Report prepared for:

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PETROLOGY REPORT

SHERBROOK GROUP

OTWAY BASIN

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Front cover:
Thin section photomicrograph, Mt Salt-1, core, depth 2716.60m. Plane light. Horizontal field of view 3.25mm.

1. SUMMARY

Essential Petroleum Resources Limited submitted 21 samples to PGPC from the Sherbrook Group in the Otway Basin for petrological description. Samples of cuttings, sidewall core and core were taken in nine wells from the Flaxman and Waarre Formations. The study was design to answer specific questions concerning sediment provenance, depositional environments and reservoir quality. The client supplied a variety of information including palynology results, selected logs, previous petrology descriptions, and descriptions of cuttings from the well completion reports to aid the petrology interpretation. All available thin sections from Mt Salt-1, Argonaut-1 and Breaksea Reef-1 were briefly reviewed prior to commencing this study.

Although valuable information can be obtained from cuttings, where rocks have disaggregated into single grains it is very difficult to ascertain reservoir quality and have confidence in the interpretation of lithology and composition of the rock. These limitations should be considered when assessing the results and interpretation in this report.

If the basal sample from Breaksea Reef-1 (4446m) is interpreted as Waarre Unit A then in the central-western Otway Basin sediment provenance in Unit A was probably different from Unit C. Unit A contains volcanic and chalcedonic lithics, plagioclase and high percentages of polycrystalline quartz. These detrital grains are absent, or less abundant in the case of polycrystalline quartz, in sandstones from Unit C. An igneous source (both volcanic and plutonic) probably had a stronger influence on sedimentation during deposition of Unit A. The volcanic terrane did not influence sedimentation in Unit C. Both Unit A and C have evidence of a metamorphic source and there was probably reworking within the sedimentary environment. These results from the western Otway Basin appear to be consistent with findings in the eastern Otway Basin.

At Bridgewater Bay-1 and Normanby-1 in Unit A there are higher percentages of volcanic lithics than at Breaksea Reef-1, and no plutonic lithics were identified at Breaksea Reef-1. This might indicate Bridgewater Bay-1 and Normanby-1 were closer to the volcanic source or more directly in the path of sediment transport. It is possible that the volcanic source was older Otway Supergroup sediments reworked from the Discovery Bay High.

Sediment provenance in the Banoon Member equivalent was dominantly from a metamorphic terrane with minor input from igneous and sedimentary environments. If there was any reworking of Waarre Formation into the Flaxman then it was from Unit A because there are volcanic lithics present.

Depositional environments in the Banoon Member equivalent included shallow marine settings close to where a river entered the sea. Distinctive chlorite rims formed in this environment but there were periods of exposure that caused oxidation of the chlorite and grains of glauconite. Bioturbation by suspension feeders occurred in this relatively high energy depositional environment. Other facies reflect lower energy settings with deposition of mudstones and muddy sandstones. Where bivalve fragments accumulated in laminae with faecal pellets fluctuations in groundwaters might indicate short periods characterised by lacustrine conditions. Siderite cements probably precipitated at this time and then pyrite when conditions became more saline. Waarre Unit A and C in the central western Otway Basin had similar depositional environments to those of the eastern Otway. Unit A ranging from shallow marine to brackish, moderate to high energy with possible evidence of a regressive sequence. Waarre Unit C was fine grained shallow marine to coarser grained possibly terrestrial/brackish environments.

Reservoir quality is very difficult to assess from cuttings because the samples are biased towards cemented parts of the sandstones. In Unit C of the Waarre Formation in south-eastern SA reservoir quality was probably good due to the high mineralogical maturity of the sandstones and relative lack of authigenic cement. In the Flaxman Formation reservoir quality in the sandstones is moderate to good

but locally limited by authigenic minerals (ferroan calcite, quartz and kaolin) and compaction. The overall control of reservoir quality was probably related to facies and the distribution of chlorite rims.

2. INTRODUCTION

Essential Petroleum Resources Limited submitted 21 samples to PGPC from the Sherbrook Group in the Otway Basin for petrological description. Samples of cuttings, sidewall core and core were taken in nine wells from the Flaxman and Waarre Formations. The study was designed to:

1. ascertain if sediment provenance was different for the Waarre A and Waarre C sands in the central-western Otway Basin,

2. determine if Waarre sands at Bridgewater Bay-1 had a different provenance to Waarre sands in Normanby-1 and Breaksea Reef-1

3. identify the depositional environment(s) and sediment provenance of the Banoon Member equivalent,

4. comment on the depositional environments of the Waarre A and C compared to the eastern Otway Basin, and

5. characterise the reservoir quality of the Waarre C and Flaxman sands in south-eastern SA.

The client supplied the following items to aid the petrology interpretation:

1. a revised unpublished biostratigraphic column from Partridge (2005),
2. wireline logs and cuttings descriptions of the relevant interval in Bridgewater Bay-1 and Caroline-1,
3. a summary of the Sherbrook Group intersected in Mt Salt-1, core descriptions of the Banoon Member equivalent sands at Mt Salt-1, and
4. a petrological description of the Banoon Member equivalent sands in Argonaut-1 at 12,139ft from an unpublished report by Mobil (1995)

Stratigraphic interpretations were provided by Essential Petroleum for each sample and the relevant palynology data available in the SA wells. All thin sections from PIRSA and AGSO were briefly studied for Mt Salt-1 and Breaksea Reef-1 prior to selecting new samples. These original thin sections were not used for detailed descriptions because of poor preparation, lack of staining for both calcite and dolomite, and the AGSO thin sections are held together with sticky tape. Where appropriate comments are included in the discussion based on these additional samples. Thin sections from Argonaut-1 held by PIRSA were found to be suitable and have been included in this study. PGPC sampled the South Australian wells in this study on behalf of Essential Petroleum. The petrology services listed below (Table 1) were provided by PGPC.

TABLE 1 SUMMARY OF SAMPLES & SERVICES

Well	Sample type	Depth (m/ft)	Unit	TS description	Visual estimate of composition
Breaksea Reef-1	cuttings	3636-3639m	Flaxman (Banoon Member)	*	*
Breaksea Reef-1		3645-3648m	Flaxman (Banoon member)	*	*
Breaksea Reef-1 ST2		4371-4374m	Waarre C	*	*
Breaksea Reef-1 ST3		4443-4446m	Waarre?	*	*
McNamara Park-1	cuttings	1668-1671m	Waarre C	*	*
		1923-1926m	Waarre A	*	*
Mt Salt-1	core	2716.60m	Flaxman (Banoon Member)	*	*
		2718.70m	Flaxman (Banoon Member)	*	*
Lake Bonney-1	cuttings	7540-7570ft	Waarre Cb?	*	*
		8600-8610ft	Waarre A?	*	*
		8680-8690ft	Waarre A?	*	*
Caroline-1	cuttings	8180-8210ft	Waarre Cb?	*	*
		8450-8460ft	Waarre Cb?	*	*
		9300-9310ft	Waarre A	*	*
Najaba-1	swc	2825m	Flaxman	*	*
Fahley-1 ST2	cuttings	2895-2900m	Flaxman	*	*
		3135-3140m	Waarre Cb	*	*
Bridgewater Bay-1	cuttings	4100-4110m	Waarre	*	*
		4140-4150m	Waarre	*	*
Argonaut-1	core	11,666ft	Flaxman (Banoon Member)	*	*
	core	12,142ft	Flaxman	*	*

3. METHODS

Thin section

Core plugs, sidewall core and cuttings were impregnated with araldite prior to thin section preparation by Petrographic Technical Services Pty Ltd. Blue dye was used in the araldite to facilitate description of porosity and permeability. Thin sections were prepared using standard techniques to produce a thickness of 30 microns (Adams *et al*, 1984). All samples were half stained with alizarin red-S and potassium ferricyanide to differentiate the carbonate species (Adams *et al*, 1984). Thin sections were systematically scanned to determine lithology, composition, porosity and textural relationships. Siliciclastics have been classified according to guidelines by Folk (1974) and carbonates using the nomenclature of Tucker (2001). Grain morphology (both sphericity and roundness) was estimated by comparison with charts in Pettijohn *et al* (1987), grain fabric (packing and texture) from the diagram in Tucker (2001) and sorting from diagrams by Harrell (1984). All percentages of composition given in the thin section descriptions are visual estimates (Terry & Chilingar, 1955) not point counts. Estimates of the relative percentages of different types of cuttings were determined from counting 100 chips.

4. PETROLOGY

4.1 Breaksea Reef-1, cuttings, depth 3636 - 3639m, Banoon Member equivalent

Rock types present:

1. Sandy mudstone (24%)

Sandy mudstone (13%) contains silt to very fine detrital grains floating in a matrix of anhedral brown clay (Fig. 1a) with rare stringers of opaque organic matter. There are chips with distinct laminae of detrital grains. Detrital grains are typically angular to subangular with low sphericity and are comprised of quartz, dusty & fresh feldspars, chert, quartzite, muscovite & zircon. Authigenic minerals of very fine sand size glauconite, grain replacing chlorite and pyrite framboids.

Minor chips of sandy mudstone/muddy sandstone (11%) contain medium to very coarse sand size detrital grains (Fig. 1b). These grains are composed of subangular monocrystalline and polycrystalline quartz, feldspars replaced by kaolin & possible quartzite (partially replaced by chlorite). Matrix is anhedral brown clay with silt to fine sand size detrital grains & stringers of organic matter. Suturing & concavo-convex grain contacts indicate moderate mechanical compaction.

2. Mudstone (7%)

Anhedral very dark brown clay matrix with rare silt size grains of quartz has been extensively replaced by pyrite.

3. Single grains (68%)

Fine sand to granule size grains of monocrystalline quartz (47%) & polycrystalline (13%) quartz with straight or sutured crystal boundaries are commonly crushed. Rare examples have a cement of clear carbonate spar (6%) which in the stained part of the section is ferroan calcite (Fig. 1c). Coarse sand size corroded K-feldspars (2%) either lack twinning or have perthite twinning. One very coarse polycrystalline quartz grain has been partially replaced along crystal boundaries by pyrite. Another polycrystalline grain is surrounded by a cement of Fe rich anhedral microspar (?siderite) that is zoned. Other chips are completely composed of anhedral Fe rich microspar.

Rock type thought to be representative of this depth:

The dominance of single grains in these cuttings would suggest that these have been derived from a quartz rich coarse grained, moderately sorted sandstone (?subarkose) that was disaggregated by sampling. It is possible that the sandstone had minor ferroan calcite cement and is interbedded with more muddy sediment (sandy mudstone).

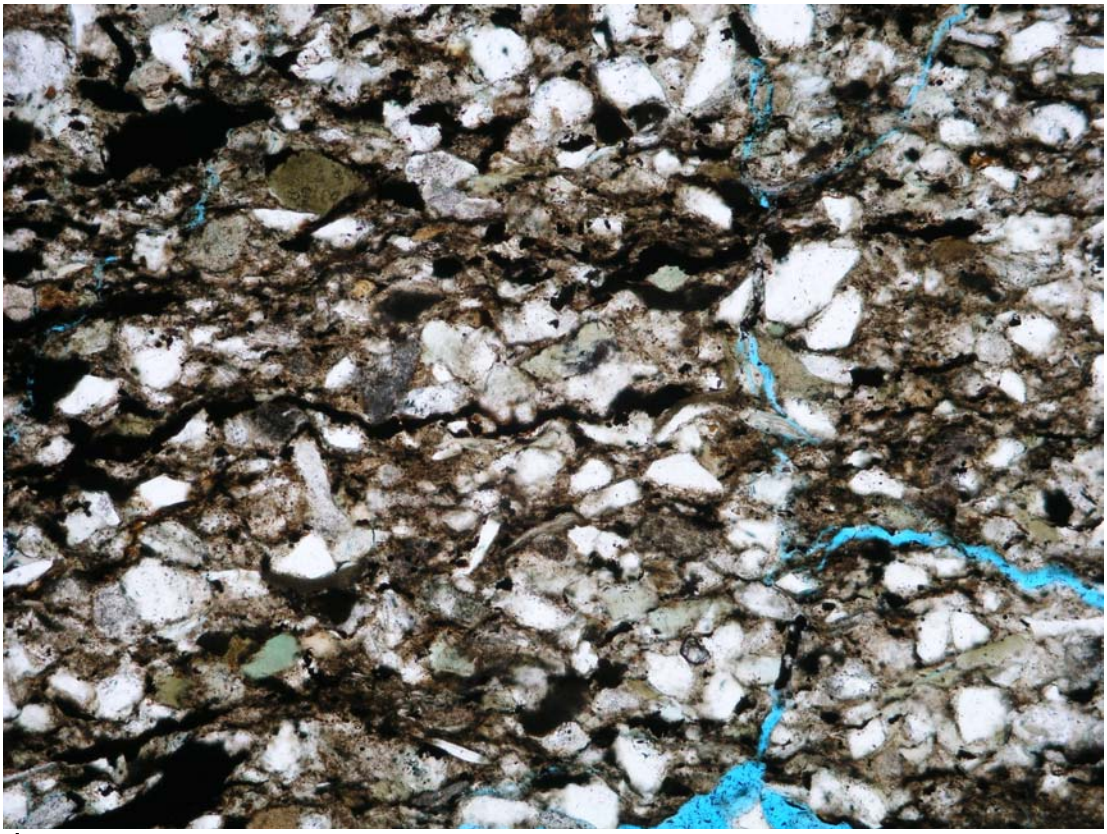

Figure 1a

Fine grained sandy mudstone with stringers of opaque organic matter. Note the bright green grain of glauconite. Breaksea Reef-1, cuttings, depth 3636-3639m. Plane light. Horizontal field of view 1.30mm.

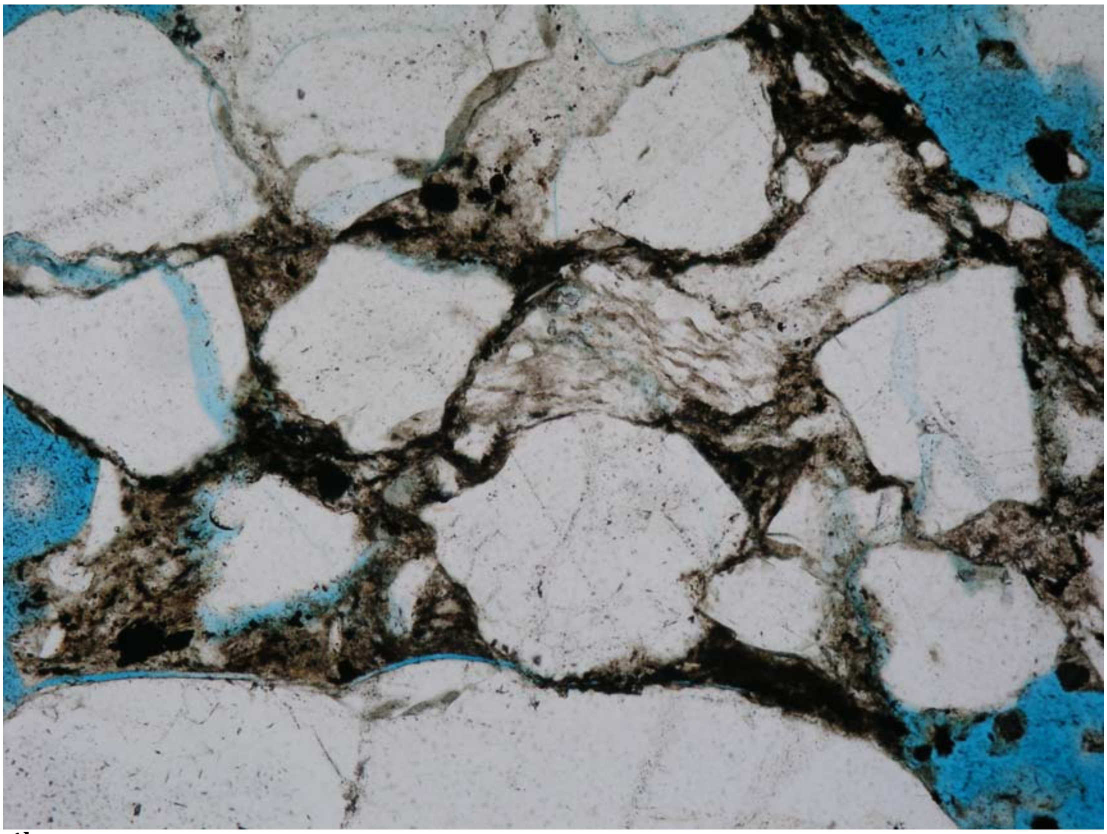

Figure 1b

Chip of medium to coarse grained sandy mudstone/muddy sandstone which shows moderate compaction. Breaksea Reef-1, cuttings, depth 3636-3639m. Plane light. Horizontal field of view 1.30mm.

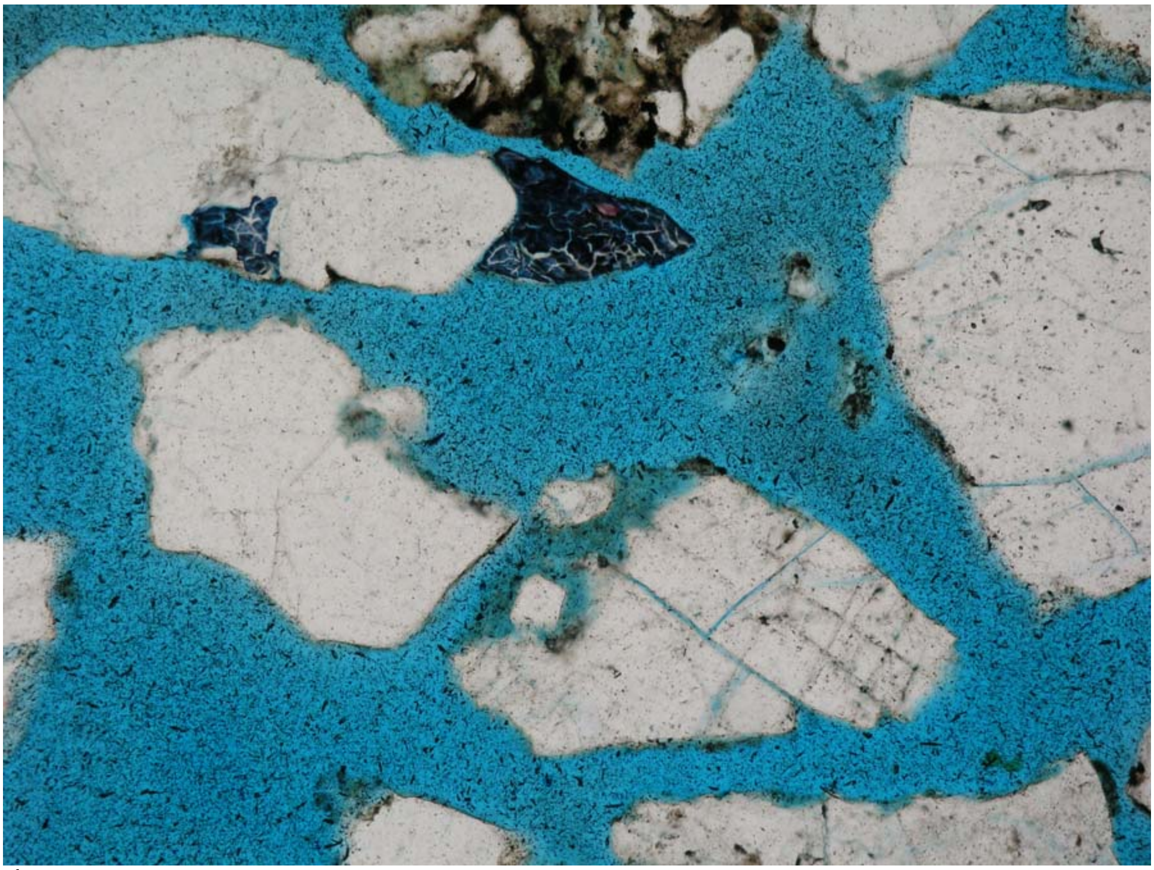

Figure 1c

Fractured and crushed grains of fine to granule size quartz are dominant in these cuttings. Rare examples were cemented and partially replaced by ferroan calcite (stained dark blue). Breaksea Reef-1, cuttings, depth 3636-3639m. Plane light. Horizontal field of view 1.30mm.

4.2 Breaksea Reef-1, cuttings, depth 3645 - 3648m, Banoon Member equivalent

Rock types present:

1. Sandy mudstone (60%)
Silt to fine sand size grains float in anhedral brown clay matrix. These chips of fine grained mudstone are dominant in the cuttings (56%). Description as per cuttings from 3639m. Very rare (4%) chips of coarse sandy mudstone may also be contaminants at this depth.

2. Carbonate cemented sandstone (7%)
Coarse to very coarse sand size subrounded grains of monocrystalline and polycrystalline quartz are cemented and partially replaced by dusty Fe rich carbonate spar. These chips represent approximately 2% of the cuttings. Staining indicates the carbonate is ferroan calcite but there are suggestions of minor calcite cement prior to the ferroan phase. Isolated chips of clear twinned carbonate spar. Rarely single crystals of blocky pyrite are evident in the clear spar. Other chips (5%) of very fine sand size quartz cemented by Fe rich microspar could be downhole contaminants.

3. Single grains (32%)
Single grains are dominated by medium to very coarse sand size grains of monocrystalline and polycrystalline quartz. The latter have straight crystal boundaries and minor replacement by pyrite. Rare euhedral terminations might indicate the presence of quartz overgrowths.

4. Fine grained ?subarkose (trace)
There is one chip of fine grained, moderately well sorted ?subarkose (Fig. 2). Detrital grains are subangular with low sphericity and range from silt to medium sand in size. The grain supported texture has close packing with tangential grain contacts dominant. There are no intergranular pores apparent. Framework grains are comprised of monocrystalline quartz, polycrystalline quartz has either straight or sutured crystal boundaries, partially corroded K-feldspars that lack twinning and bent biotite flakes up to 0.27mm in length. Biotite has been replaced by chlorite and there are traces of chlorite on grain margins. Ferroan calcite spar has replaced grains and there are pyrite framboids and minute blocky pyrite crystals replacing grains. Deformed oxidised grains of unknown origin are also apparent.

Rock type thought to be representative of this depth:
The dominant cuttings are composed of fine grained sandy mudstone which could be a contaminant at this depth since there is no lithological difference from cuttings at 3639m. The only new lithology at this depth which does not appear to be a downhole contaminant is the fine grained ?subarkose.

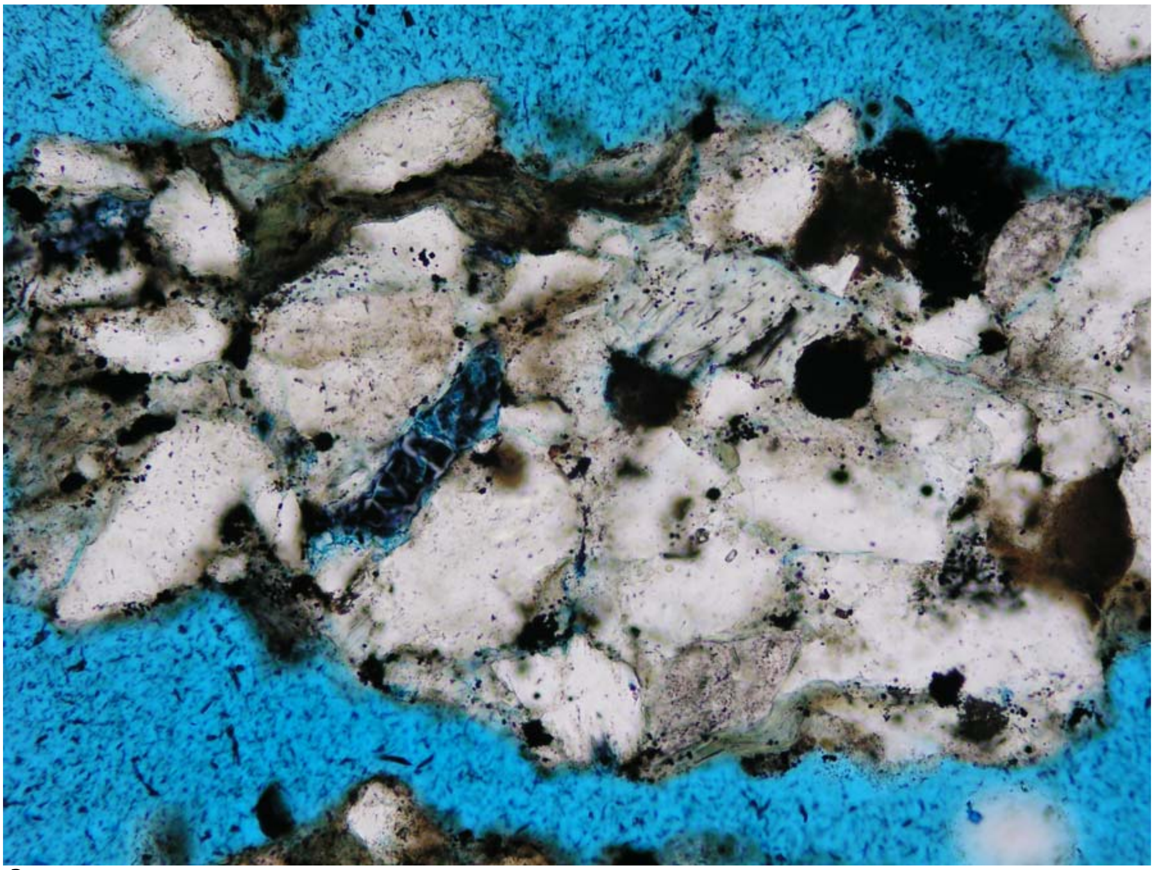

Figure 2
Chip of fine grained, subarkose with minor grain replacing ferroan calcite spar (dark blue) and pyrite (opaque). Breaksea Reef-1, cuttings, depth 3645 - 3648m. Plane light. Horizontal field of view 0.65mm.

