wall ramps in underlying thrust faults. Planes of parting dip steeply to the SW.

NW-SETRENDING THRUST FAULTS

Along the Chakluk Transect, the King Salmon Thrust décollement is within or at the base of the Sinwa Formation. Another major thrust fault (T_1) is believed to cause structural repetition of the basal (Sinemurian?) Inklin Formation (Figure 6), although biogeochronological evidence to support this is lacking. Fine-grained intervals both regionally and locally form décollement horizons. One such contorted fine-grained interval is structurally underlain and overlain by coherent wacke-dominated successions (Photo 6). A limestone breccia unit occurs within the fine-grained succession that has been sliced by a multitude of thrust faults, which are interpreted to sole into a single thrust fault (T_2) (Figure 6). Age constraints and regional mapping along strike are required to confirm or refute these structural geometries.

In the Nakina area, strata dominantly strike northwest, except north of the Sloko River where they swing to a westerly orientation (Figure 5). A major thrust (T_3) occurs within the Laberge Group in this region (Figures 5 and 7). T_3 dips steeply to the NE and is associated with a hanging-wall anticline along most of its length within the map-area. A number of subsidiary thrust faults occur in the hanging wall of T_3. These subsidiary thrust faults display bedding-parallel orientations along most of their length, and cumulative structural repetition of stratigraphy is unconstrained. A second major thrust fault (T_4) in the Nakina area is interpreted on the basis of discordant bedding (Figure 7).

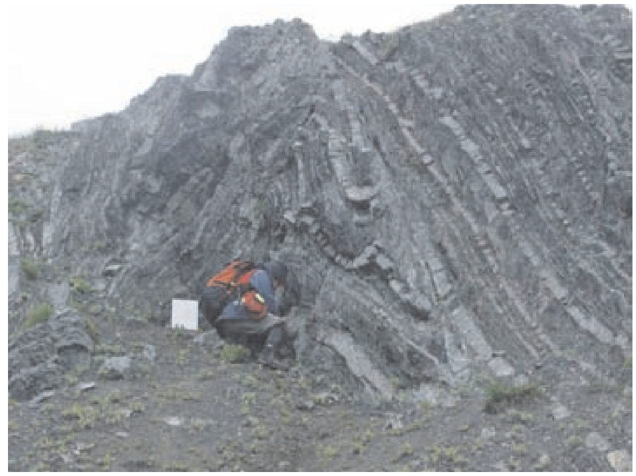

Photo 6. Décollement horizon within a fine-grained interval south of Chakluk Mountain. At this locality, a number of thrust faults cut through this sequence of interbedded sandstone and siltstone, while greywacke-dominated succession on either side remain relatively undisturbed.

