

# Miraculous Touch of Gold- Inventory, Exploration & Investment Geology and Gold Mineralisation in the Agnew Mining Camp, WA

**Vladimir David**



Liberty



Delirium and madness



Slavery



# Gold Mining – magic rush

## Magic Greed for Yellow Metal - Serra Pelada Gold Rush



Serra Pelada Gold Rush, Brazil, deposit discovered 1979; until 1980 40 - 100 tons of Au hand mined by 70,000 garimpeiros;

photo taken by Sebastião Salgado



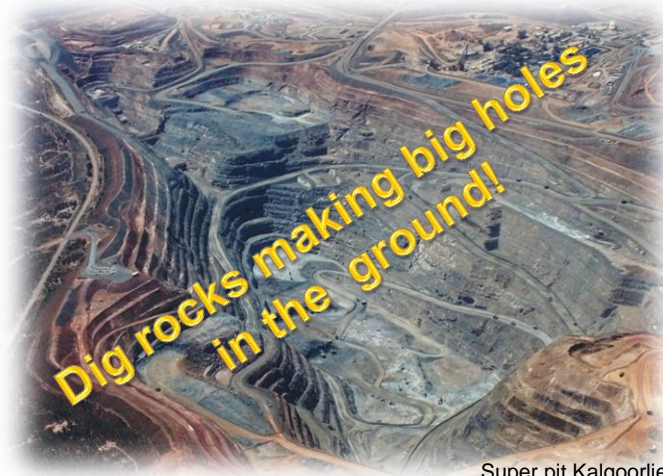
# How to get gold ?

What we are doing today to get Gold ?



**Drill hole deep holes into ground!**

Agnew Mine surface drilling



**Dig rocks making big holes in the ground!**

Super pit Kalgoorlie



**Bore the tunnels to mine the rocks!**

Agnew underground development



**Mill and dissolve the rocks!**

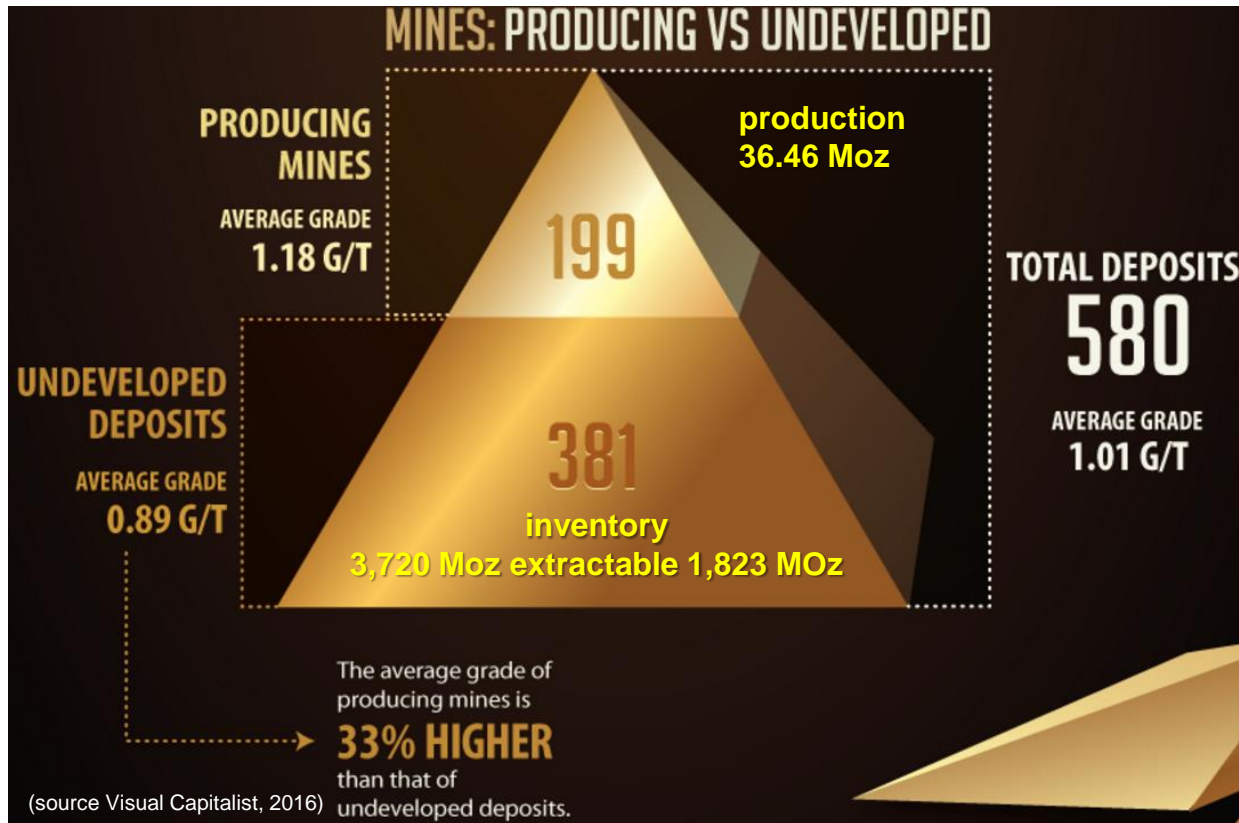
Kupol, Processing plant

**Melt rocks to get gold!**



# How much Gold is there?

## Resources and Production



- Number of gold deposits 580 – containing 3,758 MOz Au with an average grade @ 1.01 g/t Au;
- Number of mines 199 – producing 36.5 MOz Au with an average grade @ 1.18 g/t Au;
- Number of gold deposits 381 – containing 3,720 MOz Au (extractable 50%) @ 0.89 g/t Au;
- There are still 50 years of resources for gold mining with today's production rate;
- But – the remaining resources have a 33% lower grade @ 0.89 g/t Au.

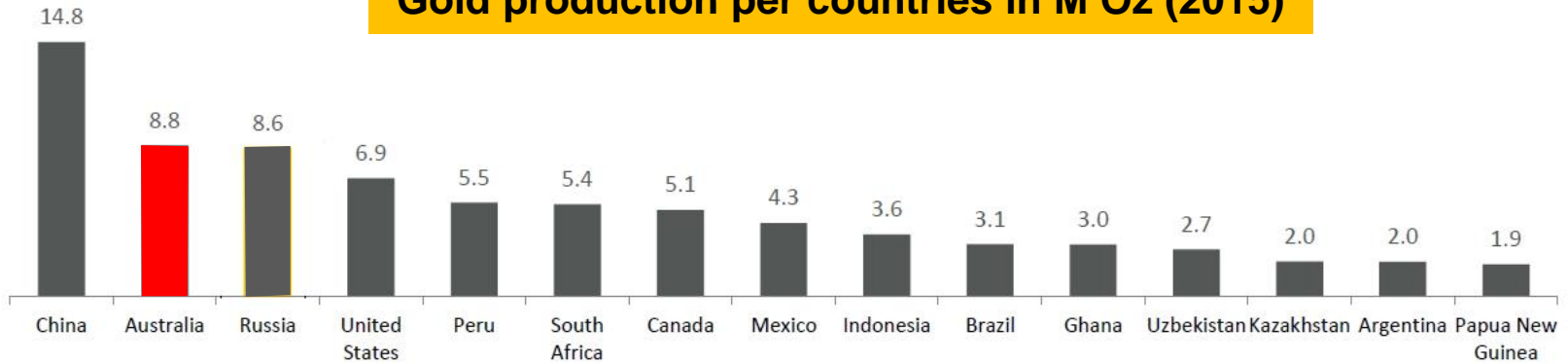
Data includes reported production and resources. Data for China are estimated.



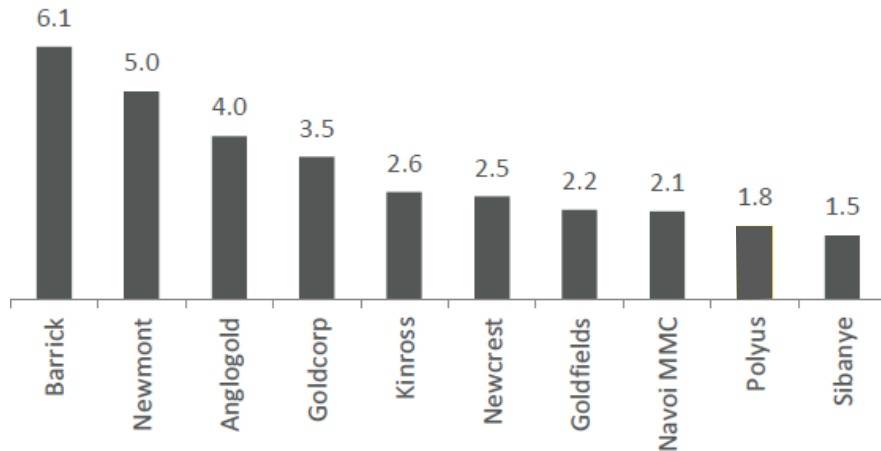
# World Gold Production

## Gold Production & Resources - Countries and Companies

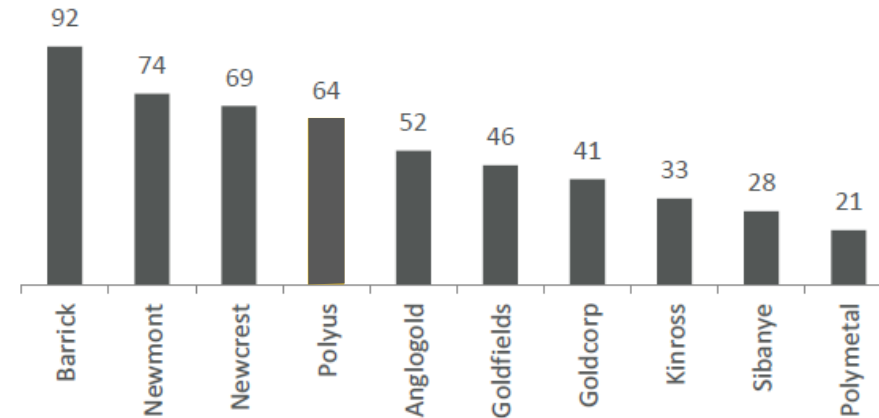
Gold production per countries in M Oz (2015)



Gold Production in M Oz (2015)



Gold Resources in M Oz (2015)

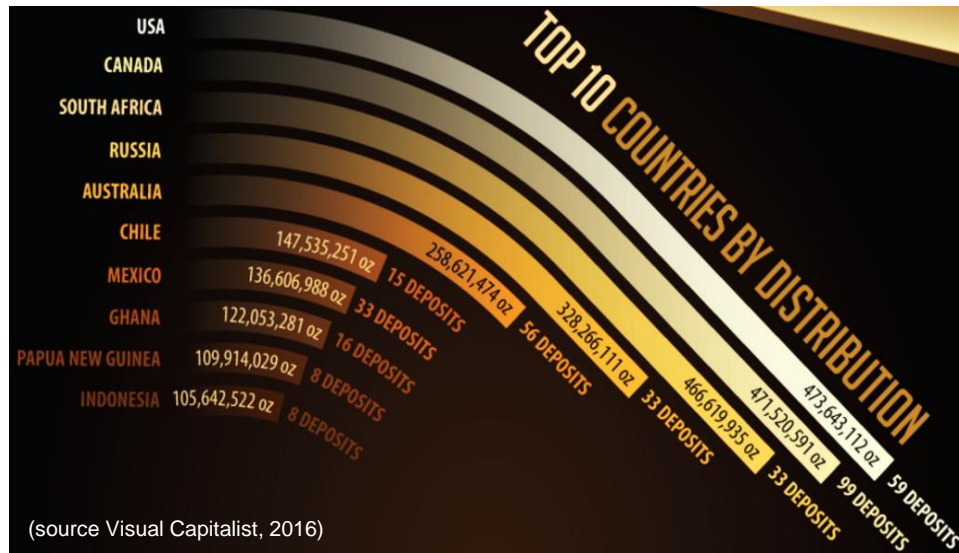


Source: Metal Focus



# World Gold Inventory

## Resources and Grade by Countries



### Gold Inventory:

1. USA 473 MOz < 1.01 g/t Au;
2. Canada 471 MOz < 1.01 g/t Au;
3. **South Africa 466 MOz @6.04 g/t Au;**
4. **Russia 328 MOz @2.02 g/t Au;**
5. Australia 258 MOz < 1.01 g/t Au;
6. Chile 147 MOz < 1.01 g/t Au;
7. Mexico 137 MOz < 1.01 g/t Au;
8. **Ghana 122 MOz < 1.94 g/t Au;**
9. **PNG 109 MOz < 1.29 g/t Au;**
10. Indonesia 137 MOz < 1.01 g/t Au

### Opportunities (underexplored regions):

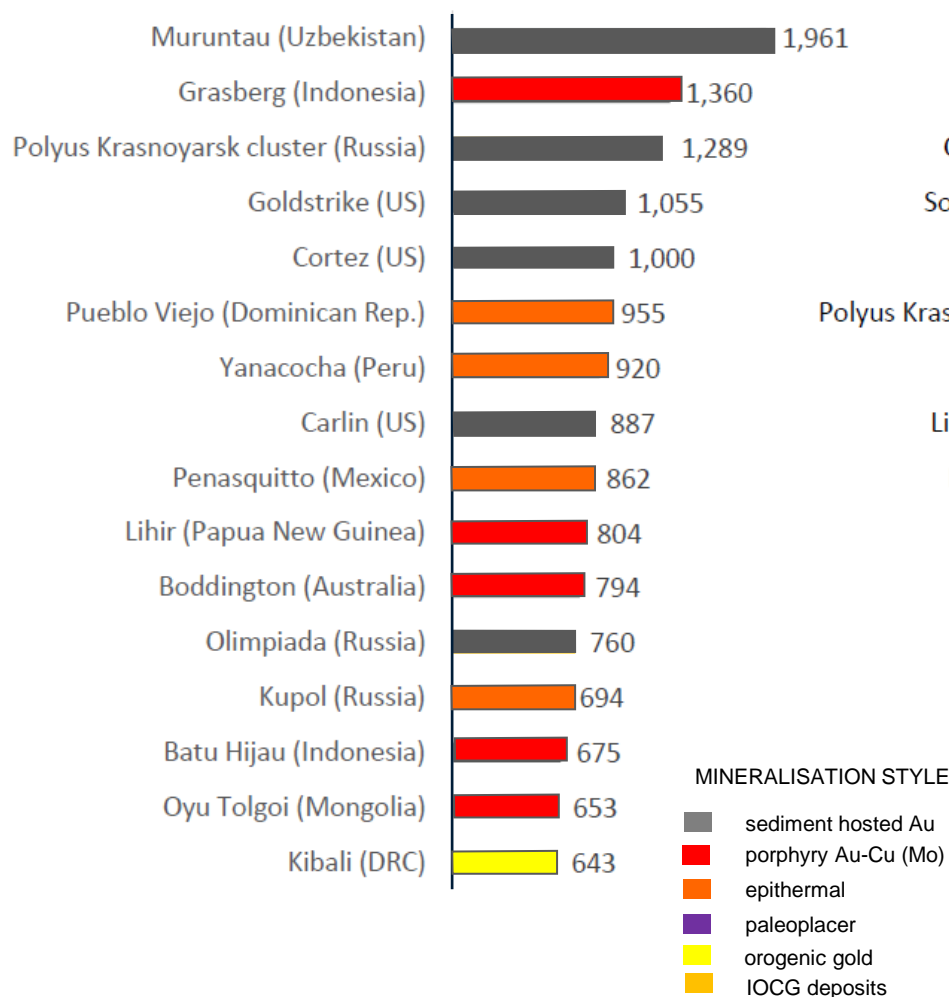
1. Tanzania (2.84 g/t Au);
2. DRC (2.59 g/t Au);
3. Mali (2.27g/t Au).



