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Petrology of Samples from OM Manganese

SCOPE

Thirteen samples associated with manganese mineralisation at Bootu Creek were submitted for petrographic descriptions in order to identify manganese minerals, textures and structures, evidence for hydrothermal alteration, relationships between manganese mineralisation and base-metal mineralisation, and paragenesis.

METHODS

Polished thin sections were prepared from the samples and were examined with a petrographic microscope using both plane-polarised and reflected light. Many manganese minerals are notoriously difficult to identify optically, and in many cases require crystal structural data for positive identification. They tend to form very fine intergrowths of acicular crystals, either manganese oxides alone or mixtures of manganese and iron oxides. It is difficult to measure optical properties for one phase, and the intergrowth tends to mask the properties of individual phases. Therefore, the identifications of some of the oxide phases in these samples are preliminary, and need to be confirmed by compositional or diffraction data.

RESULTS

BCDD0691 3.3 m

Comments

Bootu-style; hangingwall, disseminated Mn in sandstone; increase in Mn towards footwall.

Hand specimen examination

Quartz sandstone with light brown, ferruginous (?goethite) cement. The sandstone is layered, with beds of different grainsize. The ferruginous cement has been partly replaced by dark grey manganese oxides.

Petrographic examination

The sand grains are mostly single crystals of quartz, but there are some quartzite clasts. The grains vary in size from about 0.1 mm to 1 mm, and some grains are elongate and aligned. The ferruginous cement does not polish, but is probably mostly goethite with some admixed clay. It fills the interstices between the quartz grains, but also cuts across quartz grains, forming fine veins or fracture fillings (Fig. 1). It also forms sprays of acicular crystals within quartz veins (Fig. 1A). The ferruginous cement has been partly replaced by very fine grained ?cryptomelane (Fig. 1B) and another unidentified manganese mineral. The unidentified mineral forms sheaves of very fine grained acicular crystals on the margins of the cryptomelane. It is strongly bireflectant and anisotropic and may be lithiophorite. The manganese minerals also form sprays of acicular needles within quartz grains.

While most of the Mn oxides anastomose around quartz grains (Fig. 1), there are some more massive veins that cut across the rock, although generally parallel to the sedimentary layering. These are composed of cryptomelane, the unidentified Mn mineral and also goethite.

The sandstone seems to have been fractured, with fractures running through quartz grains but parallel to bedding. Interstices and fractures were filled with ferruginous cement, and later partly replaced by Mn oxides.

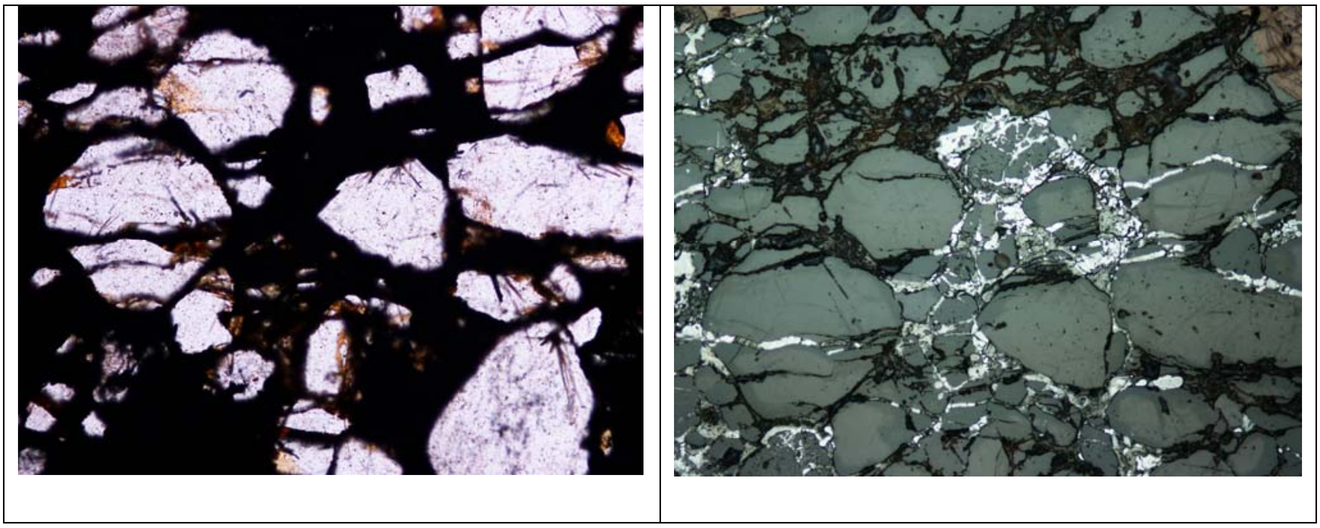

Figure 1. Sample BCDD0691: 3.3m. **A.** Fractures cutting across quartz grains filled with ferruginous cement and ?cryptomelane. Note acicular crystals growing into the quartz clasts. PPL X5 FOV 2.5 mm. **B.** Reflected light image showing poorly polished ferruginous cement and Mn oxides anastomosing around and cutting through quartz grains. PPL X5 FOV 2.5 mm.

BCDD0703 17.2 m

Comments

Bootu-style, massive Mn. psilomelane with minor pyrolusite; hydrothermal replacement after silt.

Hand specimen examination

Porous to vuggy, layered Mn oxides. Layers with a ?brecciated texture are interlayered with more massive bands, and bands with colloform textures. Fragments in brecciated layers are composed of brownish Mn oxides with rims of grey Mn oxides. Some iron oxides and ?silica in voids.

Petrographic examination

Most of the sample is composed of a mat of very fine grained, cloudy-looking ?cryptomelane. The cloudy cryptomelane is cut by veins of clearer colloform cryptomelane and/or coarser pyrolusite and voids (Fig. 2). The cloudy cyptomelane preserves a possible clastic texture composed of fragments about 50 μm across (after ?quartz) and scattered flakes of mica. The brecciated texture visible in hand specimen results from the cross-cutting network of veins of colloform cryptomelane, pyrolusite and voids. There are some bands of poorly polished Mn oxide with rosettes of better polished cryptomelane. Rare crystals of carbonate and gypsum are preserved in some voids.

