



CIMERA

CIMERA – DST-NRF
Centre of Excellence for
Integrated Mineral and Energy
Resource Analysis

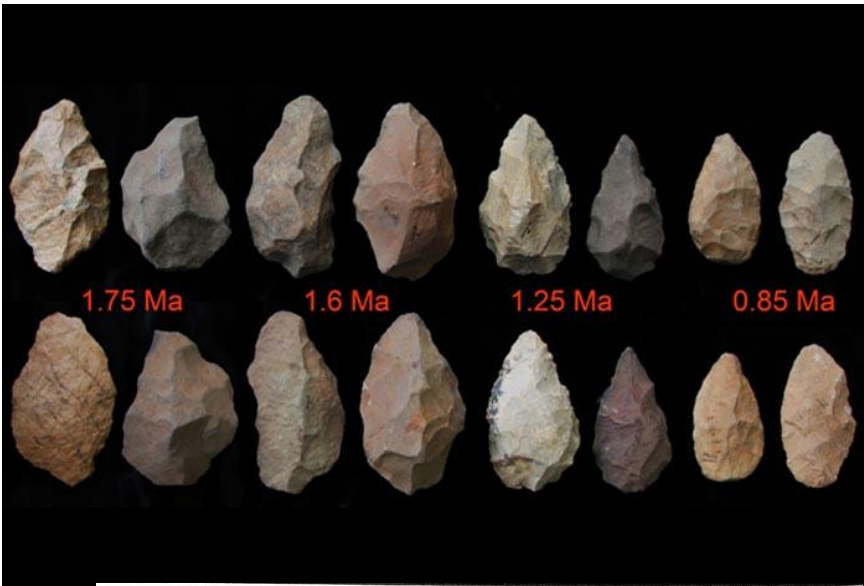
Gold, platinum and diamonds

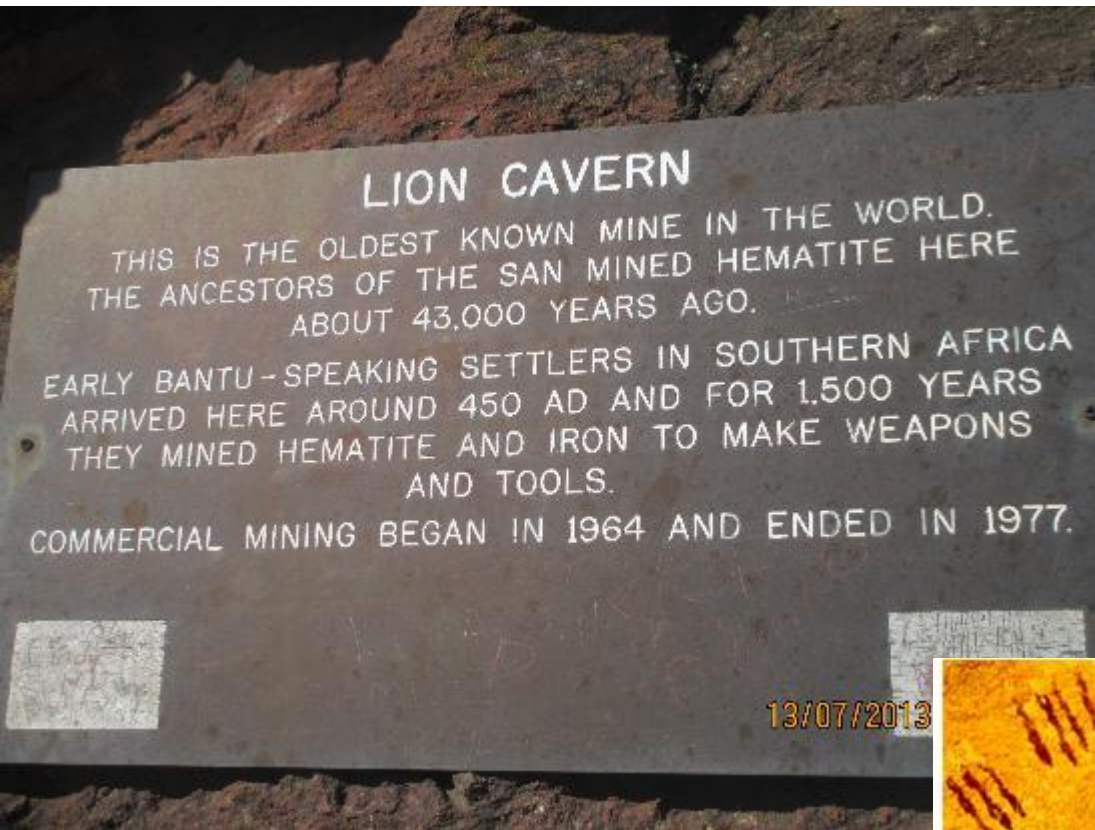
Judith Kinnaird



University of the
Witwatersrand

Mining -then





Source: Bert Woodhouse African adventure

~430 000 years ago, long before the days of Cleopatra and Helen of Troy, cosmetics were being mined to beautify men and woman - who even than recognised that nature needs a little help.



Mining - now

Sishen iron ore mine, northern Cape: 14 km long
source Anglo American



Platinum Mine, Rustenburg



South Deep gold mine, Mpumalanga; 7th deepest



Mamatwan manganese mine, northern Cape



Mining supports our daily life



2013 world standing for mineral output

commodity	major use	% world production	Rank in world
Platinum	catalysts, jewellery	73%	1 st
Rhodium	catalysts, rhodium plating	80%	1 st
Manganese	steels	22%	1 st
Titanium (TiO ₂)	steels	7%	1 st
Aluminosilicates	furnace linings	53%	1 st
Chromium	stainless steels	46%	1 st
Vermiculite	Light-weight cement, plaster board	34%	1 st
Palladium	catalysts	39%	2 nd
Antimony	fire retardants	3%	2 nd
Vanadium	steels	35%	2 nd
Zirconium	nuclear rods, catalysts	28%	2 nd
Fluorspar	ceramics, metal processing	<1%	4 th
Gold	jewellery, electronics	5%	6 th



GOLD



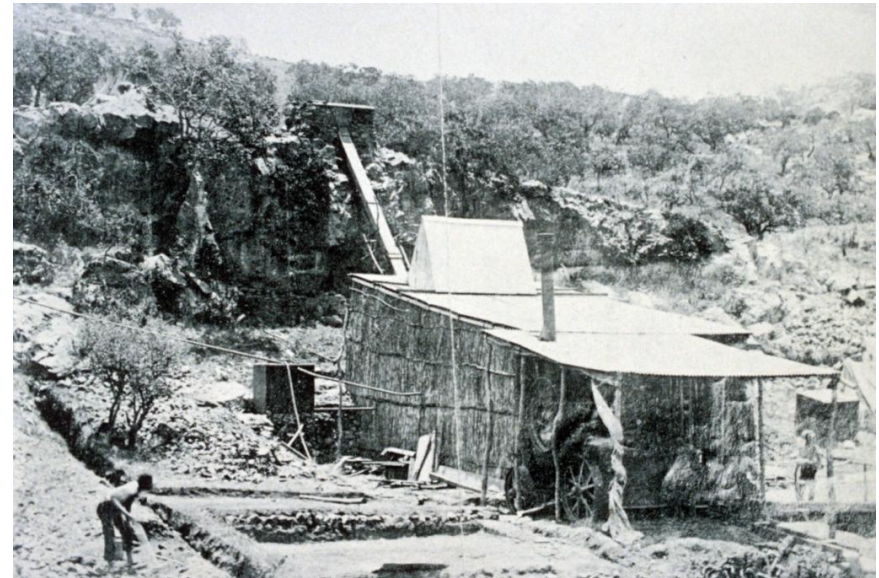
History of gold mining

- In 1884, Henry Lewis an Australian digger found gold in the Blaaubank area.
- In 1885, the nil Desperandum company was formed - the 1st gold-mining Co. in the Wits region
- Little gold produced - closed end 1887

- Between 1880 and 1885 Fred and Harry Struben found gold-bearing quartz veins in the Roodepoort area and they mined these veins.
- In Sept. 1884 Fred discovered the Confidence Reef
- This had very high grades locally but their recoveries were low

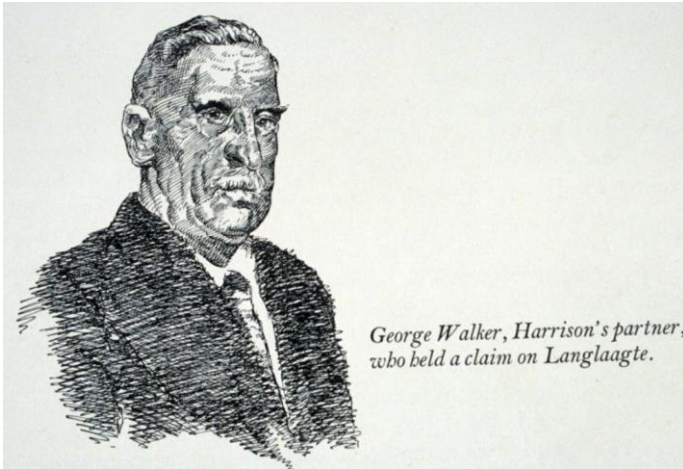


Fred Struben

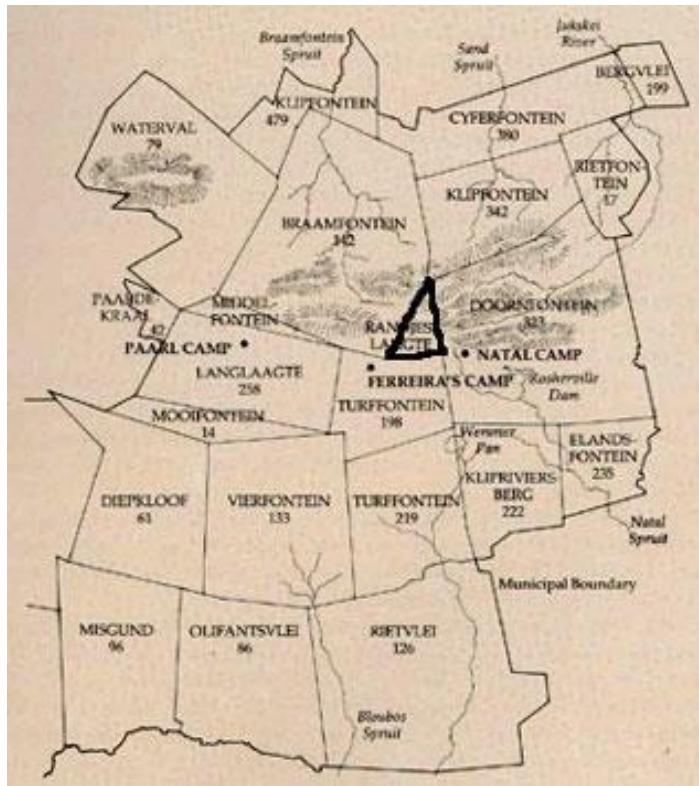


The Strubens' plant at Wilgespruit, built 1883

History of gold



- In Dec. 1885 George Walker and George Harrison, who had been in the goldfields of Australia, sailed into Durban, and made their way to Barberton.
- Walker worked at Wilgespruit
- Harrison went to work on farm Langlaate and at weekends panned streams for gold. He identified a conglomerate and panned it
- Discovered substantial gold, was awarded a discovery claim, which was bought by diamond magnates from Kimberley.



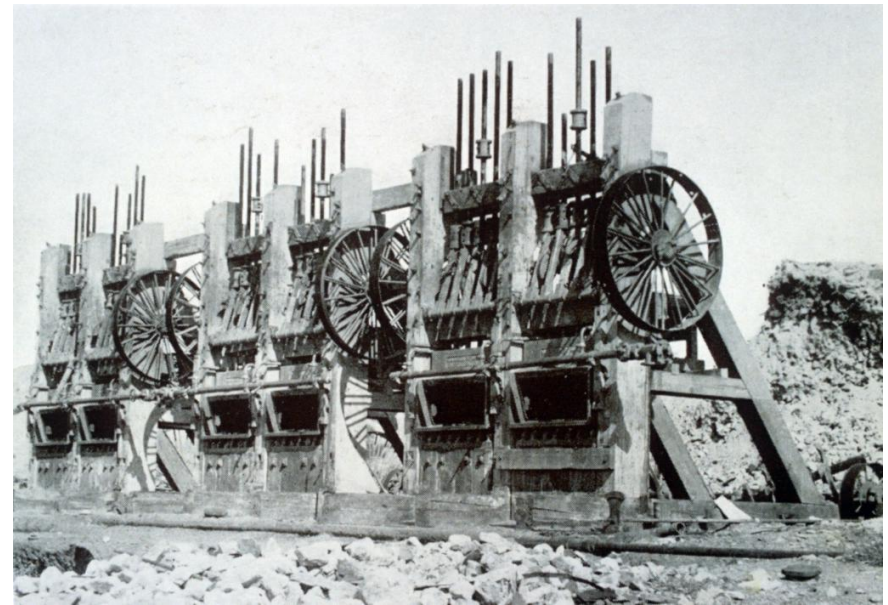
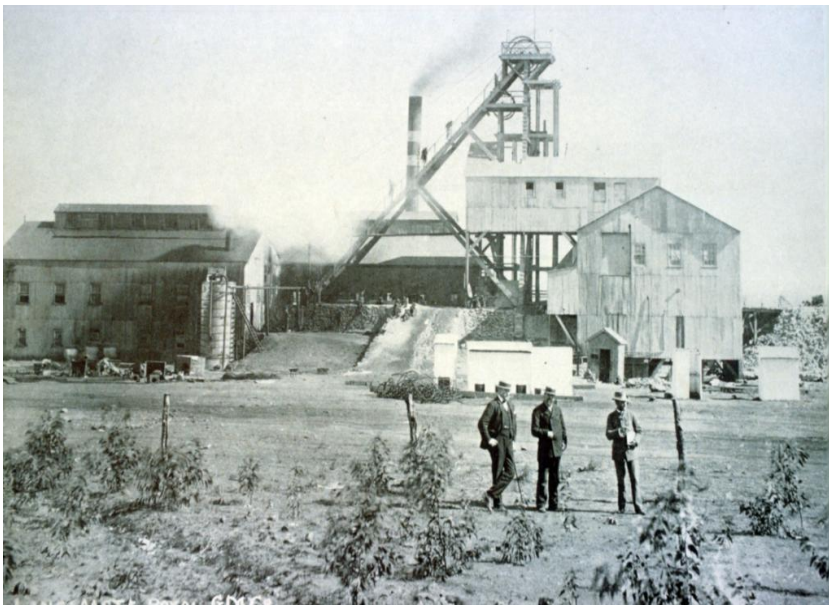


