The palaeomagnetism of glauconitic sediments

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Introduction

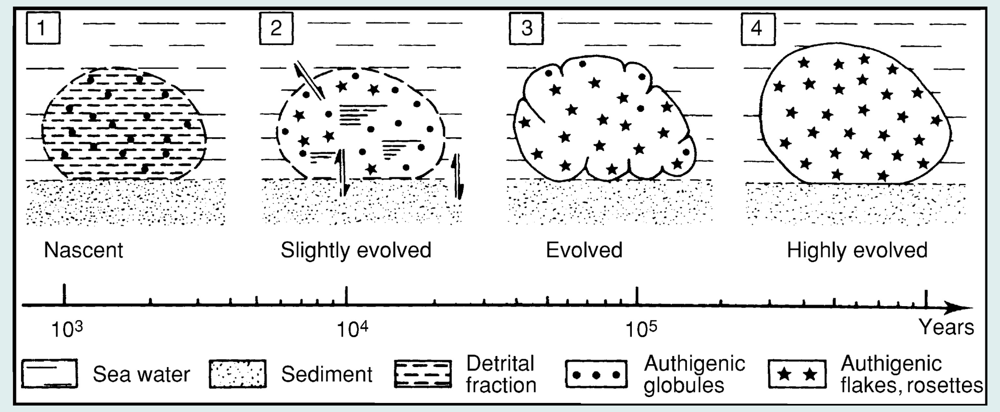
The importance of glaucony

Glaucony is found worldwide in modern and ancient marine sediments. It forms diagenetically at the sediment-water interface and provides valuable palaeoenvironmental data: glauconitic horizons are generally interpreted as indicating a low sedimentation rate, and can thus record events such as eustatic fluctuation and changes in ocean circulation. Magnetostratigraphy is an important tool for dating the events that produce glauconitic horizons, but its successful application requires a coherent understanding of glaucony's role in remanence acquisition.

Aims of the investigation

In this investigation we answer two questions:

- Can highly glauconitic sediments yield a reliable remanence?
- How should this remanence be interpreted palaeomagnetically?



Evolution of glaucony over a time span of 1 Myr, after Odin & Matter (1981) and Huggett (2005).

How can glaucony affect palaeomagnetism?

Glaucony is usually classed as paramagnetic, but the sensitivity of modern magnetometers allows us to measure remanences from very weakly magnetized (<50μA/m) sediments which would previously not have been considered remanence carriers. Glauconitic grains are large and slow-forming, with complex and various morphologies. It is thus possible that they may incorporate ferromagnetic minerals and carry a significant proportion of the remanence in weakly magnetized rocks.

The problem of diagenesis

Glaucony forms on the sea bed over long time periods (>100 kyr). If the remanence of a sediment is carried by minerals incorporated into the glaucony at a late stage, it may not reflect the Earth's magnetic field at the time of deposition, making magnetostratigraphic interpretation more difficult. Similar problems beset palaeomagnetic work on remanences carried by greigite, which also forms post-depositionally (Roberts and Weaver, 2005).

References & Acknowledgements

References

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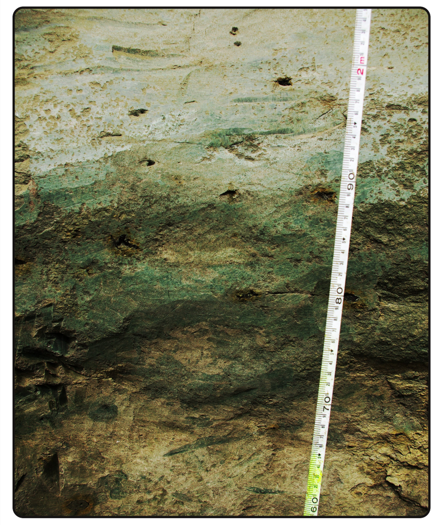
Methods

Materials for the study



For this study, we sampled a Palaeocene glauconitic horizon from Fairfield Quarry near Dunedin (south-eastern South Island, New Zealand). We drilled standard palaeomagnetic core samples from the horizon itself, and from the less glauconitic zones immediately above and below it. We also collected bulk samples from the same stratigraphic levels, for glaucony separation studies; in total, we used 36 discrete samples in the main rock magnetic study. We also conducted more limited rock magnetic experiments on samples from subantarctic Campbell Island (700km south of New Zealand) and from the mid-Waipara River (eastern South Island, New Zealand).

