Preliminary observations on the geology and mineralogy of the Rapid Creek Formation, Blow River and Davidson Mountains map area (NTS 117A/8 and NTS117 A/9), Yukon

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ABSTRACT

The Rapid Creek Formation, exposed at Big Fish River and Rapid Creek, in the Richardson Mountains of Yukon is well known for its rare phosphate minerals. Mapping, geochemical sampling, and collection of phosphate minerals and nodules from this formation occurred over a three week field program in the summer of 2012. The Rapid Creek Formation is a phosphorite-rich ironstone facies composed of alternating beds of phosphate and siderite-rich mudstones and shale. Secondary minerals collected from crosscutting mineralized veins in this area include unusual apatite, augelite, arrojadite group minerals, dypingite, lazulite, and garyansellite-kryzhanovskite. Phosphate nodules with satterlyite, wolfeite, vivianite-barićite, wicksite, and arrojadite-group minerals have been identified and collected for study.

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INTRODUCTION

Phosphate minerals were first discovered in the Rapid Creek area when Campbell (1962) identified lazulite, $MgAl_2(PO_4)_2(OH)_2$, in samples collected by B. Cameron, but this early discovery was not followed up on. In the 1970s, F.G. Young, a geologist with the Geological Survey of Canada noted this occurrence which drew the attention of Welcome North Mines (Young, 1972; Young and Robertson, 1984). Subsequently Al Kulan, prospector and Director of Welcome North Mines, found large well-crystallized specimens of lazulite and other phosphate minerals while staking claims in the area (Young and Robertson, 1984; Robinson *et al.*, 1992). The incredible quality of the crystals of rare phosphates such as wardite, $NaAl_3(PO_4)_2(OH)_4{\cdot}2H_2O$, arrojadite-group minerals, and lazulite (now recognized as Yukon's official gemstone) prompted numerous collecting trips to the area by Royal Ontario Museum mineralogists throughout the 1970s (Robinson *et al.*, 1992). There have been fifteen new minerals discovered from this region, including barićite (Sturman and Mandarino, 1976), gormanite (Sturman *et al.*, 1981a), marićite (Sturman *et al.*, 1977), nahpoite (Coleman and Robertson, 1981), satterlyite (Mandarino *et al.*, 1978), and wicksite (Sturman *et al.*, 1981b). More recently, previously collected samples from this locality have been studied with modern instruments resulting in the description of bobdownsite (Tait *et al.*, 2011), and new arrojadite group end members (Tomes, in progress). Many studies in the 1970s and 1980s described these new minerals but only studies by Robertson (1980, 1982), Young and Robertson (1984) and Yeo (1992) have considered the geological setting of these minerals.

The Rapid Creek Formation is unusual in a number of respects: (1) the formation conditions for phosphorites and siderite-rich ironstones are not complementary to one another; (2) primary mineralogy in most phosphorite consists of carbonate-rich fluorapatite (commonly known as francolite), $Ca_5(PO_4,CO_3)_3(F,O)$; however, at Big Fish River the principal mineralogy consists of microcrystalline secondary phosphate minerals with an unknown Ca-Fe-Mg phosphate origin (Robertson, 1980, 1982). (3) The geological environment that allowed these assemblages of rare phosphates to form is unique; the sedimentary rocks host several mineral species previously known only from igneous and more highly metamorphosed environments.

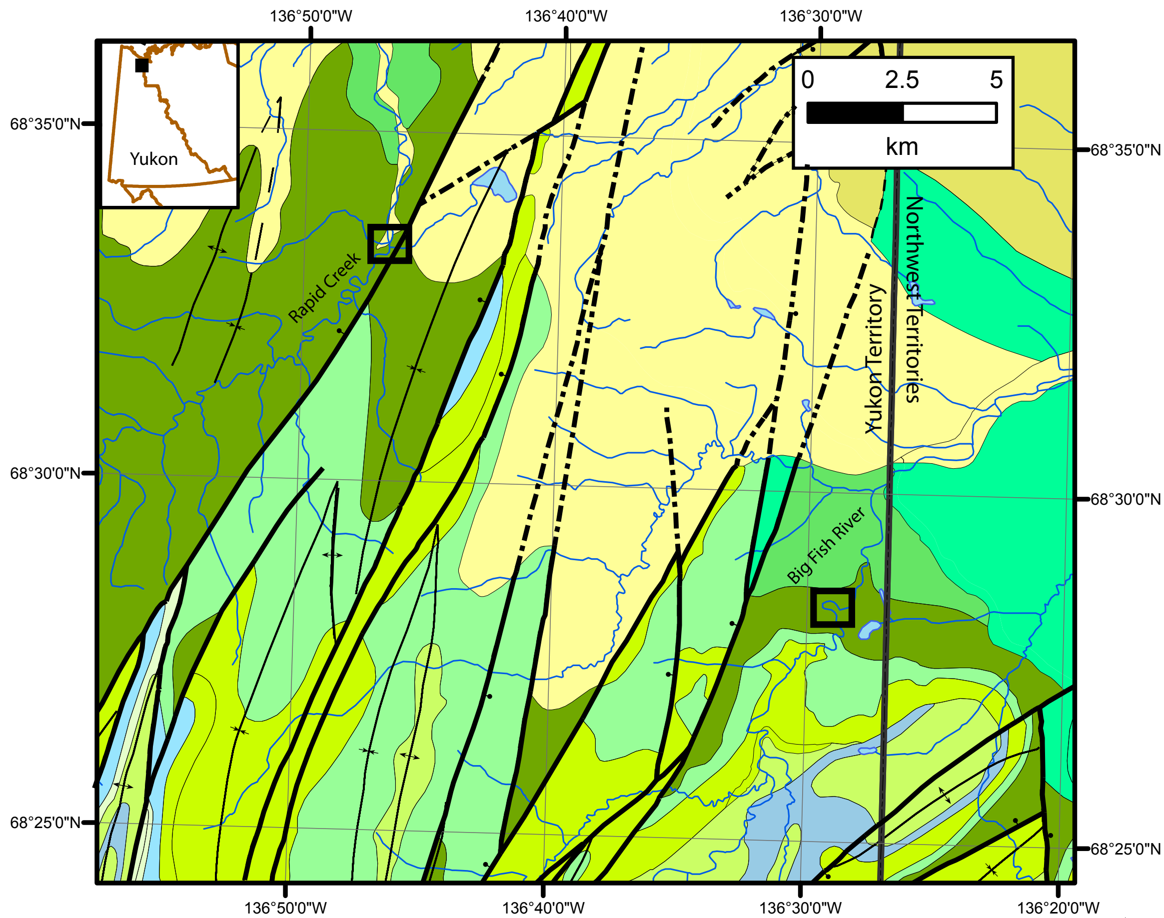
The current study has set out to elucidate the relationships between the host ironstone and the unusual secondary phosphate minerals found at this locality. In the summer of 2012, the authors completed a three week, preliminary mapping and geochemical sampling field program of the Rapid Creek Formation at Big Fish River, Yukon and collected specimens from both Rapid Creek and Big Fish River. A preliminary study of the geological setting and mineralization observed during this field program is presented here.

GEOLOGICAL SETTING

The phosphatic ironstone deposit at Rapid Creek and Big Fish River lies within the Richardson Mountains in northeast Yukon (Fig. 1; Young *et al.*, 1976). The sediments were deposited as part of an Aptian-Albian flysch sequence in the Blow trough, a structural depression about 50 km wide that runs approximately north-south (Young and Robertson, 1984; Robinson *et al.*, 1992). The sequence was bordered by the Cache Creek High to the east, where the Richardson Mountains are now located, and uplift to the west (Young and Robertson, 1984; Robinson *et al.*, 1992). The combination of subsidence of the Blow trough and erosion due to the uplift to the west resulted in the formation of a thick sequence of turbidite sandstone, conglomerate, mudstone, and shale which thins towards the eastern structural high and grades into the Rapid Creek Formation (Young and Robertson, 1984; Robinson *et al.*, 1992). The flyschoid sequence was buried by approximately 1500 to 3000 m of sediment during the Late Cretaceous and Early Tertiary, and was later affected by the onset of Tertiary Laramide deformation, which caused faulting, compression, uplift, and erosion to occur, bringing the Albian portion of the sequence to the present day surface (Young and Robertson, 1984).

