29 November, 2001

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Attention: Kumar Kuttan

FINAL REPORT: 0444-01 - EAST PILCHARD-1

CLIENT REFERENCE:	Contract 3820840/01 Cost Centre No. 61-497
MATERIAL:	Rotary Sidewall Cores
LOCALITY:	East Pilchard-1
WORK REQUIRED:	Petrology and reservoir quality

Please direct technical enquiries regarding this work to the signatory below under whose supervision the work was carried out.

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PETROLOGY

of

EAST PILCHARD-1

for

ESSO AUSTRALIA PTY LTD

by

ACS LABORATORIES PTY LTD

PETROLOGY

of

EAST PILCHARD-1 SAMPLES

A report prepared for

ESSO AUSTRALIA PTY LTD

by

JULIAN C. BAKER Ph.D.

November 2001

C O N T E N T S

Page

C O N T E N T S cont.

Page

FIGURES

TABLES

APPENDICES

EXECUTIVE SUMMARY

A petrological study was carried out on twenty msct samples from 2450.0-2764.5m in East Pilchard-1. Analytical techniques used were thin-section analysis, quantitative bulk rock/clay fraction X-ray diffraction analysis and scanning electron microscopy.

The top two samples (#1, #2) are altered basaltic volcanics composed largely of plagioclase laths that have undergone hydrothermal alteration to chlorite (#1) and sericite (#2). Interstitial matrix is mainly secondary chlorite, opaque oxides, silica and ferroan carbonate. Phenocrysts are totally replaced by ferroan carbonate, silica and chlorite. Silica-filled cavities/amygdales are included in #2, and both volcanics are cut by ferroan carbonate-healed fractures. Macroporosity is absent.

Six argillaceous samples are silty/arenaceous mudrocks (#6, #7, #9, #11), an argillaceous siltstone (#12) and a laminated, fine grained, argillaceous sandstone (#21) composed mainly of illitic/kaolinitic detrital clay, quartz, K-feldspar, plagioclase, rock fragments, mica, organic fragments and accessory heavy minerals. Detrital clay is partly replaced by microcrystalline siderite in #6, #7 and #11, and is also replaced by patchy, medium-crystalline ankerite in #6. Argillaceous samples contain little or no visible porosity and only minor microporosity.

Sample #14 is composed mainly of drilling mud contaminants and provides no clear indication of lithology at the sample depth.

Eleven samples (#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23) are variably sorted, fine to very coarse grained sublitharenites and a subarkose in which framework grains include quartz, K-feldspar, plagioclase, rock fragments, mica, organics and accessory heavy minerals. Lithic grains are mainly metamorphic rock fragments, the amount of which generally increases with decreasing grain size, and also include volcanic, granitic and siliciclastic sedimentary rock fragments.

Sandstones are derived from a continental provenance dominated by granitic and low-grade metasedimentary rocks that also included minor siliciclastics and volcanics.

Detrital clay in the sandstones forms sporadic matrix patches and is also concentrated along very thin laminae. Most sandstones lack detrital clay. Authigenic clay is mainly kaolinite that occurs where micaceous/argillaceous grains and feldspar have altered and where patchy detrital clay matrix has recrystallised. Illitic remnants of micaceous precursor grains are locally associated with authigenic kaolinite, and minor authigenic illite is associated with partly altered and compactionally deformed micaceous metamorphic rock fragments.

Porosity reduction in the sandstones is mainly the result of grain contact dissolution, ductile grain/clay compaction, authigenic clay formation, minor quartz overgrowth cementation and localised ankerite cementation. Porosity has been increased by K-feldspar dissolution.

Visible porosity in the sandstones ranges up to 18.6% and decreases with increasing clay + metamorphic rock fragment content. Visible porosity is accounted for by varying proportions of primary intergranular pores and secondary K-feldspar dissolution pores.

Sandstone reservoir quality is mainly controlled by the content of metamorphic rock fragments and, of less importance, clay. Clay + metamorphic rock fragment content is only moderately correlated with grain size, and there is wide variation in sorting. Consequently, permeability is only weakly correlated with grain size. Ankerite cement has a very localised influence on reservoir quality.

1. INTRODUCTION

A petrological study was carried out on twenty msct samples from 2450.0-2764.5m in East Pilchard-1. Samples include non-reservoir lithologies (volcanics, mudrocks, argillaceous siltstones/sandstones) and reservoir sandstones. The prime aim of the study was to determine sandstone texture, composition and diagenetic history as well as the controls on sandstone reservoir quality. Sample depths are given in Table 1.

2. ANALYTICAL PROGRAM

2.1 Thin-Section Analysis

Thin-sections were cut in kerosene and impregnated with blue dyed epoxy resin to assist in porosity recognition. All thin-sections were stained with sodium cobaltinitrite to aid feldspar identification and with Alizarin red-S and potassium ferricyanide to aid carbonate identification. Cover slips were not used. Mineral composition and visible porosity were determined by a count of 400 points in all thin-sections except #14 (which is composed of contaminants). Grain size and sorting of all thin-sections except #1, #2 (volcanics) and #14 were determined by measuring the long dimension of 100 point-counted quartz grains. From the grain size measurements, median and mean grain size and sorting (ϕ standard deviation) were calculated. Low and high magnification photomicrographs were taken of each thin-section to illustrate texture, composition, clay distribution, diagenetic effects and porosity.

2.2 X-Ray Diffraction Analysis

Bulk-rock X-ray diffraction (XRD) analysis was carried out on all samples except #1, #2, #6 and #14 in order to quantify mineral abundance. The XRD analysis used a finely ground whole rock powder sample and the SIROQUANT processing technique was used to calculate mineral abundance.

Qualitative fine-fraction XRD analysis was carried out on the same samples used for bulk rock XRD analysis in order to precisely identify clay mineralogy. The fine fraction was separated from each sample by disaggregation and settling in distilled water and was air dried on glass discs to produce oriented specimens for XRD analysis. Samples were analysed in air-dried condition and also following treatment with ethylene glycol.

2.3 Scanning Electron Microscopy

Scanning electron microscopy (SEM) was carried out on freshly broken surfaces of the same sixteen samples that were analysed by XRD. An energy dispersive spectrometer (EDS) attached to the SEM provided qualitative elemental data on clays and carbonate cements.

TABLE 1. ANALYSES PERFORMED

Sample #	Depth (mRT)	PETROLOGICAL ANALYSES					CORE ANALYSES		
		MA	GSA	XRD	SEM	PM	He Por. (%)*	Perm. (md)*†	GD (g/cm^3)
1	2450.0	X	-	-	-	X	-	-	-
2	2586.0	X	-	-	-	X	-	-	-
3	2594.0	X	X	X	X	X	20.6	3750	2.64
4	2598.0	X	X	X	X	X	19.5	3280	2.64
5	2602.0	X	X	X	X	X	19.2	1570	2.64
6	2610.0	X	X	-	-	X	-	-	-
7	2620.0	X	X	X	X	X	6.0	0.004	2.68
8	2627.5	X	X	X	X	X	17.2	135	2.64
9	2633.5	X	X	X	X	X	5.2	19.2	2.36
11	2644.0	X	X	X	X	X	1.9	0.001	2.64
12	2652.0	X	X	X	X	X	7.9	0.018	2.63
13	2663.0	X	X	X	X	X	16.0	30.8	2.65
14	2669.0	-	-	-	-	X	-	-	-
15	2700.5	X	X	X	X	X	13.9	0.73	2.64
17	2721.5	X	X	X	X	X	17.9	61.8	2.65
18	2728.5	X	X	X	X	X	17.6	573	2.64
19	2751.0	X	X	X	X	X	19.5	57.9	2.66
21	2759.0	X	X	X	X	X	4.2	0.010	2.60
22	2763.0	X	X	X	X	X	14.4	13.1	2.66
23	2764.5	X	X	X	X	X	17.0	118	2.65

MA = modal analysis GSA = grain size analysis XRD = bulk rock & fine fraction X-ray diffraction analysis SEM = scanning electron microscopy PM = photomicroscopy

* ambient † air

3. THIN-SECTION ANALYSES

Lithology and texture are listed in Table 2, a grain size comparison table is included in Appendix 1, and grain size frequency curves are presented in Appendix 2. Thin-section composition and QFR ratios are shown in Table 3, and QFR ratios are plotted in Figure 1. Raw point count data are included in Appendix 3. Annotated photomicrographs are presented in Appendix 5 and a grain/cement/porosity-type atlas that refers to the photomicrographs is given in Table 4. A key for plates in Appendix 5 is included in Table 7.

In this section, samples are discussed according to the following three lithological groups;

Volcanics	(#1, #2)
Argillaceous samples	(#6, #7, #9, #11, #12, #21)
Sandstones	(#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23)

Sample #14, which is not included in any of these groups, is composed mainly of a mixture of contaminant, sand-sized calcite and barite fragments and loose quartz grains. The sample also includes fragments of altered basaltic volcanics, marly limestone, marl, argillaceous fine sandstone, and sideritised mudrock, claystone and ferroan dolomite/ankerite cement. The sample therefore provides no clear indication of lithology at the sample depth and will not be discussed further.

3.1 Volcanics (#1, #2)

These two samples from the top of the sampled section are basaltic volcanics composed largely of an interlocking framework of 0.10-0.60mm plagioclase laths that have undergone minor hydrothermal alteration to chlorite in #1 and extensive hydrothermal alteration to sericite in #2. Interstitial matrix in #1 is mainly secondary chlorite, opaque oxides and finely-crystalline silica (altered/devitrified mesostasis), whereas in #2, interstitial phases have been largely replaced by microcrystalline siderite, concentrically-zoned spherulitic siderite, and medium/coarsely-crystalline ankerite. Phenocrysts up to 2.0mm long appear to be pyroxenes that have been totally replaced by microcrystalline siderite, medium/coarsely-crystalline ankerite, microcrystalline silica, and, in #1, chlorite. Scattered 0.1-1.2mm cavities/amygdales in #2 are filled by microcrystalline silica. Sample #1 is cut by a 0.8mm-wide fracture that is healed by siderite, chlorite, silica and ankerite. A 0.15mm-wide, ankerite microspar-filled fracture in #2 crosscuts earlier formed secondary siderite and silica. Small iron oxide clots are scattered throughout #1. Ignoring artificial fracture porosity in #2, both samples lack macroporosity.

TABLE 2. LITHOLOGY AND TEXTURE

Sample #	Depth (m)	Lithology	Median grain size		Mean grain size			Sorting	
			ϕ	mm	ϕ	mm	Class	ϕ SD	Class
1	2450.0	volcanic	-	-	-	-	-	-	-
2	2586.0	volcanic	-	-	-	-	-	-	-
3	2594.0	sandstone	0.74	0.60	0.74	0.60	coarse	0.89	moderate
4	2598.0	sandstone	-0.36	1.28	-0.01	1.01	v. coarse	1.10	poor
5	2602.0	sandstone	-0.14	1.10	-0.02	1.01	v. coarse	0.71	moderate
6	2610.0	sideritic mrk	3.06	0.12	3.19	0.11	v. fine	0.72	moderate
7	2620.0	sideritic mrk	4.06	0.06	4.21	0.05	coarse slst	0.61	mod-well
8	2627.5	sandstone	1.18	0.44	1.31	0.40	medium	0.73	moderate
9	2633.5	carb mrk	3.47	0.09	3.55	0.09	v. fine	0.83	moderate
11	2644.0	sideritic mrk	3.64	0.08	3.74	0.07	v. fine	0.78	moderate
12	2652.0	argill slst	3.84	0.07	4.02	0.06	coarse slst	0.79	moderate
13	2663.0	sandstone	0.64	0.64	0.80	0.57	coarse	0.96	moderate
14	2669.0	contaminants	-	-	-	-	-	-	-
15	2700.5	sandstone	2.25	0.21	2.36	0.19	fine	0.51	mod-well
17	2721.5	sandstone	1.32	0.40	1.49	0.36	medium	0.50	mod-well
18	2728.5	sandstone	-0.51	1.42	-0.30	1.23	v. coarse	0.87	moderate
19	2751.0	sandstone	0.09	0.94	0.28	0.82	coarse	0.95	moderate
21	2759.0	argill sst	2.84	0.14	2.99	0.13	fine	0.57	mod-well
22	2763.0	sandstone	-0.44	1.36	-0.22	1.16	v. coarse	0.69	mod-well
23	2764.5	sandstone	0.29	0.82	0.46	0.73	coarse	0.68	mod-well

argill = argillaceous carb = carbonaceous mrk = mudrock slst = siltstone sst = sandstone

GRAIN SIZE (ϕ)

Class	*ϕ*
very coarse sand	-1.0-0.0
coarse sand	0.0-1.0
medium sand	1.0-2.0
fine sand	2.0-3.0
very fine sand	3.0-4.0
silt	<4.0

SORTING (ϕSD)

Class	*ϕ Standard Deviation*
very-well sorted	<0.35
well sorted	0.35-<0.50
moderately-well sorted	0.50-<0.71
moderately sorted	0.71-1.00
poorly sorted	>1.00+

TABLE 3. THIN-SECTION COMPOSITION

Sample # Depth (mRT)	1 2450.0	2 2586.0	3 2594.0	4 2598.0	5 2602.0	6 2610.0	7 2620.0	8 2627.5	9 2633.5	11 2644.0
Quartz (mono)	-	-	56.1	50.3	51.8	14.0	14.3	60.2	16.5	28.2
Quartz (poly)	-	-	11.8	16.3	16.1	1.7	0.5	8.9	0.3	0.9
Qtz overgrowths	-	-	2.7	3.0	2.5	-	-	2.0	-	-
Chert	-	-	1.0	1.6	0.9	0.7	-	1.4	-	0.3
K-feldspar	-	-	3.0	5.5	5.1	0.7	0.3	1.1	0.6	1.1
Plagioclase	50.7	28.5	0.3	-	-	0.3	0.3	0.7	-	-
GRF	-	-	0.7	0.9	-	-	-	-	-	-
VRF	-	-	2.1	1.8	-	0.7	-	0.7	-	-
MRF	-	-	2.7	1.6	0.6	-	-	4.3	-	0.9
SRF	-	-	0.3	0.8	0.7	-	-	0.7	-	-
Mica	-	-	-	0.3	-	0.7	1.8	-	-	0.3
Organics	-	-	-	-	-	5.4	17.2	-	20.3	8.6
Heavy min	16.0	2.3	-	-	-	0.3	0.7	0.3	0.3	-
Detrital clay	-	-	-	-	2.9	47.6	34.4	2.0	60.4	26.4
Ankerite	2.7	14.9	-	-	-	9.3	-	0.3	-	-
Siderite	4.6	25.8	-	-	-	18.0	28.0	-	-	31.8
Pyrite	-	-	-	-	-	0.6	1.7	-	1.6	1.2
FeO	1.0	-	-	-	-	-	-	-	-	-
Authigenic kaol	-	-	0.7	0.6	1.7	-	0.8	6.0	-	0.3
Authigenic illite	-	26.2	-	-	0.3	-	-	-	-	-
Secondary chlor	22.0	-	-	-	-	-	-	-	-	-
Secondary silica	3.0	2.3	-	-	-	-	-	-	-	-
Vis primary por	-	-	13.6	13.8	12.2	-	-	5.4	-	-
Vis secondary por	-	-	5.0	3.5	5.2	-	-	6.0	-	-
Q	-	-	88.7	86.3	91.7	-	-	90.6	-	-
F	-	-	4.1	6.7	6.6	-	-	2.3	-	-
R	-	-	7.2	7.0	1.7	-	-	7.1	-	-

Quartz (mono) = monocrystalline quartz Quartz (poly) = polycrystalline quartz Qtz overgrowths = quartz overgrowths GRF = granitic rock fragments VRF = volcanic rock fragments MRF = metamorphic rock fragments SRF = sedimentary rock fragments Heavy min = heavy minerals FeO = secondary iron oxide Authigenic kaol = authigenic kaolinite Secondary chlor = secondary chlorite Vis primary por = visible primary porosity Vis secondary por = visible secondary porosity (%)

Q = quartz + chert F = feldspar R = rock fragments (%)

Volcanics	(#1, #2)
Argillaceous samples	(#6, #7, #9, #11, #12, #21)
Sandstones	(#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23)

TABLE 3. THIN-SECTION COMPOSITION cont.

Sample #	12	13	15	17	18	19	21	22	23
Depth (mRT)	2652.0	2663.0	2700.5	2721.5	2728.5	2751.0	2759.0	2763.0	2764.5
Quartz (mono)	58.7	53.8	59.4	58.3	34.8	52.8	39.7	40.3	50.2
Quartz (poly)	1.1	16.4	4.1	5.5	33.8	18.0	1.9	29.9	17.3
Qtz overgrowths	-	3.0	2.7	3.2	0.8	2.4	-	0.7	2.4
Chert	-	1.2	0.7	0.7	5.4	1.2	-	1.6	0.4
K-feldspar	1.5	1.6	2.7	2.9	3.6	1.6	2.2	2.6	0.7
Plagioclase	-	-	-	-	-	-	-	-	-
GRF	-	-	-	-	1.2	-	-	-	-
VRF	-	1.0	0.4	0.7	0.4	0.8	0.3	0.8	0.3
MRF	1.3	9.2	14.9	10.8	3.2	5.2	5.7	1.6	4.0
SRF	-	0.8	1.1	1.3	1.1	0.8	-	0.9	0.3
Mica	1.5	0.3	0.3	0.3	0.3	-	3.4	-	-
Organics	10.7	-	2.7	-	-	-	9.2	-	-
Heavy min	0.3	-	-	-	-	-	-	-	-
Detrital clay	21.3	-	6.1	-	-	-	34.7	-	3.0
Ankerite	0.4	0.4	-	-	2.4	-	-	10.1	2.7
Siderite	1.9	-	-	-	-	-	-	-	-
Pyrite	0.3	0.3	-	-	-	-	0.7	-	-
FeO	-	-	-	-	-	-	-	-	-
Authigenic kaol	1.0	1.6	2.0	1.8	4.0	6.4	2.2	3.7	3.7
Authigenic illite	-	1.8	0.7	0.4	0.8	0.8	-	-	-
Secondary chlor	-	-	-	-	-	-	-	-	-
Secondary silica	-	-	-	-	-	-	-	-	-
Vis primary por	-	4.4	0.7	8.1	4.1	4.8	-	3.8	9.3
Vis secondary por	-	4.2	1.5	6.0	5.1	5.2	-	4.0	5.7
Q	95.5	85.5	77.8	81.2	88.7	89.9	83.6	91.9	93.0
F	2.4	1.8	3.1	3.5	4.3	1.9	4.4	3.3	0.9
R	2.1	12.7	19.1	15.3	7.0	8.2	12.0	4.8	6.1

Quartz (mono) = monocrystalline quartz Quartz (poly) = polycrystalline quartz Qtz overgrowths = quartz overgrowths GRF = granitic rock fragments VRF = volcanic rock fragments MRF = metamorphic rock fragments SRF = sedimentary rock fragments Heavy min = heavy minerals FeO = secondary iron oxide Authigenic kaol = authigenic kaolinite Secondary chlor = secondary chlorite Vis primary por = visible primary porosity Vis secondary por = visible secondary porosity (%)

Q = quartz + chert F = feldspar R = rock fragments (%)

