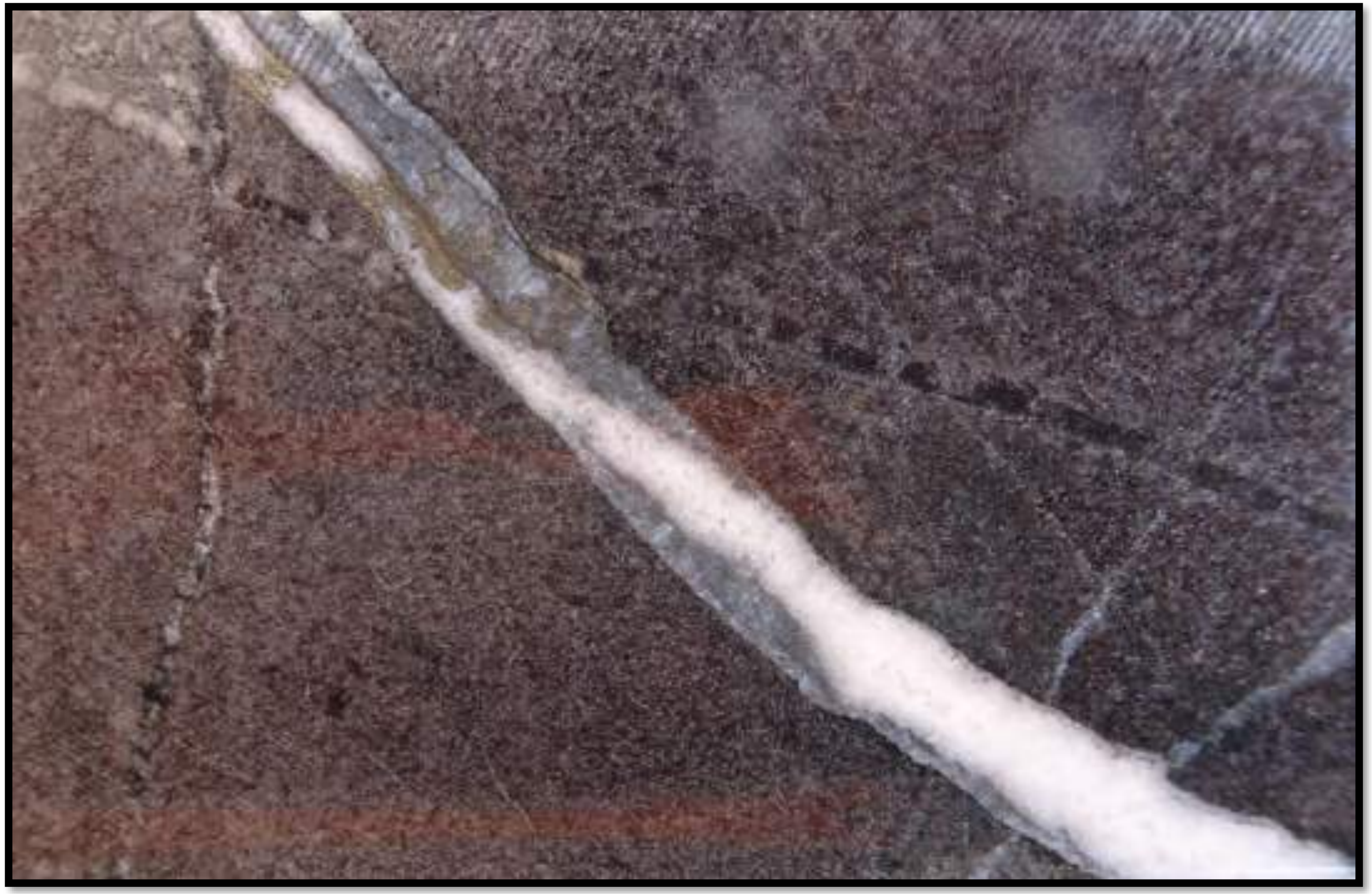


Brett Davis

Olinda Gold Structural Geology Consulting

Vein System Analysis – Composite Veins

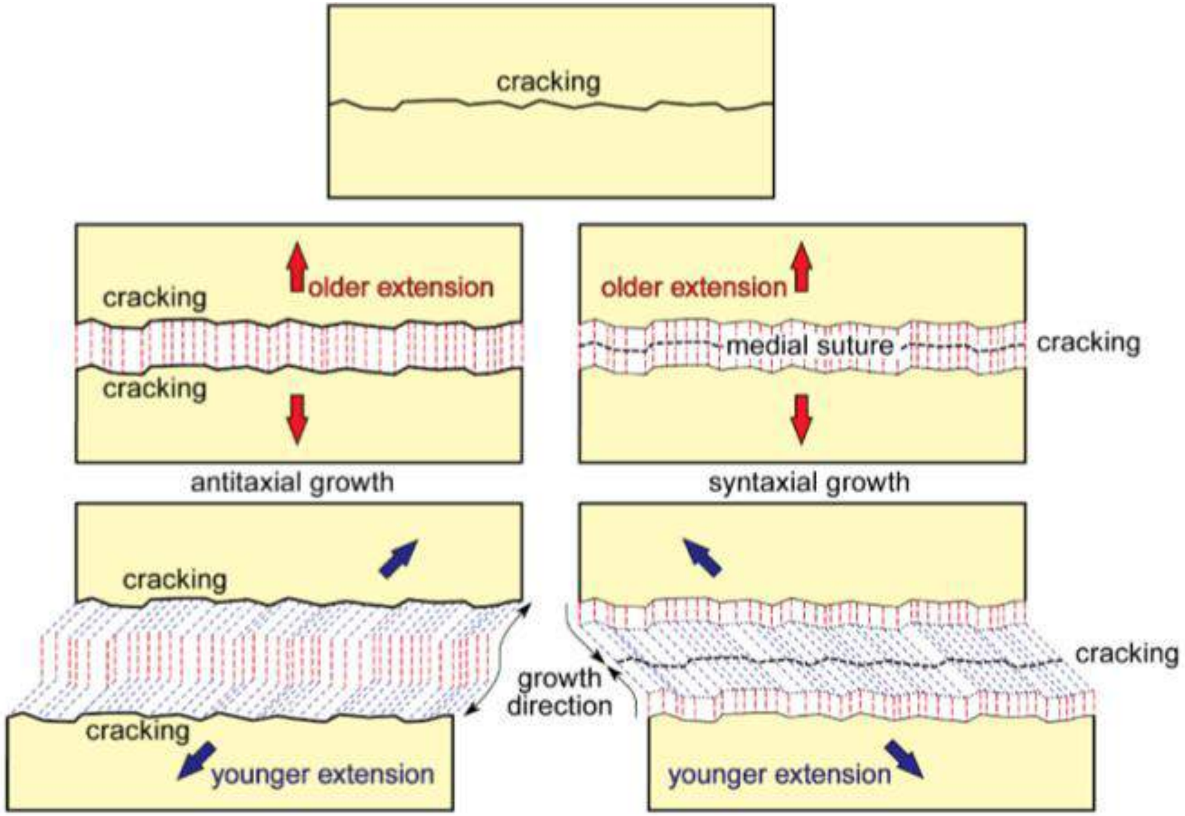
Composite veins

- The definition presented here is my own and differs from some historical definitions for the same term.
- The definition used herein fits the context of veins we observe in hydrothermal mineral systems. In terms of application to exploration and mining projects, the definition here is markedly more useful than that proposed historically.
- Much of the previous terminology centres around the definition of veins as syntaxial or antitaxial.
- The textural definition of syntaxial and antitaxial pertaining to vein fibre growth is never used by mining and exploration industry geologists when trying to resolve the context of the vein in an evolving mineral system.
- Furthermore, the historical terminology, as defined by workers, can only be applied to extension veins, severely limiting the usefulness of composite veins. It cannot be applied to shear veins where the primary growth textures and history have been destroyed.

Composite veins - terminology

The term composite vein has been used by a couple of previous workers in the following contexts:

- Alex Strekeisen (https://www.alexstrekeisen.it/english/meta/veins.php) defined composite veins as '*veins in which an antitaxial vein segment is sandwiched between syntaxial vein rims. Such a vein has three median lines.'* Strekeisen's diagram is shown at left because it is a very good one for summarizing antitaxial/syntaxial terminology.
- Bons (Bons: The formation of veins and their microstructureshttps://www.tectonique.net › wdmrom_pdf › bons) used the same definition as Strekeisen for these morphologies, citing Durney and Ramsay (1973, In: Gravity and Tectonics (edited by K. A. De Jong & R. Scholten, pp 67-96), and further commenting that *'The term composite should be reserved for veins where both morphologies and minerals occupy similar proportions of the vein.'*
- The Free Dictionary https://encyclopedia2.thefreedictionary.com/composite+vein defines a composite vein as *'a large fracture zone composed of parallel ore-filled fissures and converging diagonals, whose walls and intervening country rock have been replaced to a certain degree'.*



Composite veins – terminology/definition in the context of mineral systems = Brett's view of the world

- Composite veins, as defined by me, comprise the parallel to low-angle juxtaposition of two or more different veins that differ in terms of one or more characteristics, including mineralogy, age, morphology or conditions of formation.

