Volume 3 – Overprinting Textures

Volume Front Page

Specimen from Escondida copper mine, Chile. The specimen has been chosen to catch the eye of wealthy browsing customers. It is from a porphyry copper system, with at least three overprinting vein stockworks readily visible. Unfortunately it has been subjected to argillic alteration, and is from the zone of supergene enrichment. Hence most of the dark minerals present are chalcocite/covellite after original sulphides (chalcopyrite/pyrite?). The oxidation/secondary enrichment obscures the primary infill/alteration features, and a deeper primary ore specimen would be better for paragenetic/overprinting work. It does however illustrate the complexity in porphyry systems, and makes a nice photograph.

Plates Volume 3 • OVERPRINTING TEXTURES

1 Introduction

Many of our concepts concerning the nature of hydrothermaal systems and their relationship with rock fracturing arise from the common observation that hydrothermal fluids seem to precipitate different mineral assemblages at different times. Practically every mineral deposit will provide an example of crosscutting vein, which are conventionally interpreted as two (or a single) generations of hydrothermal fluids with an intervening period of rock fracturing. The crosscutting relationship is an example of an overprinting texture and the implied timing relationship allows the two veins to be catalogued as a temporal sequence, such as Stage 1 and Stage 2. The process of constructing a time sequence is referred to as establishing the paragenetic sequence.

Nearly every deposit exhibits some three to five stages of development, which reflect the close association between long-lived hydrothermal systems and associated tectonism. Some deposits of the epithermal or porphyry style may exhibit numerous stages, reflecting very active rock fracturing (usually due to the boiling of fluids) which continues intermittently throughout the history of hydrothermal fluid flow.

An understanding of overprinting textures and their paragenetic implications is the basis for all ore deposit studies. It would be fair to state that until this aspect is well-understood, any further studies regarding such items as fluid inclusions, stable or radiogenic isotopes, alteration geochemistry and fluid modelling, run the very grave risk of setting off from an incorrect premise. This situation is much more common than most of academia is prepared to admit! From a practical perspective the comprehension of paragenetic sequencing is equally important. Firstly, it provides the early information which serves to give the exploration team some concept of the type of hydrothermal system under investigation, and it will come as no surprise to exploration managers to learn just how many times this has been misinterpreted. Secondly, within any multiphase system it is very important to understand which phases are actually ore and to comprehend their spatial distribution.

From every perspective it becomes a prime geological requirement to fully delineate and interpret the many facets involved concerning overprinting and paragenetic sequencing. The textures provide data concerning structural environment, fluid composition, structural controls, ore distribution, mineral zoning, temporal and thermal history of fluid flow, and a host of related subtleties that sharpen comprehension and hence exploration targeting and continuing research.
Given the above it would be natural to assume that both the academic teaching system and the mineral exploration community would stress the importance of this aspect. Regretfully the world is a busy place, with academia having a large amount to fit into a three or four year programme, and industry having to find ore quickly. Most geologists would conclude that there is room for improvement, and this small text is offered in that spirit. The rocks will speak, but it always takes time to learn a foreign language.

Fortunately within the domain of overprinting and paragenesis, practically all the major observations are to be made at the outcrop and hand specimen scale. It is much easier to sort things out at the rock face scale, than beneath a microscope. Rock slabs and drill core are also prime treasures, as both provide clean smooth surfaces enabling close observation. All of the above are readily available in most exploration and mine environments, and when used in combination are powerful weapons for resolving overprinting and hence sequencing problems. The rock slab is definitely the most underutilised, and the tendency to leap from rock face (or drill core) to the microscope frequently turns an easily soluble problem into confusing situations.

In keeping with the rest of this series, the text is aimed at observations which can be made either by eye or with a hand lens. The plates have been selected to show a range of mineralisation styles, and plate descriptions have been written at length to indicate the approach and thought processes involved.

2 Overprinting Criteria

2.1 General

Within the context of this book the term overprinting refers to any textural observation which can be utilised to infer that one mineral (or group of minerals) has been deposited later than another. The aim in all overprinting observations, is to establish a sequence of mineral deposition which is referred to as a paragenetic study. Overprinting observations are thus the building blocks which produce a paragenesis. The entire process is absolutely fundamental to anyone who is trying to establish exactly "what is going on" within any form of hydrothermal mineralising system.

Overprinting criteria are very simple in theory, but tend to be rather complex in practice. There are numerous small traps awaiting the unwary or inexperienced observer, and as previously stated a good grounding in the difference between infill and alteration concepts is essential. In practice a range of techniques are utilised, which range from first to fourth order depending upon the degree of interpretation.

2.2 First Order Criteria (Confidence Building)

(a) Mineral Superimposition

Hydrothermal fluids traversing "open" channelways may precipitate minerals (infill) and where one mineral can be seen to have nucleated upon another, an obvious timing (overprinting) relationship can be inferred. Numerous examples are given in the first section of this book, and others are displayed in this text. (***Plates*** 1–*3*).

(b) Structural Superimposition

Rock or mineral failure occurring after a period of hydrothermal deposition, will fracture and/or fragment previously formed minerals. This common situation provides a range of new (overprinting) channelways for fluid flow and deposition. The net result provides the two most common criteria utilised to separate one period of mineral deposition from another:

(i) Crosscutting vein systems (each with separate infill alteration components). (***Plates*** 4–***11***).
(ii) Fragments (breccia) of early mineralisation contained within the new mineralisation (***Plates*** *12*–***15***).

2.3 Second Order Criteria (Suspicion Arousing)

Any structure which has acted as a conduit for a hydrothermal fluid and subsequent deposition, is very prone to reactivation during a subsequent rock fracturing event. In simple terms faults, veins, breccia zones tend to form the weak links in the chain which keeps on breaking in the same place. It is very common for a succession of mineralising events to occupy the same zone of structural weakness, and the simple structural superimposition criteria presented above may become rather obscure. Given that each influx of fluid will result in a new infill assemblage together with alteration of either preexisting alteration, or previously unaltered host rocks, it is not surprising that complex situations may occur. Observations that raise suspicions of multistage overprinting include the structural superimposition criteria mentioned above, as well as less obvious situations such as:

(a) Mismatches Between Alteration and Infill Components (Things Out of Proportion). Including:

(i) Small channelway structures (usually veins) traversing excessively larger areas of alteration.
(ii) Widespread alteration which does not appear to increase significantly (or at all) as it approaches a sizable channelway structure (vein, shear, "triangular vug").
(iii) Veins (usually first noted as infill structures) which although centrally located around alteration within the majority of the rock, "wander across" the alteration zone to produce grossly asymmetric situations.
(iv) Asymmetric mismatching also occurs in infill sequences. Although there is no inherent reason why minerals should deposit symmetrically on

each side of an opening, there are many situations where the observer intuitively suspects this should occur within the style of specimen being examined. An extra layer on one side is always suspicious.

(b) Inconsistent Alteration Configurations

There are many variations to this criterion, but it is very common for an alteration zone to overprint preexisting alteration. If the second alteration completely overprints the first at some points, but only partially overprints at others, the observer will be presented with different zonation patterns at different points. Thus working from the host rock inwards towards the suspected channel zone will give different results at different points.

(c) Alteration of Alteration

To some extent this is a variation on the above, but it is quite common to see alteration products which retain the texture of previously altered rock.

Examples of second order (suspicion arousing) criteria are given throughout the plates, with some selected situations being illustrated in ***Plates 16–22***.

2.4 Third Order Criteria (Indirect Overprinting)

Almost any box of core, or large rock slab, situated in the marginal zones of structurally controlled ore will exhibit isolated veinlets with alteration/infill assemblages which are obviously different to each other. The same situation will occur with isolated veins/veinlets located in two different places. The presence of two different assemblages suggests two different stages, but obviously gives no timing information.

Another very common suspicion arousing indicator is a sudden change of crystallisation style within an apparently continuous sequential infill sequence. A sudden change from coarse crystalline comb quartz to finely layered "colloform" styles would be a common example (***Plate 1***)

2.5 Fourth Order Criteria (Indirect Overprinting Temperature Inference)

Where the above isolated veinlet situation occurs, it is of considerable assistance if the observer has some concept of high temperature versus low temperature assemblages. Most paragenetic sequences represent declining fluid temperature sequences. A biotite-rich assemblage would normally indicate much higher temperature than one which was predominantly clay. It does not necessarily follow that the biotite is earlier, but it is a good working hypothesis. This style of criteria needs to be used with caution, and hence the fourth order grouping.

3 Overprinting Textures

3.1 Broad Scale Perspectives

Overprinting textures inherently refer to interpretations regarding the relative time sequencing of hydrothermal events. However, it is important to perceive that the time sequencing observations also offer the opportunity to look at each stage separately (or in combination) to establish a wider range of geological parameters concerning the structural and fluid history of an individual ore deposit. Admittedly the amount of visual information that can be extracted relates to the knowledge and experience of the observer, but the opportunity remains to consider evidence relating to ore genesis from a range of interrelated perspectives. These include:

(a) Structural evolution as reflected by the style(s) of fracturing. This could be restated as understanding the development of fluid channelways, and hence structural controls.
(b) Chemical composition and evolution of the ore fluids as reflected by the composition of the infill minerals, and their associated alteration assemblages.
(c) Factors relating to physical parameters of the ore fluids. Temperature indicators are readily available from the depositional sequence. Parameters relating to pressure and pressure variations are present in textures that can be related to processes indicative of hydraulic fracture, hydraulic brecciation and boiling. In many cases even the crystal sizes and shapes can be tentatively related to possible cooling rates, fluid saturation, or phase separations. This is especially true with quartz textures (*Dong et al., 1995*).

3.2 Recording Observations

It is always wise to record observations, and this is particularly true in overprinting studies. Many situations are ambiguous and/or subtle, and it is crucial to look carefully and not to try to force conclusions from unclear examples. It is quite surprising just how many apparently clear/simple situations are in fact complex. A useful practical suggestion, is to construct a table as indicated below.

Stage (Name)	Infill*	Alteration (Rock type altered)	Structural Style	Comment
"Chlorite"	Quartz, chlorite, pyrite	Chlorite, minor sericite? and carbonate (Basalt) Irregular edges	Small vein 2–3 cm wide blurred.	Distinction between infill and alteration blurred.
Pink vein	Pale pink minerals. Sharp edge against alteration	Darker pink (Granite) expressed by pinking of feldspars	Large vein 6–8 cm wide. Infill predominates. No brecciation. High fluid pressure – jacking fracture open?	Suspect pink infill and alteration are albite or K-spar? Cuts small chlorite vein, with no apparent effect?

* Infill. It is very rare that the sequential infill order can be easily observed on one sample.
If relationships are apparent they can be recorded. For example – quartz overprinted by chlorite, or quartz (chlorite, pyrite, uncertain timing) etc.

4 First Order Criteria – Mineral Superimposition

Sequential Infill

Textures and problems. Plates 1–3

Infill textures provide extremely valuable information concerning the sequencing of mineral deposition. Within a single stage of deposition it is very common for minerals to precipitate as crystals or layers. Early formed crystals or layers become nucleation zones for succeeding precipitation and in ideal situations it is relatively easy to determine a sequential sequence. This is most easily observed in large-scale cavities which are only partially infilled, and many geologists would be familiar with spectacular examples which occur in Mississippi Valley style environments. When the fluid space is completely infilled, sequential deductions are a little more difficult, but can generally be achieved with only minor problems. Criteria for recognising infill are presented in the first part of this book, and it is worth noting that this is a much neglected skill.

Within veins and breccia cavities crystals often nucleate as isolated individuals, rather than as the continuous layers which are so often depicted in textbooks. In this situation it can become very difficult to find examples to clearly illustrate the complete relationships between the three to five minerals which have precipitated. The problem can usually be resolved by inspecting a large number of samples of the particular stage and slowly teasing out the critical "overgrowth" relationships. Observers should not expect to discern the full sequence from one specimen, and in many cases will be left with a few uncertainties concerning depositional timing between two or more of the minerals. Common minerals which give particular problems are the chalcopyrite/pyrrhotite pair. These commonly precipitate together and neither likes to form crystals. It is also quite possible for minerals to precipitate simultaneously or continuously throughout. This can obviously produce contradictory overprinting results.

Theoretically the simultaneous or continuous precipitation problem could make the concept of sequential overprinting of limited value or impossible to apply as a practical reality. However from twenty years of experience, the writer can assure the reader that in the vast majority of cases minerals normally precipitate in a simple sequential manner, which is readily deduced with a working knowledge of the principles of infill recognition.

A much more serious problem arises when it is realised that a void space, such as a large breccia vug or an open fissure, may receive mineral precipitation over a long period of time and there is no guarantee that the sequence of precipitation deduced actually represents a single stage. Obviously the larger the void space the more the opportunity exists for this to occur. Although refracturing may have occurred and a new stage been introduced, it is commonly not reflected within the void space (it is difficult to fracture a hole!).

There are several ways of resolving a problem of this nature but the first step is to be aware of the possibility. An early warning signal is usually given by the textural and or mineralogical changes within the sequence. The inner regions of the vug may record a sharp textural change in crystal size. Alternatively the entire mineralogy may suddenly change. In many cases both textural and mineralogical changes occur which raise suspicion. With a little knowledge of temperatures of deposition, it may be obvious that very high-temperature products are suddenly succeeded by low-temperature assemblages.

A more conclusive resolution is almost always achieved by inspecting more specimens. If the suspect portion of the infill is in fact a different stage, it will appear as a distinct entity elsewhere within the new fracturing, and it is usually possible to find it crosscutting the previously-formed materials.

PLATE I

SEQUENTIAL INFILL
St. Patrick tin mine, near Irvinebank, Queensland, Australia.

This specimen has been selected to illustrate the problems of sequential infill. It will also serve as a good example of infill textures.

The specimen is composed almost entirely of quartz which shows considerable variation in both colour and style of crystallisation. The bulk of the quartz is coarsely crystalline (comb quartz) although there are several episodes of fine-grained deposition producing a layered effect. This is prominent in the mid plate region. Most of the quartz is in layered format, but there is a distinct textural change in the centre of the vein, where coarse-grained white crystals have nucleated in a relatively random manner. The final stage of deposition is cassiterite (black) which exhibits some magnificent triangular textures as it fills in, between quartz crystals.

Most of the above is readily visible but the real question is: "How many stages of deposition are represented here?" It seems that a large cavity has been progressively filled. The definition of a stage leaves a little to be desired, but is generally taken as a group of mineral precipitates which have been deposited during a continuous fluid flow. This is impossible to establish by scientific observation, and in practice a stage is defined by separating out the number of times the rocks have been "tectonically" reactivated.

With each tectonic break a new set of infill can be placed in a relative time sequence.

In the above example the eagle eyed observer can interpret a tectonic break by carefully inspecting the sequence in the region of the small side vein (bottom left). Several layers of silica seem to have been deposited before this vein opened, although even at this scale the situation is not totally clear. The gross change in style in the central zone with the introduction of cassiterite is also extremely suspicious, even though no crosscutting relationship can be observed.

The sudden change from coarse-grained crystal format to fine-grained layer format is also suspicious denoting a change from isolated nucleation to multiple nucleation sites.

Obviously the total answer cannot be accurately deduced from this specimen, and more would have to be collected from the locality. However, there is enough to suspect at least three stages with several changes of chemical and/or physical parameters. Cassiterite is a relatively high temperature mineral (say plus 200 °C).

There is also a minute crosscutting silica vein (bottom left) which traverses the side layers of the small vein and could link to the centre quartz? The cavity development across the centre seems to be a late leaching effect? One late fine black layer seems to be absent from the top sequence!


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PLATE 2

SEQUENTIAL INFILL – EPITHERMAL STYLE
Pajingo gold mine, Charters Towers region, Queensland, Australia (Scott Lode).

This plate has been selected to illustrate the problems of sequential infill in systems that are characterised by an excessive number of stages. It also illustrates the characteristic finely crustiform/colloform layering which occurs in many gold-silver epithermal systems.

Epithermal systems occurring in high level volcanic associated environments are commonly subjected to multiple and/or continuous fluid flow, which can be interrupted by repeated tectonic activity, including violent boiling and explosive events. Periodic boiling during a continuous fluid flow can result in rapid semi-rhythmic deposition to produce finely layered crustiform and colloform textures. Brecciation styles include explosive, and fault related products.

