Application Note for microsphere imaging.

Advances in Reflected Light Imaging of Ore Minerals

Mineralogical imaging with SMAL

Authors: M. Divers, Dr J.F. Einsle, Dr B. O'Driscoll,
Dr S. Vilain, Dr S. Stanescu, Dr D. Lonsdale, S. Wright.

What

This report details a direct comparison between Super-resolution Microsphere Amplifying Lens (SMAL) technology and standard 100x oil immersion for imaging rock samples in reflected light. The images and raw RGB data presented here demonstrate a clear and quantifiable increase in image quality when using the new SMAL technology.

To demonstrate proof of concept, we use a base-metal sulfide and platinum-group element enriched sample from the Eastern Layered Intrusion, Rum, NW Scotland – a ~60 million year old 'fossil' magma chamber that exhibits a similar style of PGE mineralisation to the Bushveld Complex, South Africa (the world's most productive PGE reserve).

Why

Standard reflected light and electron microscopy are unable to capture the full size range of platinum group mineral (PGM) grain sizes in natural ore samples. For example, QEMSCAN – one of the standard industrial and academic electron microscope-based techniques for quantifying mineralogy in mineralised systems – is limited to spatial resolutions of several microns due to the constraints set by throughput and electron interaction volumes. However, we expect that platinum group elements (PGE) are sited in mineral phases with grain sizes at least as small as 10's nm. SMAL lens technology represents an efficient and informative means to analyse the nano-scale mineralogical/microstructural relationships of PGE-rich minerals in these economically important ore deposits.

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100x oil immersion vs SMAL (reflected light)