- Veins commonly develop as composite structures when subsequent vein episodes exploit the weakness represented by pre-existing vein-wallrock contacts, or planar weaknesses internal to the veins (e.g. shear-induced laminations, mineralogical boundaries).

- In the case of exploitation of earlier-formed internal vein weaknesses, the younger veins will commonly track from one side of the vein to the other.

Composite veins – terminology/definition in the context of mineral systems = Brett's view of the world

- The terminology of composite veins given here largely precludes the textures that develop through the process of crack-seal and formation of fibrous extension veins.
- Crack-seal veins form when the rock and the vein-hosting structure are repeatedly fractured and infilled by successive increments of hydrothermal mineral deposition, typically as thin (microns to millimetres), parallel layers that can accumulate to produce veins of considerable thickness.
- Successive fluid cycles are typically compositionally similar, building up a vein of successive layers comprising the same mineralogy, commonly in conjunction with development of fibres at a high angle to the vein walls.
- In this respect, crack-seal veins differ from composite veins. Composite veins comprise distinctly different phases of vein material that are temporally distinct, commonly being separated in time by the formation of other structures and/or hydrothermal mineral depositional episodes.
- In the vein at right from the Tigray region in Ethiopia, there have been multiple cycles of silica-rich fluid ingress and deposition that have produced fibre growth and local formation of relatively massive quartz. Despite the multiple stages of deposition and the two obviously different vein morphologies, I would not categorise this as a composite vein.

Composite veins - recognition

- Composite veins can be recognised by:

  - An asymmetric distribution of vein minerals

  - The presence of two or more sets of minerals that have markedly different formation conditions e.g. lower greenschist-grade metamorphic minerals may comprise a vein that has adjacent bands of amphibolite-grade minerals

  - An asymmetric distribution of alteration selvedges

  - Cross-cutting relationships between the component veins that that are developed along strike/dip

  - Differing overprinting relationships between the different vein fill minerals e.g. one set of vein minerals may comprise structures that are folded whereas others are not.

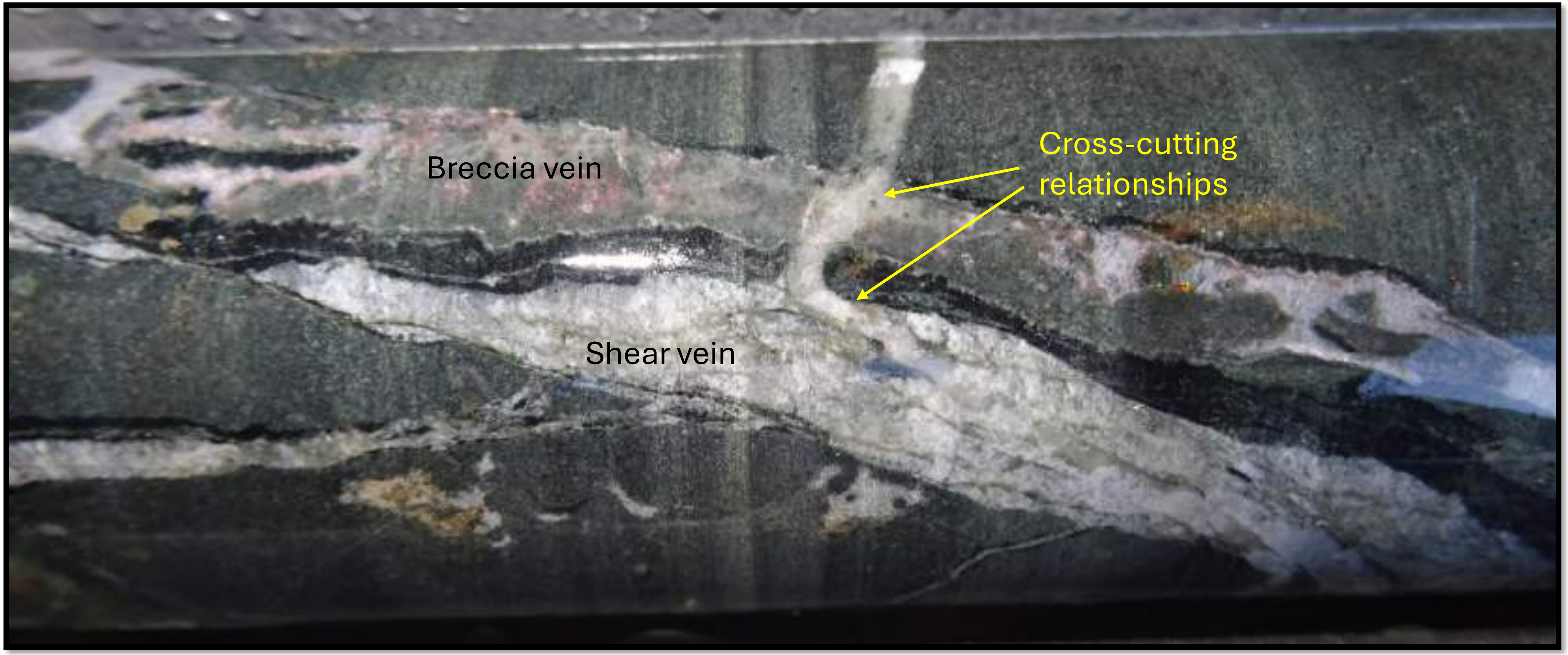
  - Differing morphology of the planar structures comprising the vein e.g. fibrous versus massive (e.g. figure at right).

  - Divergence of the component veins such that morphologically distinct veins are separated by wall-rock (e.g. figure at right).

Composite veins - recognition

A composite vein that can be identified by:

- Difference in mineralogy
- Difference in morphology (e.g. breccia veins vs shear veins)
- Cross-cutting relationships



Recognition of composite veins – the importance of turning your core over!

One of the most maddening aspects of exploration and production core logging today is the aversion by geologists to removing core from the tray.

There is a general trend of failure to review geological relationships on the entire surface of the core, with geologists preferring to simply log the exposed surface of core in the tray.

The photos at right show the opposing sides of a core interval. In the top photo we see the expression of the vein in the core as it is presented in the core tray. Here, the quartz extension vein, which has local millimetre-scale vugs, has an apparent lighter-coloured, carbonate-rich alteration halo.

In the lower photo we can see that the vein diverges from the carbonate alteration, which is an earlier stage of hydrothermal mineralization localised along a fracture that has been crosscut by the quartz vein.

Based on the overprinting relationships in the lower photo we can see that the structure is a composite feature comprising two temporally different stages of veining and alteration.

The composite nature of the structure is not immediately evident in the exposed core in the upper photo and could only be discerned with certainty when both sides of the core were examined.

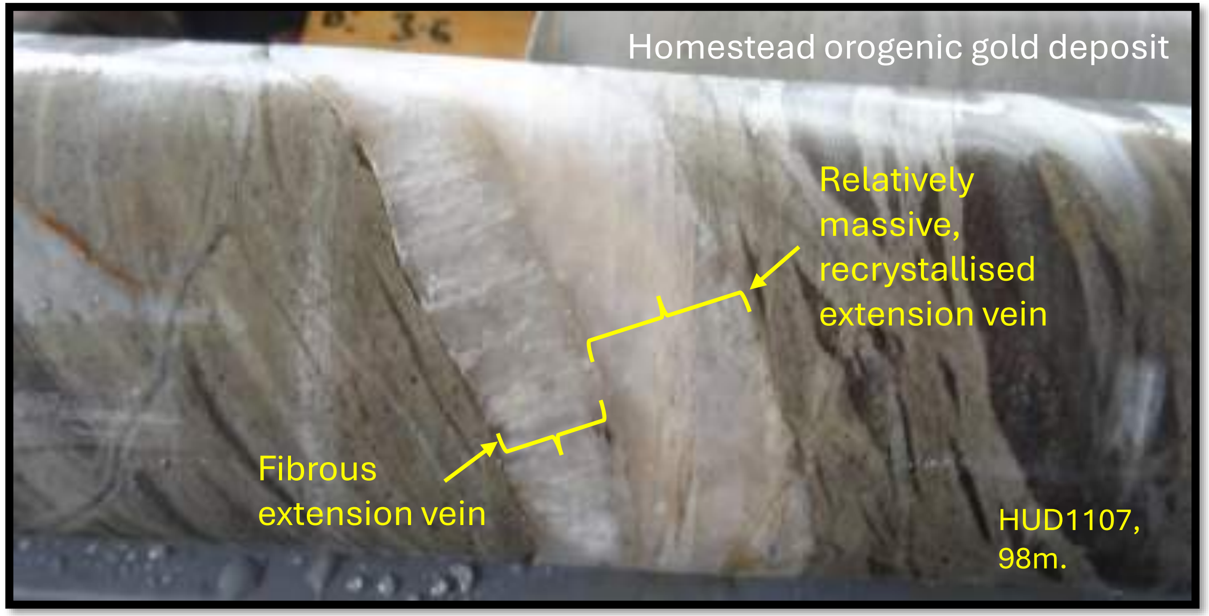
Composite veins

Examples of composite veins from Homestead orogenic gold deposit (upper and lower right) and Monty base metal deposit, Western Australia (below left).

