PETROGRAPHIC REPORT

5 Samples from the McArthur Basin, Northern Territory, Australia

MMG Ltd. (Melbourne)

(attn. Louis Cohalan)

9/2/2016

Dr Anthony J Crawford
A & A Crawford Geological Research Consultants

493 Tinderbox Rd, Hobart,
TAS, Australia 7054
Phone: 61-3-62293831
E-mail: PetrographEx@tasmanet.com.au
Mobile 0487186659

Petrographic Summary Report

Introduction

This report includes petrographic descriptions of five thin sections sampled from drillcore from MMG's zinc exploration program in the McArthur Basin (see table below). Three of these samples were selected to provide more detail on the matrix to a distinctive dolomite breccia at the basal contact of the Barney Creek Formation with the underlying Teena Dolomite. A fourth sample from the same interval is a dark, pyritic mudstone in which the nature and occurrence of the sulfides was of interest. The fifth sample required documentation of the sulfides in a very fine-grained, strongly pyritic sediment.

The two latter samples requiring diagnosis of sulfides were prepared as polished thin sections, and the remainder as standard, covered thin sections. The thin sections and offcuts were scanned, to provide some visual context beyond the 4-8 photo-micrographs provided. No background geological information or maps were provided for this exercise, so the thin section descriptions are essentially 'stand alone'.

Sample number	Hole ID	Depth	thin section type
D1391382	NB16DD025	299.4 m	Transmitted light: black matrix breccia
D1391385	NB16DD027	184.0 m	Polished thin section: pyritic black shale
D1391395	NB16DD027	583.3 m	Transmitted light: black matrix breccia
D1391396	NB16DD028	295.9 m	Transmitted light: black matrix breccia
D1897074	NB16DD020	317.2 m	Polished thin section: richly pyritic siltstone with 2.8% Zn

Petrographic Summary

The dolomite breccias are essentially identical in most respects, having angular to subrounded clasts to several cm (but usually much finer-grained) of cream dolomite in a notably darker grey matrix. The pale clasts show patchy grainsize changes in the recrystallized dolomite, and most contains sparse, fine-grained and quite fresh pyrite (as identified with a hand-held LED torch in these unpolished thin sections). In all samples, the matrix dolomite is variably charged with diverse clasts, most of which are sub-mm, rounded dolomite, but also present are platy, dark intraclasts of a dolomitic shale rarely longer than 1mm, and occasional clasts of very fine-grained siliceous

sedimentary rocks. The matrix dolomite hosting these clasts is generally relatively fine-grained, with the dark tint due to both a film of Mn-Fe oxy-hydroxides on crystal margins, and also occasional dark, extremely fine-grained, amorphous material (also Mn-Fe oxy-hydroxides and possibly some clayey and/or carbonaceous material) in interstitial sites. Where stylolites transect the rock, and around some of the larger pale dolomite fragments, pressure solution of the darker dolomite has led to concentrations of dark Mn-Fe oxy-hydroxides up to 1mm thick along stylolitic partings. The dark dolomite matrix contains only sparse, or no, fine-grained pyrite compared to the pale dolomite fragments in these breccias, and it is considered likely that the dark films and interstitial material may be due to dissolution, oxidation and local redistribution of the minor interstitial pyrite through the original matrix. If the dark amorphous material filling stylolites is a Mn-Fe oxy-hydroxide, it requires that the inferred Mn is contributed from the host carbonates.

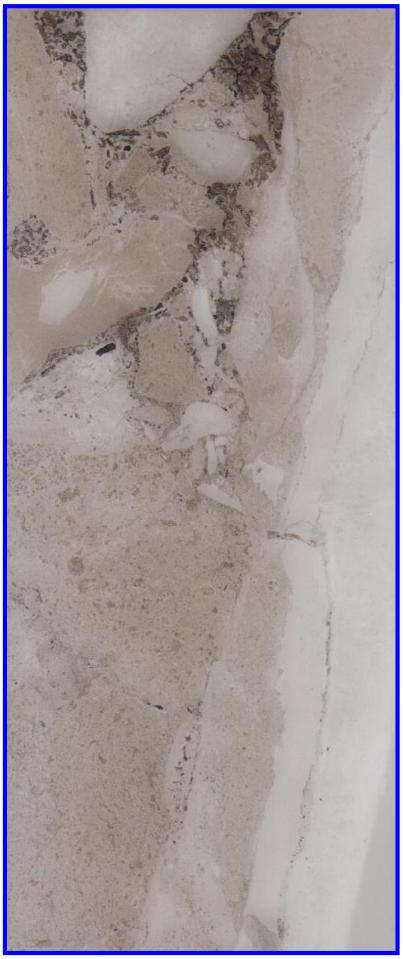
The carbonaceous and pyritic mudstone (D1391385) lacks a pronounced fissility but shows well defined laminar bedding, best defined by streams of mainly sub-10micron crystals of pyrite. Most pyrite crystals are euhedral and inclusion-free, but more rounded and irregular crystals are not uncommon. No unambiguous framboidal pyrite grains or aggregates were noted, and this sample is entirely devoid of sphalerite. It contains common, tatty carbonaceous material that is probably not crystalline enough to be referred to as graphite.

The sample from NB16DD020 @ 317.2m is a fine-grained, strongly sulfidic sedimentary rock composed of around 50% pyrite, which is present as sub-10micron euhedral crystals intergrown with dark irresolvable material that is probably dominated by dolomitic carbonate. The rock also contains a few modal% of sphalerite, present as irregular, small patches rarely larger than 50microns across, and usually enclosing a number of pyrite euhedra. This presumably (originally) impermeable, fine-grained, largely chemical sedimentary rock is inferred to have crystallized from a dolomitic carbonate rich in framboidal pyrite. The pyrite recrystallized to the present euhedral grains during late diagenetic alteration. Sphalerite is considered to be entirely ‘indigenous’, since there is no evidence that it was introduced by basinal brines, and both pyrite and sphalerite show a single ‘generation’ in terms of paragenesis and texture (compare with the 2-3 generations of sphalerite and pyrite in broadly similar rocks described from the Barney Creek Formation in Crawford (report to MMG, October 2016).

SAMPLE NUMBER D1391382 Hole NB16DD025@299.4m

SUMMARY

A dolomitic breccia with evidence for repeated episodes of fracturing and sealing by recrystallization of the dolomite. Paler dolomitic fragments carry sparse, tiny pyrite grains, with generally clean grain boundaries on the dolomite crystals. In contrast, the darker dolomite matrix carries occasional rounded clasts of quartz and very fine-grained siliceous sedimentary rocks, lacks the fine-grained pyrite and shows a film-like dark coating on the dolomite grains. Much darker small fragments occur locally in the breccia matrix and appear to include rip-up clasts of shaly dolomite. These contain common dark, amorphous Mn-Fe oxy-hydroxides that has been locally concentrated in stylolites.



SAMPLE NUMBER D1391382 Hole NB16DD025@299.4m

THIN SECTION DESCRIPTION

This is a dolomitic breccia of probable sedimentary origin, with angular fragments of paler dolomite in a dark grey dolomitic matrix. The presence of 'fragments within fragments' attests to multiple episodes of fracturing, veining and recrystallization. The paler dolomite fragments are fine-grained, with a patchy and irregular grainsize distribution that suggest it has recrystallized. Larger fragments show occasional dark partings with significant grainsize changes either side, but these lack a stylolitic appearance and may be original bedding variations. The pale fragments contain sparsely disseminated very fine-grained pyrite that includes both euhedral 'cubic' crystals and anhedral, more 'rounded' grains, and they also contain occasional sub-mm patches of an almost colourless, ultrafine-grained clay or smectite of diagenetic origin.

The darker grey matrix dolomite differs from the paler clasts in showing:

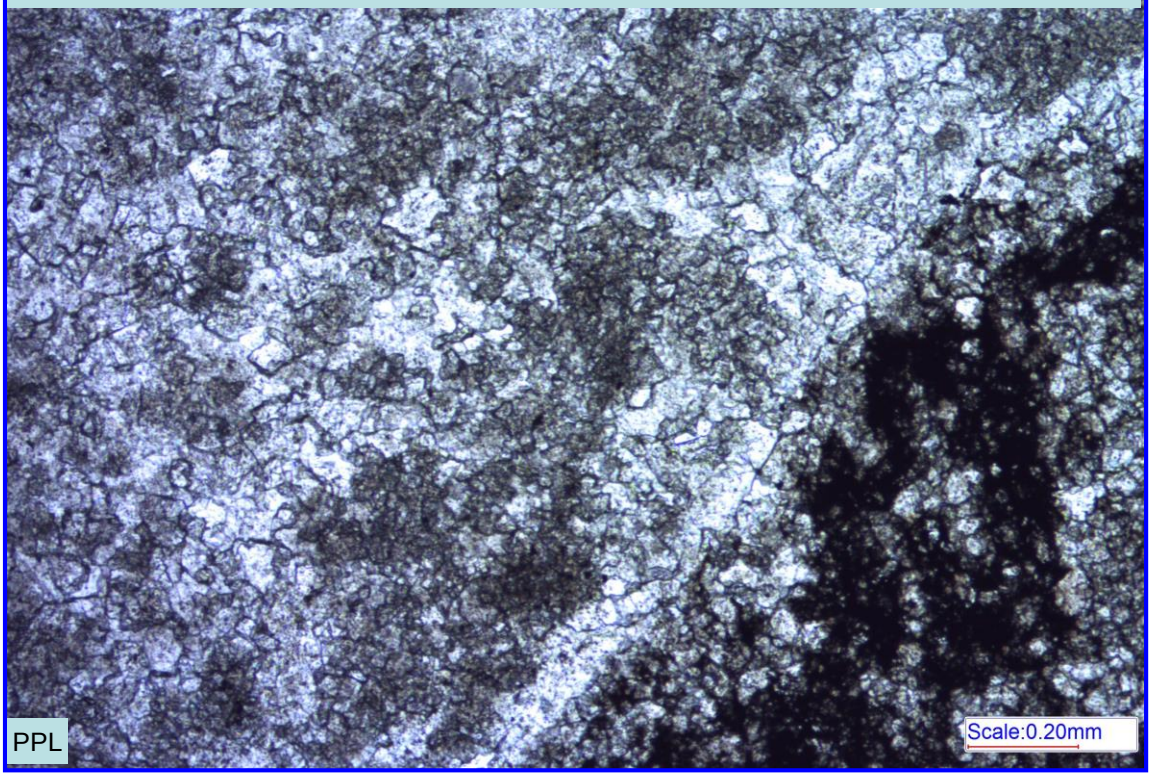
(i) occasional, smaller (mm-sized), brown-black fragments, some of which have platy shapes like rip-up clasts, others of which are quite irregular shapes. Where stylolites cut these darker domains, the stylolites and adjacent fine-grained carbonate show concentrations of extremely fine-grained, black, amorphous material that is probably a Mn-Fe oxy-hydroxide.

(ii) rare, small, rounded clasts of quartz and fine-grained siliceous(?) sedimentary rocks,

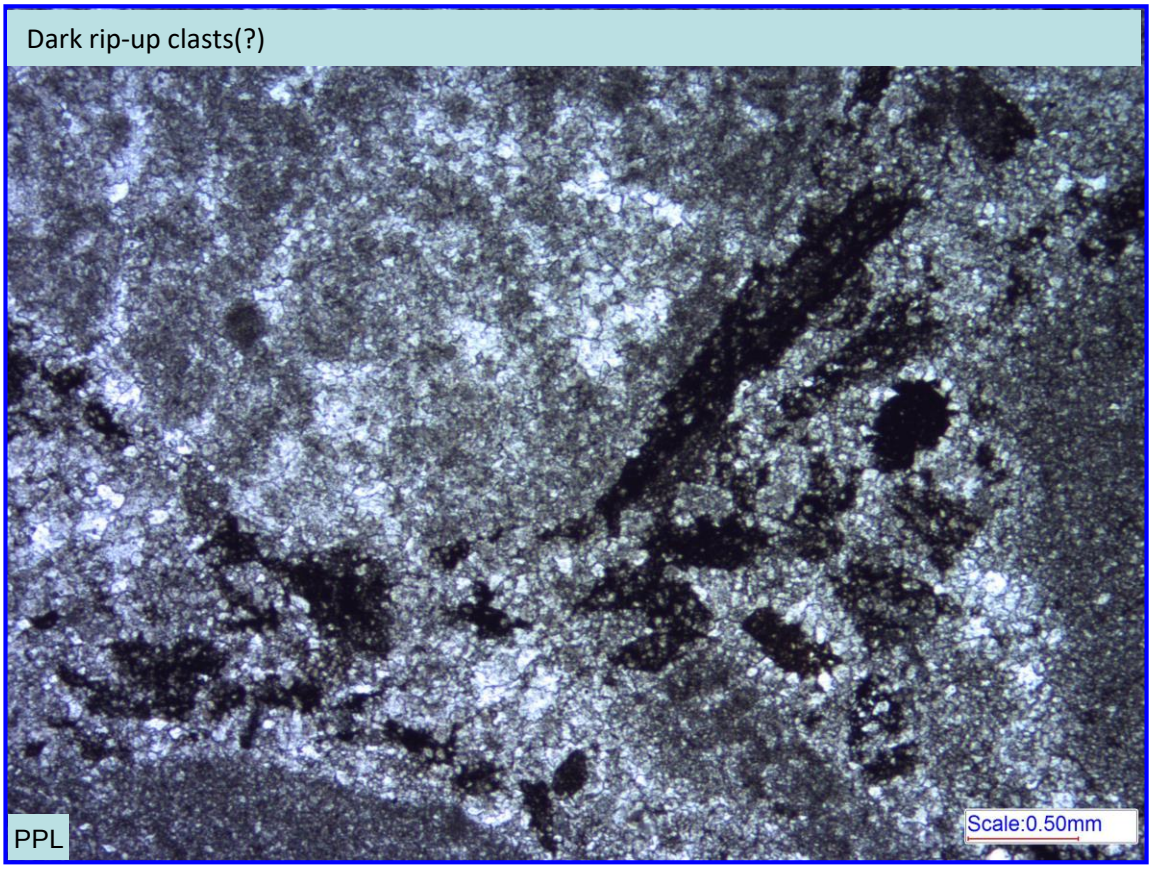
(iii) a dark, irresolvable 'coating' on almost every fine-grained crystal of dolomite, and far less fine-grained pyrite than present in the pale fragments.