RAPID CREEK FORMATION

The strata studied here have been called various names such as the Aptian-Albian flysch division (Young *et al.*, 1976), the upper Aptian to lower Albian flysch (Jeletzky, 1971), the Albian flyschoid phase (Young, 1973; Norris and Yorath, 1981), and the Aptian-Albian flysch sequence (Young, 1972). Yeo (1992) notes that Robertson (1980, 1982) proposed the name the Rapid Creek Formation but disputes this title commenting that at least three units of formation rank are described within this by Norris (1981, 1983) and Young (1977). Yeo (1992) describes a Rapid Creek group that includes three map units from Norris (1981) Ksr, Krr, and Kbr and informally calls the unit of interest the Blow River Formation. However, Yeo (1992) overlooks the description by Young and Robertson (1984)



Legend

QUATERNARY

QUATERNARY: Hummocky or ridged moraine in area of Laurentide glaciation

UPPER CRETACEOUS AND LOWER TERTIARY

FISH RIVER GROUP: Moose Channel Formation: lower part: sandstone, conglomeritic, lithic; alluvial and deltaic

TENT ISLAND FORMATION: upper member: mudstone and sandstone; marine; includes Cuesta Creek Member

BOUNDARY CREEK FORMATION: mudstone, bituminous, bentonitic, ironstone concretions; marine

LOWER CRETACEOUS

Kbr: RAPID CREEK FORMATION: sandstone, conglomerate and shale; flyschoid

Krr: RAT RIVER FORMATION: interbedded units of sandstone and shale; marine

UNDIVIDED: shale, siltstone, sandstone and coal; marine and nonmarine; includes Mount Goodenough Formation

McGUIRE FORMATION: shale, siltstone and very fine grained argillaceous bioturbated sandstone; ironstone concretions in lower beds; marine

MARTIN CREEK FORMATION: sandstone, coal, and shale; marine and nonmarine

JURASSIC AND LOWER CRETACEOUS

KINGAK FORMATION: dark grey siltstone and shale; marine

PORCUPINE RIVER FORMATION: siltstone and fine to very fine grained sandstone; marine and nonmarine

HUSKY FORMATION: shale, siltstone and ironstone; marine

Symbols

geological boundary...

syncline (defined, approximate)...

anticline (defined, approximate)...

fault, extention (solid cicle indicates downthrow side; defined, approximate).......................

Figure 1. *General geology map showing the location of the Kbr unit from Norris (1981) which is equivalent to the Rapid Creek Formation. The study areas along Big Fish River and Rapid Creek from the 2012 field season are indicated by black squares. Inset shows general location of study area in Yukon. Modified from Norris (1981).*

which formally names the ironstone facies previously known as the Bedded ironstone and shale unit (Young, 1972, 1973, 1977; Young *et al.* 1976) of the Aptian-Albian flysch division as the Rapid Creek Formation. According to the outcrop map in Young and Robertson (1984) the Rapid Creek Formation is equivalent to, at minimum, parts of the Kbr formation from Norris (1981). Here the unit is called the Rapid Creek Formation based on the formal name and description published by Young and Robertson (1984).

The Rapid Creek Formation is about 1000 m thick in the eastern Blow trough, west of Rapid Creek (Young and Robertson, 1984; Robinson *et al.*, 1992). At Big Fish River the formation thins to approximately 60 m, however faulting has overlain the unit upon itself so correlation of beds in order to determine thickness is difficult (Young and Robertson, 1984; Robinson *et al.*, 1992). The Rapid Creek Formation consists of alternating thin to medium beds of phosphatic ironstone and iron-rich dark grey shale (Fig. 2a,b), which form a widespread yet low-grade iron deposit, with reserves calculated at 10^{10} tonnes of Fe_2O_3 equivalent (Young, 1977; Young and Robertson, 1984). The Upper Cretaceous shale of the Boundary Creek Formation overlies the Rapid Creek Formation everywhere the contact is exposed (Young and Robertson, 1984). The lower contact is more variable and is within the shale and siltstone of the general flyschoid sequence in the Blow trough (Fig. 3a; Young and Robertson, 1984). It lies immediately above a facies correlative with the Aptian-aged Rat River formation, consisting of concretionary dark grey shale, sandstone, and siltstone (Fig. 3b; Young and Robertson, 1984).

The sedimentology of the Rapid Creek Formation is of interest due to the unique composition of phosphate grains within some of the ironstone facies (Robertson, 1980, 1982; Young and Robertson, 1984). The phosphate grains within the coarser grained sediments consist of arrojadite-group minerals, satterlyite, $(Fe^{2+},Mg,Fe^{3+})_2(PO_4)$-$(OH,O)$, and gormanite, $(Fe^{2+},Mg)_3(Al,Fe^{3+})_4(PO_4)_4$-$(OH)_6{\cdot}2H_2O$, the latter two of which were first described from this formation (Robertson, 1980, 1982; Young and Robertson, 1984). Robertson (1980, 1982) suggests that the sediments originally contained an unknown Ca-Fe-Mg phosphate which was altered to these unusual phosphates during low-grade metamorphism. In the mudstones, the unknown phosphate altered to carbonate-apatite, occurring with siderite, as well as gormanite-souzalite alteration/replacement (Robertson, 1980, 1982). The ironstone unit at Big Fish River has a P_2O_5 content of approximately 14%, varying up to 30% (Young, 1977).

The Rapid Creek Formation at Big Fish River is exposed as high cliffs, often with a white coating of epsomite, $MgSO_4{\cdot}7H_2O$, or possibly dypingite, $Mg_5(CO_3)_4(OH)_2{\cdot}5H_2O$ (Fig. 4). It consists of siderite-rich ironstone units of interbedded mudstone and iron-rich shale and pelletal phosphate shale (Robertson, 1982; Young and Robertson, 1984). The mudstone layers, which sometimes appear pelletal and show evidence of gormanite-souzalite alteration, are 1 cm to 1 m thick, but are typically less than 20 cm thick (Fig. 5a). A steel-blue weathering patina is characteristically found on these mudstone layers (Fig. 5b). These layers are interbedded both with splintery iron-rich shale and pelletal phosphate shale, which are often thinly bedded (Fig. 6a,b). Near

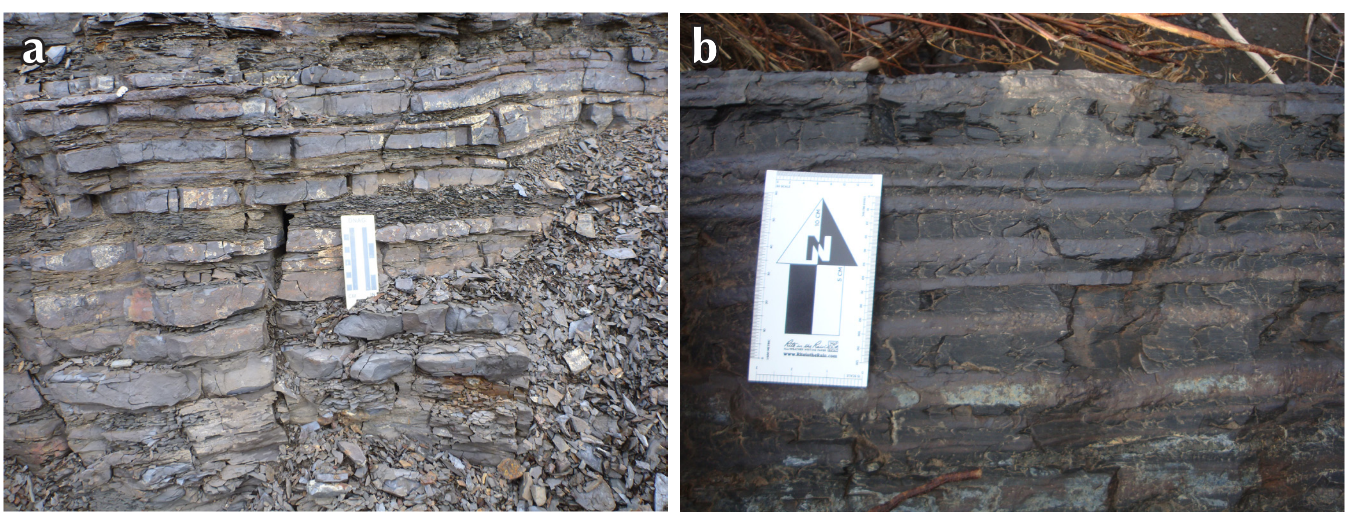


***Figure 2**. a) Intercalated thin to medium beds of phosphatic siderite-rich mudstone & shale and b) unweathered block at base of a rock slide (not in situ) showing fresh ironstone.*

