Mineral Systems review of the Kalahari Suture Zone project, Botswana

Prepared for:
Kavango Resources plc

APRIL 2020

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Executive summary

The Kalahari Suture Zone (KSZ) is located along the western margin of the Kaapvaal Craton in southwestern Botswana. It is marked by a linear magnetic anomaly 400 x <50km that strikes north-south. The KSZ comprises two distinct mafic-ultramafic systems: the older (~1000 Ma) mafic Tshane Complex, and the younger (180 Ma) post-Karoo mafics. The latter has been drilled by Kavango and represents a large mafic complex thought to be part of a feeder system to the once overlying Kalahari flood basalts. Kavango hold exploration licences along the KSZ targeting magmatic Ni-Cu-PGE sulfide accumulation related to the intrusive bodies. Geophysical interpretations have been complicated by conductive (salty) groundwater as well as conductive clays and mudstones within the Karoo sediments and overlying Kalahari beds, although this has been overcome with recent airborne EM surveys. This report provides an overview of the KSZ project from a Mineral Systems Approach (MSA) by considering evidence for, or the likelihood of several large-to-small-scale geological processes.

The MSA seeks to be a more predictive method for finding deposits by understanding the combination of geological processes that are required to form and preserve ore deposits at all scales. It considers the origin of deposits within the framework of large, lithospheric- to deposit-scale processes in relation to source, transport and sink/trap for metals, and considers evidence of these processes at each step. For magmatic Ni-Cu-PGE sulfide systems, the following are considered: 1. The geodynamic and tectonic setting; 2. The source and compositions of the ore-forming magmas; 3. The magma migration pathway at a crustal scale; 4. Mechanical and structural mechanisms for focussing magma flow; 5. Evidence for sulfide saturation, accumulation and reworking; 6. Factors affecting preservation and detectability.

The KSZ comprises two distinct mafic-ultramafic complexes of different ages that conform to many of the key features of prospective Ni-Cu-PGE sulfide mineral systems, particularly the geodynamic setting at the margins of a craton, and the association with dyke-sill complexes along major crustal lineaments (pathways) related to Large Igneous Province (LIP) magmatism. In addition, a number of features are regarded as prospective for the presence of magmatic sulfides.

The older, deeper, Tshane Complex (~1000 Ma) contains cumulates with disseminated sulfides, though the geochemical composition shows Mid-Ocean Ridge Basalt (MORB) signatures and the presence of any potential sulfide deposit would be deep (perhaps >500 m). However, the more recent mafics, that intrude the Karoo sediments, are linked to more prospective mantle plume-related magmatism, likely to represent the feeder systems to the Karoo flood basalts. These mafics are preserved at a shallower depth. Additionally, these Karoo mafic intrusions contain strong geochemical signatures (high Cu/Pd ratios) indicative of sulfide saturation in the parental magmas.

Both magmatic systems are thought to have formed during rifting, where thinning of the crust results in magmas emplaced into sedimentary basins via deep fault-driven pathways. The older Tshane
Complex (~1000 Ma), was emplaced into the sulfur and iron-rich Transvaal and Olifantshoek Supergroups. The Younger Karoo-aged mafics were emplaced into pyritic-sulfide bearing siltstone, sandstone, carbonates and coal of the Karoo sediments. Both settings represent prospective situations whereby the magmas may have assimilated S-bearing country rocks (and coal, in the case of the younger intrusions) to generate magmatic sulfides. The area is overlain by Cretaceous and post-Cretaceous Kalahari Group clays, gravels, calcretes and sand cover, and as such the area is currently underexplored yet remains significantly prospective for Cu-Ni-PGE mineralisation.

The table below summarises the known (ticks and crosses), and unknown (question marks) aspects of the Mineral System for both magmatic complexes in the KSZ. It should be noted that the question marks represent aspects that have not yet been defined prior to a field visit and further work, but may be present, and thus warrant further investigation. This is proposed to be through a follow up desk study and a Masters thesis planned to be undertaken at the University of Leicester 2020/2021.