Volcanics	(#1, #2)
Argillaceous samples	(#6, #7, #9, #11, #12, #21)
Sandstones	(#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23)

FIGURE 1. QFR COMPOSITIONS (SANDSTONES)

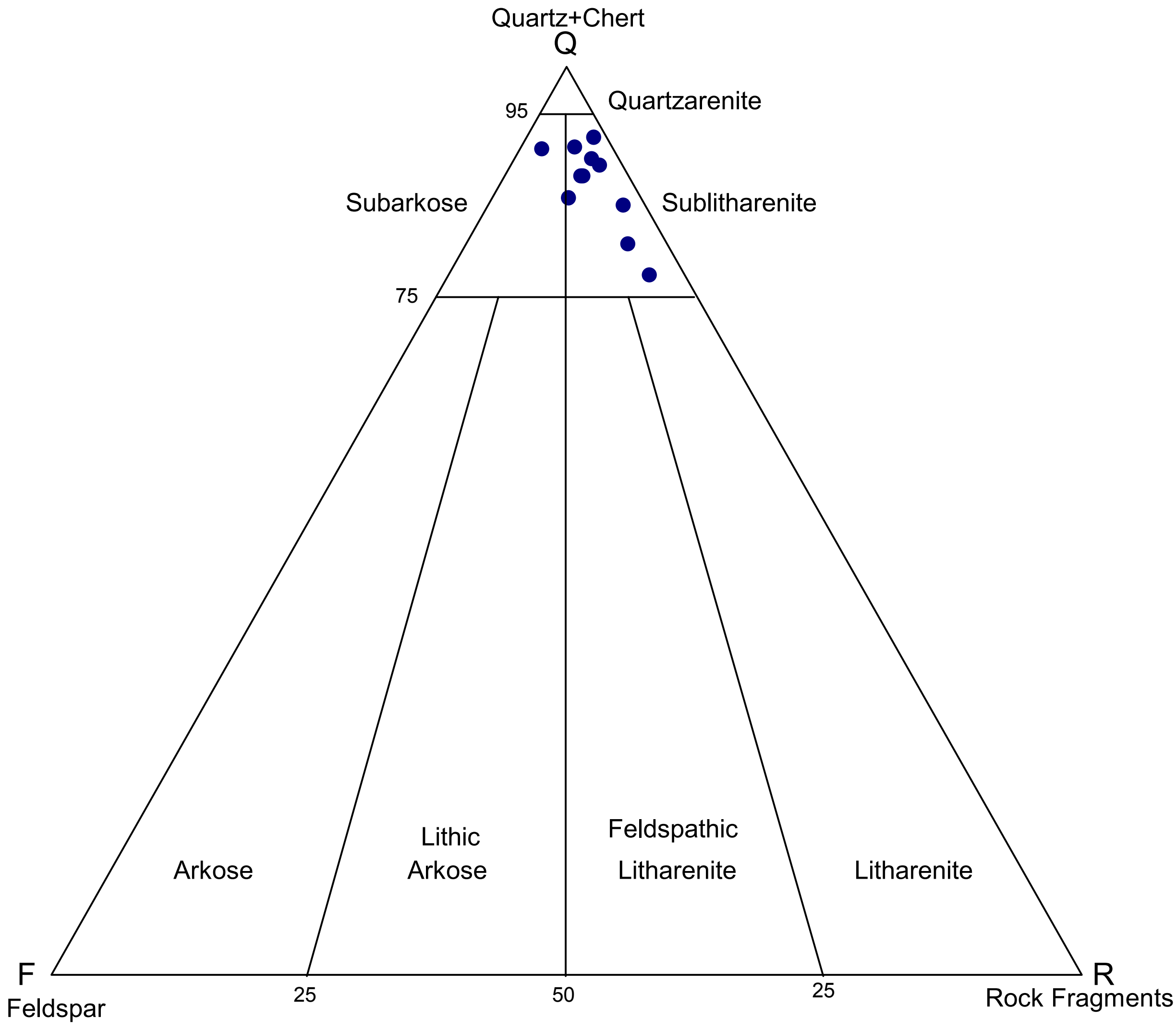


TABLE 4. GRAIN/CEMENT/POROSITY-TYPE ATLAS (SANDSTONES)

Quartz grain with syntaxial overgrowths	Plates 12, 32, 41, 42, 53
Chert	Plate 5
Granitic K-feldspar	Plates 5, 8, 11, 41, 43
Micaceous/illitic metamorphic rock fragments	Plates 32, 37, 40, 41, 56
Argillaceous sedimentary rock fragments	Plate 41
Detrital clay matrix	Plates 11, 20, 37, 55, 56
Ankerite	Plates 52, 53
Authigenic kaolinite	Plates 13, 21, 32, 42, 43, 53, 54, 55, 56, 57
Authigenic illite	Plates 39, 42, 47
Visible primary intergranular porosity	Plates 5, 12, 32, 33, 39, 40, 41, 46
Visible secondary intergranular porosity	Plates 6, 40, 41
Visible secondary intragranular porosity	Plates 6, 12, 43
Visible secondary mouldic porosity	Plate 20
Microporosity	Plate 21, Fig. 2; Plate 39, Fig. 2; Plate 53

3.2 Argillaceous Samples (#6, #7, #9, #11, #12, #21)

Texture: Samples are moderately to moderately-well sorted, silty/arenaceous mudrocks (#6, #7, #9, #11), a moderately sorted, argillaceous siltstone (#12) and a laminated, moderately-well sorted, fine grained, argillaceous sandstone (#21).

In the mudrocks, detrital clay matrix is pervasive but is commonly irregularly distributed, particularly in #7 and #11, which include sporadic, fine, irregular silty laminae (#7) and a silty/sandy zone (#11) in which detrital clay is only thinly dispersed. Elsewhere, detrital clay and associated fine siderite are sufficiently abundant to support grains. A clay-rimmed sandy burrow is included in #6, and there are silty?burrow fills associated with the silty laminae in #7. Sample #9 contains numerous, semi-aligned coaly fragments up to at least 1.2cm long, the presence of which produces planes of weakness along which the sample has split.

The argillaceous siltstone (#12) is grain supported and contains very finely dispersed detrital clay matrix, sporadic argillaceous laminae and numerous, randomly oriented organic fragments up to 4mm long.

The argillaceous sandstone (#21) contains several, closely spaced laminae that are defined by concentrations of organic fragments and detrital clay.

Quartz grains are mainly subangular to subrounded.

Composition: Grains in the argillaceous samples are mainly monocrystalline quartz and also include polycrystalline quartz, K-feldspar (orthoclase, microcline), plagioclase, chert, micaceous/illitic metamorphic rock fragments, felsic volcanic rock fragments, fresh/variably kaolinitised muscovite, organic fragments and accessory tourmaline, zircon, monazite and leucoxene. Grain content varies mainly according to clay + siderite content. More detailed descriptions of grain types are given in the next section.

Detrital clay is partly replaced by microcrystalline siderite in three of the four mudrock samples (#6, #7, #11), particularly where detrital clay is concentrated. The combined clay + siderite content of these three samples is around 60%. The other mudrock sample (#9) contains 60.4% detrital clay, and the argillaceous siltstone (#12) and argillaceous sandstone (#21) contain 21.3% and 34.7% detrital clay, respectively.

Authigenic clay does not exceed 2.2% and is almost entirely kaolinite that occurs where micaceous grains have altered. Muscovite grains are commonly partly altered to kaolinite.

Sample #6 contains 9.3% ankerite, which forms scattered, medium-crystalline patches up to 1.3mm long that replace detrital clay. Rare, coarsely-crystalline ankerite patches replace detrital clay in #12.

Opaques are mainly well compacted organic fragments, the amount of which varies from 5.4% to 20.3%. Opaques also include minor (<1.8%) fine pyrite, which is associated with organic fragments and detrital clay, and scattered leucoxene grains.

Fine authigenic anatase crystals are widely scattered throughout all samples.

Ignoring artificial fracture porosity, samples contain little (<0.3%) or no visible porosity. Rare secondary mouldic pores occur where feldspar grains have partly to completely dissolved (Plate 29), and small (<0.03mm) primary intragranular pores (remnants of cell lumen) occur within some organic fragments (Plate 27, Fig. 2).

3.3 Sandstones (#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23)

Texture: Sorting and grain size are highly variable. The top three sandstones (#3, #4, #5) are poorly to moderately sorted, coarse to very coarse grained sandstones. Sample #3 contains widely scattered pebbles up to at least 10.0mm long, and sample #4, which is the least well sorted of the sandstones, includes a 2.5cm-thick granule conglomerate ?bed that is sharply bounded by well sorted, medium grained sandstone. Sample #5 contains patchy detrital clay matrix, the presence of which has promoted localised advanced grain contact dissolution and microstylolitisation. Sample #3 is massive.

Samples #13, #18, #19, #22 and #23 are moderately to moderately-well sorted, coarse to very coarse grained sandstones. The two moderately-well sorted, coarse to very coarse grained sandstones (#22, #23) are close to being moderately sorted. Samples #13, #18, #19 and #22 are massive, whereas #23 includes sporadic patches of kaolinitised detrital clay matrix.

Sample #17 is a massive, moderately-well sorted, medium grained sandstone. The other medium grained sandstone (#8) is moderately sorted and contains patchy, thinly dispersed detrital clay matrix, the presence of which has promoted localised advanced grain contact dissolution and microstylolitisation.

Sample #15 is a moderately-well sorted, fine grained sandstone that contains patchy, very finely dispersed detrital clay matrix and sporadic very thin, irregular laminae along which detrital clay and organic fragments are concentrated.

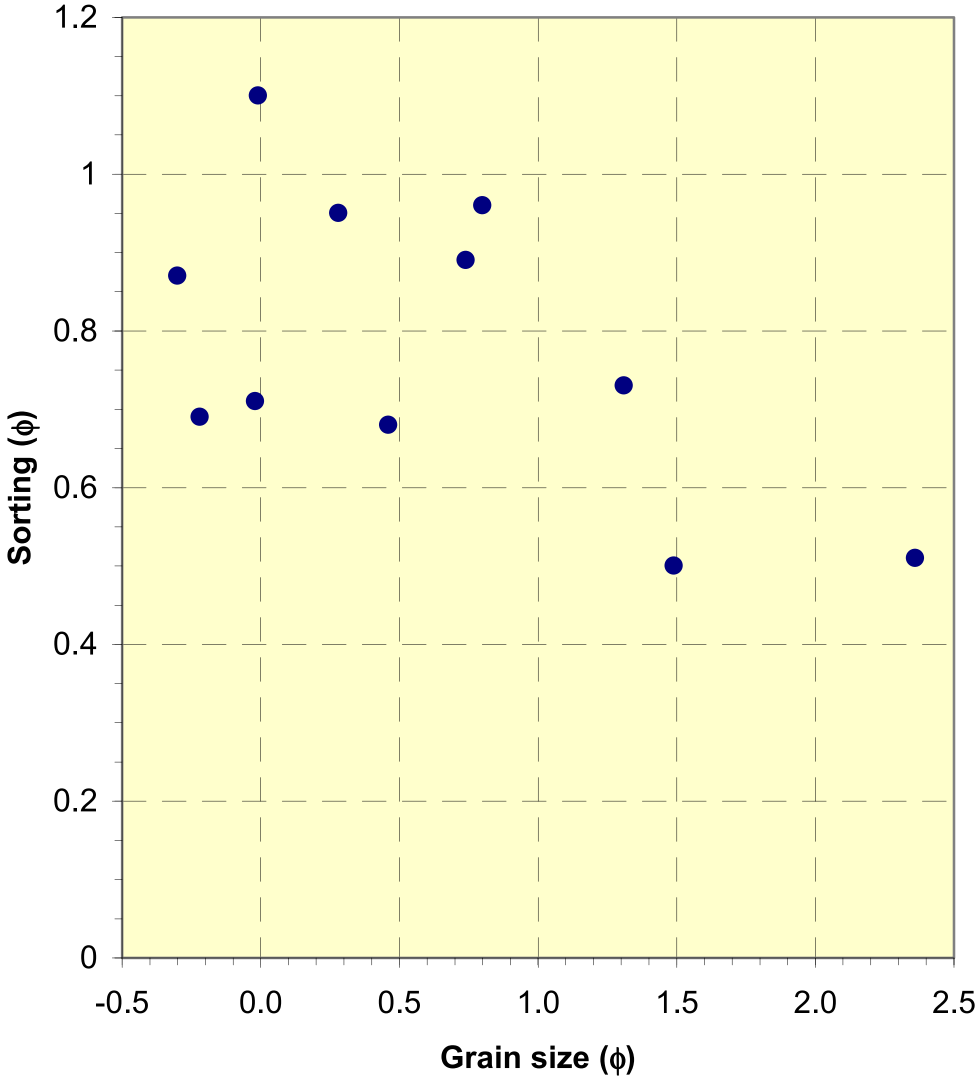
Figure 2 shows that there is a weak (R^2 = -0.336) negative correlation between grain size and sorting for the eleven sandstones.

Ignoring quartz overgrowths and the effects of grain contact dissolution, most quartz grains are subangular to subrounded.

Composition: Sandstones are sublitharenites and a subarkose (#5) (Fig. 1) with a mean QFR ratio of 87:4:9. Framework grains are mainly quartz and also include K-feldspar, plagioclase, a variety of rock fragments, mica, organics and accessory heavy minerals.

Total detrital quartz content ranges from 63.5% to 70.8% and averages 67.8%. Reflecting the generally coarse grained nature of the sandstones, a large component of quartz is polycrystalline. Quartz types include plutonic quartz, recrystallised metamorphic quartz and metaquartzite. Granitic quartz grains locally contain K-

FIGURE 2. GRAIN SIZE/SORTING CROSS-PLOT (SANDSTONES)



feldspar and plagioclase intergrowths, and metamorphic quartz locally includes oriented phyllosilicates. Quartz grains are commonly enveloped by thin syntaxial quartz overgrowths, the amount of which ranges up to 3.2%. Quartz grains also commonly have welded (including microstylolitic) grain contacts that are the result of grain contact dissolution.

Feldspar content ranges from 0.7% to 5.5% and is highest in the very coarse grained sandstones from 2598.0m (#4) and 2602.0m (#5). Feldspar is dominated by fresh to slightly altered, granitic K-feldspar (microperthite, orthoclase, microcline) and, above 2633.5m, also includes small amounts (<1%) of fresh and slightly sericitised granitic plagioclase. A significant component of K-feldspar between 2594.0m and 2602.0m is microperthite, some of which contains coarse plagioclase intergrowths. Feldspar grains are commonly etched or partly dissolved.

Rock fragment content ranges from 1.3% to 16.4%. Most lithic grains are metamorphic rock fragments, the amount of which generally increases with decreasing grain size (Fig. 3). Metamorphic rock fragments include quartz/mica schist, phyllite, illitic meta-argillite and mica/illite-bearing quartzite. In those sandstones that contain abundant metamorphic rock fragments (#13, #15, #17), mica/illite-rich metamorphic rock fragments dominate over mica/illite-poor metamorphic rock fragments. Mica/illite-rich metamorphic rock fragments are commonly compactionally deformed between adjacent rigid grains.

Other lithic grains include felsic and subordinate intermediate volcanic rock fragments, granitic rock fragments (coarsely intergrown quartz, K-feldspar, plagioclase and mica; graphic intergrowths of quartz and K-feldspar) and sedimentary rock fragments (indurated argillite; quartzose siltstone/fine sandstone). One porous argillaceous siltstone fragment in #4 contains numerous siliceous sponge spicules.

Sandstones are derived from a continental provenance dominated by granitic and low grade metasedimentary rocks and which also included minor siliciclastics and volcanics.

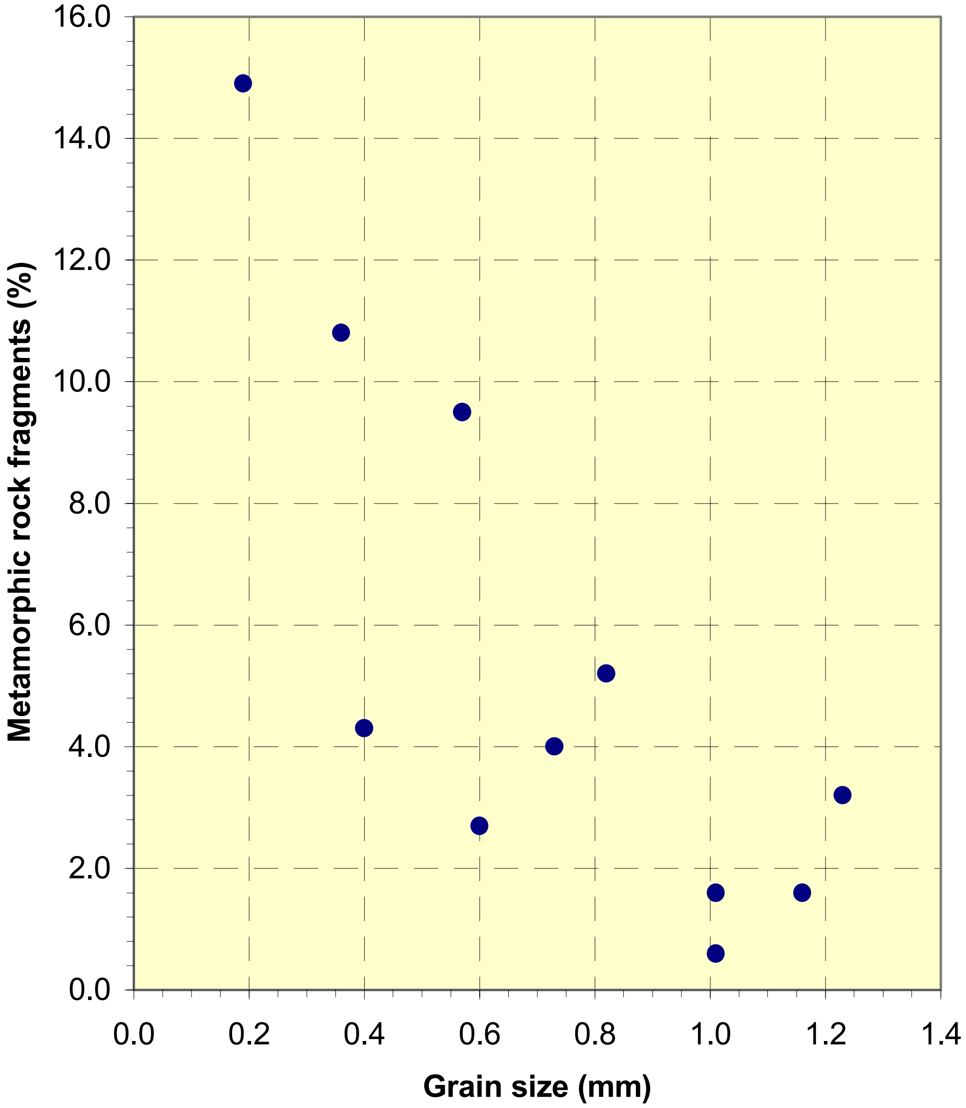
Chert content does not exceed 1.6%, except in #18, where it is 5.4%. The counted chert content does not include cherty felsic volcanic rock fragments, which were counted as volcanic rock fragments rather than chert during point counting.

