Elemental Chemostratigraphy, Isotopic Chemostratigraphy and Magnetic Susceptibility Stratigraphy of a Late Miocene Prograding Reef Complex of the Llucmajor Platform, Mallorca*

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Abstract

Stratigraphic methods such as elemental chemostratigraphy, magnetic susceptibility (MSS) and C-O isotope stratigraphy are increasingly being used in the petroleum industry to assist in constructing correlations between well bores (see Ratcliffe and Zaitlin, 2010 for review of "Modern" Stratigraphic methods). In order to test the efficacy of these methods in pure carbonate lithologies, inorganic elemental, C-O isotope and magnetic susceptibility (χ) data have been gathered from seven sections through the Llucmajor Platform, Mallorca. For a review of the methods applied in this study see Wright et al. (2010), Pearce et al. (2010), Ellwood et al. (2010a and b), and Prave et al. (2010). The aim of acquiring these data here is to determine whether a combination of stratigraphic techniques can provide chronostratigraphic information in reef complexes that have no direct (fluvial) source of terrigenous material and whether such information would be applicable to other reef complexes, particularly those which are targets of hydrocarbons in the subsurface.

The Llucmajor Platform is a series of reef complexes which crop out on the southern sea cliffs of the island of Mallorca (Figure 1). Due to their excellent exposure, these sections are much studied and have become a classic example of how reef complexes respond to sea-level fluctuations (Pomar and Ward, 1994; 1995).

Results

Magnetic susceptibility (χ)

Figure 2F shows that there are well defined fluctuations in the χ values through the CB section (location shown on Figure 1). The χ values reach a maximum at, or close to, sigmoid set bounding surfaces, irrespective of the facies in which the bounding surface exists. In the case of the CB section, two sigmoid set bounding surfaces are intersected, one in the fore reef setting (Ci/dls) and one in the reef core facies (sb). The increase in χ values at set (and co-set) bounding surfaces reflects increased terrigenous content of the sediments due to slower carbonate deposition in lower accommodation settings. Therefore, χ values enable recognition and correlation of 4th (co-set) and 5th (set) order sequence boundaries through lagoon facies, reef core facies and fore reef facies. Figure 2F also shows a series of finer scale cycles in the χ values of the CB section, each one being 10-20 m thick, which is the scale of sigmoids (Figure 2A), suggesting that these cycles are reflecting 6th order eustatic sea level fluctuations. The χ values do not show any specific long term variations in the section studied that would enable characterization of reef complexes of different ages.

Elemental Chemostratigraphy

Figure 2E shows that from deposition of the reefs in the PC section (oldest) to deposition of reefs in the CO section, Cr values gradually increase, reaching a maximum in the lower parts of the CO section. Reef core facies of the CB section (youngest) have generally low Cr values, although toward the top of the section, Cr starts to increase, suggesting the onset of another upward increase in Cr values. Zr/Cr values display an overall upward decrease, with two notable steps, one between samples from PC section and PNC section and the other between samples from the CO and CB sections. Similar changes can also be recognized in lagoonal and fore reef facies of different ages. These types of changes in elemental composition form the basis for any chemostratigraphic characterization and correlation; their recognition provides a means to differentiate, in the case of Figure 2E, reef-core facies that formed at different times. Any resultant chemostratigraphic characterization of a single facies, however, only has chronostratigraphic significance if the changes can be shown to be related to events that took place during deposition (i.e. not they are not diagenetic).

The elements relied upon for characterization in this study are Al_2O_3, TiO_2, Zr, Cr, Ga, Rb and Nb, all of which are shown here to be related to windblown terrigenous and volcanic debris. For example, changes that are identified in reef-core facies (Figure 2E) are shown to be related to variations in fine-grained heavy or opaque minerals that are Zr-rich (zircons ?) and Cr-rich (spinels ?, chromite ?). These changes must therefore be related to changes in the composition of the wind-blown debris entering the depositional system and as such will have chronostratigraphic significance.