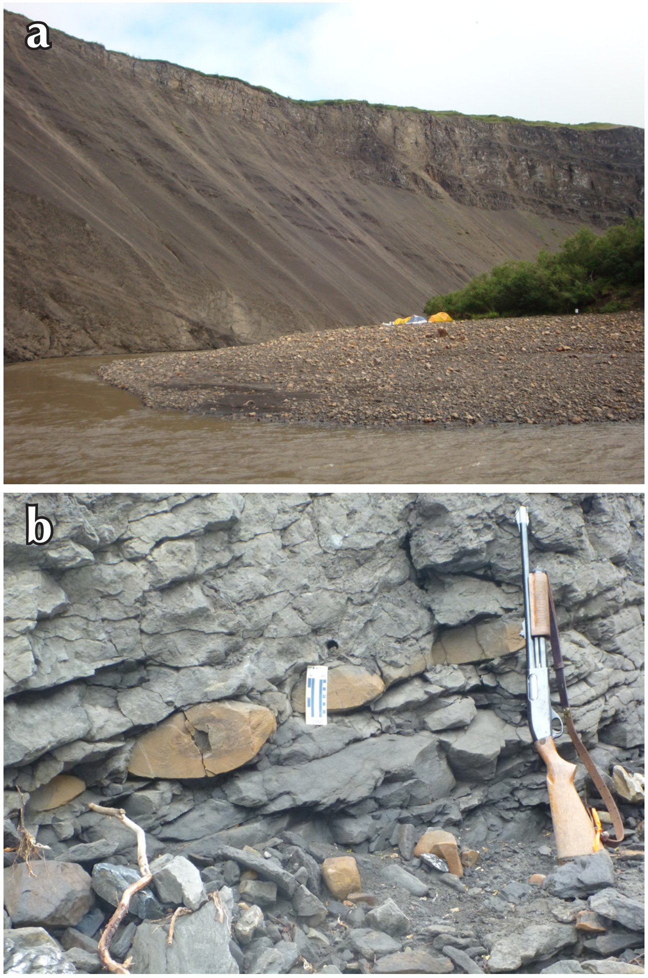


Figure 3. *a) Lower contact between Rapid Creek Formation and the Rat River Formation dark grey concretionary shale and b) large concretions in sandstones of the Rat River Formation.*

Figure 4. *Cliffs of Rapid Creek Formation at Big Fish River with a white coating of epsomite, $MgSO_4 \cdot 7H_2O$, and/or dypingite, $Mg_5(CO_3)_4(OH)_2 \cdot 5H_2O$.*

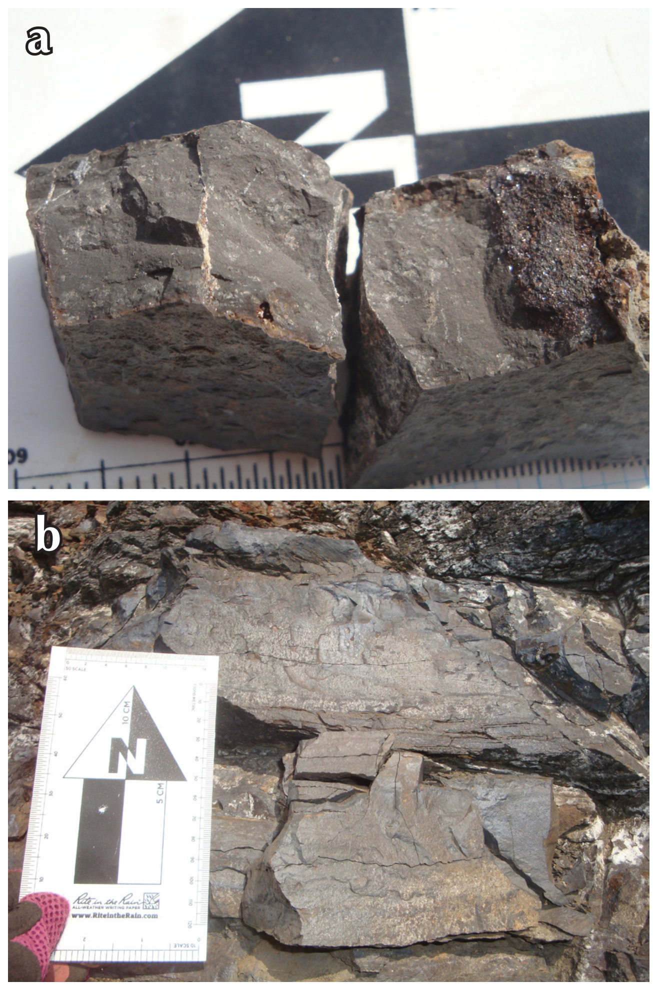


Figure 5. *a) Iron-rich mudstone layers, sometimes appearing pelletal and b) mudstone with characteristic steel-blue weathering patina.*

fault zones, the thinly bedded shale is frequently host to bedding-parallel mineralization of vivianite-barićite (Fig. 7a). These mineralized layers show growth fibres, which occasionally show minor shearing (Fig. 7b). Dark grey shale, with white unidentified spherules and small concretions (Fig. 8a-d) was identified in the former river bed near the base of the Rapid Creek Formation at Big Fish River suggesting they are part of the underlying Rat River Formation. However, the gormanite-souzalite-siderite veins occurring in these strata and their occasional presence between pelletal shale layers in the lower strata suggest they are related to the Rapid Creek Formation. Bulk analysis of the dark grey shale is being performed to identify the quantity of iron and phosphorus in this unit and detailed petrography of each of these layers is currently in progress.

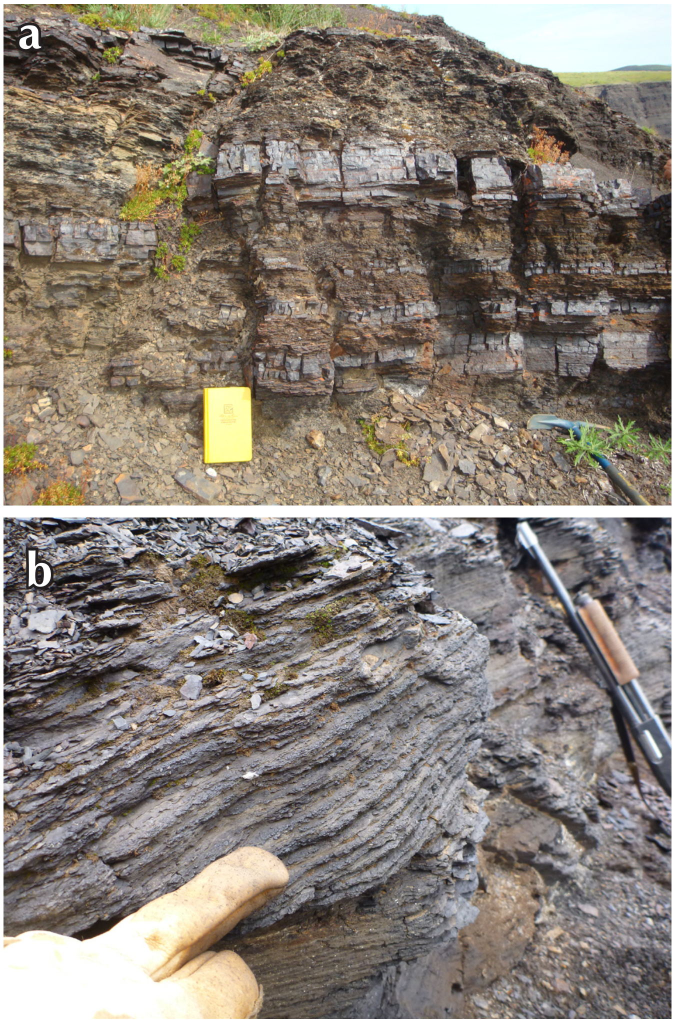


***Figure 6**. a) Interbedded mudstone and splintery iron-rich shale, notebook for scale and b) thinly bedded pelletal phosphate shale, shotgun for scale.*

