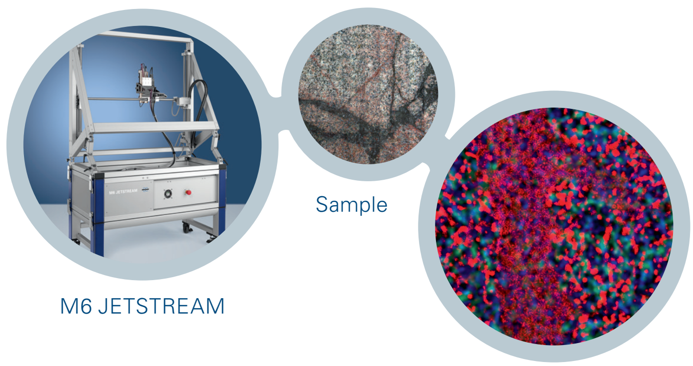

M6 JETSTREAM Sample Map

Lab Report XRF 455

Analysis of a large granite sample from the Vredefort Dome

The knowledge of the chemical composition of geological samples is fundamental for the understanding of geological processes. However, not only the composition of the samples but also information on the distribution of the elements present are of key importance. Spatially resolved Micro-XRF using a focused X-ray beam for sample excitation combines the element sensitivity of XRF with a spatial resolution in the micrometer range.

Until recently, sample sizes that could be analyzed using Micro X-ray fluorescence spectrometry were limited by the chamber size of the analytical instrument. With the introduction of the M6 JETSTREAM – the open beam instrument discussed in this report – it is now possible to investigate large samples with scan areas of up to 800 mm x 600 mm in a single run.

The sample

The sample presented here is a large polished slab of granite (130 cm x 80 cm) from the Vredefort Dome. The Vredefort Dome is located in South Africa in the Freestate, about 150 km distant from Johannesburg. It is the central part of the largest known meteorite crater on Earth, around 300 km wide. The impact of this object with a diameter of about ~20 km occurred around 2 billion years ago. The Vredefort Dome is the central uplift where lower crustal materials rose upwards by tens of kilometers during the first few minutes after the impact. This structure bears witness to rapid movement of mountain-sized lithological units within short time scales.

Sample

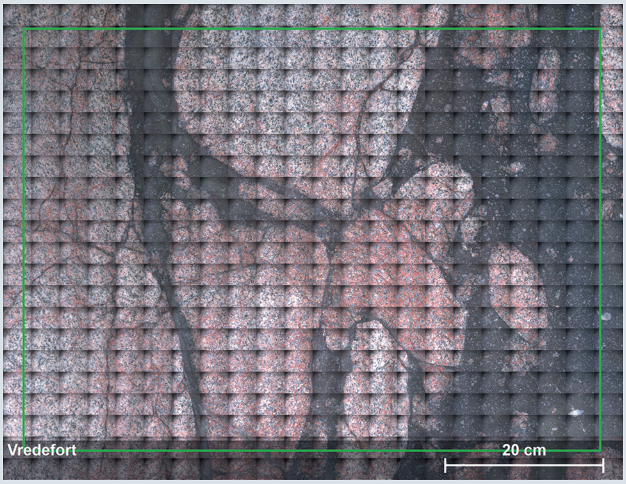

Fig. 1 Overview mosaic image of the sample, generated by the low mag video microscope of the M6 JETSTREAM. The green box indicates the area of the map shown in Fig. 3.

The lithologies within the crater structure were subject to a broad range of modifications, including vaporization, melting, fragmentation and displacement. The sample investigated here shows according signs: apart from the original granite (bright in Fig. 1) cut by centimeter-thick veins of once molten material (dark in Fig. 1). This dark and fine grained material, often containing smaller fragments of the host rock (the granite in this case), is referred to as pseudotachylitic breccia (PTB). The up to a few meter thick dikes of Vredefort PTB have been a topic of scientific controversy, whether they are a melt of local material or distal melt injected into local lithologies.