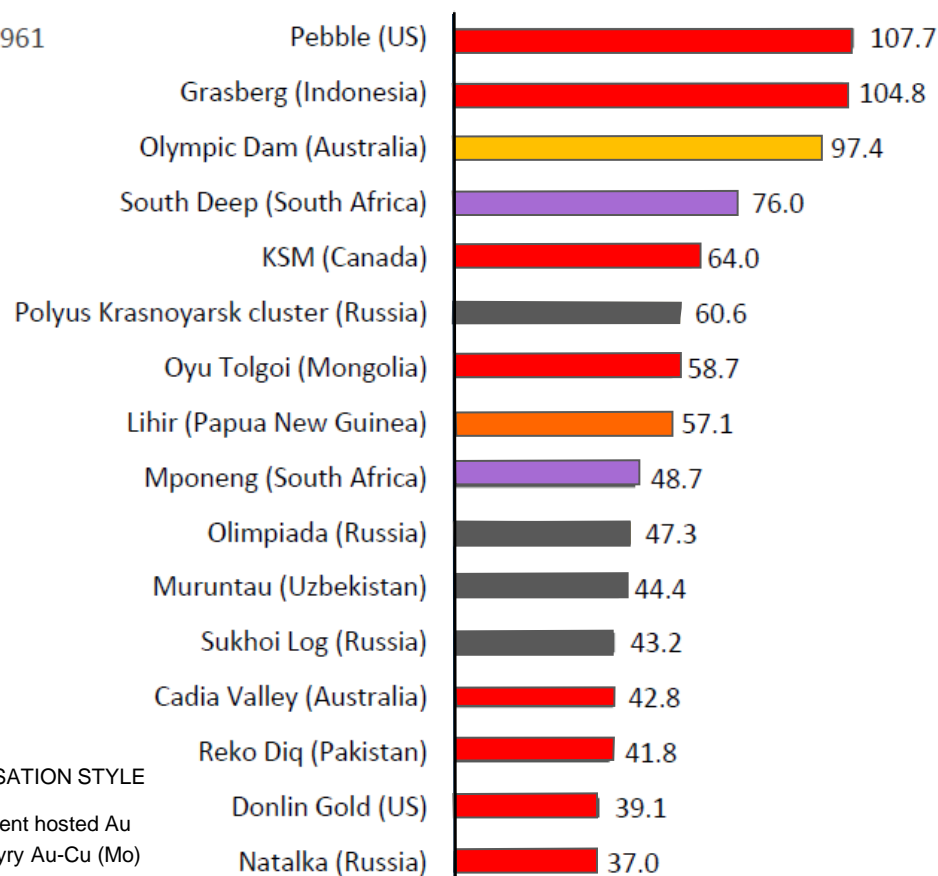
# World Gold Inventory

## Gold Production and Resources

### Gold production in KOz (2015)



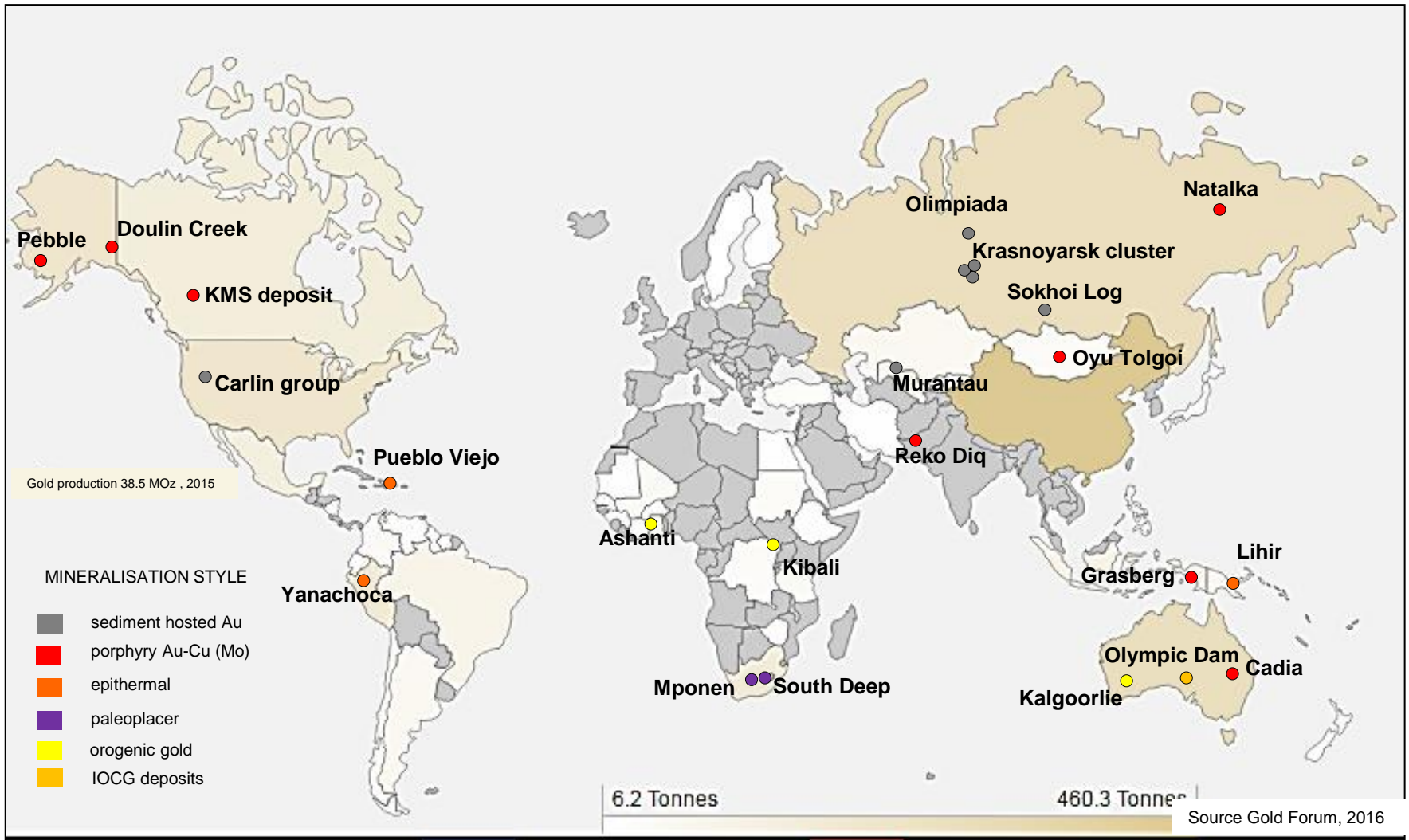
### Gold resources in MOz (2015)





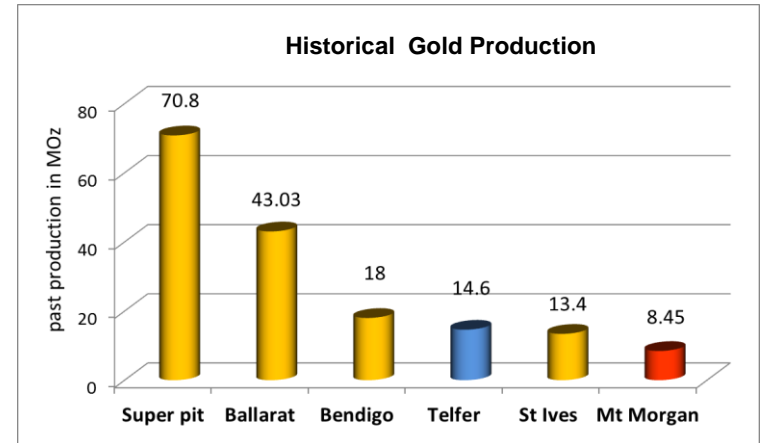
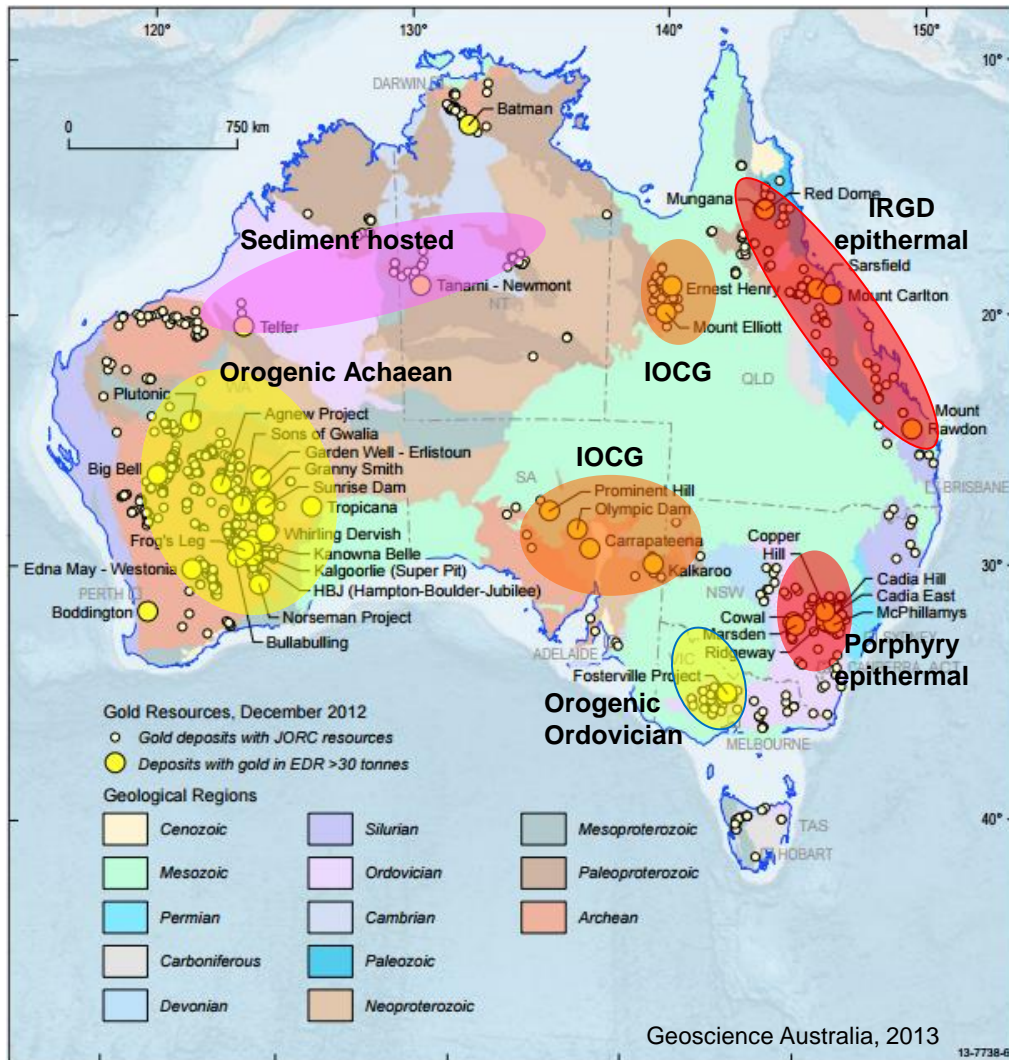
# World Gold Inventory – Geographical Distribution

## World Gold Inventory and Production in Relation to Mineralisation Style

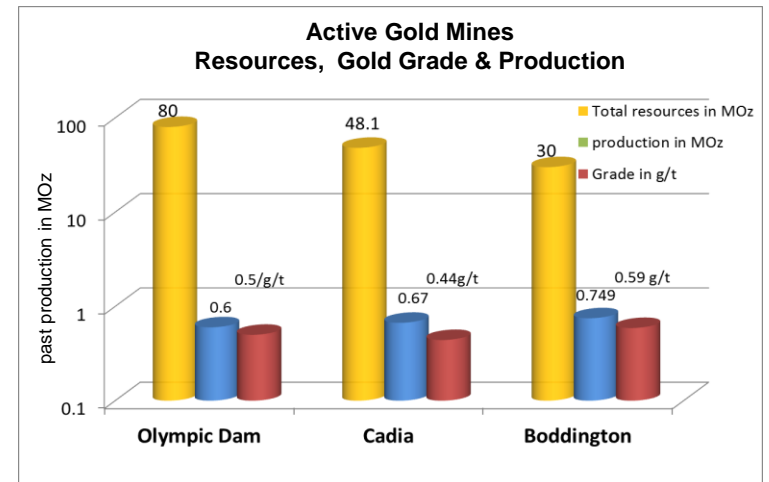


# Australian Gold Inventory

## Australian Gold Inventory of 258 MOz Au and Production of 8.8 MOz Au



- past gold production more than 80% from orogenic gold deposits



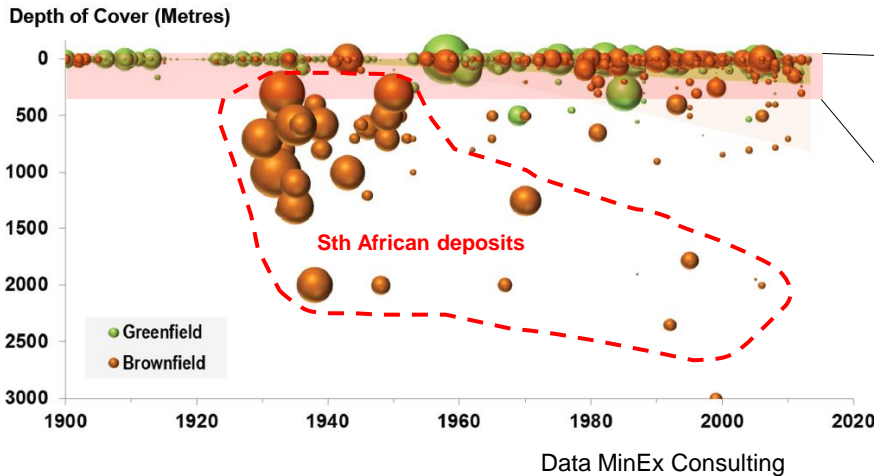
- present production – still around 40% from orogenic gold but the largest Australian mines are now porphyry mineralisation



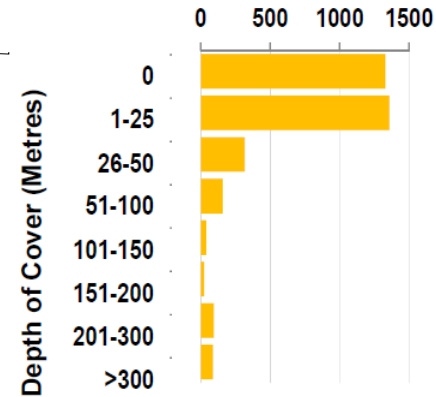
# Gold Exploration

Where to Discover Gold – do we have to explore deeper or go somewhere else ?

Primary gold deposits >100 kOz Au found in the world

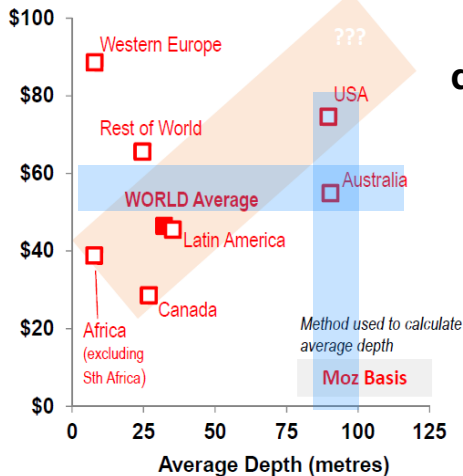


Total Metal (Moz)



Total MOz Au discovered in relation to depth >100kOz found in the world

2013 US\$/oz



Average cost for discovery (2005 -2013)

## Mature terrains:

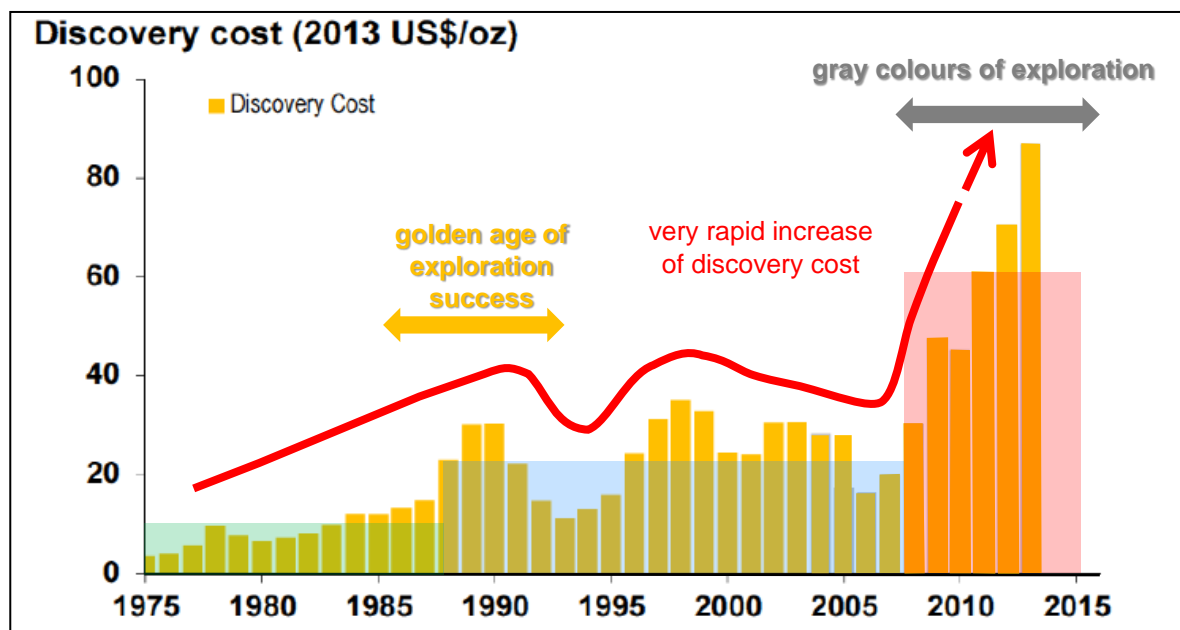
- Average depth of discovery is 90m in Australia;
- Average drilling is 700,000 m for deposit >100KOz.

## Opportunities terrains:

- Africa - depth of discovery is 9m (excluding SA);

# Mineral Discoveries Cost Worldwide

## Cost of Gold Exploration



Source, Mining Journal, August 2014

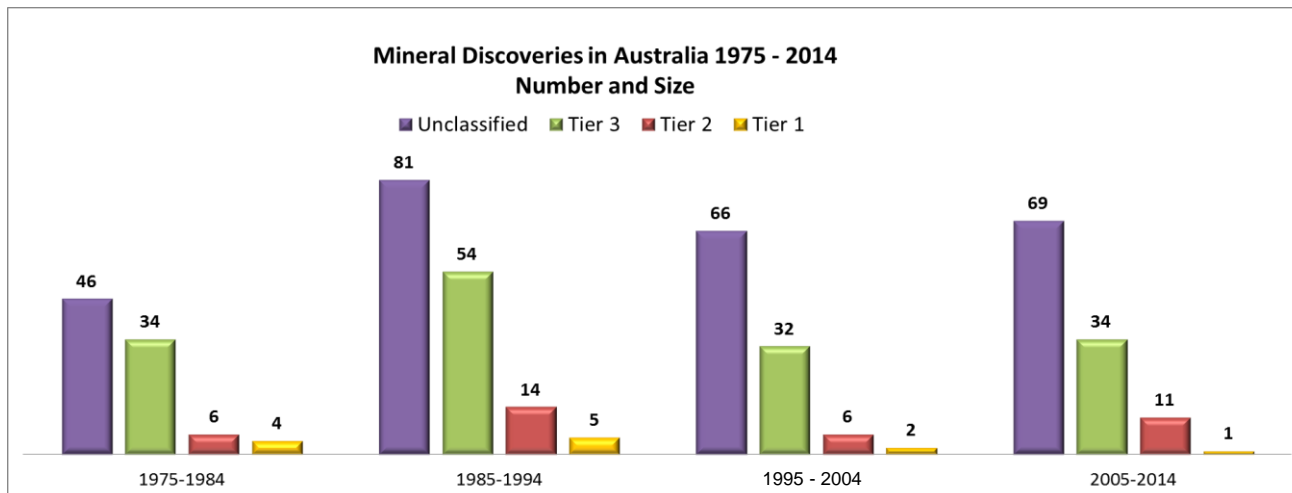
Three main periods in modern gold exploration:

- 1975 - 1987 – outcropping discoveries - cost per Oz Au < US\$ 20;
- 1987 - 2007 – discoveries under shallow cover - cost per Oz Au around US\$ 20;
- 2007 - 2014 – discoveries under cover - cost per Oz Au > US\$ 60 with steep trend upwards;



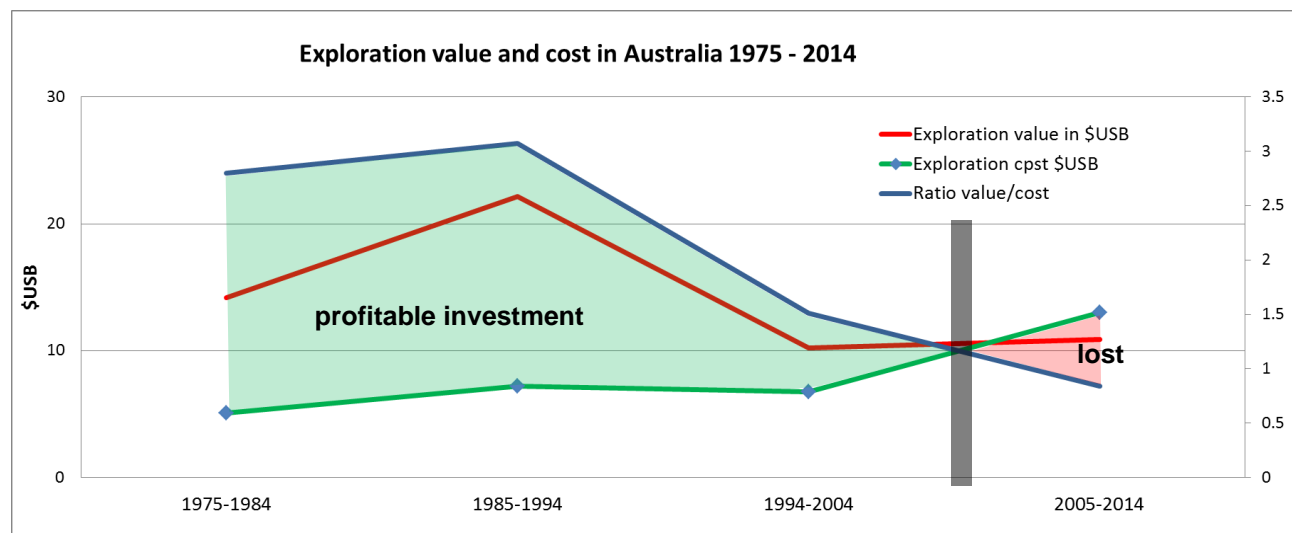
# Discovery Rate, Cost and Investment Return in Australia

## Mineral Discovery Rate and Exploration Investment



- on average, industry finds three Tier 1, ten Tier 2 and sixty Tier 3 deposits per decade;
- last decade only 1 deposit Tier 1 size.

