

PETROGRAPHIC NOTES FOR 9 SAMPLES
FROM THE IONISED PROSPECT, about 13 km S of ELOISE

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Sample List

Sample No.	DDH	Depth
(Z1)	IZP001. 17IZ001,	198.4-198.5 m.
(Z2)	IZP002. 17IZ001,	207.2-207.3 m.
(Z3)	IZP003. 17IZ001,	364-364.1 m.
(Z4)	IZP004. 17IZ006,	206.0- 206.16 m.
(Z5)	IZP005. 17IZ006,	213.59-213.69 m.
(Z6)	IZP006. 17IZ006,	213.88-213.98 m.
(Z7)	IZP007. 17IZ006,	226.3-226.4 m.
(Z8)	IZP008. 17IZ004,	136.3-136.4 m.
(Z9)	IZP009. 17IZ004,	168.7-168.8 m.
I have put the number in brackets on the offcut		

Links

Press Ctr Click on the links to bring up the thin section billet photographs. The photographs come up in Microsoft Photo in Windows 10, in a new window, and can be magnified easily, usually by double-clicking, or pressing Ctr and turning the mouse wheel. The linked files are kept in the Photos subfolder which needs to be kept in the same folder as this Word file for the links to work. Microsoft Word and Microsoft Photo can be arranged side-by-side on a wide screen.

IZP001. 17IZ001, 198.4-198.5 m. Graphitic muscovite-biotite-quartz schist with disseminated sphalerite: metamorphosed, low-grade Zn mineralisation.

Thin-section billet photograph. Scale: height of section = 26 mm.

Photomicrograph. Scale: Field width = 3.7 mm. Red-brown sphalerite disseminated in muscovite-biotite-quartz-graphite schist with minor clay-chlorite altered plagioclase.

About half the rock is <0.5-mm flaky muscovite strongly parallel to a foliation that is weakly crenulated. Anhedral <0.3-mm quartz and much subordinate microcline grains tend to be slightly flat between whitemica flakes. Quite heavily chloritised 0.1-0.3-mm biotite flakes (3-4%) are parallel to those of muscovite. Also flaky 10-200 micron graphite (c. 3%) shares the mica foliation. Minor anhedral to roughly tabular 0.2-0.5 mm plagioclase is heavily altered to chlorite and clays. Rare 0.2-mm garnets are colourless in the billet photograph. Granular <0.2-mm brown tourmaline is about 1% of the rock.

Brown Fe-rich sphalerite (2-5%) forms streaky disseminations parallel to the foliation. On the cylindrical surface of the dry core in the sun they are very hard to see under a hand lens, but their pinkish brown colour is obvious when the surface is wet. Sphalerite is the brown material in the billet photograph.

A 0.5-4 mm-thick vein subparallel with the foliation shows pinching and swelling that may be incipient boudinage. It consists mainly of 0.1-0.6 mm anhedral strained quartz with subordinate microcline of similar size, as well as <0.2-mm subhedral pyrite, and more common massive microcrystalline pyrite in thin lenses parallel with the vein. The widest part of the vein contains a few <2-mm subhedral crystals of ?hemimorphite ($\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2 \cdot \text{H}_2\text{O}$) that are partly leached and replaced by earthy material. The crystals have white internal reflections in the billet photograph. Anhedral <0.2-mm brown, Fe-rich sphalerite is only a minor vein mineral.

The vein pyrite is almost certainly a retrograde sulphidation product of peak-metamorphic pyrrhotite.

The finely disseminated graphite and sphalerite suggest that the rock could be a metamorphosed equivalent of some of the carbonaceous-shale/siltstone hosted sphalerite ore at Century (Broadbent et al., 1993). The host rock lacks the very fine octahedral pyrite common at Century but may originally have contained it, though in small enough quantities to be swallowed up as FeS component of sphalerite as the metamorphic temperature rose. The same could have happened to any small amount of siderite that was present at the diagenetic stage.

Though often occurring in contact with graphite, the sphalerite has no more intimate relationship with it than with other minerals. At Century sericite can be intergrown with carbonaceous matter at submicroscopic scale (Broadbent et al., 1993). One would pretty much expect metamorphism to completely destroy that texture.

IZP002. 17IZ001, 207.2-207.3 m. Partly retrograde-altered scapolitic calc-silicate rock

[Thin-section billet photograph](#) 1. Scale: height of section = 26 mm. Failed section.

[Thin-section billet photograph](#) 2. Scale: height of section = 26 mm. This is the actual section described, but finely patterned bubbles have formed locally in the epoxy, mostly under the partly altered clinopyroxene.

