Alternative correlation methods in low accommodation fluvial settings: an example from the Basal Quartz (Lower Cretaceous), Southern Alberta

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Abstract

Chemostratigraphy and heavy mineral analyses have been applied to the Lower Cretaceous Basal Quartz (BQ) in order to demonstrate that, in tandem, these two techniques have the potential to aid with understanding the stratigraphy of low accommodation fluvial settings. The BQ in the Western Canadian Sedimentary Basin (WCSB) is ideal to test the validity of using such alternative stratigraphic techniques in low accommodation settings because of extensive mapping and petrographic studies previously undertaken has resulted in a relatively good understanding of the stratigraphy. By sampling cores in which three component units of the BQ (the Horsefly, BAT and Ellerslie) have already been stratigraphically assigned, it is possible to demonstrate that both the geochemistry and heavy mineral composition of each unit is unique Therefore, a core or cutting sample of uncertain or unknown stratigraphy can be assigned to a unit based on its geochemistry or heavy mineral composition.

Chemostratigraphic analysis shows that silty claystones from each of the Horsefly, BAT and Ellerslie units have distinctly different geochemistries from one another, with the variations being controlled by a mixture of changing clay mineral species and changing detrital components such as feldspar, apatite and zircon. The geochemistry also suggests periodic volcanogenic input influenced the silty claystones of the BQ. Heavy mineral analysis shows that sandstones from the three units can be distinguished on the basis of a variety of ratio parameters, related to differences in sediment source areas and intensity of weathering during transport.

Introduction

Low accommodation settings commonly contain significant hydrocarbon reserves (e.g. McMurray Oil Sands, Alberta, Cutbank Field, Montana; Cruziana Field, Columbia). However, due to the development of polyphase unconformities and common incision of younger systems into underlying units, understanding the regional stratigraphy in these settings is difficult. Additionally, reservoirs are often highly compartmentalised, which makes field development complex and potentially problematic. These problems are exaggerated when biostratigraphic data are limited. In such settings, stratigraphic techniques that enable each depositional tract to be differentiated, regardless of its spatial distribution, are required. Two such techniques, chemostratigraphy and heavy mineral analysis, have been applied in tandem on the Basal Quartz (BQ) of the Western Canadian Sedimentary Basin (WCSB), southern Alberta.

The BQ, together with the overlying “Ostracode”, forms the Lower Mannville Formation of Aptian age (CSPG Lexicon of Canadian Stratigraphy, 1990). In the study area (**Figure 1**), the BQ is generally less than 100 m thick, and is composed of fluvial to estuarine quartzose sandstones and pedogenically altered claystones. The unit is ideal is to test whether chemostratigraphy and heavy mineral analysis can be successfully applied in low accommodation settings because a working stratigraphic framework has already been erected in the study area (**Figure 2**) (Zaitlin *et al.,* 2002). Within the BQ, there are two cycles, each of which records upward increasing sediment maturity (**Figure 2**). Chemostratigraphy and heavy mineral analysis have been applied to the upper of these two cycles, which comprises, in stratigraphic order, the Horsefly, the BAT and the Ellerslie.

In order to demonstrate the potential of the techniques, conventional cores through each of the Horsefly, BAT and Ellerslie were sampled. The stratigraphic assignment of the cored intervals was already known, the aim of this study being to demonstrate that chemostratigraphy and heavy mineral analysis are capable of differentiating each of the units.

The techniques

Chemostratigraphy involves the characterisation and correlation of strata using major and trace element geochemistry. For this study, data for a total of 47 elements have been determined for 90 samples from 6 wells using inductively coupled plasma optical emission spectrometry (ICP-OES) and inductively coupled plasma mass spectrometry (ICP-MS). The sample preparation and analytical procedures used in this study are detailed in Pearce *et al.* (1999a) and Jarvis and Jarvis (1995).

The key to interpreting geochemical data, rather than simply relying on variations in elements and element ratios, is to attempt to relate variations in the key elements to changing mineralogy. The primary controls on they key elements used for differentiation in this study are changes in clay mineralogy, changes in feldspar content, variations in the heavy mineral species and changes in volcanogenic input. To aid with relating elemental variations to sediment mineralogy, X-ray diffraction analyses have been carried out on selected claystones, and both the heavy mineral data and petrographic analyses of the sandstones are drawn upon.

