Metallogenesis of the Lachlan Orocline: how much of the mineral wealth of southeast Australia is due to a collision with VanDieland?

OR: It’s all Tassie’s fault!

David L Huston, Ross Cayley and David C Champion
WHY this talk

- Development of Cayley-Musgrave orocline model
- Modelling by Moresi et al. (2014)
- GA’s continued interest in Tasmanides
  - Update of Phanerozoic synthesis (in review)
  - GA’s regional drilling programs (Stavely and southern Thomson)
- Concept of “tectono-metallogenic” systems
Tectonic synthesis – Cycles
(e.g., Collins and Richards, 2008)
## Tectonic cycles of the Lachlan Orogen

*(following Glen, 2005; Gray and Foster, 2004)*

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delamerian</td>
<td>600-490</td>
</tr>
<tr>
<td>Benambran</td>
<td>490-430</td>
</tr>
<tr>
<td>Tabberabberan (includes Bindian)</td>
<td>430-380</td>
</tr>
<tr>
<td>Kanimblan</td>
<td>380-350</td>
</tr>
<tr>
<td>Hunter-Bowen</td>
<td>350-230</td>
</tr>
</tbody>
</table>
Spatial relationship of deposits in convergent margin
510-500 Ma
505-500 Ma (calc-alkalic)

510-500 Ma
505-500 Ma (calc-alkalic)

~420 Ma
~480 Ma (alkalic)

~380 Ma
~280 Ma

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*Includes high sulphidation epithermal and VHMS deposits. Size of symbol indicates relative size of deposit. Normal text indicates well constrained ages; italics indicate ages inferred from geological framework. Hatching indicates spatial and temporal distribution of major contractional deformation events.
Mineral deposits of the Lachlan Orogen

- Porphyry Cu-Au
- Epigenetic Au
- Volcanic-hosted massive sulphide
- Lode gold
- Cobar-type Cu-Au & Zn-Pb
- Granite-related Sn-W & Mo-Cu

- ~480 Ma
- 470-450 Ma
- 440-435 Ma
- 425-415 Ma
- 430-410 Ma
- ~445 Ma

- Western Lachlan
- Central Lachlan
- Eastern Lachlan
- Thomson Orogen
- Macquarie Arc
- New England Orogen
- Hill End Trough
- Sydney
- Goulburn Basin
- NSW
- ACT
- Victoria

160 km
### Why do we care?

<table>
<thead>
<tr>
<th></th>
<th>Value ($B)*</th>
<th>Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pangea-Gondwana assembly</td>
<td>558</td>
<td>100</td>
</tr>
<tr>
<td>Tasman Element</td>
<td>500</td>
<td>90</td>
</tr>
<tr>
<td>Southeast Australia (TAS, VIC and NSW)</td>
<td>373</td>
<td>67</td>
</tr>
<tr>
<td>480-410 Ma period</td>
<td>261</td>
<td>47</td>
</tr>
</tbody>
</table>

70% of southeast Australia’s mineral wealth formed between 480 Ma and 410 Ma

* Value base on production, resources and prices at 31 December 2011
Benambran Cycle - the Lachlan Orocline
(after original concept by Ross Cayley (GSV) and Robert Musgrave (GSNSW))

Moresi et al. (2014)
Squire and Miller (2003) – accretion of seamount

- ~440 Ma (Benambran Orogeny)
- Coeval orogenic gold and porphyry copper deposits
- Orogenic gold in hinterland of impactor
- Porphyry copper in arc system to north
Cayley and Musgrave (2015) – Lachlan Orocline model

- Southeastern Australian geophysics (and geology) wraps around VanDieland
- Accretion of VanDieland at ~445 Ma (Benambran Orogeny)
- Extension in eastern NSW at 440-410 Ma
*Includes high sulphidation epithermal and VHMS deposits. Size of symbol indicates relative size of deposit. Normal text indicates well constrained ages; italics indicate ages inferred from geological framework. Hatching indicates spatial and temporal distribution of major contractional deformation events.
Mineralising events – Lachlan Orocline

Age (Ma)

500  450  400

Bendigo  Stawell  Castlemaine  Ballarat

Girilambone (Tritton)

Copper Hill, Marsden

Northparkes, E39, Gidginbung, Cadia

Woodlawn, Lewis Ponds, Lake George, Benambra

Lake Cowal

Tara

Holbrook

Kikoira

Majors Creek, Ardlethan

Porphyry Cu-Au
High sulphidation Cu-Au
VHMS Zn-Pb-Cu
Lode Au

Low sulphidation Au(Ag-base metals)
Epigenetic Zn-Pb-Ag
Granite-related Sn-W
Intrusion-related gold
Metallogenic evolution of the Lachlan Orocline

(A) 480-450 Ma
- Macquarie arc (calc-alkaline phase)
- Girrilambone back-arc basin
- Tritton
- Copper Hill
- Australian plate
- Palaeo-Pacific plate
- VanDieland microcontinent

(B) 445 Ma
- Australian plate
- Stawell
- Bendigo
- Ballarat
- VanDieland

(C) 435 Ma
- Australian plate
- Northparkes
- Cadia
- VanDieland

(D) 430-410 Ma
- Australian plate
- Hill End-Goulburn extensional basin
- Kikoira
- Ardiehan
- Woodlawn
- Captains Flat
- Unicorn

