Besa River Formation in Liard basin, southeast Yukon: Report on 2012 reconnaissance fieldwork

Tiffani Fraser[1]
Yukon Geological Survey

Fil Ferri
Oil and Gas Division, BC Ministry of Energy, Mines and Natural Gas

Kathryn Fiess
Northwest Territories Geoscience Office

Leanne Pyle
VI Geoscience Services Ltd.

Fraser, T., Ferri, F., Fiess, K., and Pyle, L., 2013. Besa River Formation in Liard basin, southeast Yukon: Report on 2012 reconnaissance fieldwork. *In:* Yukon Exploration and Geology 2012, K.E. MacFarlane, M.G. Nordling, and P.J. Sack (eds.), Yukon Geological Survey, p. 37-46.

ABSTRACT

Prospective Devonian - Mississippian shale gas strata in Liard basin are the focus of a new collaborative study among research scientists of the Yukon Geological Survey, Northwest Territories Geoscience Office, and British Columbia Ministry of Energy, Mines and Natural Gas. Reconnaissance fieldwork in July 2012 involved measuring and sampling outcrops in each jurisdiction. One hundred eighty-seven metres of Besa River Formation shale and mudstone was measured and described in the Yukon part of Liard basin (NTS 95C/11). The section comprises three lithofacies: 1) mudstone and shale; 2) silty mudstone and shale; and 3) interbedded mudstone/shale and silty mudstone and shale. Shale is generally recessive, fissile, carbonaceous, very thinly laminated (<1 cm), and black on fresh surfaces. Mudstone is more competent than shale, thin to medium-bedded (1-5 cm), and medium to dark grey on fresh surfaces. Mudstone has variable silt and silica components based on observations of hand samples. Fossils are rare and include cephalopod impressions and unidentified biological fragments. The sampling program involved spectral gamma-radiation readings at one-metre intervals, and chip samples through two-metre intervals for Rock-Eval/total organic carbon, vitrinite reflectance, X-ray diffraction mineralogy, lithogeochemistry, and microfossil biostratigraphy. Laboratory results are anticipated in 2013.

[1]*tiffani.fraser@gov.yk.ca*

INTRODUCTION

The most prospective shale gas exploration targets in western Canada are the widespread organic-rich, Devonian – Mississippian, black shale and mudstone formations of the Western Canadian Sedimentary Basin (Ross and Bustin, 2008). In an effort to improve our understanding of this potential resource in Yukon, the Yukon Geological Survey (YGS) initiated a shale gas study of Devonian - Carboniferous strata in Liard basin. In July 2012, geologists from YGS, Northwest Territories Geoscience Office (NTGO), and British Columbia Ministry of Energy, Mines and Natural Gas (BCMEMNG) visited outcrops of Besa River (Yukon and BC) and Golata Formation (NWT) of the Liard basin to measure and sample one stratigraphic section in each jurisdiction. This paper presents observations from a Besa River Formation section measured in southeast Yukon, NTS mapsheet 95C/11.

STUDY AREA

The area underlain by strata of the Liard basin spans parts of Yukon, British Columbia, and Northwest Territories including parts of NTS 95C, D and 94 J, K, N, O (Fig. 1). The Yukon portion of the basin covers an area of 6500 km^2 and forms the extreme southeastern corner of the territory. Access to the region is by helicopter from either Watson Lake, Yukon or Fort Liard, NWT. A network of access roads to the Kotaneelee gas plant are accessible by barge, west of Liard River. Airstrips exist at Kotaneelee and Beaver River gas fields, the latter on the BC side of the border.

EXPLORATION HISTORY

Exploration in the Liard region began in 1955 with fieldwork by California Standard (later Chevron; National Energy Board, 2001). Drilling began in BC in 1957 on