SAMPLE NUMBER D1391382 Hole NB16DD025@299.4m

Margin of pale dolomitic fragment (left) showing diffuse concentration of Mn-Fe oxy-hydroxides in adjacent matrix

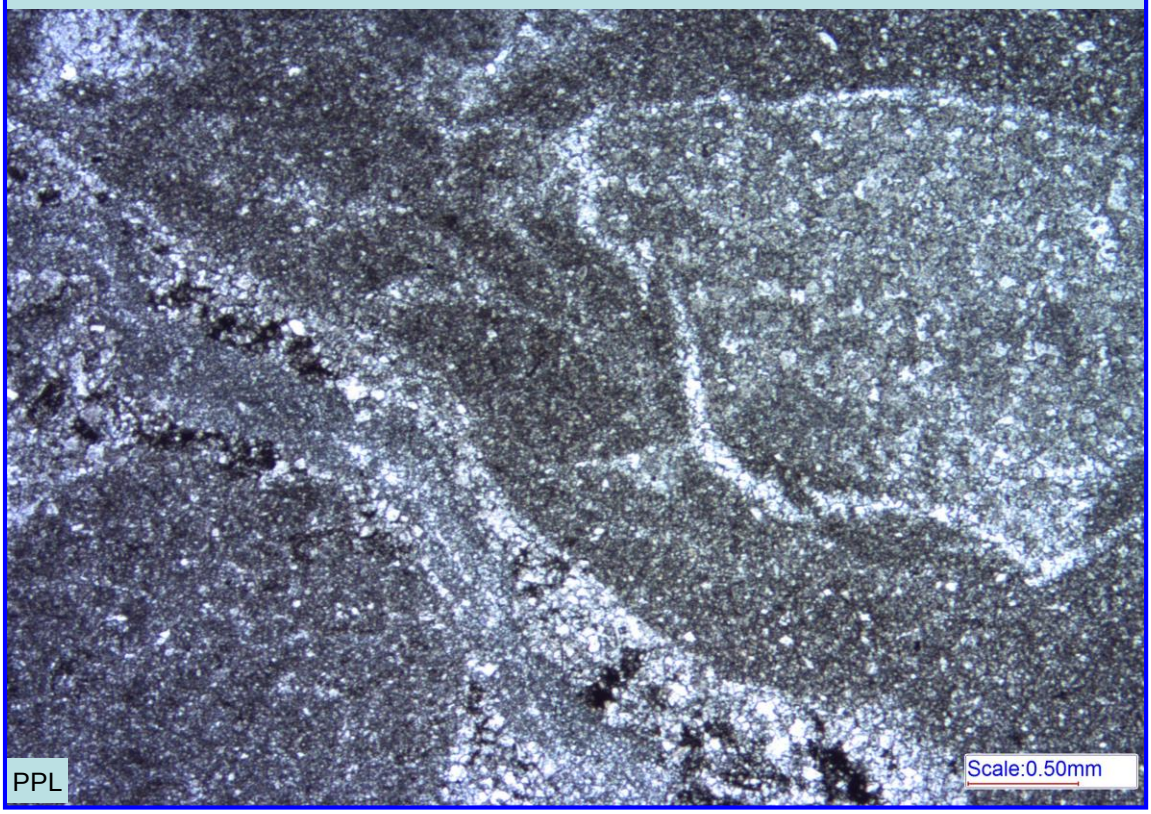


Dark rip-up clasts(?)