The hand specimen consists mainly of grey to pale pink layers on a scale of a cm or more. These contain quite abundant granoblastic scapolite and orthoclase. Other layers are characterised by coarser-grained clinopyroxene and hornblende/actinolite. The section shown in the billet photographs was made of an area where the layers are cut obliquely by a vein of irregular thickness, mainly of quartz and pyrite.

The layers with pale pink granoblastic scapolite and orthoclase are represented in the top-left of the billet photograph. The grey layers are mainly 0.1-0.7 mm granoblastic scapolite whose optics (birefringence = 0.030) suggest a composition with only about 25% marialite component ($3\text{NaAlSi}_3\text{O}_8\cdot\text{NaCl}$). The dominant scapolite components are therefore carbonate and (probably much less) sulphate. The dark laminations in this rock type are enriched in <0.5-mm anhedral to roughly prismatic partly retrograde-actinolised olive hornblende. Some dark laminations also contain quite abundant <0.5-mm anhedral pyrrhotite partly altered retrogressively to <0.2-mm anhedral to cube-shaped pyrite. Here also are minor <0.3-mm subhedral epidote and associated possible metamict allanite (not true if LREE and U are low!). The 5-10 mm-thick, pale, very slightly pinkish felsic layer between the grey felsic layer and the left-most coarse clinopyroxene-hornblende/actinolite layer consists mainly of granoblastic <1-mm orthoclase showing minor strain inversion to microcline. Granular to weakly sphenoidal <0.2-mm titanite forms a few percent of all these layers.

Much of the rest of the thin section consists of coarse material. A couple of interrupted layers are dominated by <5-mm anhedral clinopyroxene that is finely mottled white to olive in Billet photograph 1, but tends to be masked by finely patterned bubbles in Billet photograph 2. The mottled texture is due to retrograde alteration of the clinopyroxene, beginning along cleavages, to a light to dark olive brown, soft sheet silicate. Where alteration is weak to moderate, light-scattering from the refractive index contrast gives the white colour in Billet photograph 1, but heavy alteration reflects the olive colour of the sheet silicate. Widespread anhedral to weakly prismatic <2-mm hornblende (dark grey-green in the billet photographs) is partly retrograde-altered to and overgrown with actinolite (lighter grey-green). Hornblende/actinolite is partly distributed in dark layers, the most prominent of which extends towards the centre of the section from near the bottom-left corner. Associated with it is minor <1-mm anhedral to weakly prismatic scapolite, partly altered to brown material in the photograph (orange in the section) and <1-mm mainly anhedral epidote (clinozoisite). Associated with clinozoisite are traces of <0.1-mm anhedral chalcopyrite.

The pale pinkish buff masses near the top centre in Billet photograph 2 are <6-mm anhedral orthoclase with minor inclusions of fine-grained subhedral actinolite and sphenoidal titanite.

The rather irregular <4 mm-thick grey fissure vein running from the bottom right of the section in Billet photograph 2 consists mainly of <5-mm anhedral quartz. Mainly within it is a <2 mm-wide stringer of partly more-or-less massive <0.3-mm anhedral and subhedral pyrite (brassy cream in the photographs). Associated with pyrite is prominent <1-mm stubby prismatic to anhedral actinolite. A 7-mm hornblende prism near the bottom right in Billet photograph 1 (almost black there) is probably part of the vein assemblage, though it may well have formed by reaction of vein fluid with host rock. Its coarseness suggests that the vein may have been emplaced near a metamorphic peak. Minor <2-mm calcite associated with vein pyrite could be primary or retrograde. Minor fluid inclusions on sealed fractures in the vein quartz are mainly vapour-rich. These are probably retrograde. Tiny ones less obviously fracture-related are hypersaline with a prominent cube-shaped daughter crystal and possibly others. These are more likely to be hot metamorphic fluid, but that could still be retrograde.

The original host rock was probably a dolomitic or ankeritic shale. Scapolite with about 25% marialite indicates that the hot metamorphic fluid contained significant amounts of both CO₂ and NaCl. The CO₂ could have been derived from the rock itself, but the NaCl is probably from evaporites in the sequence that have largely dissolved. When scapolite reacts with retrograde fluid it releases NaCl again.

There isn't much evidence that the clinopyroxene is especially Fe-rich, though if it were, so would the whole-rock assay be. I can't see any Zn mineral in the section. It might be possible to get metamorphosed early Mississippi-Valley style mineralisation in relatives of this rock type that were carbonate-rich.

IZP003. 17IZ001, 364-364.1 m. Quartz-gahnite layer in microcline-biotite-quartz±muscovite gneiss. Retrograde(?) pyrrhotite-chalcopyrite-sphalerite-galena vein carrying host rock fragments.