In this study, the key elements are Al_2O_3, TiO_2, Na_2O, K_2O, P_2O_5, Rb, Zr, Cr and Nb. Variations in the clay mineral species are the primary controls on Al_2O_3, K_2O, Na_2O and Rb; clay mineral species present are kaolin (Al-silicate), illite (K, Al-silicate), smectite (Ca, Na, Mg, Fe, Al-silicate) and chlorite (Mg, Fe, Al-silicate), with the Horsefly being dominated by illite and BAT by kaolin. The Ellerslie contains a mixture of illite and kaolin, but contains more illite/smectite than the other two units. Petrography indicates that while feldspars are only present in small amounts in the sandstones, the Ellerslie and the Horsefly contains more than does the BAT. The K_2O/Rb ratio can be used to model changes in the feldspar contents of the fine grained facies. Heavy mineral species in the silty claystones are the primary controls on Zr (zircon) and P_2O_5 (apatite) concentrations. TiO_2 and Nb are two elements that normally occur together with a constant ratio. In this study, the BAT has an anomalous enrichment in Nb that suggests volcanogenic input.

Heavy mineral assemblages are sensitive indicators of sandstone provenance and sediment transport history, enabling discrimination of sandstones derived from different sources and/or transport systems. However, the composition of heavy mineral assemblages is not entirely controlled by source rock mineralogy, because other processes that operate during the sedimentation cycle (principally weathering, hydrodynamics and diagenesis) may overprint the original provenance signal (Morton and Hallsworth, 1999). The effects of these overprinting processes can be counteracted by determining ratios of stable minerals with similar densities, as these are not affected by changes in hydraulic conditions during sedimentation or by diagenetic processes (Morton and Hallsworth, 1994). The ratios used in this study are apatite: tourmaline, rutile:zircon and zircon:tourmaline. Of these, rutile:zircon reflects only provenance, whereas apatite:tourmaline is controlled both by provenance and the extent of weathering during transport, and zircon:tourmaline is potentially influenced both by provenance and hydrodynamics. Heavy mineral analysis was conducted on 14 samples from 3 wells.

By applying chemostratigraphy to the finer grained facies and heavy mineral analysis to the sandstones, all lithological components of the BQ can be characterised.

Differentiation of units

The most effective ways to demonstrate geochemical and heavy mineral variations are profiles (**Figure 3**), binary and ternary diagrams (**Figures 4** and **5**). Profiles for a single section are constructed by plotting the variables (element concentrations and heavy mineral abundance) against depth. In this study, however, no single core that contains both sandstones and fine grained facies from all three stratigraphic units was sampled. Therefore, for visual analysis in this study, it is far more effective to construct “synthetic” geochemical profiles. This has been done by plotting the samples in their correct stratigraphic order, but with no implication of depth (**Figure 3**).

Horsefly

Silty claystones

Low values of Zr/Al_2O_3 in conjunction with high values of K_2O /Al_2O_3 and Rb/Al_2O_3 (**Figure 3**) differentiate the Horsefly on the geochemical profiles from both the BAT and the Ellerslie. This suggests that the silty claystones of the Horsefly have relatively low zircon contents and are relatively illitic. On binary and ternary diagrams, silty claystone samples from the Horsefly are readily differentiated from those of the BAT and Ellerslie primarily by their high values of K_2O/Al_2O_3 (**Figure 4**).

Sandstones
Horsefly sandstones are markedly different to both the BAT and Ellerslie, having much higher apatite:tourmaline and lower rutile:zircon. The difference in rutile:zircon indicates that the Horsefly sandstones had a difference source to the BAT and Ellerslie. The higher apatite:tourmaline may also be related to a difference in source, but could also indicate less prolonged weathering during sediment transport history.

BAT
Silty claystones
On geochemical profiles, the BAT is clearly differentiated from both the Horsefly and Ellerslie by its low P_2O_5/Al_2O_3 and K_2O/Al_2O_3 values (**Figure 3**). The former ratio possibly suggests low apatite contents and the latter reflects the kaolinitic nature of the BAT claystones, a feature confirmed by XRD analyses. The BAT silty claystone samples are readily differentiated from those of the Horsefly and Ellerslie on binary and ternary diagrams due to their low K_2O, low K_2O/Al_2O_3 and low Na_2O/Al_2O_3 values (**Figure 4**). On the TiO_2 vs. Nb binary diagram (**Figure 4**), silty claystone samples from BAT plot on a separate linear trend to those from the Horsefly and Ellerslie, indicating that samples from the BAT contain a mineral enriched in Nb relative to Ti. In most minerals, the Ti:Nb ratio is constant, but in this study (and other proprietary datasets from Canada) a mineral preferentially enriched in Nb over Ti is present in the BAT, but not the Horsefly or Ellerslie. This mineral is thought to be of volcanogenic origin and may be related to the carbonatite complexes that are present in Alberta and Saskatchewan. Another possible explanation is that the anomalous Nb is present in rutile (Preston *et al*., 1998), but this is considered less likely since similar rutile contents are found in both the BAT and Ellerslie.

