

Proterozoic Mafic-Ultramafic Magmatism in Australia: Geological Settings and Metallogeny

Dean Hoatson, Jon Claoué-Long & Subhash Jaireth

Contributions from:
Lynton Jaques & Mike Huleatt



Australian Government Geoscience Australia



Australian Nickel Conference 22-23<sup>rd</sup> October 2008 GEOSCIENCE AUSTRALIA



# Critical Questions for Explorers ...

Where are the mafic-ultramafic magmatic systems?

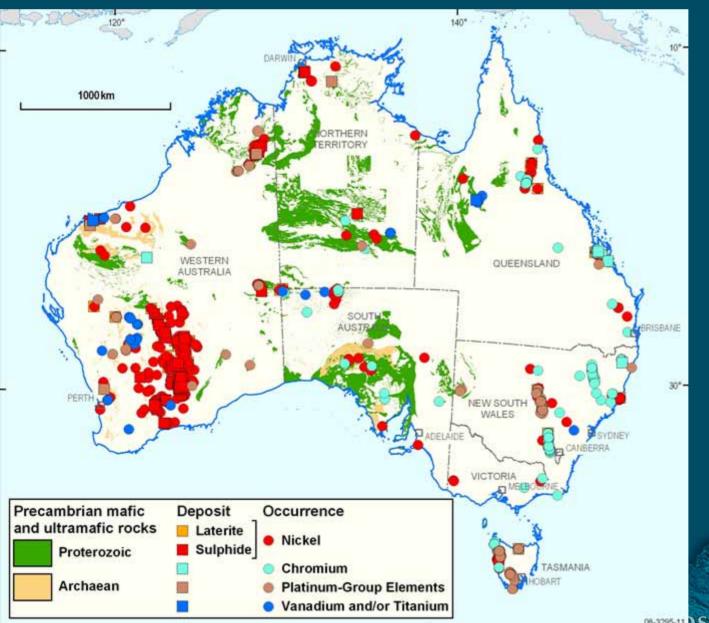
Which Magmatic Events are the big ones?

Which Magmatic Events have ultramafic magmas?

Can crustal structures narrow the exploration focus?



## **Mafic-Ultramafic Rock Associated Mineral Deposits**



Deposits:
Phanerozoic
Proterozoic
& Archaean

Where are the Proterozoic deposits?

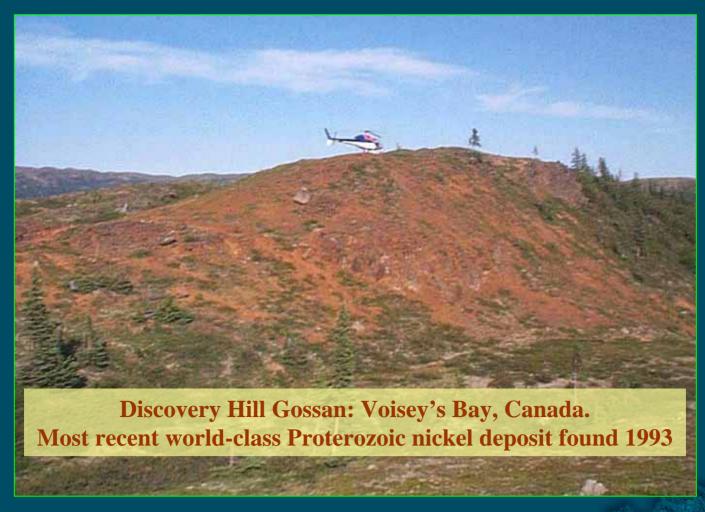
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## Australian Ni-PGE discoveries 1962 to 2008



# **Identifying Fertile Provinces**



**Photograph: Data Metallogenica** 



## Proterozoic Mafic-Ultramafic Magmatic Events: Geoscience Australia Initiative to Assist Explorers

## Timeframe of Project:

Phase 1 (2006): Western Australia

Phase 2 (2007): Northern Territory & South Australia

**Phase 3 (2008): Australia** 

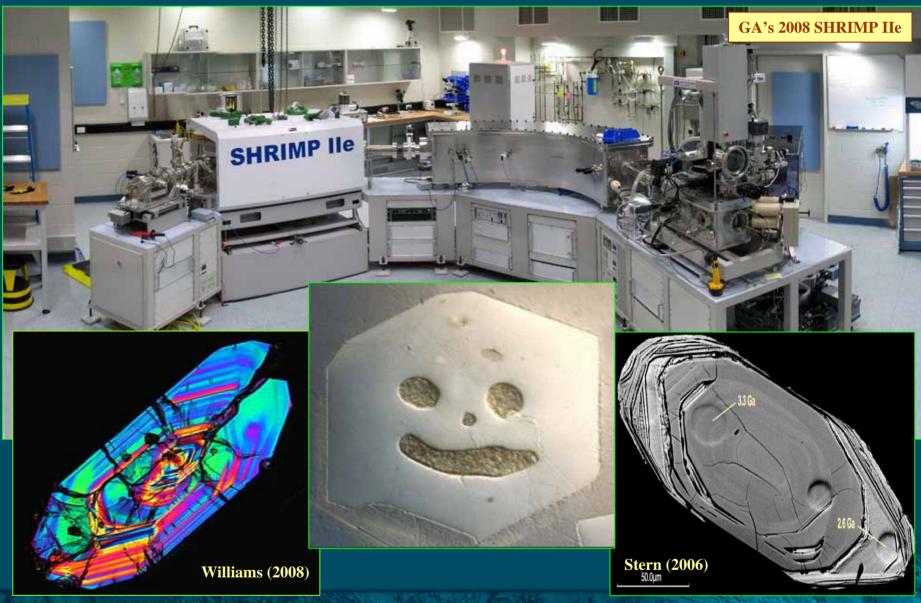
Phase 4 (2009): (1) Archaean mafic-ultramafic rocks of Australia, and

(2) Proterozoic Large Igneous Provinces

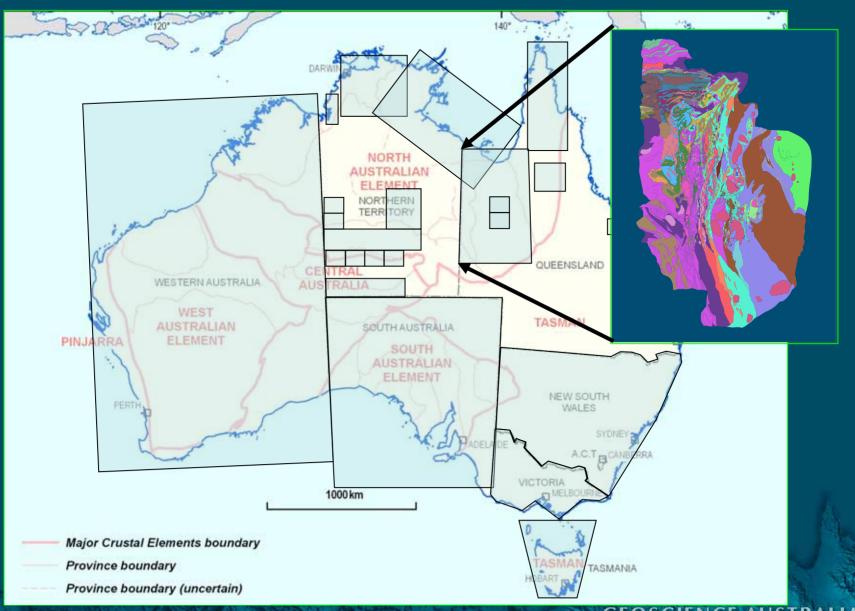
# Methods

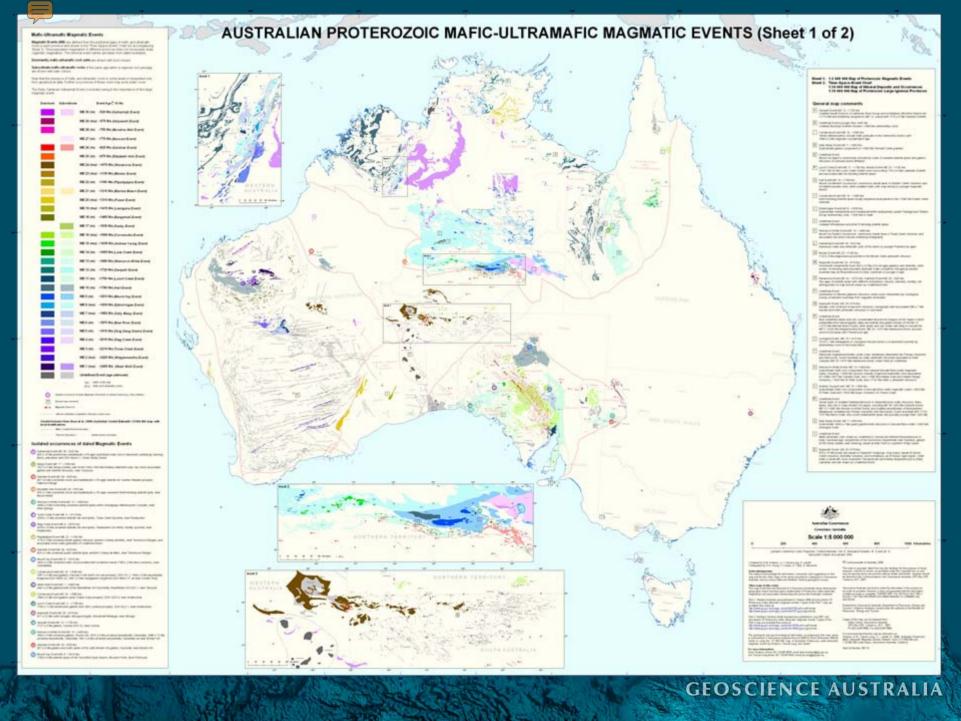
- Event: Probable geological incident of significance that is suggested by isotopic, geological, or other evidence
- Characterisation of Proterozoic Mafic-Ultramafic Rocks: Province, Formation, Age, Rock Types, Bulk Composition, Setting, Mode of Occurrence, Thickness, Country Rocks, Mineralisation. ARC GIS 9.2 environment
- Input 1: Magmatic Event Criteria. Several hundred, reliable (>90% U-Pb zirc/badd) ages of mafic & ultramafic rocks
- Inputs 2 & 3: Major Crustal Elements and Solid Geology Base Maps. Economic potential → important to assess total areal extent/volume of magmatic system