Tier 1 NPV > US\$ 1B;  
 Tier 2 NPV = US\$ 200 M – 1 B  
 Tier 1 NPV = US\$ 10 M – 200 M  
 Tier 1 NPV < US\$ 10 M



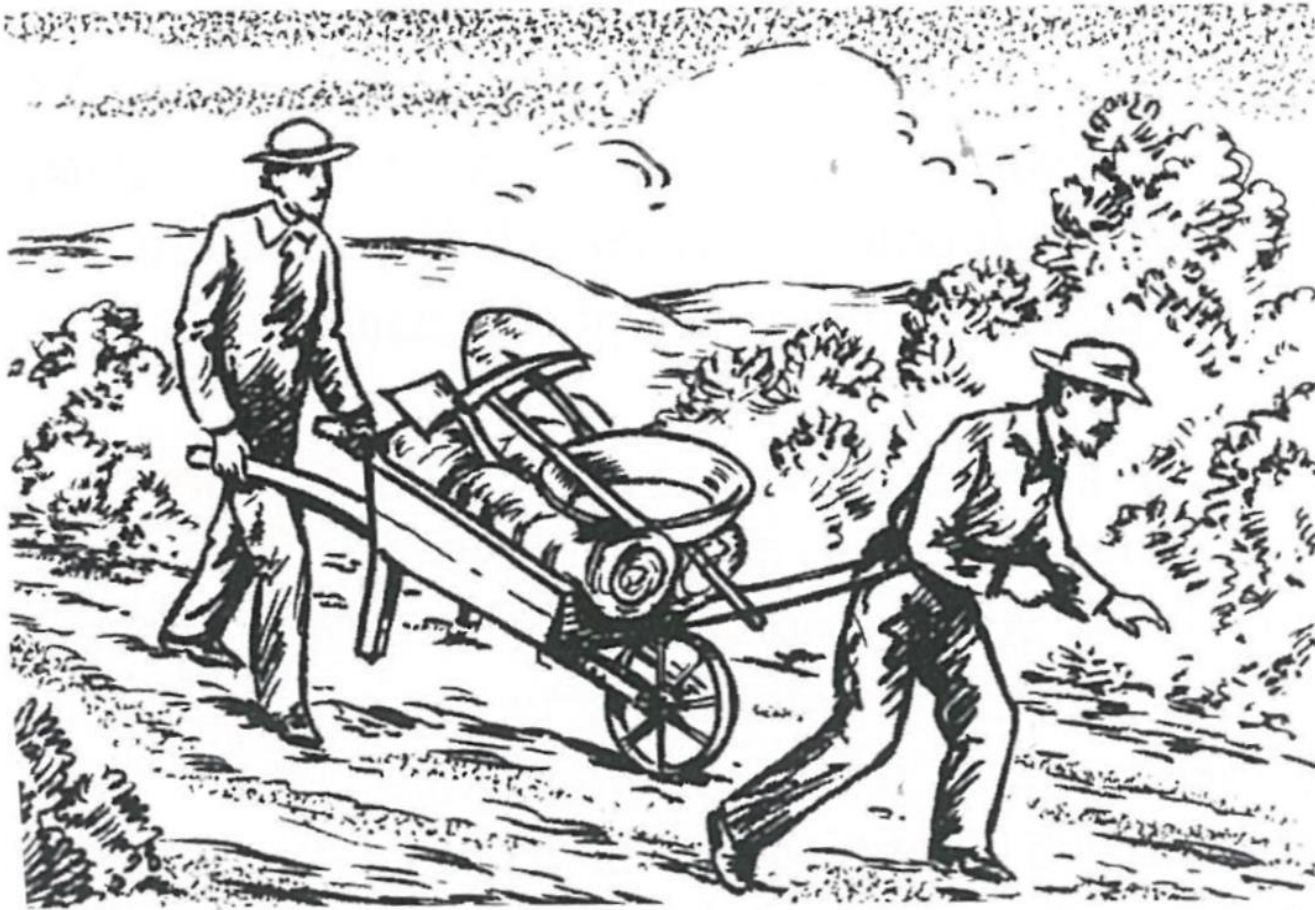
Is mineral exploration industry in Australia still a profitable industry??

Source MinExp Consulting (2015)

# Gold Exploration – Where are we now and what to do?

## Exploration Management, Strategies and Techniques

Where we are going? Are we on right track?



Mineral Exploration Expedition, NSW (Sydney Herald 1878)



Holtermann Nugget  
Weight - 630lbs  
2750oz gold



# Agnew Mining Camp Geology and Gold Mineralisation

New Holland

Genesis

Hidden Secret

Kim

Waroonga

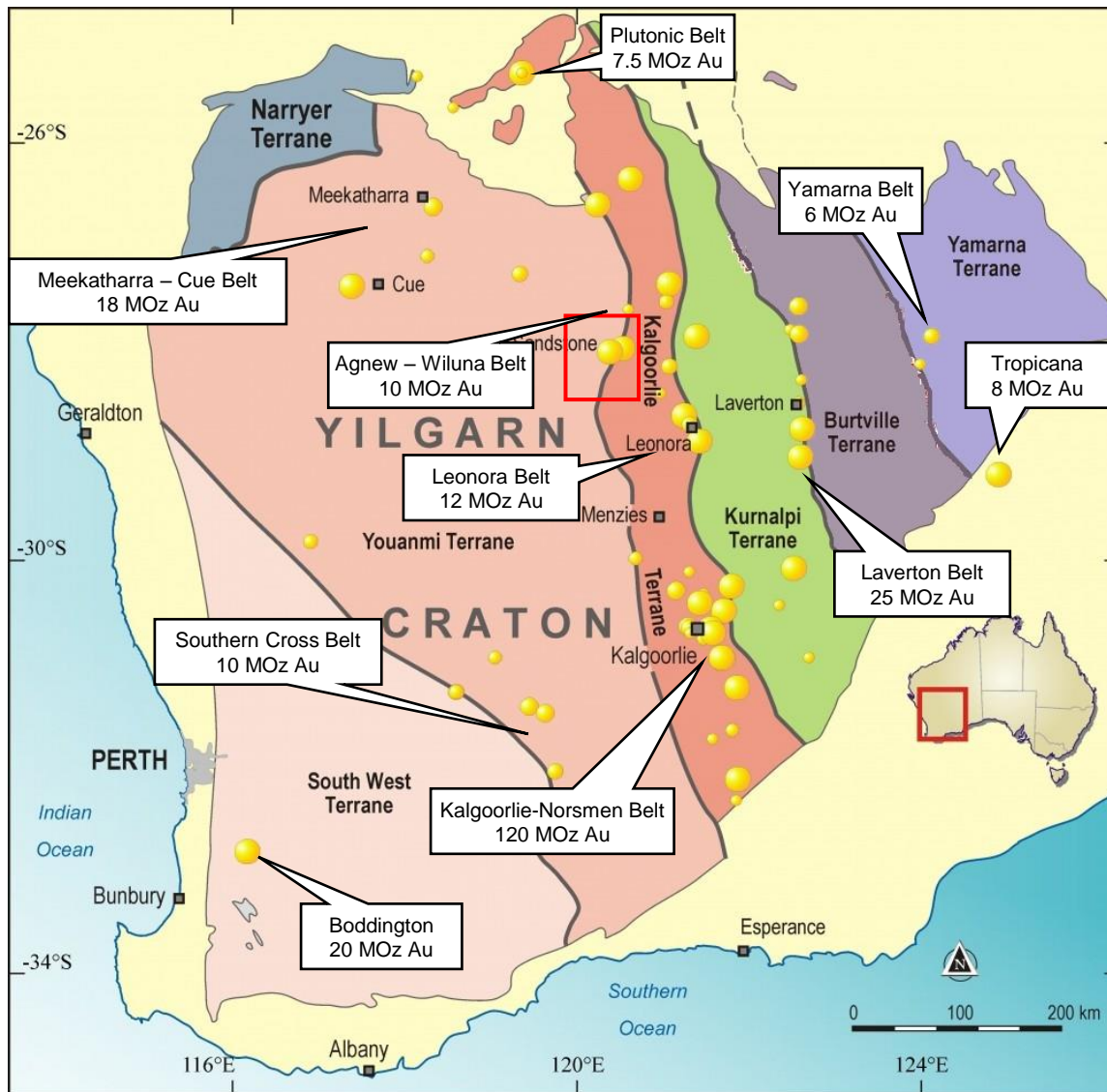
Emu Shear Zone

EMU Mining Operation



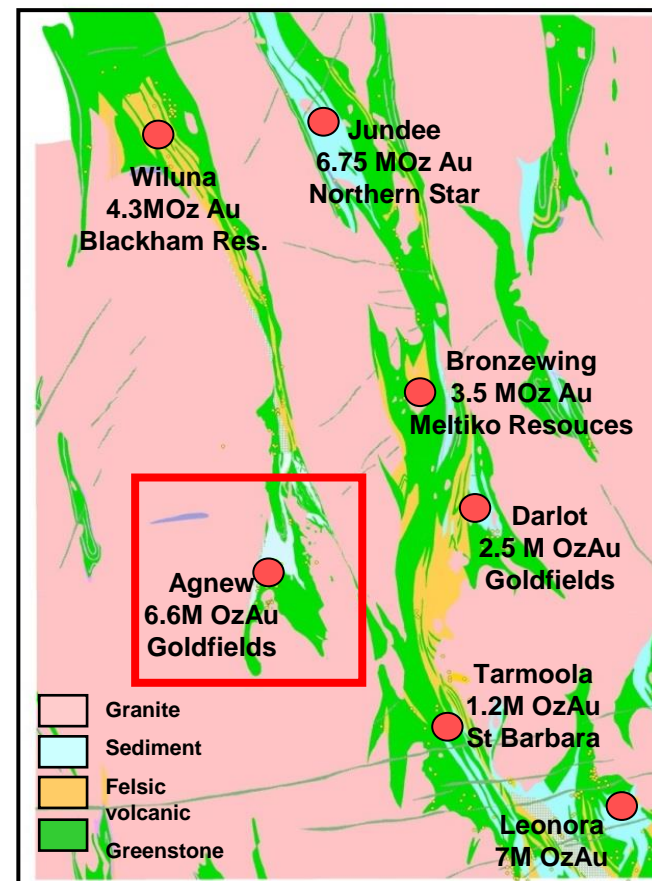
# Agnew Mining Camp - Regional Geological Setting

## Yilgarn Craton Past Gold Production



- In total Yilgarn Achaean greenstone belts produced > 246 MOz Au;
- Wiluna Belt produced > 30 MOz Au.

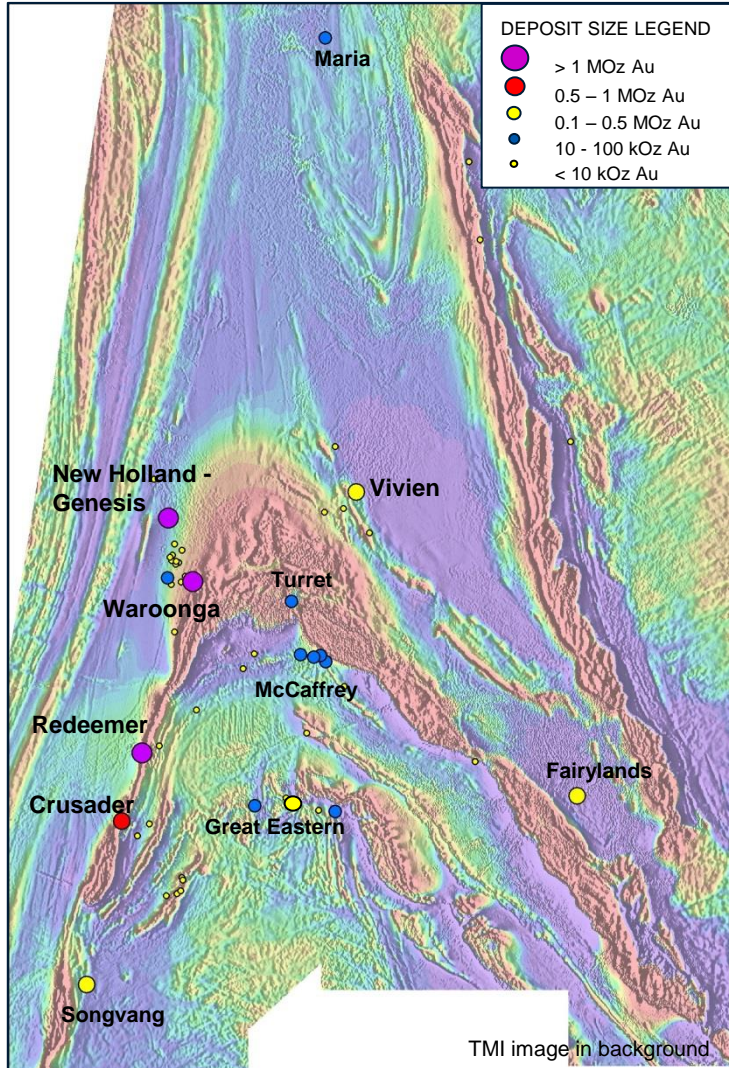
### Wiluna Belt



Modified after Czarnota *et al.* 2010b

# Agnew Mining Camp – Gold Mining

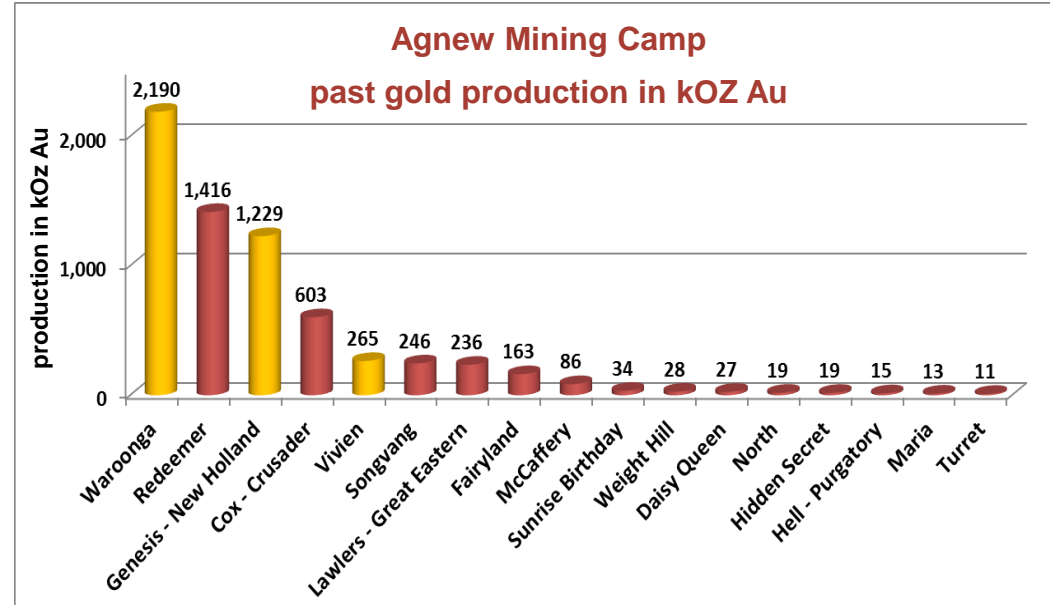
## Historical Gold Production



Agnew Mining Camp produced 6.65 M Oz Au from 54 known historical and recent mine workings (Wamex and GoldFields Annual reports).

Today there are three operating underground mines:

- Waroonga and New Holland operated by GoldFields - combined production of 250kOz/year; and
- Vivian Mine operated by Ramelius Resources with production of 25 kOz Au/year.





# Agnew Mining Camp – Mining History

## Old Mining History

GEOLOGICAL SURVEY.

Photo. 1.

Bulletin No. 28.

**Agnew Mining Camp has produced over 6.6 M Oz Au since 1892 when mining recommenced.**

### Mining history:

- **1892 - Wells Exploring Expedition travelled in the vicinity of Lawlers and noted potential to for gold mineralisation;**
- **1894 - Paddy Lawlers prospecting party find gold at Lamehorse Soak;**
- **1895 - 1909 - Great Eastern Mine in production;**
- **1896 - Lawlers town site gazetted;**
- **1895 - Gold first discovered at Waroonga (Agnew) location;**
- **1897 - 1911 - Waroonga (Emu) Gold Mine in production;**
- **1901 - Gold discovery at Vivian;**
- **1903 - 1911 - Vivian Mine in production;**
- **1935 - Waroonga Mine re-opened;**
- **1948 - Waroonga Mine closed;**

Govt Litho  
PERTH W.A.



Photo., C. G. Gibson.

East Murchison United Gold Mine, Lawlers.



# Agnew Mining Camp – Mining History

## Modern Mining History

- 1976 - Western Mining Company (WMC) acquire Waroonga mining leases;
- 1984 - Forsayth purchases Great Eastern Lease from Mintaro Queen Margaret ;
- ❖ 1985 – (April) WMC discovered Redeemer – 1.5 MOz (4100 ppb soil);
- 1987 - Redeemer commenced production and operated until 2002 (1.5 MOz);
- 1986 - Forsayth commence modern open pit mining operation at Lawlers;
- ❖ 1986 - Discovery of Cox-Crusader (600 kOz) RAB drilling by Asarco Australia;
- 1987 - Asarco and Forsayth Mining commenced producing from Cox-Crusader;
- 1992 - Plutonic Resources purchase Forsayth NL and operate the Lawlers Gold Mine;
- ❖ 1996 - Discovery of Fairyland (200 kOz) (RAB) by Plutonic; 1997 open pit mining commenced;
- 1997 - Goldfields started Vivien open pit operation and produced 185 kOz Au;
- ❖ 1998 - Discovery of underground resources at New Holland-Genesis (1.3 MOz) and underground mining commenced by Plutonic Resources;
- 1998 - Homestake acquires Plutonic;
- 2001 - Barrick merges with Homestake;
- 2001 - GoldFields Australia purchased Waroonga lease from WMC;
- ❖ 2002 - Kim (1.2 Moz) - extensional drilling; Songvong (350 kOz) – magnetics discovered;
- 2014 - GoldFields purchased from Barrick Lawlers leases including New Holland underground;
- 2014 - GoldFields operates two underground mines Woroonga and New Holland and produces more than 250 kOz Au per year.