C-O isotopes

Initial carbon and oxygen isotope results have been obtained from 3 sections, CB, CO and CC. From Figure 3 it is apparent that both the C and O isotopes have been significantly affected by dolomitization, with each being significantly enriched in the heavy isotope (^{13}C and ^{18}O) where dolomite is the pervasive phase. Figure 2G shows that undolomitized samples have light carbon values relative to marine carbonates of that age, suggesting significant freshwater diagenesis. Samples plotting between the dolomite and freshwater influenced calcite end members are probably a mixture of calcite and dolomite. Therefore, in this particular case, C-O isotopes will not help with definition of chronostratigraphic surfaces or units.

Conclusions

Sigmoid-set and co-set bounding surfaces are identified by high χ values, enabling these chronostratigraphic surfaces to be correlated between closely spaced sections. Identification of such surfaces in a subsurface setting would greatly enhance correlation potential. Elemental data which is related to the amount and composition of wind-blown terrigenous and volcanic material within the carbonate sediments can be characterized and show sufficient variation through time to allow characterization and correlation of reef complexes. By enabling such chronostratigraphically significant rock units to be identified in the subsurface, elemental data would greatly enhance the potential for defining chronostratigraphic correlation frameworks. Both magnetic susceptibility stratigraphy and chemostratigraphy can be carried out on core and ditch cutting samples and would therefore provide potentially vital information for the definition of chronostratigraphies in, for example, detached or isolated carbonate platform sequences.

Although, in this example, C-O do not seem to help with chronostratigraphic correlation, their clear relationship to meteoric water diagenesis and dolomitization suggest that if this where a hydrocarbon system in the subsurface, the stable isotopes would be supplying information on reservoir quality, which when combined with the chronostratigraphic information supplied by chemostratigraphy and MSS would provide an excellent reservoir modeling tool.

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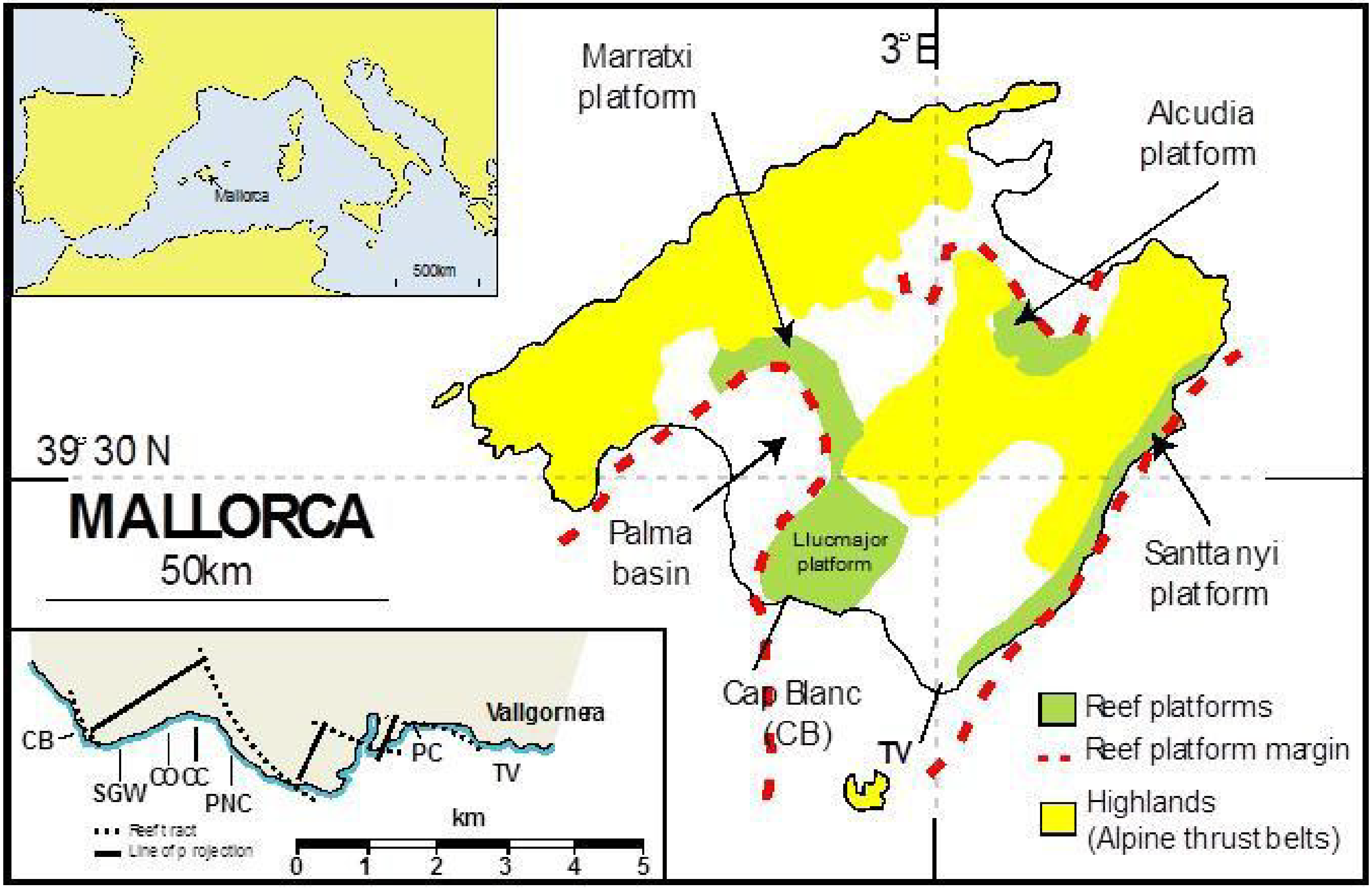