<table>
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<th>COMPONENT OF THE MINERAL SYSTEM</th>
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<td>Geodynamic and tectonic setting</td>
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<td>Rifted craton margin</td>
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<td>Mantle plume</td>
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<td>Magma migration pathways</td>
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<td>Ni-depletion in olivine and pyroxenes</td>
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<td>Large droplets of sulfide</td>
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<td>Preservation</td>
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<tr>
<td>Erosion level no deeper than feeders to flood basalts</td>
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Introduction

This report provides a concise overview of the prospectivity of the Kalahari Suture Zone project area in Botswana from a Mineral Systems Approach. The report contextualizes currently available data on the project area, including drill results, internal reports, and public domain documents within the magmatic Ni-Cu-PGE sulfide Mineral System.

Terms of reference

Kavango Resources (Kavango) commissioned D&D GeoConsultants (D&D) to produce a concise, independent technical validation report on the Kalahari Suture Zone (KSZ) project area, Botswana. It is understood that Kavango are interested in gaining an independent overview of the prospectivity of the KSZ project for magmatic Ni-Cu-PGE sulfides that can be used to promote the project and attract investment, and identify key areas for follow up research by a Masters project based at the University of Leicester, UK. This report provides an overview of the KSZ project from a Mineral Systems Approach, as agreed following the proposal dated 22 February 2020.

Qualification of consultants

D&D consultants have extensive experience in magmatic Ni-Cu-PGE systems, with a particular focus on southern Africa. Dr David Holwell (BSc (Hons) MSc MCSM, PhD FSEG) has 20 years’ experience researching, exploring and reviewing Ni-Cu-PGE sulfide mineralization, publishing over 40 peer reviewed papers. He has worked extensively on mineralisation in the Bushveld Complex, South Africa, and magmatic sulfide mineralization in Greenland, Zambia, Europe and Australia. He is a Fellow of the Society of Economic Geologists and Regional Vice President, Europe, for the Society of Geology Applied to Mineral Deposits (SGA). Daryl Blanks (MGeol (Hons) sAusIMM) has eight years’ experience of exploration and postgraduate research working on a variety of ore deposits in Africa, Europe and Australia with a specialising in Ni sulfides.

Data provided

Kavango provided D&D with the following documents:

- An internal Kavango summary report on the project area
- A technical report on the lithogeochemistry authored by Dr Martin Prendergast.
- A series of drill core logs from Kavango drilling
- Petrological report on five samples from the project area
- A report on the SkyTEM survey
- Bulletin 27 from the Botswana Geological survey
- Logs of historical cores

In addition, D&D have made use of any public domain documents or papers available.
Disclaimer
This report is the result of a desk study using data obtained through Kavango and other public domain sources. D&D has not yet visited the areas under consideration and cannot qualify that the data herein exactly match the geology of the specific districts or areas referred to. A site visit is planned for later in 2020. The opinions of D&D within this document are based on the information available, plus previous experience of the personnel involved in similar areas and geological domains in southern Africa and around the world. D&D do not guarantee the legitimacy or accuracy of any information utilised in this report that has been obtained from secondary sources. It is the opinion of D&D that the full value of the areas can only be confirmed through further systematic field data collection and analysis and a more thorough review of the current dataset, which is outside the scope of this current report.
Introduction to the KSZ project

The Kalahari Suture Zone (KSZ) is located along the western margin of the Kaapvaal craton in southwestern Botswana (Fig. 1). It is marked by a linear magnetic anomaly 400 x <50km that trends north-south. Drilling has targeted surficial Zn, Fe and Cu soil anomalies together with magnetic and AEM anomalies, although the latter are affected by the conductive (salt) water and overlying clays and mudstones; hence we use a broad scale Mineral Systems Approach to assess the prospectivity of the project. The KSZ is thought to host a late Karoo magmatic plumbing system thought to be part of a feeder system to the overlying Kalahari flood basalts. Many of the world’s largest ore deposit occur in the plumbing systems beneath areas of flood basalts (e.g. Noril’sk beneath the Siberian traps). Kavango hold exploration licences along the KSZ targeting the intrusive systems as magmatic Ni-Cu-PGE sulfide accumulations related to intrusive bodies.

