The Bushveld Complex in the Context of the Geology of South Africa’s Kaapvaal Craton
The Kaapvaal Craton is a fragment of the Earth’s crust and underlies almost half of South Africa. To the North it is separated from the Zimbabwe Craton by the highly metamorphosed rocks of the Limpopo Belt. The Craton began to form about 3.600 Ma ago and suffered little deformation for more than 2.600 Ma. However the Archaean basement is now largely covered by younger rocks. The craton is the host of the world’s number one resources of Au, PGE, V- and Mn-ores and also contains large reserves of iron-ores, uranium, vermiculite, fluorspar and copper.

Worldwide distribution of Archaean cratons older than 2‘500 Ma. Many of these cratons carry world-class ore-deposits. It underlines the importance of the Archaean as a metallogenetic period.
Geological Map of north-eastern South Africa exhibiting the area underlain by the Kaapvaal Craton
Stratigraphic positions of major ore mineralizations in the Kaapvaal Craton

- **Bushveld and Phalaborwa Complexes**
- **Manganese and iron ores of the Transvaal Supergroup**
- **Witwatersrand gold-uranium deposits**
- **Primary gold-deposits associated with greenstone belts**
Geological map of the **Barberton greenstone belt** showing the sites of some of the major gold mines. A: Consort; B: Sheba; C: Fairview; D: Agnes. The belt hosts some of the oldest recognised gold ores on Earth.

** Geological Map of northeastern South Africa exhibiting position of major greenstone belts within Archaean granit-gneiss terrane. **
• In the Kaapvaal Craton **greenstone belts** are best exposed in the north-east of South Africa. They often form linear shaped structures deeply infolded into the granitic gneisses which dominate the Archaean terrane.

• The **belts formed between 3‘500 and 3‘000 Ma** and at their base consists of mafic volcanics overlain by sedimentary rocks such as shales, greywackes, cherts, banded iron-formations and conglomerates.

• The first primary gold mineralization in the country was discovered at Eersteling in the Pietersberg Belt in 1871. However, **the largest gold mines occur in the Barberton Belt and since 1884 produced about 320 t of gold.**

• The **mesothermal gold ores are** generally associated with incompetent sedimentary rocks. They form sulfide bearing gold-quartz veins and in the Barberton Belt exhibit an **age of about 3’100 Ma.**

• The **Murchison Belt** contains the largest known Archaean **antimony deposit** now mined by Metorex Ltd. It has an age of 2’900 Ma and occurs as **quartz-carbonate-stibnite veins** in tension fractures.
Barbrook Mine, Barberton

Pillow lavas of the Onverwacht Group

Algoma-type banded iron-formation (BIF) of the Fig Tree Group
Simplified Geological Map of Witwatersrand Goldfields

The Witwatersrand near Johannesburg

The ,,Witwatersrand“ near Johannesburg

Witwatersrand Basin: Au, U

Geological Map of northeastern South Africa showing positions of major Witwatersrand goldfields
The intercratonic Witwatersrand Basin contains the largest known gold deposit on Earth. Since its discovery in 1886 this deposit yielded more than 50,000 t of gold, or about 40% of all the gold ever mined by mankind.

Remaining gold resources are about 36,000 t or 40% of the world’s total gold resources. In addition the Basin also contains some 350 kt of uranium resources.

The gold reefs occur in the 7,000 thick pile of shales and conglomerates forming the 2,900 to 2,700 Ma old Witwatersrand Supergroup.

Sedimentation took place in shallow waters by rivers that flowed into the basin from highlands to the north and north-east depositing large fluvial fans which can be correlated with the major present goldfields.

Rounded pyrite and uraninite particles associated with gold occur in the conglomerate matrix and most investigators regard them as being of detrital origin. This interpretation was recently substantiated by rhenium-osmium age dating of gold particles which yielded an age of 3,030 Ma, an age older than that of the conglomerates confirming the placer origin of the gold.

Detrital pyrite and uraninite which are not stable under present day atmospheric conditions speak for the existence of an oxygen-poor atmosphere during the Archaean. The change to an oxidizing atmosphere occurred after Witwatersrand times in an interval lasting from 2,300 to 1,700 Ma. Thus, Witwatersrand type gold-uranium placers can only be found in sediments older than 2,300 Ma. So far they have also been recognized in the Blind River conglomerates of Canada and in the Brazilian Serra Jacobina conglomerates.
Matrix-supported conglomerate with large vein-quartz pebbles. Note: pyrite together with gold and other heavy minerals occur in matrix.

