The Geology and Historical Importance of the Abenab Vanadium Mine in the Otavi Mountainland (Namibia)

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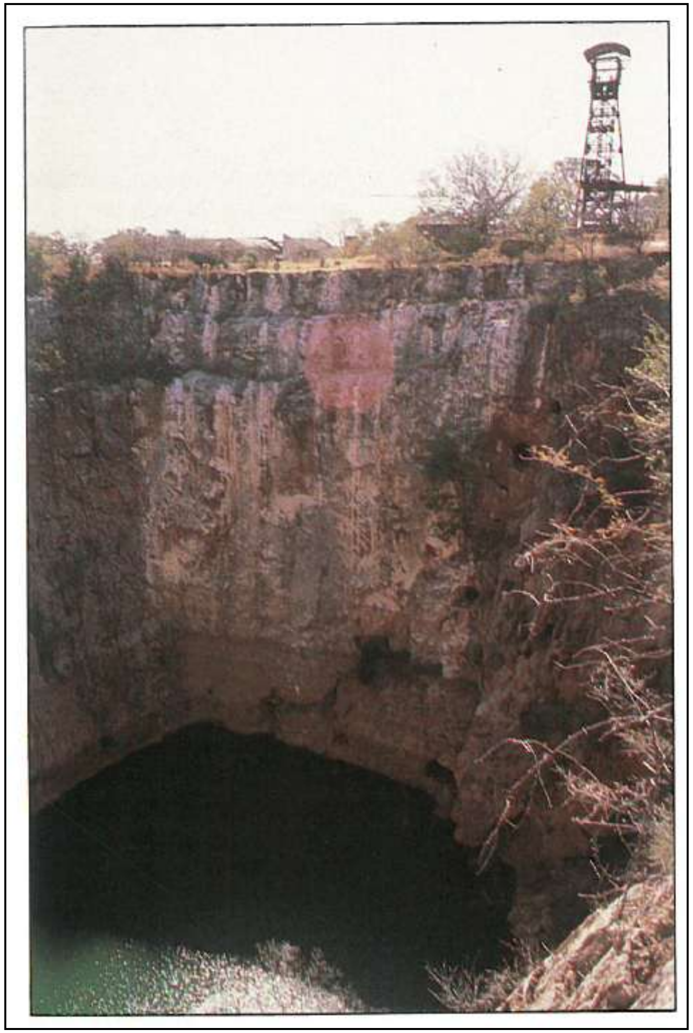
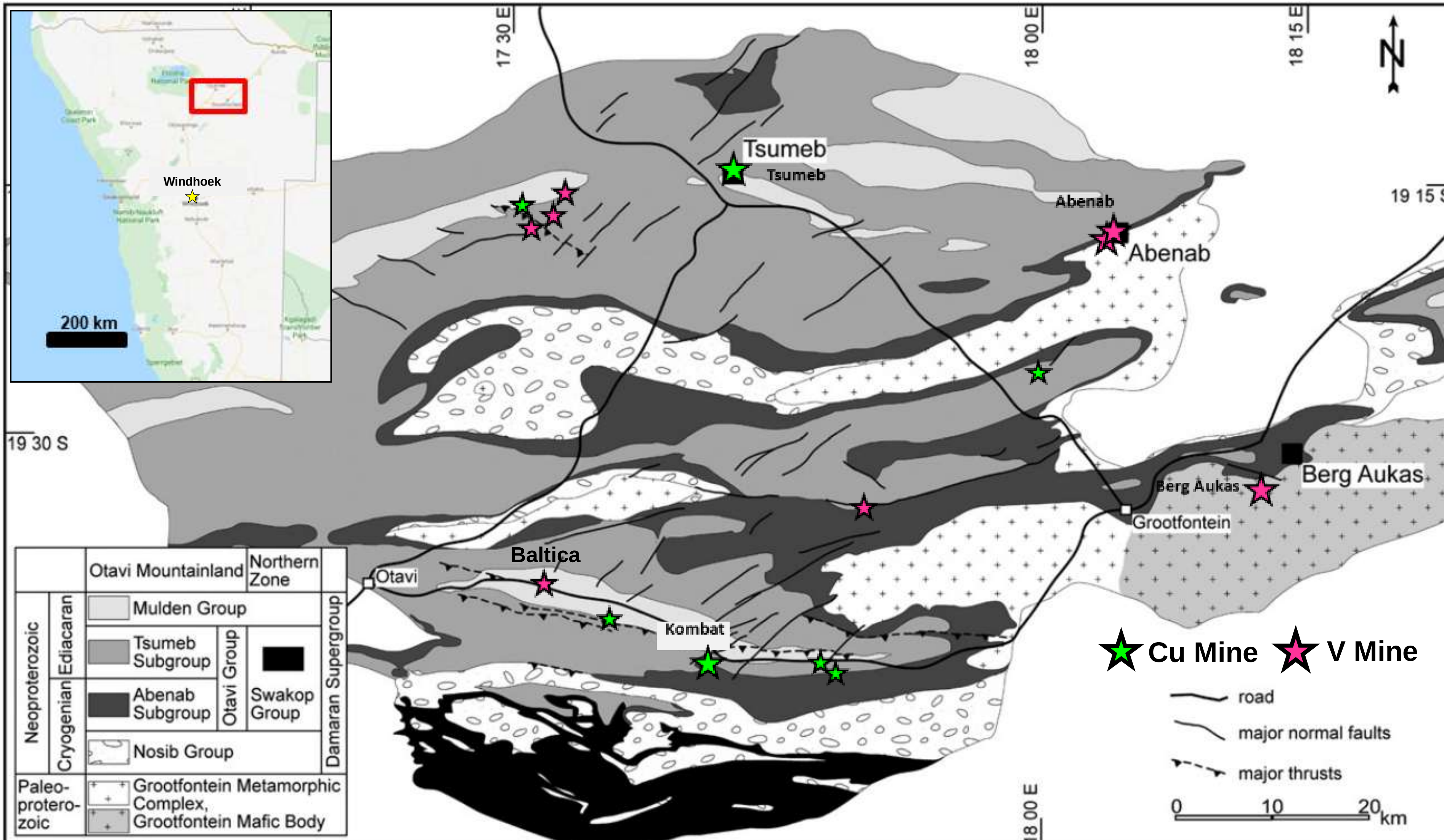
Descloizite associated with calcite vein

