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**The current state of play of gold in Victoria**

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Good morning everyone.

I’m just going to kick things off today talking about the current state of play of gold in Victoria.

[Slide: Talk outline]

Victorian gold was famous in the mid to late nineteenth century, but now the potential has been newly rediscovered.

So in this talk I’m going to set the scene.

I’m going to talk about a lot of the new stuff that’s happened that’s led to, we think, this fantastic new awakening of the industry in Victoria.

[Slide: The Tasmanides Orogenic System in Eastern Australia]

Victorian gold sits within the Tasman Fold Belt System, the bedrock that forms most of eastern Australia.

This bedrock was converted into continental crust during three to four cycles of subduction-accretion spanning the early to mid-Palaeozoic.

It started off in the Cambrian with the continent dipping subduction system that created among other things the Stavely Arc and also the Dundas Trough in Western Tasmania, and then that evolved through time into the Ordovician Macquarie Arc System further east, which eventually migrated and grew eastward to form most of the crust of eastern Australia.

And that in turn evolved into the New England System and of course that system still continues today offshore in New Zealand and in Vanuatu.

These orogenic systems created an awful lot of crust that all looks very similar throughout eastern Australia, and much of this crust hosts early Palaeozoic orogenic gold deposits.

However, it’s really only the Bendigo Zone in Victoria that has the proven Giant (Tier 1) orogenic gold deposits; this really points to something unusual happening in Victoria.

And that is what a lot of the recent research has gone into: trying to unravel this mystery.

[Slide: Gold in Victoria]

Just how significant is the gold in Victoria?

The goldfields occupy about a quarter of the state by volume.

There are some other little deposits outside these main areas but this is where most of the main gold recovery has come from in Victoria.

So thinking about it on a world scale, total all-time gold mined globally is a bit under 200,000 tonnes to date, meanwhile Victoria’s recorded gold production is around about 2,500 tonnes, but possibly up to almost as much as another 1,000 tonnes from unrecorded alluvial gold that was pulled out before the records started to be properly kept.

So that’s 1.5% of world gold production from only about 0.15% of the global land area.

It’s even less if you take into account the surface area of the goldfields, that’s really just 0.03% of the global land area.

What does this mean?

Well, it means that Victoria’s goldfield geology is 2 orders of magnitude or 100 times richer in gold than the global continental crustal average.

Slide: Map of different zones in Victoria]

This is a geology map of the main goldfield zone in Victoria, and the goldfields are coloured in as the polygons, colour coded by age.

So in the Stawell Zone and the Bendigo Zone most of the goldfields there appear to be late Ordovician to early Silurian in age.

In the Melbourne Zone further east most of the goldfields there are Devonian in age, and that’s really dictated by the age of the rocks that are hosting that gold.

And you can see there’s a little bit of overlap there into the Bendigo Zone with those younger deposits as well.

Now, these goldfield terrains are separated by major faults that have been long recognised at the surface, and so in central Victoria there’s the Heathcote Fault and in western Victoria there’s the Moyston Fault, and the Moyston Fault really sort of separates Delamerian age arc systems to the west from the sort of turbidite dominant packages further east.

As well as these Lachlan Fold Belt deposits, there are also older rocks poking through which have their own deposits of gold, for example ‘Hill 800’ in the Jamieson Volcanics poking through the eastern Melbourne Zone, and ‘Thursday’s Gossan’ in the Stavely Arc which is in the footwall of the Moyston Fault in the Delamerian Fold Belt.

But first let’s focus on the most common and well-known gold deposits which span the Bendigo Zone and the Stawell Zone.

[Slide: Lachlan Supergroup]

The most common host rock for Victoria’s orogenic gold deposits is the most common rock – and that’s these sort of deep marine early-Palaeozoic age siliciclastic turbidites; and they’ve been strongly deformed, and the orogenic gold is hosted in structures that have deformed these turbidites.

Now, what’s interesting about these rocks is although they’re a great host for gold, they’re not actually a great source for gold.

So although they have got pyritic black shale in them, and that pyritic black shale has possibly been a source for some of the gold, that doesn’t explain the full story.