# **Input 1: Geochronology**



## Inputs 2 & 3: Crustal Elements and Solid Geology Maps







### AUSTRALIAN PROTEROZOIC MAFIC-ULTRAMAFIC MAGMATIC EVENTS (Sheet 2 of 2)





### Non-Steam Steam Chart

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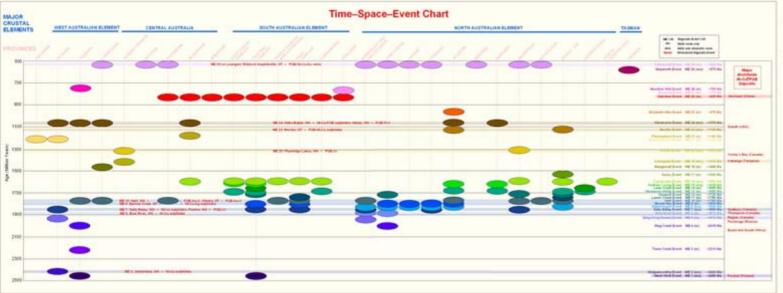
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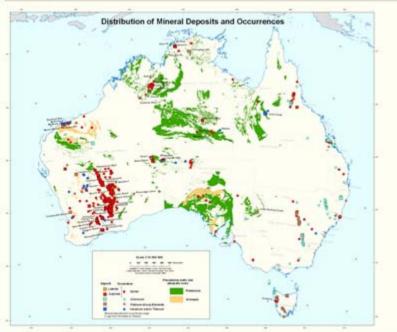
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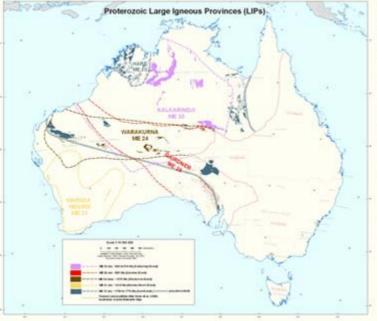
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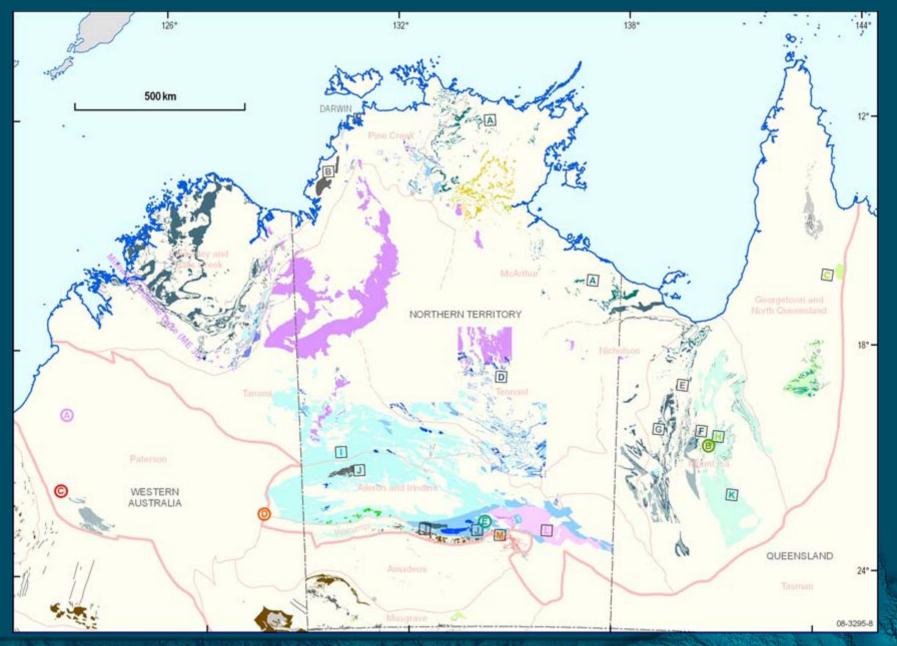
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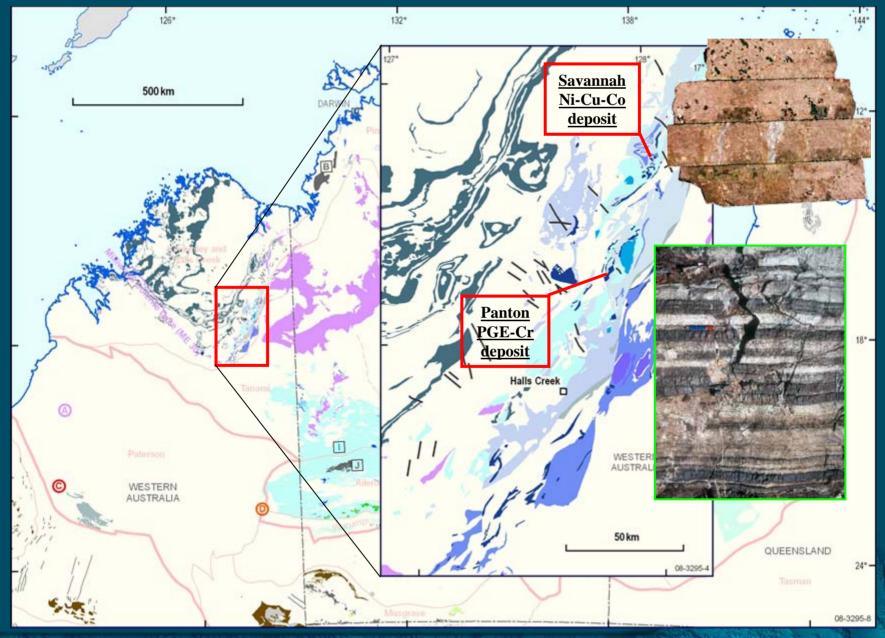












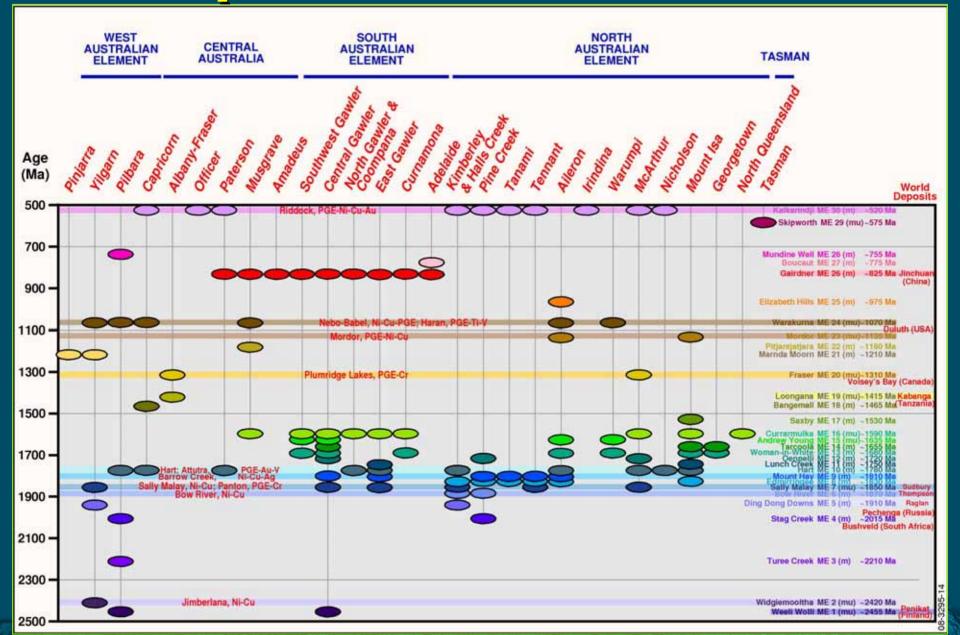
# Magmatic Events Major mafic-ultramafic rocks = bold colours

# **Minor mafic-ultramafic rocks with other rocks = pale colours**

Major Minor E	went Age +10 Ma	Major M	liner	Fuent Age	+10 M=
	vent Age ±10 Ma	Major M		Event Age	\$\pi_0,0000000
ME 30:	~520 Ma Kalkarindji		М	E 14: ~1655 Ma	Lane Creek
ME 29:	~575 Ma Skipworth		М	E 13: ~1680 Ma	Woman-in-White
ME 28;	~755 Ma Mundine Well		М	E 12: ~1720 Ma	Oenpelli
ME 27:	~775 Ma Boucaut		М	E 11: ~1750 Ma	Lunch Creek
ME 26:	-825 Ma <i>Gairdner</i>		М	E 10: ~1780 Ma	Hart
ME 25:	~975 Ma Elizabeth Hills		М	E 9: ~1810 Ma	Mount Hay
ME 24:	~1070 Ma Warakurna		М	E 8: ~1830 Ma	Edmirringee
ME 23:	~1135 Ma <i>Mordor</i>		М	E 7: −1850 Ma	Sally Malay
ME 22:	~1180 Ma <i>Pitjantjatjara</i>		М	E 6: ~1870 Ma	Bow River
ME 21:	-1210 Ma Marnda Moorn		м	E 5: -1910 Ma	Ding Dong Downs
ME 20:	~1310 Ma Fraser		М	E 4: ~2015 Ma	Stag Creek
ME 19:	~1415 Ma Loongana		М	E 3: ~2210 Ma	Turee Creek
ME 18:	~1465 Ma Bangemall		М	E 2: -2420 Ma	Widglemooltha
ME 17:	-1530 Ma Saxby		М	E 1: −2455 Ma	Weeli Wolli
ME 16:	~1590 Ma Curramulka		U	ndefined Event (a	ige unknown)
ME 15:	~1635 Ma Andrew Young				