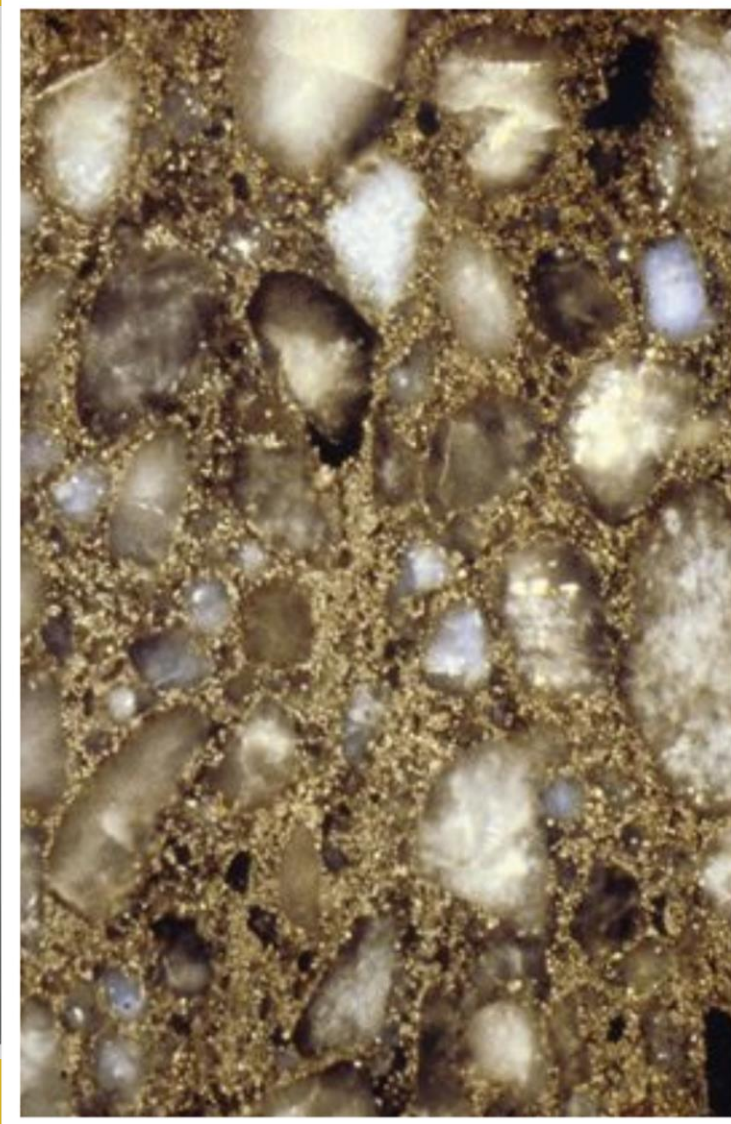
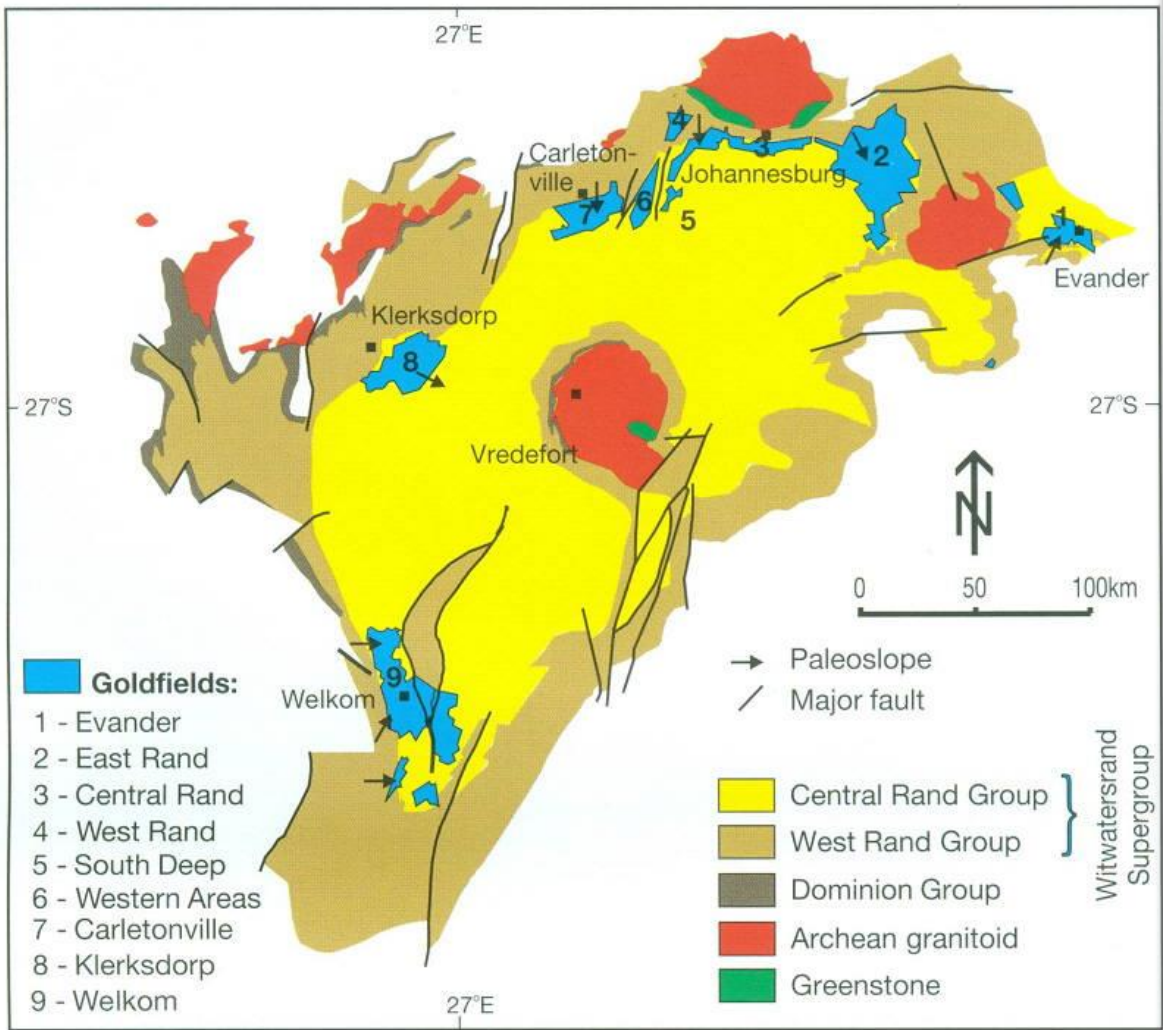
Tents and huts, Johannesburg in 1886