Other framework grains include very minor to rare muscovite, altered biotite, organic fragments and accessory heavy minerals (tourmaline, zircon, monazite, leucoxene). A 3mm-long silicified wood fragment with well preserved cellular structure (xylem) is included in #4.

Monazite grains are rimmed by radiogenically immobilised bitumen in #8 and #15.

Samples #5, #8 and #23 contain 2.0-3.0% detrital clay that forms sporadic matrix patches. Sample #15 contains 6.1% detrital clay that forms patchy, very finely dispersed matrix and is concentrated with organic fragments along very thin, irregular laminae. Detrital clay is absent in the other sandstones.

FIGURE 3. GRAIN SIZE/METAMORPHIC ROCK FRAGMENTS CROSS-PLOT (SANDSTONES)



Authigenic clay ranges up to 7.2% and is mainly kaolinite that occurs where micaceous/argillaceous grains and feldspar have altered and where patchy detrital clay matrix has recrystallised. Muscovite grains are locally partly altered to kaolinite, and rare mica-like kaolinite grains occur where biotite has altered. Illitic remnants of micaceous precursor grains are locally associated with authigenic kaolinite, and minor authigenic illite is associated with partly altered and compactionally deformed micaceous metamorphic rock fragments.

Sample #22 contains 10.1% ankerite that forms scattered, coarsely-crystalline cement/replacement patches. Similar ankerite occurs in #18 and #23, where it does not exceed 2.7%. The other samples contain little (<0.5%) or no carbonate.

Visible porosity ranges from 2.2% to 18.6%. In the top three sandstones (#3, #4, #5), where visible porosity exceeds 17.2%, primary intergranular porosity dominates over secondary grain dissolution porosity, whereas in the other sandstones, both primary and secondary porosity are significant components of total visible porosity. Visible porosity varies mainly according to clay + metamorphic rock fragment content (see Fig. 8). Large artifact pores occur in some of the coarser sandstones (#4, #5, #22).

4. X-RAY DIFFRACTION ANALYSES

Quantitative bulk-rock and fine-fraction XRD analyses were carried out on all samples except the volcanics (#1, #2), a sideritic mudrock (#6), and the sample composed mainly of drilling mud contaminants (#14). Annotated XRD traces are presented in Appendix 4.

Quantitative XRD analyses complement the thin-section analyses but cannot be compared directly. This is because thin-section clay and siderite components include microporosity, and therefore total thin-section clay and siderite are elevated relative to other grain types. In addition, XRD analyses do not include visible porosity. Therefore, in the case of those sandstones that contain significant visible porosity, component abundances as determined by XRD analysis will be higher than those determined by thin-section analysis. Finally, the thin-section rock fragment and clay components include quartz, feldspar, mica and various clay minerals that are recorded as these phases by XRD.

Quantitative XRD analyses (Table 5) accord with the thin-section analyses by showing that the sandstones (#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23) are overwhelmingly dominated by quartz (81-93%) and also contain minor K-feldspar (1-4%), plagioclase (<0.3-2%), kaolinite (1-8%), illite/mica (<0.3-8%) and ankerite (0-4%). Much plagioclase occurs as intergrowths in microperthite, hence plagioclase:K-feldspar ratios determined by XRD are higher than those determined by thin-section analysis. Most detected illite/mica would occur as a constituent of metamorphic rock fragments.

Minerals detected in the argillaceous samples (#7, #9, #11, #12, #21) are quartz (41-84%), K-feldspar (2-5%), plagioclase (1-3%), kaolinite (8-26%), illite/mica (5-26%), siderite (0-17%) and anatase (1%).

TABLE 5. BULK ROCK XRD ANALYSES

Sample #	Depth (mRT)	Qtz	KF	PF	I/M	Ka	Sid	Ank	Ana
3	2594.0	91	3	2	2	2	-	-	-
4	2598.0	93	4	1	1	1	-	-	-
5	2602.0	90	4	1	1	4	-	-	-
7	2620.0	40	2	3	26	16	12	-	1
8	2627.5	91	1	2	2	4	-	-	-
9	2633.5	59	3	2	15	20	-	-	1
11	2644.0	55	5	2	10	10	17	-	1
12	2652.0	83	2	-	5	8	1	-	1
13	2663.0	87	2	1	4	5	-	1	-
15	2700.5	81	3	-	8	8	-	-	-
17	2721.5	91	2	-	4	3	-	-	-
18	2728.5	93	3	-	-	3	-	1	-
19	2751.0	91	4	-	1	4	-	-	-
21	2759.0	55	2	1	15	26	-	-	1
22	2763.0	88	3	-	1	4	-	4	-
23	2764.5	92	2	1	1	2	-	2	-

Qtz = quartz KF = K-feldspar PF = plagioclase I/M = illite/mica Ka = kaolinite Sid = siderite
Ank = ankerite Ana = anatase

TABLE 6. CLAY MINERALOGY

Sample #	Depth (mRT)	Ka	I/M	I/S	Sm	Chl
3	2594.0	A	m	-	-	-
4	2598.0	A	m	-	-	-
5	2602.0	A	m	-	-	-
7	2620.0	M	M	-	-	-
8	2627.5	A	m	-	-	-
9	2633.5	M	m	-	-	-
11	2644.0	M	m	-	-	-
12	2652.0	A	m	-	-	-
13	2663.0	A	m	-	-	-
15	2700.5	M	m	-	-	-
17	2721.5	A	m	-	-	-
18	2728.5	A	m	-	-	-
19	2751.0	A	m	-	-	-
21	2759.0	M	m	-	-	-
22	2763.0	A	m	-	-	-
23	2764.5	A	m	-	-	-

Ka = kaolinite I/M = illite/mica I/S = mixed-layer illite/smectite Sm = smectite
Chl = chlorite

A = abundant M = major m = minor T = trace

Sandstones (#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23)

Argillaceous samples (#7, #9, #11, #12, #21)

Figure 4 shows that quartz varies mainly according to clay + siderite content. Table 5 shows that, in terms of mineralogy, the sandstones differ from the argillaceous samples only by lacking siderite and anatase and by containing ankerite.

Fine-fraction XRD analyses (Table 6) indicate that the only clay minerals in both the sandstones and argillaceous samples are kaolinite and discrete illite. Much higher kaolinite:illite ratios in the sandstones compared with the argillaceous samples reflect the dominance of authigenic kaolinite over authigenic illite in the sandstones and the presence of illite as a significant clay mineral component of detrital clay in the argillaceous samples.

5. DIAGENESIS

The main diagenetic processes to have affected the argillaceous samples (#6, #7, #9, #11, #12, #21) are physical compaction, grain contact dissolution and the replacement of clay and micaceous grains by microcrystalline siderite (#6, #7, #11) (Plates 17, 26) and by patchy, medium-crystalline ankerite (#6) (Plate 15). Minor diagenetic effects in the argillaceous samples include fine pyrite (Plate 27, Fig. 1) and anatase precipitation and mica alteration to kaolinite. The argillaceous samples are not considered further in this section.

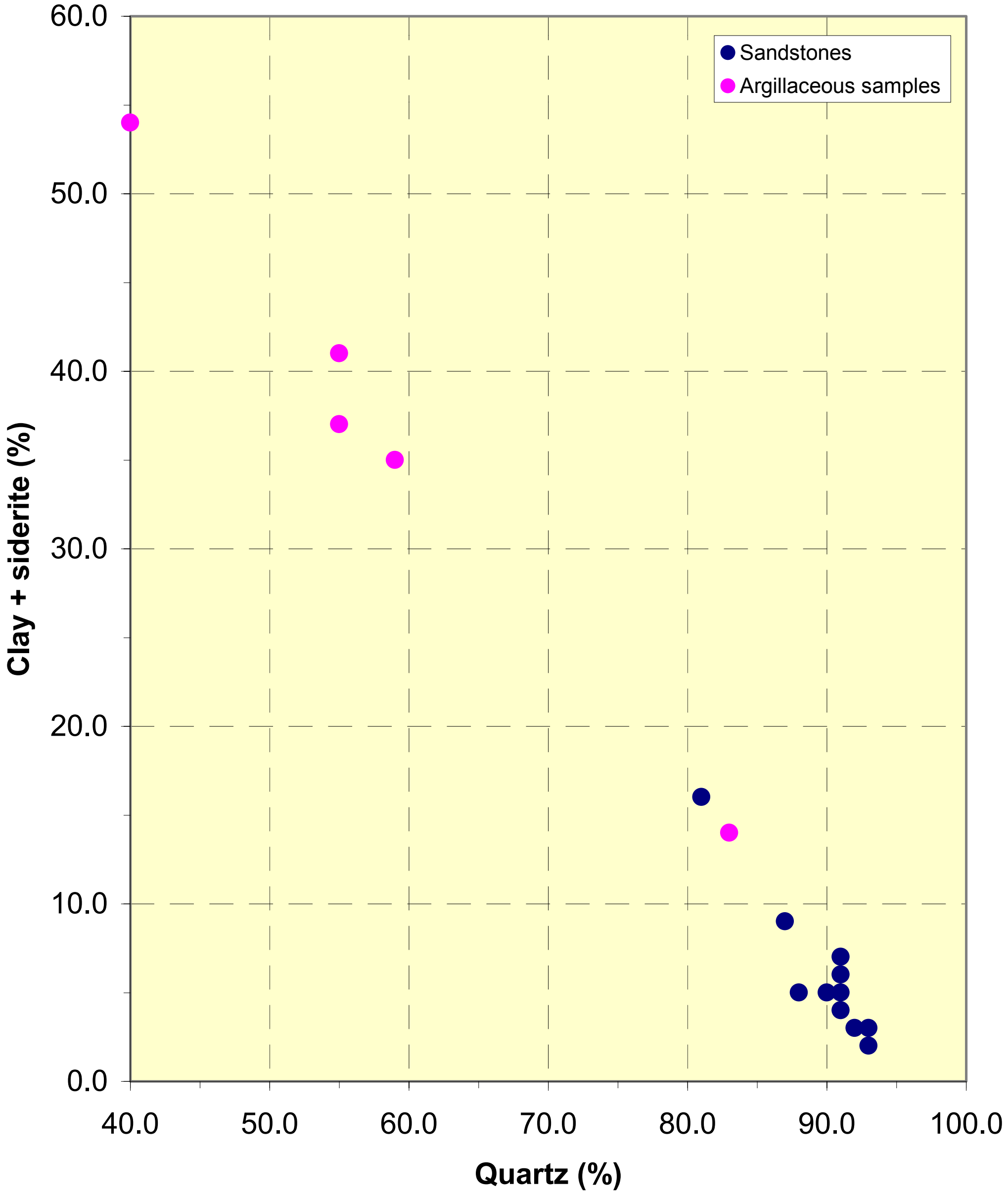
Diagenetic processes that have affected the sandstones (#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23) are grain contact dissolution, labile grain dissolution, authigenic clay formation, ductile grain/authigenic clay compaction, and cementation by quartz overgrowths and ankerite.

Grain contact dissolution has increased framework grain packing density by producing long, embayed and rare sutured grain contacts between most juxtaposed quartz grains, quartzose/illitic rock fragments and feldspar grains (Plates 6, 32, 37, 40, 43, 44, 52). Advanced grain contact dissolution and microstylolitisation have occurred within localised argillaceous areas in #5, #8 and #15 (Plates 11, 20), where grain contact dissolution was promoted by the presence of thin illitic clay films between grains.

Feldspar grains have commonly dissolved to form secondary intergranular (Plate 40), intragranular (Plate 6; Plate 57, Fig. 1) and mouldic (Plate 20) pores, and there are large over-sized secondary pores that have formed by complete dissolution of feldspar grains (Plate 11; Plate 42, Fig. 1). A few labile rock fragments have also dissolved. Secondary K-feldspar dissolution porosity makes up a large component of total macroporosity, particularly below 2620.0m.

Most authigenic clay is kaolinite that forms scattered grain-sized patches and, in #5, #8 and #23, matrix patches that occur where micaceous/argillaceous grains and feldspar have completely altered and where patchy detrital clay matrix has recrystallised (Plates 13, 20, 55, 56). Muscovite grains are locally partly altered to kaolinite, and rare mica-like kaolinite grains occur where biotite has altered (Plate 56). The kaolinite forms loosely packed, 10-50μm plates that are locally stacked together to form vermicules (Plate 13, Fig. 2). The other authigenic clay present is illite, which is mainly associated with partly altered and compactionally deformed

FIGURE 4. QUARTZ/CLAY + SIDERITE (XRD) CROSS-PLOT



micaceous metamorphic rock fragments (Plate 39). Total authigenic clay content does not exceed 7.2%.

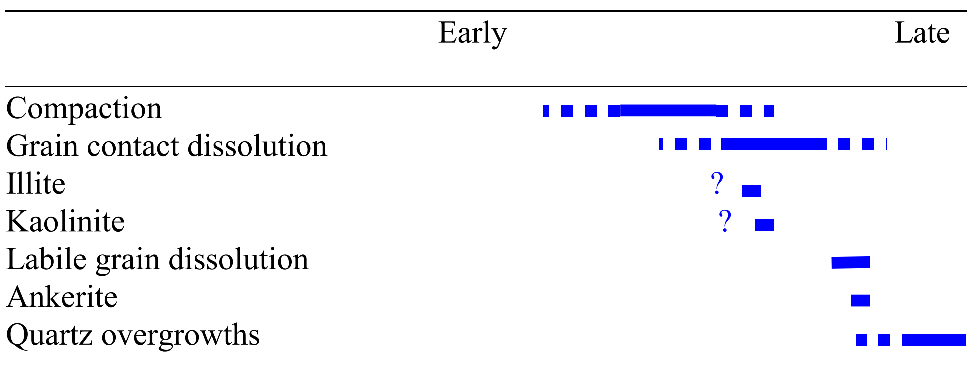
Micaceous/illitic metamorphic rock fragments, mica and authigenic clay patches are commonly compactionally deformed (Plates 32, 37), particularly in #13, #15 and #17, which have elevated amounts of micaceous/illitic metamorphic rock fragments.

The sandstones are poorly cemented by quartz overgrowths, the amount of which does not exceed 3.2%. Although common, quartz overgrowths are only thinly developed on quartz grain surfaces and thus only occlude a small proportion of total available intergranular space (Plates 12, 32, 42). In many areas, quartz overgrowth development was inhibited by the presence of compacted ductile grains and authigenic clay.

Ankerite cement occurs sporadically within the sampled section. Sample #22 is cemented by 10.1% ankerite, which forms coarse rhombic crystals and coarsely-crystalline patches that occupy pores and replace framework grains (Plate 52). Elsewhere, ankerite does not exceed 2.7%. The only other carbonate in the sandstones is siderite, which forms rare clusters of fine rhombic crystals that partly replace labile rock fragments.

The interpreted paragenetic history of the sandstones is given in Figure 5. Quartz overgrowths engulf authigenic kaolinite (Plate 13, Fig. 2; Plate 21, Fig. 2; Plate 33, Fig. 2; Plate 39, Fig. 1; Plate 53; Plate 57, Fig. 2) and illite (Plate 39, Fig. 2), indicating that authigenic clay predates quartz overgrowths. Ankerite replaces authigenic kaolinite (Plate 53) and encases quartz grains that, unlike quartz grains in adjacent non-ankerite cemented areas, lack quartz overgrowths, indicating that ankerite postdates kaolinite and predates quartz overgrowths. Ankerite also encases quartz grains with welded grain contacts resulting from grain contact dissolution, indicating that ankerite postdates grain contact dissolution. Secondary feldspar dissolution pores are bounded by compacted clay, indicating that feldspar dissolution postdates clay compaction. Grain contact dissolution and microstylolitisation have occurred between quartz grains and now-dissolved feldspar grains, indicating that feldspar dissolution also postdates grain contact dissolution and microstylolitisation. Quartz overgrowth cementation appears to be the latest diagenetic event.

FIGURE 5. DIAGENETIC PARAGENESIS



6. RESERVOIR QUALITY

6.1 General

Measured porosity and permeability values for the sandstones (#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23) and argillaceous samples (#7, #9, #11, #12, #21) are given in Table 1 and plotted in Figure 6. The plot excludes one argillaceous sample (#9), which has anomalously high permeability due to the presence of artificial fractures. Figure 6 shows that the argillaceous samples have 1.9-7.9% porosity and 0.001-0.018mD permeability, whereas the sandstones have 13.9-20.6% porosity and 0.73-3750mD permeability. Considering all samples as a single population, measured porosity and permeability are strongly correlated (R^2 = 0.936). The correlation is reduced (R^2 = 0.745) by excluding the argillaceous samples (Fig. 6).

Figure 7 shows that there is also a strong positive correlation (R^2 = 0.883) between visible (thin-section) porosity and permeability. Even if the argillaceous samples are excluded, visible porosity and permeability are still strongly (R^2 = 0.783) correlated.

The argillaceous samples are not considered further in this section since it is clear that they all have very low porosity and permeability on account of being fine grained and composed largely of tightly packed clay (Plates 18, 24, 27, 30, 51) and, in the case of #6, #7 and #11, microcrystalline siderite.

Figure 8 shows that, if #22 is excluded, there is a strong (R^2 = -0.764) negative correlation between detrital/authigenic clay + metamorphic rock fragment content and visible porosity. Sample #22 has anomalously low visible porosity for its clay + metamorphic rock fragment content on account of being cemented by patchy ankerite.

Given that sandstone visible porosity is positively correlated with permeability (Fig. 7) and that clay + metamorphic rock fragment content is negatively correlated with visible porosity (Fig. 8), then clay + metamorphic rock fragment content should be negatively correlated with permeability. Figure 9 confirms that there is in fact a very strong (R^2 = -0.980) negative correlation between clay + metamorphic rock fragment content and permeability (excluding #22), indicating that permeability variation within the reservoir sandstones is due almost entirely to differences in detrital/authigenic clay + metamorphic rock fragment content. Metamorphic rock fragments influence permeability on account of being largely micaceous/argillaceous and thus prone to compactional deformation and dispersion, commonly to form pseudomatrix.

Permeability is much more influenced by metamorphic rock fragment content than by clay content, with metamorphic rock fragment content being strongly (R^2 = -0.822) correlated with permeability, and clay content being only weakly (R^2 = -0.444) correlated with permeability.