Eastern Victoria has a lot more black shale and a lot less orogenic gold, so something else must be happening, and that’s really borne out by studies that look at the potential of these rocks to be a source rock for gold.

And really on a scale of 1 to 100 turbidites are closer to one than anything else.

They’re not the worst, granite is the worse source rock, but they are far from a great source rock for gold; something else is going on.

The other important research that has been done is looking into the nature of the structures that host gold.

So, in the case of the metasediments, it’s a folded succession, and the folds are often an important host for gold especially anticlinal hinges.

And another important host for gold is the faults that cut through the folded succession.

So folds form in the ductile regime but as these rocks are uplifted and eroded through geological time they’ve transitioned into a brittle regime.

So when they were subjected to further shortening - the deformation which accompanied gold mineralisation - faults have cut through the folded succession, and it’s really common to get dilation in places where the faults are cutting through oppositely- dipping limbs.

And this is a really key critical site in a lot of well-known deposits, including for example the Fosterville site.

Now, I’ve used Fosterville as a great example, but this is actually a very common process across all the goldfields in Victoria, so it’s not uncommon to see these sort of relationships of bedded faults flattening across the fold hinge into an oppositely dipping limb in goldfields across Victoria.

[Slide: Grant Goldfield]

This is the Grant Goldfield for example in eastern Victoria, it’s not a huge goldfield but the processes that have led to the dilation and formation of these gold-bearing shoots is exactly the same.

The full predictive power of this sort of understanding has yet to be applied to all of Victoria’s goldfields.

There’s a lot of opportunity there to discover blind, completely fresh gold deposits in some of these other fields as well, just like as what happened for Fosterville.

Whole other provinces may have significant unrecognised gold, even of a completely different style.

And we’ve got new data, new understanding, new knowledge, and new models that are pointing to this ‘golden future’.

Hill 800 illustrates the potential and as does Stavely further west.

We’ve got a bunch of published yet-to-find gold estimates for Victoria but these haven’t fully considered all these new possibilities, especially the idea of being able to find something like a Fosterville in the middle of a ‘brownfields’ terrain.

So when you take that into account, and the benefit of hindsight as to what’s happened more recently, Victoria’s yet-to-find gold estimates look way low.

And part of the reason for the estimates looking way low is that these systems have great depth extent.

[Slide: Great Extended Hustler’s Shaft]

So this is Herman’s 1914 plan of the ‘Hustler’ line of reef in the Bendigo goldfield, and you can see there that they’ve been mining this thing down below 1,400 metres below surface.

Most of the structures in that cross-section are depicted as the famous ‘saddle reefs’, where dilations were occurring around anticlinal closures, and whilst some of them have been reinterpreted in the light of more modern geology, there’s no doubt that saddle reefs do occur, here’s a beauty mined out in the Blackwood goldfield closer to Melbourne.

[Slide: Saddle reef - modern mapping]

Modern mapping can add geological context to those old mine plans, and that gives you much more predictive powers to how to chase these… repeats of these sorts of packages in adjacent areas.

[Slide: Map of goldfield areas]

Turbidites aren’t the only important rock in the goldfields of Victoria, the other important rock is the rock that underlies these marine turbidites, and that is, unsurprisingly, Cambrian oceanic crust, and it’s exposed only along large reverse faults that cut through the sequence that have thrust this underlying succession towards the surface.

Here are the Cambrian metavolcanics at Heathcote.

They’ve got pillow structures in them which confirms they are a submarine deposit, and it’s also confirmed by the conformably overlying silicic chert; thats a pelagic deposit accumulated in an open ocean far from a continent.

[Slide: Photos of various rock types]

Now these rocks and these associations are really widespread, they also turn up in Stawell underground in the Magdala mine, you can see some pillow basalts there that have been flattened a bit.

[Slide: Geological Survey of Victoria graph]

One of the important characteristics of the Cambrian igneous rocks that underlie the turbidites, is that they are a credible source of lots of gold.