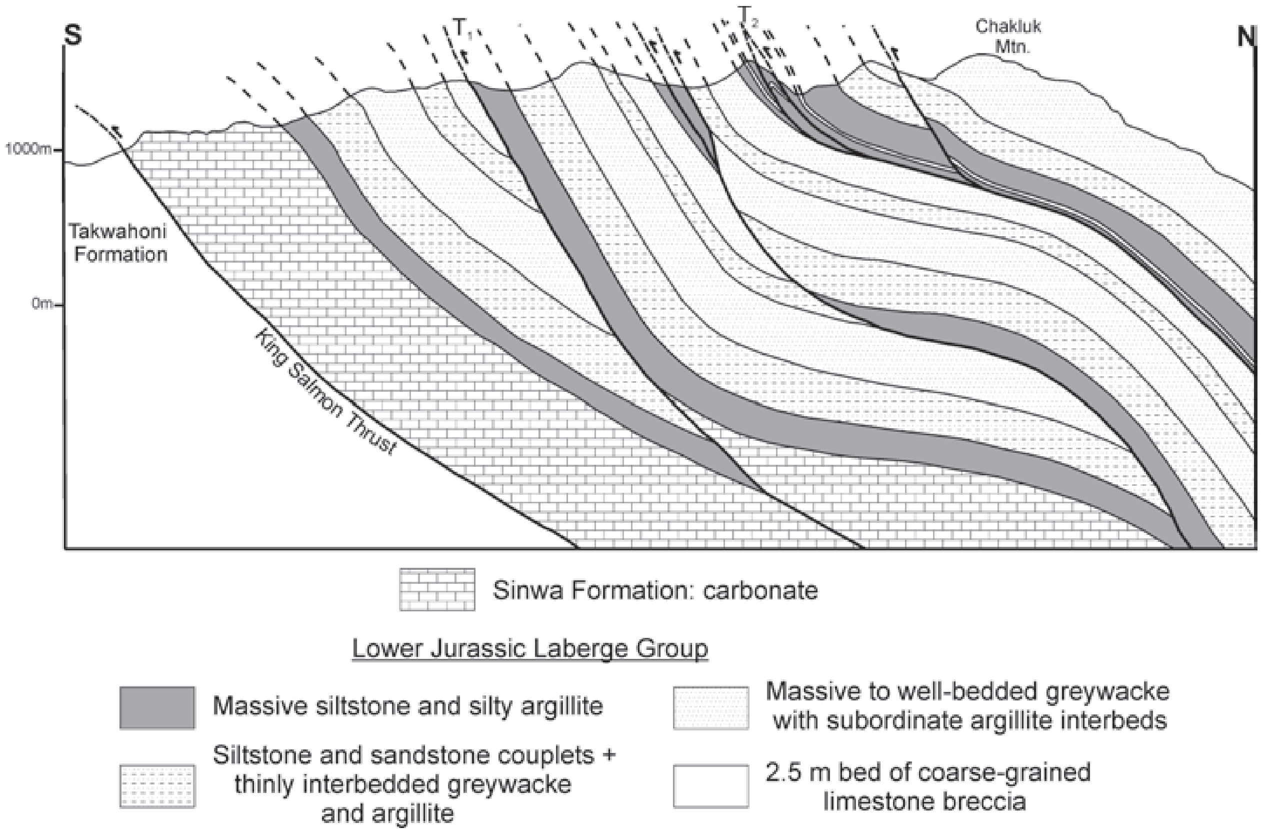

Figure 6. Composite cross-section of the Chakluk Transect area; *see* Figure 2 for section line.

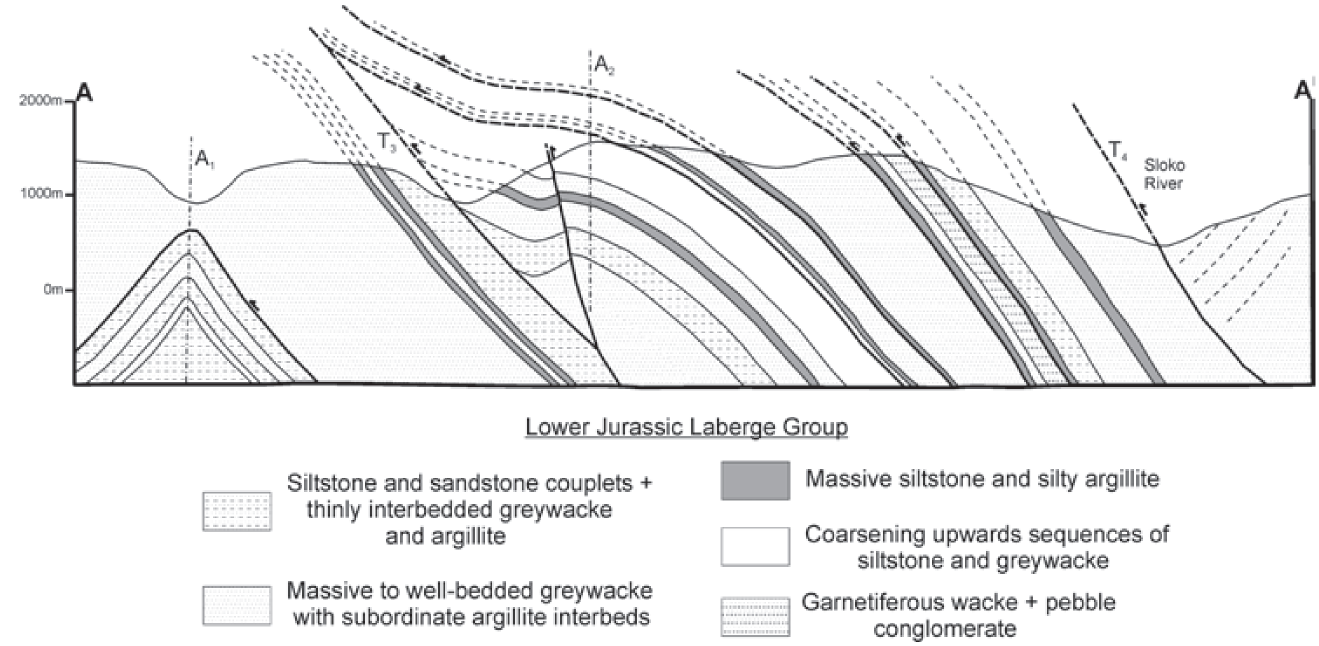

Figure 7. Cross-section of the Nakina area; *see* Figure 5 for section line.

NW-TRENDING FOLDS

There are a number of NW-trending folds in the Nakina map-area (Figure 5). An open anticline (A_1) in the south-western corner of the map-sheet plunges gently towards 310^0. Another anticline (A_2) is carried in the hanging wall of thrust fault T_3. Subsidiary thrust faults may terminate in the core of these anticlines. Another anticline (A_3) and syncline (S_1) are interpreted in the western portion of the Laberge Group in the Nakina area to explain changes in bedding attitude, although faulted contacts cannot be ruled out due to poor exposure.

NE-TRENDING OPEN FOLDS

NE-trending open folds were also mapped in the Nakina area. The major northeast structure is an open syncline (S_2) that runs through Paradise Peak (Figure 5). NW-trending folds to the north of this syncline plunge ~ 40^0 to the south, whereas similar structures to the south plunge in the opposite direction. The orientations of Laberge strata and thrust faults swing from ~ 300^0 to ~ 330^0 across this synclinal structure. A broad anticline is tentatively interpreted north of the Sloko River on the basis of a similar swing in the orientation of strata.

LATE BLOCK FAULTS

The structure of the Laberge Group has been modified by Eocene block faults, and dike/sill emplacement related to Sloko volcanism. Diking and block faulting is particularly well developed in the Paradise Peak area, and appears to crosscut all folds and thrust faults in the region. Subvertical block faults vary in orientation from NNE to ENE and may be extensional in origin. Dikes related to Sloko volcanism follow similar orientations. Sloko volcanic and intrusive rocks are described in Mihalynuk *et al.* (2003).