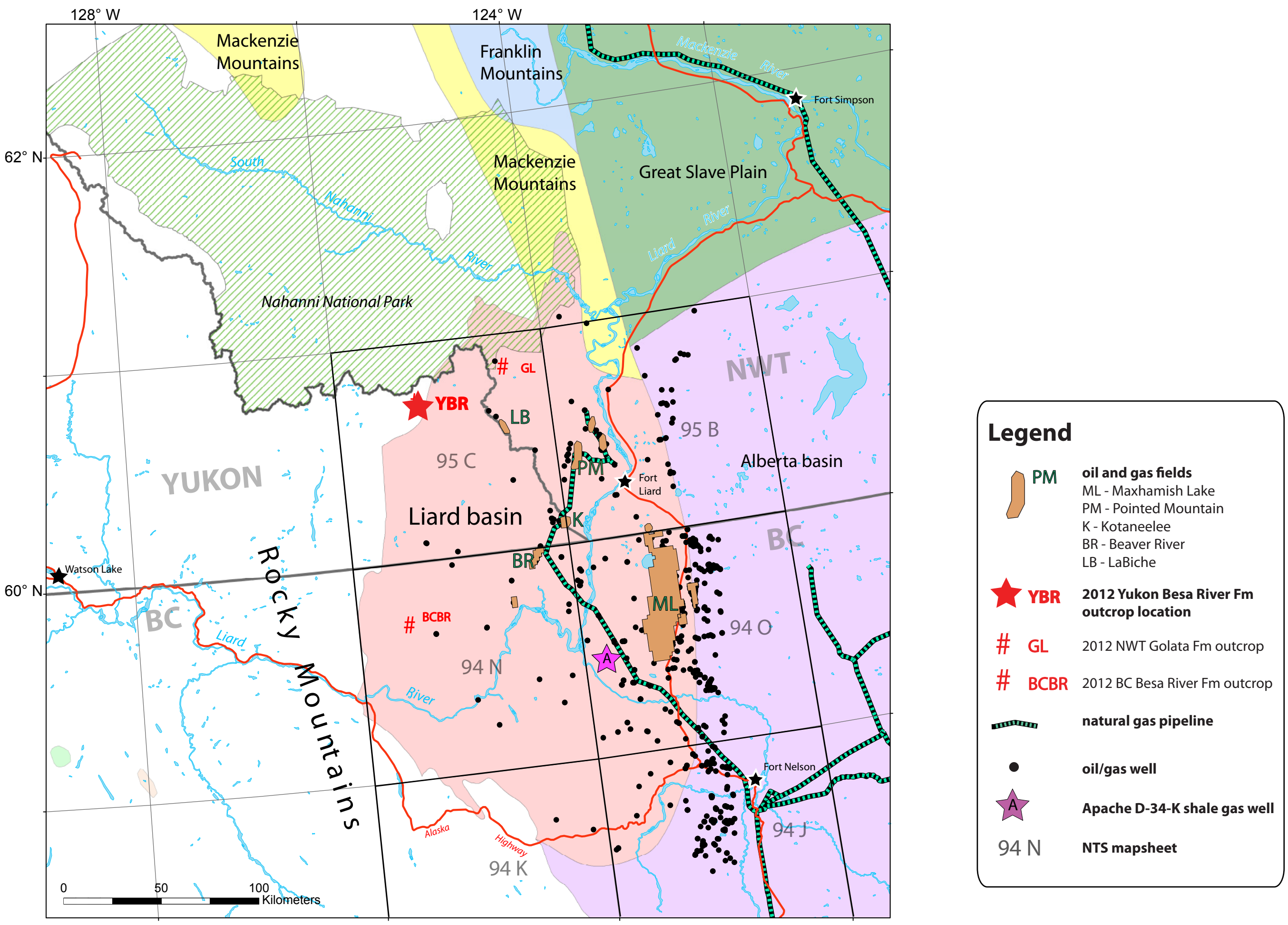

Figure 1. *Location of Liard and adjacent sedimentary basins (after Mossop et al., 2004), oil and gas activity, and 2012 field locations.*

the Beaver River anticline near the Yukon border (Pan Am A-1 Beaver River well). This well is notable for the present study because it encountered a blow-out in fractured shales and siltstone of the Besa River Formation at a depth of 2549 metres below Kelly Bushing. The first well drilled in the Liard area of Yukon was Pan Am et al A-1 Kotaneelee YT P-50 discovery well in 1963, also on the Beaver River structure. Since then, 12 additional wells have been drilled, the most recent of which was in Kotaneelee in 2005 (Devon et al Kotaneelee L-38). Of the thirteen wells, eight are currently abandoned, one is suspended gas, three are flowing gas, and one is a disposal well (Energy, Mines and Resources, 2012). In addition, 570 km of 2D-seismic data have been acquired for the Yukon portion of the basin (Energy, Mines and Resources, 2011). The main exploration target has been the Manetoe hydrothermal dolomite facies in the Middle Devonian Nahanni Formation (Dunedin Formation equivalent).

Portions of three gas fields extend into the Yukon including Kotaneelee, Beaver River, and LaBiche (Fig. 1). Kotaneelee recently suspended gas production in Fall 2012 (J. Ewert, pers comm, 2012). Produced gas was transported to Fort Nelson by the Beaver River lateral pipeline. Current Yukon land dispositions in the region include eight production licenses in Kotaneelee and two special discovery licenses in La Biche.

Liard basin has been explored more actively in NWT and BC. Eighty-one wells have been drilled in NWT to date, and over 400 in BC. BC has recently had a remarkable shale gas discovery in the basin. Apache's D-34-K well (Fig. 1), drilled in 2009, has been called "the most prolific shale gas resource test in the world" (Macedo, 2012). The projected formation is listed as the Upper Devonian Fort Simpson, an equivalent of the Besa River Formation. The well had a 30-day initial production rate of 21.2 MMcf per day and an estimated ultimate recovery of 17.9 Bcf (Macedo, 2012).

REGIONAL GEOLOGY

Liard basin lies within the eastern part of the Canadian Cordillera and consists of broadly folded Paleozoic and Mesozoic strata (Fig. 2). The basin was originally defined on the basis of its thick Carboniferous Mattson Formation (Gabrielse, 1967), but it also preserves a thick Cretaceous section (MacLean and Morrow, 2004). The eastern margin of the basin is marked by the north-trending Bovie fault (Fig. 2; Williams, 1977; Leckie *et al.*, 1991; Wright *et al.*, 1994; MacLean and Morrow, 2004). This feature separates a thicker Paleozoic - Mesozoic succession in Liard basin to the west from a thinner succession in the Interior Plain (Morrow *et al.*, 2006), and has dropped prospective Devonian shale gas horizons much deeper in Liard basin compared with the Horn River basin east of the fault (Ferri *et al.*, 2011; Fig. 3).

