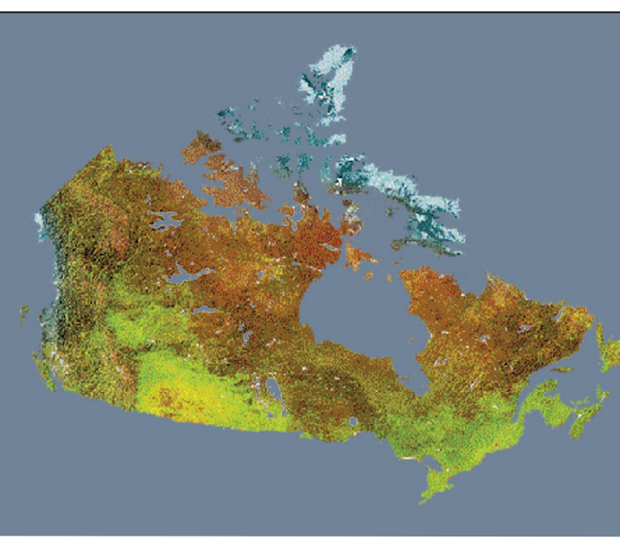
Geological Survey of Canada
Scientific Presentation 160

PHOSPHATIC, MANGANIFEROUS IRONSTONES OF THE RAPID CREEK FORMATION (NORTHWEST TERRITORIES), A PRELIMINARY STUDY

M.G. Gadd[1], N. Bingham-Koslowski[2], D.C. Petts[2], and M. Polivchuk[2]



Background

The Rapid Creek Formation contains substantial accumulations of manganiferous ironstones (>15 wt.% Fe) and phosphorites (>18 wt.% P_2O_5) – marine sedimentary rocks deposited on continental margins – that are located in the northern Richardson Mountains of Yukon and Northwest Territories (Fig. 1). It was deposited in the northern portion of the Beaufort-Mackenzie basin during the Aptian-Albian (late Early Cretaceous), a significant period in Earth's history associated with oceanic anoxic events. Potentially economically significant iron, phosphorus and manganese resources have been documented in the formation; phosphatic ironstones average approximately 33 wt.% Fe_2O_3, 14 wt.% P_2O_5 and 5 wt.% MnO (Young, 1977).

The Rapid Creek Formation is best known for its rare phosphate mineralogy, where it is the source of Yukon's official gemstone (lazulite) as well as the type locality for several phosphate species. These minerals are mostly secondary (i.e. post-depositional), typically filling fractures or forming epitaxially in veins. Otherwise, the Rapid Creek Formation has seen little new work since the early reconnaissance-scale studies in the 1970s. Manganese is a critical mineral, and Mn oxides and sedimentary phosphates have a high affinity for rare earth elements (REE), both of which provide impetus for renewed studies of the Rapid Creek Formation.