Faced with this situation there is often little point in trying to accurately define the number of individual phases in the conventional manner. It could easily exceed fifty and vary throughout the system, as different regions boil and/or fracture at different times.

The specimen graphically illustrates the problem and it becomes almost futile trying to sort out the brecciation and infill sequencing. Despite the very clear photograph the observer will quickly run into problems trying to piece the story together. Obviously it depends upon how desperately the total sequence is required. The beginner can rest assured that in 99.9 % of cases a rationalisation is adopted, with such statements as “multistage deposition” being employed! Strangely enough despite the multistage nature of many of these deposits the actual gold is typically restricted to a very narrow (or several very narrow) time bands. This is rarely acknowledged in scientific accounts which often “fudge” or ignore the paragenesis. The wall-rock fragments in the above plate are “fine-grained” silicified “volcanics”. The Pajingo deposit consists of a vein system, which is bonanza style in that some sections such as the Scott Lode, reach three figure gold values. High grade zones are often dark coloured as silica layers associate with fine-grained sulphides.

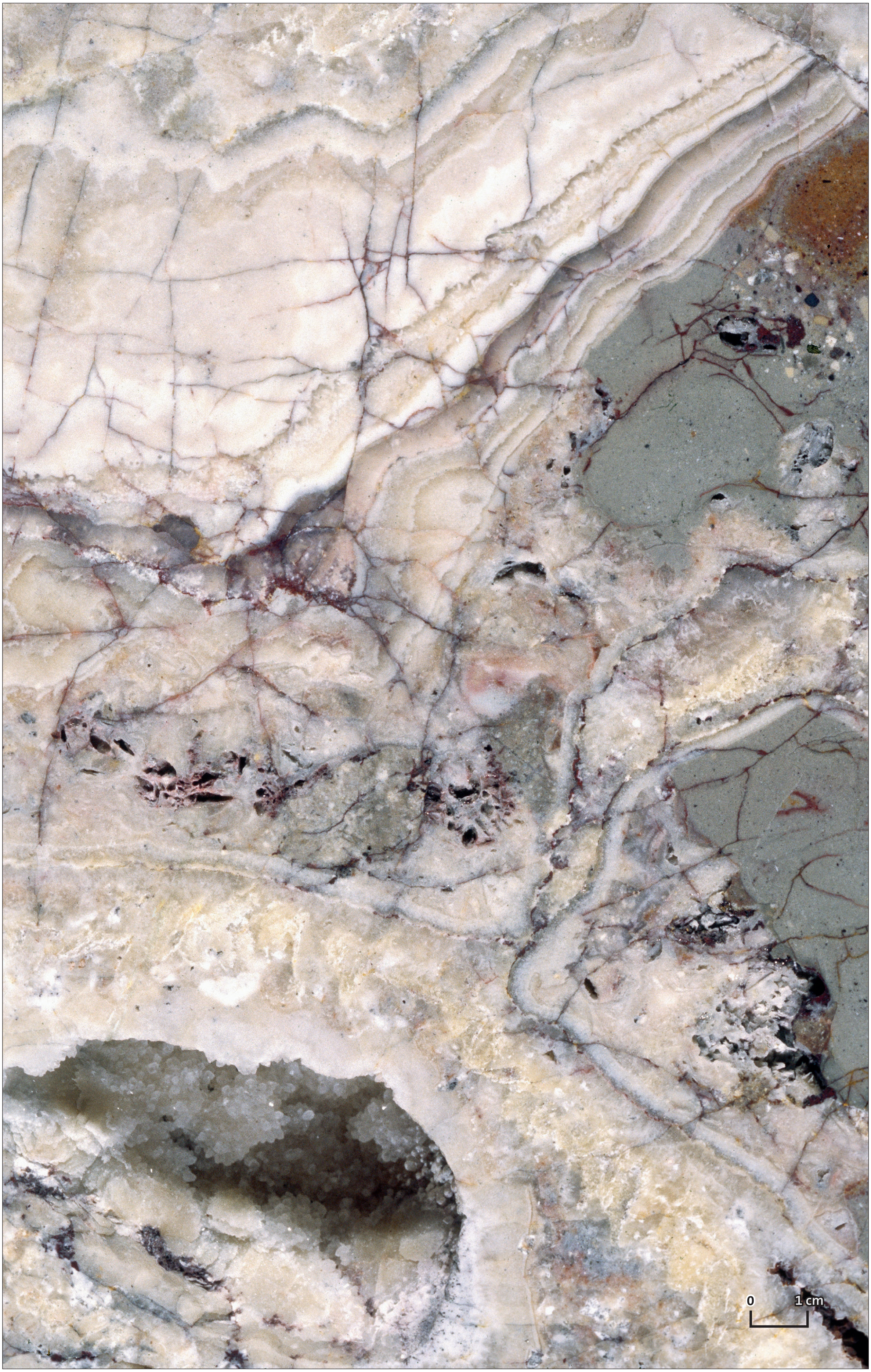
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PLATE 3

SEQUENTIAL INFILL. STRUCTURAL SUPERIMPOSITION – CROSSCUTTING VEIN. Telfer gold mine, Telfer, Western Australia, Australia (M 10 Reef).

This plate has been included to illustrate a more complex example of sequential infill accompanied by fracturing. It covers the criteria of mineral superimposition and structural superimposition.

The left hand side depicts a complete vein section. The host rocks are carbonate units which are just visible as dark slivers on the top contact.

The basal zone commences with grey /white quartz and progresses to a mixture of quartz (grey/white) chalcopyrite (brass yellow) and pyrite (pale yellow). This passes upwards into a finer-grained zone of quartz, pyrite with minor chalcopyrite. The complex upper section consists of prominent bands of granular pyrite, white calcite, grey materials (dolomite and silica) and a network layer of pyrite/chalcopyrite which is similar in texture to the region just below the prominent calcite zone.

The enlargements show the details of the upper and lower regions of the vein.

The lower section (bottom right) is composed of grey/white quartz which is clearly some form of infill. Hexagonal crystal outlines, partially hexagonal outlines, corroded looking grains are all evident, and outlined by excellent triangular textures of chalcopyrite/pyrite infilling around the hazy quartz crystals. Pyrite crystal shapes suggest that it nucleates prior to chalcopyrite. The quartz grains are also characterised by vague dark rims which suggest some form of alteration (recrystallisation of silica?) relating to sulphide deposition. It is also apparent that the sulphide component cuts through the quartz crystals in places (bottom right). A brown mineral is also present as infill?

The texture is difficult to interpret as many of the quartz crystals appear to nucleate from no obvious substrate. They are clearly earlier than the sulphides, and from their appearance seem to be either fragments exhibiting mild corrosion, or a network of crystals growing in a random lattice format. The latter would provide the space required to produce the course-grained sulphide infill. The crosscutting sulphide relationship suggests mild tectonic disturbance either prior to, or accompanying, the fluid responsible for sulphide deposition. Has the fluid flow/pressure disrupted and mildly corroded preexisting silica crystals prior to sulphide deposition?

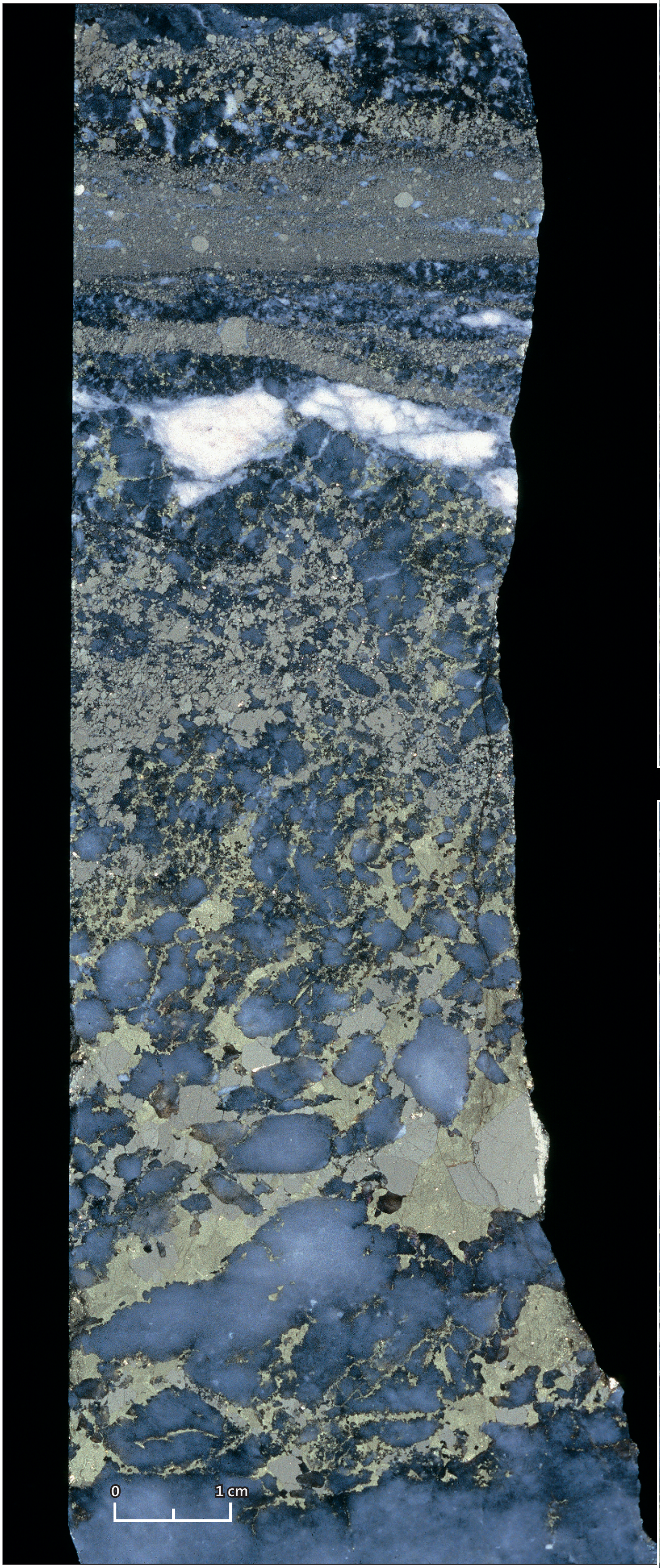
The interstitial sulphide becomes pyrite-dominant upwards, and both the grain size of quartz and interstitial void space decrease in size. This is a consistent feature of the saddle reef vein style of the M10 Reef at Telfer. This obviously requires some explanation. The texture suggests more rapid nucleation. The entire upper section of the specimen presents many textural problems. The interstitial pyrite-quartz (chalcopyrite) textures are present but are disrupted (overprinted) by prominent, vaguely vein-like layers of finer-grained duller pyrite, and also contain significant amounts of carbonate (white).

In detail the finer pyrite layers are composed of pyrite crystals of extremely variable grain size, and it is difficult to interpret whether they represent an infilling or an alteration component. The writer would suspect rapid nucleation with infill being dominant, although there is an impression of shear style in the fabric suggesting alteration pyrite could also be present. The problem cannot be resolved by eye.

The carbonate (white) component also appears to be vein-like infill where it traverses the width of the rock, and small tension style gashes are particularly prominent above the upper fine pyrite layer (top left) which could well relate to the original main horizontal fracturing. The white wisps, in and around the fine pyrite layers, again suggest shearing fabric associated with this zone. The carbonate thus seems to postdate the bulk of the main pyrite-chalcopyrite and silica stages, but predate the finer pyrite layers.

It is conceded that not everyone might agree on the precise details, but the general pattern of open space infill grading from coarse to finer moving upwards, with later stages of finer and/or shear? related components occurring within the top quarter, is present throughout all the underground exposures of this vein. Scheelite is also recorded at some points within the M10 Reef.

The Telfer geometry of stacked crescent, saddle reef shaped structures related to fold outlines requires interpretation within the above textural context. Early high fluid pressures have probably played a major early role in opening up the appropriate structural zones, with later shear? related fabric becoming focused in the upper portion. It is not the intent of this description to speculate further, but simply to illustrate that the observational process of understanding overprinting from a combination of infill, alteration, and structural perspectives opens up a wide realm of crucial genetic thinking.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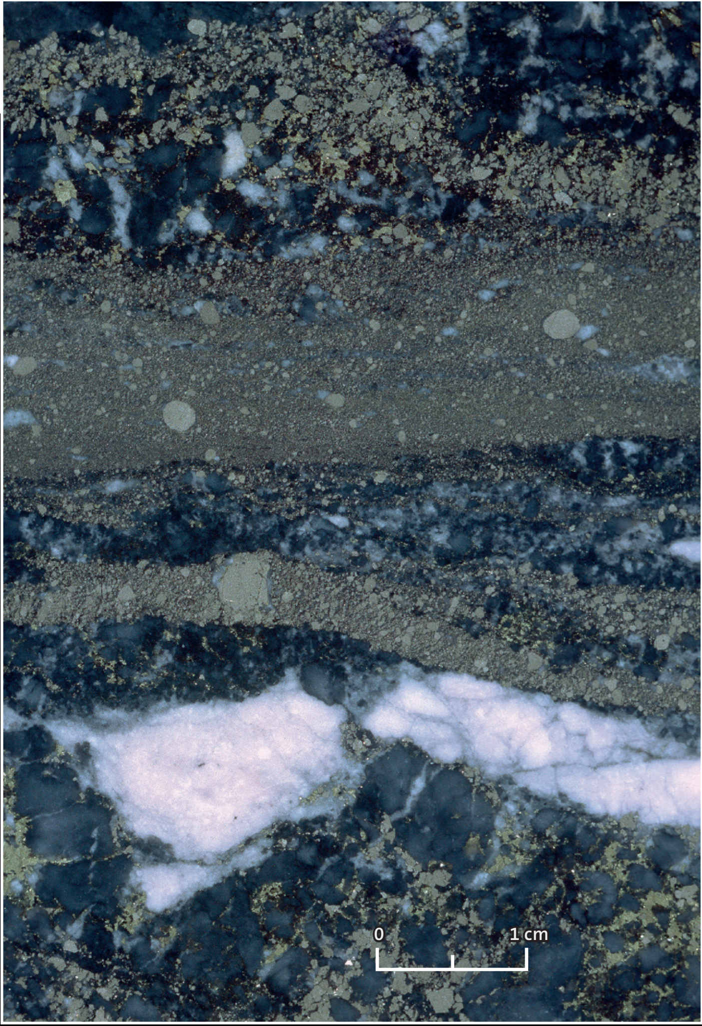
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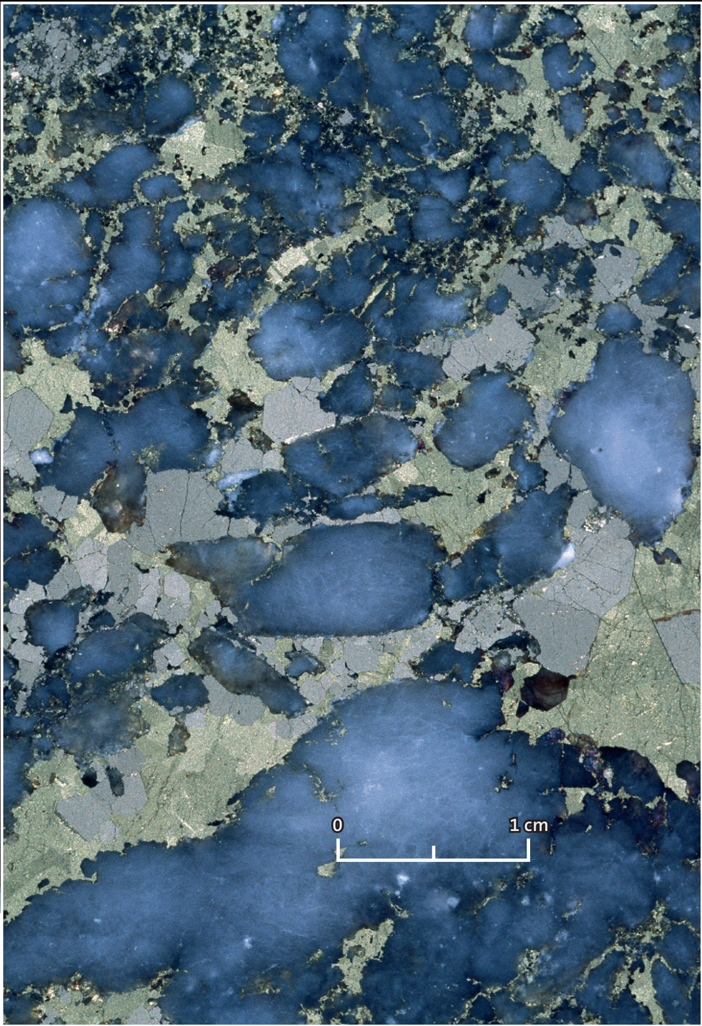
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5 First Order Criteria – Structural Superimposition

Crosscutting Veins – Stockwork and Other Vein Styles

Textures and Problems. Plates 4–11

Crosscutting veins are the most obvious of overprinting textures and usually present very few problems. Most systems consist of a relatively low number of stages (4–6) which are distinctly different and can be easily differentiated. However, there are some systems which by their very nature involve multiple stages of fracturing and deposition. The fracturing event may be closely allied to the depositional event. A good example would be epithermal systems, where repeated boiling over a short time span may result in 10–100 almost identical individual stages expressed as complex overprinting stockworks or multilayered colloform veins. Similar situations occur within some porphyry copper and porphyry molybdenum stockworks, and in fibre style crack-seal veins.

