

Preliminary investigations into the rare-earth elements in the Carlile Formation and Pierre Shale across southwestern Manitoba (parts of NTS 62G, K)

by V.L. Markstrom

In Brief:

- Geological investigations into the Upper Cretaceous shales in Manitoba and collecting samples for future geochemical analysis
- Characterizing rare earth element concentrations within the Carlile Formation and the Pierre Shale contributes to the economic development of these critical minerals

Citation:

Markstrom, V.L. 2025: Preliminary investigations into the rare-earth elements in the Carlile Formation and Pierre Shale across southwestern Manitoba (parts of NTS 62G, K); in Report of Activities 2025, Manitoba Business, Mining, Trade and Job Creation, Manitoba Geological Survey, p. 162–166.

Summary

Rare-earth elements (REEs) are essential for many modern technologies and are in high economic demand. Recent research has highlighted the potential economic development of secondary sources of REEs, including enriched sedimentary basin deposits. In Manitoba, anomalously high concentrations of REEs have been previously documented in the Upper Cretaceous Pierre Shale, but further work is required to confirm, constrain and characterize the elevated REE concentrations in Manitoba's Upper Cretaceous shales. During the 2025 field season, a total of 34 samples were collected from the Boyne Member of the Carlile Formation and the Gammon Ferruginous and Pembina members of the Pierre Shale from four sites across southwestern Manitoba. Over the next year, geochemical analysis will be conducted on these samples to assess the REE potential in the Carlile Formation and the Pierre Shale. Investigating the REE enrichment within the strata is critical for improving the understanding of these types of shale deposits and contributing to the economic development of REEs in Manitoba.

Introduction

The growing demand for REEs has led to increased interest in exploring alternative sources for these critical minerals. While most REEs are currently produced from hard rock deposits, recent studies have highlighted the potential of sedimentary basins as secondary sources. In particular, modern deep-sea sedimentary basin deposits in the western North Pacific Ocean have shown up to 5000 ppm total REEs and yttrium (REYs; Tanaka et al., 2020, 2023). Li et al. (2023) determined that REEs were primarily hosted within the bioapatite of disseminated skeletal elements found within the ocean sediments of the Indian Ocean Basin. Recent efforts have been made to identify, explore and understand the mechanism of REE accumulation in modern deep-sea sediments. These global findings have drawn attention to older sedimentary successions that may have preserved anomalous REE concentrations.

In Manitoba, the Upper Cretaceous strata consist of a thick package of oceanic sedimentary rocks with a depositional environment that may be analogous to modern ocean basins, sediments of which contain economic REE concentrations. In fact, preliminary studies found REE contents exceeding 3000 ppm within the Upper Cretaceous Gammon Ferruginous Member of the Pierre Shale (Bamburak and Nicolas, 2010; Bamburak et al., 2012, 2013, 2014), thus suggesting these shale deposits may be a potential resource.

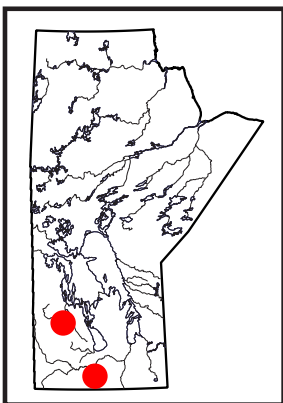
Following these preliminary findings in Manitoba, more work was needed to understand the mechanisms of REE enrichment within fine-grained, basinal mudstone and shale deposits and the depositional controls that led to these elevated REE concentrations. The goal of this project is to

- 1) confirm elevated REE concentrations in the Boyne Member of the Carlile Formation and the Gammon Ferruginous and Pembina members of the Pierre Shale across southwestern Manitoba; and
- 2) characterize and compare the REE geochemistry of these three members.

This report includes a description of the field sites and sample locations that form the foundation for the geochemical sampling program for this study. This will help to further evaluate the potential of Upper Cretaceous shales as a resource for REEs in Manitoba.

Previous work

Elevated total REE (TREE) concentrations in the Gammon Ferruginous Member were first described by Bamburak and Nicolas (2010), based on samples collected from various sites in the Pembina Hills area and at one site along the Vermilion River on Riding Mountain near Dauphin, Manitoba. This study also noted high concentrations of other elements, such as Pt, Pd, Cu, Ni, V and Zn. In a follow-up investigation, Bamburak et al. (2012) constrained REE concentrations in drill cuttings



from Relative Daly Sinclair HZNTL 8-31-7-29W1 well (oil and gas well licence 7639, Manitoba Business, Mining, Trade and Job Creation, Winnipeg). Samples from the Morden and Boyne members of the Carlile Formation, as well as the Gammon Ferruginous and Pembina members of the Pierre Shale were analyzed. The chondrite-normalized REE plot from this report shows that all four members have similar REE signatures.