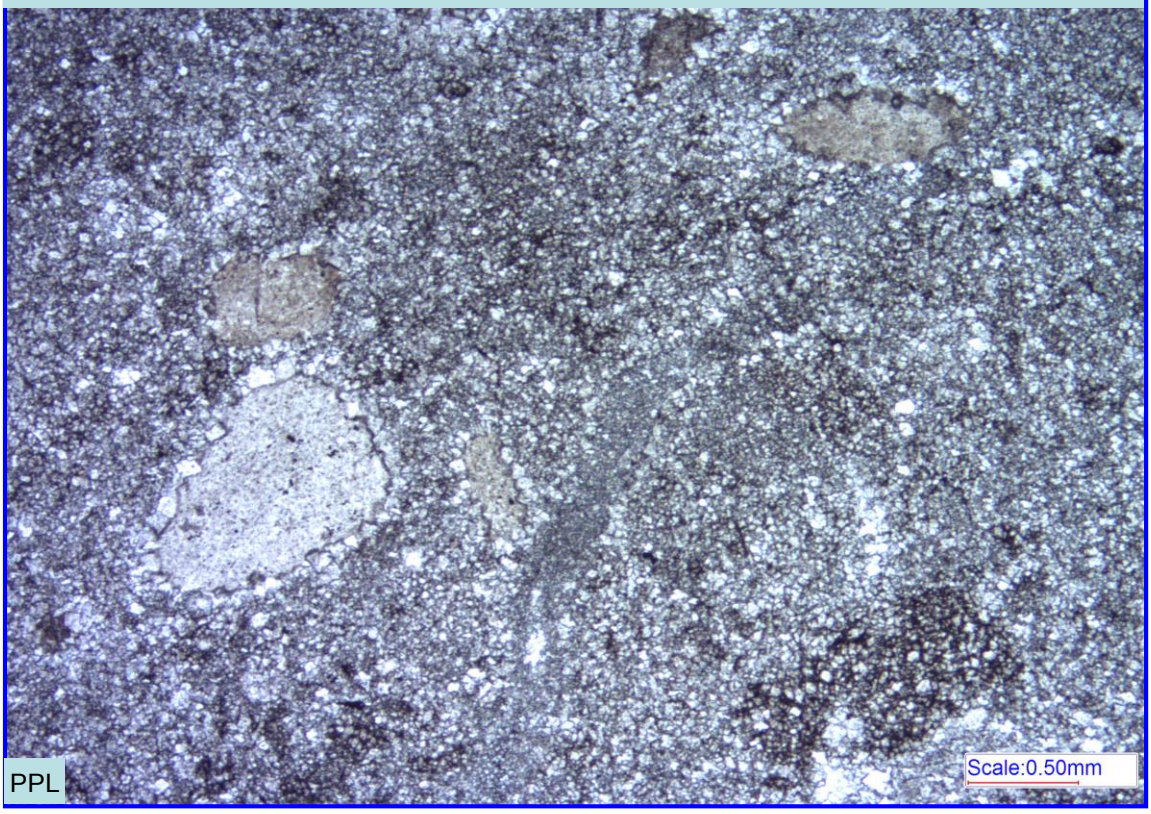


SAMPLE NUMBER D1391382 Hole NB16DD025@299.4m

‘Clasts in clasts’ in dolomite breccia

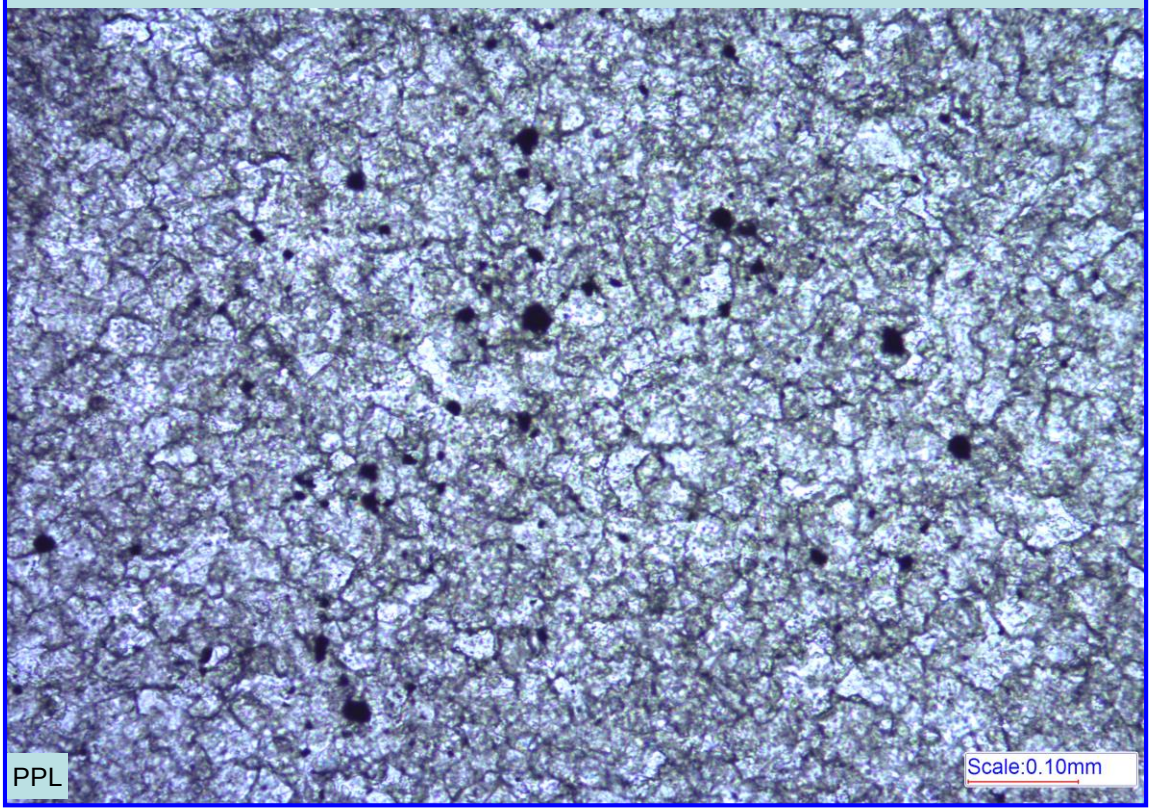


Breccia matrix with small clasts of rounded, fine-grained, siliceous rocks

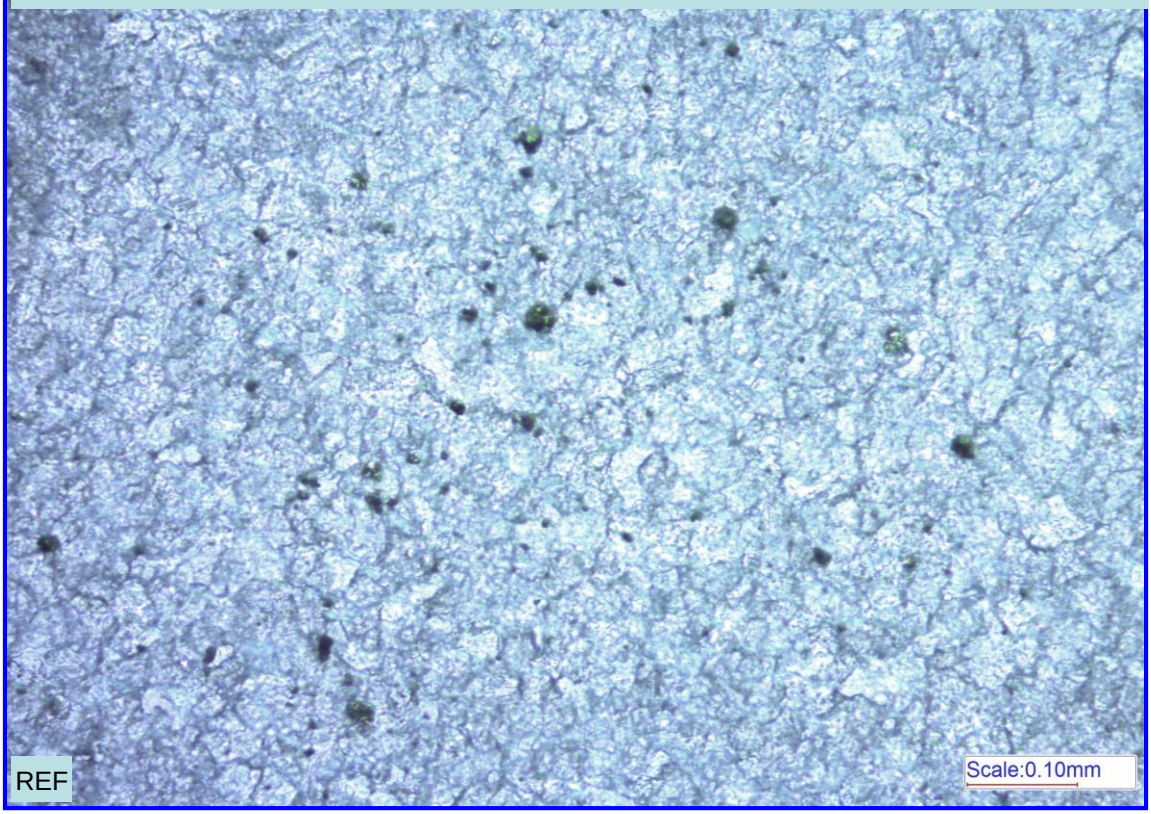


SAMPLE NUMBER D1391382 Hole NB16DD025@299.4m

Tiny sparsely disseminated pyrite in pale dolomitic fragment

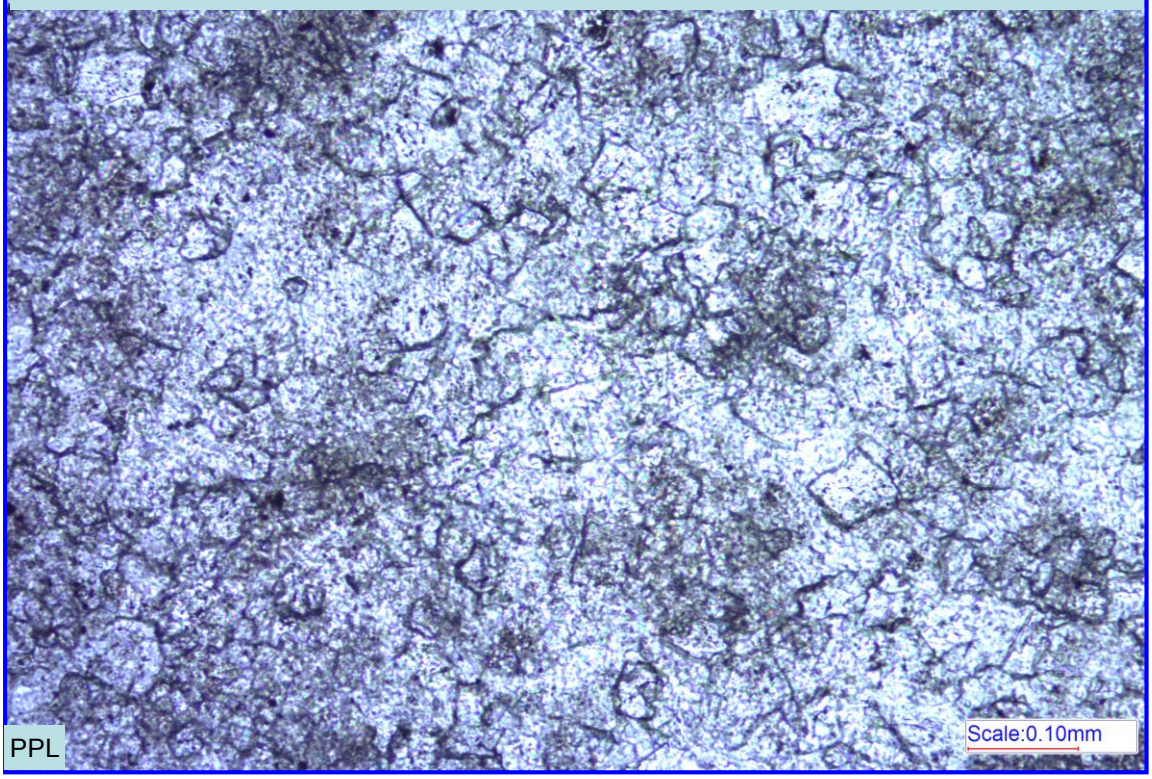


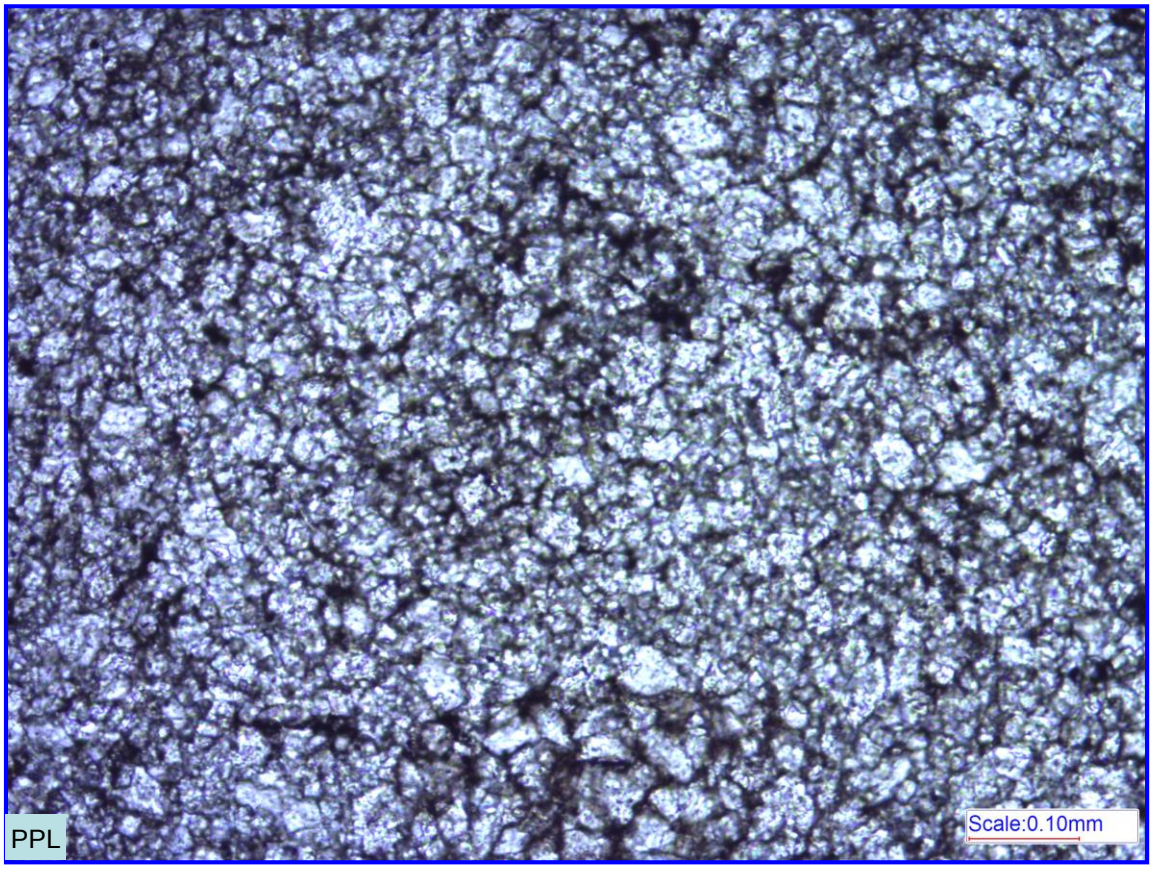
As above, in reflected LED light to show pyrite grains



SAMPLE NUMBER D1391382 Hole NB16DD025@299.4m

Contrasted dolomite in pale clasts top, and darker matrix (lower) showing the darker nature of the latter due to films and interstitial tiny spots of dark, amorphous material.

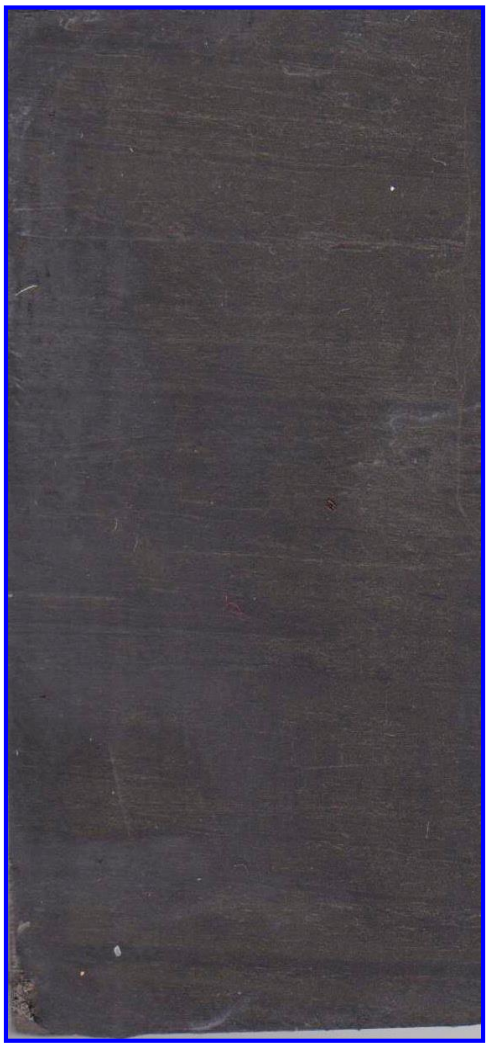


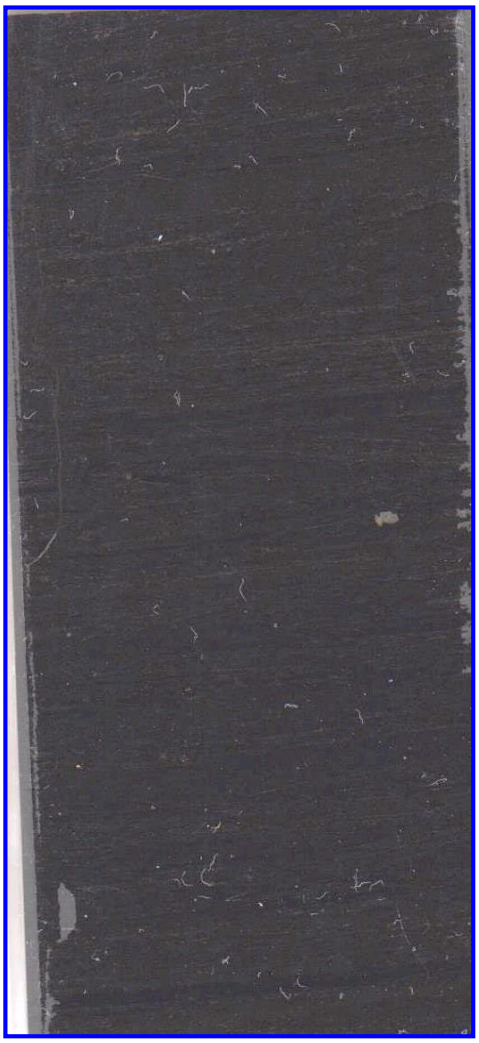


SAMPLE NUMBER D1391385 Hole NB16DD027@184.0m

SUMMARY

A dark, carbonaceous and pyritic mudstone consisting of ~50% pyrite in an irresolvable clay-carbonaceous material matrix, with a few larger detrital quartz grains and tiny lithic clasts. Pyrite occurs as fairly evenly disseminated <10micron-sized crystals, occasionally aggregated into short streams that parallel bedding. Pyrite crystals range from dominantly inclusion-free euhedra, to more irregular and rounded grains, but no framboidal pyrite was noted, and the rock lacks any trace of sphalerite. Tatty, amorphous, fine-grained carbonaceous material is abundant.





SAMPLE NUMBER D1391385 Hole NB16DD027@184.0m

THIN SECTION DESCRIPTION

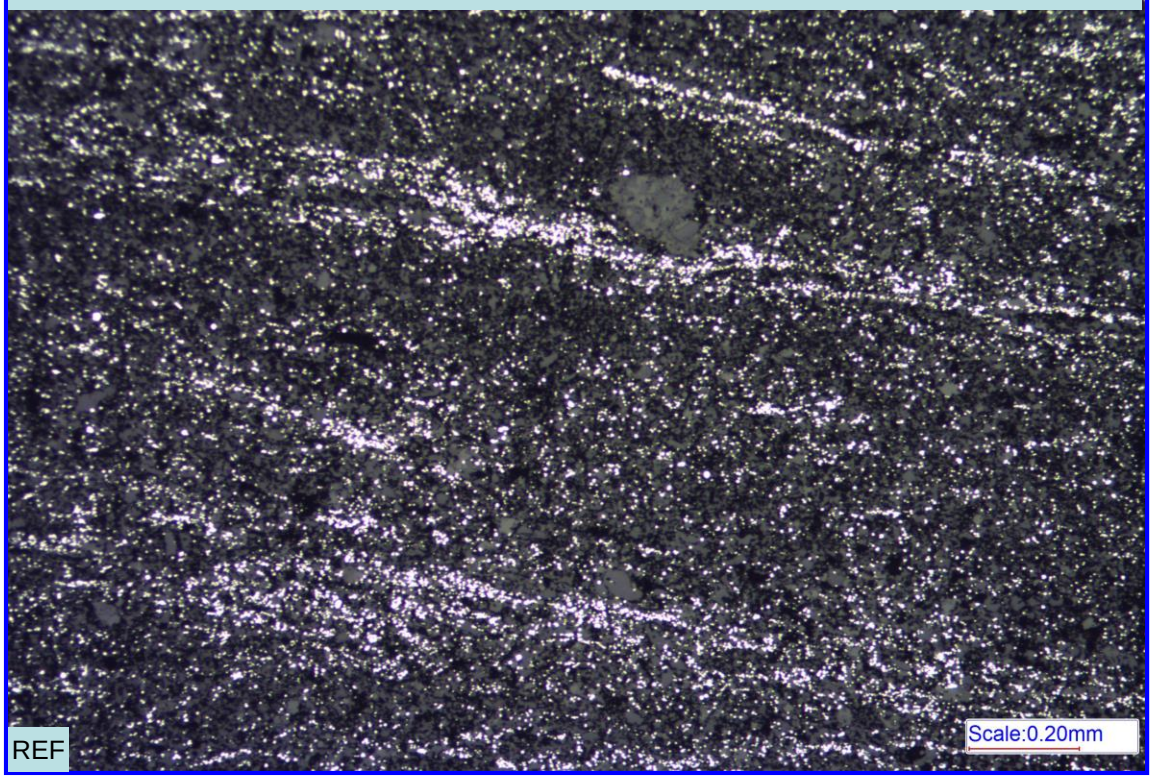
This is a weakly laminated but not fissile, dark, pyritic mudstone composed of a turbid, extremely fine-grained and almost irresolvable intergrowth that in previous work was shown to consist of recrystallized clays heavily peppered with amorphous carbonaceous material and short, bedding-parallel streams of extremely fine-grained but euhedral pyrite crystals. Detrital grains in this sample make up <<1% of the rock and include murky ultrafine-grained lithic clasts, angular quartz, and scattered, small, detrital muscovite plates. Bedding is not perceptible in thin section.

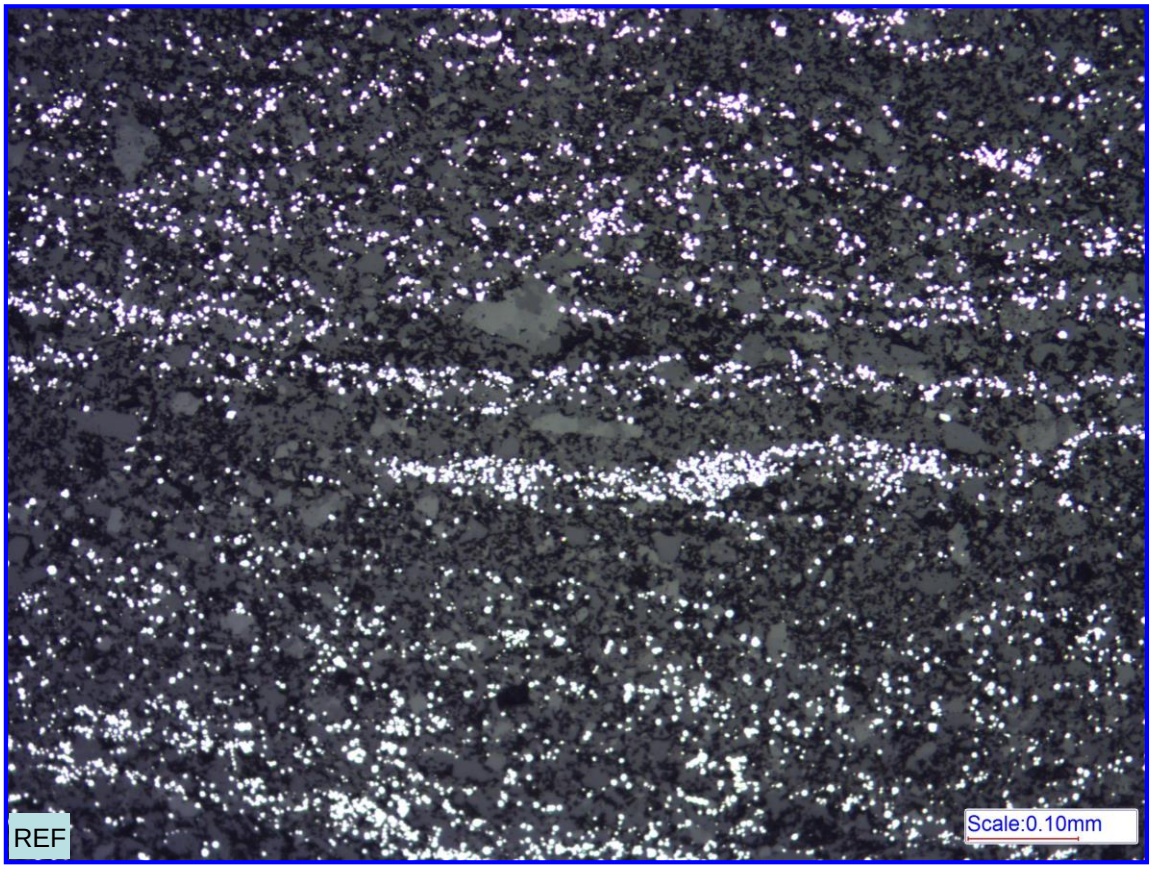
Reflected Light Microscopy

In reflected light, the abundant very fine-grained pyrite is seen to average ~ 10-15% of this rock, and occur as both disseminated tiny (<10microns) crystals, and as short streams of crystal aggregates. Pyrite crystals vary from common euhedral grains, to more rounded grains, but no convincing framboidal grains were noted. Importantly, no trace of sphalerite was seen in this sample, but scrappy, amorphous carbonaceous material is common.