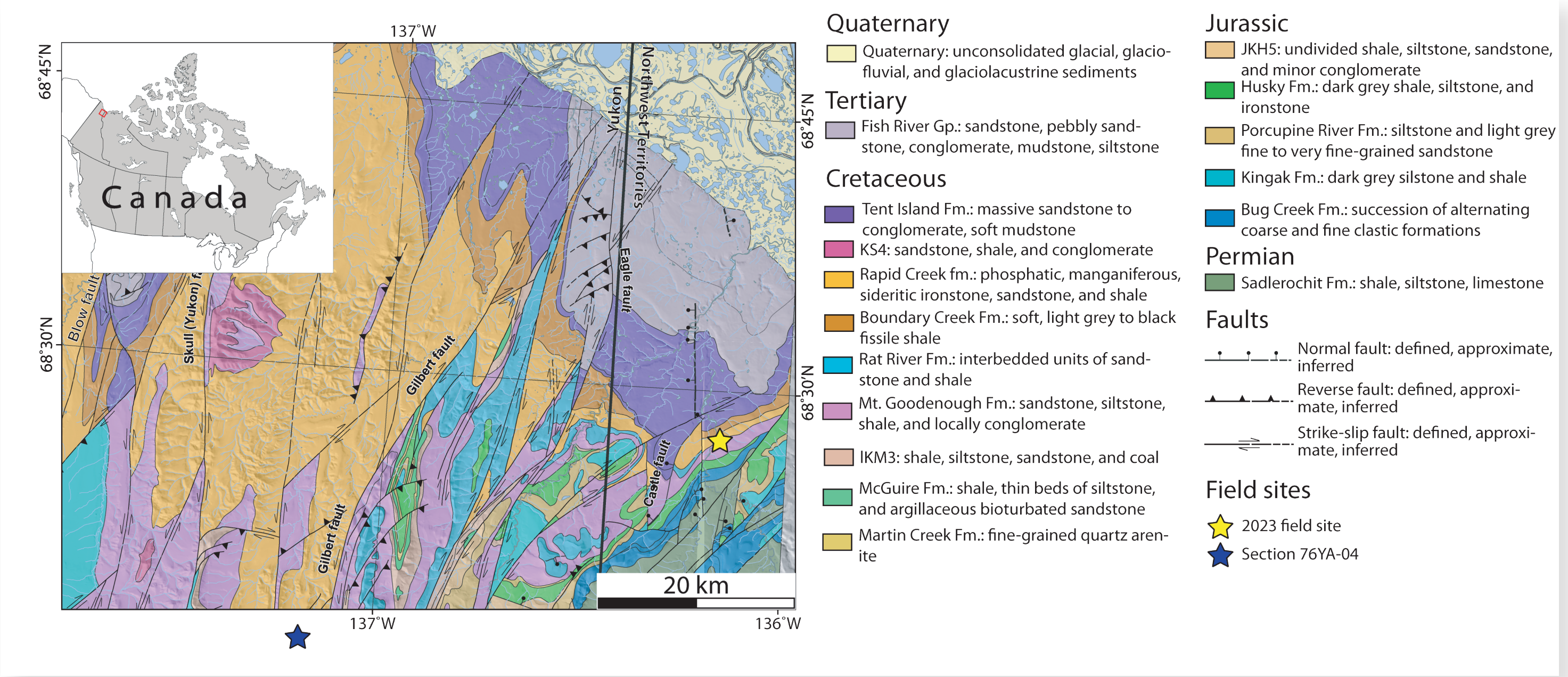


Fig. 1: Geological map showing distribution of Rapid Creek formation in northern Yukon and Northwest Territories. NB: section YA76-04 is just off the southern margin of the map. Modified after YGS (2022).

Stratigraphy

Mount Goodenough Formation: A sedimentary unit that comprises sandstones, siltstones, shales, and local conglomerates that deposited during the Barremian to Aptian. The basal contact is a regional unconformity thought to correspond to regional paleohighs (e.g. Cache Creek uplift; Dixon et al., 2019). The Albian portion of this unit interfingers with the Rat River Formation (Norris, 1997; McNeil et al., 2020; Millar et al., 2023).

Rat River Formation: Consists of interbedded sandstones and shales deposited during the Aptian. Ironstone concretions are common in both shale and sandstone units. The Rat River Formation is about 100 m thick at its type locality (Dixon and Jeletzky, 1991).

Aptian-Albian flysch: An informal unit that comprises interbedded conglomerates, shales, and sandstones that was deposited during the Aptian-Albian. Its thickness varies greatly from approximately 4 km in the west (near Blow Fault, Figs. 1, 2) to <100 m in the east (Figs. 1, 2). Its contact with the underlying Rat River Formation ranges from conformable to unconformable (Young et al., 1976). The upper kilometer or so consists of phosphatic ironstone of the Rapid Creek formation.

Rapid Creek formation: Consists of phosphatic-, ironstone-bearing manganiferous shales and sandstones (Fig. 3) deposited during the Aptian-Albian. Its thickness varies from about 1000 m in the west to 60 m in the east (Fig. 2). The Rapid Creek formation is overlain everywhere by the Boundary Creek Formation (Young, 1977; Young and Robertson, 1984).

Boundary Creek Formation: Consists of grey to black fissile shales deposited during Cenomanian-Turonian. The nature of the lower contact ranges from transitional (east) to unconformable (west) (Young, 1977; Fraser and Reinhardt, 2015).

References

Dixon and Jeletzky, 1991; Geological Survey of Canada Paper 90-21; pp. 41
Dixon et al., 2019; The Sedimentary basins of the United States and Canada, 2nd ed.; pg. 695-717
Emsbo et al., 2015; Gondwana Research; v. 27, p. 776-785
Fraser and Reinhardt, 2015; Yukon Exploration and Geology 2014; p. 45-71
Norris, 1997; Geological Survey of Canada Bulletin 422; pp. 401
McNeil et al., 2020; Bulletin of Canadian Petroleum Geology; v. 68, p. 141-157
Millar et al., 2023; Bulletin of Canadian Enery Geoscience; v. 70, p. 53-79
Pufahl, 2010; Facies Models 4; p. 477-504
Robertson, 1982; Canadian Mineralogist; v. 20, p. 177-187
Young, 1977; Geological Survey of Canada Paper 77-1C; p. 67-74
Young and Robertson, 1984; Canadiian Society of Petroleum Geology Memoir 9; p. 361-372
Young et al., 1976; Geological Survey of Canada Paper 76-11; pp. 63
Yukon Geological Survey, 2022; Yukon digital bedrock geology; https://data.geology.gov.yk.ca/Compilation/3 [accessed on April 20, 2023]

Tectonic setting

There are relatively few syntheses of Mesozoic to Cenozoic tectonic history for the Beaufort-Mackenzie basin; however, the available information suggests three phases (Dixon et al., 2019). 1) Rifting during Early Jurassic to Aptian, dominated by extensional faulting on a continental margin. The prevailing sediment types are shoreface to marine shelf deposits such as the Bug Creek, Husky, and Mount Goodenough formations. 2) Rifting continued from the late Aptian into the Albian, and a major transgression onto the craton altered the sedimentology. Moreover, the combination of rifting and compression during the second phase resulted in the development of deep-water troughs (e.g. Blow trough) wherein coarse- to fine-grained siliciclastic sediments were deposited (e.g. Aptian–Albian flysch). Albian flysch deposition marks the encroachment of the Cordilleran orogen (Dixon et al., 2019). Phosphorites and ironstones of the Rapid Creek formation were deposited on the Cache Creek uplift, a horst-like structure on the eastern flank of the Blow trough (Fig. 2). 3) Compressional tectonics initiated in the Cenomanian and extended into the Cenozoic (Dixon et al., 2019). Black shales of the Boundary Creek Formation mark the onset of this phase, which (mostly) unconformably overlie Aptian–Albian flysch and Rapid Creek formation (Fig. 2).