In some cases a complete sequencing is not only impracticable but impossible. Rationalisation is the usual approach, and typically large portions of sequence become arbitrarily lumped into one complex stage. This approach should not be used as an excuse for not really looking. Many porphyry stockworks are well worth pulling apart, with the complex sequence resulting from overprinting of a series of porphyries, rather than a single body. The recognition of nested porphyries each with its own system is a valuable piece of information.

Despite the apparent simplicity of the crosscutting criterion, it is quite surprising just how deceptive crosscutting relationships can be. The writer could recount hundreds of occasions where a casual visual conclusion had to be rapidly corrected when a hand lens was utilised. Quartz veins are particularly skilled at the art of deception!

The problems here mostly relate to the eye filling-in the crosscutting picture at the broad scale and not recording finer details. Typical eye deceivers are:

- An abrupt narrowing of a crosscutting silica vein as it cross cuts another silica vein. A prominent alteration halo around a quartz vein may disappear with the change in rock type as it crosses an earlier silica vein. This easily creates a false visual impression of being cut off. (See also ***Plate 9***).
- Late fracture reactivation commonly propagates across preexisting veins. A new fracture may propagate across a quartz vein, and link into earlier veins on either side. The net effect can easily mislead observers.

The following plates include examples of stockwork situations which illustrate the need for care.

PLATE 4

STRUCTURAL SUPERIMPOSITION – VEINS
Kidston gold mine, Einasleigh region, Queensland, Australia.

This plate has been selected to illustrate that crosscutting relationships are not always as simple as might be expected, especially in systems dominated by silica. It also shows some typical laminated style quartz veins, which are very characteristic of porphyry molybdenum systems.

The relationship between the quartz veins within this plate is quite a mind puzzle. The central vein seems to cut everything and is composed of fairly uniform dark grey silica. There is little real evidence to delineate the proportions of infill versus alteration, although the relatively good matching of the walls suggest infill predominates. Against this it seems that some selective alteration has occurred of the vein intersection at the top right. A very close inspection reveals a very small darker silica vein within the central vein which is visible in the upper region of the plate and appears to contain wafer thin slivers of the host vein?

The central vein seems to occupy a fault zone, as none of the veins on either side can be confidently matched. The well-laminated (light and dark layered) vein (centre-left) appears to be symmetrical sequential infill and the dark spots are probably molybdenite. The sharp matching edges suggest little if any alteration. None of the other veins convincingly match this infill sequence.

The vein to the top right has some elements of the above sequence (especially to the extreme right), but seems to be cut by another generation of silica at a shallow angle. This is either cut off, or is running up the side of the main central vein. The minute link vein just below this intersecting vein set graphically illustrates the problem of decision making concerning which stage to group it with.

This account could continue describing all the other small veins within the stockwork. However, it is apparent that precise delineation of the number of stages is rather difficult. It is also apparent that all of the stages look very similar in general, and the system would be interpreted as a continuous fluid flow intimately associated with multiple periods of brittle fracture. Fluid pressure is difficult to estimate but seems enough to hold veins apart? The fine-grained nature of the laminated silica and molybdenite suggest rapid deposition with multiple nucleation sites. These observations trigger a series of questions. What is the cause of the repeated brittle fracture which appears to be part of a continued tectonic event within a relatively short period of time? What is the cause of rapid and/or fine-grained nucleation? Why is alteration so limited? Why is the lamination and probably molybdenite deposition not present in the central vein system? Why does the stockwork exhibit a vague vein parallelism within the darker silica stages? Why is this style of veining so characteristic of porphyry-related molybdenum deposits?

Molybdenite is generally regarded as a high temperature, magmatic-related mineral. The rock is actually a fragment within the main Kidston breccia pipe.


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PLATE 5

STRUCTURAL SUPERIMPOSITION – VEINS. SUSPICION AROUSING – ASYMMETRIC INFILL

Watsons (lead, zinc) mine, Century region, Queensland, Australia.

This plate has been included to illustrate the difficulties involved in observing crosscutting relationships where the mineralogy of successive phases is similar. This is especially true of silica veins.

The plate illustrates several stages of silica veining, which consist of infill with very little alteration. Clean cut off sets have occurred, involving very little gouge effects. The cracks have opened under fluid pressure, such that they have reasonably well matching walls. This criterion is often used to identify infill from alteration. A few slivers of wall rock are included within some of the smaller veins, and in some cases seem fixed as "floating" fragments (central region). No one seems to have offered convincing explanation for "floating" fragments in silica veins which occur commonly at much larger scales. In many cases they are of high SG and should sink! Are they held apart by fluid pressure long enough for silica to precipitate commonly as comb quartz? Does the silica go through a gel phase at some time?

The most obvious stage is represented by the widest vertical veins, with the pale cream material consistently on the left hand side. The pale cream material (carbonate?) immediately arouses suspicion as it is blatantly asymmetric. Is this a later vein creeping up the side, or is the silica vein opening on one side of a preexisting carbonate vein? There is very little evidence to support either hypothesis. It is noted that the carbonate vein is actually at different distances away from the dark wall rock margin at different points, and that at some points (top) triangular textured cream infill seems to fill in between the quartz crystals. This favours a later origin for the carbonate. Against this these are a few points where the carbonate vein is discontinuous, with short patches of silica between the gaps. On balance the author favours the first hypothesis.

The obvious offsets of the main vein, contain a second silica stage which is slightly darker. A third even darker stage of silica angles across at about seventy degrees (bottom middle – to right middle). This also contains late cream carbonate infill and fragment(s) of the second stage silica.

Readers are invited to note the scale and reflect upon how difficult this would be to observe under normal conditions.


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PLATE 6

STRUCTURAL SUPERIMPOSITION – VEINS, STOCKWORK.
Grasberg (copper, gold) mine, Ertsberg district, Papua, Indonesia.

This plate has been included to illustrate the complex detail that can occur within a porphyry copper stockwork. It is definitely not for the faint hearted. The stockwork is so intense that there is little recognisable rock texture remaining.

The latest stage recognisable is the green malachite resulting from surface oxidation. A copper-rich fluid has penetrated a small crack along the contact of the quartz vein (bottom left) resulting in micro-infill along the crack, and minor alteration of pink feldspars.

The obvious silica vein (bottom right) has been overprinted by a crackle style of brecciation, channelling fluids throughout the rock and precipitating pyrite (pale yellow) and chalcopyrite (brass yellow) as micro-infill, in a complex spider web stockwork. It seems that pyrite precipitation precedes chalcopyrite, although this is questionable. No alteration is evident. Note that at some points the sulphides occupy a crack in the centre of a quartz vein. This situation is common and if seen in isolation can easily misguide the observer.

The quartz vein(s) appear to have no alteration component and are composed of sugary grey and white infill. Their relatively high width suggests high pressure fluid control?

The remainder of the plate (top left) is occupied by very small black veins of biotite occurring as infill. Less obvious are the grey/black small veins and rounded grains of magnetite, and the remnants of a fine-grained porphyritic igneous rock (diorite?). Although timing evidence is a little contradictory, the majority of the black biotite veins cut the magnetite. This tiny wispy vein style is very typical of secondary biotite in porphyry coppers, and although usually referred to as potassic alteration they are actually potassic infill! The biotite alteration occurs within the ferromagnesian minerals of the host rock. The square/oblong black clots in the top left corner, are probably hornblende converted to very fine-grained aggregates of biotite. The conversion blurs the edges of originally sharp bordered phenocrysts. It is very probable that the pink feldspars are also alteration products of plagioclase, and are now changed to potassium feldspar. (The biotite/potassium feldspar assemblage constitutes the classic potassic alteration of porphyry copper systems. In the more mafic style porphyries, biotite prevails in relation to potassium feldspar).

The magnetite thus represents the earliest stage of stockwork brecciation/alteration. Small veins are visible, and the rounded magnetite grains are alteration of the host rock feldspars.

The general sequence of stages – magnetite-biotite silica-sulphides represents a declining salinity and temperature sequence (600 °C to 350 °C?) The intensity of stockworking implies repeated fracturing (semi-random shattering) by a process of repeated high energy release. (Gas release? Explosive? Hydraulic overpressuring?). The exact mechanism for multiple fracturing in porphyry copper systems is unknown. It is quite common for two stages of identical character to overprint each other, suggesting a strong link between fracturing and fluid release.

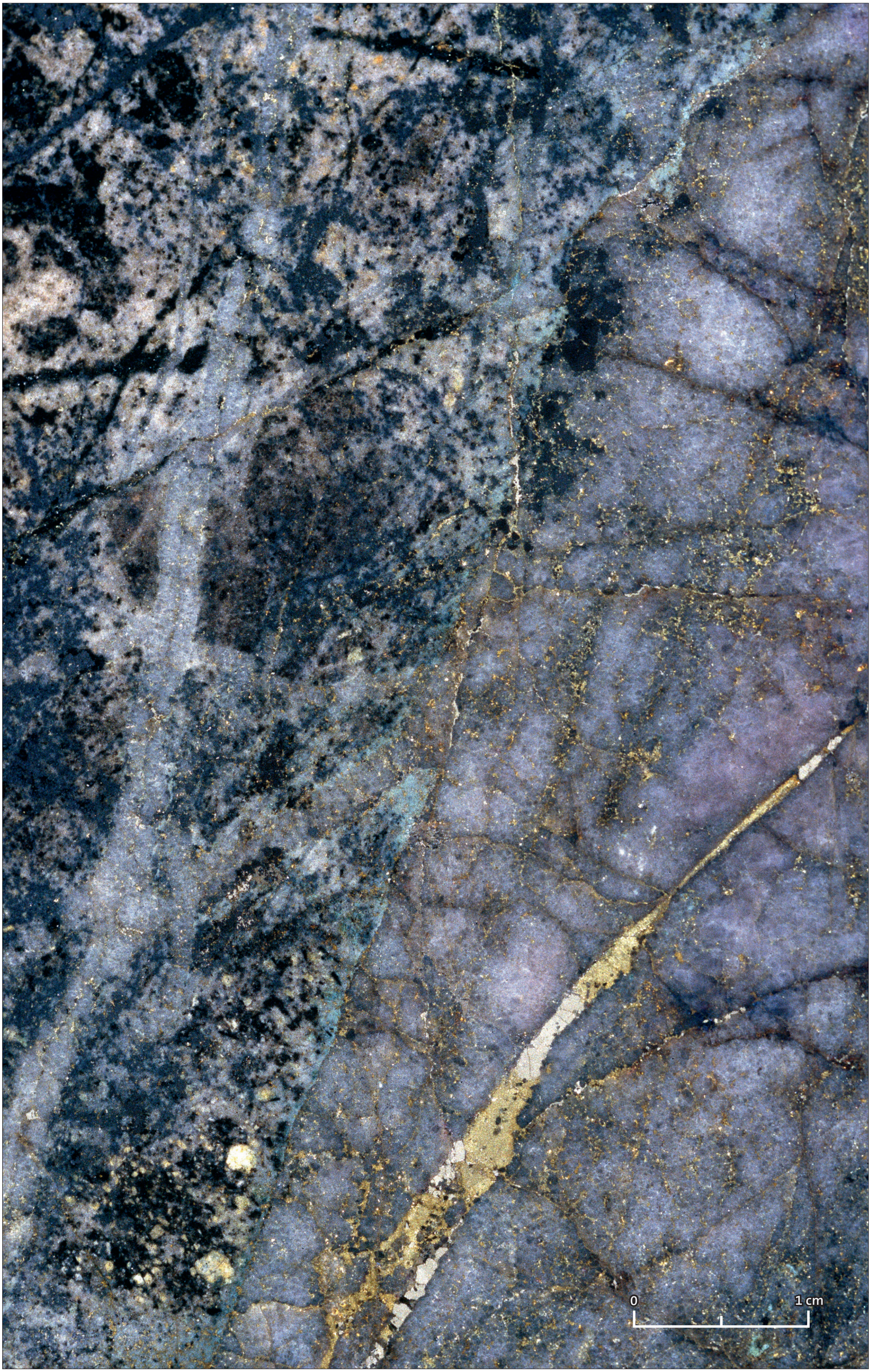
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PLATE 7

STRUCTURAL SUPERIMPOSITION – VEINS, STOCKWORKS.
Pea Ridge, Missouri, United States of America.
(Specimen provided by R. E. Myers).

This plate has been selected to again illustrate the complexity and difficulties encountered even within well-defined stockwork systems. The real question here is just how many stages of brecciation and infill are involved?

Disregarding the minute vertical cracks which look like very late veins, the latest stage is clearly represented by the system of angled (right to left) veins which contain a variable mineralogy including quartz (white-grey with vugs at centre right) fine-grained grey material (magnetite, sulphides) and equally fine-grained greenish areas (epidote?). The stage is infill-dominated, and it is difficult to discern any alteration effects. There is a very good example (centre left) of an abrupt right angle turn where the stage swings into a preexisting vein orientation.

It is a little difficult to ascertain the next stage back, but it seems to be a dark-to mottled grey (silica-sulphide/magnetite) vein system, best seen in the bottom left hand corner where it clearly cuts both the pink and green material, and is in turn cut by the grey material described above. This stage is present as small veins (bottom left) and as minute fracture networks (E-W, across mid slide). Alteration is variable. The pink wall rock seems to suffer very little, whereas the green (epidote) becomes darker. The darker alteration (silica?) is particularly noticeable in the E-W anastomosing fracture network (centre).

The next stage is probably the clearest, being represented by the very visual green (epidote) in both breccia and small vein format. There are numerous examples of well-defined infill (green epidote, with darker green quartz) which have nucleated on vein walls and around fragments. It is possible that there is some whiter quartz in the centre of larger veins (bottom left). Alteration associated with this infill seems negligible. Fragments are predominately pink and dark green/black and the breccia appears to be fault style, probably associated with high pressure fluid introduction (hydraulic jacking).

The early history of the rock is best seen in the top third of the plate. The epidote stage clearly overprints a dark black stage (silica?) which occurs as breccia fragments and as asymmetric thin edges on veins which have been reopened by the epidote hydrofracking.

Also present in the top left hand quadrant are minute pink infill veins (feldspar?) which cut a dull grey (silica-magnetite) background crackle-mesh network breccia system. This system appears to have a considerable dark silica alteration component. From this examination it would seem that the rock has been broken up and subjected to hydrothermal fluid systems on at least six occasions. No doubt the reader would question some of the above, as it is clearly a complex overprinting situation requiring very good observation and extreme care. The specimen has been included to make exactly this point. Very commonly all is not obvious, and more specimens, together with controlled petrology are required. The original rock is a little enigmatic. The pink crystals are presumably feldspar, the white blebs are pyrite, within a very fine-grained matrix. A species of pophyritic volcanic or intrusive rock is suggested.