Sandstones
Heavy mineral assemblages in BAT sandstones are distinguished from the Horsefly by having lower apatite:tourmaline and higher rutile:zircon (**Figure 4**). They have similar apatite:tourmaline to the Ellerslie, but can be distinguished on the basis of higher zircon:tourmaline and slightly lower rutile:zircon. The source of the BAT sandstones is therefore markedly different to that of the Horsefly, but differs from the Ellerslie principally by being more zircon-rich.

Ellerslie
Silty claystones
The Ellerslie is clearly differentiated from the Horsefly and the BAT on geochemical profiles by its high values of K_2O/Rb. On other ratios, such as Rb/Al_2O_3 and K_2O/Al_2O_3, samples from the Ellerslie plot with values that are intermediate between those of the Horsefly and the BAT. Similarly, on binary and ternary diagrams samples from the Ellerslie plot in a position intermediate between those of the Horsefly and BAT (**Figure 4**).

Sandstones
Ellerslie sandstones have similar apatite:tourmaline and rutile:zircon to the BAT, differing markedly to the Horsefly. They are distinctive in having higher tourmaline contents compared with the BAT, resulting in lower zircon:tourmaline ratios (**Figure 4**).

Conclusions

Both silty claystones and sandstones from the Horsefly, BAT and Ellerslie can be differentiated from one another despite their physically similar appearances. Silty claystones from each unit are differentiated from one another using variations in the concentrations of key elements (Al_2O_3, TiO_2, Na_2O, K_2O, P_2O_5, Rb, Zr, Cr and Nb.). The chemical variations reflect:

- Changes in clay mineralogy, which in turn are controlled by changes in the intensity of weathering (i.e. changing palaeoclimate)
- Changes in detrital mineralogy (feldspar and heavy mineral contents)
- Periodic volcanogenic input.

Sandstones from the three units can also be differentiated on the basis of their heavy mineral assemblages.

- The Horsefly has high apatite:tourmaline, high zircon:tourmaline and low rutile:zircon;
- the BAT has low apatite:tourmaline, high zircon:tourmaline and relatively high rutile:zircon; and
- the Ellerslie has low apatite:tourmaline, low zircon:tourmaline and relatively high rutile:zircon. The differences in these parameters reflect changes in sediment source and intensity of weathering during transport.

This study, therefore, demonstrates that by combining chemostratigraphy and heavy mineralogy, it should be possible to assign a core or cutting sample to the Horsefly, BAT or Ellerslie, allowing even the complex stratigraphy associated with low accommodation settings of the BQ in the WCSB to be unravelled.

Both chemostratigraphic and heavy mineral techniques rely on identification and modeling of changes through time in provenance, detrital input and palaeoclimate. In low accommodation settings, where relatively thin successions represent large periods of time, there is a greater chance for a change in provenance and/or paleoclimate to be recorded by the sediments. Therefore, in some ways, low accommodation settings are ideal for the application of chemostratigraphy and heavy mineralogy.