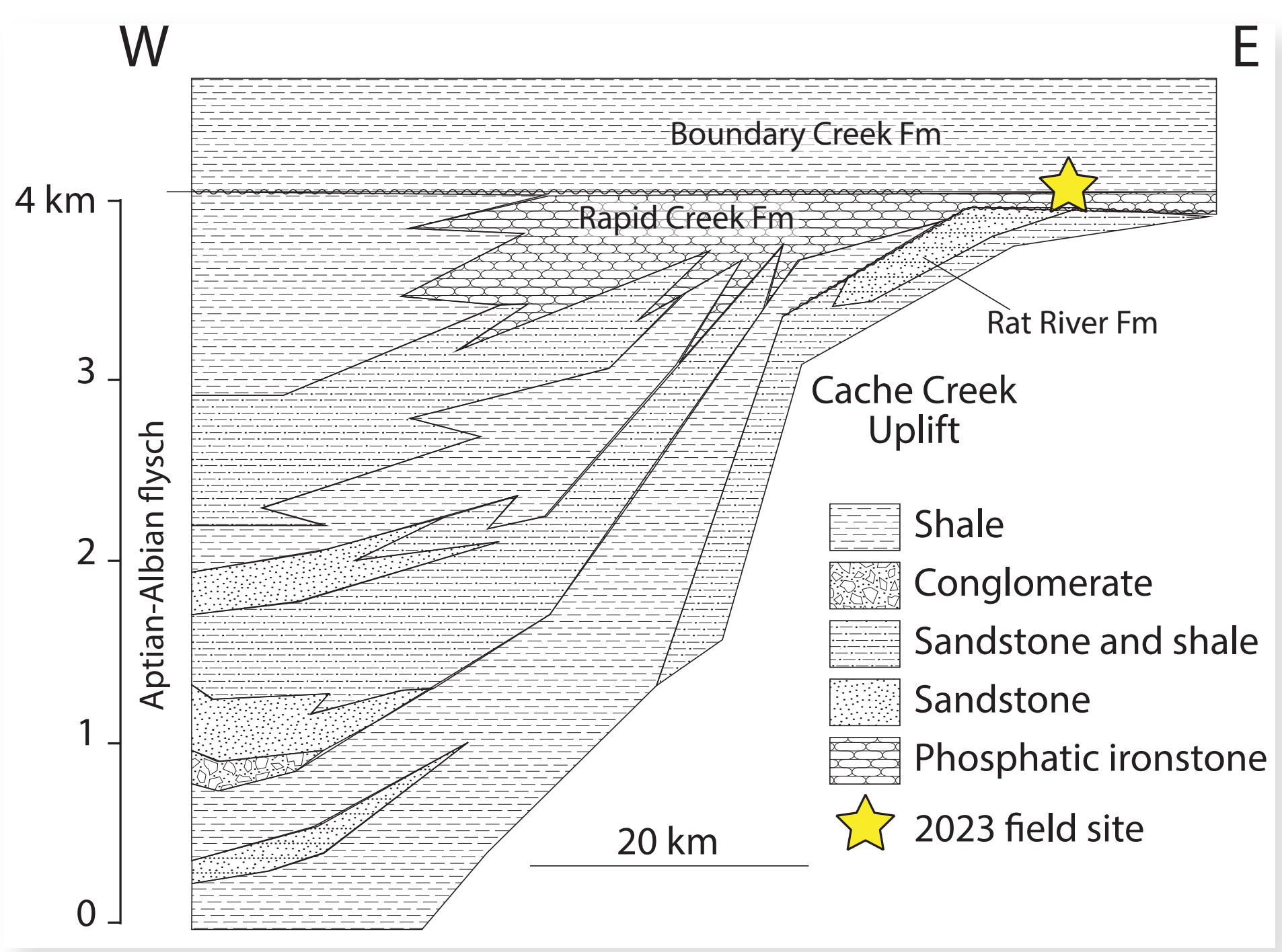


Fig. 2: Composite, schematic regional profile of mid-Cretaceous stratigraphy showing the stratigraphic distribution of Aptian–Albian flysch and Rapid Creek formation. Modified after Young and Robertson (1984).