STRATIGRAPHY

Liard basin is a sub-basin of the extensive Western Canadian Sedimentary Basin and has a stratigraphic succession comparable to that in neighbouring northeast BC and northwest Alberta. The region preserves a thick (maximum >6000 m) sedimentary package ranging in age from Cambrian to Cretaceous (National Energy Board, 2001). Basement Proterozoic siliciclastic and volcaniclastic sediments are overlain by Cambrian to Middle Devonian carbonate and minor siliciclastic rocks that, from Silurian time, transition westward and northward to basinal shales of the Road River Group (Fallas *et al.*, 2004, 2005). Overlying the carbonates are shales of the Devonian – Mississippian Besa River Formation (Figs. 3 and 4; discussed below). The uppermost Besa River Formation grades eastwardly into Mississippian Golata Formation shale and carbonate (Richards, 1989; Hynes *et al.*, 2003). During the late Mississippian and early Pennsylvanian, a thick package of deltaic sandstone was deposited over the study area (Mattson Formation; Richards, 1989). Pennsylvanian and Permian strata consist of shale and carbonate of the Kindle and Fantasque formations which are overlain by Triassic shale and siltstone of the Toad-Grayling Formation (Pigage, 2006, 2007). The basin is overlain by Cretaceous foreland basin sandstone and shale (Leckie *et al.*, 1991).

This field study focuses on the Middle Devonian to Lower Carboniferous Besa River Formation. The type section is located 1.2 km north of the Muskwa River, in the Kluachesi Lake area (NTS 94G/13) in northeastern BC (Kidd, 1963). In Liard basin, the Besa River Formation contains basinal equivalents to the platform carbonate succession of the Upper Keg River to Debolt formations (Figs. 3 and 4; Ferri *et al.*, 2011). The Besa River Formation also contains facies equivalents of the Horn River, Fort Simpson, Exshaw, and Golata formations. Organic-rich black shale source rocks in the lower part of the Besa River Formation are equivalent to the rich source rocks in the Middle Devonian Horn River Group in Mackenzie Plain area (Morrow *et al.*, 1993). The "first black shale" in the Besa River Formation is another known source