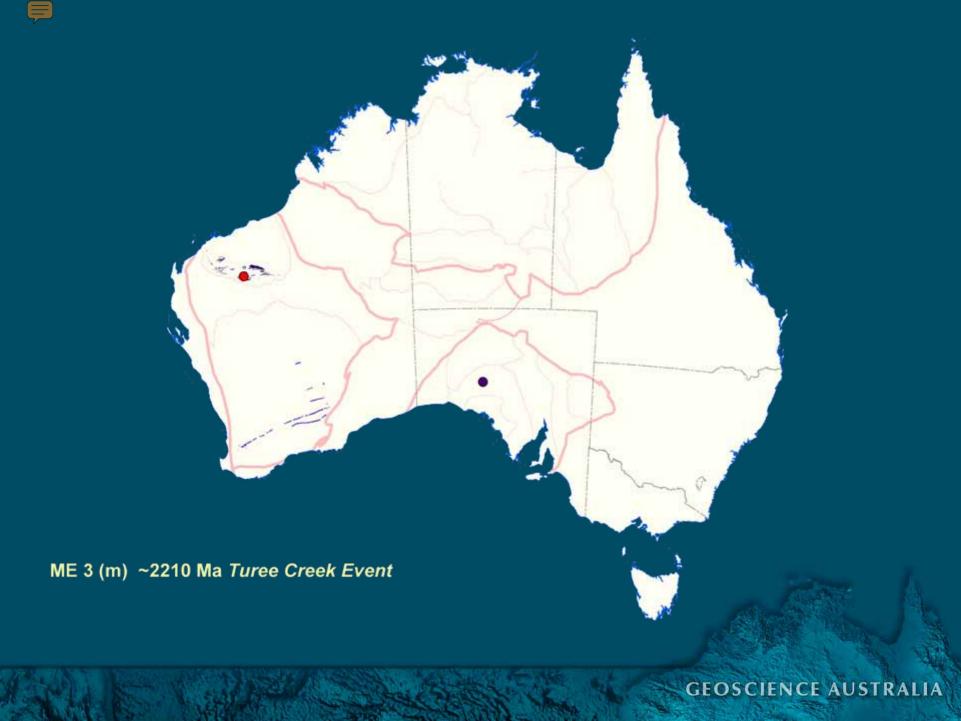


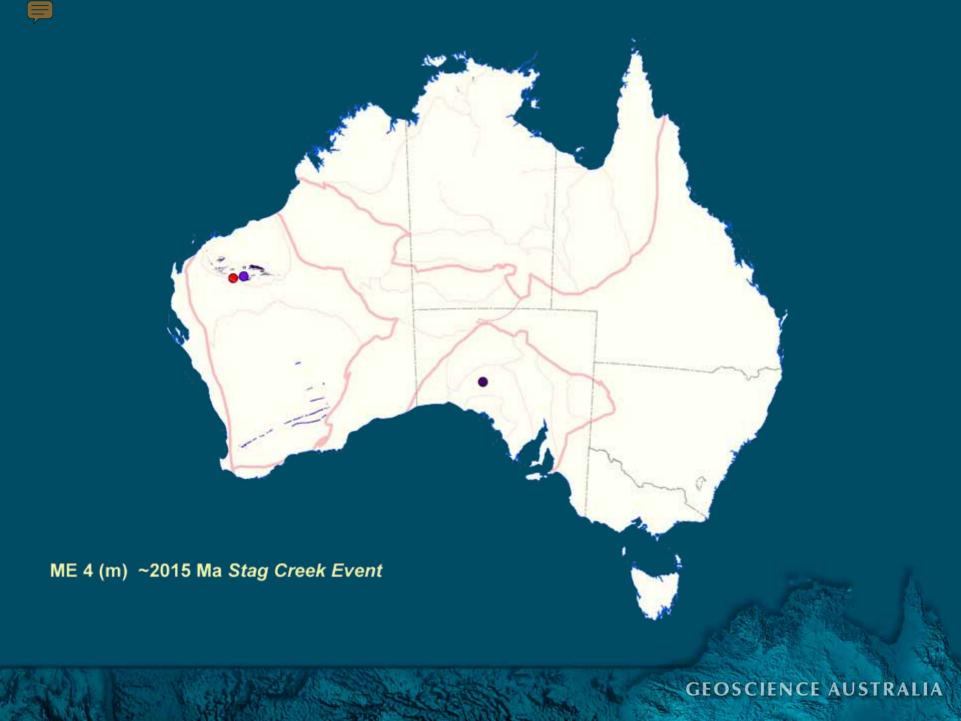
## Time-Space-Event Chart: 30 Proterozoic Events

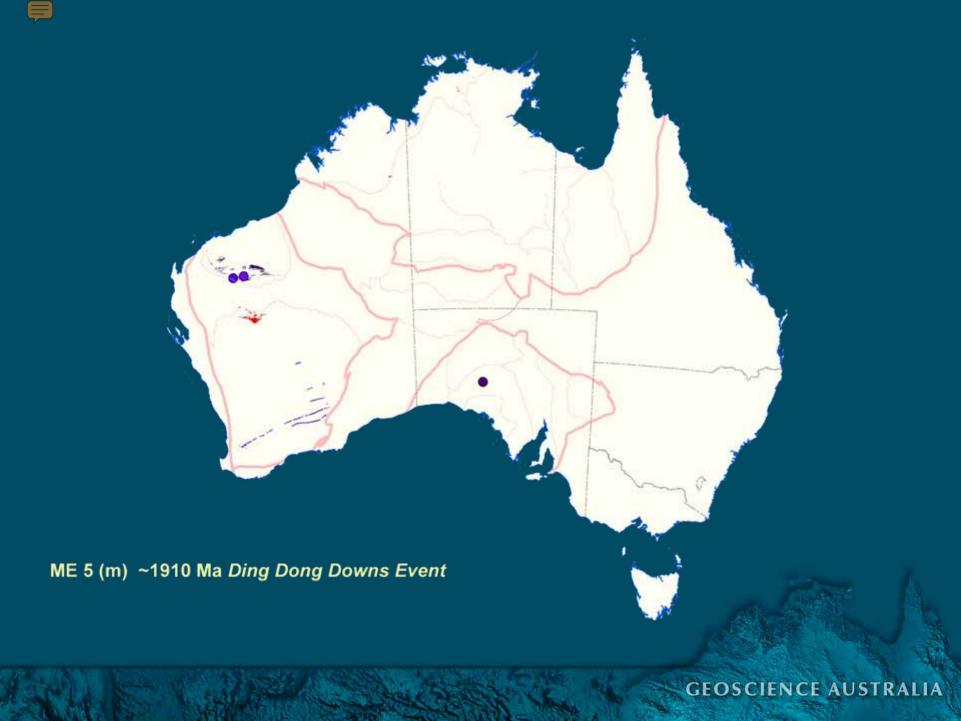


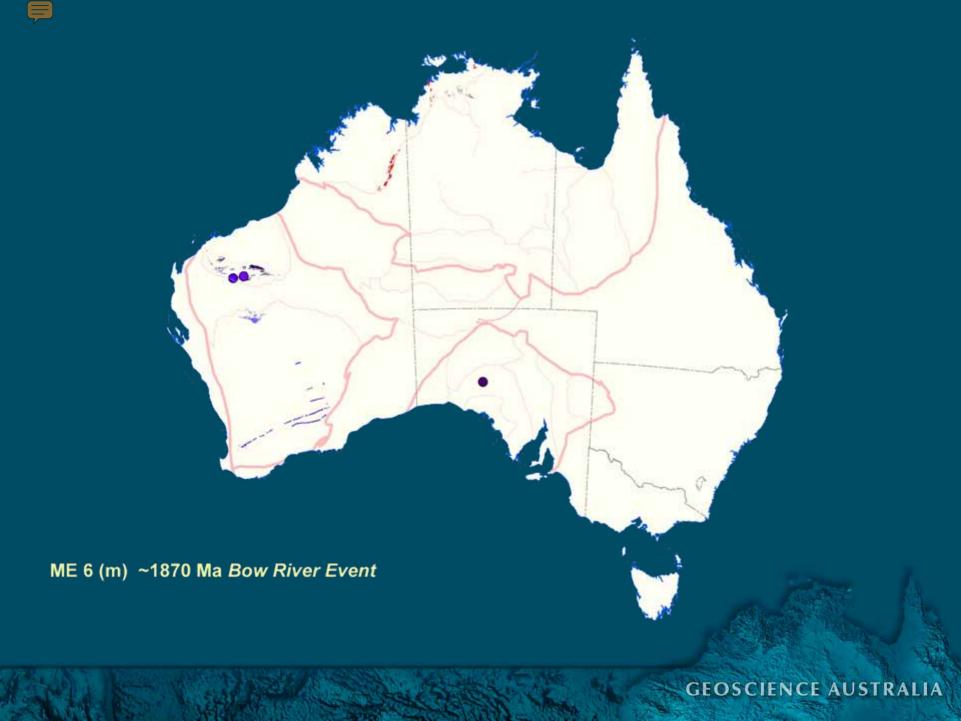
# Time-Slice Maps of 30 Proterozoic Magmatic Events ME 1 (mu) ~2455 Ma Weeli Wolli Event GEOSCIENCE AUSTRALIA



