**Video Transcript**

**Victorian Gold Mining and Exploration Forum - The five key ingredients for a world-class gold district**

[Title: The five key ingredients for a world-class gold district: lessons from the Bendigo Zone - Rob Duncan, Senior Economic Geologist]

*Rob Duncan*

Good morning everyone.

We quickly get to take a look at our current understanding of the key ingredients that a world-class orogenic gold systems that we see preserved in the Bendigo Zone of Victoria.

The geological characteristics of these systems has been intensely studied by industry, academia and the Geological Survey of Victoria over the past 170 years, so they actually make pretty excellent case studies for mineral explorers in the state who are dealing with both the current challenges of exploring under Murray Basin cover, but also extending search horizons into other tectonic stratigraphic zones across Victoria.

Together, these ingredients we’ll speak about will help us actually understand why Victoria is responsible for 2% of the world’s gold production that has come from only 0.00004%of the world’s land surface.

[Slide: Tectonic triggers; Pathway architecture; Metal and fluid sources; Structural physio-chemical traps; Preservation]

We’re going to start at the end, and here’s the key ingredients to the Bendigo Zone gold recipe.

Some of these like tectonic triggers, physio-chemic traps and preservation history are pretty similar across other deposits in Victoria.

To form economic concentrations of gold in the deposit we actually need a series of geological events, processes and environmental conditions to coincide in both space and time.

We’ve got evidence in Victoria that gold was mobile and became concentrated during at least three phases of orogen assists in deformation related to transient 445 and 380 Ma.

GSV, the V shaped geometry of first order crustal-scale faults with opposing dips in the Bendigo and Stawell Zones, and there are a series of inflection points where they transition from relatively flat line structures to dipping structures, and it’s during deformation that these were the actual key to transitioning from structures that were relatively open to ones that were relatively closed, and this generated a series of fluid escaped structures, 2nd order structures, and those are the ones that exert a strong control and a distribution of well-endowed goldfields.

In terms of gold sources there’s two really good candidates that dominate Victorian geology across most of the Lachlan Fault belt, although it’s controversial which one is actually key, and the orogenic events provide plenty of scope for metamorphic fluid generation at depth to provide a transport mechanism from the metal from the source to trap.

At the deposit scale we see the physio-chemical traps for mineralisation occur where there are relatively flat portions of faults intersect with fold axes and these represent dilational sites during transpression and compression.

This generates a structural trap for mineralisation, it’s also the opportunity in this dilational zone for the fluid to undergo relatively rapid changes in physio-chemical characteristics to drive gold precipitation.

In the Bendigo Zone we see preservations for these systems is relatively high because of the tectonic quiescence that’s occurred between 465 Ma.

Yes, unfortunately some of the orogenic gold systems have been eroded but progressive uplift in erosion over this time has brought these world-class gold systems relatively to surface.

[Slide: Tectonic triggers - large scale]

We won’t dwell on the large scale tectonic triggers, but again the three major back-arc inversion events related to changes on far-field subduction arrangement to the east occurred at 445 Ma with the Benambran orogeny, at 415 Ma with the Bindian Orogeny and 390 Ma with the Tabberabberan orogeny.

Cumulatively these events generated a 70% crustal shortening, most have been accommodated in the formation of that shaped geometry across the Stawell and Bendigo Zones between the Delamerian Orogeny and the Selwyn Block.

Gold production from the Bendigo Zone has mostly been focused above the Mount William Fault which represent the boundary between the Bendigo Zone and the Selwyn Block and the Melbourne Zone above the Selwyn Block.

[Slide: Tectonic triggers - smaller scale]

Moving onto a smaller scale we see that there’s a progressive structure change in structural deformation as preserved in the rocks.

So, we actually go from bedding parallel flexural slip and open folds, to progressive tightening of these folds.

When they continue to develop they actually get locked up under continued compression, and during that there’s a failure and a series of low angled displacement faults, cross cut fold hinges, those are those key structural sites for mineralisation because they are linked by a fracture mesh that is permeable during periods of fluid over pressure.

Within the Castlemaine Group itself rheological contrasts between the lithologies in the turbidites enhance this network, but also they make it more irregular.

And we can see that the highest periods of fluid flux coincide with the shortening events.

GSV works identified that gold mineralisation more likely took place away from major intrazonal faults related to more second order and third order structures, that are characterised by a single major phase of deformation, slaty and no crenulation cleavage upright, non- rotated actual planar faults with sub-horizontal fold axes, and that’s in contrast to more poly-deformed rocks that you might see closer to those major scale structures.

[Slide: Maps of various gold areas]

If we examine known areas of gold mineralisation we can clearly say that high grade gold mineralisation is collocated where these third order faults refract from bedding parallel into more horizontal positions, and that occurs in relation where they start interact to fold closures.