The earliest phase of Mn mineralisation was the cloudy cryptomelane, followed by colloform cryptomelane, then pyrolusite.

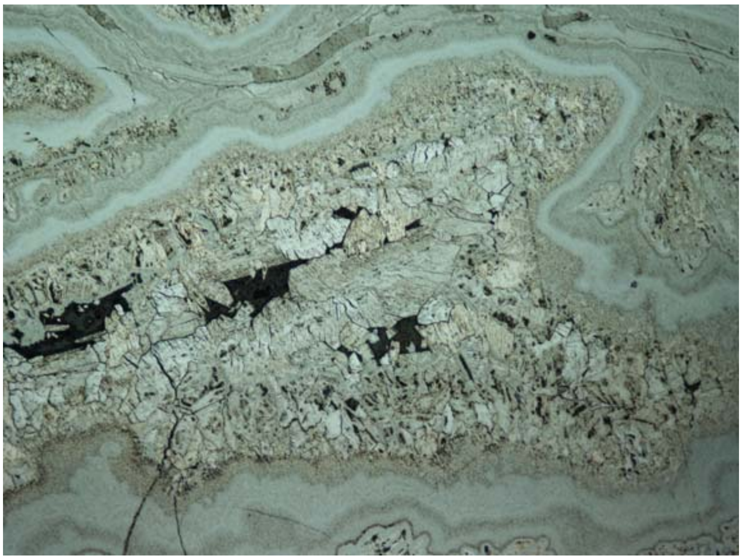

Figure 2. Sample BCDD0703: 17.2m. Void (black) almost filled with medium-grained pyrolusite and surrounded by colloform ?cryptomelane. RL X5 FOV 2.5 mm.

BCDD0691 14.8 m

Comments

Bootu-style, footwall, silt – dolomitic silt; oxidised bleached zone; Mn dendrites.

Hand specimen examination

Cream to pale-brown siltstone with Mn dendrites. There are two sizes of Mn dendrite: coarser ones 2-3 mm across surrounded by a bleached zone, and finer ones about 1 mm across in interstices between the coarser ones. Cross-cutting vuggy veins of Mn oxide with bleached margins and branching dendrites.

Petrographic examination

The rock consists of a matrix of pale-brown, iron-stained clay with quartz grains 50-100 μm across, and scattered flakes of mica. The Mn oxide dendrites are not well polished and therefore cannot be identified petrographically, but appear to infiltrate around the quartz grains of the siltstone matrix. The Mn oxide veins also are not well polished, but there are polished patches of aggregates of very fine grained ?cryptomelane. Veins of chalcedonic quartz branch out from the Mn oxide vein.

P377

Comments

Attack Creek: ironstone after silt-sandstone; Mn staining.

Hand specimen examination

Layered ferruginous sandstone, with layering caused by differences in grainsize. The quartz grains are generally well rounded within a red ferruginous cement, although some layers have a dark cement. The weathered surface of the sample is black, possibly due to Mn staining, but on a cut surface the matrix is mostly red.

Petrographic examination

The rock is a sandstone with clasts from 0.1-1.0 mm across. Most of the clasts are single crystals of quartz, but there are rare clasts of quartzite and chert. Some clasts are elongate but not aligned, and the clasts float within the ferruginous matrix, i.e. they are matrix supported (Fig. 3A). Fractures within the quartz grains are iron stained. Unlike the sandstone from BSDD0691, there is no pervasive fracturing of the quartz grains in this sample, and no acicular crystals growing in the quartz grains. The ferruginous matrix (goethite) 'flows' around the quartz clasts, and shows some colloform banding (Fig. 3B). There is no evidence of Mn mineralisation in this sample.

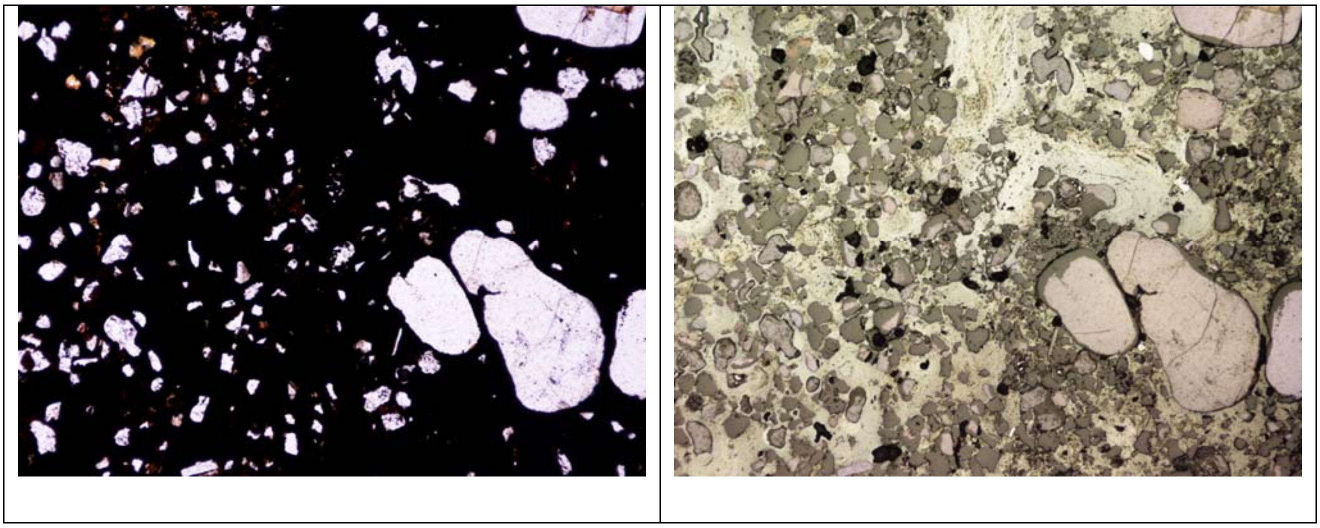

Figure 3. Sample P377. **A.** Quartz grains in ferruginous cement showing matrix-supported fabric and variation in grainsize. PPL X5 FOV 2.5 mm. **B.** Reflected light image showing ferruginous cement 'flowing' around quartz grains. RL X5 FOV 2.5 mm.