In 2013, the Gammon Ferruginous Member was measured to contain up to 3178 ppm TREEs, 0.124% heavy rare-earth elements (HREEs) and 0.225% light rare-earth elements (LREEs; Bamburak et al., 2013). Bamburak et al. (2014) further suggested that the REEs in the Gammon Ferruginous Member are likely hosted in bioapatite derived from microscopic fossil fragments. More recently, elevated but highly variable REE concentrations have also been measured in some macrofossils from the overlying Pembina Member. The average TREE concentration is similar to previous research, suggesting that the REEs in Manitoba's Upper Cretaceous shale strata are hosted within the bioapatite in fossilized material (Markstrom, 2023). However, a recent publication by Nicolas and Bamburak (2025) reported lower TREE concentrations (150–350 ppm) in samples of the Boyne, Gammon Ferruginous and Pembina members that were collected near Dauphin, suggesting variability in REE enrichment across southwestern Manitoba.

Geological setting

The Carlile Formation was deposited during the Santonian to early Campanian (Late Cretaceous Period) and is primarily composed of chalky, calcareous and noncalcareous grey to black shale. The Carlile Formation has two members, the Morden and Boyne members, separated by a sharp unconformable contact (Nicolas, 2009). The Boyne Member is characterized by grey, variably calcareous shale and is subdivided into a lower calcareous unit and an upper chalky unit. The Boyne Member records deposition during a relative sea-level rise associated with the transgressive stage of the Niobrara cyclothem, with the upper chalky unit deposited during the late stage of the transgression (McNeil and Caldwell, 1981; Shaw et al., 2017). The Boyne Member is unconformably overlain by the Gammon Ferruginous or Pembina members of the Pierre Shale (McNeil and Caldwell, 1981; Nicolas, 2009; Muehlbauer et al., 2014).

The Pierre Shale is primarily composed of black shale deposited during the late Campanian and interpreted to be deposited during the regressive stage of the Niobrara cyclothem (McNeil and Caldwell, 1981; Shaw et al., 2017). The Pierre Shale has been divided into the Gammon Ferruginous, Pembina, Milwood, Odanah and Coulter members. The Gammon Ferruginous Member is characterized by uniform dark grey, noncalcareous shale with reddish-brown ferruginous and sideritic concretions. It is absent in certain parts of the province and has an unconformable contact with the overlying Pembina Member. The Pembina Member is characterized by calcareous black shale, interbedded with a series of yellow-grey bentonite beds (McNeal and Caldwell,

1981). The Pembina Member has a conformable contact with the overlying Milwood Member of the Pierre Shale (Nicolas, 2009).

Current investigations

During the 2025 field season, three sites in the Pembina Hills region and one site along the Vermilion River on Riding Mountain were visited (Figure GS2025-17-1a, b). A total of 34 shale samples were collected from the Boyne, Gammon Ferruginous and Pembina members. Site location and stratigraphic position of samples taken can be seen in Figures GS2025-17-2 and -3.

Site 120-25-003 – Spencer's Ditch

The outcrop at the Spencer's Ditch site is a 13 m thick exposure on an east ravine wall located at L.S. 15, Sec. 31, Twp. 3, Rge. 6, W 1st Mer. (abbreviated 15-31-3-6W1). The outcrop consists of an approximately 9.3 m thick exposure of the Boyne Member, a 0.25 m thick exposure of the Gammon Ferruginous Member and a 3.5 m thick exposure of the Pembina Member. This site has been studied previously and was sampled by Bamburak et al. (2013). For this project, two measured sections were chosen, and a total of six samples were collected from this site: one from the Boyne Member, one from the Gammon Ferruginous Member and four samples from the Pembina Member (Figure GS2025-17-2a, b).

Site 120-25-006 – Glencross

The Glencross site is an approximately 6 m thick roadcut exposure at SW7-2-5W1. Although the Boyne and Gammon Ferruginous members have been recognized at this site in the past, both members have been eroded and only the Pembina Member was present at the time of sampling in 2025. A total of seven samples of the Pembina Member were collected from this site (Figure GS2025-17-2c).