SAMPLE NUMBER D1391385 Hole NB16DD027@184.0m

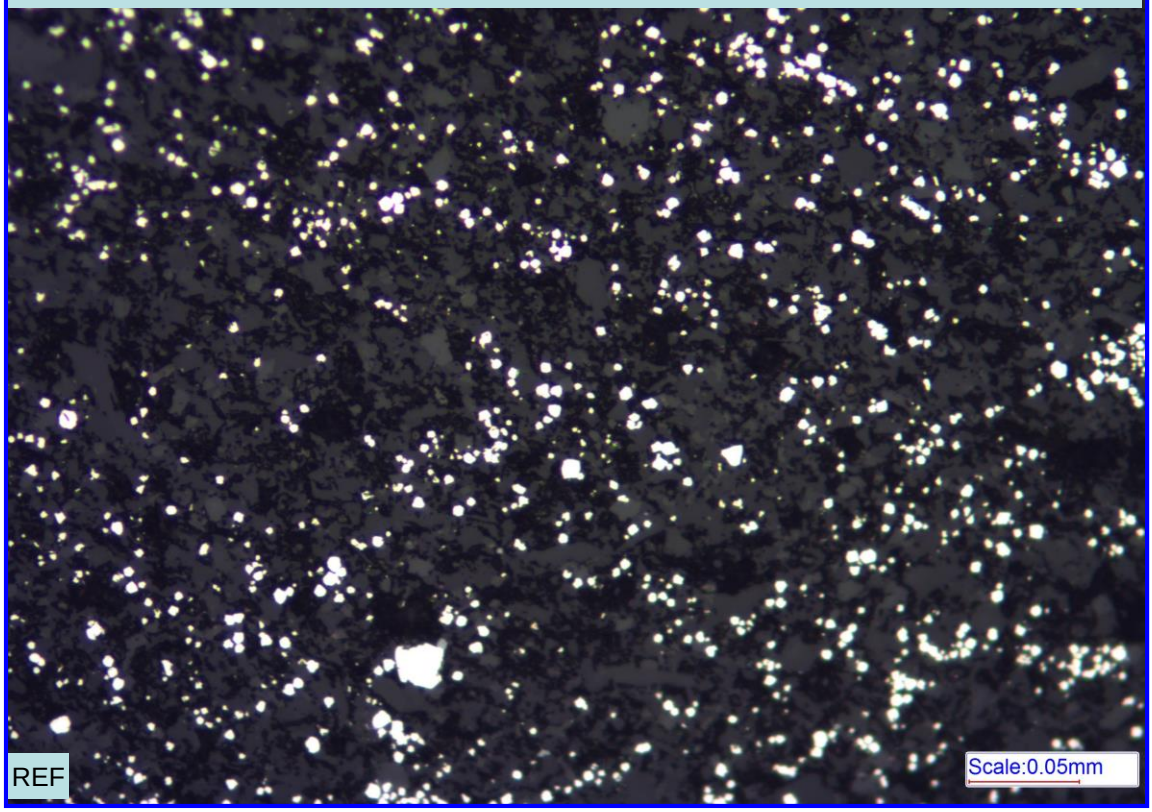
Both images: pyritic and carbonaceous mudstone with bedding-parallel streams and more common disseminated pyrite, and occasion larger clastic grains of quartz and muscovite.

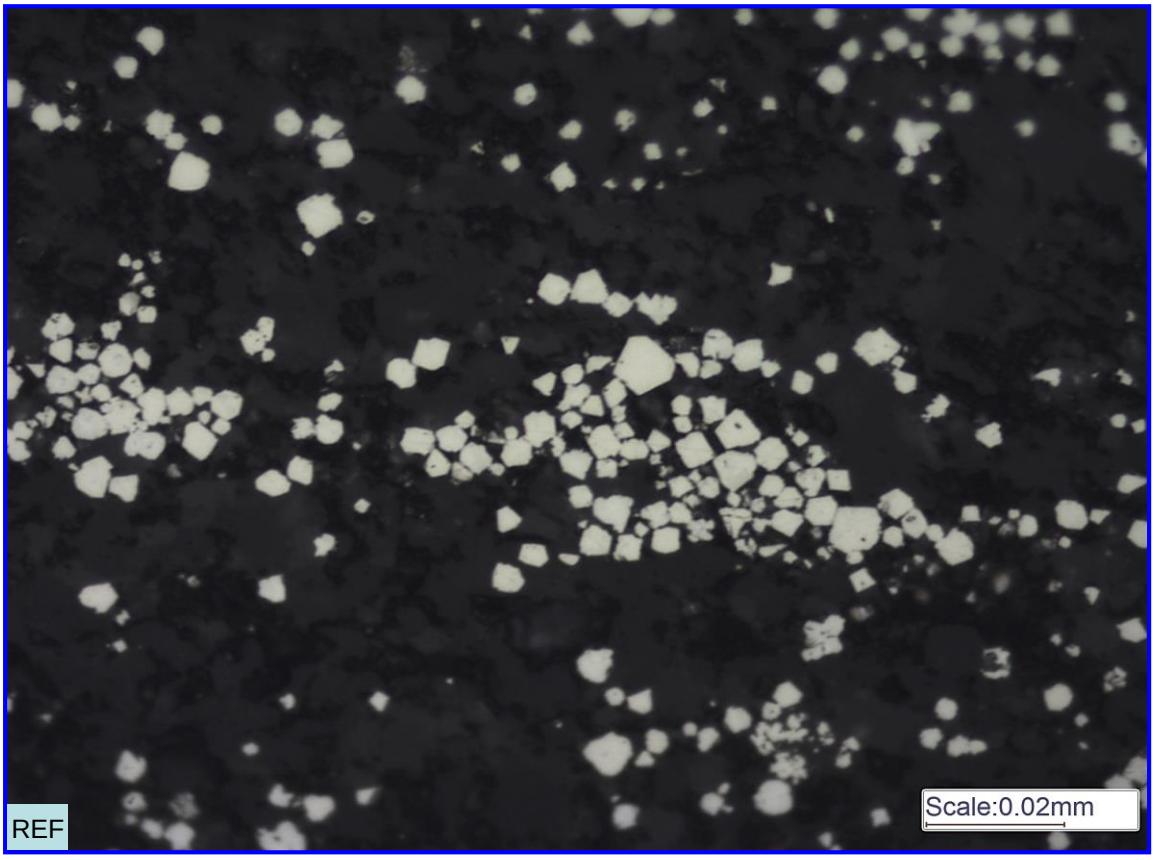




SAMPLE NUMBER D1391385 Hole NB16DD027@184.0m

Tiny euhedral to rather rounded and irregular pyrite crystals in carbonaceous mudstone

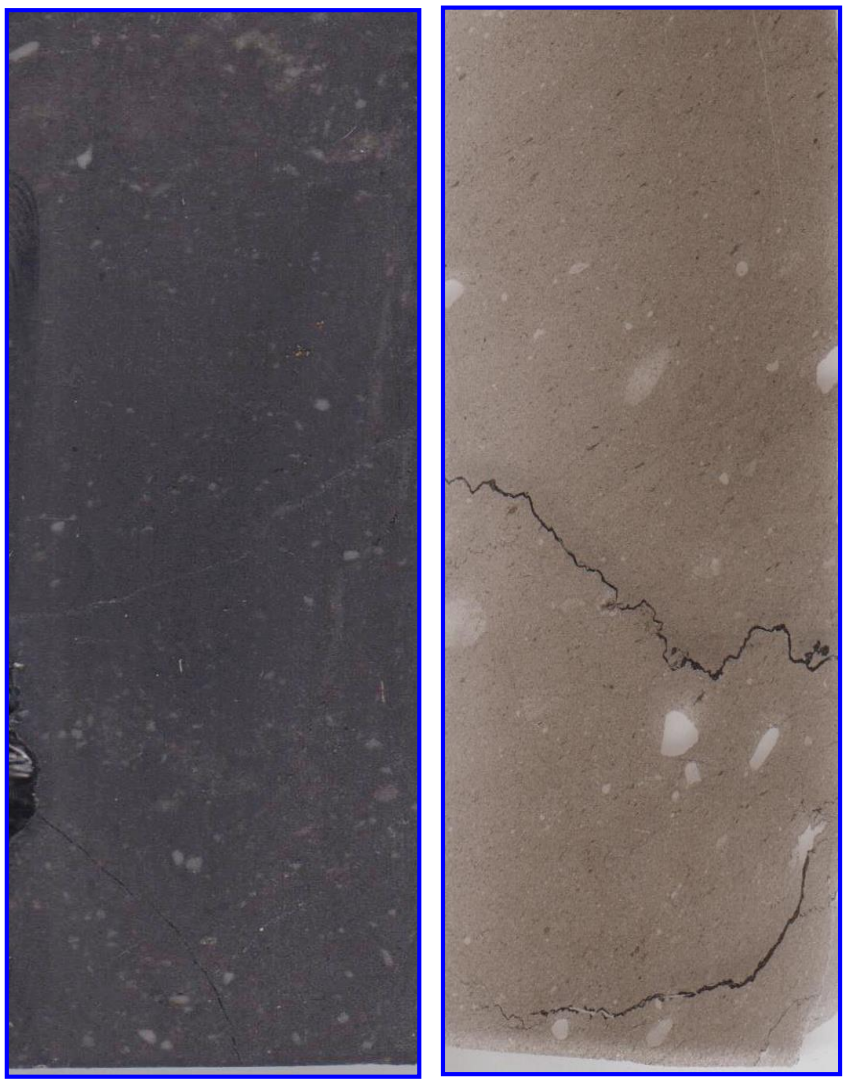




SAMPLE NUMBER D1391395 Hole NB16DD027@583.3m

SUMMARY

A fine-grained dolomite containing a few modal% of rounded clasts of pale dolomite in a darker dolomitic matrix composed of recrystallized, often rhombic crystals of dolomite with quite common detrital quartz and muscovite grains. Fine-grained pyrite, varying from fresh to altered, is disseminated through the rock and weathering-oxidation of this pyrite is probably responsible for the brown staining on grain boundaries and dark colour of the dolomite, although the presence of interstitial clay is also likely in this rock.