4.3 Breaksea Reef-1 ST2, cuttings, depth 4371 - 4374m, Unit C Waarre Formation

Rock types present:

1. Fine grained sandstone (17%)
Chips of this sandstone are typically composed of fine grained, moderately well sorted, mineralogically mature sublitharenite. Grain size ranges from very fine to medium grained sand and grains are subangular with moderate sphericity. Texturally the sandstone is grain supported with moderately close packing characterised by tangential, concavo-convex & rare sutured grain contacts. Rare intergranular pores, grain size dissolution pores & corroded feldspars that have produced honeycomb pores. Framework grains are dominated by monocrystalline quartz with rare examples of polycrystalline quartz with straight crystal boundaries, fresh feldspars with simple twinning, corroded K-feldspars, lithics of dusty chert, ?granite, quartzite & micaceous schist, bent biotite & accessory silt size rutile. Rounded fine sand size grains with wormy texture are brown in colour & could represent oxidised glaucony. Deformed bright green grains with a fibrous texture have been replaced by chlorite. Chips are cemented by interlocking quartz overgrowths and minor twinned ferroan calcite spar has filled pores after the quartz. Spar has also partially replaced feldspars. Trapped within the quartz overgrowths there are remnants of chlorite rims. Blocky and framboidal pyrite is scattered along grain margins (where it could have replaced the chlorite rims) & has partially replaced grains.

2. Mudstone to sandy mudstone/ muddy sandstone (11%)
Matrix in the mudstone consists of anhedral dark brown clay with traces of organic matter. Minor angular silt to very fine sand floats within the matrix.

Sandy mudstone contains up to 10% detrital grains that are very fine to fine sand in size. These grains are composed of monocrystalline & polycrystalline quartz, chert & glaucony.

3. Fe rich carbonate (trace)
Crushed chips of Fe rich microspar

4. Single grains (33%)
Fine to coarse grained monocrystalline and polycrystalline quartz, chert, one fine grain of fresh plagioclase, grains of dusty K-feldspar, intergrowth of feldspar + quartz possibly representing a granitic lithic & silt size zircon.

5. Crushed grains & drilling mud contaminant (38%)

Rock type thought to be representative of this depth:
Brief observations of cuttings samples from the PIRSA collection indicate that shallower samples are dominated by mudstone and silty/sandy mudstone. Therefore these lithologies are probably a contaminant at this depth. The most likely rock type to be representative of this depth is the fine grained sublitharenite which could have been the source for most of the single grains. Relative lack of lithics, especially volcanics might suggest this is Unit C of the Waarre Formation.

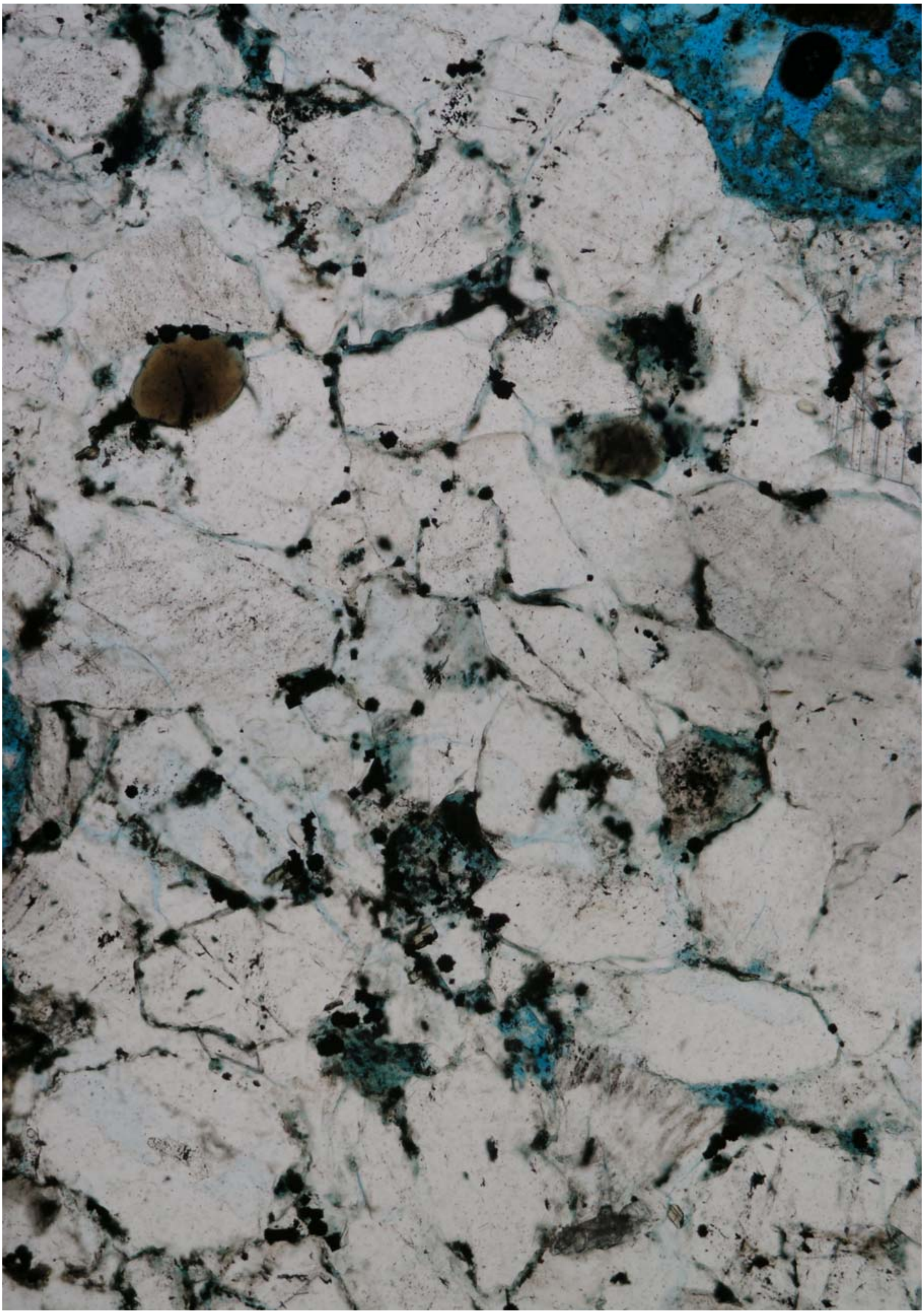

Figure 3

General field of view illustrating the poor preservation of porosity (blue) within this fine grained sublitharenite chip. Note the oxidised grains of glaucony (brown) and concentration of pyrite (opaque) along grain margins. Breaksea Reef-1 ST2, cuttings, depth 4371 - 4374m. Plane light. Horizontal field of view 1.30mm.

4.4 Breaksea Reef-1 ST3, cuttings, depth 4443 - 4446m, Unit C Waarre Formation

Rock types present:

1. Fine to medium grained sandstone (12%)
Typically the texture and composition are very similar to the sandstone described from 4374m but there are slightly more lithics, especially chert, and rare grains have been replaced by kaolin booklets. One chip of medium grained sand includes a chloritised grain which might have been a volcanic lithic (Fig. 4a). There is one chip which shows that the fine grained sandstone could be interbedded with sandy mudstone (Fig. 4b). Contact between the beds is planar and sharp and there has been significant compaction in the muddy bed.

2. Very fine to medium grained carbonate cemented sandstone (6%)
It is impossible to know whether this lithology is part of a continuum with the fine grained sandstone. Chips are composed of a few grains of embayed monocrystalline quartz and rare chert cemented by Fe rich anhedral spar (Fig. 4b). The spar did not respond to staining and therefore is probably either siderite or ankerite in composition. Trace amounts of minute blocky pyrite are scattered throughout the spar.

3. Silty/ sandy mudstone (24%)
Silty to sandy mudstone is the dominant lithology present. Detrital grains are commonly angular with low sphericity and composed of monocrystalline quartz, with rare polycrystalline quartz, dusty feldspars, chert, quartzite, muscovite and biotite. One chip contains a calcareous microfossil filled with pyrite. Grain replacing chlorite, deformed grains of bright green glaucony with wormy texture, framboidal and blocky pyrite, anhedral matrix replacing ?siderite and rare grain replacing ferroan calcite spar are evident. Matrix of anhedral brown clay & stringers of opaque organic matter.

4. Single grains (57%)
Silt to very coarse sand size grains (average medium) of monocrystalline quartz (56%), with trace amounts of polycrystalline quartz (dominantly straight crystal boundaries & up to very coarse sand size), corroded K-feldspars, fresh plagioclase (andesine), chert, quartzite, carbonate spar, muscovite, tourmaline & zircon.

One coarse grain of monocrystalline quartz has a quartz overgrowth which is inhibited on one side of the grain by a partial chlorite rim (Fig. 4d). The overgrowth formed prior to a cement of twinned carbonate spar. Other single grains also have either chlorite rims or quartz overgrowths.

Rock type thought to be representative of this depth:
The relative abundance of single grains might indicate the disaggregation of quartz rich medium grained sandstone at this depth. Tentative identification of one volcanic lithic and the relative increase in chert might indicate this is Unit A of the Waarre Formation. This sandstone might be interbedded with finer sandstones and silty/sandy mudstones.

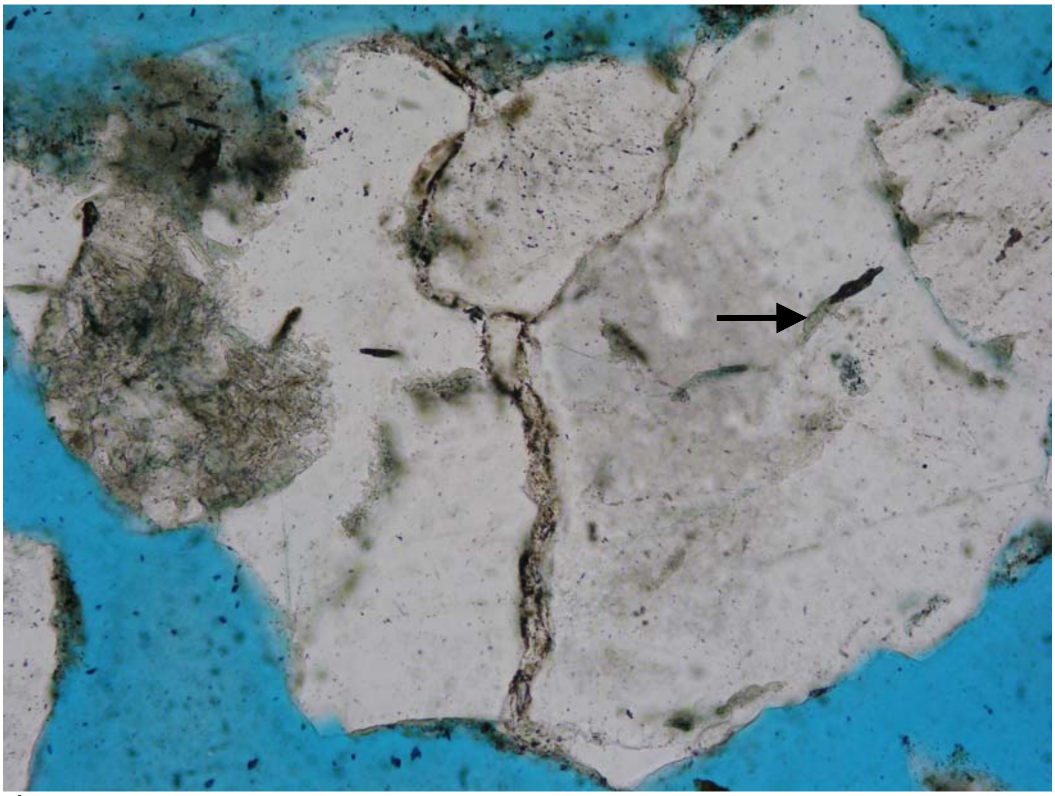

Figure 4a

Medium sand size grains of monocrystalline and polycrystalline quartz have partial rims of chlorite (arrow) and one grain (LHS) has been extensively replaced by chlorite. The latter contains feldspar laths which might suggest it was a volcanic lithic. Breaksea Reef-1, cuttings, depth 4443-4446m. Plane light. Horizontal field of view 0.65mm.

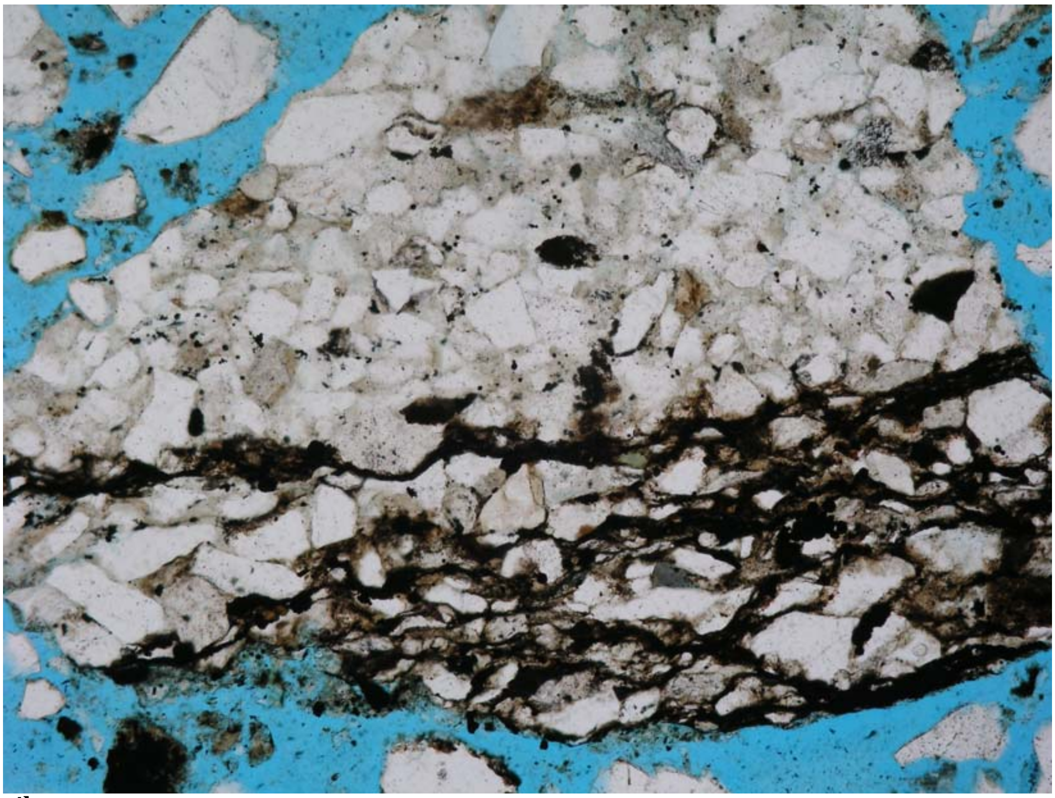

Figure 4b

Chip illustrating the contact between fine grained sublitharenite and sandy mudstone. The latter could be laminae within the sandstone. Breaksea Reef-1, cuttings, depth 4443-4446m. Plane light. Horizontal field of view 1.30mm.

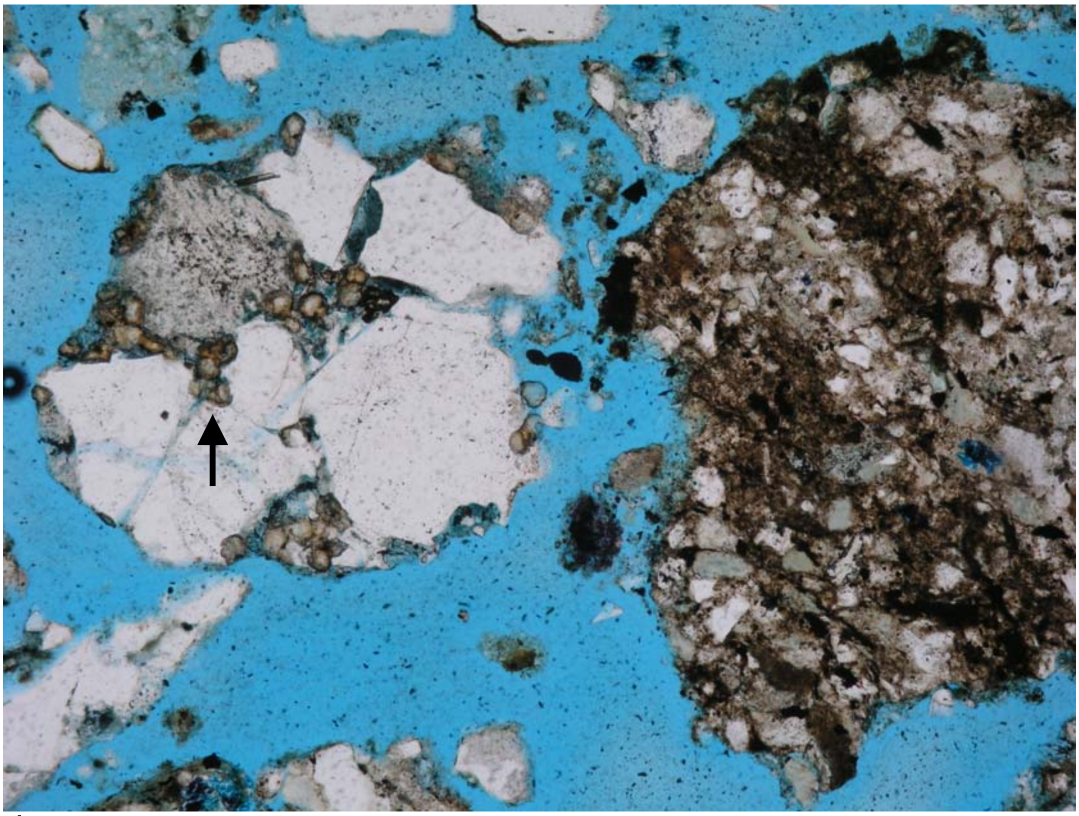

Figure 4c

An example of the carbonate cemented sandstone showing the very anhedral nature of the spar (arrow). The adjacent chip is composed of silty mudstone. Breaksea Reef-1, cuttings, depth 4443-4446m. Plane light. Horizontal field of view 1.30mm.

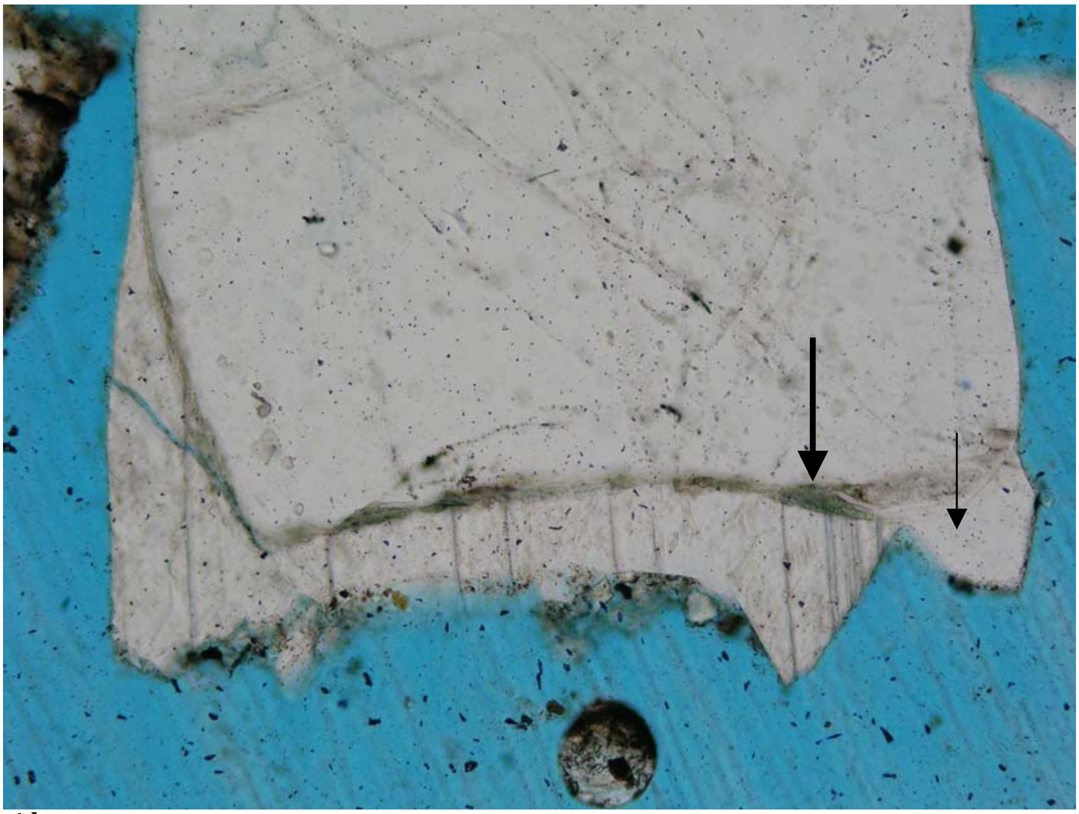

Figure 4d

This coarse grain of quartz has a partial chlorite rim (large arrow) but where it is absent there is a prismatic quartz overgrowth (small arrow). Clear twinned carbonate spar postdates the chlorite. Breaksea Reef-1, cuttings, depth 4443-4446m. Plane light. Horizontal field of view 0.65mm.

4.5 McNamara Park-1, cuttings, depth 1668 - 1671m, Waarre Formation Unit C?

Rock types present:

1. Silty to sandy mudstone (6%)
Silty mudstone has a matrix of brown anhedral clay and stringers of opaque organic matter. Silt size detrital grains float within the matrix.

Sandy mudstone contains silt to coarse sand size grains of monocrystalline and polycrystalline quartz with sutured grain contacts where organic matter is present. Fe rich microspar (?siderite) has partially replaced the clay matrix.

2. Siderite cement (2%)
Chips of Fe rich anhedral microspar are probably composed of siderite. There are examples which show zoning within the cement and partial replacement by pyrite. Silt to medium sand size grains of quartz float in the carbonate cement.

3. Single grains (91%)
Single grains are subrounded to rounded with low to moderate sphericity. Average grain size is approximately coarse sand with a range from fine to very coarse sand. Dominantly monocrystalline quartz (70%) with minor polycrystalline quartz (18%) that has either straight or sutured crystal boundaries. Rare coarse grains of chert (2%), ?shale (cross cut by veins of polycrystalline quartz), quartzite (trace), medium sand size ?granite (intergrowth of K-feldspar + polycrystalline quartz), dusty corroded and fresh medium to coarse sand size feldspars (4%) with remnants of tartan twinning, fine sand size zircon (trace) and silt size tourmaline (trace). Coarse sand size grains have been replaced by pyrite.

The only evidence of cement is the rare preservation of quartz overgrowths outlined by euhedral terminations and dust rims, and blocky pyrite attached to grain margins.

4. Contaminant
Drilling mud and crushed material

Rock type thought to be representative of this depth:
Based on the abundance of single grains it would appear that a medium to coarse grained, moderately well sorted subarkose has been disaggregated. The sandstone is probably cemented by quartz and pyrite but these are only minor cements and would not have filled intergranular pores.