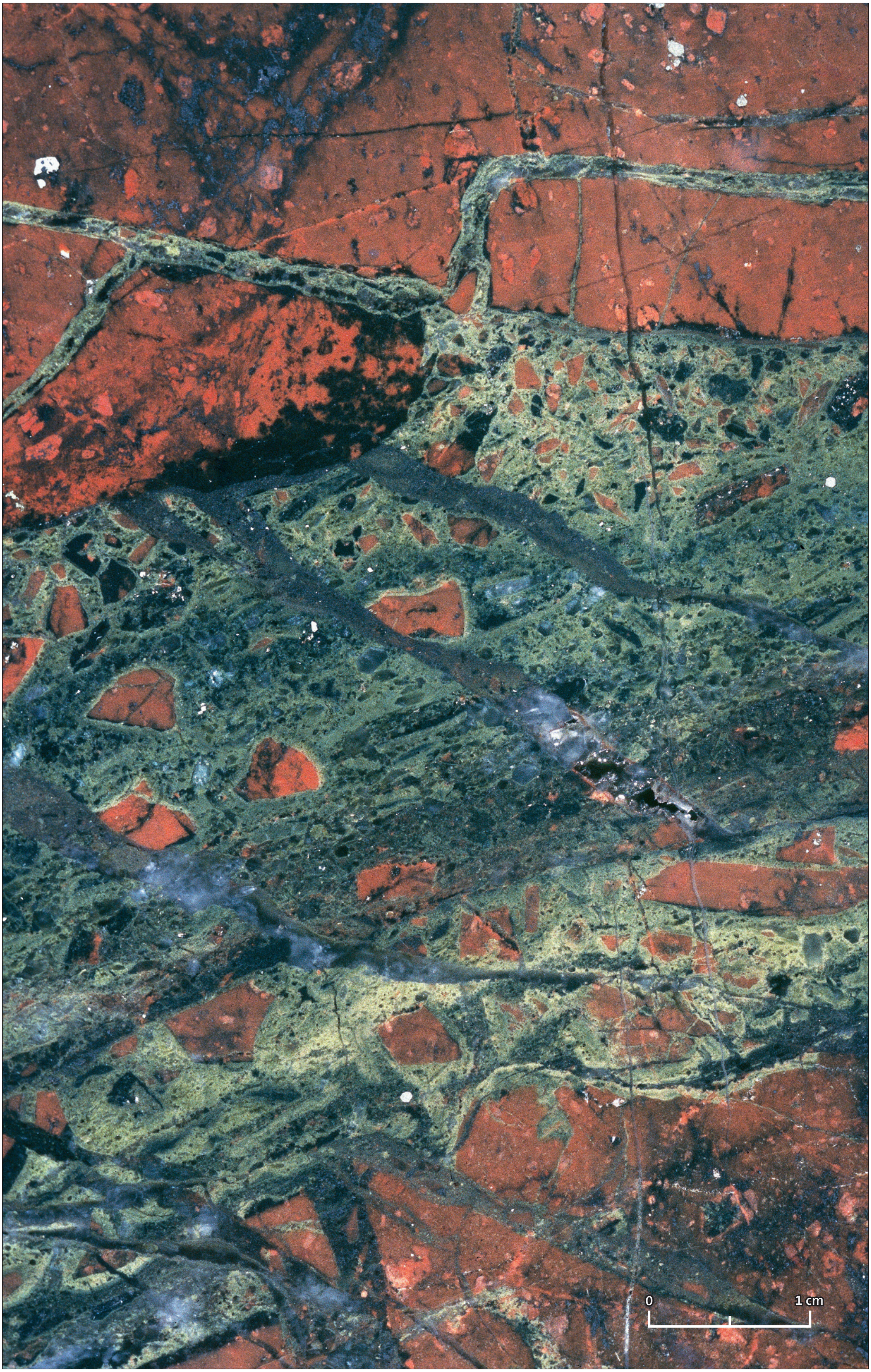
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PLATE 8

STRUCTURAL SUPERIMPOSITION – VEINS STOCKWORKS.
Red Dome (copper, gold) mine, Chillagoe, Queensland, Australia.

This plate has been included as a good example of a multiple overprinting stockwork. It also illustrates that even with clearly visible components, timing relationships and alteration/infill distinction requires very careful observation/consideration.

The last stage within this rock is represented by the prominent dark, vertical, central vein of bornite. The same stage is visible at many other points as impersistent lines (small veins) of dark spots, and vague alignments of diffuse vein-like spots/blotches. The latter are prominent within a vertical yellow band (garnet) on the right hand side. This style of texture is common in skarns, and all of the dark material marks subtle channelways. The identification of infill versus alteration is impossible, although it is clear that most of the spots are alteration. Some infill may be present in the main vein?

The preceding stage is represent by the narrow veins (grey quartz) which run E-W across the plate. These are infill (matching walls), and best represented at the top of the plate. Close inspection of this region reveals that despite initial impressions the quartz vein does not actually cut through the bornite. Similar relationships are more obvious towards the base of the plate.

Both the bornite and quartz veins overprint the rather vague diffuse yellow garnet veins (right hand vertical, and top left corner). Sight variations in texture are visible, but the infill/alteration distinction is not clear (probably mostly alteration). The yellow garnet occurs as alteration of red garnet (bottom-centre).

At this point life becomes difficult! The obvious remaining materials are garnet (red-centre vein/layer) and white (wollastonite). Wollastonite clearly cuts over the red garnet (bottom left quadrant). Careful inspection of the general white colour of the rock reveals grey zones, which suggest that mass wollastonite alteration of an unknown host rock (siliceous carbonate??) has occurred.

Infill/alteration distinction of the wollastonite stage is impossible, although obviously alteration predominates.

Even closer observation reveals that the red garnet is cut by impersistent dark green vein structures (pyroxene). These are best seen in the region of the red garnet/wollastonite crosscutting vein relationship (bottom left quadrant), and the wollastonite also cuts the dark green pyroxene veins?

The reader may well be reaching a point of scepticism by this stage, but this sequence can actually be observed from other rocks in the mine area, and is records two overprinting stages of skarn development.

The short form paragenesis becomes:

1. Red garnet veins (alteration predominant, textural variation suggests some infill?).
2. Dark green pyroxene veins (alteration predominant? Not really visible).
3. Wollastonite (mostly as alteration, minor infill).
4. Yellow green garnet veins (mostly as alteration).
5. Quartz veins (infill).
6. Bornite veins (mostly as alteration, possibly minor infill?).

Obviously more specimens are required to achieve more information on the early stages, and wall rock composition. The specimen is however a very good example for honing observational skills!


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PLATE 9

STRUCTURAL SUPERIMPOSITION – VEINS. SUSPICION AROUSING – WANDERING CENTRAL INFILL

Jumna tin mine, Irvinebank, Queensland, Australia.

This specimen has been included to illustrate that overprinting vein structures can be considerably more complex to unravel than is popularly supposed.

It is always good technique to work from the latest event through to the earliest.

On this specimen the latest event seems to be a series of very inconspicuous tiny pale brown veins (siderite) which are best seen in the lower central region where they cut through the dark grey-white zone as well as both quartz veins and the black (quartz-tourmaline) veins. In this region they are infill-dominated and without alteration halos. However, this is a trap for the inexperienced as the same veins in the upper region produce irregular alteration fringes of orange (rusty? siderite) and pale creamy-orange materials (pristine siderite?). This appears to be at the expense of greenish sericite in the host rock. The latter is some form of feldspathic sandstone, in which the feldspars are sericitised (top zone).

Thus the alteration associated with this stage is dependent upon the rock type. Within this context it is probable that the conspicuous orange/cream central "vein" is in fact part of this assemblage, representing alteration associated with an E-W fracture crossing a zone of relatively unaltered host. A very good example of a false central channel is present within the lower narrow black vein. Close inspection reveals a minute central pale brown vein of the siderite stage wandering along the horizontal dark tourmaline infill, but connecting to the vertical system.

The next set of veins are the dark horizontal set which consist of dark infill (tourmaline) and variable amounts of grey/white (silica) and dark (tourmaline) alteration. The latter probably alters an original feldspathic component in the rock and may grade out into the green sericite mentioned above. It is obviously a strong alteration in relation to the small infill channels.

This stage again illustrates the need for very careful inspection of seemingly crosscutting veins, as there are many examples where the tourmaline veins cut earlier quartz veins, but turn to quartz infill without alteration. This is common in many situations and can easily give the wrong impression to a superficial glance.

The earliest vein set is the white-grey quartz veins which contain dark (tourmaline) central zones and coarsely crystalline comb quartz. The veins display no alteration and their relative width suggests a high fluid pressure. There is also a hint of a brown mineral (cassiterite) at some points.

A paragenetic/structural control chart is shown below. This format is very useful for recording data.

Stage (Name)	Infill	Alteration (Rock type altered)	Structural Style	Comment
Siderite	Siderite, mm scale	Siderite (sericitised? wall rock) Nil (Silica-tourmaline rocks) Nil (Quartz veins)	Microvein network mm scale	Small scale
Tourmaline	Tourmaline mm scale	Quartz tourmaline (sericitised? wall rock) Originally feldspathic sandstone)	Subparallel system of small discontinuous microveins	Alteration extensive
Quartz tourmaline	Quartz tourmaline cassiterite ? cm scale	Nil	Subparallel veinlets around 1 cm wide	Fluid pressure high? Comb quartz

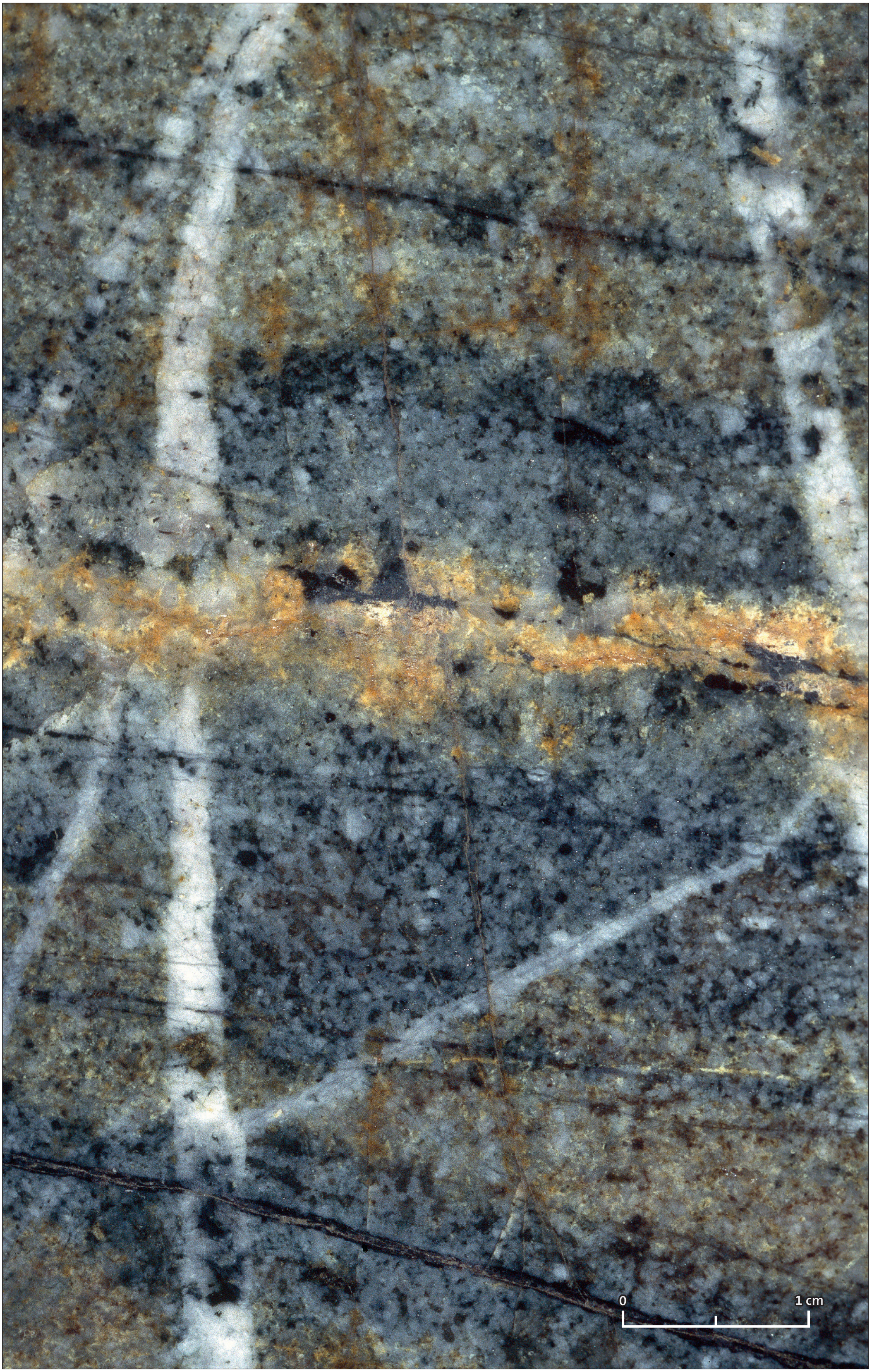
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PLATE 10

STRUCTURAL SUPERIMPOSITION – VEINS, PARALLEL REACTIVATION.
Unknown tin mine, Kangaroo Hills tinfield, Queensland.

This specimen has been selected to illustrate the difficulty in establishing overprinting relationships in situations where infill is not accompanied by significant alteration. It also illustrates a much overlooked situation in that feldspathic alterations are commonly accompanied by feldspathic infill.

The wall rock (bottom left) is composed of pale (pink/white) fine-grained granite, composed mostly of feldspar (pink/white) and quartz (grey). This has been altered (bottom right) to a texturally retentive rock with the original feldspars converting to white albite. The infill component for this is represented by the coarser-grained white albite associated with black spots of cassiterite and grey quartz. Careful observation will reveal small crystals of oblong albite projecting into the small "triangular" cavities containing cassiterite crystals.

Subsequent fracturing along the central and marginal region of the vein, has provided access for fluid depositing coarse cassiterite in an anastomosing vein mesh. This is not accompanied by any obvious alteration and possibly occurs in close time sequence to the cassiterite associated with the albite infill?

The major quartz stage (grey) appears to be all infill (top and middle) occurring as crystals, although it is possible that some of the paler albite rich slivers (top left) might be partially silicified. The timing of the quartz stage is a little difficult to discern as it appears to have cassiterite (dark) as a partial lining at several points. However on balance it seems more probable that a high pressure fluid has exploited previously earlier cassiterite veins and simply forced (hydrofractured) them open.

The prominent orange layer (lower middle) is iron staining related to ground water percolation along the vein margin.


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PLATE 11

STRUCTURAL SUPERIMPOSITION – VEIN, BRECCIA

Mt Isa (lead, zinc, copper) mine, Mt Isa, Queensland, Australia.

This specimen has been selected to illustrate a very clear cut case of overprinting relationships in breccia format.

The most striking feature is the comprehensively shattered, crackled white material (dolomite) which is associated with a network of narrow veins containing chalcopyrite (yellow) and dark material(?). The vein network links to more substantive blotches dominated by chalcopyrite and minor pyrite (paler yellow).

It is very difficult to determine whether or not the chalcopyrite represents infill or alteration. This is a common problem with chalcopyrite which very rarely forms clearly recognisable crystals. The substrate dolomite (white) also gives very little help in terms of providing clearly recognisable crystals projecting into potential chalcopyrite-filled vugs. Some of the ragged edged dolomite and small fragments? (mid to lower right) suggest that dolomite may have been dissolved prior to chalcopyrite deposition or simply altered to chalcopyrite? However, without further data it is impossible to be certain of the proportions of infill versus alteration concerning chalcopyrite. The writer would suspect both are present.

The fracture system controlling chalcopyrite also cuts the dark (siliceous) fragments, and although not totally clear may link with some dirty grey dolomite veinlets (bottom right) associated with grey spotting (alteration) within the fragment.