The upper right photo shows a laminated quartz-carbonate vein that has been emplaced along the margin of a relatively massive quartz vein. Local cross-cutting relationships and divergence of the two veins provide information on relative ages.

The lower right photo shows a fibrous quartz extension vein that is juxtaposed against a relatively massive quartz extension vein. Relative ages are difficult to evaluate.

The lower left photo shows juxtaposition of an early carbonate extension vein against a later chlorite-quartz breccia vein.



Composite veins

Examples of composite veins from the structurally controlled Havieron Cu-Au deposit in Western Australia, showing an asymmetric distribution of alteration selvedges.

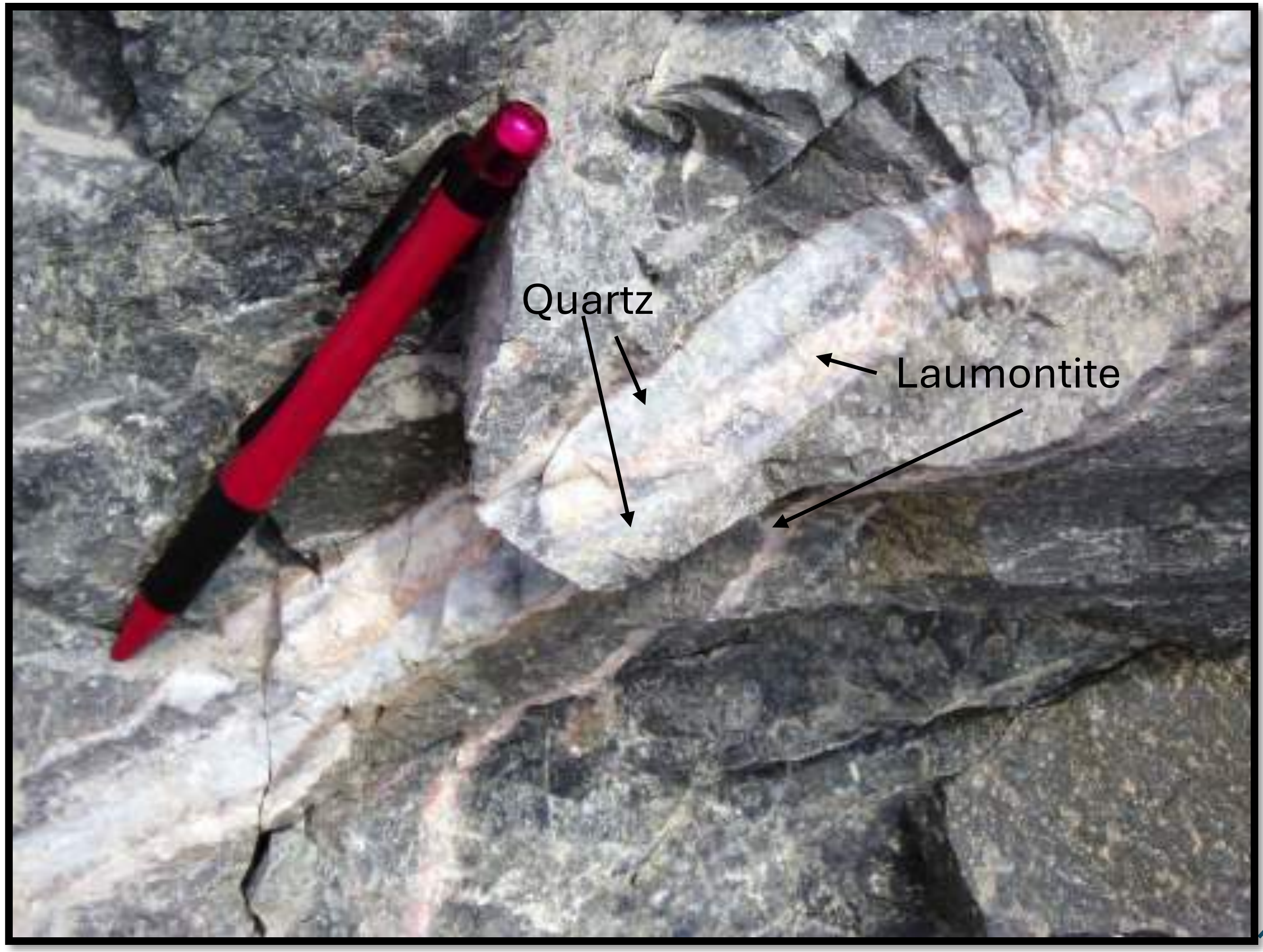
In both examples, fine-grained biotite alteration is preferentially developed on one side of the composite vein.

In the upper photo, the two veins can be seen to diverge at the lower left of the image.

In the lower photo, the alteration is associated with relatively thin quartz-carbonate veins that have been emplaced along the contact of the older carbonate-actinolite veins.

Composite veins

Example of a composite vein from the Chatree epithermal deposit, Thailand.

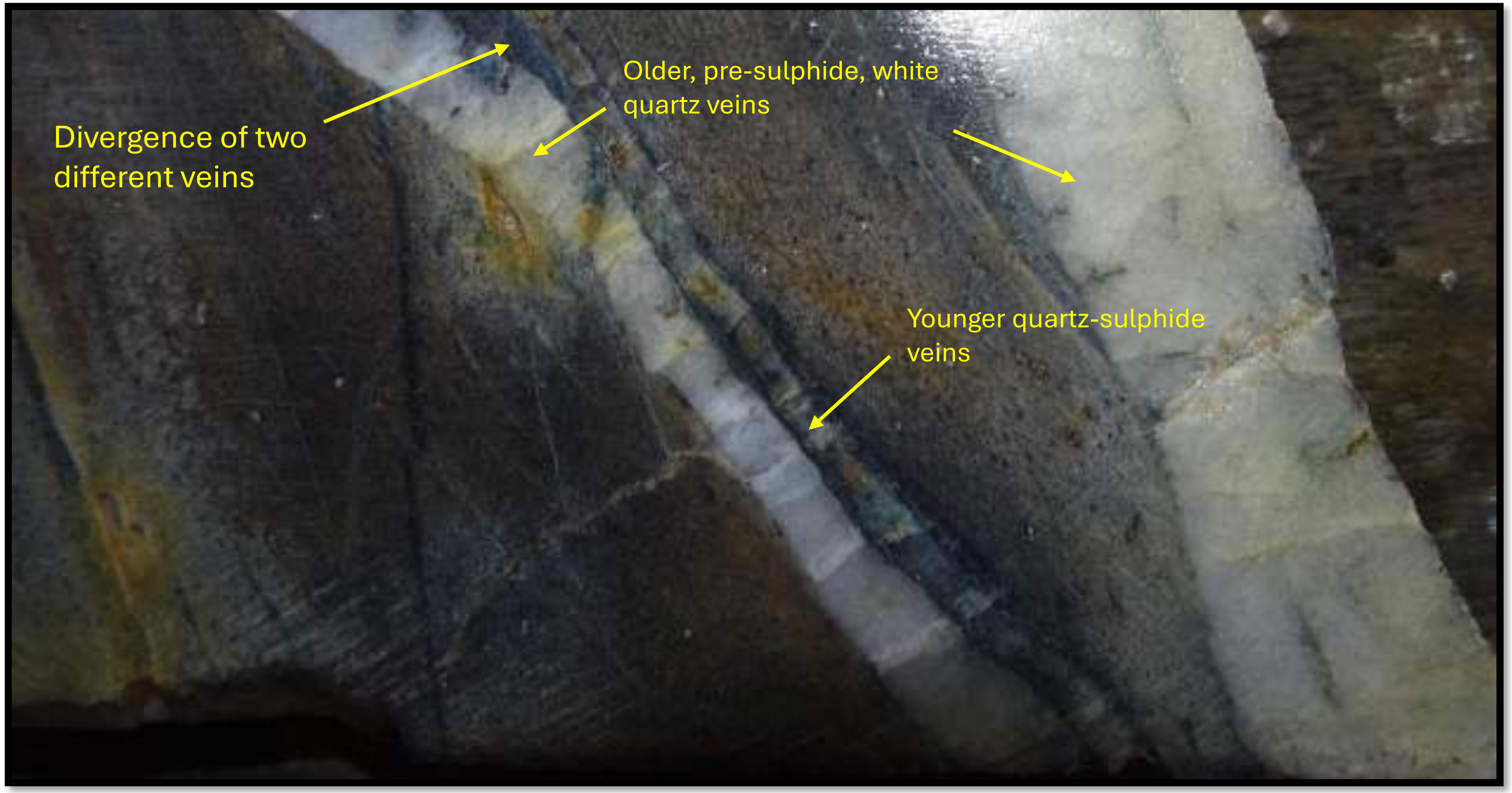


The older grey quartz vein is overprinted by a subparallel pink laumontite vein that progressively cuts across the older quartz vein along strike.