SECONDARY MINERALS

The Rapid Creek and Big Fish River localities are most famous for their exceptional rare and unique mineral specimens. These minerals are generally found in thin fracture filling veins typically a few centimetres wide, with the most spectacular specimens plucked from wider pockets. These veins crosscut the strata of the Rapid Creek Formation and occur in specific mineralogical associations which are described in Robertson (1982). Generally, these veins are abundant with a greater variety of mineral species occurring near to fault zones. Descriptions of some of the minerals collected during the 2012 field program follow.

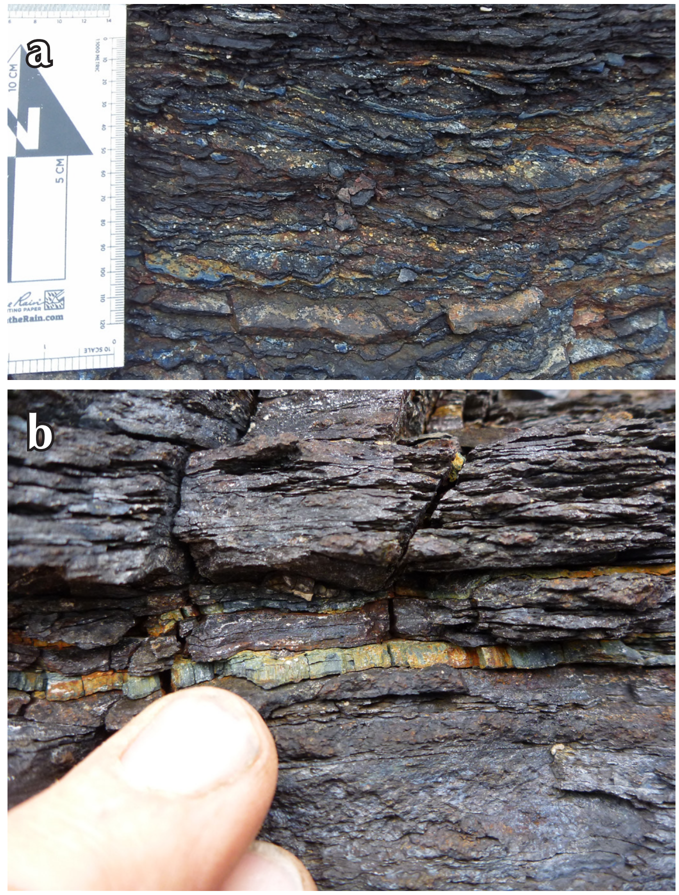


***Figure 7**. a) Thinly bedded shales hosting to bedding-parallel mineralization of vivianite-baricite (blue mineral in photo) and b) Fibrous growth of vivianite-baricite mineralization.*

APATITE-GROUP MINERALS

Although Rapid Creek is known more for the other rare-phosphates the area has yielded some spectacular purple crystals of apatite. These purple crystals have been found in three areas at this locality, with the finest ones from locality 8 as noted on the map in the Mineralogical Record 23, no. 4, 1992 paper. This find is on an unnamed creek, approximately 1.7 km south of the tributary to Rapid Creek, sometimes referred to as “Crosscut Creek” (68°32′30″N, 136°47′40″W).

In 1983, George Robinson collected some very pale mauve apatite crystals from locality 1, area ‘A’, ‘Kulan camp’ and in 1984 Joel Grice and Bob Gault collected pale mauve crystals from ‘Grizzly Bear Creek’, locality 14, area ‘B’, ‘Stoneman camp’. Whereas these crystals were larger than those from locality 8, area A, they were much paler in colour. These apatite crystals are most commonly

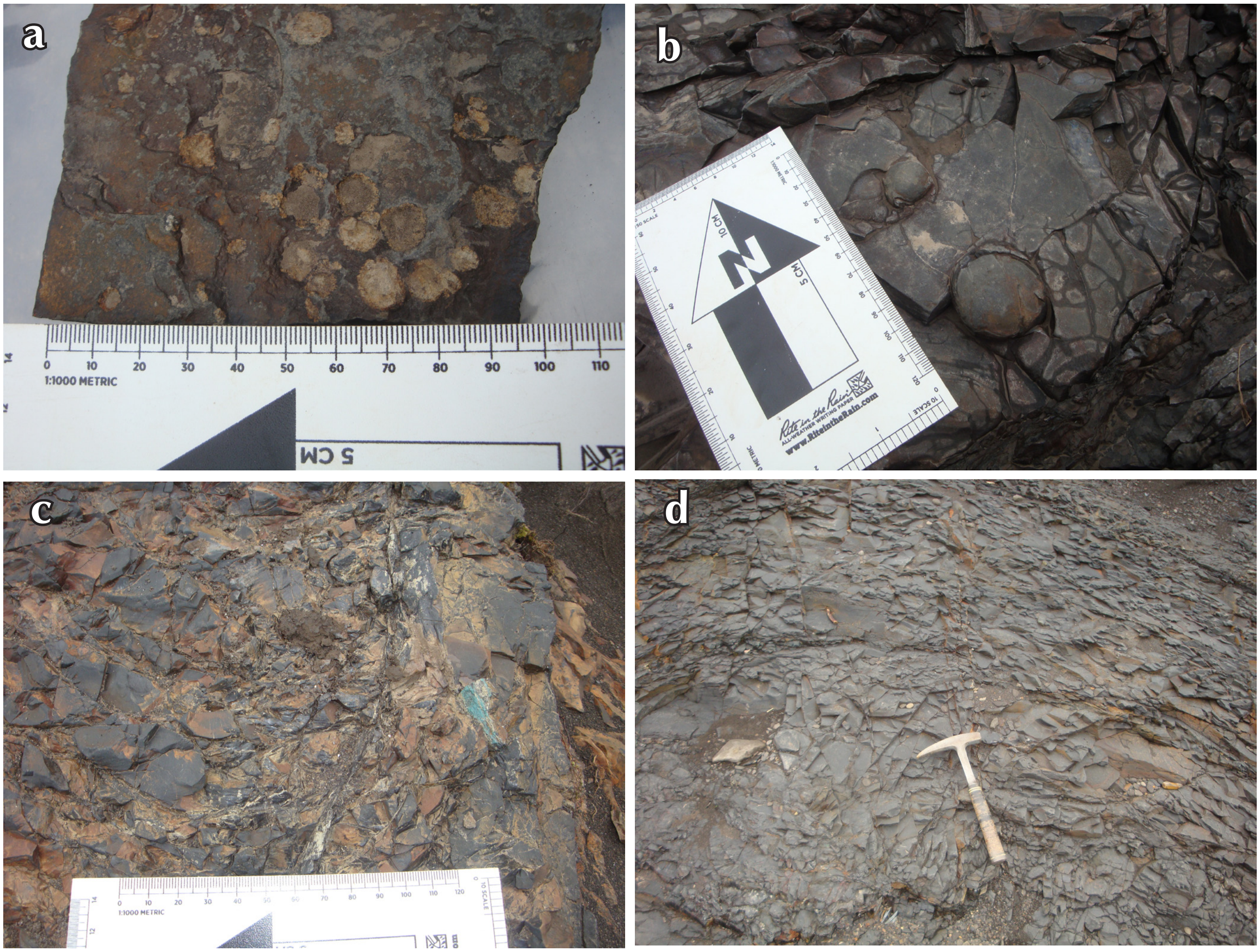


Figure 8. *Dark grey shales: a) white unidentified spherules; b) small concretions; c) gormanite-siderite veins occurring in the dark grey shale; and d) weathered dark grey shale, no white spherules.*

associated with lazulite, quartz, and siderite and range in size from microscopic to nearly 2 cm across.