SAMPLE NUMBER D1391395 Hole NB16DD027@583.3m

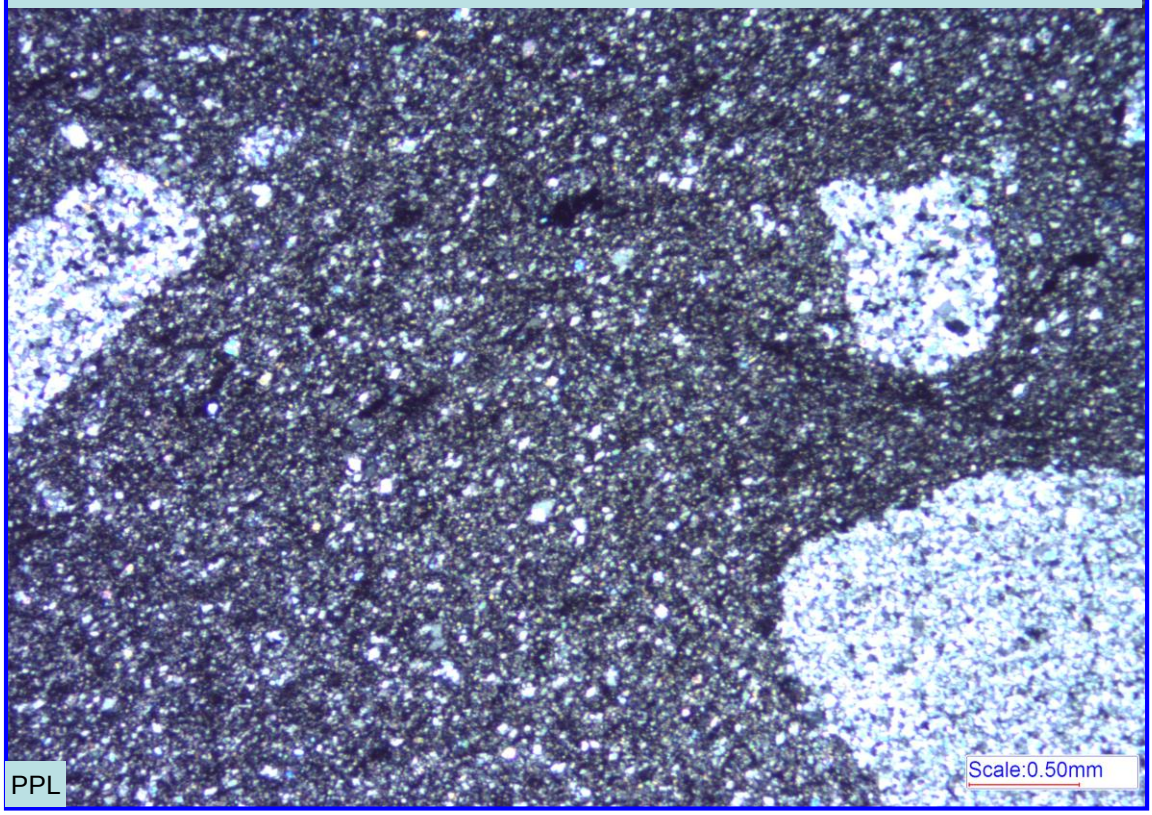
THIN SECTION DESCRIPTION

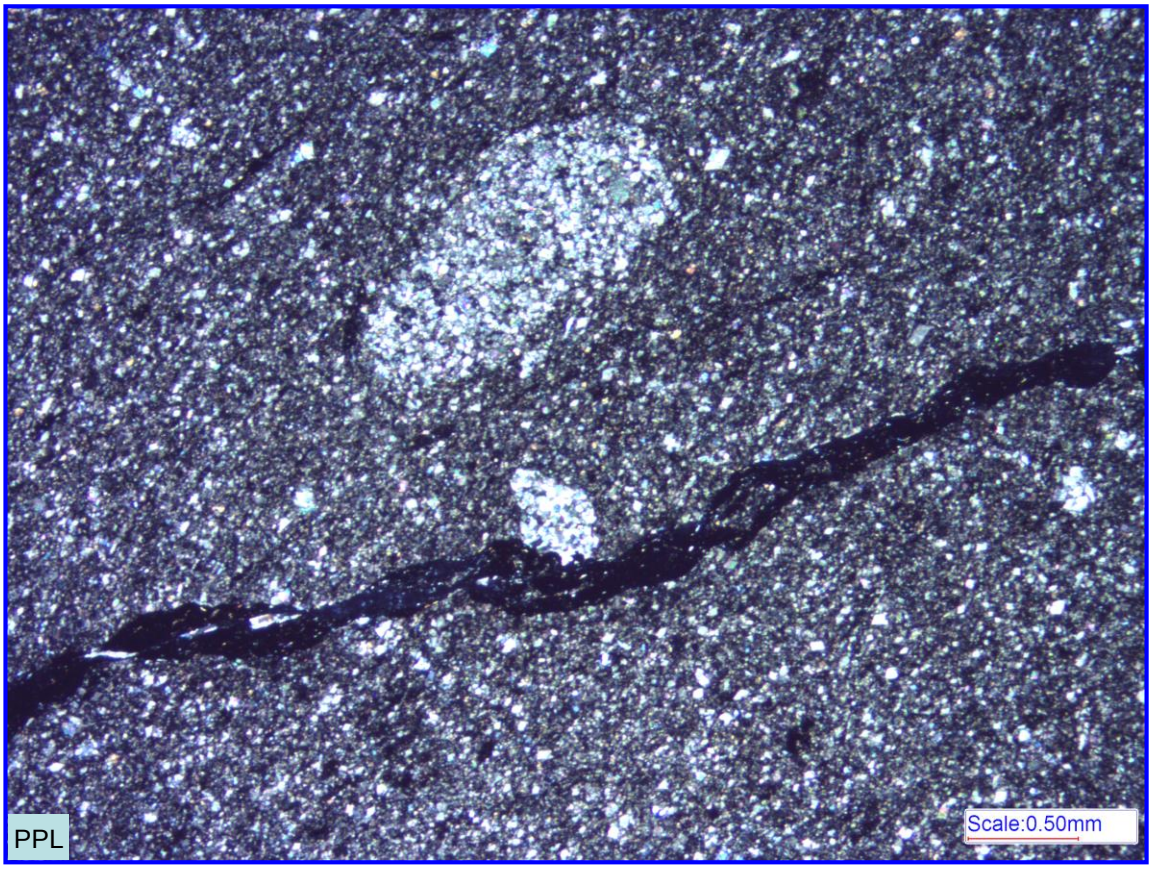
This is another sample focussed on the dark, fine-grained dolomitic matrix of the dolomitic breccia at the contact between the Teena Dolomite and Barney Creek Formation. It lacks the large, angular fragments of pale dolomite that characterize D1391382 and D1391396. However, the rock shows scattered, quite well rounded clasts to 2-3mm long of pale dolomite set in a much finer-grained, silty to fine sandstone matrix. This dolomite contains more abundant, fine-grained detrital silicate material than those described above, including common (but probably <1-2%), small detrital quartz grains and muscovite plates. These are set in a recrystallized dolomitic matrix with abundant well formed rhombic crystals and common very fine-grained dark material, some of which is probably clay. Tiny, tatty pyrite grains and aggregates of very fine-grained pyrite crystals are also common andvary from fresh to oxidized, and may be responsible for the almost pervasive dark tint in the dolomite, which is largely due to staining along dolomite crystal margins.

A number of well defined but quite irregular stylolites marked by dark concentrations of fine-grained, amorphous Mn-Fe oxy-hydroxides transect the thin section.

SAMPLE NUMBER D1391395 Hole NB16DD027@583.3m

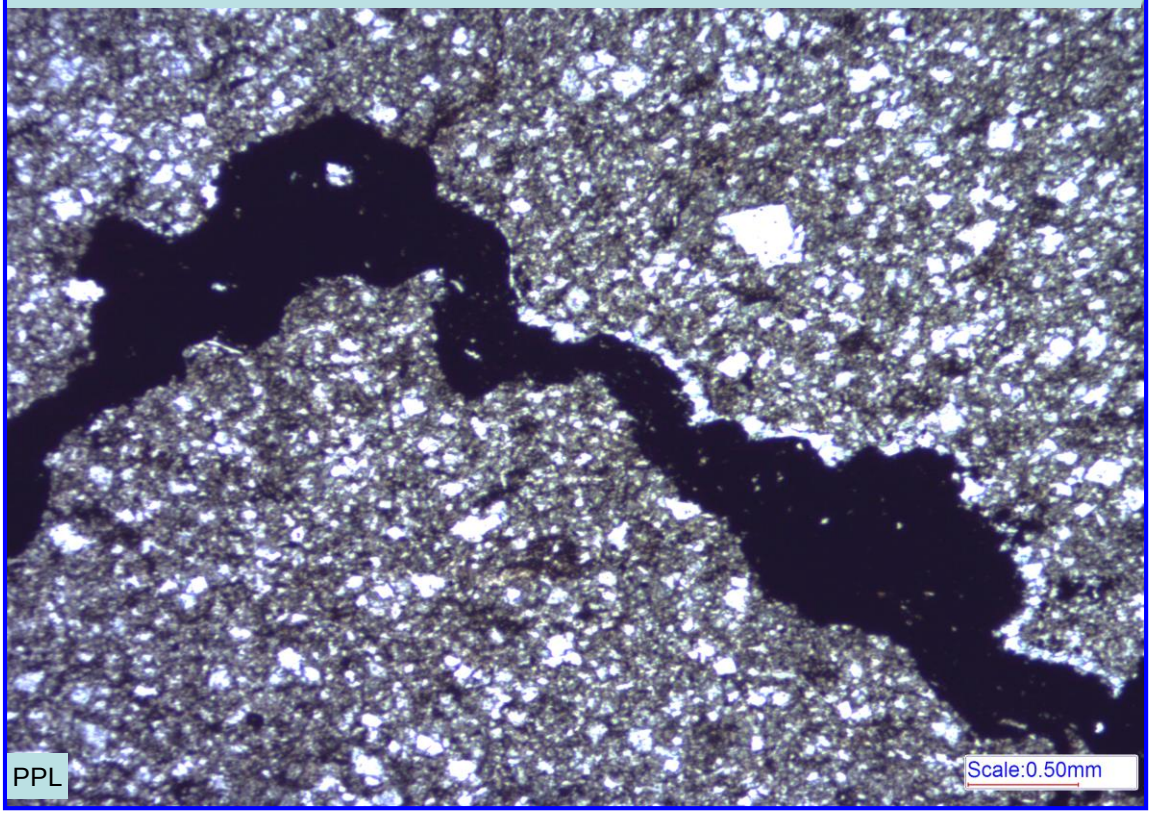
Both images: Small, rounded clasts of pale dolomite in a darker dolomitic matrix.