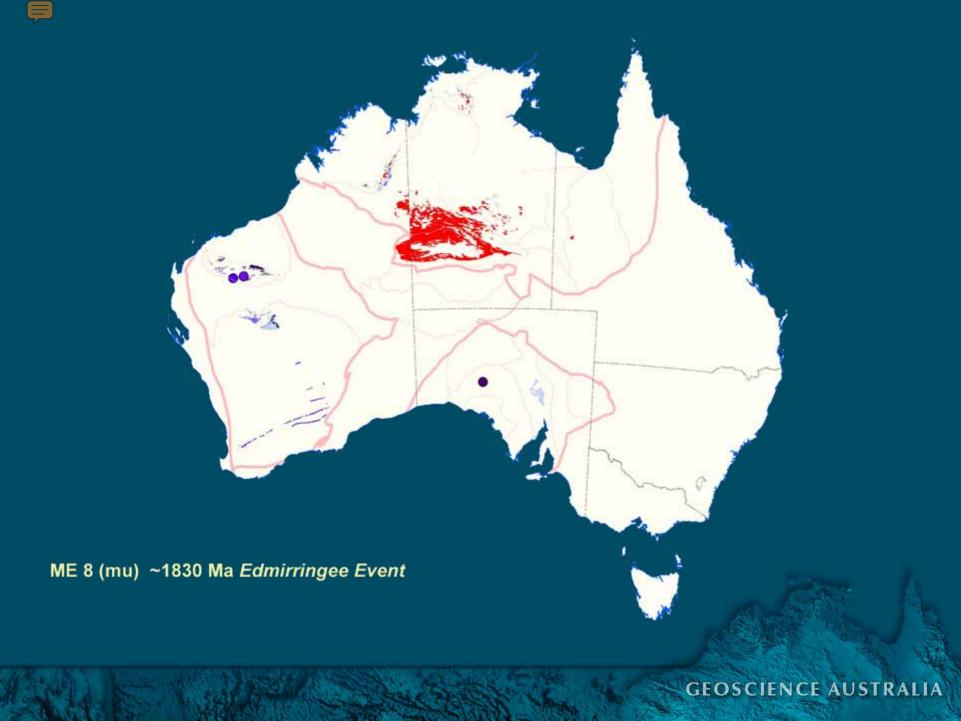


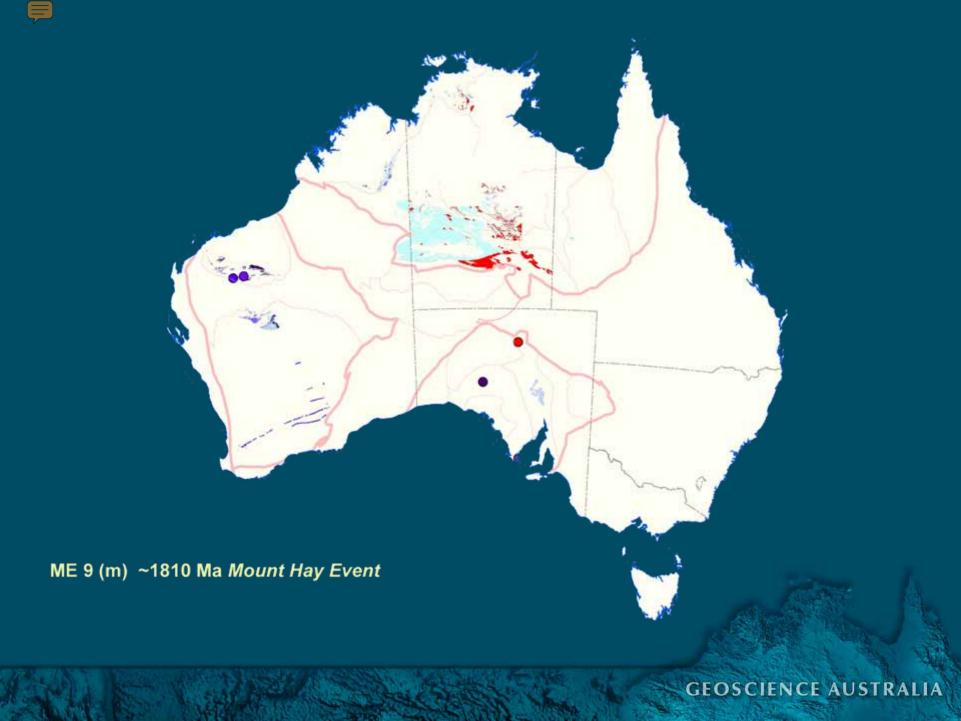


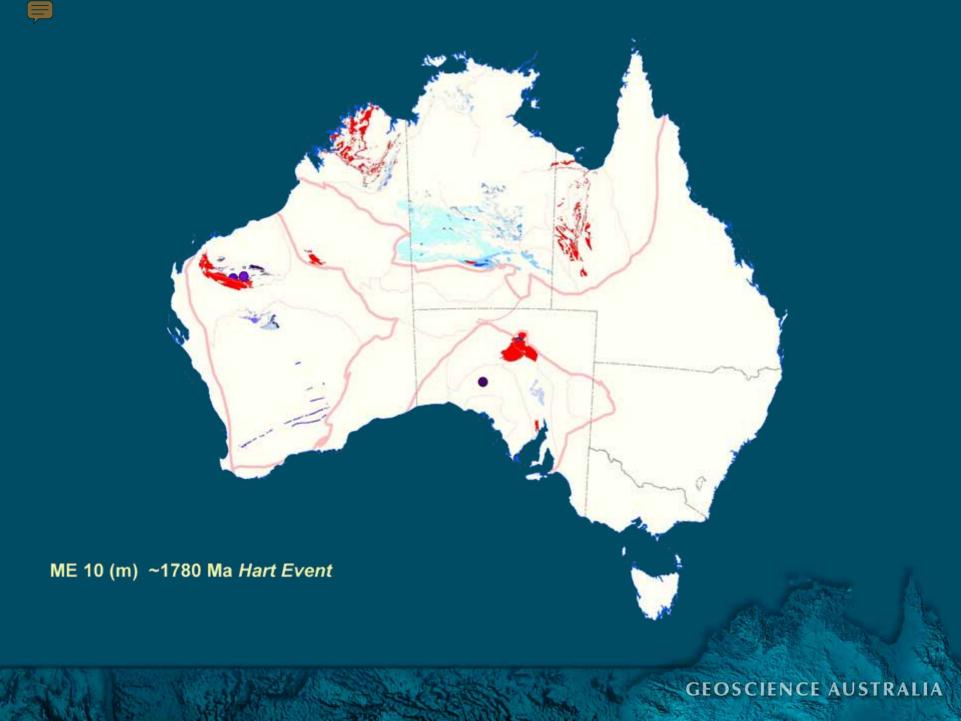


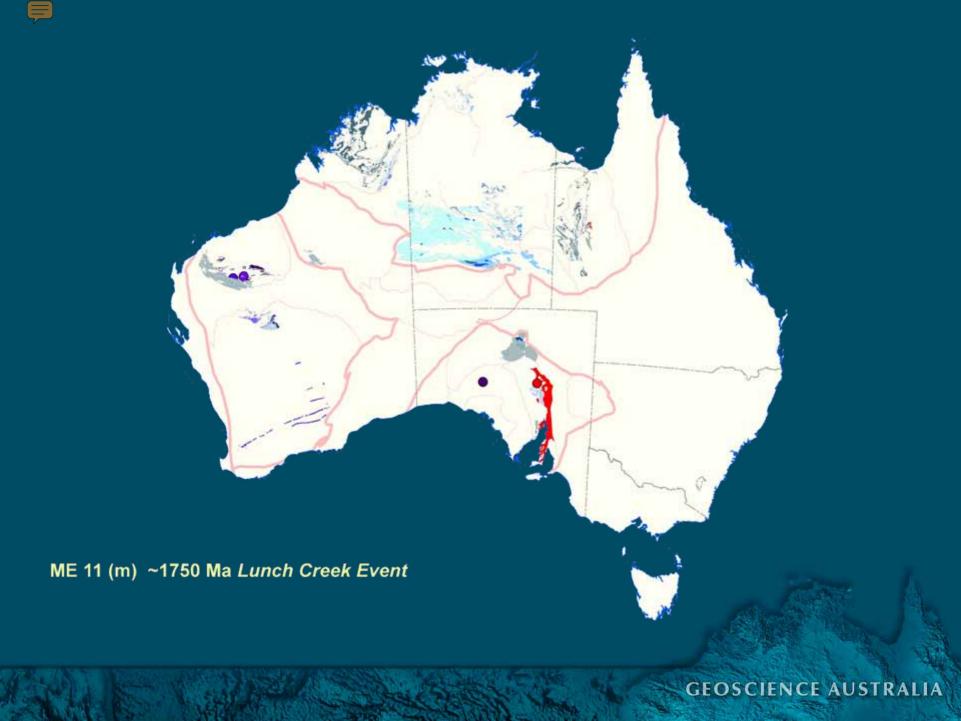


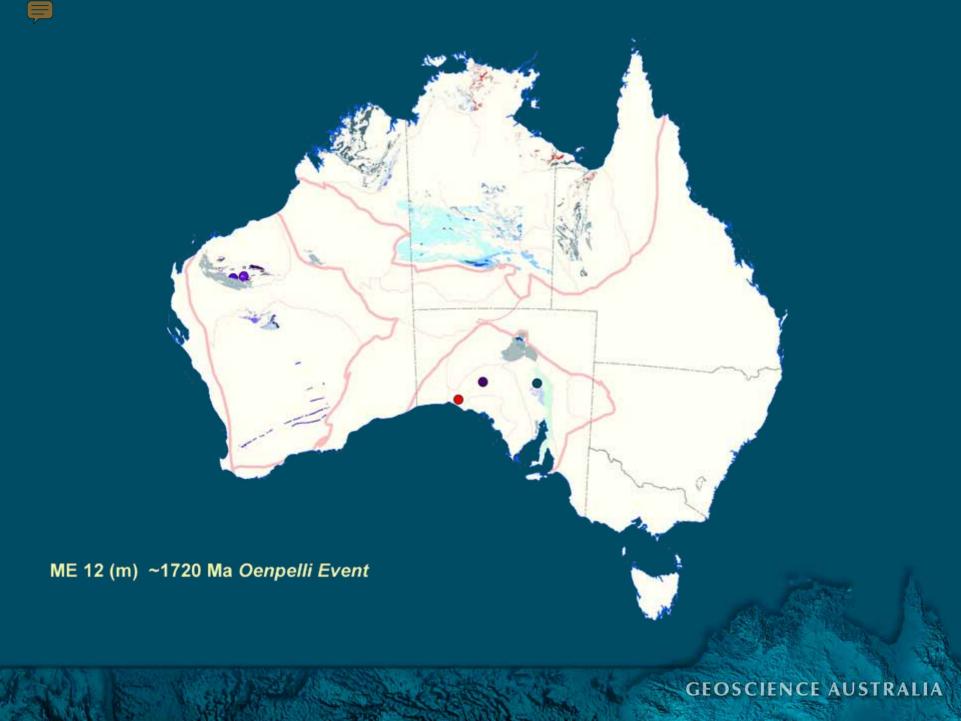




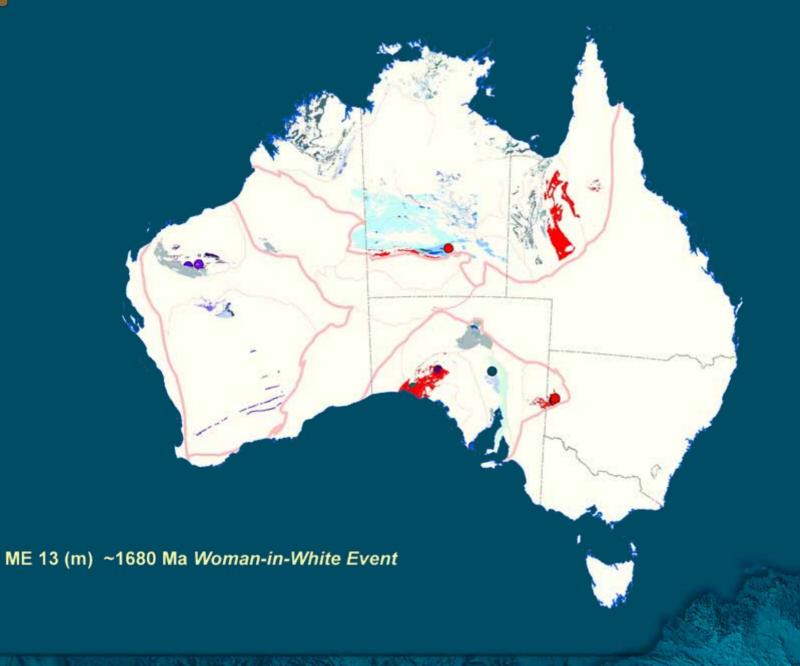


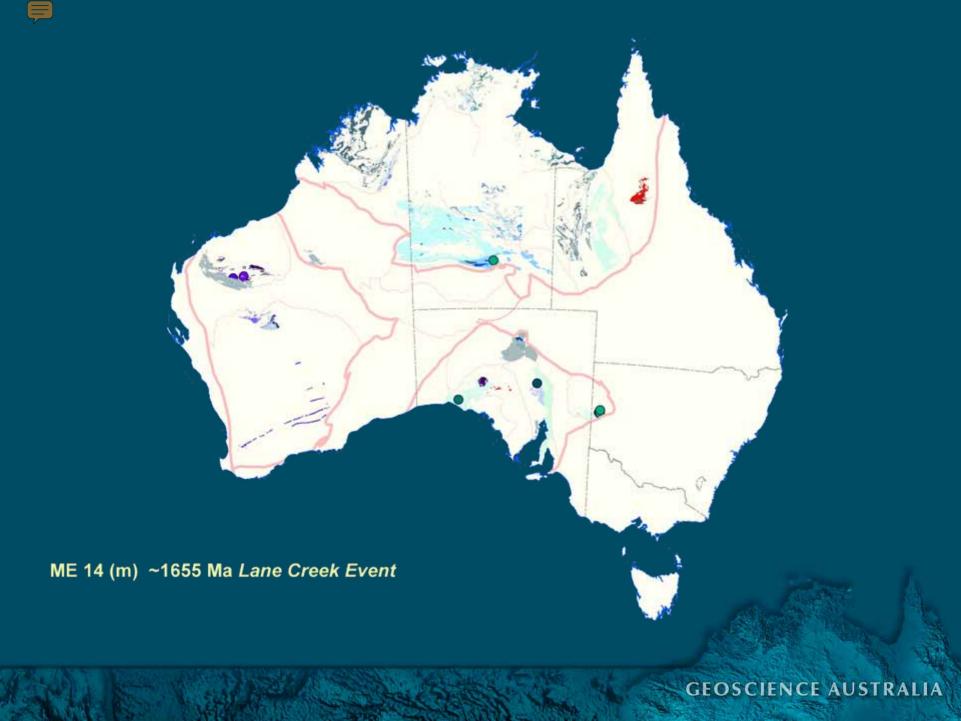


