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the Sverdrup basin, Nunavut and Northwest Territories**

S.E. Grasby and J.M. Galloway

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Permanent link: <https://doi.org/10.4095/330202>

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Recommended citation

Grasby, S.E. and Galloway, J.M., 2022. Rare-earth elements of Permian through Cretaceous strata of the Sverdrup basin, Nunavut and Northwest Territories; Geological Survey of Canada, Open File 8894, 1 .zip file.
<https://doi.org/10.4095/330202>

INTRODUCTION

Global use of rare earth elements (REEs) has increased significantly since the 1960s, as their special properties make them invaluable for a growing range of applications, including: computers, aerospace, metallurgy, medical equipment, and military defense systems. REEs also play a critical role in emerging clean technologies, such as wind power turbines, electric vehicles, energy-efficient lighting, and catalytic converters. Permanent magnets, an essential component of modern electronics, are the largest end use for REEs.

The term REEs refers to a group of 17 metallic elements, including the 15 that form the lanthanoid series in the periodic table of elements, along with scandium and yttrium that exhibit similar properties to the lanthanides and are commonly found in the same ore bodies (Balaram, 2019). Despite the name, REEs are relatively abundant in the Earth's crust. Their rarity derives from minable concentrations being less common than most other mineral commodities. The principal economic sources of REEs are the minerals bastnasite, monazite, and loparite found in igneous rocks formed by alkaline magmas, including carbonatite, pegmatite, and nepheline syenite, as well as in association with ion-adsorption on lateritic clays (Balaram, 2019). High REE abundances also occur in modern deep marine sediments (Deng et al., 2017; Kato et al., 2011). More recently, high REE concentrations have been recognised in phosphorite deposits (Emsbo et al., 2015). Sedimentary phosphorite deposits are a particularly appealing source of REEs as they are nearly 100% recoverable during phosphate extraction, using a process that has both low cost and low environmental-impact (Emsbo et al., 2015). To date, there has been little work to assess REE occurrences in sedimentary sequences in Canada, and in particular in phosphorites. Such deposits could be highly attractive as P is also an essential element for fertilizer production.

For this report, REE potential of sedimentary rocks in the Sverdrup Basin (Embry and Beauchamp, 2019) in the Canadian Arctic Archipelago (Fig. 1) were examined as part of the TGI6 Program of the Geological Survey of Canada. This includes analyses of pre-existing collections of 871 samples that together form a composite profile through a large part of the sedimentary column from the Late Permian through to Late Triassic strata, as well as Cretaceous strata. Jurassic data is incomplete. Sampling has focused on shale dominated successions deposited in relatively deep water environments. One anomaly is the Middle Triassic phosphorites of the Murray Harbour Formation, an organic-rich black shale characterised by abundant phosphate nodules. The host shale and nodules were analysed separately for REEs, including 128 phosphate nodule analyses.

As there is inconsistent terminology in the literature when describing REEs, for clarity, the following definitions are used in this report:

Σ REEs = La, Ce, Pr, Nd, Sm, Eu, Gd, Y, Tb, Dy, Ho, Er, Tm, Yb, Lu

Light (LREE) = La, Ce, Pr, Nd

Medium (MREE) = Sm, Eu, Gd, Y, Tb, Dy

Heavy (HREE) = Ho, Er, Tm, Yb, Lu

RESULTS

Results of the sedimentary REE profile are shown in Figure 2, with Σ REE plotted relative to geologic time. To create this plot an age model was created by assuming constant deposition rates between each defined chronostratigraphic age boundary. There is a sample gap for the Jurassic that has poor coverage in existing collections. Throughout the sampled intervals, Σ REE values have only minor variability (21.3 to 557 ppm, mean 157 ± 48 ppm), indicating that REEs are generally not enriched in shales. Figure 2 also shows the range of values for Σ REE of phosphate nodules of the Triassic Murray Harbour Formation. In contrast to host mudstones, these phosphates are highly enriched in REEs (417 to 3260 ppm, 1290 ± 622 ppm). Figure 3 shows that REEs in shales are dominated by LREEs, ranging from 60 to 80% of Σ REE values, and are very low in HREEs (< 5% of total). The MREE values comprise 20 to 40% of Σ REE. In contrast to shales, phosphate nodules have higher average MREE (~38%) and slightly lower LREEs (~58%). The HREE values in nodules are low, similar to those of host shales.

Scholler diagrams of the Post Archean Average Shale (PAAS) normalised REE distribution were produced for each time interval and are shown in Figure 4a-o. These plots indicate that few shale samples have individual REE values that exceed those of PAAS. For all time periods, mean values are also below PAAS (Fig. 4p). In contrast, phosphate nodules all have individual REE elements with values that exceed PAAS, with the MREE elements being the most enriched, some reaching up to 20x PAAS (Fig. 4q). In comparison to host shale, phosphate nodules have much greater overall REE enrichment, and more so for the MREEs (Fig. 4r).