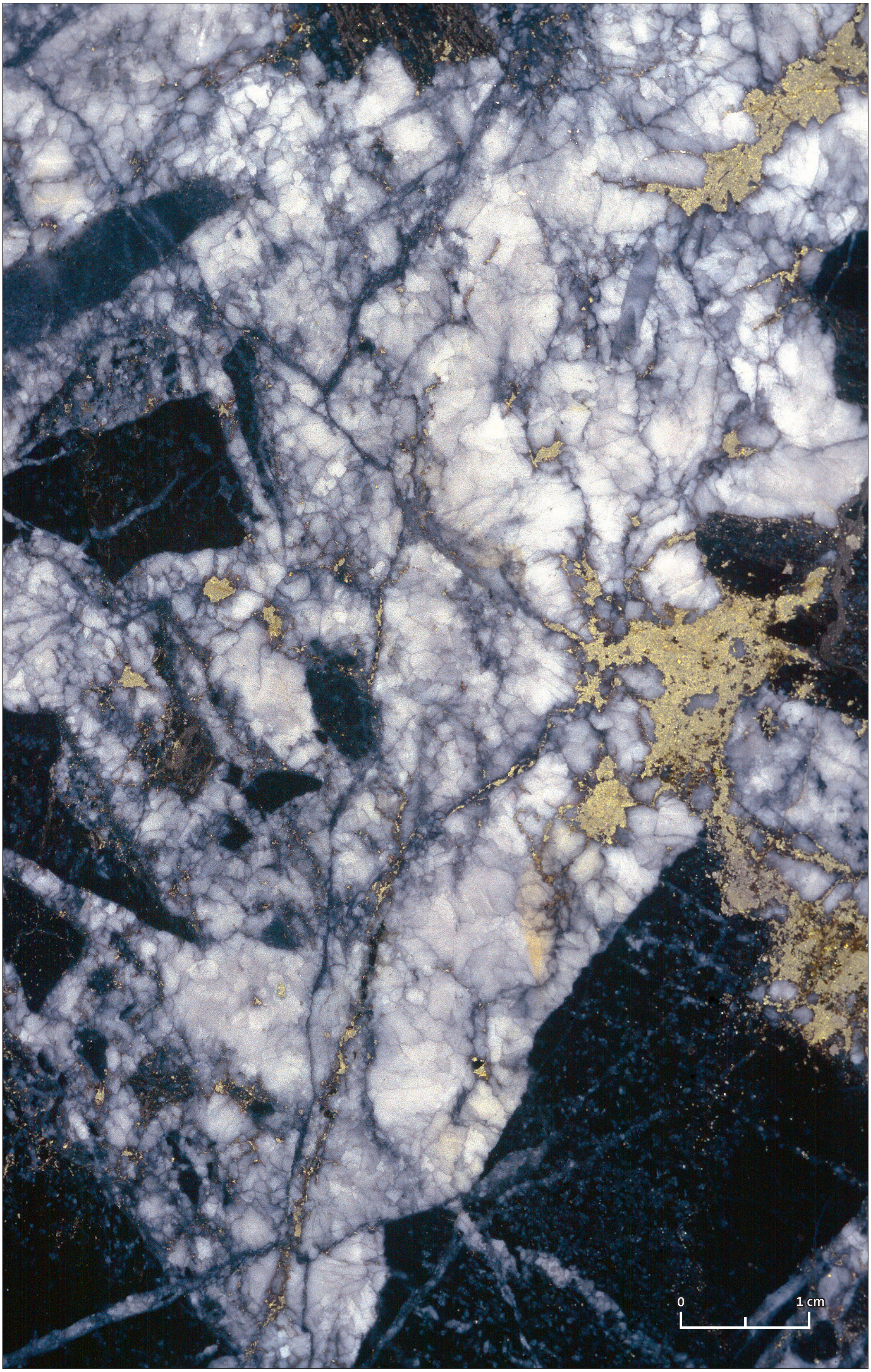
The relationship between the dark siliceous fragments and the white dolomite is especially interesting. Taken at face value there is almost no evidence to suggest that the fragments have been altered. They have sharp edges, and there are several examples of fragments which are veined by dolomite. In these cases the sharp walls can be matched and/or partially matched, leaving the overall impression of high pressure fluid jacking with subsequent coarse-grained dolomite infill. The current concepts at Mt Isa which regard most of this dolomite as alteration (replacement) certainly merit re-examination.

The siliceous nature of the fragments is also very suggestive of alteration prior to fragmentation.

All of this suggests a three stage paragenesis of:

- Early dark silica alteration (channelways uncertain?)
- Major fracturing and tectonic brecciation involving a high pressure fluid which precipitates dolomite (mostly infill).
- Major fracturing and brecciation/crackling linked to the introduction of the copper-rich fluids. (proportions of infill v alteration uncertain).

This specimen is typical of much of the copper orebody. Obviously some good petrographic observation is required to sharpen this perception.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6 First Order Criteria – Structural Superimposition

Breccia (Fragments of Early Stage Mineralisation Contained Within Later Stages)

Textures and Problems Plates 12–15

Recognition of overprinting utilising this criterion would at first reading seem very straight forward, and there are many breccias where relationships are extremely well-defined. However, anybody aquainted with the breccia world, will readily testify that coping with mineralised breccias is frequently one of the most difficult textural operations in economic geology. Indeed there are numerous examples where brecciation was not even recognised during many years of production.

Brecciation produces a mix of void spaces, large fragments, and finer fragmental (matrix) materials. The variation in scale, proportions, and distribution of these components is enormous. The highly broken zone is usually flanked by regions of shattered and mildly jostled rock. The highly permeable result forms a perfect focus for migrating ore fluids. Hydrothermal activity results in alteration of both fragments and matrix with precipitation occurring within the voids. Fluid flow through large bodies of breccias is usually very irregular, producing very erratic distribution of alteration/infill.

Breccia bodies (especially fault-related breccias) are commonly sites of reactivation. Rebrecciation and new fluid flow can produce complex overprinting textures. The new fluid may precipitate in already partially filled voids, or occupy the new voids. Similarly alteration may alter preexisting alteration (or infill) or attack areas of original unaffected breccia. The process may be repeated several times.

Common problems include:

(a) Recognition of altered fragments
(b) Distinction between highly altered fragments and similarly altered matrix.
(c) Distinction of infill textures, and their relationship to the above.
(d) Infill/alteration pairing. Within multibrecciated systems which involve extensive alteration, it can become extremely difficult to decipher which alteration belongs to which infill.

In complex breccia overprinting situations, the observer is strongly advised to immediately cease activities and move towards the edge zones. The "crackle" zone at the periphery, is highly likely to contain a mass of minor overprinting veins. Infill and alteration pairing becomes much easier utilising a consistent wall rock, crosscutting textures are more obvious, and the information can then be applied to the main body. Unraveling overprinting within complex multiply reactivated breccia zones requires good technique, good observation, and patience.

PLATE 12

STRUCTURAL SUPERIMPOSITON – BRECCIA
Disraeli gold mine, Rishton district, Queensland, Australia.
Specminen provided by G. W. Clarke.

This specimen has been selected to illustrate many of the problems associated with overprinting in breccia mode. These are three phases of hydrothermal fluid introduction involved, and three types of fracturing/ brecciation. Working with brecciation is frequently much more difficult than is generally conceived, and many breccias are overlooked. Readers are invited to test their observational skills on the opposite plate, before reading the detail below.

The last stage is easily the most obvious, consisting of calcite (white) and minor silica (grey) infill without alteration, occupying a crackle style brecciation. (This stage is actually overprinted by another crackle style fracturing which is unmineralised and possibly caused by blasting activity.)

The middle stage is best observed by tracking the pale yellow-buff materials, which are varying combinations of sericite and pyrite. These actually all link together in a complex network at both a coarse and fine scale of fracturing. The differentiation between infill and alteration within this stage is not really possible. Intuitively it seems that pyrite is involved as infill, but it also probably occurs as an alteration product. Sericite is clearly involved, largely as alteration.

The mode of brecciation is a stockwork of brittle fracture which seems to have involved the production of very small fragments of wall rock (fragments and gouge associated with a crushing/shearing movement). This matrix forms the main focus for alteration (top third of plate) and fluid flow.

When this breccia is eliminated the rest of the rock remains, and is composed of well-defined dark fragments and grey silica. The fragments are "granite", and are well-separated with many being well-rounded. One "granite" fragment has an attached silica edge and other smaller silica fragments are present. The matrix of the early breccia is very difficult to discern through the overprinting sericitic alteration. It seems siliceous? and possibly finely fragmental. (The fragment at the top right seems to be different and possibly silica-altered). All of this suggests that the early breccia may well be of the hydrothermal intrusive (milled) variety. It is possible that some silicification (quartz veining) occurred before this brecciation. If this were so, it would imply another phase preceeding the interpreted silicified hydrothermal intrusive breccia. Obviously a wise observer would move and try to find less overprinted material of the early stages. However, there is enough within the plate to lead the observer to suspect an intrusive breccia pipe environment?

Selective assaying is required to track the gold. The middle pyrite-rich stage is the most probable candidate.


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PLATE 13

STRUCTURAL SUPERIMPOSITION (AND MINERAL SUPERIMPOSITION) – BRECCIA
Ravenswood gold mining district, Queensland, Australia (Area 2 vein Carpentaria Gold).

This specimen has been included as an example of complex infill overprinting and brecciation which reflects a long history of deposition within a vein structure.

With situations of this style it is always very difficult to know where to start. The working backwards principle (from the latest to earliest) is not always appropriate. It is often more effective to settle on one small segment that is clear, and then select another. This can often be done by working from clear crystal shapes to see the next mineral to be deposited, or alternatively from a layer which is coating either crystals or broken material.

A most striking feature is the strongly brecciated material (lower left hand edge). This is predominately finely comminuted sphalerite (black) and arsenopyrite (silver) within a black (silica?) matrix. The fragments are sharply angular to well-rounded, and give a very good idea of how the two different sulphides break up. The breccia breaks through preexisting sulphides, and fragments have clearly been forcefully transported. Some style of explosive/intrusive brecciation (milling) can be inferred as a late-stage event.

In the left hand top corner a continuous rim of arsenopyrite (silver), some with good crystal form coats a large sphalerite crystal (dark). The latter seems to exhibit a crystal shape, although it does look a little "ragged" along the margins. The arsenopyrite rim is directly overgrown by chalcopyrite (yellow) associated with some good crystals shapes of pyrite (pale yellow).

Direct sequencing is difficult here. Has the arsenopyrite been fractured to form isolated clumps? Which came first, chalcopyrite or pyrite? The author's preferred interpretation is that the arsenopyrite has been disrupted and that the pyrite is slightly earlier, in a pyrite-chalcopyrite paring.

The pale buff material, siderite? (right hand side) is quite clearly infill with good triangular textures, and equally clearly some of the earlier arsenopyrite/pyrite/chalcopyrite has been disrupted prior to siderite deposition. The 20/20 vision observer may just see a rare thin arsenopyrite layer coating some of the pyrite preceding siderite? deposition. Fragments of the pale buff siderite occur in the finely brecciated (black) material mentioned above (middle-right hand edge). Some lozenge shard-like cream crystals (calcite?) also appear in this region, and seem to coat the buff siderite, but predate? the violent brecciation. Their precise association is not clear.

Obviously a few more rocks might clear up some of the problems. However, the smorgasbord approach has partially unravelled the problem, which is one of vug filling with periods of selective fragmentation. The sequence appears to be sphalerite (possible fragmentation) arsenopyrite (probable fragmentation) pyrite-chalcopyrite (definite fragmentation) siderite-calcite (explosive fragmentation) dark silica. Much of the fragmentation is probably in response to high fluid pressures within vugs rather than direct tectonic brecciation. The more vigorous "explosive" event could be triggered by fluid boiling and streaming gas (CO_2?) discharge.

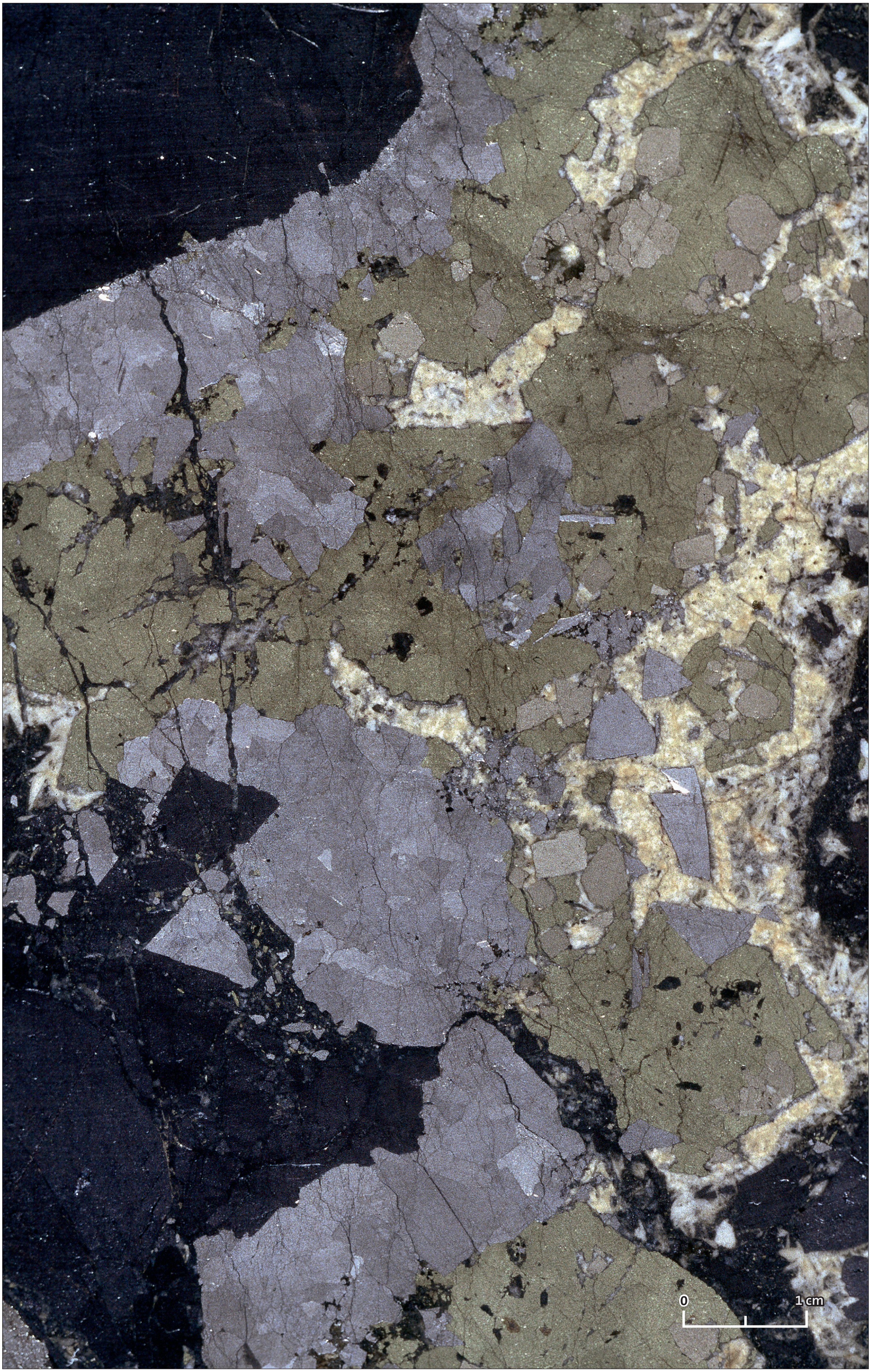
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PLATE 14

STRUCTURAL SUPERIMPOSITON (AND MINERAL SUPERIMPOSITION) – BRECCIA
Mistake tungsten mine, Emuford, Queensland, Australia.

This specimen has been included to illustrate the prime value of breccia in paragenetic sequencing. The working principles involved with breccia are firstly to determine the most recent event, and then to work progressively backwards within the remaining fragments. The process continues as different fragments become isolated. In complex brecciation it is sometimes more practical to just work in small segments (where things are clear) and then piece the results together.