[Thin-section billet photograph](#). Scale: height of section = 26 mm.

The host rock is a fine-grained microcline gneiss that is clearly lineated when the core is viewed in hand specimen. The section cut parallel to the lineation, consists in the right half of the billet photograph of <5-mm poikiloblastic anhedral multiply albite-pericline-twinned microcline (pale grey in the billet photograph) enclosing varying proportions of granular 0.5-mm quartz, and <0.2-mm red-brown biotite flakes enriched in <7 mm-thick streaky layers (rods?). Prominent minor <2-mm sodic plagioclase is flattened/stretched parallel to the biotite foliation/lineation. The patchy yellow staining visible in the billet photograph is weak retrograde sericitic alteration of plagioclase.

Minor <1-mm locally corroded whitemica flakes, most of them parallel to those of biotite, begin to appear (2-3%) as the quartz-gahnite layer is approached. Here also, disseminated sulphides first occur. These are anhedral <1-mm chalcopyrite surrounded by <0.5-mm galena (near the top-right corner of the photograph). Very minor anhedral <0.5-mm dark red-brown, sphalerite has formed in the same layer. A 3-mm mass of early sphalerite enclosing many euhedral microcline, albite, and anhedral quartz grains has since been leached of Fe, but enough remains to give it an orange colour in the photograph. A 2-mm lenticular mass of fine brownish sheet silicate in this region of the sample is a quite likely alteration product of rare cordierite. A lens of <0.5-mm anhedral to roughly octahedral gahnite occurs within the host rock gneiss a couple of mm from the boundary with the quartz-gahnite layer.

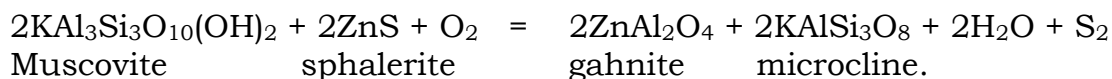
In the 20 mm-thick quartz-gahnite layer, Anhedral 5-8mm quartz (mid grey in the billet photograph) predominates, with a couple of discontinuous c. 3 mm-thick layers of <2-mm roughly octahedral gahnite (dark grey-green) forming about 15% of this layer. Subrounded prismatic c. 50-micron zircons through the coarse-grained quartz and the microcline-rich host rock, accounting for perhaps 100-200 ppm Zr, suggest that this was not vein material or even chert, but metamorphosed clastic sediment. Very minor <0.3-mm stubby prismatic apatite inclusions occur widely in the coarse-grained quartz.

Even the freshest, most euhedral gahnite is rimmed with <2-mm anhedral albite, and locally with <2-mm anhedral to roughly tabular fairly Fe-rich (i. e. optically negative) chlorite, some of which could be a retrograde alteration product of biotite, which rarely envelops gahnite. Gahnite in the left-most layer (nearest the sulphides) is heavily degraded. By far the commonest replacement product of gahnite is randomly oriented 20-micron to 0.8-mm roughly tabular to anhedral whitemica (probably muscovite). Anhedral <0.5-mm Fe-rich sphalerite (red-brown-grey in the billet photograph) is only locally abundant, suggesting that some Zn has been lost, probably as chloride complex in hypersaline retrograde fluid. Pyrrhotite and chalcopyrite locally form <0.2 mm-thick rims on whitemica-altered gahnite. Very minor c. 1-mm stubby prismatic rutile (mid-dark grey in the photograph) associated with altered gahnite is coarse enough to date from a metamorphic peak.

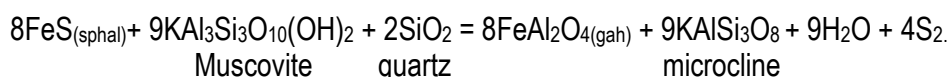
To the left of the quartz-gahnite layer is an irregular sulphide layer of mostly massive pyrrhotite (dull, partly tarnished bronze colour in the billet photograph, along which the core has broken. The massive pyrrhotite encloses fragmental aggregates each of a few quartz grains, some also containing gahnite. The next commonest sulphide is chalcopyrite (bright brassy yellow) which appears to be filling fissures that have opened up in the quartz-gahnite layer. The biggest fissure is filled with a 6-mm mass of several chalcopyrite grains whose brightness in oblique reflected light in the photograph varies with crystal orientation. Minor <1-mm sphalerite partly included in pyrrhotite is dull grey-red-brown in the photograph. This may be a breccia texture that formed because sulphides were more ductile than silicates.