Agnew mill capacity 300 000/ year

# Agnew Mining Camp – Mining History

## EMU Mine Flood Disaster – the Tuesday 13<sup>th</sup> June 1989



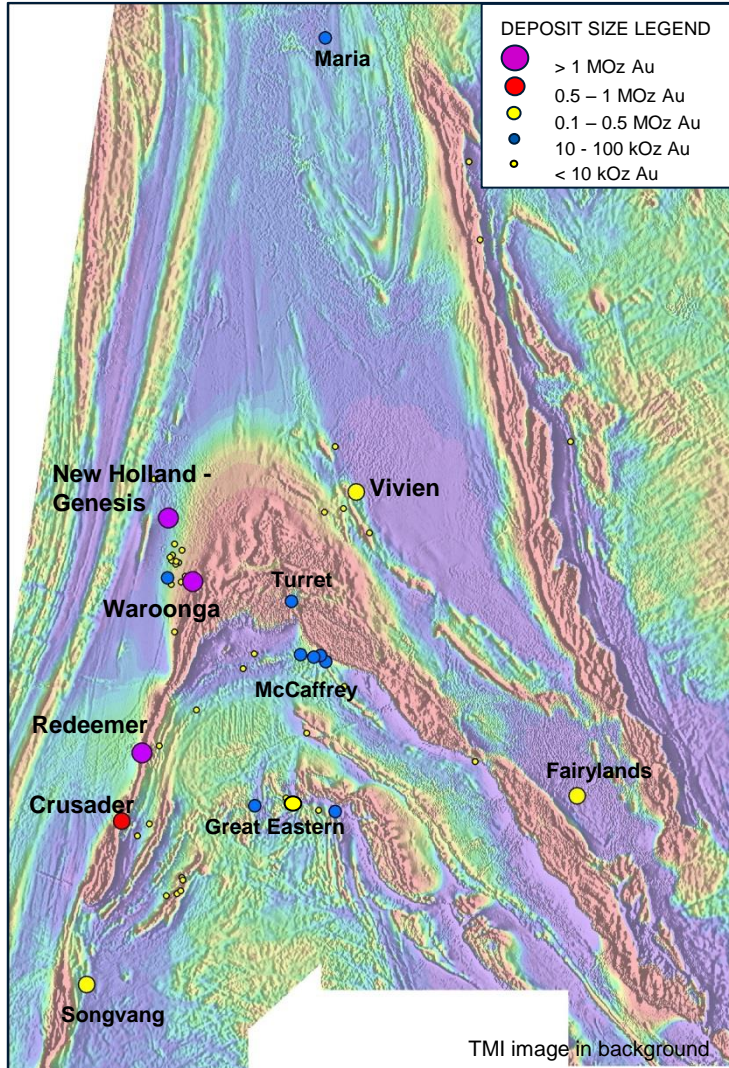
- East Murchison United (EMU) gold mining operation at Waroonga (Agnew) used void of adjacent old open pit as additional water storage;
- Extremely heavy rainfall filled pit to a point where overflow occurred in the area of the separating ‘pillar’ between pits;
- Overflow rapidly eroded pit wall which collapsed and discharged water into Main Open Cut;
- Main Open cut had decline at the pit floor level and miners were working underground;
- Twelve people died including Mine Manager who had gone underground to warn and withdraw miners;
- **This tragedy was the worst in living memory for the WA mining industry.**

Official report: *“a wave of water rushed across the AG Southern Extension, a small portion flowing down the old Emu Shaft while the remainder cascaded over the southern wall of the Main AG Pit. Its flow towards the decline retarded slightly by a bund of road base material which had been built during the day to prevent nuisance water flowing down the decline”.*



# Agnew Mining Camp – Gold Mining

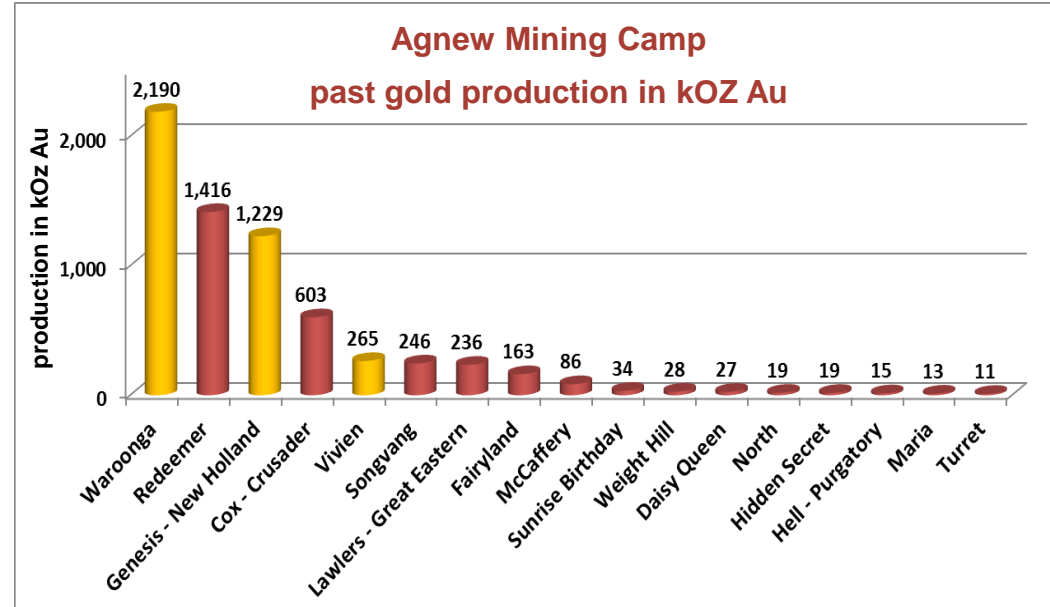
## Historical Gold Production



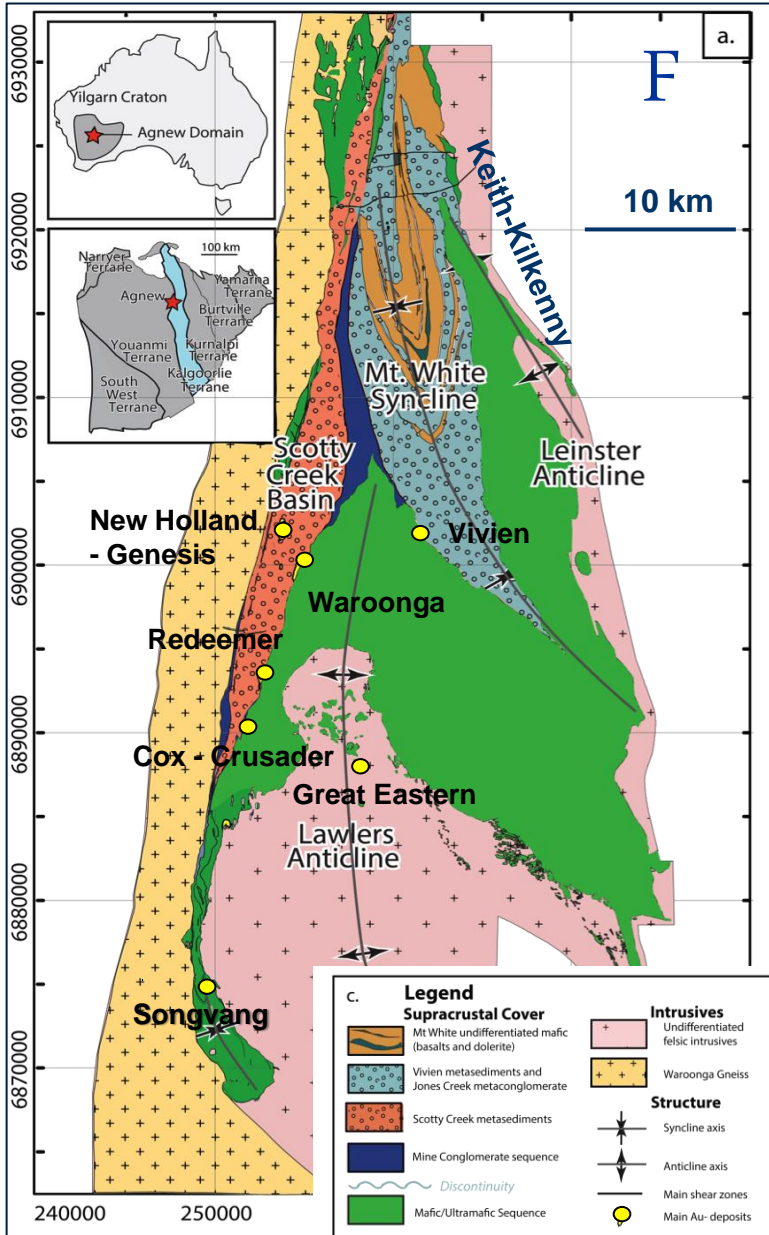
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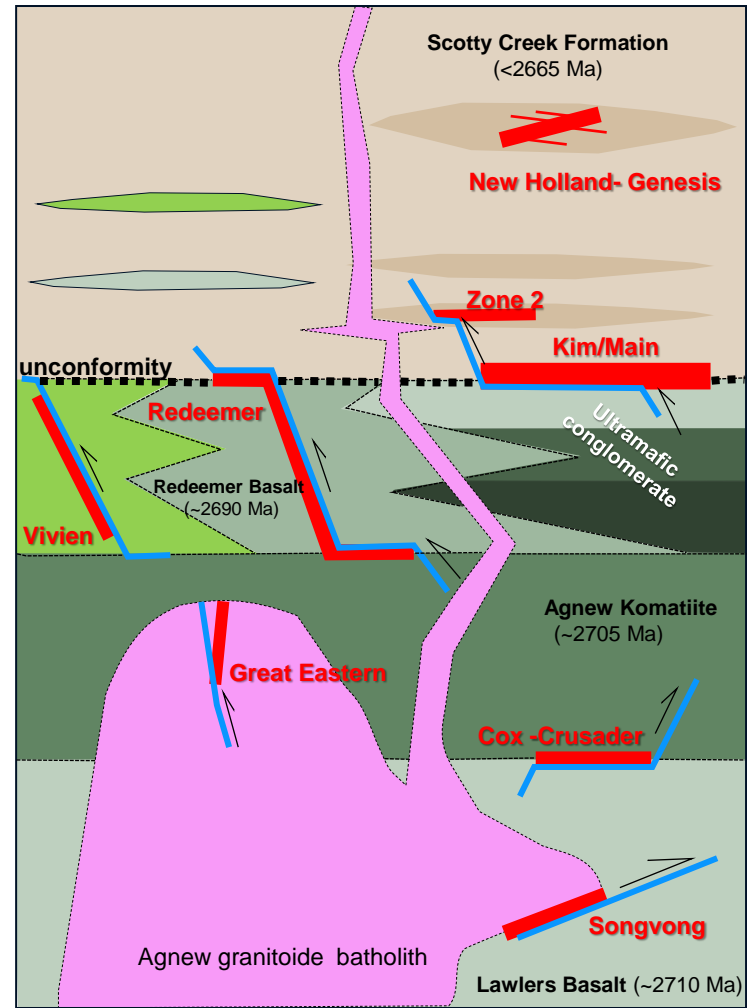
- Waroonga and New Holland operated by GoldFields - combined production of 250kOz/year; and
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# Agnew Mining Camp Geology

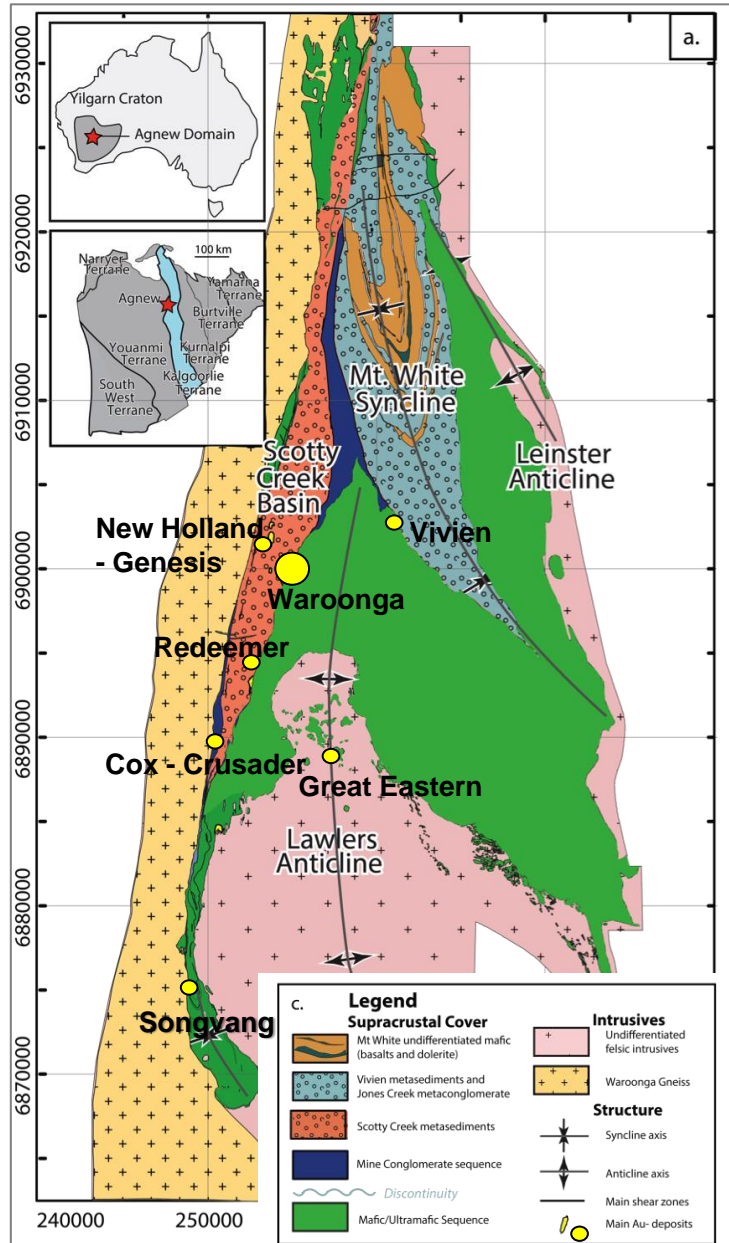


## Lithostratigraphic setting of gold deposits

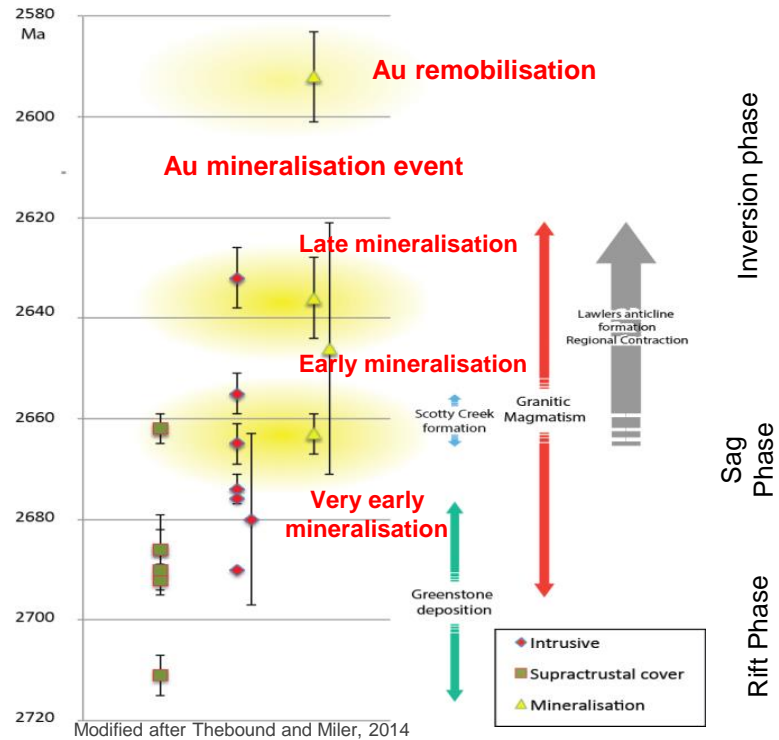


- gold deposits are hosted through the entire greenstone sequence in every lithology adjacent to structure, commonly on lithological contact.

# Agnew Mining Camp Geology



## Geological History



- Norseman-Wiluna Greenstone Belt of Yilgarn Craton;
- Mafic to ultramafic volcanics and sediments folded to form Lawlers Anticline plunging north at 30-40°;
- Folded mafic/ultramafic sequence intruded by granodiorite and leucogranite;
- Clastic sedimentation in the Late Basins - Scotty Creek Formation.
- Waroonga Shear Zone and the Emu Shear Zone.



