Emerging geological concepts, and how they are changing Victorian gold and base metals prospectivity

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Presentation outline

- **Challenges for the State**
  - Multi-disciplinary, cross-agency collaboration – the firepower needed to grapple with some tricky problems
  - Arcs – What are they? Why are they important? How can you tell when you’ve found one?
  - Oroclines – Giant folds of whole mountain ranges. So what?
  - A paradigm shift for Victorian gold and base-metals prospectivity – rhetoric or reality?
Victoria: current perceptions
(areas of focus in this presentation in black)

- Large historic gold production – ‘old-style’ high-grade Au deposits are huge, but not suited to modern development (eg. high-profile failure of Bendigo), and impossible to predict.

- World class Gippsland Basin energy resources

- Emerging Heavy Minerals Sands sector; world class, some technical hurdles (grainsize, geochemistry)

- Some other deposits (eg. Benambra Cu), but not much else of interest to global or mid-tier explorers
But Victoria does have predictable deposit types, proven to be suited to modern development....

Stawell — 5 M oz+ Au total endowment from a single greenstone-hosted shear system mined continuously since the early 1980’s; currently mined.

Fosterville — multi-million oz Au total endowment from a metasediment-hosted fault system; currently mined.

Benambra (Cu) — VHMS — undergoing redevelopment

GSV predicts that improved geological understanding will help find more of these and new deposit styles to boot.....
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• Oroclines – Giant folds of whole mountain ranges. So what?

• A paradigm shift for Victorian gold and base-metals prospectivity – rhetoric or reality?
The problem: most of the prospective bedrock of Eastern Australia – the Palaeozoic Delamerian and Lachlan fold belt rocks that host large primary gold and base metals deposits – lies buried beneath younger cover rocks, pale grassland in this image.
This map makes it clear – prospective bedrock crops out over way less than 50% of Victoria. We need to understand the other 50% better, so we can predict where to explore under cover.

Victoria can help develop regional-scale tectonic models, because it is the only place where outcrop does span the width of the Lachlan and eastern Delamerian fold belts.
Collaboration is key, and the following geoscience data and concepts could not have happened without a dedicated collaborative effort between scientist working for the organisations below, and others. This work is ongoing.——
Defeating the tyranny of cover: complete aeromagnetic data coverage across the nation.

Turning this.....
…into this.....

Regional
Total Magnetic Intensity

a window to the underworld
Vandieland (Cayley, 2010, G.R)

A Mesoproterozoic microcontinent.....

includes Western Tasmania and the ‘Selwyn Block’ (Cayley et al., 2002, AJES)...

embedded within the Paleozoic Lachlan Fold Belt...
New, high quality
Aeromagnetic data infill......
.....where it matters......
...and advances in processing quality.....and testing interpretations with regional deep seismic reflection transects (including in Victoria: yellow lines).
Central Victorian deep seismic data, acquired in 2006……..
…led to validation of geological models such as the east-dipping Moyston Fault and Selwyn Block (Tasmania connection) concepts, and gave geometries that could be forward modelled (blue square).
Forward model of part of Line 06GA-V2. Measured and modelled gravity profiles are a close match, using model density values measured directly from rocks that occur along the transect (and are interpreted to depth)… shows interpretation is possible…….
and gives the confidence needed to begin to construct 3-D geodynamic models (2-D + time). Also highlights limitations in understanding exist (?).
...which were addressed by extending the deep seismic transect into western Victoria, to test/develop models for the Delamerian Fold Belt – the Southern Delamerian project, 2009 -.
Southern Delamerian deep seismic project, 2009, line locations.
Note inset square, where one line tests geological concepts from past GSV mapping…
Testing existing concepts, Moyston Fault, Moornambool Metamorphic Complex wedge ‘pop-up’ geometry......
Vibroseis transect is designed to replicate a cross-section previously drawn across the metamorphic complex…….
Seismic data and interpretation matches the geometry of the previously drawn cross-section.