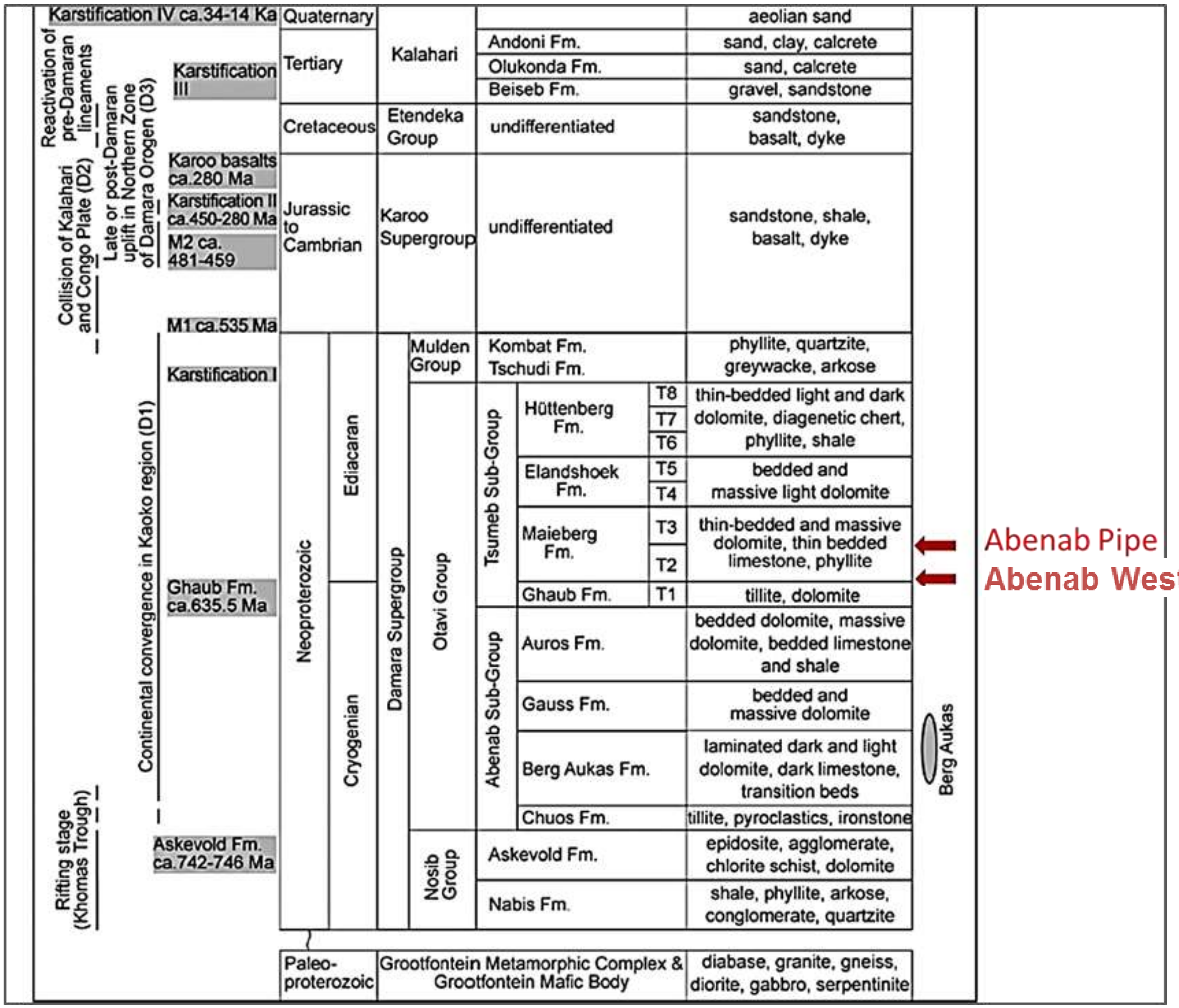


Abenab Open Pit and Shaft Headgear

Regional Geology of the Otavi Mountainland



Stratigraphy Setting of the Otavi Mountainland

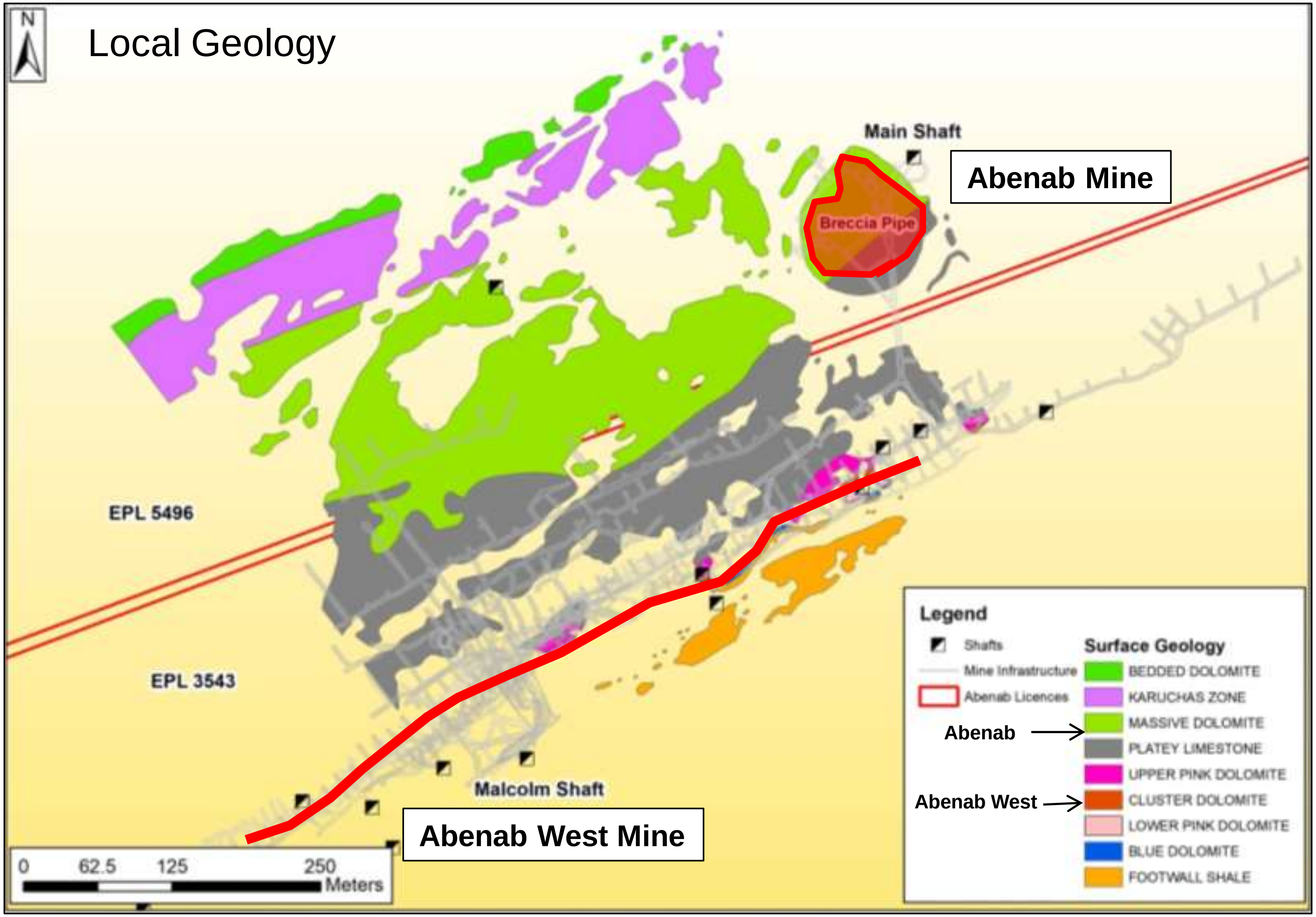


(adapted after Schneider et al., 2008)

Historical Significance

- 1842: Sir Francis Galton reports the presence of copper smelting by the local population at Tsumeb.
- 1908: Mottramite (copper rich member of adelite-descloizite group) identified at Tsumeb.
- 1921: Discovery of V-Pb-Zn deposits at Abenab.
- 1924: Discovery of Abenab West.
- 1947: Closure of Abenab Mine at a depth of 215m.
- 1958: Closure of Abenab West. Total production from both mines was 1.85Mt at 1.03% V_2O_5 .
- 1958: Berg Aukas Mine starts production.
- 1978: Berg Aukas ceases operation after producing 1.6Mt at 0.77%V_2O_5.
- 2009: Latest phase of exploration by Avonlea and Golden Deeps Limited aimed at defining a resource at Abenab down to a depth of 415m.

Abenab Geology



Geology of Abenab and Abenab West

1. Abenab
   - Abenab is a pipe – like breccia dipping steeply towards the north that is developed on the contact between limestone and dolomite.
   - Mineralisation occurs as descloizite $(Pb,Zn)_2(OH)VO_4$ crystals on the contacts of the breccia clasts and within the breccia matrix which consists of calcite and clay.
   - Additional Pb and Zn minerals are mostly absent.
   - The pipe is 100m by 80m and extends in depth beyond 415m downplunge.