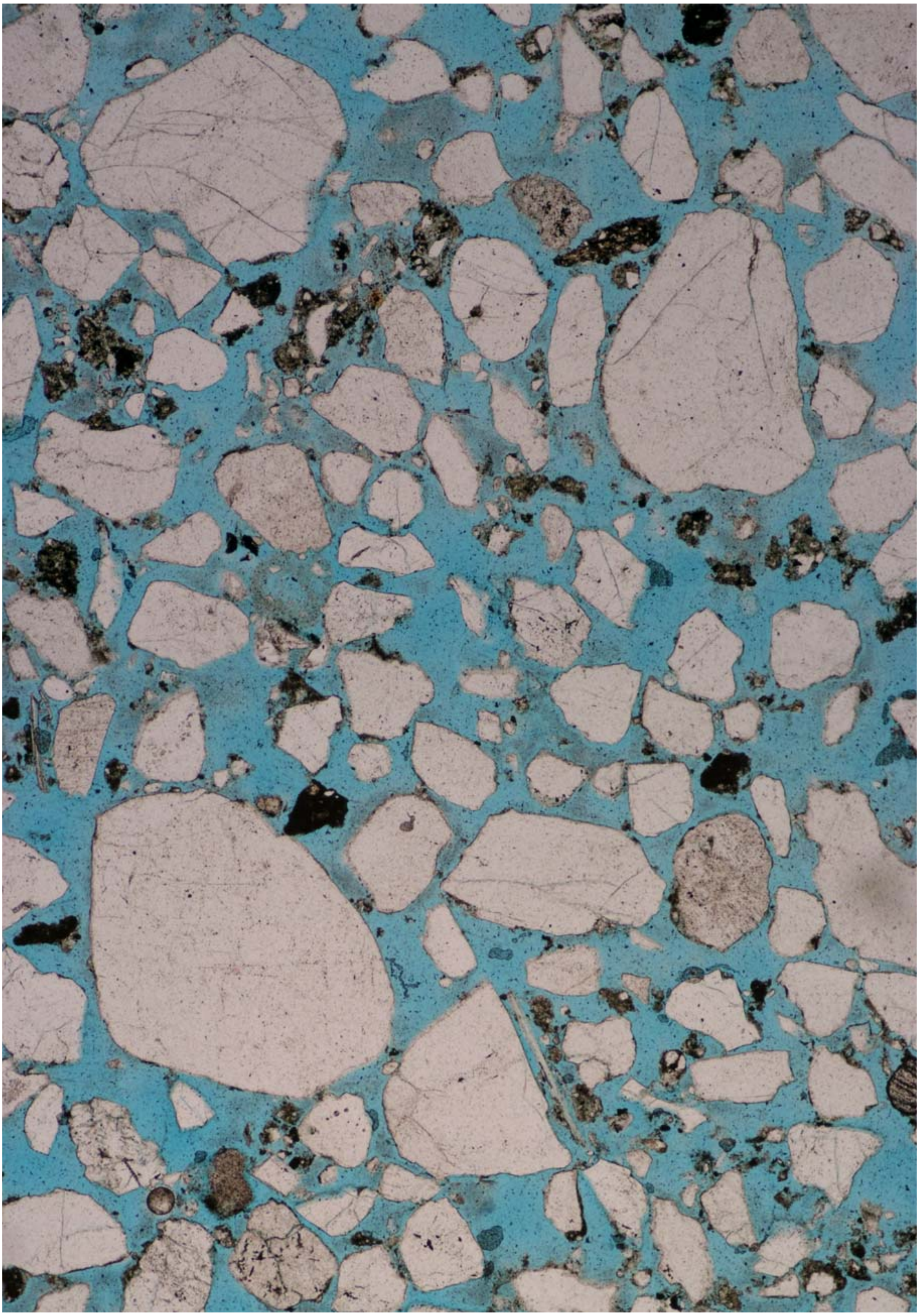

Figure 5
General field of view demonstrating the abundance of single grains in these cuttings. Minor drilling mud and silty mudstone (brown) is also apparent. Note the rounded nature of the very coarse quartz grains. McNamara Park-1, cuttings, depth 1668-1671m. Plane light. Horizontal field of view 3.25mm.

4.6 McNamara Park-1, cuttings, depth 1923 - 1926m, Waarre Formation Unit A

Rock types present:

1. Single grains (98%)

Single grains of monocrystalline (59%) and polycrystalline (30%) quartz range from silt to granules in size. Although average grain size is approximately coarse sand it would appear that the grain size distribution is bimodal with peaks near fine-medium sand and very coarse to granule size grains. Polycrystalline quartz is less abundant and is dominated by grains with straight crystal boundaries. Typically grains were subangular to subrounded with low to moderate sphericity prior to fracturing during sampling. Other single grains include lithics (7%) of quartzite, chert, chalcedony, micaceous schist & ?shale, sericitised & corroded K-feldspars (2% - rarely with remnants of tartan twinning), tourmaline (trace), silt size zircon (trace) and two grains with an open spherulitic texture. The latter are composed of radiating feldspar laths but the intercrystal material has been dissolved. It is possible that these grains had an igneous origin.

Rare euhedral terminations on the grains of monocrystalline quartz indicate the presence of quartz overgrowths. Isolated intragranular pores are evident in the grains of quartzite. One very coarse grain of monocrystalline quartz has Fe rich carbonate spar attached to one side.

2. Carbonate cemented fine sandstone (1%)

There three chips of this lithology which is a fine grained, well sorted, subarkose to quartzarenite. Detrital grains are subangular to subrounded with low sphericity and range in size from fine to medium sand. Texturally the sandstone is grain supported with moderately open packing. There are honeycomb pores, intragranular pores and micropores apparent. Framework grains are composed of monocrystalline quartz, polycrystalline quartz with straight crystal boundaries, dusty corroded K-feldspar & lithics of quartzite & chert. Authigenic minerals of grain replacing kaolin and pervasive pore filling and grain replacing poikilotopic ferroan calcite spar.

3. Pyrite cemented fine sandstone (trace)

Remnants of fine quartz grains float within and have been replaced by pyrite cement. These chips might represent nodular cement within a sandstone.

4. Contaminants

Crushed grains and drilling mud.

Rock type thought to be representative of this depth:

The abundance of single grains with two different grain sizes might suggest that either a very poorly sorted coarse sandstone or beds of fine-medium grained and very coarse-granule size sandstones were representative of this depth. In the fine grained sandstone there could be localised cements of ferroan calcite and pyrite. The relative abundance of lithics might suggest that the sandstones were sublitharenites. There is a significant increase in the proportion of polycrystalline quartz compared to sandstones at 1671m but only a slight increase in the number of lithics.

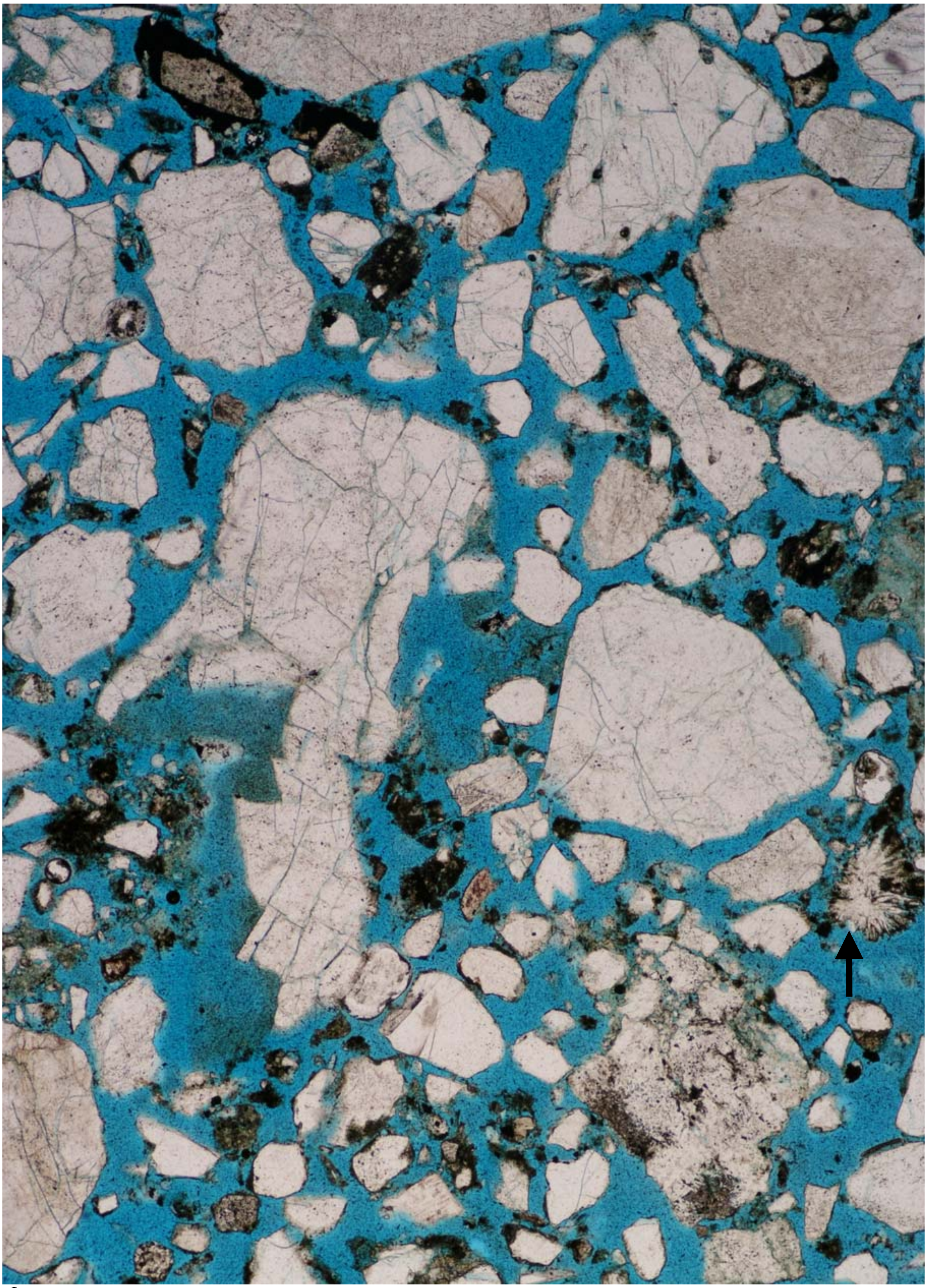

Figure 6

Single grains in these cuttings are a mixture of two different grain sizes as seen in this field of view. Note the grain with spherulitic texture (arrow) that has minor associated drilling mud (brown). McNamara Park-1, cuttings, depth 1923-1926m. Plane light. Horizontal field of view 3.25mm.

4.7 Mt Salt-1, core 30, depth 2716.6m, Flaxman (Banoon Member)

Rock classification: **Sublitharenite**

Texture:

Sedimentary structures: laminae outlined by changes in grain size have been disrupted possibly due to bioturbation

Average grain size: coarse sand (~0.65mm), but probably bimodal distribution with peaks near medium sand & very coarse sand

Range in grain size: fine sand to granules

Roundness / sphericity: subangular to subrounded with low to moderate sphericity

Sorting: moderately sorted

Texture: grain supported

Packing / grain contacts: open packing/ point & tangential grain contacts

Pore types: primary intergranular pores dominant (possibly good permeability), grain size dissolution pores, honeycomb pores where feldspars partially corroded, grain fracturing is probably an artifact of sampling, micropores could be associated with authigenic chlorite, extensive invasion by drilling mud

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries up to granules in size, partially corroded K-feldspars either lack twinning or have perthite twinning, lithics of chert, quartzite, micaceous schist, ?pyrophyllite, ?granite (quartz + feldspar), deformed mudstone (illitic clay with blocky organic matter) & highly altered grains that might have been ?volcanic lithics, bent & splayed biotite flakes up to 0.6mm in length, rare muscovite flakes up to 0.25mm in length, accessory medium sand size tourmaline & fine sand size zircon

Matrix: blocky opaque organic matter

Authigenic minerals: chlorite rims up to 10 microns thick are comprised of platelets oriented perpendicular to the detrital grain, these rims are absent at some grain contacts, chlorite has also partially replaced inclusions within quartz grains, pale green coarse grains with irregular shaped oxidised cores might have been composed of glauconite & represent incipient ooids, rare minute pyrite framboids associated with the organic matter

Visual Estimate of Composition			Volume %
Framework grains	Quartz	monocrystalline	59
		polycrystalline	7
	K-Feldspar		3
	Lithics	igneous	1
		metamorphic	3
		sedimentary	1
	Biotite		1
	Muscovite		tr
	Accessory minerals		tr
Matrix	Organic matter		tr
Authigenic minerals and cements	Glaucony		1
	Chlorite		5
	Pyrite		tr
Porosity	Intergranular		15
	Dissolution		3
	Micropores		tr

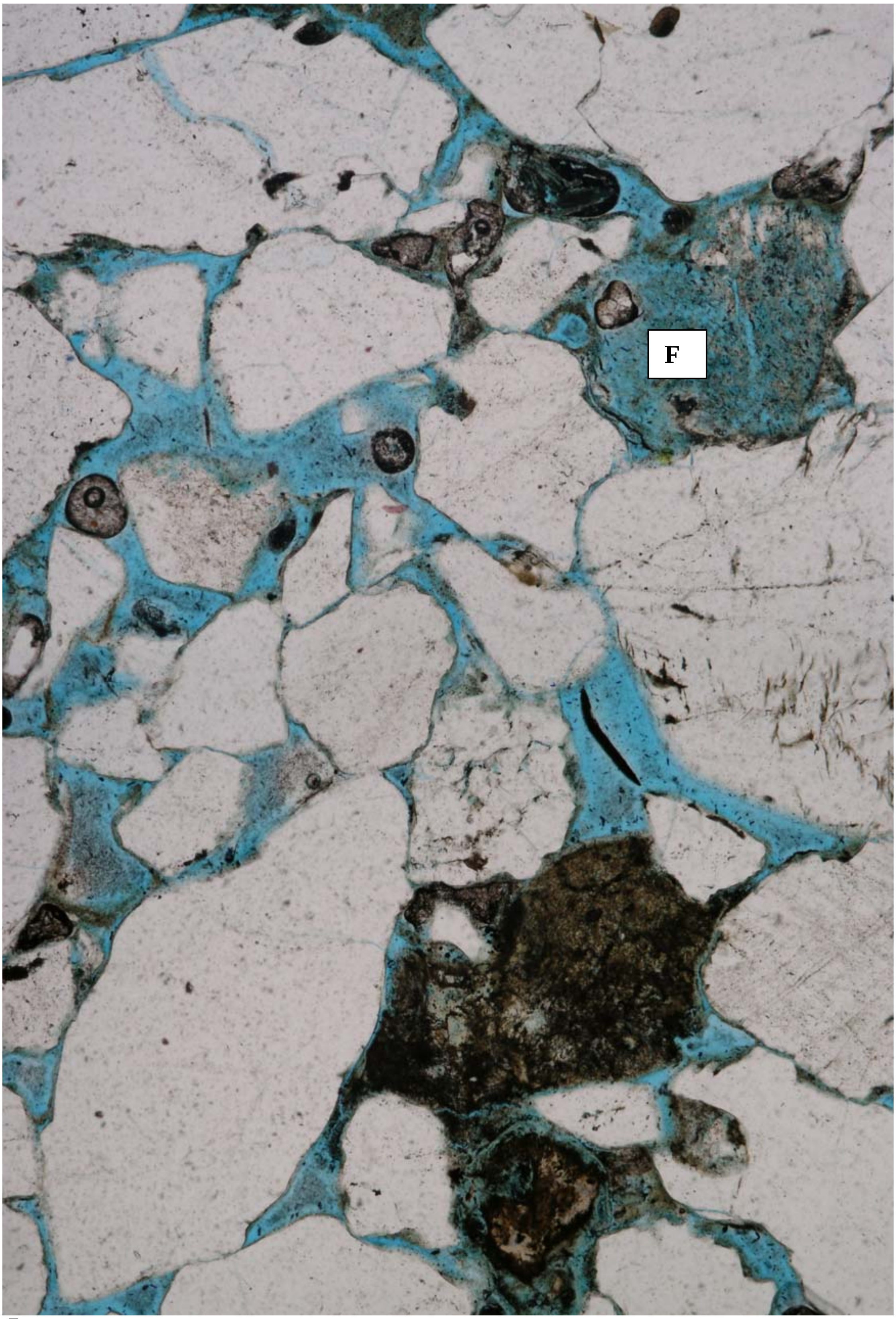

Figure 7a

General field of view illustrating the dominance of primary intergranular pores with minor partial corrosion of feldspars (F). Altered lithics and grains of glaucony appear dark brown. Mt Salt-1, core 30, depth 2716.6m. Plane light. Horizontal field of view 1.30mm.

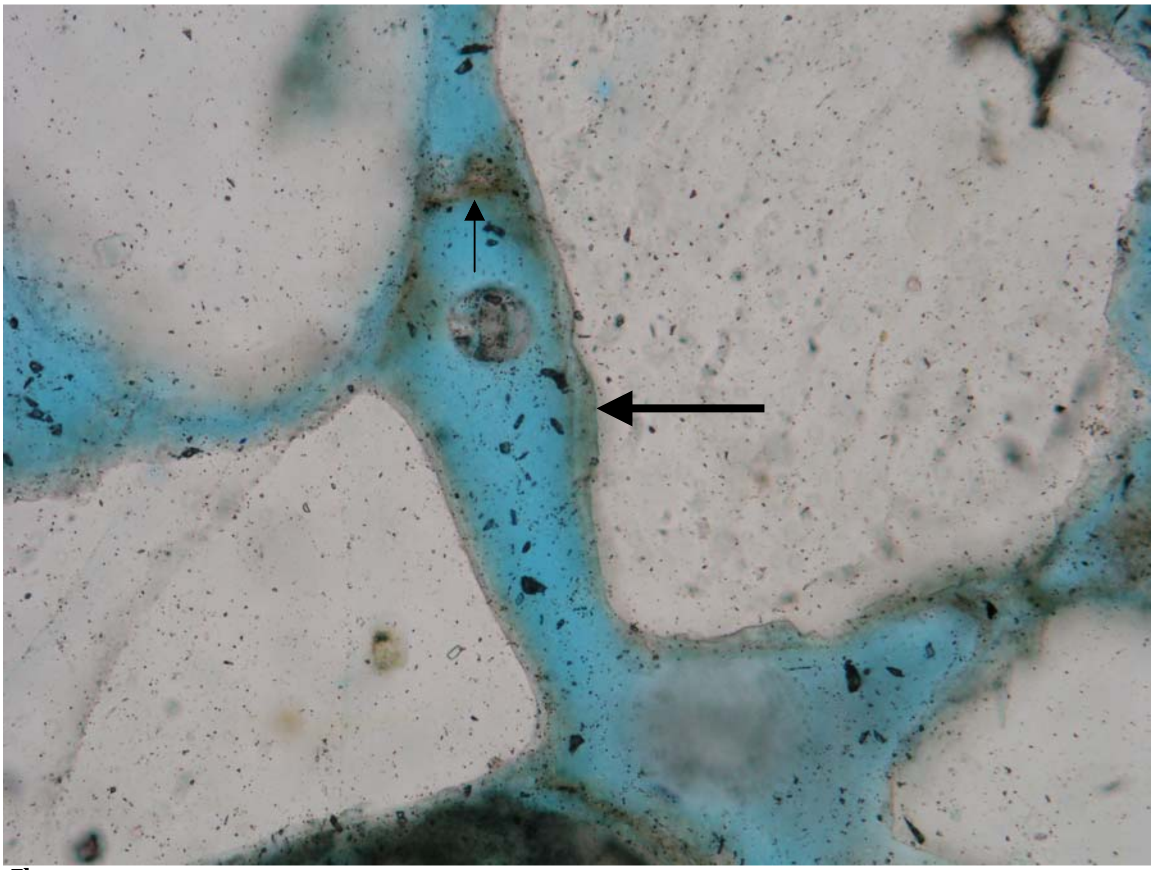

Figure 7b

Closer view showing the irregular thickness of chlorite rims (large arrow). These rims formed prior to the invasion of drilling mud that has bridged pores (small arrow). Mt Salt-1, core 30, depth 2716.6m. Plane light. Horizontal field of view 0.33mm.

4.8 Mt Salt-1, core 30, depth 2718.7m, Flaxman (Banoon Member)

Rock classification: **Carbonate cemented sublitharenite**

Texture:

Sedimentary structures: none apparent but lack of grain orientation might suggest bioturbation, there are isolated grains of very coarse sand (nearly granule size)
Average grain size: medium sand (~0.30mm)
Range in grain size: very fine to very coarse sand
Roundness / sphericity: subangular with low sphericity
Sorting: moderately well sorted
Texture: grain supported
Packing / grain contacts: moderately open / point & tangential grain contacts
Pore types: intergranular pores, grain size dissolution pores, rare honeycomb pores where feldspars are corroded & intragranular pores where inclusions have been dissolved from quartz, micropores associated with kaolin

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with straight & sutured crystal boundaries, relatively fresh K-feldspars with perthite & simple twinning, other K-feldspars are corroded & lack twinning, lithics of chert, deformed mudstone, quartzite, micaceous schist, pyrophyllite, ?granite & highly altered volcanics (laths replaced by chlorite & pyrite), remnants of biotite & muscovite flakes up to 0.70mm in length, accessory silt to very fine sand size ?monazite, sphene & rutile, fine sand size opaques & zircon, & fine to medium sand size tourmaline

Authigenic minerals: fine sand size greenish altered grains with shrinkage cracks were probably composed of glauconite, isolated grains replaced by chlorite & rare examples of grains partially rimmed by chlorite, irregular, rhombohedral & prismatic quartz overgrowths formed prior to carbonate, pervasive pore filling & grain replacing (including biotite & feldspars) euhedral blocky poikilotopic ferroan calcite spar, grain replacing & pore filling kaolin booklets are typically up to 10 microns in diameter but where micas have been replaced booklets are much larger, framboidal & blocky pyrite has replaced grains (especially chloritised & oxidised grains) & occurs as single crystals along grain margins, pyrite also has partially replaced feldspars & quartz along crystal boundaries & possible cleavage traces to produce very irregular spider-web like patterns, rare oxidised grains of unknown origin & irregular oxidised patches on grain margins

Visual Estimate of Composition			Volume %
Framework grains	Quartz	monocrystalline	47
		polycrystalline	2
	Feldspar		3
	Lithics	igneous	tr
		metamorphic	2
		sedimentary	1
	Mica	muscovite	1
		biotite	1
	Accessory minerals		1
Authigenic minerals and cements	Glauconite		tr
	Chlorite		tr
	Quartz		5
	Ferroan calcite		20
	Pyrite		6
	Kaolin		1
	Oxide		2
Porosity	Intergranular		5
	Dissolution		2
	Micropores		tr

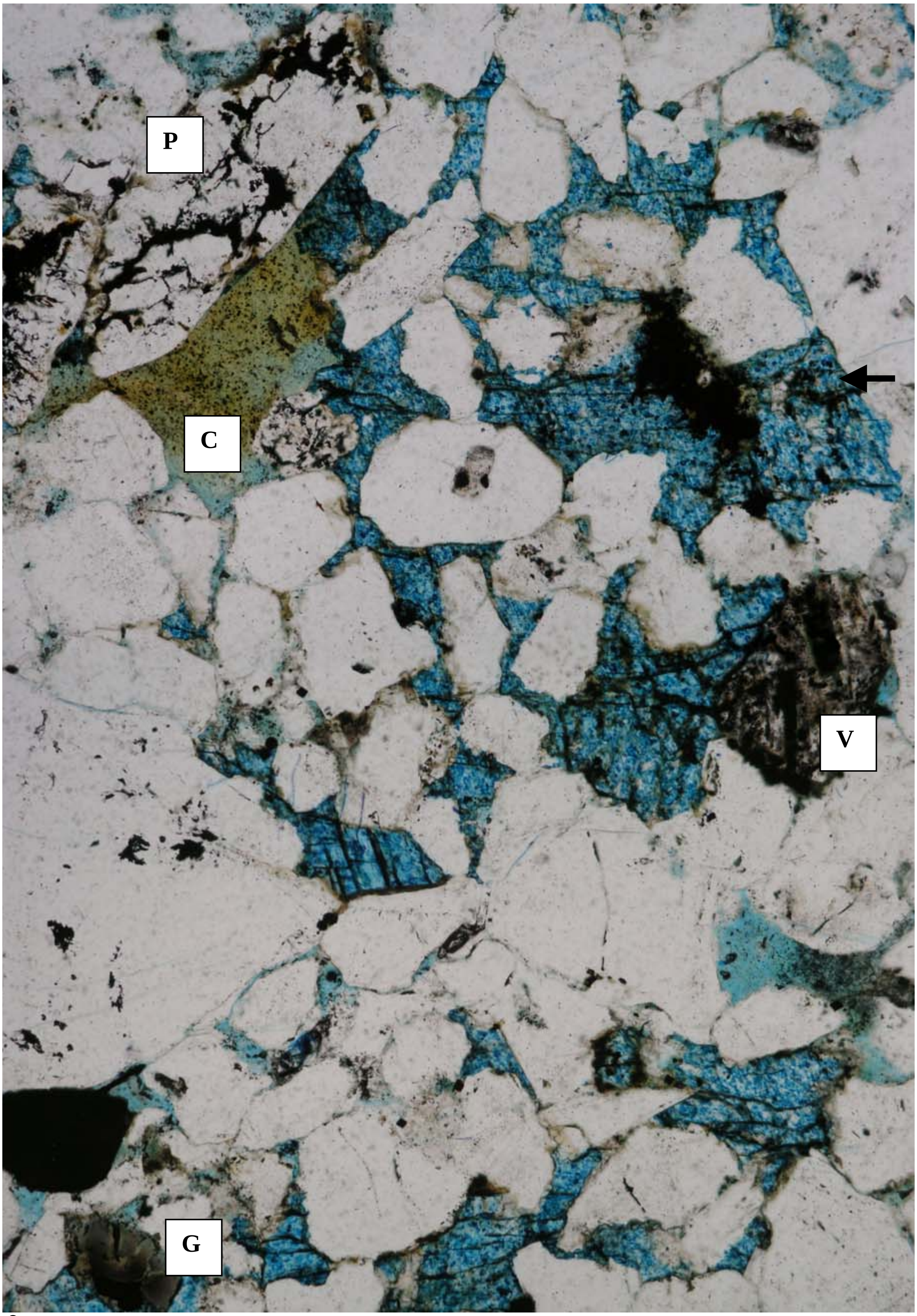

Figure 8

Ferroan calcite spar (dark blue) both cements & replaces grains (arrow) in this sublitharenite. Note the volcanic lithic (V), irregular pattern on the partially pyritised grain (P), a chloritised grain (C) and shrinkage cracks in a grain of glaucony (G). Mt Salt-1, core 30, depth 2718.7m. Plane light. Horizontal field of view 1.30mm.