# Agnew Mining Camp Geology

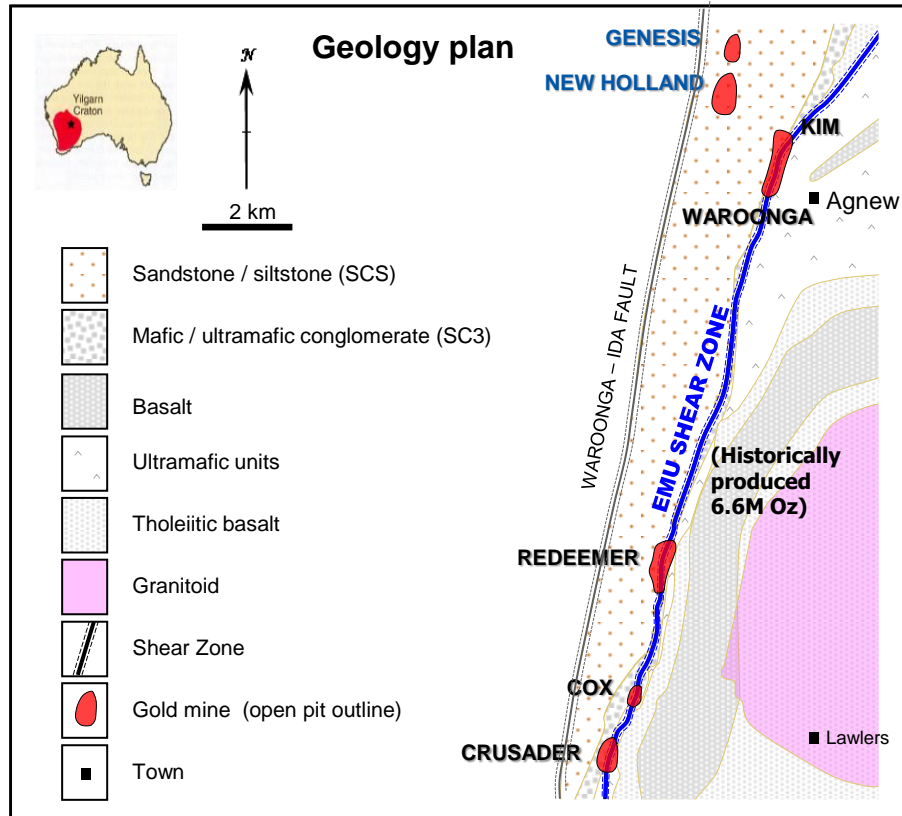
## Understanding Geology and Terrain Evolution – Structural History

Platt., (1978)	AMIRA P718A (2006)	SRK McCuaig et al., (2003)	Blewett et al., (2007)
Deposition of supracrustal cover	Deposition of supracrustal cover	De1 N-S extension and deposition of ultramafic stratigraphy, Black Flag and sedimentary sequence	D1 extension and deposition of supracrustal cover.
Tonalite intrusion	<b>D1 Nappe-s'</b> gently dipping isoclinal folding	<b>D1</b> compression Basin inversion of mafic ultramafic stratigraphy	D2 NE-SW compression (~2668Ma)
Erosion of Mafic and tonalite to produce Scotty Creek	<b>D2 E-W extension, sill-like tonalite intrusion</b>	<b>D2</b> deposition of the Scotty Creek formation	D3 extension, Late Basins, Metamorphic core complex, doming (2655-2665 Ma)
<b>D1 (layer parallel S1, gently dipping isoclinal folding.</b>	Erosion and sedimentation	<b>D3</b> compression, tonalite intrusion and formation of Lawlers anticline <b>Au</b>	<b>D4 a and b ENE-WSW to ESE-WNW compression</b> Upright folding, reverse shearing and sinistral <b>Au</b> shearing (2645 -2655 Ma)
Leucogranite intrusion	<b>D3 E-W compression leading to re-folding and shearing. Au</b>	<b>D3</b> continued E-W compression. Shearing <b>Au</b>	<b>D5 dextral strike slip Au</b> along N to NE striking faults (2650 to 2638 Ma)
<b>D2 ENE-WSW shortening and dextral shearing Au</b> Upright folding		<b>D4</b> brittle faulting (strike E-W)	<b>D6</b> Extension Regional orogenic collapse (normal brittle faulting)

Controversial structural history by different authors

# Agnew Mining Camp – Gold Mineralisation Styles

## Waroonga - Kim and New Holland – Genesis Mineralisation



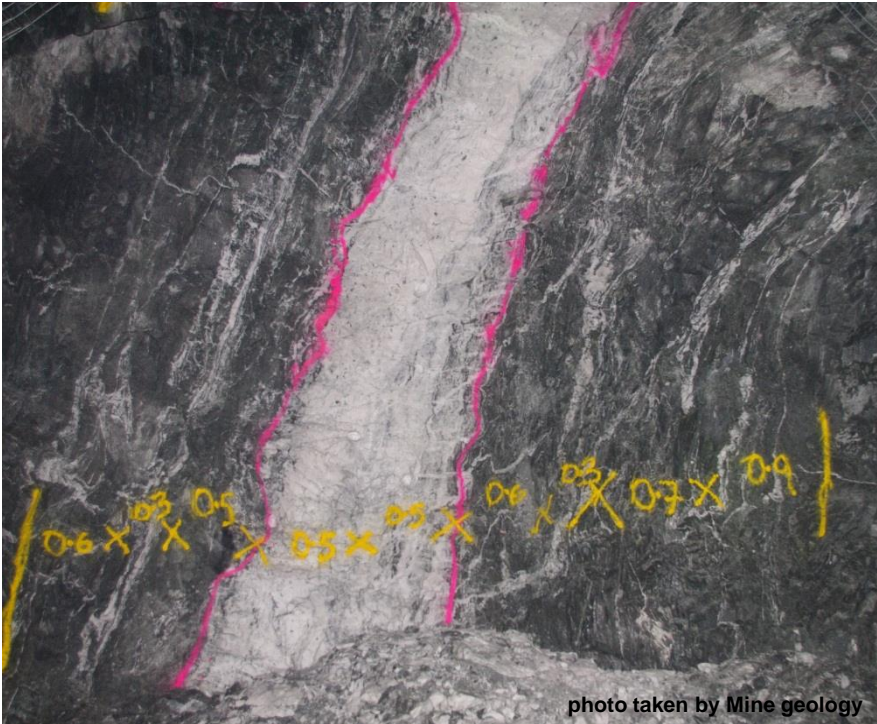
Two major mineralisation styles occur over two main subsequent periods (Fletcher et al, 1998):

- Early mineralisation event - **Waroonga style**; controlled by the Emu Shear geometry in a progressing oblique-reverse faulting in the compressional tectonic environment (deformation event D2);
- Deposits have vertical extension over 1000 m and moderate strike extension up to 200m; deposits are steep ( $60^{\circ}$  - $70^{\circ}$  to west); hosted in monomict unsorted mafic conglomerates; large size: Waroonga, Redeemer and Cox-Crusader.
- Later mineralisation event – **Holland style - Genesis** hosted in Scotty Creek Formation between the Waroonga and Emu Shear in a right lateral-reverse tectonic environment;
- Deposits are gently plunging to south and occur as multiple flat laying veins in a vertical succession limited to the coarse greywacke sandstone; large to medium size: Genesis and New Holland.

# Main Mineralisation Styles in Agnew Mining Camp

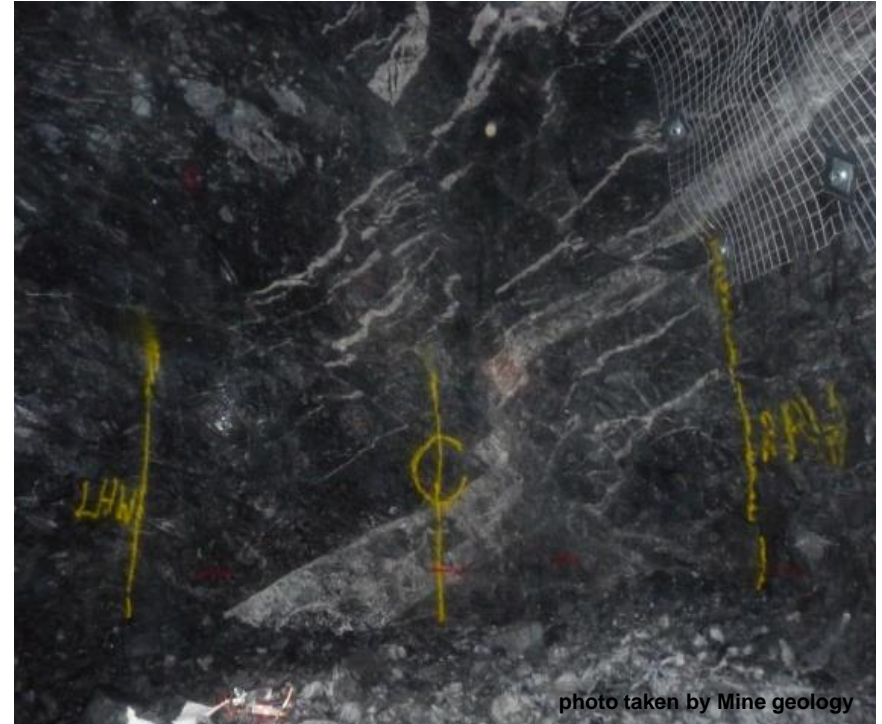
## Mineralisation Geometry

Waroonga style mineralisation style



Kim Ore body – level 500

New Holland – Genesis mineralisation style



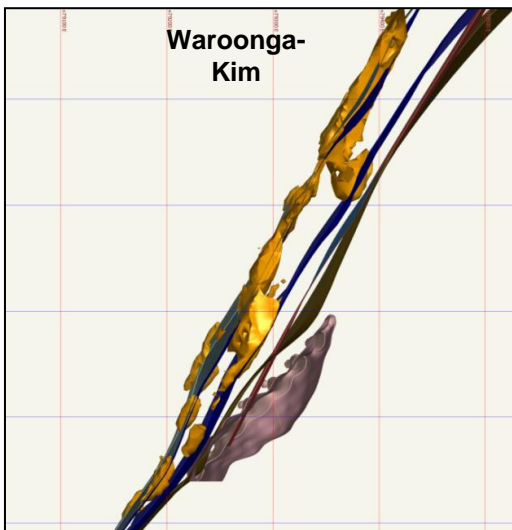
Series 500 Westerly structure



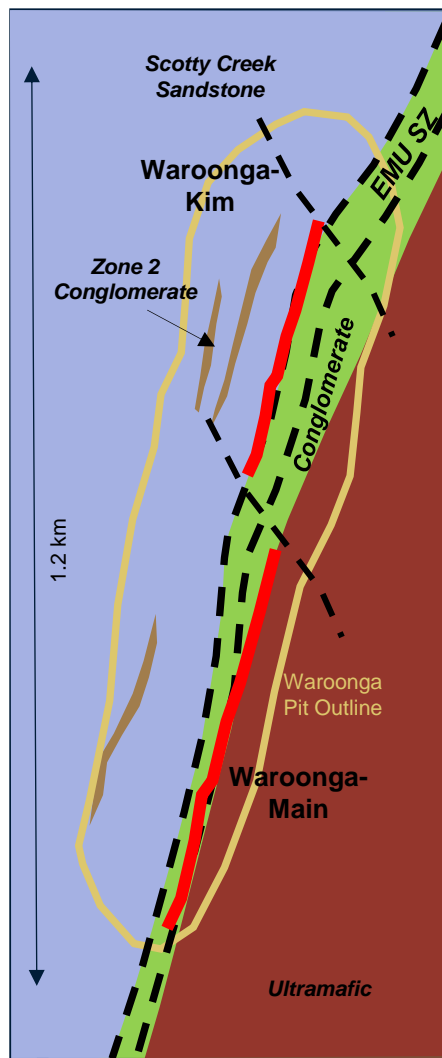
# Waroonga - Kim Geology

## Geometry of Mineralisation

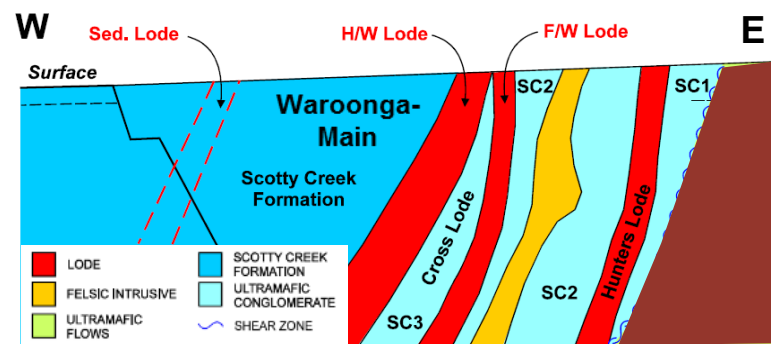
- Mineralization occurs at the contact of Scotty Creek sandstone and ultramafic breccia where intersected by NNW trending shears and right deflection;
- Mineralisation comprises several quartz/quartz breccia lodes from 1m – 5m wide;
- Mineralisation dips 55° to the west, plunges 65° to the north.



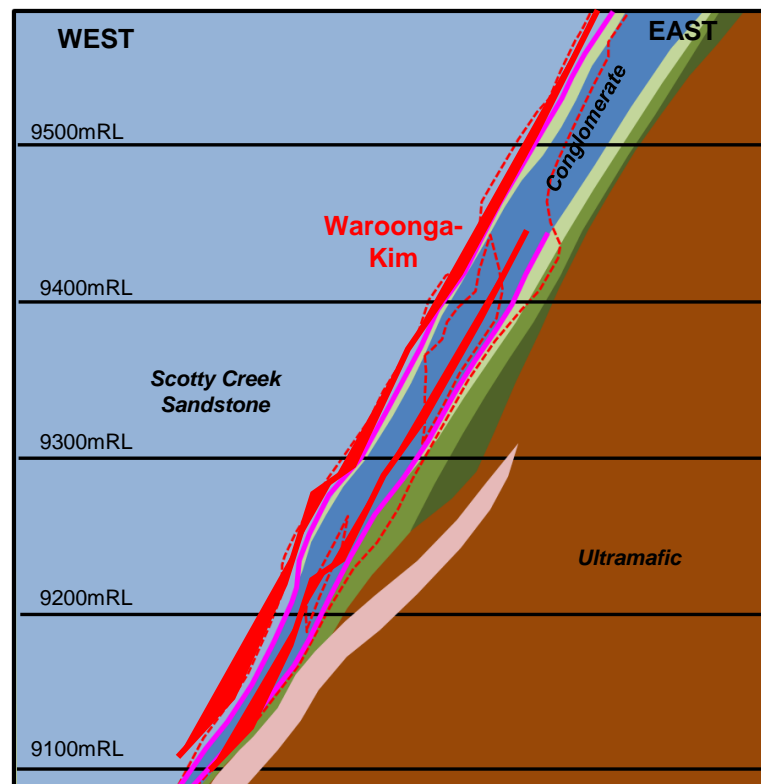
Perspective view of 3D model



Surface solid geology map

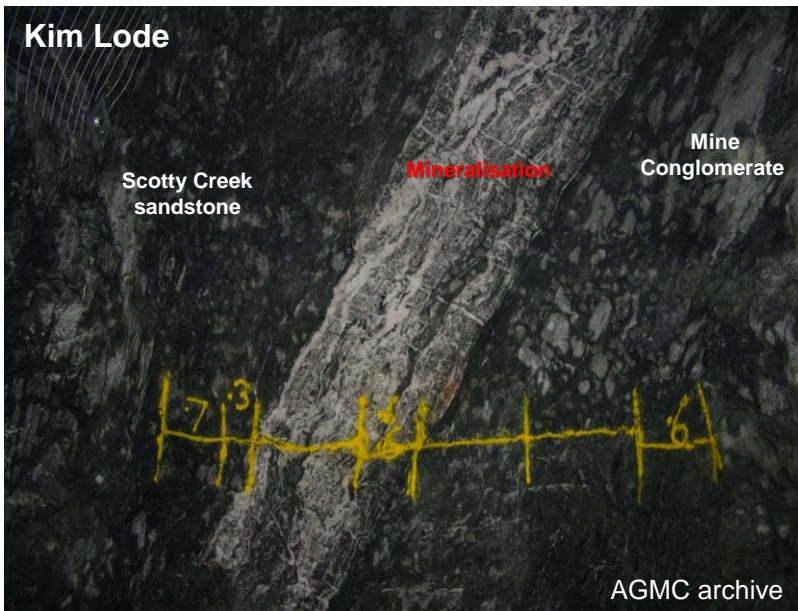
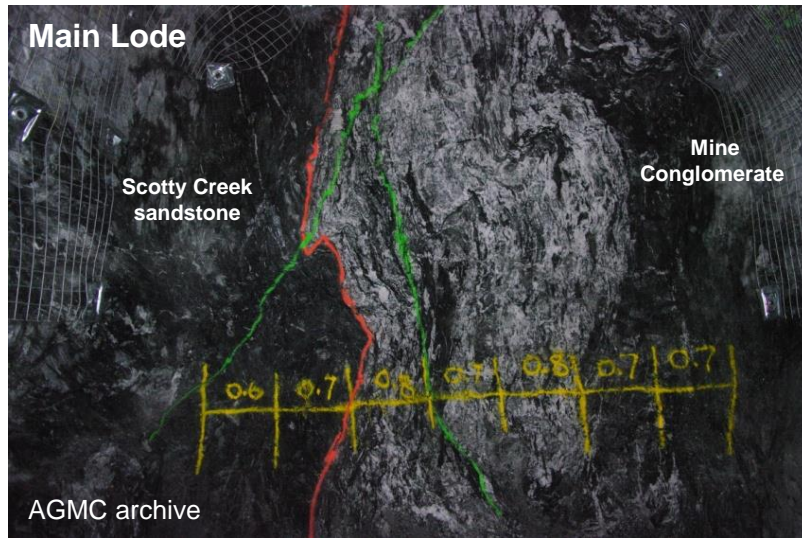


North looking cross section - surface



North looking cross section

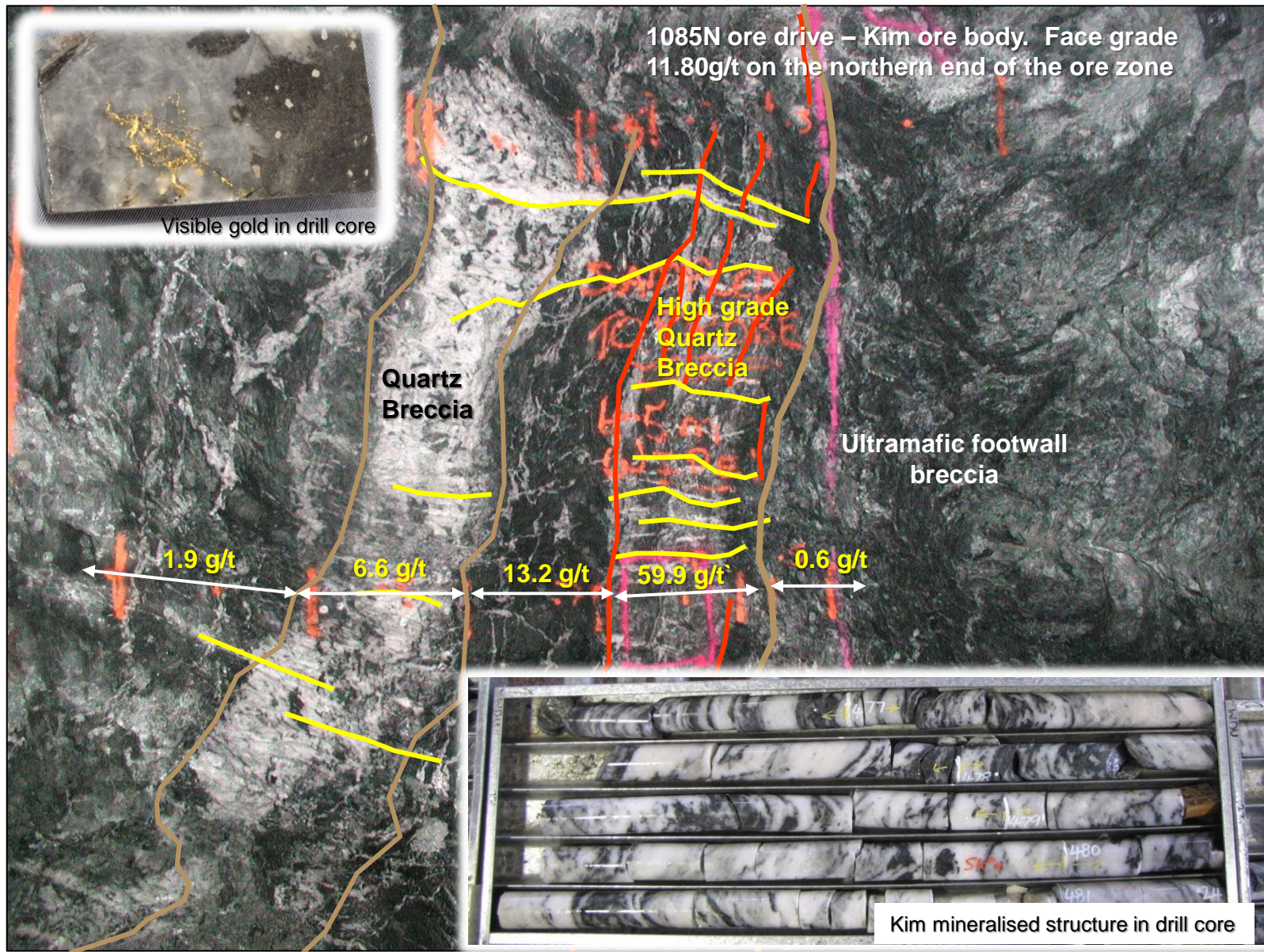
## Main and Kim Lode



- Scotty Creek sandstone in the Hw and Mine conglomerate (SKCU3) in the Fw;
- Central zone of veining and hydraulic breccia - referred to as the Kim core breccia; width from 20cm to 6m and Au-grades from 10 – 20g/t Au range, locally up to 100g/t Au;
- Adjacent to the core breccia are the Hw and Fw alteration zones are comprised of amphibole-arsenopyrite assemblage with numerous veinlets both parallel and orthogonal to the core breccia.
- Au-grades and widths of the Hw and footwall alteration zones are highly variable. Locally, the Hw alteration zone in the immediate contact with the core breccia can have a higher gold grade than the core breccia itself.