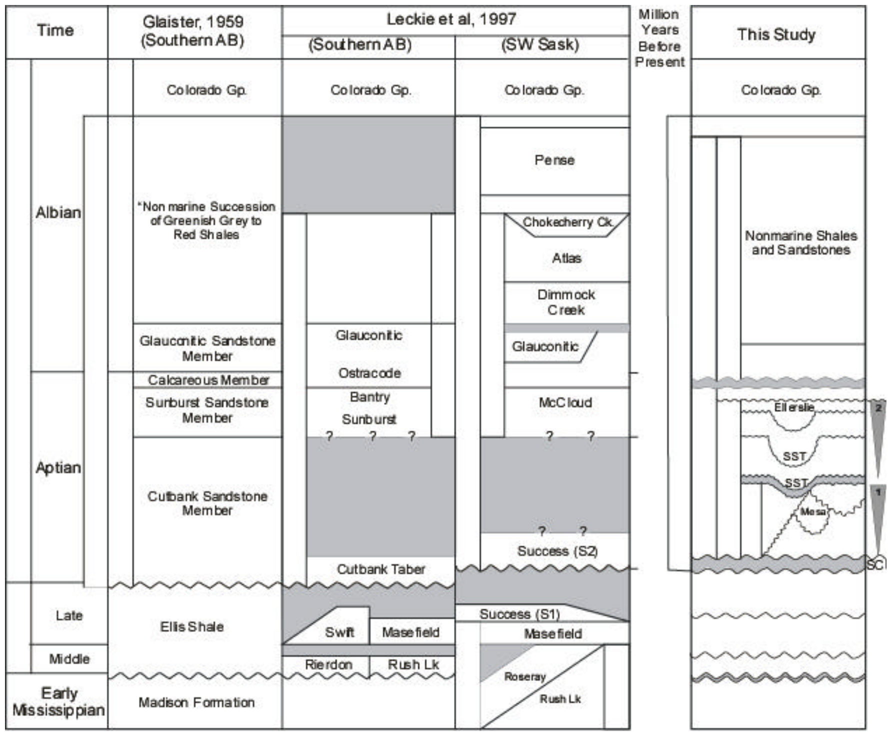

FIGURE 1: Early Cretaceous stratigraphic nomenclature in Southern and Central Alberta (AB) and Southwest Saskatchewan (Sask). A Sandstone (including Regional A, Carmangay, Mesa Incised Valley (I.V.), A Valley and Terrace (V&T), Horsefly Sandstone (SST), BAT SST (Bantry – Alderson – Taber) and Ellerslie SST are informal stratigraphic units described in this study. Cycles 1 and 2 refer to mineralogical and textural cycles described in text. Geologic ages from Gradstein et al. (1994). Gp = Group; Fm = Formation; Mbr = Member; SCU = Sub-Cretaceous unconformity.

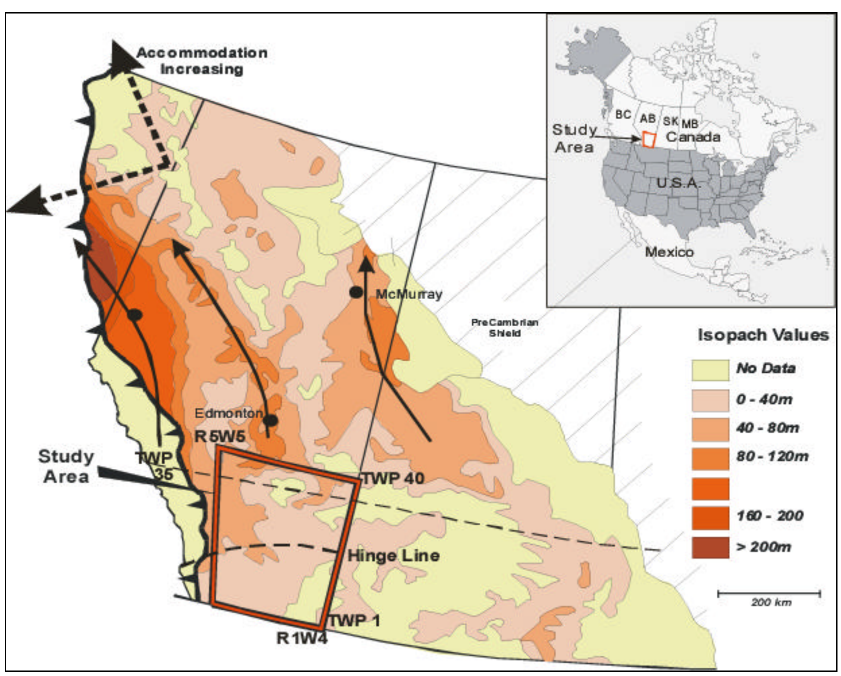

FIGURE 2: Location map showing location of study area in North America with a detailed map of the study area in Alberta on which isopach grades for the Lower Mannville are displayed.