Figure 1. Location of the KSZ project in Botswana.
The Mineral Systems Approach applied to magmatic Ni-Cu-PGE systems

Most modern exploration strategies now increasingly focus on applying a holistic Minerals Systems Approach (MSA) to prospectivity analysis and target generation. The MSA seeks to be a more predictive method for finding deposits by understanding the combination of geological processes that are required to form and preserve ore deposits at all scales. It considers the origin of deposits within the framework of large, lithospheric- to deposit-scale processes in relation to source, transport and sink/trap, with a decreasing scale of detectability of these processes from source to sink. Initially developed for the petroleum industry, the MSA has been shown to be applicable to metalliferous ore deposits as well and is an effective tool in exploration targeting (McCuaig et al., 2010; Fig. 2).

Figure 2. An example of the scale dependency of targeting elements for komatiite-hosted Ni-Cu sulfide mineral systems, from McCuaig et al. (2010).

At each scale, it is key to identify the relevant processes that operate in the system. In turn, each process will produce characteristic geological features determined by these processes, and therefore at each scale the geology can be interpreted to represent the operation of such processes. Finally, there are tools and techniques in terms of datasets and knowledge that can be used to test for the presence of these. This sequential methodology can then be used to make area selection decisions in target generation.

D&D have utilised the MSA to assess the prospectivity of the KSZ project area for ultramafic/mafic-hosted magmatic Ni-Cu-PGE sulfide mineral systems, by applying the framework proposed by Barnes et al. (2016) who applied the MSA specifically to magmatic Ni-Cu-PGE systems to address the major parts along the ‘life cycle’ of a magmatic Ni-Cu-PGE deposit (Naldrett, 2011). Barnes et al. (2016) recognised six major components along the source-transport-sink pathway in these mineral systems:
1. *The geodynamic and tectonic setting*
2. *The source and compositions of the ore-forming magmas*
3. *The magma migration pathway at a crustal scale*
4. *Mechanical and structural mechanisms for focussing magma flow*
5. *Evidence for sulfide saturation, accumulation and reworking*
6. *Factors affecting preservation and detectability*

Furthermore, Barnes et al. (2016) expanded on points 4 and 5 to include multiple pieces of evidence that can be used to detect the smaller scale processes towards the sink end of the mineral system. The following sections follow this framework and highlight the prospective nature of the KSZ for Ni-Cu-PGE mineralization within this framework.

1. **Geodynamic and tectonic setting**

Most major Ni-Cu-PGE sulfide camps (e.g. Noril’sk, Voisey’s Bay, Jinchuan, Thompson nickel belt, Raglan) are associated with *rifted environments* along *craton margins*, where voluminous mafic-ultramafic magmas, derived from *mantle plumes* (*Large Igneous Provinces; LIPs*), were channeled up through lithospheric fault systems and emplaced into sedimentary basins that contain abundant *sulfur-bearing country rocks*.

**Geodynamic and tectonic setting of the KSZ**

The Kalahari Suture Zone project and licence areas are located in southwestern Botswana and is geologically situated along the western margin of the Kaapvaal Craton, within the Botswana segment of the Kheis Orogenic Belt (Fig. 3) that extends into the Northern Cape province of South Africa.

The Kheis Belt (Fig. 1, 3) represents a major deformation zone comprised of low-grade metasedimentary and metavolcanics rocks that separates the Kaapvaal Craton to the east from the Nosop basin to west. The belt is interpreted to represent a tectonically active zone originating during a 1.8 Ga collisional event, which later underwent periods of subsequent rifting (~1.1 Ga and 180 Ma).

The Kalahari Suture Zone is situated adjacent to the Kheis Belt; a two component structure comprised of the Kalahari and Makgadikgadi Lines in Botswana. The Makgadikgadi line has been interpreted to represent the northwestern boundary of the Kaapvaal Craton, whereas the Kalahari line is situated parallel to the Kheis Orogenic belt. The Kalahari Suture Zone is observed by a distinct magnetic discontinuity marked by several prominent coincident magnetic and gravity anomalies ranging from 10 to 40km in width, which include the Tshane, Tsetsend and Xade mafic-ultramafic complexes that run from the Okwa complex down to the South African Border (Fig 3, 4). Locally the areas of interest comprise basement sedimentary rocks of the Transvaal Supergroup, overlain by the Olifantshoek Supergroup that are regionally overlain by rocks of the Karoo Supergroup (Fig. 1).
Figure 3. Tectonic map of the basement rocks of Botswana showing the KSZ project area (in red) located along the western margin of the Kaapvaal Craton as an extension of the Kheis Belt (KhB). (Modified from Singletary et al., 2003 and Chisenga, 2015)