Note that laumontite-only veins are also present in the wall-rock below the main vein.

Composite veins

- The example here is from the Twangiza orogenic gold deposit in the Democratic Republic of Congo.
- The relatively thicker white quartz veins comprise the same population.
- The contact of the left-hand vein has been exploited by a younger quartz-sulphide vein with a graphite(?) or chlorite(?) alteration selvedge.
- Divergence of the two vein types can be seen at the top of the photo.



Composite veins

In the example immediately below, two parallel, planar veins comprise a composite vein.

The earlier vein is a khaki-grey colour and the younger vein is a white colour.

The younger vein can be seen to run parallel to the older vein until the centre of the photo where it swaps sides to the other margin.

In the example at right, two parallel veins have different mineralogy and colour.

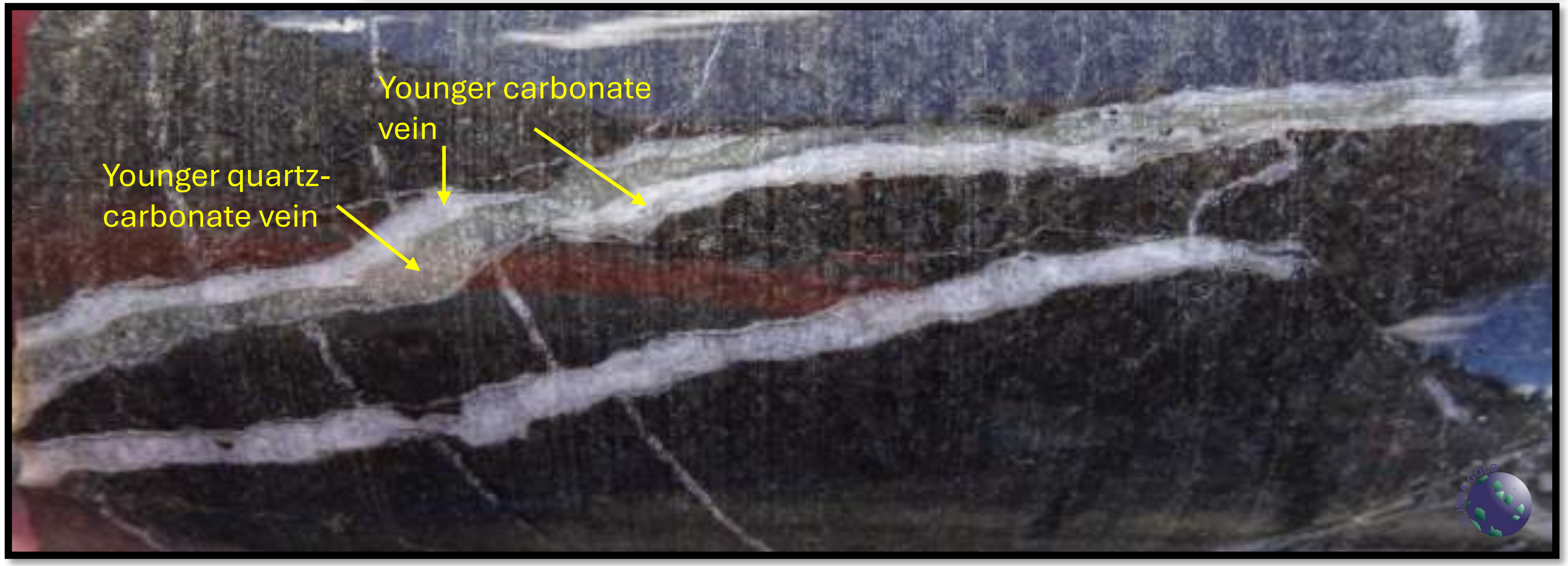
The younger white carbonate vein can be seen to cut across the grey quartz-rich vein on the right-hand side of the image.

Composite veins

The images show opposite sides of an interval of half-core.

A composite vein is comprised of an older white carbonate-only vein and a younger quartz-carbonate vein that has overprinted it.

In the upper photo, the two vein stages are subparallel. In the lower photo, an overprinting relationship is developed, with the quartz-carbonate vein cutting back and forth across the white carbonate-only vein.



Composite veins

The upper photo shows a relatively younger, thinner laminated, quartz extension vein that has been emplaced along the contact of the older, thicker relatively uniform, monomineralic quartz vein.

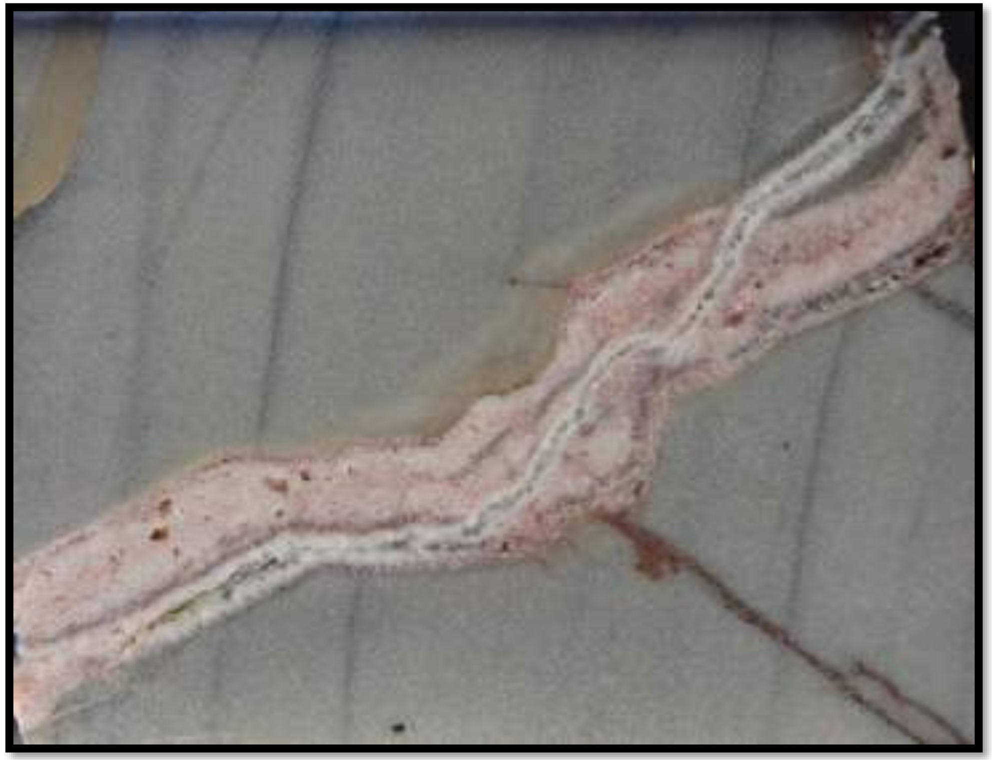
The lower photo shows a black, chlorite-rich shear vein that has bifurcated. The younger white carbonate veins have been emplaced dominantly along the contacts of the chlorite veins. However, local splays off the carbonate vein faithfully mimic the asymmetric shear fabric and the continuous portion of the younger vein locally cuts across the chlorite veins.