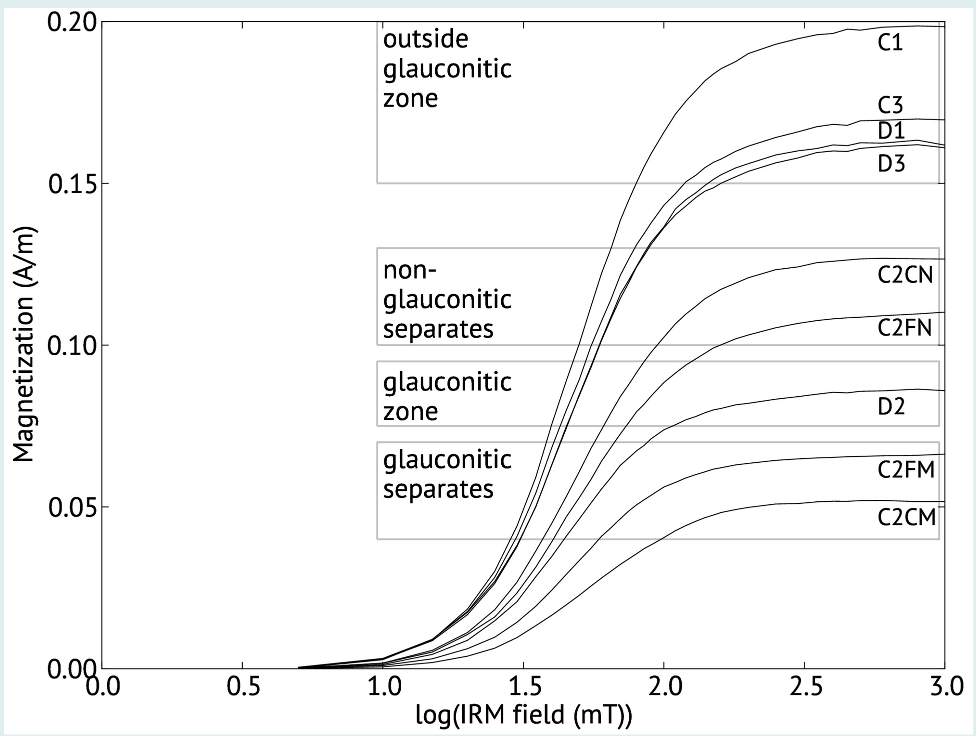
Determining the role of glaucony

In order to determine the relationship of glaucony to the remanence carriers, we produced glauconitic and non-glauconitic separates from the sampled sediment by disaggregating, sieving, and magnetically separating bulk samples. The separates were subjected to the same analyses as the drilled samples.

Identifying the remanence carriers

We applied a battery of rock magnetic and mineralogical techniques to the sampled material in order to identify the minerals carrying the magnetization:

- stepwise acquisition of isothermal remanent magnetization (IRM) followed by stepwise backfield application (‘DC demagnetization’)
- stepwise acquisition of an anhysteretic remanent magnetization (ARM) followed by stepwise alternating-field (AF) demagnetization
- temperature dependence of magnetic susceptibility (TDMS)
- stepwise thermal demagnetization of a triaxial IRM (Lowrie, 1990)
- optical and electron microscopy
- electron probe microanalysis (EPMA)

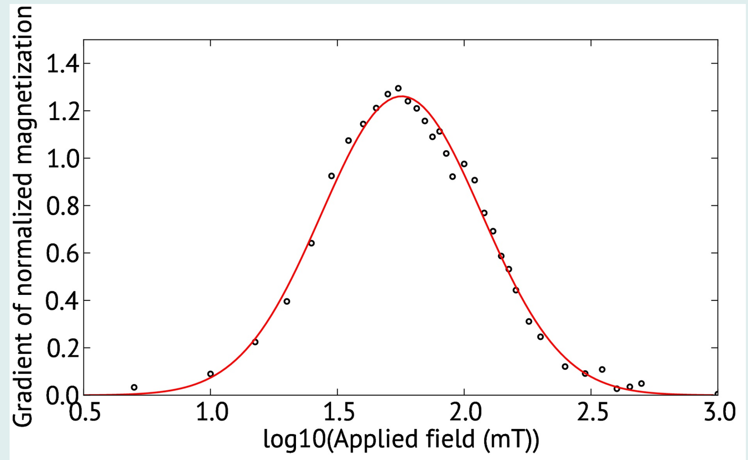


Comparative IRM acquisition curves for glauconitic and non-glauconitic zones, and for glauconitic and non-glauconitic separates. Note the inverse correlation of glauconitic content with saturation magnetization, and the similarity of curve shapes despite the wide variation in saturation magnetization.