SUMMARY

Results of this study show an overall low abundance of REE in shales in the Sverdrup Basin. However, phosphate nodules within the Middle Triassic Murray Harbour Formation are enriched in REEs. A return to oceanic normal upwelling conditions along the NW margin of Pangea following the Early Triassic Greenhouse occurred during deposition of the Murray Harbour Formation (Grasby et al., 2016). This paleoenvironmental change suggests that phosphorite occurrence should be more widespread at this time. Indeed, the Murray Harbour Formation is temporally equivalent to other phosphate-rich units, such as the Doig Phosphate zone in the western Canada Sedimentary Basin and the Shublik Formation of northern Alaska. The results of this study indicate that further analysis of the spatial distribution of phosphate-rich zones is warranted. The sampling gap of Jurassic strata misses some potentially phosphate-rich zones and further study of this interval is recommended. Finally, as the REEs are concentrated within the phosphate nodules, the resource potential of Middle Triassic phosphate-rich strata requires more detailed study to assess the net phosphate content to assess bulk values. Such work would also provide insight into resource potential as phosphate deposits.

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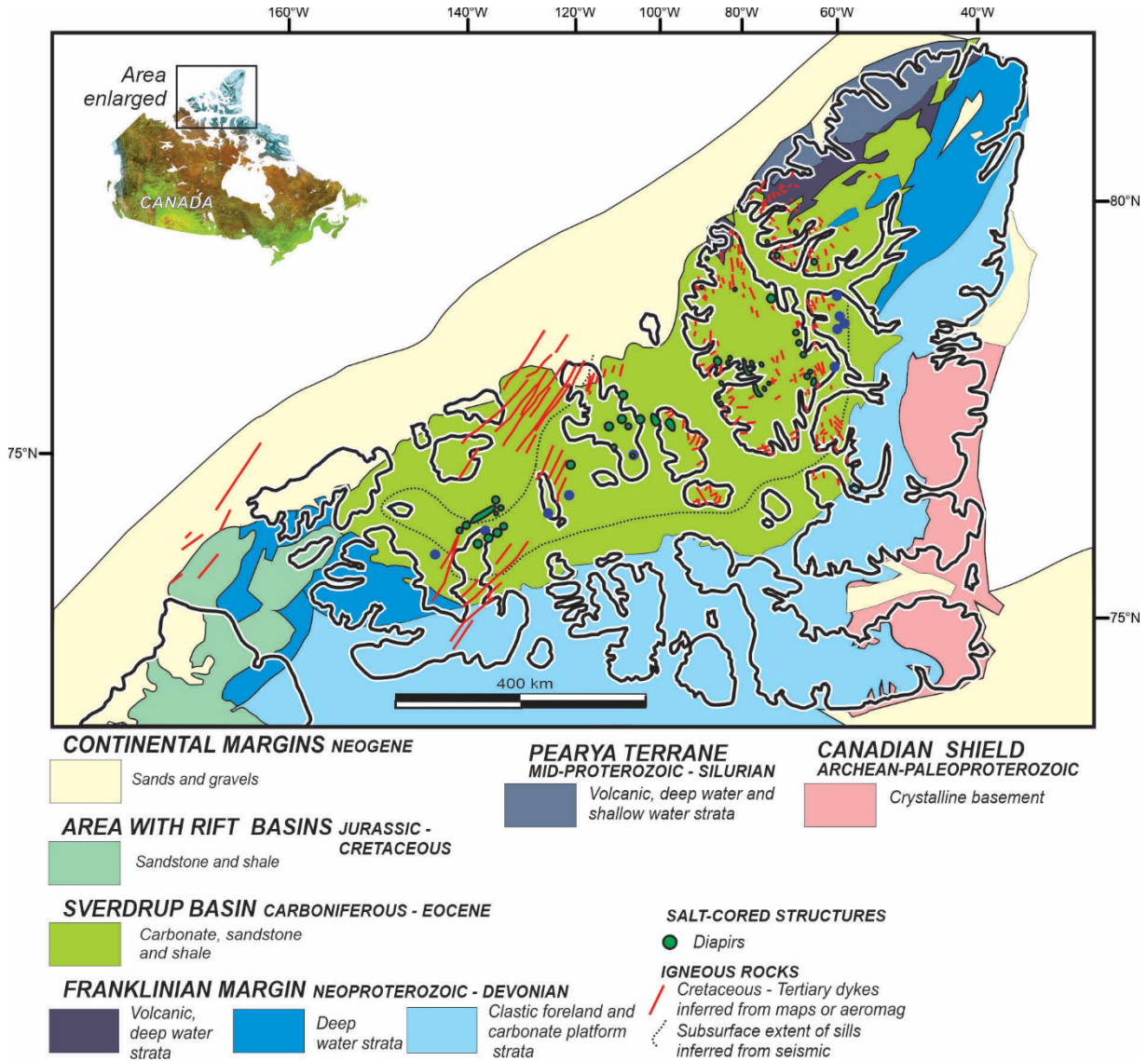