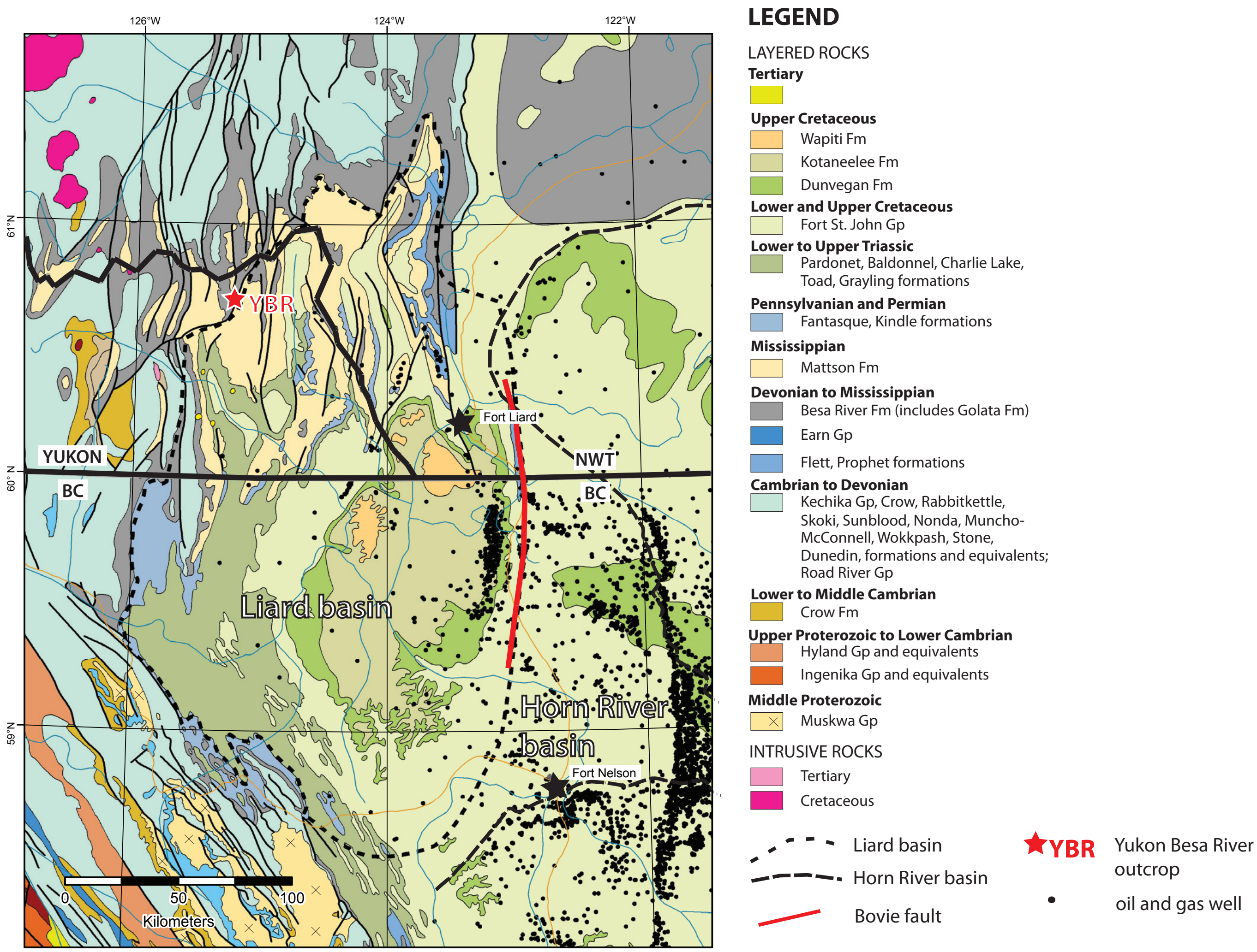

Figure 2. *Geological map of Liard basin region. Also shown is Horn River basin, oil and gas wells, Bovie fault surface trace, and the location of the Yukon Besa River section. Generalized geological map units after Wheeler and McFeeley (1991). Outline of Liard basin is from Mossop et al. (2004). Eastern limit of Horn River basin is eastern limit of Horn River Group shale (Oldale and Munday, 1994).*

rock, a lateral equivalent to the uppermost Devonian to lowermost Carboniferous Exshaw Formation (Fowler *et al.*, 2001). Besa River Formation is conformably overlain by the Middle to Upper Mississippian Mattson Formation (Richards, 1989).

FIELDWORK

Fieldwork was based out of Fort Liard, NWT, in July 2012. One day of aerial reconnaissance identified shale outcrops in NWT and Yukon. As anticipated, the recessive nature of shale posed challenges in finding complete, continuous, and accessible sections. Six days were spent measuring stratigraphic sections in NWT (Golata Formation), Yukon (middle Besa River Formation), and BC (lower Besa River Formation). The Yukon Besa River section, which is the subject of this paper, was measured on July 10th and 11th.

A team of five field workers (4 geologists, 1 assistant) measured, described, and sampled 187 m of Besa River Formation shale and mudstone. The section is located on the north side of an east-west tributary of Whitefish River, NTS 95C/11 (Figs. 1 and 5). The east-southeastwardly dipping section was measured over five segments. Total stratigraphic thickness, including two large covered intervals, is approximately 254 m. The Besa River Formation overlies resistant Devonian carbonate in the region, but the basal contact of the formation is rarely exposed in this area of Yukon, with the exception

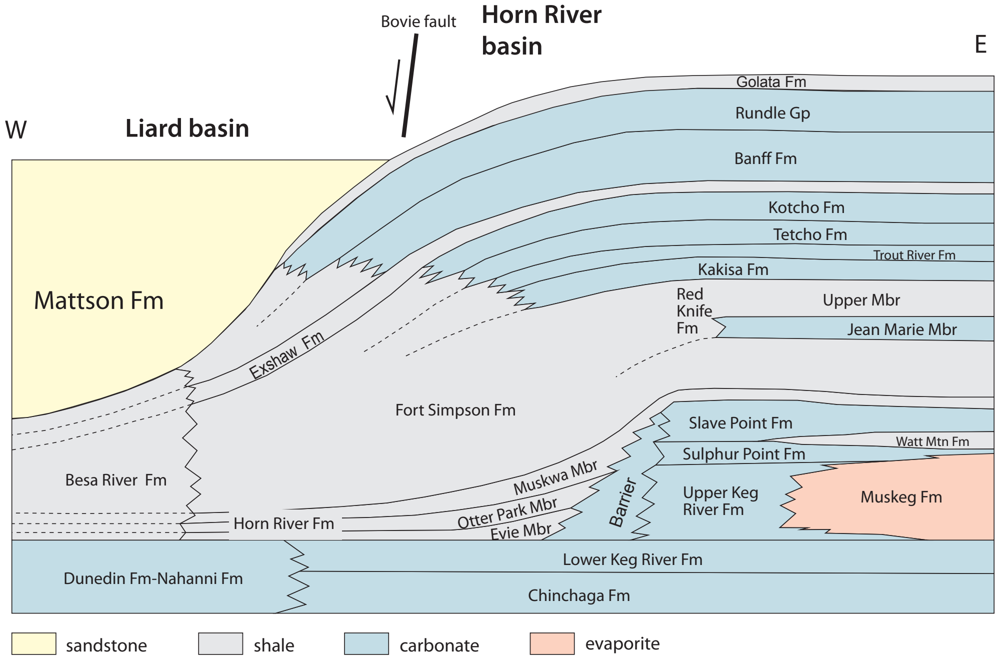

Figure 3. *Schematic diagram showing facies transitions of Middle to Upper Paleozoic shelf and offshelf successions from west to east across Bovie fault (after Ferri et al., 2011). Note that the Besa River facies equivalents include the Horn River, Fort Simpson, Exshaw, and Golata formations. Ages of units indicated in Figure 4.*

of an inaccessible cliff-section in the Pool Creek area (NTS 95C/5). Likewise, the upper contact with the resistant sandstone of the Mattson Formation was also not exposed. The section is thought to be in the middle part of the Besa River Formation, pending further refinement from microfossil dating.