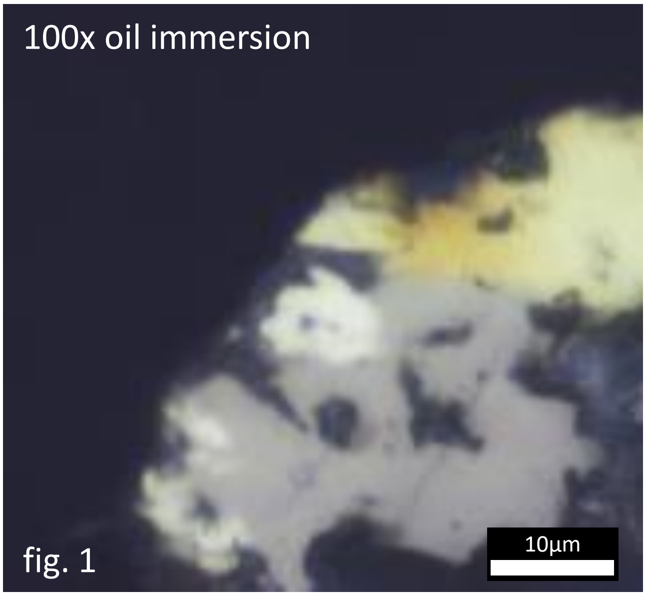


fig. 1

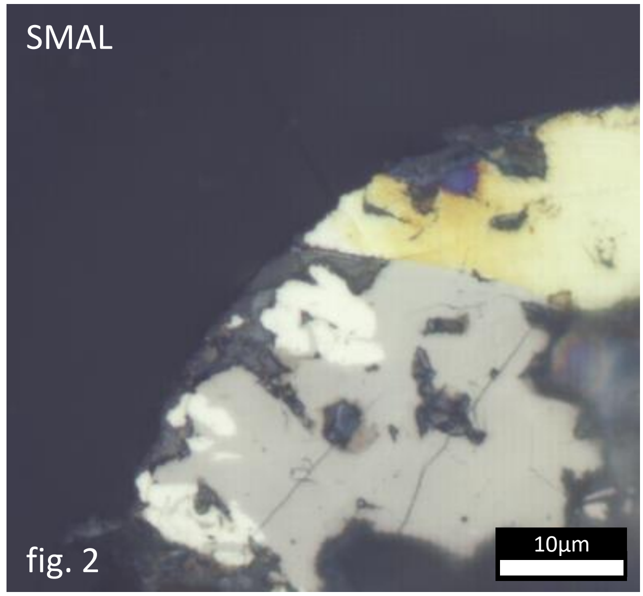


fig. 2

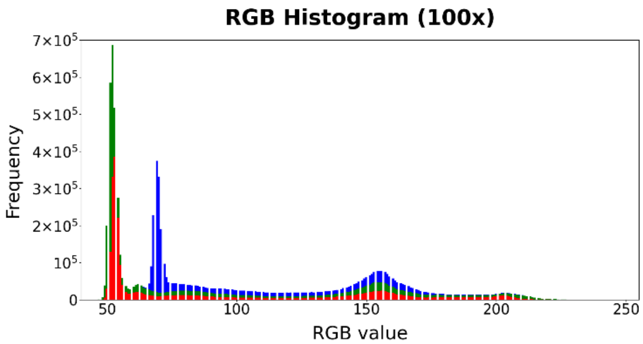


fig. 3

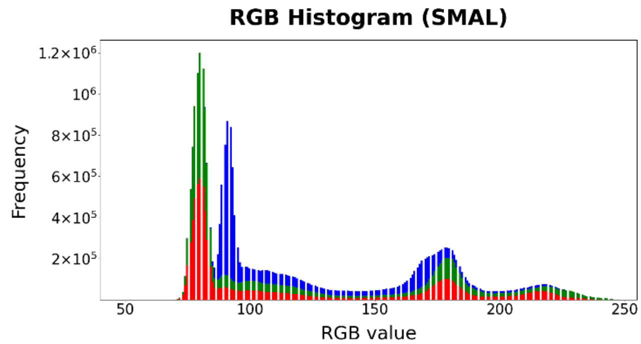
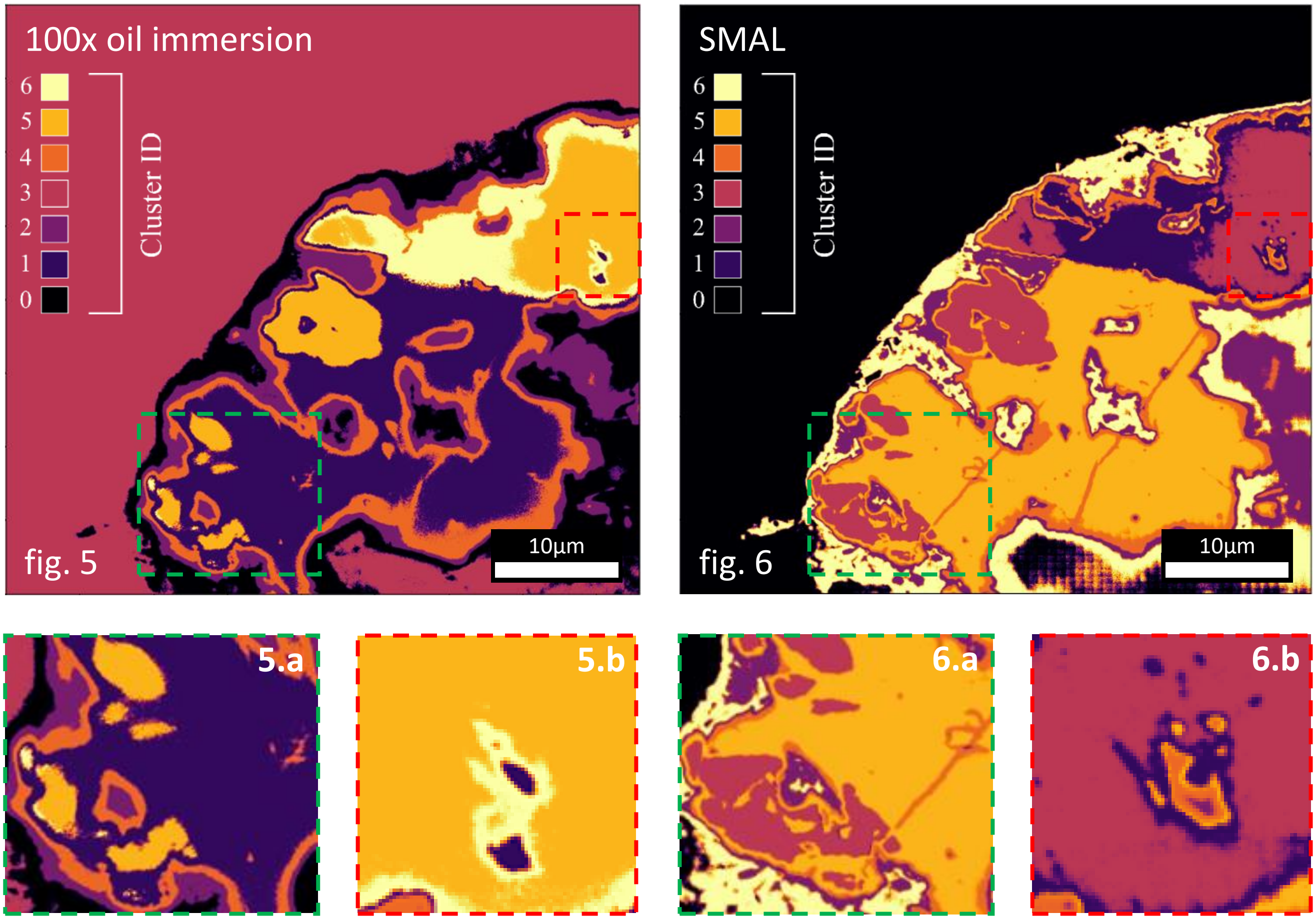