The most recent event on this plate is the central white vein traversing diagonally from top left to bottom right. The picture is a little confused by the orange iron staining, but the vein consists of central white silica with a lining of grey-green-buff fluorite. At this point the situation becomes confusing as the two sides of the lining do not match very well. A thin zone (top left) of creamy fluorite runs along the top edge of the lower lining, and although difficult to trace seems to cut off a vein of pale grey-green-buff fluorite traversing diagonally from bottom left to top right. The net result is a degree of confusion as to whether there are one or two generations of the grey-green-buff fluorite (two are suspected).

Working backwards becomes difficult from here. The basal segment (base of plate) contains several clearly recognisable fragments (mottled buff-green) and numerous less obvious fragments (grey-green to grey-white). Good infill recognition is required at this point to recognise the small black crystals (wolframite) growing in association with dark blue-grey silica. A general (admittedly confused) sequence of dark blue-grey silica progressing to white silica is commonly picked out. The wolframite occurs in both, and despite the complexity seems to be a coherent infill package.

The fragments are obviously mixed, and clues to some of their origins are seen in the top right region. Here the mottled buff-green material is clearly surrounded by grey-green silica as a separate earlier breccia. This has been fragmented to produce the fragment mix associated with the wolframite-silica described above. A good example is seen of an early breccia fragment at mid-centre left. The mottled buff-green material is fine-grained granite wall rock. Several partially silicified examples can be located, and there is even a hint that this may have been broken by a white silica breccia generation prior to the grey-green silica!

The difficult breccia situation is even further extended with the realisation that a complete stage of pale emerald-green fluorite is present (top edge). This is cut by the late-stage veins, and appears to have deposited on top of the wolframite dark silica stage.

There is ample evidence on this plate to illustrate a minimum of four stages of brecciation and infill. The fine-grained granite has been fragmented and infilled by grey-green silica (stage I). This has in turn been fragmented and infilled by the wolframitegrey-white silica (stage II). The green fluorite represents another infill probably related to another brecciation (Stage III) and this has been cut by the late (grey-green fluorite) veins (stage VI).

Given that there could be two generations of the latter, and that both early silicification and sericitisation of the initial granite wall rocks are possible, there could be as many as seven stages involved! Obviously more samples would clarify some of the questions. It should be noted that the wolframite-silica stage is quite separate from the later fluorite stages. The specimen comes from a vein, and again illustrates the propensity of veins to constantly form focal points for fragmentation and new fluid flow. This complex breccia is nearly all composed of infill with very little alteration effects. If alteration had been a major component it is not hard to imagine how difficult it would be to unravel! The styles of brecciation represented are another aspect which needs consideration!

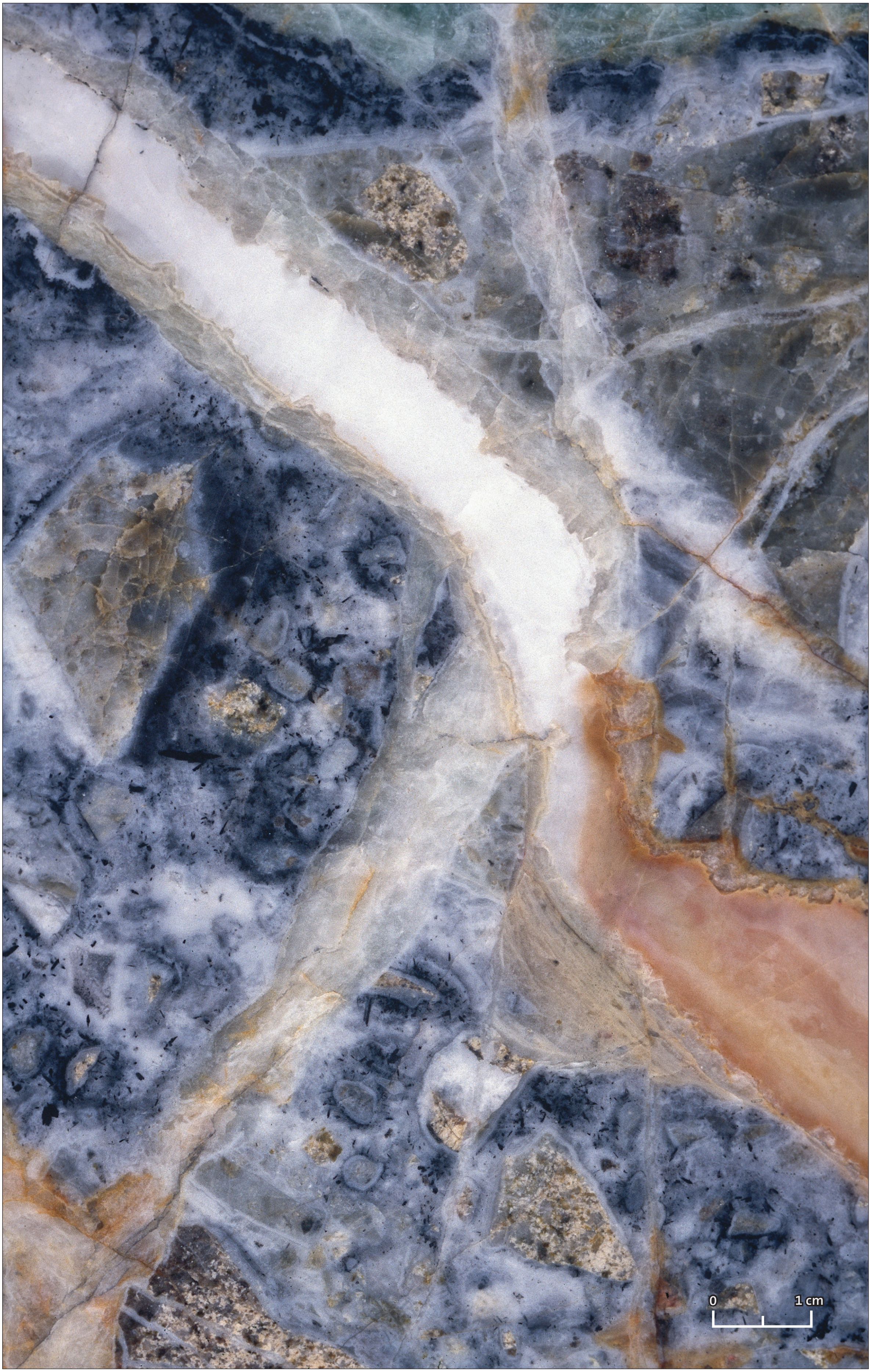
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PLATE 15

STRUCTURAL SUPERIMPOSITION – VEINS, BRECCIA

Unknown tin mine, Kangaroo Hills tinfield, north Queensland, Australia.
(Specimen provided by G. W. Clarke).

This plate has been included to illustrate the necessity for careful observation. It also serves to show some of the frustrations involved with low angle cross-cutting silica-rich veins and also to exhibit difficulty in observing breccia. The question to be answered is how many stages are present?

The plate contains multiple generations of quartz-rich veins some of which are involved with accompanying alteration. Vision is partially obscured by a yellow (iron-oxide) staining due to weathering, where surficial fluids have selectively channelled along vein margins and elsewhere. This is prominent in the mid-left of the plate, adjacent to a prominent quartz infill vein. This prominent silica vein has a Y shaped branching form and is distinguished by coarse-grained comb quartz infill. Within the comb quartz, dark triangular textures and cavities are visible. The dark mineral is unidentified, but seems to be prone to weathering. There is no clear-cut alteration associated with this stage. The vein width tends to suggest a fairly high fluid pressure which has pushed the walls apart. The lack of gouge or included fragments further suggest it was originally some kind of relatively simple cracking rather than a major displacive fault zone.

The lower branch of this comb quartz stage (base-middle) is cut off by a later similar, although slightly whiter silica vein in the bottom right hand corner. A close inspection of the comb stage silica vein, below the fork of the Y shape, reveals very narrow white silica veins within the comb quartz. These parallel the comb quartz vein, and can only be traced within it. Do they represent the crosscutting stage in the bottom right hand corner?

A third stage is strikingly represented by the narrow (vertical) band of dark material adjacent to the Y fork in the centre of the plate. This stage is an exercise in frustration. It appears to have a double black zone with a white centre at some points, but proves impossible to trace with any certainty through the various siliceous components.

The problems become even more acute when the various slivers of material surrounding the Y shaped comb quartz are inspected. For instance the bottom left hand sector is composed of vague fragments, some of which seem to be in the process of alteration (silicification) set in an anastomosing system of sugary granular slightly pink quartz. This breccia appears to be a very shattered feeder system, allowing easy ingress to an early-stage quartz infill/alteration system. Similar material is noted to the right of the vertical elongate dark central patch.

Even this dark material on close inspection is fragmentary and consists of dark green (chloritised) material containing reddish minerals (cassiterite?) which may link with the white silica to the immediate left which also contains the red/pink mineral. This all suggests another stage of silica (cassiterite) associated with chloritic alteration. The wall rocks are probably the grey/white fragmental materials (metagreywacke) seen as a vertical spindle shaped sliver, which just touches the middle-right hand side of the plate, and extends almost the full length of the plate.

At this point the observer will probably have collapsed in confusion, which was the reason for selecting this plate. Obviously things are not as easy as they seem, with overprinting veins/brecciation. More rocks would help!

The final!! interpretation is:

1. Fragmental metagreywacke wall rock (centre-right spindle)
2. Quartz-cassiterite infill with dark chlorite alteration (left and right of centre)
3. Quartz (sugary pink) infill and alteration (bottom left)
4. Narrow dark vein (centre) possibly part of 2 above?
5. Comb quartz vein (Y shaped)
6. Quartz vein (bottom right and possibly within the comb quartz vein)


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7 Second Order Criteria; Suspicion Arousing

Textures and Problems Associated with Vein Re-Opening, Including-Overprinting Parallel Infill, Alteration-Infill Mismatching, Inconsistent Alteration Selvages and Alteration of Alteration

PLATES 16–22

The following section of illustrations has been selected to illustrate suspicion arousing or second order criteria.

The majority of these occur where preexisting channelway structures (usually veins) have been reactivated. The reactivation of planar structures naturally focuses the failure surfaces in a parallel, or semi-parallel, manner to the original fracture. Most commonly, failure occurs along vein margins, or directly up the central zone, and ranges from non-disruptive simple fracture propagation to disruptive brecciation. In most cases, the reactivation will also result in new fracture surfaces within the surrounding host rocks. These are especially concentrated around the fringe zones of the original fracture. Most of the new features are best approached by looking for, and collecting specimens whilst in the field, and this should be the first approach at normal visual scale. Thus at outcrop or drill core scale the first action should be to move away from the centre of mineralisation and seek isolated small veins within uniform host rocks. The objective is always to try and decide which infill assemblages belong to which alteration assemblages.

Fortunately infill assemblages are usually less affected by changes in host rock than alteration assemblages, and in the rare cases of multiple host rocks it quickly becomes apparent that variations in alteration do in fact belong to one mineralising stage and simply reflect the chemistry of different host rocks.

If the observer only has an individual slab/specimen of rock, and is unable to move there are many helpful suspicion arousing circumstances *(see page 105)*.

PLATE 16

SUSPICION AROUSING COMPLEX OVERPRINTING, PARALLEL REACTIVATION, STRUCTURAL SUPERIMPOSITION – VEINS. Ravenswood gold mining district, Queensland, Australia (SYC Pit? Carpentaria Gold).

This specimen has been included to illustrate the common situation of repeated re-opening, and infilling of the same fracture system. It also illustrates just how difficult this can be to decipher. The problem is compounded when each stage contains similar components.

The narrow vein system traverses a slightly "weathered" granitic rock, composed of quartz (grey-white) and feldspar (pink-orange iron-stained) with minor biotite? (rusty brown). The feldspars are slightly argillised and minor acid leaching has occurred via some of the crack systems. These traverse the vein horizontally and link to low-angle fractures (left hand side). No clear alteration halo borders the vein system. A close inspection of the vein indicates that it contains at least three separate components.

The upper-left vein section is noticeable, as it contains very well-developed white quartz crystals growing irregularly from the vein wall, succeeded by pyrite (pale yellow). This region is closely associated with small elongate brown components (mildly oxidised marcasite?). This assemblages can be traced along most of the left hand side of the vein, and then becomes vague, but re-appears in the bottom right hand edge. The bottom right hand occurrence is clearly cut off, by an assemblage of slightly greyer silica associated with arsenopyrite (silver). This can be traced along most of the right hand side of the vein, and is visible again to the right of the first stage assemblage at the top of the plate.

The arsenopyrite-grey quartz stage is in turn cut by another vein, which is less well-defined, and composed of dark brown (sphalerite) crystals, associated with pale buff (siderite?) material, and probably pale yellow pyrite and quartz.

The relationships between these stages are very confused and difficult to decipher. Indeed the author is by no means positive that the above interpretation is totally correct. This serves to illustrate just how effectively veins of similar composition can "hide" as they overprint along the same controlling structural weakness. Once again inspection of more examples is required to confirm initial suspicions. This example also illustrates the need for very careful observation. The vein is gold-bearing, and it is not certain which of the stages is gold-related!

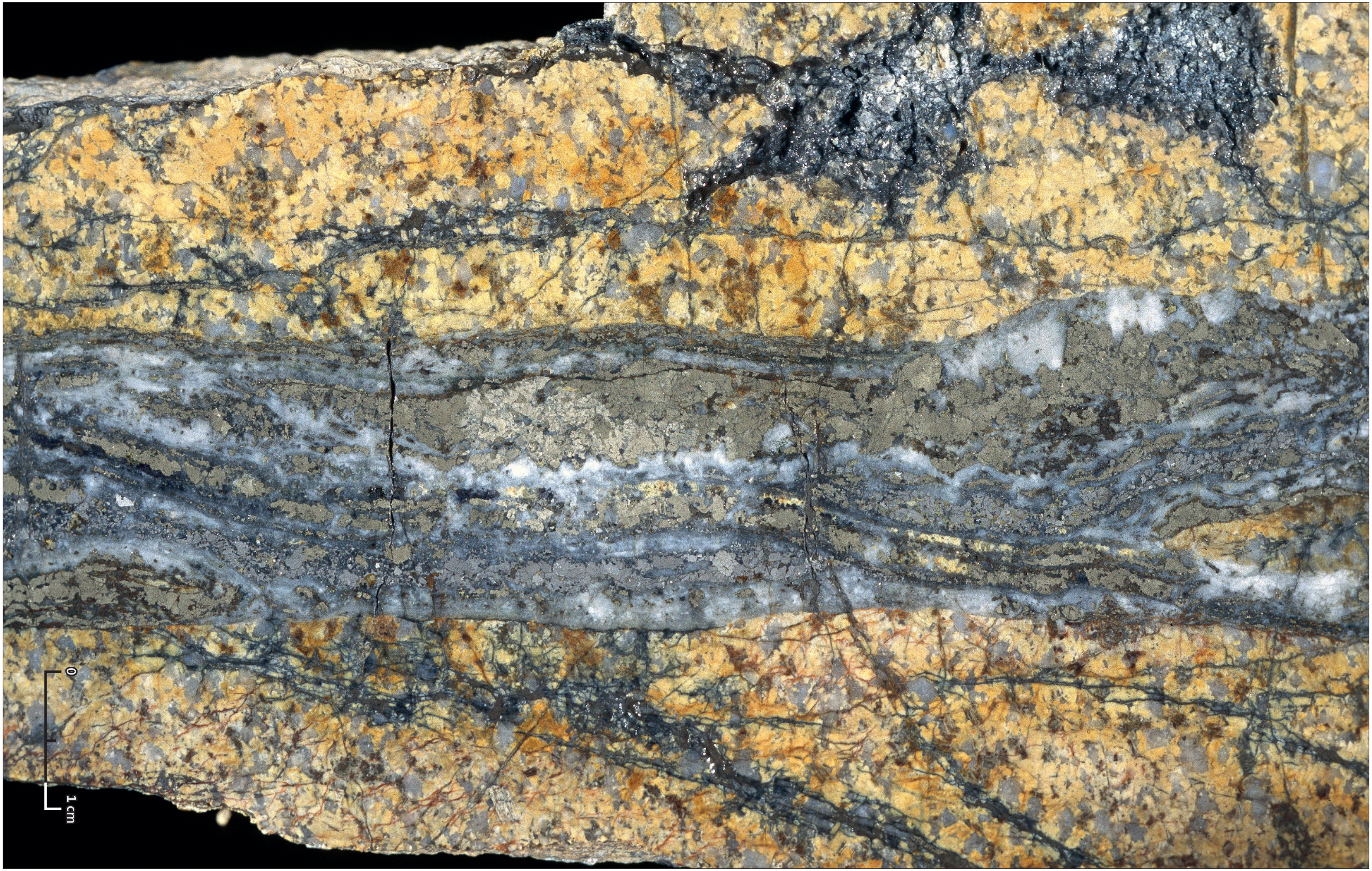
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PLATE 17

SUSPICION AROUSING – COMPLEX OVERPRINTING, PARALLEL REACTIVATION. STRUCTURAL SUPERIMPOSITION – VEINS. Ravenswood gold mining district, Queensland, Australia (Buck Reef – SYC Pit, Carpentaria Gold).