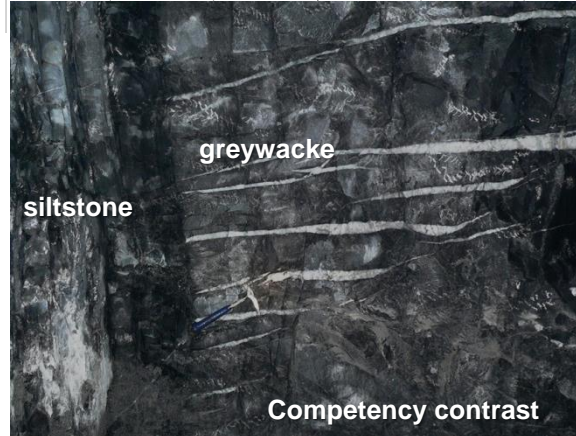
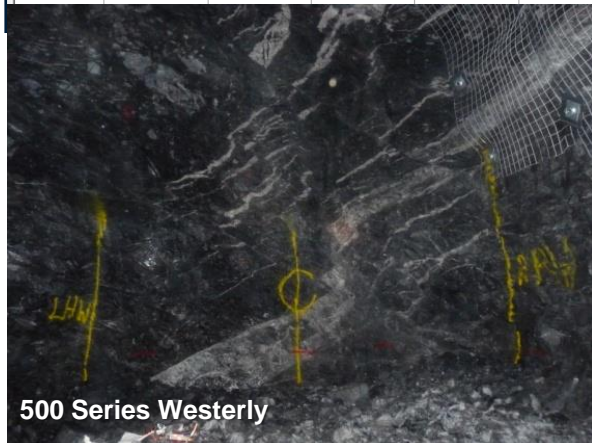
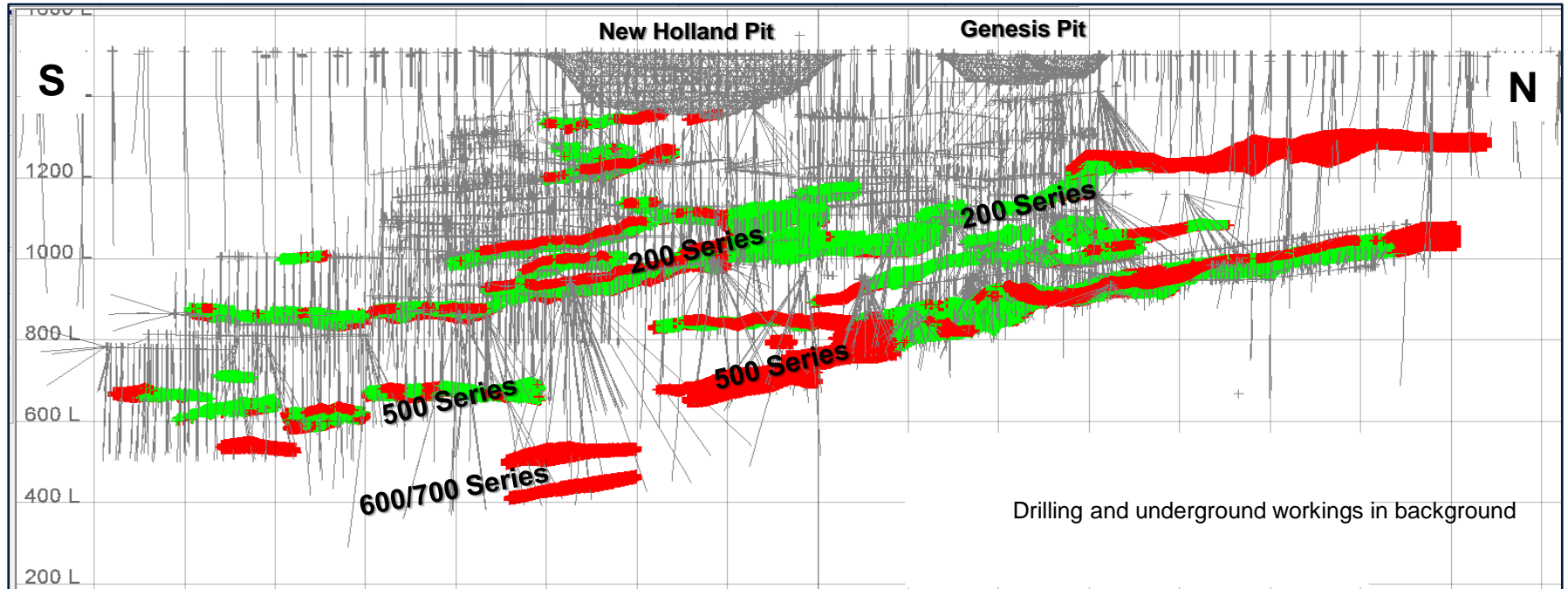
# Waroonga - Kim Mineralisation





# New Holland - Genesis Geology

## Long Section with Major Westerly Lodes



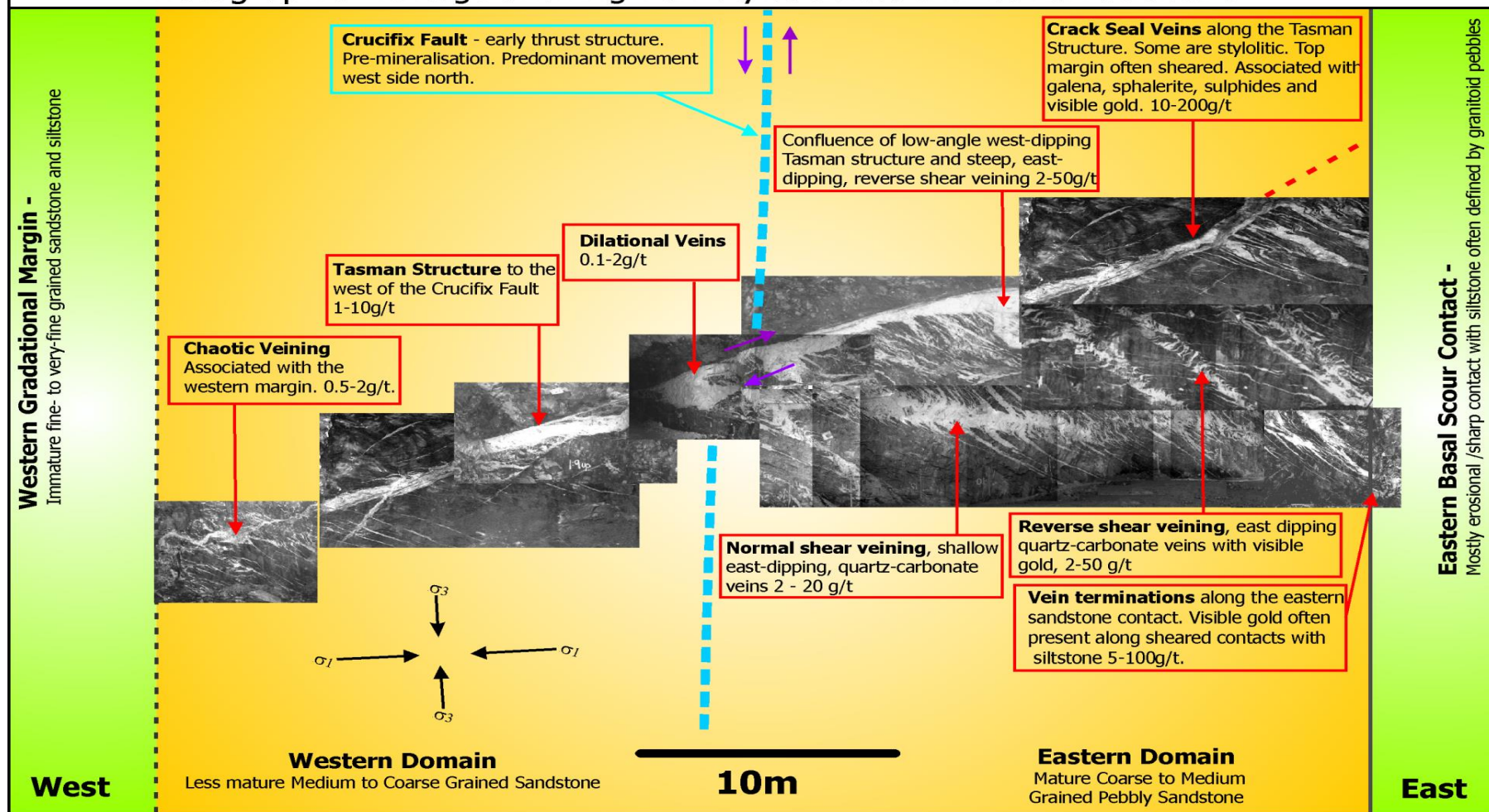


# New Holland - Genesis Geology

## Cross Section with Major Westerly Lode and adjacent Easterlies

### New Holland Gold Deposit

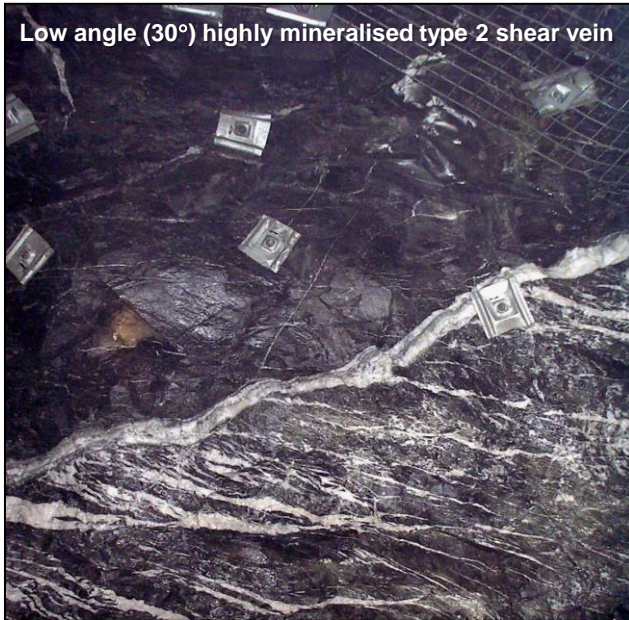
#### Photographic Montage Showing Vein Styles across the Tasman Structure



Source Homestake archive

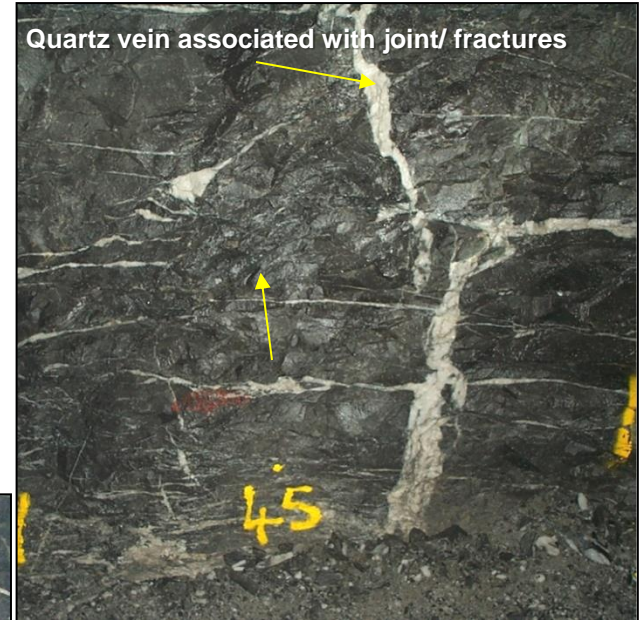
# New Holland - Genesis Mineralised Vein Styles

## Vein geometry



Low angle (30°) highly mineralised type 2 shear vein

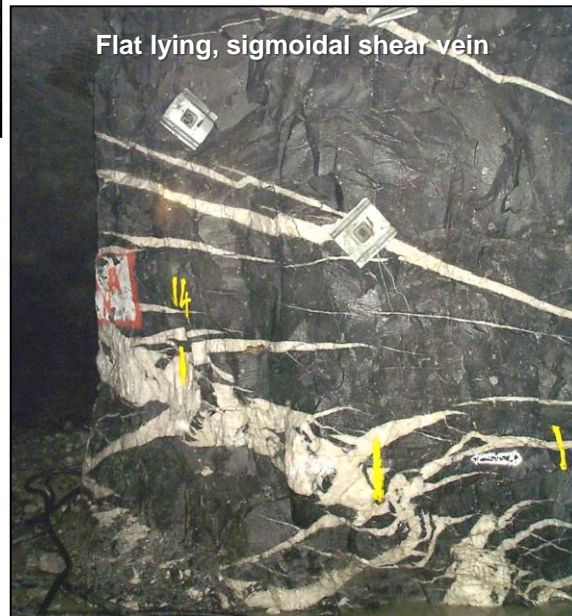
Extension Veins with progressive development of sigmoidal younger veins



Quartz vein associated with joint/ fractures

Horizontal veins associated with vertical interconnecting veins

Extension Veins with capped Hw



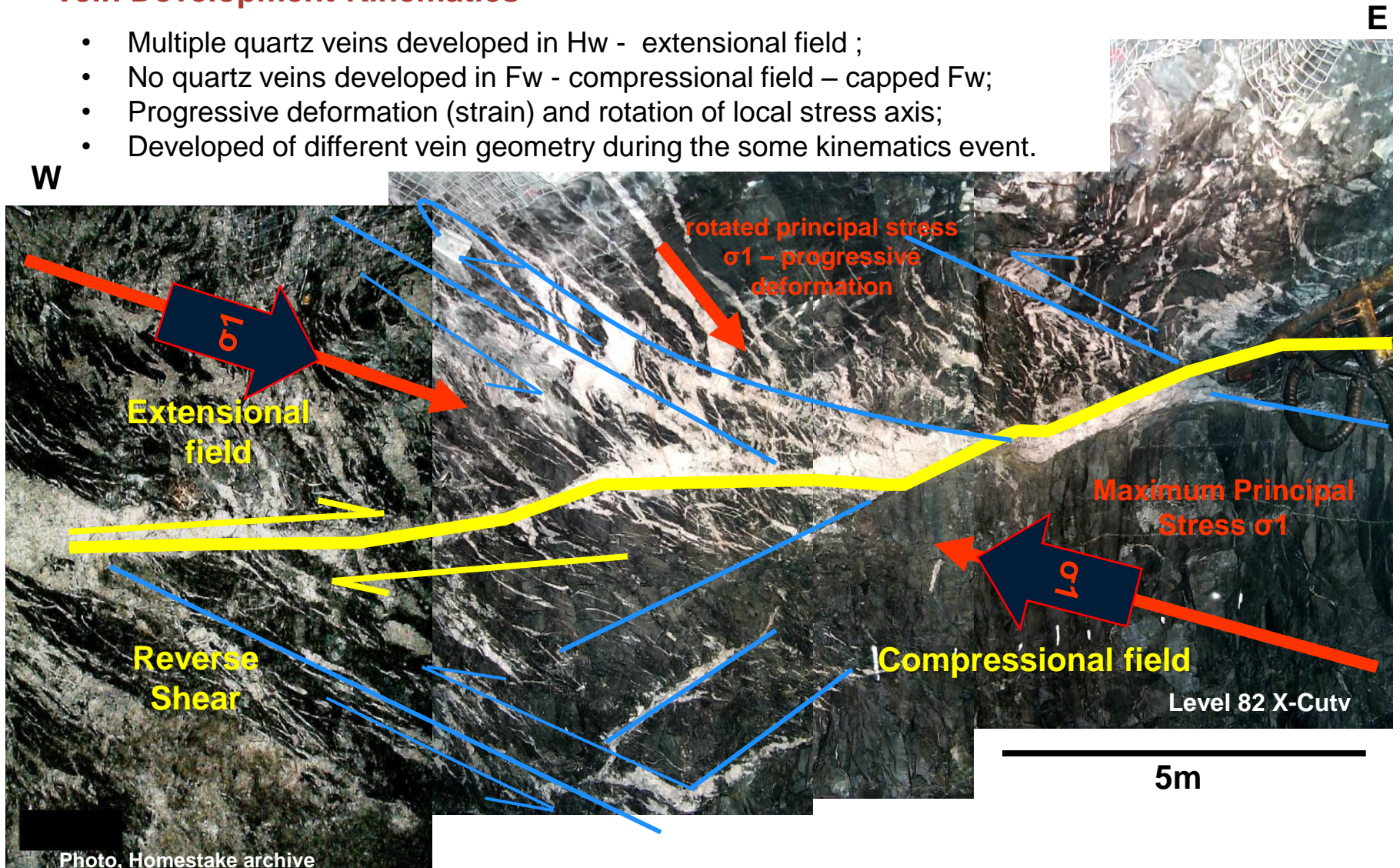
Flat lying, sigmoidal shear vein



# New Holland - Genesis Structural Kinematics

## Vein Development Kinematics

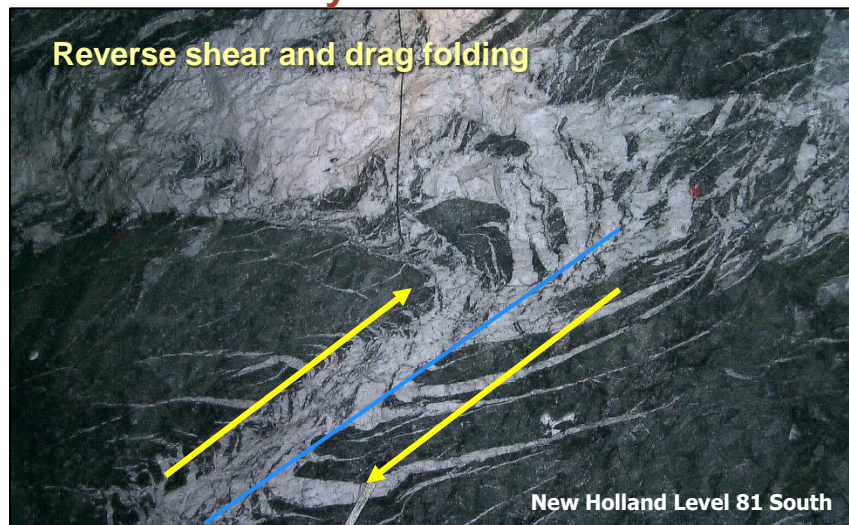
- Multiple quartz veins developed in Hw - extensional field ;
- No quartz veins developed in Fw - compressional field – capped Fw;
- Progressive deformation (strain) and rotation of local stress axis;
- Developed of different vein geometry during the some kinematics event.





