**Video Transcript**

**Goldfields Tender Briefing the Five Key Ingredients for a World Class Gold District**

[Slide: The Vic gold cookbook: Understanding the 5 key ingredients that made a world class gold district - Rob Duncan, Senior Economic Geologist, GSV]

*Rob Duncan - Senior Economic Geologist*

So we’re going to be looking at the five ingredients that we believe are really key to forming these world class gold systems that we see in Victoria.

It should have been really about, it’s specifically about the Bendigo Zone, so not about some of the other deposits we did find across Victoria.

Let’s just jump straight in.

If we just hop onto Google and just search orogenic gold we get over half a million hits.

[Slide: Significant of Vic orogenic Au Google search]

If we put orogenic gold and Victoria we lower those amount of returns obviously, but we get nearly 150,000 results.

And cudos to our marketing team our website is the number one hit when you Google that.

In terms of academic research that’s actually been completed on the Victorian gold systems, nearly one in five peer reviewed papers contains mention or results about orogenic gold systems in Victoria, so there’s been a large amount of research completed on these deposits.

And as Ross said, we’re approaching 2% of the world’s gold from a very small fraction of its continental surface area.

[Slide: Right place at the right time]

So we need to be in the right place at the right time, and there’s multiple reasons why a gold system doesn’t form, probably more reasons why it doesn’t form rather than it forms.

So we need to look for a series of geological events, processes and conditions that coincide in both space and time that generate gold mineralisation.

There’s multiple stages at which that can break down as the diagram on the left shows.

But across central Victoria we’ve got evidence that during at least those three periods, those orogenies that Ross was talking to, gold was mobile and became a concentrated in economic quantities.

[Slide: Key Takeaways]

So a good place to start is at the end, so these are the five key ingredients that are in the Victorian pantry.

So we’re looking at the tectonic triggers, those three orogenic events between 445 and 380 Ma, which were all related to inversion in a back-arc position, and that allowed a series of seismic events to generate crustal scale fluid flow.

Metal and fluid sources, again we’ve got two good candidates that academics argue back and forth about which is more important, there’s turbidites, there’s carbonaceous material in those turbidites, or those meta-basalts.

But hey, who cares, maybe the fact that we actually do need both of them to generate these world class gold deposits.

The fluid source, we’ll get to that, there’s only a single fluid source.

The pathway architecture we see from that GSV-led seismic data that it’s a v-shaped geometry with first order crustal scale faults.

So in the west they’re dipping east, and in the east they’re dipping west, and the shallow portions of those can easily become reactivated.

But what is key is those inflection points where fluids escape because they can no longer go up those steeply dipping structures where they become steep, and they’re being held shut, so they escape a lot of second order structures.

And everything about structural physio-chemic traps, we’ll see that there’s flat portions on the deposit scale but important dilation sites, so it’s specifically where those meet anticlinal structures that dilate a lot during compression or transpression.

And there’s numerous physio-chemical parameters that change in these systems that allow us to precipitate gold.

And as well, those processes don’t necessarily need to be very effective, and that’s why we get gold precipitated out over a large vertical section of the crust.

And then we’ll briefly touch on the dispersion and preservation history of these deposits, but what is key is throughout the three orogenic events essentially gold’s been forming and then that orogenic events have created increased dedication rates, so progressively during those three events the gold systems have actually been brought up closer to the surface, so they’ve been partially unroofed.

And then essentially between the Devonian and the Cretaceous there was a period of tectonic quiescence when the Lachlan Fold Belt had actually been cratenised.

[Slide: Geochron data]

Before we get into those ingredients, I just want to spend a bit of time discussing Geochron data.

There’s a lot of available Geochron data for the Victorian goldfields.

It’s not all plotted here.

What I’ve done is I’ve picked and chosen specific dates that are pretty high quality dates which give us more confidence that we’re actually dating some real geological event.

One issue with a lot of the data is a lot of it is Argon-Argon which is susceptible to various issues including resetting and issues to deal with grain size.

But the takeaway message is that in the Benambran we’ve got evidence of mineralisation for Ballarat East, Ballarat West, Bendigo and in between those two Bs, between Ballarat and Bendigo, so that was around 445.

Then during the Bindian we’ve got evidence of more gold coming in at Ballarat and between Bendigo and Ballarat.

And then in the Tabberabberan, so 380-370 we’ve got more gold coming in.

There’s a lot of data in that Tabberabbera space and a lot of that might be related to, that’s [0:05:42] with intrusion of a lot of granites in Victoria.