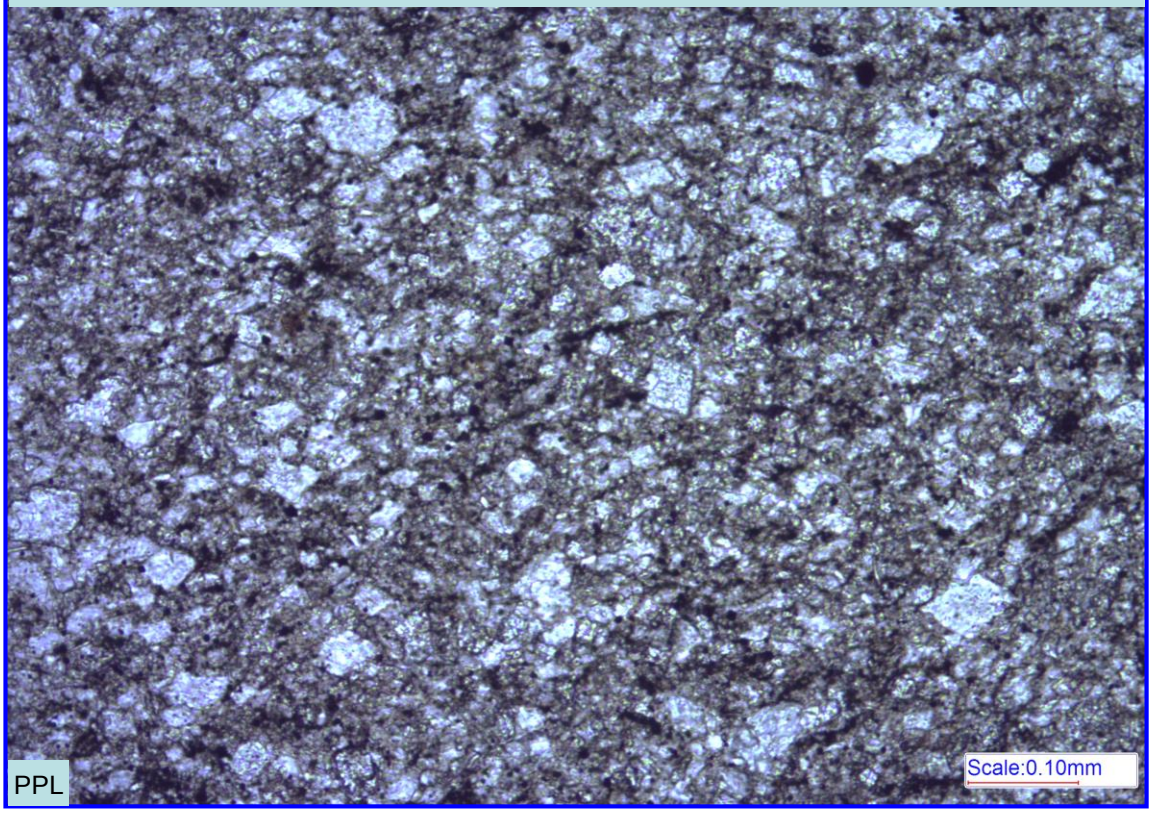


SAMPLE NUMBER D1391395 Hole NB16DD027@583.3m

Stylolite through dark dolomite

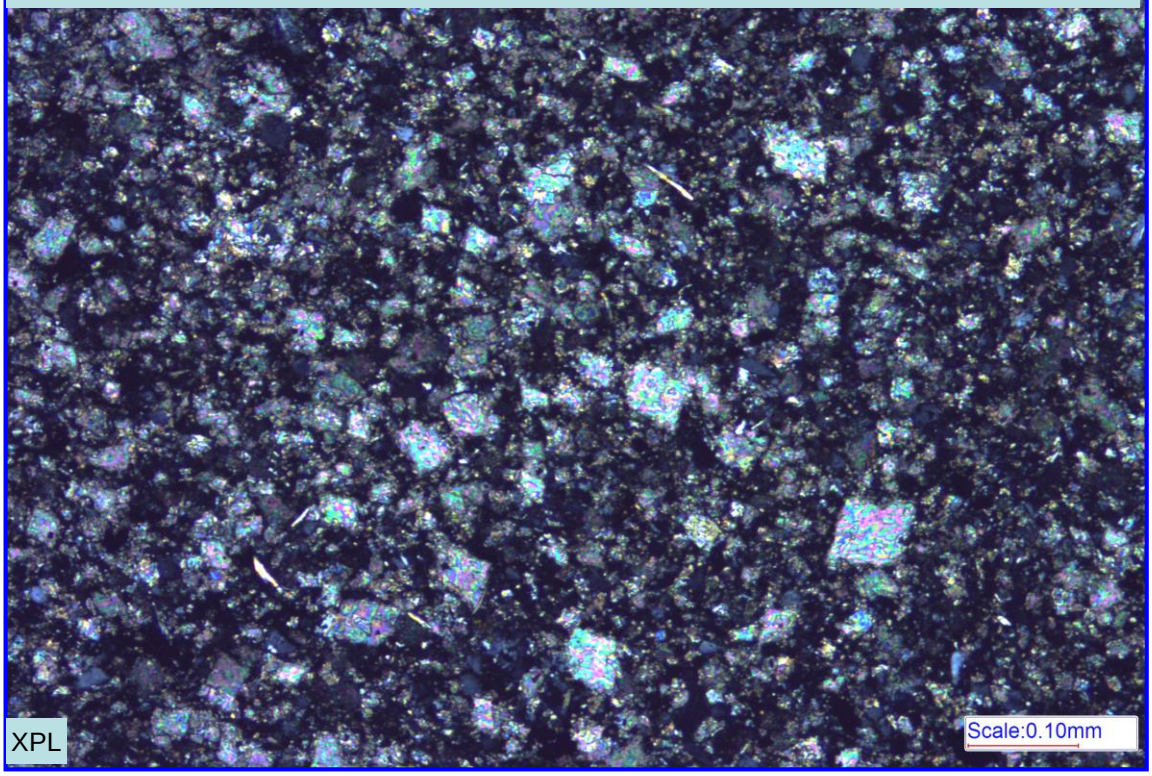


Recrystallized rhombs of dolomite throughout matrix of dolomite breccia

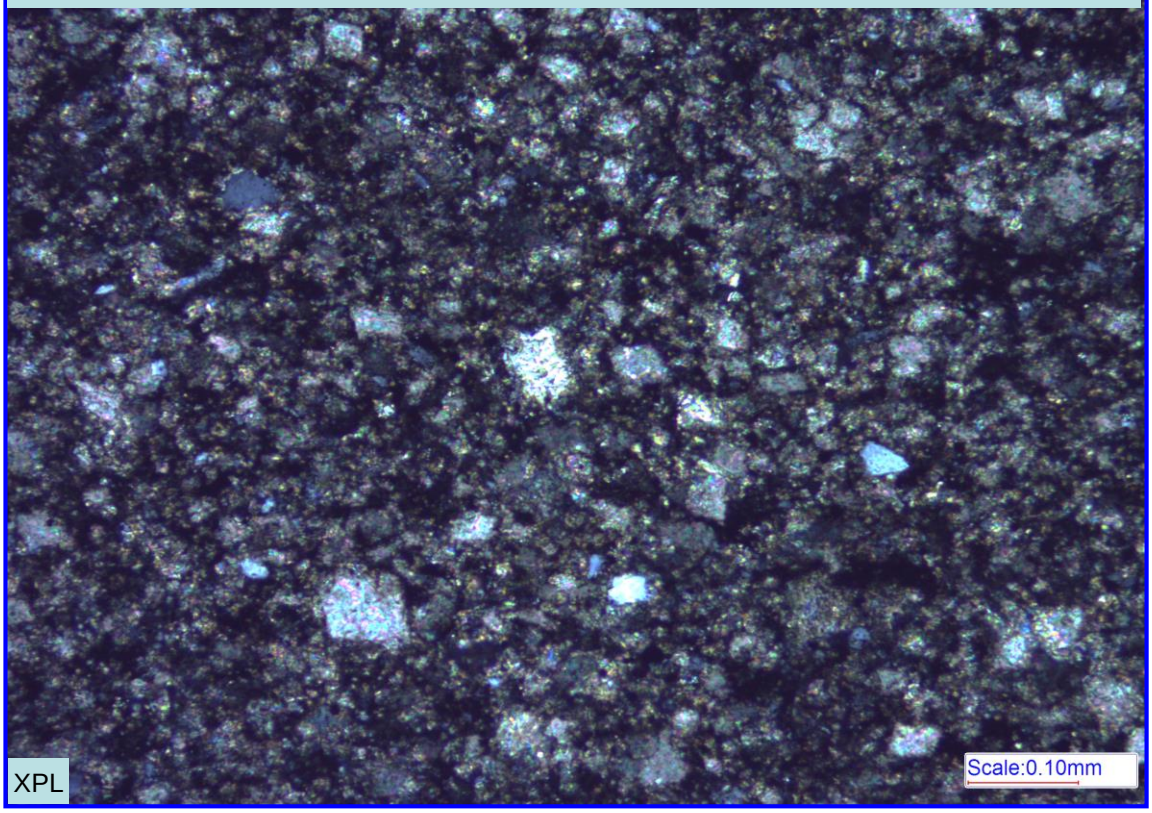


SAMPLE NUMBER D1391395 Hole NB16DD027@583.3m

Rhombs of recrystallized microsparry dolomite and common fine-grained detrital muscovite plates.



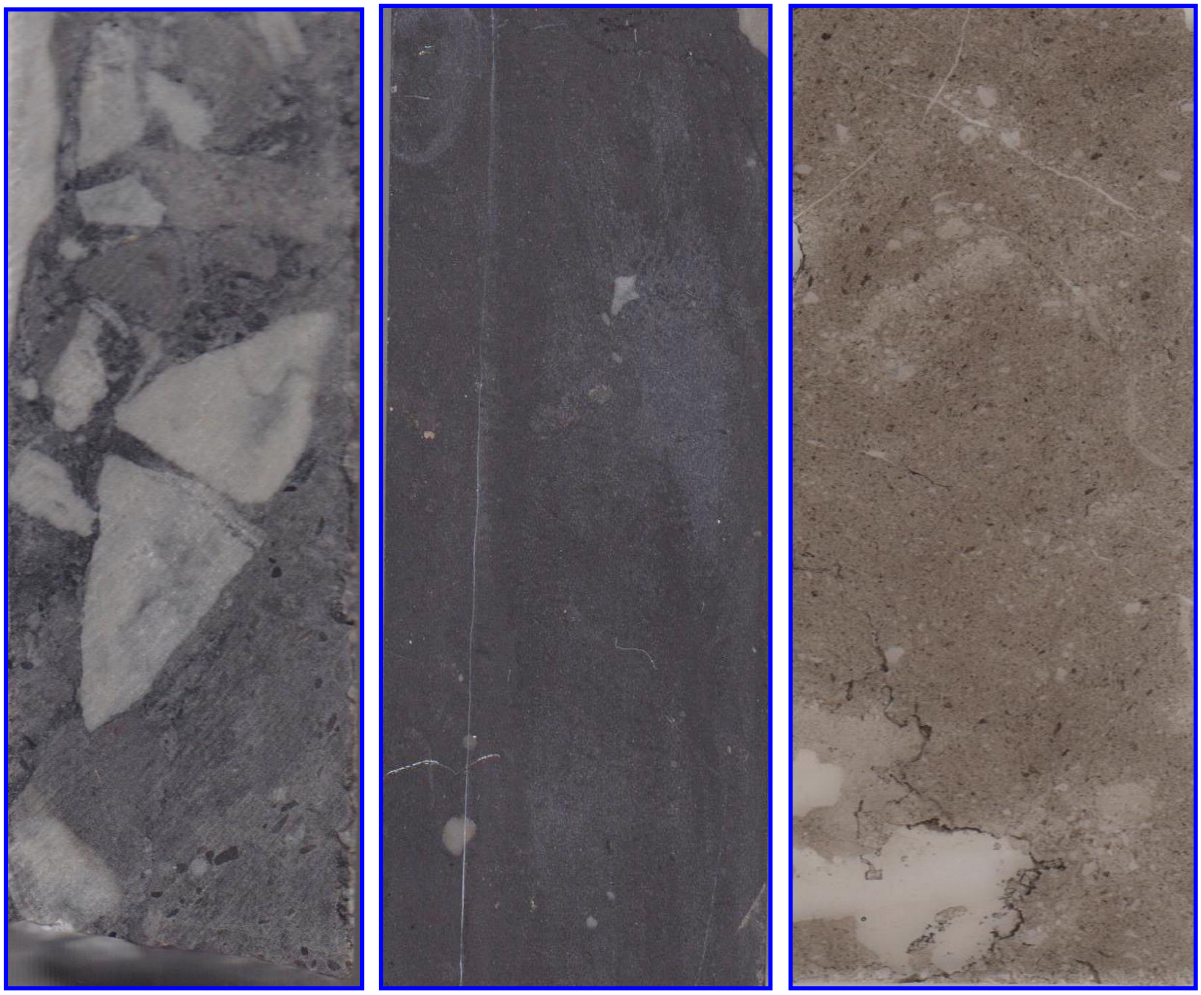
Small grey grains of detrital quartz in recrystallized dolomite



SAMPLE NUMBER D1391396 Hole NB16DD028@295.9m

SUMMARY

This slide samples the matrix of a dolomite breccia. It shows a single fragment of a pale, fine-grained dolomite like those in D1391382 with sparse, fine-grained, disseminated pyrite within a darker dolomitic matrix that contains common, mainly sub-mm-sized clasts that include rounded fine-grained dolomite, very fine-grained siliceous sedimentary clasts, and dark intraclasts of dolomitic shale. As in D1391382, the matrix dolomite shows pervasive, grain margin films and interstitial spots of brown-black amorphous material considered to be Mn-Fe oxy-hydroxides. The same material defines well developed 'stylolitic' concentrations reflecting pressure solution around the margins of the coarser, pale dolomite fragment.



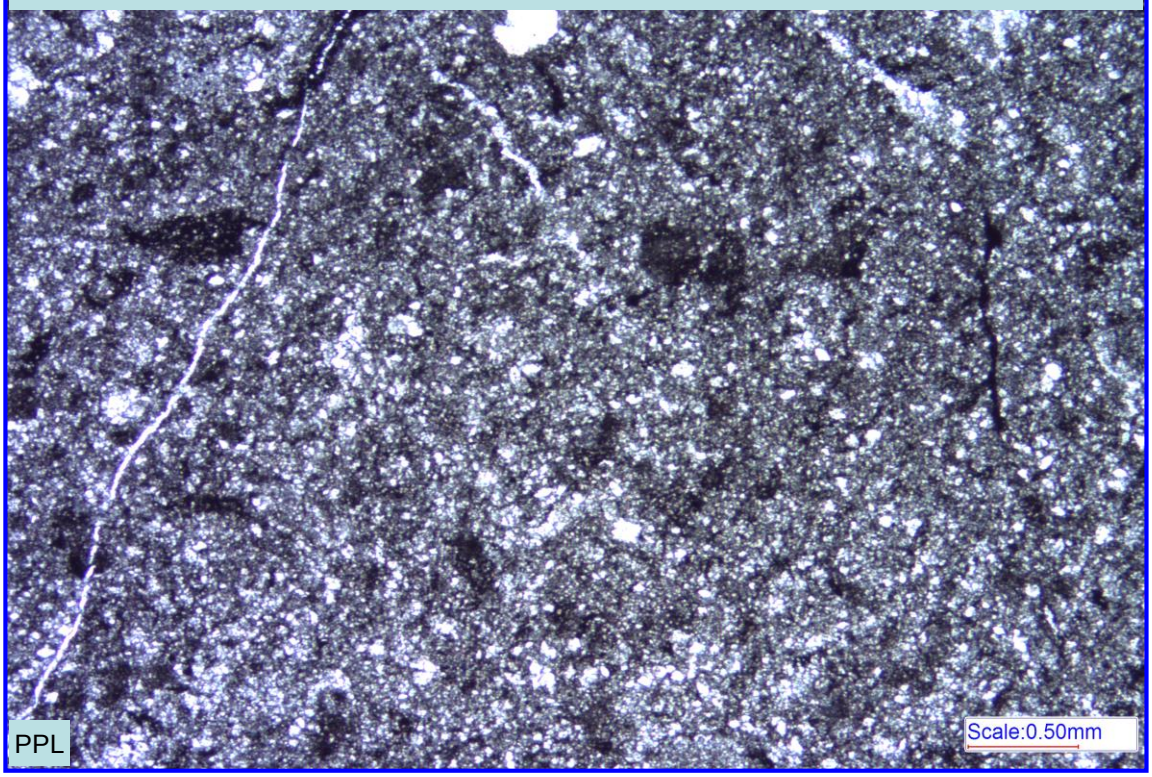
SAMPLE NUMBER D1391396 Hole NB16DD028@295.9m

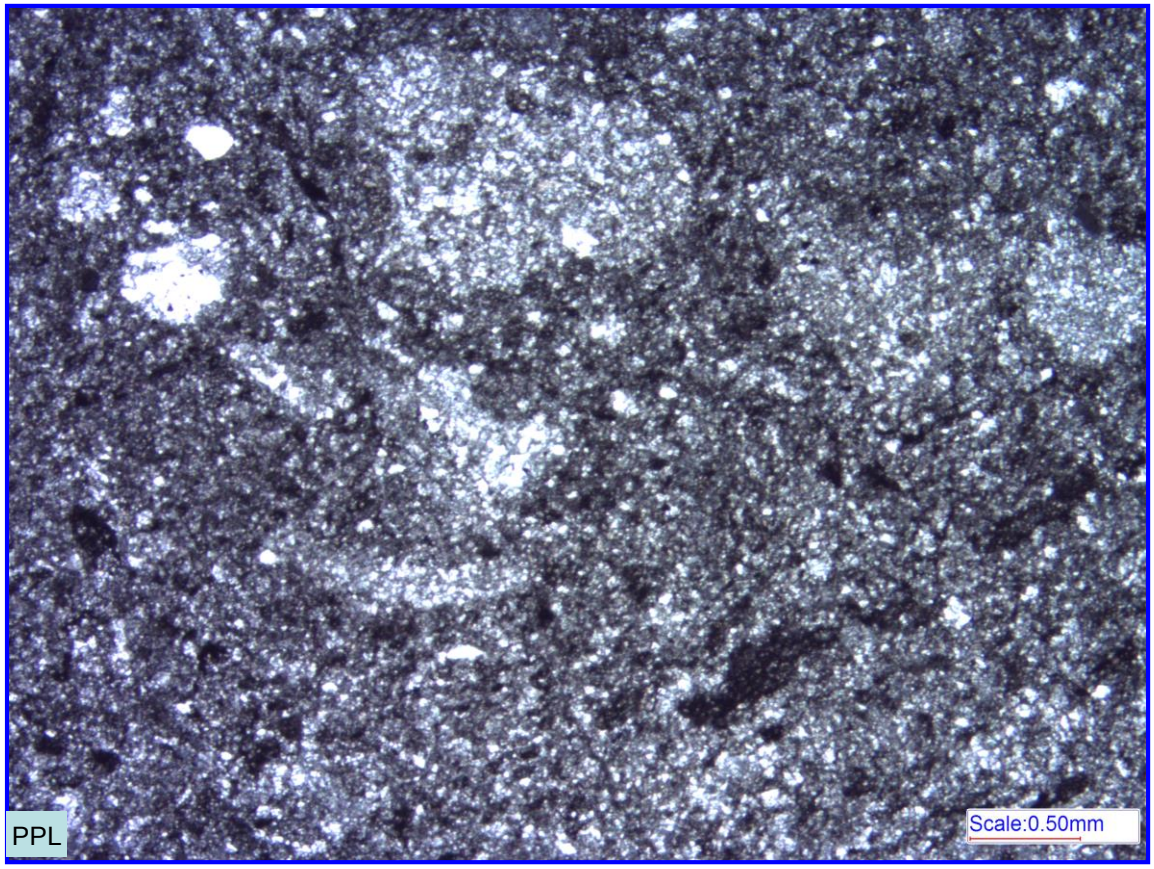
THIN SECTION DESCRIPTION

This thin section was focussed on the matrix of a dolomitic breccia that in core slice/offcut is essentially identical to D1391382, with often angular clasts of pale dolomite often >1cm long in a darker dolomitic matrix. In this thin section, a single fragment of pale dolomite is present, and consists of 'clean', recrystallized, fairly fine-grained dolomite, with a discontinuous concentration of dark stylolite-like Mn-Fe oxy-hydroxides around part of the margin where this fragments abuts the darker matrix. The latter hosts common, mainly sub-mm-sized clasts that include rounded, fine-grained dolomite, very fine-grained siliceous sedimentary clasts, and more platy, dark intraclasts of dolomitic shale that are rarely >1mm long. The matrix dolomite shows pervasive, grain margin films and interstitial spots of brown-black amorphous material, considered to be Mn-Fe oxy-hydroxides, that are responsible for the darker nature of the matrix compared to the 'cleaner' dolomitic clasts. The clast-rich, dark dolomitic matrix of this sample is essentially identical petrographically to that in sample D1391382.