There is a moderate (R^2 = -0.550) negative correlation between clay + metamorphic rock fragment content and grain size (Fig. 10). Accordingly, given that there is a strong negative correlation between clay + metamorphic rock fragment content and permeability (Fig. 9), there should be a positive correlation between grain size and permeability. Figure 11 shows that, if #22 is excluded, there is in fact a positive

FIGURE 6. POROSITY/PERMEABILITY CROSS-PLOT

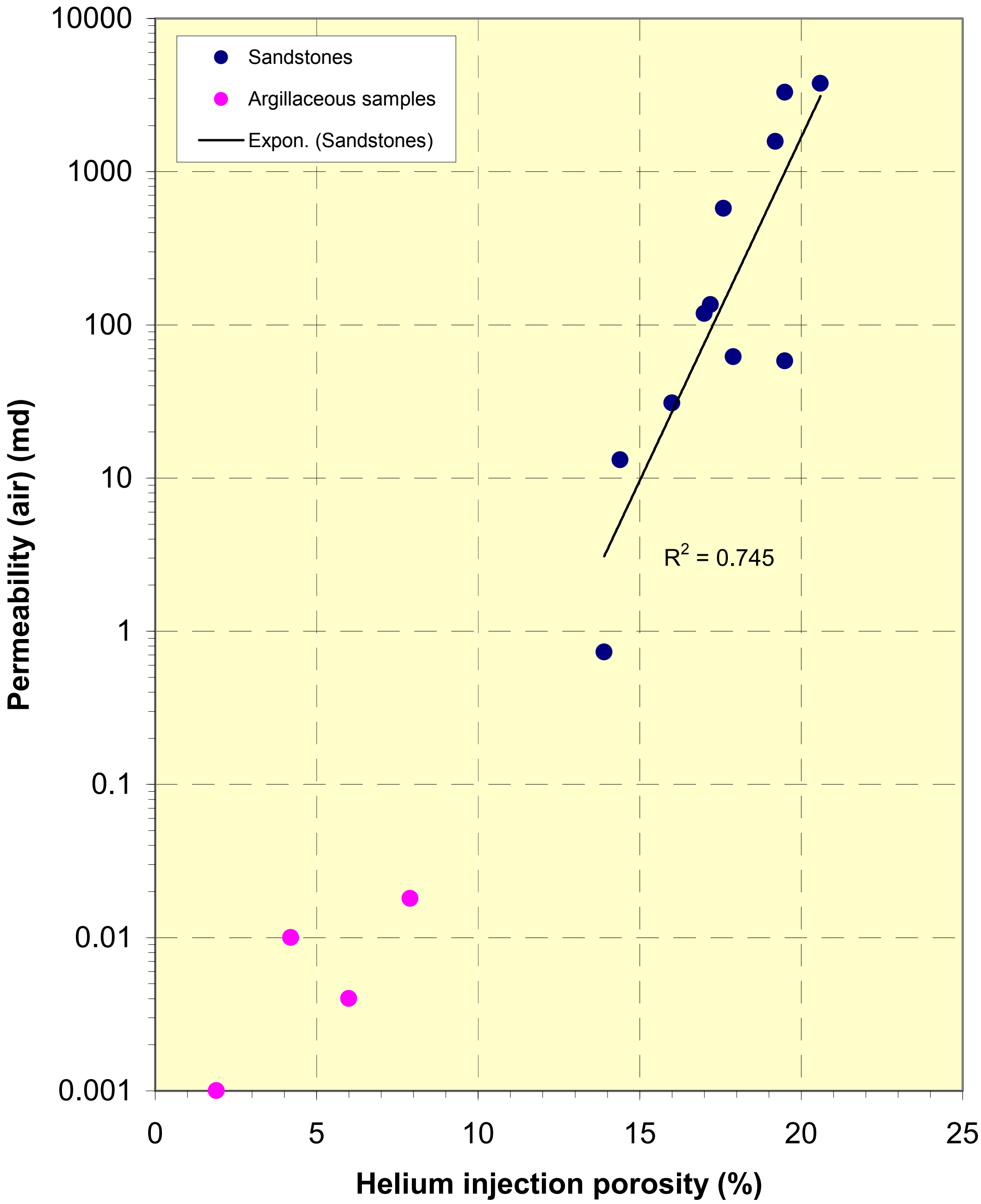


FIGURE 7. VISIBLE POROSITY/PERMEABILITY CROSS-PLOT

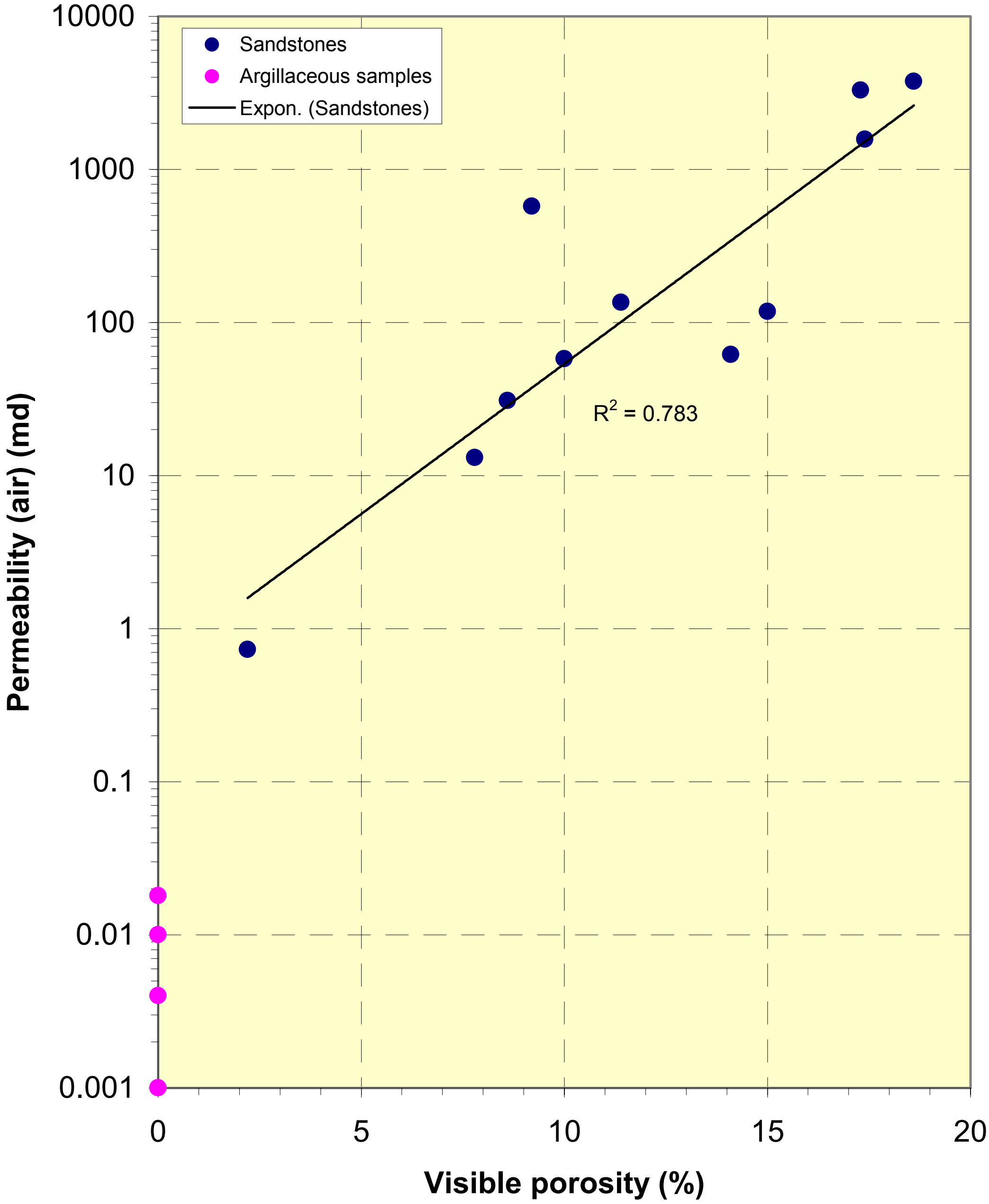


FIGURE 8. CLAY + METAMORPHIC ROCK FRAGMENTS/VISIBLE POROSITYCROSS-PLOT (SANDSTONES)

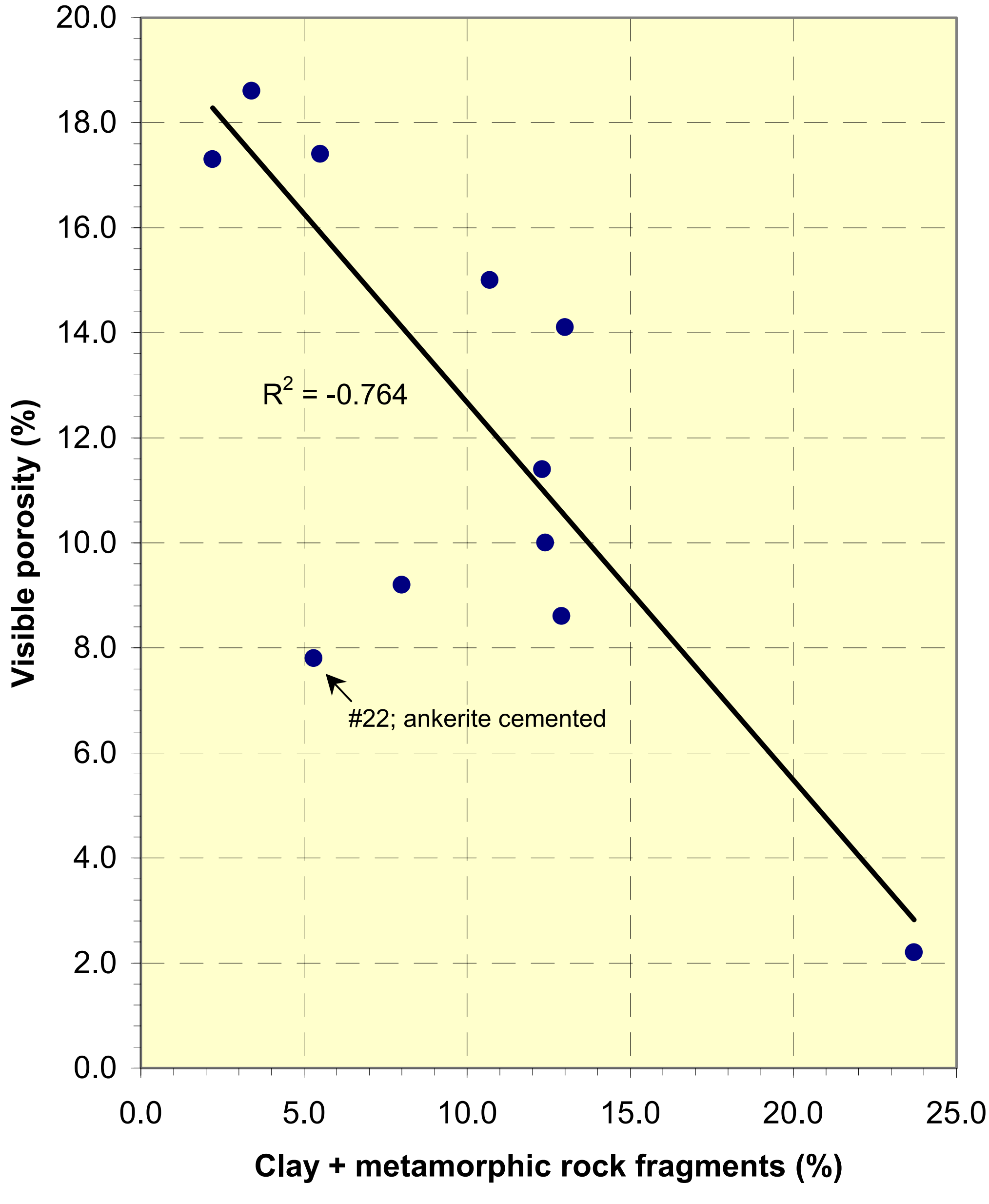


FIGURE 9. CLAY + METAMORPHIC ROCK FRAGMENTS/PERMEABILITY CROSS-PLOT (SANDSTONES)

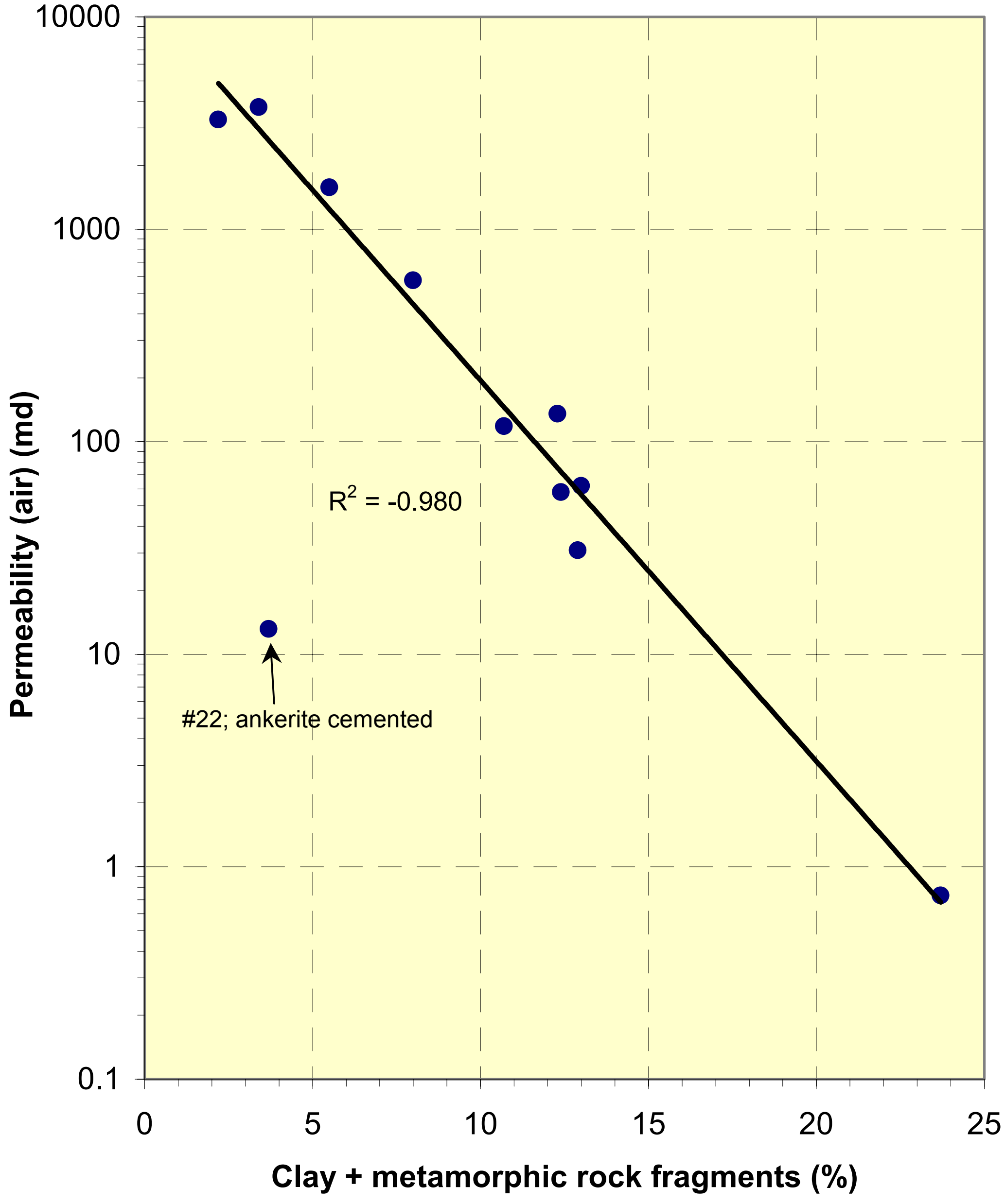


FIGURE 10. CLAY + METAMORPHIC ROCK FRAGMENTS/GRAIN SIZE CROSS-PLOT (SANDSTONES)

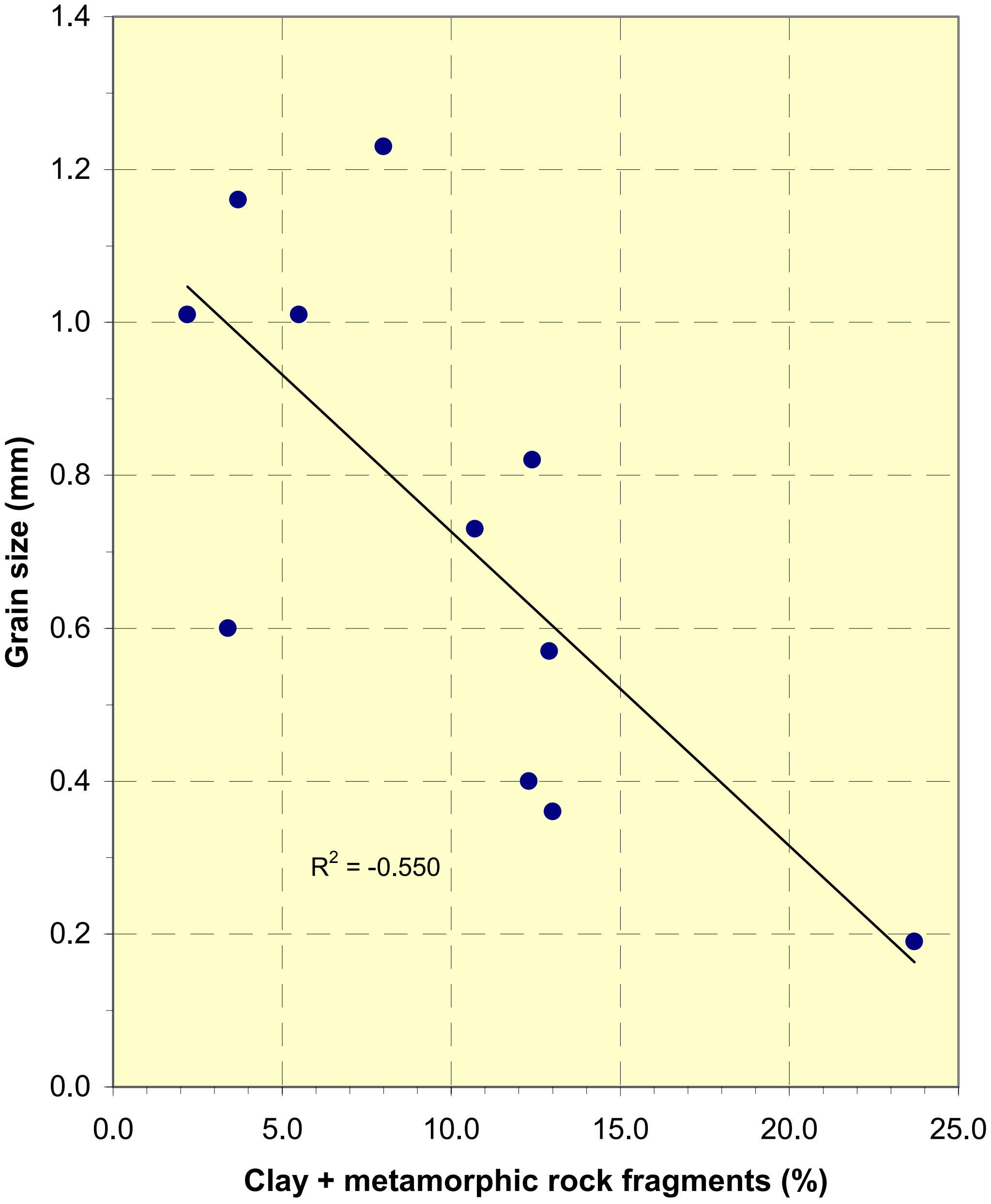
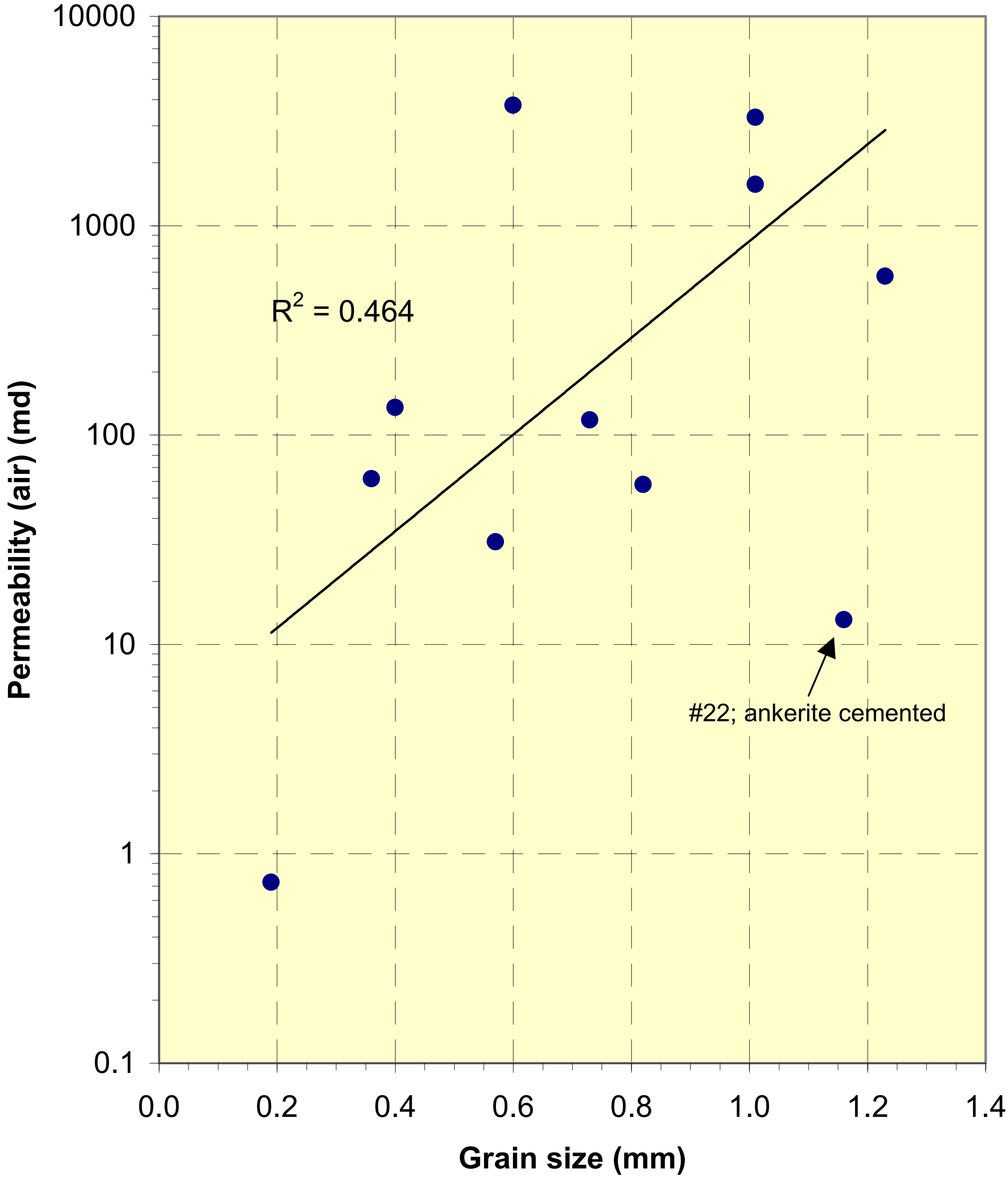