Fluid inclusions, mainly along sealed fractures, are large and abundant in the quartz of the quartz-gahnite layer. Most are aqueous with a small vapour bubble and a small, cube-shaped, isotropic halite daughter crystal (consistent with the quite common albite rims on gahnite. Another common population of otherwise similar-looking fluid inclusions, mostly in their own sealed fractures, lacks daughter crystals.

Given the mineral assemblage here, the most probable reaction controlling the prograde appearance of gahnite is:



Distribution of Fe between gahnite and sphalerite would probably be controlled by the following reaction:



These reactions go to the right at low f_{S_2} . They are different from the reactions controlling gahnite Zn/Fe in the granulite-facies at Broken Hill (O'Brien et al., 2015). Metamorphic conditions here are further from the very high-T region of hercynite-quartz stability than those at Broken Hill, and I would expect the gahnite here to have less hercynite component, that is, higher Zn/Fe than in Broken-Hill rocks with quartz, garnet and sillimanite. The host rocks here are quite rich in Kfeldspar, and muscovite appears only within a cm or so of the quartz-gahnite layer. The enclosing host rocks are closer to Potosi Gneiss than sillimanite gneiss in major-element composition (they would probably give a garnet-biotite-feldspars assemblage on metamorphism in the granulite facies), though they may have a different origin (Kfeldspar alteration of siltstone?) and trace-element composition from the Potosi Gneiss which is probably meta-igneous.

Just how this environment affects the trace-element content of gahnite is not clear, but it may be different from Broken Hill. As an exploration guide from O'Brien et al. (2015), the gahnite occurrences extending north along the "line of lode", that is, Potosi, Round Hill, Flying Doctor, and Globe seem most relevant to finding the "big one". In terms of trace elements, these trend from compositions similar to those in the Broken Hill ore body towards higher Principal Component 2, but not lower Principle Component 1 as the gahnites in the sillimanite gneisses and pegmatite-related gahnites do. Perhaps that is the kind of trend to look for if you were to do some laser probe work on this material.

Retrogression of gahnite is roughly in the opposite direction to the prograde desulphidation reactions, though the fall in T is probably more important than a drop in f_{S_2} . Aqueous chloride-complexed Zn seems to have been a significant retrograde product as well as sphalerite, even taking into account the lower molar volume (24 ml) compared with gahnite (40 ml). It is not clear whether the sulphide layer is retrograde or pre-dates the gahnite. Much of it looks retrograde, but sulphides tend to reequilibrate at various

stages during retrogression. Sphalerite varies from Fe-rich to Fe-poor, but much of it has probably readjusted to retrograde conditions. Gahnite almost certainly formed by desulphidation of sphalerite. The galena and chalcopryrite are unlikely to be here by coincidence, so it seems likely that this was original Cu-Zn-Pb mineralisation.

Gahnite is hard to dissolve. If hand-held XRF gives higher Zn values than ICPMS, then the XRF is probably more accurate.

IZP004. 17IZ006, 206.0- 206.16 m. Garnet-biotite-sillimanite-muscovite-quartz schist.

[Thin-section billet photograph](#). Scale: height of section = 26 mm.

This mercifully homogeneous rock contains 0.3-3 mm subhedral rose-pink, undoubtedly almandine-rich garnet (5%), <10x4-mm knots of <1-mm columnar to fibrous prismatic sillimanite (white in the billet photograph, 35%), and subparallel parallel trains of <2.5-mm tabular muscovite (grey-brown, 15%) and biotite (almost black, 15%) that anastomose between them. Moderately strained granular <1-mm quartz (pale grey, 30%) occurs mostly in and around the sillimanite knots. Very minor fine-grained zircon and apatite are present, some producing pleochroic halos in biotite.

Very minor <0.2-mm roughly tabular ilmenite occurs mostly within biotite, from which it may have exsolved on cooling. The only sulphide seems to be clustered <1-mm anhedral chalcopryrite, enough to indicate slightly anomalous Cu in the section at least.

The original rock was probably a quartz siltstone containing chlorite, illite, and kaolinite. I think the aluminous composition is more likely to primary than a result of alteration. The sillimanite knots could be prograde replacement products of andalusite which probably had abundant quartz inclusions. The fairly low-P trend from andalusite to sillimanite is the usual P-T-t path for the Cloncurry area.

IZP005. 17IZ006, 213.59-213.69 m. Garnet "sandstone" with Ca-amphibole veining.

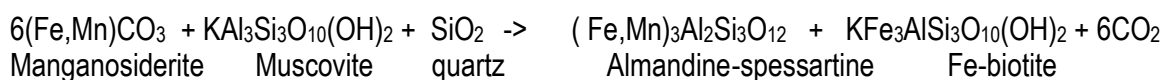
[Thin-section billet photograph](#). Scale: height of section = 26 mm.