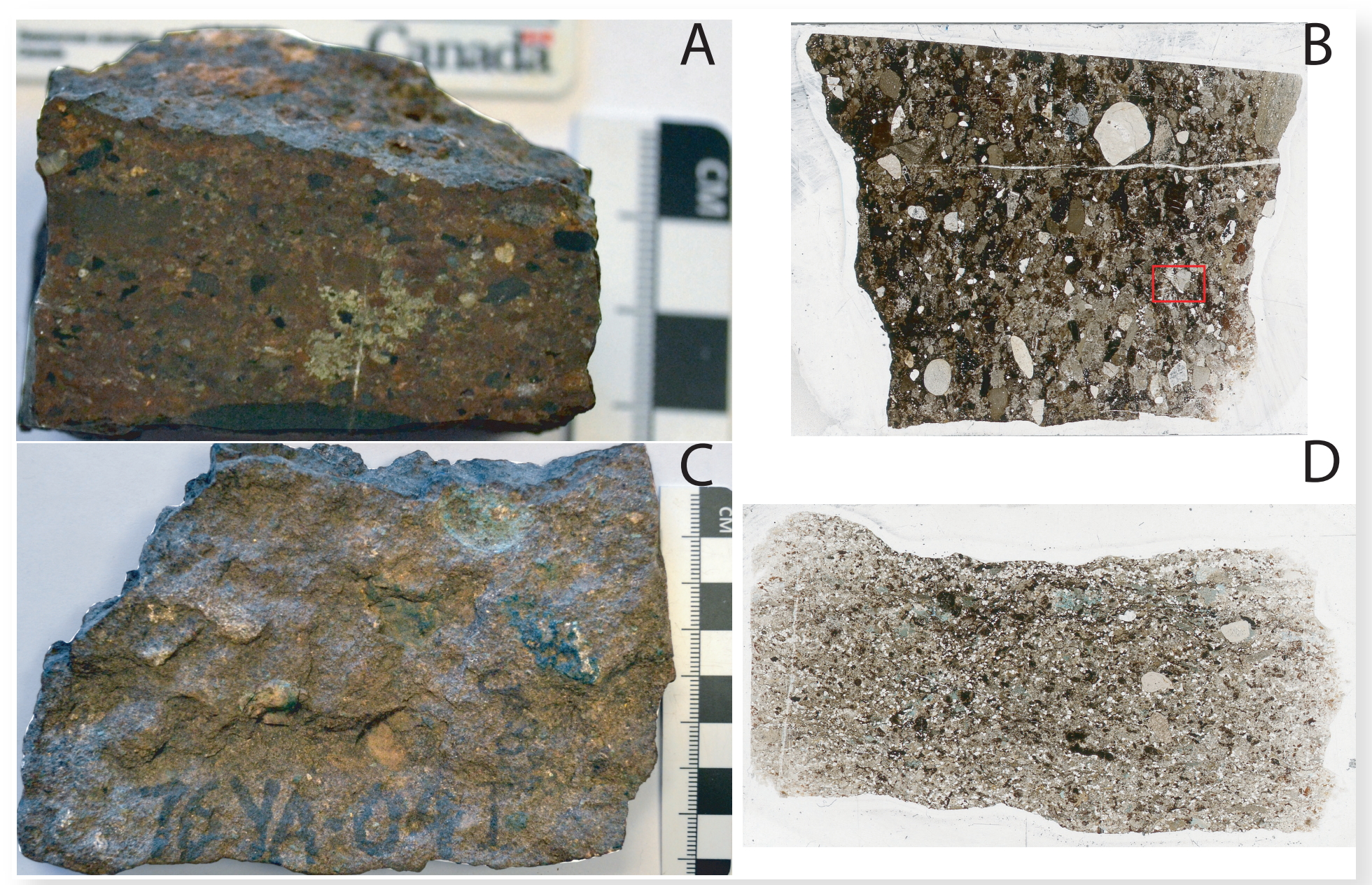


Fig. 3: Phosphatic ironstone from the Rapid Creek formation, including: A) Phosphatic hardground with terrigenous clasts and collophane rip-up clasts, and B) arrojadite-cemented sandstone. B) and D) are thin sections of A) and C), respectively. Note red box in B) is LA-ICP-MS map area in Fig. 7.

Preliminary results

Petrography

Preliminary petrography shows complex textural relationships within phosphatic ironstone samples. In one sample (Figs. 3A, B and 4A, B), apatite, chert, and feldspathic clasts are present in a matrix of apatite and Fe-Mn-oxides, with minor pyrite (Fig. 4B) and siderite. Apatite may be very fine-grained (collophane) or recrystallized and is partially replaced by gorceixite ($BaAl_3[PO_4][PO_3OH][OH]_6$) (Fig. 4A). Fe-Mn-oxides partially replace apatite, siderite, and pyrite. Wispy kulanite ($Ba[Fe^{2+},Mn^{2+},Mg]_2[Al,Fe^{3+}]_2[PO_4]_3[OH]_3$) veins cross-cut all these phases (Fig. 4A). In the other sample (Figs. 3C, D and 4C, D), sand-sized quartz grains are present in a matrix of arrojadite-group minerals, gormanite ($[Fe^{2+},Mg]_3[Al,Fe^{3+}]_4[PO_4]_4[OH])]_6 \cdot 2H_2O$), apatite, and Fe-Mn-oxides (Fig. 4C, D). Apatite and Fe-Mn-oxides also form as spheroidal, or perhaps coated, grains that are complexly intergrown (Fig. 4D).

Bulk geochemistry

Low-density stratigraphic sampling (legacy section 76YA-04, Fig. 1) shows no systematic variability in select major element abundances (Fig. 5), where lithology is the salient control on bulk geochemistry. The four lithotypes from this section are shale, quartz arenite, phosphatic and iron-rich siltstone/shale (>1 wt.% P_2O_5, <15 wt.% Fe), and phosphatic ironstone (>1 wt.% P_2O_5, >15 wt.% Fe).