4.9 Lake Bonney-1, cuttings, depth 7540-7570ft, Waarre Formation Unit Cb?

Rock types present:

1. Single grains (82%)
Medium sand to granule size subrounded grains of monocrystalline (56%) & polycrystalline (26%) quartz, chert & quartzite (trace). Polycrystalline grains have either straight or sutured crystal boundaries but the examples with straight boundaries are dominant. Average grain size is very coarse sand. Trace amounts of ferroan calcite spar are attached to the margins of grains & rarely euhedral quartz overgrowths are apparent.

2. Very fine to fine grained sublitharenite (5%)
Very fine to fine grained, poor to moderately sorted, mineralogically submature sublitharenite with rare laminae of silty mudstone. Grains are typically subangular with low sphericity and range in diameter from silt to medium sand. Texturally the sandstone is grain supported with close packing characterised by tangential & concavo-convex contacts. No porosity is apparent. Framework grains are comprised of monocrystalline quartz, polycrystalline quartz, lithics of chert, shale & micaceous schist, muscovite flakes & opaques. Matrix of anhedral brown clay forms partial rims on grains. Authigenic minerals of grain replacing & pore filling chlorite, & blocky pyrite. Rarely the chlorite appears to form partial rims on grains.

3. Medium grained carbonate (?siderite) cemented sandstone (7%)
Medium grained, moderately sorted, carbonate cemented quartzarenite. Grain size ranges from very fine to coarse sand size and grains are angular to subrounded with low sphericity. Texturally the sandstone is grain supported with point & tangential grain contacts characterising open packing. There are isolated dissolution pores where grains have been dissolved. Framework grains are composed of monocrystalline & polycrystalline quartz, & rare lithics of chert. Pervasive carbonate spar has embayed & replaced grains & filled pores. The spar is Fe rich, rarely displays zoning, it did not respond to staining & therefore could be composed of siderite or ankerite, & typically has a scalenohedral habit which is common in siderite. Framboidal to blocky pyrite is scattered throughout the carbonate.

4. Mudstone to silty mudstone (6%)
Angular silt to fine sand size grains float in anhedral to illitic brown clay & associated organic matter. Detrital grains are composed of quartz, quartzite, shale, dusty K-feldspars, mica & accessory zircon. Authigenic minerals of pale green glaucony, Fe rich microspar (?siderite) & framboidal pyrite. The microspar replaces grains & is scattered throughout the matrix.

Rock type thought to be representative of this depth:
The dominance of single grains suggests that a very coarse grained, well sorted, mineralogically mature quartzarenite was disaggregated during sampling. This sandstone probably had minor ferroan calcite and quartz cements.

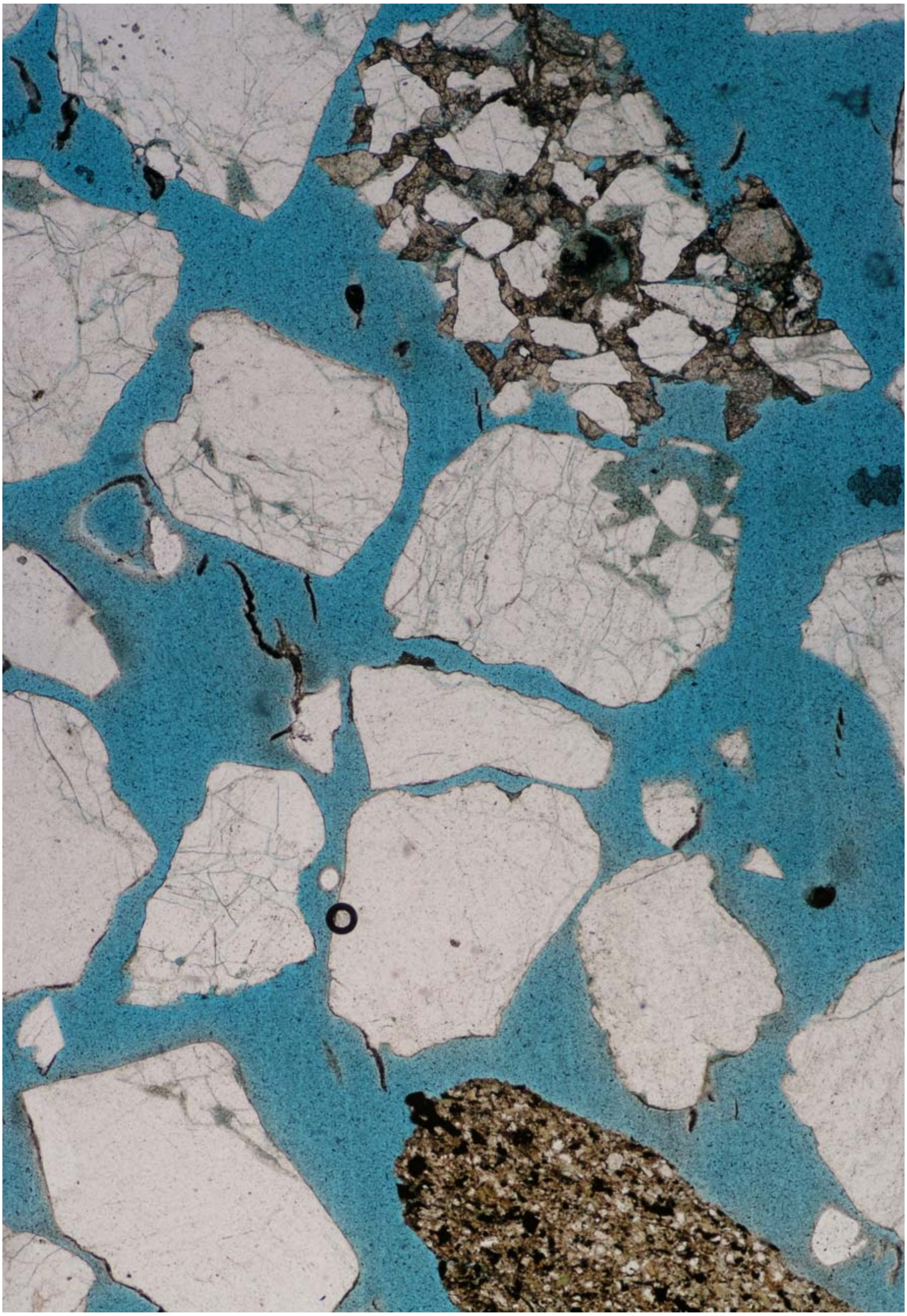

Figure 9
General field of view showing the dominance of single grains of quartz (white). One chip of medium grained, carbonate cemented sandstone and one chip of silty mudstone are also apparent. Lake Bonney-1, cuttings, depth 7540-7570ft. Plane light. Horizontal field of view 3.25mm.

4.10 Lake Bonney-1, cuttings, depth 8600 - 8610ft, Waarre Formation Unit A?

Rock types present:

1. Mudstone to sandy mudstone (33%)
Brown anhedral clay matrix in which there are varying amounts of silt to medium sand & organic matter. Mudstone to silty mudstone represents 24% of the cuttings and sandy mudstone is 9%. The medium sand includes lithics of chert & volcanics with trachytic texture. Rare chips of mudstone have planar laminae of very fine grained sandstone. Other chips indicate extensive replacement of matrix by Fe rich micrite (?siderite).

2. Single grains (34%)
Coarse sand to granule size grains of quartzite, ?granite (quartz + K-feldspar), monocrystalline (18%) & polycrystalline (10%) quartz. Granule size grains of monocrystalline quartz are well rounded with moderate sphericity. Ferroan calcite spar & traces of kaolin are attached to grain margins.

3. Very fine to medium grained moderately sorted sublitharenite with chlorite rims (11%)
This lithology was apparent at 7550-70ft but in this sample there are chips which are up to medium grained. Typically these medium grained chips have distinctive chlorite rims. In addition, the framework grains include relatively fresh plagioclase, chalcedony, mudstone, chloritised volcanics (laths of feldspar in a chlorite groundmass) & micas, & accessory tourmaline & zircon. Rare grains are replaced by ferroan calcite spar. In one chip of medium grained sublitharenite with chlorite rims there is clear blocky spar cement which has also partially replaced grains.

4. Medium to coarse grained carbonate cemented sublitharenite (21%)
Medium grained, moderately well sorted, mineralogically submature sublitharenite with carbonate cement. Grain size ranges from very fine to very coarse sand and grains are subangular to subrounded with low to moderate sphericity. The grain supported texture has open packing with tangential & point grain contacts. Intergranular pores are preserved where the carbonate spar is absent. Framework grains are dominated by monocrystalline quartz with rare feldspars with granophyric texture, polycrystalline quartz with straight crystal boundaries, lithics include chert, quartzite, shale, chloritised volcanics & ?granite (quartz + sericitised feldspar). There is a pervasive cement of poikilotopic ferroan calcite spar which has filled pores & replaced grains. Trace amounts of framboidal & blocky pyrite are also apparent in the spar & other chips have pore filling pyrite. Rare euhedral terminations on quartz grains indicate that there were minor quartz overgrowths prior to the carbonate spar.

Rock type thought to be representative of this depth:
Given the relative abundances of these cuttings it would appear that this depth might be interbedded. Examples of mudstones with laminae of fine sandstone are consistent with this hypothesis. It is possible that the single grains have been derived from the medium grained, carbonate cemented sublitharenite and this could be the dominant lithology at this depth.

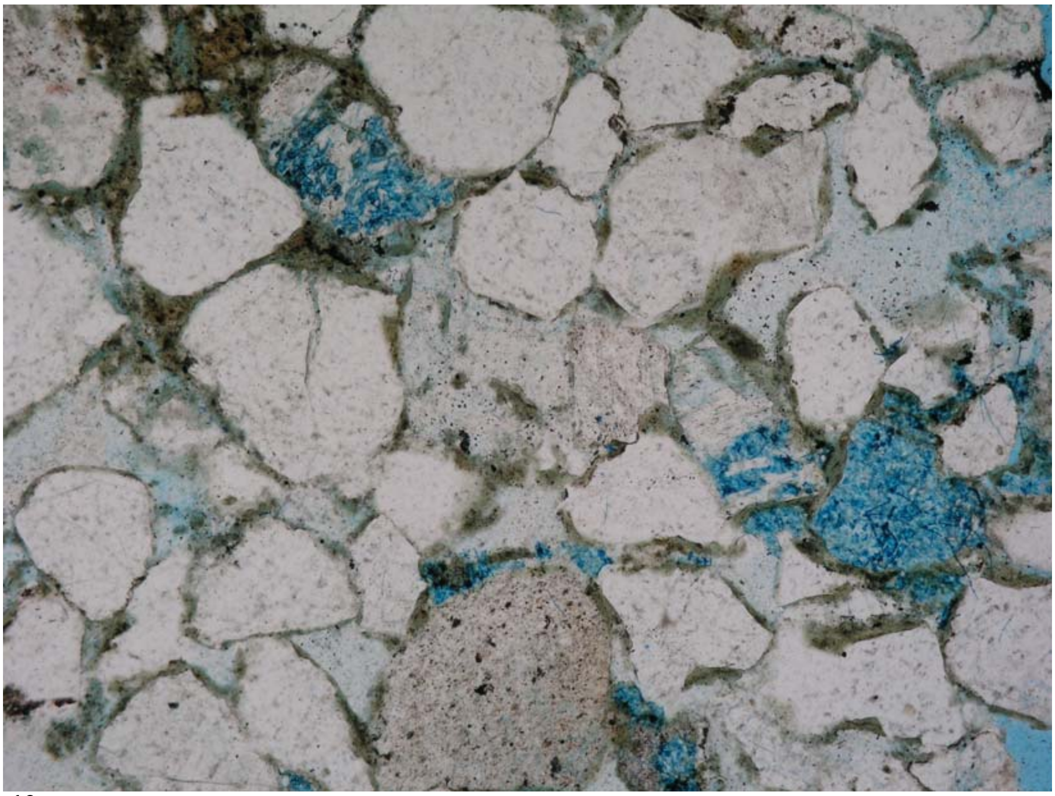

Figure 10a

Medium grained sublitharenite with distinctive chlorite rims (brownish-green) and minor grain replacing ferroan calcite spar (stained dark blue). Lake Bonney-1, cuttings, depth 8600-8610ft. Plane light. Horizontal field of view 1.30mm.

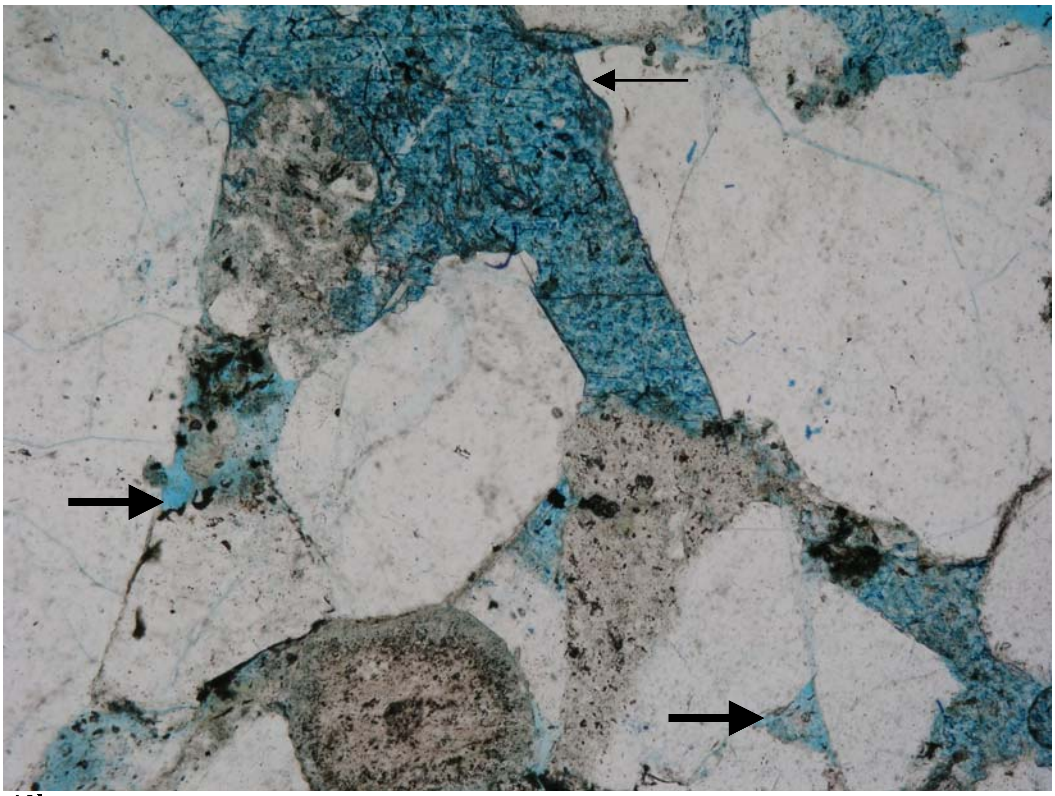

Figure 10b

In this chip of medium to coarse grained sublitharenite there were minor quartz overgrowths (small arrow) prior to a cement of ferroan calcite spar (stained dark blue). Rare intergranular pores (large arrows) are also apparent. Lake Bonney-1, cuttings, depth 8600-8610ft. Plane light. Horizontal field of view 1.30mm.

4.11 Lake Bonney-1, cuttings, depth 8680 - 8690ft, Waarre Formation Unit A?

Rock types present:

1. Mudstone to sandy mudstone (21%)
These lithologies are interbedded as indicated by the presence of laminae. Description as per 8610ft.

2. Single grains (52%)
Medium sand to granule size grains of monocrystalline (36%) & polycrystalline (13%) quartz, dusty K-feldspars (trace) & quartzite (2%). Intact grains are subrounded with moderate sphericity and the average grain size is coarse sand.

3. Medium to coarse grained carbonate cemented sublitharenite (19%)
In addition to intergranular pores there are examples of grain size pores in chips from this depth. The intergranular pores indicate that there are areas in the sublitharenite that lack carbonate cement. Description as per 8610ft.

4. Fe rich (?siderite) micrite (3%)
Chips of Fe rich micrite also contain trace amounts of silt to medium sand size quartz & rare lithics. The carbonate did not respond to staining and therefore could be either siderite or ankerite in composition. Rarely the micrite is a slightly coarser crystal size of anhedral microspar.

5. Fine grained sublitharenite (4%)
Description as per 8610ft but less chlorite rims.

6. Pyrite cement (trace)
Medium sand size grains replaced by blocky pyrite & chips of sandy mudstone extensively replaced by pyrite.

Rock type thought to be representative of this depth:
It is possible that the single grains and the carbonate cemented sublitharenite chips were all derived from the same sandstone. Only those areas which had localised cement have remained intact. If this interpretation is correct then the sandstone at this depth was a coarse grained, moderately well sorted, sublitharenite. Reservoir quality could be moderate to good and only limited by localised carbonate and possibly pyrite cement. Mudstone and sandy mudstone could be interbedded with the relatively clean sublitharenite.

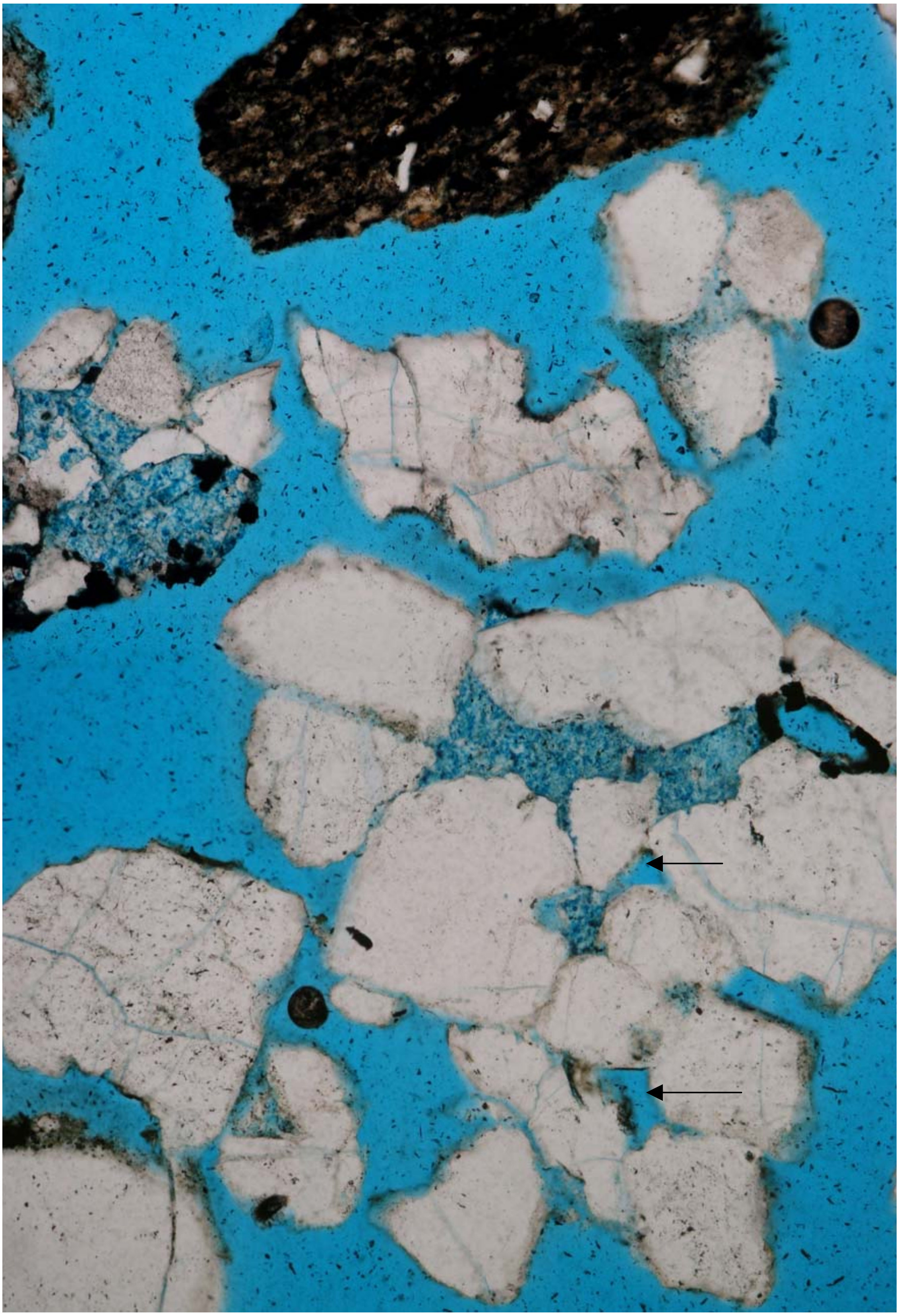

Figure 11
This chip indicates that the ferroan calcite cemented (dark blue) sublitharenite did have intergranular pores (arrows) and grain size dissolution pores. The latter is rimmed by blocky pyrite (opaque). A chip of mudstone (brown) is also apparent. Lake Bonney-1, cuttings, depth 8680-8690ft Plane light. Horizontal field of view 1.30mm.

4.12 Caroline-1, cuttings, depth 8180-8210ft, Waarre Formation Unit Cb?

Rock types present:

1. Laminated silty to sandy mudstone (27%)
Silt to fine sand size grains float in anhedral brown illitic clay. Detrital grains are concentrated in laminae and there are lenses of clay which might represent ripples. Stringers of opaque organic matter are also evident in the matrix. Detrital grains of monocrystalline quartz, polycrystalline quartz, lithics of shale, quartzite & other metasediments, flakes of fresh muscovite & accessory ?monazite. Authigenic minerals include pyrite framboids, grains of colourless glaucony with wormy texture & micritic Fe rich carbonate (?siderite).

2. Fine grained sandstone (litharenite) (45%)
Chips of fine grained sandstone are moderately sorted, mineralogically submature litharenites. Bedding is indicated by stringers of detrital clay and opaque organic matter. Grain size ranges from silt to fine sand and grains are commonly angular to subangular with low sphericity. Texturally the sandstone is grain supported with close packing characterised by tangential and concavo-convex grain contacts. Rare grain size dissolution pores are apparent. Framework grains are composed of monocrystalline quartz, polycrystalline quartz, sericitised K-feldspar, altered ?plagioclase, lithics of chert, chalcedony, shale, quartzite & micaceous schist, bent muscovite, accessory rutile, zircon, tourmaline & ?monazite. Authigenic grain replacing kaolin, grain & matrix replacing anhedral Fe rich (?siderite) micrite & microspar, & oxidised grains of unknown origin. Rare chips have minor grain replacing & pore filling ferroan calcite spar.

3. Fine to coarse grained ?siderite cemented sandstone (15%)
Irregular zones of anhedral Fe rich microspar are interspersed with areas containing detrital grains which float in the cement. Rarely zoning is evident in the microspar. Framework grains of monocrystalline quartz, polycrystalline quartz, plagioclase, muscovite, shale & quartzite are highly embayed by the ?siderite. These chips might represent part of a siderite nodule (s) within the fine grained sandstone or beds with the medium grained sandstone.

4. Medium grained sandstone (sublitharenite) (11%)
There are minor chips of medium grained, moderately to moderately well sorted, mineralogically mature sublitharenite. Very thin crenulated stringers of organic matter might outline a burrow. Grains range from very fine to very coarse sand and are typically subangular with low sphericity. The sandstone is grain supported with moderately close packing characterised by tangential, concavo-convex & rare sutured grain contacts. Minor intergranular pores, intragranular pores within quartzite lithics, grain size dissolution pores, honeycomb pores where feldspars are corroded and micropores associated with kaolin are apparent. Framework grains are dominated by monocrystalline quartz, with minor polycrystalline quartz that has sutured or straight crystal boundaries, corroded K-feldspars lack twinning, fresh feldspars with granophyric texture & tartan twinning, lithics of chert, deformed mudstone, shale & quartzite, & accessory zircon & monazite. Compaction is greatest near the very coarse sand size mudstone lithic which could be a faecal pellet or rip-up clast. Quartz overgrowths have a jagged contact with grain replacing kaolin booklets & formed prior to a phase of pore filling ferroan calcite spar. The mudstone lithic has been partially replaced by micritic ?siderite which did not respond to staining. Micrite is also scattered along grain margins. A third phase of euhedral rhombohedral carbonate (?siderite) spar has replaced grains, possibly micas. Rare minute pyrite framboids have replaced grains & mudstone, & are clustered in pores. In one chip the blocky pyrite forms localised cement.

5. Single grains (1%)
Subrounded coarse grains of monocrystalline quartz.

Rock type thought to be representative of this depth:
The composition of the medium grained sublitharenite is more typical of Unit C than the fine grained litharenite chips. Silty and sandy mudstone could be interbedded with either of the sandstone lithologies.