More than half the rock is subhedral-euhedral 0.03-1.5-mm brownish pink-red garnet. Filling fine interstices between individual garnet crystals is <1-mm pale actinolite showing late alteration along boundaries with garnet to very dark blue-green hornblende (probably Cl-bearing ferrohastingsite, $(\text{Na,K})\text{Ca}_2(\text{Fe,Mn})^{2+}_4\text{Fe}^{3+}\text{Al}_2\text{Si}_6\text{O}_{22}(\text{OH,F,Cl})_2$). Interstitial quartz varies from rare in the more garnet-rich parts of the section, to several percent near the dark, amphibole-rich veins. Fine-grained interstitial amphibole is partly altered (mainly in the top-right of the photograph) to clays with a yellowish

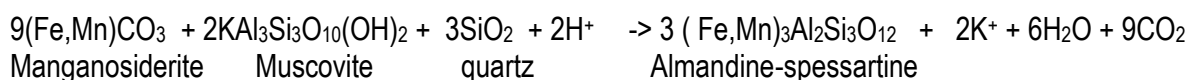
reflection off their basal planes. Very minor interstitial <0.3-mm anhedral interstitial apatite forms patchy <5-mm disseminations.

The dark, <10 mm-thick veins consist mainly of <7-mm anhedral to weakly columnar prismatic dark blue-green ferrohastingsite (dark grey-green in the billet photograph) with subordinate <0.3-mm (rarely 1-mm) anhedral quartz and minor <0.5-mm anhedral to tabular biotite (black in the photograph). The latest, <1 mm-thick veinlet cutting the core axis at a high angle in the left half of the billet photograph is almost monomineralic ferrohastingsite with a crack-seal texture in which amphibole fibres lie at high angles to the vein walls.

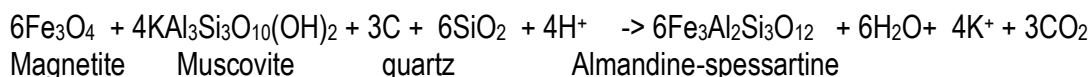
I think the garnet is probably mostly almandine-spessartine, and that some of these garnet sandstones are products of metamorphism of manganosiderite-altered siltstones that can be associated stratigraphically and laterally with mineralisation.



Or if K is mobile and little biotite forms,



Another way near-monomineralic almandine-rich garnet rocks form is by reaction along the stratigraphic contact between BIF and pelite.



That may have happened here. Graphite or methane from the pelite serve to reduce the Fe^{3+} in magnetite.

The actinolite suggests some early low-T Ca phase such as ankerite, dolomite, or calcite was associated with manganosiderite. Its partial conversion to ferrohastingsite suggests partial buffering by Na-Ca-Fe-Cl bearing fluid at high enough T (at least upper greenschist facies?) for ferrohastingsite to be stable. The latter fluid was probably responsible for the veining. Another possibility is that significant Ca was introduced in a fluid.

IZP006. 17IZ006, 213.88-213.98 m. Magnetite-rich Fe formation with quartz, apatite, amphibole, pyrite, pyrosmalite and retrograde carbonates.

[Quarter-core sample photograph](#). Height of core = 28 mm. The left end contains a possible fold in barely visible greenish cream layers (containing carbonate-chlorite altered Ca-amphibole) that form a U shape.

[Thin-section billet photograph](#). Scale: height of section = 26 mm

The bulk of the sample consists of c. 1-mm single crystals and masses of anhedral to weakly octahedral magnetite, <1-mm quartz, and <0.5-mm subhedral prismatic dark blue-green hornblende (probably ferrohastingsite) heavily altered to calcite and chlorite. Anhedral 0.1-mm apatite, about 10% of the rock, is concentrated in lenses to 10 mm thick. Very minor unevenly disseminated <1-mm anhedral to subhedral pyrite may be a late alteration product of magnetite. Weak magnetite-rich and magnetite-poor layering on a scale of a few mm lies at a high angle to the core axis.

The grey-cream area on the left in the billet photograph but the right in the core-sample photograph consists of 0.1-0.5 mm anhedral quartz, 20% to rarely 70% of c. 0.1-mm granular apatite, with minor parallel linear streaks of magnetite and heavily calcite-chlorite altered Ca-amphibole. In three dimensions this material is a fairly thin lens.

The <3.5 mm-thick fissure vein on the right in the billet photograph consists mainly of <4-mm euhedral prismatic to anhedral pyrosmalite (brownish cream). Other minerals are rare clustered <0.2-mm subhedral stubby prismatic to anhedral quartz, pyrite, siderite, and calcite filling interstices between pyrosmalite prisms. Fine-grained pyrite and (?mangano)siderite encrust pyrosmalite, and the remaining space is filled with anhedral curved-crystal calcite.