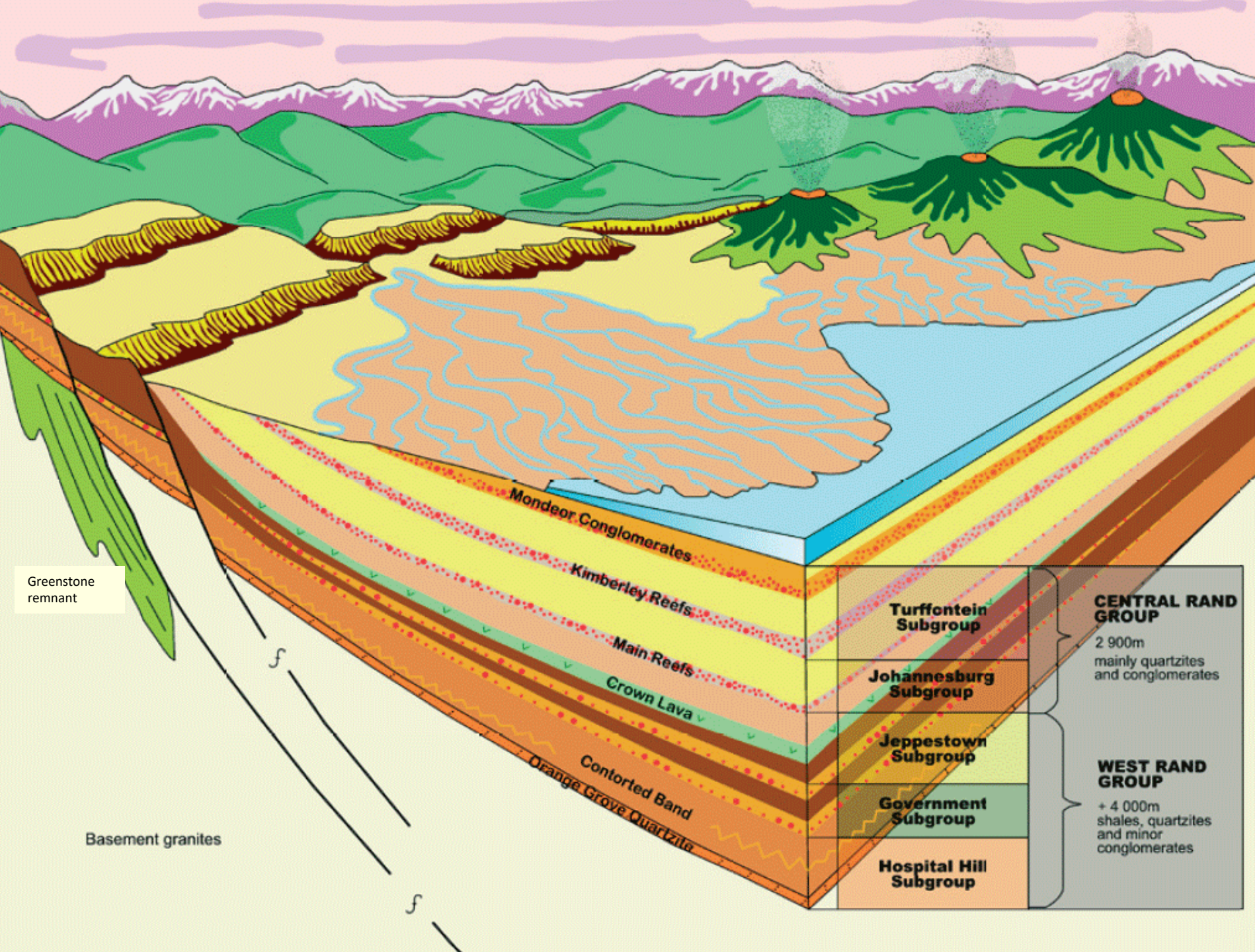


Johannesburg around
1890 Ferreira's camp

Rissik Street







Greenstone remnant

Basement granites

Mondeor Conglomerates

Kimberley Reefs

Main Reefs

Crown Lava

Contorted Band

Orange Grove Quartzite

Turffontein Subgroup

Johannesburg Subgroup

Jeppestown Subgroup

Government Subgroup

Hospital Hill Subgroup

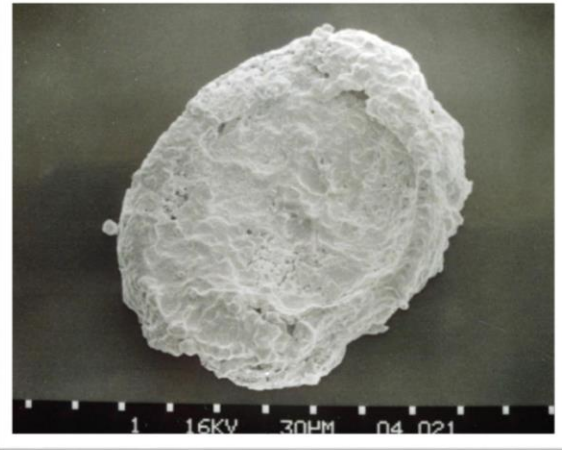
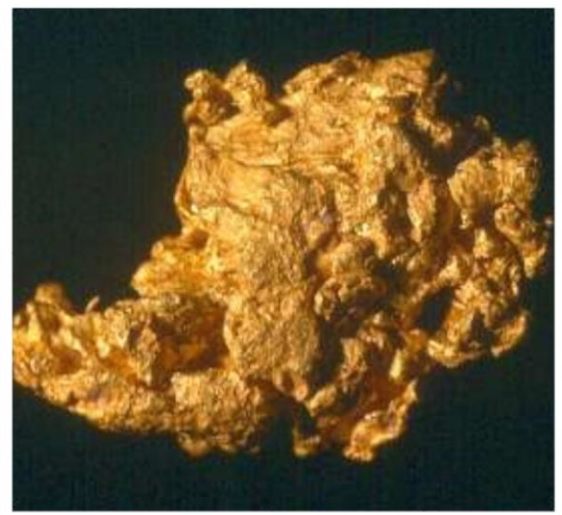
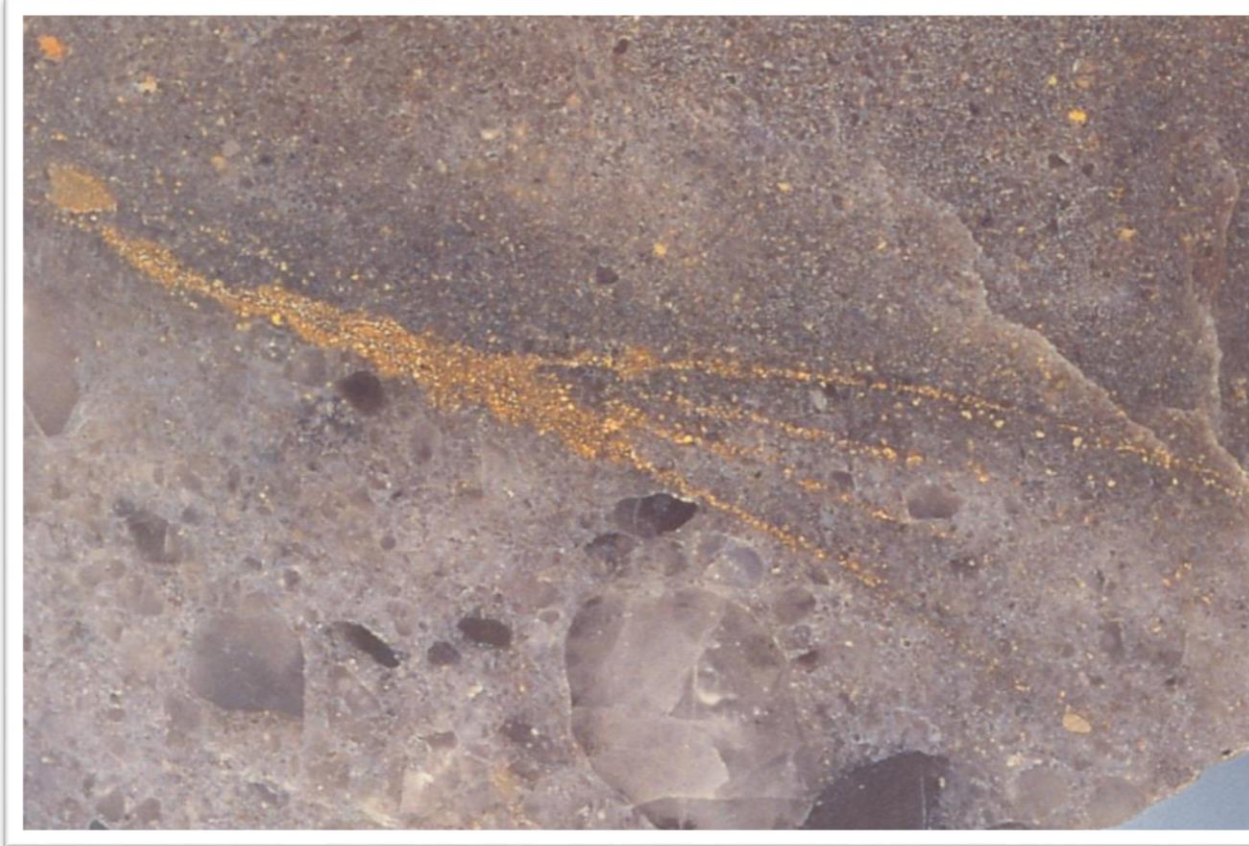
CENTRAL RAND GROUP

2 900m
mainly quartzites
and conglomerates

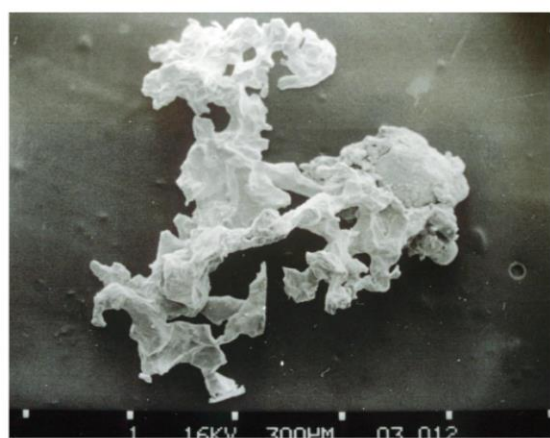
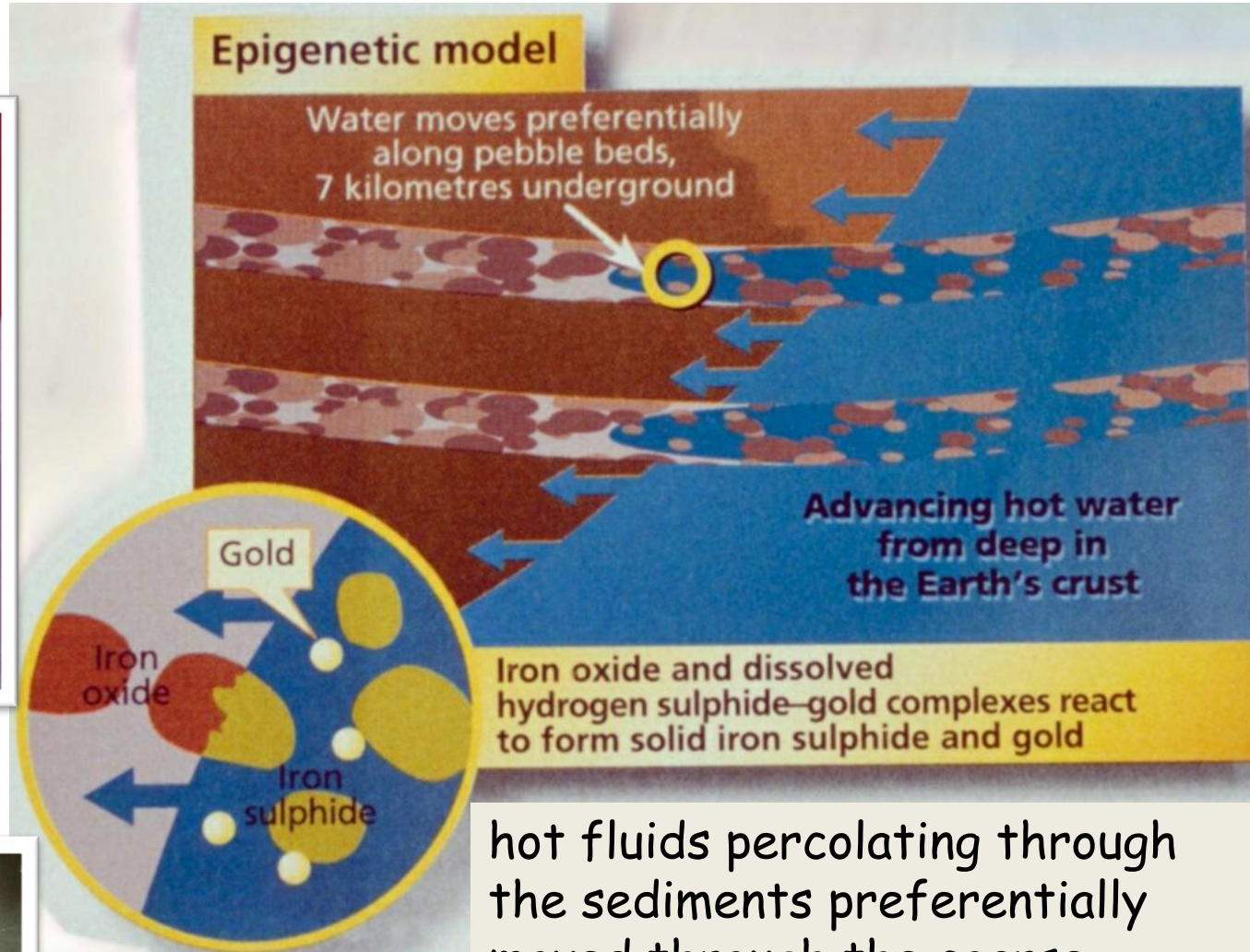
WEST RAND GROUP

+ 4 000m
shales, quartzites
and minor
conglomerates

Placer model

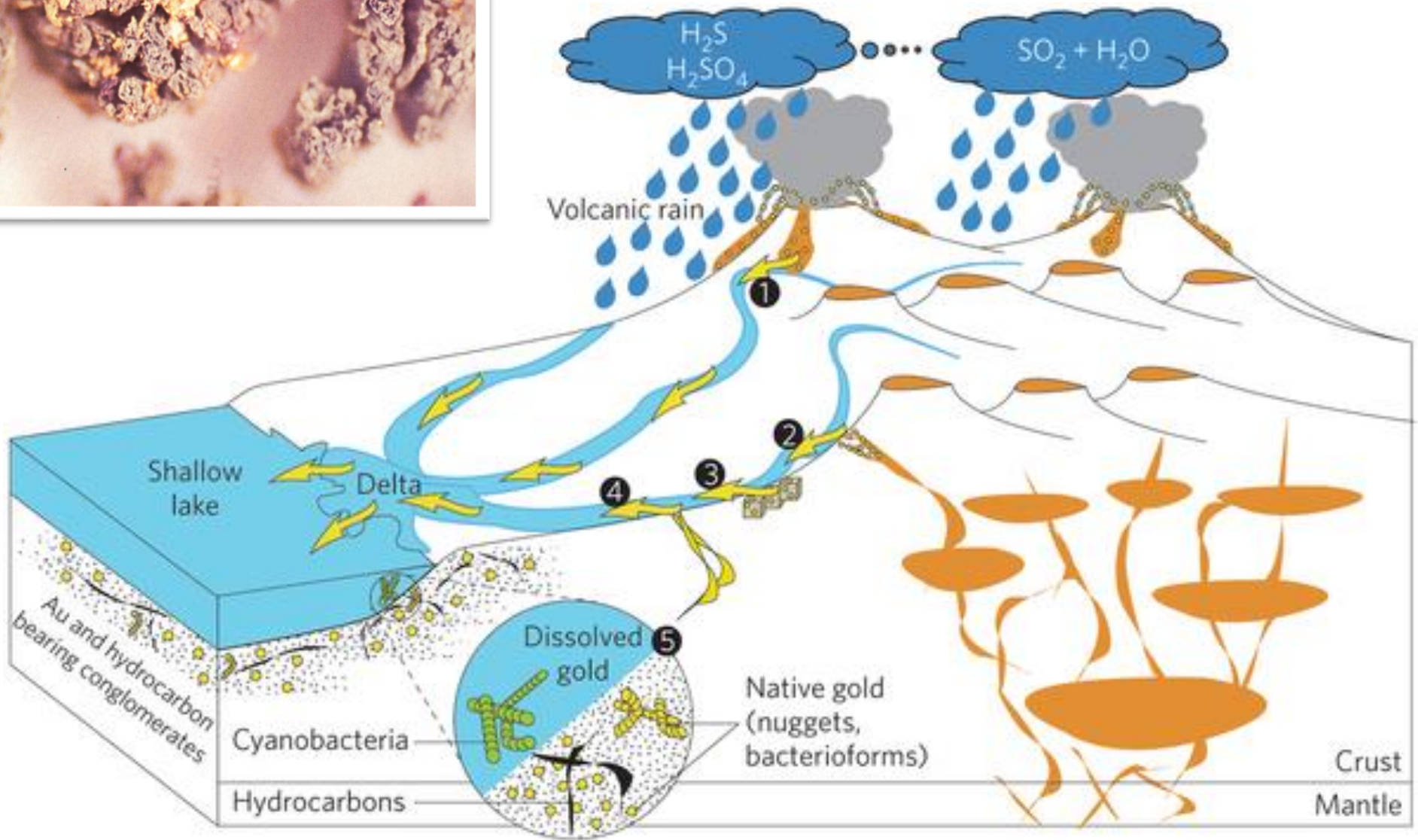


- gold concentrated in coarse sands and conglomerates
- micro-nuggets of gold, which are typical of detrital deposition. also flattened and rolled gold grains
- Both the gold and rounded pyrite are older than the sediments



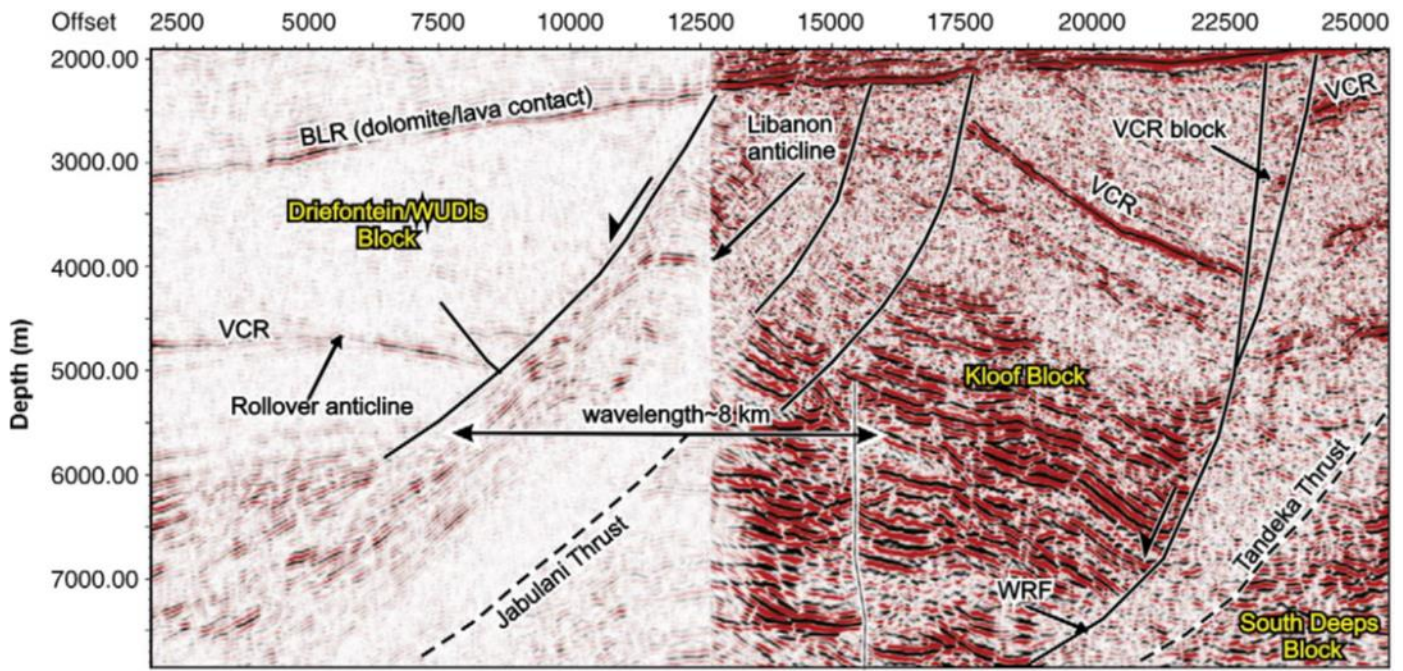
hot fluids percolating through the sediments preferentially moved through the coarse gravels to form an epigenetic gold deposit.