Site 120-25-007 – Roseisle

The Roseisle site is a series of roadcut exposures, the outcrop visited for this study is located at 16-10-6-8W1. The outcrop is approximately 20 m thick, but only 3.5 m on the westernmost side was accessible. Although the Pembina Member has been recognized at this site in the past, only the Boyne Member was present during the 2025 field season. A total of three Boyne Member samples were collected at this site (Figure GS2025-17-2d).

Site 120-25-008 – Vermilion River

This site is located at 15-15-23-20W1 along the Vermilion River. The outcrop is approximately 35 m thick and has a 3 m thick exposure of the Gammon Ferruginous Member and an approximately 32 m thick exposure of the Pembina Member. This site has been sampled for previous studies by Bamburak et al. (2014) and Nicolas and Bamburak (2025). Due to the large size of the outcrop, two measured sections were chosen, one at ground level and one at the top of the outcrop. The lower section has the Gammon Ferruginous Member–Pembina Member contact

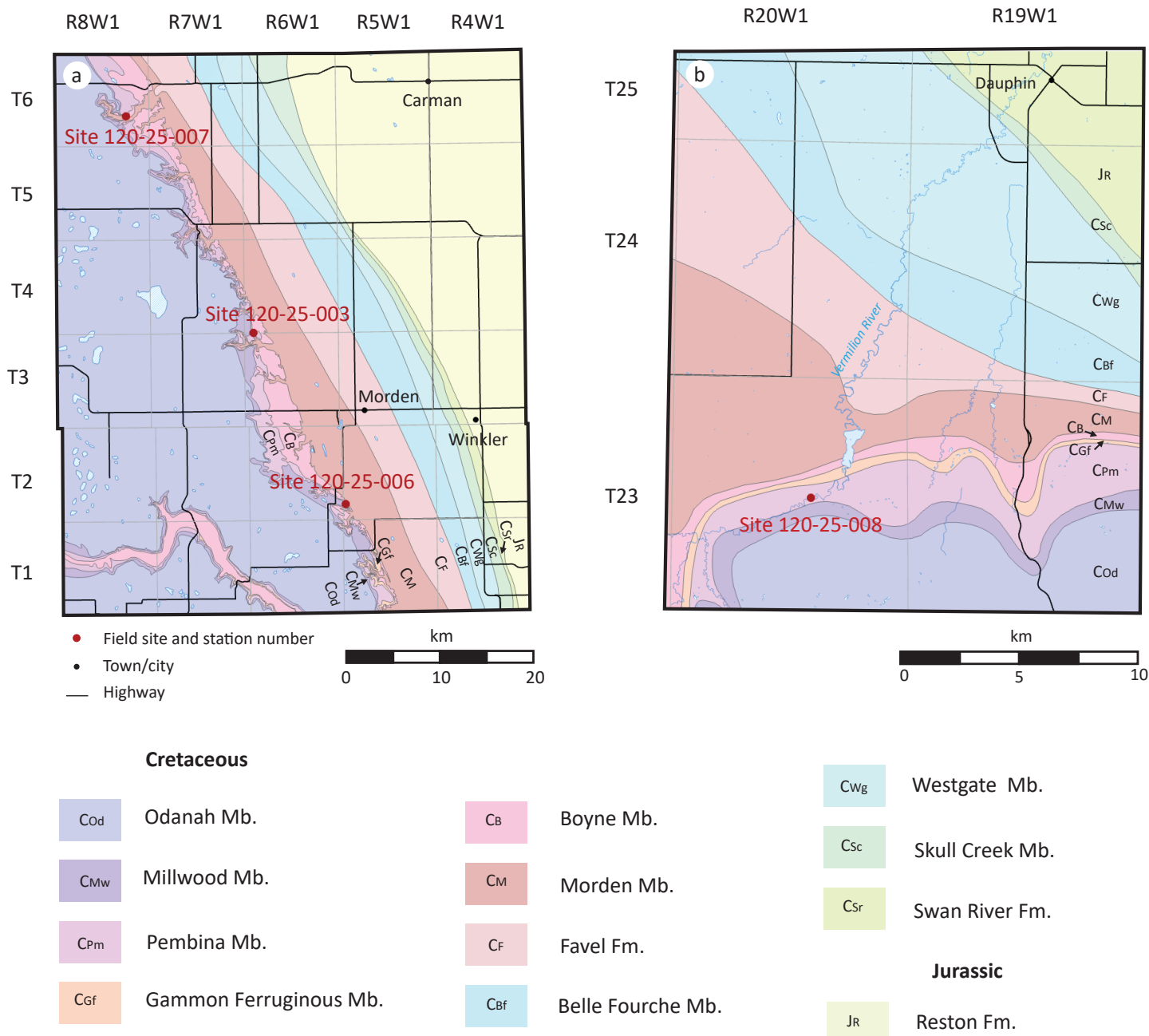


Figure GS2025-17-1: Bedrock geology map (modified from Nicolas et al., 2010) showing field sites visited in the 2025 field season: **a)** Pembina Hills area, **b)** Riding Mountain area, southwestern Manitoba.

and eight samples were collected, four samples from each member (Figure GS2025-17-3a). Two Pembina Member samples were taken between the two sections (Figure GS2025-17-3a). Eight samples were taken from the upper section, all of which were from the Pembina Member (Figure GS2025-17-3b).

Future work

Samples collected during the 2025 field season have been submitted to Activation Laboratories Ltd. (Ancaster, Ontario) for analysis; results are pending. The samples will be analyzed using lithium metaborate-tetraborate fusion digestion followed

by inductively coupled plasma–optical emission spectroscopy (ICP-OES) and inductively coupled plasma–mass spectrometry (ICP-MS) to determine REE concentrations. These results will be used to assess the distribution of elevated REE concentrations across southwestern Manitoba. Additional sampling from other sites across the Manitoba escarpment will expand the spatial and stratigraphic scope of this project. The results of this study and others in Manitoba will be compared to other REE-enriched organic-rich shales reported in the literature, as well as modern REE-enriched deep-sea sites in the Indian Ocean Basin. This comparison will lead to a better understanding of REE deposits and the mechanisms of REE enrichment in ocean sediments.