In the field, detailed lithological descriptions were made of the section. Spectral gamma-radiation counts (GR) of uranium, thorium, and potassium were measured with a handheld spectrometer at one-metre intervals. Shale chip samples were collected through two-metre intervals for: Rock-Eval/total organic carbon (RE/TOC); vitrinite reflectance (VR); inductively coupled plasma-emission/mass spectroscopy lithogeochemistry (ICP-ES/MS); x-ray diffraction mineralogy (XRD) and; microfossil biostratigraphy.

FIELD OBSERVATIONS

The graphical log for the Yukon Besa River section (Fig. 6) identifies main rock types and lithofacies, units measured in the field, and locations of chip and microfossil samples. Three main lithofacies were identified in approximately equal proportions: mudstone and shale; silty mudstone and shale and; an interbedded mudstone and shale and silty mudstone and shale.

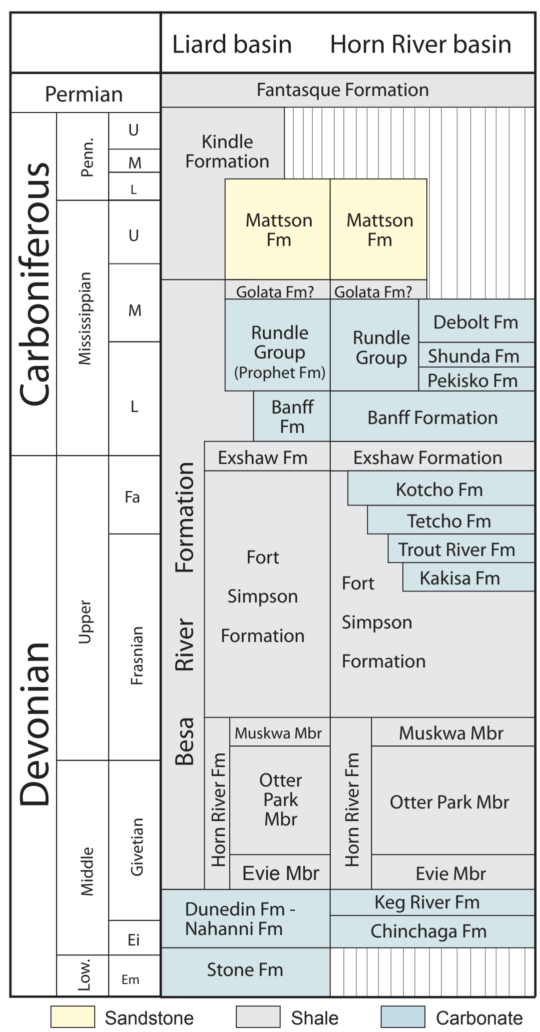

Figure 4. *Time-stratigraphic chart of middle to upper Paleozoic strata of Liard and Horn River basins (after Ferri et al., 2011).*

The mudstone and shale lithofacies is composed of the finest-grained rock types. It is dark grey to black on fresh surfaces, and weathers to a variety of colours including light to medium grey, orange-brown, and blue-grey, with local yellow-brown coatings (possibly jarosite). This lithofacies contains interbedded mudstone and shale, with shale normally accounting for <50% and often as little as 5% of the unit (*e.g.,* Fig. 7). All beds and laminations are planar. The shale component is fissile to platy, weathering into thin (<1 cm) paper sheets or laminae. It is locally soft and sooty or earthy in nature, crumbling easily (Fig. 8). These sootier intervals are commonly carbonaceous. The mudstone component is more competent in nature than the shale, weathering as plates or blocks up to 5 cm thick. Bedding is 1-5 cm thick on average. Locally, it is highly siliceous in nature, with chert-like properties such as a conchoidal fracture and a characteristic porcelain-breaking sound.

Figure 5. *Besa River Formation outcrop on a tributary of Whitefish River, NTS 095C/11.*

A silty mudstone and shale lithofacies is a marginally coarser grained and overall more competent unit than the mudstone and shale lithofacies. It is dark grey to black on fresh surfaces, and weathers grey, beige, yellow, orange, and rusty brown in colour. The silty mudstone intervals dominate the section with shale forming, thin