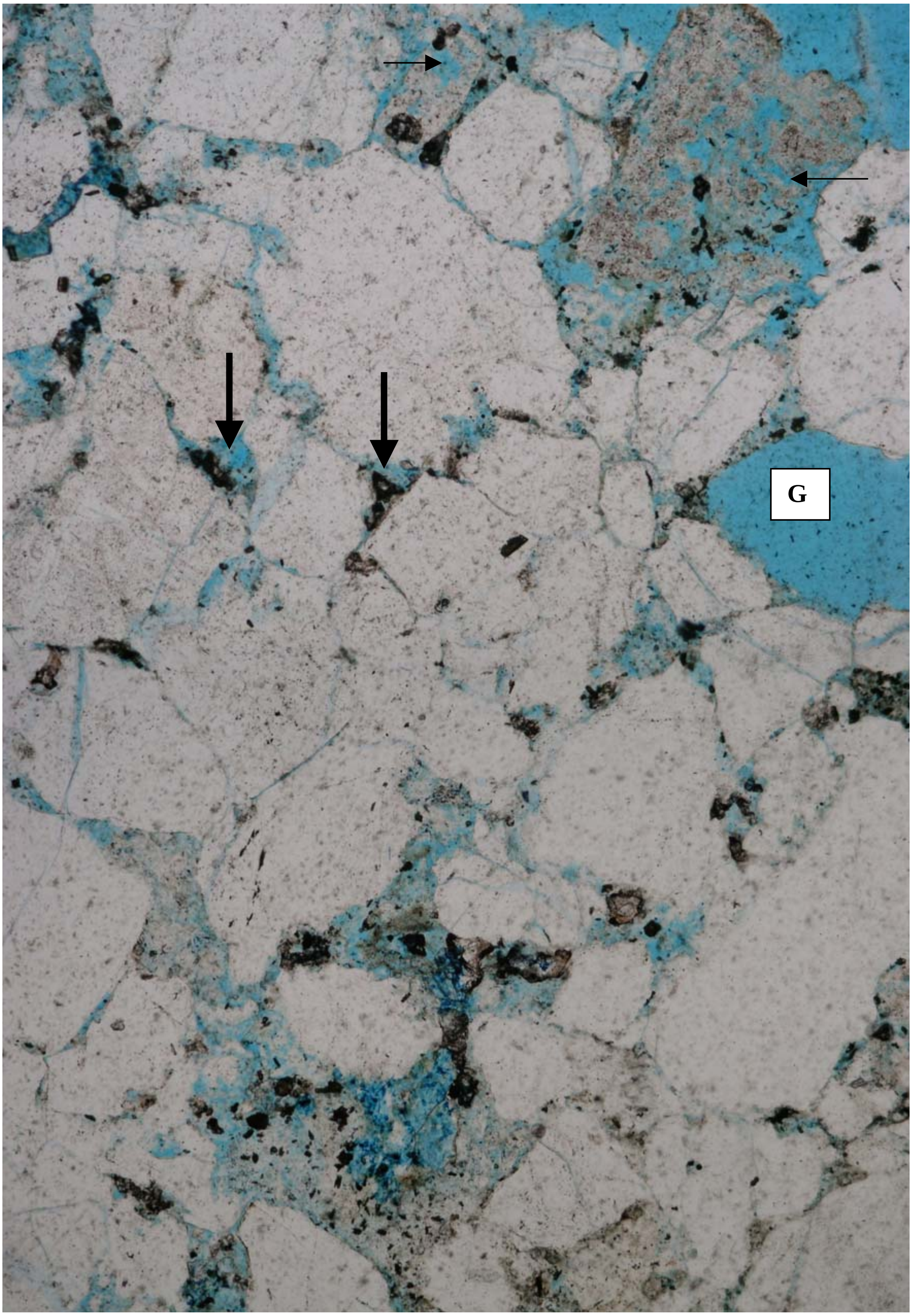

Figure 12

Medium grained moderately well sorted sublitharenite showing various pore types; grain size (G), intergranular (large arrows), and honeycomb (small arrow). Grinding paste & drilling mud are present in the intergranular pores. Grain replacing ferroan calcite (stained dark blue) is also apparent. Caroline-1, cuttings, depth 8180-8210ft. Plane light. Horizontal field of view 1.30mm.

4.13 Caroline-1, cuttings, depth 8450 - 8460ft, Waarre Formation Unit Cb?

Rock types present:

1. Silty to sandy mudstone (10%)
As per the description from 8190-8210ft but the sediment is not laminated. Very fine sand size grains of glaucony are bright green.

2. Medium to coarse grained sublitharenite(14%)
Medium grained, moderately well sorted, mineralogically mature sublitharenite. No sedimentary structures are apparent. Grains range in size from very fine to coarse sand with an average near medium sand. Subangular to subrounded grains with low sphericity have a grain supported texture. Grain packing was moderately close with tangential and concavo-convex grain contacts. Minor intergranular pores are preserved & there are examples of grain size, honeycomb & intragranular dissolution pores & micropores associated with kaolin. Framework grains are composed of monocrystalline & polycrystalline quartz, sericitised & corroded feldspars, lithics of chert, chalcedony, shale & quartzite. These grains are cemented and partially replaced by poikilotopic ferroan calcite spar. Minor grain replacing & pore filling kaolin booklets are also apparent. Quartz overgrowths formed prior to the carbonate spar & have a jagged contact with the kaolin.

3. Fine grained litharenite (6%)
As per the description from 8190-8210ft

4. Fine grained ?siderite cemented sandstone (3%)
As per the description from 8190-8210ft

5. Single grains (66%)
Fine sand to granule size grains of monocrystalline (50%) & polycrystalline (16%) quartz & rare quartzite (trace). Average grain size is coarse sand and grains were probably moderately sorted. Coarse grains are subrounded with moderate sphericity. Polycrystalline quartz has dominantly straight crystal boundaries but there are examples that are sutured. Rare framboidal pyrite cement, carbonate spar (ferroan calcite) & quartz overgrowths are attached to the grain margins.

Rock type thought to be representative of this depth:
The dominance of coarse single grains would suggest these have disaggregated from a quartzarenite at this depth. The quartzarenite might have been moderately sorted and had moderate reservoir quality since there was minimal cement. Other lithologies could either be downhole contaminants or represent minor interbeds.

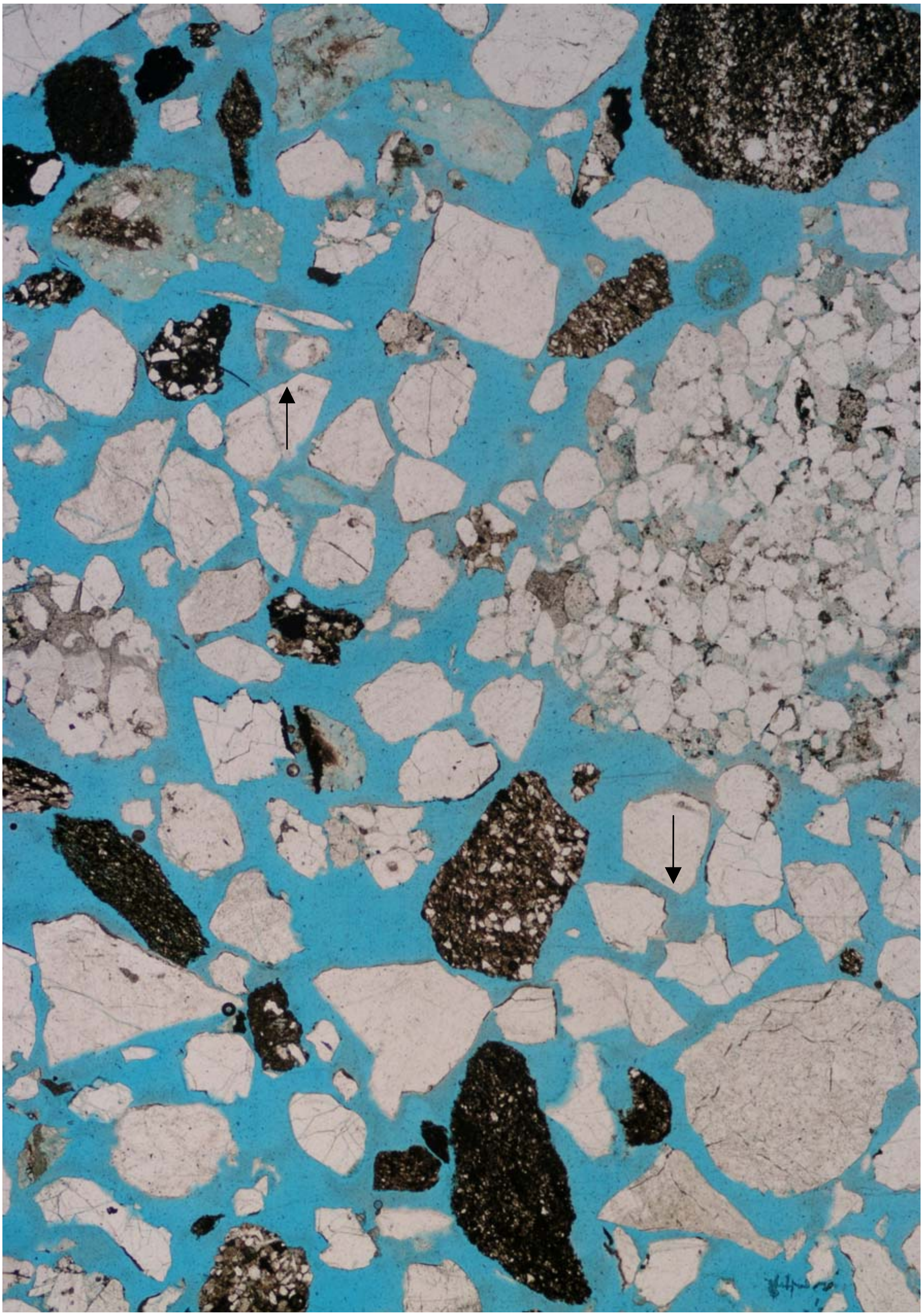

Figure 13

Many of the single grains in this field of view appear angular due to fracturing during sampling and there are examples with euhedral terminations due to the presence of quartz overgrowths (arrows). Chips of mudstone (dark brown), fine grained litharenite and medium grained sandstone are also apparent. Caroline-1, cuttings, depth 8450-8460ft. Plane light. Horizontal field of view 6.5mm.

4.14 Caroline-1, cuttings, depth 9300 - 9310ft, Waarre Formation Unit A

Rock types present:

1. Fine to coarse grained ?siderite cemented sandstone (16%)
Detrital grains are embayed and cemented by Fe rich anhedral to subhedral spar which did not respond to staining. Grains are composed of monocrystalline quartz, sericitised feldspars, chert, quartzite & opaques. Localised pyrite cement.

2. Medium grained sublitharenite- ferroan calcite & kaolin cemented (14%)
As per description from 8460ft. In addition there is minor ?siderite spar filling pores.

3. Silty mudstone to sandy mudstone/muddy sandstone (3%)
Angular to subrounded grains of silt to very fine sand float in illitic clay matrix. Stringers of organic matter indicate the orientation of bedding. Sandy mudstone has a higher percentage of sand size grains & lenses of detrital brown clay.

4. Single grains (62%)
Medium to granule size grains of polycrystalline quartz (23%), monocrystalline quartz (37%), K-feldspar which lacks twinning (trace), chert & quartzite (2%). Polycrystalline quartz is up to granules in size, it has straight crystal boundaries and rare Fe rich spar attached to the rim. Monocrystalline quartz grains have rhombohedral quartz overgrowths. One quartzite lithic has kaolin booklets attached to the edge of the grain. Very coarse grains were subrounded with moderate sphericity prior to fracturing during sampling. Average grain size is near the coarse to very coarse sand size boundary. Sorting was probably moderate to moderately well.

5. Fine grained litharenite (4%)
Fine grained, moderately well sorted, mineralogically submature litharenite. Grain size ranges from very fine to medium sand and grains are subangular with low sphericity. Texturally the litharenite is grain supported with close packing characterised by concavo-convex contacts. No porosity is apparent. Framework grains of monocrystalline quartz, fresh plagioclase with albite twinning, abundant lithics of shale & ?micaceous schist, & accessory zircon. Authigenic minerals consist of chlorite rims on grains, grain replacing ferroan calcite & traces of grain replacing pyrite.

Rock type thought to be representative of this depth:
The high percentage of single grains would suggest that a very coarse grained, moderately well sorted quartzarenite has been disaggregated during sampling. There is significantly more polycrystalline quartz in this sandstone than the sandstone at 8460ft.

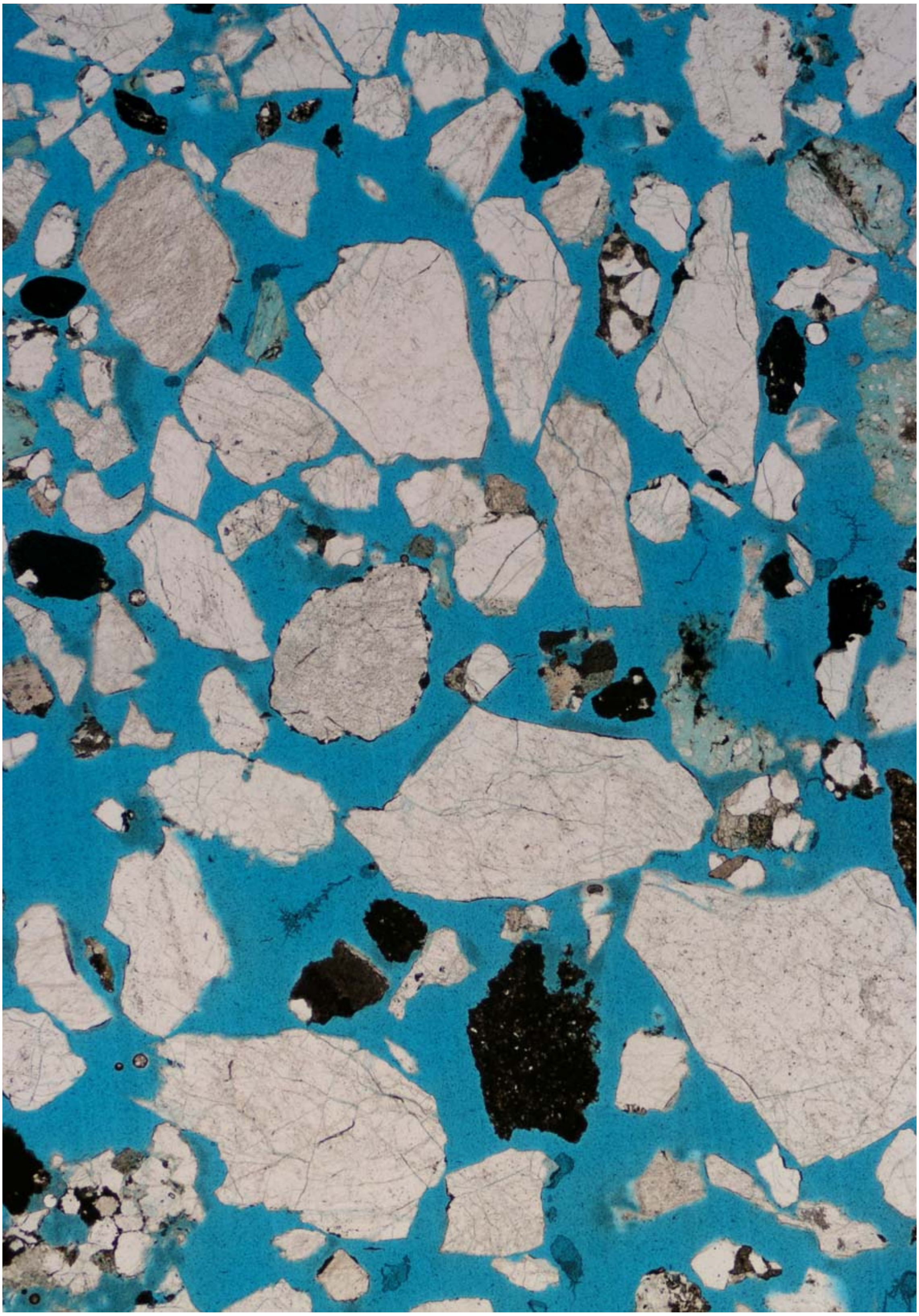

Figure 14

General field of view illustrating the abundance of single grains of quartz in these cuttings. The angular nature of grains is due to fracturing during sampling & the presence of quartz overgrowths. Caroline-1, cuttings, depth 9300-9310ft. Plane light. Horizontal field of view 6.5mm.

4.15 Najaba-1, swc, depth 2825m, Flaxman Formation

Rock classification: **Quartzarenite**

Texture:

- Sedimentary structures: crenulated stringer of oxidised matter replaced by pyrite indicates the orientation of bedding, granule size ?mudstone lithics or ?faecal pellets
- Average grain size: medium sand (~0.29mm)
- Range in grain size: fine to medium sand
- Roundness / sphericity: subangular to subrounded with low to moderate sphericity
- Sorting: well sorted
- Texture: grain supported
- Packing / grain contacts: moderately close / tangential & rare concavo-convex grain contacts
- Pore types: intergranular pores, grain size dissolution pores, intragranular pores within siltstone lithics, honeycomb pores where feldspars are partially corroded, micropores associated with kaolin

Composition:

- Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, corroded & dusty K-feldspars, relatively fresh plagioclase with albite twinning, lithics of chert, dark brown mudstone, silt size metasediments (rarely chloritic) & quartzite, remnants of mica flakes within patches of kaolin, bent muscovite flakes up to 0.65mm in length, accessory silt size zircon, very fine sand size sphene, up to medium sand size tourmaline
- Authigenic minerals: deformed fine sand size grains replaced by chlorite, yellowish oxidised (?goethite) rims on grains (Fig. 15a) are of variable thickness (~5-10 microns) & are absent at grain contacts, rarely these rims fill intergranular pores, where rims are absent (Fig. 15b) the straight grain contacts suggest the presence of quartz overgrowths, oxidised rims have been extensively replaced by single crystals of blocky & framboidal pyrite, framboids are up to 25 microns in diameter, blocky pyrite has replaced other grains including granule size mudstone lithics or lenses, rare deformed grains of unknown origin replaced by illite, grain replacing kaolin booklets & verms are up to 45 microns in diameter, these booklets have been squeezed into adjacent intergranular pores, pore filling & grain replacing twinned poikilotopic ferroan calcite spar, rarely this spar is rimmed by hematite

Visual Estimate of Composition			Volume %
Framework grains	Quartz	monocrystalline	55
		polycrystalline	5
	Feldspar		1
	Lithics	metamorphic	1
		sedimentary	1
	Muscovite		tr
	Accessory minerals		tr
Authigenic minerals and cements	Chlorite		tr
	Oxide		5
	Quartz		2
	Ferroan calcite		5
	Pyrite		15
	Kaolin		3
	Illite		tr
Porosity	Intergranular		4
	Dissolution		2
	Micropores		tr

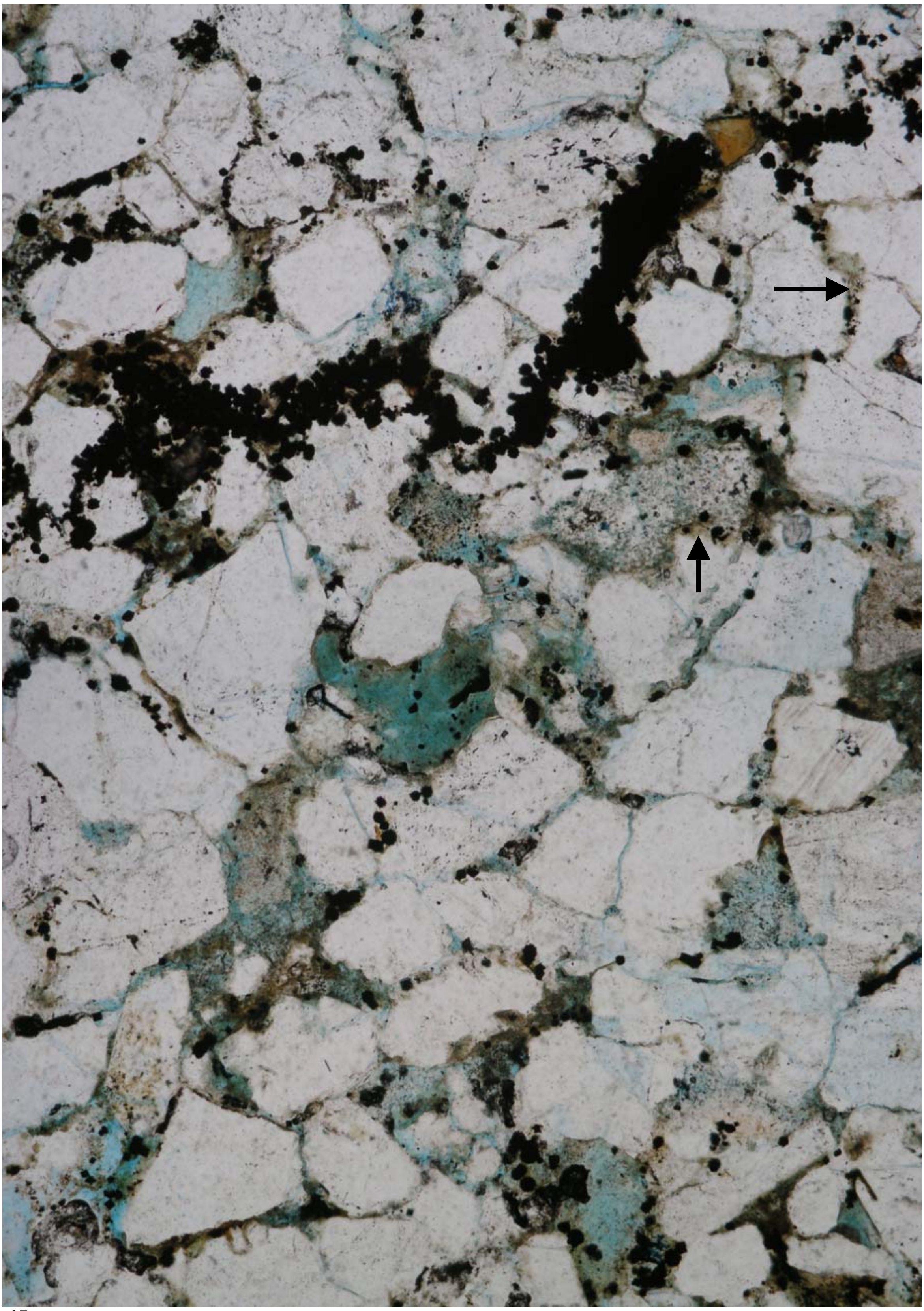

Figure 15a

The area adjacent to this pyritised (opaque) crenulated stringer shows detrital grains with oxidised rims (arrows). Accessory tourmaline (yellow) occurs within the stringer. Secondary dissolution pores (blue) are also apparent. Najaba-1, swc, depth 2825m. Plane light. Horizontal field of view 1.30mm.

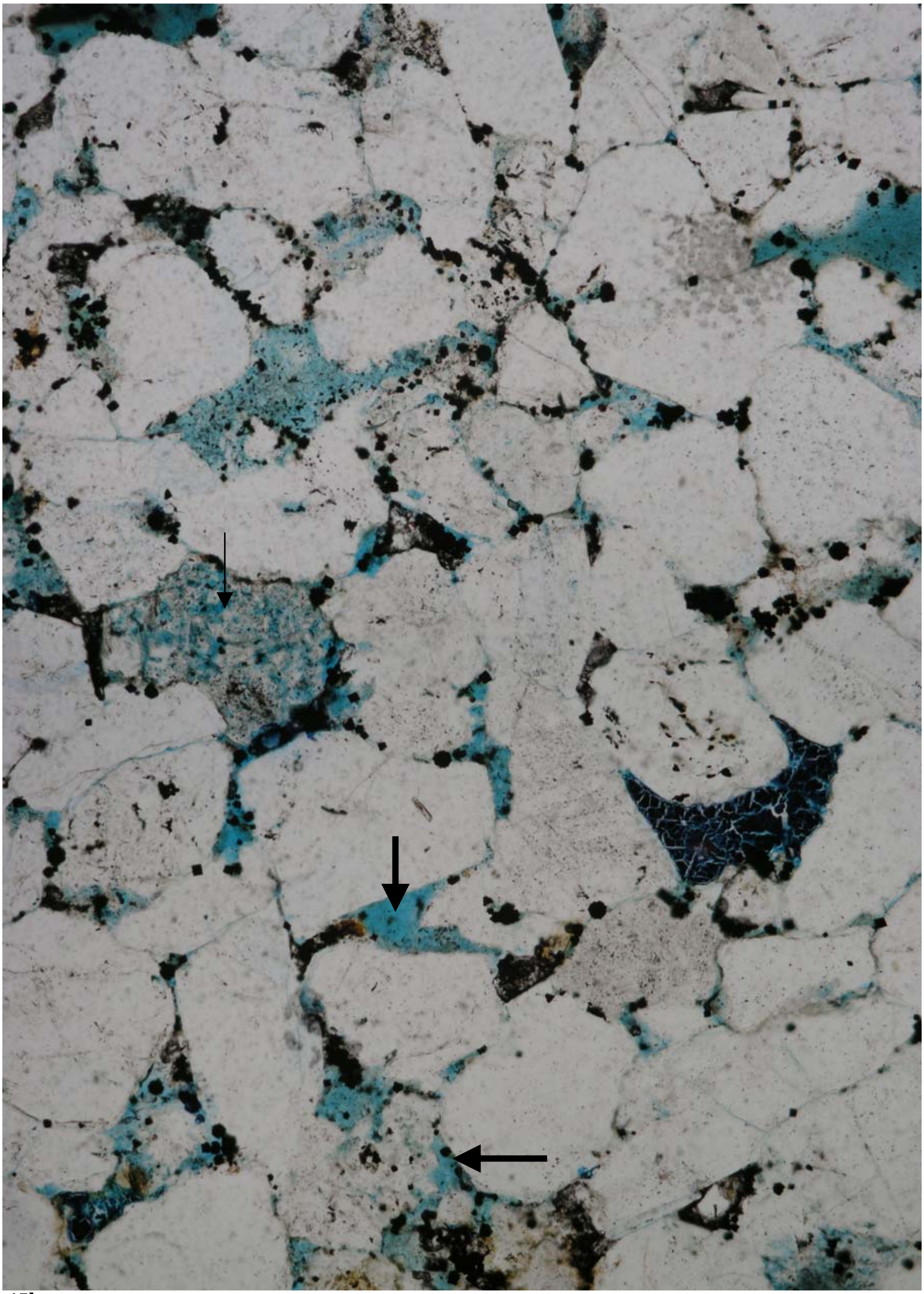

Figure 15b

This part of the section lacks the oxidised rims but blocky pyrite (opaque) is still present. Minor pore filling ferroan calcite (dark blue), intragranular pores (small arrow) and intergranular pores (large arrows) are evident. Note the euhedral terminations on quartz grains adjacent intergranular pores due to quartz overgrowths. Najaba-1, swc, depth 2825m. Plane light. Horizontal field of view 1.30mm.