2. Abenab West
   - Strata-bound dolomite horizon dipping steeply to the north.
   - Mineralisation occurs as descloizite $(Pb,Zn)_2(OH)VO_4$ which is associated with willemite (Zn_2SiO_4), cerrusite $(PbCO_3)$ and anglesite $(PbSO_4)$ near surface, with galena (PbS) and sphalerite ((Zn,Fe)S) becoming the prominent ore minerals at depth.

Ore Minerals of Abenab and Abenab West

Abenab

Abenab West

Descloizite $(Pb,Zn)_2(OH)VO_4$

Willemite (Zn_2SiO_4) – bearing mud

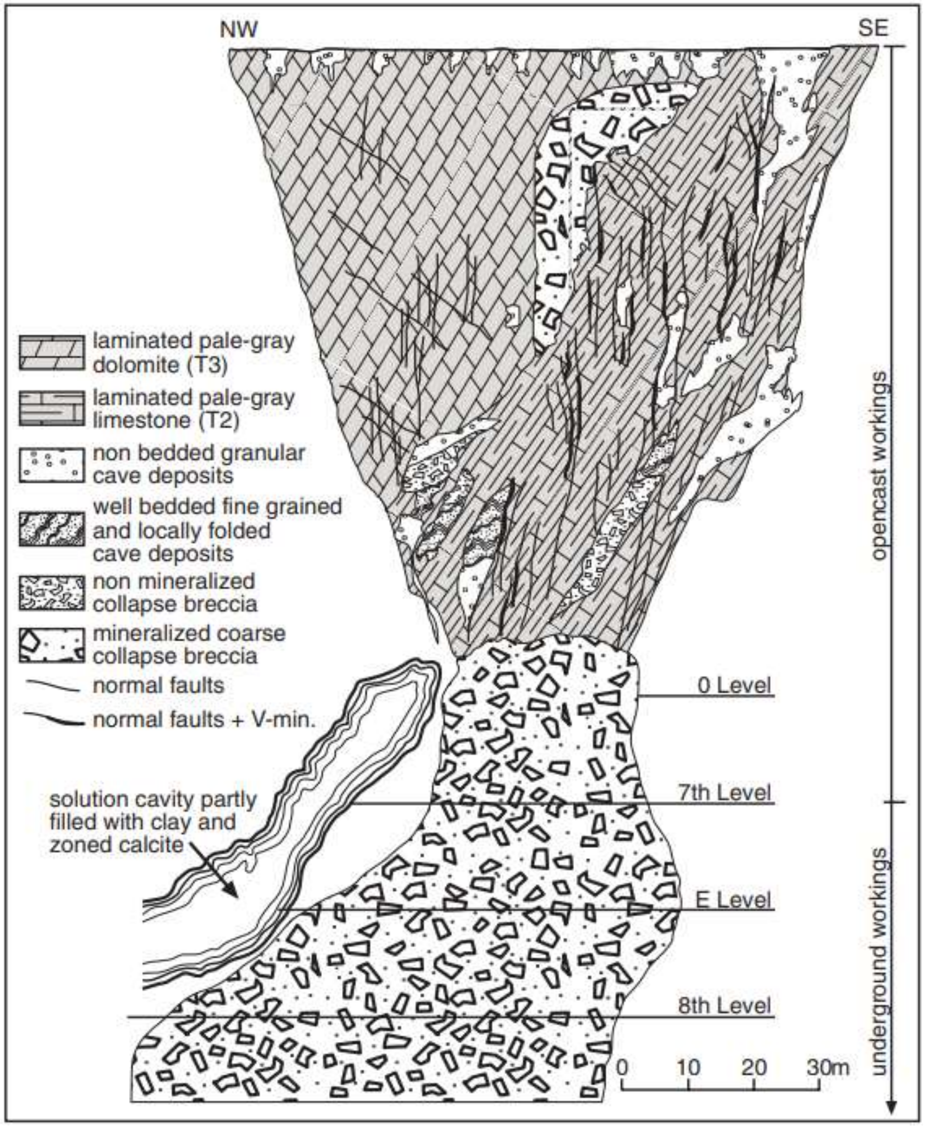
Cerrusite ($PbCO_3$)