On the same scale as the turbidites the research suggests that they’ve got a capacity between about five and about 50 times of turbidites in terms of volume to supply gold, mainly from interflow sediments.

Where these rocks sit at surface in fault zones they’re also a potential host for orogenic gold, and the poster-child for this of course is at Stawell in western Victoria.

So Stawell primarily consists of the Magdala mine and it’s actually the flank of the competent basalt block that has focussed faulting and dilation to form the ‘Central Lode System’, and this has been a multimillion ounce deposit, and you can see the depth extent there of that cross-section heading down below 1,500 metres worked from the surface.

So the scale of these systems are similar to the one in Bendigo.

There’s a lot of potential.

South along strike from Stawell the geology persists, it’s not surprising, it’s related to a Cambrian subduction-accretion system.

It’s a giant scale system so it’s no surprise that you’re getting similar sorts of deposits, for example in the ‘Irvine gold prospect’ Navarre are working on at the moment, south of Stawell.

And given the continental scale of these systems it would be no surprise to us to see that this prospectivity extends under cover north and south as well.

[Slide: Talk Outline]

What I want to talk about now is the size of the prize.

Why are people so interested in Victoria today?

[Slide: Significant Drill Intersections of 2017]

Of course it was done by Fosterville wasn’t it?

No-one could ignore numbers like 15 metres at 1,429g/t.

[Slide: Fosterville - approaching ~10Moz]

Fosterville as a goldfield is now approaching 10 million ounces.

You can look at the numbers there but, you know, no-one would ever complain about having those sorts of numbers, the question is are there other places we can find similar deposits like this, but we think: yes, there are other opportunities, and that’s why it’s so exciting.

[Slide: Talk Outline]

We’ve got lots of new data to help support our system’s thinking about trying to put things like Fosterville into a broader context.

[Slide: Various logos of research collaboration]

You can’t do this sort of work by yourself, so we’re really grateful for the years of productive collaboration between Geological Survey of Victoria, Geoscience Australia, the federal government, and of course all our other research partners at universities and other funding bodies.

[Slide: Map of Australia and close-up of Victoria and Tasmania]

New data includes things like comprehensive airborne geophysics turning the Murray Basin which you can see there covering most of south-east Australia into something that allows us to interpret the geology at depth beneath those rocks.

And that’s important, not just to understand the geology underneath the Murray Basin, but it’s a feedback into Victoria to understand the system’s analysis, and to allow the geology of all the different states to be correlated with one another.

[Slide: Graphs of Victoria and NSW]

Aeromagnetic data is important because it allows us to take our understandings from areas of Palaeozoic rock outcrop in Victoria, in the midlands and highlands, and extend it north under the Murray Basin to understand the shape of this system at a sort of subcontinental scale.

And because we understand the age and context of the rocks exposed in Victoria we can take that understanding and extend it underneath the Murray Basin as well, and start to populate a basic bedrock geology map of a large part of eastern Australia.

Aeromagnetic data gives you two dimensions and the ability to see through cover, but for full understanding of the crust you really need to understand the third dimension, and for Victoria that’s where deep seismic reflection profiling has come to the party, and we’ve now got profiles that go right across the full width of Victoria.

[Slide: Deep Seismic Reflection]

The first of these surveys we undertook in 2006 across the Victorian goldfields, and this data was instrumental in a step change in our understanding of how these goldfields are formed.

[Slide: Interpretation of the seismic]

This is an interpretation of the seismic, and you can see some key elements coming out of the data.

One of them is the realisation that faults that were previously mapped at the surface, like the Heathcote fault zone, really extended down to great depths in the crust.

[Slide: Detail of the Heathcote Fault Zone]

You can see that the fault we’ve mapped at surface is a long linear persistent structure; it’s also linear and persistent down-dip, right down into the mid- and lower crust.

This is a key revelation for understanding the Lachlan Fold Belt and the goldfields terranes, because it told us that the geology was behaving in a thick skin fashion which was different to the prevailing paradigm at that time.

This has led to ‘whole-of-systems’ thinking for geological models in Victoria, and that includes geological models that explain the context of the orogenic gold endowment, and that’s got predictive capacity.