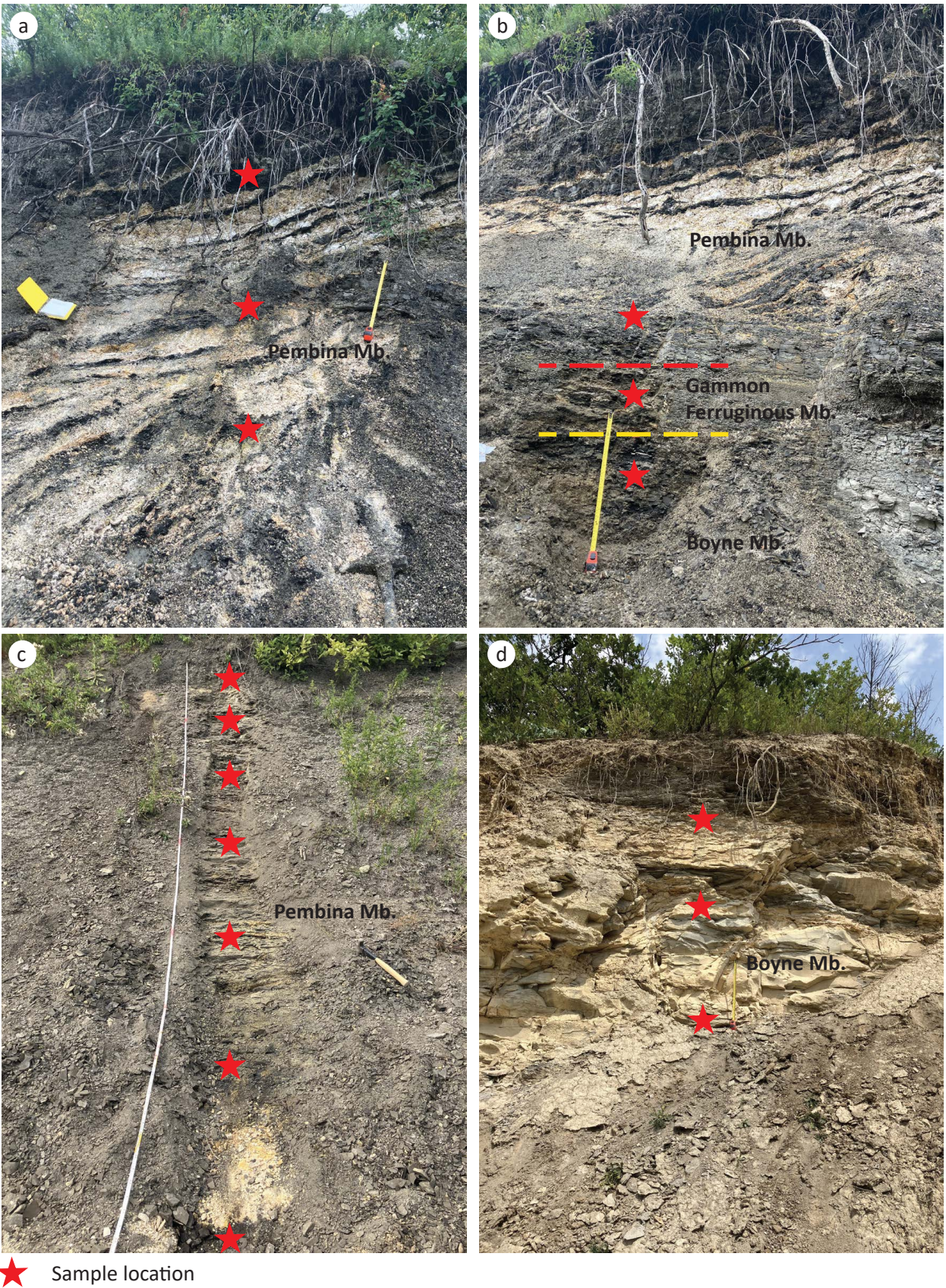
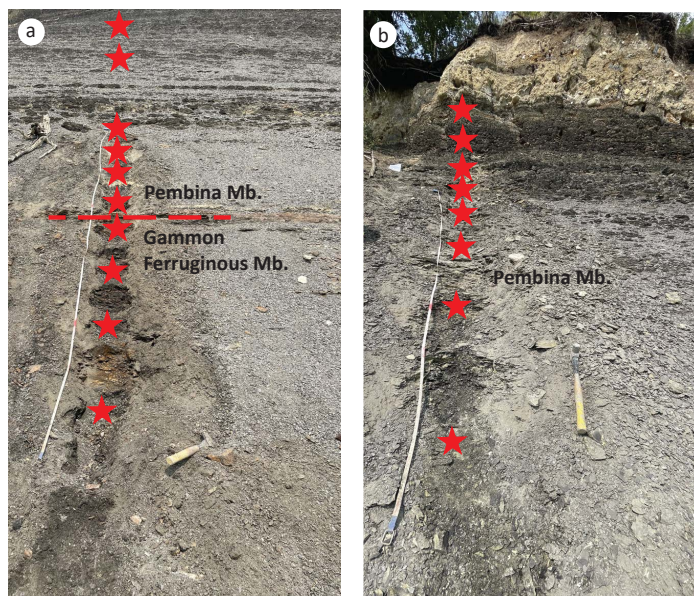


Figure GS2025-17-2: Stratigraphic position of samples collected at **a)** the upper section at site 120-25-003 – Spencer’s Ditch, 0.5 m measuring tape for scale; **b)** the lower section at site 120-25-003 – Spencer’s Ditch, 0.5 m measuring tape for scale; **c)** site 120-25-006 – Glencross, 6.2 m measuring tape for scale; and **d)** site 120-25-007 – Roseisle, 0.5 m measuring tape for scale. The yellow dashed line indicates approximate contact between the Boyne and Gammon Ferruginous members and the red dashed line indicates approximate contact between the Gammon Ferruginous and Pembina members.



★ Sample location

Figure GS2025-17-3: Stratigraphic position of samples collected at site 120-25-008 – Vermilion: **a)** lower section, 6 m measuring tape for scale; **b)** upper section, 4.3 m measuring tape for scale. Samples from both sections were collected every metre. Red dashed line indicates approximate contact between the Gammon Ferruginous and Pembina members.

Economic considerations

Rare-earth elements are listed as critical minerals because they are critical to modern technology. They have a wide range of industrial uses, including the production of magnets, lasers, camera lenses, hybrid/electric vehicle batteries, computer hard drives, monitors and phones. As demand for these products increases, exploration for new sources of REEs is increasing and the importance of sources like REE-enriched sedimentary deposits will continue to rise. Studying deposits in the rock record, like the Upper Cretaceous shales of southwestern Manitoba, may provide valuable insight into the development of secondary REEs resources in the province.

Acknowledgments

The author thanks J. Gellert (University of Manitoba) for providing enthusiastic field assistance, as well as C. Epp, E. Ralph and P. Belanger (Manitoba Geological Survey) for thorough logistical field support. Reviews of this report were provided by P.E. Fraino and M.P.B. Nicolas of the Manitoba Geological Survey.