During the summer of 2012 another apatite association was noted here. The arrojadite-quartz-(±apatite) veins were part of a crosscutting system not part of, what appeared to be, the primary depositional sequence. In these veins, well crystallized arrojadite group minerals and quartz were common, but in the larger pockets, apatite crystals were common, but were quite small (3-7 mm). They are transparent, colourless, striated, hexagonal prisms.

Right at the base of the bobdownsite-whitlockite locality, along a cliff face in the water, a new vein was observed. The vein crosscuts the primary strata, with milky, opaque, tabular (~1.2 cm) hexagonal shaped crystals (Fig. 9). These crystals are shortened along their *c*-axis compared to more typical apatite from Rapid Creek or Big Fish River (or most

Figure 9. *Tabular apatite from Big Fish River, FOV = 5x3 cm. Photo courtesy of the Royal Ontario Museum, ©ROM.*

other localities for that matter) and have virtually no discernible pinacoid faces. Under magnification they are actually composite crystals composed of multiple individuals in parallel growth which, none the less, maintain an overall hexagonal outline macroscopically.

ARROJADITE-GROUP MINERALS

Arrojadite-group minerals are a large group of phosphates with exhibiting complex chemical variations. They have the general formula $A_2 B_2 Ca_1 Na_{2+x} M_{13} Al (PO_4)_{11} (PO_3OH_{1-x})W_2$ where *A* are monovalent cations (K, Na) or large divalent cations (Ba, Sr, Pb) plus vacancy; *B* are either monovalent (Na) cations or small divalent cations (Fe, Mn, Mg) plus vacancy; *M* can include Fe, Mn, Mg, Zn, or Li; and *W* is OH or F (Chopin *et al*., 2006). The base name "arrojadite" is used only when the *M* cation is predominantly Fe, whereas an Mg dominant species would be "dickinsonite". Dickinsonite end-members have not been identified from these localities. Members of this group were thought to be primarily found in granitic pegmatites until being discovered in the sedimentary ironstones at Rapid Creek in the 1970s (Chopin *et al.*, 2006; Robinson *et al.*, 1992). Group members have also been found more recently in metamorphic quartzite (Demartin *et al.*, 1996).

Rapid Creek is the type locality for the iron-rich end member arrojadite-KNa (KNa) $Na_2CaNa_2Fe_{13}Al(PO_4)_{11}(PO_3OH)(OH,F)_2$ (Cámara *et al.*, 2006) and recently Ba-rich and Sr-rich end members have been identified from Big Fish River samples (Tomes, 2011). The end members present here all show evidence of zoning in some samples, often alternating between arrojadite-KNa and the Ba-rich end member (Robinson *et al.*, 1992; Tomes, unpublished thesis). Crystals with Sr-rich zones are strongly zoned with the Ba-rich end member (Tomes, unpublished thesis).

Arrojadite-group minerals occur at both the Rapid Creek and Big Fish River exposures of the Rapid Creek Formation. Arrojadite-KNa is fairly common at both localities, while the Ba-rich end member has been found primarily at Big Fish River, although is present in some zoned crystals from Rapid Creek (Robinson *et al.*, 1992; Tomes, unpublished thesis). The Sr-rich end member has only been identified from Big Fish River (Tomes, unpublished thesis). Arrojadite-group minerals are found as 1-2 mm, tabular to bladed, clear to yellow to green crystals in 0.5 mm to 3 cm veins with occasional open pockets which crosscut the bedding planes. Crosscutting arrojadite veins were abundant near faulted zones at Big Fish River and the veins have brecciated the surrounding shale and mudstone layers up to approximately 3-5 cm away from the vein (Fig. 10a). Arrojadite-group minerals were associated with quartz and less frequently, small hexagonal apatite crystals (Fig. 10b). In contrast, Robertson (1980, 1982) noted the relative scarcity of veins along his stratigraphic sections at Big Fish River, when compared to the abundance of simple and complex veins at Rapid Creek. Robertson (1980, 1982) notes that arrojadite occurs with vivianite-barićite and quartz in bedding-plane parting surfaces and Robinson *et al.* (1992) report the presence of crystal lined fractures at Big Fish River. Robinson *et al.* (1992) also include kryzhanovskite, whiteite, and metavivianite as minerals associated with arrojadite; however these associations were not confirmed in the present study.

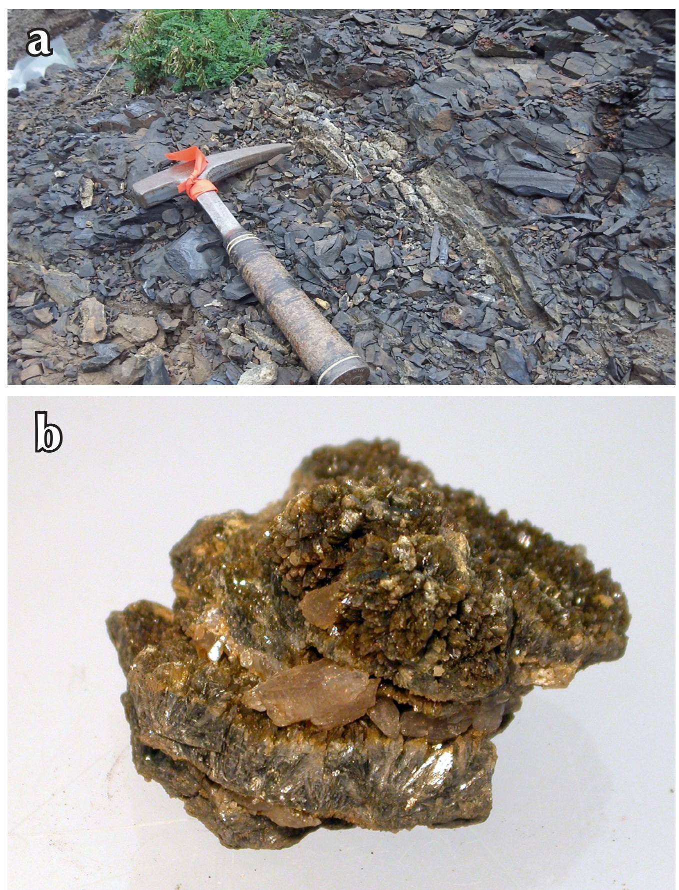


Figure 10. *Arrojadite-group minerals. a) Arrojadite-quartz-apatite vein in situ and (b) yellow-green arrojadite crystals with quartz, FOV 6 x 4 cm.*

AUGELITE

Just before the waterfall, mid-way up "Crosscut Creek", a steep defile cuts back into the southern wall of the creek's canyon at an approximate 45 degree angle. This narrow draw winds its way from the creek bed up to the tundra level and is clearly a drainage feature as water can be seen coming down a short cliff face and heard percolating through the jumbled rocks which form the floor of the canyon. A number of years ago an excellent occurrence of well crystallized lazulite specimens was discovered in a steeply dipping, heavily brecciated vein in the eastern wall of this canyon near the cliff face. The breccia zone runs parallel to the direction of the defile (approximately north-south) and reaches a maximum width of about 15 cm. Visiting the area again in 2012 an extensive amount of overburden was moved, following the course of the breccia zone, in search of more lazulite specimens. Unfortunately, the ground beneath the loose overburden was frozen, preventing further excavation. However, adjacent to the lazulite bearing vein and running approximately parallel to it were a number of tighter quartz/siderite veins which, upon closer inspection and excavation, were found to contain augelite crystals up to 5 mm in size formed on beds of childrenite and siderite crystals. The childrenite crystals reach a maximum length of 3 mm and width of approximately 1 mm and are a typical chocolate-brown colour. The augelite crystals are pale blue-green in colour.