Figure 1. Llucmajor location map with inset showing positions of analyzed sections.

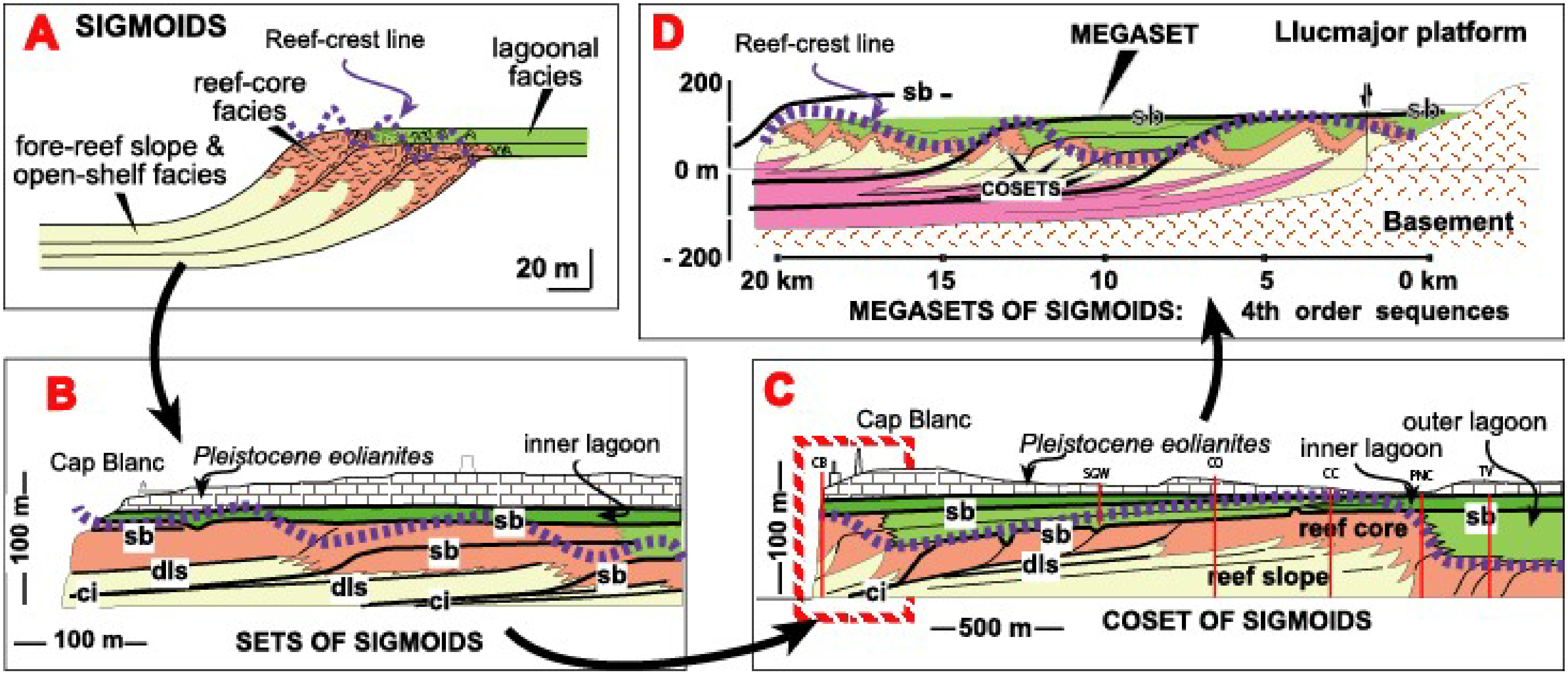

Figure 2 (A-D). The hierarchical stacking of sigmoidal depositional units described by Pomar and Ward (1994). (2A) Sigmoids, the basic building block, representing a depositional sequence related to the highest-frequency sea-level cycle recognized. (2B) Sigmoids stack in sets of sigmoids as seen on the sea cliffs on Mallorca. (2C) Sigmoid sets stack in co-sets of sigmoids. (2D) Sigmoid co-sets stack into megasets, three of these megasets build the whole Llucmajor Platform.