Figure 1. Geologic map of the Sverdrup Basin (after Dewing et al. 2007).

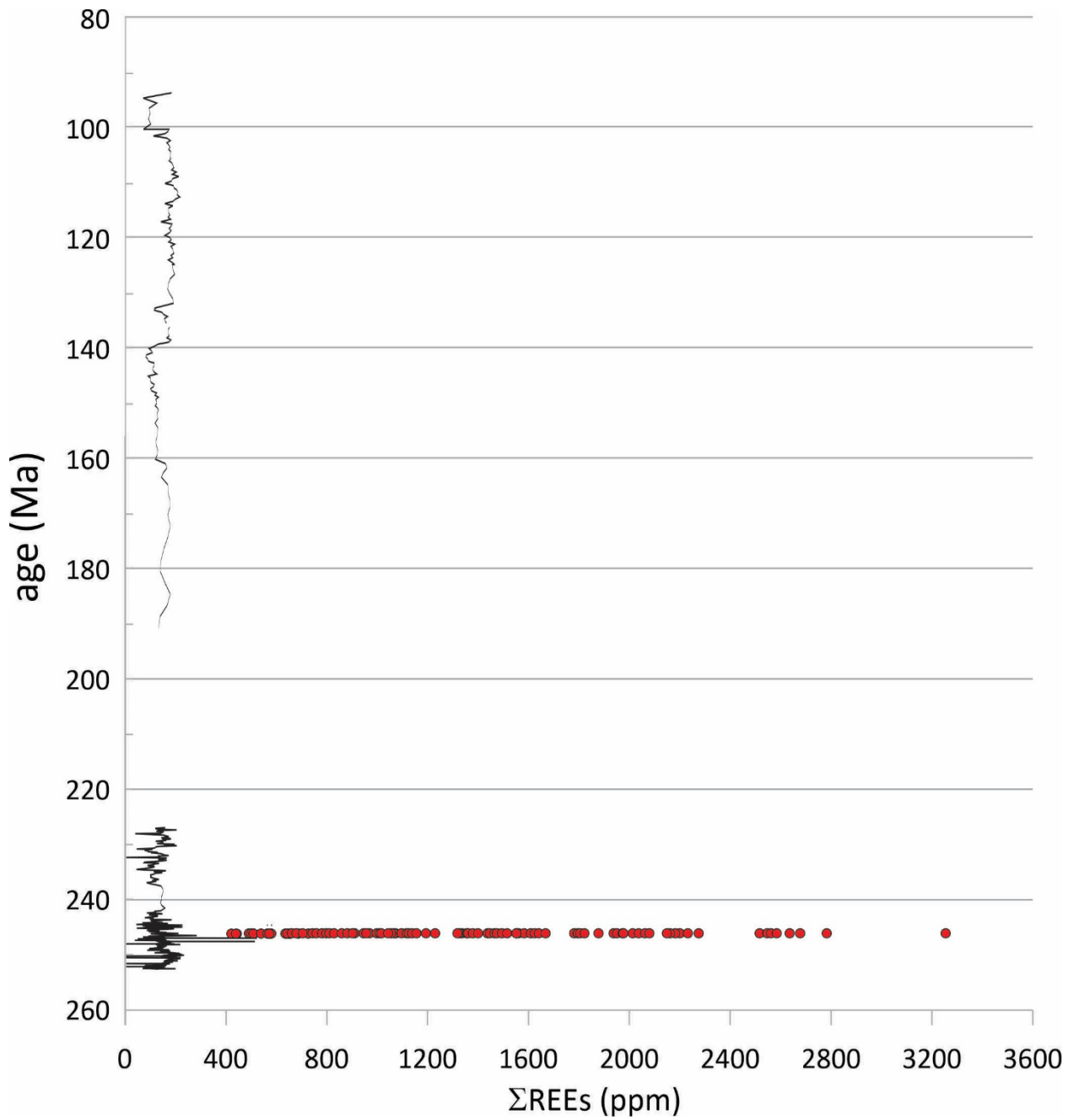


Figure 2. Plot of Σ REE concentrations of shales on the Sverdrup Basin plotted as a function of age (lines). The break in lines represents a sample gap in the Jurassic. Red dots are Σ REE values for phosphate nodules of the Middle Triassic Murray Harbour Formation.