SAMPLE NUMBER D1391396 Hole NB16DD028@295.9m

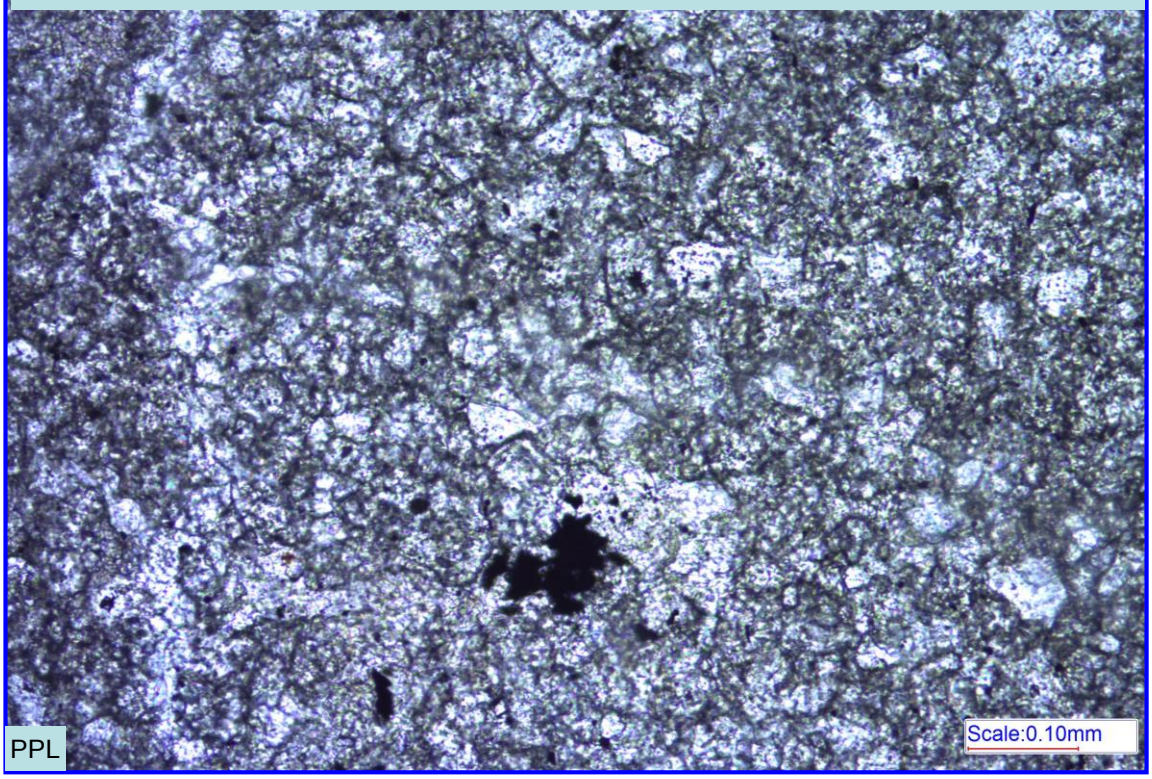
Both images: Rounded clasts of dolomite and laty dark, dolomitic shale, with rare detrital quartz grains, in matrix of dolomitic breccia

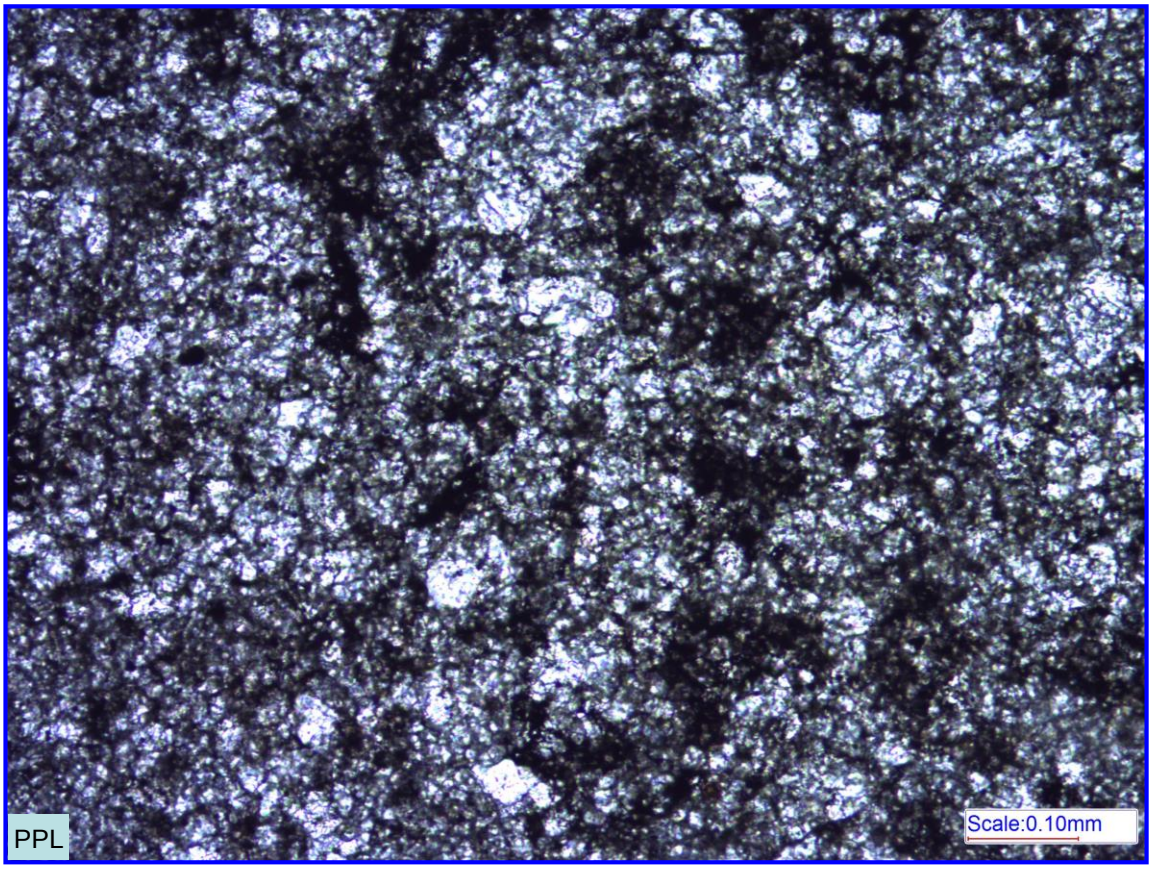




SAMPLE NUMBER D1391396 Hole NB16DD028@295.9m

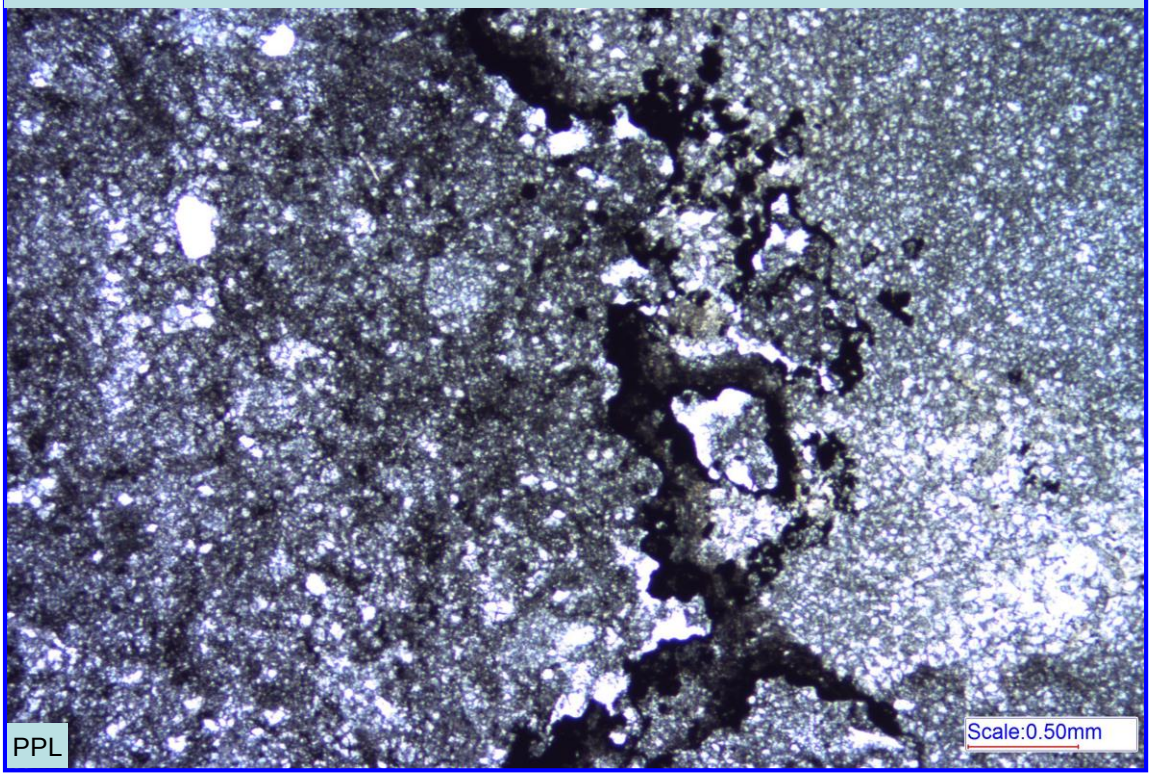
Contrasting dolomite in (top) pale breccia fragments (dark grains are fresh pyrite), and (lower) dark dolomite matrix



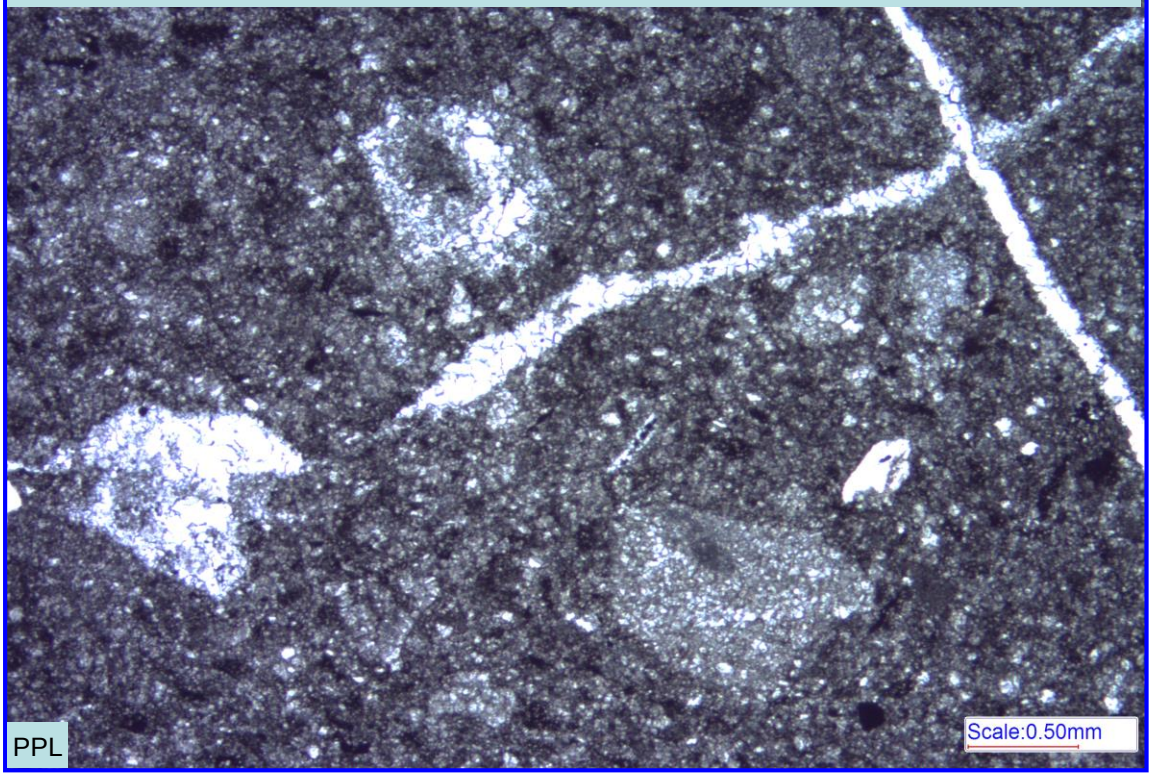


SAMPLE NUMBER D1391396 Hole NB16DD028@295.9m

Concentration of dark Mn-Fe oxy-hydroxides developing on margins of pale dolomite fragment by pressure solution of matrix dolomite



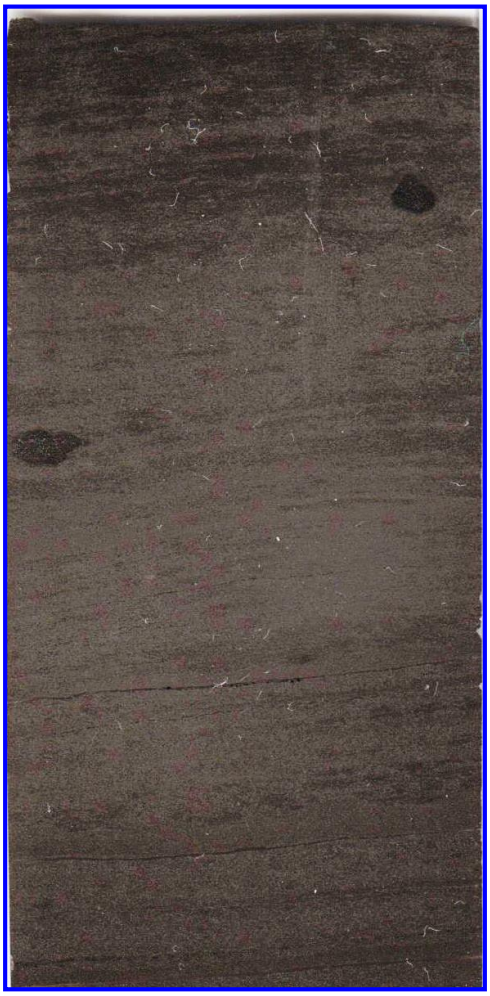
Dark matrix dolomite hosting small, rounded clasts of dolomite and siliceous sedimentary rocks



SAMPLE NUMBER D1897074 Hole NB16DD020@317.2m

SUMMARY

A bedded sulfidic sedimentary rock composed almost entirely of pyrite (~50%) and irresolvable silicate or carbonate matrix, with a few % of interstitial sphalerite. The abundant pyrite is present as sub-10micron perfectly euhedral crystals presumably recrystallized from sedimentary framboidal pyrite during late diagenesis. Several mm-sized pyrite porphyroblasts have grown, probably during low grade burial metamorphism, from the fine-grained pyrite, and they deflect bedding. Sphalerite occurs as small, irregular patches that typically enclose a number of pyrite euhedra, and these undoubtedly grew simultaneously with the pyrite, from components present in the sulfidic sediment at deposition.