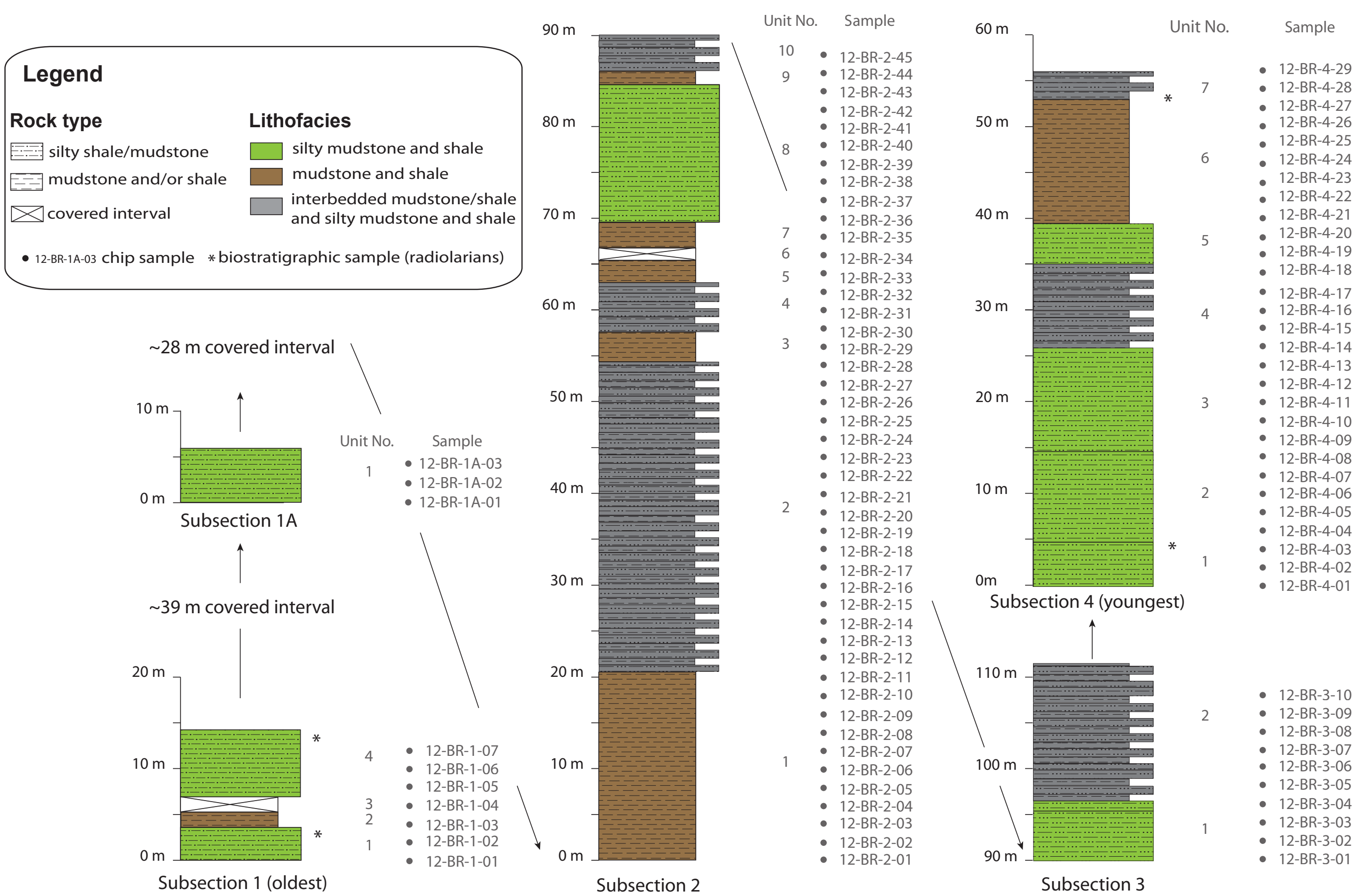

Figure 6. *Measured stratigraphic section from Besa River Formation, shown in Figure 5. All listed samples will be analysed for RockEval/TOC and ICP-ES/MS lithogeochemistry. A subset of these samples will be analysed for VR and XRD mineralogy. Note samples submitted for biostratigraphy (radiolarian identification).*

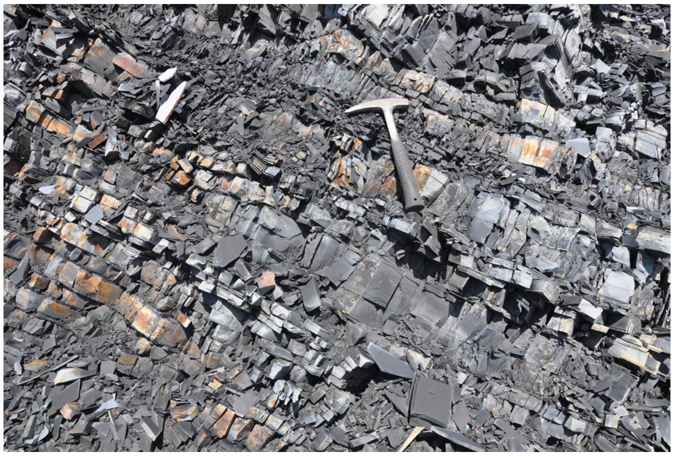

Figure 7. *Mudstone and shale lithofacies. Mudstone intervals are thicker and more resistant than shale intervals, and weather into blocks. Shale in this section is <10% and forms thin (<1 cm) partings between blockier mudstone beds. Rock hammer for scale.*

Figure 8. *Black, soft, sooty shale interval (near point of hammer) between more resistant mudstone beds.*

(<5 cm) interbeds or partings. Silty mudstone intervals are up to 15 cm thick and weather into thick plates or blocks of this thickness (Fig. 9). Silt-sized silica grains are commonly visible on bedding surfaces. Beds are planar and generally 1-5 cm thick. It is locally carbonaceous, and highly siliceous, forming chert-like beds. Shale interbeds are fissile, recessive, carbonaceous, and weather in thin papery sheets (Fig. 10).

The third lithofacies, interbedded mudstone and shale and silty mudstone and shale, is a combination of the units described above in approximately equal proportions. The lithofacies appears with gradational boundaries between lithologies. Locally, this lithofacies is very competent, particularly in siliceous intervals.

Overall the bedding is planar and homoclinal. Local variations from this occur where beds may be truncated, folded, faulted, and form brecciated zones (Fig. 11), possibly from syn-sedimentary deformation and/or regional tectonics.