All 10 samples have REE-Y abundances that are the same as (Fig. 6A) or less than (Fig. 6B-D) post-Archean average shale (PAAS). The shale-normalized profiles are relatively flat regardless of lithology, with minimal fractionation of Ce, Eu, and Y (relative to neighboring REE).

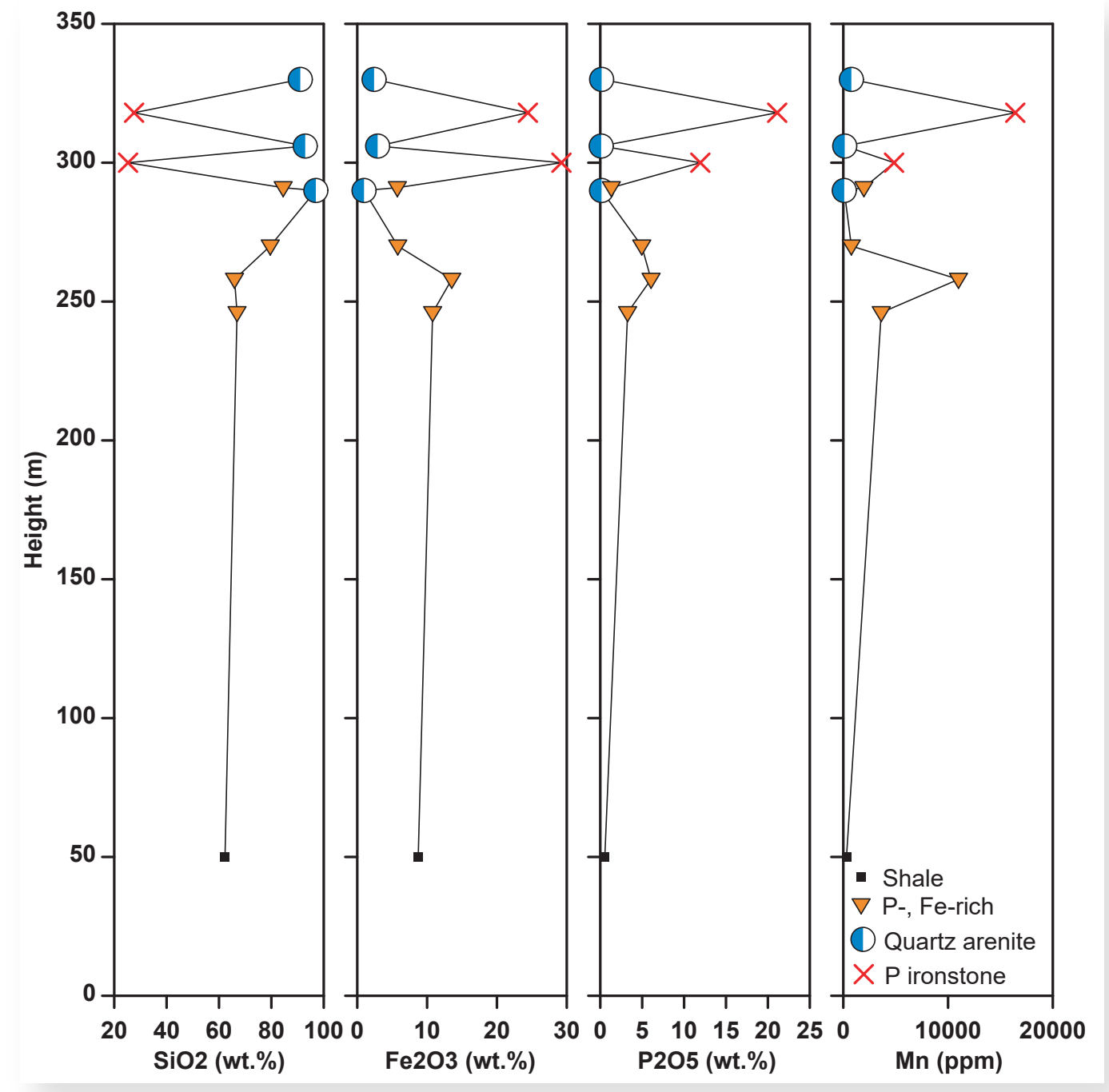


Fig. 5: Select major element compositions through section 76YA-04.