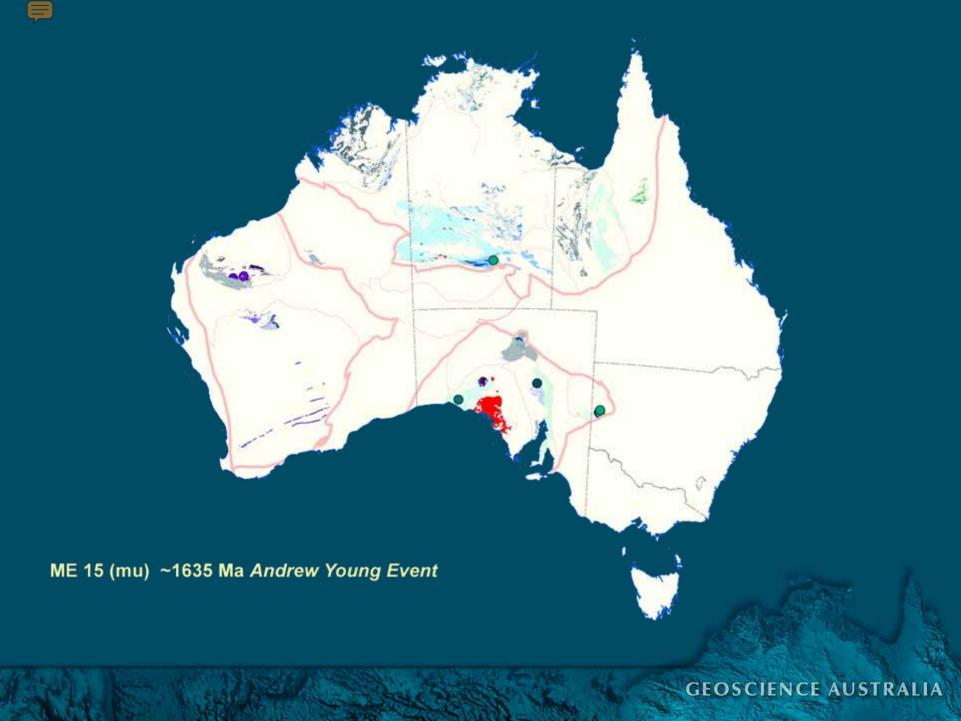


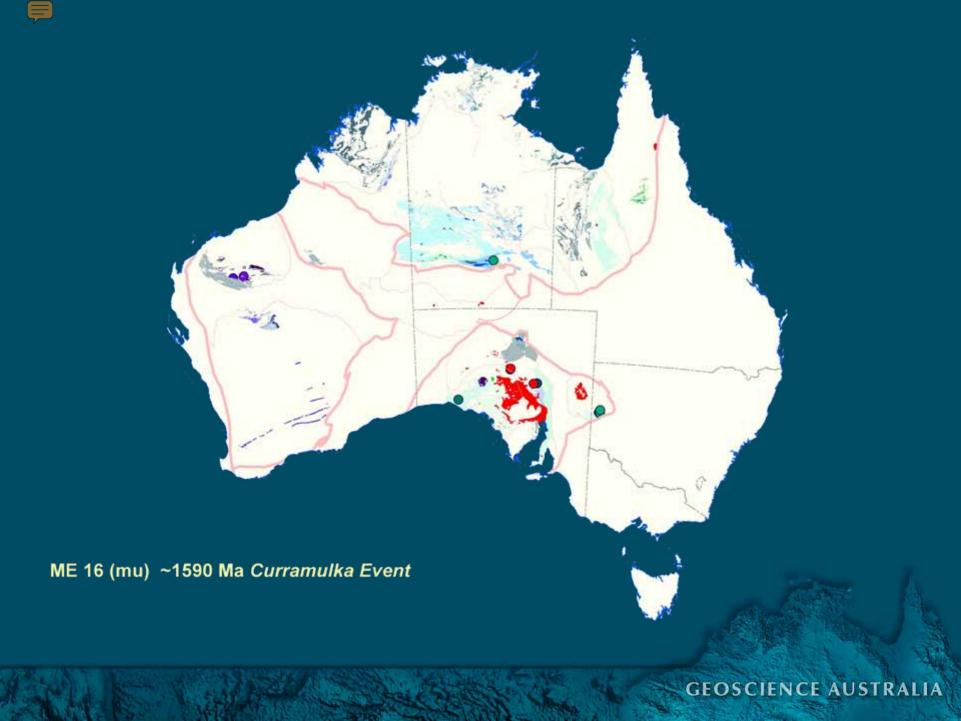


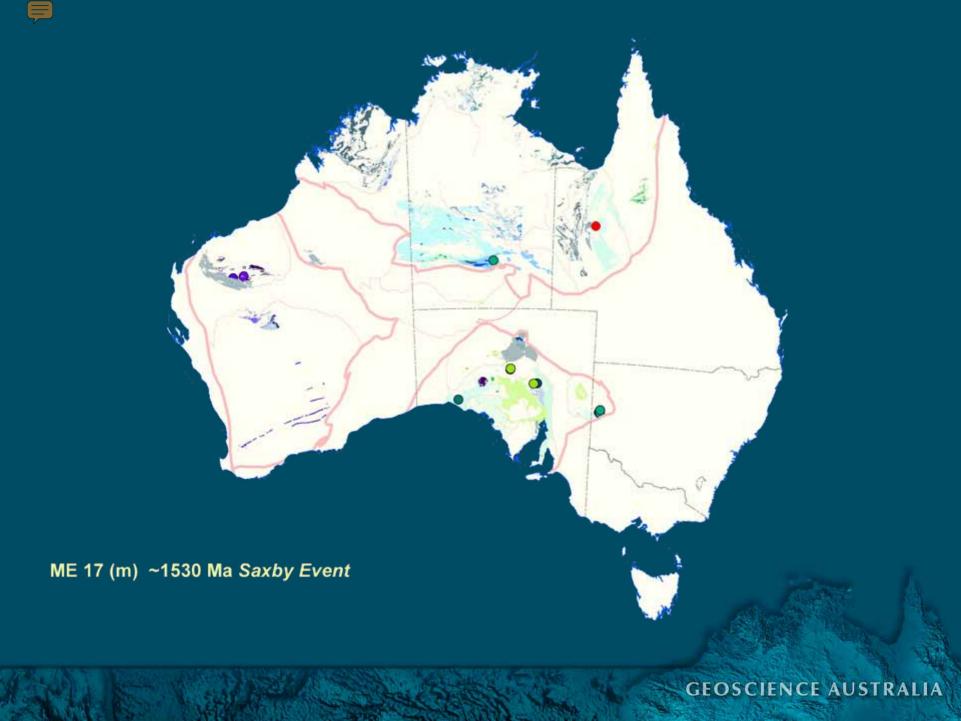


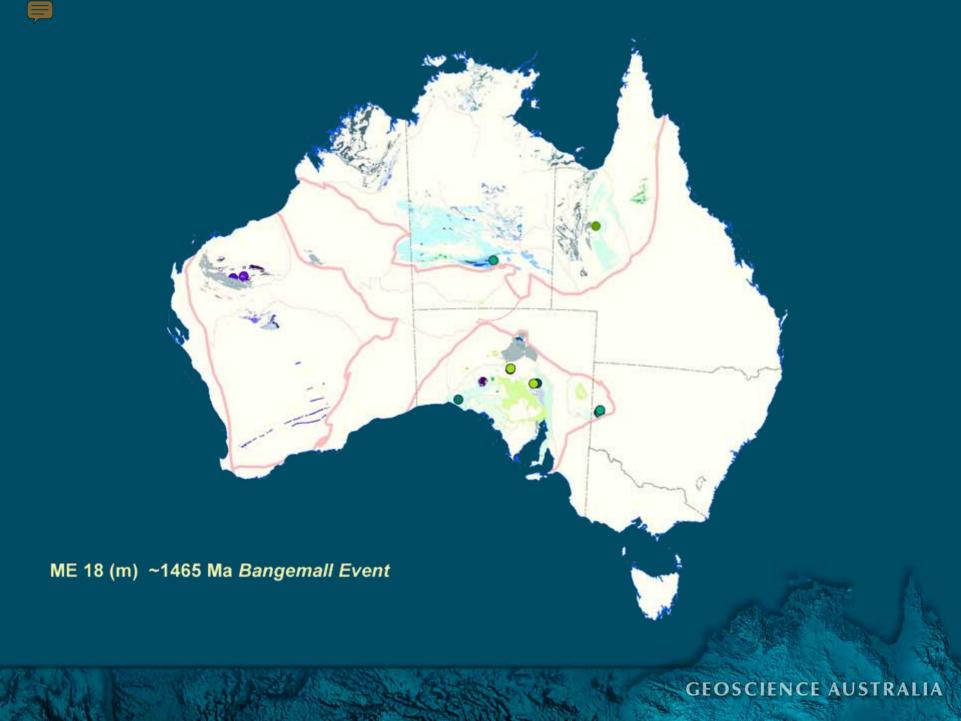


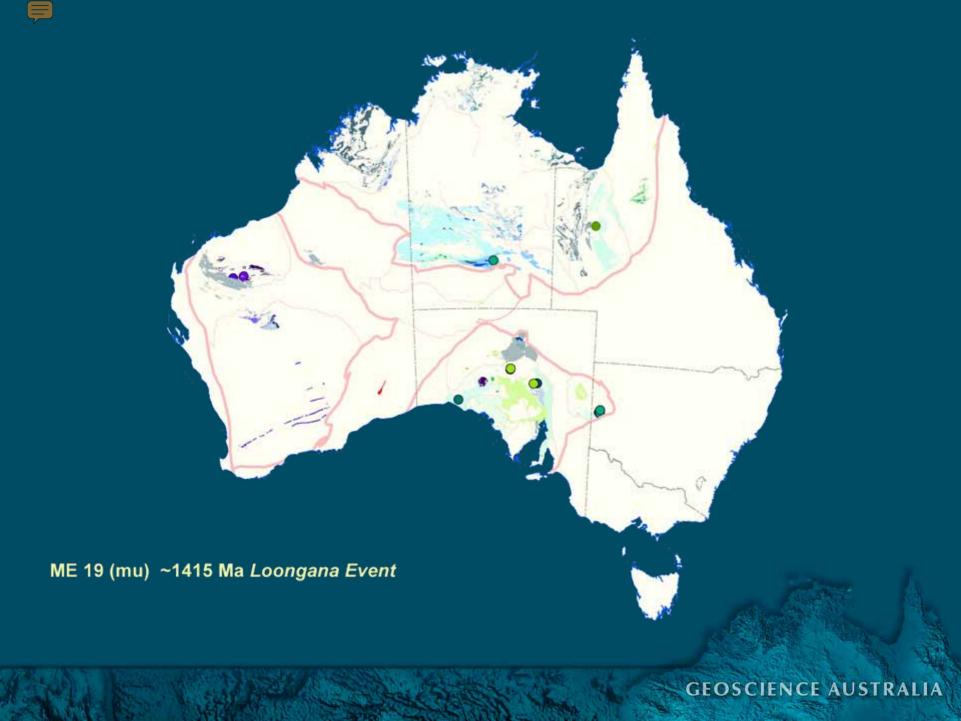


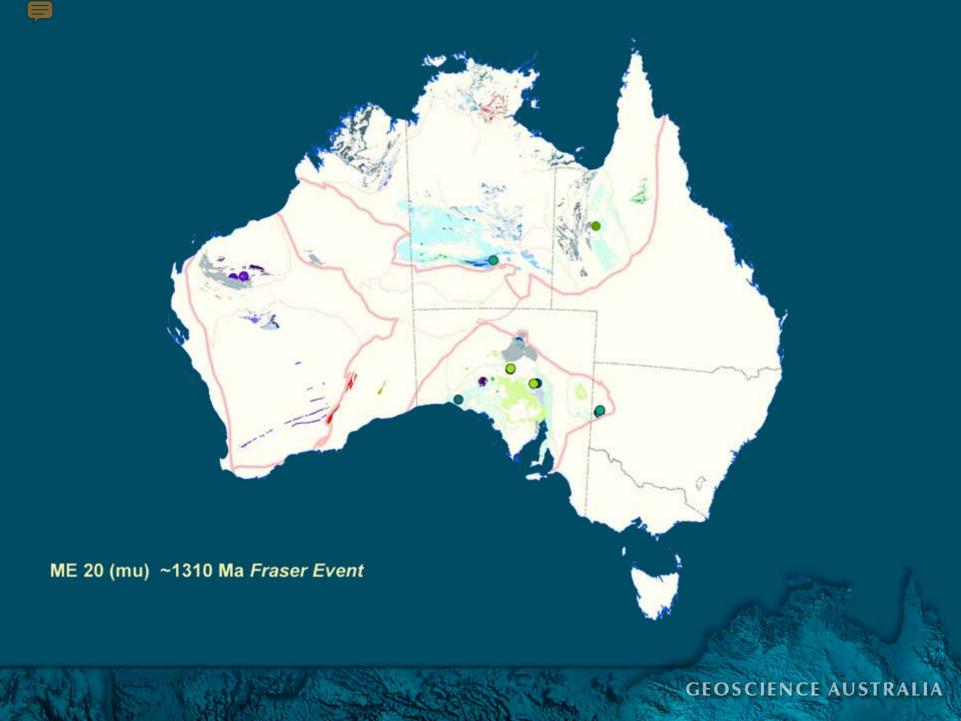