Origin of the sample

Fig. 2 Abandoned quarry at Leeuwkop Hill, Vredefort, where the sample was taken from. Image courtesy Axel Wittmann

The objective of the analyses described in this report was to determine the origin of the Vredefort PTB. Therefore high spatial resolution XRF elemental mapping including major and trace element distribution analysis of large areas was carried out to investigate the chemical relation between the host rock and the once molten dark material.

Instrumentation

The measurements were performed with a Bruker M6 JETSTREAM. This Micro-XRF spectrometer is characterized by

- Large scan area of 800 mm x 600 mm
- Tiltable measurement rig for sample analysis in horizontal and vertical position
- High speed on-the-fly measurement capability, up to 100 mm/s stage travel
- Efficient excitation of fluorescence radiation using a high brightness X-ray tube together with X-ray optics for concentration of tube radiation to spot sizes down to 100 µm
- Detection of fluorescence radiation using a silicon drift detector (SDD) with high count rate capability.

Measurement conditions

The sample was measured with the following tube settings: 50 kV, 600 µA. The rig was tilted for sample measurement in horizontal position (top-down). A map was obtained of an area of 725 mm x 530 mm in a single run, using a step size of 0.2 mm and 2 ms dwell time, resulting in an overall measurement time of around 12½ hours for the 9.6 megapixel map (3625 pixels x 2650 pixels).

Measurement results

Analytic data was accumulated with HyperMap, i.e. a complete spectrum was saved for each of the 9.6 megapixels (hyperspectral imaging) of the map. Therefore data evaluation could be performed at any time during or after acquisition using a wide variety of options.

Element distributions

The map in Fig. 3 shows the distributions of the major elements iron (Fe), calcium (Ca), and potassium (K). The element distributions reflect the optical appearance of the sample. The granite grains can be distinguished by two of their main constituents: feldspar, characterized by K and Ca, and biotite/amphibole, mainly characterized by Fe. The cryptocrystalline veins appear far more homogeneous than the coarse grained granite.