Two main suites of mafic-ultramafic intrusions have been identified to date, a 1000 – 1100 Ma suite during intracontinental rifting comprising a series of mafic-ultramafic (gabbro and gabbronorite) intrusions intruded into Proterozoic basement comprised of banded iron formations and sulphur bearing-rocks of the Transvaal and Olimantshoek Supergroups. Younger post-Karoo (180 Ma) mafic dolerite and gabbro intrusions (with potential links to the southern African Karoo LIP) had the potential to not only interact with the sulfur and iron-rich Proterozoic basement (similar to the Ni-Cu-PGE deposits of the Platreef, South Africa; Holwell et al. 2007) or interact/ rework sulfide in the Tshane Complex, but were emplaced into pyritic-sulfide bearing siltstone, sandstone, carbonates and coal of the Karoo sediments (analogous to Tertiary macrodykes of east Greenland; Holwell et al., 2012).
The highly magnetic Tshane Complex is the largest of the mafic-ultramafic complexes and may represent potential targets for Cu-Ni-PGE mineralization. However, the Tshane Complex is almost completely overlain by Karoo and Kalahari Group sedimentary rocks and as such often lies buried remains relatively underexplored.
Key points - KSZ licences:

- Situated along *craton margin*: located along the western margin of the Kaapvaal craton. Other Ni sulfide deposits in a similar setting in the region include the Munali deposit, Zambia (Blanks and Holwell, 2018).

- Situated in a *rifted environment*: adjacent to the Kheis Belt; mafic-ultramafic magmatism associated with at least two phases of rifting:
  - >1 Ga intracontinental rifting along the Kaapvaal margin;
  - Karoo and post-Karoo rifting (<180 Ma).

- Magmatism related to *plumes*:
  - Karoo mafic intrusions interpreted to be related to the plume-driven Karoo large igneous province (LIP), with extensive continental flood basalts.

- Intrusion into sedimentary basins containing abundant *sulfur-bearing rocks*:
  - 1> Ga intrusions emplaced into sulfur and iron-rich Transvaal and Olifantshoek Supergroups.
  - Karoo mafic intrusions are emplaced or spatially associated with sulfur and iron-rich Transvaal Supergroup sediments and pyritic-sulfide bearing siltstone, sandstone, carbonates and coal of the Karoo Sequence.

**2. Source and composition of ore forming magmas**

The sources of metals in magmatic ore deposits are overwhelmingly derived from the magmas themselves and thus from their mantle source (Barnes, Holwell and Le Vaillant, 2017). These are generally thought to be from *mantle plumes* in many cases (hotter than Mid-Ocean Ridge magmatism), and the degree of mantle melting determines the composition (the more melting, the higher the MgO). High degree partial melts, such as those that formed Archaean komatiite deposits are very high in MgO, and have high Ni/Cu ratios, forming Ni-rich ore deposits. Towards *the Phanerozoic*, the magmas tend to be *picritic or basaltic, and have lower Ni/Cu ratios, with ores that are enriched in both Cu and Ni*. *Large Igneous Provinces* (LIPs) associated with plume magmatism are thought to be highly prospective.

Many of the world’s largest ore deposit occur in the *plumbing systems beneath areas of flood basalts* (e.g. Noril’sk beneath the Siberian traps) and represent major magmatic events as part of LIPs. Insizwa in South Africa is associated with Karoo LIP, and as such represents a good potential analogue. This is host to globular and massive chalcopyrite, pentlandite and pyrrhotite (Lightfoot et al., 1984).

Key points - KSZ licences:
Prendergast (2015) analysed ten samples of mafic rocks intersected in boreholes from Kavango’s licence area. Geochemically, these samples are very similar, indicating a similar origin, with the exception of one sample with significantly different rare earth element (REE) characteristics.
• Most of the samples have trace element characteristics indicative of plume related (Ocean Island Basalt; OIB) compositions with a degree of crustal contamination. It is interpreted that these rocks are part of the Karoo LIP.

• The sample that is distinct has a more Mid Ocean Ridge Basalt (MORB) like geochemical signature. This supports the identification of two separate magmatic events recorded in the area. One may be significantly older, and if it has MORB like characteristics, may be less prospective (possibly the 1071 Ma event). Distinction of these two intrusive types and assessment of their respective prospectivities is key.