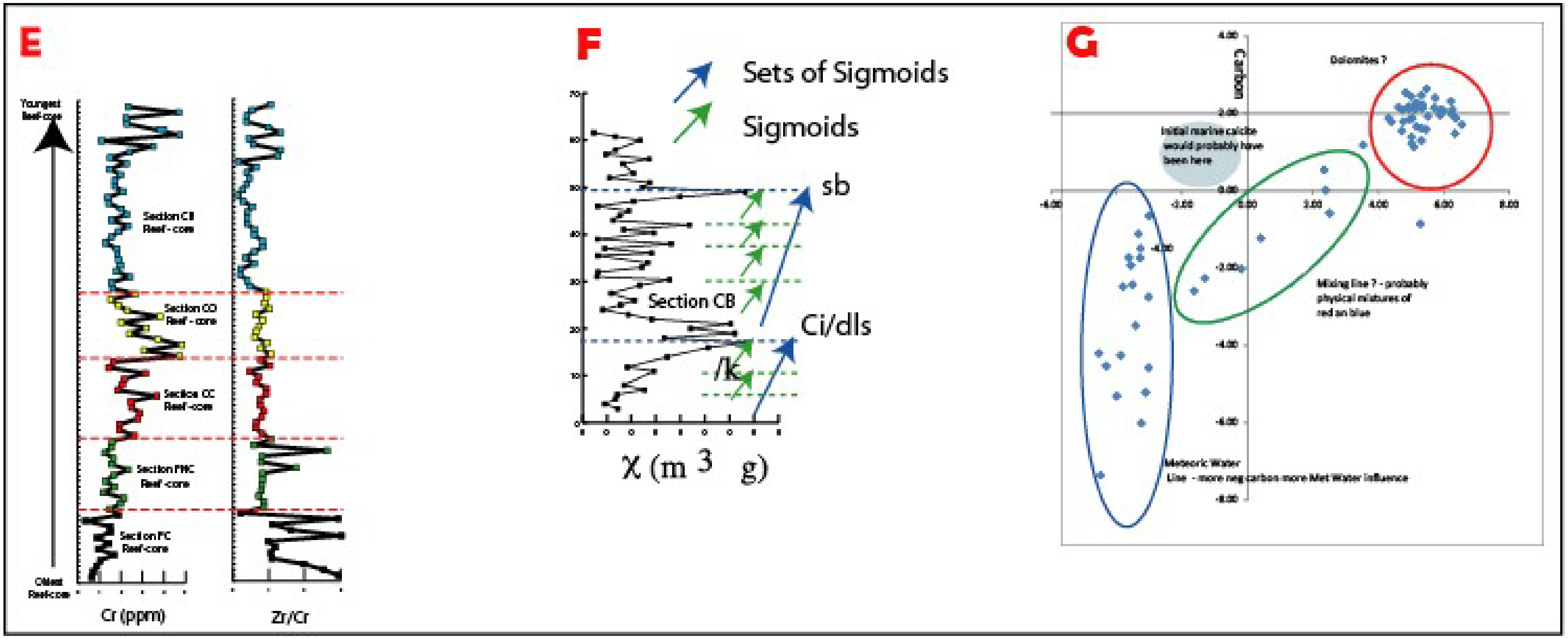

Figure 2 (E-G). (E) Chemical logs showing changes in Cr and Zr/Cr in Reef-core facies through time. (F) Magnetic susceptibility log for CB section. (G) Carbon Oxygen isotopes data