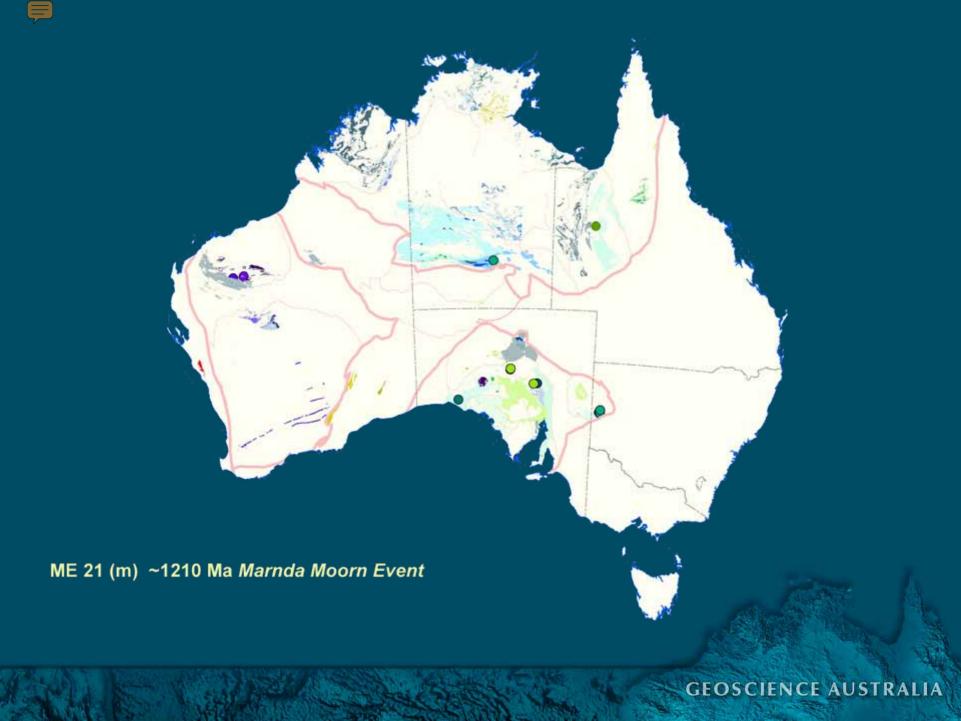


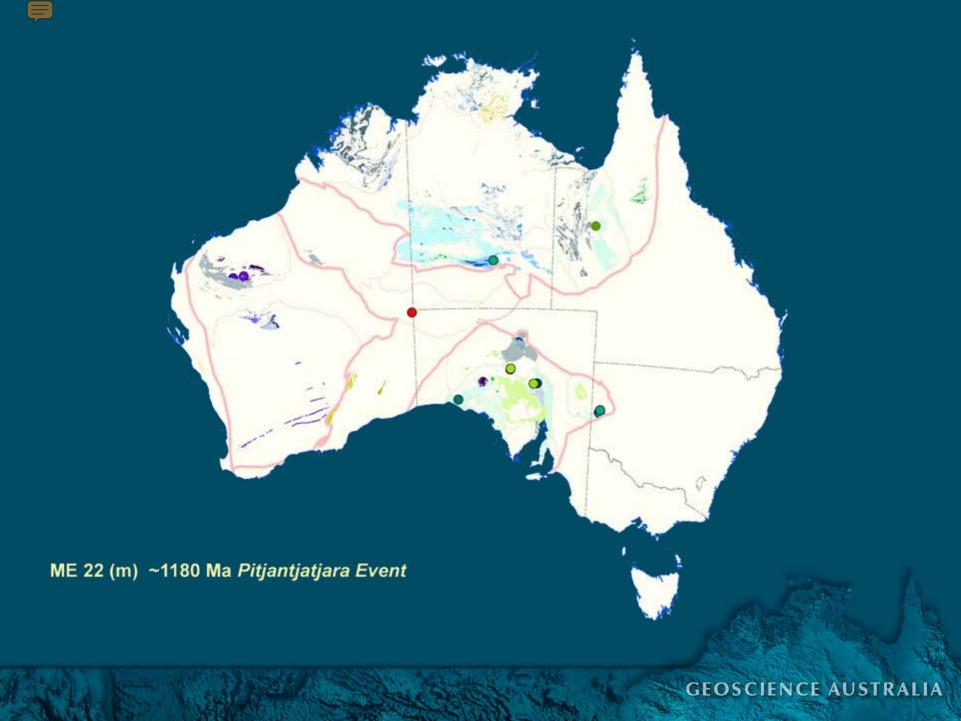


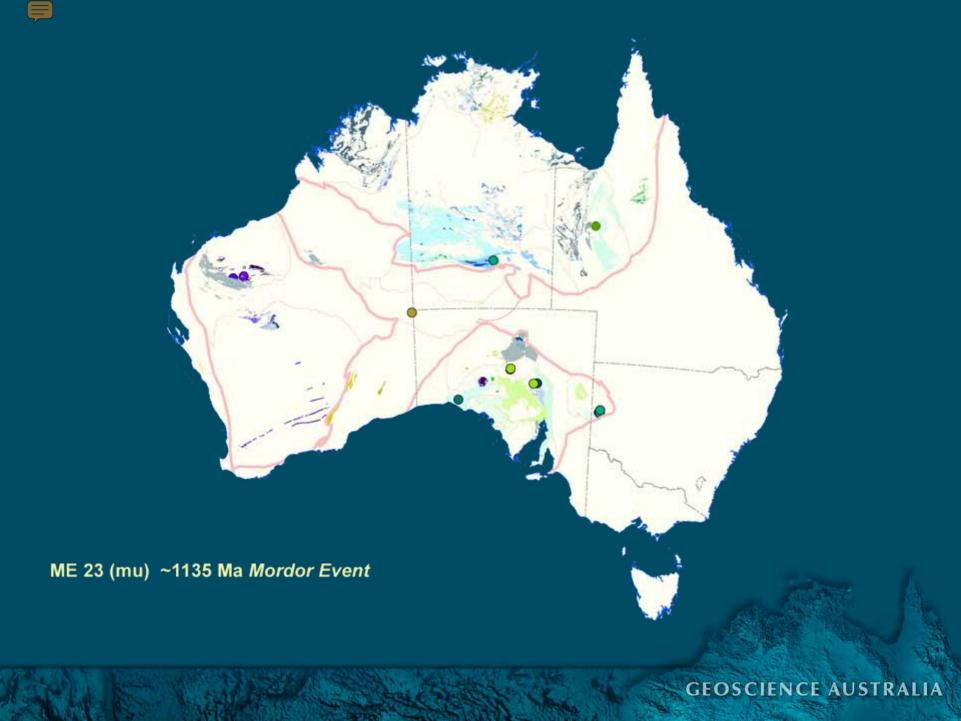


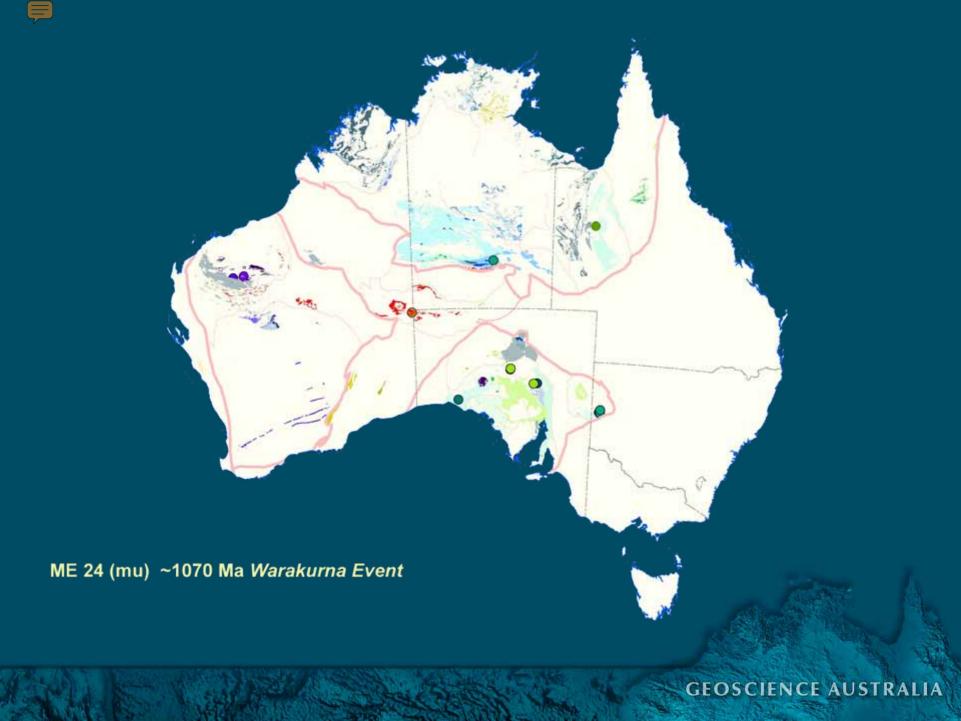




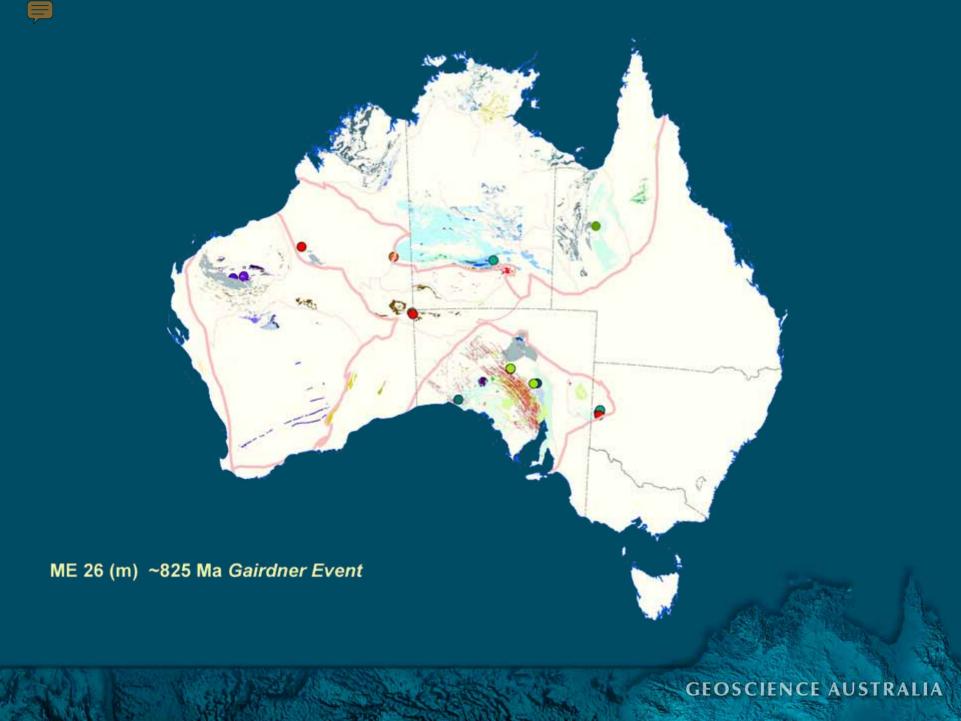


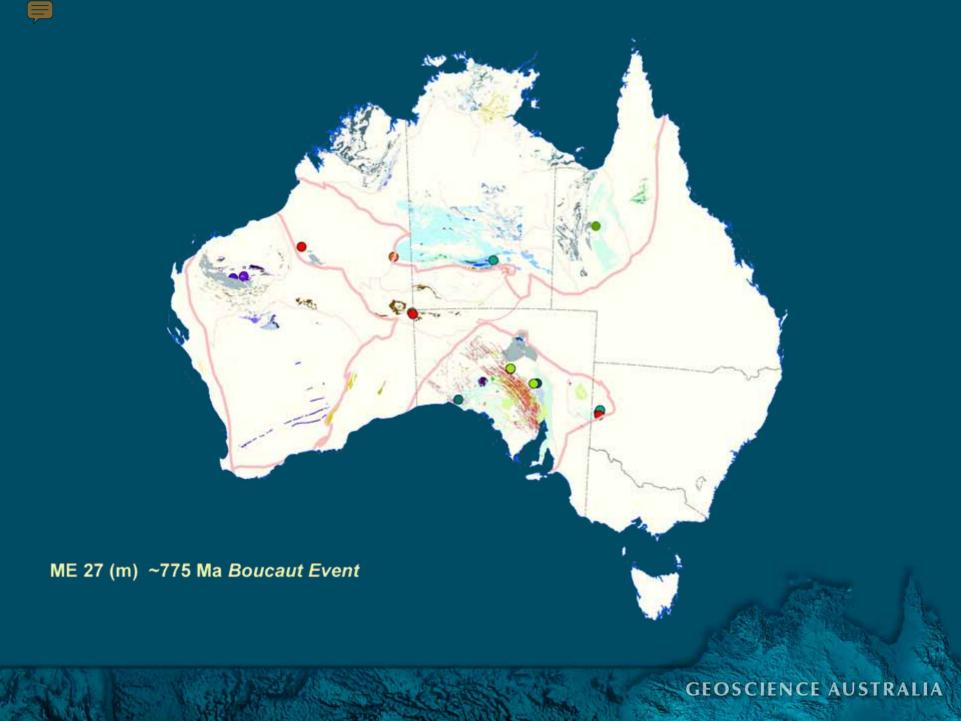






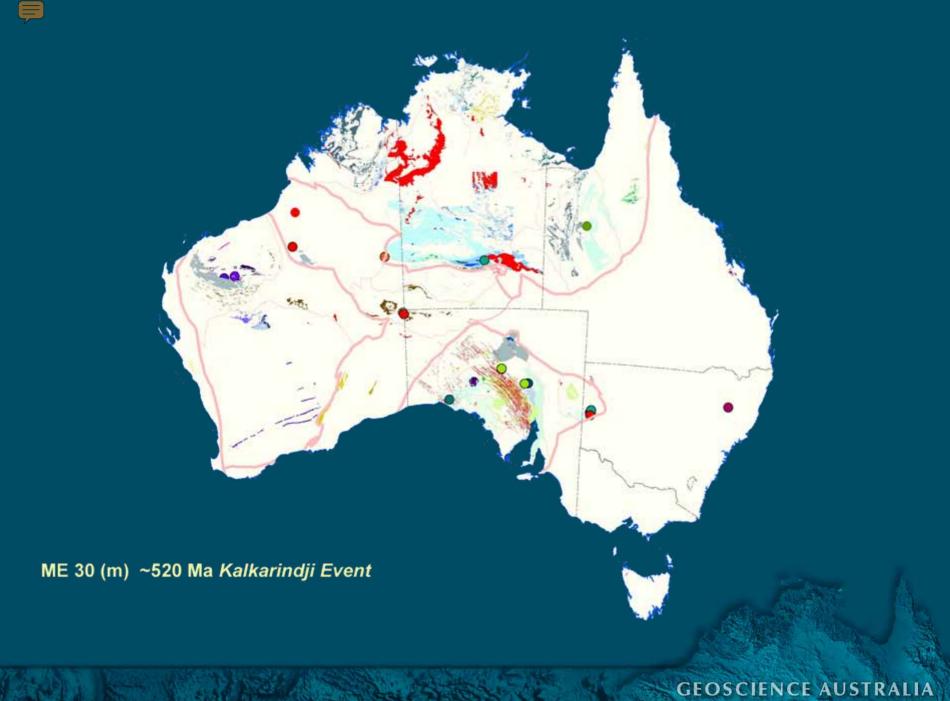




