Preliminary bedrock geology for NTS 95D/6 (Otter Creek area), southeast Yukon

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ABSTRACT

The Otter Creek area contains sedimentary and volcanic strata of the ancient North American miogeocline: Neoproterozoic to Lower Cambrian shale (Narchilla Formation) and siltstone (Vampire Formation); Late Cambrian to Middle Ordovician argillaceous to massive limestone (Rabbitkettle Formation) and dolostone (Sunblood Formation); Cambrian to Ordovician basalt and associated diabase; Silurian to Devonian MacDonald carbonate platform strata (unit SDc-south) and Selwyn basin shale (Road River Group-north); and thinly bedded silty shale likely of the Devonian to Carboniferous Besa River Formation. The rocks are deformed by six mappable north-trending, east-verging, asymmetric, macroscopic folds with amplitudes of 500-2000 m. Argillaceous and silty units contain a pervasive, axial-planar slaty cleavage. Shortening caused by the folding is about 25%. The Narchilla Formation is structurally emplaced upon Upper Cambrian-Devonian sedimentary rocks on the western margin of the map area, along an east-verging thrust fault with unknown displacement. Late northeast-striking normal faults preserve younger stratigraphic units to the south. Deformation is poorly constrained to the Mesozoic-Cenozoic Cordilleran orogeny.

Four epigenetic(?), stratabound zinc±lead±barite deposits and showings occur at the stratigraphic contact between massive limestone and argillaceous limestone within the Rabbitkettle Formation. Two occurrences contain significant smithsonite, suggesting supergene enrichment of primary sulphide mineralization. Previous lead-isotope studies of galena from the Mel deposit suggest that the age of primary mineralization is Devonian. Primary mineralization cannot be definitively classified within existing genetic deposit models, but is most consistent with manto replacement or Mississippi Valley-type deposit models.

RÉSUMÉ

La région du ruisseau Otter recèle des strates sédimentaires et volcaniques du migéoclinal de l'Amérique du Nord. Elle compte des shales (Formation de Narchilla) et des siltstones (Formation de Vampire) datant du Néoprotérozoïque au Cambrien précoce, des grès (Formation de Rabbitkettle) et des dolomies (Formation de Sunblood) argileux à massifs datant du Cambrien tardif à l'Ordovicien moyen, des basaltes et des diabases connexes cambriens à ordoviciens, des shales du bassin de Selwyn (Groupe de Road River – nord) et des strates de carbonates (unité de carbonates siluriens à dévoniens – sud) de la plate-forme de MacDonald datant du Silurien au Dévonien, ainsi que des shales silteux finement interstratifiés qui sont probablement de la Formation de Besa River, qui date du Dévonien au Carbonifère. Ces roches ont été déformées en six plis macroscopiques asymétriques à vergence est et à direction nord, qui peuvent être cartographiés et dont l'amplitude va de 500 à 2000 m. Les unités argileuses et silteuses renferment un clivage ardoisier pénétratif dans le plan axial. Le raccourcissement attribuable au plissement totalise environ 25 %. À la limite ouest de la zone cartographique, la Formation de Narchilla repose structuralement sur des roches sédimentaires datant du Cambrien tardif au Dévonien le long d'une faille de chevauchement à vergence est dont le déplacement est inconnu. Des failles normales tardives orientées vers le nord est ont conservé des unités stratigraphiques plus jeunes vers le sud. La déformation est grossièrement circonscrite à l'orogenèse de la Cordillère, qui date du Mésozoïque au Cénozoïque.

Quatre indices et gisements de zinc±plomb±barite stratoïdes épigénétiques(?) se retrouvent le long du contact stratigraphique entre un calcaire massif et un calcaire argileux, dans la Formation de Rabbitkettle. Deux occurrences renferment d'importantes quantités de smithsonite, ce qui laisse supposer un enrichissement supergène de la minéralisation sulfurée primaire. Des analyses antérieures des isotopes du plomb de la galène du gisement Mel semblent indiquer que la minéralisation primaire date du Dévonien. Bien que cette dernière ne puisse être définitivement classée parmi les modèles de gisements existants, elle correspond davantage aux modèles de filons de barite, de remplacement ou de gisements de type Mississippi-Valley.

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INTRODUCTION

The Yukon Geological Survey has been involved with bedrock mapping projects in southeast Yukon since 2000 to provide better definition of the stratigraphy, structure, and mineral and hydrocarbon potential of the area. Recent geological mapping in NTS areas 95C/5 and 95D/8 has significantly revised the stratigraphy and facies relations of Neoproterozoic to Paleozoic strata (Pigage and Allen, 2001; Pigage, 2004b, 2006; Fallas *et al.*, 2004, 2005). Bedrock mapping in 95D/6 during 2006-2007 (Fig. 1) is a continuation of this earlier work to determine if bedrock geology identified further east extends westward into this area.

Seven weeks were spent doing fieldwork in NTS 95D/6 during 2006 and 2007. In 2006, fieldwork was curtailed by active fires immediately north of the map area. In 2007, challenges related to high water levels in streams and lakes were met through August.

This paper summarizes the bedrock geology documented by the fieldwork. It is a companion to the 1:50 000-scale geology map released by the Yukon Geological Survey as Open File 2007-4 (Pigage, 2007). Figure 2 summarizes the bedrock geology, and Figure 3 illustrates two east-west vertical cross-sections perpendicular to structural trend. These sections were not balanced for this interpretation. Lateral thickness variations in formations are probably related to a combination of poor field constraints on stratigraphic contacts, structural thickening related to uninterpreted faults and folds, and original sedimentary thickness variations. All rock descriptions are based on field observations. The geological map encompasses map sheet NTS 95D/6 and marginal parts of 95D/3, 5 and 7. These marginal areas are included to incorporate information from outcrops along the Coal River and Rock River.

LOCATION AND PHYSIOGRAPHY

NTS map sheet 95D/6 is located 90 km northeast of Watson Lake (Fig. 1) in the Hyland Plateau (Mathews, 1986). Topography consists of low rounded hills and broad open valleys with incised stream drainages. Elevations range from 660 m to 1380 m. The area is heavily forested with no ridges extending above tree line.