This plate illustrates good second order suspicion arousing criteria which lead the observer to suspect two stages of mineralisation.

The first reaction to the rock is to note the sulphide-rich infill channel, and the attendant dark alteration zone. The host rock is tonalite, and the alteration is biotite. Biotite alteration is conventionally associated with minute veins in porphyry copper systems, but is actually quite widespread in many other magmatic-associated fluid systems (especially in mafic units associated with skarns) and can assume major proportions. The suspicion arousing circumstances relate to the thin veins, which extend at low angles into the host rock. These are composed of pyrite silica? (infill), but have no alteration halo. Given the intensity of the black biotite alteration this is an obvious anomaly.

Close inspection of the infill channel reveals two distinctly different materials. Coarse-grained pyrite crystals form one association with hints of black triangular textures (biotite?) occurring around the centre left region. A second association contains grey-white material (silica) with finer-grained elongate stringy pyrite. A small vein crosscutting the biotite alteration appears to link to this (bottom right).

The relationship between the two infilling stages is difficult to discern. Intuitively, the author suspects the biotite-related material to be early utilising the indirect criterion concerning temperature of deposition. Biotite alteration/infill implies high temperature (>400 °C). This plate is another good example of refracturing along a preexisting channelway, and again emphasizes the need for good understanding of the infill/alteration linking. Infill textures at this scale are commonly overlooked.

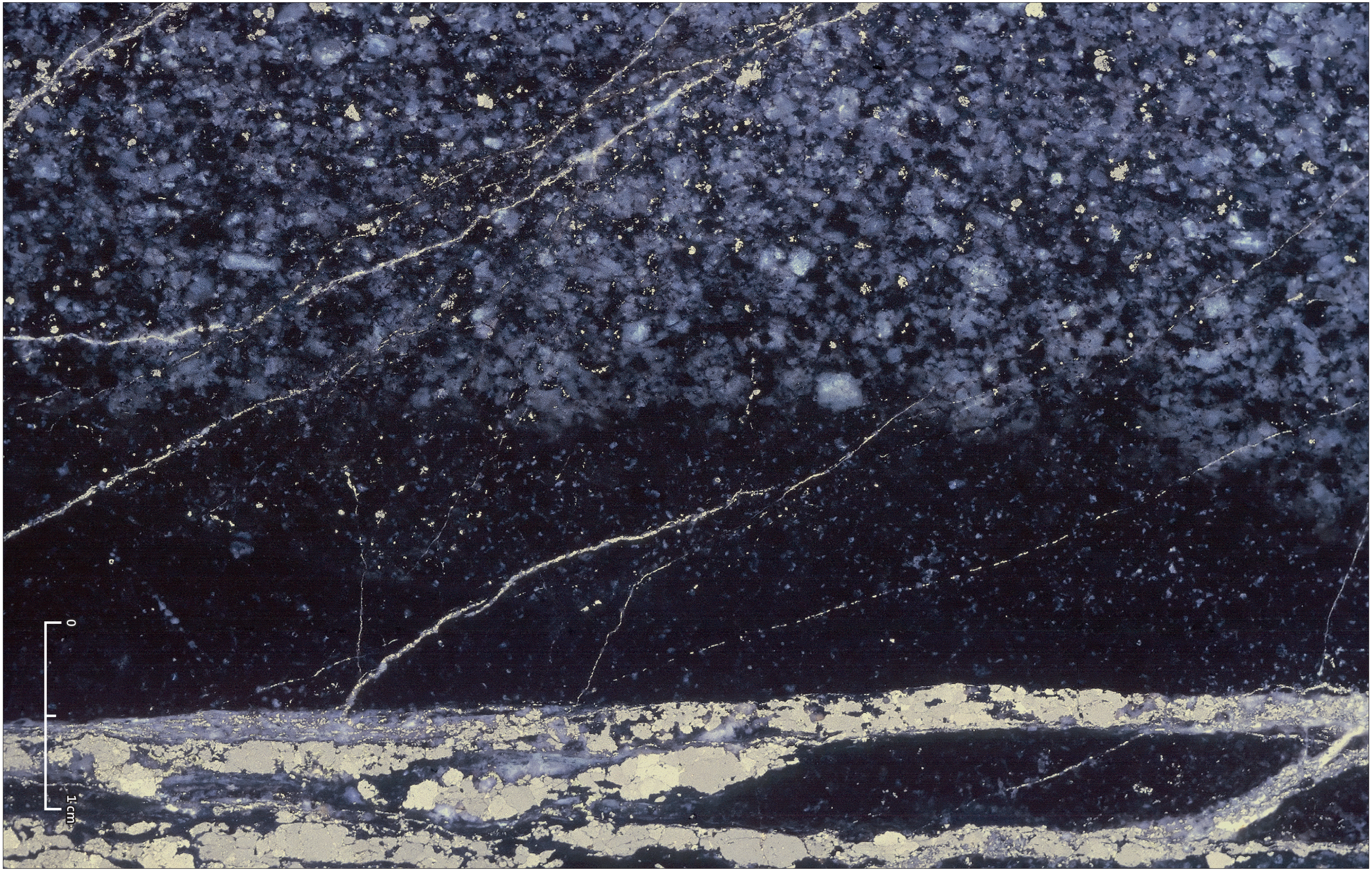
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PLATE 18

SUSPICION AROUSING – COMPLEX OVERPRINTING PARALLEL REACTIVATION, ALTERATION MISMATCH. STRUCTURAL SUPERIMPOSITION – VEINS.
Ravenswood gold mining district, north Queensland, Australia (Nolans Pit, Carpentaria Gold).

This plate has been included for two reasons. Firstly it has many suspicion arousing overprinting criteria, and secondly it will make the point that it is unwise to try and resolve problems in the central regions of overprinting vein systems. Where faced with conflicts of mismatching alteration, or possible crosscutting indications, the observer is advised to move. Observation at the vein margins (crackle zones) or elsewhere, may quickly isolate individual stages and establish infill/alteration pairs.

The plate contains two sulphide veins which contain sphalerite (dark) arsenopyrite (silver) and minor pyrite (pale yellow). The sphalerite has a few silvery flashes due to cleavage reflectance. These appear to be infill minerals, and at first sight the arsenopyrite seems to line the walls of the channel. However, there are some suspicion arousing problems with this seemingly natural arrangement of high-temperature arsenopyrite overprinted by sphalerite. Firstly there is a disturbing lack of arsenopyrite on the side walls of both veins towards the top of the plate, and secondly there are several hints that arsenopyrite may be in tiny veins that cross the sphalerite. The sphalerite occurs in the typical coarse -grained rounded crystal form, and individual grains look to be broken open in the upper section of the right hand vein. There is not enough evidence to be certain, but from other specimens this is indeed the case. The arsenopyrite is later, and a fracture has utilized the sphalerite vein walls to channel in the arsenopyrite -precipitating fluid. The suspicion arousing criteria are giving the correct signal!

The situation regarding alteration pairing becomes even more suspicion arousing. The original rock is tonalite, and the darker rock units prominent on the bottom centre and bottom centre-right zones most closely represent the original rock texture.

The sphalerite andarsenopyrite veins clearly present a problem even if they are regarded as one stage. At most points they seem to relate to the yellowish alteration, but towards the top left a sphalerite infill is in direct contact with dark wall rock and there is no yellow alteration. This alteration mismatch is again suspicion arousing. The yellow (sericite) alteration could just be matched to the arsenopyrite or more likely is related to the thin pale (pyrite) veins. Neither are particularly convincing! Several points can be observed where the dark green mineral in the host rock is partially converted to into the dull waxy yellow green sericite. Even the original rock is not what it seems as the dark green mineral represents chloritised feldspar and chloritised hornblende!

In simple language there are suspicion arousing criteria everywhere. At least three and quite probably four stages are possible. This is the wrong specimen for overprinting resolution, and the observer should stop attempting mission impossible and move to less confusing situations in the immediate vicinity. *This situation is common*. All of this fails to answer the vital question of "Which stage is gold-bearing?"

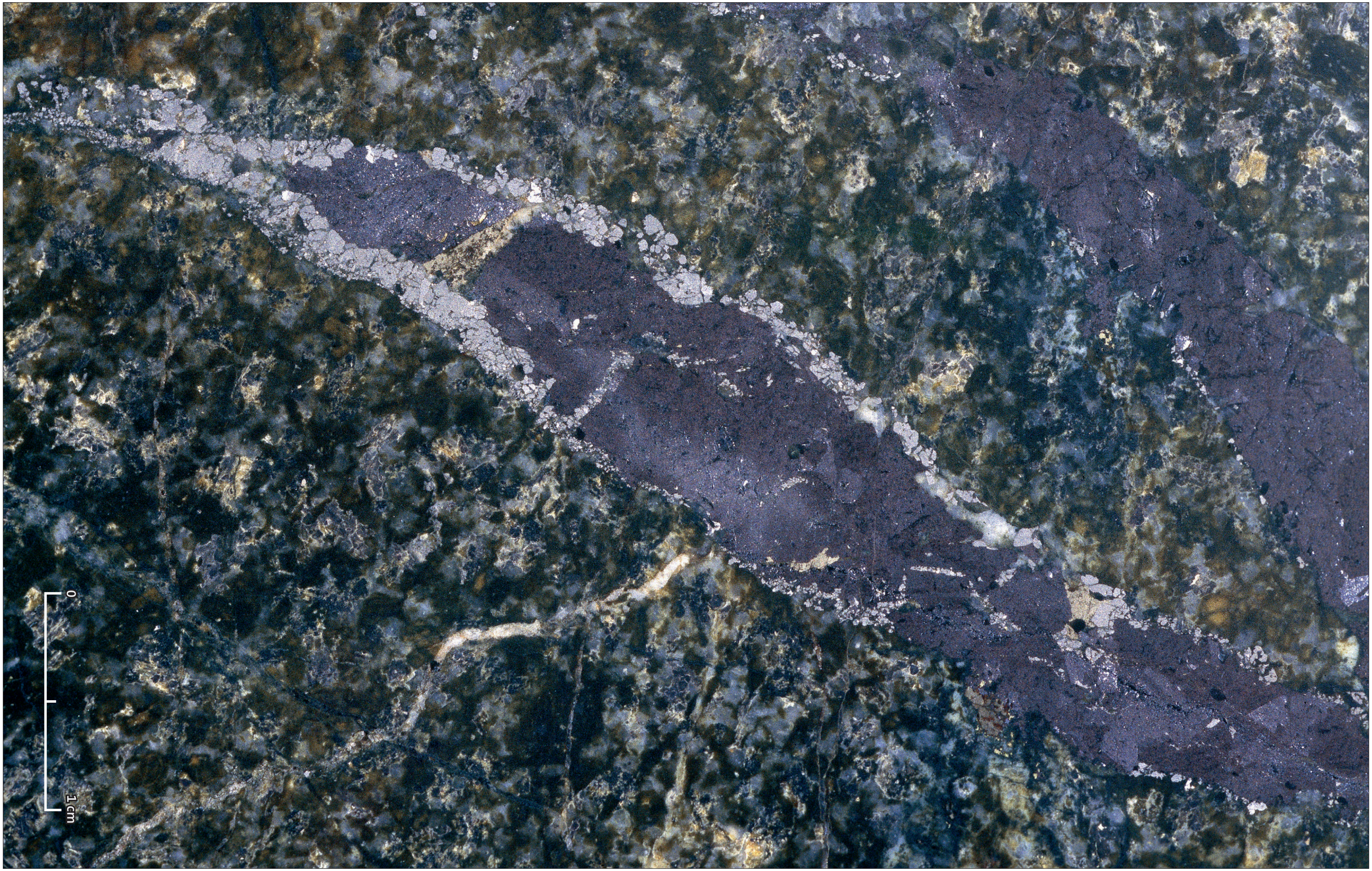
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PLATE 19

SUSPICION AROUSING – INCONSISTENT ALTERATION – COMPLEX OVERPRINTING, PARALLEL REACTIVATION STRUCTURAL SUPERIMPOSITION – VEINS.
Sorensons tin mine, Mount Mowbray district, Queensland, Australia.

This plate has been selected to exhibit a suspicion arousing inconsistent alteration configuration.

The wall rock (bottom left) is granite, composed of feldspar (pink-orange), quartz (grey) and mica (brown). The most obvious feature is a dark vein (top) which contains very clear infill textures. These resolve themselves as dark black-brown equant crystals of cassiterite with well-developed triangular textures of infilling potassium feldspar (pink) and quartz (grey). The alteration pair that links to the infill is clearly the pink potassium feldspar, seen to alter preexisting granite feldspar and possibly quartz (top left).

A problem immediately arises as the sequence from central infill to unaltered granite is obviously different in the top left hand corner to that in the bottom right. This is a classic inconsistent alteration configuration raising the suspicion that two stages are involved. A very careful examination of a series of minute veins paralleling the main infill structure (best seen mid left) composed of quartz, feldspar and rare cassiterite reveals that they actually cut the anomalous grey alteration zone. The grey alteration zone (mid to bottom right) is in fact a previous alteration which has been overprinted by the feldspar stage. It is composed of silica (grey) and sericite (dark grey-brown iron-stained). The infill pairing to this alteration is not visible on this plate, but is confirmed as silica elsewhere on the property. The central infill zone of cassiterite-feldspar quartz actually has two different wall rocks. These are the granite as described above, and the previously altered silica-sericite rock (bottom left). The feldspar alteration within the latter has selectively picked out the sericite on the fringes.

A quartz infill vein (bottom left) without any associated alteration may represent a third stage (untimed).

