StreamLine Plus™ Raman imaging of a banded iron formation core section

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Abstract

StreamLine Plus™ Raman imaging has been used to characterise the minerals in a banded iron formation (BIF) core section originating from the Hamersley Ranges of Western Australia. Analysis of the Raman data reveals information about the mineralogical content and its spatial distribution. Magnetite was found to be the dominant iron species in a varied mineralogical composition. The technique used would be valuable for exploration geologists seeking data on the type and quantity of iron ore within core sections acquired from exploration sites. Researchers seeking to interpret the geological history of some of the earth's earliest sediments will also benefit from the mineralogical information provided by Renishaw's StreamLine Plus™ Raman imaging.

Introduction

Banded iron formations (BIFs) are of great importance in geological science, both for the information they provide about the early evolution of the earth, and as the world's richest source of commercial iron ore. BIFs are chemically precipitated sedimentary rocks, primarily comprising alternating bands of iron oxide and silica. BIFs form some of the oldest sediments on Earth, first appearing in the geological record about 3,800 million years ago (mya) at Isua, Greenland[1]. They are found across all continents, spanning a wide range of the Precambrian era, which includes around 85% of all geological time. The Precambrian era spans from the Earth's origin ~4,500 mya, to the 'Cambrian Explosion' ~542 mya, in which there was a rapid diversification of complex multicellular organisms. Economically important BIF deposits, mined for their high iron content, include the Hamersley Ranges of Western Australia[1,2], the Lake Superior region of the USA, and the Quadrilátero Ferrífero province of Minas Gerais, Brazil[3].


Figure 1. The Hamersley Ranges of Western Australia.

Raman spectroscopy is a non-destructive optical technique with a high (~1 µm) spatial resolution that provides information on the molecular vibrations of a material. In geology this technique is important as it offers a quick and easy method for chemical identification of minerals. Renishaw's flagship

Raman product, the inVia Raman microscope, incorporates a Raman spectrometer with a research-grade optical microscope. This allows the co-localised collection of traditional petrographic data and Raman data.

Renishaw's StreamLine Plus Raman imaging combines advanced automated optics and detector technologies, significantly reducing measurement times over more conventional point mapping, enabling large samples to be mapped at high resolution in practical time scales.

Here, StreamLine Plus imaging is applied to a very large (145 mm × 20 mm) Archaen BIF core section from the Marra Mamba formation (~2600 mya)[4] of Western Australia's Hamersley Ranges. The ability to study the spatial distribution of mineral species in this section offers an opportunity to improve the understanding of the underlying geology, and demonstrates that this technique is a powerful analytical tool for mining and research applications.

Experimental

StreamLine Plus imaging was carried out on a long core section using a Renishaw inVia Raman microscope. A 20× (NA 0.4) microscope objective was used to collect over 73,000 spectra in less than one hour. Raman spectra were collected from a narrow strip with dimensions approximately 88 µm × 71,000 µm running through multiple bands in the section.

Figure 2. Renishaw's inVia Raman microscope.

A 514 nm laser excitation source was used for the StreamLine Plus Raman measurements with a laser power on the sample of ~20 mW. The line focus geometry of StreamLine Plus enables a high laser power to be focused onto the sample without causing sample damage allowing faster data acquisition.

A multivariate component analysis method (direct classical least squares) was used to generate Raman images of the section. This method correlates the spectrum at a given location with a series of reference spectra chosen by the user, determining which is the best fit and colouring the image appropriately.