Another thing is if we start tearing about the paragenisis, and some studies were better at documenting the paragenisis of these samples that were dated better than others, if we look at those ones that are associated with the Benambran Orogeny, we kind of start to see a consistent pattern of those that are related directly with arsenopyrite.

Then if we look at the ones associated with the Bindian Orogeny there seems to be a quartz carbonate association.

And then the Tabberabberan Orogeny there seems to be a quartz stilalytic and antimony association, and that’s significant when we look at deposits like Fosterville, and we see in the upper right-hand corner here, we’ve got gold hosted, or Arsenopyrite gold mineralisation in that example, and that is obviously cross-cut in time and we’re not sure about the time gap between those two styles of mineralisation to the high grade visible gold that we see at depth, so that’s something significant to keep in mind.

[Slide: Hydrothermal history refractory versus free gold]

And that hydrothermal history is related in this example.

So this is a pyrite laser oblation map where we see a low gold but high arsenic tenor and it’s kind of associated with a moderate gold event.

But then we see on the edge in the light blue we see pyrite with really high gold and no arsenic.

So that pattern that we’re seeing, at least [0:07:23] with crust cutting relationships, we’re starting to see at smaller scale and in individual grains in the deposits.

[Slide: Tectonic triggers - large scale]

I won’t dwell on this too long because Ross did a pretty comprehensive coverage of this.

But the tectonic triggers, so the large scale, the three back-arc inversion events followed by transient extension, and that’s based on far-field subduction zone advancement and retreat, and that generated up to 70% shortening of the Bendigo Zone.

The tectonic events were largely focused in that v-shaped geometry in between the Delamerian Orogeny to the west and the Welwyn Block to the east.

And a lot of the gold production from the Bendigo Zone is focused from above the Mount William Fault, so that’s the boundary between the Bendigo and Melbourne Zones.

[Slide: Tectonic triggers - smaller scale]

If we zoom in and look at a smaller scale, essentially what we see is we see gentle folding and then the folds tighten and an actual play in that cleavage forms.

And then we see continued compression, the faults will lock up and actually fail and we’ll see low displacement of faults cutting across those structures, and that’s where an important site for gold mineralisation.

So there’s a series of low displacement sheers that are linked by hydraulic extension fracture mesh and that is open at times of fluid overpressure.

And the fact that the Castlemaine Group is rather heterogeneous package of sandstones, silkstone and shales means that that fracture network is highly irregular and a little bit unpredictable, but it’s during the shortening events that we see the best amount, or the largest amount of focused fluid flow along those structures.

In the top left-hand corner what we’ve got here is, there’s kind of a Goldilocks zone where you need to be able to step in from those major intrazonal structures, you need to be a distance from them to actually see where there’s a single phase of deformation, and it’s not been overcomplicated by poly-deformed deformational processes associated with movement, progressive movement along those intrazonal faults, so that’s pretty significant for the location of gold mineralisation.

[Slide: Examples from Ballarat, Wattle Gully, Four Eagles, Fosterville, Lockington (South)]

And if we look at these we can back these observations up with empirical observations.

And we see it’s not always the case, but obviously in all these examples, Ballarat, Wattle Gully, Four Eagles, Fosterville and Lockington, we do see that relatively high grade mineralisation in these systems that’s associated with relatively shallow portions of these structures where they cross-cut anticlinal structures.

[Slide: Fluid source]

Moving onto the fluid source, it’s pretty easy to generate a lot of fluid and so prograde metamorphism will do that of both the Castlemaine Group and the metabasalts.

So we see a common P-T-t path in these orogens of rapid burial and slower temperature increase, so there might be an offset in time from the compressional event to the generation of fluid.

The most important temperature is 550 degrees, so that’s right at the greenschist amphibolite transition, and we see that that transition is 100% controlled by temperature and nothing to do with pressure.

The key thing that’s produced is an aqueous-carbonic, low salinity fluid.

And the key mineral reaction for that is the breakdown of chlorite to amphiboles, but also we couldn’t explain the CO2 composition of the fluid solely on the basis of that reaction, so at that transition we’re also breaking down carbonates as well to put CO2 into the fluid.

[Slide: Fluid source: noble gas]

There was work done under the GSV’s Gold Undercover program on the noble gas and halogen compositions of fluid inclusions related to gold mineralisation in Victoria.

We see here, so it’s a plot of argon 40 over 36, and just argon 36 content of the fluid inclusions.