THERMAL MATURATION

Thermal maturation can be determined by a number of different techniques including: metamorphic mineral assemblages, colour alteration indices (CAI's), vitrinite reflectance, fission-track dating, cooling ages and programmed pyrolysis. In this report, metamorphic grade and conodont colour alteration indices are utilised to assess the hydrocarbon potential of the northern Cache Creek terrane, while new programmed pyrolysis data is presented for the Laberge Group.

CACHE CREEK TERRANE + REGIONAL CAI DATA

Regional metamorphic grade of the Cache Creek rocks in the Atlin area is prehnite-pumpellyite facies. The level of organic maturation (LOM) corresponding to prehnite-pumpellyite facies metamorphism is generally considered to be above the oil-window (Table 1). Metamorphic grade increases in the aureoles of post-emplacement plutons.

Conodont colour alteration index (CAI) values are also available for the Cache Creek terrane, Sinwa Formation and from clasts of Upper Triassic carbonate within Laberge Group conglomerates (Table 2; Figure 8). The CAI is based on a calibration of the colour change of a conodont element

TABLE 1
COMPARISON OF VARIOUS INDICATORS OF THERMAL MATURITY WITH ZONES OF OIL AND GAS GENERATION

Oil and Gas generation	Tmax	Romax	Conodont CAI's	Metamorphic assemblage
			7	Biotite + Garnet zones
			6	Chlorite zone
			5	
		4	4	Prehnite-
dry gas		~2.5		Pumpellyite
generation		1.5	3	facies
oil +	~465	~1.35		
wet gas		1.1	2	
generation	~430	~0.5		Zeolite facies
		0.43	1	

compiled from Peters (1986), Allen and Allen (1990), and Greenwood *et al.* (1991)

with time. The oil-window lies at CAI values of 1.5-2.8. In the Atlin area, including the Nakina Transect, CAI values are typically in the 5-6 range, corresponding to the chlorite to biotite zone. This apparent discrepancy with observed metamorphic grade (prehnite-pumpellyite) may be due to the comparison of metamorphic grade for different protoliths. These data preclude the preservation of hydrocarbons within the Cache Creek terrane.

CAI values from the Sinwa Formation and from clasts of Sinwa limestone within the Inklin Formation in the Tagish Lake area fall in the range of 5-6. In the Tulsequah region, CAI values from these same lithologies fall in the 2-4 range, and hence may be prospective for hydrocarbon exploration (Figure 8). No data from Laberge Group conglomerates within the Nakina area is available yet, although results from 26 samples are pending.

LABERGE GROUP – NAKINA AND CHAKLUK AREAS

Systematic sample collection for programmed pyrolysis was undertaken in the Chakluk and Nakina Transect areas in order to assess the hydrocarbon potential of the central Whitehorse Trough. Programmed pyrolysis of whole rock using the Rock-Eval VI system provides information on the type, maturity and quantity of associated organic matter (Espitalié *et al*., 1977). Aliquots of sediment samples were dried and powdered for Rock-Eval/TOC analysis at the Geological Survey of Canada Calgary (GSCC). A Vinci Technologies Rock-Eval VI instrument was used. Duplicate analyses of samples were carried out to test reproducibility of data. Each sample of finely ground source rock is put in a furnace at 250^0C, raised to 550^0C, and then allowed to cool. The hydrocarbons liberated during heating are analysed by a flame ionisation detector, which separates the components into three peaks (Figure 9). The

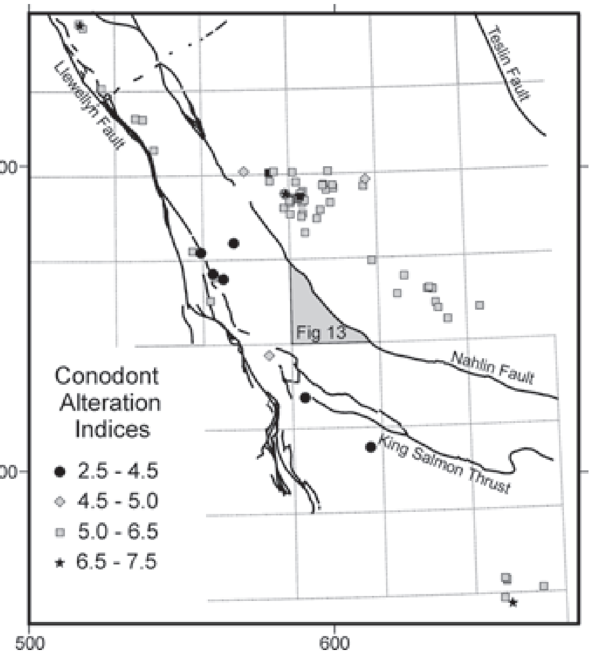

Figure 8. Map of NW British Columbia illustrating the distribution of CAI values. The Whitehorse Trough lies between the Llewellyn Fault/King Salmon Thrust and the Nahlin Fault.

first peak, denoted S_1 (mg $_{HC}$/g $_{rock}$), indicates 'free bitumen' already in the sample. The second peak, denoted S_2 (mg $_{HC}$/g $_{rock}$), results from thermal breakdown of kerogen, while the third peak, S_3 (mg $_{CO2}$/g $_{rock}$), represents the oxygen-bearing compounds released at high temperature. The temperature of the S_2 peak (T_{max}) is an indicator of source rock maturity, although this value is only reliable when $S_2 > 0.2$ (Peters, 1986), and is also affected by organic matter type. ($S_1 + S_2$) gives an indication of source rock richness. Other determined parameters include the Hydrogen Index (S_2/TOC) and the Oxygen Index (S_3/TOC); these parameters are used to determine the type of organic matter present in the potential source rock.