Sample overview measurement

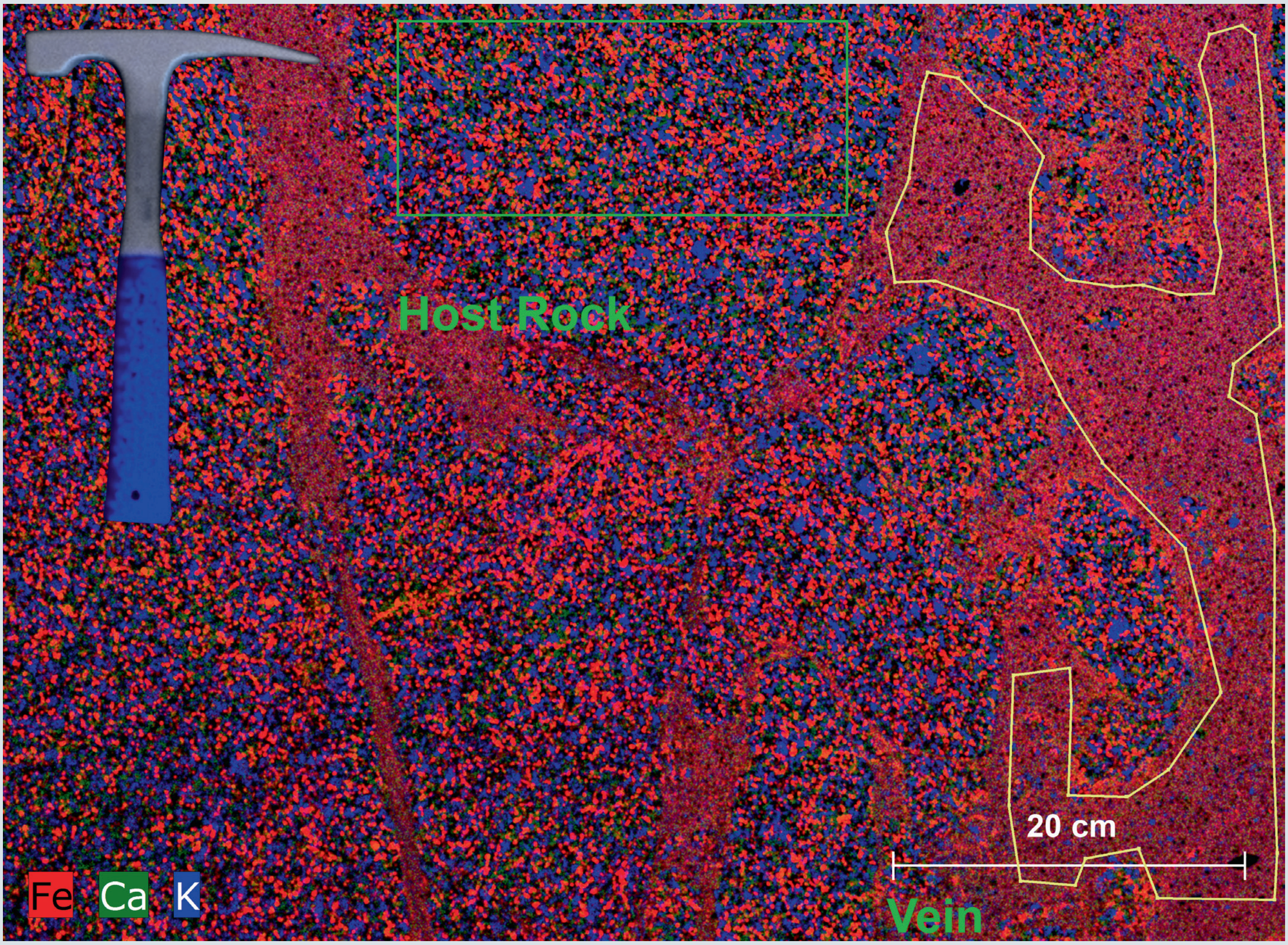

Fig. 3 Map of the sample allowing a clear distinction between host rock and veins. The host rock is characterized by its granular structure. Sum spectra for host rock and vein were extracted from the accordingly labeled regions. A scan of a 14 ounce rock hammer in original size was overlaid for comparison of scale. In this case blue represents chlorine from the vinyl handle and gray iron and titanium contained in the hammer head.

Comparison of sum spectra

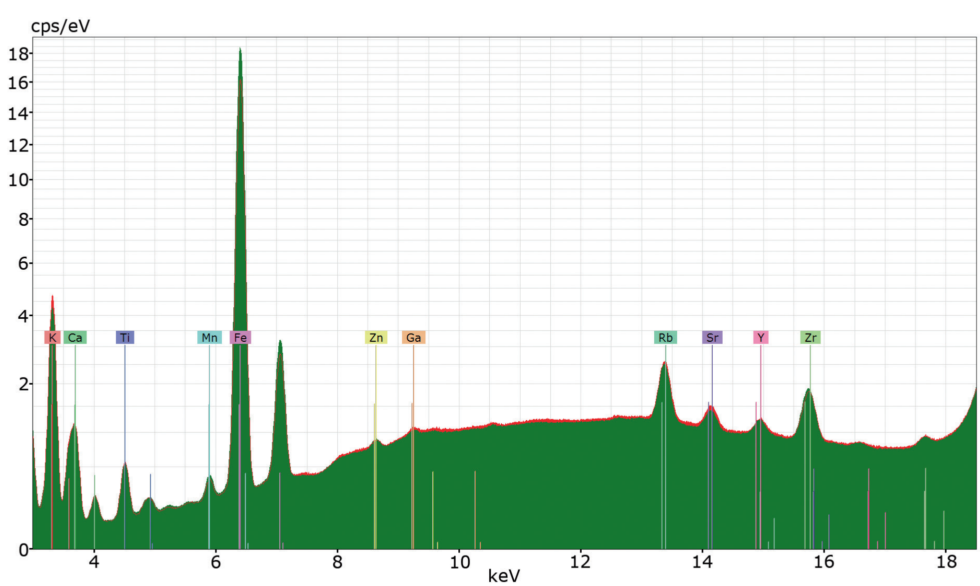

Fig. 4 Comparison of sum spectra of host rock (red) and vein (green), y axis in square root scaling. No significant differences between the two phases are visible.