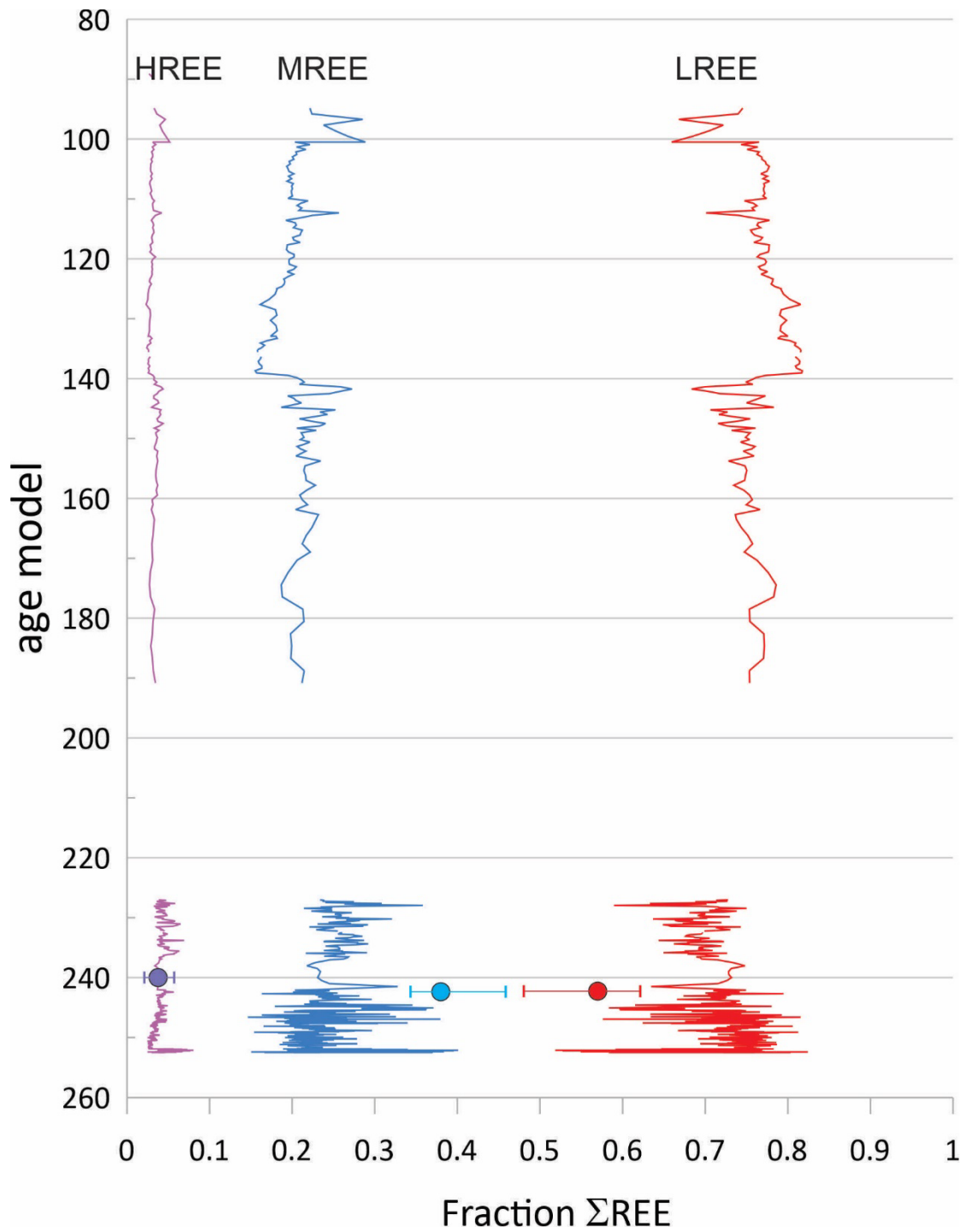
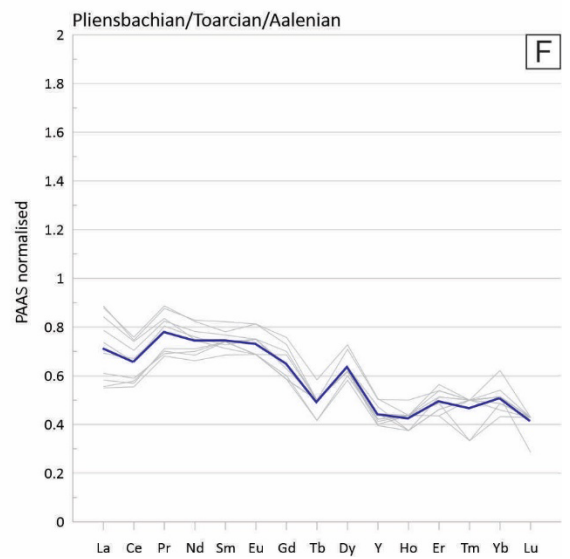
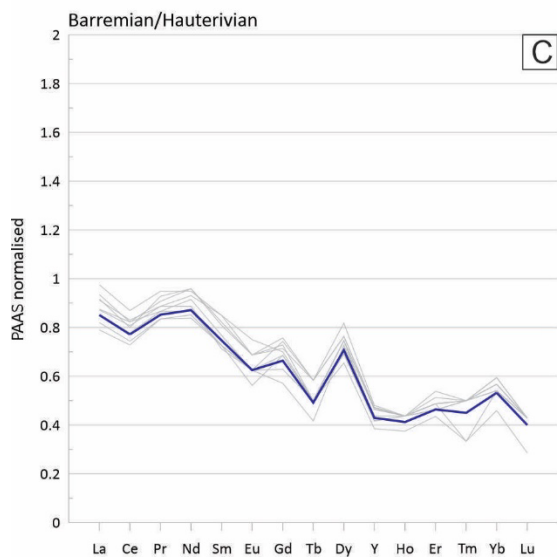