- Proves that geological mapping and aeromagnetic data interp. can produce meaningful results.
- Proves that deep seismic reflection profiling can meaningfully image map-scale structures.
- Time to test areas with less existing geological control
A comprehensive understanding means we can build meaningful 3-D geological models…..

Full-crustal-thickness (40km!) geological model at 1:250 000 scale
Combined: A powerful new paradigm for geological and tectonic interpretations...

All available online, right now….for free
From the well-known, to the less well-known – imaging far western Victoria
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• **Ards – What are they? Why are they important? How can you tell when you’ve found one?**

• Oroclines – Giant folds of whole mountain ranges. So what?

• A paradigm shift for Victorian gold and base-metals prospectivity – rhetoric or reality?
• Magmatic arcs form in the crust above subduction zones at plate boundaries. At a continent margin (e.g. the Andes)...

• or in the ocean... an island arc

Why are they important? Porphyry and VMS systems!!!! (Au, Cu, Mo, etc)
Modern magmatic arcs occur around the Circum-Pacific, above active continent-dipping subduction zones….but these evolve through time, so earlier arc generations also occur, like the Ordovician-aged Macquarie Arc (yellow arrow).
Cadia Hill Porphyry Cu-Au Mine, central NSW
Magnetic data suggests that the Macquarie Arc extends into eastern Victoria somehow…. but how to test? And how does Benambra fit?

..and, what are the magnetic rocks in far western Victoria?
Previous academic work gives the critical clues – a convergent continental margin, active around 500 My ago, passed through western Victoria (green line shows cross-section location).
A continent-dipping subduction zone gives regional context for a continental magmatic arc beneath parts of western Victoria around 515-500 My – can we map it?

Boninites at ~514Ma: *Kemp, 2003*
The 2009 seismic lines are the critical test....let's put them together......
......and the result is an overthrust Cambrian arc succession, superimposed on a former Proterozoic rifted passive margin to Gondwanaland. And it has porphyries!

Note offset Moho.....
...matches east-dipping thrust faults that marine-seismic can trace west to Kangaroo Island and the Fleurieu Peninsula.
A Cambrian continental margin arc in Western Victoria

Interpreted seismic data related to a theoretical plate tectonic scenario:

A Cambrian back arc – arc – accretion complex succession.
A: >515 Ma

Cartoon can be undeformed, to reveal likely geometry when the system was forming…….

B: 500 - 495 Ma

Delamerian Fold Belt (upper plate) | Lachlan Fold Belt (lower plate)

…location of porphyries….
A: Neoproterozoic: passive margin, a relic of Rodinia breakup (Hummocks Serpentinite)

Gondwanaland

Paleoproterozoic crystalline basement

Paleopacific

west east

B: early Cambrian: evolution to convergent margin, with continent-fringing Miga Arc

C: early – middle Cambrian: slab rollback pulls arc east, opening backarc basin (Truro Volcanics)

...and a comprehensive geodynamic scenario can be developed...

D: late Cambrian: Delamerian Orogeny

Delamerian Fold Belt (upper plate)  Lachlan Fold Belt (lower plate)

west  east

Paleoproterozoic Australian craton

Continuing deep marine sedimentation on undeformed Bendigo Zone crust

Forced (flat) subduction drives upper plate convergence?
Miga Arc porphyries may be old, but are still preserved, because arc-accretion involved overthrusting of both arc-flanks, burying the arc, preserving it until today...
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• **Oroclines – Giant folds of whole mountain ranges. So what?**

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Modern magnetic data shows buried extensions to the Stawell Zone in western Victoria extend north under Murray Basin cover as a giant curved orogen, marked by red line...
Regional

Total Magnetic Intensity

...what if it was a giant fold, like the New England Orocline?...

...and what if that fold extended into the eastern Lachlan Fold Belt as a giant Z-shaped structure?
Regional

Total Magnetic Intensity

…unfolding is a test of this concept..
...the unfolded Lachlan fold Belt appears thin and simple, with a single, shallow continent-dipping subduction zone active along the east- Gondwanaland margin...