A select sample of the Rock-Eval pyrolysis data is presented in Table 3 (the complete dataset may be obtained at the BCGS website: Geofile 2003-1; Fowler, 2003). Source

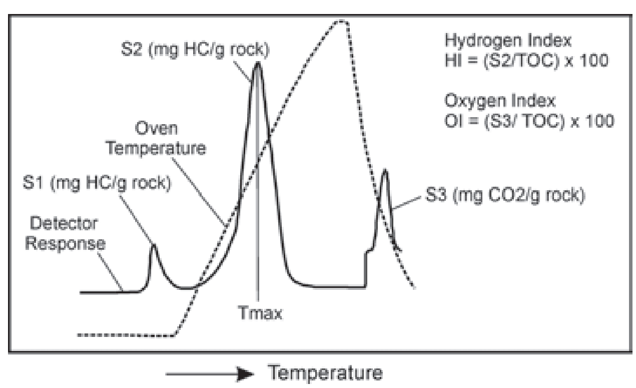

Figure 9. Schematic pyrogram illustrating the liberation of hydrocarbon during heating of the rock sample. Determined parameters include S_1, S_2, S_3, T_{max}, and the hydrogen and oxygen indices.

TABLE 2
COMPILATION OF CAI VALUES AVAILABLE FOR
NW BRITISH COLUMBIA

Conodont Alteration Indices					
Sample No.	**Rock Unit**	**Age**	**CAI**	**Easting**	**Northing**
C-087061	Cache Creek Group	Lower Carboniferous: late Visean-Serpukovian	5.0-6.0	589368	6588227
C-087062	Cache Creek Group	Upper Carboniferous: Bashkirian-Moscovian	5.0-6.0	586495	6589709
C-087063	Cache Creek Group	Upper Carboniferous: Bashkirian-Moscovian	5.5-6.5	589371	6588071
C-117316	Laberge Group: Inklin Fm	Upper Triassic: late Norian-Rhaetian	3.0-4.0	563636	6562893
C-117329	Sinwa Formation	Ordovician - Triassic	3.0-4.0	560278	6564540
C-117331	Sinwa Formation	Upper Triassic: late Norian-Rhaetian	4.5-?	560804	6563373
C-117454	Laberge Group: Inklin Fm	Upper Triassic: late Norian-Rhaetian	2.0-3.0	567092	6574771
C-143216	Cache Creek Group	Permian	6.0-7.0	578410	6597805
C-143218	Cache Creek Group	Carboniferous-Permian	5.5-?	586075	6598075
C-143223	Cache Creek Group	Upper Carboniferous: Bashkirian-Moscovian	5.0-5.5	588880	6589360
C-143225	Cache Creek Group	Upper Triassic: ?late Carnian	5.0-?	597750	6598525
C-143229	Cache Creek Group	probably Permian	5.5-?	579899	6598175
C-143230	Cache Creek Group	Ordovician - Triassic	5.5-?	597100	6592400
C-143231	Cache Creek Group	Permian- basal Triassic	5.0-5.5	594220	6582995
C-143233	Cache Creek Group	Ordovician - Triassic	5.0-5.5	598515	6588140
C-143234	Cache Creek Group	Permian	5.5-?	595275	6585750
C-143235	Cache Creek Group	Lower Carboniferous: Serpukovian	5.0-6.0	587290	6594860
C-143237	Cache Creek Group	Lower Carboniferous: ?Serpukovian	5.0-6.0	599510	6592975
C-143244	Cache Creek Group	Lower Carboniferous: Visean-Serpukovian	5.0-6.0	599200	6593950
C-143245	Cache Creek Group	Lower Carboniferous: ?Serpukovian	5.0-?	589450	6591780
C-143248	Cache Creek Group	Lower Carboniferous: Visean-Serpukovian	5.0-7.0	589675	6589040
C-143250	Cache Creek Group	Ordovician - Triassic	5.5-?	588820	6591200
C-153992	Stuhini Group	Upper Triassic: Carnian	4.5-6.0	559450	6555800
C-154209	Cache Creek Group	Upper Carboniferous	5.5-6.5	596250	6594150
C-154210	Cache Creek Group	Upper Carboniferous?	5.0-5.5	596040	6593830
C-154213	Cache Creek Group	Lower Carboniferous: Serpukovian	5.0-?	586085	6598070
C-156725	Cache Creek Group	Upper Carboniferous: Bashkirian-Moscovian	?-5.0	583300	6586300
C-156731	Cache Creek Group	Upper Carboniferous: Bashkirian-Moscovian	5.5-?	590200	6588900
C-156733	Cache Creek Group	probably Upper Carboniferous	?->5.0	586200	6589200
C-156735	Cache Creek Group	Permian	?-~6.0	588200	6589500
C-156737	Cache Creek Group	Permian	?->5.0	586200	6589200
C-167752	Cache Creek Group	Permian	5.0-?	609340	6593730
C-167756	Cache Creek Group	probably Triassic	4.5-5.0	609925	6595910
C-167759	Cache Creek Group	Permian	6.5-?	583900	6590850
C-167761	Cache Creek Group	Permian	5.0-?	578600	6594950
C-167762	Cache Creek Group	Upper Triassic: early Norian	4.5-?	585700	6588850
C-167765	Cache Creek Group	Permian - Triassic	4.5-?	583750	6590950
C-167767	Cache Creek Group	probably Triassic	4.5-?	585250	6588750
C-167773	Cache Creek Group	Upper Carboniferous - Lower Permian	5.5-?	585500	6588450
C-167776	Cache Creek Group	Upper Carboniferous - Lower Permian	5.0-6.0	590350	6578300
C-168201	Cache Creek Group	Ordovician - Triassic	6.0-?	588710	6590000
C-168202	Cache Creek Group	Permian - Lower Triassic	4.5-5.0	570300	6598150
C-168203	Cache Creek Group	Upper Triassic: early-mid Norian	5.0-?	585500	6588010
C-168204	Cache Creek Group	Permian - basal Triassic	5.0-6.0	585550	6584225
C-168214	Cache Creek Group	Middle-Upper Triassic	4.5-5.0	583740	6590975
C-168216	Cache Creek Group	Upper Triassic: late Carnian-early Norian	4.5-?	585250	6588750
C-168217	Cache Creek Group	Upper Carboniferous - Permian	5.5-?	589480	6584520
C-168220	Cache Creek Group	Upper Carboniferous - Permian	5.5-?	589200	6583510
C-087011	Stuhini Group: Honaktah? Fm	Upper Triassic: early Norian	3.0-4.0	611873	6508049