gold between columns of carbon (Hallbauer, 1975)





South Deep, South Africa



Manzi et al, 2013

Platinum Mine, Rustenburg



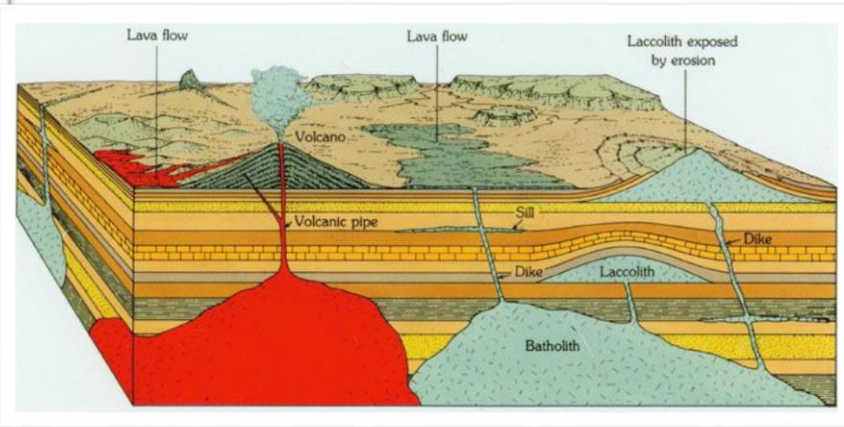
PLATINUM

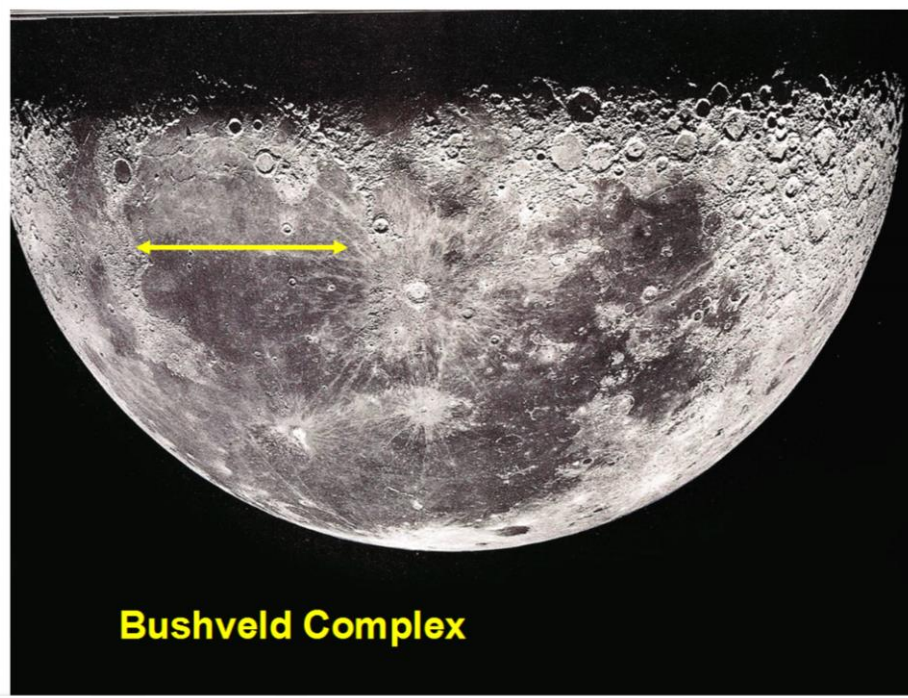
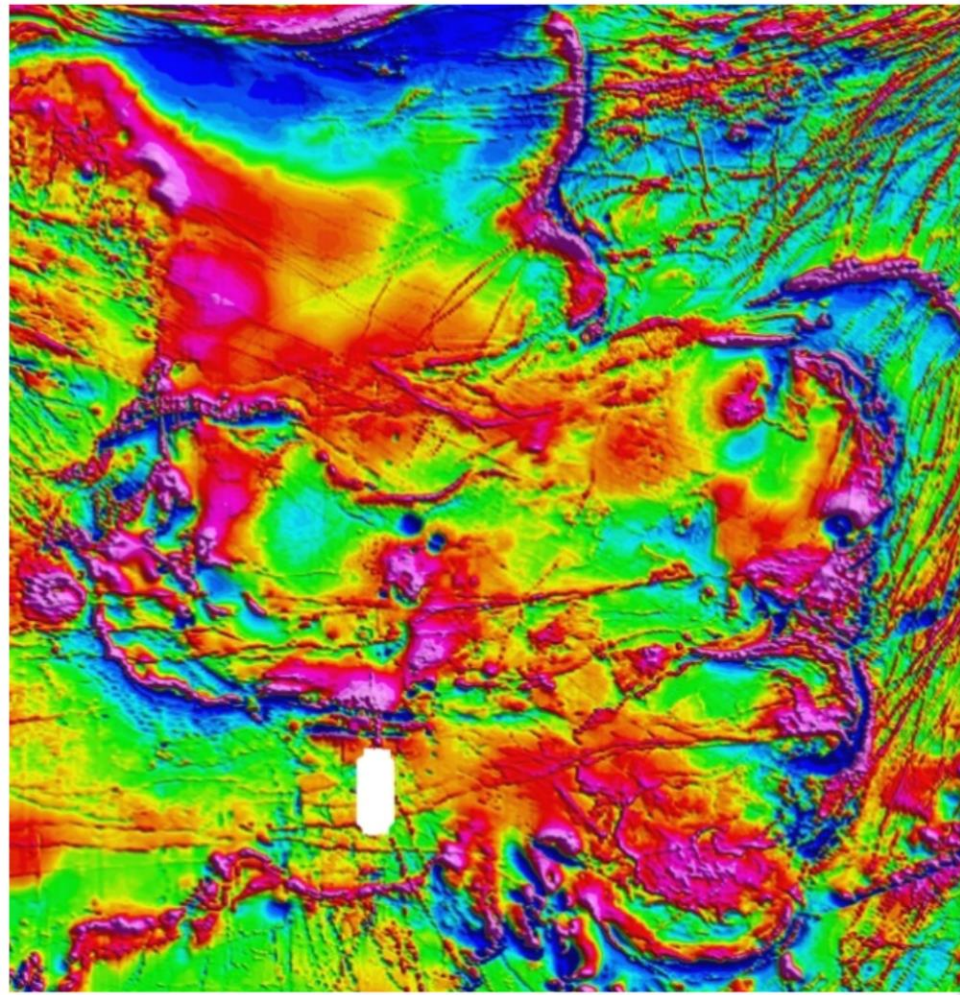




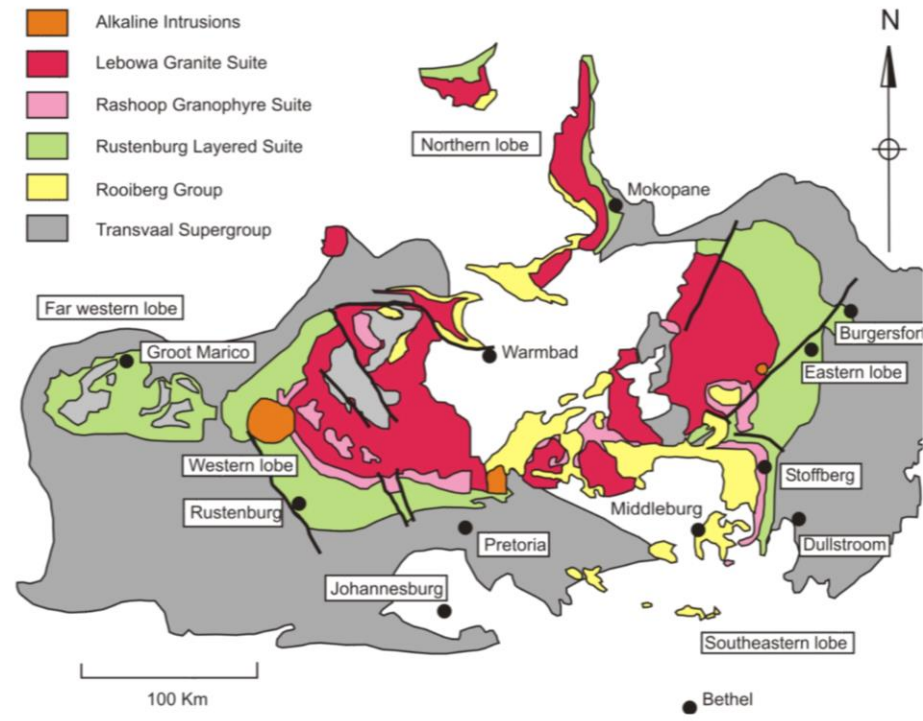
Volcanic activity in South Africa has been important in the past for making a contribution to our mineral wealth