Ventersdorp Contact Reef overlain by metabasalts: Mponeng Mine

Outcrop of Witwatersrand conglomerates at Rietkuil, West Rand

Open stope at Saaiplaas
Transvaal Supergroup
2'650 – 2'050 Ma:
Thabazimbi and Sishen: Fe-ores
Kalahari Manganese Fields
Northern Cape: Asbestos

Geological map of north-eastern South Africa showing localities of iron-ore deposits, manganese ores and asbestos deposits
The Transvaal Supergroup with an age of 2'650 to 2'220 Ma consists of a thick pile of chemical and clastic sediments and minor volcanics. In it lower part quartzites, cherts and carbonate rocks with interbedded banded iron-formation (BIF) predominate. They are overlain by shales, sandstones, minor dolomites and manganiferous ironstones in the west.

The carbonate sediments are of special interest as they contain well preserved stromatolite structures formed from blue-green algae. Through oxygen producing photosynthetic processes these primitive life-forms were instrumental in the conversion of the early reducing atmosphere to an oxidizing one.

The chemical sediments are economically of special interest as they carry extensive BIF-horizons which at Sishen and Thabazimbi form world-class iron deposits. In the Northern Cape along the western margins of the craton the dolomites contain more than 80% of the world’s known land-based resource of manganese metal.
• The iron- and manganese deposits of the Transvaal Supergroup formed as a result of the rapid increase of free oxygen in the Earth’s atmosphere. During the Archaean the ocean waters carried abundance of soluble ferrous iron and any oxygen produced by early blue-green algae was rapidly taken up by the oxidation of ferrous to insoluble ferric iron which precipitated to eventually form BIF-ores.

• At around 2’300 Ma dissolved ferrous iron began to be depleted and manganese began to precipitate to form the primary deposits of the Kalahari Manganese Fields.

• Iron-ore deposits of the BIF-type form the world’s most important iron resource. They are chemical sediments, have an age of 2’500 to 1’800 Ma and formed in sea waters as a result of the increased oxygen production released by early photosynthetic primitive life-forms. The deposits occur world-wide on many Archaean cratons, e.g. the itabirites of the Quadrilátero Ferrífero in Brazil, the Hamersley Iron Province in Australia, or the Superior Province of Canada.
Impala Platinum

Bushveld Complex: PGE, Cr, V, Fluorite

Geological map of north-eastern South Africa indicating positions of western, eastern and northern limbs of Bushveld Complex.
### Bushveld Lithostratigraphy and Positions of Mineral Deposits

<table>
<thead>
<tr>
<th>Lebowa Granite Suite</th>
<th>Rashoop Granophyre Suite</th>
<th>Rustenburg Layered Suite</th>
<th>Rooiberg Group Group</th>
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</thead>
<tbody>
<tr>
<td>granites</td>
<td>granophyres, porphyritic granites</td>
<td>Upper Zone (diorite, gabbro-norite magnetite layers)</td>
<td>rhyolites, dacites, basaltic andesites</td>
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<tr>
<td>cassiterite</td>
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<td>Main Zone (norites, gabbro-norites)</td>
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<tr>
<td></td>
<td></td>
<td>Critical Zone (norites, pyroxenites, anorthosites, chromitites)</td>
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<td></td>
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<td>Magnetite layers cont. vanadium</td>
<td>fluorspar</td>
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<td></td>
<td></td>
<td>MR UG2</td>
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<td></td>
<td></td>
<td>Cr chromitite seams</td>
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</tr>
<tr>
<td></td>
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<td>Lower Zone (pyroxenites, dunites, harzburgites, bronzitite)</td>
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<tr>
<td></td>
<td></td>
<td>Marginal Zone (norites, pyroxenites)</td>
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</tr>
</tbody>
</table>

**Elements:**

- Sn
- V<sub>2</sub>O<sub>5</sub>
- PGE
- Cr
- F

**Images:**

- Main Magnetite Layer at Steelport
- Merensky Reef
- Chromitite layers at Jagdlust
The 2’060 Ma old Bushveld Complex of about 66’000 km² extent is a saucer-shaped layered igneous intrusion and one of the great geological wonders of the world.

The Complex is made up of ultramafic to felsic igneous rocks and formed by repeated injection of magma into an enormous chamber. Cooling and fractional mineral crystallisation was a slow process leading to the mineral accumulation into different sub-horizontal layers or group of layers. They can be traced for distances of more than 200 kilometres.