determined from whole rock samples from sections CC, CB and CO.

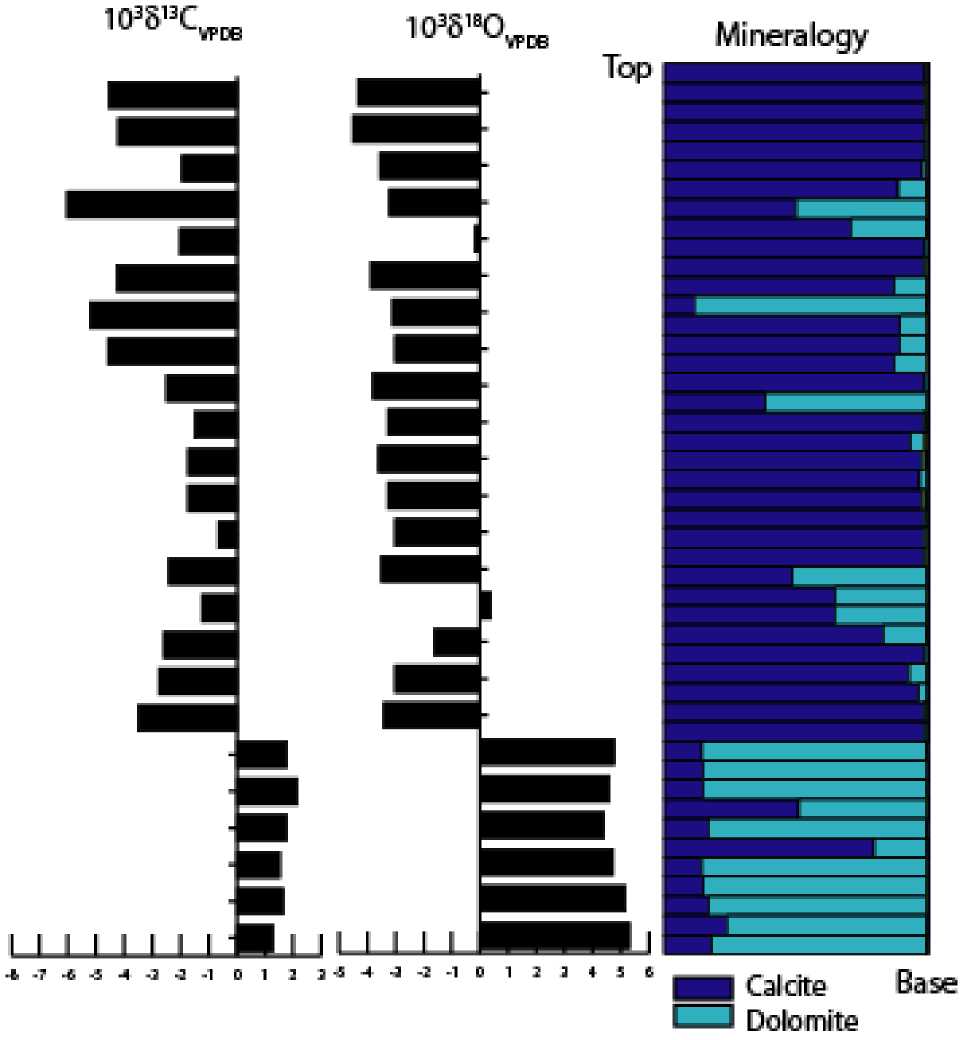

Figure 3. Carbon and Oxygen isotopes for the CC section, plotted against the mineralogy as calculated from the elemental data.