Volcanic activity in the DRC





Bushveld Complex



RUSTENBERG LAYERED SUITE

Granites

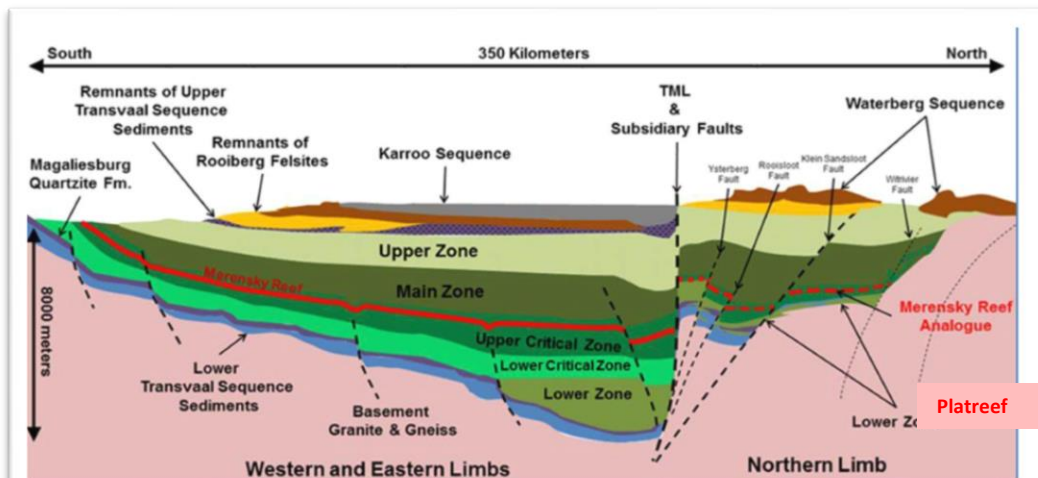
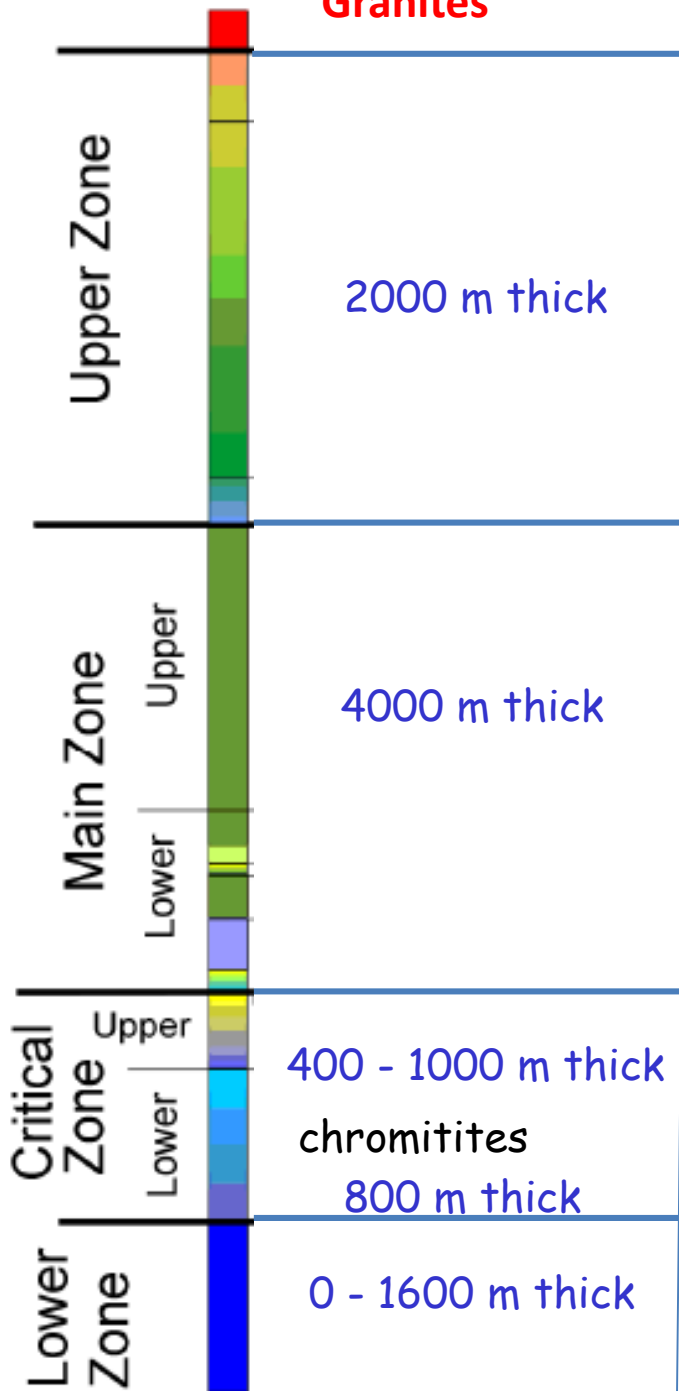
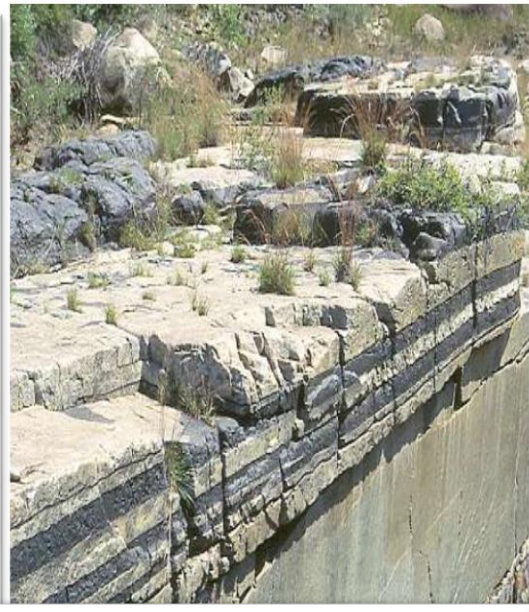
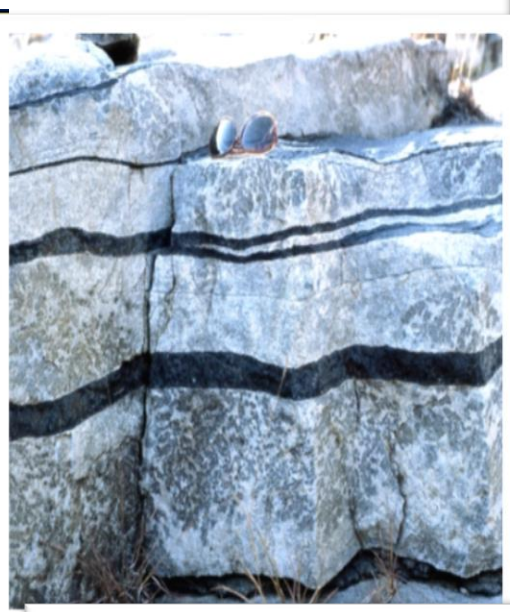
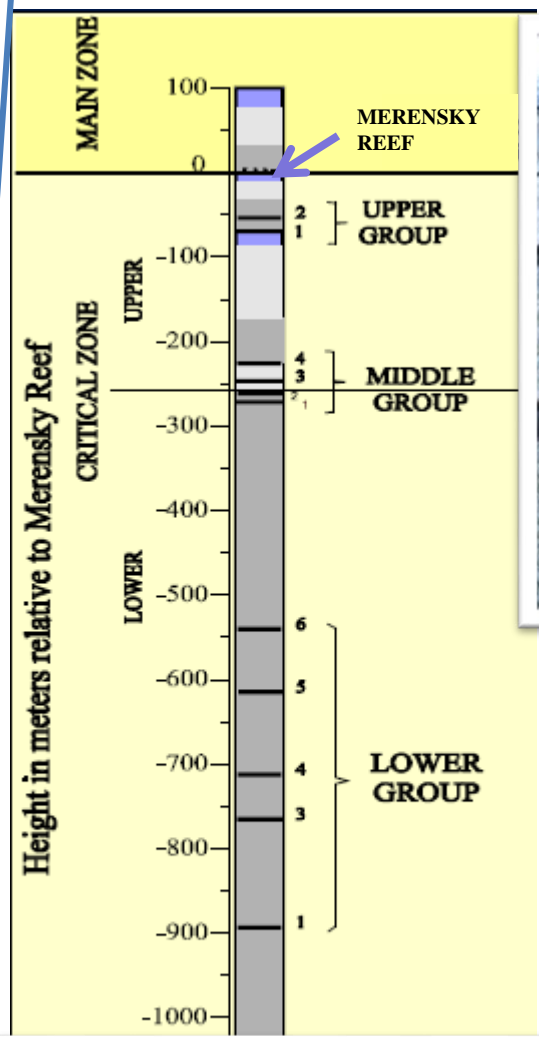
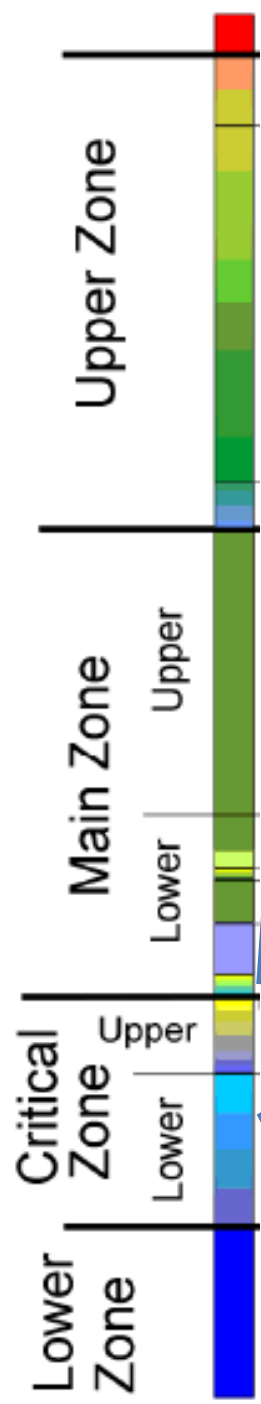


Figure courtesy Ivanhoe, 2012; modified after Kruger, 2005. Figure is schematic and not to scale. Section line illustrated is shown on Figure 7.1.





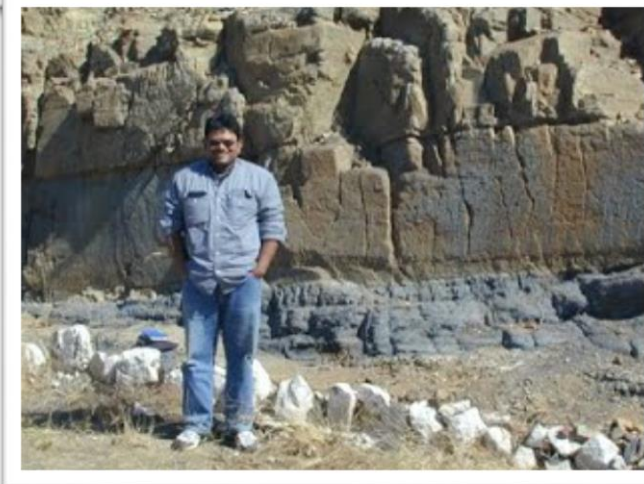
LG6 chromitite

Chromitite packages

		PGM g./t.	
		West	East
Merensky Reef		3.5-9.5	4.8-6.8
UPPER GROUP	UG2	4.8-6.5	4.5-8.0
	UG1	1.2	3.4
Anorthosite Norite			
UPPER CRITICAL ZONE	MG4A	1.2	0.9
	MG4B	1.8	2.2
	MG3	2.0-3.0	4.0
MIDDLE GROUP	MG2	1.4-2.7	5.5
	MG1	1.5	2.1
Pyroxenite			
LOWER CRITICAL ZONE	LG7	0.2	
	LG6A	1.1	
	LG6	1.0	2.1
	LG5	1.5	1.7
	LG4	0.3	
	LG3	0.3-0.8	
	LG2	0.2-1.1	
	LG1	0.3-0.4	
LOWER GROUP			

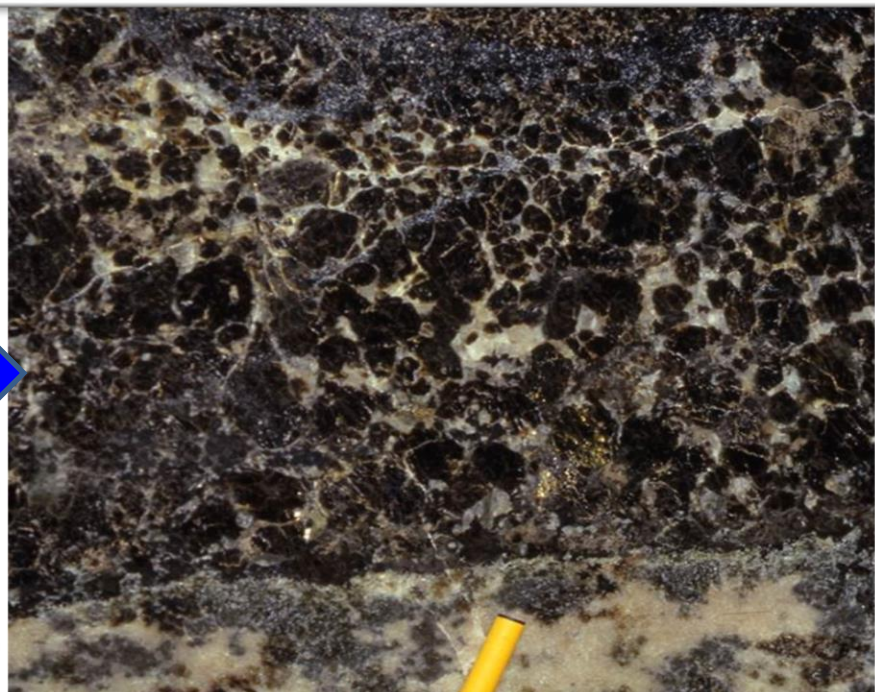
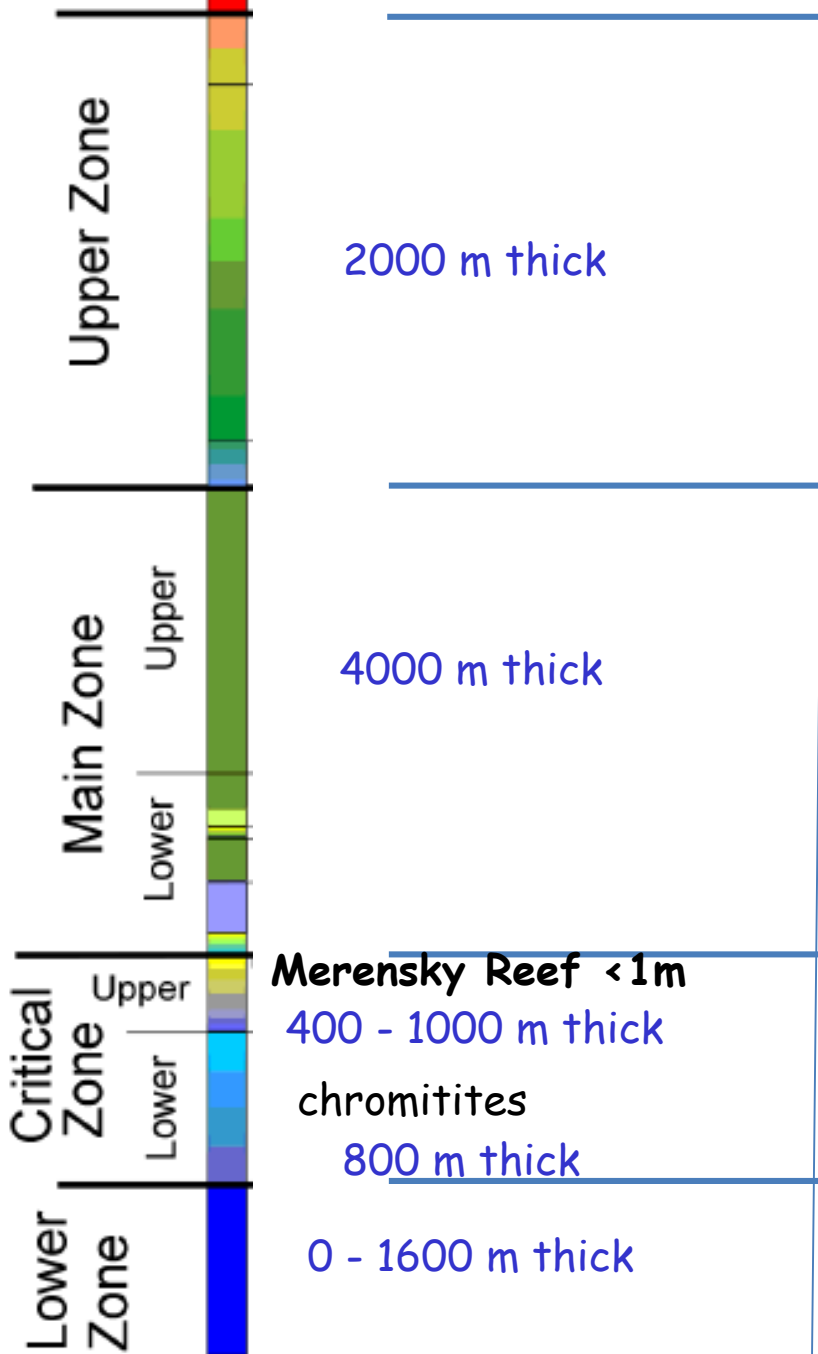


UG2



- Chromitite layers occur in 3 groups
- Upper Group UG 1-2
- Middle Group MG 1-4
- Lower Group LG 1-7
- Note the enrichment of PGE