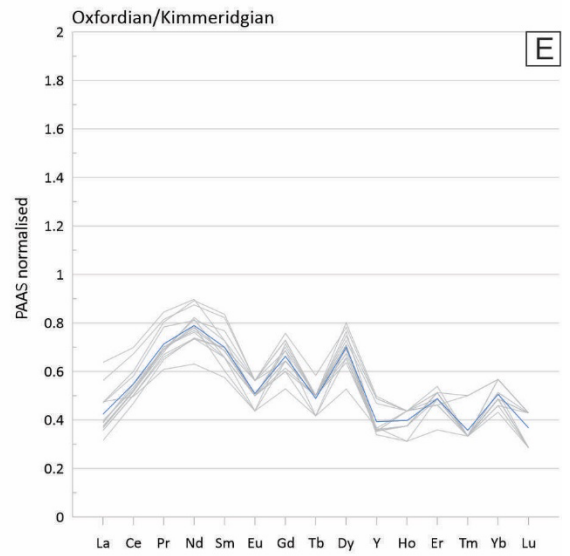
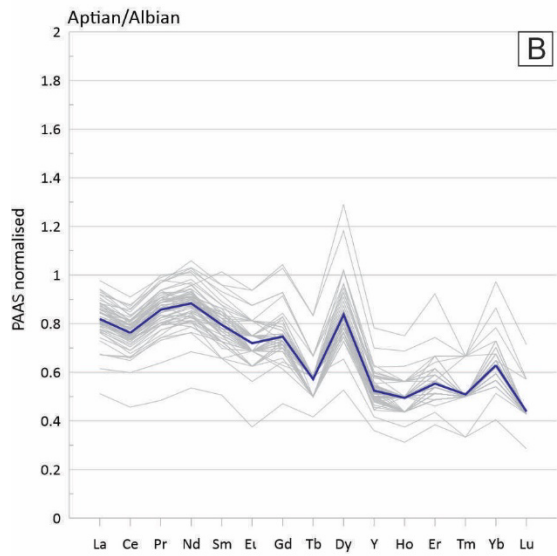
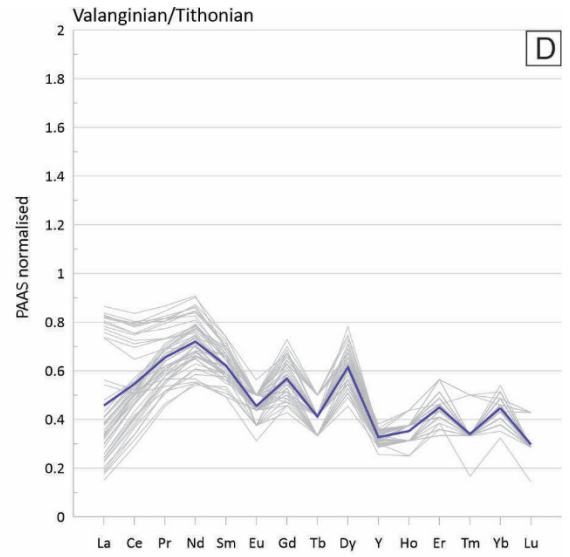
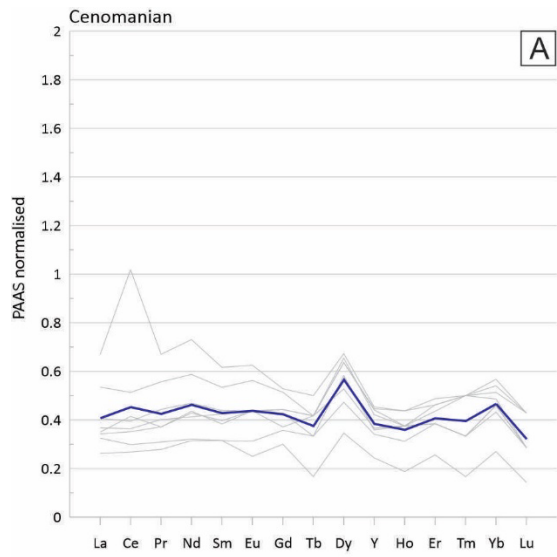