fig. 4

Figures 1 and 2 show the same ~50x50 µm region, where the reflective phases comprise an aggregate of different base-metal sulfides – areas typically expected to be enriched in PGM. The images were captured using 100x oil immersion (figure 1) and SMAL technology (figure 2) with estimated pixel sizes of 29.1 nm and 16.3 nm, respectively. This comparison reveals a quantifiable increase in clarity for all textural features <1 µm in size, including grain boundaries, fractures and inclusions.

Figures 3 and 4 display histograms of the RGB data in its raw state for 100x oil immersion and SMAL lenses. A modest increase to the tonal range can be seen by comparison of these figures; however, the most notable difference is the improved contrast, represented by an increase in peak width of up to 70%. This reveals itself to the eye as improved image clarity (figure 2) and is thought beneficial to the numerical analysis of the samples, as discussed below.

Enhanced image segmentation with SMAL



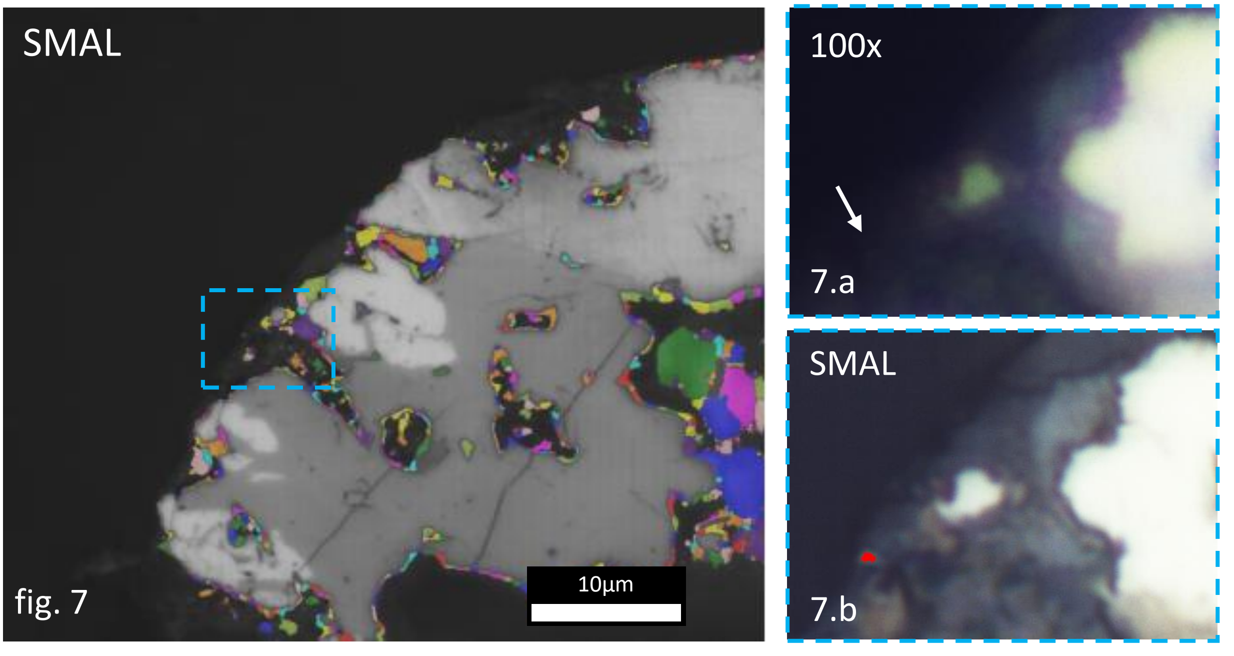
Super-resolution optical imaging offered by SMAL technology is currently being employed alongside unsupervised machine learning algorithms. The aim of this approach is to quantify traditionally qualitative datasets, whilst also providing the spatial resolution necessary to observe nano-scale features and mineral phases. Figures 5 & 6 show the results of clustering both optical images – 100x and SMAL, respectively – into 7 categories using the K-means algorithm.