480-450 Ma
- Subduction
- Oblique convergence
- Extension
- Subduction retreat
- Volcanic-hosted massive sulphide
- Calc-alkaline porphyry Cu-Au

~445 Ma
- Epithermal Au
- Orogenic gold

~435 Ma
- Alkaline porphyry Cu-Au

430-420 Ma
- Granite-related Sn-W and Mo-Cu
- Volcanic-hosted massive sulphide
Evolution of the Lachlan Orocline – Stage 1

- 480-450 Ma: NW-directed subduction; formation of arc and back-arc basin
- Calc-alkaline magmatism and associated porphyry copper-gold in Macquarie Arc (Marston and Copper Hill)
- Tholeiitic magmatism in back-arc and associated pelitic-mafic (Besshi-type) VHMS deposits (Tritton)

**BUSINESS AS USUAL**
(no perturbations, smallish deposits)
Evolution of the Lachlan Orocline – Stage 2

• ~445 Ma: Accretion of VanDieland; Benambran Orogeny

• Orogenic gold in hinterland (most of Victorian goldfields)

• No mineralisation outside of western Victoria

ACCRETION (big perturbation, big deposits)
Mineralisation associated with post-orogenic extension

Adapted from Richards (2009)
Evolution of the Lachlan Orocline – Stage 3

- ~435 Ma: (Post-orogenic) extension in eastern NSW
- Alkaline magmatism and associated porphyry copper-gold deposits in Macquarie “arc”
- No mineralisation SW of Baragwanath transfer zone

OROCLINE
(big perturbation, big deposits)
Evolution of the Lachlan Orocline – Stage 4

- 430-410 Ma: Continued extension in eastern NSW
- Re-establishment of west-directed subduction
- VHMS mineralisation in extensional basins (Goulburn, Hill End and Cowombat troughs: 420 Ma; northward younging?)
- Granite-related Sn, Mo and Au mineralisation (430-410 Ma)
- No mineralisation SW of Baragwanath transfer zone
Mineral potential?

- Lachlan Orocline model explains metallogeny of Lachlan Orogen well
- Boundary between Melbourne and Tabberabbera zone is a fundamental metallogenic boundary
- ~445 Ma orogenic gold potential extends undercover to north and south of Victorian goldfields
- 480-450 Ma calc-alkaline porphyry copper-gold potential in undercover Hay-Booligal Zone
- ~480 Ma VHMS potential along eastern margin of Central Lachlan and north of Hay-Booligal Zone
- Undercover ~420 Ma VHMS potential north of Hill End Trough?
Conclusions

• Mineralisation in eastern Australia is linked to tectonic cycles that developed episodically during the evolution of the Tasman Element
• The style of mineralisation is related to both spatial and temporal location within tectonic cycles
• Accretion of VanDieland (western 2/3rds of Tasmania + Melbourne Zone) triggered development of Lachlan Orocline
• Much mineralisation in southeast Australia can be linked to the evolution of the Lachlan Orocline, particularly the world-class Victorian goldfields and Macquarie Cu-Au province
• Big deposits are linked to big tectonic disturbances
Where to next?

Testing the orocline model

• Prediction: eastern Tasmania is a wrap-around from the Lachlan;
  Tests: lead isotope characteristics, lithological comparisons
• Prediction: extensions of 480-450 Ma arc-backarc system along eastern margin of Central Lachlan;
  Tests: drilling Hay-Booligal Zone, igneous geochemistry and geochronology

Better understanding of the fourth dimension – time

• Dating different mineral systems using same isotopic system (Re-Os, Ar-Ar): are differences in timing real?
• Spatial-temporal changes in deposit types (temporal changes in Silurian VHMS ages? granite-related ages?)

Relationships with other tectonic elements

• Proterozoic Australia
• Thomson and Delamerian orogens
Take home points

• The Cayley-Musgrave Lachlan Orocline model explains the metallogenesis of southeast Australia well

• Local researchers can provide critical data to further develop this concept
  • Marc Norman (ANU) – Re-Os and cassiterite U-Pb geochronology
  • Sebastien Meffre (UniTas-MacquarieUni-UniMel ARC Linkage) – geochemistry, ore genesis, geochronology, tectonics

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Plate tectonic and ore deposit evolution of SE Australia

An Australian Research Council Linkage proposal 2016-2019

Collaboration between universities, industry and surveys

Aims:

• Address some of the key remaining problems within the Lachlan Orogen geology.
• Apply new geochemical and geophysical tools to evaluate ore deposit genesis and prospectivity.
• Evaluate new tectonic models and their implications for ore deposit distribution.

Multidisciplinary team:

• Expertise in geochemistry, ore deposit geology, geochronology, tectonic reconstruction, geophysics and geo-statistics
  – Sebastien Meffre, David Cooke, Matt Cracknell, Jo Whittaker (UTas)
  – Elena Belousova (Macquarie Univ.) and Roland Mass (Univ. of Melbourne)

More details from Sebastien.Meffre@utas.edu.au or David.Cooke@utas.edu.au