References

Bamburak, J.D. and Nicolas, M.P.B. 2010: Gammon Ferruginous Member of the Cretaceous Pierre Shale in southwestern Manitoba: distribution and mineral potential (parts of NTS 62F, G, J, K, N, O, 63C); *in* Report of Activities 2010, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 170–177.

Bamburak, J.D., Hatcher, J. and Nicolas, M.P.B. 2012: Chemostratigraphy, paleontology and mineral potential of the Gammon Ferruginous Member of the Cretaceous Pierre Shale in southwestern Manitoba (parts of NTS 62F, G, H, J, K, N, O, 63C, F); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 141–150.

Bamburak, J.D., Martins, T., Nicolas, M.P.B. and Yang, X.M. 2014: Update on the rare-earth element potential of the Gammon Ferruginous Member of the Upper Cretaceous Pierre Shale in southwestern Manitoba; *in* Report of Activities 2014, Manitoba Mineral Resources, Manitoba Geological Survey, p. 172–180.

Bamburak, J.D., Nicolas, M.P.B., Hatcher, J. and Yang, X.M. 2013: Rare-earth element potential of the Gammon Ferruginous Member of the Upper Cretaceous Pierre Shale in southwestern Manitoba; *in* Report of Activities 2013, Manitoba Mineral Resources, Manitoba Geological Survey, p. 123–128.

Li, J., Shi, X., Huang, M., Yu, M., Bi, D., Song, Z., Shen, F., Liu, J., Zhang, Y., Wang, H. and Sun, Y. 2023: The transformation and accumulation mechanism of rare earth elements in deep-sea sediments from the Wharton Basin, Indian Ocean; *Ore Geology Reviews*, v. 161, art. 105655.

Markstrom, V.L. 2023: Thermoregulation in Late Cretaceous marine reptiles of Manitoba; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 105 p.

McNeil, D.H. and Caldwell, W.G.E. 1981: Cretaceous rocks and their foraminifera in Manitoba Escarpment; Geological Association of Canada, Special Paper 21, 439 p.

Muehlbauer, R., Kelly, D.C., Bamburak, J.D. and Nicolas, M.P.B. 2014: Late Cretaceous (Santonian–Campanian) marine microfossils of the Manitoba escarpment, southwestern Manitoba; *in* Report of Activities 2014, Manitoba Mineral Resources, Manitoba Geological Survey, p. 181–186.

Nicolas, M.P.B. 2009: Williston Basin Project (Targeted Geoscience Initiative II): summary report on Mesozoic stratigraphy, mapping and hydrocarbon assessment, southwestern Manitoba; Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Paper GP2009-1, 19 p.

Nicolas, M.P.B. and Bamburak, J.D. 2025: Whole rock geochemistry results from Cretaceous outcrops along the Vermilion River and drill cuttings from an oil well, southwestern Manitoba (parts of NTS 62F11 and 62K16); Manitoba Business, Mining, Trade and Job Creation, Manitoba Geological Survey, Data Repository Item DRI2025020, Microsoft® Excel® file.

Nicolas, M.P.B., Matile, G.L.D., Keller, G.R. and Bamburak, J.D. 2010: Phanerozoic geology of southern Manitoba; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Stratigraphic Map SM2010-1, 2 sheets, scale 1:600 000.

Shaw, D.J., Nicolas, M.P.B. and Chow, N. 2017: Stratigraphy and geochemistry of the Cretaceous Boyne Member, Carlile Formation, in the Manitoba Potash Corporation core at 3-29-20-29W1, southwestern Manitoba (parts of NTS 65K1); *in* Report of Activities 2017, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 173–182.

Tanaka, E., Mimura, K., Nakamura, K., Ohta, J., Yasukawa, K. and Kato, Y. 2023: Rare-earth elements in deep-sea sediments in the South Pacific Gyre: source materials and resource potentials; *Geochemistry, Geophysics, Geosystems*, v. 24, no. 3, art. e2022GC010681.

Tanaka, E., Nakamura, K., Yasukawa, K., Mimura, K., Fujinaga, K., Iijima, K., Nozaki, T. and Kato, Y. 2020: Chemostratigraphy of deep-sea sediments in the western North Pacific Ocean: implications for genesis of mud highly enriched in rare-earth elements and yttrium; *Ore Geology Reviews*, v. 119, art. 103392.