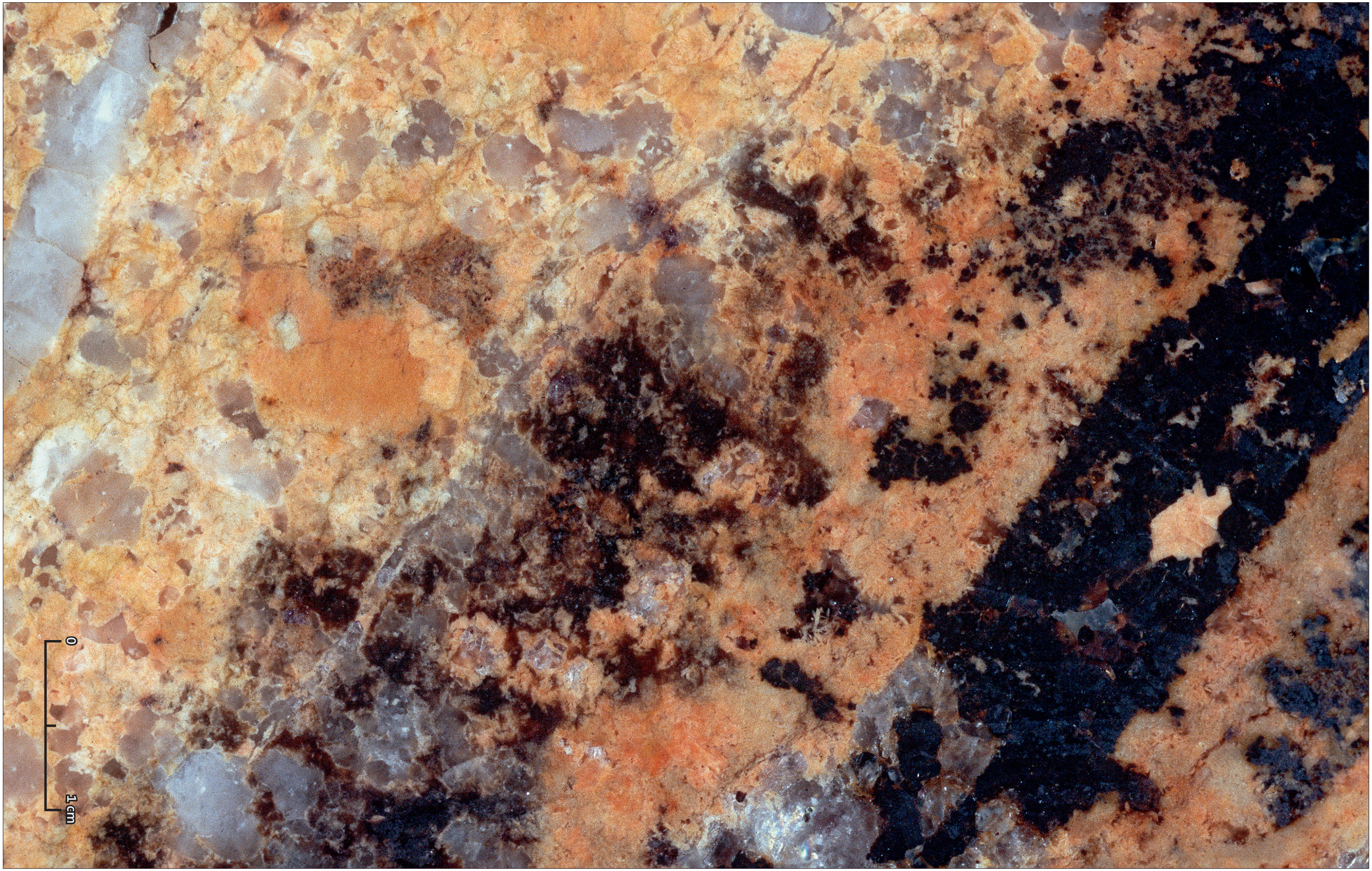
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PLATE 20

SUSPICION AROUSING – INCONSISTENT ALTERATION, COMPLEX OVERPRINTING, ALTERATION OF ALTERATION. STRUCTURAL SUPERIMPOSITION – VEINS.
Albite alteration, Mallee Gap Creek, Cloncurry region, Queensland, Australia. (Specimen provided by P. J. Williams).

This rock has been included as it exhibits three overprinting stages and gives a very good small-scale example of the very common situation where there is an asymmetry which gives the clue to separating an apparently single stage into two.

The wall rock (bottom, centre) is composed of fine-grained albite (grey) with occasional pink (feldspar?), white (quartz), and dark(?) spots. It seems to be a species of altered metasediment.

The most obvious stage is the earliest dark vein (bottom left), which is strikingly overprinted by the white/pink materials (top right). With very careful inspection the dark vein can be divided into two different domains. Centrally located, vague zones, of dark black (amphibole) infill, and surrounding zones of slightly less dark alteration (silica, amphibole?).

The overprinting materials (white/pink) clearly exist as alteration, with the whiter (albite) occurring as an alteration of the host rock. At first sight the white (albite) seems to occur as a fringe to the pink material and an initial interpretation would assess this as a zoned alteration front. However if the observer carefully tracks all around the front, there is a point (centre-top) where the pink actually comes directly into contact with host rock with no intervening white zone. The pink material is a separate stage and occurs as an alteration of the white albite, and probably the altered metasediment.

Separating the infill zones to go with the two feldspars is very difficult, and this is usually the case in feldspathic systems.

The white albite infill is just visible (bottom right) where it is distinguished by a slightly coarser grain size, and a creamy colour in relation to the adjacent alteration. Within the red material the writer cannot differentiate infill from alteration.

The pink-red material which looks like K-feldspar is in fact hematite-albite (P. J. Williams , pers. comm.) which serves to illustrate the problem of identifying pink alteration. The dark grey country rock is also albite and presumably part of the regional sodic alteration assemblage so prevalent in the Cloncurry region.

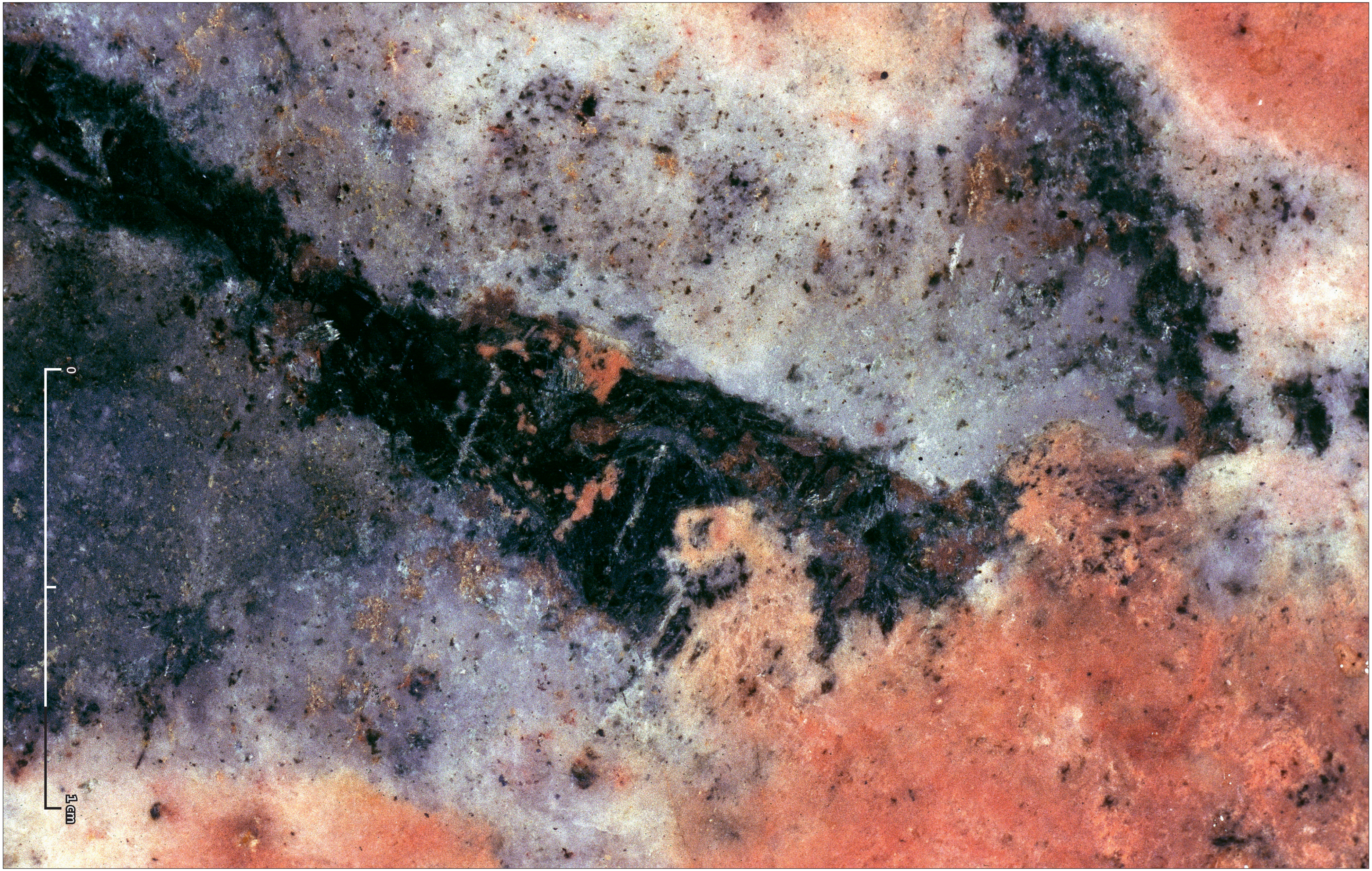
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PLATE 21

SUSPICION AROUSING – INCONSISTENT ALTERATION, ALTERATION OF ALTERATION. STRUCTURAL SUPERIMPOSITION – VEINS. Pegmont (lead, zinc) prospect, Cloncurry region, Queensland, Australia. (Specimen provided by P. J. Williams).

This plate has been selected to illustrate subtle overprinting textures, with good examples of inconsistent alteration halos, and alteration of alteration. It will be of special interest to many readers, as it is part of the stockwork system which underlies the Pegmont lead-zinc prospect.

The host rock(s) are fine-grained metasediment(s) in the sand to silty-sand, size range. These are composed of varying combinations of minerals, pale green-grey (feldspar?) pale grey (quartz) dark black-green (chlorite, biotite?) and glassy red (garnet?).

The most obvious channelway is represented by a dark infill vein structure (centre right). The dark materials (grey quartz and black tourmaline) seem to relate to a very irregular alteration halo which is mostly white, with some irregularly distributed pale yellow components. The actual vein is impersistant, and there are blotches of dark-buff material associated with its apparent termination region in mid plate.

The left hand side exhibits two clearly different alteration styles, one of which trends vertically is mostly pale yellow with white fringes and texturally resembles the alteration described above. It seems to be controlled by minute vertical cracks, and overprints an earlier (grey, grey-white) subhorizontal alteration. This material is K-feldspar, and with close observation it appears to be replaced by the yellow-white material (sericite). This is an example of alteration of alteration, and despite the confusion relating to similar colour tones, establishes that there are two totally distinct alteration styles, and their relative timing.

It is a little difficult to relate the obvious dark infill channel (centre right) to either alteration, and the whole question of fluid channelways and ingress is not resolvable on this rock. Obviously small cracks, and variations in host rock grain size/chemistry have played a major role, with alteration predominating over infill.

This rock has been examined under the microscope and the early K-feldspar assemblages are overprinted by the sericite. Although the situation is not totally clear on the hand specimen, there are ample suspicion arousing circumstances to suggest the presence of two overprinting (and possible more?) systems, selectively utilising similar permeability zones.

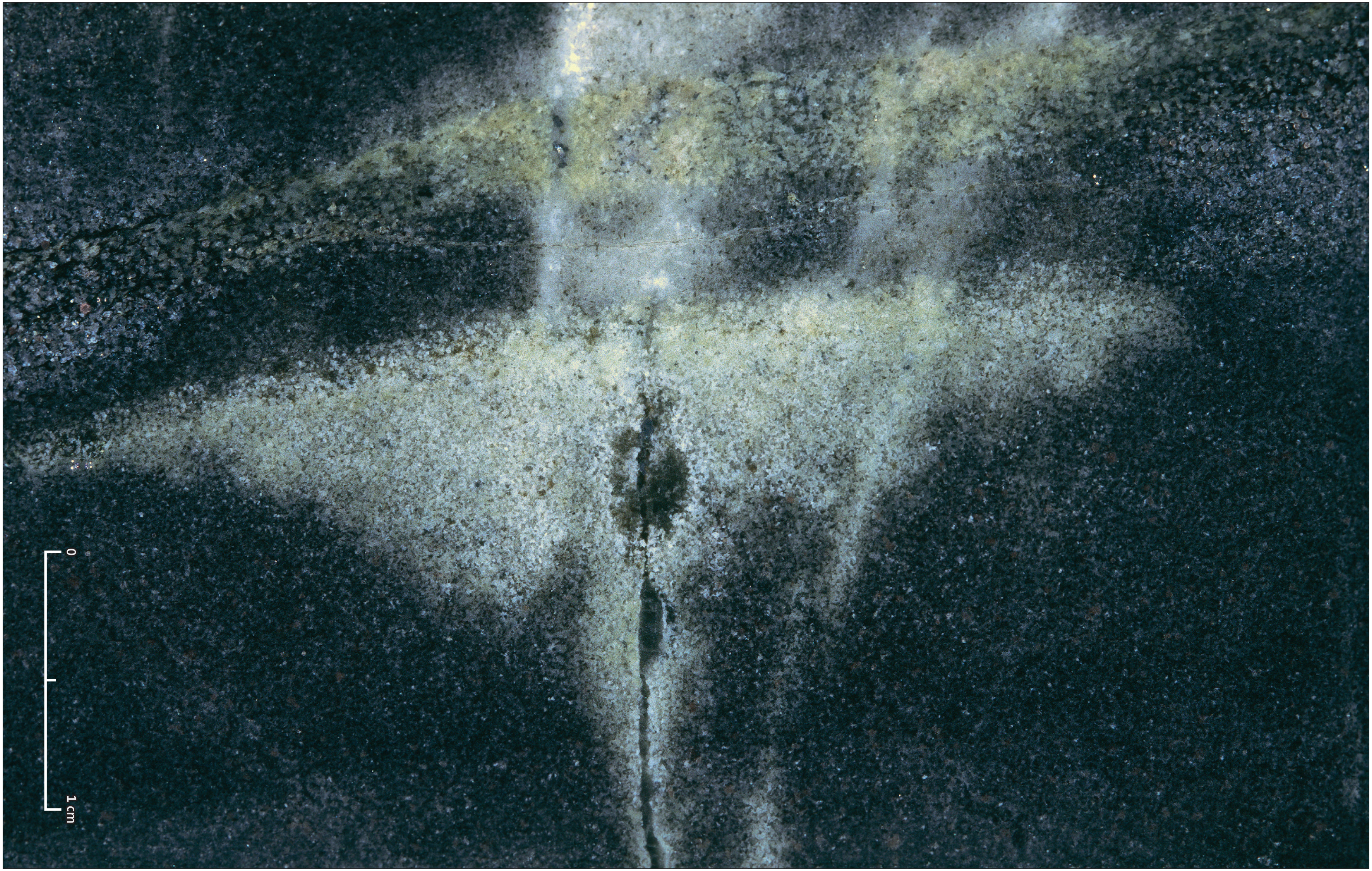
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PLATE 22

SUSPICION AROUSING – ALTERATION OF ALTERATION, LAYER CONTROL

Tick Hill gold mine, Cloncurry region, Queensland, Australia.

This rock has been included to illustrate relatively obscure overprinting which is essentially layer controlled. It also shows a subtle example of alteration of alteration.

The specimen originates from the Tick Hill gold mine, and the pink rock is the gold-bearing unit. It is composed of albite (pale and red pink) and silica (grey). The two major components vary considerably in both format and quantity, but seem to have acquired their configuration via intense ductile deformation. The original nature of the rock is contentious, with opinions ranging from an altered representative of felsic igneous derivation though to sodium-rich lake sediments!

The situation is not made any easier by the overprinting alteration (middle to lower region). This preserves most of the original textures and results in a mixture of pale grey (quartz), pale green-white (scapolite) dark green (chlorite?) together with red brown iron-oxides. The darker zones link together and represent the main channelways controlling fluid entry. A minute pale green crack within the central portion could be an infill channel? Elsewhere on the property, the green scapolite-rich alteration can be seen taking out the entire pink rock on a major layer-controlled front.

The brown iron-oxide which occurs at many points within the plate is also an overprint, and occurs as an alteration of both the pink and green. A small crosscutting vein is well-displayed (left hand side centre) where it crosscuts the green rock and alters the dark? and/or remnant albite (pink) component. This alteration occurs sporadically along the boundary between the two major rock units (pink and green) and from field relationships is not due to weathering.

The top of the plate just covers a change in rock type. This unit is primarily quartz (white grey) and chlorite? (dark green-black) which seems to have been affected by the iron-oxide alteration (brown). A small vein-layer of magnetite (grey-blue) is visible (top left).


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1 cm

8 References

Dong, G., Morrison, G. W., and Jaireth, S., 1995. Quartz textures in epithermal veins, Queensland: classification, origin and implication: Economic Geology, v. 90, p. 1841–1856.

2 FROGS

This photograph is totally irrelevant, but adds a north Queensland flavour depicting two very friendly Townsvillian Bumpy Rocket Frogs. Despite close inspection normal textural terms such as overprinting, structural superimposition, or even sequential infill are considered inappropriate.

The plate comes from the surperb collection of Stephen Richards (Zoology Department of James Cook University). The correct name for these non-publicity seeking beasts is ***Citoria Inermis***.

However, the author is assured that they would prefer to be addressed as Mr and Mrs Frog.