(Blue= Ordovician metasedimentary strata. Yellow = Macquarie Arc red line shows cross-section location)

Plate convergence was sinistral-oblique, eventually drawing a microcontinent into the subduction zone: Vandieland (Tasmania and the Selwyn Block, green).....
…collision of the Vandieland microcontinent stalled subduction…

With plate-convergence stalled, the sinking slab switched the system into roll-back – a tectonic ‘mode switch’ (green arrows; red line shows cross-section location)

LFB rollback – see: Collins, 2000 (Geology)

Roll-back caused fragmentation of the Macquarie Arc, and rapid upper-plate extension

Roll-back proceeded oceanward, but remained pinned at its southern margin by Vandieland……
...generating a curved system.....the beginning of the Lachlan Orocline....

Note progressive fragmentation of the Macquarie Arc (in yellow)
...eventually the orocline grew to the point where the geometry of parts of the Macquarie Arc accretionary complex (in blue) appeared effectively ‘reversed’ in geometry....
...one ‘reversed portion’ is the Tabberabbera Zone. Oroclinal folding is a simple alternative to the previous double-divergent subduction models proposed to explain apparently complex Lachlan Fold Belt geometries. 

(eg. Gray & Foster, 2000)
...this is a large-scale tectonic model, evolving through time.....

Subduction rollback superimposed on an accreted orogen...
...and now supported by independent crustal-scale geodynamic numerical modelling.....

Moresi, Betts, Miller, Cayley, 2014: NATURE
...a similar modern analogue is the Scotia Arc, where rollback and oroclinal folds are superimposed on Andean crust, once uplifted and continuous between South America and the Antarctic Peninsula, but now extended and sunk beneath the south Atlantic......
Implications for mineral exploration.....the model demonstrates how and where the Macquarie Arc extends into Victoria.....and elsewhere......
...it lies buried beneath the Deddick Zone.....
.....and we can model where it may extend at greater depths (Macquarie Arc in yellow).

It may underlie a region rich in base metal deposits.
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...the Oroclinal fold model shows how the gold-rich terrane of the Bendigo Zone may extend east around a fold hinge into the Tabberabbera Zone.....
Cambrian and Ordovician arc-systems, of the type known to host giant porphyry-type Cu–Au ore deposits

...and how Victoria may have 2 magmatic arcs.....
...It provides understanding that allows, for the first time, a systematic characterisation of Victoria’s mineral exploration fairways ......

1. Kanmantoo-Strathalbyn SEDEX Base-Metals Fairway: newly recognised opportunity extending from southeast South Australia; Cambrian age mineralisation.
4. Stawell Zone Orogenic Gold Fairway: greenstone (+/- VMS) – gold association. Ordovician age mineralisation (hosted by Cambrian rocks +/- VMS); Multi-million oz plays.
6. Selwyn Block Base-Metals (Gold) Fairway: recently recognised opportunity extending from western Tasmania into Central Victoria – Mt Read Volcanics and Avebury Ni play types; Cambrian age mineralisation.
7. Wagga-Omeo Zone Tin Fairway: Plays in Koetong Supersuite igneous rocks. Silurian age mineralisation.
There are Australia-wide implications – it’s a paradigm shift for everyone

Cayley & Musgrave, in prep.
Still a work in progress…

- Regional geology still too uncertain for most

- But, hard work and modern geoscience are finally closing the gap.

- Exciting opportunities available for early-adopters

- Victorian Government keen to foster collaboration with industry to maximise value from existing mines and new exploration opportunities
What might success look like?

- New Stawell-type or Bendigo/Fosterville-type deposits located under cover (Tandara….)
- New porphyry system discoveries….
- Bonus opportunities (eg. extension of Kanmantoo-Strathalbyn SEDEX into western Victoria)

Note for comparison:
Beaconsfield Gold intersected
35m @ 3.7% Cu at Junction 1, Mt Stavely
and 7.7m @ 4.2% Cu at Thursdays Gossan.
What next for the GSV?
Testing our new models against reality.....
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