MINERAL RESOURCES *for energy storage*

A Council for GeoScience team reports on vanadium-related research

Enormous quantities of rubble associated with outcropping magnetitite pipes form small conical hills in the Main Zone.

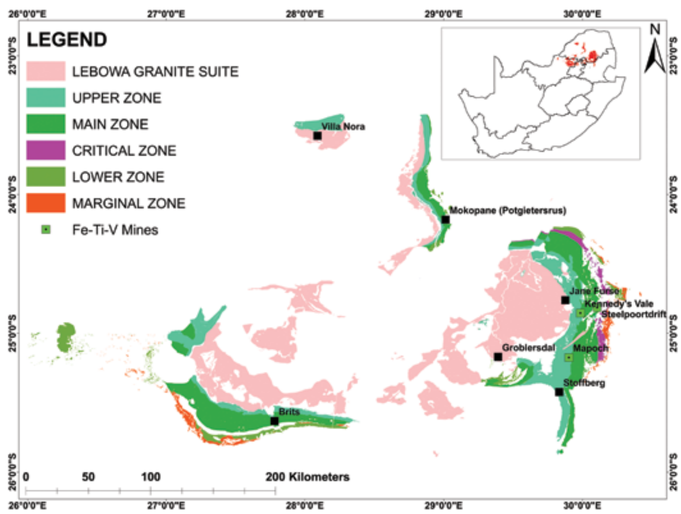
South Africa's Council for Geoscience, under the theme 'Geoscience for Minerals and Energy', is undertaking research into hydrothermal and magmatic mineralisation in the Bushveld Basin. One of the key mineral resources being investigated is vanadium.

The demand for vanadium has traditionally been primarily from the steel market, but recent interest in vanadium centres on its role as a potential battery element for energy storage. Bushveld Minerals will be rolling out vanadium-based electricity storage devices for Eskom as part of their flagship 360 MW/1440 MWh battery energy storage system (BESS). South Africa, the third largest producer of vanadium, is particularly well positioned for the development of vanadium redox batteries (VRB) because of the abundant vanadium resources in the Bushveld Complex. It is anticipated that the increase in battery usage for large-scale energy storage, particularly at wind farms and solar power plants, will stimulate market demand for vanadium.

The Rustenburg Layered Suite of the Bushveld Complex has the world's largest resource of high-grade primary vanadium, found in vanadium titanomagnetite pipes (VTMP) and as layers of magnetitite. The magnetitite pipes occur erratically from the base of the Main Zone up to the Upper Zone, transgressing the stratigraphy of the Rustenburg Layered Suite. The vanadium pentoxide (V_2O_5) content of the magnetitite pipes seems to correspond approximately to that of the layers in their vicinity, with the lowermost layers containing the highest V_2O_5 content. Pipes occurring below the main magnetitite layer may contain higher V_2O_5 grades.

Fieldwork and laboratory analyses

During fieldwork undertaken in the 2018/19 financial year, outcropping magnetitite pipes in the Main Zone were sampled. Here, the magnetitite pipes form enormous quantities of magnetitite rubble and, in places, small conical hills. The dimensions of these pipes are difficult to determine in the field because of sand cover, with evidence of minor rubble on the surface in places.



A map of the Bushveld Complex, showing the position of mines exploiting iron, titanium and vanadium.

Samples from 10 magnetitite pipes within the Main Zone returned consistent grades of 1.7% V_2O_5 (whole-rock XRF analysis) and 1.9% V_2O_5 (electron microprobe analysis [EMPA] of magnetite) respectively, and compare favourably with the average resource grade of the Mapoch Mine (estimated to be 1.52% V_2O_5 according to an ASX Announcement dated 22 March 2018). EMPA results of five samples exceeded 2% V_2O_5, which is higher than many prominent vanadium-producing mines globally. These results further promote the advancement of the project, as they suggest that the pipes contain high-grade vanadium with strong potential to underpin a simple low-cost, high-grade direct shipping ore (DSO), which can be sold to end users as feedstock for a downstream processing plant, or as a solution to meet growing energy-storage demand.

Since these results were received, investigations into the potential for other pipes in the eastern limb of the Bushveld Complex from a number of current and historical sources have been undertaken. These include historical reports, geological maps, high-resolution aeromagnetic data, remote sensing data as well as Landsat imagery. Additionally, further work on the subsurface extent, length and geometry of these pipes is required to determine their potential contribution to future mineral resource estimations. For example, the high-grade Steelpoortdrift (SPD) vanadium project under development by Australian-based Vanadium Resources (VR8, formerly Tando) in the Nebo mapped area, north of the study area, is already estimated to host a resource three times bigger than similar projects, at over 500 million tonnes. The discovery of further magnetitite pipes outside of that resource could indicate significant potential upside.

The advantage of magnetitite pipes is that they comprise almost 100% magnetite, meaning that there is no stripping of waste material required to obtain the mineral-bearing ore. Ore from the Kennedy's Vale Mine was extracted using the direct leaching method, which simplifies the processing, resulting in a higher-purity vanadium product. Similarities between the SPD project, Mapoch Mine and the Kennedy's Vale Mine mean that these operations could also possibly extract the magnetite using direct leaching, which would make exploitation attractive to makers of vanadium redox batteries. These types of deposits may virtually amount to 'dig and ship' operations. Given that the areas are relatively small, they will be reasonably quick to drill out, and if these operations are successful in finding a number of the magnetitite pipes, yielding a 5–10 million tonne resource, they would provide at least five years' worth of feed. Selectively mining the pipes means that these operations could fast-track production.