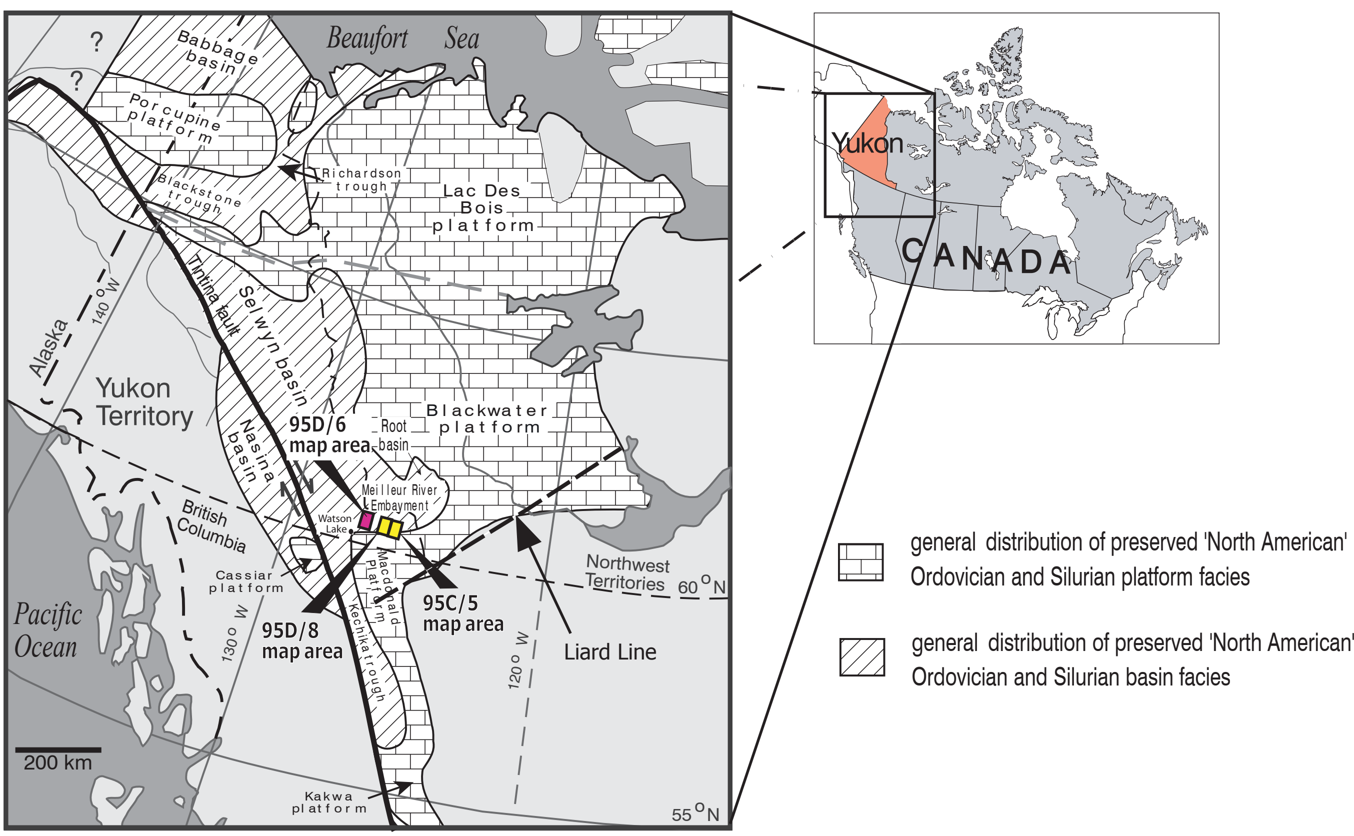


Figure 1. *Location of NTS map sheet 95D/6 in southeast Yukon. General distribution of Ordovician-Silurian platform carbonate and basinal shale facies for Canadian Cordillera and Alaska are indicated. Modified from Cecile et al. (1997).*

Much of the area has experienced major burns with extensive regrowth.

Coal River and Rock River flow south through the area into the Liard River. Scattered small lakes and marshy areas form abundant wetlands maintained by numerous beaver dams (Fig. 4). Bedrock exposure is less than 5% with most extensive exposures along streams, rivers and lakes (Fig. 5).

Fieldwork was completed primarily by foot and boat traverses from temporary base camps established by helicopter from Watson Lake. Exploration roads connecting the major mineralized properties in the west and central part of the map sheet were useful for walking and gaining access to selected ridge tops. Coal River and Rock River are suitable for navigation using an outboard jet with an inflatable boat; several traverses were completed on the Rock River in 2006 by this means. Spot checks and short traverses were completed in a few other areas where helicopter landings or 'toe-ins' were feasible.

PREVIOUS WORK

The Geological Survey of Canada completed 1:253 440-scale bedrock geological mapping of the Coal River map sheet (NTS 95D) in May and June of 1967 (Gabrielse and Blusson, 1969). Mineral exploration between 1967 and 1997 identified five Yukon MINFILE[1] occurrences. Three of these occurrences have detailed-scale bedrock geology maps and diamond drill reports (Miller, 1977, 1983, 1984, 1985; King, 1995; Senft, 1997).

REGIONAL GEOLOGY

Nelson and Colpron (2007) presented an excellent synopsis of tectonic history and metallogeny of the western North American margin which is summarized here. Rifting of the supercontinent Rodinia to form the passive margin of ancestral North America (Laurentia) began no later than about 750 Ma with deposition of the coarse clastic rocks of the Windermere Supergroup (Ross, 1991). The western margin of North America in Yukon subsequently showed clear west-deepening polarity with shallow marine sediments in the east, with a transition to deep marine sediments in the west during Neoproterozoic through Silurian time (Nelson and Colpron, 2007). NTS map area 95D/6 (Fig. 1) is located in the Cordilleran miogeocline, a depositional prism of sedimentary rocks of Precambrian to Middle Jurassic age along the relatively stable western continental margin of ancestral North America (Abbott *et al.*, 1986). It contains eight sedimentary units ranging in age from Late Neoproterozoic to Lower Carboniferous. The Silurian-Devonian transition from MacDonald platform carbonates (south) to Selwyn basin marine shales (north) (Figs. 1, 2) occurs within the map area.

All layered units have been deformed, predominantly by east-verging, asymmetric, north-trending folds. Argillaceous units contain a pervasive axial-planar slaty cleavage. Deformation is considered to result from the accretion of pericratonic and oceanic terranes to ancestral North America from Middle Jurassic through Tertiary time; it initiated development of the transpressional/transtensional orogenic belt broadly referred to as the Cordilleran orogen.

STRATIGRAPHY

INTRODUCTION

Figure 2 illustrates the map distribution of Late Neoproterozoic through Carboniferous layered units in the map area. Field descriptions for these units are presented in this section.

NARCHILLA FORMATION (HYLAND GROUP) (P̶ЄN)

Several exposures along the Coal River and on the ridge immediately west of the MEL property (Yukon MINFILE 095D 005) have been assigned to the upper Narchilla Formation in the Hyland Group (Gordey and Anderson, 1993). The lower contact is structural and consists of an east-verging thrust fault placing Narchilla sediments on Cambrian-Devonian strata. The upper contact is not exposed in the map area.

The Narchilla Formation in NTS 95D/6 consists predominantly of medium green, silvery-tan-weathering, soft, thin-bedded, noncalcareous phyllite. Bedding is typically on a scale of 1-10 cm in shades of green; locally the phyllite contains thin white, fine-grained, laminated quartz sandstone interbeds (Fig. 6). On the ridge top west of the MEL deposit (Yukon MINFILE 95D 005) the green phyllite is locally interbedded with maroon phyllite (Fig. 7). One exposure along the Coal River contains a thick (greater than 3 m) interbed of coarse-grained, quartzose sandstone. Quartz clasts within the sandstone are up to 1 cm across and are locally bluish in colour.

[1] *http://www.geology.gov.yk.ca/databases_gis.html*

In the type area the Narchilla Formation is Neoproterozoic to Early Cambrian (Gordey and Anderson, 1993). It is regionally laterally correlative with the Vampire Formation and the upper member of the Backbone Ranges Formation (Gordey and Anderson, 1993; Abbott (1981). Gabrielse and Blusson (1969) included the Narchilla Formation as part of their units 1 and 2.

VAMPIRE FORMATION (ꝑЄV)

The north central part of NTS 95D/6 contains several inaccessible exposures tentatively assigned to the Vampire Formation (Fritz, 1982). Exposures from the air in NTS 95D/6 have a blocky appearance in contrast to the platy-weathering, silvery exposures of the overlying Rabbitkettle Formation. Two helicopter stops were made in 2007 to look at Vampire Formation outcrops above tree line in map sheet NTS 95D/11.

Lower and upper contacts of the Vampire Formation are not exposed in NTS 95D/6. It is unconformably overlain by Rabbitkettle Formation and/or Cambrian-Ordovician basalt. Erosion is not extensive enough to expose the lower contact.