TABLE 2, CONTINUED
COMPILATION OF CAI VALUES AVAILABLE FOR
NW BRITISH COLUMBIA

Sample No.	Rock Unit	Age	CAI	Easting	Northing
C-086421	uPc	possibly Triassic	5	391800	6638200
C-102003	Sinwa Formation	Upper Triassic: late Norian	5	517500	6644950
C-102004	Sinwa Formation	probably Upper Triassic: Norian	7.0-8.0	516700	6646000
C-102005	Sinwa Formation	Upper Triassic: mid-late Norian	6	516300	6646350
C-102008	Sinwa Formation	Upper Triassic: late Norian	4	556250	6571500
C-153920	Stuhini Group (Sinwa?)	Upper Triassic: late mid-late Norian	5.5	523775	6625350
C-153934	Laberge Group: Inklin Fm	Upper Triassic: late mid-late Norian	4.5-5.5	540800	6605150
C-153936	Laberge Group: Inklin Fm	Upper Triassic: late mid-late Norian	4.5-5.5	537100	6615000
C-153939	Laberge Group: Inklin Fm	Upper Triassic: late mid-late Norian	4.5-5.5	534750	6615500
C-153954	?	Upper Triassic: Carnian	6	553500	6572000
C-189503	Cache Creek Group	Ordovician - Triassic	?-5.0	612055	6569241
C-189850	Stuhini Group	?Triassic	5	656550	6464500
C-189851	Stuhini Group	Middle - Upper Triassic	5.0-5.5	656500	6464850
C-189852	Stuhini Group	?Silurian - Lower Triassic	5.5-6.0	655950	6465240
C-189856	Stikine Assemblage Group	Triassic	5.5-6.5	656000	6458800
C-189863	Stikine Assemblage Group	Ordovician - Triassic	6.0-7.0	658500	6457125
C-189873	Stikine Assemblage Group	Triassic	5.0-5.5	668500	6462400
C-202907	Sinwa Formation	Permian - Triassic	4	590400	6524198
C-208191	Stuhini Group?	?Upper Triassic	4.5	578650	6537950
C-306173	Cache Creek Group	?Triassic	5	622756	6564406
C-306178	Cache Creek Group	Mid-Upper Triassic: late Ladinian-early Carnian	5	620615	6558443
C-306186	Cache Creek Group	Middle Triassic: Anisian	5	633081	6555787
C-306187	Cache Creek Group	?Permian	>5	633980	6553869
C-306189	Cache Creek Group	?Permian	>5	632100	6560081
C-306190	Cache Creek Group	?Triassic	5	630381	6560265
C-306191	Cache Creek Group	Upper Carboniferous: Bashkirian - Moscovian	>5	630968	6560595
C-306192	Cache Creek Group	?Permian	>5	647468	6554472
C-306195	Cache Creek Group	?Triassic	5	637065	6550442

Based on MJOrchard's reports of conodont collections at GSC Vancouver

"Report on conodonts and other microfossils: Atlin (104N)"

"Report on the conodont component of the Atlin TGI project"

"Triassic conodonts: 104M/K"

rocks with 0-0.5% total organic carbon (TOC) are considered poor, those with 0.5-1% TOC are fair, those with 1-2% TOC are good, and finally those with > 2% TOC are considered to be very good (Peters, 1986). Figure 10 shows a plot of TOC versus residual carbon. Most samples are classified as poor to fair source rocks, with 23% classified as good, and 9% classified as very good. However, Figure 10 also illustrates that TOC is almost equal to residual carbon in the majority of samples, i.e. there is little generative potential left in these rocks; pyrolysable carbon (PC) is low. Therefore, depending on organic matter type, these samples may have had much higher TOC's initially. All samples from the Chakluk Transect have no generative potential remaining.