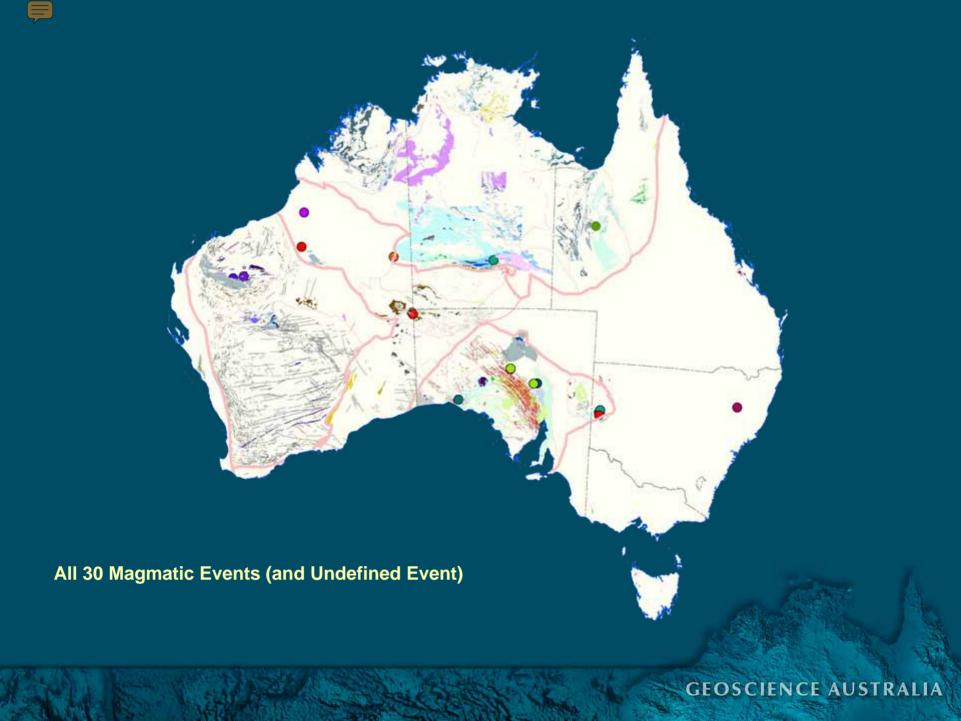




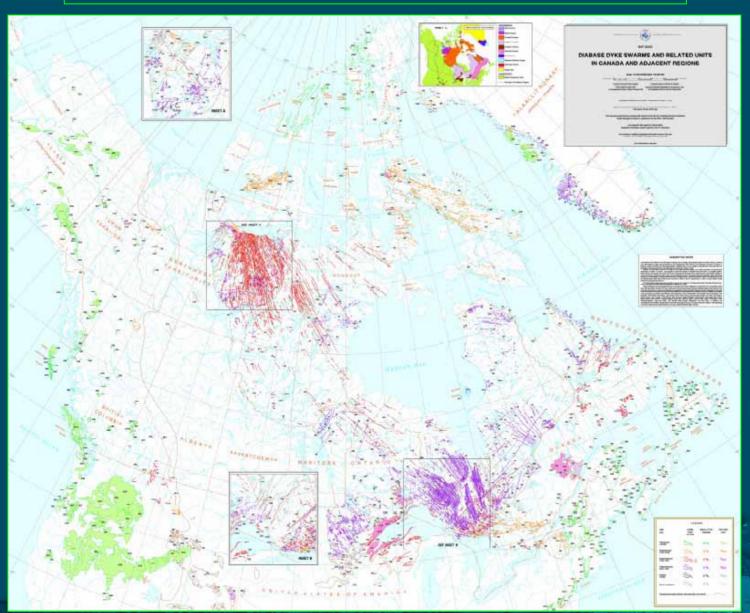








## **Five-Event Dyke Chronology: Canada**



# Large Igneous Provinces: Potential for 'Noril'sk-type' Ni-Cu-PGE Deposits

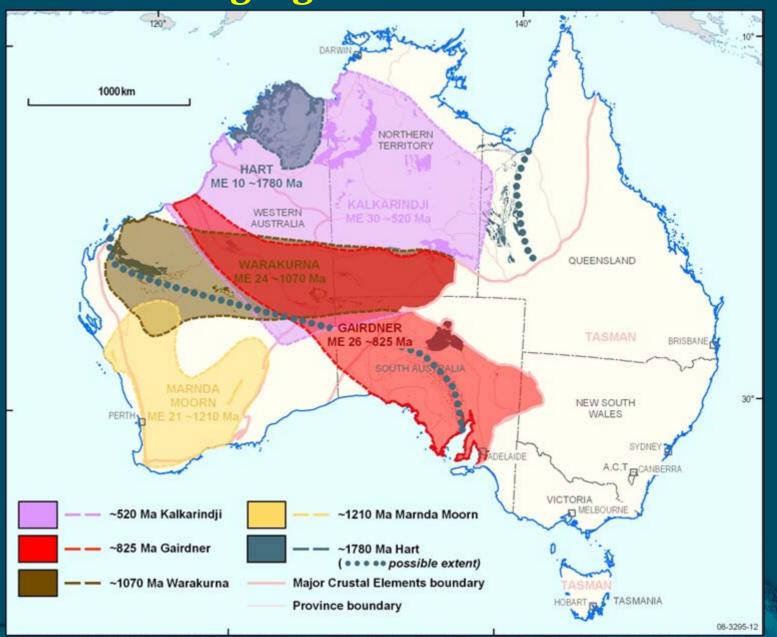
#### Large Igneous Provinces (LIPS):