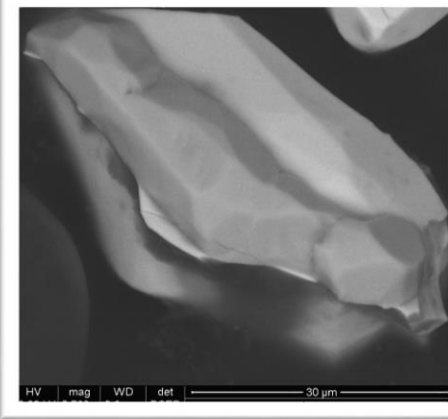
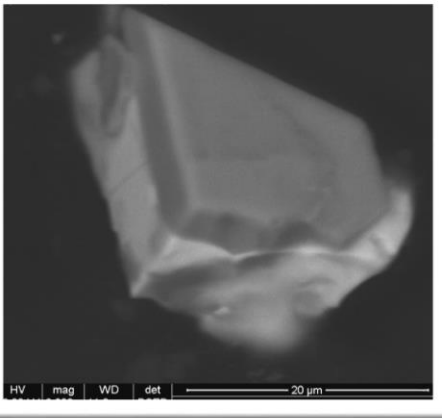
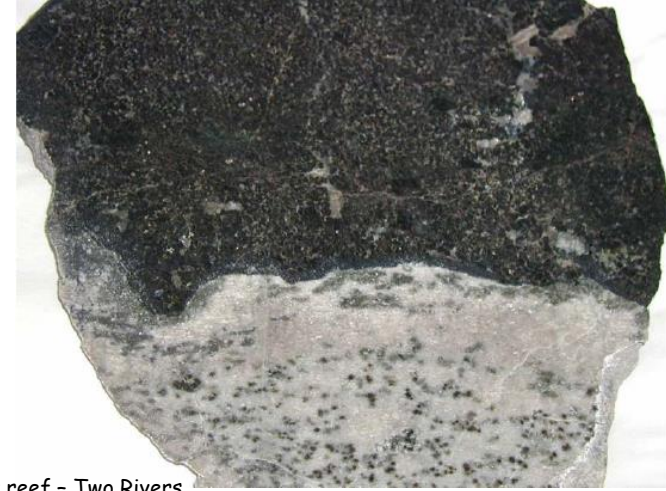
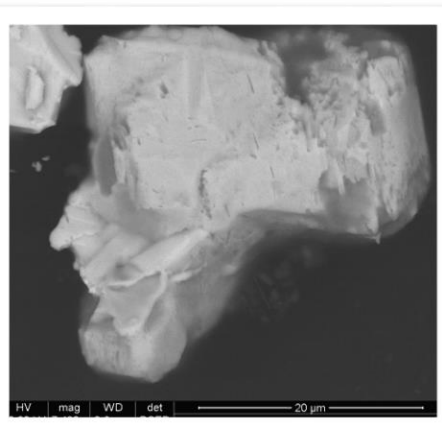
Granites



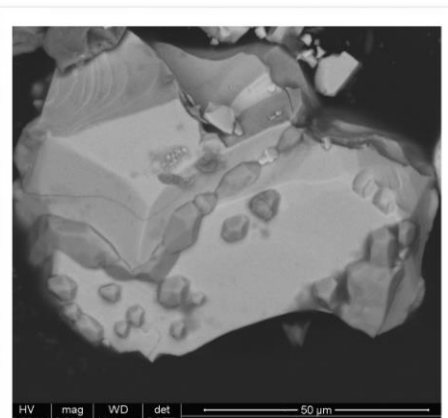
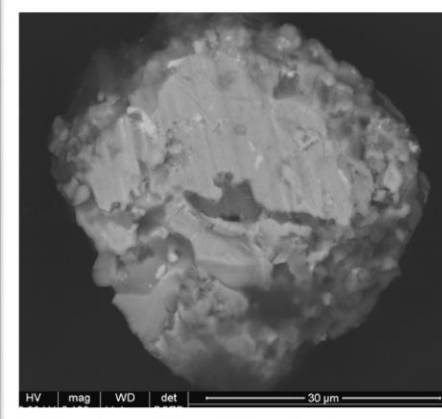
Merensky pyroxenite from Two Rivers illustrating the upper chromitite stringer

Merensky Reef Mine



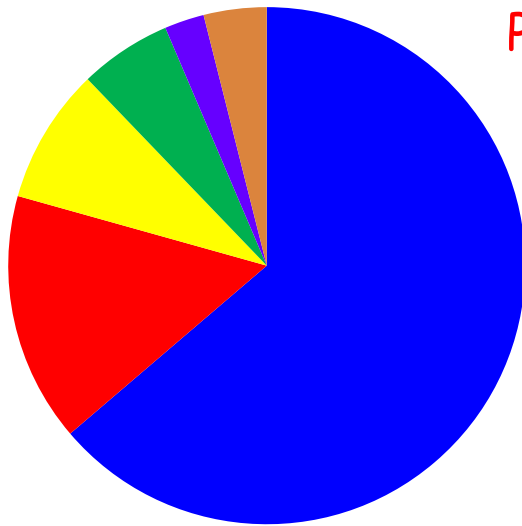


PGM's have been produced from the Merensky Reef since 1926 - typically around 1 m thick, shallow dipping tabular layers with 5-8g/t PGE+Au.