This reflects two potential Ni-sulfide mineral systems. An older (~1000 Ma) suite of MORB-like magmatism (the Tshane Complex), and a younger (180 Ma) suite of more prospective plume-like magmatism. It is possible that mineralisation in the Tshane Complex may have been reworked into the younger magmas, and this may be a further source of metals and sulfur in the younger intrusions.

3. Magma migration pathways

The most favorable and established mechanism to transport dense, mafic-ultramafic magmas up through the crust is through buoyancy. This ascent takes place through the propagation of dyke-sill networks. The ascent of magmas through an established crack network, such as a rift basin with deep-seated fault systems (Fig. 5), requires a long-lived and continuous supply of magma.

Figure 5. A) Channelisation of plume-related magmas up through the crust via dyke-sill networks facilitated by deep seated crustal fault systems such as those at rifted cratonic margins (from Barnes et al. 2016). B) Crustal cross-section across the Nosop Basin, Kheis Belt and Kaapvaal craton (Chisenga, 2015).
Key points: KSZ licences:

- **Rift basin setting**: Mafic-ultramafic magmatism within the Kalahari Suture zone were emplaced during extensional rifting environments, which will have promoted the development of deep-seated fault systems that may have acted as conduits for the ascending magmas with the increased likelihood for interaction of S-bearing country rocks, such as the Transvaal Group or Karoo sediments.

- **Presence of dyke-sill complexes**:
  - The ~1000 Ma intrusions represent series of large mafic and ultramafic intrusions indicative of voluminous dyke-sill complex.
  - The Karoo mafic intrusions are present as thin gabbro-dolerite sills (Fig. 6) and are temporal to the regional Karoo continental flood basalts. It is probable that these mafic intrusions may be associated with conduit feeders to the flood basalts. Conduit feeder dykes are prospective for Ni-Cu-PGE due to acting as narrow conduits for large volumes of fertile magma.
  - EM surveys indicate mafic feeder conduits with sills propagating laterally that have been intersected by the drilling.

![Figure 6. Kavango geological model. Recent drilling has intersected thin sills. The Red Spot Gabbro is a large magnetic and gravity anomaly interpreted to be a blind mafic intrusion. Potential for massive sulfides exist in the areas of high magma flow within, or close by to country rocks with a source of S and or C (i.e. the Karoo sediments).](image)

4. **Mechanisms of focusing magma flow at trap sites**

All Ni-Cu-PGE sulfide deposits show evidence of being hosted within magmatic environments that have experienced protracted throughput of mafic-ultramafic magma. Large volumes and fluxes of magma are considered to be highly advantageous in generating deposits as they:

- Provide environments whereby wall rocks can be effectively assimilated, allowing for sulfide formation through contamination.
- Can concentrate large volumes of originally dispersed sulfide liquid droplets into pools at trap sites.
- Facilitate the enrichment of sulfide liquid (metal tenors) by allowing prolonged opportunity for the sulfide liquid to scavenge metals from a continuous supply of fertile magma.

Figure 7 illustrates the schematic development of a magmatic system that attains all of the features outlined above. It is quite possible that the sills intersected by the recent Kavango drilling, and interpreted from the EM surveys, and the older bodies of the Tshane Complex intersected by the historic drilling represent parts of such systems. Figure 7 therefore shows where one might expect to find massive sulfides in such a system in the KSZ. It is in many ways, this is similar to the east Greenland macrodykes (Holwell et al., 2012) that conform to almost all of the MSA factors listed here, but are exposed at a deeper level (with a greater volume of sulfide is preserved, interpreted to imply proximity to massive sulfides).

Figure 7. Schematic representation of dyke-sill-feeder systems and the likely location of sulfide accumulations (red). From Barnes et al. (2015). Blue star = possible location of recent Kavango drilling intersecting sills. Red star = feeder to Karoo flood basalts. Yellow star = potential massive sulfides in traps within deeper magmatic system.
Barnes et al. (2016) listed a number of geological features that are indicative of the right pathways for prospective magmatic sulfide systems. These are listed below as (a) to (e) with an assessment of the relevant features in the KSZ.

a) High abundances of **cumulate rocks**, particularly the presence of coarse-grained cumulates near intrusion margins. Olivine and chromite bearing cumulates are positive indicators in many cases.