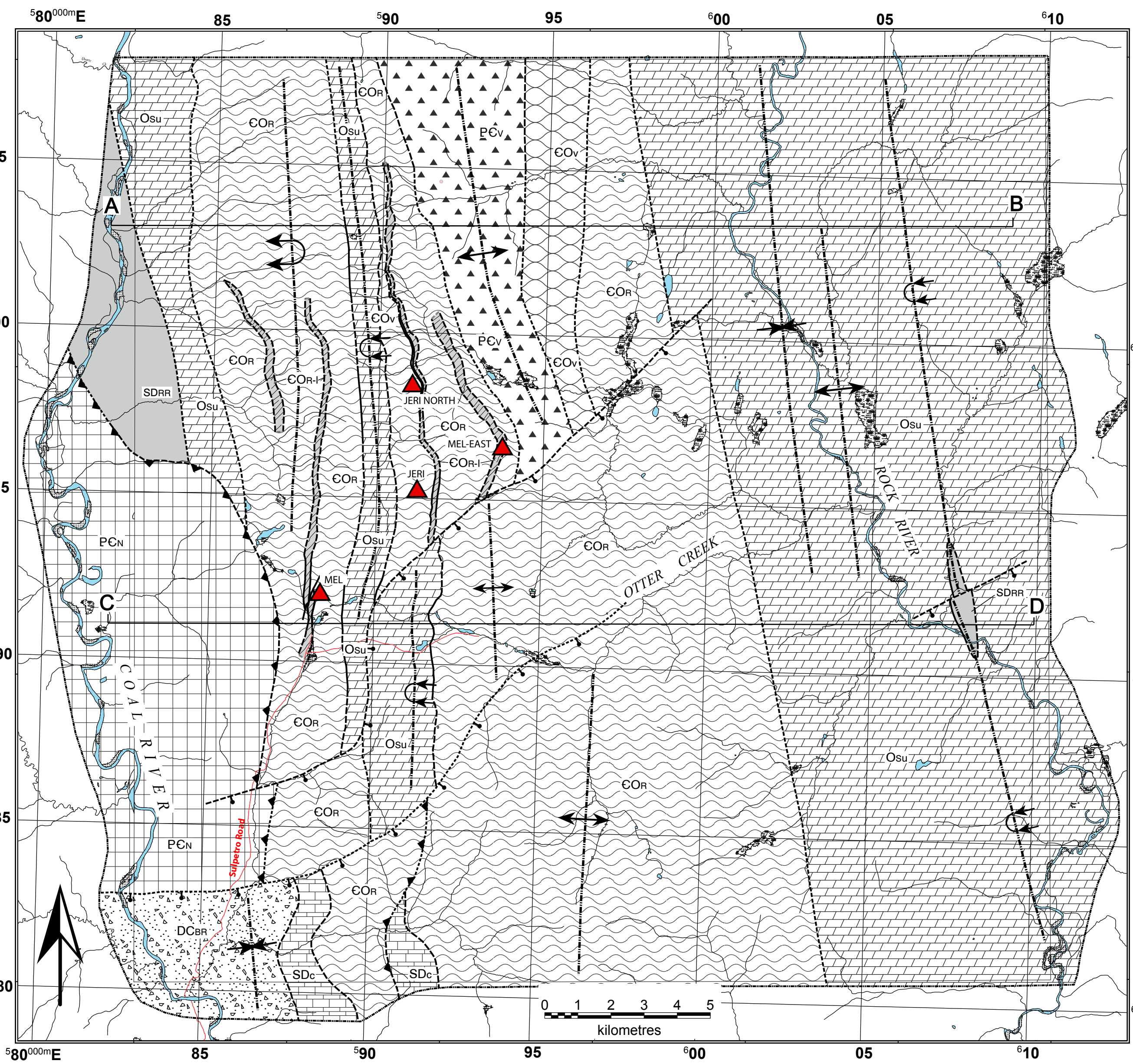


Figure 2. *Bedrock geology map for NTS map sheet 95D/6 in southeast Yukon. Map coordinates are UTM NAD83, zone 9N. Yukon MINFILE occurrences are shown with triangles. Legend is on next page.*

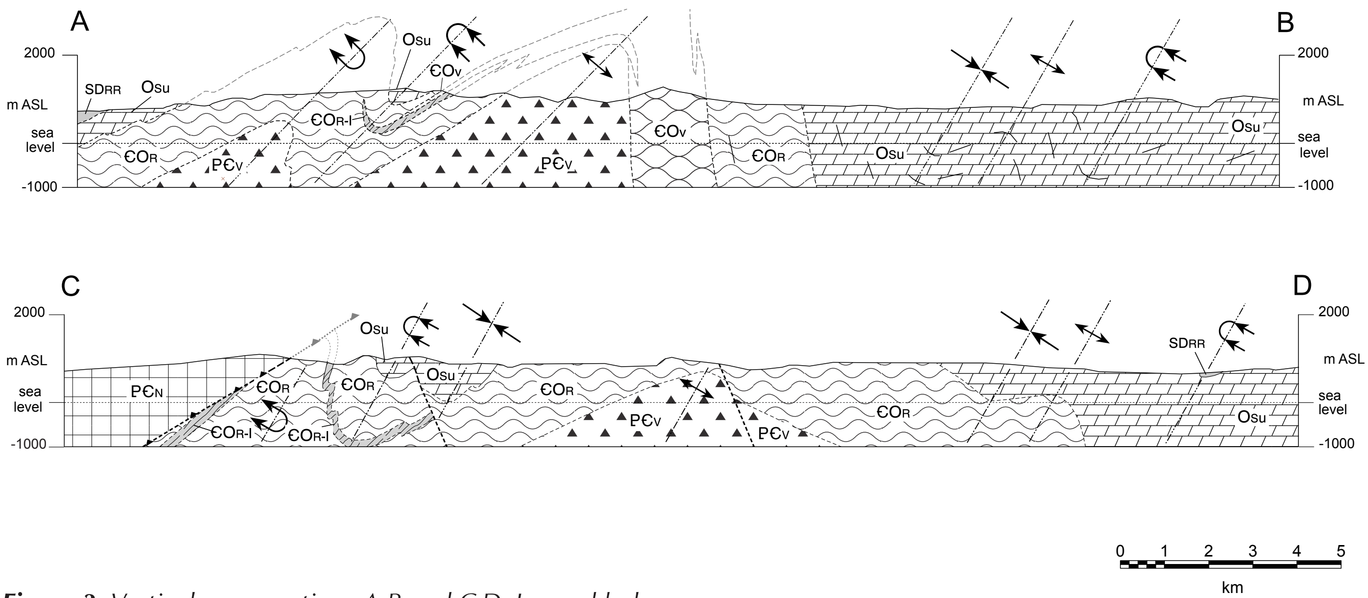
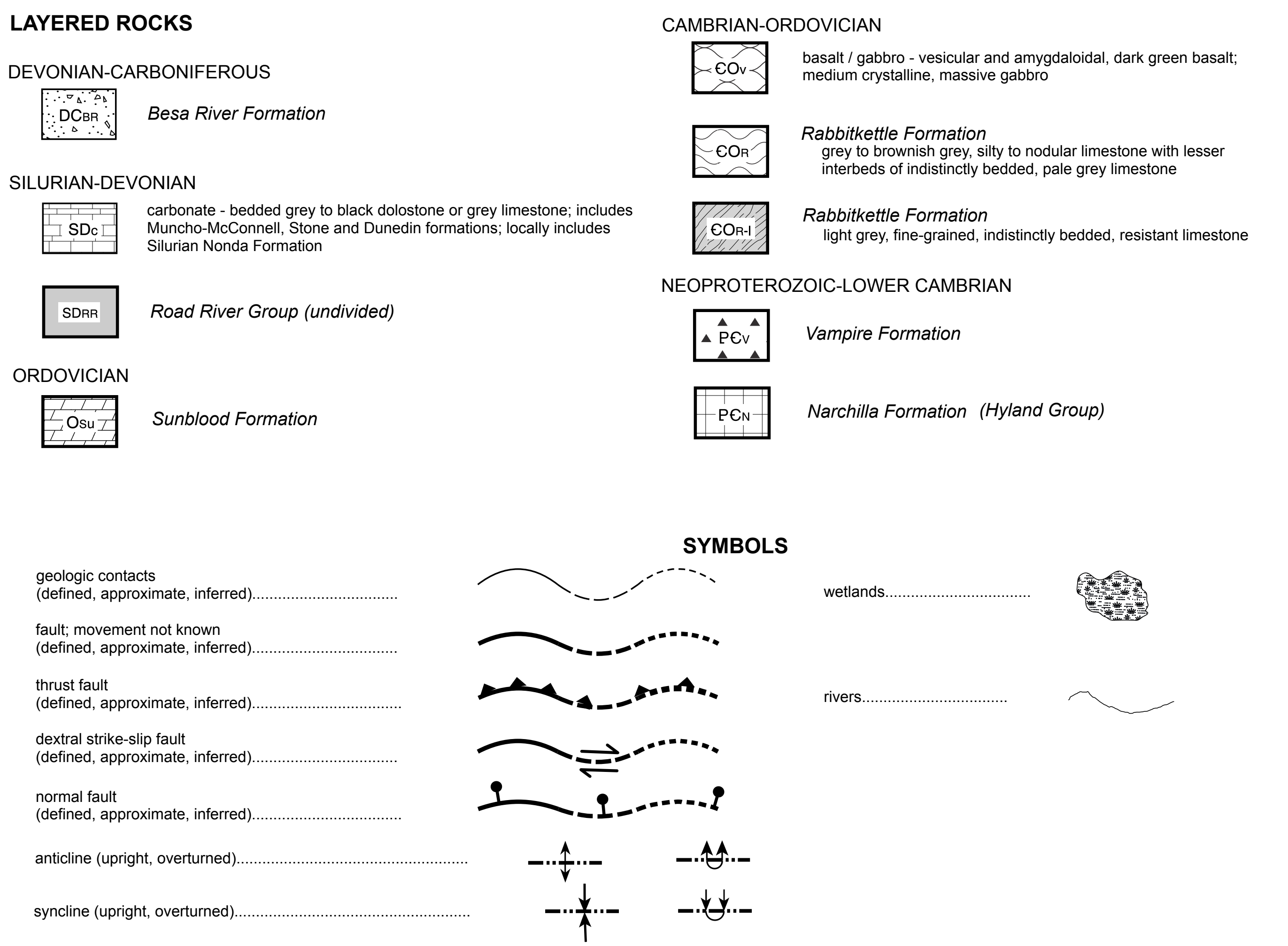