The layered sequences dip generally to the centre of the complex and are grouped into the Rustenburg Layered Suite which is divided into the following principal zones: the Marginal, Lower, Critical, Main and Upper Zones.

Of utmost economic importance is the Critical Zone. At the base it contains chromitite layers carrying between 50 and 85% chromite. Best Cr/Fe values are found in the lowest layers which currently produce about 40% of the world’s chromium. Higher up in the Zone two horizons, the UG2 and the Merensky Reef host the largest accumulation of PGMs known on Earth producing close to 60% of the world’s PGM supply.

The Merensky Reef is a feldspathic pyroxenite with a thin basal chromitite stringer which is associated with the highest PGM contents. The UG2 comprises a main chromite layer, carrying most of the mineralization, followed by a poorly mineralised pegmatoidal pyroxenite footwall.

The Upper Zone hosts the magnetite layers of which all contain vanadium, decreasing from 2% at the base to 0.3% V₂O₅ at the top of the zone. The Main Magnetite Layer occurs 130 m above the base of the Upper Zone. It is 2 m thick and is mined in the eastern and western limb. It yields close to 50% of the world’s vanadium supply.
Another source of chromium and PGMs is the 2’500 Ma old Great Dyke of Zimbabwe. It is an elongated layered intrusion that bisects the country. It is 550 km long and has a maximum width of 11 km. **Exploitable PGMs occur in the 2 to 3 m thick Main Sulfide Zone.** It commonly contains iron-nickel-copper sulphides with elevated PGM concentrations at its base. However, these concentration are lower than that of Bushveld ores with grades of less than 4 g/t with a platinum content of 55%. In contrast to the Bushveld Complex visual identification of the mineralization is often difficult.

Due to the political situation of the country only one mine is currently in operation.
Dwars River, eastern Bushveld: UG1 chromitite layers within light coloured anorthosite

Potgietersrus, northern limb: Platreef, Sandsloot pit, Amplats

False colour Landsat image of Great Dyke

Great Dyke of Zimbabwe
Phalaborwa pit with failed slope due to underground block caving

Phalaborwa Complex coeval with Bushveld Complex Cu, phosphate and vermiculite
The economical **Phalaborwa Complex** situated in the north-east of the country formed contemporaneous to the Bushveld Complex. **It is the site of the largest copper mine in South Africa and contains a world-class phosphate (apatite) and vermiculite deposit.**

The complex is a igneous intrusion composed of three volcanic feeder pipes that occupy an area of 8 km by 4 km. **The complex can be interpreted as the deeply eroded zone of an ultramafic carbonatite-type volcano.**

The core of the **northern pipe** has been altered to serpentinite and vermiculite and the core of the **southern pipe** comprises a phlogopite/vermiculite pegamloid rich in pyroxene and apatite.

The **central copper bearing pipe consists of carbonatite**, an unusual rock composed of mainly limestone and dolomite. Foskorite another unusual intrusion surrounds the carbonatite core. It is composed of apatite and Ti-bearing magnetite.

The copper minerals bornite, chalcopyrite and valeriite of the central pipe are mined by the **Palabora Mining Co. (PMC)**, a member of the Rio Tinto Group. **Open-pit mining** started in 1956 and by reached 2002 a final depth of 750 m when **underground mining by the block-caving method** started. The underground mine has production rate of 30'000 t/day with an average grade of about 0.8 % Cu. Total copper production so far amounts to 2.7 million tons of copper and the projected life of the mine is another 20 years.

In addition to copper **PMC also mines vermiculite** and is the world’s largest producer of high-grade vermiculite.

The Phalaborwa Complex is South Africa’s most important source of **phosphate**. Is is mainly derived from apatite present in the foskorite which is **mined by Foskor Ltd.** having the exclusive rights to phosphates in the entire complex.
Besides hosting some of the world’s greatest geological wonders the **Kaapvaal Craton** is also extraordinary in its mineral wealth (see below table). This indicates that during Archaean times metallogenic elements such as gold, PGE, nickel, copper and uranium were more efficiently transferred from the mantle to the continental lithosphere and that this transfer decreased in its density and diversity with time:

**South Africa role in world mineral production and resources, 2005**

(Chamber of Mines of SA)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Production</th>
<th>%</th>
<th>Rank</th>
<th>Resource base</th>
<th>%</th>
<th>Rank</th>
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<td>PGMs</td>
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<td>70'000 t</td>
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<td>200'000 t</td>
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<tr>
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<td>Iron ore</td>
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