  **Key points - KSZ licences:**

  **>1000 Ma magmatism**

  - The Tshane Complex is made up of medium to coarse grained gabbros. It would be logical to assume that these are the mafic components of a large system that includes more ultramafic rocks at depth. Gabbronorites and pyroxenites have also been recorded with **cumulate texture** (Hansen et al., 2006; Robertson, 2018)

  **Karoo Magmatism**

  - It is not known if the Karoo aged intrusions contain similar cumulate rocks, though dolerites grading into **gabbronorites** are mentioned by Robertson, 2018).

b) Characteristic **tube-like morphologies**, forming a continuum with elongate canoe-shaped flared or blade-shaped dykes, in otherwise more convoluted intrusive systems

  **Key points - KSZ licences:**

  **>1000 Ma magmatism**

  - Some thick intersections (tens to <150 m) of gabbro from the **Tshane Complex** indicate large bodies of gabbro, which are consistent with the magnetic anomaly that runs the length of the KSZ.

  **Karoo Magmatism**

  - The recent Kavango drilling has intersected relatively thin sills intruded into **Karoo sediments** that may branch off larger feeder dykes and conduits.

  - Geophysics reveals a number of anomalies that have been interpreted to be magmatic bodies (CSAMT resistors) or even sulfides (CSAMT and EM conductors) at depth.

  - The current model suggests that the KSZ represents a large linear magmatic system that forms a feeder to the overlying basalts of the Karoo LIP. It is more than likely that some of these feeders would have been key zones of magma flux. Further drilling would be required to constrain favorable morphologies.

c) Evidence for strong interactions with country rocks such as **xenoliths; marginal breccias; pegmatoidal marginal rocks** ("taxites") indicating solidification under anomalously high volatile contents from initially dry magmas.
Key points - KSZ licences:

>1000 Ma magmatism

- In some of the historical drilling (e.g. CKP-5C), Tshane Complex gabbros are intruded into sediments of the Palaeoproterozoic Transvaal Supergroup. These are key contributors to external sulfide in the generation of the giant Platreef deposit in South Africa (Holwell et al., 2007).

Karoo Magmatism

- Abundant evidence of interaction with reactive country rocks. The country rocks are ideal units for triggering sulfide saturation, including shales and coals which are sources of both crustal S in the form of pyrite, and coal as a reductant (as it is at Noril’sk). Extensive contact alteration is recorded around the intrusives intersected in the recent drilling.
- Trace element geochemistry indicative of crustal contamination (Prendergast 2015).
- There is abundant pyrite and quartz clots in some of the rocks from the sills intersected in the recent drilling. These are almost certainly sourced from the host sedimentary rocks as micro xenoliths. As such, assimilation of favourable country rocks is present.
- Evidence of slow cooling such as poikilitic textures, thermal aureoles.

Key points - KSZ licences:

Karoo Magmatism

- The thin sills are surrounded by baked margins in the country rocks that show intense alteration for distances of up to 8m either side of the sills. This suggests continuous flow of magma over a protracted period.

e) Evidence of sulfide liquid fractionation

Key points - KSZ licences:

- Sulfides identified in the gabbro and dolerite sills in the Karoo and the older Tshane Complex so far include fine disseminated Ni and Cu sulfides.
- Assays of up to 400 ppm Ni in the Karoo sills drilled by Kavango are above that expected of unmineralized dolerite/gabbro and may indicate the presence of Ni sulfides.

5. Evidence of sulfide saturation

Figure 7 illustrates some of the mechanisms and traps for massive sulfides within dyke-sill-conduit systems. Any particular system that has experienced sulfide saturation will have produced sulfide liquid within the host magma. In order for an ore deposit to form, the sulfide droplets need to
accumulate, and concentrate metals within the sulfide by interacting with large volumes of magma as stated in section 4.

However, the volume of sulfide in any particular magmatic system is very small compared to the volume of magma, and therefore in exploration, it is much more likely that unmineralized magmatic bodies are encountered than the deposits themselves. The key to successful exploration is to be able to identify proxies for sulfide formation and accumulation in rocks that are not necessarily mineralised themselves, but are part of a fertile system.