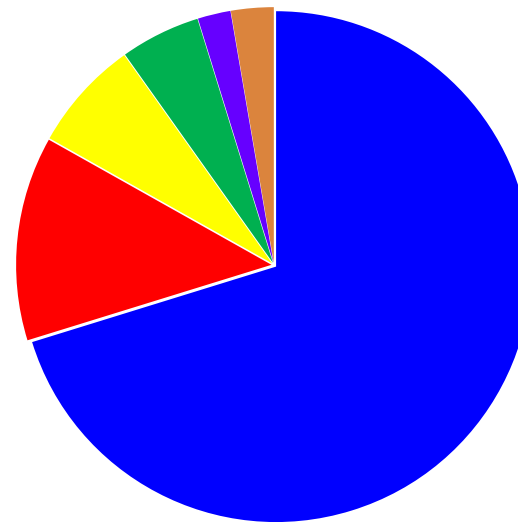
PRODUCTION

Platinum 2014



- South Africa
- Russia
- Zimbabwe
- Canada
- United States
- Other

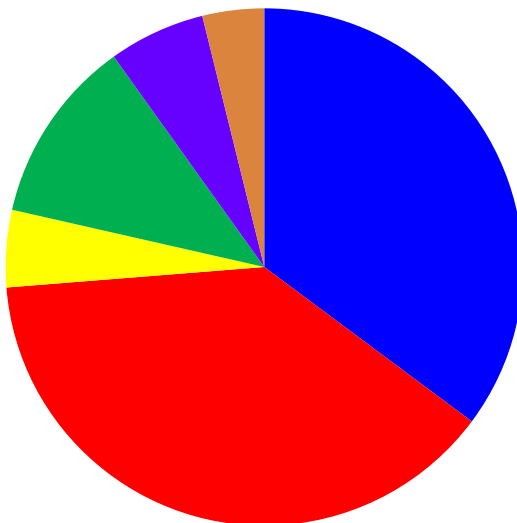
Platinum 2015



- South Africa
- Russia
- Zimbabwe
- Canada

6076 000 oz

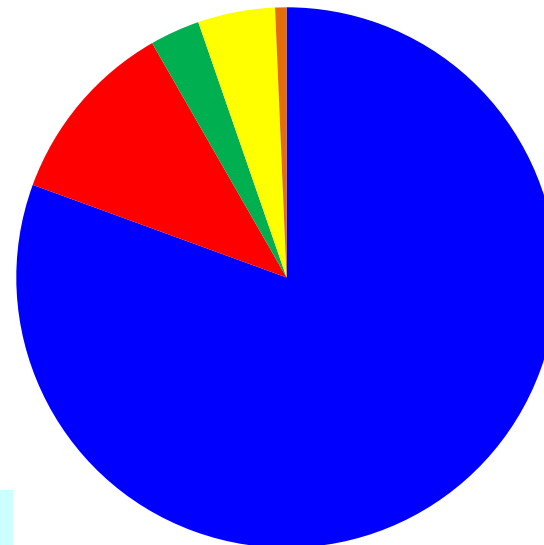
Palladium 2015



- South Africa
- Russia
- Zimbabwe
- Canada
- United States
- Other

6426 000 oz

Rhodium 2015



- South Africa
- Russia
- North America
- Zimbabwe
- Others

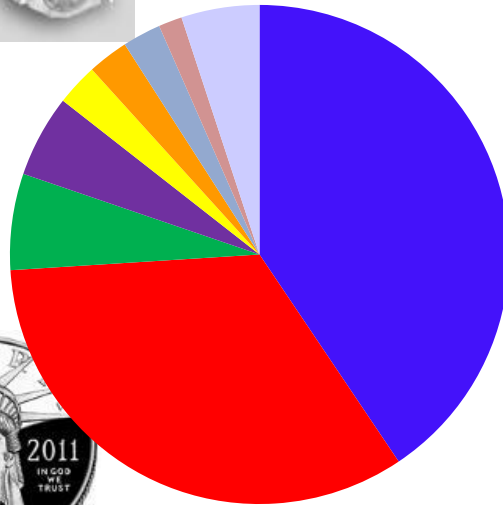
754 000 oz

Uses of platinum and palladium 2015

Johnson Matthey, May 2016

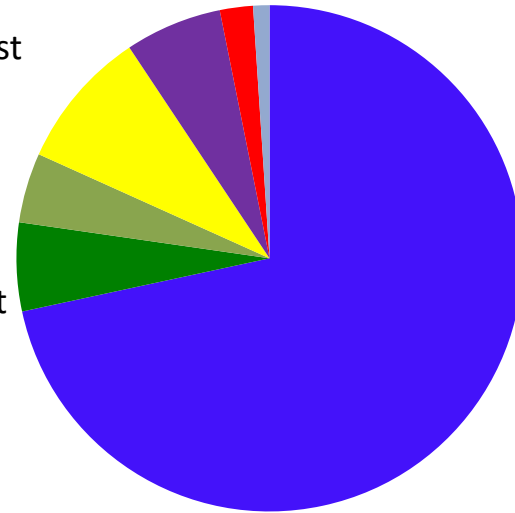


PLATINUM



- autocatalyst
- jewellery
- chemical
- investment
- electrical
- glass

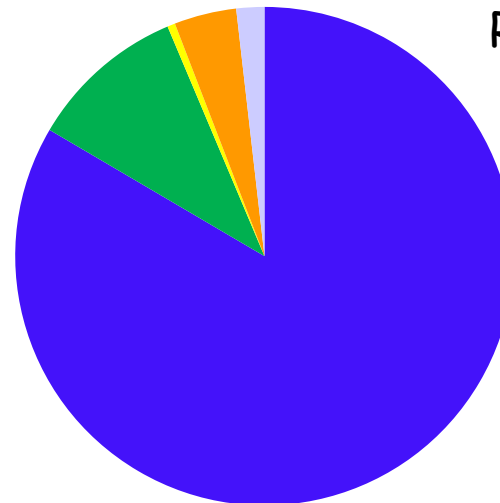
PALLADIUM



- autocatalyst
- chemical
- dental
- electrical
- investment
- jewellery
- other



RHODIUM

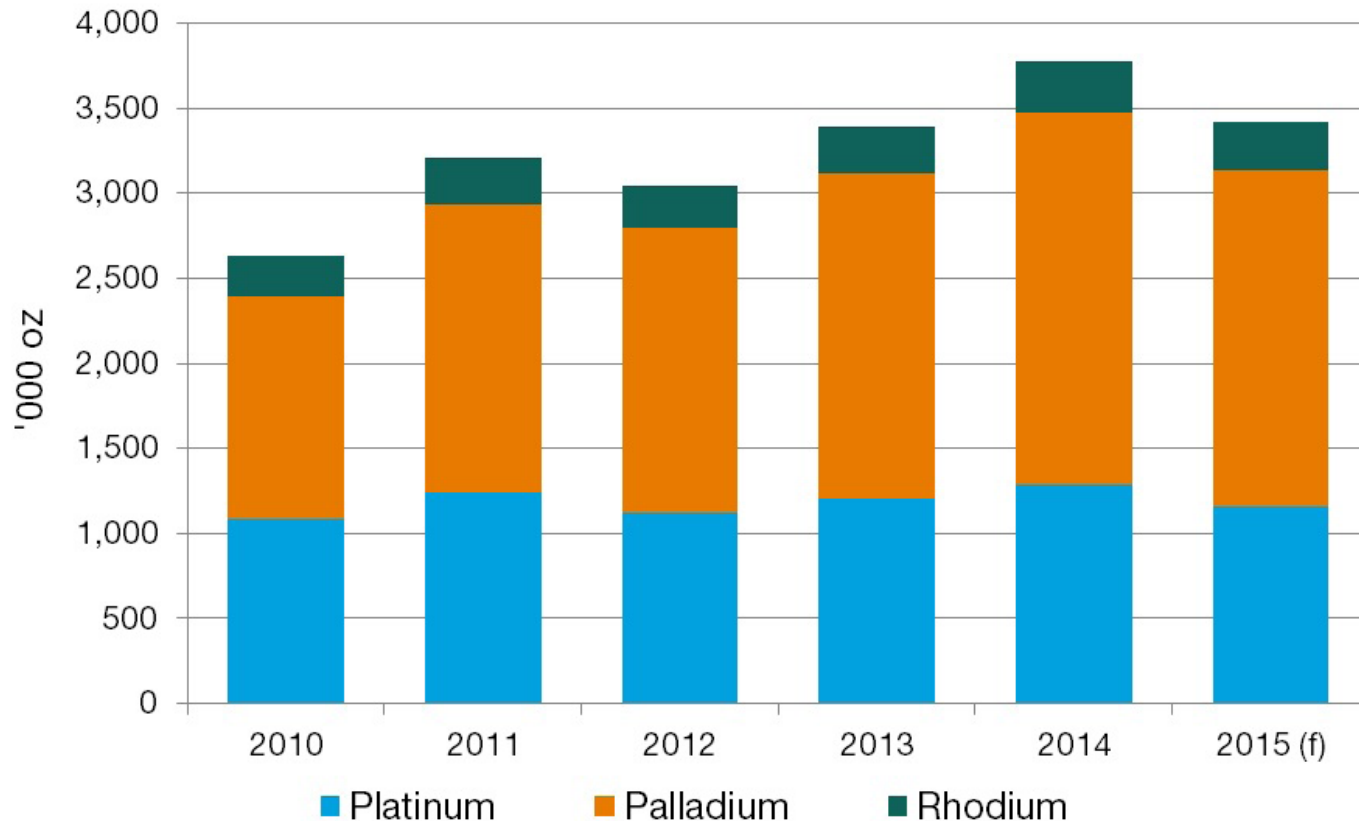


- autocatalyst
- chemical
- electrical
- glass
- other

Recycling

Johnson Matthey

Autocatalyst recovery by metal

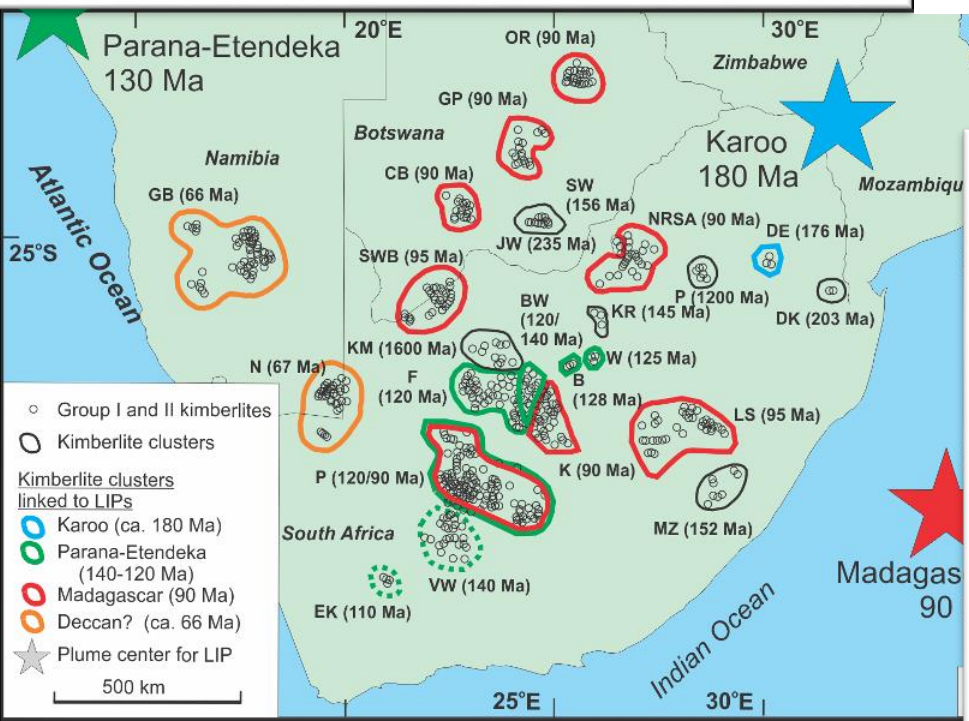
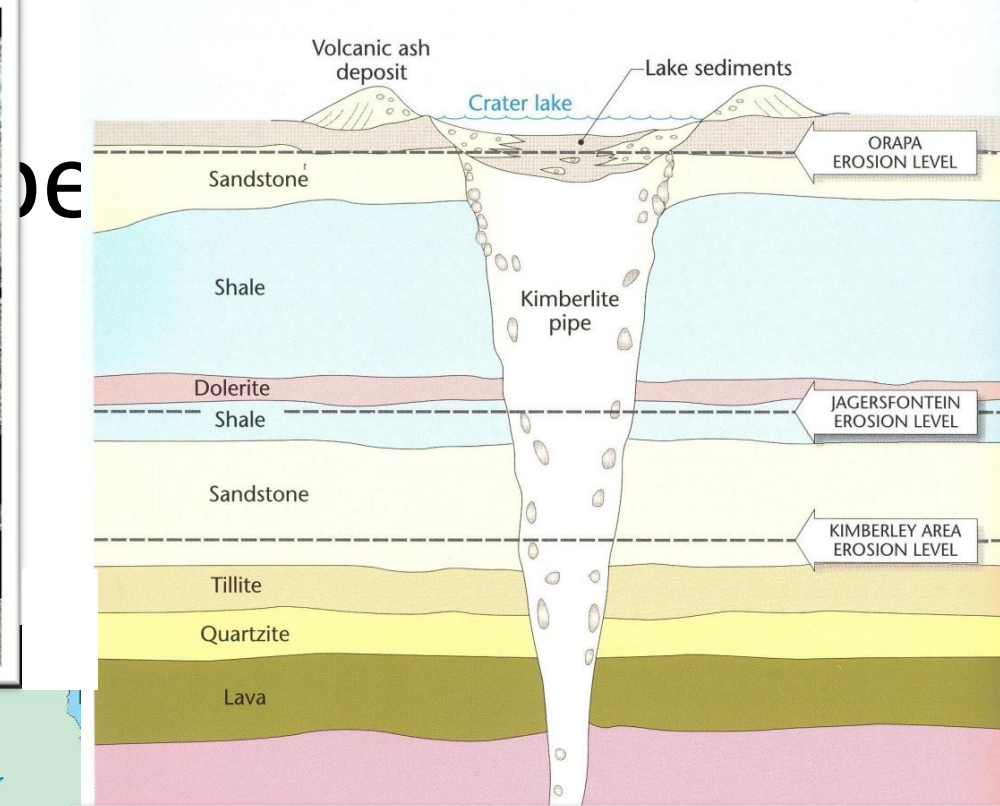


- An estimated 125,000 kg of platinum, palladium, and rhodium was recovered globally from new and old scrap in 2015, including about 55,000 kg from automobile catalytic converters in the United States.
- Johnson Matthey expected significant re-processing of catalytic converters in 2015, but this hasn't happened - possibly due to the downturn in Pt price.

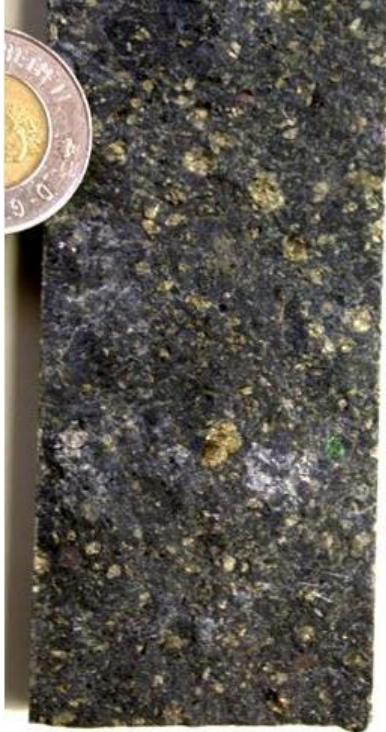


DIAMONDS





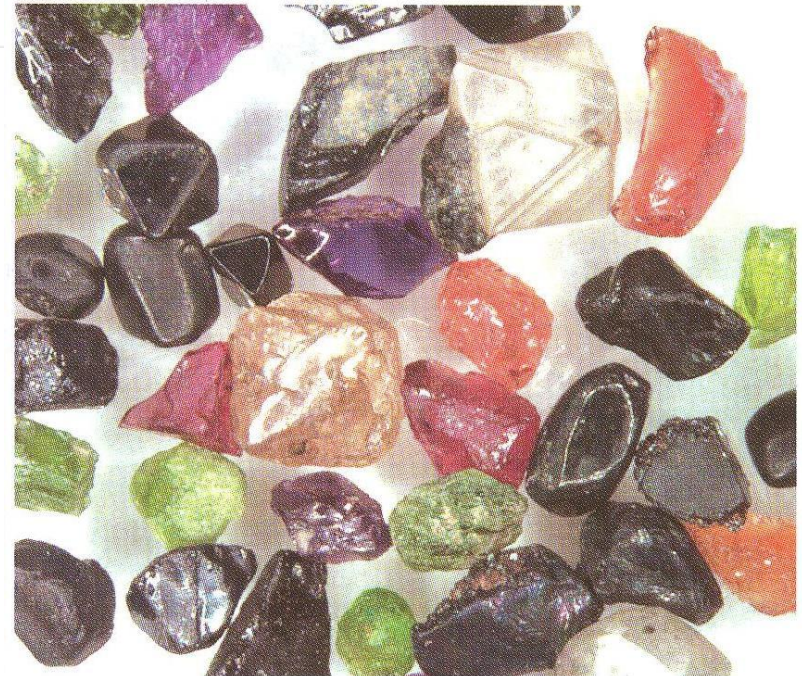
Kimberlites in hand specimen

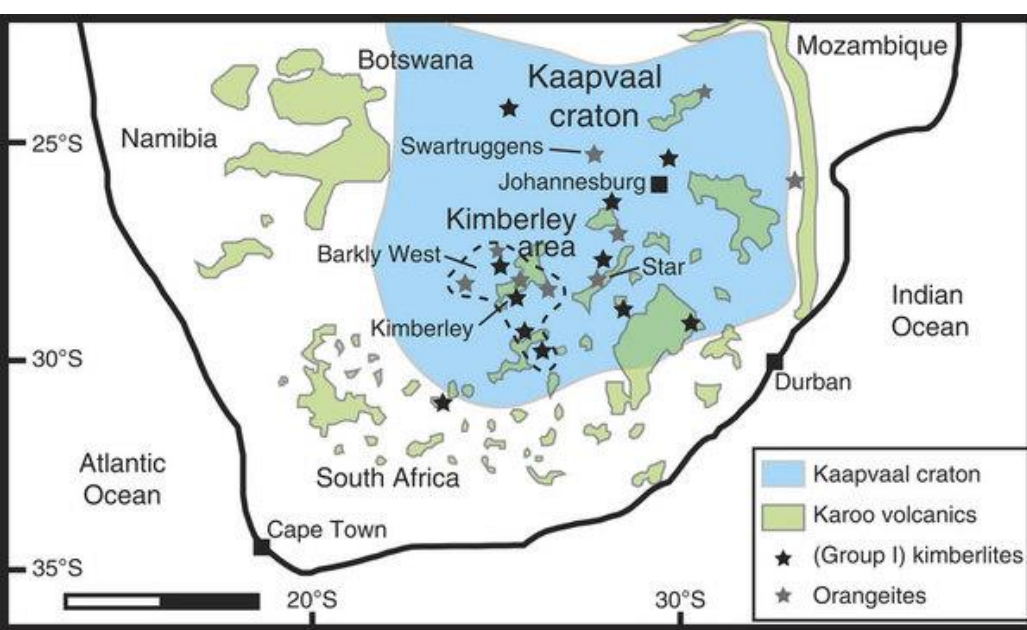


minor phases

- Minor phases include rutile, magnetite, perovskite, armalcolite (Mg,Fe^{2+}) Ti_2O_5 , pyrite, chalcopyrite, heazlewoodite (Ni_3S_2) and native metals
- indicator minerals during prospecting are magnesian ilmenite, pyrope garnet, chrome diopside (and diamond)
- all are very hard and survive river transport

KIMBERLITE INDICATOR MINERALS

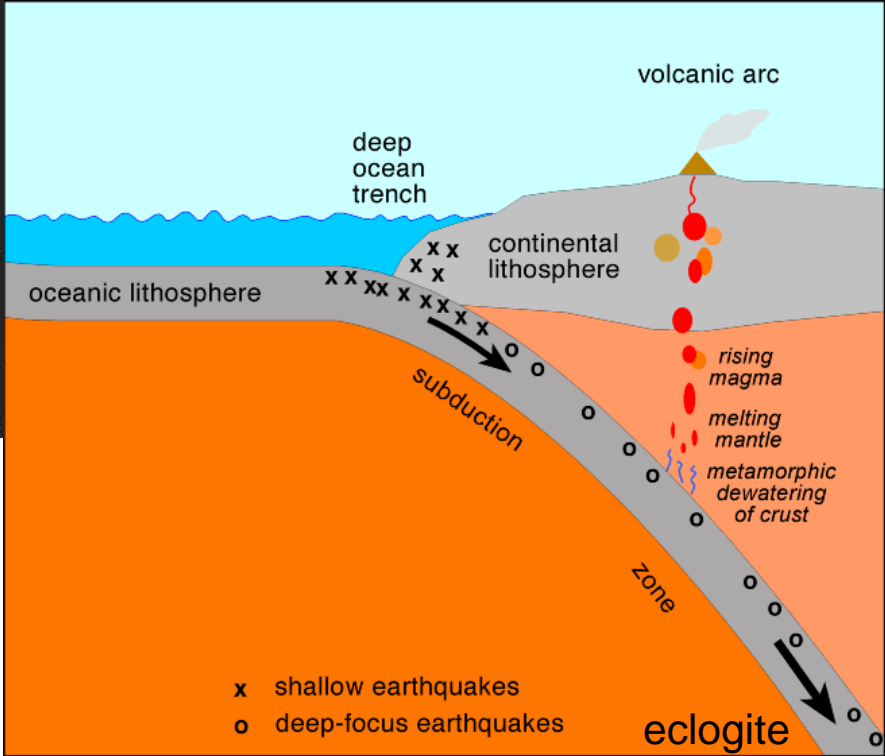




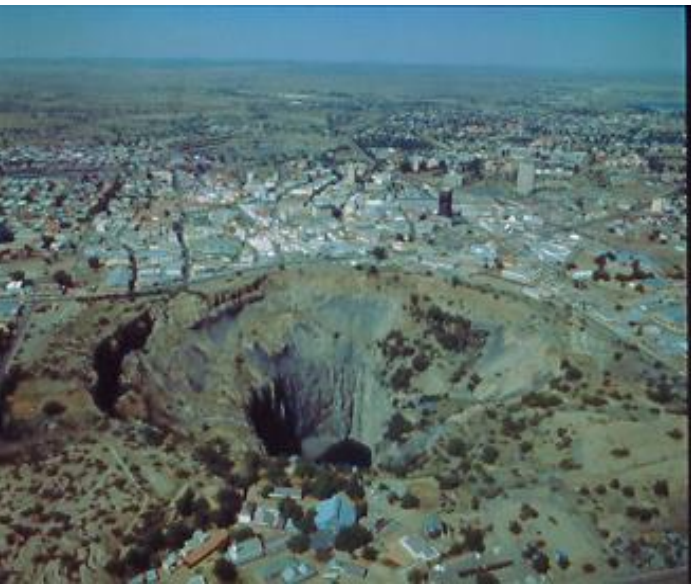
850 kimberlites in SA
Only 50 have diamonds

Kimberlites erupted at different times:
1800 Ma at Kuruman, 1200 Ma at Cullinan,
560-520 at Alldays, 250-200 Jwaneng,
110-100 Ma - major period

Why is South Africa so diamondiferous?