P247

Comments

Renner; massive Mn in chert breccia; probably pyrolusite.

Hand specimen examination

Chert breccia with matrix of Mn oxides. The chert fragments are pink to red and surrounded by Mn oxides in massive black matrix or veins. There are vugs lined with fine quartz crystals.

Petrographic examination

The chert fragments have very fine grained ferruginous inclusions that give them the red-pink colour (Fig. 4A). The fragments are chert with veins of cherty quartz. There appears to be a relict texture within the chert defining rounded fragments, suggesting that it is a replaced sedimentary rock, possibly carbonate (Fig. 4a). There are some patches and veins of coarser grained saccharoidal quartz.

The chert is cut by a network of Mn oxide veins. Mats of very fine crystals of ?cryptomelane make up the larger areas of Mn oxide, and these in turn are cut by finer veins of ?cryptomelane and fine pyrolusite. Some of the cryptomelane is colloform banded (Fig 4B). The finer veins tend to be pyrolusite where they cut chert and cryptomelane where they cut earlier cryptomelane. Some voids have elongate crystals of pyrolusite growing into them, with the crystals aligned perpendicular to the edge of the void (Fig. 4B).

If the rock was originally a carbonate sedimentary rock, it was replaced by chert before being invaded by coarse 'veins' of massive ?cryptomelane, giving rise to a chert breccia, then invaded by finer veins of colloform ?cryptomelane and pyrolusite.

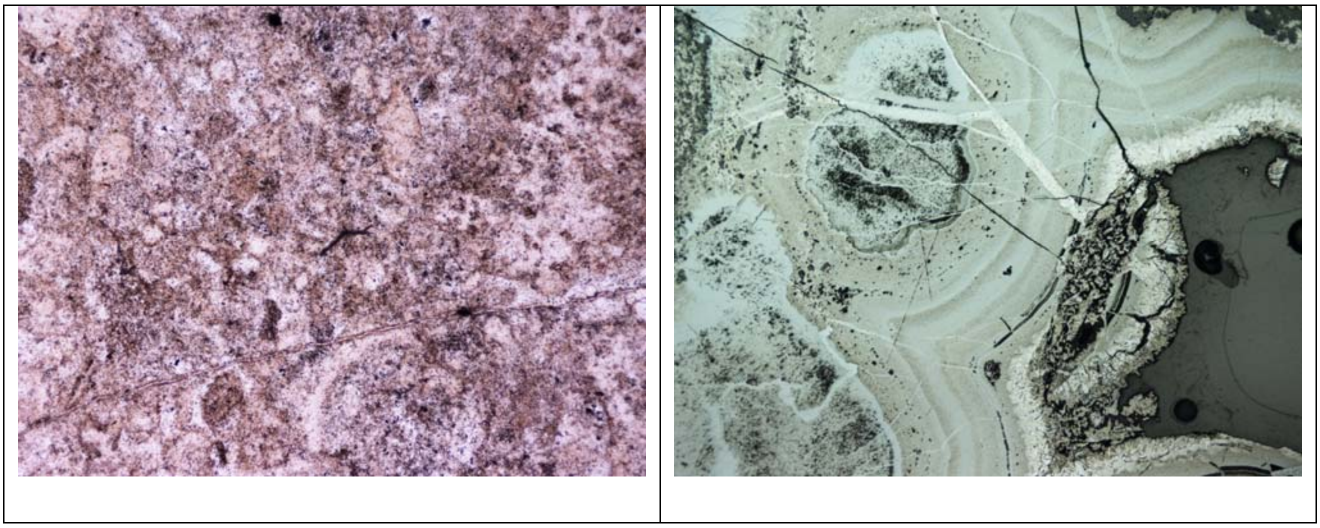

Figure 4. Sample P247. **A.** Possible relict clastic texture in red-pink chert. PPL X5 FOV 2.5 mm. **B.** Reflected light image showing colloform ?cryptomelane around a vug (dark grey). The cryptomelane is cut by finer veins of pyrolusite (brightest) and there is also some pyrolusite on the margin of the vug. RL X5 FOV 2.5 mm.

P291

Comments

Renner; dolomite; base to Mn mineralised dissolution zone.

Hand specimen examination

Layered ferruginous quartz sandstone, with layering (~1 cm scale) due to variations in grainsize and amount of ferruginous matrix. Clasts are mostly quartz, but there are also some lithic (ferruginous siltstone) clasts. There are discontinuous lenses about 0.5 mm wide of black Mn oxides parallel to the sedimentary layering.

Petrographic examination

The quartz clasts are poorly sorted and moderately rounded (Fig. 5). Some grains are elongate but not aligned with the sedimentary layering. Grainsizes range from 0.1-0.5 mm. Some quartz grains have syntaxial quartz overgrowths (quartz cement), but it is not clear if this grew during the current depositional cycle. Other clasts are chert, 'limonite', ferruginous siltstone and claystone, muscovite and tourmaline. The clasts are generally grain supported and are in a cement of ferruginous carbonate. The carbonate is iron stained, but most of the oxide grains in the sample are poorly polished (Fig. 5B), so whether the iron staining is due to hematite or goethite is not clear.