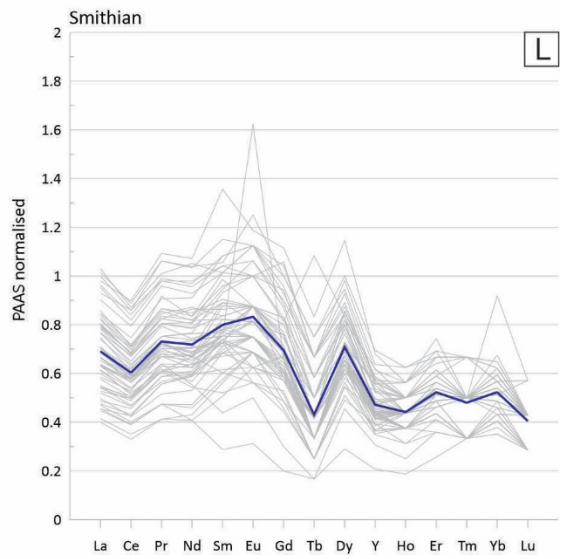
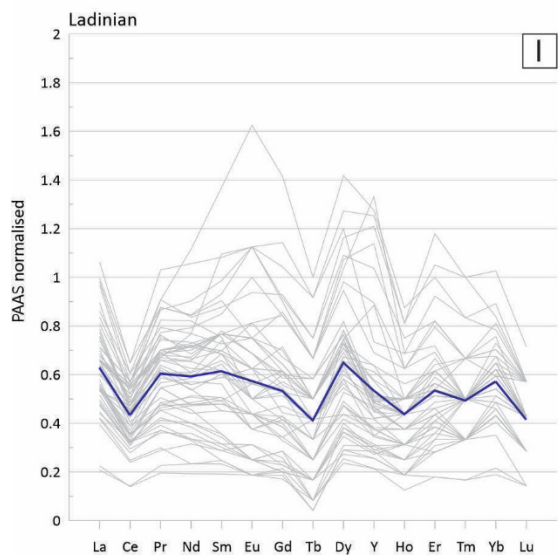
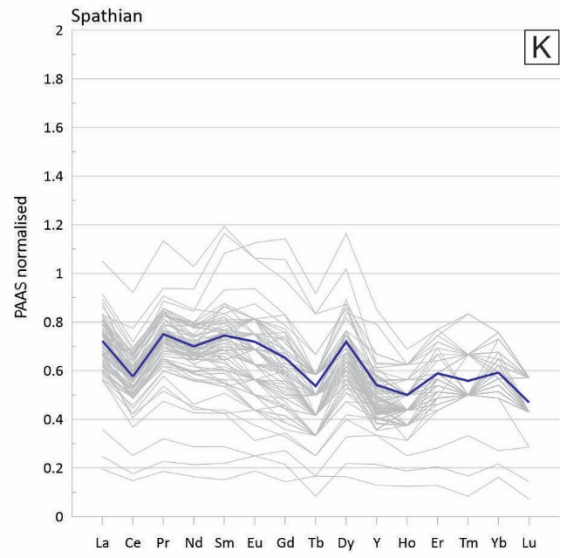