The organic matter type in a source rock can be determined by plotting Hydrogen Index against the Oxygen Index (Espitalié *et al*., 1977; Figure 11). Figure 11 suggests that none of the potential source rocks sampled here are oil prone; the majority are inert (low Hydrogen Index) due to the lack of any generative potential, while the rest are gas prone. The lack of generative potential may be due to the high thermal maturity. From a spatial standpoint, samples that are gas prone and have some generative potential left are almost entirely from the northern part of the Nakina map-area. They are also interpreted to be the structurally and stratigraphically highest units within the Laberge Group in this region.

T_{max} can be used as an indicator of thermal maturation as long as $S_2 > 0.2$. Unfortunately, for the majority of samples, this qualifier rules out the interpretation of the pyrolysis data for maturation purposes. Once again, qualifying samples tend to come from the northern part of the Nakina map-area, and these samples are within the oil and gas windows (Table 3; Figure 12). Although, T_{max} values of samples with $S_2 < 0.2$ must be viewed cautiously, it can be

TABLE 3
PROGRAMMED PYROLYSIS DATA FOR THE ‘LOW-GRADE’ SAMPLES OF THE NAKINA MAP-AREA

Sample	Easting	Northing	Qty	S1	S2	S'2	PI	S3CO2	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OICO	OICO2	OIRE6	MINC%
JEN02-5-3	587534	6558021	100.5	0.07	0.42	0.01	0.14	0.18	471	510	0.03	0.04	0.75	0.71	57	4	24	20	0.1
JEN02-5-7	588036	6557555	100.5	0.48	3.77	0.10	0.11	1.23	476	515	0.42	0.38	5.58	5.20	69	8	22	21	0.2
JEN02-6-2a	588883	6557054	99.9	0.06	1.08	0.04	0.05	2.89	467	506	0.27	0.11	2.74	2.63	41	10	105	82	0.2
JEN02-6-2b	588883	6557054	100.4	0.05	0.43	0.01	0.11	1.00	479	518	0.06	0.04	0.90	0.86	49	7	111	85	0.1
JEN02-30-5	586737	6563390	100.4	0.05	0.67	0.01	0.07	0.53	451	490	0.17	0.07	1.11	1.04	61	15	48	43	0.1
JEN02-30-6	588164	6563785	100.3	0.09	1.76	0.04	0.05	1.08	456	495	0.30	0.17	2.97	2.80	61	10	36	32	0.2
JEN02-31-2	585873	6563191	100.4	0.01	0.20	0.01	0.05	0.30	448	487	0.07	0.02	0.32	0.30	66	22	94	81	0.1
JEN02-31-7	586728	6560367	100.3	0.03	0.44	0.01	0.07	0.57	457	496	0.10	0.04	1.08	1.04	42	9	53	44	0.1
MMI02-5-2-3	586590	6556676	100.5	0.04	0.26	0.01	0.14	0.87	480	519	0.15	0.03	0.83	0.80	33	18	105	87	0.1
MMI02-5-3-4	586566	6556299	99.8	0.05	0.30	0.01	0.15	0.06	474	513	0.01	0.03	0.64	0.61	48	2	9	8	0.1
MMI02-5-3-8	586566	6556299	100.4	0.05	0.20	0.01	0.20	0.64	486	525	0.02	0.02	0.61	0.59	34	3	105	78	0.1
MMI02-5-3-10	586566	6556299	100.6	0.08	0.38	0.01	0.18	0.81	486	525	0.02	0.04	1.24	1.20	31	2	65	48	0.1
MMI02-5-3-11	586566	6556299	100.4	0.06	0.38	0.01	0.13	0.36	486	525	0.04	0.04	1.18	1.14	33	3	31	24	0.1
MMI02-5-3-12	586566	6556299	100.8	0.08	0.38	0.01	0.16	0.33	490	529	0.02	0.04	1.14	1.10	34	2	29	22	0.1
MMI02-8-1p2	592967	6556671	100.3	0.02	0.45	0.01	0.05	0.41	453	492	0.07	0.04	0.80	0.76	58	9	51	42	0.1
MMI02-9-6	592783	6557915	100.1	0.01	0.28	0.01	0.04	0.50	441	480	0.14	0.03	0.73	0.70	40	19	68	60	0.1
MMI02-9-6b	592783	6557915	99.8	0.04	0.32	0.00	0.11	0.46	456	495	0.08	0.03	0.29	0.26	110	28	159	132	0.1
MMI02-9-7-1	592672	6558016	100.2	0.03	1.20	0.03	0.03	2.10	448	487	0.40	0.12	2.64	2.52	47	15	80	67	0.2
MMI02-9-7-2	592672	6558016	100.7	0.03	0.47	0.01	0.06	0.00	448	487	0.05	0.04	0.68	0.64	71	7	0	4	0.1
MMI02-9-7-3	592672	6558016	100.0	0.01	0.22	0.01	0.05	0.48	451	490	0.01	0.02	0.51	0.49	45	2	94	70	0.1
MMI02-9-14-2	592186	6559230	99.7	0.18	2.02	0.02	0.08	0.26	440	479	0.08	0.19	1.78	1.59	115	4	15	13	0.1
ORO02-6-1c	589770	6555472	100.8	0.63	10.03	0.15	0.06	0.56	465	504	0.21	0.91	6.19	5.28	164	3	9	8	0.3
STJ02-2-12	592443	6552969	100.3	0.16	0.73	0.02	0.17	0.59	475	514	0.07	0.08	1.38	1.30	54	5	43	34	0.1
STJ02-3-3a	591257	6553403	100.2	0.12	0.53	0.01	0.18	0.19	476	515	0.07	0.06	0.98	0.92	55	7	19	18	0.1