Figure 3. *Vertical cross-sections A-B and C-D. Legend below.*



Figures 2 and 3. *Legend.*

One exposure of Vampire Formation in NTS 95D/11 consists of dark grey-green, fissile, pinstriped, noncalcareous, silty phyllite (Fig. 8). Pinstriping is delineated by very thin, orange-weathering laminae containing fine pyrite. The second exposure consists of interbedded massive quartz sandstone and conglomerate. Quartz sandstone is cream, grey-weathering, and consists dominantly of subangular quartz clasts (Fig. 9). Fine pyrite aggregates weathers as small, orange, vuggy openings. The conglomerate in the same outcrop consists of a single 1-m-thick bed. It is clast-supported with dominant clasts being clear quartz grains up to 1-2 cm across in a tan matrix consisting of smaller quartz grains. About 30% of the clasts in the conglomerate consist of large, angular pieces of randomly oriented, fine-grained, orange-weathering quartz sandstone up to 40 cm across (Fig. 9). Locally the conglomerate also contains large clasts of pale silvery green phyllite up to 20 cm across.

Vampire Formation in its type area is Neoproterozoic to early Lower Cambrian (Fritz, 1982). It is laterally correlative with the Narchilla Formation and the upper

Figure 4. *View looking southeast toward Rock River from Jeri North property. Foreground is old burn; middle area contains extensive wetlands with beaver dams. Field station 07LP033.*

Figure 5. *View looking east at small lake on Otter Creek. Outcrops visible on north side of lake are Sunblood Formation dolostones with vertical bedding. Field station 06LP005.*

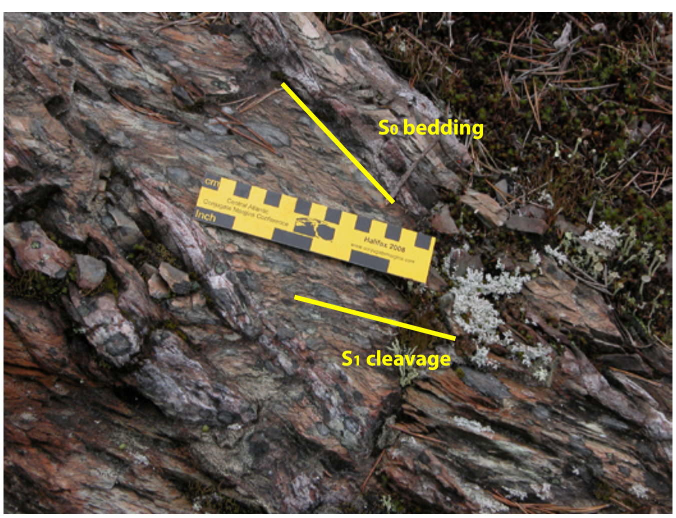


Figure 6. *Tan-weathering phyllite of the Narchilla Formation, field station 07LP001. Immediately below scale is a thin, white sandstone bed. Scale is parallel to the S_1 slaty cleavage.*

Figure 7. *Interbedded pale green phyllite and maroon phyllite of the Narchilla Formation, field station 07LP003. This specimen was pulled from the outcrop for the photograph.*

Figure 8. *Dark greenish-grey-weathering siltstone of the Vampire Formation, field station 07LP054. Bedding is vertical in photo. View looking north.*

member of the Backbone Ranges Formation (Fritz, 1982). Gabrielse and Blusson (1969) mapped the Vampire Formation as their units 4c or 2a depending on location.

RABBITKETTLE FORMATION (ЄOR, ЄOR-l)

Major portions of NTS 95D/6 are underlain by Rabbitkettle Formation (Gabrielse *et al.*, 1973). It unconformably overlies the Vampire Formation and is overlain by the Sunblood Formation. Recent work in NTS 95D/8 suggests that, at least locally, the upper contact with the Sunblood Formation is conformable (Pigage, 2006). Outcrops of Rabbitkettle Formation in the north-central part of the map area are accessible from exploration roads. Rabbitkettle outcrops in the southern and northern parts of the area are not readily accessible.

The predominant lithology in the Rabbitkettle Formation is a light grey- to brownish-grey-weathering, silty to argillaceous, locally nodular limestone (Fig. 10). Nodules are typically up to 10 cm long and 5 cm thick and consist of pale grey, recessive-weathering, fine-grained limestone which is locally parallel laminated. The silty to argillaceous, anastamosing matrix contains a well developed slaty cleavage (Fig. 11). Informally the formation has been called the 'wavy-banded limestone' as limestone nodules impart a wavy appearance to the beds.

The nodular to silty limestone commonly contains lesser interbeds of pale grey, fine-grained, massive limestone. Typically these massive beds are less than 2 m thick and constitute 50% or less of any outcrop (Fig. 12). In the

Figure 9. *Cream quartz sandstone with a 1-m-thick, tan-weathering quartzose conglomerate interbed, Vampire Formation; field station 07LP056. Bedding is vertical. Arrow just to right of hammer points to large, fine-grained quartz sandstone clast in the conglomerate.*

Figure 10. *Nodular, 'wavy-banded', silty limestone, Rabbitkettle Formation; field station 06LP021. Hammer handle is parallel with bedding. Orientation of S_1 slaty cleavage is indicated. View looking south.*

north-central portion of NTS 95D/6 the Rabbitkettle Formation contains one (or possibly two) massive limestone horizon (Unit ЄOR-l) up to 150 m thick which has been differentiated on the geology map. This massive limestone horizon consists of light grey to off-white, very fine-grained limestone (Fig. 13). It typically contains ghosted white calcite and tan siderite veinlets. In at least one location (Jeri North property) the limestone has a ghost burrow mottling texture. On the Mel property the limestone horizon contains small, irregular lenses of pale green to cream, noncalcareous phyllite to mudstone (Fig. 14).