[Slide: Laterally diverse crust in the Lachlan Fold Belt]

With this depth understanding, and with the knowledge from the aeromagnetic data and the mapping that gives us the lateral extent control, we can combine geological mapping, the aeromagnetics to seismic, to the concepts and start to build three dimensional models.

[Slide: Victoria - Statewide informed 3D model]

And we’ve done this for Victoria 10 years ago and we’ve refined it ever since to this day.

[Slide: Interpretation Cayley et al, 2011]

Focusing in on the Bendigo Zone system and the richest gold deposits, including Bendigo and Fosterville, seismic for the Eastern Bendigo Zone shows an unreflected upper crust which we know to be dominated by the early Palaeozoic turbidites that host the major gold deposits like Bendigo and Fosterville, underlain by much more reflective crust, which can be traced to the surface where it’s exposed in the Heathcote Fault Zone as the Cambrian metavolcanics.

So because of this contrast in reflective character, and because of the mapping we’ve done, we can take the Heathcote Fault Zone volcanics we’ve mapped at surface, and extend them down along the Heathcote Fault into the mid and lower crust.

One thing it certainly confirms is that goldfields geology is thick-skinned.

The other thing it shows is that there are thousands of cubic kilometres of these Cambrian metavolcanic rocks which are a credible source for orogenic gold at depth underneath the goldfields.

[Slide: Interpretation Cayley et al, 2011 and Willman et al, 2010]

They will have been subjected to heating to and beyond the greenschist to amphibolite facies transition.

And research shows that when that happens in rocks like this lots of fluids are given off at that transition, and those fluids carry gold, and that gold-bearing fluid has to travel upwards because downwards is even hotter, and the structures that can facilitate that transport are low angle faults that can be open when the rocks are under compression.

Now what the geometry of the seismic also shows is that the low angle faults at depth that can carry the fluids transition to high angle faults higher in the crust. So they are listric.

Now what’s interesting about that is, the high angle portions of these faults are going to be pushed shut during the very compression that’s resulting in the crustal thickening, and when faults are pushed shut they’re not good fluid conduits, so what we think has been happening is that fluids have been leaking up subsidiary structures above the inflection point.

And this explains the observed offset between the biggest goldfields like Bendigo and the large faults that outcrop to the east and west of them.

A similar scenario is possible for goldfields like Fosterville, and one of the interesting ideas that this new data throws up is the idea that structures that host the gold, like the Fosterville Fault at Fosterville, may not have been the important structure for the plumbing of the gold at depth, that could have been an underlying structure that has undergone this inflection point change.

The other thing to emphasise about these processes is they need not be very efficient.

The data indicates there’s thousands of cubic kilometres of potential source rocks, so it’s possible to still form multimillion ounce deposits even though perhaps only 5% of the gold or less is actually ending up trapped in that sort of system.

[Slide: Deep seismic reflection - new tectonic and mineralisation models]

As a result of this work done in 2006 we published a series of new tectonic and mineralisation models, and that new understanding formed the foundation for a bunch of testing that has happened after that.

[Slide: Talk Outline]

And that really relates to trying to develop a stronger predictive capacity and looking at new horizons - new opportunities this new understanding is outlining.

[Slide: The value add: Mineral Systems map - Key Commodities]

An example of predictive capacity is a mineral systems map where we’ve looked at the geology, the early Palaeozoic geology of the state, and then had a think about what its tectonic setting was at the time the goldfields were forming, and so therefore what sorts of mineral systems are likely to be formed in those rocks depending on their tectonic setting.

So let’s zoom back in to the goldfields we’re talking about here.

[Slide: Full crustal section, Stawell and Bendigo Zones]

Looking at individual faults within the system, they’ve got this listric profile.

The fault is steep at the surface, the fault is shallow at depth, and there is an inflection point and that’s captured by the 3D model.

So we can grab a part of this model and look at it in full 3D.

[Slide: Inflection point mapping, using the 3D model]

These are the fault mesh shapes overlaid on the seismic.

These are the surface fault traces, and these are the inflection point positions built into the 3D model for western Victoria.