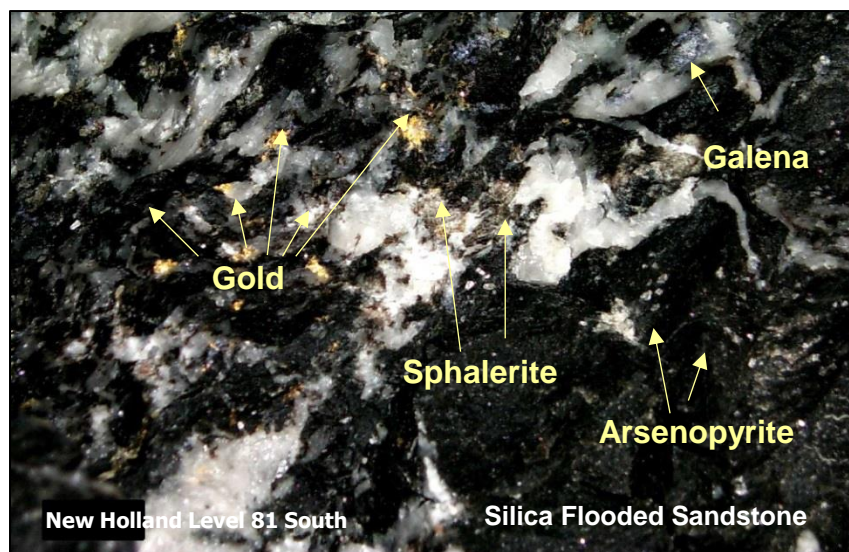
# New Holland - Genesis Structural Kinematics

## Vein Geometry



- Semi-brittle reverse shear zone in sandstone lithology (reverse structure);
- Syntectonic quartz vein formed during reverse displacement;
- Drag folded quartz vein implies progressive deformation in a simple shear tectonic environment.

## Vein Mineralisation



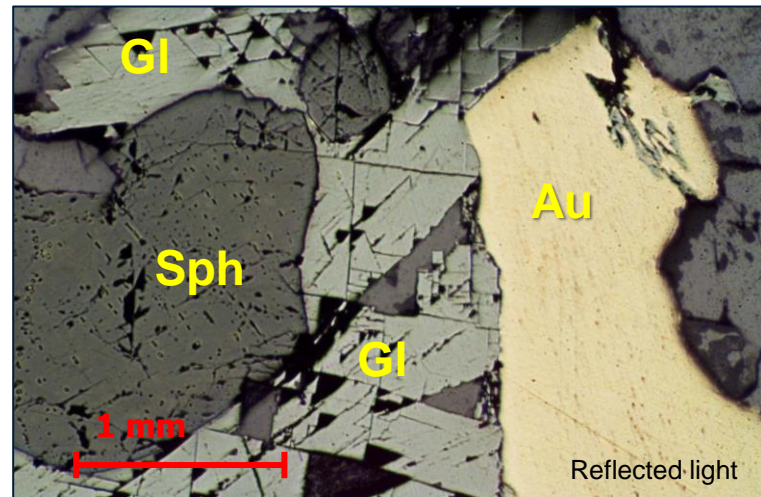
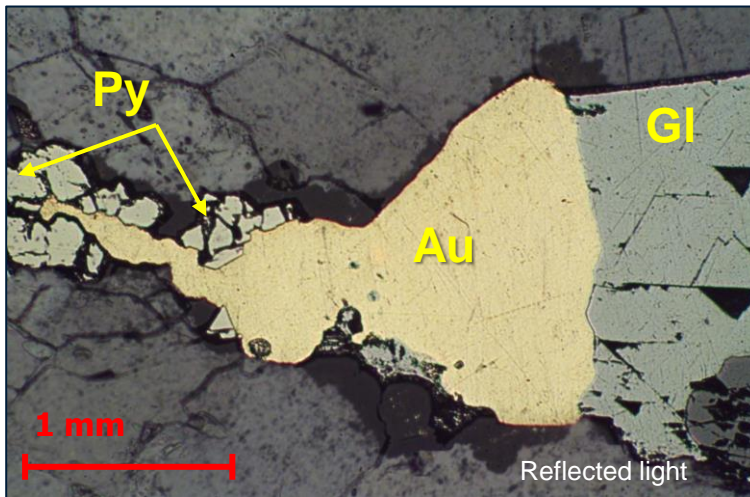
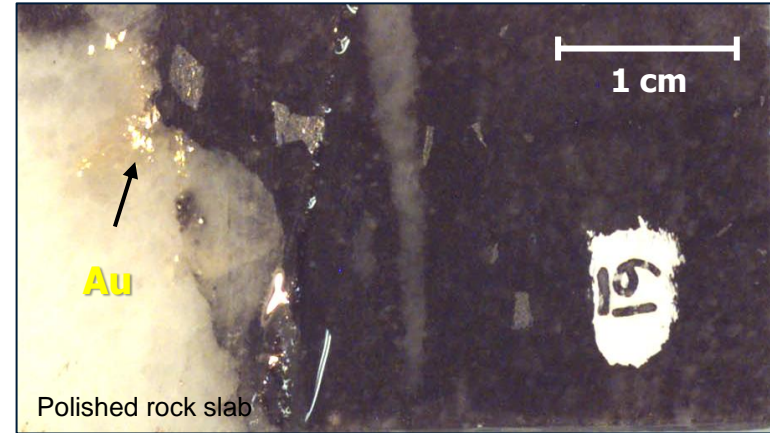
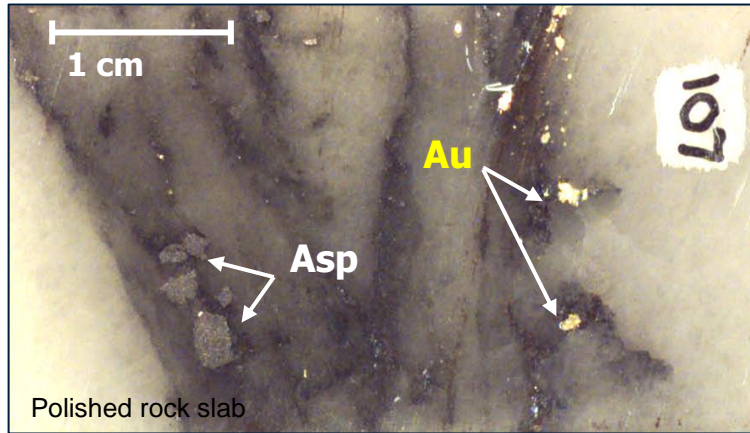
- Gold mineralisation is concentrated along lower contact of flat lying vein within wall rocks in an intense silicified wall rocks.
- Gold is associated with brecciation, silicification, chlorite and biotite alteration, disseminated arsenopyrite.
- Gold occurs with galena, pyrite, pyrrhotite and sphalerite.



# New Holland – Genesis Gold Mineralisation

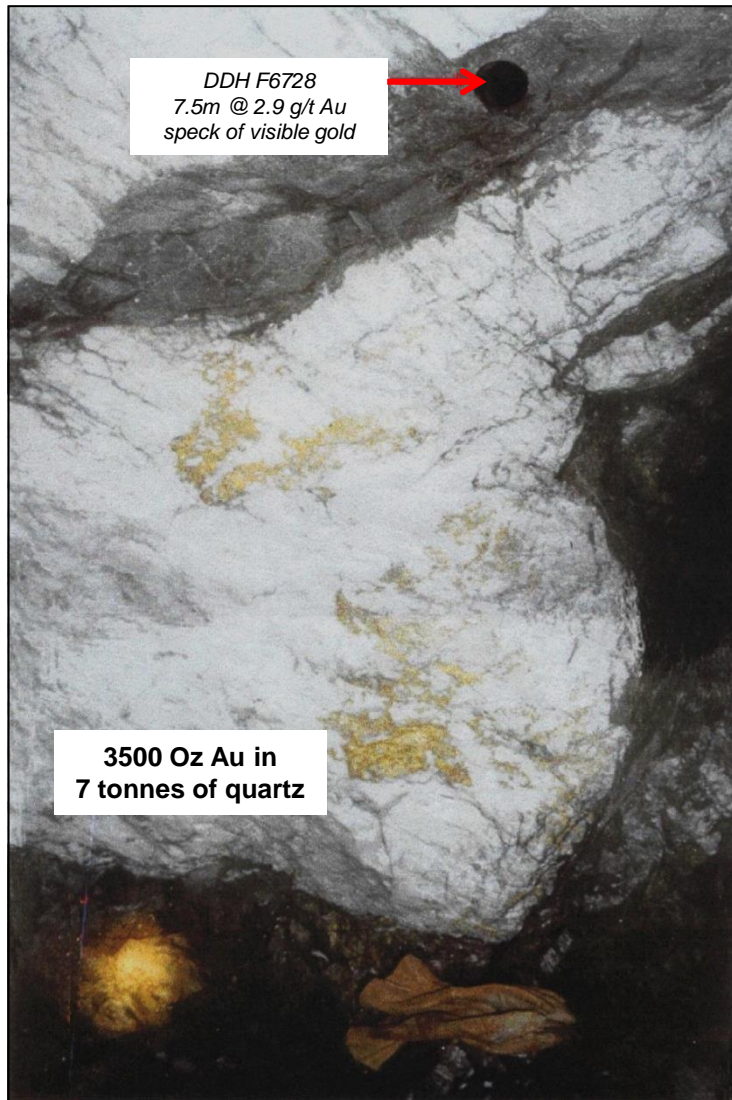
## Gold Mineralisation - Microphotography

- Crack-seal veinlets with visible gold on the quartz vein margins;
- Gold associated with pyrite, arsenopyrite, galena and sphalerite.



# New Holland – Genesis Gold Mineralisation

## Nugget Effect of Gold Mineralisation

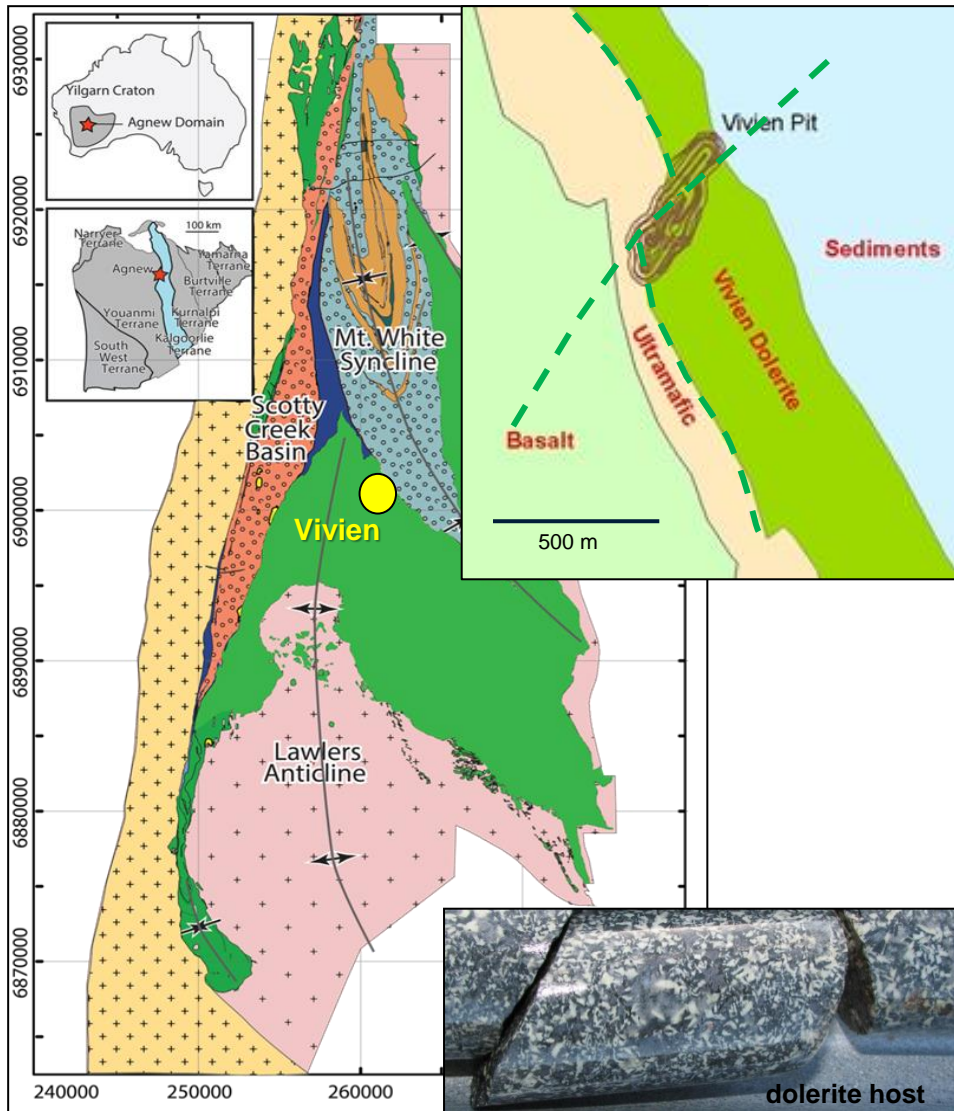


- Mineralisation is discontinuous – structurally with a pinch and swell character and a very high nugget effect in gold grade.
- Gold-grade correlation had to be conducted in conjunction with structure style, quartz type, quartz thickness, alteration style and structure type.
- Mineralised structures often if reactivated along shears locally can be constrained by a capping structure (Tasman-style) where Hw of Fw have a sharp cut in gold grade impaling a compression zone and kinematic of a lock-up environment with no displacement and no structure opening.



# Vivien Gold Deposit

## Geological Setting



## Historical facts:

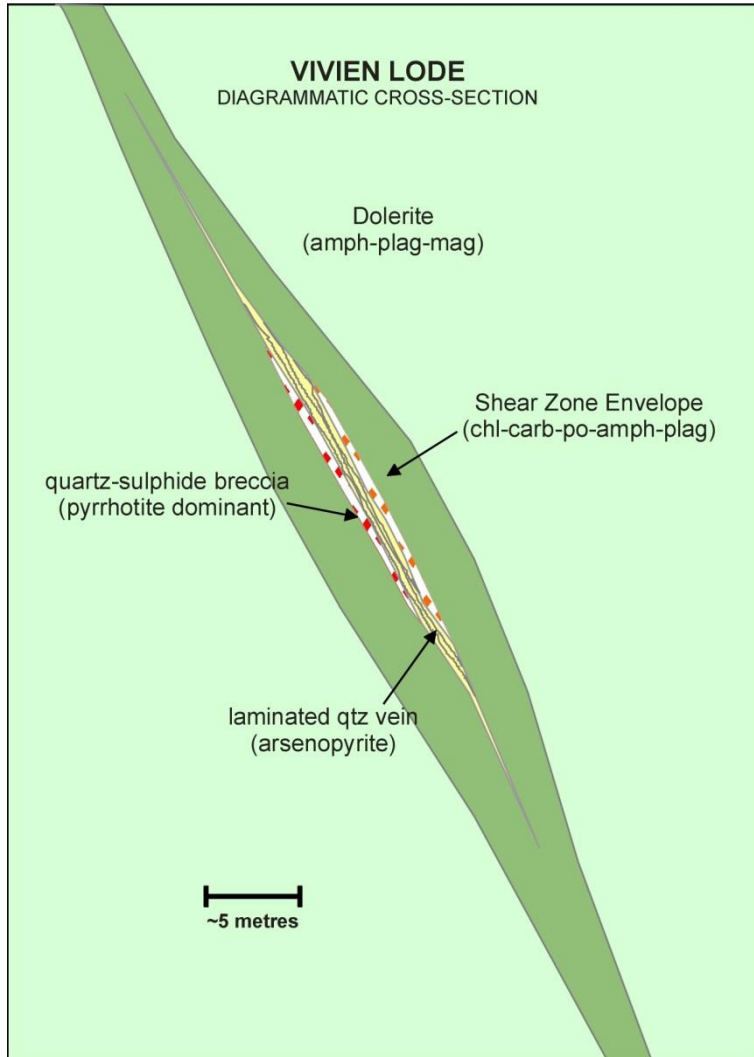
- The earliest recorded mining activity date from 1901 with a full-scale production by 1903;
- Large-scale mining ended in 1911, having produced 76,816 OzAu ore grading 11.2g/t Au;
- Smaller-scale operations continued in 1912-1914, 1936 and 1940-1941;
- Goldfields developed the deposit as an open pit operation in 1997 and produced 185 kOz @7.6 g/t;
- Currently deposit is mined by Remelius Resources as an underground operation;
- Historic production ~350 Koz from original underground and recent open pit.

## Geological features:

- Deposit is located on the Eastern Limb of the Lawlers Anticline within NE dipping, medium-grained diorite emplaced between arkosic metasediment to the NE and talc-carbonate-magnetite phyllite to SW;
- The NW trending synthetic shear zones in Vivien dolerite host and NE accommodation structure;
- Mineralisation in SE dipping shear zones/quartz veins in multiple NE plunging ore shoots.

# Vivien Deposit

## Mineralisation Style



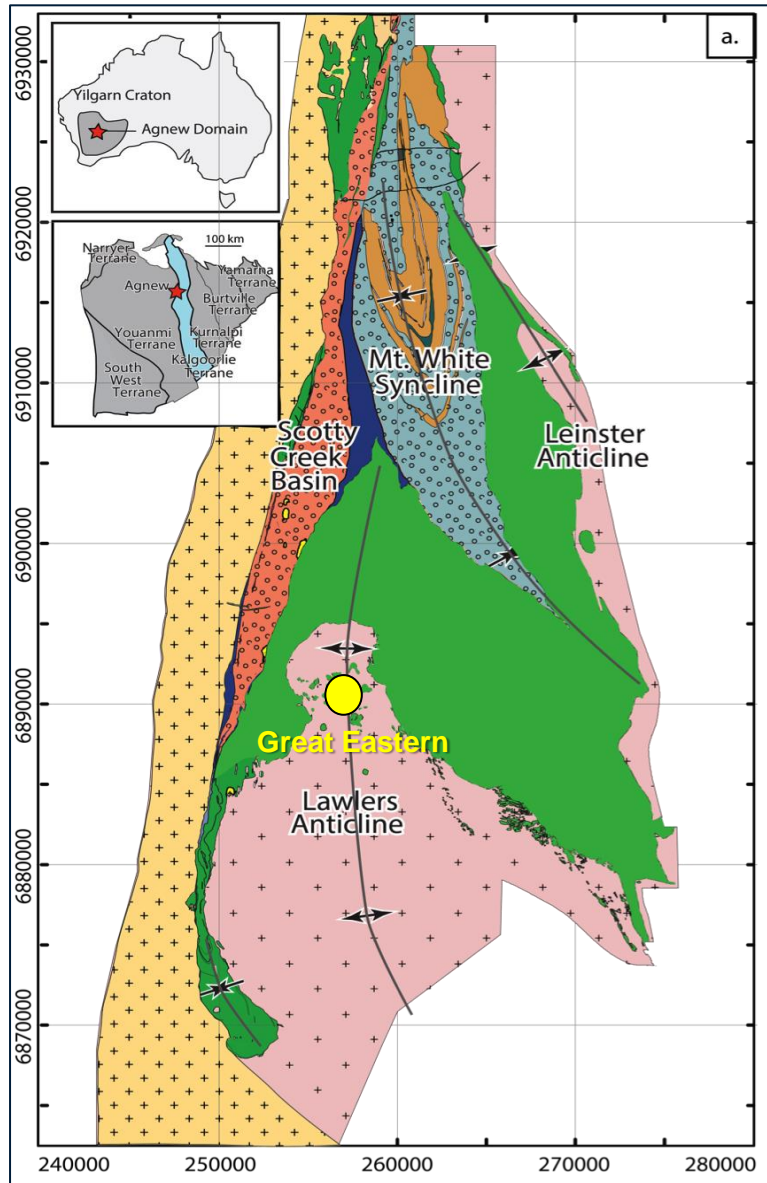
- Vivien mineralisation occurs as moderately (30-50°) dipping shoots (quartz veins) gentle plunge to north-west;
- Mineralisation is characterised with multiple vein sets limited within NE overlapping shear zones associated with massive sulphide veins (po, cpy) within a halo of disseminated sulphides (py, po, cpy).