Pyrosmalite, $(\text{Fe}^{2+}, \text{Mn})_8\text{Si}_6\text{O}_{15}(\text{OH}, \text{Cl})_{10}$, occurs in (Fe,Mn,Cl)-rich environments. It a gangue mineral and also forms daughter crystals in fluid inclusions at the Osborne gold mine. I have seen it now and then in the Eastern Succession. Retrograde fluids here can be strongly saline when loaded with the retrograde breakdown products of scapolite and maybe even Cl-bearing amphiboles.

I can't see any pyroxene here.

IZP007. 17IZ006, 226.3-226.4 m. Staurolite-sillimanite-garnet-biotite-muscovite-quartz-pyrite-chalcopyrite schist. Psammopelite.

[Thin-section billet photograph](#) 1. (Failed section, but note the staurolite cross twin at the bottom left of the staurolite cluster). [Thin-section billet photograph](#) 2. (section described). Scale: height of section = 26 mm.

The pervasive schist texture is due to parallel thin tabular <4-mm muscovite (grey-brown to brownish cream in the billet photographs) and subordinate <3-mm partly chloritised biotite (black). The micas are interleaved with <2-mm lenses of <3.5-mm anhedral quartz (grey-white to light grey-cream), and especially on the right side of Billet photograph 2, with <2 mm-thick lenses of partly kaolinised sillimanite needles (light grey to bright white). The right half of Billet photograph 2 contains about 7% of <1.5-mm subhedral rose-pink garnet (probably almandine-rich).

The orange mineral concentrated with sulphides in the middle of billet photograph 2 is staurolite, $(\text{Fe}^{2+}\text{Mg,Zn})_2\text{Al}_2(\text{Si,Al})_4\text{O}_{20}(\text{O,OH})_4$, which can accommodate up to 13.13% ZnO (55% Zn end-member; Soto & Azanon, 1993). In this sample it forms <5-mm poikiloblastic subhedral stubby

prisms, with clustered <1-mm subhedral pyrite and subordinate anhedral chalcopyrite (brighter and yellower than pyrite in the billet photograph). Garnet is greatly depleted where staurolite is abundant, and sillimanite is present, indicating a much more aluminous composition than the main rock type. Its association in the sample with pyrite and chalcopyrite also suggests that staurolite here may be partly a product of a metamorphic desulphidation reaction of sphalerite with aluminous silicates. The pyrite texture looks like a lower-T one than one would expect in a metamorphic rock of this grade. It is probably retrograde and may replace pyrrhotite. Small masses of fine-grained retrograde chlorite associated with pyrite may be a product of S-deficient retrograde alteration of pyrrhotite.

Very minor zircons can be quite coarse (<0.1-mm) and euhedral, suggesting a psammopelite precursor. Very rare <0.1-mm granular Fe-poor sphalerite is clearly retrograde.

I have described former cross-twinning zincian staurolite at Balcooma that has been replaced by clusters of gahnite during progressive metamorphism. Gahnite is the product when things get too hot for zincian staurolite. But gahnite (with high Zn/Fe) could crystallise in the staurolite P-T stability field where the a_{FeO} was too low for staurolite and the f_{S_2} was too low for sphalerite. In the example of Soto & Azanon (1993), a_{FeO} decreased because of an increase in f_{O_2} and the staurolite broke down to gahnite + hematite. The explanation for the gahnite-bearing IZP003 (17IZ001, 364-364.1 m), only 800 m from here, and which probably never contained staurolite, was low initial a_{FeO} in the host rock.

IZP008. 17IZ004, 136.3-136.4 m. Iron formation cut by post-metamorphic galena-adularia-quartz-dolomite veins with strong pyrite wall-rock alteration.

[Thin-section billet photograph](#). Scale: height of section = 26 mm. Unfortunately, the big grain of galena in this vein is blown-out white in the photograph, apparently due to light reflecting off a cleavage.

The dominant mineral is <1.5-mm roughly octahedral to anhedral magnetite. Prominent sub-mm to cm-sized cavity fillings consist mainly of anhedral quartz, and more rarely biotite or plagioclase (oligoclase). Tabular to anhedral <1-mm biotite (3%) is black in the billet photograph, and olive green in thin section, indicating a low Ti content. Very minor fine-grained chlorite or Fe-rich clay on fractures or replacing magnetite or biotite is probably very late.