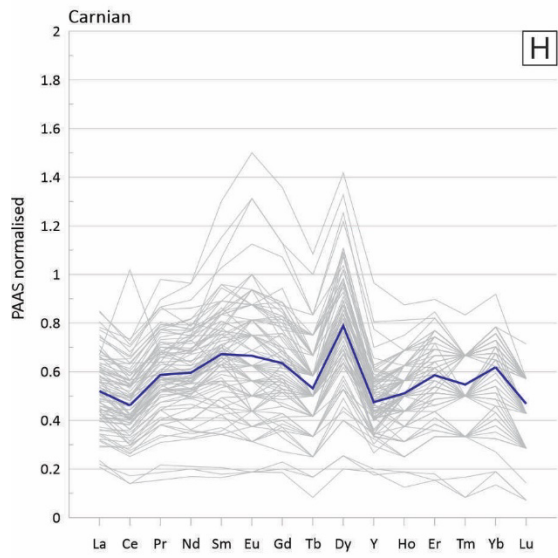
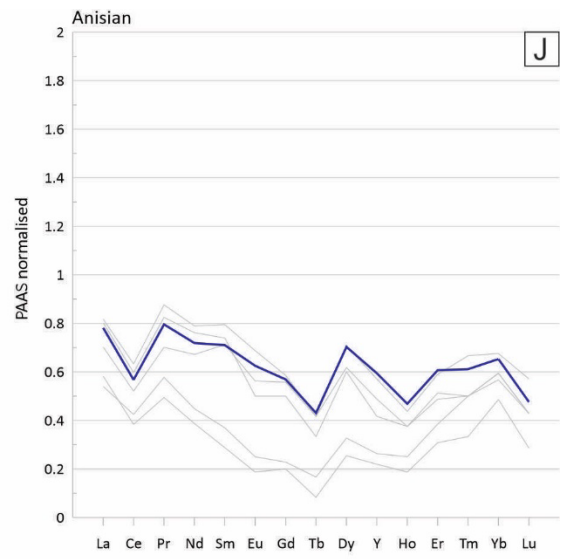
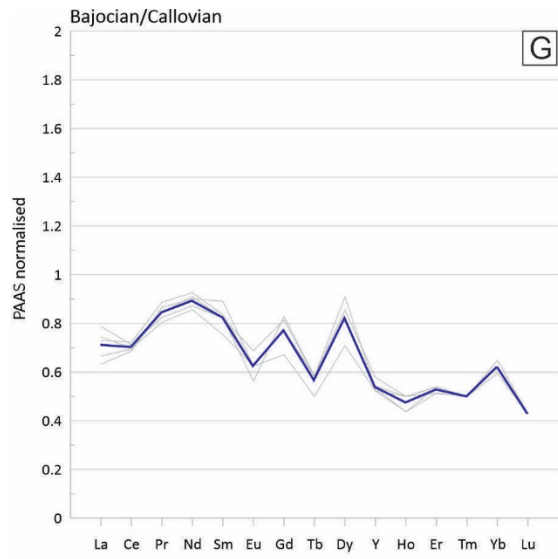