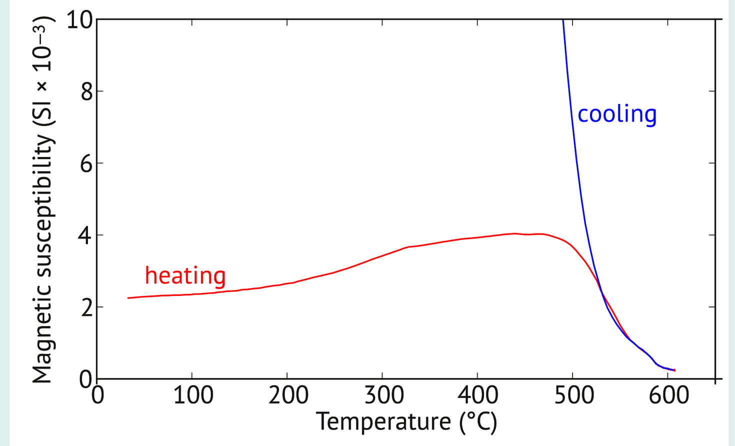
Results

Magnetic mineralogy

IRM acquisition curves showed that the sediments had a low remanent coercivity, consistent with magnetite. For a more accurate mineralogical diagnosis, we unmixed the IRM acquisition curves using the expectation-maximization technique of Heslop (2002). The IRM results could not definitively exclude a possible pyrrhotite or greigite component; however, TDMS results were successful in ruling these out, establishing magnetite as the only significant remanence carrier. Rock magnetic parameters indicated a stable single domain or pseudo-single domain magnetic grain size, so the magnetite is capable of retaining a primary remanence.



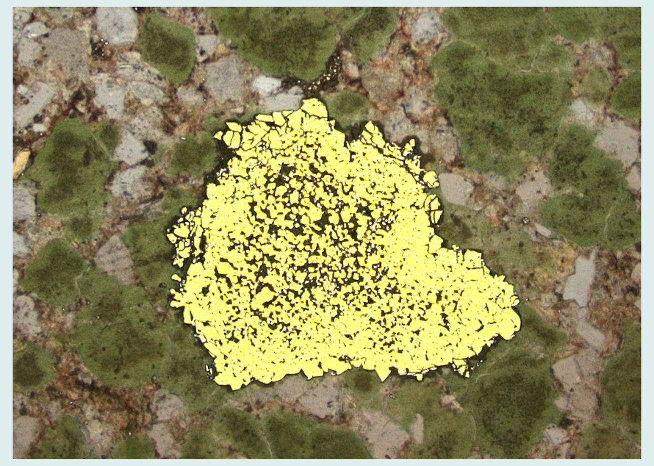
Typical IRM acquisition behaviour, shown as gradient of acquisition curve. A single log-Gaussian curve gives a good fit to the data points, indicating that the remanence is carried by a single mineral phase.

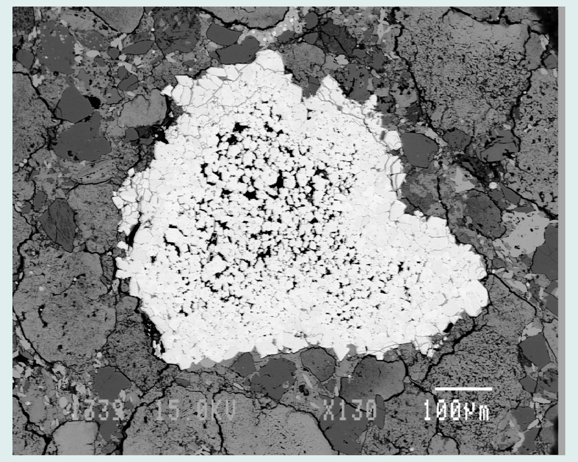


Temperature dependence of magnetic susceptibility for a typical specimen. The gradual increase in susceptibility, followed by a complete loss of susceptibility at around 580°C, is indicative of magnetite. The cooling curve diverges significantly from the heating curve due to heating-induced alteration.

Pyritization

All iron-bearing grains subjected to electron microprobe analysis were found to be stoichiometric pyrite, confirming the absence of intermediate pyritization products such as greigite. The combination of high glaucony content and extensive pyritization led to very low concentrations of magnetite (below 1 p.p.m. as estimated from saturation IRM).





A large pyrite grain surrounded by glaucony, imaged with optical and electron microscopy (the optical image is under both transmitted and reflected light). Extensive pyritization left less than 1 p.p.m. of magnetite as a remanence carrier in these sediments.

The role of glaucony

We compared the rock magnetic results between the glauconitic and non-glauconitic zones, and between the glauconitic and non-glauconitic separates. In both cases, the results showed that most rock magnetic parameters did not differ according to the glaucony content. The only major variation was in saturation magnetization, which was inversely correlated with glaucony content. These results show that glaucony itself does not carry a remanence, and that its palaeomagnetic effect is mainly to dilute the magnetization of the other components.