And generally what we see is that that’s in the right ball park for being a metamorphic fluid.

We do see variation in the actual content and that’s based on a function of the CO2 to H2O ratios in the actual source but also things like fluid-rock interaction as well.

One important observation is that on here it’s Fosterville that’s got the biggest envelope, and maybe these processes, or a combination of these processes are more evident at Fosterville than the other deposits, and that may explain higher grades or potentially higher endowment.

[Slide: Fluid source: halogens]

Moving on to the halogens, so even though these are of low salinity the halogens are important because they’re a conservative tracer of how the salinity was acquired.

So we look at bromine/chlorine ratios and iodine/chlorine ratios, and we see that there’s a various essentially from west to east, so we see Stawell sits in the magmatic box, and that’s likely because the salinity is partially acquired from the metabasalts which are collocated with mineralisation at Stawell, but not in the other systems.

And then as we move into the Bendigo Zone we see higher iodine/chlorine ratios.

And finally out into the Melbourne Zone deposits such as, was point of Walhalla, we see high iodine/chlorine ratios which signify there’s been interaction of the mineralising fluid with organic rich sediments.

[Slide: Metal and S Source(s)]

So sulphur and likely gold are sourced by the pyrite to pyrrhotite conversion which effectively takes place at that transition from greenschist to amphibolite facies metamorphism, and the likely sources for that have been the metabasalts and also the Castlemaine Group.

If we look at the sulphur isotopes down here on the left-hand side, don’t worry about Fiddlers Reef, we’re not sure about the paragenisis of those samples, but we see mostly in the range of plus five to minus five, so that’s either signifying that it’s sulphur that was derived from a magmatic source, and that could be the metabasalts, or that we had sulphur from a variety of sources and it just became really well mixed, and that’s not impossible given the large fluid flow paths that we’re talking about in these systems.

If we look at the actual content of the gold and arsenic content, which is obviously an important pathfinder in these systems, in the volcanics we’re talking 0.5 to 5 PPB gold, and arsenic 0.1 to 1 PPM arsenic.

And in the Castlemaine group in the black shale units, in the black shale units only not in the sandstone or silkstone, we’re talking in order of magnitude of greater than 10PPB gold, and then an order of magnitude arsenic, and that’s pretty significant because that just higher endowment in those elements both suggest they’re a more likely source of the metals by weight.

[Slide: Metal Source - Bendigo pyrite study]

At Bendigo there’s been a pretty extensive pyrite laser oblation study done by the guys down at Codes, they’ve actually saw a pretty amazing depletion in gold and arsenic as we convert diagenetic pyrite to pyrrhotite, so we see that the mean gold content of the diagenetic pyrite was 0.6 PPM, and in the pyrrhotite it’s almost essentially, it’s 0.04 so essentially there’s been a crazy efficient geological process to extract that, and the same with arsenic.

And that is we go from hydrothermal pyrite gold contents and arsenic contents in the turbidites themselves and into laminated quartz veins, and then into the reefs we see a gradual increase in those gold and arsenic numbers.

The theory here is they were actually tracking the metal movement through the system.

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

But as Ross said, so the black shales are a really good source, but in the Castlemaine Group it’s regionally we’re talking less than 5% black shale, so even though it could be a really efficient process we are thinking that there’s a large thickness of metabasalt which most likely represents a more voluminous source.

And then if we compare it to stratigraphy in the east, in the Tabberabberan Zone, we have Ordovician sequences there that are almost exclusively black shale.

So what’s the difference for that?

And in terms of exploration implications is it just because the Tabberabberan Zone has been relatively underexplored, because there are differences in the metamorphic grade that’s not likely, so there’s a few things to think about there.

[Slide: Transport: from source to sink]

So we’ve got our gold source and we’ve got our sulphur source, now we need to look at a transporting mechanism to transport it from the source into the sink into the deposit, so gold’s transported as Au1+ in two sulphide complexes, and it’s the low salinity fluid and the electro-negativity of gold means that gold will go with these sulphide complexes, but copper, zinc and lead will be left behind, so that’s why we see not so much of a rich of those systems with those elements which would be transported by [0:17:52] complexes.

And that also explains the similar geochemical behaviour of arsenic and antimony in these systems.

And the diagram on the top left there is a FOT pH diagram which demonstrates that gold is most soluble under near neutral pH, and below the sulphate buffer there.

So if we look at the optimal conditions for the sulphur release to get the sulphur into a sulphide complex to transport the gold, we’re also looking at that greenschist amphibolite transition.