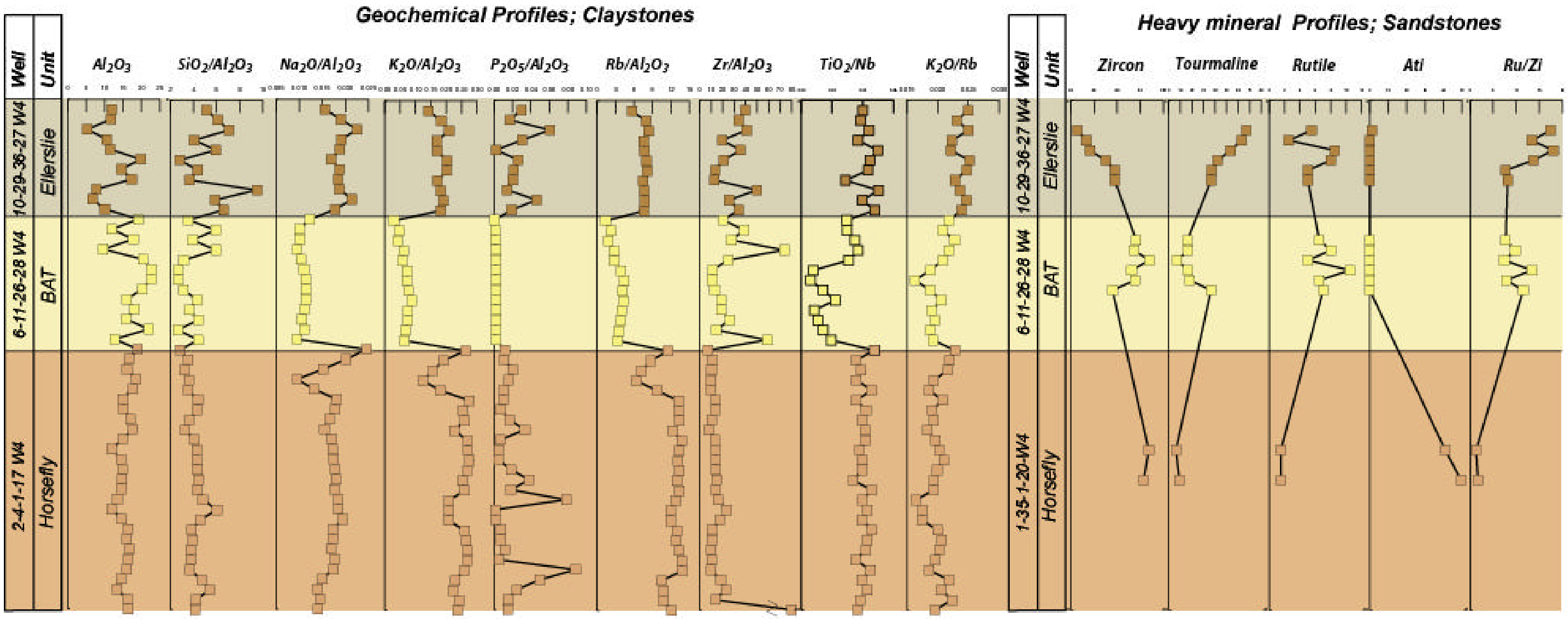

FIGURE 3: "Synthetic" geochemical and heavy mineral profiles constructed for samples from the Horsefly, BAT and Ellerslie. The profiles are constructed to visually display geochemical and heavy mineral differences between the units such that each sample is in the correct stratigraphic order, but there is no inference of its absolute depth (see text for discussion). Each square represents an analyzed sample