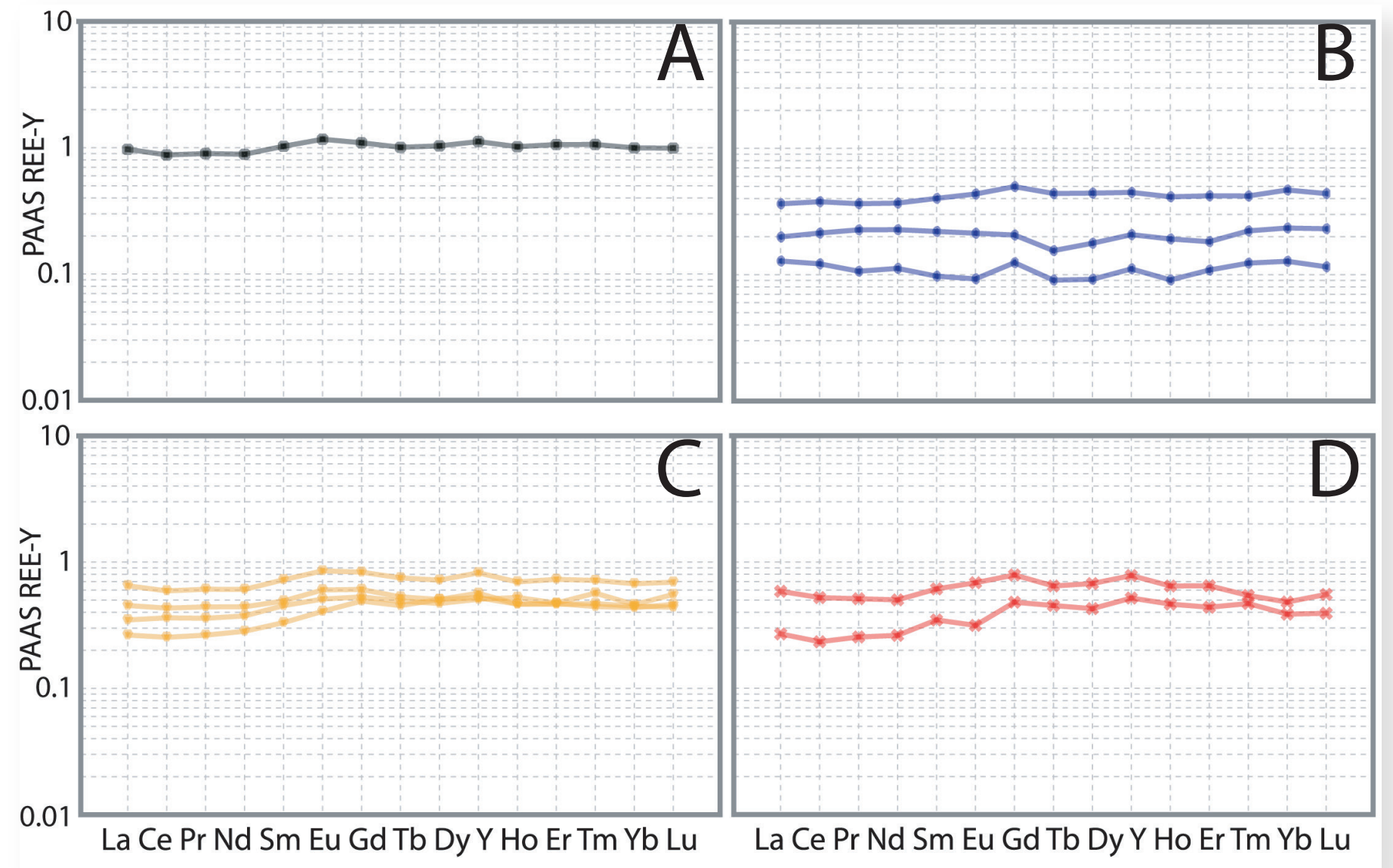


Fig. 6: Post-Archean average shale-normalized REE-Y profiles of A) shale, B) quartz arenite, C) phosphatic, Fe-rich sandstones, and D) phosphatic ironstones.