SAMPLE NUMBER D1897074 Hole NB16DD020@317.2m

THIN SECTION DESCRIPTION

This strongly sulfidic, fine-grained sedimentary rock consists mainly of very fine-grained pyrite and interstitial, irresolvable material that appears to be largely a carbonate phase (dolomite), with minor interstitial sphalerite. Laminar, sub-mm-scale bedding remains obvious and is largely due to subtle changes in the proportions of pyrite and interstitial material.

Reflected Light Microscopy

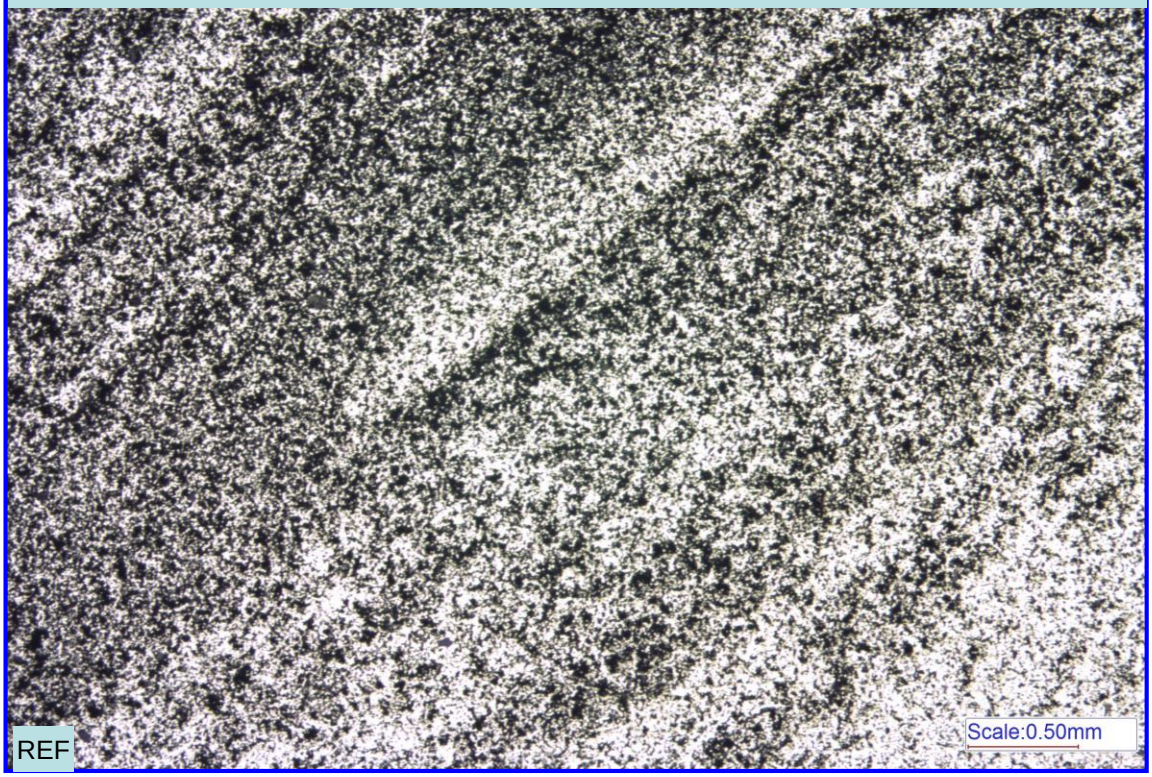
Mainly sub-10micron, euhedral crystals of pyrite, rarely in contact with neighbouring pyrite grains, make up ~50% of this rock. There is no trace of framboidal pyrite, and all pyrite is particularly well formed, tiny, inclusion-free crystals. Several 1-2mm-sized pyrite porphyroblasts have deflected bedding, and grown by aggregation of the tiny euhedral pyrite grains, presumably during very low grade 'burial metamorphism'. Interstitial matrix between pyrite crystals includes a few % of sphalerite, and abundant irresolvable material that often shows rhombic outlines against sphalerite patches, and is likely to be largely dolomitic carbonate. As transmitted light cannot penetrate through the matrix in this rock, it is not possible to estimate the sphalerite Fe content from its colour.

Other Comments

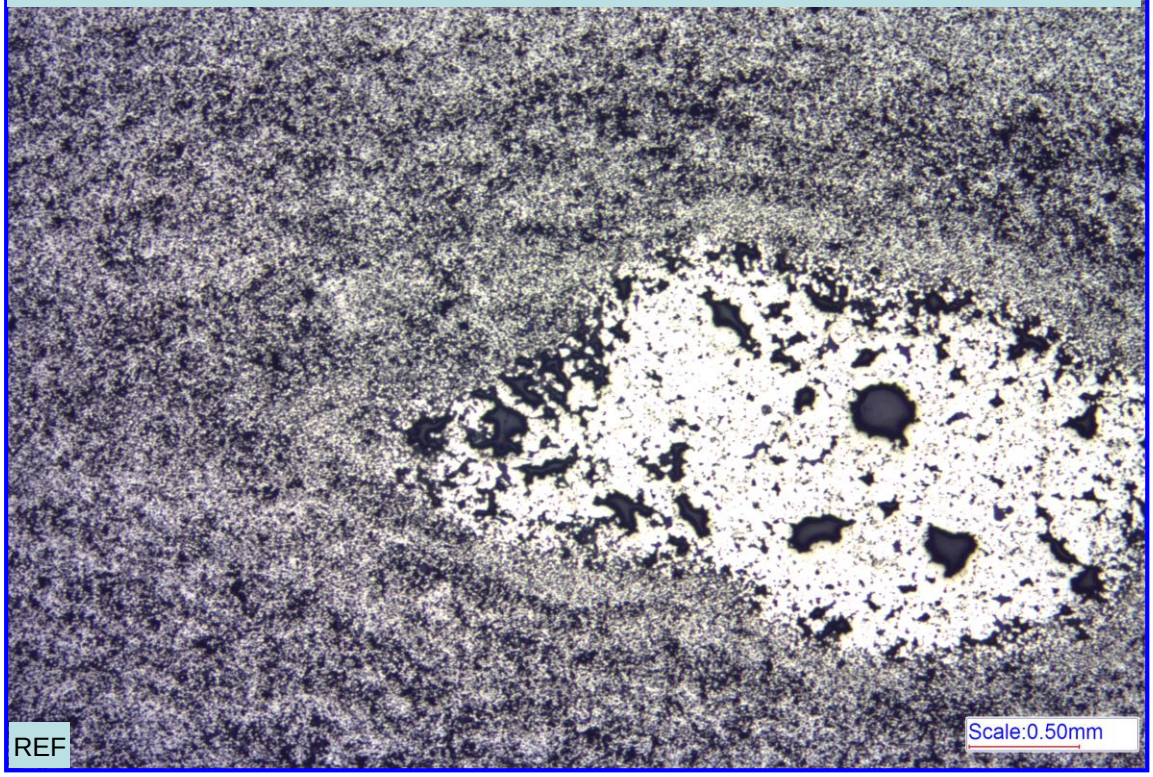
The euhedral pyrite probably crystallized during late diagenesis from exceedingly fine-grained, probably framboidal, sedimentary pyrite. During the same event, sphalerite and dolomite (re)crystallized along with the pyrite. The chemical components of sphalerite are likely to have been in the original sedimentary rock, and were unlikely to have been introduced via pervasive percolation of metal-rich basinal brines through this impermeable rock.

SAMPLE NUMBER D1897074 Hole NB16DD020@317.2m

Bedded, very fine-grained pyrite, with bedding defined by changing proportions of pyrite to irresolvable matrix

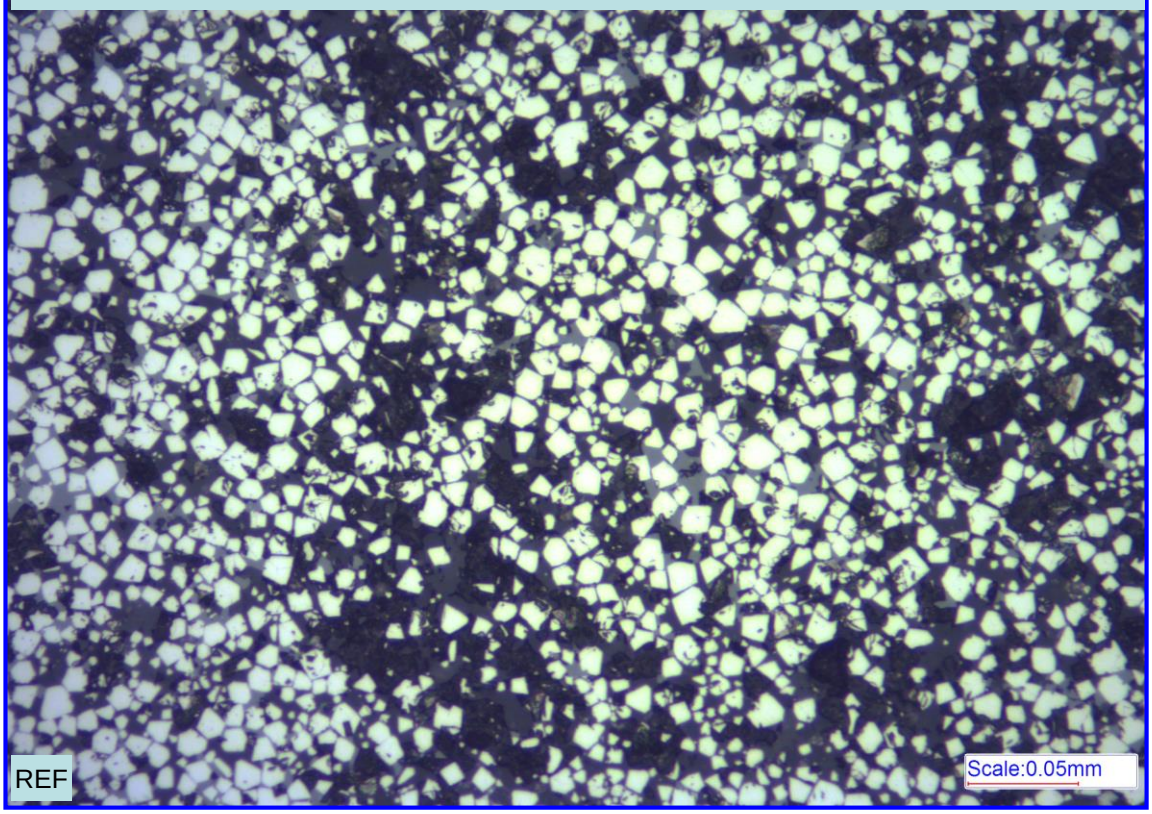


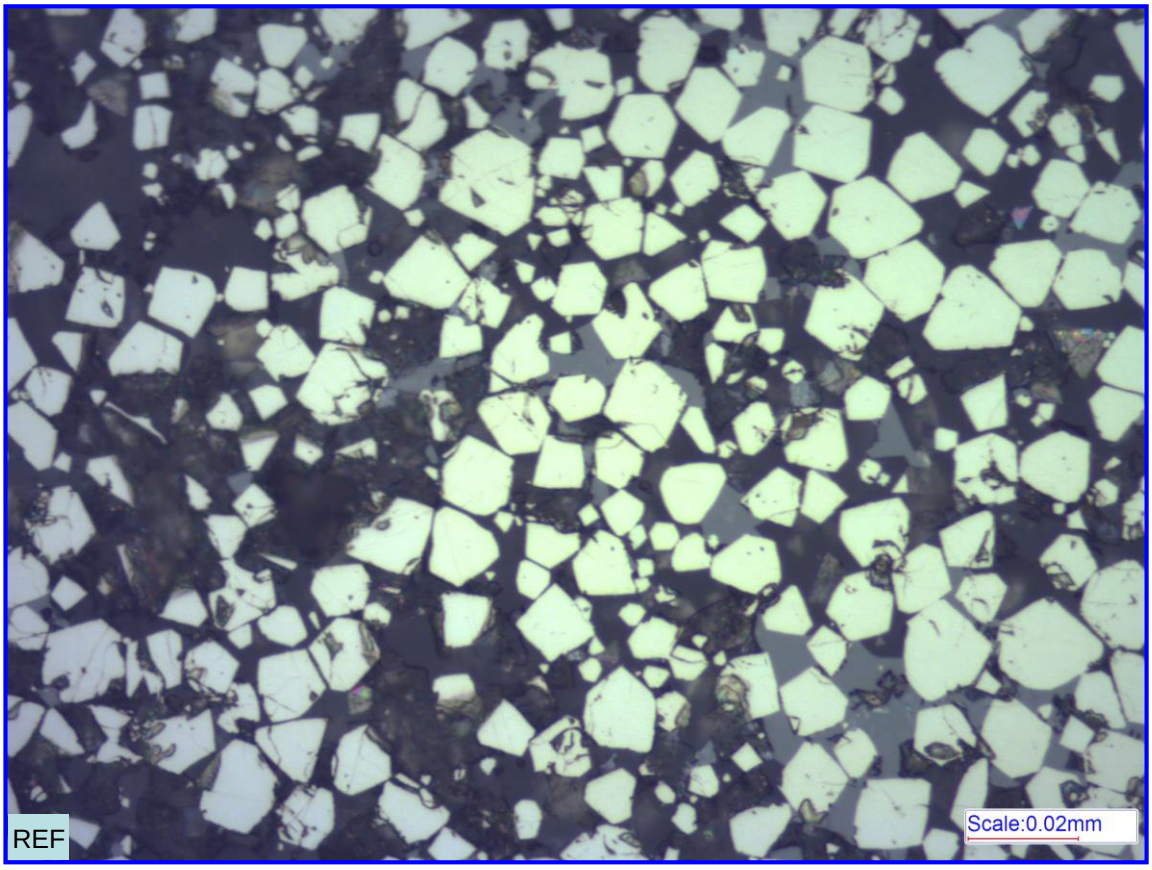
Porphyroblast of pyrite deflecting bedding, and growing from aggregation of tiny pyrite euhedra



SAMPLE NUMBER D1897074 Hole NB16DD020@317.2m

Both images: Detail of tiny euhedral pyrite with mid-grey interstitial sphalerite.





SAMPLE NUMBER D1897074 Hole NB16DD020@317.2m

Both images: Mid-grey sphalerite spots in gangue between pyrite euhedra.