The increased resolution, clarity and contrast afforded by the SMAL lens allows for the K-means algorithm to segment the same area to a higher degree of accuracy and precision. Comparing insets 5.a to 6.a, and 5.b to 6.b, demonstrates the wide range of scenarios where SMAL can outperform traditional 100x imaging. This includes larger mineral phases and ~500 nm wide fractures more easily distinguished by SMAL technology's superior contrast (figure 5.a, figure 6.a), and small inclusions or grains (down to 165 nm), only visible due to the increased spatial resolution provided by SMAL (figure 5.b, figure 6.b).

Spatial resolution showcase

"SMAL technology represents a step-change in reflected light microscopy in terms of improvements in resolution and image clarity."

- Dr Brian O'Driscoll, Senior Lecturer in Petrology, The University of Manchester.



Following implementation of the K-means algorithm, the clusters can be further segregated into their constituent grains by watershed analysis. This allows for the separation of neighbouring features placed into the same cluster, and for grain metrics to be calculated (e.g. grainsize). Figure 7 displays the SMAL image overlaid with the watershed results of cluster 2 (figure 6) and an inset area highlighted; this inset is shown in figure 7.a (100x) and figure 7.b (SMAL), and detailed comparison reveals a wealth of new optical information within the SMAL image at both high resolution and high contrast. Additionally, the area highlighted red in 7.b is a sulfide grain with major and minor axis length of 215 nm by 133 nm that is revealed by the clustering/watershed analysis. The arrow on 7.a shows where this same grain should be visible, however, this nano-scale feature cannot be observed in either the 100x image or in the watershed analysis of the 100x image – as is the case for many of the sub-micron features in the thin-section.

The future of SMAL in ore geology

SMAL technology has clearly demonstrated the added value of super-resolution optical nanoscopy, having been used to add layers of depth to mineralogical and structural interpretations of a typical PGM-bearing sample. With fewer constraints to throughput (compared to methods using electron microscopy, e.g. QEMSCAN), enhancements to image clarity and contrast, as well as super (spatial) resolution imagery, SMAL technology is a powerful new tool in PGM analysis.

In the future, SMAL technology may be combined with different detectors or filters – for example plain/cross polarisation, or Raman spectroscopy – to provide more robust mineral classification beyond reflected white light. Ultimately the Nanoro allows for nanoscale mineralogical ground truthing previously only achievable by electron microscopy and related microanalysis.

> “SMAL technology has clearly demonstrated the added value of super-resolution optical nanoscopy ... SMAL technology is a powerful new tool in PGM analysis.”
>
> - Matt Divers, Post Graduate Research, University of Glasgow.

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LIG NANOWISE
Unit 11 Williams House
Manchester Science Park
M15 6SE

(+44) 0161 342 0515
www.lig-nanowise.com

For more information please contact:
enquiry@lig-nanowise.com
JoshuaFranz.Einsle@glasgow.ac.uk