Figure 3. Plot of light, medium, and heavy REE fractions as a function of time (definitions are given in text). Filled circles represent the mean value (and range) of REE fractions for phosphate nodules of the Murray Harbour Formation.





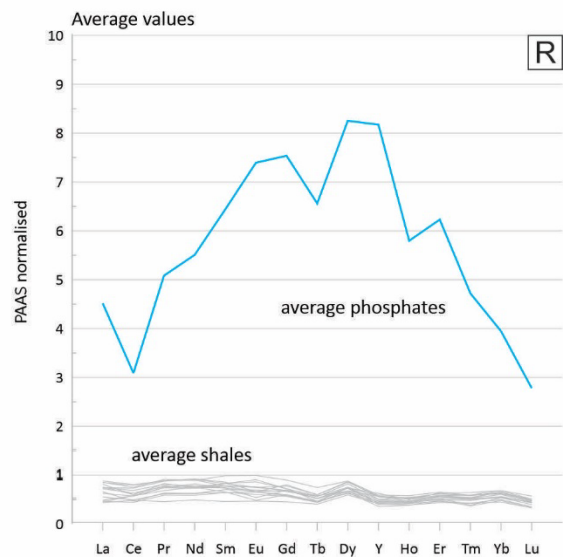
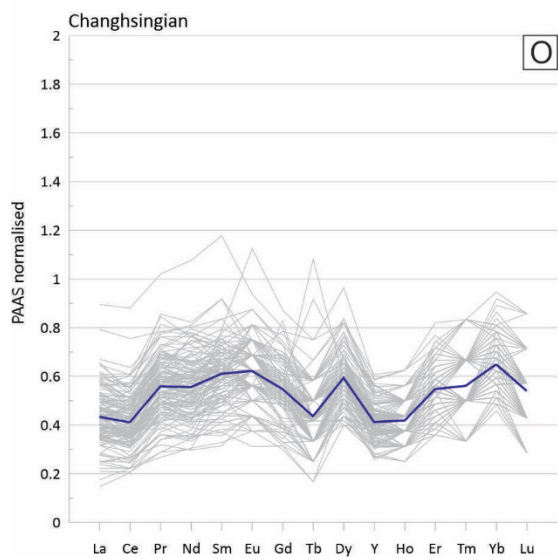
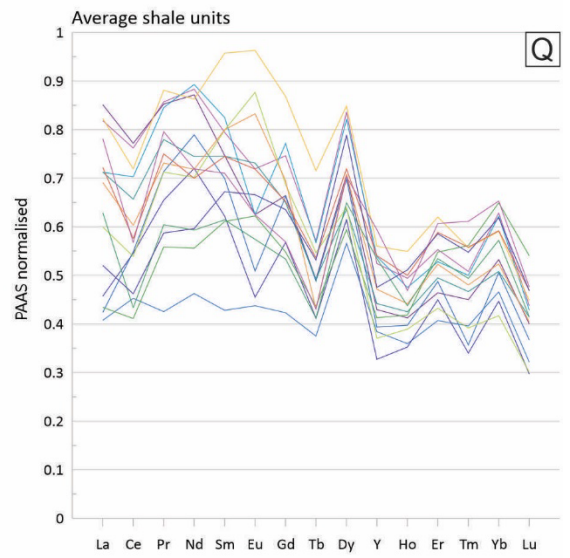
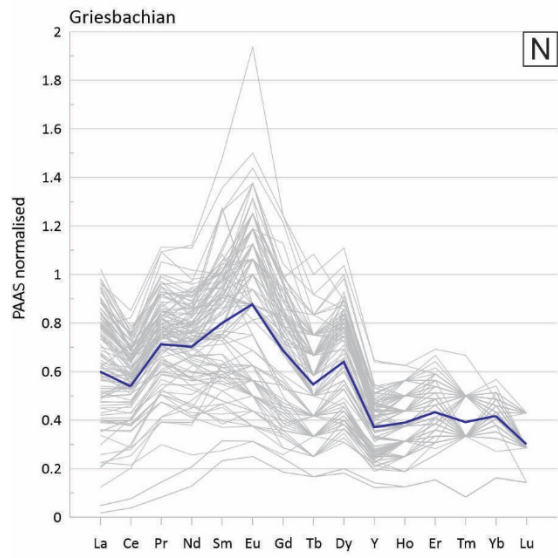
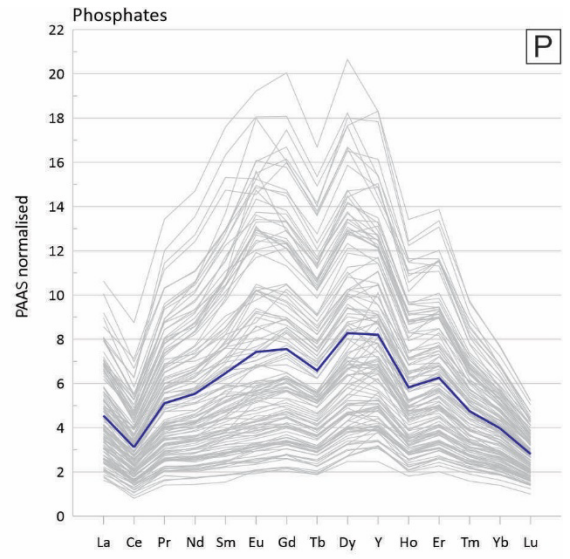
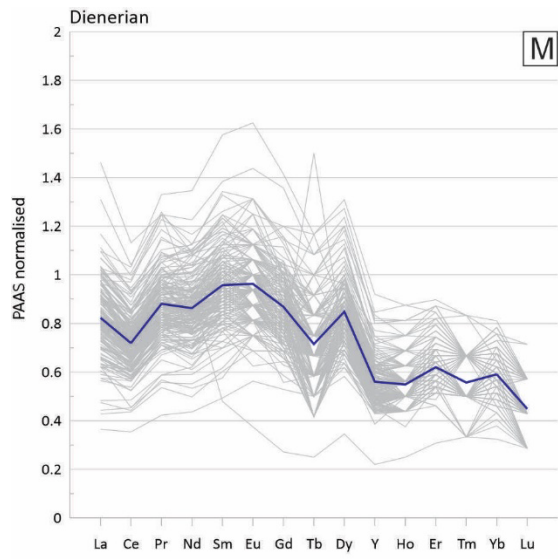


Figure 4. Plots of PAAS normalised REE values for samples in each time period (A-O), as well as for phosphate nodules (P). Grey lines represent individual samples and blue line is the mean for each time period. Means for all time periods are show in (Q). The mean of phosphate nodules (blue line) is shown at the same scale as means of shale units (grey lines).