And we can take those inflection point positions at depth in the crust and project them to surface, so we end up with two different sets of lines on our geology map.

[Slide: Rawling et al, 2011]

What the two different sets of lines show is actually something quite exciting.

The surface fault traces are the red lines, and if you put a 1,500 metre buffer around those red lines, those buffers capture 41% of the known gold deposits and 27% of the intermediate to large deposits.

The purple lines with the green buffer, they are the inflection point positions projected to surface.

Those projected lines capture 67% of the known gold deposits and most of the large ones, so what this means is: inflection point projections win as a goldfield predictor.

The gold at surface is honouring the inflection point positions at depth much more strongly than it’s honouring the mapped fault positions at surface: this is a toolkit for exploring under cover……

[Slide: Mineral Exploration Fairways - orogenic gold discoveries under cover]

….In areas such as to the north of the Bendigo Zone and it was this sort of thinking that informed the GSV’s decision to capture detailed ground gravity in the Northern Bendigo Zone, and that detailed ground gravity was really important in things like the Four Eagles discovery.

[Slide: Talk Outline]

How do we solve these problems?

One of the ways has been with new technology.

[Slide: Victorian Seamless Geology - graphs]

Getting back to our cross-section through the western Victorian goldfields, it’s possible to take the shapes that we’ve established with the seismic and the mapping and the other geophysics, and start building more detailed numerical models of those.

So, here’s a numerical model built by Leader and Wilson, to test the idea of fluid flow modelling at that crustal scale.

[Slide: Generic fault]

So it’s a 2.5D model, full crustal thickness.

Here’s another one built by Peter Schaubs around the same time, and idea we’re playing with here is we have the known cross-section and known plan distribution of the faults that we think are important for gold mineralisation, and we can squash that crust, look at the behaviour of the faults as they get reactivated, and model the likely fluid flow along those faults.

And what you can see here is faults that high fluid flow at depth, develop low fluid flow where they steepen near the surface.

This is repeated in multiple faults.

This is a validation of the theoretical models that were previously published.

[Slide: Talk Outline]

Putting all this new understanding together, I think it’s really improved people’s confidence in dealing with these systems.

They’ve got an idea about how it’s possible to find gold in them and what might be important in controlling the gold, and this gives people hope to design an exploration program, especially under cover.

[Slide: World Class Gold]

There’s lots of areas now across Victoria which are having some success looking for new gold deposits, or looking for extensions of old gold deposits.

And really, it’s about this multidisciplinary modern applied geoscience bringing to bear the fruits of 20 years of labour coming into these sorts of thinking.

[Slide: Victorian gold: new opportunities]

So we have the opportunity to grow our goldfields terrane, not just along strike from the existing known goldfields but also into completely new terranes where there hasn’t really been any indication that there’s been orogenic gold found before.

[Slide: Healthy Exploration Activity]

With this renewed confidence we’re getting healthy exploration activity, growing its percentage of Australian expenditure.

[Slide: Increasing Mineral Exploration]

Our expenditure is rising more steeply than the Australian average, and this is really showcasing the health of the Australian gold sector.

[Slide: Listed Junior Value in Victoria]

And this success is being reflected in the average share price of gold explorers who are active in Victoria as well.

It looks like it’s been a good place to be.

[Slide: Exploring for the Future]

Government is committed to support; there’s new funding announced federally for the ‘Exploring for the Future’, and this will be another opportunity to continue our long-standing collaborations with Geoscience Australia trying to understand the geology of Victoria and realise its potential.

[Slide: Conclusions]

So in conclusion: we think we’ve got a ‘new dawn’ for Victorian gold exploration, it’s really underpinned by data, technology, concepts and confidence.

All these things have advanced.

Fosterville has really changed the game.

It single-handedly added nearly 10 million ounces to Victoria’s gold inventory probably and counting.

How many others can there be?

The geology suggests several.

The workflows to get there are going to be discussed by Phil and Rob in the subsequent talks.

We think Victoria has crossed a threshold of data and understanding to what looks like sustained success.

Thank you.