4.16 Fahley-1 ST 2, cuttings, depth 2895 - 2900m, Flaxman Formation

Rock types present:

1. Fine to medium grained sandstone (20%)
Fine grained (13%), moderately sorted, mineralogically mature quartzarenite (Fig. 16a) has a grain supported texture. Discontinuous stringers of brown anhedral clay are rare. Detrital grains range from silt to coarse sand in size and are typically subangular with low sphericity. Packing is moderately close with tangential & concavo-convex grain contacts. Grain size and intragranular dissolution pores are apparent. Detrital grains consist of monocrystalline quartz, polycrystalline quartz with straight crystal boundaries, corroded K-feldspars that lack twinning & others with tartan twinning, lithics of quartzite & pyrophyllite, straight muscovite flakes, and accessory silt size zircon & very fine sand size opaques. Trace amounts of brown anhedral clay represent the matrix. Authigenic minerals of very fine sand size green glauconite, chlorite which has replaced grains & forms partial rims on grains, the latter have locally inhibited quartz overgrowths, grain replacing & pore filling poikilotopic ferroan calcite spar, deformed grains replaced by illite & pyrite replacing matrix.

Chips of medium grained (7%), moderately well sorted quartzarenite (Fig. 16b) have a texture and composition similar to that of fine grained quartzarenite. However, matrix is absent from these chips, there is one example with a coarse sand size ?granitic lithic and there are examples with pervasive carbonate cement.

2. Silty to sandy mudstone (19%)
Grain alignment in the silty mudstone (Fig. 16c) indicates the orientation of bedding and there are subtle changes in the proportion of detrital grains that could reflect laminae with gradational contacts. Rare patches of clean very fine sand within the silty mudstone (16%) could represent burrows. Matrix consists of anhedral brown clay with abundant stringers of opaque organic matter. The texture is matrix supported with deformation of ductile grains indicating moderate compaction. Detrital grains in the silty mudstone are subangular and dominantly composed of monocrystalline quartz with minor corroded K-feldspars, muscovite & biotite flakes. Authigenic minerals of grain replacing chlorite, traces of Fe rich microspar (?siderite) & pyrite.

Sandy mudstone (3%) contains detrital grains that are subangular to subrounded and up to medium sand in size. These grains are composed of monocrystalline quartz, feldspars with simple twinning, chert and quartzite.

One chip of very dark brown mudstone contains rare silt to fine sand size grains.

3. Single grains (60%)
Medium to granule size grains of monocrystalline (40%) and polycrystalline quartz (19%), and quartzite (trace). The coarsest grains are of polycrystalline quartz with straight crystal boundaries. Rarely traces of clear carbonate spar are attached to the quartz grains. Other grains have been irregularly replaced by pyrite.

Rock type thought to be representative of this depth:
The relative abundance of single grains suggests that a quartz rich very coarse grained sandstone at this depth, or shallower, has been disaggregated during sampling. The other lithologies could be interbedded with the sandstone.

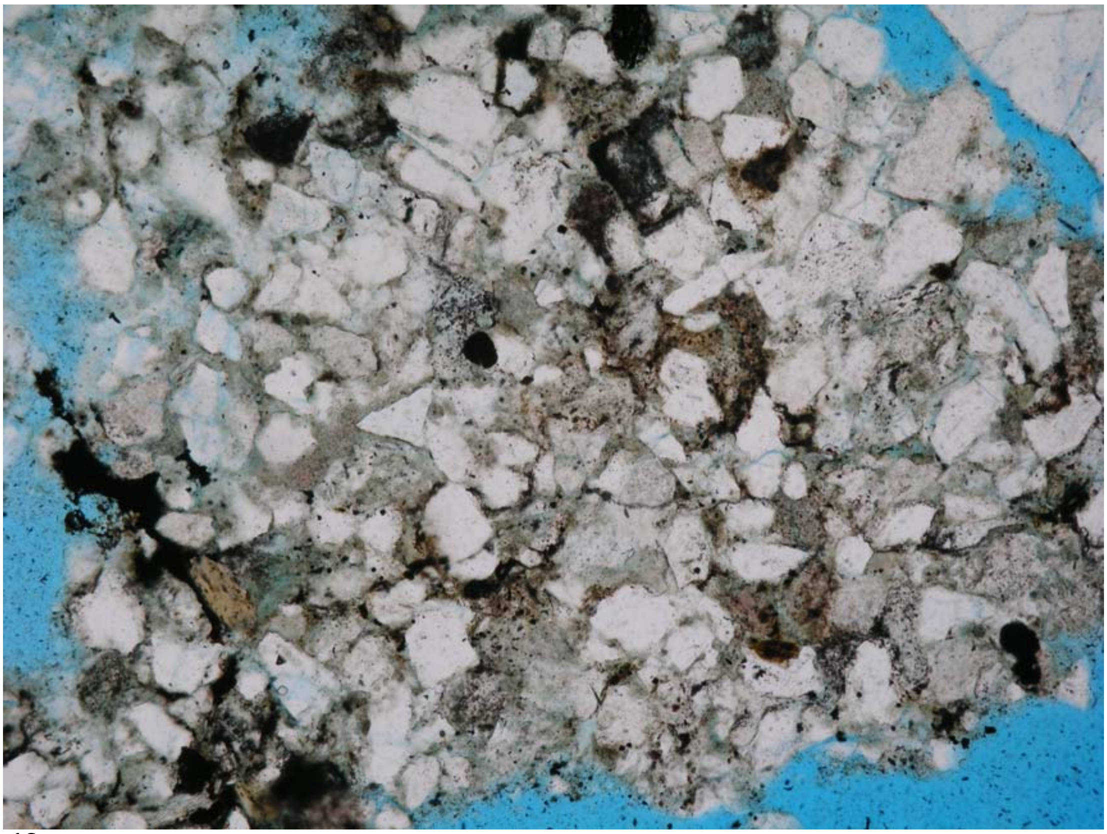

Figure 16a
Typical chip of fine grained moderately sorted quartzarenite with chlorite rims and minor detrital brown clay. Fahley-1, cuttings, depth 2895-2900m. Plane light. Horizontal field of view 1.30mm.

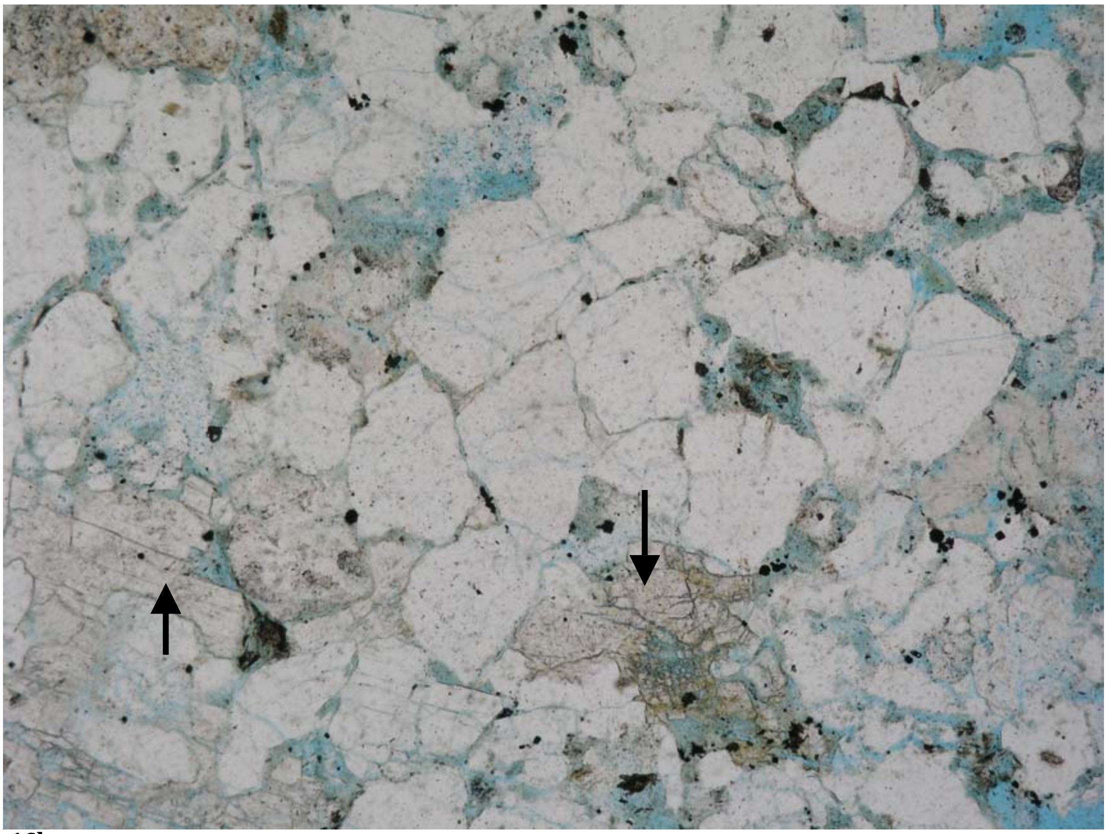

Figure 16b
Medium grained quartzarenite with minor dissolution pores and localised carbonate cement (arrows). Grain fracturing is probably an artifact of sampling. Fahley-1, cuttings, depth 2895-2900m. Plane light. Horizontal field of view 1.30mm.

Figure 16c

This chip of silty mudstone shows very subtle variations in the proportions of detrital grains which could reflect the presence of laminae. Fahley-1, cuttings, depth 2895-2900m. Plane light. Horizontal field of view 1.30mm.

4.17 Fahley-1 ST2, cuttings, depth 3135 - 3140m, Waarre Formation Unit Cb

Rock types present:

1. Silty mudstone to muddy sandstone (26%)
As per description from 2900m. The mudstone category includes chips of very dark brown mudstone. Muddy sandstone has crenulated stringers of organic matter and grains are up to coarse sand in size.

2. Fine grained sublitharenite (34%)
Fine grained, poor to well sorted, mineralogically mature sublitharenite. Rare chips indicate that the fine grained sandstone is either interbedded with, or contains laminae of silty mudstone. Grain size in the sandstone ranges from very fine to fine sand and grains were subangular with low to moderate sphericity prior to silicification. Texturally the sandstone is grain supported with close packing and sutured grain contacts. There is no porosity apparent. Framework grains are dominantly composed of monocrystalline quartz with minor lithics of shale & chert, & rare dusty K-feldspars, muscovite flakes & accessory zircon & tourmaline. Authigenic minerals consist of pervasive quartz overgrowths that have filled pores, grain replacing kaolin, framboidal & blocky pyrite, grain replacing ferroan calcite & irregular patches of anhedral ?siderite concentrated along grain margins. In the muddy intervals there are very fine sand size bright green grains of glauconite.

3. Medium to coarse grained quartzarenite (18%)
Medium to coarse grained, moderately well sorted, mineralogically mature quartzarenite. Grain size ranges from fine to coarse sand and grains were rounded with moderate sphericity prior to silicification. Grain packing is moderately close with tangential and concavo-convex contacts apparent. There are micropores associated with the kaolin. Framework grains are dominated by monocrystalline quartz, minor polycrystalline quartz with straight crystal boundaries, chert & rare muscovite flakes. The quartzarenite is cemented by euhedral quartz overgrowths with minor grain replacing & pore filling poikilotopic ferroan calcite spar, traces of anhedral zoned ?siderite concentrated along grain margins, grain replacing kaolin booklets & framboidal pyrite.

4. Fine sand in siderite cement (5%)
Rare chips consist of isolated silt to fine sand size grains of quartz & organic matter floating in anhedral micritic ?siderite. These chips might represent a continuum with, or a localised cement /nodule within the fine grained sublitharenite.

5. Single grains (17%)
Coarse grains of monocrystalline (12%) & polycrystalline (5%) quartz (sutured crystal boundaries). One grain of quartz has kaolin booklets attached to the margin.

Rock type thought to be representative of this depth:
Medium to coarse grained quartzarenite and fine grained sublitharenite might be interbedded with the silty mudstone/sandy mudstone. In both the quartzarenite and sublitharenite the abundance of quartz cement might indicate poor reservoir quality.

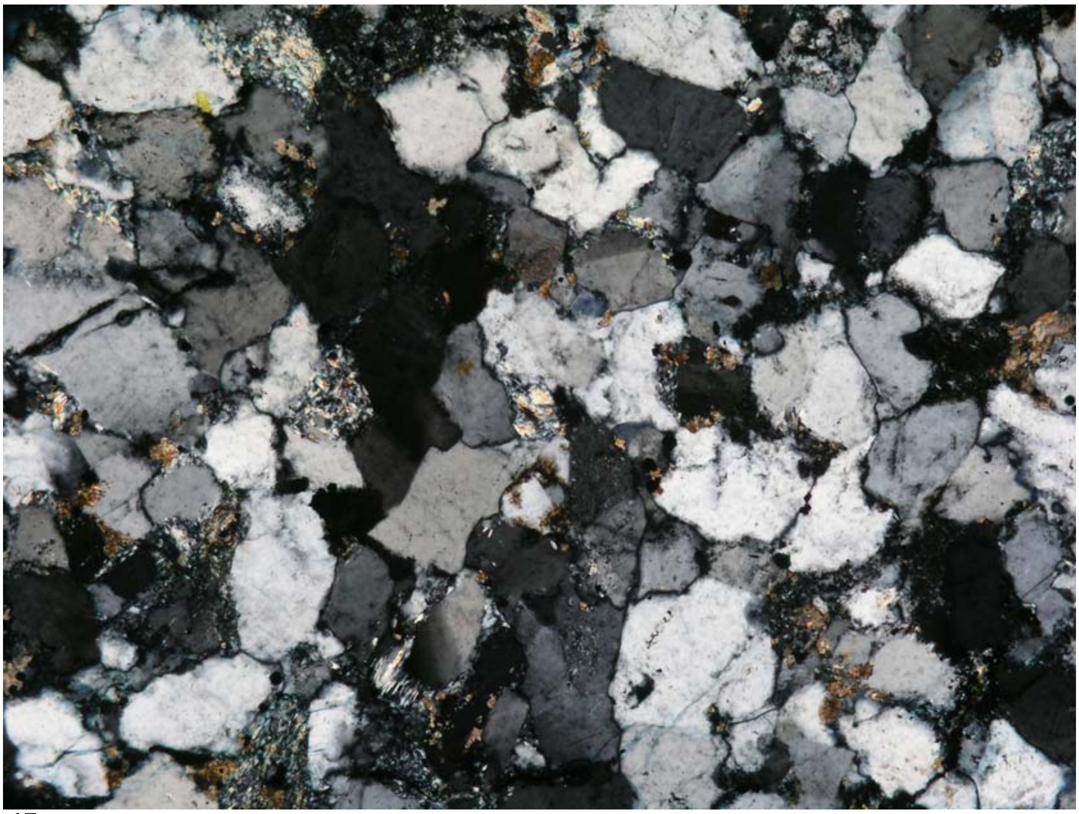

Figure 17a

Chip of fine grained sublitharenite which has close packing. Monocrystalline quartz is the dominant framework grain, there are shale lithics & traces of anhedral Fe rich micrite (reddish) apparent. Fahley-1 ST2, cuttings, depth 3135-3140m. Crossed nicols. Horizontal field of view 1.30mm.

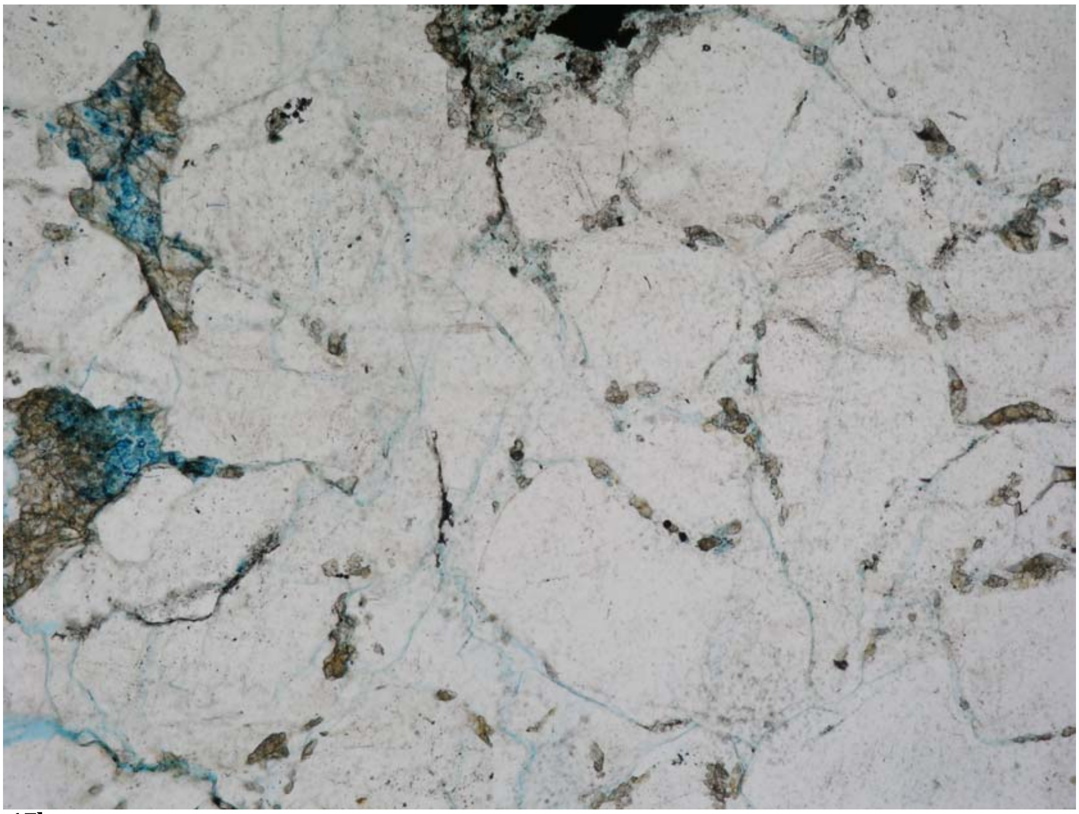

Figure 17b

In this example of medium grained quartzarenite the grains have partial rims of anhedral Fe rich microspar (?siderite) and there is minor grain replacing ferroan calcite (stained dark blue). Fahley-1 ST2, cuttings, depth 3135-3140m. Plane light. Horizontal field of view 1.30mm.

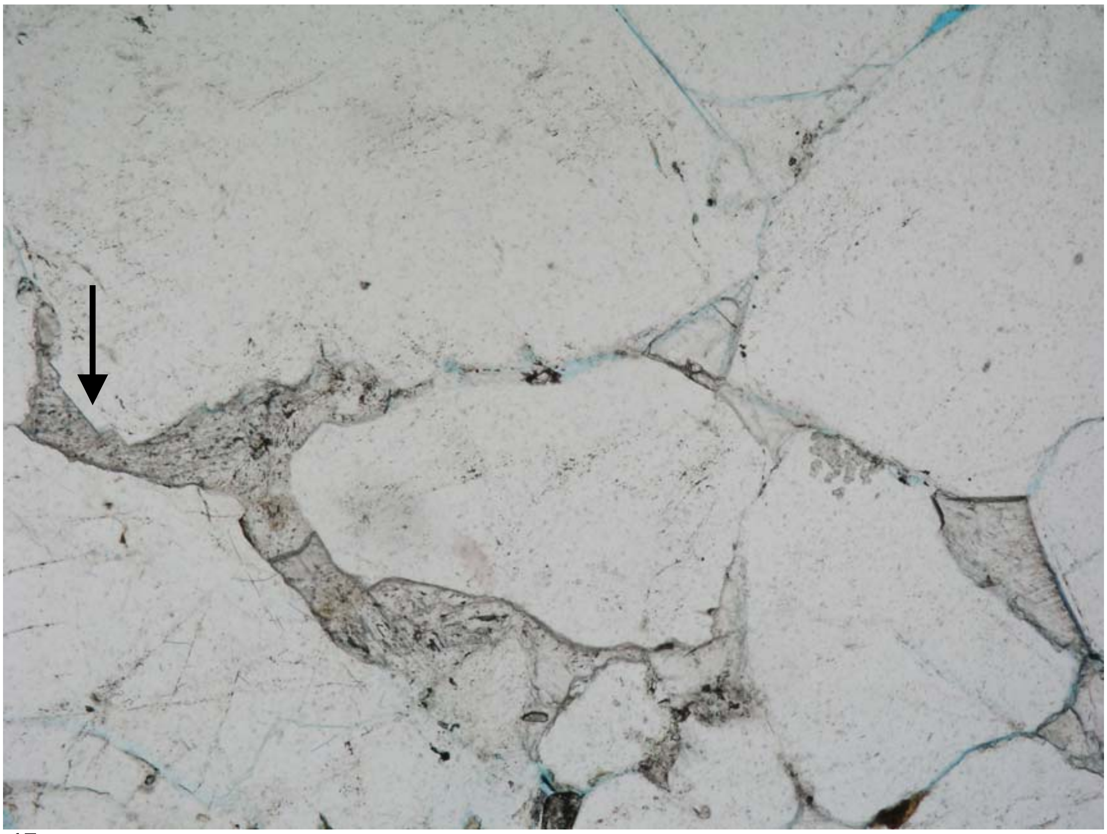

Figure 17c

In this chip of coarse grained quartzarenite the packing is open but pores are filled by quartz overgrowths (arrow) followed by dusty carbonate spar (ferroan calcite). Fahley-1 ST2, cuttings, depth 3135-3140m. Plane light. Horizontal field of view 1.30mm.

4.18 Bridgewater Bay-1, cuttings, depth 4100-4110m, Waarre Formation

Rock types present:

1. Fine to medium grained feldspathic litharenite (90%)

Fine to medium grained, poor to moderately sorted, mineralogically immature feldspathic litharenite. Typically detrital grains are subangular to subrounded with low to moderate sphericity. Grain size ranges from very fine to coarse sand. The grain supported texture is characterised by close packing with tangential & concavo-convex grain contacts. There are intragranular & honeycomb pores where grains are partially corroded & micropores associated with kaolin. Framework grains are composed of monocrystalline quartz, polycrystalline quartz with sutured crystal boundaries, relatively fresh & sericitised K-feldspars which lack twinning or have simple twinning, relatively fresh plagioclase with albite twinning (andesine), lithics of chert, chalcedony, deformed mudstone, shale, micaceous schist, quartzite, ?granite (quartz + feldspar) & abundant highly altered fine grained volcanics (some with trachytic texture), rare muscovite & other altered micas & accessory very fine sand size garnet (red - ?almandite). Matrix is comprised of rare blocky opaque organic matter. Authigenic minerals of dusty anhedral micrite rimming grains, followed by pore filling & grain replacing euhedral ferroan calcite spar. Rare deformed grains replaced by minute kaolin booklets.

2. Fe rich carbonate (?siderite) (trace)

Chips of anhedral microspar with traces of organic matter. The microspar did not respond to staining which indicates it could be either siderite or ankerite.

3. Muddy sandstone to sandy mudstone (2%)

Stringers of opaque organic matter & detrital brown clay indicate the orientation of bedding. Silt to fine sand size angular grains are matrix supported. Detrital grains of monocrystalline & polycrystalline quartz, dusty feldspars, lithics, muscovite & zircon. Authigenic pyrite framboids, grain replacing anhedral carbonate microspar & grain replacing ferroan calcite spar.

4. Single grains (7%)

Medium to coarse sand size grains of monocrystalline quartz, quartzite, micaceous schist, dusty K-feldspars with traces of carbonate spar, polycrystalline quartz with either straight or sutured crystal boundaries & chalcedony.

Rock type thought to be representative of this depth:

Fine to medium grained feldspathic litharenite is the dominant lithology in the cuttings. Single grains could be derived from this sandstone and the muddy sandstone to sandy mudstone might be interbedded with the litharenite. The relative abundance of lithics in this sandstone would be consistent with descriptions of Unit A from the Waarre Formation.