Anglesite ($PbSO_4$)

Galena (PbS)

Sphalerite ((Zn,Fe)S

Abenab Pipe Architecture



(modified from Schwellnus, 1945)

- Pipe –like body plunging towards the north.
- Pipe is associated with the contact of the Platey Limestone and the overlying Laminated Dolomite.
- Associated with karstification on the contact.
- Mined down to a depth of 215m.
- Drilling has confirmed that the pipe and associated mineralisation extend to at least 415m depth.
- V grades start to drop of at depth, whereas Pb and Zn grades increase at depth.

Breccia Formation

Calcite-descloizite filled joints

Breccia: calcite-descloizite veining

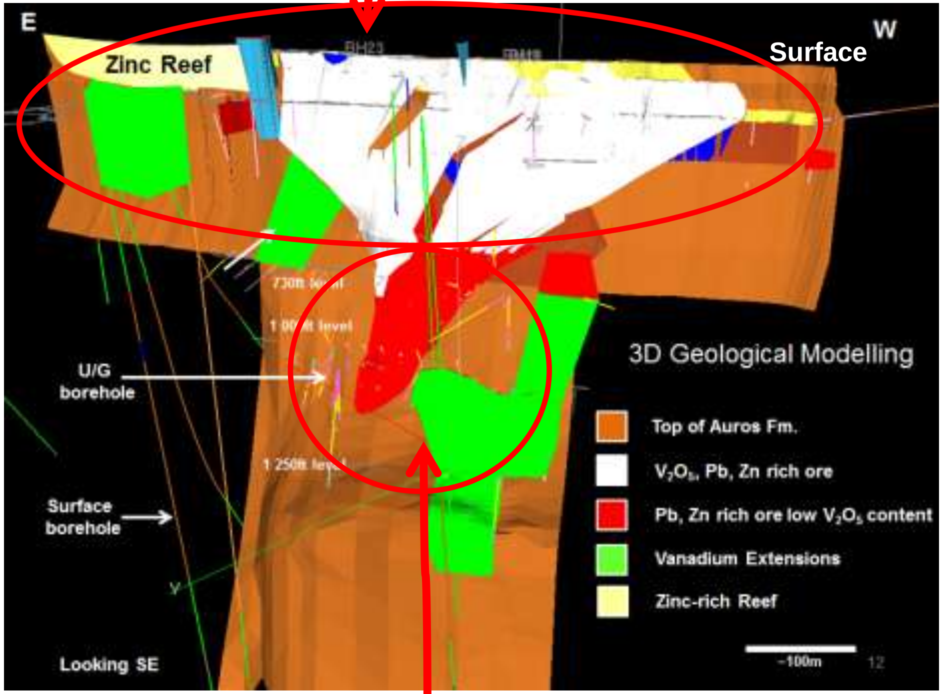
- Steeply dipping set of north-south trending joints intersect the limestone-dolomite contact.
- Calcite-descloizite bearing fluids intersect bedding plane faults on the limestone – dolomite contact.
- Fluid infiltration results in the development of a breccia.
- Carbonic acid dissolution causes the eventual collapse of the breccia, resulting in the development of a karstic collapse breccia.

Collapse Breccia: variably orientated clasts

Abenab West Architecture and Mineralisation

Long Section through Abenab West looking south

Descloizite, cerrusite, willemite, anglesite galena and sphalerite mineralisation



Galena, sphalerite and descloizite mineralisation

- Mineralisation associated with a narrow stratigraphic horizon (Cluster Dolomite) within the Maieberg Formation.
- Auros Formation underlies the Maieberg Formation, formimg the footwall of the mineralisation.
- Steep northerly dip with a mineralised strike of ~750m.
- Pb and Zn minerals form clusters of mineralisation within the Cluster Dolomite, and are associated with V mineralisation.
- V grades start to drop of at depth, whereas Pb and Zn grades increase at depth.