The lenses of Mn oxide are also poorly polished. They seem to be made of aggregates of very fine grains, possibly cryptomelane, and are associated with fine layer-parallel carbonate veins (Fig. 5B). There is also a coarse-grained vein of carbonate + gypsum + quartz about 1 mm wide perpendicular to the layering, and smaller veins of fine-grained quartz perpendicular to layering. The layer-parallel Mn oxide and fine carbonate veins cut across the fine quartz veins (Fig. 5). The fine carbonate veins also cut the coarser carbonate-gypsum vein, although the Mn oxide veins are not seen cutting the carbonate-gypsum vein.

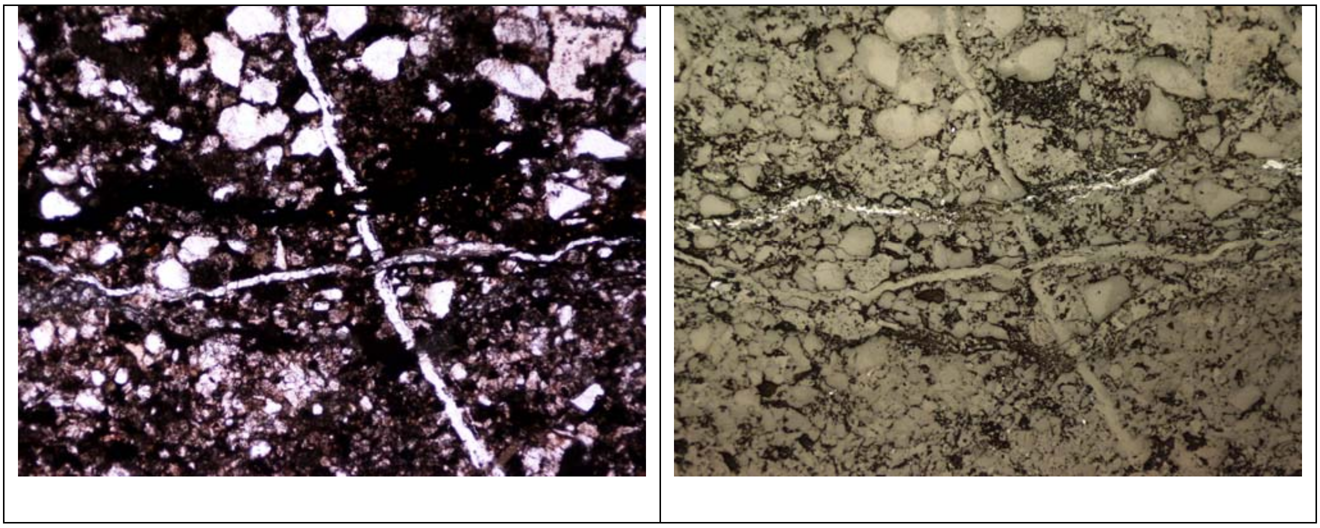

Figure 5. Sample P291. **A.** Quartz grains in ferruginous carbonate cement. Veins of fine quartz (vertical) are cut by veins of Mn oxide (black) and carbonate (white). PPL X5 FOV 2.5 mm. **B.** Reflected light image of the same view as A showing the Mn oxide veins. RL X5 FOV 2.5 mm.

P290

Comments

Renner; Mn mineralised dissolution zone.

Hand specimen examination

Iron stained vuggy Mn oxides. The Mn oxides form grey-black masses about 5 mm across, with rims of silica. Iron staining is mostly on the surface of the sample and in vugs. Vugs are also lined with silica.

Petrographic examination

Most of the Mn oxide masses are very poorly polished and cannot be identified from their optical properties. They appear to be composed of masses of very fine crystals, and red internal reflections indicate that there may be Fe oxides as well as Mn oxides in the masses. The masses are rimmed by quartz growing into vugs (Fig. 6). The quartz is very fine grained on the margins of the Mn oxide, but increases to microplumose grains ~0.1 x 0.05 mm across within vugs (Fig. 6B). There is some iron staining on the edges of the quartz in the vugs. Veins of fine-grained quartz, and some comb-textured quartz cut across the Mn oxide masses.

The Mn oxide masses are cut by veins of coarse-grained pyrolusite (Fig. 6A), although the pyrolusite does not cut the quartz rims. Some of the quartz veins that cut the Mn oxide masses also cut the pyrolusite veins, so the quartz is later than the pyrolusite. Quartz rims may be intergrown with colloform ?cryptomelane, and some of the pyrolusite has been altered to cryptomelane. Iron oxides (?goethite) may also be intergrown with the quartz rims.

The massive Mn(Fe) oxides were first to form and were later cut by veins of pyrolusite. The quartz, cryptomelane and goethite were the last phases to form, mostly filling vugs in the massive Mn oxides.