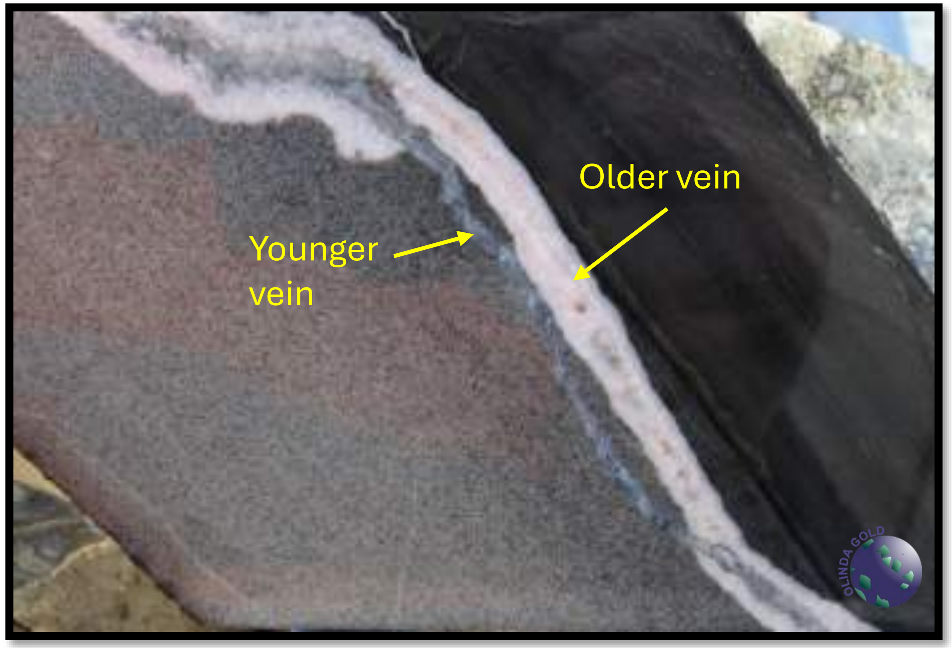
Composite veins

Obvious examples of composite veins.

In the upper right photo, the white quartz-carbonate vein is at a high angle to pre-existing quartz-carbonate-actinolite veins. However, it locally trends subparallel to the older vein set, forming a composite structure.

Similarly, the relatively thinner, younger veins in the lower right and lower left photos traverse country-rock and locally cut across the older veins, producing composite structures where they intersect.





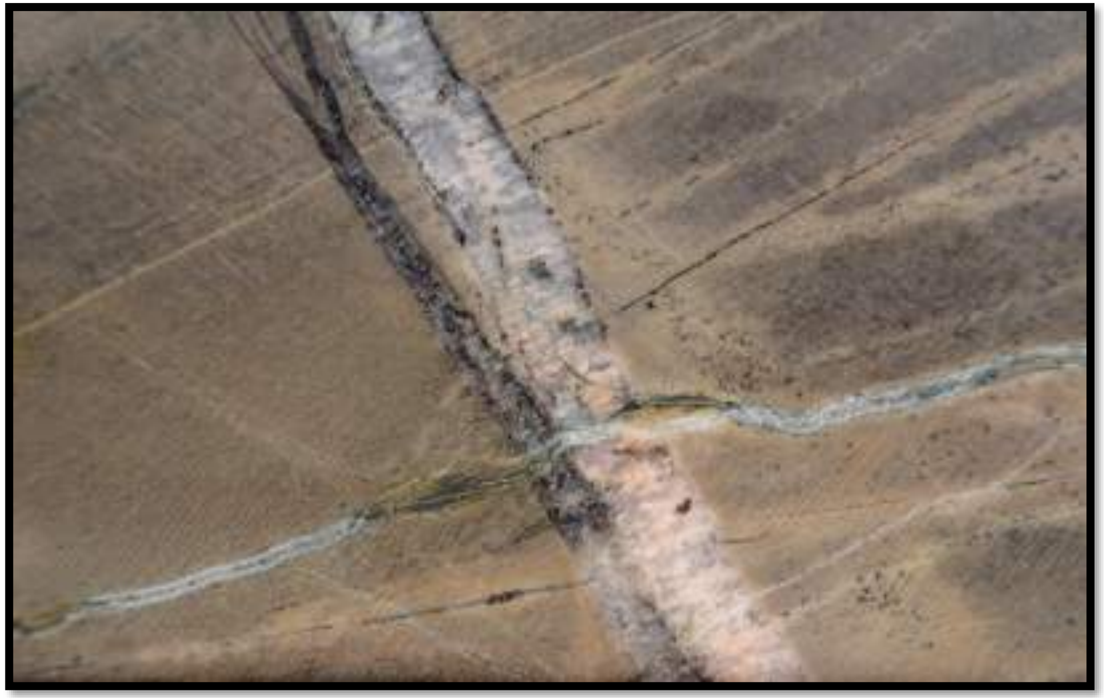
Composite veins

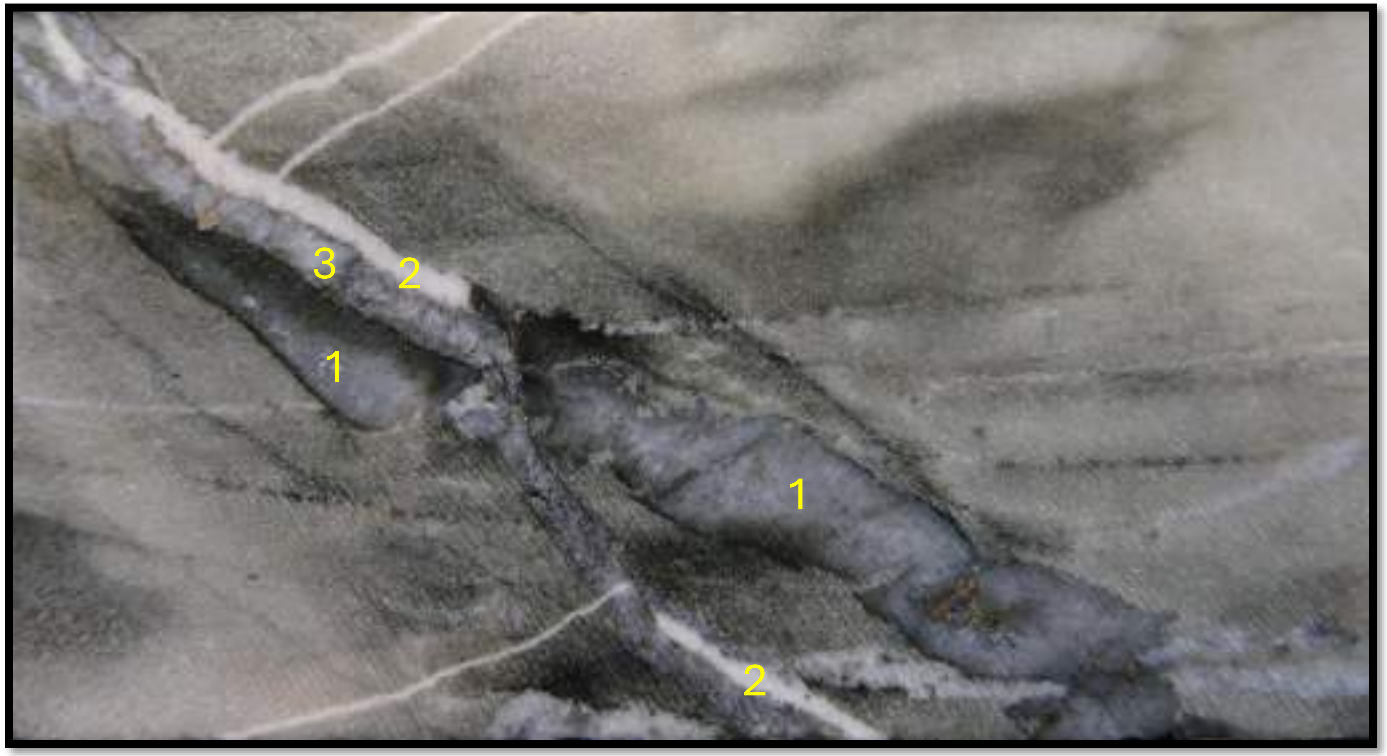
The veins here are from the strongly structurally controlled Havieron Cu-Au deposit in Western Australia.

In the upper right photo, the two vein populations are subparallel, locally contacting to form a composite vein in the lower portion of the photo.

In the lower right photo, the two veins comprising the composite vein are evident by their different colours, mineralogy, and texture.

The lower left figure shows development of a composite vein in the upper left of the figure where three veins coalesce. Cross-cutting relationships show the order of emplacement of the veins (1 oldest to 3 youngest).





Composite veins

The photo here shows a composite chalcopyrite-carbonate vein from the Kinsevere copper deposit, Democratic Republic of Congo.

Note how the veins diverge on the left-hand side of the photo into component chalcopyrite-only and carbonate-only veins.

Composite veins

Composite veins comprising a host vein containing younger veins that acutely cut across it.

The photo at top right is from the Buritica deposit, Colombia, and shows a pyrite vein overprinting the host carbonate vein.