Plot of net intensities

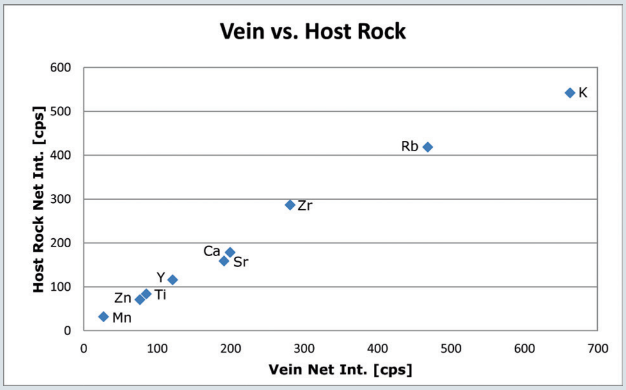

Fig. 5 Plot of element net intensities in cps from the host rock vs. the vein spectrum. The graph shows the chemical similarities of both areas: the data points are very close to the 1 : 1 ratio diagonal. Fe was omitted in the plot as the intensities are too high to fit the chosen scale.

Sum spectra

Fig. 4 shows an overlay of sum spectra taken from the regions outlined in Fig. 3. As can be seen, the spectra are largely identical. This applies to both the major elements Si, K, Ca, and Fe as well as to the minor and trace elements manganese (Mn), zinc (Zn), gallium (Ga), rubidium (Rb), strontium (Sr), yttrium (Y), and zirconium (Zr). This is further confirmed by the graph in Fig. 5. It contains a plot of the net intensities in counts per second (cps) from the host rock vs. the net intensities in the veins, taken from the same areas as above. Data points are close to the diagonal in the graph, indicating relations of close to 1 : 1 for all elements plotted.

Conclusions

The findings from both the distribution analysis and the evaluation of sum spectra support the conclusion that it was the granite itself that was partially molten during the meteorite impact, as not only the same elements are present in both rock and melt, also their concentrations are almost identical at a macroscopic level. It is therefore highly improbable that the PTB comes from an external source, such as from a large melt pool within the now eroded part of the crater (see also Mohr-Westheide et al., 2009; Mohr-Westheide and Reimold, 2010).

Fast and accurate elemental analysis of large samples with the M6 JETSTREAM is a non-invasive technique that allows to visualize the major and trace element distribution on a macroscopic scale. Visualization of the chemical map and the selection of areas of interest enable advanced post processing of the HyperMap data cube.

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References

- Reimold, W. U., Tagle, R., Fritz, J. (2013): X-ray spectrometry of pseudotachylitic breccia from Vredefort: Further evidence for in situ formation of melt. Abstract for the 76th Annual Meteoritical Society Meeting.
- Mohr-Westheide, T., Reimold, W. U. (2009): Chemical analysis of small-scale pseudotachylitic breccia in Archean gneiss of the Vredefort Dome, South Africa. Abstract for the 40th Lunar and Planetary Science Conference.
- Mohr-Westheide, T., Reimold, W. U. (2010): Microchemical investigation of small-scale pseudotachylitic breccias from the Archean gneiss of the Vredefort Dome, South Africa. "Large Meteorite Impacts and Planetary Evolution IV", GSA Special Paper, 465, 619-643.
- Mohr-Westheide, T., Reimold, W. U., Riller, U., and Gibson, R. L. (2009): Pseudotachylitic breccia and microfracture networks in Archean gneiss of the central uplift of the Vredefort Impact Structure, South Africa. South African Journal of Geology, 112, 1-22.
- Mohr-Westheide, T., Reimold, W. U. (2011): Formation of pseudotachylitic breccias in the central uplifts of very large impact structures: Scaling the melt formation. Meteoritics and Planetary Science, 46, 543-555.

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