Mineralisation Style

- Boni et al (2007)* describe the Otavi Mountainland as follows:

> Zn-Cu-Pb vanadate ores (descloizite, mottramite, and vanadinite) in the Otavi Mountainland, Namibia, once were considered the greatest vanadium deposits in the world, with resources estimated at several million tons of vanadium ore. The deposits, now mostly exhausted, occurred in collapse breccias and solution cavities related to a karstic network associated with the post-Gondwana land surfaces in carbonate rocks of the Neoproterozoic Otavi Group, which already contained primary sulfide orebodies. Although a supergene, post-Damaran origin has been generally accepted, the timing and genesis of this mineralization style remains controversial. Mottramite and Cu descloizite are particularly abundant around Cu sulfide deposits (Tsumeb type), whereas descloizite occurs in the areas surrounding primary sphalerite-willemite orebodies (Berg Aukas type). The V deposits the Otavi Mountainland represent a special low-temperature, weathering-related, nonsulfide ore type, also fairly widespread in other areas of southern Africa (e.g., Zambia, Angola).

- The mineralisation at Abenab is similar to the Berg Aukas type of mineralisation.

- V mineralisation is associated with the interaction of V-rich meteoric waters with primary Pb-Zn Mississippi Valley Type (MVT) horizons.

- At Abenab the primary MVT mineralisation have been completely replaced by descloizite.

- At Abenab West the primary MVT mineralisation has partially been replaced by descloizite.

*Boni, M., Terracciano, R., Evans, N.L., Laukamp, C., Schneider, J. and Bechstädt, T.(2007): Genesis of Vanadium Ores in the Otavi Mountailand, Namibia. Society of Economic Geologists v.102 pp. 441-469

Spatial Association of the Vanadate Mineralisation with the Primary Sulphide Ore

- The apparent spatial relation of vanadate mineralisation and primary MVT ore is most likely dictated by concentrations of the latter creating point sources of Pb and Zn which entered in solution in V-bearing surface water.
- Favourable point sources developed where primary massive MVT sulphide concentrations were exposed to supergene weathering and erosion, e.g. Abenab West, Berg Aukas and others.
- Vanadium is derived from surface water and suspended ferric oxy-hydroxide and clay minerals. Crustal rocks (mafic) are known to carry significant quantities of vanadium which is mobilised by meteoric water during weathering and erosion. Mafic rocks are present in the basement rocks to the south of Abenab.
- The Pb-Zn-V laden waters found their way into fractures and solution cavities in a karstic environment and under increasing pH conditions (buffered by carbonate) precipitated vanadate minerals in the cavity-fill sediments.
- Boni et al (2007) determined that a distinct period of descloizite formation between 24 and 33Ma based on (U-Th)/He thermochronology. Paleontological evidence indicates that descoizite was forming as recently as Middle to Upper Miocene (13 - 9Ma) (Pickford, 1992*).

*Pickford, M. 1992: Age of supergene ore bodies at Berg Aukas abd Harasib 3A, Namibia 16th Colloquium of African Geology. 14th to 16th September, 1993. Mbabane, Swaziland

Shango Solutions

Summary of Geological Setting and Depositional Controls at the Abenab Project

Source:

- Pb, Zn:
  - MVT mineralisation served as point sources.
- V
  - Surface water (in solution; adsorbed on ferric oxide/hydroxides and clay minerals) flowing over metamorphic terrain onto carbonate rocks.

Trap:

- Solution cavities (karstification events since Karoo peneplanation)
- Structurally deformed MVT horizons result in the development of open joints and bedding planes, allowing fluid ingress.
- Descloizite(-mottramite) and vanadinite crystallisation in situ (drying, high pH).

Thank You