- Large volumes of coeval mafic-dominated magmas (flood basalts, dyke swarms & sills, intrusions)
- Indicators of: thermal mantle plumes, rift environments regional-scale uplift, continental breakup, Ni-Cu-PGE mineralisation events

#### **Exploration Criteria:**

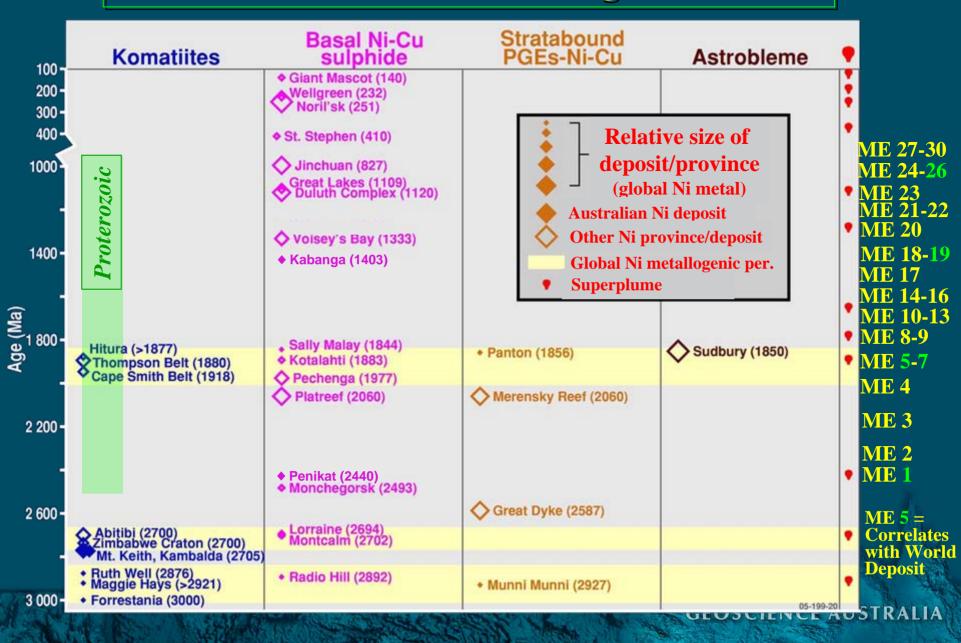
- Continental-scale flood basalt provinces
- Controlling faults, magma plumbing systems, feeder conduits
- Depletion of chalcophile metal elements coincident with geochemical signatures (Th/Nb, La/Sm) of crustal contamination

### **Large Igneous Provinces**





#### **Correlation of Proterozoic Magmatic Events**





# Proterozoic Magmatic Ni-Cu-PGEs: Exploration

#### **NICKEL:**

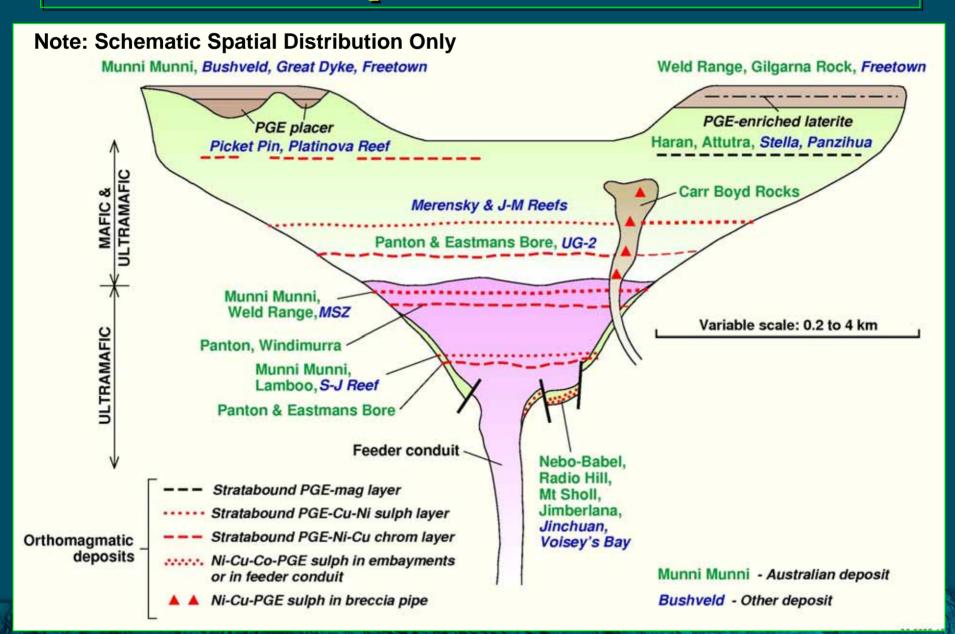
- focus: mafic intrusions
- small to large tholeiitic bodies
- massive sulphides
- basal contacts, feeder conduits
- high-magma flux zones

#### PGEs:

- focus: ultramafic-mafic intrusions
- >1000 concentration factor
- giant magmatic systems
- high-Mg primitive magmas
- late S saturation
- crustal contamination, magma mixing

#### **异**

#### Nickel and PGE Deposits: Mafic-Ultramafic Intrusion





# **Preliminary Findings from National Study**

- Thirty major Proterozoic magmatic events: tholeiitic mafic>>>ultramafic; komatiitic systems not identified; protracted tholeiitic magmatism 1870 to 1590 Ma (35% of all events)
- Nine Magmatic Events are mineralised: six are coeval with major overseas deposits (~827 Ma Jinchuan, 1850 Ma Sudbury)
- Apparent deficit of significant Proterozoic mineralisation discovered, but Magmatic Events have mineralised correlatives elsewhere in the continent (1070 Ma Giles Event in WA & SA-NT) & high % of Prot intrusions under shallow cover & untested
- Large volume, continent-wide igneous provinces (>1 x 10<sup>6</sup> km<sup>2</sup>) ~1790 Hart; ~1210 Marnda Moorn; ~1070 Ma Warakurna; ~825 Ma Gairdner; ~520 Ma Kalkarindji

# Critical Questions for Explorers... Revisited

#### Where are the mafic-ultramafic magma systems?

- continent-wide spatial & temporal correlations
- potential under cover

#### Which Magmatic Events are the big ones?

- Large Igneous Provinces
- several Magmatic Events correlate continent-wide

### Which Magmatic Events have ultramafic magmas?

• 11 Magmatic Events have an ultramafic component

### Can crustal structure narrow the exploration focus?

- clear relationships with Major Crustal Elements
- LIPs feeder focus in Central-Western Australia



**Basic Concepts:** Formation of **Tholeiitic** Ni-Cu+PGE **Sulphide Deposits** Sulphide settling and repeated injections of basaltic magma Sulphides Sulphur

Emplacement in crust,

contamination, and

- **Eruption of basaltic lavas** depleted in metals
  - Onset of sulphide liquid separation
- sulphur saturation Cu Sulphur Ascent of magma

- 4. Surface Setting: Depleted basalts  $\rightarrow$  vectors for sulphide separation at depth
- 3. Sub-Volcanic Setting: Suphides scavenge Ni, Cu, PGEs in high-level contaminated sills (Noril'sk)
- 2. Intrusive Setting: Late S saturation of magma in chamber  $\rightarrow$  stratabound PGE layer (Merensky Reef, Munni Munni); early S saturation  $\rightarrow$ massive Ni-Cu sulphides at basal contact & feeder conduit (Voisey's Bay, Sally Malay)
- 1. Mantle Setting: Fertile magmas derived from melting of mantle plume

Partial melting

mantle plume



Basic Concepts:
Formation of
Tholeiitic
Ni-Cu±PGE
Sulphide Deposits

Sulphur

mantle plume

**Eruption of basaltic lavas** depleted in metals Sulphide settling and repeated injections of basaltic magma Onset of sulphide liquid separation Emplacement in crust,

Sulphur Sulphur
Sulphur

Ascent of magma

Partial melting

contamination, and

4. Surface Setting:

Kalkarindji ME 30 Hart ME 10

3. Sub-Volcanic Setting:

Gairdner ME 26

Warakurna ME 24

**Bangemall ME 18** 

2. Intrusive Setting:

**Mordor ME 23** 

Fraser ME 20

Loongana ME 19

**Andrew Young ME 15** 

**Lunch Creek ME 11** 

**Mount Hay ME 9** 

**Edmirringee ME 8** 

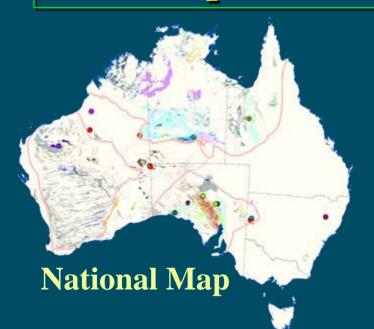
Sally Malay ME 7

Widgiemooltha ME 2

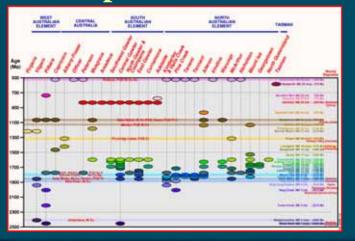
GEOSCIENCE AUSTRALIA

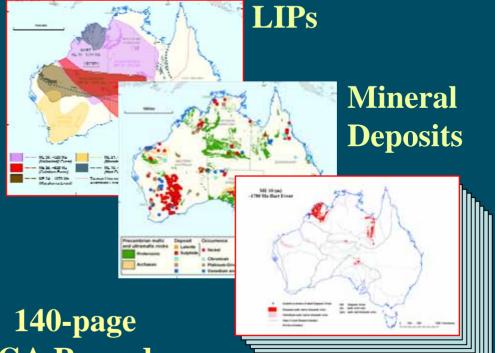
Sulphides -

## Free GA products: download at www.ga.gov.au



**Time-Space-Event Chart** 





140-page GA Record 2008/15



Time-Slice Maps



State/Territory
Data Tables



# Visit Geoscience Australia's booth #27 and website\* for:

• Magmatic Events & nickel exploration maps, reports

• Comprehensive review of Australia's nickel sulphide

deposits (Ore Geology Reviews v 29)

Other products to assist explorers

## Thank you

Contact: Dean.Hoatson@ga.gov.au

\*www.ga.gov.au/minerals/research/pubspres.jsp