FIGURE 11. GRAIN SIZE/PERMEABILITY CROSS-PLOT (SANDSTONES)



correlation between grain size and permeability, but the correlation is only weak (R^2 = 0.464) Sorting ranges from moderately-well to poor, hence, given that intrinsic porosity and permeability decrease with decreasing sorting, it is likely that the control of grain size on permeability is being largely masked by the wide range of sorting coupled with the fact that the correlation between clay + metamorphic rock fragment content and grain size (Fig. 10) is only moderate. The presence of patchy ankerite cement results in #22 having anomalously low permeability for its grain size.

In summary, permeability variation between the reservoir sandstones is mainly due to differences in the amount of metamorphic rock fragments and, of less importance, detrital/authigenic clay. Clay + metamorphic rock fragment content is only moderately correlated with grain size, and there is wide variation in sorting. Consequently, grain size and permeability are only weakly correlated. Ankerite cement has a very localised influence on reservoir quality.

6.2 Samples

Sandstone samples are briefly described in order of increasing permeability.

#15. This fine grained, largely microporous sandstone is the finest of the sandstone sample suite. In most areas, intergranular porosity has been completely eliminated by pore filling by compacted ductile micaceous/argillaceous grains, clay and quartz overgrowths. Further porosity loss is due to grain contact dissolution. The sandstone was prone to physical compaction on account of its high content of micaceous/argillaceous metamorphic rock fragments. Primary intergranular pores and secondary mouldic pores are widely scattered and thus have little or no interconnection. K = 0.73md.

#22. Despite being very coarse grained, this sample has low (13.1md) permeability due to significant porosity reduction by grain contact dissolution, ductile grain/clay compaction, ankerite cementation and authigenic clay formation. Primary intergranular pores and secondary K-feldspar dissolution pores are erratically distributed, hence have limited interconnection. The sample has anomalously low permeability for its grain size and clay + metamorphic rock fragment content due to the presence of patchy ankerite cement.

#13, #19. Significant porosity reduction in these coarse grained sandstones is the result of grain contact dissolution, ductile grain/clay compaction, authigenic clay formation and minor quartz overgrowth cementation, which, in some areas, have completely eliminated intergranular porosity. However, the sandstones still contain modest amounts of primary intergranular porosity that is supplemented by scattered secondary K-feldspar dissolution pores. With pores and pore throats commonly being occupied by compacted ductile grains, clay and quartz overgrowths, permeability is relatively low (30.8md, 57.9md).

#17. This medium grained sandstone has good primary intergranular porosity, even though grain contact dissolution, ductile grain/clay compaction and quartz overgrowth cementation have totally eliminated intergranular space between some grains. Primary intergranular pores provide connection for scattered secondary pores that occur where K-feldspar grains have partly to completely dissolved. K = 61.8md.

#23. In this coarse grained sandstone, porosity has been reduced by grain contact dissolution, ductile grain/clay compaction, minor ankerite and quartz overgrowth cementation and localised pore filling by kaolinitised detrital clay matrix. However, primary and secondary porosity is abundant in large parts of the sandstone, and the sandstone is consequently moderately permeable (118md).

#8. This sample is a medium grained sandstone in which there has been significant intergranular porosity reduction by pore filling by patchy kaolinitised detrital clay matrix and also by advanced grain contact dissolution/microstylolitisation within argillaceous areas. Where clay matrix is absent, porosity has been reduced by grain contact dissolution, ductile grain compaction and quartz overgrowth cementation, but there is still abundant primary intergranular porosity and secondary K-feldspar dissolution porosity within clean areas, the presence of which results in moderate (135md) permeability.

#18. Porosity has been reduced in this very coarse grained sandstone mainly by grain contact dissolution, ductile grain/clay compaction and authigenic clay formation, which, in some areas, have completely eliminated intergranular porosity. However, the sandstone still contains modest primary and secondary intergranular porosity, which, together with the very coarse grain size, results in good (573md) permeability.

#3, #4, #5. These three coarse to very coarse grained sandstones are distinguished from the other sandstones by their high (1570-3750md) permeability. They contain abundant, clean, evenly distributed, hence well interconnected primary and subordinate secondary intergranular pores, despite porosity reduction by grain contact dissolution and, of much less importance, quartz overgrowth cementation. The samples originally contained few labile metamorphic rock fragments, hence were not prone to physical compaction and authigenic clay formation. Sample #5 has a much lower permeability than #3 and #4 on account of containing scattered patches of detrital clay matrix, the presence of which has promoted grain contact dissolution and microstylolitisation where the clay is thinly dispersed.

7. SUMMARY AND CONCLUSIONS

- Samples from 2450.0-2764.5m in East Pilchard-1 are non-reservoir volcanics (#1, #2), non-reservoir mudrocks and argillaceous siltstones/sandstones (#6, #7, #9, #11, #12, #21) and reservoir sandstones (#3, #4, #5, #8, #13, #15, #17, #18 #19, #22, #23). One sample (#14) is composed mainly of drilling mud contaminants and provides no clear indication of lithology at the sample depth.

- **Volcanic samples** (#1, #2) are altered basaltic volcanics composed largely of plagioclase laths that have undergone hydrothermal alteration to chlorite (#1) and sericite (#2). Interstitial matrix is mainly secondary chlorite, opaque oxides, silica and ferroan carbonate. Phenocrysts are totally replaced by ferroan carbonate, silica and chlorite. Silica-filled cavities/amygdales are included in #2, and both samples are cut by ferroan carbonate-healed fractures. Macroporosity is absent.

- **Argillaceous samples** are silty/arenaceous mudrocks (#6, #7, #9, #11), an argillaceous siltstone (#12) and a laminated, fine grained argillaceous sandstone (#21) composed mainly of illitic/kaolinitic detrital clay, quartz, K-feldspar, plagioclase, rock fragments, mica, organic fragments and accessory heavy minerals. Detrital clay is partly replaced by microcrystalline siderite in #6, #7 and #11, and is also replaced by patchy, medium-crystalline ankerite in #6. Argillaceous samples contain little or no visible porosity and, with detrital clay being tightly compacted, contain only minor microporosity.

- **Sandstone samples** are variably sorted, fine to very coarse grained sublitharenites and a subarkose in which framework grains include quartz, K-feldspar, plagioclase, rock fragments, mica, organics and accessory heavy minerals. Most lithic grains are metamorphic rock fragments (quartz/mica schist, phyllite, illitic meta-argillite, mica/illite-bearing quartzite), the amount of which generally increases with decreasing grain size. Other lithic grains include volcanic, granitic and siliciclastic sedimentary rock fragments.

- Sandstones are derived from a continental provenance dominated by granitic and low grade metasedimentary rocks and which also included minor siliciclastics and volcanics.

- Minor detrital clay in the sandstones forms patchy matrix and is also concentrated with organic fragments along very thin laminae. Most sandstones lack detrital clay.

- Authigenic clay in the sandstones ranges up to 7.2% and is mainly kaolinite that occurs where micaceous/argillaceous grains and feldspar have altered and where patchy detrital clay matrix has recrystallised. Illitic remnants of micaceous precursor grains are locally associated with authigenic kaolinite, and minor authigenic illite is associated with partly altered and compactionally deformed micaceous metamorphic rock fragments. Clay minerals detected in the sandstones by XRD are kaolinite and minor discrete illite.

- Diagenetic effects in the sandstones besides authigenic clay formation include grain contact dissolution/microstylolitisation, labile grain dissolution, ductile grain/authigenic clay compaction, and cementation by quartz overgrowths and ankerite.

- Porosity reduction in the sandstones is mainly the result of grain contact dissolution, ductile grain/clay compaction, authigenic clay formation, minor quartz overgrowth cementation and localised ankerite cementation.

- Visible porosity in the sandstones ranges from 2.2% to 18.6% and decreases with increasing clay + metamorphic rock fragment content. Visible porosity is accounted for by varying proportions of primary intergranular pores and secondary K-feldspar dissolution pores.

- Sandstone reservoir quality is mainly controlled by the content of metamorphic rock fragments and, of less importance, detrital/authigenic clay. Clay + metamorphic rock fragment content is only moderately correlated with grain size, and there is wide variation in sorting. Consequently, permeability is only weakly correlated with grain size. Ankerite cement has a very localised influence on reservoir quality.

- A summary of reservoir quality is given in Table 7.

TABLE 7. RESERVOIR QUALITY SUMMARY

Sample #	Depth (mRT)	Comments	Plate # (Appendix 5)
1	2450.0	Non-reservoir, altered basaltic volcanic.	1, 2
2	2586.0	Non-reservoir, altered basaltic volcanic.	3, 4
3	2594.0	Clean, poorly cemented, coarse grained sandstone with a system of evenly distributed, hence well interconnected primary and secondary intergranular pores. Minor porosity reduction by grain contact dissolution and, of much less importance, quartz overgrowth cementation.	5, 6, 7
4	2598.0	?Interbedded granule conglomerate and medium grained sandstone with abundant clean primary and subordinate secondary intergranular porosity. Minor porosity reduction by grain contact dissolution and, of much less importance, quartz overgrowth cementation.	8, 9, 10
5	2602.0	Very coarse grained sandstone with sporadic patches of detrital clay matrix, the presence of which has promoted localised advanced grain contact dissolution and microstylolitisation. Abundant primary and subordinate secondary intergranular porosity in clean areas.	11, 12, 13
6	2610.0	Non-reservoir, sideritic mudrock.	14, 15
7	2620.0	Non-reservoir, sideritic mudrock.	16, 17, 18
8	2627.5	Medium grained sandstone in which there has been significant porosity reduction by pore filling by patchy kaolinitised detrital clay matrix and as a result of advanced grain contact dissolution/microstylolitisation within argillaceous areas. Good macroporosity in clean areas.	19, 20, 21
9	2633.5	Non-reservoir, carbonaceous mudrock.	22, 23, 24
11	2644.0	Non-reservoir, sideritic mudrock.	25, 26, 27
12	2652.0	Non-reservoir, argillaceous siltstone.	28, 29, 30

TABLE 7. RESERVOIR QUALITY SUMMARY cont.

Sample #	Depth (mRT)	Comments	Plate # (Appendix 5)
13	2663.0	Coarse grained sandstone in which significant porosity reduction is the result of grain contact dissolution, ductile grain/clay compaction and, of much less importance, authigenic clay formation and quartz overgrowth cementation. Modest primary and secondary macroporosity.	31, 32, 33
14	2669.0	Drilling mud contaminants.	34, 35
15	2700.5	Fine grained sandstone in which intergranular porosity has been largely eliminated by ductile grain/clay compaction, grain contact dissolution and pore filling by detrital clay and localised quartz overgrowths. Widely scattered, hence poorly interconnected macropores.	36, 37, 38, 39
17	2721.5	Medium grained sandstone with good primary and secondary intergranular porosity, despite porosity reduction by grain contact dissolution, ductile grain/clay compaction and quartz overgrowth cementation, which between some grains have totally eliminated intergranular space.	40, 41, 42
18	2728.5	Very coarse grained sandstone in which significant porosity reduction is the result of grain contact dissolution, ductile grain/clay compaction, authigenic clay formation and, of much less importance, ankerite cementation. Modest primary and secondary macroporosity.	43, 44, 45
19	2751.0	Coarse grained sandstone in which significant porosity reduction is the result of grain contact dissolution, ductile grain/clay compaction, authigenic clay formation and very minor quartz overgrowth cementation. Modest primary and secondary macroporosity.	46, 47, 48
21	2759.0	Non-reservoir, laminated, fine grained, argillaceous sandstone.	49, 50, 51
22	2763.0	Very coarse grained sandstone in which intergranular porosity has been largely eliminated by grain contact dissolution, ductile grain/clay compaction, ankerite cementation and authigenic clay formation. Macropores are erratically distributed hence have limited interconnection.	52, 53, 54
23	2764.5	Coarse grained sandstone with good primary and secondary intergranular porosity, despite porosity reduction by grain contact dissolution, ductile grain/clay compaction, and ankerite and quartz overgrowth cementation. Patchy kaolinitic detrital clay matrix also reduces porosity.	55, 56, 57

APPENDIX 1

GRAIN SIZE COMPARISON TABLE

APPENDIX 1. GRAIN SIZE COMPARISON TABLE

Millimetres	Microns	Phi (ϕ)	Wentworth Size Class
4096		-12	
1024		-10	Boulder (-8 to -12)
256		- 8	
			Cobble (-6 to -8)
64		- 6	
16		- 4	Pebble (-2 to -6)
4		- 2	
3.36		- 1.75	
2.83		- 1.5	Granule
2.38		- 1.25	
2.00		**- 1.0**	
1.68		- 0.75	
1.41		- 0.5	Very coarse sand
1.19		- 0.25	
1.00		0.0	
0.84		0.25	
0.71		0.5	Coarse sand
0.59		0.75	
1/2 --- 0.50	500	1.0	
0.42	420	1.25	
0.35	350	1.5	Medium sand
0.30	300	1.75	
1/4 --- 0.25	250	2.0	
0.210	210	2.25	
0.177	177	2.5	Fine sand
0.149	149	2.75	
1/8 --- 0.125	125	3.0	
0.105	105	3.25	
0.088	88	3.5	Very fine sand
0.074	74	3.75	
1/16 -- **0.0625**	**62.5**	**4.0**	
0.053	53	4.25	
0.044	44	4.5	Coarse silt
0.037	37	4.75	
1/32 -- 0.031	31	5.0	
			Medium silt
1/64 -- 0.0156	15.6	6.0	
			Fine silt
1/128 - 0.0078	7.8	7.0	
			Very fine silt
1/256 - 0.0039	3.9	8.0	
0.0020	2.0	9.0	
0.00098	0.98	10.0	Clay
0.00049	0.49	11.0	

APPENDIX 2

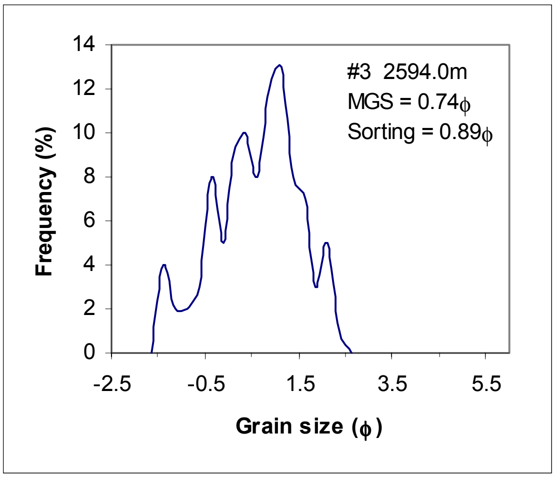
GRAIN SIZE FREQUENCY CURVES

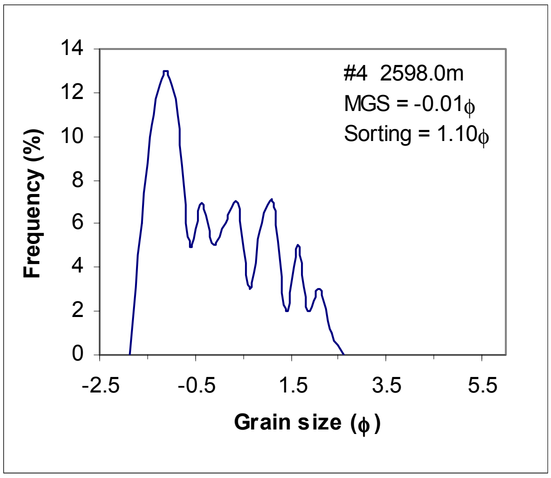
MGS = mean grain size

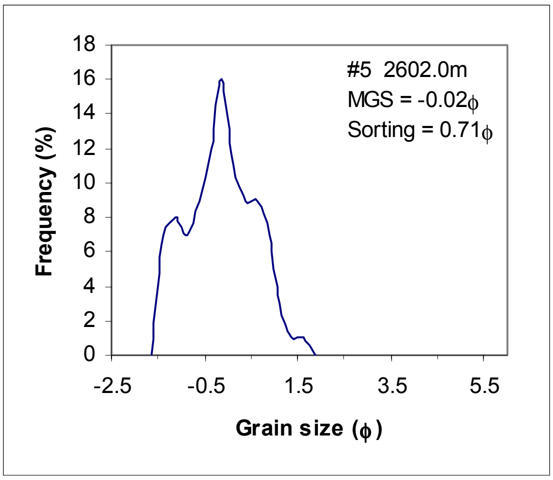
(-1-0ϕ = very coarse sand; 0-1ϕ = coarse sand; 1-2ϕ = medium sand; 2-3ϕ = fine sand)