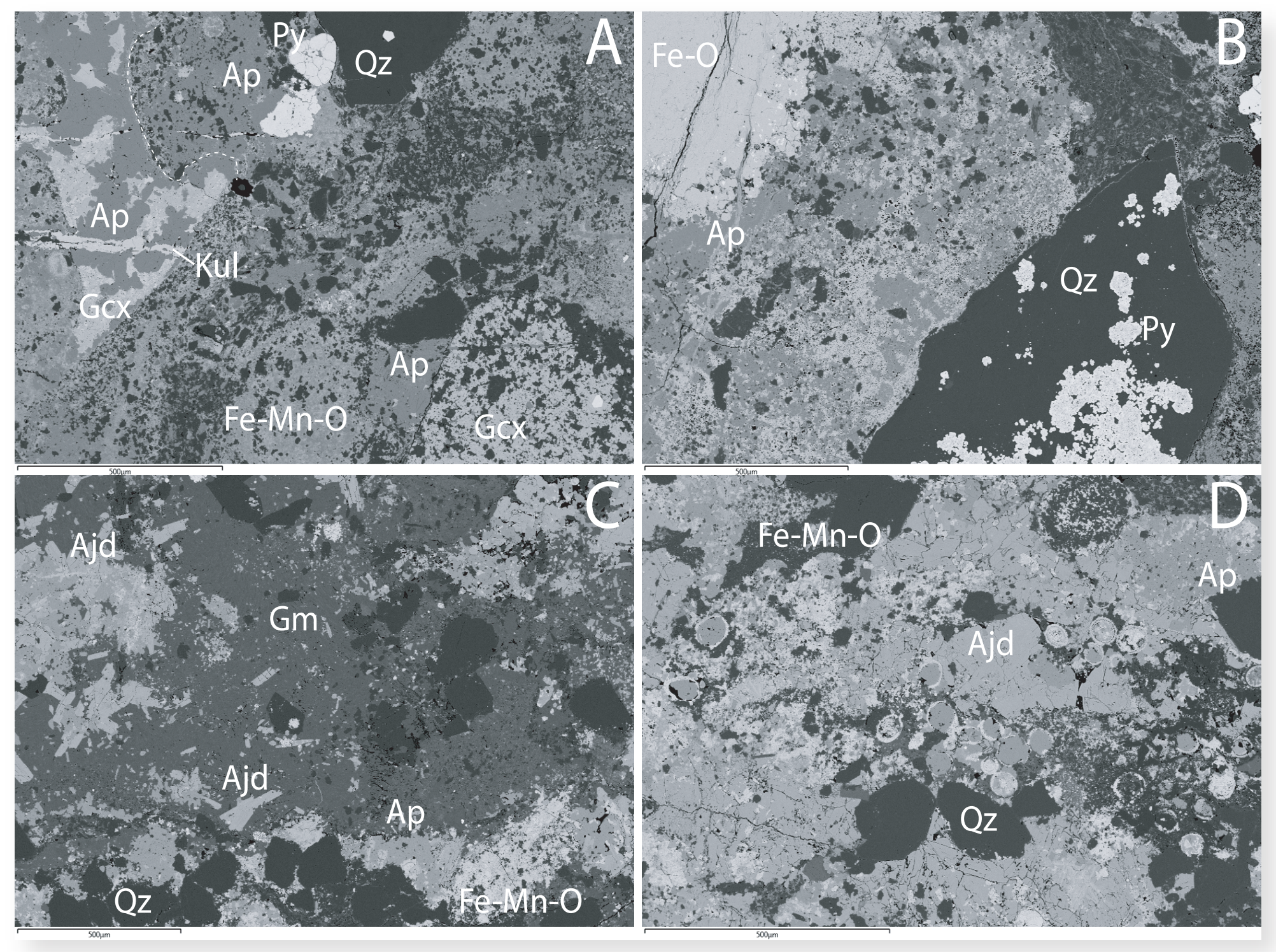


Fig. 4: Backscattered electron images of phosphatic ironstone samples C-049893 A), B) and C-049895 C), D). Ajd = arrojadite; Ap = apatite; Gcx = gorceixite; Gm = gormanite; Kul = kulanite; Py = pyrite; Qz = quartz.

LA-ICP-MS

Elemental mapping of ironstone samples reveals a complex chemical variability among mineral phases (Fig. 7). Key take-aways include:

- Apatite is the main host of REE (≈190 ppm), Y (≈100 ppm), and U (≈100 ppm). Trace element compositions within grains show some variability, whereas the range of abundances is similar for different textural styles of apatite. There is a weak negative Ce anomaly (≈0.8), nil Eu anomaly (≈1.1), and super-chondritic Y/Ho (≈38).
- Fe-Mn-oxide phases generally lack trace elements, with minimal amounts of REE (particularly light REE) and Y. There is a weak positive Ce anomaly (≈1.1), positive Eu anomaly (≈2.3), and super-chondritic Y/Ho (≈ 57).
- Gorceixite is the main host of Ti (≈1 wt.%), Zn (≈4000 ppm), Ge (≈150 ppm), and Sr (1 wt.%). It is largely devoid of REE-Y.

Discussion and future work

The Rapid Creek formation is an atypical phosphorite in many respects. It is associated with sideritic ironstone, which typically forms under different geochemical conditions compared to phosphorites; however, the preliminary data suggest that Rapid Creek phosphorites may have more in common with others than was previously recognized. For example, Figures 3B and 7 show phosphorite hardground textures with collophane and terrigenous rip-up clasts in a matrix of fine-grained apatite. These textures form in condensed sections, which is a common environment for both modern and ancient phosphorites (Pufahl, 2010). The mineralogy is unique among phosphorites, in that the Rapid Creek formation contains many minerals found previously only in pegmatites (Robertson, 1982). The secondary minerals that set the Rapid Creek formation apart from other phosphorites are poorly understood, which hampers a deeper understanding of how and why the secondary minerals formed. For example, primary apatite and pyrite are partially replaced by Fe-Mn-oxides but the nature of the fluids and the origin of the metals are unknown.

Bulk geochemistry shows limited information, especially for commonly used petrogenetic indicators such as REE-Y chemistry. The chemistry of apatite grains suggests that it is fairly typical for phosphorite-hosted apatite (cf. Emsbo et al., 2015), but REE-Y in other phases mute the subtle signature of apatite.

The LA-ICP-MS analyses revealed previously unknown Zn and Ge enrichments in gorceixite. The uniform contents of these elements suggest they are lattice substitutions, which must have come from a Zn- and Ge-bearing fluid. Barium, Zn, and Ge are commonly associated in hydrothermal sediment-hosted mineral systems, but the source of such metals is unknown in the vicinity of the Rapid Creek formation.

Fieldwork in summer of 2023 will focus on mapping the Rapid Creek formation in a stream cut of the Little Fish River (Fig. 1), with the aim of systematic sample collection at high stratigraphic resolution for subsequent mineralogical and geochemical studies.