DYPINGITE

Dypingite $Mg_5(CO_3)_4(OH)_2{\cdot}5H_2O$, closely associated with hydromagnesite $Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$ and lansfordite, was collected from an open fracture system above permafrost in the Rapid Creek — Big Fish River area in August 2012 (Fig. 11). Dypingite occurs in a botryoidal habit consisting of very fine radiating crystals forming a translucent crust of spheroidal aggregates (Fig. 12a-c). Some of the spheroids can be up to 1 mm in diameter. The fracture system is on a northwest facing slope and dypingite is found 10 cm or more below the surface coating surfaces on open fractures. The dypingite is often covered with loose and chalky hydromagnesite that is brittle and falls away from the fracture surface. The relationship suggests that the hydromagnesite forms as a dehydration product of dypingite at this locality. Elsewhere in Canada, dypingite has been observed as an alteration product of ultramafic rocks and forms through the breakdown of olivine and the introduction of CO_2 from the atmosphere (Wilson *et al.,* 2009). In some

***Figure 11**. Botryoidal habit of dypingite (white mineral). Spheroids up to 1 mm in diameter.*

areas, the formation of hydrous magnesium carbonates is accelerated through biological activity (Power *et al.,* 2009). Several mineral species belong to the hydrous magnesium carbonate mineral group. Anhydrous magnesite $MgCO_3$ is followed by barringtonite $MgCO_3{\cdot}2H_2O$, nesquehonite $MgCO_3{\cdot}3H_2O$, and lansfordite $MgCO_3{\cdot}5H_2O$ as hydration increases. Pokrovskite $MgCO_3(OH)_2$ and Mcguinnessite $(Mg, Cu)CO_3(OH)_2$ have hydroxyl as an additional anion. Dypingite $Mg_5(CO_3)_4(OH)_2{\cdot}5H_2O$, hydromagnesite $Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$, and artinite $Mg_5(CO_3)_4(OH)_2{\cdot}3H_2O$ have both hydroxyl and water as essential components. All of these phases have the potential to participate in the sequestration of carbon dioxide from the environment and are the subject of recent research by many investigators (Mavromatis *et al.,* 2012). The Big Fish River occurrence of dypingite is unusual as it is not related to the alteration of ultramafic rocks but is located within a sequence of phosphate-rich sedimentary rocks. However, a magnesium sulfate, epsomite ($MgSO_4{\cdot}7H_2O$), is commonly coating cliff faces throughout the area.

GARYANSELLITE-KRYZHANOVSKITE

The phosphoferrite group is a complex group of hydrated phosphate minerals. They have the general formula $A_3(PO_4)_2{\cdot}nH_2O$ where $A = Fe^{2+}, Fe^{3+}, Mg, Mn^{2+}$ and n is dependent on the oxidation state of the cations and the presence of OH/H_2O (Gaines *et al.*, 1997). There are three ideal end members in this group — reddingite, $Mn^{2+}{}_3(H_2O)_3(PO_4)_2$, phosphoferrite, $Fe^{2+}{}_3(H_2O)_3(PO_4)_2$, and kryzhanovskite, $Fe^{3+}{}_3(OH)_3(PO_4)_2$ — and they form a

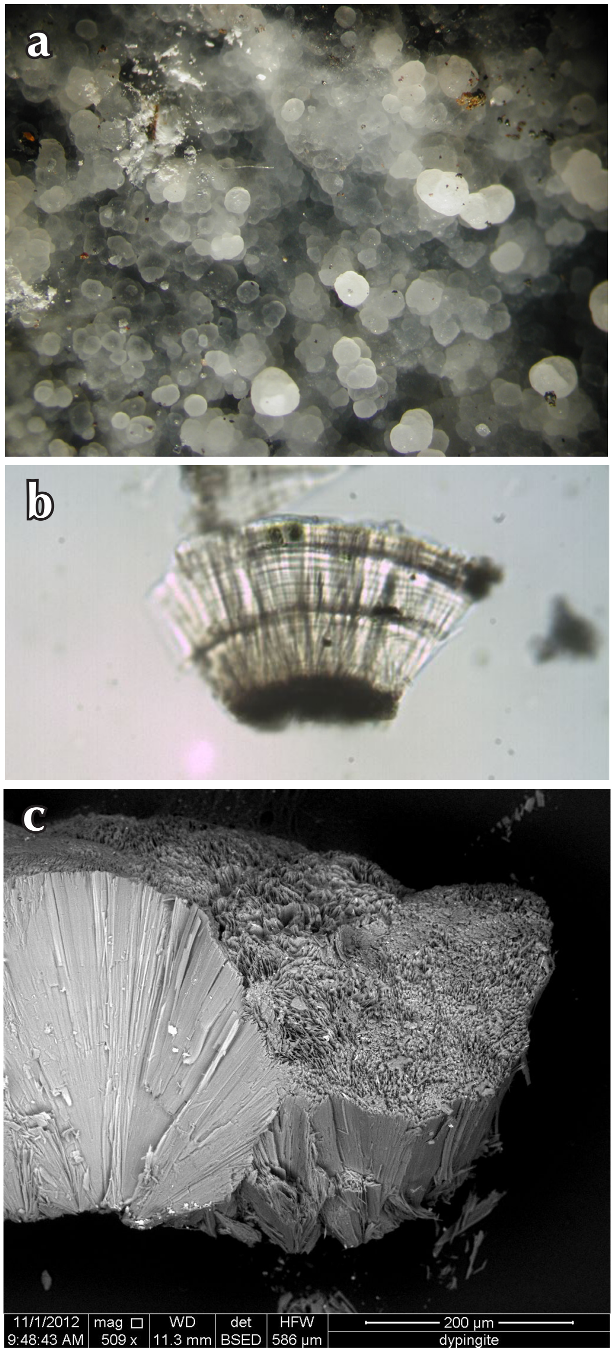


***Figure 12**. Crystals of dypingite: a) Botryoidal habit forming a translucent crust of spheroidal aggregates; FOV = 10 mm; b) very fine radiating crystals; FOV = 1 mm; and c) backscattered electron image of showing the fine radiating crystals, scale bar at the bottom of the image is 200 microns.*

complex triple series (Moore *et al.*, 1980). Other members include: garyansellite, $(Mg,Fe^{3+})_3(PO_4)_2(OH,O)\cdot 1.5H_2O$ and landesite, $(Mn^{2+}Mg)_9Fe^{3+}{}_3(PO_4)_8(OH)_3\cdot 9H_2O$. Minerals in the phosphoferrite group can be found in select regions in the world, but two key members of this group are found at Rapid Creek, with garyansellite first being described from here.

Up until now, kryzhanovskite (Fig. 13) and garyansellite are the two minerals within the phosphoferrite group that are described in the Rapid Creek region (Robinson *et al.*, 1992). The kryzhanovskite at this locality typically exist in its intermediate form, with the chemical formula $MnFe^{3+}{}_2(PO_4)_2(OH)_2\cdot H_2O$. The minerals are also relatively enriched in magnesium (Robinson *et al.*, 1992). Furthermore, most of the samples collected by Robinson *et al.* (1992) show evidence of zoning within individual crystals. They also suspected some samples may contain zones of garyansellite.