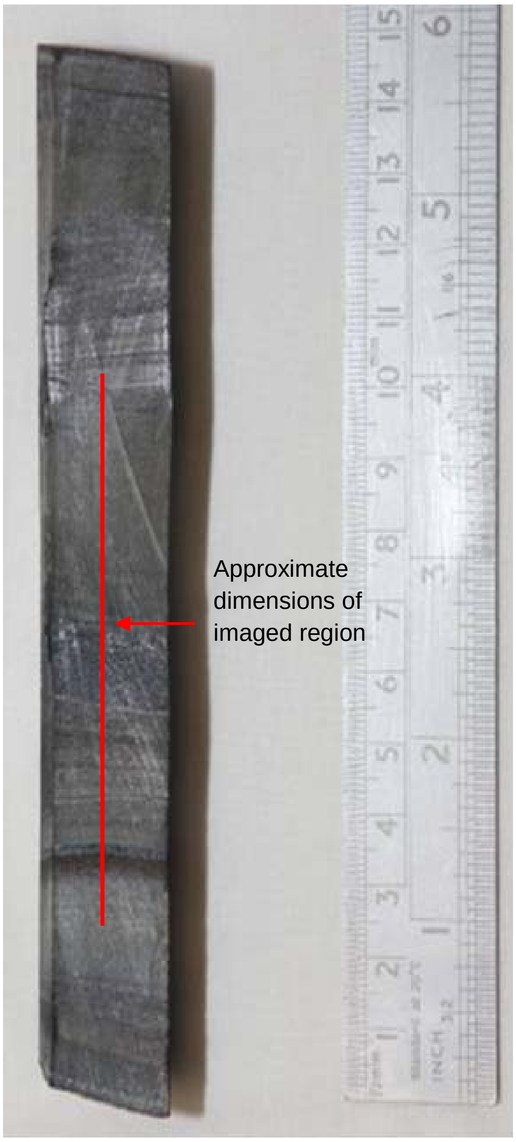

Figure 3. Image of BIF core measuring 145 mm × 20 mm indicating the region imaged using StreamLine Plus.

Results and discussion

Individual species were identified from the StreamLine Plus data, and their spectra used as references for image generation. Reference spectra are shown in Figure 4.

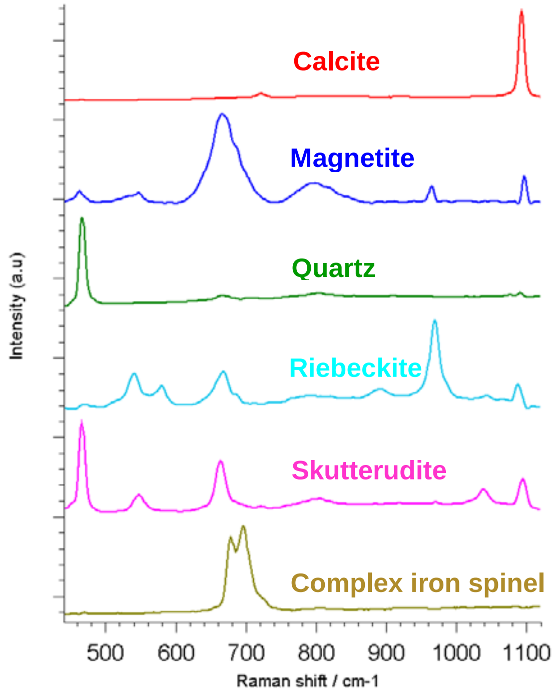

Figure 4. Reference spectra derived from the StreamLine Plus Raman image.

Bulk constituents were identified as quartz, calcite, magnetite, riebeckite, and skutterudite (a cobalt arsenide mineral). A less abundant species, thought to be a complex iron spinel, was also found. Figure 5 shows a StreamLine Plus Raman image highlighting the variations in mineral spatial distribution between the relatively thick (~ 1 cm) bands (dominated by quartz, magnetite, and riebeckite), and the finely laminated regions between them. The major regions dominated by magnetite were determined to be approximately 12 mm and 4 mm thick. This mineralogical information is vital, as single iron bands can be laterally continuous over hundreds of kilometres, allowing geologists to trace economically important seams over wide areas. In the Hamersley Ranges, for example, microbanding (iron-rich laminae) has been traced over distances of 300 km in surface exposures[5].