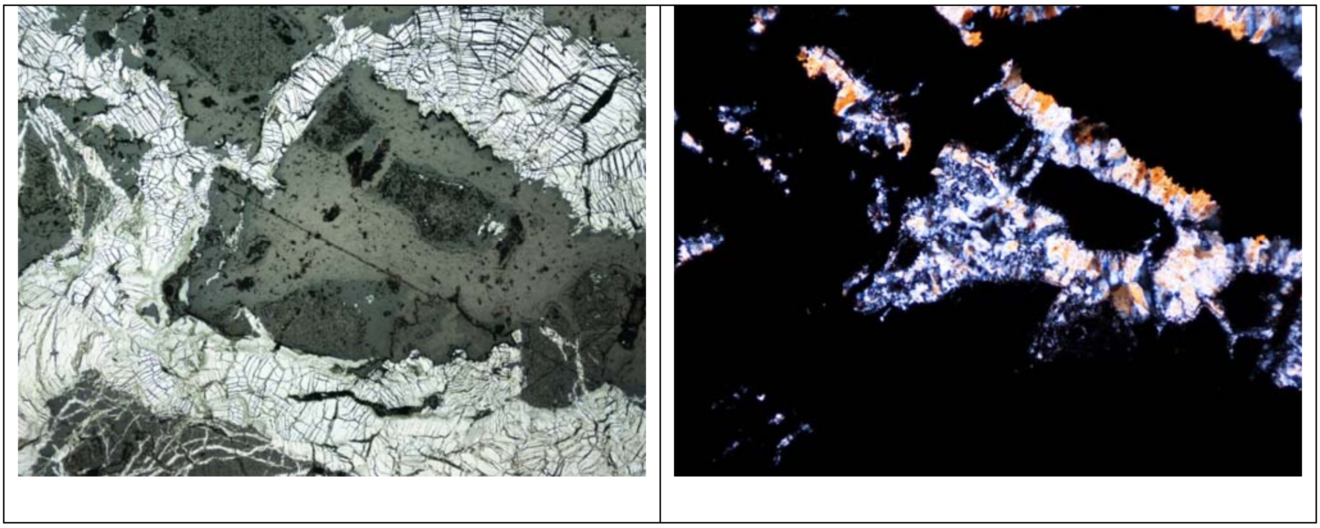

Figure 6. Sample P290. **A.** Vug (dark grey) surrounded by quartz (mid-grey) and cut by veins of coarse pyrolusite. RL X5 FOV 2.5 mm. **B.** Image of the same view as A in cross-polarised light showing microplumose quartz crystals. XPOL X5 FOV 2.5 mm.

P181

Comments

Bootu; massive Mn after stromatolitic dolomite.

Hand specimen examination

Iron stained, vuggy Mn oxides, with possible relict stromatolites. The stromatolites consist of massive columns separated by columns composed of thin layers of Mn oxides about 0.5 mm thick alternating with fenestrae. The Mn oxides form grey-black masses about 5 mm across, with rims of black Mn oxides. Some fenestrae contain iron-stained silica.

Petrographic examination

There are relicts of ferruginous siltstone, with quartz grains up to 100 μm across set in a ferruginous ?clayey matrix. These relicts are almost opaque and do not polish well, so not much information can be derived from them. The rest of the sample consists of ?siltstone that has been replaced by Mn oxides. This part of the sample is opaque, but quartz clasts up to 100 μm across and flakes of mica, largely replaced by ?cryptomelane, can be seen in reflected light (Fig. 7). They are set in a mat of very fine grained Mn oxides, most likely cryptomelane although the crystals are too fine to determine optical properties. The cryptomelane masses are bordered by rims of inclusion-free colloform ?cryptomelane about 50 mμ wide, and cut by veins of the same material (Fig. 7). Some veins are layered, with a core of fine ?cryptomelane, then a rim of another strongly bireflectant and anisotropic mineral (possibly lithiophorite: the same mineral as in BCDD0691 3.3 m), then an outer rim of clear fine-grained ?cryptomelane (Fig. 7B). In the stromatolitic portion of the sample, voids are lined by acicular crystals of ?cryptomelane. Some voids are filled with iron-stained gypsum, or quartz.

The rock is a ferruginous siltstone, perhaps dolomitic, that has been replaced by Mn oxides. Stromatolitic structures are preserved in parts of the sample.

Figure 7. Sample P181. **A.** Very fine grained quartz grains surrounded by ?cryptomelane and cut by veins of clearer ?cryptomelane (brightest). RL X10 FOV 1.25 mm. **B.** Vug lined with an unidentified Mn mineral and clear ?cryptomelane. RL X20 FOV 0.625 mm.

P262

Comments

Renner; massive Mn in chert breccia, probably pyrolusite.

Hand specimen examination

Chert breccia, composed of fragments of red to pink chert in a matrix of vuggy grey to black Mn oxides. Some vugs are lined with fine silica, and there are some botryoidal textures in the Mn oxides. The Mn oxides have rims and veins of silvery Mn oxides.

Petrographic examination

Fragments of quartz, quartzite and ferruginous chert in Mn oxides. In fact, most of the opaque 'Mn oxides' consist of quartz with very fine inclusions of ?goethite and ?cryptomelane. There are some larger patches of cryptomelane within the quartz-rich fragments, and a network of veins of pyrolusite + cryptomelane (Fig. 8). In places, the veins coalesce to form masses with a core of cryptomelane + pyrolusite, then a rim of coarse-grained pyrolusite, then more cryptomelane and a rim of colloform ?quartz and goethite. Vugs have linings of very fine-grained cryptomelane, ?quartz and goethite (Fig. 8).