Other minerals

Apart from containing valuable vanadium, the magnetitite pipes have a high iron and titanium content. In the past, the exploitation of these resources for titanium has been restricted by a combination of the economic viability of smelting such titanium-rich iron ore, the shortage of vanadium (used as a strengthening agent in titanium alloys), and metallurgical problems with the extraction of titanium oxide (TiO_2) from the slag.

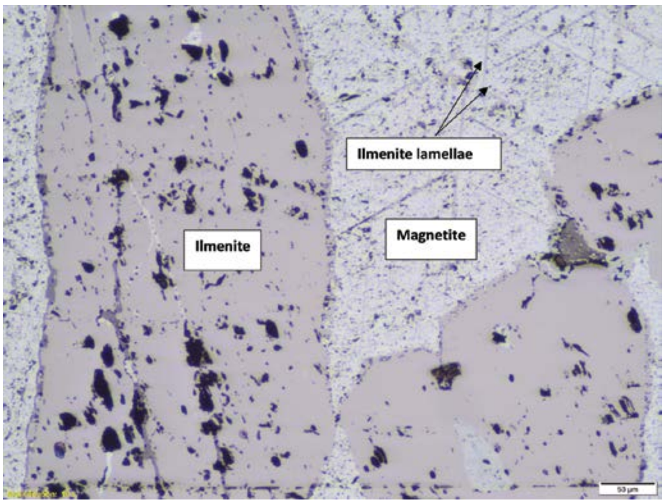
Recent research has, however, resulted in the development of economic processes for the simultaneous recovery

Hand specimen of vanadiferous titanomagnetite from the Roossenekal mapped area.

of iron (Fe) and V_2O_5, and the production of high-titania products is now technically feasible. On the other hand, the recovery of economic minerals depends largely on parameters such as grain size distribution, chemical composition, texture, and the presence of inclusions or intergrowths with other minerals.

An assessment was therefore conducted on the potential of vanadium-bearing titaniferous iron ores from the sampled magnetitite pipes to be used as raw materials for the recovery of V_2O_5, TiO_2 and Fe. The results are considered applicable to all Fe-TiO_2 pipes in the Upper Main Zone and Lower Upper Zone of the Bushveld Complex.

A microscopic assessment of the mineralogical character of the samples was undertaken with the aid of an optical microscope as well as scanning electron microscopy (SEM) equipped with energy dispersive x-ray spectroscopy (EDS). The aim was to identify minerals and investigate the textural properties, phase association and grain size. The magnetitite pipes typically consist of 90% magnetite and 10% granular ilmenite. Most of the vanadium (± 1–2 wt.%



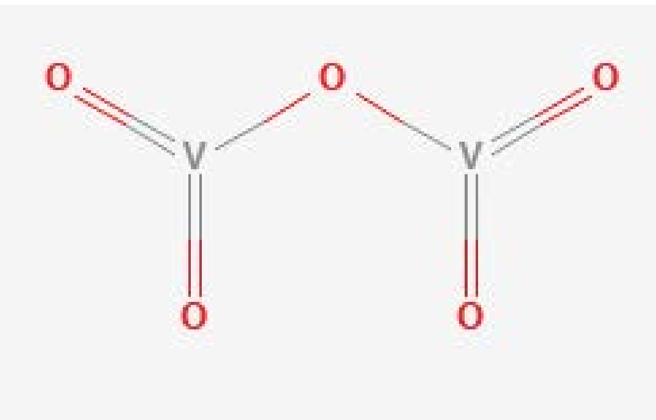
Photomicrographs of magnetite and ilmenite from magnetitite pipes in the Main Zone of the Rustenburg Layered Suite. The magnetite is characterised by coarse ilmenite lamellae, as well as finer lamellae down to submicron level.

Franco Esposito/Bushveld Minerals

Bushveld Minerals owns vanadium mines at Brits and Mokopane, as well as two processing facilities.

V_2O_5) is incorporated in the magnetite, but ilmenite hosts higher concentrations of titanium (± 50 wt.% TiO_2). The magnetite grains are massive and very coarse, with variable sizes of ilmenite (<1 µm and >1 mm).

The pipes offer huge economic potential due to the high vanadium (~2% V_2O_5) and titanium (~12%) content. The magnetite can be recovered by magnetic separation after comminution (i.e. reduced to a smaller size by grinding, crushing, vibrating, etc), and then subjected to hydrometallurgical processes involving roasting, leaching and precipitation to recover vanadium as V_2O_5 powder. The non-magnetic fraction of the magnetite ore can be targeted to recover ilmenite grains for their titanium content.



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The inorganic compound vanadium pentoxide (V_2O_5) is the most recovered form of vanadium, found in about 80 different mineral ores.

Alternatively, the pyrometallurgical approach can be used to produce pig iron, with vanadium being recovered from the slag. The titanium present in a variety of extremely fine-grained micro intergrowths cannot be liberated by mechanical means.

Adapted from two articles in the Council for Geoscience newsletter, GeoClips, written by:

- *Flora Maja, Hakundwi Mandende, Chris Hatton & Senza Ndumo. GeoClips 58, September 2019*
- *Hakundwi Mandende, Themaba Mothupi & Flora Maja. GeoClips 60, March 2020.*

For more information on vanadium and vanadium redox batteries, see the article '10 Transition Metals' in Quest Vol. 15.1.

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2020

Quest Volume 16 Number 2 2020

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Academy of Science of South Africa (ASSAf), (2020). Quest: Science for South Africa, 16(2). [Online] Available at: http://hdl.handle.net/20.500.11911/150

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