Discussion

Remanence acquisition model

Given the extensive pyritization and lack of intermediate pyritization products (greigite and pyrrhotite), it is likely that the sparse remaining magnetite was physically protected from corrosive pore fluids by overgrowth of inert material such as silica (Karlin, 1990) or pyrite (Canfield & Berner, 1987).

Glaucony and magnetism

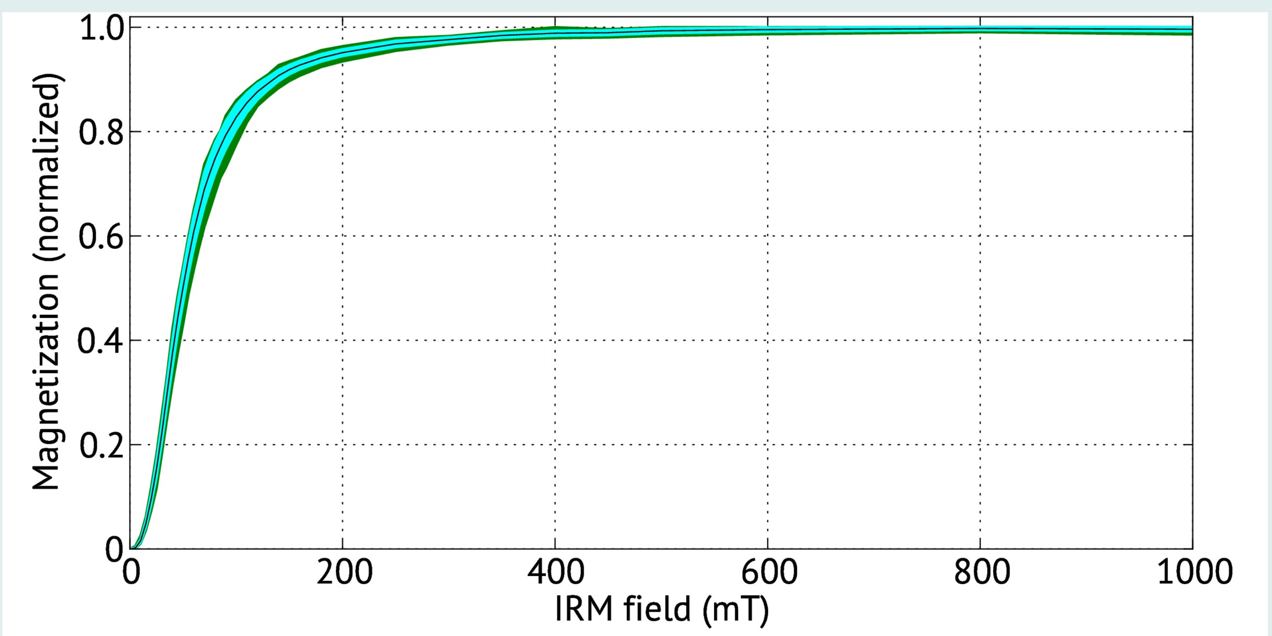
Glaucony holds little or no remanence. Glauconitic sediments are thus not ideal for palaeomagnetic study, since magnetizations are likely to be very low. However, since glaucony itself does not carry a remanence, it does not affect the interpretation of any magnetization which can be measured.

Pyritization and magnetism

The low remanences were due not only to glauconitic content but to the almost complete pyritization of detrital magnetite. However, the lack of intermediate pyritization products means that the only problem for palaeomagnetic study is one of accurate measurement rather than determining when remanence was acquired: in such a strongly pyritizing environment, magnetite could not have formed authigenically, and it is thus very likely that it carries a depositional magnetization.

Palaeomagnetic implications

In these sediments, pyritization and glauconitization combine to produce natural remanences near the lower limit for palaeomagnetic analysis. The rock magnetic analyses, however, show that the remaining magnetization is carried by magnetite and that the sediments can provide a reliable palaeomagnetic signal. The problems of palaeomagnetic analysis are therefore mainly connected with the accuracy of measurement, which can be improved by such techniques as multiple remeasurements and manual correction for sample holder remanences; post-depositional chemical remanences are unlikely to be a problem. Glauconitic horizons and the marine events that produce them can thus be accurately dated using magnetostratigraphic techniques.



Normalized IRM acquisition curves for all the specimens in the study, showing that magnetic mineralogy is similar throughout, with the chief variation being in concentration. The black line shows the mean IRM acquisition curve. The green area shows the entire range of magnetizations at each field strength. The cyan area shows the standard deviation of the magnetization.