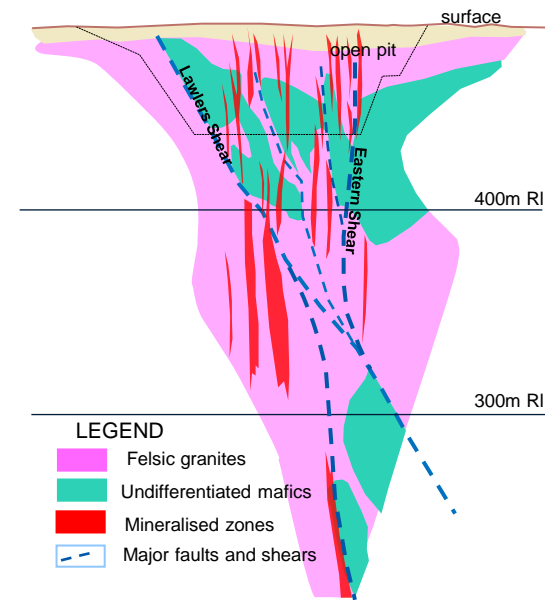


# Great Eastern Deposit

## Simplified Geology and Mineralisation



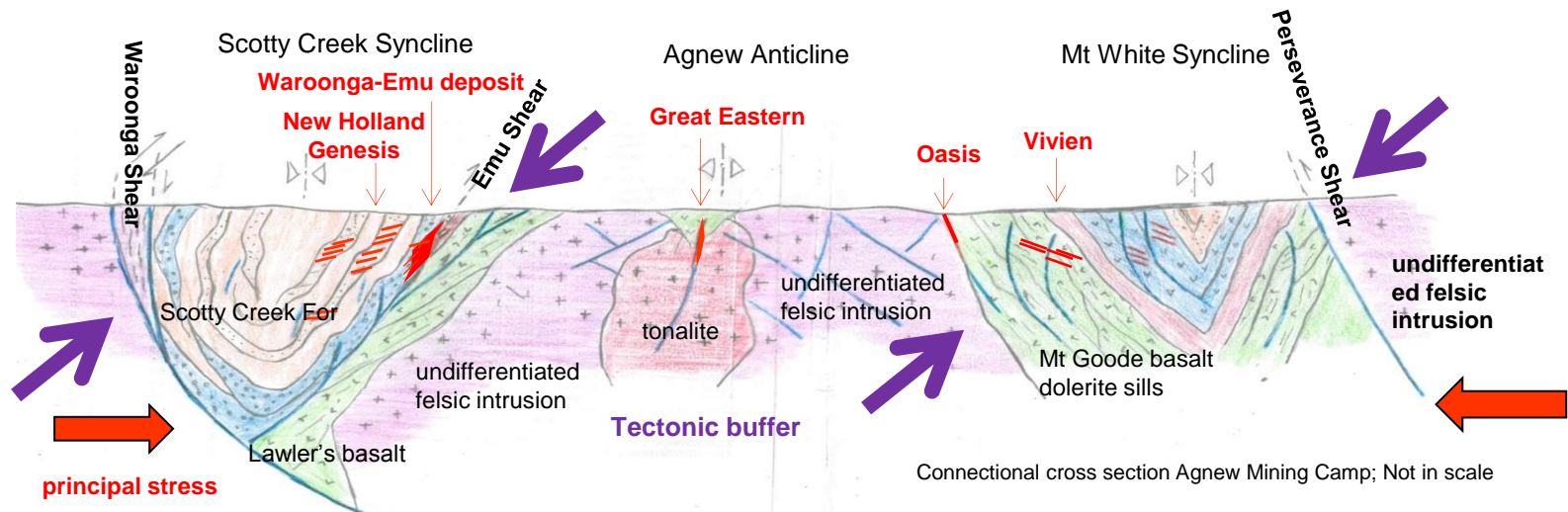
## Simplified geology cross section



- Historically, Great Eastern produced 235 kOz@11g/t Au @16.3 g/t Au;
- Gold mineralisation is hosted in felsic intrusion (tonalities) and on the contact felsic intrusion and mafic;
- Mineralisation is controlled with E-W trending, 20m - 30m wide zone of Caroline structure delineated with Eastern and Lawlers shears;
- Mineralisation occurs as multiple pinch and swell array of quartz veins and breccia zones interconnected with tension gashes;
- Mineralised shoots are steeply (80°) dipping to north with a gentle plunge to west; with a strike >800m and depth extension >400m.
- Source of gold is probably magmatic.

# Mineralisation Trap - Structural Control

## Structural Control – Compressional - Transpressional Thin-skinned Tectonic Style



### Waroonga, Redeemer – compressional inversion structures controlled with Emu shear

- NE trending reverse oblique slip fault zone with overlapping pattern (strike-slip and reverse); dilation and compressional bends and jogs and fault nucleation and termination;
- Second order fault splays, structural junction and triple junction of NE trending structures and NNW trending accommodation structures.

### Vivian, Fairylands– compressional inversion structures

- NNW faults and shears formed as a pre-buckle thrust faults with overlapping faults (strike slip and reverse) associated with accommodation SW and NE structures activated in transtensional regime;

### New Holland - Genesis– transtensional inversion structures

- NNW flexural zones and shears and their overlapping areas in strike slip oblique-reverse kinematics (coarse arenitic lithology);
- Flat laying reverse oblique slip faults (insignificant displacement) formed in a interaction zone between Waroonga and Emu shear zones.

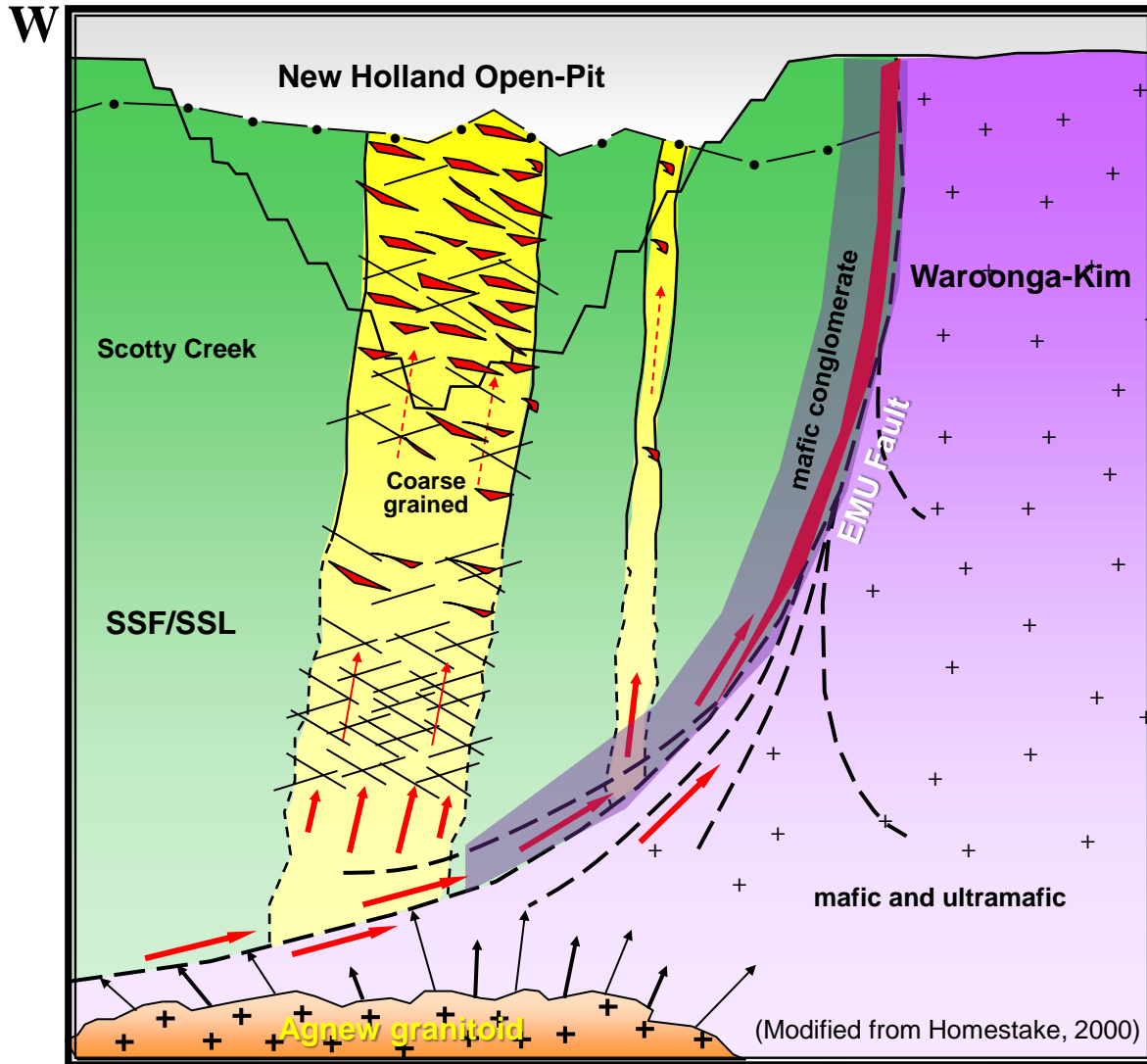
### Great Eastern – compressional inversion structures

- W-E tension faults developed in anticline hinge with strike slip components associated with N-S extension;
- Interference of extension faults developed in extensional field of compressional tectonic regime.



# Geology Overview

## Mineralisation Model



### Stage 1: Pervasive hydrothermal alteration → post-D2, pre-D3

- Pervasive, early hydrothermal alteration overprinting regional metamorphic mineral assemblage;
- Hydrostatic pressure < lithostatic pressure; no brittle fracture of coarse grained units.

### Stage 2: Hydrothermal alteration associated with Au / sulphide mineralisation → syn-D3 and

- Hydrostatic pressure exceeds lithostatic pressure; brittle fracture occurred in sandstone packages;
- Formation of gold bearing quartz veins;
- Fine-grained sandstone and siltstone behave in ductile manner.

### Stage 3: Minor, late stage hydrothermal alteration → syn-D3 (late)

- Late stage fluid movement / pulse along brittle-ductile fractures and shear zones.

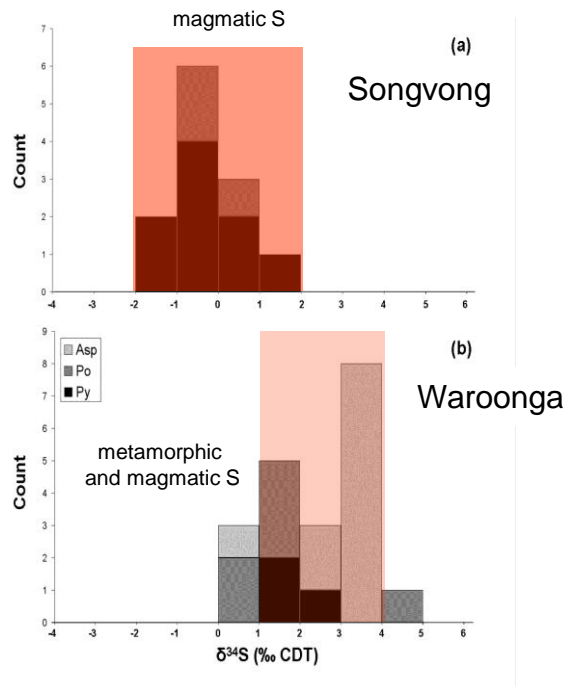
# Ore Genesis Model

## Fluid Source, Path and Depositional Trap

### Fluid sources ( $\Delta 34S$ and metal zonation):

- magmatic fluid;
- metamorphic fluid;
- mixed source.

### Stable isotope S34



### Fluid path ( $\Delta 34S$ and metal zonation):

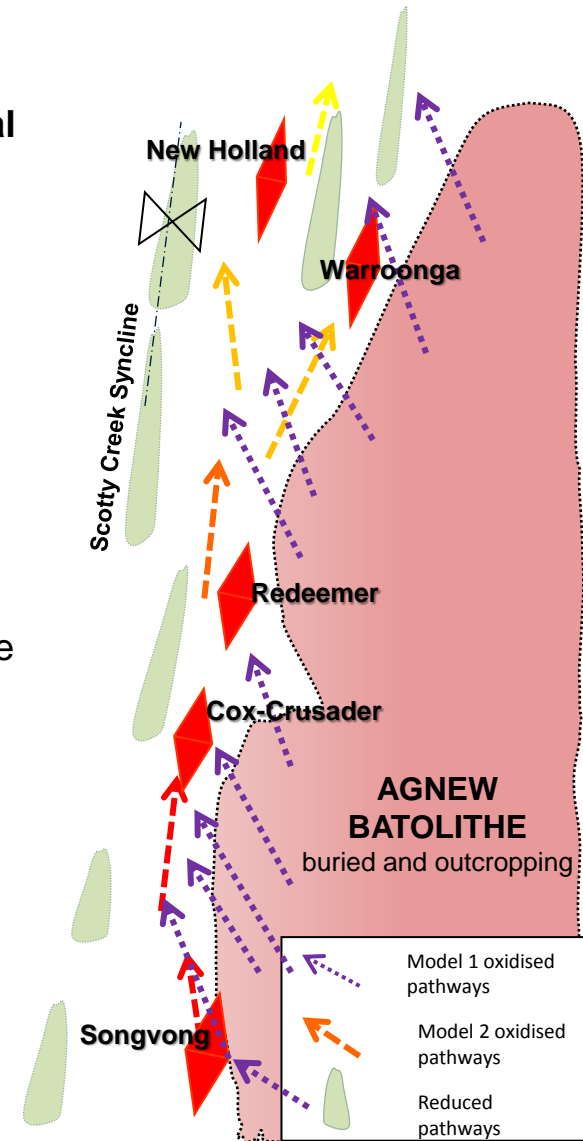
- regional  $340^\circ$  structures;
- permeable lithology of Scotty Creek Formation;
- combination of both.

### Depositional trap:

- structure opening – suction pump formed in basin inversion phase causing sudden pressure and temp drop;
- redox property of coarse grained lithology.

### Post mineralisation:

- metamorphic modification;
- exhumation and preservation.



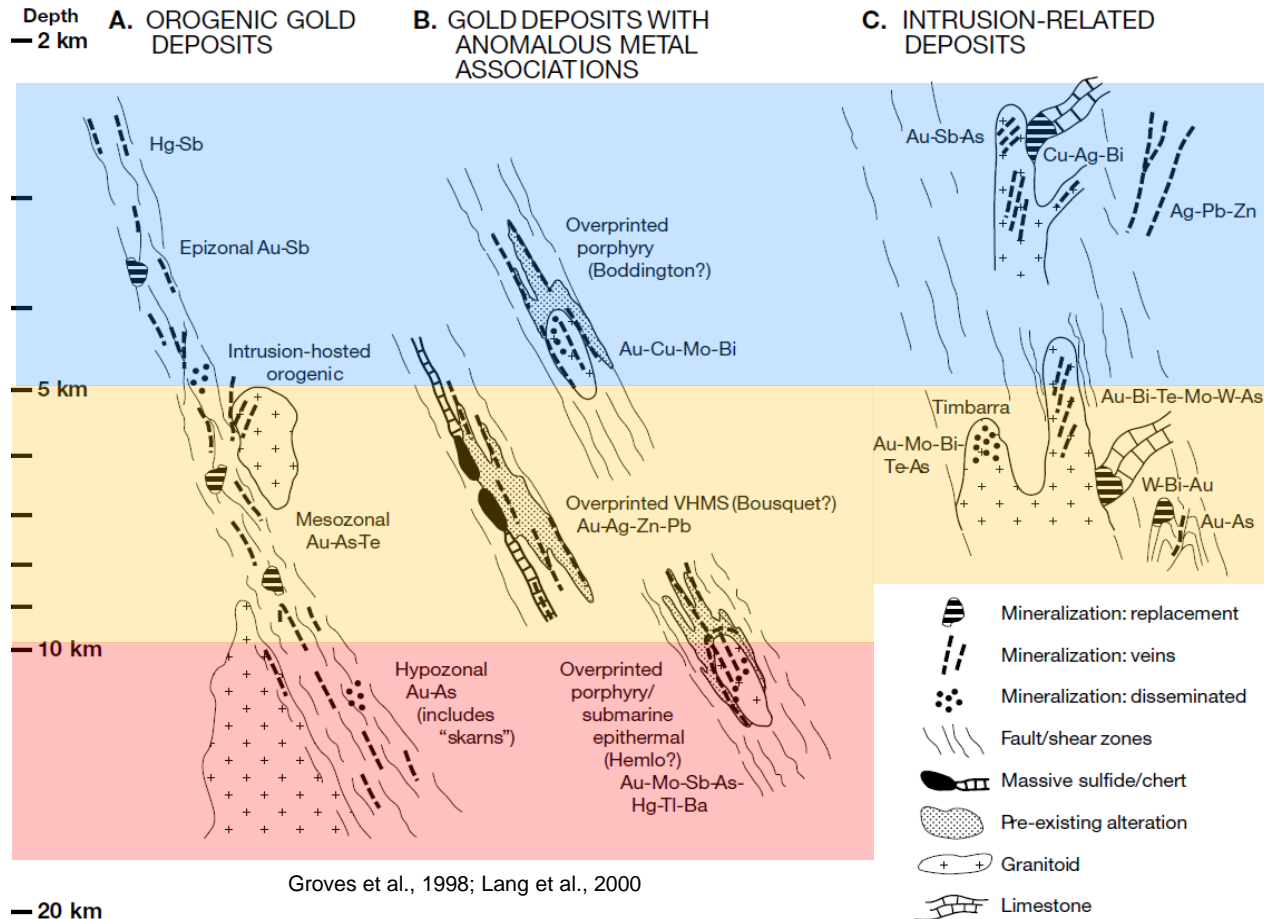
Modified from CSIRO, 2011, L. Fisher, S. Barnes, J. Cleverley, I. Sonntag, R. Hough



**“Qui audit, adipiscitur”** - fortune favours the brave who dare to enquire –

## Genetic Models - Crustal Environment - Associations

What were precursor deposits? Where were precursor deposits?



### What were precursor deposits?

- VMS, IRGS, porphyry, epithermal ??
- Metamorphosed up to amphibolite facies; - mineralisation pre-date metamorphism??
- Geometry is structurally controlled - overprinted and transposed;
- Structurally up-graded – and chemically/mechanically re-mobilised.



# Gold mining future?