Barnes et al. (2016) listed a number of geological features that are indicative of sulfide segregation and accumulation. These are (a-c):

a) Anomalously high or low PGE concentration, relative to incompatible elements, e.g. Ti and Zr.
   Key points: KSZ licences:
   • Prendergast (2015) reported a range of precious metal contents that are both depleted and enriched (Au: <1 – 5 ppb; Pd: 1 to 66 ppb; Pt: 2 – 58 ppb). A ‘primitive’ signature would be around 10-20 ppb for these elements, therefore some are significantly depleted by an order of magnitude, which indicates sulfide segregation in the system. The elevated concentrations > 20 ppb most likely represent sulfide-bearing rocks.
   • Cu/Zr ratios (1.15–2.41) are slightly elevated above mantle (1), which may indicate sulfide accumulation.
   • But the strongest evidence for sulfide saturation and the formation of magmatic sulfides in the system is in the Cu/Pd ratios that are way above the mantle range (1000-7000): 8000 – 19,118, with one as high as 84,000, indicating the parent magmas to the Karoo-aged mafics segregated sulfide, which concentrated Pd (and other chalcophile metals) into an earlier sulfide liquid.

b) Depleted Ni contents in olivine and pyroxenes. Nickel is more compatible in sulfide than it is in silicate minerals and therefore if sulfide is present in a magmatic system, then the Ni content of olivine and pyroxene will be anomalously low, as Ni will partition into the sulfide rather than the olivine.
   Key points: KSZ licences:
   • No work on the silicate mineral chemistry has yet been undertaken.

c) Presence of sulfide liquid droplets
   Key points: KSZ licences:
• Historical drilling of the Tshane Complex has identified occurrences of magmatic sulfides comprised of *chalcopyrite-pyrite-pentlandite* (plus the tentative identification of sphalerite)
• The presence of disseminated sulfides in itself does not necessarily indicate the presence of a massive sulfide body in the system. However, it does show that the magmas were sulfide saturated, and therefore had the potential to accumulate economic concentrations.
• Identification of more rounded/globular sulfides would help to vector towards any massive sulfide bodies as large droplets are unlikely to have been mobilized far from the site of accumulation.

### 6. Preservation and detectability

The final aspect of the mineral systems approach is the chance of an ore deposit being exposed and preserved through its history of emplacement, tectonism, uplift, erosion and weathering. Magmatic Ni-Cu-PGE systems can form at a variety of crustal levels. As such, they have some advantages over high level, upper crustal deposit styles such as porphyry and epithermal systems that are subject to rapid uplift and erosion.

Many of the world’s largest ore deposit occur in the *plumbing systems beneath areas of flood basalts* in LIPs (e.g. Noril’sk beneath the Siberian traps).

**Key points - KSZ licences:**
The KSZ is likely to be a feeder to the Karoo flood basalt province. In the KSZ, the current erosion level exposes the sedimentary basin below the flood basalts onto which they were erupted. *The feeders to these basalts and the deeper plutonic intrusions are prospective and these occur at depth.* From historical drilling it is indicated that the major mafic bodies occur at 500-700 m below the surface in the north, but are <300 m in the south. For comparison, Ivanplats are currently developing their underground PGE-Ni-Cu mine on the Platreef, South Africa at around 800 m.

Given the erosion level of the Karoo LIP, any accumulations of sulfide in the deeper plumbing systems *will most likely be preserved.* The detection of these requires relatively deep drilling and geophysics. However, the intersection of sills art shallower levels is potentially very useful in identifying geochemical signatures of sulfide saturation as per section 5 above.

The older (~1000 Ma) mafic-ultramafic rocks of the Tshane Complex may also host magmatic Ni-sulfide systems, however they are likely to be at a greater depth than the younger complex.
Summary

The KSZ comprises two distinct mafic-ultramafic complexes that conform to many of the key features of prospective Ni-Cu-PGE sulfide mineral systems. The older Tshane Complex (~1000 Ma) does contain cumulates with disseminated sulfides, though the composition is more MORB like and the presence of any potential sulfide deposit would be much deeper (perhaps >500 m). However, the more recent mafics that intrude the Karoo sediments are likely to represent the feeder systems to the Karoo flood basalts. They are more plume-related in composition and preserved to a shallower depth. They also contain strong geochemical signatures indicative of sulfide saturation in the parental magmas.

Table 1 summarises the favorable, unknown or unfavorable aspects of both magmatic systems. It also highlights the current unknowns within the project area in terms of fully defining the mineral system (see Recommendations).