The only probable primary layering I can see is in the bottom right, cutting the core axis at a fairly low angle. The layer(?) in the very corner of the section consists of <0.7-mm granoblastic oligoclase, and <0.7-mm roughly tabular biotite with a preferred orientation at a high angle to the layer. Minor magnetite in this layer, and magnetite abutting it tends to form coarse idiomorphic octahedra. Minor <50-micron stubby prismatic apatite is

mostly included in oligoclase. Granoblastic <0.7-mm quartz with the oligoclase is only minor. The lens of fine-grained magnetite and interstitial darker material in the billet photograph is an intergrowth of fine granular magnetite and minor apatite with coarse poikiloblastic quartz.

The other features of the rock are veins and cavity fillings. Probably the earliest vein is the 2-2.5 mm grey quartz vein trending ENE in the billet photograph. It consists of 0.2-1.5 mm granoblastic to anhedral quartz, with minor <0.4-mm anhedral magnetite. Some magnetite is concentrated in thin layers parallel to the vein walls suggesting crack-seal origin. The quartz texture in this vein indicates that it was present during metamorphism. Coarse-grained anhedral quartz (grey in the billet photograph) with minor magnetite and very minor anhedral to prismatic apatite also fill prominent minor <10-mm irregular early cavities lined with coarse magnetite.

A set of NNW-trending sheeted veins and veinlets have exquisitely preserved primary textures indicating, that they post-date the high-grade metamorphism.

The left-most vein in the photograph, along which the core has broken, has a maximum thickness in the section of 2.5 mm. It consists of early 1-mm euhedral rhombs of adularia and interstitial <5-mm galena and dolomite (as indicated by moderate acid resistance). Very minor masses of fine chlorite have replaced some of the galena along its grain boundaries. Very minor <0.2-mm subhedral fairly Fe-rich sphalerite is included in galena in the bottom-left corner of the section in the photograph. The second vein about 5 mm inboard of the first, also contains about 10-15% of coarse galena. The galena, together with <5-mm dolomite fill interstices between <2-mm euhedral quartz prisms that line the vein but are only weakly comb-textured. In this vein all the galena present is visible as light grey crystals in the billet photograph.

The prominent bands of almost massive pyrite are zones of wall-rock alteration of the magnetite-quartz Fe-formation host. The early ENE-trending quartz vein is still present in the pyritic alteration zone on the right of the second vein, but appears to have been displaced about 5 mm to the S and turns up again right at the bottom-left of the section. Note that the magnetite in the early quartz vein has been pyritised where it passes into the pyrite wall-rock alteration zone of the galena-bearing veins. There are small amounts of fine-grained siderite along the boundary between the pyrite alteration zone and the unaltered magnetite.

The <0.5 mm-thick NNW-trending veinlets near the centre of the billet photograph consist of <0.3-mm anhedral grains of siderite with very minor adularia infill. The rose-red staining in the left one of these (and in some thinner, clearly related siderite veinlets) is visible in thin section as submicron films of hematite on grain boundaries, cleavages and fractures in siderite.

I can't see any galena or sphalerite disseminated in the Fe formation. The tiny, weakly yellow-green specular highlights in the billet photograph are off very minor very small, late clay-chlorite flakes. There is no indication of how far the Pb may have come, but its timing is certainly post-metamorphic, probably after D3. It could have come from an ore deposit, or

from feldspars destroyed or altered by post-metamorphic fluids. Generally, albite and Kfeldspar are stable because the fluids have high enough Na^+/H^+ and K^+/H^+ . Red-rock alteration always produces retrograde alteration of minerals like hornblende, and in some cases seems to be in the stability field of pumpellyite-actinolite. Kfeldspar (the most likely carrier of trace amounts of Pb) is pervasively stained by hematite. This could mean that it has adjusted to low-T conditions where Pb is most likely to fractionate into the retrograde fluid phase. Pb could precipitate again if brine carrying it mixed with a S-rich fluid in the presence of magnetite which could buffer the mixed fluid at a relatively high pH. I have not been able to find anything on this subject, but it could mean that the Pb in galena-bearing veins may not necessarily be sourced in an ore deposit.

IZP009. 17IZ004, 168.7-168.8 m. Layered aluminous metasediment containing staurolite, garnet, sillimanite, magnetite, pyrrhotite, biotite, oligoclase, apatite, and quartz.

[Thin-section billet photograph](#). Scale: height of section = 26 mm.

The main rock type in the core sample is the one on the right in the billet photograph, with about 35% of c. 1-mm subhedral garnet (probably almandine-rich) in an aggregate consisting mainly of <1-mm anhedral quartz, subordinate <0.5-mm plagioclase (oligoclase) and close to randomly oriented <0.5-mm roughly tabular biotite (15%). It contains a couple of percent opaque phases: <0.5-mm locally retrograde-pyritised pyrrhotite and anhedral to roughly octahedral magnetite.