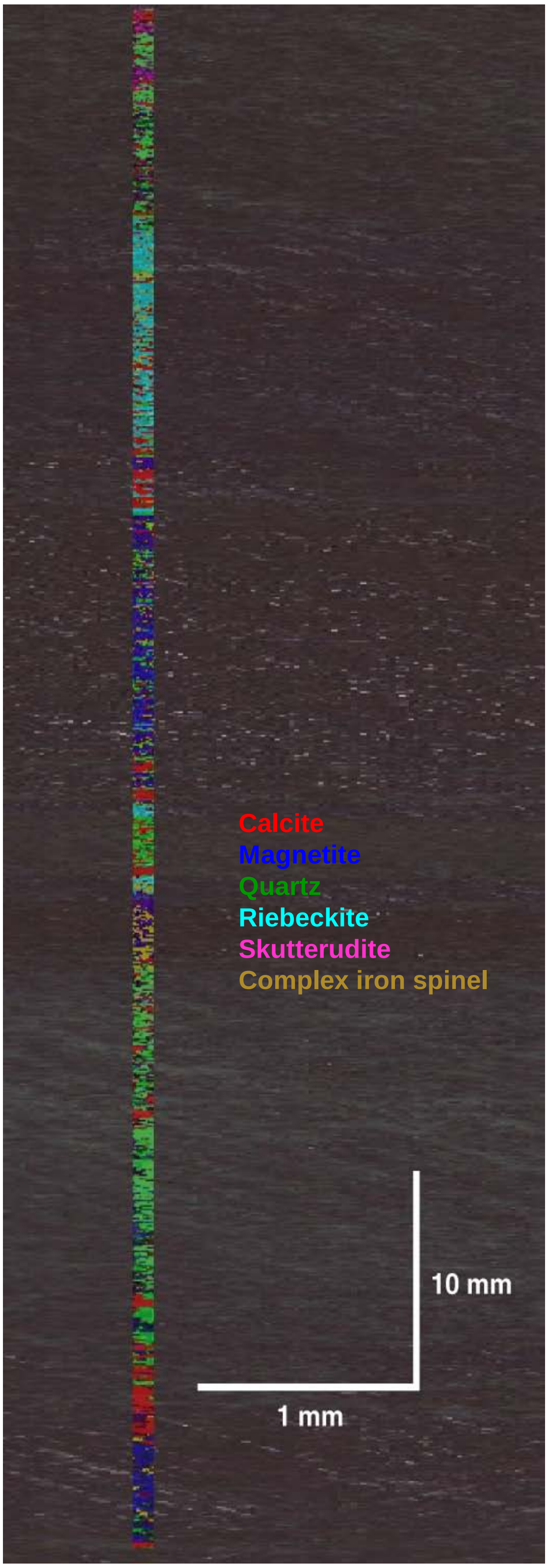

Figure 5. StreamLine Plus Raman image of BIF core.

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All of the StreamLine Plus spectra were combined to form a single spectrum shown in Figure 6. This spectrum provides complementary information about the relative quantity of magnetite within the core and displays strong Raman modes from the present mineral species including dominant bands from quartz, magnetite, riebeckite, and calcite; as well as features from other minor constituents such as skutterudite. This average spectrum provides a comprehensive summary of the species present in the BIF core. When considering cores taken from different core sites the variations in Raman mode intensity from average spectra could be used to assess the relative concentration of valuable minerals at each site.

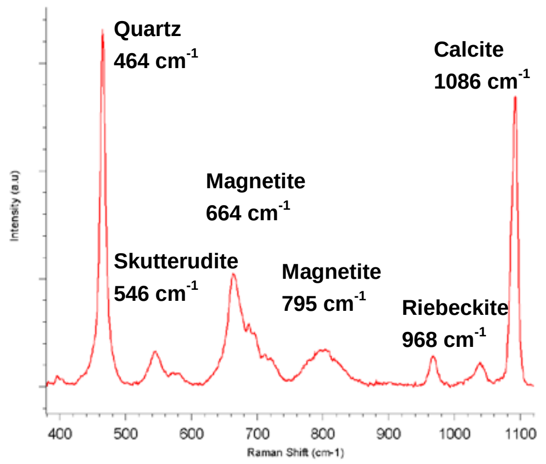

Figure 6. Average Raman spectrum of the BIF core, generated from 73,650 spectra.

Conclusions

This study demonstrates the applicability of StreamLine Plus imaging to both the industrial and academic study of BIFs. StreamLine Plus Raman imaging can be used to determine the presence and spatial distribution of minerals within a BIF core, including the thickness of magnetite bearing regions. The mineralogical data derived in this study will be of benefit to academic researchers seeking to determine the geological history of BIFs.

In addition, the accurate spatial determination of core minerals by StreamLine Plus imaging could prove highly valuable to resource geologists tracing iron rich bands over hundreds of kilometres. Average spectra derived from large StreamLine Plus datasets can provide semi-quantitative information on the relative amounts of core minerals. Using this method, it is envisaged that the economic feasibility of mining operations in a particular region could be investigated by comparing the relative content of valuable ore minerals from different core sites.

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