Detailed drill logs from the Jeri and Jeri North properties (Miller, 1985; King, 1995; Senft, 1997) and surface geology from the Mel-East property (Miller, 1983) indicate that the uppermost portion of the massive limestone on these properties contains layers of silicified, pale grey, brown- to tan-weathering, locally burrow mottled

Figure 11. *Well developed S_1 slaty cleavage in Rabbitkettle Formation; field station 07LP031 on the Jeri North property. Scale is parallel with bedding. View looking north.*

Figure 12. *Interbedded massive limestone and argillaceous limestone in cliff face, Rabbitkettle Formation; field station 07LP005. View looking south at cliff face from helicopter. Upper massive limestone bed is about 2 m thick. Slaty cleavage dips down to right more steeply than bedding.*

Figure 13. *Close-up view of massive limestone within Rabbitkettle Formation; field station 06LP008, Mel property. View looking south. Note irregular network of carbonate veins in limestone which appear recessive.*

Figure 14. *Close-up view of olive-green mudstone within limestone, Rabbitkettle Formation. Core from Mel drill hole 75-11, depth 254 feet.*

Figure 15. *Massive amygdaloidal basalt from Unit ЄOv, field station 07LP044. Brandon Pike for scale. View looking south.*

dolostone. It is uncertain whether this dolostone is a common feature or whether it is only associated with the mineralization on these properties. It is also uncertain whether the limestone horizon on the Mel-East property is a second limestone horizon or is the same massive limestone horizon from the Jeri and Jeri North properties that has been structurally repeated.

Rabbitkettle Formation is only sparsely fossiliferous. Fossils collected regionally from the formation range from Late Cambrian (Franconian) through Early Ordovician (Gabrielse *et al.*, 1973; Tipnis *et al.*, 1978; Cecile, 1982). Two collections of trilobite and coral fragments submitted by D. Miller from immediately above the massive limestone horizons on the Mel and Mel-East (Joni) properties on this map sheet have a Late Cambrian through Early Ordovician age range (Norford, 1984; Miller and Wright, 1986).

Gabrielse and Blusson (1969) mapped the Rabbitkettle Formation as their unit 8. In some areas of 95D they mapped the massive limestone horizons, interpreted here as being within the Rabbitkettle Formation, as a separate unit 5. The uppermost part of the Rabbitkettle Formation has been regionally correlated with pink to cream, coarse sandstone interbedded with conglomerate and maroon silty shales of the Crow map unit underlying the Sunblood Formation in NTS 95D/8 and NTS 95C/5 to the east (Pigage, 2006).

UNIT ЄOv

Mafic volcanic rocks west of Rock River in the northern part of the map area are interpreted to be Cambrian-Ordovician basalt. A single helicopter landing was made on this unit in NTS 95D/6. A second helicopter landing was made on the same unit slightly to the north in map sheet NTS 95D/11. A 30-m-thick horizon of poorly exposed basalt occurring immediately above the massive limestone horizon on the Jeri North property (Yukon MINFILE 95D 032) is also considered part of this same unit on the west side of the anticline cored by the Vampire Formation. Representative material from this unit has been forwarded for lithogeochemical analysis.

The surface exposure in NTS 95D/6 (field station 07LP044) consists of massive, dark green, silvery-green to red-brown weathering, fine-grained basalt (Fig. 15). The basalt is vesicular to amygdaloidal with sparse 1-cm-diameter vugs or calcite amygdules. Bedding was not visible in the outcrops visited. Exposures locally contain a pervasive foliation. One exposure on the Jeri North property has an autobrecciated texture with angular to rounded chloritic clasts in a green chlorite-rich matrix.

The exposure visited in NTS 95D/11 (field station 07LP055) consists of massive, blocky, unfoliated, medium-grained, hornblende-plagioclase diabase. Locally it contains irregular veinlets of epidote with minor calcite.

Gabrielse and Blusson (1969) correlated this unit (their unit 3) with the Toobally volcanic unit (Goodfellow *et al.*, 1995) immediately west of the Toobally Lakes (NTS 95D/8) and considered it to be Precambrian on that basis. More recently, Pigage (2004b, 2006) delineated four alkali basalt layers in NTS 95D/8 occurring at different horizons within the pink to cream sandstone unit informally called the Crow map unit which is correlated with the Rabbitkettle Formation. These four horizons are correlated with the Toobally and Gusty Lakes volcanic units as described by Goodfellow *et al.* (1995). The uppermost of the four volcanic layers (Gusty Lakes volcanics) was bracketed by conodont samples as having a Tremadocian (Early Ordovician) age. Pigage (2006) discussed the possible age of the volcanic horizons and the enclosing Crow map unit and suggested a preferred age range of Late Cambrian through Early Ordovician for the entire Crow map unit and enclosed volcanic horizons. Geochemistry and age of the volcanic horizons from the Crow map unit are similar to that of the Cambrian-Ordovician Menzie Creek formation in the Faro area (Pigage, 2004a, 2004b, 2006).

Figure 16. *Interbedded light and dark grey dolostone of the Sunblood Formation in cliff exposure on Rock River, field station 06LP043. Cliff is about 40 m high; light-coloured beds are generally between 1 and 2 m thick. View looking north.*

Extensive outcrops of Unit ЄOv occur on the east side of the Vampire Formation in the core of an inferred anticline. Unit ЄOv is interpreted as overlying the Vampire Formation and underlying the Rabbitkettle Formation, providing an approximate age range of Early Cambrian to Early Ordovician. On the Jeri North property the ЄOv horizon occurs immediately above a massive limestone horizon within the Rabbitkettle Formation, which is interpreted as the same Upper Cambrian to Lower Ordovician massive limestone horizon on the Mel property. Using these different constraints and correlations Unit ЄOv is considered to be Late Cambrian to Early Ordovician in age.

SUNBLOOD FORMATION (OSu)

The Sunblood Formation (Kingston, 1951) outcrops extensively on the Rock River and along smaller streams draining into the Rock River. It also occurs as a small series of exposures along the Coal River in the northwest corner of the map area. In the central part of the map area, Sunblood Formation is preserved in north-trending synclinal fold keels. It conformably overlies the Rabbitkettle Formation and is unconformably overlain by the Road River Group.

In all occurrences it consists predominantly of thick-bedded, pale grey, laminated to bioturbated dolostone (Fig. 16) interbedded with thick-bedded, dark grey, bioturbated dolostone (Fig. 17). Bedding in both lithologies ranges from 10 cm to 2 m in thickness. Laminae in the pale grey dolostones are millimetres thick; commonly the laminae are parallel although rarely they outline cross-bedding. The dolostones do not generally contain a readily visible structural fabric; rarely, they exhibit an indistinct fracture to slaty cleavage. These rocks are typically tan to buff weathering. One exposure of Sunblood Formation on the Rock River is a pale grey, thick-bedded, very fossiliferous limestone (Fig. 18).

In the 'type area', Sunblood Formation is Middle Ordovician (Gabrielse *et al.*, 1973; Ludvigson, 1975). More recent conodont collections from Sunblood Formation in NTS 95D/8 and 95C/5 demonstrate that the Sunblood Formation in those areas ranges in age from Early Ordovician (Tremadocian) to early Late Ordovician (Caradocian) (Pigage, 2004b, 2006).

Figure 17. *Light and dark grey, bioturbated dolostones of the Sunblood Formation, field station 06LP041. View looking west.*

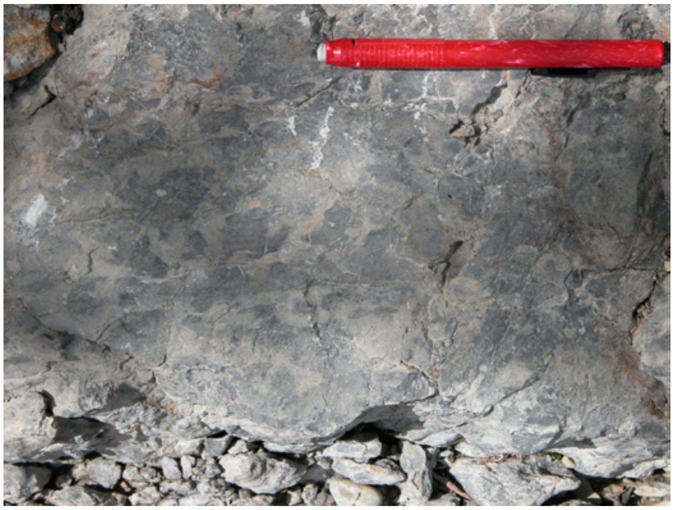


Figure 18. *Burrow mottling texture in limestone of Sunblood Formation, field station 06LP035. Pencil eraser (13 cm long) is parallel to bedding.*