The mid-grey body on the far left in the billet photograph is very largely <10-mm anhedral quartz with weakly sutured grain boundaries. Minor <0.5-mm minerals mostly included in the coarse quartz are partly retrograde-pyritised pyrrhotite, and traces of <0.1-mm anhedral chalcopyrite partly included in pyrrhotite, partly retrograde chloritised biotite (black in the photograph), <0.3-mm anhedral retrograde siderite and widely disseminated (minor) <0.1-mm roughly octahedral magnetite that is probably responsible for the grey colour. At the extreme left partly cut off in the photograph is a mostly fine-grained aggregate of magnetite (gun-metal grey), and aggregates of kaolinite and chlorite wholly replacing 20-50 micron grains of higher-T phases. It has a hint of Fe-formation about it, but may be a metamorphosed cherty exhalative horizon like quartz-gahnite rocks. Veils of probably late fluid inclusions on sealed fractures are visible in the quartz in the billet photograph. The N-S set is aqueous with a small vapour bubble, and the E-W set is CO_2 . The NW fracture at the top is not sealed and may be a product of sampling or sample preparation. Whether this coarse quartz body is a conformable layer or a vein is not clear.

The zone (layer?) separating the coarse quartz from the main rock type contains about 15% brown porphyroblasts of <5-mm poikiloblastic staurolite with abundant inclusions of <0.3-mm anhedral oligoclase and widespread minor <50-micron roughly octahedral magnetite, probably giving it the muddy colour compared with staurolite in 17IZ006, 226.3-226.4 m,

which has only quartz inclusions. Garnets like those in the main rock type are similar in grain size and texture, but form only 5-10% of the rock here. Sillimanite forms prominent minor <4-mm clumps of <2-mm columnar prisms that are dull mid-grey in the billet photograph. It seems likely that the sillimanite formed as a prograde metamorphic product of pre-existing andalusite porphyroblasts. A 4-mm dense cluster of <0.2-mm prismatic and granular apatite near the bottom-centre of the staurolite-bearing zone of the photograph is yellowish grey. The light grey to almost white matrix material in this zone is slightly clay-altered <1-mm granoblastic oligoclase. It occurs with randomly to weakly oriented <0.5-mm biotite tablets. Minor fine granular minerals here are magnetite and apatite, but pyrrhotite is hard to find. Coarser, commonly anhedral biotite, black in the billet photograph, is concentrated around many garnet and some staurolite grains. There is no quartz in the bulk of the staurolite-bearing zone.

It would certainly be worth checking with a hand-held XRF to see whether the staurolite-bearing layer/zone contains Zn. It may have soaked up Zn originally from sphalerite once in or associated with the coarse quartz, which could be related to quartz-gahnite layers at Broken Hill and here in IZP003 at 17IZ001, 364-364.1 m. The staurolite-sillimanite bearing layer is much more aluminous than the layers either side, and is quartz-free, so alteration as well as desulphidation would be necessary. It therefore seems most likely that the zones are early compositional layers. The staurolite-bearing layer could have been a more clay-rich bed. The relatively oxidised (magnetite-bearing rather than graphitic) pelitic composition could have resulted from alteration by oxidised oil-field brines (Sverjensky, 1984, 1987) at a lower stratigraphic level than the part of the redoxcline at which metals deposited.

The fine-grained oligoclase-biotite matrix recalls the weakly developed oligoclase-biotite layer in the Fe formation at 136.3-136.4 m 32 m up-hole.

There is no olivine here. (I guess you were on the lookout for fayalite-tephroite as at Cannington).

Zincian staurolite at Broken Hill is in the late retrograde shear zones, but here in the mid-amphibolite facies, below the temperature of muscovite-quartz breakdown, it is prograde.

REFERENCES

BROADBENT G. C., R. E. MYERS, & J. V. WRIGHT (1998). Geology and origin of shale-hosted Zn-Pb-Ag mineralization at the Century deposit, northwest Queensland, Australia. *Econ. Geol.*, **93**, 1264-1294.

SOTO, J. I. & J. M. AZANON (1993). The breakdown of Zn-rich staurolite in a metabasite from the Betic Cordillera (SE Spain). Mineralogical Magazine, **57**, 530-533.

SVERJENSKY, D. A. (1984). Oil-field brines as ore-forming solutions. Econ. Geol., **79**, 23-38.

SVERJENSKY, D. A. (1987). The role of migrating oil-field brines in the formation of sediment-hosted Cu-rich deposits. Econ. Geol., **82**, 1130-1141.

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