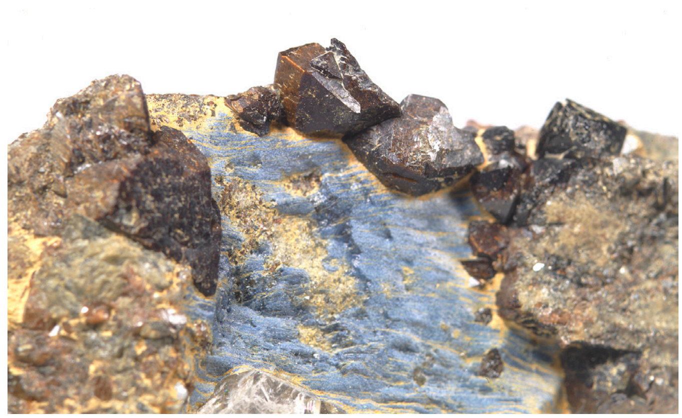


***Figure 13**. Kryzhanovskite crystals (dark brown) with vivianite (blue), metavivianite (yellow) on quartz (lighter brown) accession number M52270 from Rapid Creek, Yukon, FOV = 6x4 cm. Photo courtesy of the Royal Ontario Museum, ©ROM.*

Veins of garyansellite and kryzhanovskite are found high above Rapid Creek (68° 34′N and 136° 46′W) about 1 km north of the junction of Lake Creek. Many samples were found loose in the talus slope leading up to the outcrop. On most specimens garyansellite-kryzhanovskite occurs as plates, 1-3 mm in size, associated with ludlamite, arrojadite-group minerals, quartz, vivianite, metavivianite, and souzalite. They range from chocolate to clove to reddish brown and typically exist as subhedral to euhedral crystals, with a characteristic bronze lustre.

LAZULITE

Lazulite, $MgAl_2(PO_4)_2(OH)_2$, specimens consisting of deep blue crystals, 3-5 mm in size, closely associated with siderite and quartz, were collected from ironstone beds in the cliffs along "Crosscut creek" (Fig. 14). Lazulite is the magnesium-rich end member of a series with scorzalite

Figure 14. *Lazulite (blue) in ironstone (brown) from "Crosscut Creek", Rapid Creek area, Yukon.*

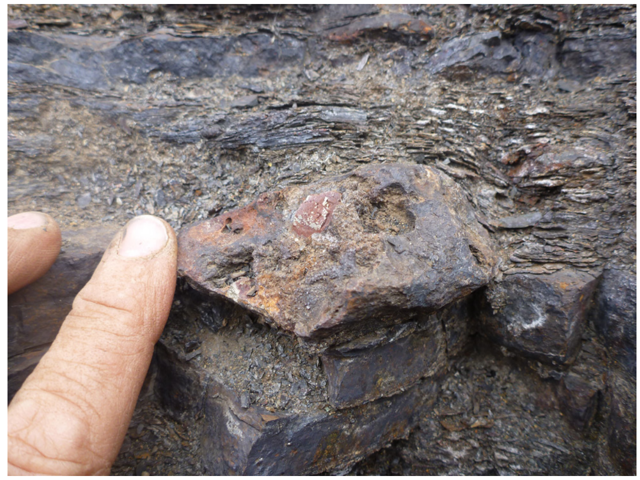


Figure 15. *Highly weathered ammonite nodule, now replaced with pyrite, which has preferentially weathered out leaving holes in the nodule.*

$Fe^{2+}Al_2(PO_4)_2(OH)_2$, which is not found in the Rapid Creek and Big Fish River area. While lazulite is abundant at Rapid Creek in crosscutting veins both in "Crosscut Creek" and nearby the garyansellite-kryzhanovskite locality, it is noticeably absent from the mineralized crosscutting veins at Big Fish River.

PHOSPHATE NODULES

The lower portion of the Rapid Creek Formation at Big Fish River is well known by collectors as the location for unusual phosphate nodules that host a variety of rare phosphate minerals (Robertson, 1980, 1982; Young and Robertson, 1984; Robinson *et al*., 1992). According to Robertson (1980, 1982) the phosphate nodules appear to be recrystallized replacement of ammonites and pelecypods, although some bear only a slight resemblance and some bear no resemblance at all to ammonites or pelecypods. Phosphatic nodules from Big Fish River are known to be dominantly composed of satterlyite, wolfeite, marićite, ludlamite, pyrite, and vivianite-barićite (Robertson, 1980, 1982). Big Fish River is the primary locality for these nodules, however Robertson (1980, 1982) reports that they also occur at Boundary Creek.

Nodules were identified both *in situ* and on talus slopes at all exposures along Big Fish River, although the type of nodules varied with position in the section. The lower portion of the Rapid Creek Formation is dominated by microcrystalline pyritic nodules (this study; Robertson, 1980, 1982). Phosphate nodules are highly weathered *in situ* making field identification of minerals difficult in some samples (Fig. 15). However, preliminary analyses of some nodules have found wicksite, arrojadite-group minerals, vivianite-barićite, satterlyite, and wolfeite. In nodules, these minerals are often found radiating from the center at the base of the nodule. Not all nodules are disc or ammonite shaped, as "cigar" shaped nodules are found at one exposure with similar "nodule-type" mineralization. Also, massive sprays of nodule-like mineralization (frequently satterlyite) were identified in large lenses parallel to the bedding planes (Fig. 16a,b) and found to be connecting small nodules within the shale layers (Fig. 17). Satterlyite was identified as radiating masses in crosscutting veins up to 15 cm wide (Fig. 18a-c). These veins are located in close proximity to fault zones. Small phosphate nodules were collected *in situ* with surrounding host rock in order to determine if these nodules are replacements, of ammonites for example, or if they grew in place, putting stress and causing small fractures in the surrounding shale (Fig. 19a,b). Extensive collection of phosphate nodules during the 2012 field season will allow determination of the distribution of mineralization in the phosphatic and pyrite nodules as well as insight into their relationship with the shale and mudstone layers.

SUMMARY

The Rapid Creek Formation, exposed at Big Fish River and Rapid Creek, in the Richardson Mountains of Yukon is well known for its rare phosphate minerals. The Rapid Creek Formation is a phosphorite-rich ironstone facies composed of alternating beds of phosphate and siderite-rich mudstones and shale. A three week field program in the

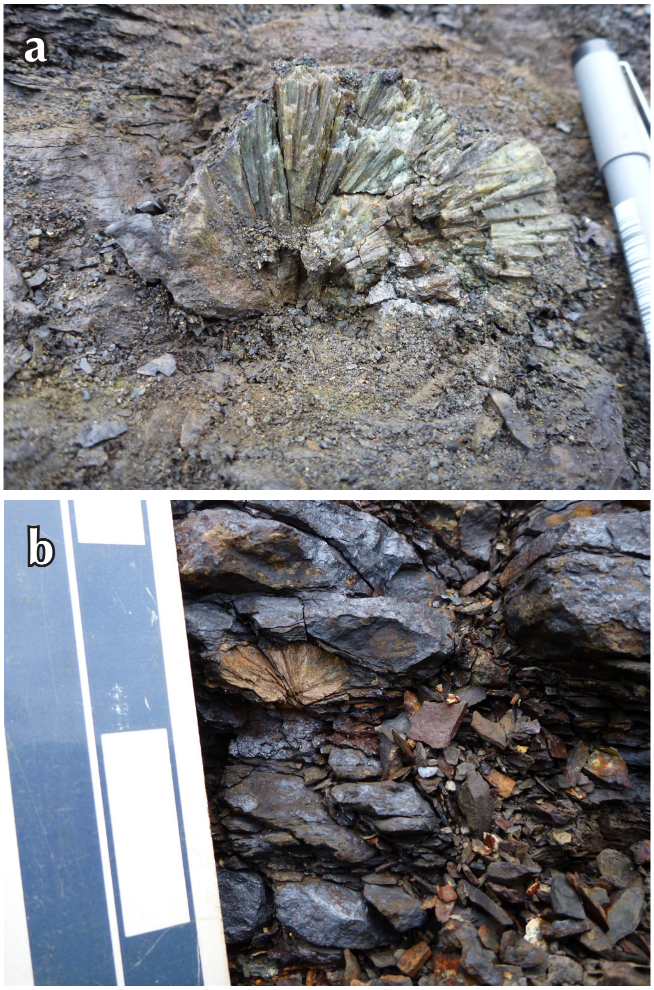


Figure 16. Nodules showing the radiating mineralization of a) appears to be highly altered satterlyite/wolfeite and b) highly weathered wolfeite.