The strata are generally barren of macrofossils; however, scree below the section contains rare cephalapod impressions (Fig. 12). Unidentified biological remains were

Figure 9. *Siliceous silty mudstone and shale outcrop. Mudstone is resistant and forms >90% of unit. The silty mudstone weathers into blocks with semi-conchoidal fracture. Shale is observed as thin partings (<1 cm) between mudstone beds.*

Figure 10. *Shale-dominant unit showing thin planar laminations weathering into thin, paper-like sheets.*

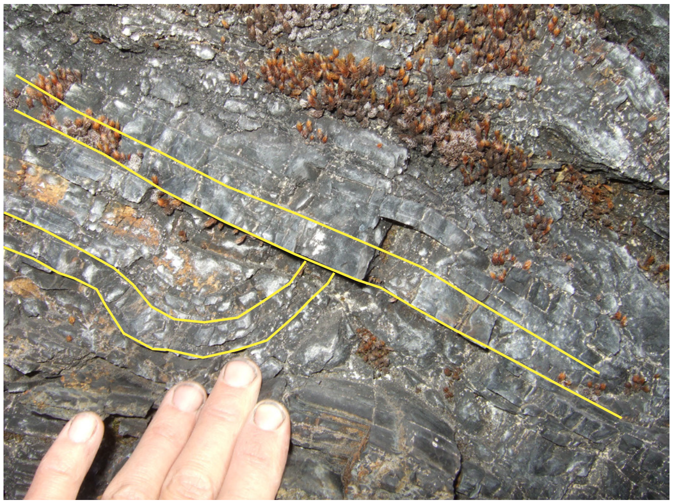

Figure 11. *Zone of deformed strata showing folded, truncated and brecciated shale beds. Yellow lines denote bedding surfaces.*

Figure 13. *Possible fossils on bedding surface of weathered scree. These features occur throughout the section.*

also seen on bedding surfaces (Fig. 13). Several samples have been submitted for radiolarian biostratigraphy.

Mineralogy is difficult to determine in the field due to the fine-grained nature of the rocks. Silica-dominant zones are identified based on chert-like properties and the competent nature of some intervals. In addition, minor, disseminated pyrite grains occur on bedding surfaces.

Samples for RE/TOC, VR, ICP-MS/ES, XRD, and microfossil biostratigraphy are currently undergoing analysis in respective laboratories.

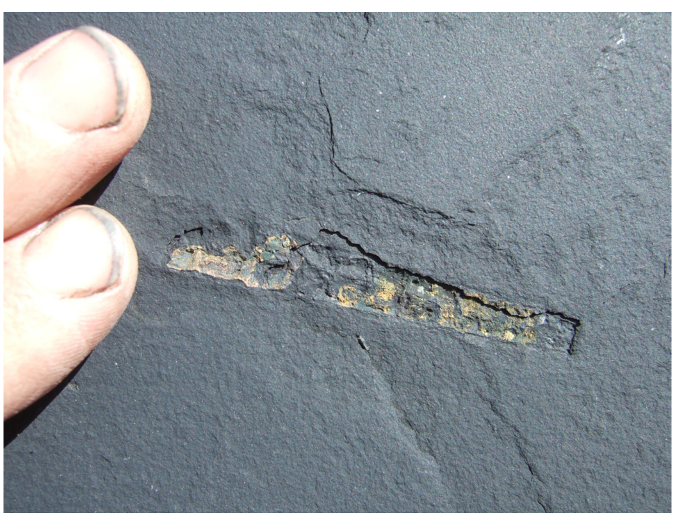

Figure 12. *Cephalopod fossil impression on bedding surface.*

CONCLUSIONS AND FUTURE WORK

A collaborative geoscience study of Devonian to Carboniferous shale units in Liard basin was initiated by YGS, NTGO, and BCMEMNG in 2012 with goals of improving the knowledge of the regional Upper Devonian – Lower Carboniferous geology, including stratigraphy, sedimentology, correlation and distribution of shale units, and hydrocarbon potential. In 2012, one section was measured in each jurisdiction. In southeast Yukon, a 189 m section of middle Besa River Formation was measured on a tributary of Whitefish River, NTS 95C/11. Samples were collected for RE/TOC, VR, ICP-MS/ES lithogeochemistry, XRD mineralogy, and biostratigraphy. Spectral gamma-ray radiation was measured to aid in future correlation with subsurface gamma logs from wells.

Further fieldwork is anticipated for the future. Identifying new Besa River Formation outcrop sections will be critical in moving this project forward. In addition, correlating outcrop sections to subsurface well logs will define the regional distribution of Devonian shale in the Liard basin area. Comments or suggestions on future research in this area are encouraged.

ACKNOWLEDGEMENTS

Funding for the project came from the Yukon Geological Survey, Northwest Territories Geoscience Office, and British Columbia Ministry of Energy, Mines and Natural Gas. Arend Stamhuis provided superior field and lab assistance. The Geological Survey of Canada is acknowledged for labwork support and the use of the gamma-ray spectrometer. Great Slave Helicopters supplied excellent flying services to field locations. The manuscript was reviewed by Don Murphy, Yukon Geological Survey.

REFERENCES

Energy, Mines and Resources, 2011. Yukon oil and gas, a northern investment opportunity 2011. URL http://www.emr.gov.yk.ca/oilandgas/index.html. Adobe file downloaded December 15, 2012.