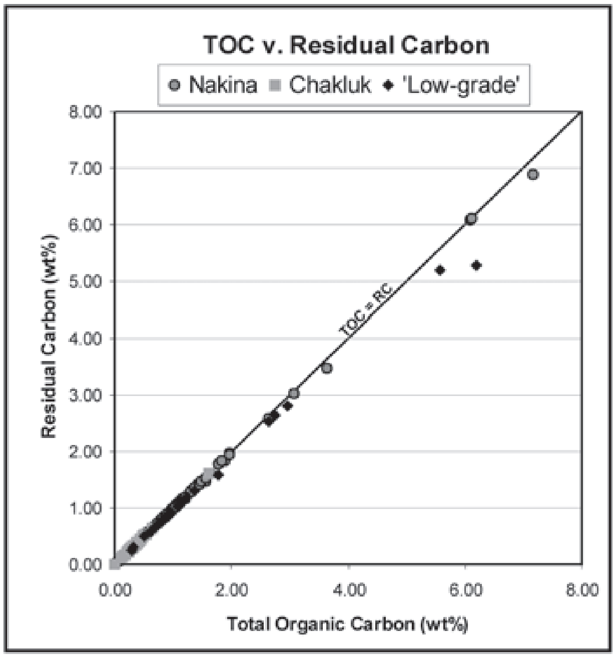

Figure 10. Plot of total organic carbon (TOC) versus residual carbon for samples from the Nakina and Chakluk areas. 'Low-grade' samples form a subset of the Nakina samples, for which $S_2 > 0.2$ and $T_{max} < 480\ ^0C$.

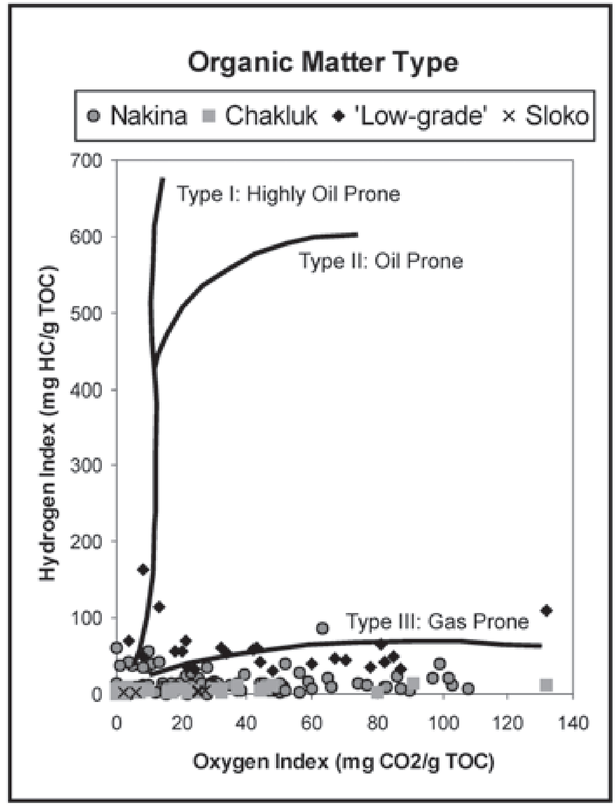

Figure 11. Plot of hydrogen index versus oxygen index for samples from the Nakina and Chakluk areas. 'Low-grade' samples form a subset of the Nakina samples, for which $S_2 > 0.2$ and $T_{max} < 480\ ^0C$. Sloko samples are from Eocene coal-bearing strata in the Paradise Peak area. The organic matter type in a source rock can be determined from this plot (Espitalié *et al*., 1977).

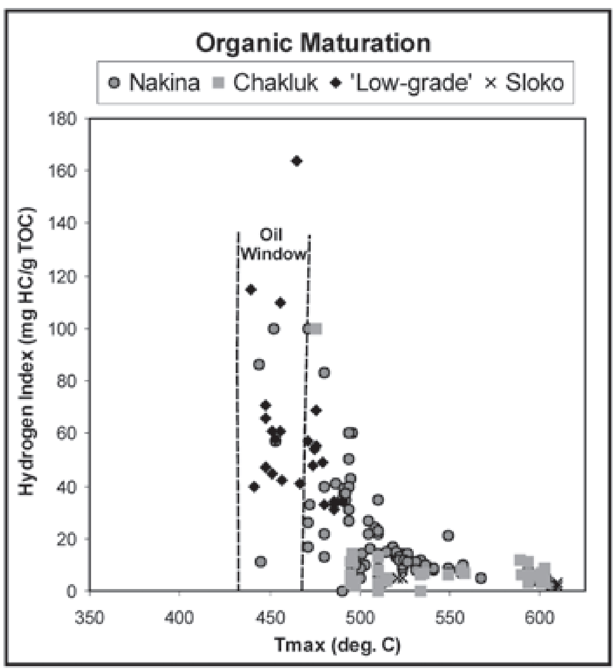

Figure 12. Plot of hydrogen index versus T_{max} for samples from the Nakina and Chakluk areas. 'Low-grade' samples form a subset of the Nakina samples, for which $S_2 > 0.2$ and $T_{max} < 480\ ^0C$. Sloko samples are from Eocene coal-bearing strata in the Paradise Peak area.

graphically shown that most samples from the southern part of the Nakina map-area and from the Chakluk Transect are overmature (Figure 12). Distribution of mature and overmature areas of the Nakina area can been seen by contouring thermal maturation data (Figure 13).