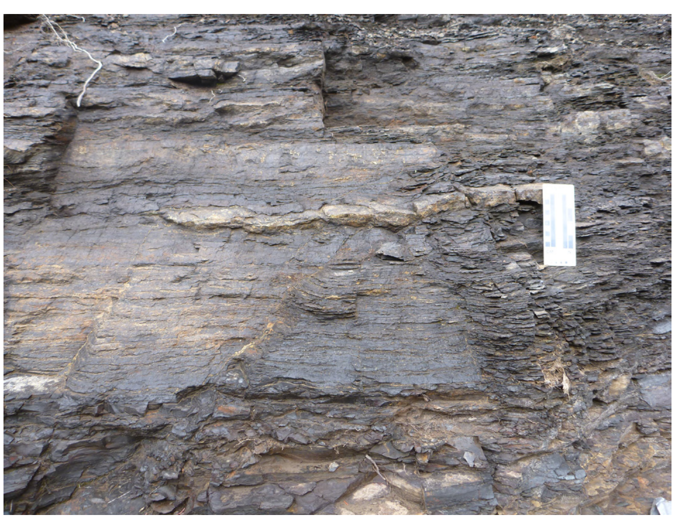


Figure 17. Large lense of nodule material in ironstone.

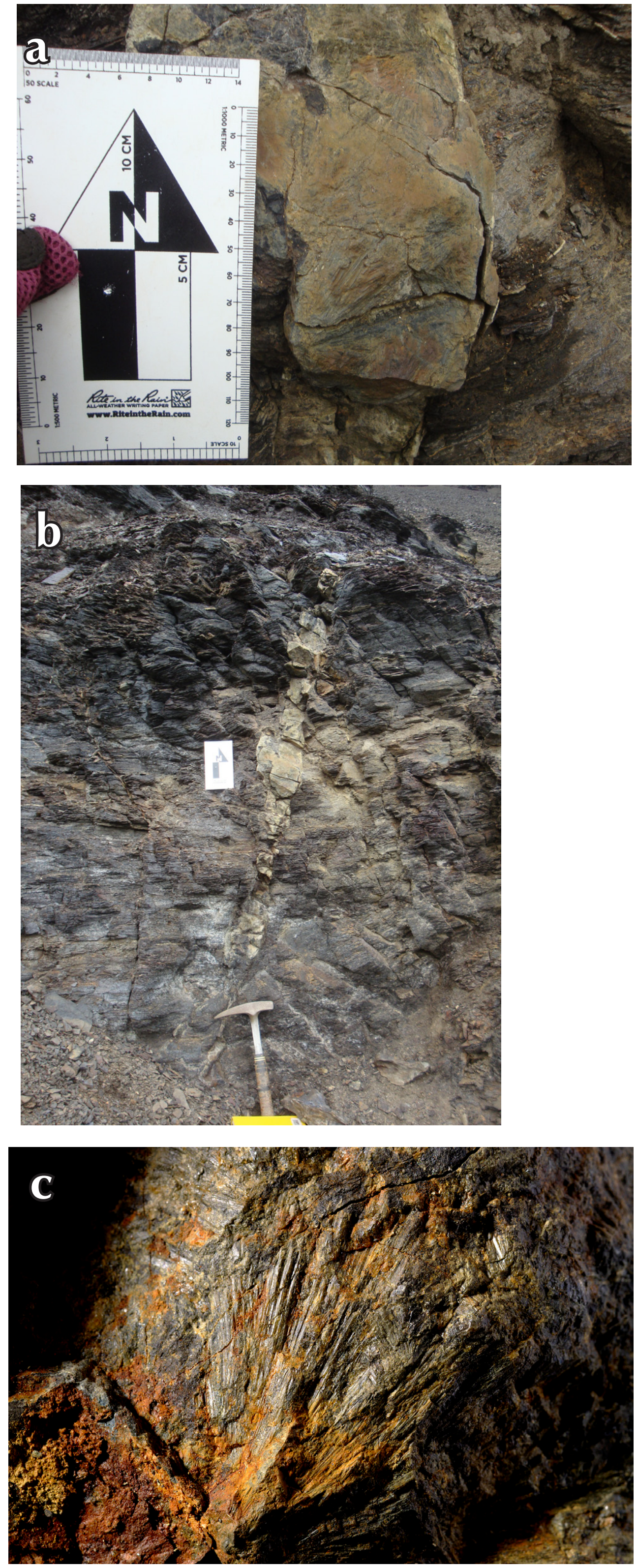


Figure 18. a,b) Satterylite "nodule-like" vein in situ, vein is up to ~15 cm wide; and c) satterlyite (green radiating mineral) vein material, FOV = 3 x 2 cm. Photo courtesy of the Royal Ontario Museum. ©ROM

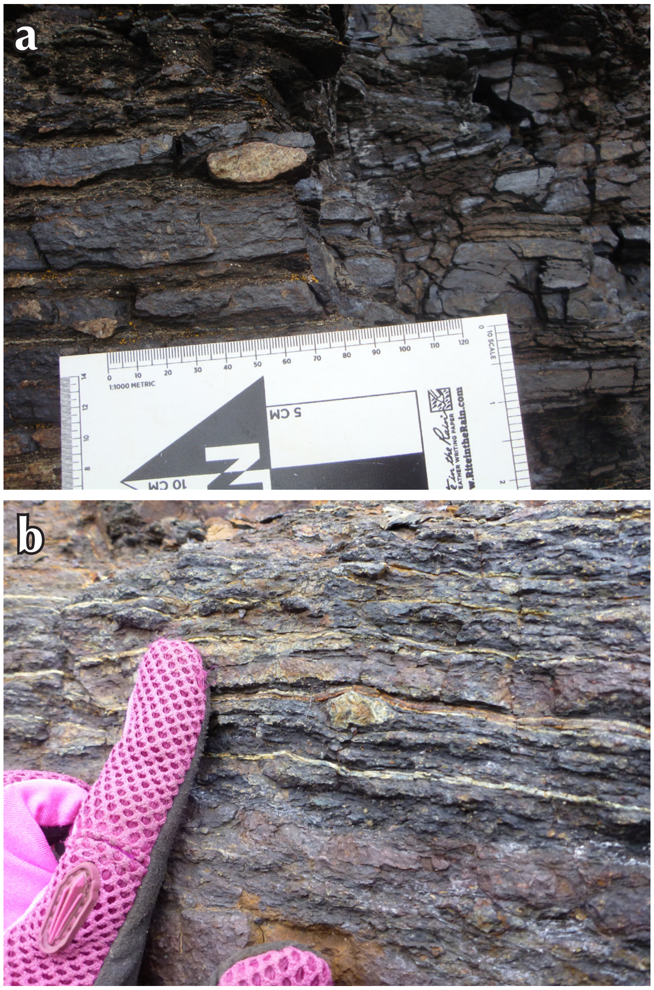


***Figure 19**. Small phosphate nodules in situ a) between layers of iron-rich shale and mudstone; nodule 3 cm long and b) In thinly bedded shale with bedding-parallel mineralization of vivianite-barićite; nodule 1.3 cm long.*

summer of 2012 was carried out to map this region, and collect specimens for a detailed geochemical survey of the region. The Rapid Creek Formation is unusual in a number of respects: (1) the formation conditions for phosphorites and siderite-rich ironstones are not complementary to one another; and (2) primary mineralogy in most phosphorites consists of carbonate-rich fluorapatite (commonly known as francolite), $Ca_5(PO_4,CO_3)_3(F,O)$ which are not observed in this region. The geological environment that allowed these assemblages of rare phosphates to form is unique; the sedimentary rocks host several mineral species previously known only from igneous and more highly metamorphosed environments. We anticipate many more discoveries with our field samples as we progress with a more detailed geochemical investigation.

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