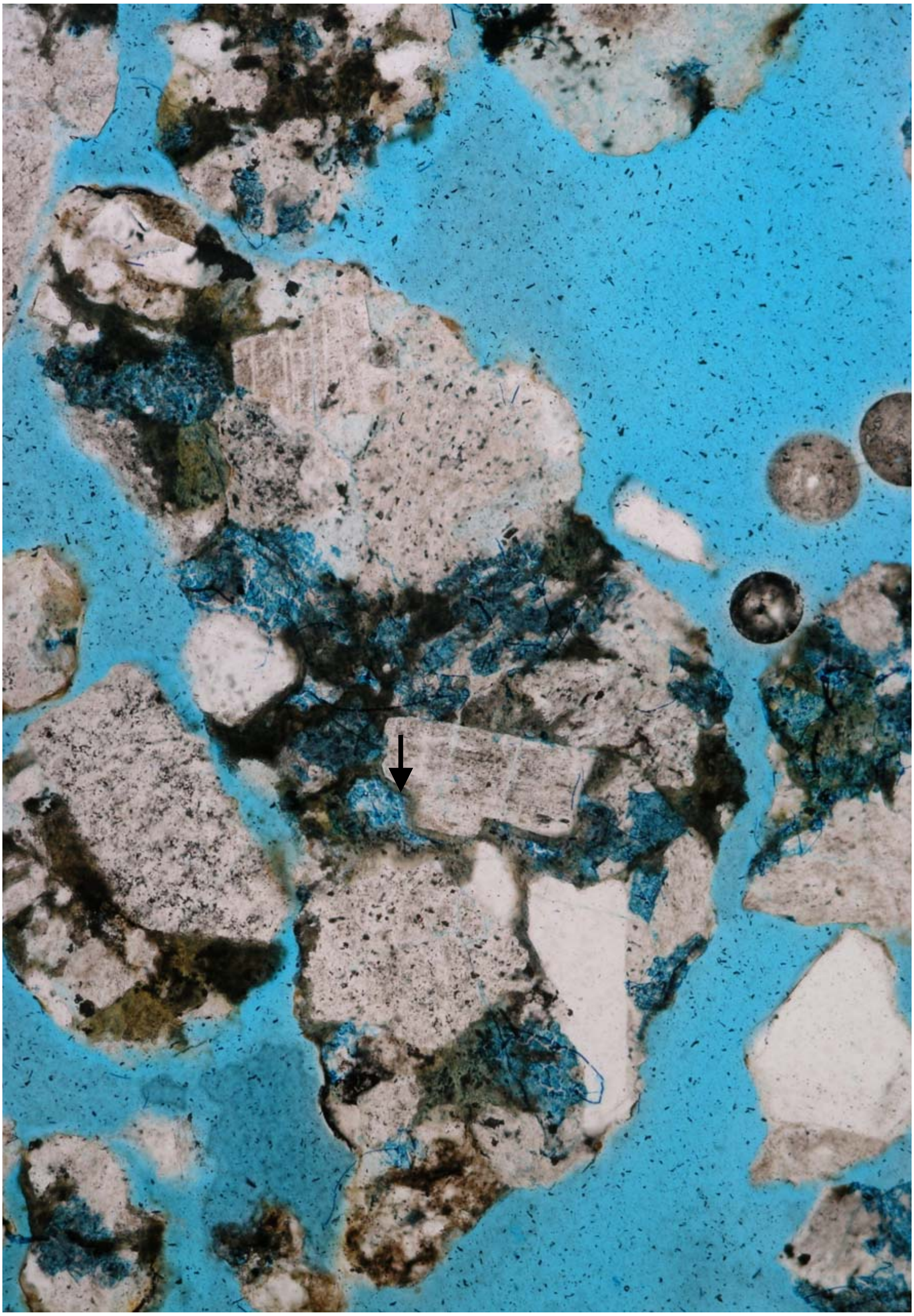

Figure 18

Typical chips of feldspathic litharenite with minor ferroan calcite cement (dark blue). In the central chip there are two angular feldspars apparent and all except the very white grain are lithics. Note the distinctive anhedral rims on grains (arrow) prior to the calcite. These rims might originally have been chlorite that is now replaced by ?siderite. Bridgewater Bay-1, cuttings, depth 4100-4110m. Plane light. Horizontal field of view 1.30mm.

4.19 Bridgewater Bay-1, cuttings, depth 4140-4150m, Waarre Formation

Rock types present:

1. Silty mudstone (7%)

Angular silt to fine sand size quartz grains, dusty feldspars, chert, lithics, muscovite and fragments of organic matter float in detrital brown clay. Authigenic minerals include rare pyrite framboids & rounded very fine bright green glaucony with wormy texture (glauconite).

2. Fine to medium grained feldspathic litharenite (82%)

As per description from 4105-4110m. Where the anhedral rims on grains have a uniform thickness of 10 microns it would appear that chlorite rims have been replaced by ?siderite.

3. Single grains (10%)

Medium to very coarse sand size grains of monocrystalline & polycrystalline quartz, fresh plagioclase, chert, micaceous schist.

4. Fe rich carbonate (?siderite) (trace)

Chips of anhedral Fe rich spar (?siderite) that did not respond to staining have isolated angular silt size grains of quartz & traces of organic matter.

5. Contaminants

Large mica flakes, drill bit scale & drilling mud.

Rock type thought to be representative of this depth:

The high percentage of fine to medium grained feldspathic litharenite suggests this lithology is representative of this depth. There is probably a silty mudstone interval between this sandstone and the sand at 4105-4110m.

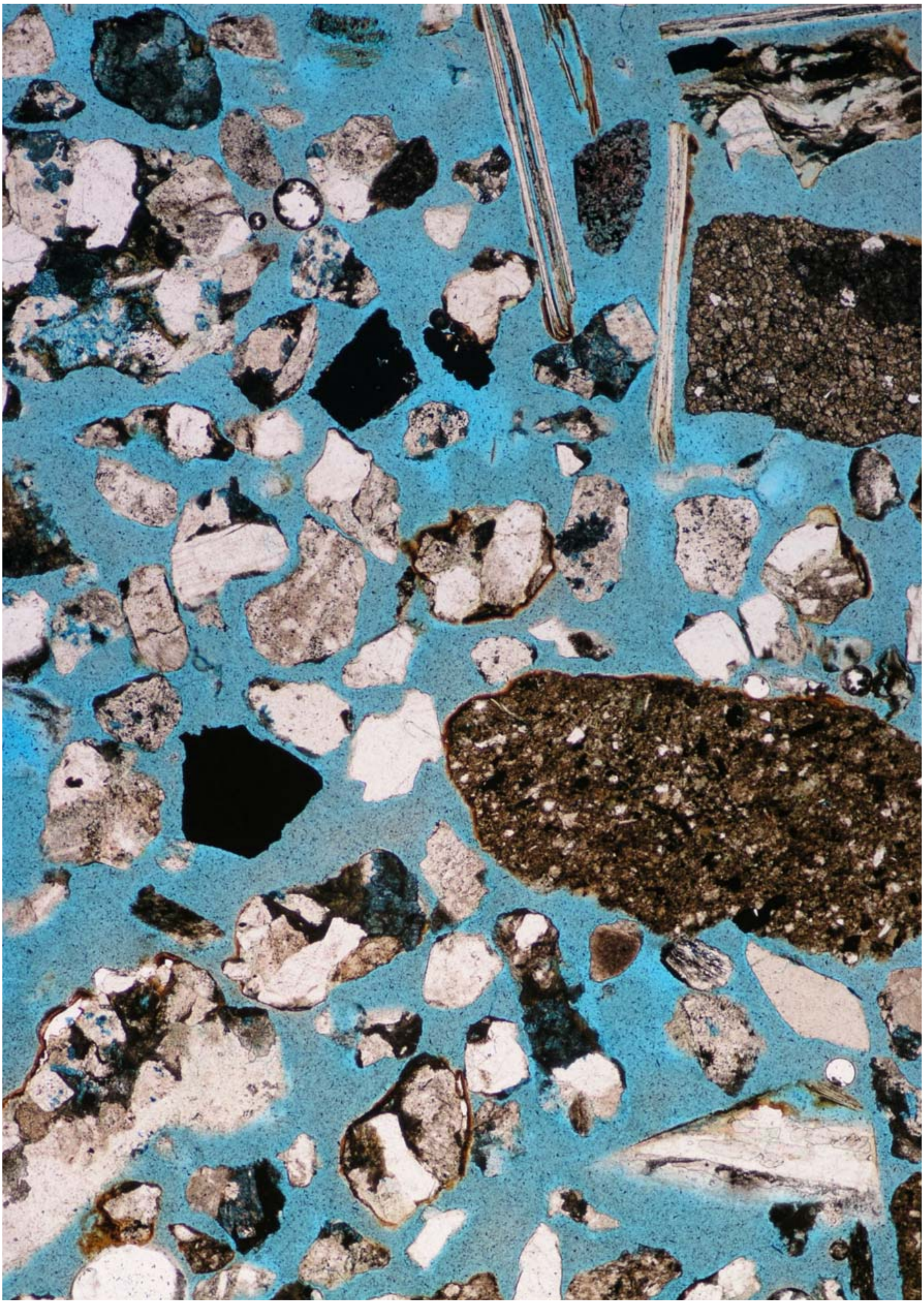

Figure 19
General field of view including chips of feldspathic litharenite with ferroan calcite cement (dark blue), Fe rich spar (brown at this magnification), silty mudstone, contaminants & single grains. Bridgewater Bay-1, cuttings, depth 4140-4150m. Plane light. Horizontal field of view 3.25mm.

4.20 Argonaut-1, core, depth 11,666ft, Flaxman (Banoon equivalent)

Rock classification: **Laminated sublitharenite**

Texture:

- Sedimentary structures: laminae with undulose erosional contacts, shell fragments & faecal pellets aligned along one lamina, differences in clay & organic matter content outline bedding
- Average grain size: very fine sand
- Range in grain size: clay to medium sand
- Roundness / sphericity: subangular with low sphericity
- Sorting: poorly sorted
- Texture: grain supported
- Packing / grain contacts: close packing / tangential & concavo-convex grain contacts
- Pore types: fracturing parallel to bedding is probably an artifact of sampling

Composition:

- Framework grains: monocrystalline quartz, polycrystalline quartz, sericitised & fresh plagioclase, fresh & dusty K-feldspars with tartan twinning, lithics of chert, shale, quartzite & ?possible chloritised volcanics, shell fragments consist of curved segments with serrated margins that have been replaced by chert, moulds of ?bivalve tests were also replaced by chert and then Fe rich carbonate microspar, ovoid faecal pellets up to 6mm in diameter, bent muscovite & biotite flakes up to 0.3mm in length, accessory silt size zircon, tourmaline, ?monazite & rutile
- Matrix: crenulated stringers of anhedral brown clay & opaque organic matter
- Authigenic minerals: grain replacing fibrous green chlorite, pale to bright green deformed grains with wormy texture typical of glauconite, deformed grains of unknown origin replaced by illite, pyrite framboids concentrated along grain margins in laminae that have minimal microspar, anhedral Fe rich microspar has replaced & rimmed grains, it concentrates in the lamina with shell fragments & faecal pellets, rarely the microspar is zoned with a more Fe rich core and outer rim which gives the appearance of sphaerosiderite & there are examples of euhedral scalenohedral crystals up to 20 microns in diameter, calcite spar could postdate the Fe rich phase (the calcite might be ferroan but the thin section was not stained to differentiate this difference), rare grains replaced by kaolin booklets that are up to 10 microns in diameter

Visual Estimate of Composition			Volume %
Framework grains	Quartz	monocrystalline	41
		polycrystalline	tr
	Feldspar		1
	Lithics		5
	Fossils		1
	Mica		10
	Accessory minerals		tr
Matrix	Clay		12
	Organic matter		7
Authigenic minerals and cements	Chlorite		tr
	Glauconite		tr
	Fe microspar		17
	?Calcite spar		2
	Illite		3
	Kaolin		tr
Porosity	Fractures		tr

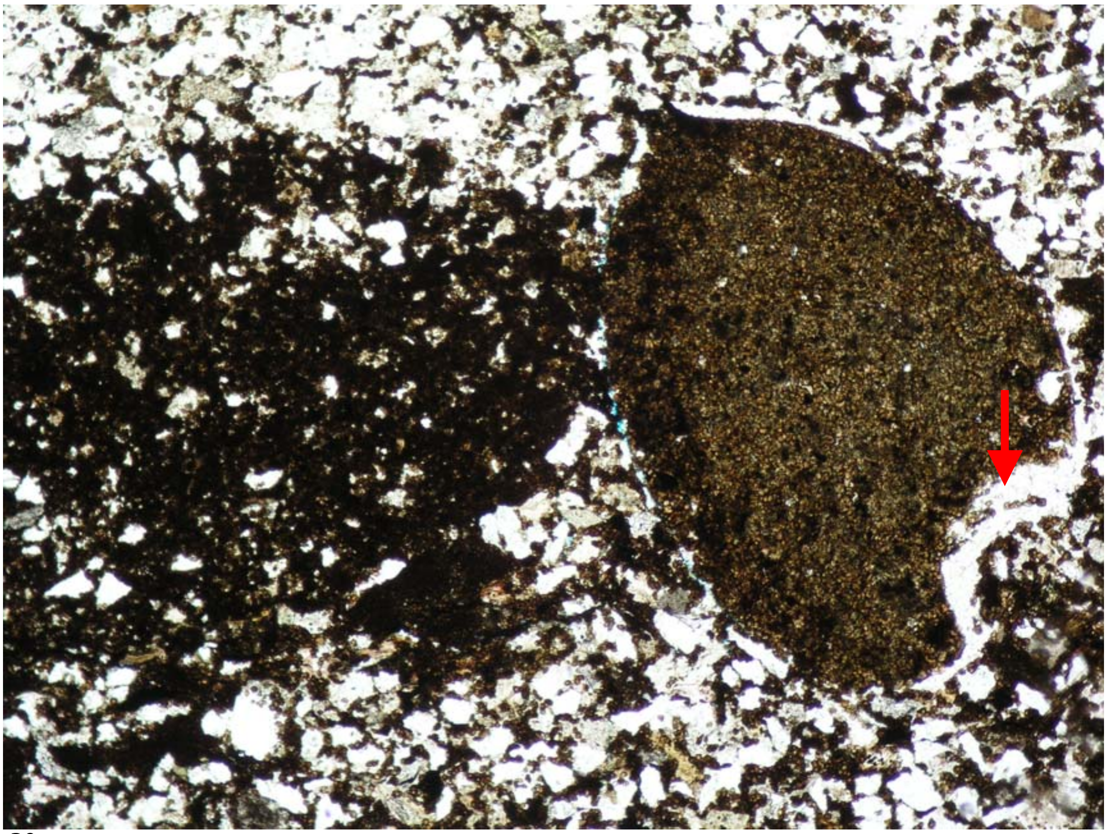

Figure 20a
The fossil on the RHS has a white rim (arrow) which is composed of chert but the remainder of the test has been replaced by Fe rich microspar. The ovoid structure on the LHS was probably a faecal pellet. Argonaut-1, core, depth 11,666ft Plane light. Horizontal field of view 3.25mm.

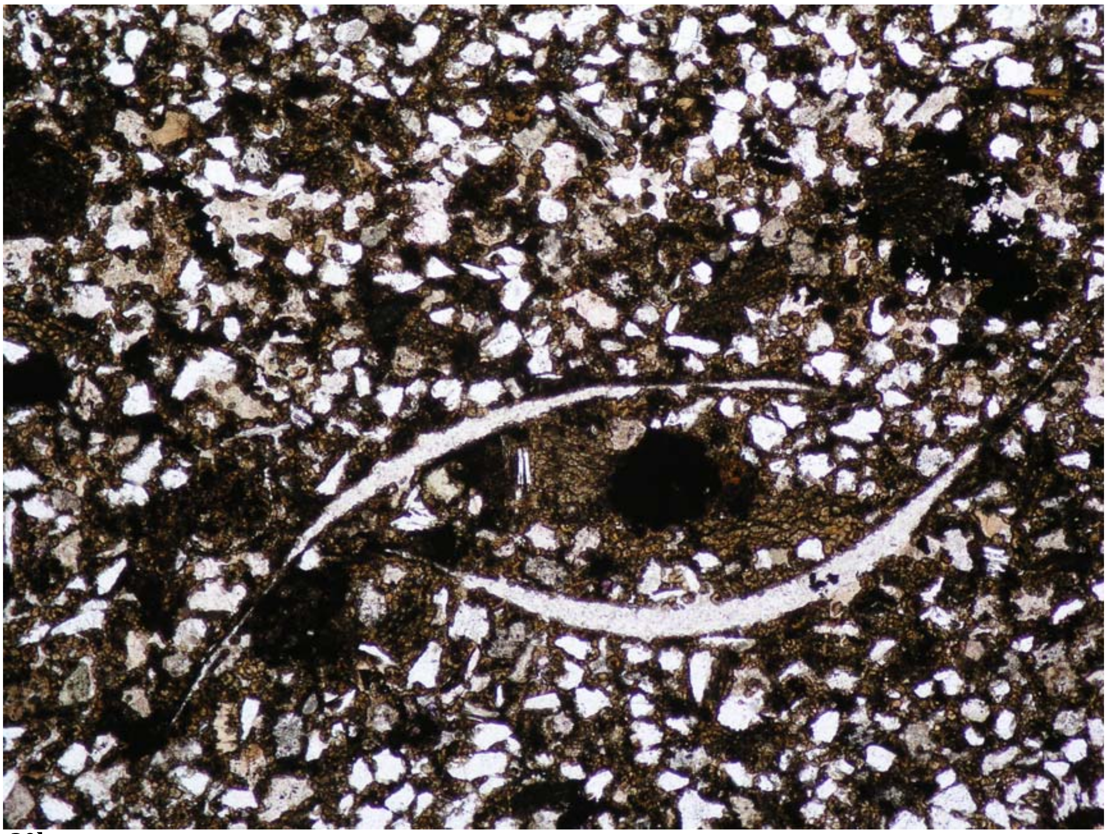

Figure 20b
In the same lamina as the fossil in Figure 20a are these curved shell fragments that have been replaced by chert. Argonaut-1, core, depth 11,666ft Plane light. Horizontal field of view 3.25mm.

4.21 Argonaut-1, core, depth 12,142ft, Flaxman Formation?

Rock classification: **Sublitharenite**

Texture:

Sedimentary structures: low amplitude stylolite outlined by organic matter & detrital clay, planar laminae indicated by changes in grain size & sorting

Average grain size: medium sand

Range in grain size: clay to coarse sand

Roundness / sphericity: subangular to subrounded with low to moderate sphericity

Sorting: moderately sorted

Texture: grain supported

Packing / grain contacts: moderately close packing/ dominantly tangential but sutured near the stylolite

Pore types: primary intergranular pores, grain size dissolution pores, honeycomb pores where feldspars are corroded, intragranular pores where inclusions have been dissolved in quartz grains & micropores associated with kaolin

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, relatively fresh plagioclase with albite twinning (andesine), corroded K-feldspars either lack twinning or have remnants of tartan twinning (microcline), lithics of chert, shale, micaceous schist, quartzite, ?devitrified volcanic glass & ?granite (quartz + feldspar), bent muscovite & biotite flakes concentrate in the stylolite & are up to 1.4mm in length, accessory silt to fine sand size ?monazite, opaques & tourmaline

Matrix: brown anhedral to illitic clay & blocky opaque organic matter

Authigenic minerals: syntaxial quartz overgrowths are jagged adjacent to pore filling & grain replacing kaolin, typically overgrowths have euhedral terminations resulting in angular intergranular pores, minute kaolin booklets have replaced grains & been squeezed into intergranular pores, micas were replaced where kaolin booklets are up to 30 microns in diameter & are associated with traces of illite, minor pore filling euhedral Fe rich carbonate spar with curved crystal boundaries typical of ferroan dolomite postdates the quartz overgrowths, anhedral Fe rich carbonate (?siderite) has replaced organic matter & detrital clays & rarely occurs on grain margins

Visual Estimate of Composition			Volume %
Framework grains	Quartz	monocrystalline	54
		polycrystalline	4
	Feldspar		tr
	Lithics		4
	Mica		tr
	Accessory minerals		tr
Matrix	Clay		5
	Organic matter		2
Authigenic minerals and cements	Quartz		8
	Kaolin		7
	Illite		1
	?Ferroan dolomite		3
	?Siderite		2
Porosity	Intergranular		6
	Dissolution		3
	Micropores		tr

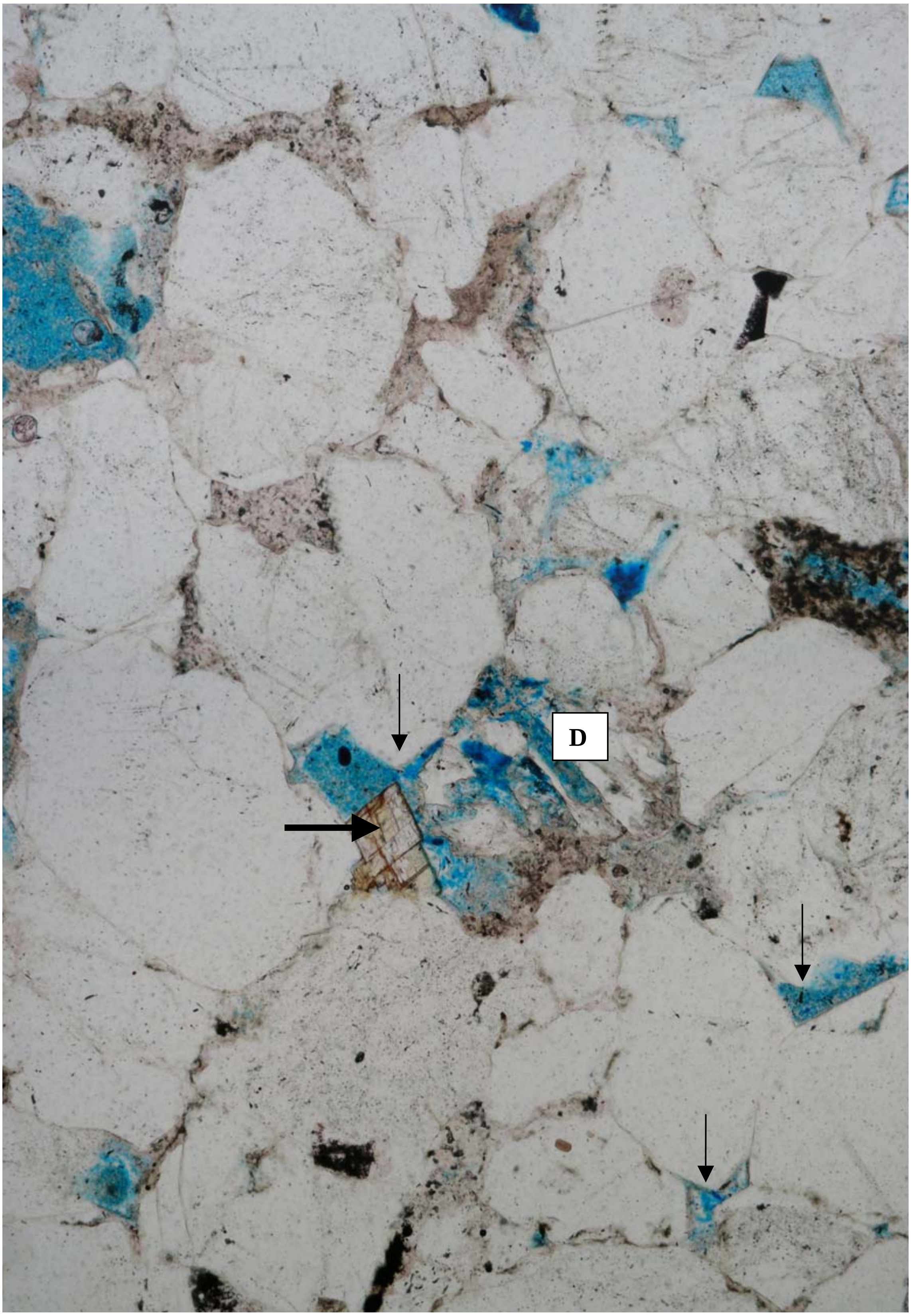

Figure 21

Intergranular pores (blue) are isolated and angular in this sublitharenite due to the abundance of quartz overgrowths (small arrows). Dissolution pores (D) formed before the pore filling ?ferroan dolomite spar (large arrow). Argonaut-1, core, depth 12,142ft Plane light. Horizontal field of view 1.30mm.

5. DISCUSSION

Interpretations based on petrology descriptions where only cuttings are available should be considered with caution. It is possible that the lithology thought to be representative of a particular depth has not been identified correctly because of downhole contamination. Cuttings are biased towards those parts of a rock which are better cemented and therefore do not give an accurate indication of reservoir quality.

1. Was sediment provenance different for the Waarre A compared to the Waarre C sands in the central-western Otway Basin?

Key wells: McNamara Park-1, Caroline-1, Lake Bonney-1 & Breaksea Reef-1

Sharp and Wood (2004) noted in the Casino Field from the eastern Otway Basin that there is a significant difference in sediment provenance between Unit A and Unit C of the Waarre Formation. They described Unit A as comprised of medium grained, poor to moderately well sorted feldspathic litharenites and carbonate cemented sublitharenites. These lithic rich sandstones had a mixed source derived from both metamorphic and igneous terranes. The overlying Unit C sands lack volcanic lithics and there is a decline in both the feldspar and lithic contents (Sharp & Wood, 2004).