DISCUSSION

Cache Creek rocks in the Nakina area are prehnite-pumpellyite grade and CAI values > 4. Thus, they are uniformly overmature and not prospective for hydrocarbon exploration. On the other hand, source rocks within the Laberge Group in the Nakina area are gas prone, although many are overmature and have no remaining generative potential. Samples from the northern part of the Nakina map-area show the highest potential. They are mature and have organic-rich gas, prone source rocks (Figures 11 and 12). Lower-grade organic metamorphism within the northeastern part of the trough is consistent with the interpretation of higher structural and stratigraphic levels near the Nahlin Fault. Samples to the southwest are higher-grade, consistent with a progressive transition to stratigraphically and structurally lower levels. This transition may reverse south of the King Salmon Thrust in the foreland of the fold and thrust belt.

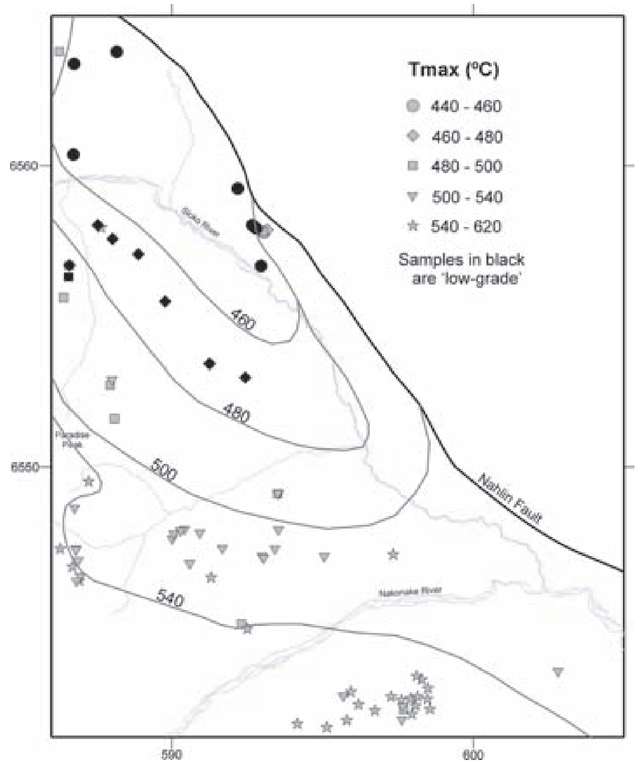

Figure 13. Contoured thermal maturation map for NTS 104N/3 based on T_{max} values. Note: T_{max} values are poorly constrained for relatively 'high-grade' samples due to the low S_2 values.

Structural style within the central Whitehorse Trough is analogous to the Rocky Mountain fold and thrust belt, where structural traps are important for accumulating hydrocarbons. Gas has been generated during basin burial and deformation within the Trough; whether any of this gas is still present remains unknown. A more rigorous assessment of gas potential necessitates constraints on the timing of hydrocarbon generation and also on the timing of burial, heating, and deformation. It is possible that some hydrocarbon generation may have occurred within the oldest strata due solely to sedimentary burial, prior to Middle Jurassic deformation. However, structural burial of sediments during this contractional event likely caused a major pulse of gas generation. The hydrocarbon potential of the central Whitehorse Trough hinges on the persistence of gas traps that may have been filled during its deformational history.

FUTURE WORK

- The thermal maturation of a select group of samples will be investigated using vitrinite reflectance in order to augment maturation data from programmed pyrolysis.
- A number of samples will be submitted for palynological investigation to acquire age constraints on the Laberge stratigraphy in this region. Age constraints are of vital importance in attempting to correlate stratigraphy, as well as in assessing the displacement and geometry of thrust faults, and in interpreting structural burial.
- Additional mapping of the stratigraphy and structure of the Laberge Group in this region is planned. It will help to constrain the geometry of structures, and allow a more efficient assessment of possible traps within the basin.

CONCLUSIONS

The first results of a preliminary hydrocarbon assessment of the BC portion of the Whitehorse Trough and the adjacent Cache Creek terrane are reported here. Cache Creek rocks in the Nakina area are prehnite-pumpellyite grade and have CAI's > 4. This indicates that they are overmature and not prospective for hydrocarbon exploration. Potential source rocks within the Laberge Group in the Nakina and Chakluk areas are gas-prone, although many are overmature and have no remaining generative potential. Mature organic-rich, gas prone source rocks occur in the northern part of the Nakina map-area. A major phase of gas generation probably occurred during structural burial of the Laberge sediments associated with a Middle Jurassic deformational event. The hydrocarbon potential of the central Whitehorse Trough hinges on the preservation of structural and stratigraphic traps that may have been filled at this time.

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