Energy, Mines and Resources, 2012. Well activity record. URL http://www.emr.gov.yk.ca/oilandgas/exploration.html. Excel spreadsheet downloaded December 15, 2012.

Fallas, K.M., Pigage, L.C., and MacNaughton, R.B.(comps.), 2004. Geology, LaBiche River southwest (95C/SW), Yukon Territory and British Columbia. Geological Survey of Canada, Open File 4664, 1:100 000, 2 sheets.

Fallas, K.M., Pigage, L.C., and Lane, L.S. (comps.), 2005. Geology, La Biche River northwest (96C/NW), Yukon and Northwest Territories. Geological Survey of Canada, Open File 5018, scale 1:100 000.

Ferri, F., Hickin, A.S., and Huntley, D.H., 2011. Besa River Formation, western Liard basin, British Columbia (NTS 094N); geochemistry and regional correlations. Geoscience Reports 2011, British Columbia Ministry of Energy and Mines, p. 1-18.

Fowler, M.G., Stasiuk, L.D., Hearn, M., and Obermajer, M., 2001. Devonian hydrocarbon source rocks and their derived oils in the Western Canadian Sedimentary Basin. Bulletin of Canadian Petroleum Geology, vol. 49, p. 117-148.

Gabrielse, H., 1967. Tectonic evolution of the northern Canadian Cordillera. Canadian Journal of Earth Sciences, vol. 4, p. 271-298.

Hynes, G.F., Fallas, K.M., and Lane, L.S., 2003. Geology, Etanda Lakes, (95C/16), Northwest Territories and Yukon Territory. Geological Survey of Canada, Open File 1676, scale 1:50 000.

Kidd, F.A., 1963. The Besa River Formation. Bulletin of Canadian Petroleum Geology, vol. 11, p. 369-372.

Leckie, D.A., Potocki, D.J., and Visser, K., 1991. The Lower Cretaceous Chinkeh Formation: a frontier type play in the Liard basin of western Canada. Bulletin of the American Association of Petroleum Geologists, vol. 75, p. 1324-1352.

Macedo, R., 2012. Apache validates new shale play in B.C.'s Liard basin. Daily Oil Bulletin, June 14, 2012.

MacLean, B.C. and Morrow, D.W., 2004. Bovie structure: its evolution and regional context. Bulletin of Canadian Petroleum Geology, vol. 52, p. 302-324.

Morrow, D.W., Potter, J., Richards, B., and Goodarzi, F., 1993. Paleozoic burial and organic maturation in the Liard Basin region, northern Canada. Bulletin of Canadian Petroleum Geology, vol. 41, p. 17-31.

Morrow, D.W., Jones, A.L., and Dixon, J., 2006. Infrastructure and resources of the Northern Canadian Sedimentary Basin. Geological Survey of Canada, Open File 5152, 59 p.

Mossop, G.D., Wallace-Dudley, K.E., Smith, G.G., and Harrison, J.C. (comps.), 2004. Sedimentary basins of Canada; Geological Survey of Canada, Open File Map 4673, scale 1:5 000 000.

National Energy Board, 2001. Petroleum resource assessment of the Liard plateau, Yukon Territory, Canada. Oil and Gas Resources Branch, Department of Economic Development, Government of Yukon.

Oldale, H.S. and Munday, R.J., 1994. Devonian Beaverhill Lake Group of the Western Canada Sedimentary basin (Chapter 11). *In:* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comps.), Canadian Society of Petroleum Geologists and Alberta Research Council, URL http://www.ags.gov.ab.ca/publications/wcsb_atlas/atlas.html, accessed December 13, 2012.

Pigage, L.C., 2006. Stratigraphy summary for southeast Yukon (NTS 95D/8 and 95C/5). *In:* Yukon Exploration and Geology 2005, D.S. Emond, G.D. Bradshaw, L.L. Lewis, and L.H. Weston (eds.), Yukon Geological Survey, p. 267-285.

Pigage, L., 2007. Yukon Stratigraphic Correlation Chart, v. 3.0. Yukon Geological Survey and Oil and Gas Management Branch, Yukon Geological Survey, Open File 2007-2.

Richards, B.C., 1989. Uppermost Devonian and Lower Carboniferous stratigraphy, sedimentation, and diagenesis, southwestern District of Mackenzie and Southeastern Yukon Territory. Geological Survey of Canada, Bulletin 390.

Ross, D.J.K. and Bustin, R.M., 2008. Characterizing the shale gas resource potential of Devonian-Mississippian strata in the Western Canada sedimentary basin: application of an integrated formation evaluation. American Association of Petroleum Geologists Bulletin, vol. 92, p. 87-125.

Wheeler, J.O. and McFeely, P., 1991. Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America: Geological Survey of Canada, Map 1712A, 1:2 000 000.

Williams, G.K., 1977. The Celibeta structure compared with other basement structures on the flanks of the Tathlina high, district of Mackenzie. Geological Survey of Canada, Paper 77-1B, p. 301-310.

Wright, G.N., McMechan, M.E., and Potter, D.E.G., 1994. Structure and architecture of the western Canada Sedimentary basin (Chapter 3). *In:* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comps.), Canadian Society of Petroleum Geologists and Alberta Research Council. URL http://www.ags.gov.ab.ca/publications/wcsb_atlas/atlas.html. Accessed December 13, 2012.