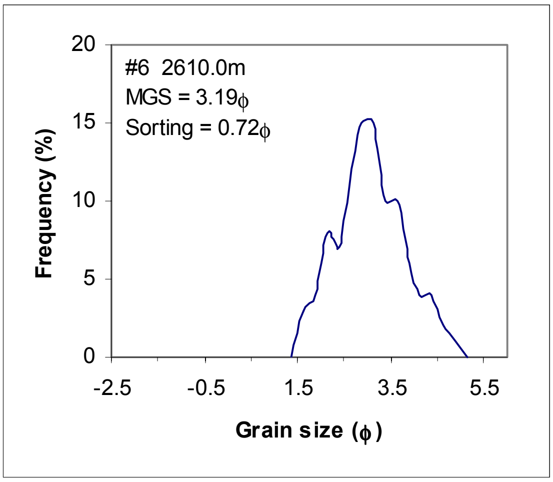
Sorting (ϕSD)

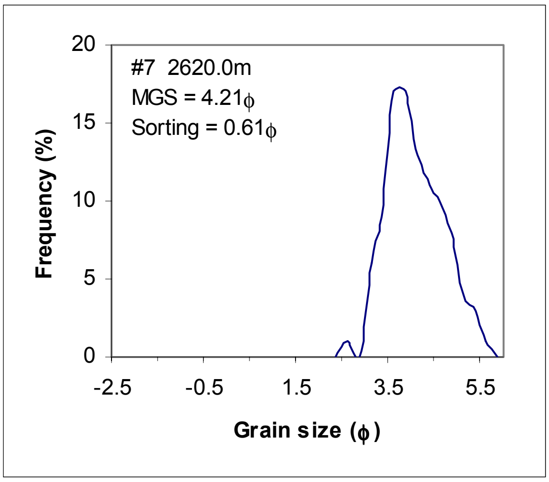
Class	*ϕ Standard Deviation*
very well sorted	<0.35
well sorted	0.35-<0.50
moderately well sorted	0.50-<0.71
moderately sorted	0.71-1.00
poorly sorted	>1.00+

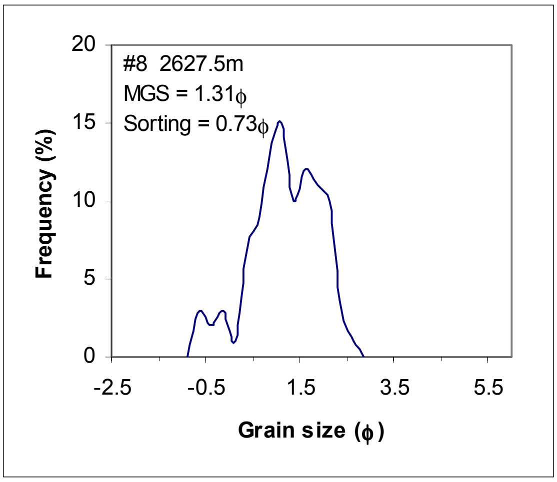

#3 2594.0m
MGS = 0.74ϕ
Sorting = 0.89ϕ
Frequency (%)
Grain size (ϕ)
14
12
10
8
6
4
2
0
-2.5
-0.5
1.5
3.5
5.5

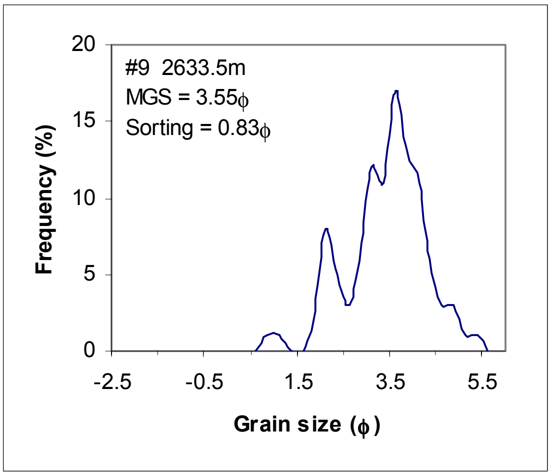

#4 2598.0m
MGS = -0.01ϕ
Sorting = 1.10ϕ
Frequency (%)
Grain size (ϕ)
14
12
10
8
6
4
2
0
-2.5
-0.5
1.5
3.5
5.5

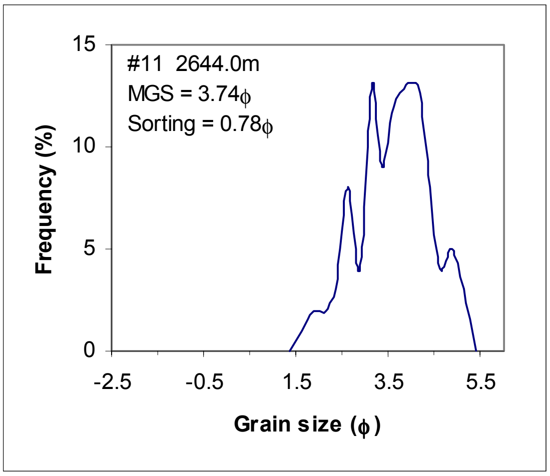

#5 2602.0m
MGS = -0.02ϕ
Sorting = 0.71ϕ
Frequency (%)
Grain size (ϕ)
18
16
14
12
10
8
6
4
2
0
-2.5
-0.5
1.5
3.5
5.5

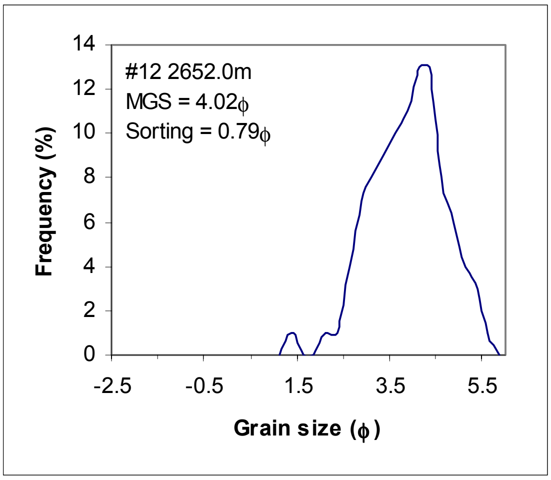

#6 2610.0m
MGS = 3.19ϕ
Sorting = 0.72ϕ
Frequency (%)
Grain size (ϕ)
20
15
10
5
0
-2.5
-0.5
1.5
3.5
5.5

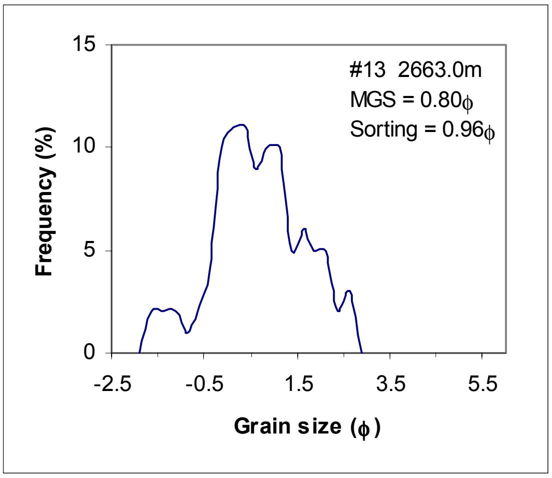

#7 2620.0m
MGS = 4.21ϕ
Sorting = 0.61ϕ
Frequency (%)
Grain size (ϕ)
20
15
10
5
0
-2.5
-0.5
1.5
3.5
5.5

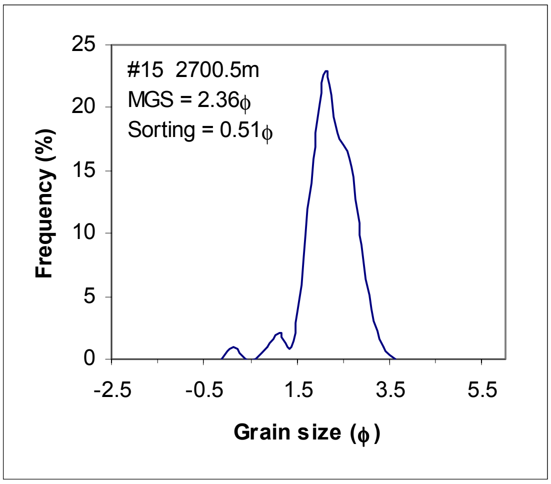

#8 2627.5m
MGS = 1.31ϕ
Sorting = 0.73ϕ
Frequency (%)
Grain size (ϕ)
20
15
10
5
0
-2.5
-0.5
1.5
3.5
5.5

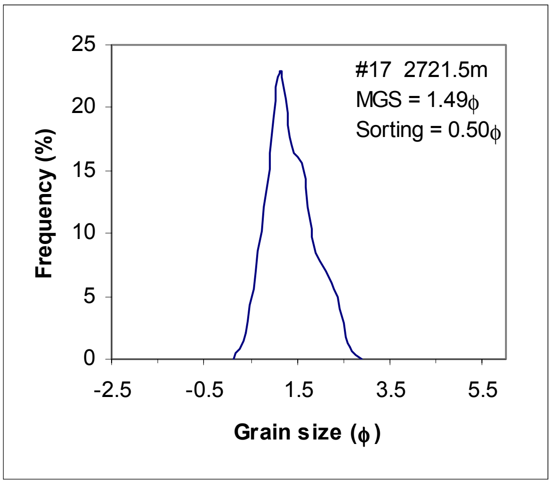

#9 2633.5m
MGS = 3.55ϕ
Sorting = 0.83ϕ
Frequency (%)
Grain size (ϕ)

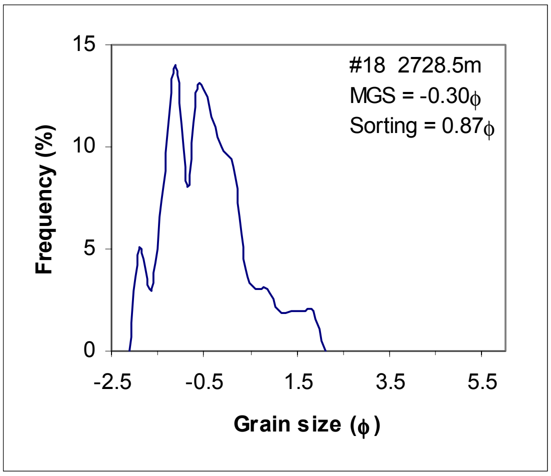

#11 2644.0m
MGS = 3.74ϕ
Sorting = 0.78ϕ
Frequency (%)
Grain size (ϕ)

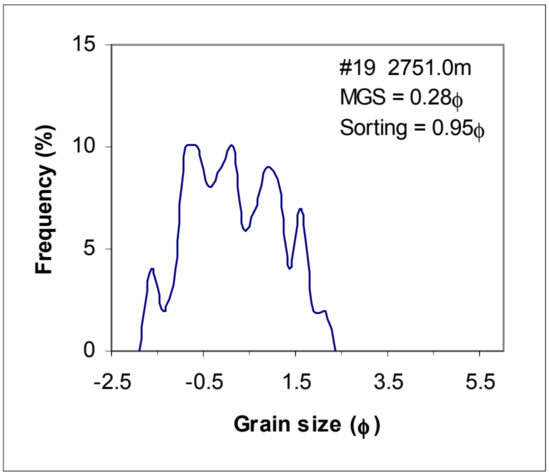

#12 2652.0m
MGS = 4.02ϕ
Sorting = 0.79ϕ
Frequency (%)
Grain size (ϕ)

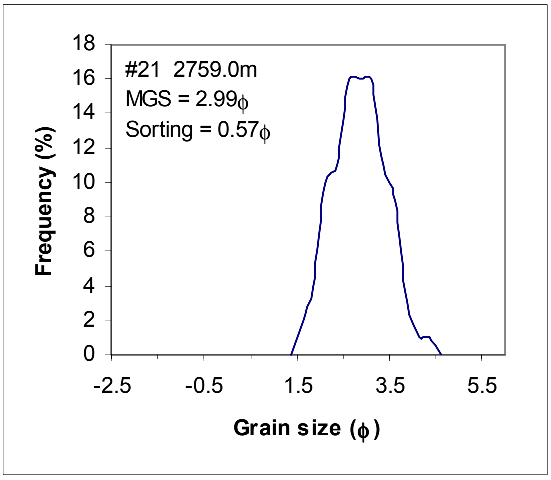

#13 2663.0m
MGS = 0.80ϕ
Sorting = 0.96ϕ
Frequency (%)
Grain size (ϕ)

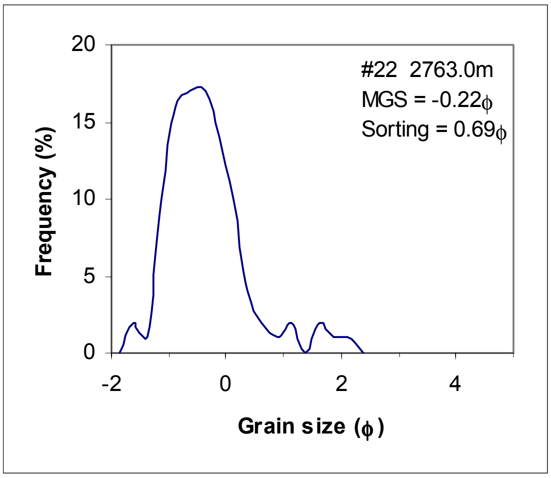

#15 2700.5m
MGS = 2.36ϕ
Sorting = 0.51ϕ
Frequency (%)
Grain size (ϕ)

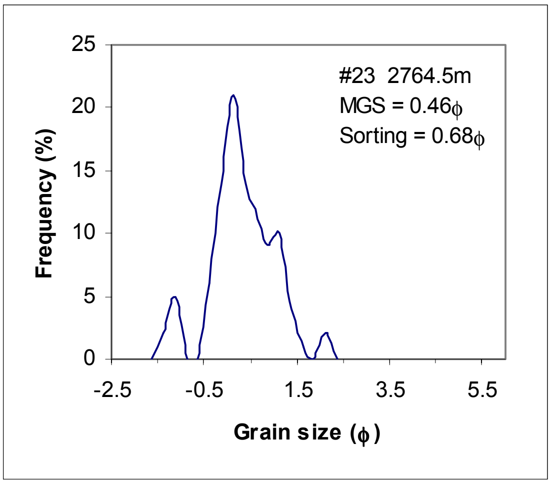

#17 2721.5m
MGS = 1.49ϕ
Sorting = 0.50ϕ
Frequency (%)
Grain size (ϕ)


#18 2728.5m
MGS = -0.30ϕ
Sorting = 0.87ϕ
Frequency (%)
Grain size (ϕ)
0
5
10
15
-2.5
-0.5
1.5
3.5
5.5


#19 2751.0m
MGS = 0.28ϕ
Sorting = 0.95ϕ
Frequency (%)
Grain size (ϕ)
0
5
10
15
-2.5
-0.5
1.5
3.5
5.5


#21 2759.0m
MGS = 2.99ϕ
Sorting = 0.57ϕ
Frequency (%)
Grain size (ϕ)
0
2
4
6
8
10
12
14
16
18
-2.5
-0.5
1.5
3.5
5.5


#22 2763.0m
MGS = -0.22ϕ
Sorting = 0.69ϕ
Frequency (%)
Grain size (ϕ)
0
5
10
15
20
-2
0
2
4


#23 2764.5m
MGS = 0.46ϕ
Sorting = 0.68ϕ
Frequency (%)
Grain size (ϕ)
0
5
10
15
20
25
-2.5
-0.5
1.5
3.5
5.5

APPENDIX 3

RAW POINT COUNT DATA

REFNO/Well ID	Well Name	Well Number	Depth (mRT)	Depth (TVDss)	GRUN	GCUN	QZUN	QZMO	QZPO	QZEX	FSUN	FSPL
	East Pilchard	East Pilchard-1	2450.0	2450.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.7
			2586.0	2586.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.5
			2594.0	2594.0	0.0	0.0	0.0	56.1	11.8	0.0	0.0	0.3
			2598.0	2598.0	0.0	0.0	0.0	50.3	16.3	0.0	0.0	0.0
			2602.0	2602.0	0.0	0.0	0.0	51.8	16.1	0.0	0.0	0.0
			2610.0	2610.0	0.0	0.0	0.0	14.0	1.7	0.0	0.0	0.3
			2620.0	2620.0	0.0	0.0	0.0	14.3	0.5	0.0	0.0	0.3
			2627.5	2627.5	0.0	0.0	0.0	60.2	8.9	0.0	0.0	0.7
			2633.5	2633.5	0.0	0.0	0.0	16.5	0.3	0.0	0.0	0.0
			2644.0	2644.0	0.0	0.0	0.0	28.2	0.9	0.0	0.0	0.0
			2652.0	2652.0	0.0	0.0	0.0	58.7	1.1	0.0	0.0	0.0
			2663.0	2663.0	0.0	0.0	0.0	53.8	16.4	0.0	0.0	0.0
			2669.0	2669.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			2700.5	2700.5	0.0	0.0	0.0	59.4	4.1	0.0	0.0	0.0
			2721.5	2721.5	0.0	0.0	0.0	58.3	5.5	0.0	0.0	0.0
			2728.5	2728.5	0.0	0.0	0.0	34.8	32.8	0.0	0.0	0.0
			2751.0	2751.0	0.0	0.0	0.0	52.8	18.0	0.0	0.0	0.0
			2759.0	2759.0	0.0	0.0	0.0	39.7	1.9	0.0	0.0	0.0
			2763.0	2763.0	0.0	0.0	0.0	40.3	29.9	0.0	0.0	0.0
			2764.5	2764.5	0.0	0.0	0.0	50.2	17.3	0.0	0.0	0.0

FSKF	FSIG	FSEX	RFUN	FSPR	RSUN	RSCT	RSQZ	RSCL	RSCB	RSEX	RVUN	RVFS	RVMF	RVTF	RVEX	RMUN	RMMP	RMMR	RMEX
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.9	1.1	0.0	0.0	0.7	0.0	1.0	0.0	0.3	0.0	0.0	0.0	1.5	0.3	0.3	0.0	0.0	2.0	0.7	0.0
3.8	1.7	0.0	0.0	0.9	0.0	1.6	0.0	0.8	0.0	0.0	0.0	1.2	0.3	0.3	0.0	0.0	1.0	0.6	0.0
4.0	1.1	0.0	0.0	0.0	0.0	0.9	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
0.7	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.7	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	3.5	0.8	0.0
0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.3	0.0
1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.6	0.0
1.6	0.0	0.0	0.0	0.0	0.0	1.2	0.5	0.3	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.7	8.8	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.7	0.0	0.0	0.0	0.0	0.0	0.7	0.0	1.1	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	3.0	11.9	0.0
2.9	0.0	0.0	0.0	0.0	0.0	0.7	0.3	1.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	3.1	7.7	0.0
3.6	0.0	0.0	0.0	1.2	0.0	5.4	0.7	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	2.5	0.7	0.0
1.6	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	2.8	2.4	0.0
2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	1.1	4.6	0.0
2.6	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.9	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.7	0.9	0.0
0.7	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	2.6	1.4	0.0