Figure 19. *Interbedded black chert and dark grey, siliceous dolostone, Road River Group, field station 07LP060. Chert bed on left specimen is about 5 cm thick.*

ROAD RIVER GROUP (SDRR)

The Road River Formation was first described and defined in northern Yukon (Jackson and Lenz, 1962). In southern Yukon, Gabrielse *et al.* (1973) restricted the Road River Formation to include only the upper recessive carbonaceous-shale-dominated portion of the original formation; the lower portion was excluded from the Road River and assigned to the Rabbitkettle Formation. More recently, Fritz (1985) and Gordey and Anderson (1993) raised the Road River Formation to formal group status. Gordey and Anderson (1993) retained the exclusion of Rabbitkettle Formation from the Road River Group. This discrepancy over what is included within the Road River Group has not been resolved, and reflects differences in mapping practices between northern and southern Yukon. Pyle and Barnes (2000) have followed the definition proposed by Gabrielse *et al.* (1973) in describing their detailed sections in northeastern British Columbia. More extensive discussion concerning the current status and usage of Road River may be found in Morrow (1999).

Carbonaceous silty shales of the Road River Group outcrop on the Coal River in the northwest part of the map area and in a stream draining southward into the Rock River in the east-central part of the map area. In both areas it unconformably overlies the Sunblood Formation. The unit was examined in the east-central exposures near the Rock River during 2007.

In this area, Road River Group can be divided into two units. The lower unit is about 15 m thick and consists of thinly interbedded black chert and grey-weathering, black, silty dolostone (Fig. 19) on a scale of 2-15 cm, giving the unit a distinctly striped appearance. Both chert and dolostone layers are locally nodular. It forms small cliffs which are locally highly fractured (Fig. 20). The upper unit is thick-bedded, noncalcareous, graptolitic, pinstriped, dull black, silty shale (Fig. 21). Bedding is on a scale of 10-40 cm; pinstriping is on a 1 cm scale. The upper unit weathers recessively into thin platelets along primary bedding. A distinctive, 1.5-m-thick, cream-weathering, black dolostone bed occurs just above the lower contact with the lower unit (Fig. 21).

The exposures in this stream were combined by Gabrielse and Blusson (1969) as both Nonda (their unit 12) and Road River (their unit 11) formations. Graptolite and coral fossils collected from outcrops along the stream have an Early Silurian age (late Llandovery; Norford, 1967; reported in Gabrielse and Blusson, 1969). Fossil collections from Road River Group in NTS 95C/5 range upward to Early Devonian (Lochkovian) in age (Pigage, 2006). Road River lithologies have the same age range as unit SDc (see next section) and are therefore correlative with it. This major change from a thick carbonate succession to black shales marks the southern margin of Selwyn basin during Silurian to Early Devonian time. Although the transition is not directly visible, it occurs within a lateral north-south distance of 12 km.

UNIT SDc

The southwest part of the map area contains the northernmost exposures of a thick assemblage of undivided Silurian to Devonian carbonate. Gabrielse and Blusson (1969) reported this assemblage (their unit 13) as overlying the Silurian Nonda Formation. For purposes of this report, the Nonda Formation has been included within this unit because of limited exposures in the map area. Based on the regional mapping immediately south in map sheet NTS 95D/3, unit SDc is interpreted as overlying Rabbitkettle Formation (Gabrielse and Blusson, 1969).

One exposure at the stratigraphic top of this assemblage in the southwest corner of the map area was accessed from Coal River using a trap-line trail (field station 07LP065). At this location, unit SDc consists of indistinctly laminated, massive, fine-grained, pale grey limestone (Fig. 22).

Gabrielse and Blusson (1969) report this undivided carbonate assemblage as ranging from Early Silurian to early Middle Devonian in age. Unit SDc therefore correlates with Nonda, Muncho-McConnell, Stone and Dunedin formations. It represents the northernmost exposures of the Paleozoic MacDonald carbonate platform forming the southern margin to Selwyn basin marine shale strata during the Silurian and Devonian.

BESA RIVER FORMATION (DCBR)

In the southwest corner of the map area immediately east of Coal River, overlying unit SDc is a silty shale which has been tentatively correlated with the Devonian to Lower Carboniferous Besa River Formation (Kidd, 1963). Several exposures were examined in 2007 along Coal River and

Figure 20. *Interbedded black chert and dark grey, siliceous dolostone of lower unit in Road River Group in outcrop; field station 07LP060. View looking south; bedding is overturned with younging to the left. Shrub in foreground is about 1 m high.*

Figure 21. *Black, silty shale with one cream-weathering dolostone bed, Road River Group; field station 07LP060. View looking north. Dolostone is about 1.5 m thick. Bedding is overturned with younging to the right.*

Figure 22. *Limestone of unit SDc on north side of west-flowing stream; field station 07LP065. Trees on top of outcrop are about 3-4 m high.*

the stream near the Sulpetro Road draining west into the Coal River.

Exposures consist of tan-orange to tan-weathering, striped, greenish-grey, soft, generally noncalcareous, argillaceous siltstone (Fig. 23). Bedding ranges from 2-20 cm in thickness. Orange-weathering stripes are light grey siltstone. Locally, some beds consist of dark grey siltstone. Outcrops contain a moderately well developed slaty cleavage.

Northwest of the Sulpetro Road the formation contains a thick interbed of massive, commonly argillaceous, grey to cream, grey-weathering, poorly sorted quartz sandstone.

Figure 23. *Striped silty shale of Besa River Formation, field station 07LP063.*

Quartz clasts are subangular and clast size is variable. The sandstone is crosscut by abundant (20-30%) planar and irregular white quartz veinlets up to 20 cm thick, locally with open space in the vein centre. This quartz sandstone unit is at least 30 m thick in one location. In one small exposure, a dark grey limestone conglomerate with subangular limestone clasts is associated with the quartz sandstone.

This unit has been correlated with Besa River Formation largely because of its stratigraphic position overlying unit SDc; it does not have the carbonaceous shales and cherts typical of the Besa River Formation in map sheet NTS 95C/5 (Pigage, 2006). The Besa River Formation is Middle Devonian to Lower Carboniferous (Viséan; Richards, 1989).

STRUCTURE

The predominant structures within the map area are north-trending, east-verging, asymmetric, locally overturned, macroscopic folds with sharp hinge zones (Figs. 2, 3). Outcrop-scale minor folds in the map area are rare. All argillaceous to silty lithologies contain a single, pervasive, axial-planar slaty cleavage or spaced fracture cleavage. Cleavage is best developed within the Rabbitkettle Formation. Orientation of S_0 primary bedding relative to the S_1 slaty cleavage has been utilized to help map axial traces of primary folds. Intersection lineations between bedding and slaty cleavage plunge gently to moderately both north and south.

The Mel property (Yukon MINFILE 095D 005) is located on the west overturned limb of a north-trending syncline cored by the Sunblood Formation. West of the syncline, the axial trace of an overturned anticline is within Rabbitkettle Formation, and the axial trace of the upright anticline to the east is located within Vampire Formation. East limbs of these anticlines are vertical to overturned.

A second asymmetric syncline with an overturned west limb located immediately east of the Rock River is cored by Road River Group. Along Rock River, smaller scale parasitic folds on the west limb of this syncline result in abrupt changes in bedding within the Sunblood Formation from vertical to gently to moderately west dipping (Figs. 2, 3).

Cross-section interpretation of this fold pattern (Fig. 3) suggests fold amplitudes ranging from 500 to 2000 m. On vertical section A-B, along the Rabbitkettle-Sunblood contact, shortening related to folding was calculated to be about 25%.

Narchilla Formation is thrust eastward over Cambrian through Devonian strata on the west side of the map area along a west-dipping thrust fault with unknown displacement. In the southern part of the map area, an east-verging thrust results in the structural repetition of west-dipping unit SDc.