In the example below, also from the Buritica deposit, the younger vein has exploited a fracture that is at an acute angle to the host carbonate vein orientation. It is unlikely that the younger vein was part of the same structure-fluid event as the host vein because it has a white alteration selvedge that has overprinted the host carbonate.

Composite veins

The upper photo shows a quartz vein that has been overprinted by a relatively thinner quartz-haematite vein to produce a composite vein.

The lower photo shows a composite vein comprising veins of different thickness and colour. Note that a zone of pyrite mineralisation occurs along the contact of the two veins, possibly representing a reaction product between the two structures.

Composite veins

Both examples here show thin carbonate veins overprinting quartz-carbonate-sulphide veins to produce composite veins.

In the top photo from the Buritica deposit, Colombia, the host is a quartz-sphalerite vein with minor carbonate.

In the lower photo the host is a pyrite-carbonate-quartz vein from the Curraghinalt orogenic gold deposit in Northern Ireland. Note that the younger thin carbonate vein has a grey alteration selvedge (fine-grained pyrite?) that overprints the host vein.

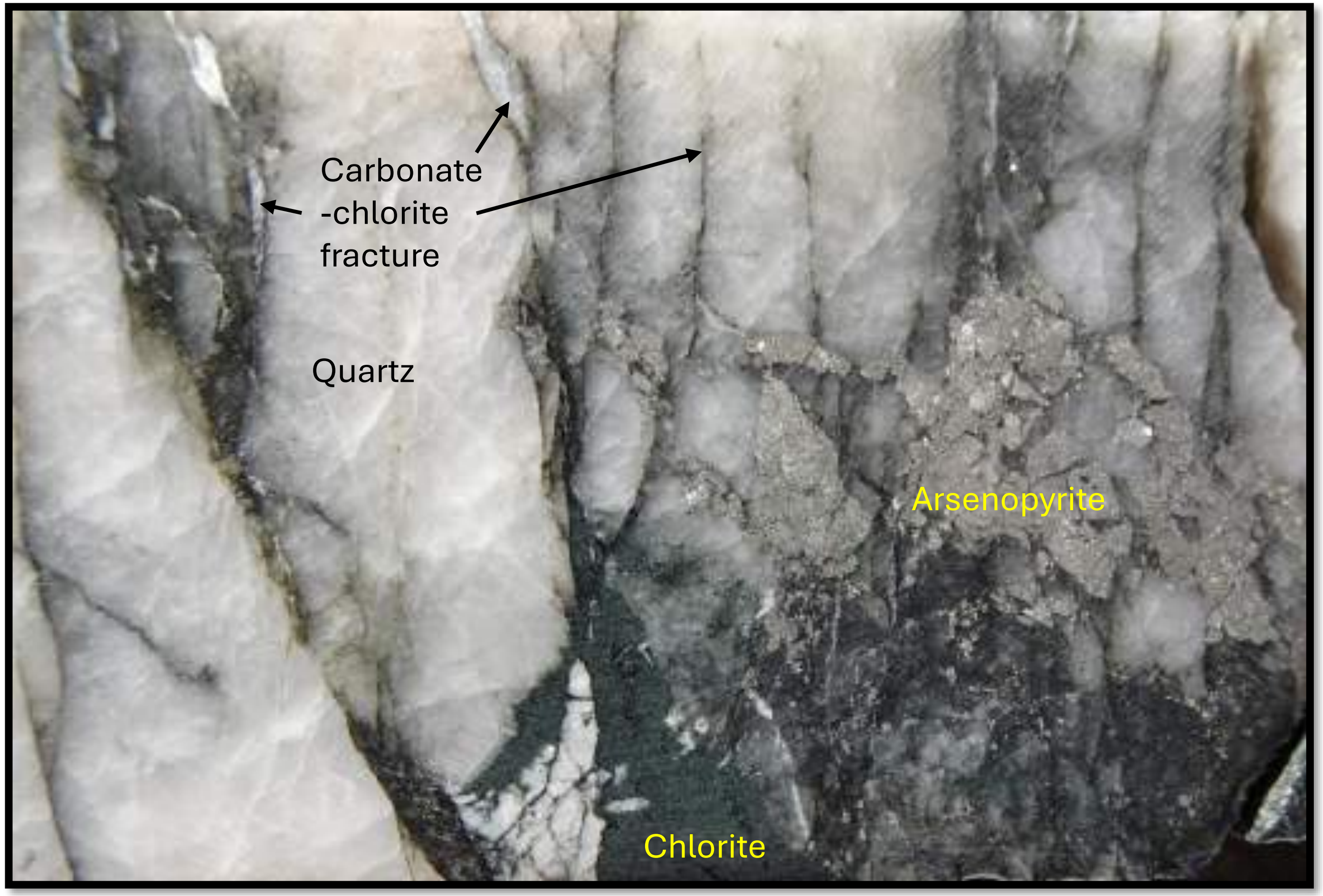
Composite veins

In the lower photo the host is a pyrite-carbonate-quartz vein from the Curraghinalt orogenic gold deposit. Note that the younger thin carbonate vein has a grey alteration selvedge that overprints the host vein.

In the photo at right, the younger white quartz-pyrite vein has exploited the grey quartz-carbonate vein.

Composite veins - structure development and reworking/overprinting of veins

- Reworking of structures is commonplace – it occurs with veins, foliations, and lineations.
- With regard to veins, which are products of hydrothermal mineral deposition, reworking occurs due to:
  - Favourable compositions for textural replacement and destruction by subsequent hydrothermal fluids.
  - Permeability afforded by voids in earlier-formed veins that allows ingress of subsequent fluids
  - Rheological contrasts between wall-rock and veins that promotes fracturing, in turn allowing ingress of subsequent fluids
  - Rheological contrasts between different veins comprising the composite vein that promotes fracturing, in turn allowing ingress of subsequent fluids
- It is absolutely essential that veins comprising mineralogy from different hydrothermal episodes be resolved i.e. that the overprinting history is understood.
- **We accept and commonly tout reactivation of shear zones but rarely document composite veins that are the product of reactivation, overprinting and reworking. Why?**
- Consider the quartz vein shown here that hosts euhedral arsenopyrite veins, the detail of which is discussed in the next slide.



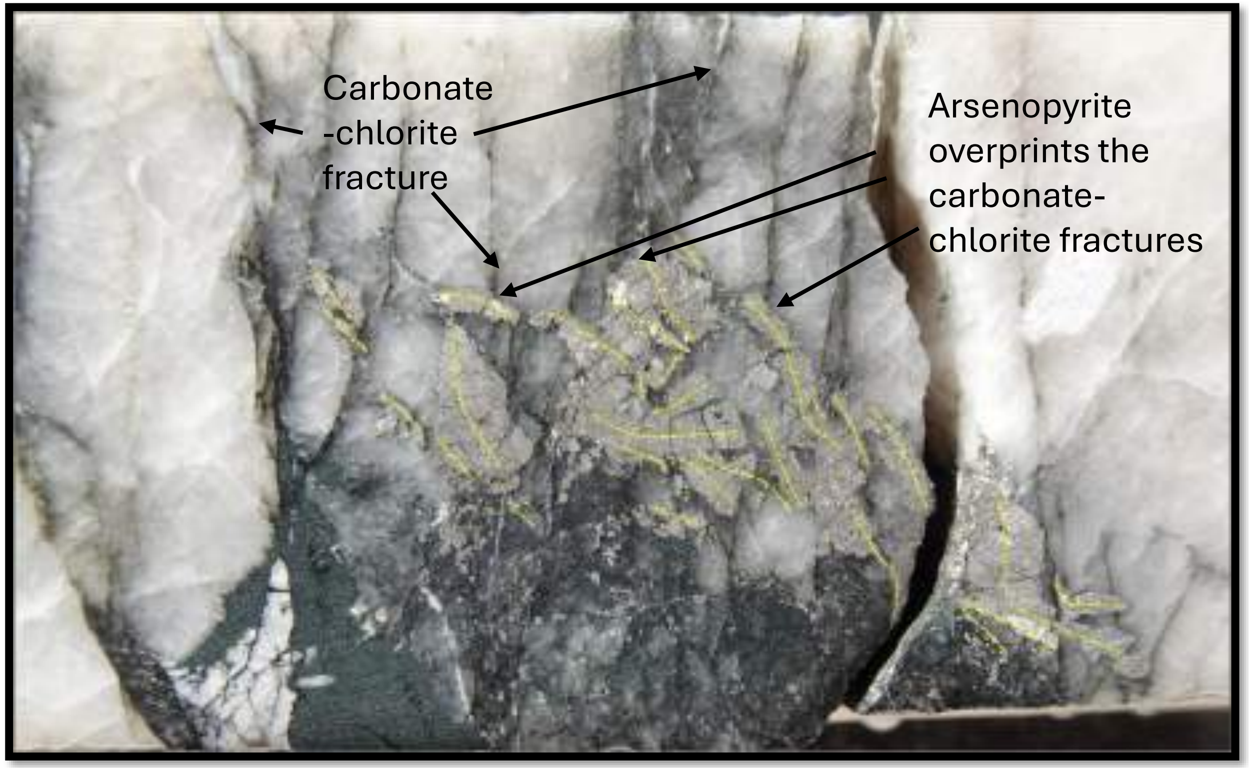
Composite veins - structure development and reworking/overprinting of veins

The euhedral arsenopyrite crystals hosted by quartz veins commonly occur in association with the fine-grained arsenopyrite-rich shears and disseminated wall-rock arsenopyrite, all being interpreted to be of the same paragenetic age.