[Slide: Fluid source]

Considering fluid source we can see that during the tectonic events it’s relatively easy to generate lots of fluid during prograde metamorphism.

The transition from greenschist amphibolite facies is at 5500C and that’s characterised by the formation of amphiboles from chlorite, so that generates lots of water, and we can see that that’s 100% temperature controlled and independent pressure.

So, it’s pretty easy to consider how under these temperature conditions we can generate voluminous aqueous low salinity fluids, and we see these fluids preserved across all the Victorian orogenic gold systems.

We also see a lot of CO2 in these fluids and that can be explained by the breakdown of carbonates just above the transition from the greenschist amphibolite grade conditions.

[Slide: Fluid source: noble gas]

Given the similarities of some of these fluids that we see in the deposits across Victoria, some extra work’s been done in terms of examining the fluid sources using noble gas and halogen analyses, and this work was completed at this GSV Gold Undercover Project.

On the left we see a plot of 36 argon over the ratio of 40Ar/36Ar, so this ratio down here actually helps us distinguish between air saturated water which goes down here, and metamorphic fluids, so we can see that most of them plot away, in fact all of the plot away from air saturated work, so we’re comfortable that it is metamorphic fluids involved.

And then just the 36Ar concentration actually is a function of the carbon dioxide, water, H2O in both the fluid and the source of lithologies, but also a measure of fluid-rock interaction, and we see a few different things going on here.

One thing of note is that this is the box for Fosterville here and that maybe that tells us something about how there were more processes there that might have generated gold depositions than other deposits, and that might help us explain some of the extreme gold grades that we see in that deposit.

On the right we see halogens which are a trace of salinity, even though they’re low salinity they’ve still got some salinity.

And we see major differences between deposits in the west and the east, so this box here, this is Stawell and there’s low iodine chlorine concentration ratios relate to interaction of the fluids with metabasalts which are collocated with mineralisation at Stawell.

As we progress into the Bendigo Zone we see that influence less and less, but what we do see is a transition, especially into the Melbourne Zone, into high iodine chlorine ratios which demonstrates that there’s been an interaction of those fluids with organic rich sediments which dominate the stratigraphy in the Melbourne Zone.

[Slide: Au sources]

When we examine potential gold sources the metabasalts and the metasedimentary rocks of the Castlemaine Group could both be plausible sources of gold.

When we use global averages for similar rocks in similar tectonic settings we see that basalts have slightly less gold around 5 ppb compared with sandstones and shales.

In turn shales are a bit more enriched in gold compared with the sandstone, this means that relatively small zones of carbonaceous materials such as these preserved here, could be important metal reservoirs of Victorian orogen at gold systems, and moreover that shales, and to a lesser extent sandstones could also be the source of arsenic given their relatively high concentrations compared with the basalts and arsenic because it’s considered an important pathfinder in these orogenic systems.

[Slide: Au sources - Bendigo case study]

We can use the study of Thomas et al, who looked at laser ablation element mapping of paths across the Bendigo Zone deposits to illustrate evidence of gold, mean gold, and arsenic being removed from diagenetic pyrite.

Here we’ve got a plot of mean gold and arsenic in pyrites at various paragenesis from across the Bendigo system.

Note that there’s a locked system.

Diagenetic pyrite has a mean area of 0.6 pp in gold and 1300 ppm arsenic.

When diagenetic pyrites have been affected by metamorphism an desulfurized to pyrrhotite we can see that pyrrhotite would plot, the pyrrhotite mean compositions would plot somewhere down here, so they’d have a content, the gold content of 0.04 ppm and a mean arsenic content of 4 ppm, so that means over 93% of the gold and 99.9% of the arsenic has been removed from this pyrrhotite to pyrite transition.

It’s actually pretty remarkable that a geological process could be that efficient.

Then if we look at, we can see, look as we pass into gold-bearing reefs we actually see that the arsenic and gold contents in the pyrites as we move towards the mineralised zone increases, and that ultimately when we reach the gold-bearing reefs we see that gold is nine times enriched in the pyrite, in the gold-bearing reefs compared with the original diagenetic pyrite.

So what we’re actually seeing here is mapping out potential gold mobility in Victorian orogenic gold systems.

[Slide: OK so black shales are good Au source]

So we’ve seen that diagenetic pyrites most likely hosting carbonates show could provide an important source of the gold, however no comparable studies exist for the amount of basalts, that’s where the GSV is just starting on now.

So if we consider the regional stratigraphic setting in the Castlemaine Group is less than 5% black shale, and in certain areas, especially in the southern portion of the Bendigo Zone, goldfields are hosted in sequences that are largely dominated by sand, it’s hard to actually imagine how we can only appeal to stripping of gold from diagenetic pyrites to be the only source of metal in these deposits.