In the central-western Otway Basin Unit A (Table 2) at Lake Bonney-1, Mc Namara Park-1 and Caroline-1 is comprised of medium to very coarse grained, poor to moderately well sorted sublitharenites and quartzarenites. Detrital grains indicate the sediment was derived from metamorphic, igneous and possibly sedimentary sources. Volcanic lithics are present but the number of these lithics are significantly less than in wells to the southeast at Normanby-1 and Bridgewater Bay-1. This difference could reflect the coarser grain size of the central-western Otway Basin rather than a change in sediment source. It might also be an artifact of the poor data preserved in cuttings which have disaggregated into single grains. However, regardless of any potential sampling problems there is a high percentage of polycrystalline quartz (Table 2) with straight crystal boundaries relative to monocrystalline quartz in the central-western Otway Basin. An igneous terrane (plutonic) was probably the source for this polycrystalline quartz. Since many of these grains are up to granules in size this might suggest relatively short distances of sediment transport since polycrystalline grains are normally disaggregated during transport. Sediment in Unit A was also derived from a metamorphic terrane that shed lithics of shale, micaceous schist and quartzite and there is minor evidence of reworking within the sedimentary environment from the presence of mudstone lithics.

Unit C of the Waarre Formation in the central-western Otway Basin (Table 3) is comprised of fine to very coarse grained, moderately to well sorted sublitharenites, subarkoses and quartzarenites. These lithologies contain less lithics and in particular volcanics and chalcedony may be absent compared to Unit A. In addition, the relative proportion of polycrystalline quartz would appear to be much lower in Unit C than in Unit A. However, the actual source of this sediment does not appear to have changed significantly from Unit A and included both igneous (plutonic) and metamorphic terranes. Mudstone lithics at Caroline-1 (8180-8210ft) may indicate reworking within the depositional environment.

The only possible volcanic lithic in Unit C was identified in Breaksea Reef-1 at 4446m and this same sample contains both K-feldspar and plagioclase. Other samples from Unit C lack plagioclase and it is only Unit A at Bridgewater Bay-1 and Normanby-1 that contains plagioclase. Based on these observations it is possible that the cuttings from Breaksea Reef-1 at 4446m might represent Unit A. If this interpretation at Breaksea Reef-1 is correct then no volcanics have been found in Unit C and this source was cut off during this period of sedimentation.

TABLE 2 SUMMARY OF WAARRE FORMATION UNIT A

Well	**Lake Bonney-1**	**Lake Bonney-1**	**McNamara Park-1**	**Caroline-1**	**Bridgewater Bay -1**	**Bridgewater Bay -1**
Depth	8600-8610ft	8680-8690ft	1923-1926m	9300-9310ft	4100-4110m	4140-4150m
Sample type	cuttings	cuttings	cuttings	cuttings	cuttings	cuttings
Lithology	sublitharenite	sublitharenite	sublitharenite	quartzarenite	feld litharenite	feld litharenite
Grain size	medium	coarse	coarse sand (bimodal)	very coarse	fine-medium	fine -medium
Range in grain size	medium - granules	medium - granules	silt - granules	medium - granules	v fine - coarse	v fine- coarse
Roundness	SA - SR	SR	SA-SR	SR	SA-SR	SA -SR
Sorting	mod well	mod well	poor	mod - mod well	poor-mod	poor-mod
Structures	interbedded	?interbedded	-	-	?interbedded	?interbedded
Framework grains						
quartz - mono	* (18)	* (36)	* (59)	* (37)	*	*
- poly	* (10) str	*(13)	* (30) str	* (23) str	* sut	* sut
feldspars	*	*	*(2)	* (tr)	* K & P	* K & P
total lithics			*(7)			
lithics - sedimentary	* c	* c	*c, ch	* c	*c, ch, mud	*c, ch, mud
- igneous	* v, g	* v, g	*?spherulitic		*v, g	*v, g
- metamorphic	*qt, s,	*qt	* ms, s	* qt	* ms, s, qt	* ms, s, qt
micas	-	-	-	-	*	*
accessory	-	-	tr T, Z	-	* G	* G
Matrix						
clay	-	-	-	-		
organic matter	-	-	-	-	*	*
Authigenic						
quartz	*	*	*	*	-	-
ferroan calcite	* pervasive	*	*	*	*	*
siderite	-	-	-	-	*	*
kaolin	*	*	-	*	*	*
pyrite	*	*	-	-	-	-
Porosity						
Intergranular	*	*	-	-	-	-
Dissolution	-	* gs	* intra	-	* intra, hc	* intra, hc
Micropores	-	-	-	-	*	*

str = straight crystal boundaries, sut =sutured crystal boundaries, K & P = K-feldspar & plagioclase

c = chert, ch= chalcedony, mud = mudstone, ms = micaceous schist, s = shale, qt = quartzite, v = volcanics, g = ?granite, T = tourmaline, Z = zircon, G = garnet, gs =grain size, intra = intragranular, hc = honeycomb

Note: numbers given in brackets are based on the number of single grains in the cuttings of this type which could have been disaggregated from a sandstone. These values are only intended to indicate relative proportions not the actual percentage of these grains in the sandstone.

* indicates the component has been identified in the cuttings

TABLE 3 SUMMARY OF WAARRE FORMATION UNIT C

Well	Breaksea Reef-1	+Breaksea Reef-1	Lake Bonney-1	McNamara Park-1	Caroline-1	Caroline-1	Fahley-1
Depth	4371-4374m	4443-4446m	7540-7570ft	1668-1671m	8180-8210ft	8450-8460ft	3135-3140m
Sample type	cuttings	cuttings	cuttings	cuttings	cuttings	cuttings	cuttings
Lithology	sublitharenite	sublitharenite	quartzarenite	subarkose	sublitharenite	quartzarenite	quartzarenite
Grain size	fine	medium	very coarse	coarse	medium	coarse	medium-coarse
Range in grain size	v fine-medium	silt – v coarse	medium - granule	fine – v coarse	v fine – v coarse	fine - granules	fine – coarse
Roundness	SA	SA	SR	SR-R	SA	SR	R
Sorting	mod well	mod well	well	well	mod-mod well	mod	mod well
Structures	-	?interbedded	-	-	?burrow, interbedded	?interbedded	interbedded
Framework grains							
quartz - mono	*	*	* (56)	* (70)	*	* (50)	*
- poly	* str	* str	* (26) str, sut	* (18) str, sut	* str, sut	* (16) str, sut	* str
feldspars	* K	* K & P	-	* K (4)	* K	-	-
total lithics		more than 4374m					
lithics - sedimentary	*c	*c	* c	* c (2)	* c, mud	-	* c
- igneous	*?g	*?v	-	* ?g	* ?g	-	-
- metamorphic	*qt,ms	*	*qt	*qt	*s, qt	* qt	-
micas	*	*	-	-	-	-	*
accessory	* R	*	-	* Z, T	*Z, M	-	-
Matrix							
clay	-	-	-	-		-	-
organic matter	-	-	-	-		-	-
Authigenic							
glaucony	?	-	-	-		-	-
chlorite	*	*	-	-		-	-
quartz	*	*	*	*	*	*	*
ferroan calcite	*	*	*	-	*	*	*
siderite	-	-	-	-	*	-	*
kaolin	-	*	-	-	*	-	*
pyrite	*	*	-	*	*	*	*
Porosity							
Intergranular	*	*	-	-	*	-	-
Dissolution	*gs,hc	*	-	-	* gs, hc	-	-
Micropores	-	?	-	-	*	-	*

str = straight crystal boundaries, sut =sutured crystal boundaries, K & P = K-feldspar & plagioclase

c = chert, ch= chalcedony, mud = mudstone, ms = micaceous schist, s = shale, qt = quartzite, v = volcanics, g = ?granite, T = tourmaline, Z = zircon, G = garnet, R = rutile, M = monazite, gs =grain size pore, intra = intragranular pore, hc = honeycomb pore

Note: numbers given in brackets are based on the number of single grains in the cuttings of this type which could have been disaggregated from a sandstone. These values are only intended to indicate relative proportions not the actual percentage of these grains in the sandstone.

* indicates the component has been identified in the cuttings

+ this sample from Breaksea Reef-1 might represent Unit A

2. Did Waarre sands at Bridgewater Bay-1 have a different provenance to Waarre sands in Normanby-1 and Breaksea Reef-1?

At Bridgewater Bay-1 (4100-4110m & 4140-4150m) the Waarre sands are fine to medium grained, poor to moderately sorted feldspathic litharenites with abundant fine grained volcanic lithics consistent with the lithology of Unit A in the eastern Otway Basin. Similarly at Normanby-1 (Phillips, 2003) there are medium grained, moderately sorted litharenites with volcanic lithics that have been assigned to Unit A. The relatively high percentage of volcanic lithics at both Bridgewater Bay-1 and Normanby-1 in Unit A might reflect a difference in sediment provenance to the basal sand in Breaksea Reef-1 (4446m). This medium grained, moderately well sorted sublitharenite does contain volcanics and plagioclase typical of Unit A but the number of volcanic lithics is significantly less and there is no evidence of a plutonic source.

These observations might suggest that Bridgewater Bay-1 and Normanby-1 were closer to the volcanic source, or at least more directly in the path of sediment transported from this provenance. Therefore the most likely provenances were the reworking of Otway Supergroup sediments from the Discovery Bay High, or volcanics from the Outer Margin High (Moore *et al* 2000). More recently, Boult *et al* (2005) reinterpreted the rocks in the Outer Margin High as Cambrian and Precambrian which would negate this as a possible volcanic source.

3. What was the depositional environment(s) and sediment provenance of the Banoon Member equivalent?

Key wells: Mt Salt-1, Breaksea Reef-1, Argonaut-1, Najba-1 & Fahley-1

a. <u>Sediment provenance</u>

Partridge (2001) suggested that the decrease in quartz pebbles and sand in the Flaxman Formation type section with distance above the Waarre Formation was evidence that these grains were sourced from the Waarre Formation. Although there are isolated very coarse grains of quartz in the core from Mt Salt at 2718.7m this grain size is concentrated in laminae at 2716.6m where grain size is bimodal. The latter could suggest either two sources of sediment, or two modes of sediment transport. Any decrease in quartz pebbles and sand at Mt Salt is related to bedding and therefore possibly the hydraulic regime of the depositional environment. This decrease does not necessarily indicate reworking from the Waarre Formation.

Based on the framework grains in sandstones from the Banoon Member equivalent it would appear that sediment was derived dominantly from a metamorphic terrane, with minor input from igneous and sedimentary environments. In all samples there are metamorphic lithics of quartzite, and polycrystalline quartz with sutured crystal boundaries, which might only reflect the mineralogical maturity of the sediment. Additional support for a metamorphic source could be evident from the presence of micaceous schist, ?pyrophyllite, micas and silt size metasediments. In the core at Mt Salt (2726.6m & 2718.7m) there are rare volcanic and possible granitic lithics, and up to medium sand size accessory tourmaline which might reflect the igneous source. Volcanic lithics are also reported from Argonaut-1 at 12,139ft (Mobil, 1995) and 11,666ft (this report), but there are no igneous lithics apparent at Najaba-1, Fahley-1 or Breaksea Reef-1. In part this distribution might have been influenced by the fact that only cuttings were available, but this was not the case at Najaba-1 where texture is well preserved in the sidewall core. Accessory tourmaline is present at Najaba-1 therefore the absence of igneous lithics might only be due to the small sample size. If the igneous lithics were reworked from the Waarre Formation then it was probably from Unit A since elsewhere there are no volcanics in Unit C (Sharp & Wood, 2004). Volcanics might also have been reworked directly from the older Otway Group.

Sedimentary lithics are rare and comprised of deformed mudstone at Mt Salt-1, Najaba-1 and Argonaut-1. These lithics could have been reworked within the sedimentary environment either as rip-up clasts or as faecal pellets. Chert is also present in the sandstones but this could have been derived from a number of sources (sedimentary and volcanic), or because of its mineralogical maturity it might have been reworked from older sedimentary sequences.

b. Depositional environments

At the type section in Port Campbell-2 the Banoon Member of the Flaxman Formation is described as an oolitic ironstone (Partridge, 2001). It would appear from this study that in the central-western Otway Basin the Banoon Member equivalent is lithologically more variable and does not include an ironstone. Although there is no evidence of an ironstone, at least one facies was Fe rich and this favoured the development of chlorite rims on detrital grains in fine to medium-very coarse grained sandstones. These rims have imparted a greenish colour to the core from Mt Salt-1 and are evident at Breaksea Reef-1 (3648m), Fahley-1 (2900m) and possibly Najaba-1 (2825m). At Najaba-1 the rims have been oxidised and this might reflect subsequent exposure in the depositional environment, or alteration of the sidewall core after sampling. Chlorite rims commonly form in shallow marine environments close to where a river mouth enters the sea. Terrestrial sourced iron is transported via hydroxyls on clays which are flocculated on contact with the sea water. The rims in the Flaxman developed after initial compaction due to burial and are therefore absent at grain contacts. The elements for chlorite precipitation may also have been sourced from the alteration of ferromagnesium minerals within volcanic lithics.

Possible rare grains of glauconite confirm that the depositional environment was marine but at least some of these grains could have been reworked from further offshore. The oxidised core of an incipient, or superficial ooid at Mt Salt-1 (2716.6m) is consistent with minor exposure during reworking in the depositional environment. If these superficial ooids were concentrated in a particular depositional setting, such as a mouth bar, then an ironstone could develop.

Bioturbation in core 30 at Mt Salt-1 is characterised by vertical burrows which could reflect suspension feeders associated with either Glossifungites or Skolithos ichnofacies. This was a relatively high energy depositional environment but with breaks in sedimentation that were long enough to allow colonisation.

Other facies in the Banoon Member reflect lower energy marine depositional settings. Sediments have a significant clay content and range from mudstone to muddy sandstone. Typically the mudstones are silty and/or sandy with grain size commonly of very fine to fine sand. Trace amounts of silt size fresh glauconite confirms the marine setting. These deposits might have accumulated on a delta front in distal bars where coarser sands were only rarely deposited after storms.

Shell fragments and intact tests of bivalves at Argonaut-1 (11,666ft) with associated ovoid faecal pellets might confirm the shallow marine depositional setting but bivalves can also characterise brackish and freshwater environments. Extensive replacement of the shells by chert could indicate either the groundwaters were supersaturated with respect to silica, or there was high organic productivity. Alkalinity was probably high due to the dissolution of the aragonitic bivalve shell fragments and this would favour the precipitation of opal-CT in the moulds. Later the opal-CT was converted to chert. Cherts of this type do form in both lacustrine and marine settings. Concentration of siderite in the same lamina as the shell fragments might suggest exposure and/or flushing by meteoric waters. This would tend to favour interpretation of very shallow water depths (?lacustrine) and the presence of sphaerosiderite may confirm fluctuating groundwaters similar to those in a water logged pedogenic environment. These conditions prevailed for short intervals and were then inundated by saline waters which favoured pyrite precipitation.

4. Identify depositional environments for the Waarre A and C, and compare these results to the eastern Otway Basin.

Key wells: Bridgewater Bay-1, Normanby-1, Breaksea Reef-1, Caroline-1, McNamara Park-1, Fahley-1 & Lake Bonney-1

a. Waarre Unit A

In the eastern Otway Basin depositional environments in Unit A range from fluvial to shallow marine and there were a variable number of transgressive and regressive cycles recognised (Sharp & Wood, 2004). The marginal marine setting was identified from marine microplankton and the presence of both glaucony and framboidal pyrite.

Glaucony has not been recognised in any of the samples from Unit A in the central-western Otway Basin which might suggest there was less of an open marine influence. However, there are possible chlorite rims at Bridgewater Bay-1 (4100-4110m), Breaksea Reef-1 (4446m) and Lake Bonney-1 (8610ft) which could reflect a shallow marine setting close to where rivers entered the sea. The lack of glaucony might simply be due to shallower water depths because glaucony commonly forms on continental shelves in water depths of 50 to 200m and chlorite occurs at depths shallower than 40m. At Normanby-1 where there are no chlorite rims there is abundant siderite both as nodules and single crystals rimming and replacing grains. Siderite forms when carbonate activity is high but sulphide levels are low. The latter is rarely attained in marine conditions because there is too much dissolved sulphate in sea water. This might suggest a more terrestrial/brackish depositional setting at Normanby-1. The fact that chlorite rims are probably replaced by anhedral siderite at Bridgewater Bay-1 could imply that the original marine conditions were later replaced by a more terrestrial influence possibly during regression.

Framboidal pyrite was identified at Lake Bonney-1 (8610 & 8690ft) which could confirm the shallow marine influence. Trace amounts of framboidal pyrite were also noted at Normanby-1 and that might suggest temporary brackish conditions.

There is nothing to indicate a marine influence at Caroline-1 (9310ft) or McNamara Park-1 (1926m) but both these samples were disaggregated into single grains and the information available is limited. Possible bimodal grain size at McNamara Park-1 could either be the result of two sediment sources, or two mechanisms of sediment transport. Average grain size in the samples from Unit A probably reflects a moderate to relatively high energy depositional setting.

b. Waarre Unit C

In the eastern Otway Basin there is a significant change in depositional environments within Unit C from fine grained marine influenced at the base (Unit Ca), to medium to coarse grained fluvial dominated (Unit Cb) at the top (Sharp & Wood, 2004).

In the central western Otway Basin there was only one sample that might be shallow marine and therefore representative of Unit Ca. Cuttings from Breaksea Reef-1 at 4374m were fine grained and there is evidence of oxidised glaucony, chlorite rims and framboidal pyrite to confirm the marine influence. All other samples were medium to very coarse grained and lack both glaucony and chlorite which might suggest a more terrestrial depositional setting. Siderite microspar at both Caroline-1 (8180-8210ft) and Fahley-1 (3140m) is consistent with this interpretation. Although the presence of framboidal pyrite in both these samples might also indicate a phase of brackish conditions when sulphide activity was high.

5. What is the reservoir quality of the Waarre C and Flaxman sands in south-eastern SA?

Key wells: Breaksea Reef-1, McNamara Park-1, Mt Salt-1, Argonaut-1, Lake Bonney-1 & Caroline-1

a. Waarre Unit C

Reservoir quality in Unit C is probably good because of the high mineralogical maturity of the sediment and the lack of cement. Primary intergranular pores are preserved in the cuttings and these may indicate the presence of permeability. In addition, there are secondary grain size and honeycomb dissolution pores where feldspars have been corroded. Micropores associated with grain replacing kaolin may also contribute to total porosity. Given that only cuttings are available from Unit C it is extremely difficult to provide an actual porosity percentage. It would be best to calculate this value from the logs. In the medium grained sublitharenite from Caroline-1 where chips have retained some textural integrity there could be at least 10% porosity.

Quartz overgrowths are present in all samples from Unit C and these would provide a rigid framework that could minimise mechanical compaction. Furthermore, in the samples available there is limited evidence of pervasive carbonate cements that might limit reservoir quality.

b. Flaxman sands

Observations by PGPC of core 30 from Mt Salt (2716.4m -2719m) at the time of sampling indicated that this interval of medium to coarse grained sublitharenite typically has good reservoir quality. The petrology sample at 2716.6m which has approximately 18% porosity was thought to be representative of the interval. Typically thin section estimates of porosity are lower than results from routine core analysis because this is a two dimensional measure which is strongly influenced by permeability. The fact that porosity is dominated (15%) by primary intergranular pores at Mt Salt-1 should indicate that there is at least moderate permeability. Secondary dissolution pores (3%) may be effective where adjacent to intergranular pores. Micropores associated with the chlorite rims are unlikely to be effective for oil but could be for gas. The PIRSA sample from Mt Salt at 2717.9m of very fine to coarse grained sandstone has oxidised chlorite rims which lack micropores but the macroporosity is estimated as 15-20%. These results are consistent with observations from Argonaut-1 at 12,139ft (Mobil, 1995) where thin section estimates of reservoir quality are moderate to good (10-12% porosity) with dominantly primary intergranular pores. Similarly at 12,142ft in Argonaut-1 primary intergranular pores are dominant (6%) and there are dissolution pores (3%) that are grain sized, honeycomb and intragranular in nature. In this sample there are micropores associated with the kaolin. It would appear from these observations that the Flaxman sands do retain good to moderate reservoir quality.

However, reservoir quality in the Flaxman sandstones is locally limited by authigenic minerals (carbonate, quartz and kaolin) and compaction. At 2718.7m in Mt Salt-1 there is an interval of ferroan calcite cement which has reduced intergranular porosity to an estimated five percent. The extent and spatial distribution of these cements is not clear but carbonate cement has also reduced reservoir quality at 2872.13m in Mt Salt-1. This same PIRSA sample contains a crenulated muddy laminae which would locally limit vertical permeability. Furthermore, the absence of chlorite rims has allowed greater silicification similar to that in Argonaut-1 at 12,142ft. Deeper in the Mt Salt sequence at 2997.1m and 3006.2m the PIRSA thin sections are of fine to coarse grained sandstones with abundant ?oxidised chlorite rims, grains replaced by chlorite and others replaced by kaolin. In these sandstones there has been significant mechanical compaction due to the ductile nature of these replaced grains. Microporosity could be significant in these samples. Therefore, it would appear that where chlorite rims are absent there is a tendency for reservoir quality to decline but also if there is too much grain replacing chlorite then compaction has reduced reservoir quality. It is possible that the major control of reservoir quality in sandstones from the Flaxman Formation at Mt Salt-1 was related to facies and the relative abundance of chlorite, but later carbonate cement has a localised influence.

Based on cutting samples from Breaksea Reef-1 it is very difficult to assess reservoir quality. Typically in cuttings it is the better cemented sands that retain textural integrity and these have the poorest reservoir quality. Therefore any comments on reservoir quality might be unnecessarily pessimistic. At 3639m the dominance of single grains of fine sand to granule size quartz might indicate a relatively clean coarse grained sandstone with minimal cement and no chlorite rims. Comparison with the Mt Salt-1 data could reflect limited reservoir quality due to silicification. Deeper in the sequence at 3648m the fine grained moderately well sorted

?subarkose does have traces of chlorite rims but there was significant compaction and this has limited reservoir quality.

6. CONCLUSIONS

1. In the central-western Otway Basin sediment provenance in Unit A of the Waarre Formation was probably different from Unit C. Unit A contains volcanic and chalcedonic lithics, plagioclase and high percentages of polycrystalline quartz. These detrital grains are absent, or less abundant in the case of polycrystalline quartz, in sandstones from Unit C. An igneous source (both volcanic and plutonic) probably had a stronger influence on sedimentation during deposition of Unit A. The volcanic terrane did not influence sedimentation in Unit C.

2. At Bridgewater Bay-1 and Normanby-1 in Unit A there are higher percentages of volcanic lithics than in Breaksea Reef-1. This might indicate the volcanic source was older Otway Supergroup sediments reworked from the Discovery Bay High.

3. Sediment provenance in the Banoon Member equivalent was dominantly from a metamorphic terrane with minor input from igneous and sedimentary environments.

4. Depositional environments in the Banoon Member equivalent included shallow marine settings close to where a river entered the sea. Distinctive chlorite rims formed in this environment but there were periods of exposure that caused oxidation of the chlorite and grains of glauconite. Bioturbation by suspension feeders occurred in this relatively high energy depositional environment. Other facies reflect lower energy settings with deposition of mudstones and muddy sandstones. Where bivalve fragments accumulated in laminae with faecal pellets fluctuations in groundwaters might indicate short periods characterised by lacustrine conditions.

5. Waarre Unit A in the central western Otway Basin had similar depositional environments to those of the eastern Otway, ranging from shallow marine to brackish, moderate to high energy with possible evidence of a regressive sequence. Waarre Unit C is also consistent with interpretations of depositional settings in the eastern Otway ranging from fine grained shallow marine to coarser grained possibly terrestrial/brackish settings.

5. Reservoir quality is very difficult to assess from cuttings because the samples are biased towards cemented parts of the sandstones. In Unit C of the Waarre Formation in south-eastern SA reservoir quality was probably good due to the high mineralogical maturity of the sandstones and relative lack of authigenic cement. In the Flaxman Formation reservoir quality in the sandstones is moderate to good but locally limited by authigenic minerals (carbonate, quartz and kaolin) and compaction.

7. GLOSSARY OF TERMS

<u>Boehm lamellae</u>
Parallel trails of vacuoles in quartz that are thought to form during deformation (metamorphism) of grains.

<u>Framboid</u>
A cluster of pyrite crystals with a spheroidal outline.

<u>Glaucony</u>
A term used to describe green minerals without any genetic connotations. If the green minerals can be identified, a specific mineral name is given.

<u>Glauconite</u>
An Fe-rich dioctahedral illite. The term is also used to refer to a family of Fe-rich dioctahedral clays with varying ratios of expanded (smectite) and non-expanded layers.

<u>Granophyric Texture</u>
A variety of micrographic intergrowth of quartz and alkali feldspar that is either crudely radiate or is less regular than micrographic texture.

<u>Honeycomb Porosity</u>
Secondary porosity produced by the corrosion (etching) of detrital grains.

<u>Hydrocarbon envelope</u>
Solid bitumen surrounding a mineral containing radioactive elements. Radiation causes polymerisation of hydrocarbon chains within oil that rims grains.

<u>Micrographic Intergrowth</u>
A regular intergrowth of two minerals.

<u>Microporosity</u>
Porosity directly associated with clay minerals.

<u>Neomorphism</u>
All transformations between a mineral and the same mineral, or another of the same general composition.

<u>Poikilotopic</u>
A sedimentary textural term denoting a single crystal of carbonate enclosing more than one framework grain.

<u>Radiate Texture</u>
Textures in which elongate crystals diverge from a common nucleus.

<u>Trachytic</u>
A textural term applied to the groundmasses of volcanic rocks in which there is a subparallel arrangement of microcrystalline, lath shaped feldspars. The term is not restricted in use to rocks of trachyte composition.

<u>Vacuole</u>
Gas or liquid filled inclusion.

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