- Diamonds - made of carbon - are the hardest mineral but not the toughest.
- Carbon has two main isotopes ^{12}C and ^{13}C
- Organic carbon in plants fixes ^{12}C
- Inorganic carbon from the mantle has more ^{13}C
- Diamonds fall into two groups i) with primordial mantle ^{13}C ii) with biogenic ^{12}C
- Diamonds with biogenic ^{12}C derived C from organisms on the basaltic ocean floor that was subducted into the mantle, where eclogite and diamonds were formed



Kimberley

April 1874



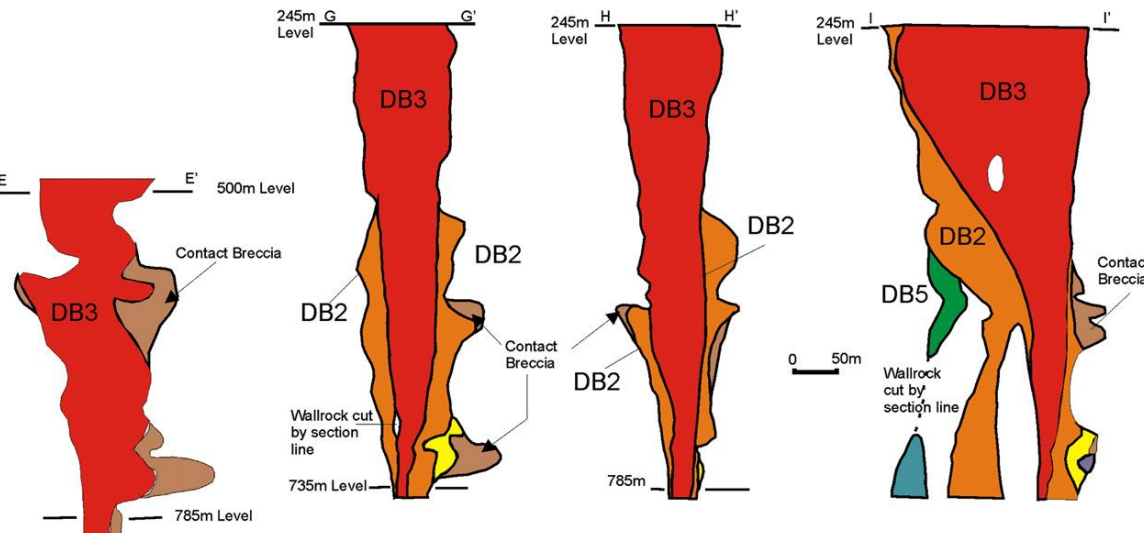
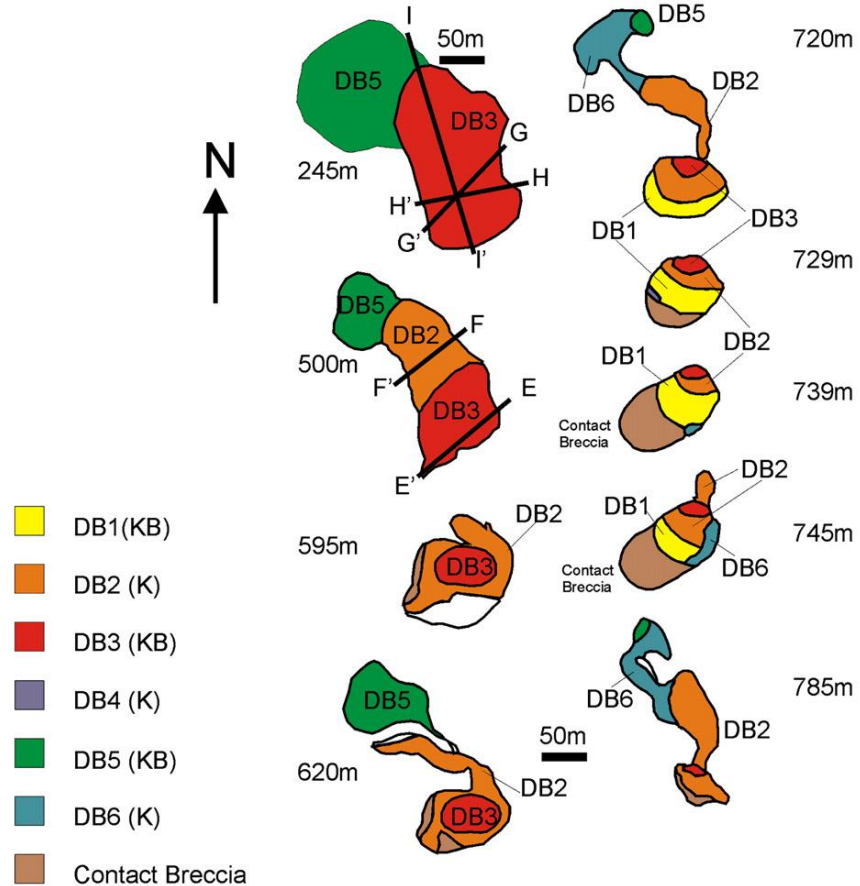
- discovered in 1871, one of the oldest diamond mines in SA
- became de Beers mines in 1888
- Had the mine on care and maintenance since 2007 and built up a stockpile of 500 000 T, estimated to contain 90 000 carats of diamonds
- In 2012 Petra made US\$ 19.8 M from sale of 61 895 carats from 587 065T of rock mined



1895

De Beers pipe, Kimberley

- A number of different kimberlites might use the same conduit
- Not all will be diamondiferous
- Diamonds are divided into P types - derived from peridotite and E-type derived from eclogite
- Most mines are exploiting diatreme although some dykes or 'blows' are economic

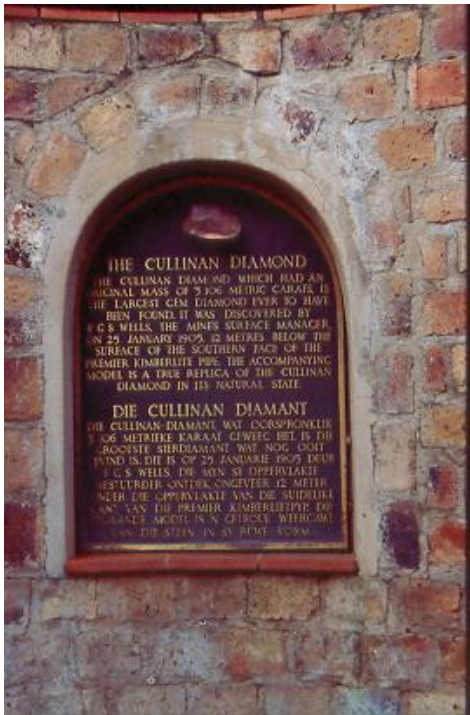
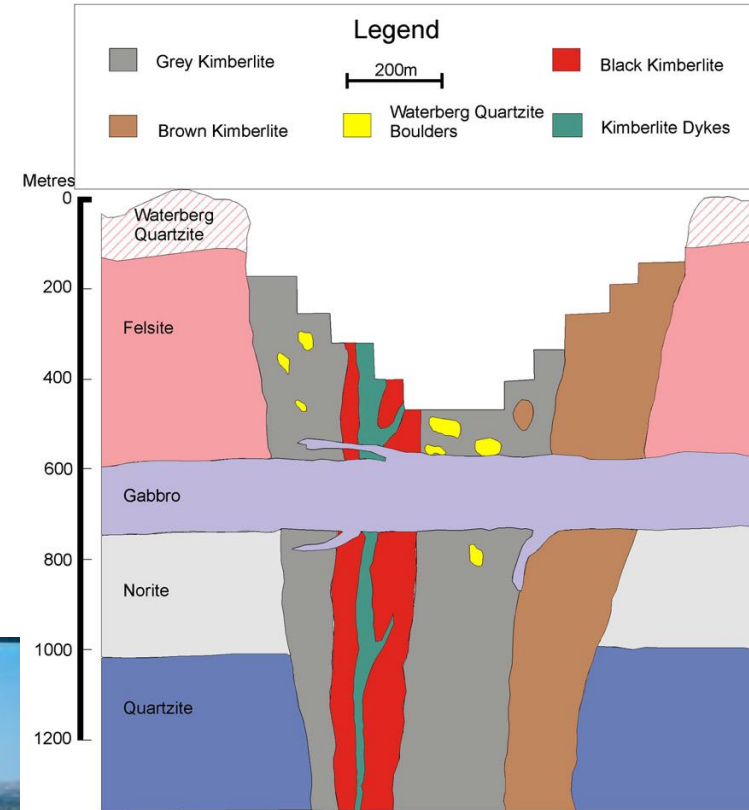
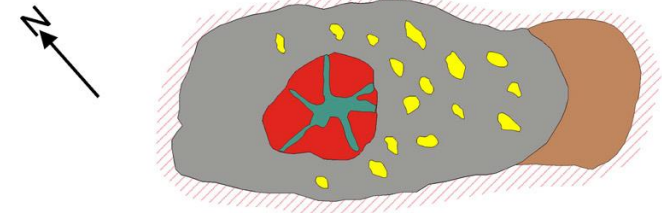


After Clement and Skinner, 1979, 1985

Cullinan - Premier pipe

- One of the major pipes in SA
- one of 11 pipes in the area
- unusual as it intruded 1200 Ma ago
- 3 major kimberlite types in pipe
- mining began in 1903; still a major producer

The Generalized Geology of Premier Mine



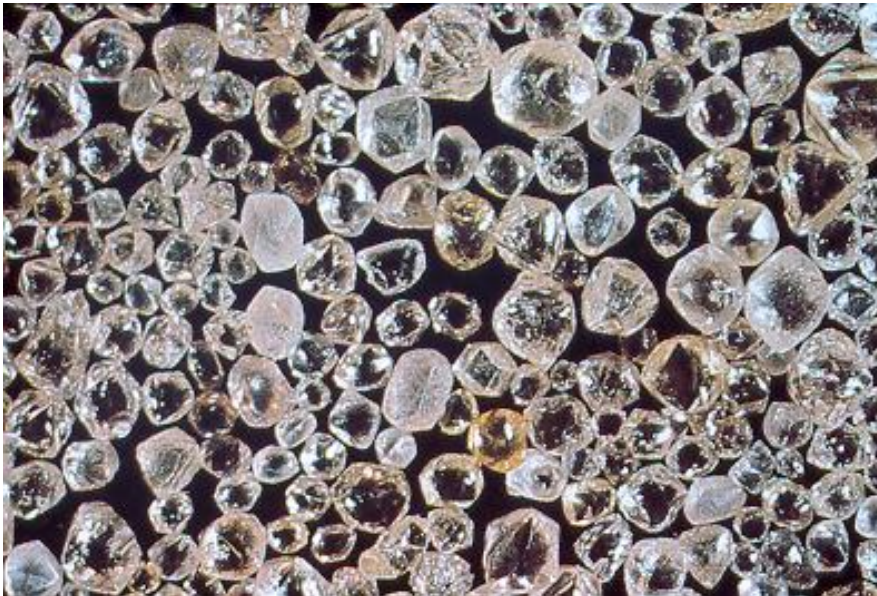
From Bartlett, 1998

- 1905 - produced the 3 106 ct Cullinan diamond which was cut into 9 main stones + numerous smaller stones
- also has produced more diamonds larger than 100 ct than any other mine (>300)
- 20 - 30% are gems, the rest are near gems or industrial
- diamond inclusions have been dated at 1200, 1900 and 3200 Ma - intrusion was 1200 Ma



168ct white diamond found in Sept 09 by Petra Diamonds sold in Nov09 for \$6,28-million

- Typical diamond grades in economic kimberlites are 10 to 100 carats per 100 tonnes
(1 carat = 200 mg or 0.2 of a gram).
- This grade includes both gem quality and industrial stones and the value per carat varies widely between deposits



Oct 2006 - the Lesotho Promise, 603 ct stone is 15th biggest sold for US\$ 12.37m = R150 m



478ct Light of Letšeng - 20th largest diamond - sold for US\$ 18.4 m



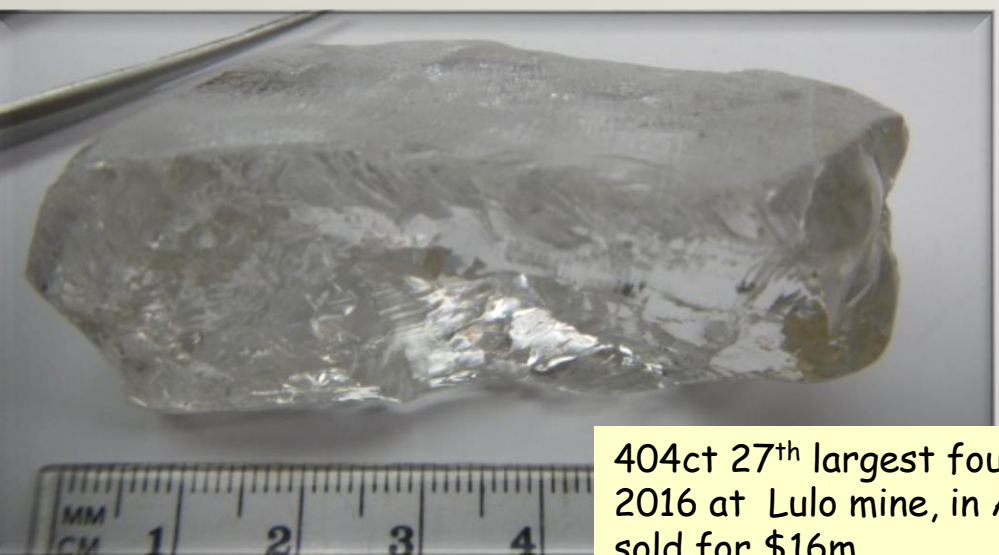
SCIENCEPHOTOLIBRARY

Cullinan diamond 3106 ct

168ct white found by Petra at Cullinan sold in Nov 09 for \$6.28 million



Letseng Legacy - 493ct, found in 2007 18th largest stone - sold for US\$10



404ct 27th largest found Feb 2016 at Lulo mine, in Angola sold for \$16m.



Cullinan diamond found in Jan 1905, cut into 9 major stones, now in the Crown Jewels