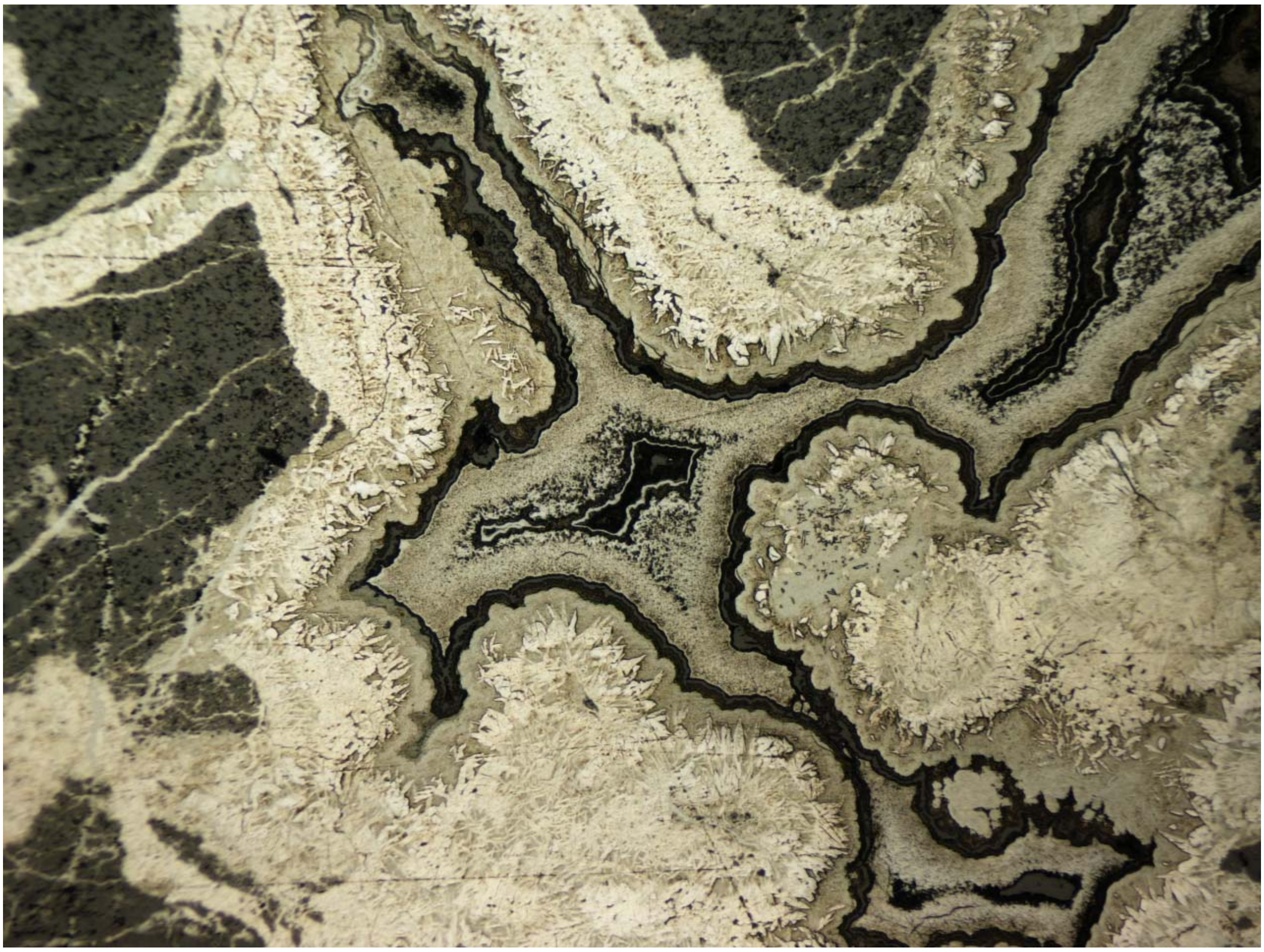

Figure 8. Sample P262. Masses of poorly polished Mn oxides (e.g. left of image) with rims comprising ?cryptomelane + coarser pyrolusite (white); cloudy cryptomelane (brownish); quartz (dark-grey to black); then more cryptomelane with goethite and quartz (brown-grey). RL X5 FOV 2.5 mm.

P231

Comments

Renner; massive Mn in chert breccia, probably pyrolusite.

Hand specimen examination

Vuggy manganese-rich chert breccia. The fragments are mostly chert partly replaced by Mn oxides so that they appear dark grey. Some coarser quartz is present around vugs, and there are some fine quartz veins.

Petrographic examination

Fragments of ferruginous chert largely replaced by ?cryptomelane. There is much less quartz than in P262, but this sample seems to have a similar origin. The fragments are mostly mats of very fine grained cryptomelane, but have rims of coarser pyrolusite. There are also some more extensive areas and veins of pyrolusite. Vugs have been filled with quartz crystals 50-100 μm across (Fig. 9), and there is also some gypsum in the vugs. Some of the cryptomelane is colloform to botryoidal, and may be intergrown with goethite.

The sequence of events is therefore: replacement of ferruginous chert by cryptomelane; rims and veins of coarser pyrolusite; filling of voids by more cryptomelane, goethite and quartz, with rare gypsum.

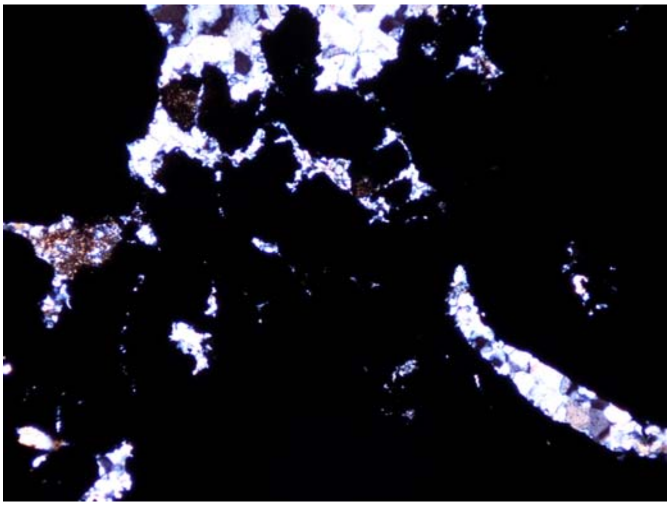

Figure 9. Sample P231. Quartz crystals 50-100 μm across filling vugs in Mn oxides. XPOL X5 FOV 2.5 mm.

BCRC0933A

Comments

Bootu; black silt? N.B. The RC chip samples were BCRC0933A & B and BCRC0954. There was no sample for BCRC0947.

Hand specimen examination

Chips of pale green to pink siltstone.

Petrographic examination

The sample is a dolomitic siltstone or marl. It has a very fine foliation due to alignment of mica flakes. It is composed of quartz grains with ~50 μm average grain diameter, muscovite flakes, carbonate and ?clay, with some iron staining. One sample has more iron staining and is pink. There are no sulphides in this sample.

BCRC0933B

Comments

Bootu; black silt; sulphide-bearing sub-unit 5-20 m below the Mn ore zone; py-cpy-gn; Cu 1.2% @ 59 m.

Hand specimen examination

Chips of black shale and more massive grey siltstone

Petrographic examination

The black shale is composed of silt-sized (~50 μm) quartz grains, muscovite flakes, carbonate and very fine black organic matter + clay. It is dusted with very fine crystals of pyrite, 2-10 μm across. There is coarser grained chalcopyrite in fine veins or single grains ~10 x 60 μm across (Fig. 10). The chalcopyrite veins are parallel to the shale fissility and contain very fine pyrite, surrounded by chalcopyrite, and also some bornite. There are some veins of folded carbonate perpendicular to the lamination.