OMUN	OMMS	OMBT	OGGL	OGPH	OGFL	OGPL	OGHV	OGEX	PFUN	MXUN	MXCL	MXSI	MXCB	MXOR	MXEX	CMUN	CBUN	CBCA
0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.7	0.0	0.0	0.0	0.0	5.4	0.3	0.0	0.0	0.0	47.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	1.8	0.0	0.0	0.0	0.0	17.2	0.7	0.0	0.0	0.0	34.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	20.3	0.3	0.0	0.0	0.0	60.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.3	0.0	0.0	0.0	0.0	8.6	0.0	0.0	0.0	0.0	26.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	1.5	0.0	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	21.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.3	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	3.4	0.0	0.0	0.0	0.0	9.2	0.0	0.0	0.0	0.0	34.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CBDO	CBSD	CBAK	CBEX	CMQZ	CMSI	CMFS	CMPY	CMFE	CMZE	CMAN	CMHC	CMXA	CMXB	CLUN	CLCH	CLKT	CLIS	CLEX	IRUN
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	1.2	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	8.2	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	1.8	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ICUN	ICCA	ICDO	ICSD	ICAK	ICEX	IRSI	IRPY	IRZE	IRCL	IRCH	IRKT	IRIS	IRXA	IRXB	PVUN	PVIG	PVSC	PVPR	PVSE	PVFR	PVEX
0.0	0.0	0.0	4.6	2.7	0.0	3.0	0.0	0.0	0.0	22.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	25.8	14.9	0.0	2.3	0.0	0.0	0.0	0.0	0.0	26.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	13.6	1.5	0.0	3.5	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	13.8	0.7	0.0	2.8	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.3	0.0	0.0	0.0	12.2	1.1	0.0	4.1	0.0	0.0
0.0	0.0	0.0	18.0	9.3	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	28.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.3	0.0	0.0	5.4	0.3	0.0	5.7	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	31.8	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	1.9	0.4	0.0	0.0	0.3	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.8	0.0	0.0	0.0	4.4	0.8	0.0	3.4	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.7	0.0	0.0	0.0	0.7	0.0	0.0	1.5	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.4	0.0	0.0	0.0	8.1	0.3	0.0	5.7	0.0	0.0
0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.8	0.0	0.0	0.0	4.1	0.8	0.0	4.3	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	0.8	0.0	0.0	0.0	4.8	0.0	0.0	5.2	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	3.8	0.0	0.0	4.0	0.0	0.0
0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	9.3	0.0	0.0	5.7	0.0	0.0

QZTO	FSTO	RSTO	RVTO	RMTO	OGTO	RFTO	MXTO	CBTO	CLTO	CMTO	ICTO	IRTO	PVTO	GFTO	PFTO	GTOT
0.0	50.7	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	66.7	33.3	0.0
0.0	28.5	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	1.0	69.2	0.0	30.8	69.2	0.0
67.9	3.3	1.3	2.1	2.7	0.0	6.8	0.0	0.0	0.0	2.7	2.0	0.7	18.6	77.3	3.4	0.0
66.6	5.5	2.4	1.8	1.6	0.3	6.7	0.0	0.0	0.0	3.3	3.0	0.3	17.3	78.2	3.6	0.0
67.9	5.1	1.6	0.0	0.6	0.0	2.2	2.9	0.0	0.0	2.5	4.0	2.0	17.4	75.2	7.4	0.0
15.7	1.0	0.7	0.7	0.0	6.4	1.4	47.6	0.0	0.0	0.0	5.0	27.9	0.0	24.5	75.5	0.0
14.8	0.6	0.0	0.0	0.0	19.7	0.0	34.4	0.0	0.0	0.0	6.0	30.5	0.0	35.1	64.9	0.0
69.1	1.8	2.1	0.7	4.3	0.0	7.1	2.0	0.0	0.0	4.0	7.0	4.6	11.4	78.0	10.6	0.0
16.8	0.6	0.0	0.0	0.0	20.6	0.0	60.4	0.0	0.0	0.0	8.0	1.6	0.0	38.0	62.0	0.0
29.1	1.1	0.3	0.0	0.9	8.9	1.2	26.4	0.0	0.0	0.0	9.0	33.3	0.0	40.3	59.7	0.0
59.8	1.5	0.0	0.0	1.3	12.5	1.3	21.3	0.0	0.0	0.0	10.0	3.6	0.0	75.1	24.9	0.0
70.2	1.6	2.0	0.7	9.5	0.3	12.2	0.0	0.0	0.0	3.3	11.0	3.8	8.6	84.3	7.1	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0
63.5	2.7	1.8	0.4	14.9	3.0	17.1	6.1	0.0	0.0	2.7	13.0	2.7	2.2	86.3	11.5	0.0
63.8	2.9	2.0	0.7	10.8	0.3	13.5	0.0	0.0	0.0	3.2	14.0	2.2	14.1	80.5	5.4	0.0
67.6	3.6	6.5	0.4	3.2	0.3	11.3	0.0	0.0	0.0	2.0	15.0	6.0	9.2	81.6	8.0	0.0
70.8	1.6	2.0	0.8	5.2	0.0	8.0	0.0	0.0	0.0	2.4	16.0	7.2	10.0	80.4	9.6	0.0
41.6	2.2	0.0	0.3	5.7	12.6	6.0	34.7	0.0	0.0	0.0	17.0	2.9	0.0	62.4	37.6	0.0
70.2	2.6	2.5	0.8	1.6	0.0	4.9	0.0	0.0	0.0	8.9	18.0	5.6	7.8	77.7	14.5	0.0
67.5	0.7	0.7	0.3	4.0	0.0	5.0	3.0	0.0	0.0	4.2	19.0	4.6	15.0	73.2	11.8	0.0

KEY TO PETROGRAPHIC CATEGORIES

EXXON PRODUCTION RESEARCH COMPANY

ABBR.	CATEGORY
	Grains
GRUN	Grain, undifferentiated or unknown
GCUN	Clay grain, undifferentiated
	Quartz
QZUN	Quartz, undifferentiated
QZMO	Quartz, monocrystalline
QZPO	Quartz, polycrystalline
QZEX	Quartz, other
	Feldspar
FSUN	Feldspar, undifferentiated
FSPL	Plagioclase feldspar
FSKF	Potassium feldspar
FSIG	Feldspar intergrowth
FSEX	Feldspar, other
	Rock Fragments
RFUN	Rock fragment, undifferentiated
FSPR	Plutonic rock fragment
RSUN	Sedimentary rock fragment, undifferentiated
RSCT	Chert
RSQZ	Quartz-rich sedimentary fragment
RSCL	Clay-rich sedimentary fragment
RSCB	Carbonate rock fragment
RSEX	Sedimentary fragment, other
RVUN	Volcanic rock fragment, undifferentiated
RVFS	Felsic volcanic fragment
RVMF	Mafic/intermediate volcanic fragment
RVTF	Tuff/glass fragment
RVEX	Volcanic fragment, other
RMUN	Metamorphic fragment, undifferentiated
RMMP	Mica-poor metamorphic fragment
RMMR	Mica-rich metamorphic fragment
RMEX	Metamorphic fragment, other
	Other Grains
OMUN	Mica, undifferentiated
OMMS	Muscovite
OMBT	Biotite
OGGL	Glauconite
OGPH	Phosphatic grain
OGFL	Fossil fragment
OGPL	Plant/wood fragment
OGHV	Heavy mineral or opaque
OGEX	Grain, other

ABBR.	CATEGORY
	Pore Fill
PFUN	Pore fill, undifferentiated
	Matrix
MXUN	Matrix, undifferentiated
MXCL	Clay matrix
MXSI	Siliceous matrix
MXCB	Carbonate matrix
MXOR	Organic matrix
MXEX	Matrix, other
	Authigenic Cement & Clay
CMUN	Cement, undifferentiated
CBUN	Carbonate cement, undifferentiated
CBCA	Calcite cement
CBDO	Dolomite cement
CBSD	Siderite cement
CBAK	Ankerite cement
CBEX	Carbonate cement, other
CMQZ	Quartz overgrowth
CMSI	Silica cement, other
CMFS	Feldspar overgrowth
CMPY	Pyrite/marcasite cement
CMFE	Iron oxide cement
CMZE	Zeolite cement
CMAN	Anhydrite cement
CMHC	Hydrocarbon pore fill
CMXA	Cement, other 1
CMXB	Cement, other 2
CLUN	Authigenic clay, undifferentiated
CLCH	Chlorite cement
CLKT	Kaolinite cement
CLIS	Illite, smectite, or I/S cement
CLEX	Authigenic clay, other
	Replacement
IRUN	Replacement, undifferentiated
ICUN	Carbonate replacement, undifferentiated
ICCA	Calcite replacement
ICDO	Dolomite replacement
ICSD	Siderite replacement
ICAK	Ankerite replacement
ICEX	Carbonate replacement, other
IRSI	Siliceous replacement
IRPY	Pyrite/marcasite replacement
IRZE	Zeolite replacement
IRCL	Clay replacement, undifferentiated

Porosity

PVUN	Visible porosity, undifferentiated
PVIG	Intergranular primary porosity
PVSC	Intragranular secondary porosity
PVPR	Intragranular primary porosity
PVSE	Intergranular secondary porosity
PVFR	Fracture porosity
PVEX	Porosity, other

Subtotals

QZTO	Total quartz
FSTO	Total feldspar
RFTO	Total rock fragments
RSTO	Total sedimentary rock fragments
RVTO	Total volcanic rock fragments
RMTO	Total metamorphic rock fragments
OGTO	Total other grains

Replacement (cont)

IRCH	Chlorite replacement
IRKT	Kaolinite replacement
IRIS	Illite, smectite, or I/S replacement
IRXA	Replacement, other 1
IRXB	Replacement, other 2

Subtotals

MXTO	Total matrix
CMTO	Total cement & clay
IRTO	Total replacement
PVTO	Total porosity
GFTO	Total grains
PFTO	Total pore fill

KEY TO PETROGRAPHIC CATEGORIES

EXXON MOBIL UPSTREAM RESEARCH COMPANY

#	CODE	Description
		Grains
1	**GRUN**	Grain, undifferentiated or unknown
2	**GCUN**	Clay grain, undifferentiated
		Quartz
3	**QZUN**	Quartz, undifferentiated
4	**QZMO**	Quartz, monocrystalline
5	**QZPO**	Quartz, polycrystalline
6	**QZEX**	Quartz, other
		Feldspar
7	**FSUN**	Feldspar, undifferentiated
8	**FSPL**	Plagioclase feldspar
9	**FSKF**	Potassium feldspar
10	**FSIG**	Feldspar intergrowth
11	**FSEX**	Feldspar, other
		Rock Fragments
12	**RFUN**	Rock fragment, undifferentiated
13	**FSPR**	Plutonic rock fragment
14	**RSUN**	Sedimentary rock fragment, undiff.
15	**RSCT**	Chert
16	**RSQZ**	Quartz-rich sedimentary fragment
17	**RSCL**	Clay-rich sedimentary fragment
18	**RSCB**	Carbonate rock fragment
19	**RSEX**	Sedimentary fragment, other
20	**RVUN**	Volcanic rock fragment, undiff.
21	**RVFS**	Felsic volcanic fragment
22	**RVMF**	Mafic/intermediate volcanic fragm.
23	**RVTF**	Tuff/glass fragment
24	**RVEX**	Volcanic fragment, other
25	**RMUN**	Metamorphic fragment, undiff.
26	**RMMP**	Mica-poor metamorphic fragment
27	**RMMR**	Mica-rich metamorphic fragment
28	**RMEX**	Metamorphic fragment, other
		Other Grains
29	**OMUN**	Mica, undifferentiated
30	**OMMS**	Muscovite
31	**OMBT**	Biotite
32	**OGGL**	Glauconite
33	**OGPH**	Phosphatic grain
34	**OGFL**	Fossil fragment
35	**OGPL**	Plant/wood fragment
36	**OGHV**	Heavy mineral or opaque
37	**OGEX**	Grain, other
		Pore Fill
38	**PFUN**	Pore fill, undifferentiated
		Matrix
39	**MXUN**	Matrix, undifferentiated
40	**MXCL**	Clay matrix
41	**MXSI**	Siliceous matrix
42	**MXCB**	Carbonate matrix
43	**MXOR**	Organic matrix
44	**MXEX**	Matrix, other

#	CODE	Description
		Authigenic Cement & Clay
45	**CMUN**	Cement, undifferentiated
46	**CBUN**	Carbonate cement, undifferentiated
47	**CBCA**	Calcite cement
48	**CBDO**	Dolomite cement
49	**CBSD**	Siderite cement
50	**CBAK**	Ankerite cement
51	**CBEX**	Carbonate cement, other
52	**CMQZ**	Quartz overgrowth
53	**CMSI**	Silica cement, other
54	**CMFS**	Feldspar overgrowth
55	**CMPY**	Pyrite/marcasite cement
56	**CMFE**	Iron oxide cement
57	**CMZE**	Zeolite cement
58	**CMAN**	Anhydrite cement
59	**CMHC**	Hydrocarbon pore fill
60	**CMXA**	Cement, other 1
61	**CMXB**	Cement, other 2
62	**CLUN**	Authigenic clay, undifferentiated
63	**CLCH**	Chlorite cement
64	**CLKT**	Kaolinite cement
65	**CLIS**	Illite, smectite, or I/S cement
66	**CLEX**	Authigenic clay, other
		Replacement
67	**IRUN**	Replacement, undifferentiated
68	**ICUN**	Carbonate replacement, undiff.
69	**ICCA**	Calcite replacement
70	**ICDO**	Dolomite replacement
71	**ICSD**	Siderite replacement
72	**ICAK**	Ankerite replacement
73	**ICEX**	Carbonate replacement, other
74	**IRSI**	Siliceous replacement
75	**IRPY**	Pyrite/marcasite replacement
76	**IRZE**	Zeolite replacement
77	**IRCL**	Clay replacement, undifferentiated
78	**IRCH**	Chlorite replacement
79	**IRKT**	Kaolinite replacement
80	**IRIS**	Illite, smectite, or I/S replacement
81	**IRXA**	Replacement, other 1
82	**IRXB**	Replacement, other 2
		Porosity
83	**PVUN**	Visible porosity, undifferentiated
84	**PVIG**	Intergranular primary porosity
85	**PVSC**	Intragranular secondary porosity
86	**PVPR**	Intragranular primary porosity
87	**PVSE**	Intergranular secondary porosity
88	**PVFR**	Fracture porosity
89	**PVEX**	Porosity, other

APPENDIX 4

XRD TRACES

Key to abbreviations:

A = anatase

An = ankerite

Ba = barite (contaminant)

Ca = calcite (contaminant)

I = illite/mica

K = kaolinite

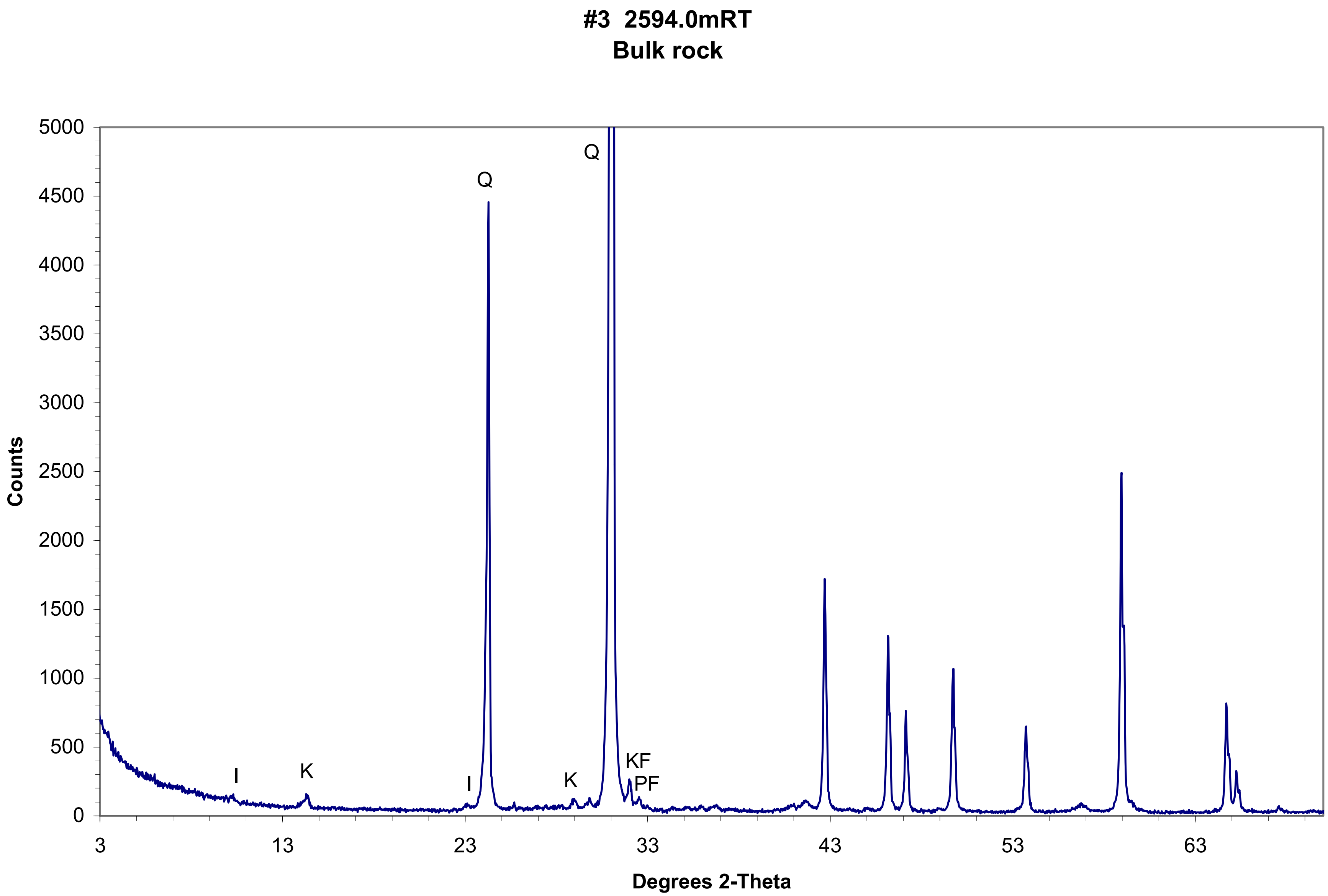
KCl = potassium chloride (contaminant)