The arsenopyrite crystals overprint the quartz veins. Some evidence of the relative age of the veins and arsenopyrite is given in the photos at right:

- In the upper example, a suite of chlorite- and carbonate-filled fractures have cut the quartz vein, and these are in turn overprinted by the arsenopyrite.
- In the lower photo, mapping out of the crystal long axes shows them to define folds with constant asymmetry and planar structures at an acute angle to the vein walls. Two trends are apparent, one that defines sinuous fold geometries (black lines) and one that is at a high angle (blue lines) and probably reflects an axial planar orientation.

The arsenopyrite may represent local reconstitution of that associated with the earlier, pre-vein stages.



Composite veins - structure development and reworking/overprinting of veins

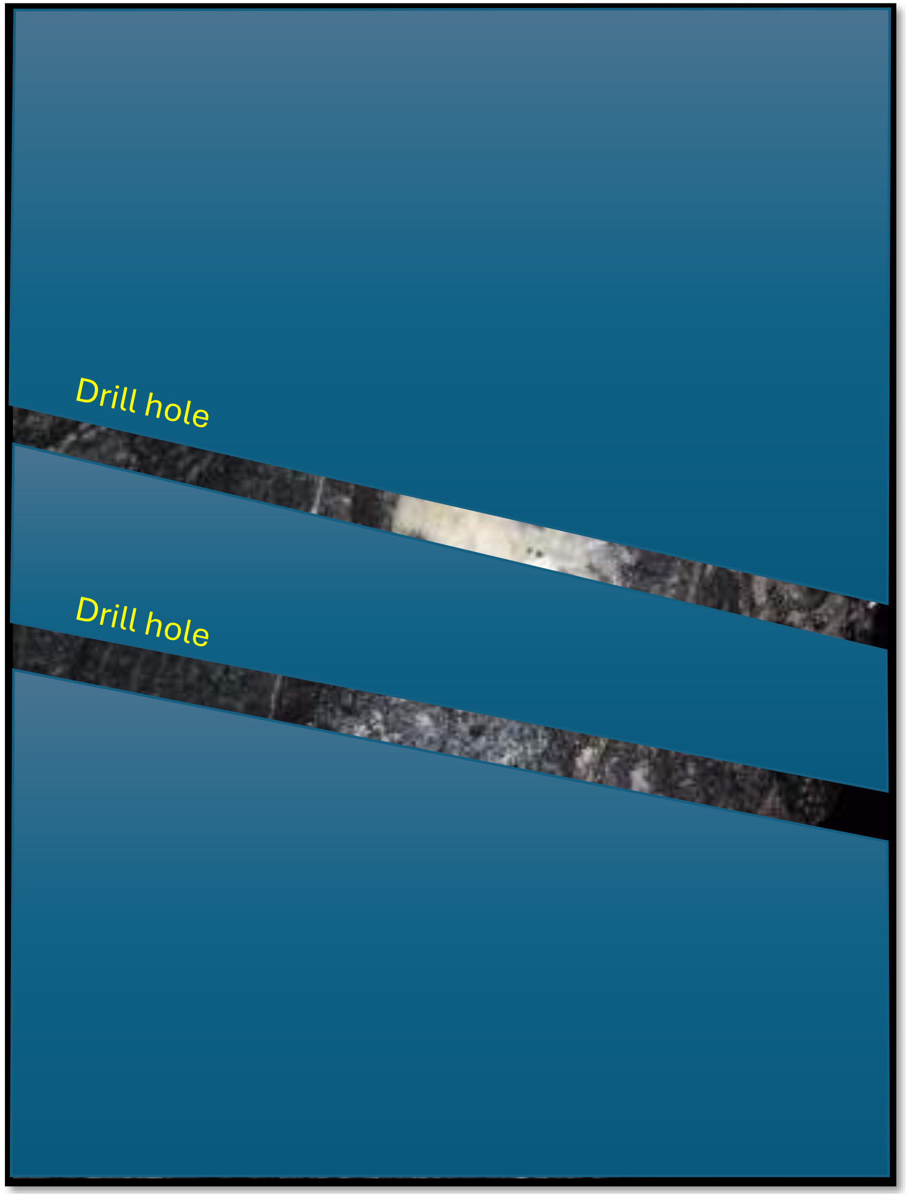
The vein shown at far right is from the Pahtavarra orogenic gold deposit in Finland, and shows a quartz vein that has been variably fractured.

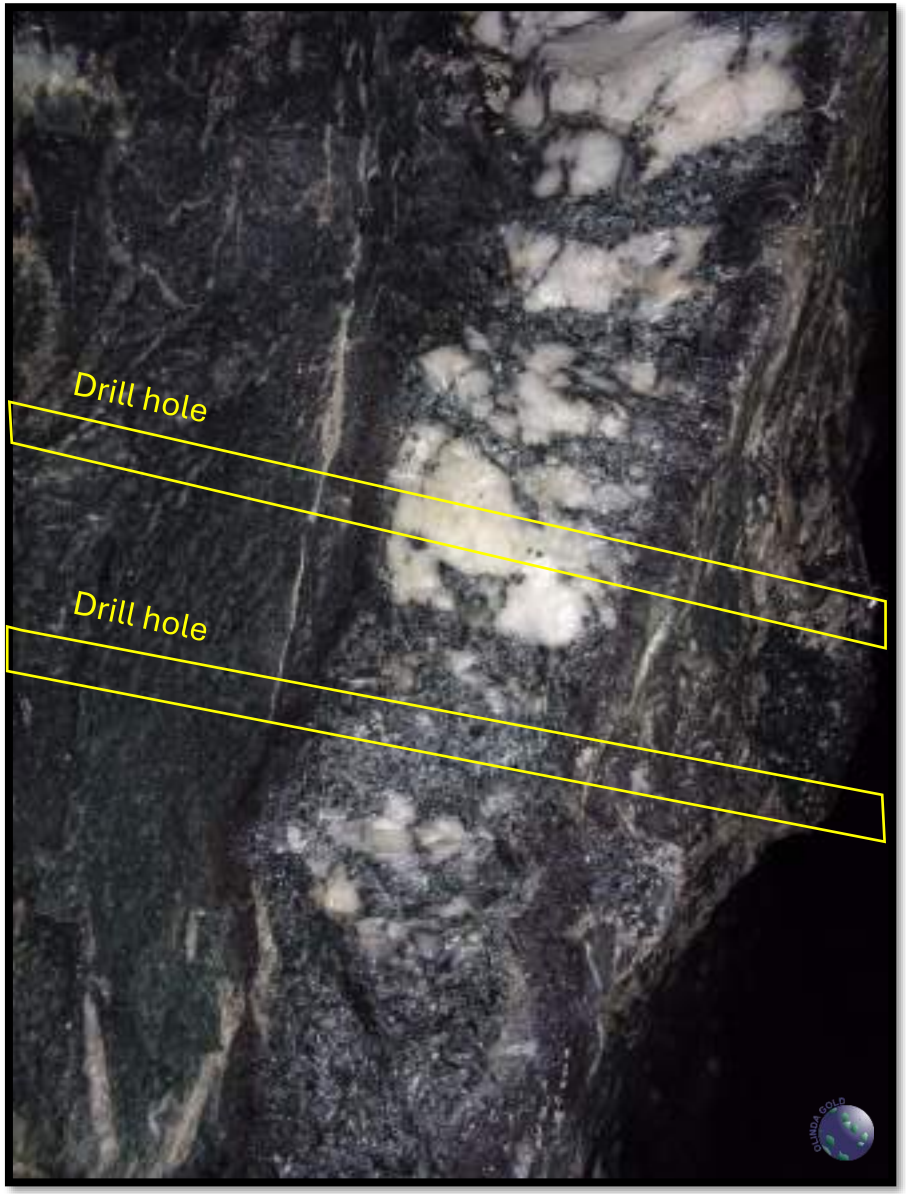
The fractures have localised subsequent infill by amphibole, producing a composite mineralogy due to structural-hydrothermal reworking of the original vein.