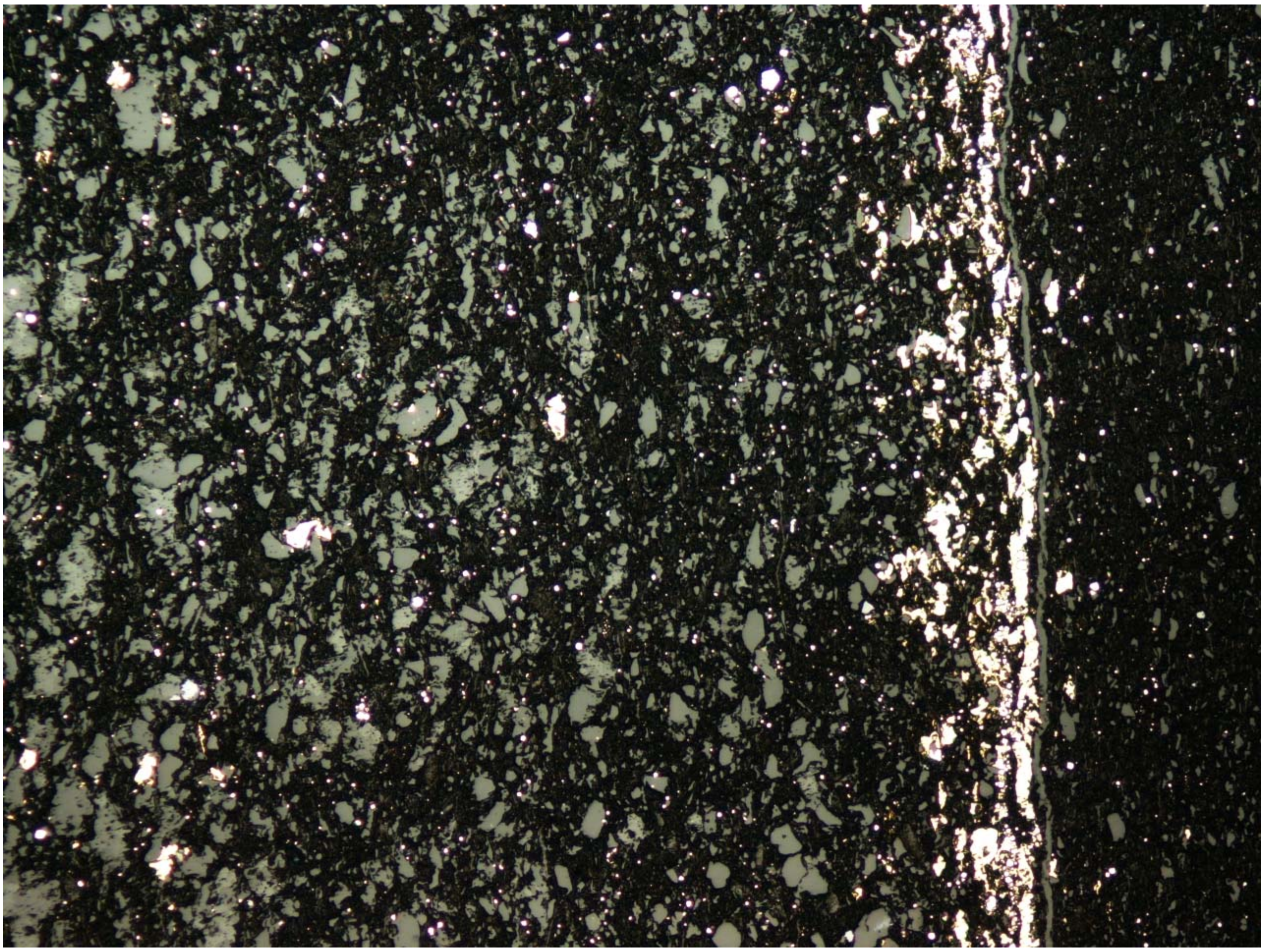

Figure 10. Sample BCRC0933B. Vein of fine chalcopyrite in pyritic black shale/siltstone. RL X10 FOV 1.25 mm.

The chips of more massive grey siltstone are in fact mostly carbonate. The black shale has been invaded and replaced by veins of very fine (50 μm) cloudy carbonate. With more extensive replacement, wisps of black organic matter occur within very fine grained carbonate. The shale remnants have very fine pyrite crystals, whereas veinlets of coarser chalcopyrite, with some pyrite and bornite, are associated with the carbonate veins (Fig. 11).

There are also some veins of coarser grained sparry carbonate (0.2-0.3 mm grainsize). Rare galena is present in the sparry carbonate.