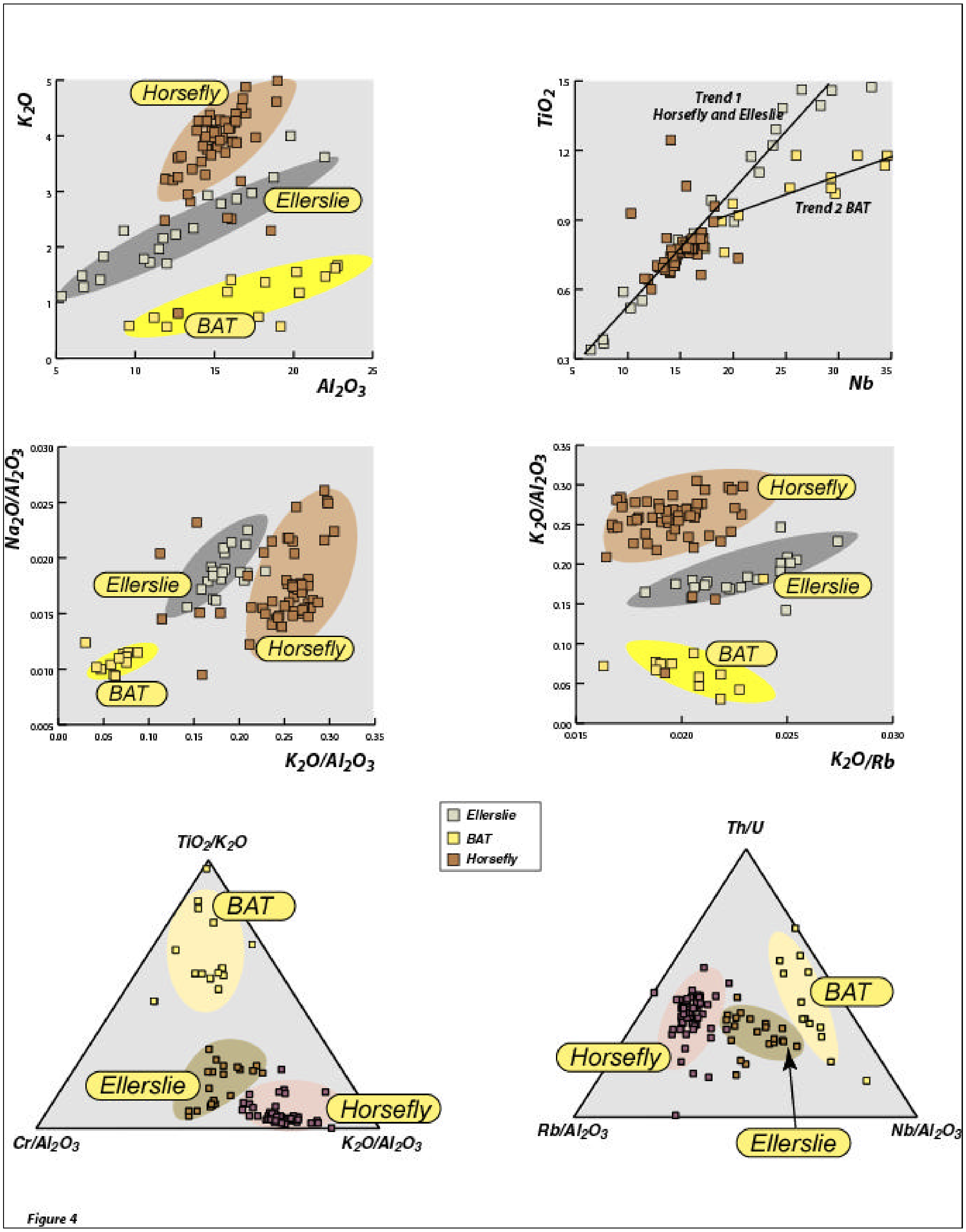

Figure 4. Graphical differentiation of silty claystones frfom the Horsefly, BAT and Ellerslie using geochemical data.

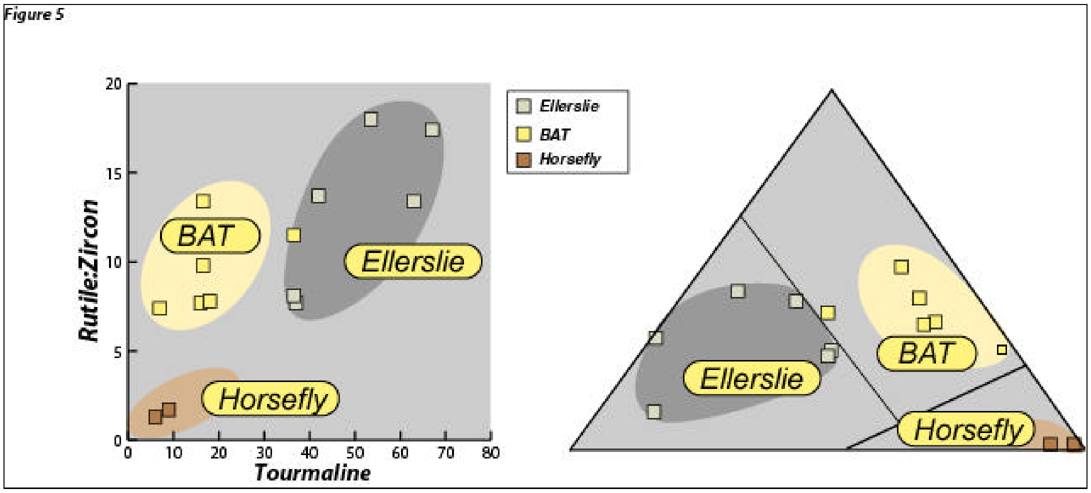

Figure 5. Graphical differentiation of sandstones from the Horsefly, BAT and Ellerslie using heavy mineral data.

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