<table>
<thead>
<tr>
<th>COMPONENT OF THE MINERAL SYSTEM</th>
<th>KSZ - Tshane</th>
<th>KSZ - Karoo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geodynamic and tectonic setting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rifted craton margin</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Mantle plume</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Intrusion into sedimentary basins</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Source and composition of magmas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plume related</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Large volumes of basaltic magma</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Magma migration pathways</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyke-sill complexes</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cumulate rocks</td>
<td>✓</td>
<td>?</td>
</tr>
<tr>
<td>Tube-like or bladed dyke morphologies</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Xenoliths and interaction of country rocks</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Slow cooling textures</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Sulfide liquid fractionation</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Chemical/physical mechanisms of sulfide accumulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Cu/Zr ratio</td>
<td>?</td>
<td>✓</td>
</tr>
<tr>
<td>High Cu/Pd ratio</td>
<td>?</td>
<td>✓</td>
</tr>
<tr>
<td>Ni-depletion in olivine and pyroxenes</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Large droplets of sulfide</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Preservation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion level no deeper than feeders to flood basalts</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 1 Summary of the component parts of the Ni-Cu-PGE sulfide Mineral System for the KSZ mafic complexes. Note that the question marks represent aspects that have not yet been defined, and thus warrant further work.
Kalahari Suture Zone summary

Recommendations

From Table 1, key areas that require further clarification/investigation/confirmation (as represented by question marks in the table) are:

- What is key contaminant that may cause sulfide saturation? The basement Transvaal Supergroup or the Karoo basin? The depth of sulfide deposits is dependent on this. Sulfur isotope analysis would address this.
- Analysis for prospectivity indicators like Ni content in silicates (e.g. olivine) in the intrusions should be undertaken
- Ultramafic rocks (in situ or as xenoliths) should be investigated as likely hosts for sulfides.
- A detailed synthesis of the regional geology within the MSA framework would be advantageous, especially with regards to the two different mafic suites.
- A target generation exercise using geophysical anomalies, plus geochemical/mineralogical vectors should be performed using the MSA framework as a guide to prospectivity.

These points could effectively be addressed by further desk review, site visit, and the targeted applied research project proposed to be undertaken at the University of Leicester.

Some of the recommendations for further exploration proposed by Kavango include:
- Downhole geophysics (especially EM)
- Low frequency ground EM using very large loops and high power transmitters
- Gravity surveys
- Computer modelling
- CSAMT resistivity surveying
- Further soil sampling – especially for Cu, Ni, Fe and Ni.

Review of the Kalahari Suture Zone system using the Mineral Systems Approach (MSA), shows evidence for some of the key components of the framework.

- The Karoo age dyke-sill complex appears the most prospective with good potential to host economic deposits of Cu-Ni-PGE sulfides.
- If the Karoo intrusives represent feeder zones it is likely that deposits hosted by these intrusions would be significant.
- The Karoo-ages intrusives remain highly prospective.
- In addition, the older Tshane Complex represents a separate magmatic complex within the same licence area that is also prospective for magmatic Ni-Cu-PGE sulfides.
- The area is relatively underexplored and to date there is no evidence from an MSA perspective that would be unfavorable towards potential discovery.
For and on behalf of D&D GeoConsultants:

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BSc (Hons) MSc MCSM PhD FSEG
Kalahari Suture Zone summary

References
Barnes, SJ, Cruden, AR, Arndt, N and Saumur, BM. 2016. The mineral system approach applied to magmatic Ni–Cu–PGE sulfide deposits. Ore Geology Reviews. 76, 296-316.


APPENDIX 1

Exploration to date by Kavango:

These activities have not been reviewed or verified, but are recorded in documentation provided by Kavango

Field exploration work by Kavango has included:

- Over 25000 regional and detailed soil samples
- Re-logging of historical drill holes
- Whole rock geochemistry analysis of the KSZ gabbros done Prendergast (2015)
- A number of CSAMT surveys over historical drill holes and soil anomalies
- A 21km CSAMT line across the KSZ
- Two helicopter-borne EM surveys covering a total of 4,070 line-kms.
- The 3D EM model.
- 1092m of combined RC and DD drilling with assays for PGE, Au and base metals.
- Thin section microscope work.