Three northeast-trending normal faults have been identified in the map area. These faults consistently have south-side down displacement resulting in preservation of younger strata to the south. The two major normal faults in the central part of the area displace the north-trending syncline and anticline axial traces, placing faulting as later than folding and suggesting the normal faults also have a component of strike-slip displacement.

Gabrielse and Blusson (1969) inferred a major east-directed thrust fault, the Rock River fault, which would have been responsible for emplacing Precambrian volcanic rocks upon Sunblood Formation in the northern portion of the map area. They placed this fault trending southwest through Otter Creek, south of the Jeri and Mel-East mineral showings. However, volcanic rocks interpreted by Gabrielse and Blusson (1969) to be Precambrian are here interpreted to be Cambrian-Ordovician basalts on the east, vertical limb of a north-trending anticline cored by Vampire Formation; a thrust fault is not required with this interpretation. In the area along Otter Creek south of the Jeri and Mel-East showings, the Rock River fault is re-interpreted as a northeast-trending normal fault which displaces the syncline cored by Sunblood Formation.

Folding is loosely constrained to be post-Carboniferous since all units, including the Besa River Formation in the southwest corner of the map area, are folded and contain the same axial planar slaty cleavage. Thrusting is considered to be coeval with folding because of the similar orientation of the deformation trends.

On a regional scale, compressional deformation in the miogeocline is broadly related to the Jurassic through Tertiary Cordilleran orogeny (Nelson and Colpron, 2007). In map sheet NTS 95D/08 (40 km east of 95D/06), Early Triassic sedimentary rocks are deformed in the footwall of the Toobally thrust fault, restricting the timing of deformation to later than Early Triassic (Pigage, 2004b). The Rock River valley in NTS 95D/11 immediately north of the map area contains shallowly dipping, unfolded, Late Eocene and Oligocene fluvial mudstones and coals (Long and Sweet, 1994), restricting the timing of compressional folding to pre-Late Eocene.

Northeast-trending normal faults in the map area are younger than the north-trending folds and thrust faults. Wright and Miller (1986) infer a northeast-trending fault in NTS 95D/11 offsetting the late Eocene-Oligocene sediments in the Rock River basin, suggesting that at least some movement on the normal faults is post-Oligocene.

MINERALIZATION

NTS 95D/6 contains four zinc±lead±barite deposits and showings (Yukon MINFILE 095D005, 095D 027, 095D 032). Each of these mineral occurrences is stratabound and occurs at the stratigraphic contact between massive, fine-grained limestone (stratigraphic footwall; ЄOR-l) and argillaceous limestone (stratigraphic hanging wall; ЄOR) within the Rabbitkettle Formation. The Mel deposit (Yukon MINFILE 095D 005) is the largest of these with a published, pre-NI43-101 drill-indicated reserve of 6.78 million tonnes grading 54.69% barite, 7.10% Zn, and 2.03% Pb (King, 1995). Miller and Wright (1986) give an overview description of the Mel deposit and also summarize the geology characteristics of the other mineral occurrences. The following descriptions are summarized largely from their article.

The Mel deposit consists of very coarse-grained, white barite and reddish-brown, coarse-grained sphalerite with late interstitial galena occurring along fractures and as selvages. Pyrite, chalcopyrite, tennantite/tetrahedrite, and covellite occur in very minor amounts. Fine-grained pyrite is disseminated in thin bands in mudstone and cherty quartz and as crosscutting veinlets through other sulphide minerals. Surface and near-surface exposures contain smithsonite, locally replacing sphalerite (Carne, 1976).

Mineralization at the Mel deposit is stratabound and forms a lens about 800 m long and up to 22 m thick near its centre. The deposit has been drill-tested to a depth of 300 m; it remains open at depth. Barite content is greatest at the centre of the deposit and zinc content is greatest at the margins. Lead content is greatest in an irregular band extending to depth near the centre of the deposit.

Alteration associated with mineralization consists of silicification and locally dolomitization of the limestone. Mudstone bands in the limestone in the vicinity of the deposit are sericitic.

The Mel-East showings (095D 027) were discovered in 1981 while following up stream geochemistry. Mineralization consists of disseminated smithsonite blebs ranging from less than 1 mm to 20 mm in size at the stratigraphic top of a thick massive limestone bed in Rabbitkettle Formation. It is poorly exposed for a strike length of 170 m. True width is unknown but may exceed 3 m. Mineralization is associated with dolomitization and silicification of the massive limestone over a width of 10 m.

Smithsonite mineralization was found in three occurrences in silicified dolostone at the stratigraphic top of a massive limestone unit in Rabbitkettle Formation on the Jeri claims (095D 032) in 1984. Mineralization comprises veins and discontinuous masses of smithsonite up to 1 m thick with the total width of mineralization exceeding 11 m.

Mineralization at the Jeri North was discovered in 1995 by drilling on coincident IP and geochemical anomalies north of the Jeri zone (also 095D 032). Mineralization consists of coarse brown sphalerite and quartz infilling fractures in a strongly silicified limestone at the top of the same massive limestone unit hosting the Jeri smithsonite occurrences.

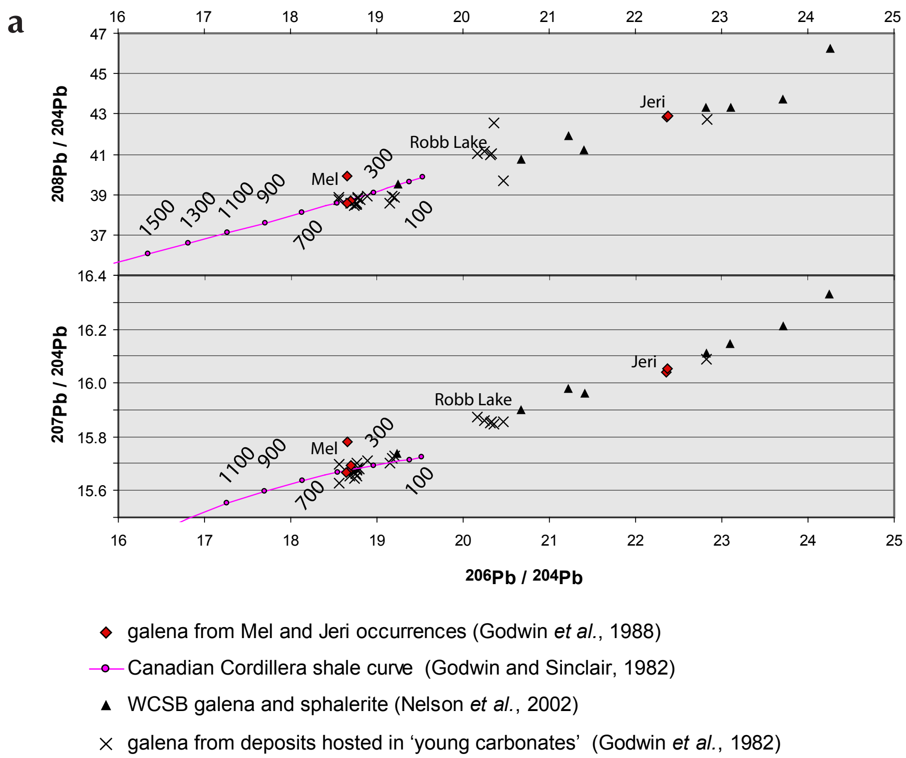
Mineralization at the above occurrences has been difficult to classify unambiguously into a particular deposit type. Yukon MINFILE descriptions currently consider the occurrences as replacement (Mel), sedimentary exhalative (SEDEX, Jeri), or Mississippi Valley-type (MVT, Mel-East) mineralization. In all occurrences, mineralization is stratabound. Extensive silicification and dolomitization are generally associated with the mineralization. Mineralization is coarse-grained; fine laminar mineralization has not been noted at any of the occurrences. Smithsonite occurrences at the Jeri and Mel-East showings are most likely related to supergene weathering of primary sphalerite (Hitzman *et al.*, 2003). Miller and Wright (1986) noted that these different features do not preclude either a syngenetic or epigenetic origin. Possible deposit models include SEDEX (syngenetic), manto replacement (epigenetic), barite vein (epigenetic) and MVT (epigenetic). The barite vein model is not considered plausible given the general stratabound character of the different occurrences.