And in the bottom left what we see on the left-hand side is there’s a yellow window there which is essentially the sulphur-bearing window in pyrrhotite, so there’s a large area relative on the right, so on the right that’s the sulphur generation window for mafic rocks.

So even though we might be invoking the metabasalts as a good source of gold, sulphur may have been an important sulphur source was likely the metabasalt, the carbonaceous sediments.

And all the thermodynamic modelling seems to point towards that sulphur can be – ten times the amount of sulphur can be generated from the mafic rocks.

From the carbonaceous better sediments, with the metabasalts it’s a little bit more difficult because any of the sulphur would be taken up by iron silicates.

[Slide: What makes Au precipitate?]

So what actually makes the gold precipitate?

So there’s a variety of reasons that we can investigate.

And the big one that most people always go to is the rapid depressurisation in areas of dilation and that’s great, because if we’ve obviously got a lot of areas of dilation.

But what that rapid decrease in pressure generates is also a lot of physio-chemical changes which actually explain why the gold drops out of solution.

So there’s a variety of pH fO2 as you saw on those previous diagrams can drive gold precipitation and the activity of those sulphide species, plus also temperature.

So below around 200 degrees it becomes nearly impossible to transport sulphide complexes so it will just drop out.

We can do it through a series of reactions, so simple decreases in sulphide complex activity.

We can do it through pyrite formation and that would explain why some gold is locked in pyrite.

And we can also do it through chemical absorption.

So when you generate arsenopyrite in these system it slightly lowers the pH which obviously is a pretty efficient way to drop out the gold from solution.

And we can also look at the actual fluids.

What can the fluids and the wall rocks tell us about what’s going on?

So there’s the role of CO2.

So we see a lot of evidence of face separation in these systems, so a lot of variation of liquid and vapour ratio, and a bit of variation in the CO contents in those phases.

So what that does is when CO2 unmixes from the fluid and it drives to a lower pH, and you pop out gold that way as well.

And we can also drop it out through an interaction of the fluid with a reductant to drive gold precipitation.

There’s also a lot of people who have spoken about the role of methane.

So methane is important in some deposits.

It’s not immediately identifiable in the a lot of the fluid inclusions in the Victorian systems, but what methane does is again it unmixes and lowers the fO2.

So we’re not talking about pH, but it lowers the fO2 in that bit that gets unmixed, and relatively increases the fO2 and you drop out gold that way.

So that’s why in systems such as WA you get a lot of magnetite.

[Slide: Evidence of Au precipitation mechanisms]

And what’s great about some of these, we can actually see evidence for these in the rocks, so that’s pretty neat.

So we look at – there’s muscovite alterations, so high aluminium muscovite alteration associated with the quartz [0:22:07] pyrite assemblage around the gold systems in Victoria.

And we also see a lot of carbonate evidence for the CO2 unmixing in the veins and the wall rocks.

[Slide: Preservation - Dispersion]

And speaking about the preservation, again it’s coming back to those three unroofing events which bring the orogenic gold systems in Victoria progressively through close to the surface over time, but also since the Devonian it’s been relatively tectonically quiet.

Obviously there have been periods of erosion which have formed the alluvial goldfields so they’ve historically been worked.

Just touching on dispersion, so this is just a cartoon schematic of lithogeochemical rock data, just demonstrating that arsenic is a lot more mobile in the near surface environment than antimony and gold, but obviously those can be used as a potential factors to mineralisation.

[Slide: Bendigo Zone: multiples of five]

Now just summing up, we’ve got multiple reasons why gold’s enriched in the Bendigo Zone, in these world class orogenic systems.

We’ve got three major orogenic events, so the Benambran, the Bindian and the Tabberabberan that occur over 65 million years.

We’ve got two plausible metal and sulphur sources and that’s great because two’s always better than one.

And we’ve only got one fluid.

And that pathway architecture, so we’ve got numerous faults and mesh networks to pump fluid from the source into the gold systems, and they’re all in a suitable orientation to be reactivated by these three shortening events.

We’ve examined why we’ve got numerous precipitation mechanisms that explain the variable gold deportment that we see in the Bendigo Zone gold systems, and the geological characteristics and alterations to [0:24:10], sorry, that was see in the rocks, and that near surface preservation due to those three unroofing events and relative tectonic stability since the Devonian.

And that’s it.

[Victoria State Government / Jobs, Precincts and Regions - Authorised by the Victorian Government, Melbourne]