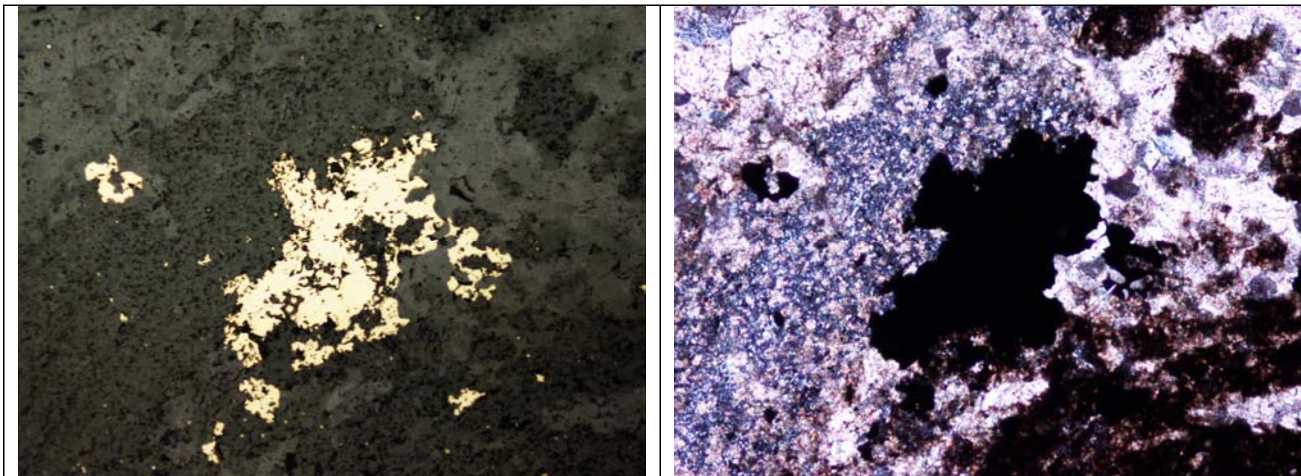

Figure 11. Sample BCRC0933B. **A.** Chalcopyrite in carbonate that has replaced black shale/siltstone. RL X10 FOV 1.25 mm. **B.** The same view as A showing carbonate matrix and veins. XPOL X10 FOV 1.25 mm.

BCRC0954

Comments

Bootu; black silt; sulphide-bearing sub-unit 5-20 m below the Mn ore zone; py-cpy-gn; Cu 0.4% @ 100 m.

Hand specimen examination

Chips of black shale and more massive grey siltstone – very similar to BCRC0933B. Some chips have veins of coarser sparry carbonate.

Petrographic examination

The black shale is composed of silt-sized (~50 μm) quartz grains, muscovite flakes, carbonate and very fine black organic matter + clay. It is dusted with very fine crystals of pyrite, 2-10 μm across. There is some slightly coarser grained chalcopyrite that is associated with discontinuous carbonate veins.

The shale has been invaded and replaced by even-grained, 0.1 mm brownish carbonate. The carbonate contains scattered fine-grained pyrite and coarser chalcopyrite (Fig. 12A). The chalcopyrite grows around the pyrite, producing inclusions of pyrite in chalcopyrite.

Coarser veins of clearer carbonate and quartz-carbonate cut the carbonated shale, and contain coarse crystals of chalcopyrite and pyrobitumen (Fig. 12B).

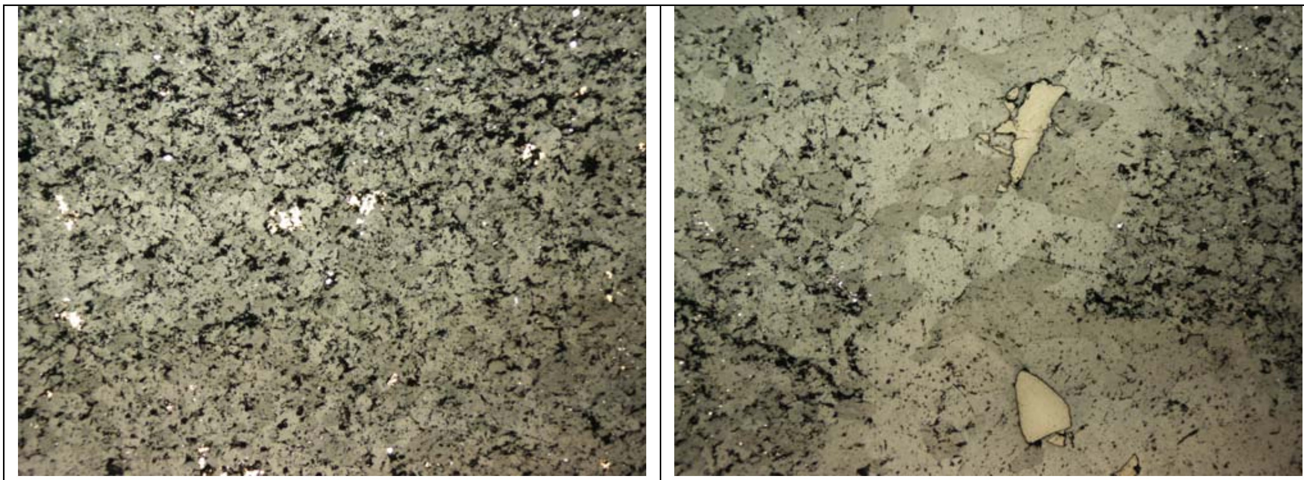

Figure 12. Sample BCRC0954. **A.** Chalcopyrite and very fine grained pyrite in carbonate that has replaced black shale/siltstone. RL X5 FOV 2.5 mm. **B.** Vein of coarser sparry carbonate with pyrobitumen (high relief). RL X5 FOV 2.5 mm.

In both BCRC0933B and BCRC0954 pyritic black shale has been replaced by fine-grained carbonate, and the growth of chalcopyrite is associated with this replacement. Later coarse-grained sparry carbonate veins introduced some galena and chalcopyrite, and may be related to the production of oil as they contain pyrobitumen. There is no obvious relationship between replacement of the black shale by carbonate, and replacement of sandstones and siltstones by manganese oxides.

SUMMARY

In many of the samples the manganese mineralogy is difficult to determine by optical examination. This is because many samples are composed of mats of very fine acicular crystals. These mats may be composed of one or more different minerals, but they are too fine grained to determine their optical properties. Pyrolusite forms coarser crystals and can be more confidently identified.

In most samples, the manganese minerals are predominantly ?cryptomelane and pyrolusite, with possible lithiophorite in a few samples. The first-formed manganese mineral is ?cryptomelane, which replaces quartz and chert fragments, and may be intergrown with iron oxides or hydroxides. Many samples have a ferruginous cement or iron-staining that predates manganese mineralisation, although it is not clear whether the iron mineralisation is related to the manganese mineralisation. Pyrolusite commonly forms coarser grained veins cutting the fine-grained mats, but is older than colloform cryptomelane, goethite and quartz that fill or partly fill vugs. Diffraction studies and/or compositional information would be required to confirm the identities of some of the manganese minerals described in this report.