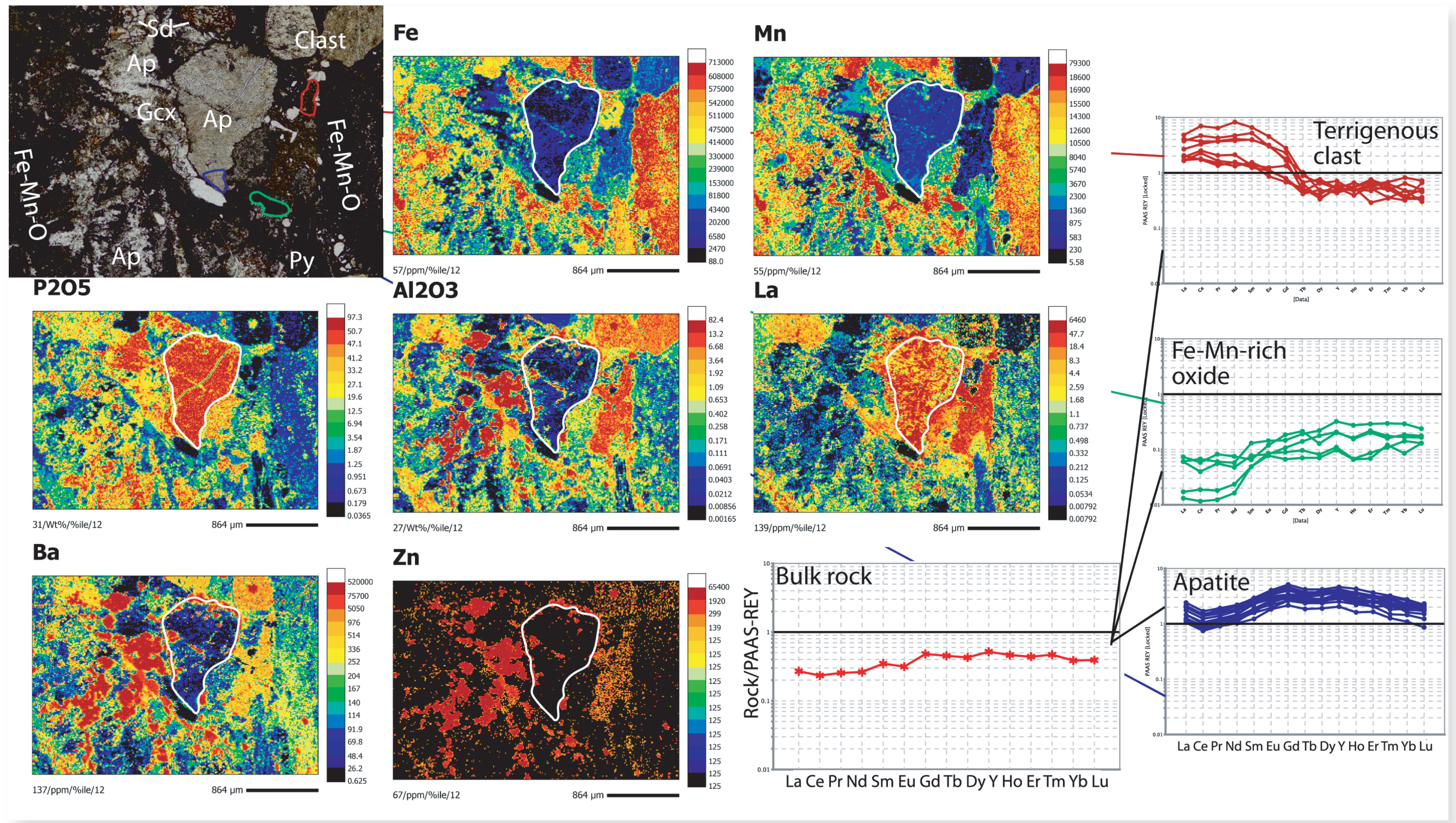


Fig. 7: Photomicrograph of phosphatic ironstone sample C-049893, with LA-ICP-MS maps of select elements. Bulk-rock REE-Y is compared with REE-Y compositions of the most dominant components (apatite, Fe-Mn-oxides, clasts) within the sample. Ap = apatite; Gcx = gorceixite; Py = pyrite; Qz = quartz; Sd = siderite.

Acknowledgments

This work was done using legacy samples that were collected in 1976 from the traditional lands of the Gwich'in and Inuvialuit.

[1]Geological Survey of Canada, 3303 33rd Street, Northwest, Calgary, Alberta
[2]Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario

For more information, please contact: M.G.Gadd (michael.gadd@nrcan-rncan.gc.ca).

Natural Resources Canada
Ressources naturelles Canada

2023

Permanent link: https://doi.org/10.4095/332073

Presented at Geological Assocation of Canada-Mineralogical Association of Canada Annual Meeting
Date presented: May 24-27, 2023

Recommended citation
Gadd, M.G., Bingham-Koslowski, N., Petts, D.C., and Polivchuk, M., 2023.
Phosphatic, manganiferous ironstones of the Rapid Creek Formation (Northwest Territories), a preliminary study; Geological Survey of Canada, Scientific Presentation 160, 1 poster. https://doi.org/10.4095/332073

ISBN 978-0-660-49867-6
Catalogue No. M41-11/160-2023E-PDF