The left-hand image shows how two hypothetical, closely-spaced drill holes through the vein would intersect apparently mineralogically different veins comprising quartz or amphibole.

However, the bigger picture shows a single vein comprising both minerals.

This emphasises the importance of resolving the overprinting history!





Composite veins - structure development and reworking/overprinting of veins

- The example here is from the Twangiza orogenic gold deposit in the Democratic Republic of Congo.
- The relatively more steeply dipping, older veins have a mineralogy that is the product of at least two hydrothermal mineral deposition events.
- The younger veins with a lower dip have cross-cut the older veins.
- Sulphide in the older veins has been sourced from the younger ones and is localised proximal to intersections with younger sulphide-bearing veins.

Composite veins – limitations/conflicts

- As with many textures, geometries and overprinting relationships in geology, there are grey areas of interpretation and application.

- In the case of composite veins, the question arises as to whether mineralogically different layers in a vein are the products of markedly different prevailing conditions, or if they simply represent the evolution of vein growth under relatively similar conditions.

- This complexity is especially difficult if the mineralogy of the veins does not change markedly from layer to layer e.g. carbonate-quartz-sulphide bands next to carbonate-quartz bands.

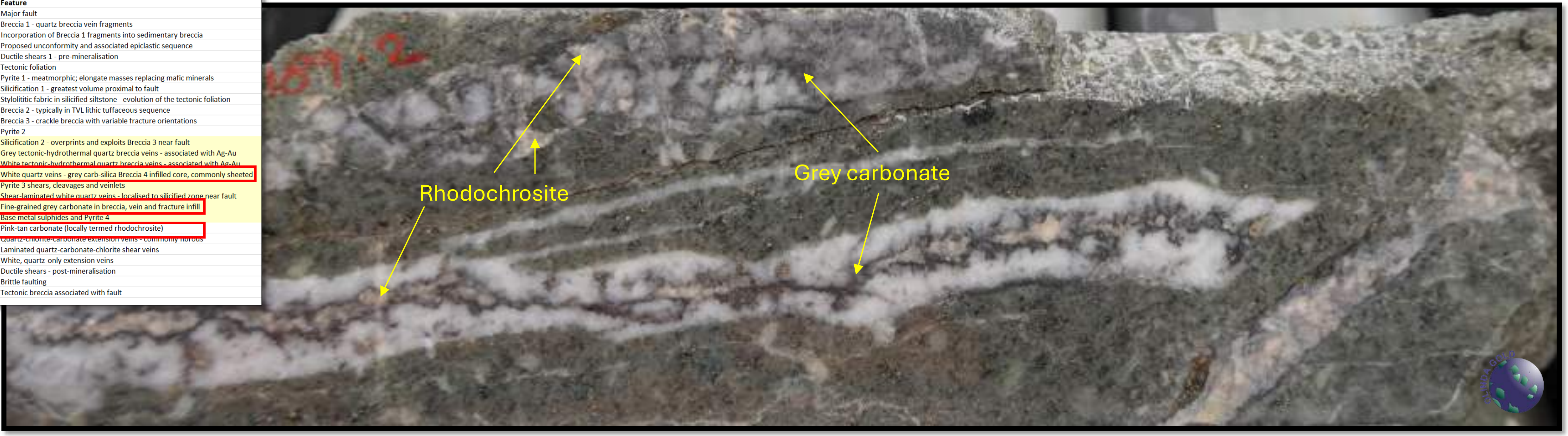
- In such cases of mineralogical similarity, other vein attributes have to be compared, e.g. there may be extension vein fibres developed adjacent to shear vein textures. Generally, unequivocal cross-cutting relationships will define a vein as being a composite feature.

- Note that different features comprising a composite vein don’t necessarily imply a large intervening time period. For example, breccia vein textures internal to chalcedonic layering in an epithermal vein may have formed over a very short time.

Composite veins – limitations/conflicts and grey areas

- In this case, this is not a composite vein *per se*, in that it doesn't comprise juxtaposed planar veins. Rather it is a vein representing the composite product of temporally separate hydrothermal phases.
- The white vein has a centreline of grey and orange carbonate (rhodochrosite?) infilling the vuggy core, whereas the upper vein has both carbonate species occurring as fracture-fill that overprints the vein and cuts across it.
- An extreme example of this overprinting character by the carbonate species is given by the vein in the lower-right of the sample, which is totally dominated by fracture-filling grey and orange carbonate.
- Based on consistent overprinting relationships in hundreds of metres of drill core, the quartz veins and carbonate species were resolved as products of three separate geological events (shown in red in the geological history), with other periods of hydrothermal mineral deposition separating them.
- These relationships are consistent with successive stages of reworking of the quartz phase of the veins.

	Feature
Pre-mineralisation	Major fault
	Breccia 1 - quartz breccia vein fragments
	Incorporation of Breccia 1 fragments into sedimentary breccia
	Proposed unconformity and associated epiclastic sequence
	Ductile shears 1 - pre-mineralisation
	Tectonic foliation
	Pyrite 1 - meatmorphic; elongate masses replacing mafic minerals
	Silicification 1 - greatest volume proximal to fault
	Stylolititic fabric in silicified siltstone - evolution of the tectonic foliation
	Breccia 2 - typically in TVL lithic tuffaceous sequence
	Breccia 3 - crackle breccia with variable fracture orientations
	Pyrite 2
Syn-mineralisation	Silicification 2 - overprints and exploits Breccia 3 near fault
	Grey tectonic-hydrothermal quartz breccia veins - associated with Ag-Au
	White tectonic-hydrothermal quartz breccia veins - associated with Ag-Au
	White quartz veins - grey carb-silica Breccia 4 infilled core, commonly sheeted
	Pyrite 3 shears, cleavages and veinlets
	Shear-laminated white quartz veins - localised to silicified zone near fault
	Fine-grained grey carbonate in breccia, vein and fracture infill
	Base metal sulphides and Pyrite 4
Post-mineralisation	Pink-tan carbonate (locally termed rhodochrosite)
	Quartz-chlorite-carbonate extension veins - commonly fibrous
	Laminated quartz-carbonate-chlorite shear veins
	White, quartz-only extension veins
	Ductile shears - post-mineralisation
	Brittle faulting
	Tectonic breccia associated with fault



Composite veins – limitations/conflicts and grey areas

The sample at lower right is from the Golden Grove VHMS deposit, Western Australia.

There are compositional differences, and the lower fibrous, chlorite-bearing portion of the vein locally diverges from the white vein core.

In this case the vein could be either a composite structure, or part of a single vein population in which the fluid composition has changed over the period of formation.

This is a good example of the grey area in definition.

Composite veins – limitations/conflicts and grey areas

The vein shown here is from Kanowna Belle gold mine, Western Australia.

It could be defined as a composite vein, based on variations in mineralogy and texture of adjacent compositional layering.

However, there is enough uncertainty to suggest they may also be products of development of the same veining episode.

The portion of the vein at top right, comprises a white quartz vein on top of a quartz-sulphide vein that shows extension textures.

However, there is no discernible cross-cutting relationship and the bulk mineralogy of the upper and lower portions of the vein differ only with respect to the presence of sulphide.

As such, it is probably best to consider this as part of a single vein population in which the fluid composition has changed over the period of formation i.e. not a composite vein.

During vein formation, the sites of opening have probably changed, causing different textures to comprise different layers in the vein.

Composite veins – limitations/conflicts and grey areas

The vein shown here could be defined as a composite vein, based on variations in mineralogy and texture of adjacent compositional layering.

However, there is enough uncertainty to suggest it may also be products of development of the same veining episode.

The vein comprises several layers that vary in mineralogy, texture, and wall-rock clast content.

Overall, however, the vein is largely quartz, with variations in graphite content.

The breccia texture may simply be a product of relatively more explosive opening of the structure but with infill of essentially the same fluids that formed the white, monomineralic layers.

As such, this is probably not a composite vein.

Composite veins – limitations/conflicts and grey areas

The photo here shows a quartz vein that has had a complicated and protracted evolution. The three annotated lower runs have been photographed from the yellow rectangle in the upper run and there is overlap between the photos. The overall vein intersection was greater than 20m, so we are only seeing a portion of it here.

The vein intersection comprises numerous structural morphologies with local cross-cutting relationships that represent separate stages of vein formation and infill. Furthermore, some of the vein episodes host sulphides, indicating a compositionally distinct stage of fluid ingress.

This vein looks superficially like the one in the previous slide. However, given the size of the vein, the diversity of veining styles, the local cross-cutting relationships, plus the local compositional differences, I would be happy to call this a composite vein.

The vein was hosted in strongly deformed argillaceous sedimentary rocks from G2 Goldfield's project in the Oko Aremu district in Guyana.