And if we look further afield we can see that whilst – not only is there a large thickness of metabasalts and that’s what this is a map of here, we see a lot of the gold deposits are collocated with those large thicknesses or just to the edge of, when we also compare the stratigraphy in the Castlemaine Groups with that of the Melbourne Zone and the Tabberabberan Zone which have had far less historic gold production, we can actually see that the stratigraphy there is almost completed dominated by black shales, so that’s something we’re having to work through, that that order of magnitude, less historic gold production, does that relate to the relatively underexplored nature of the Tabberabberan Zone, or does it relate to differences like things in metamorphic grade and availability of fluids.

[Slide: S source(s)]

Sulphate is considered key in the orogenic gold systems because it’s widely considered that gold is transported in the systems by sulphide and by sulphate complexes, and that can explain the lack of base metals in these systems because those will be transported by chloride complexes.

If we recall that the major fluid release is temperature dependent and occurs at the greenschist amphibolite metamorphic rate transition, and that’s associated with the desulfurization of pyrite to pyrrhotite also appears around this temperature, we can see that that’s probably also providing the likely source of sulphur in these systems.

We can see, if we look on here, this is the bulk sulphide signatures of orogenic gold systems across Victoria, and we can see that they range from +5 to -5 per ml, and that’s pretty typical as either being sourced from diagenetic sulphides and/or magmatic rocks, so we can’t really distinguish between either one.

If we look on the right-hand side we can look at the work of Tomkins et al, who looked at the sulphur mobility windows for pelites under a range of pt conditions in the metabasalts as well, we can see there’s a much larger range of sulphur producing window in there which might point to the Castlemaine Group being the more likely source of sulphur.

[Slide: What makes Au precipitate?]

In simple terms gold is precipitated in the structural traps that generate rapid physiochemical changes that a brought around by rapid depressurisation.

But what does that depressurisation drive in terms of Pt conditions but also other physiochemical parameters that may generate gold precipitation?

On the bottom left here we have a fo2 pH slide that we see that gold is most soluble under near neutral pH just below the sulphate boundary, and across both sulphide and bi-sulphide complex stability fields.

If we look at how tightly packed these contours are we see the quickest way to form gold is an increase – to precipitate gold is an increase in fO2, but we don’t see a bunch of sulphates preserved in the systems in Victoria unlike deposits elsewhere.

So in terms of other changes near neutral pH can shift in both directions to generate gold precipitation, and we can also see temperature drops such as here.

It’s really hard to transport gold in sulphide or bi-sulphide complexes below 2000C.

We can also see that simple decreases in sulphide complexes in activity can also precipitate gold.

We can precipitate it through pyrite formation, and we can also precipitate it through chemisorption reactions but slightly lower the fO2 and generate arsenic pyrite hosting gold.

In addition we can look at the rocks to actually understand what is happening in the sites of gold precipitation, where we can see phase separation evidence in fluid inclusions in liquid to vapour ratios, the CO2 content of the fluids, so CO2 mixing in these dilation sites would lower the pH and make gold-bearing complexes unstable.

And similarly, the fluid could interact with the reductant through wall-rock reactions to allow gold to precipitate.

[Slide: Evidence of Au precipitation mechanisms]

And, we can examine the likely scenarios that are important for Victorian orogenic systems by actually looking at the rocks for clues, and we can see that high aluminium phengitic muscovite associated with quartz pyrite assemblages across gold systems in Victoria ascend in this sodium aluminium potassium aluminium plot, and that’s evidence for slightly acidic hydrothermal fluid which is associated with alteration related to gold mineralisation, so that’s saying that pH changes are an important factor in gold precipitation.

We also see a lot of evidence for CO2 unmixing from the fluid and that’s preserved as vein, veinlets and spotting in mineralised zones and in the wall-rock.

[Slide: Preservation - Dispersion]

And just quickly ‘cause we’re really short on time, the three events responsible for gold mobility, just in terms of those tectonic events, has also been responsible for the progressive unroofing of the Bendigo Zone and its rocks and gold mineral systems from the Devonian, and this has brought the gold orogenic systems closer to the surface.

Since the Devonian and the Lachlan fault have been largely cratonised, so it’s been relatively stable until the Cretaceous rift uplift and erosion between that time and the Pliocene partially eroded the orogenic systems that generated the alluvial goldfield across Victoria.

And if we think about geochemical dispersion for a moment, that might help us more readily identify gold mineralisation, we can see that arsenic is the most mobile and their surface environments followed by antimony and this schematic demonstrates the relative size of that dispersion, maybe in excess of 10 kilometres from known areas of gold mineralisation in Victoria.

[Slide: Key geological factors responsible]

And, I think I’ll leave it there and save any questions for the panel Q&A, or feel free to email me on this email address.

Thank you very much for your time.