Selwyn basin and Kechika trough contain major syngenetic zinc-lead-barite deposits that formed during regional mineralizing events of Cambrian-Ordovician (Anvil district), Silurian (Howards Pass district), and Devonian-Mississippian ages (MacMillan Pass and Gataga districts; Abbott *et al.*, 1986). Previous lead-isotope studies of galena samples from Selwyn basin and Kechika trough provide pertinent information for assigning the mineralization of the NTS 95D/6 mineral occurrences to one of these mineralizing events.

Three galena samples from the Mel deposit and one galena sample from the Jeri showing were analysed as part of a Canadian Cordillera study (Godwin *et al.*, 1988). Figure 24a displays the galena lead isotope ratios for the Mel and Jeri occurrences; the figure also shows the lead isotope growth curve for average shales in the Canadian Cordillera as derived from syngenetic SEDEX deposits of known age (Godwin and Sinclair, 1982) and galena lead isotope ratios for epigenetic mineralization as reported in Godwin *et al.* (1982) and Nelson *et al.* (2002). Figure 24b is a more detailed chart for the Paleozoic part of the Cordillera shale curve and includes galena-lead isotope ratios for the Mel deposit, Silurian syngenetic deposits (Howards Pass), and Devonian-Mississippian syngenetic deposits (MacMillan Pass, Gataga; Godwin *et al.*, 1988; Godwin and Sinclair, 1982). Two of the Mel galena samples are noticeably more radiogenic than the galena samples from the Silurian Howards Pass deposits and plot on the shale curve in the same general cluster as the Devonian-Mississippian SEDEX deposits from Selwyn basin and Kechika trough. This is consistent with Mel galena being deposited from Selwyn basin regional hydrothermal fluids in Devonian-Mississippian time. Mel mineralization is therefore consistent with epigenetic deposition.

The Jeri galena-lead ratios are much more radiogenic (Fig. 24a) and plot along a straight line delineated by galena occurrences in Middle Ordovician to Devonian carbonates (Godwin *et al.*, 1982; Nelson *et al.*, 2002). The lower limit for this straight line coincides with the cluster of Devonian-Mississippian syngenetic SEDEX and Mel galena-lead ratios. Godwin *et al.* (1982) and Nelson *et al.* (2002) suggested that this linear trend defines a mixing line between Devonian-Mississippian shale curve lead and an extremely radiogenic end-member. Regional flow of Devonian-Mississippian hydrothermal fluids dissolved the radiogenic lead by nonequilibrium processes during transport before deposition. Jeri galena-lead ratios, therefore, can also be considered consistent with a Devonian-Mississippian mineralization event.

Mel and Jeri galena-lead isotope ratios are consistent with the Devonian-Mississippian mineralizing event in Selwyn basin. Since the mineralized showings occur in the Cambrian-Ordovician Rabbitkettle Formation, mineralization is considered epigenetic rather than syngenetic. Therefore manto replacement and MVT



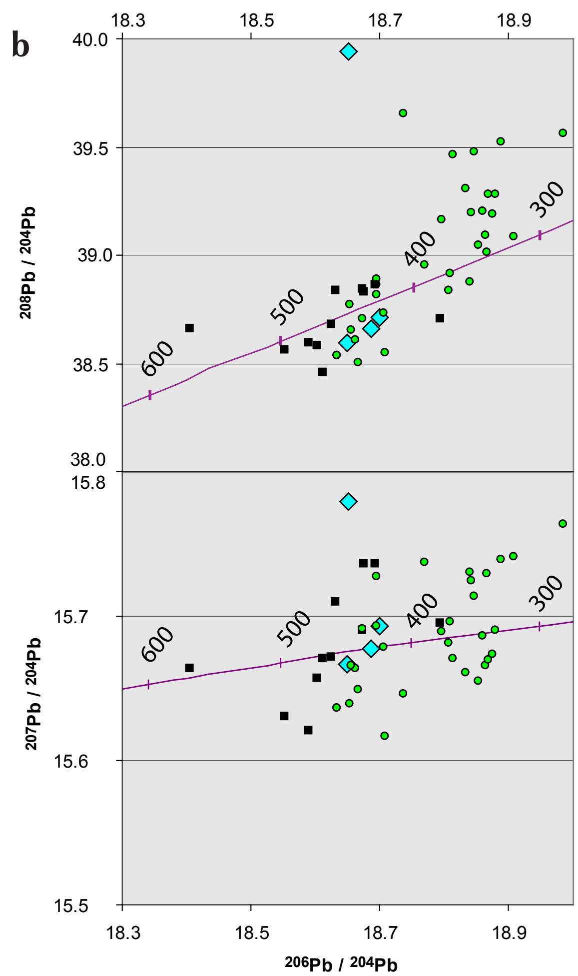


Figure 24. (a)*Galena-lead isotope ratios for Mel and Jeri occurrences from Godwin et al. (1988). Cordilleran shale growth curve (Godwin and Sinclair, 1982) also plotted on figure; inclined numbers are ages in Ma along shale curve. Silurian and Devonian shale-hosted SEDEX deposits, zinc-lead occurrences from Ordovician-Devonian carbonates (Godwin et al., 1982; Nelson et al., 2002), and NTS 95D/6 mineralization.* ***(b)*** *Enlargement of Silurian and Devonian shale-hosted SEDEX deposits and Mel galena-lead isotope ratios.*

deposit models are most appropriate for the 95D/6 zinc-lead-barite occurrences.

Nelson *et al.* (2002) and Nelson and Colpron (2007) presented an overview of tectonics and metallogeny for the western margin of North America during Devonian-Mississippian time. They argued for shale-hosted SEDEX deposits and some volcanic massive-sulphide (VMS) deposits of Selwyn basin and Kechika trough and carbonate-hosted MVT deposits of MacDonald and Mackenzie platforms being precipitated from the same basinal hydrothermal brines. Expulsion of these fluids occurred along deep-seated extensional structures in a back-arc to continental tectonic environment. Extension was caused by slab roll-back of the eastward-dipping subducting plate located west of the ancient North American continent margin.

SUMMARY

Sedimentary units within map sheet NTS 95D/6 range in age from Neoproterozoic through Lower Carboniferous. Strata are part of the ancestral North American miogeocline. The map area contains the south to north transition between Silurian-Devonian carbonate of the MacDonald platform and carbonaceous marine shales of Selwyn basin.

All units were deformed during the Jurassic-Tertiary Cordilleran orogeny. The predominant deformation style consists of north-trending, east-verging, asymmetric, tight folds accompanied by an axial-planar slaty cleavage. Six macroscopic fold axial traces have been identified in an east-west transect across the map area. Shortening due to folding is about 25%; macroscopic folds have interpreted fold amplitudes of 500 to 2000 m. Narchilla Formation is thrust eastward with unknown displacement over Cambrian-Devonian strata along the west margin of the map area. One small-scale east-verging thrust in the southern part of the map area places Cambrian-Ordovician strata over Silurian-Devonian carbonates. Late northeast-trending normal faults consistently have south-side down displacement, preserving younger strata to the south. Normal faults offset fold-axial traces, indicating a strike-slip component to fault movement.

Four epigenetic zinc±lead±barite deposits and occurrences are located at the stratigraphic contact between massive limestone and argillaceous limestone within the Cambrian-Ordovician Rabbitkettle Formation. Classification of the occurrences according to genetic models has not previously been systematic because of confusing characteristics recorded for the different showings. Characteristics of the mineralization and lead isotopes in galena suggest that mineralization is most consistent with an epigenetic Mississippi Valley-type or manto replacement type deposit model. Mineralization is correlated with the major Cordilleran Devonian-Mississippian mineralizing event which formed SEDEX and some VMS deposits in Selwyn basin and MVT deposits in adjacent MacDonald and Mackenzie platform carbonates.

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