KF = K-feldspar

PF = plagioclase

Q = quartz

S = siderite



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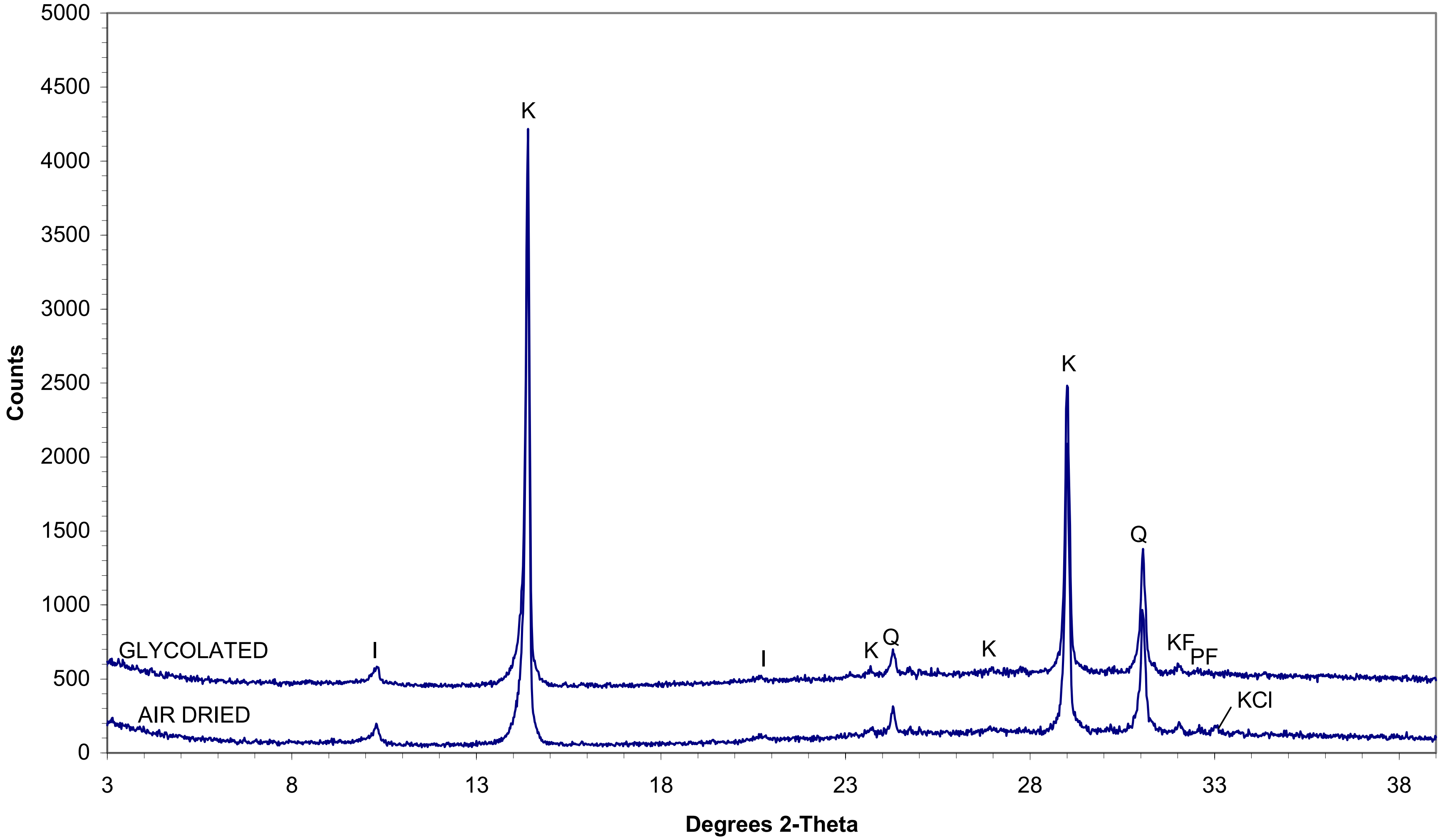
Bulk rock
Counts
Degrees 2-Theta
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
3
13
23
33
43
53
63
I
K
I
Q
K
Q
KF
PF

#3 2594.0mRT
Fine fraction



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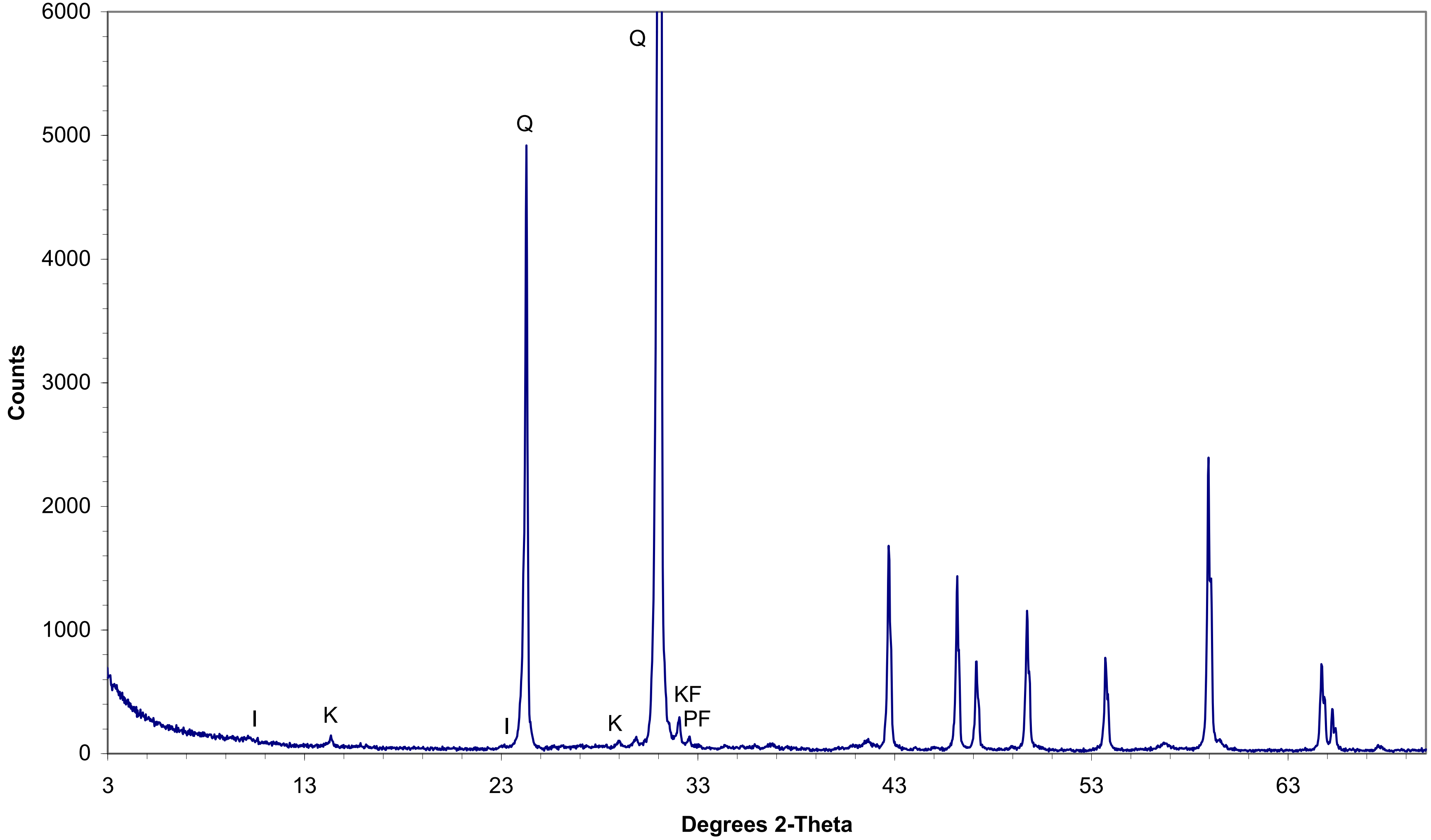

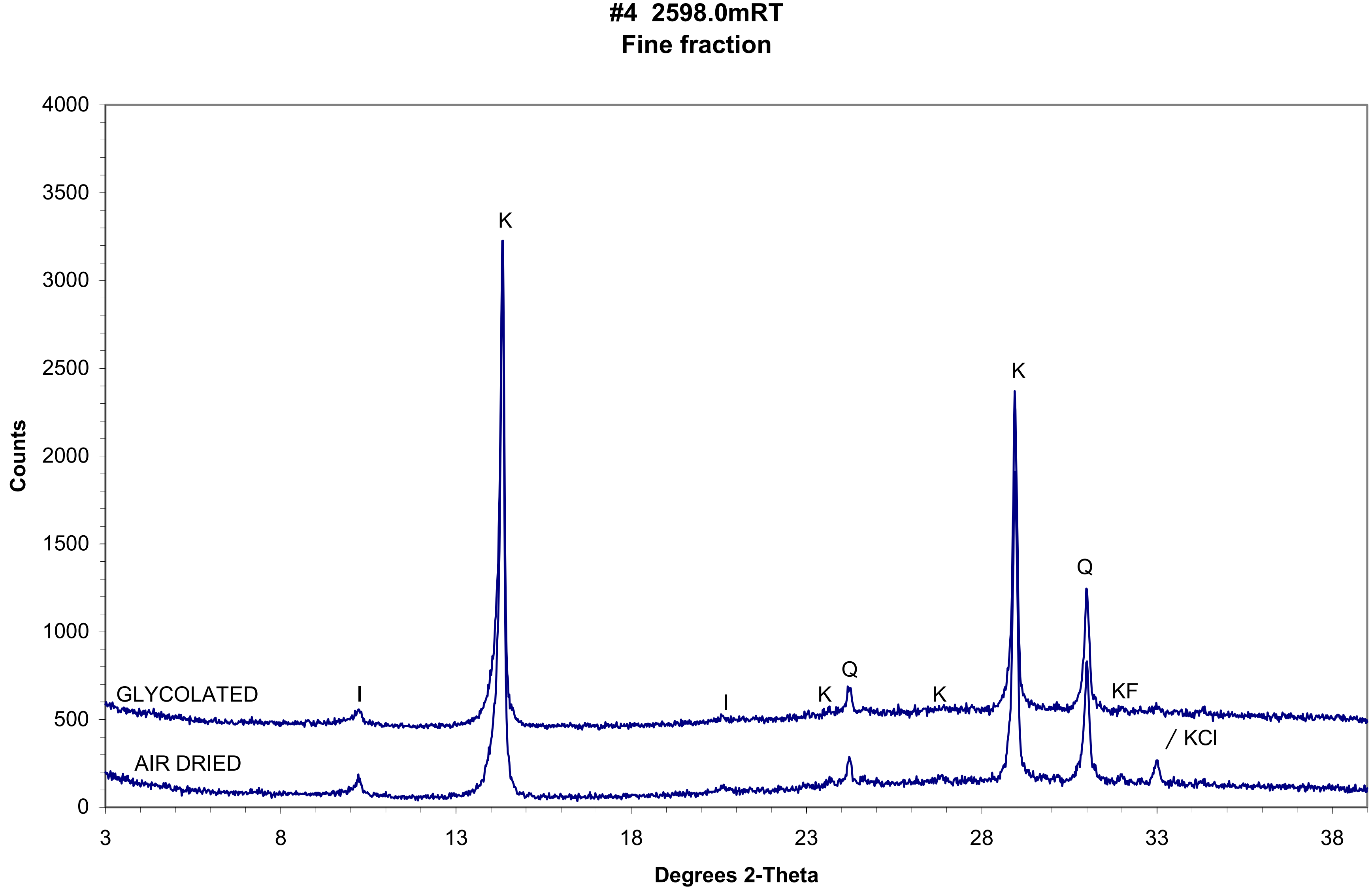
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2500
2000
1500
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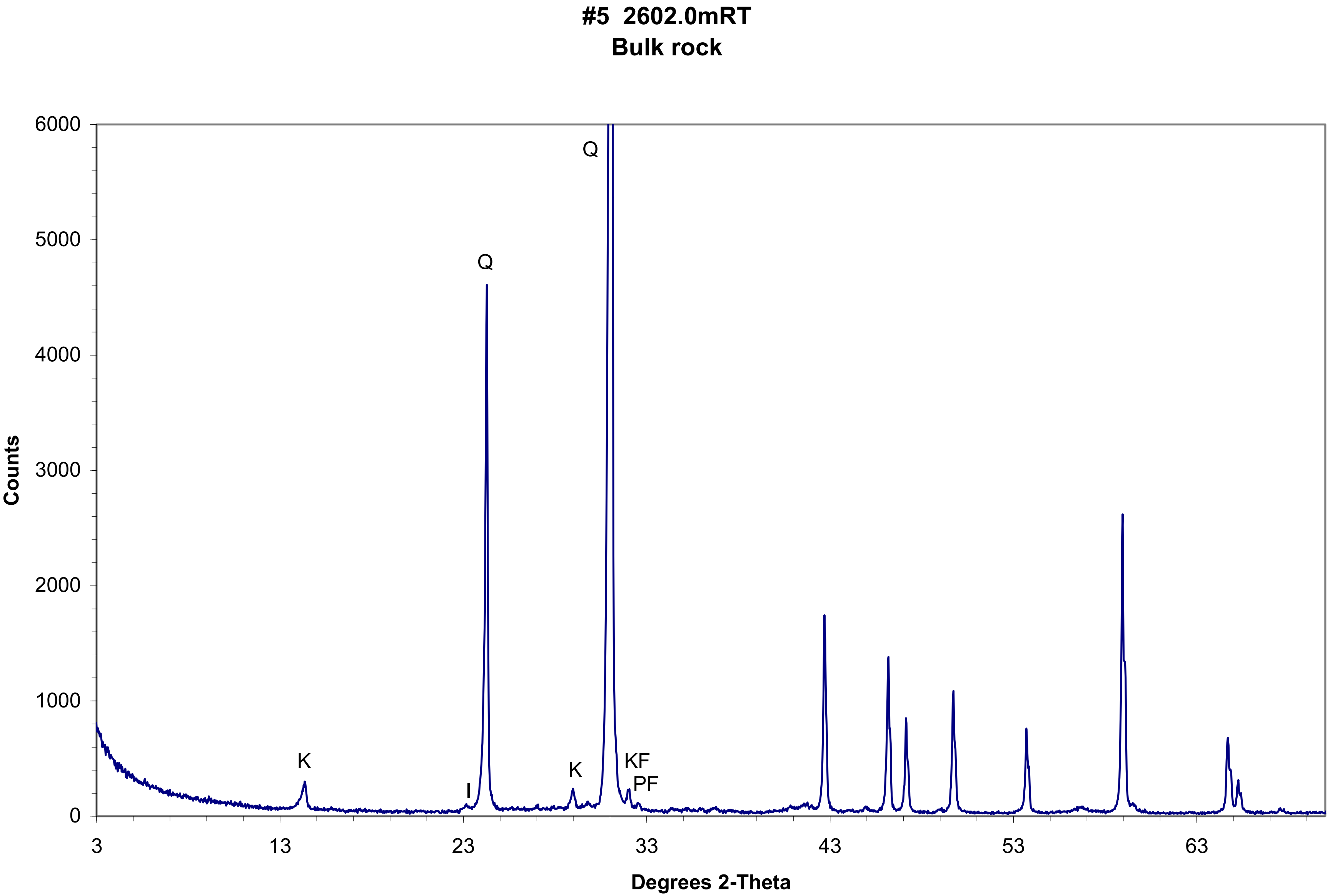
500
0
Counts
K
K
Q
Q
I
I
K
K
KF
/ KCl
GLYCOLATED
AIR DRIED
3
8
13
18
23
28
33
38
Degrees 2-Theta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K
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K
KF
PF
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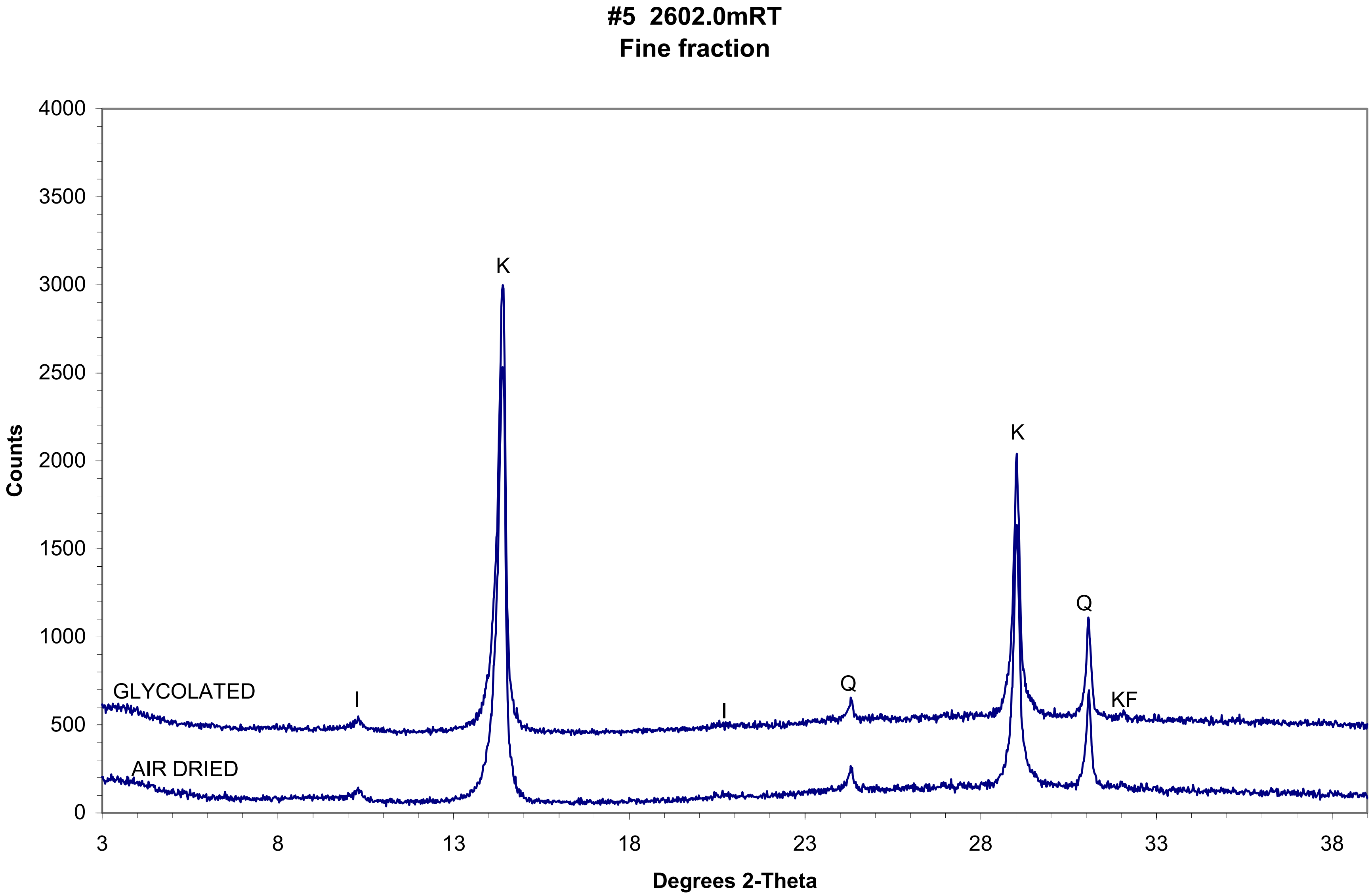
13
23
33
43
53
63
Degrees 2-Theta



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Counts
Degrees 2-Theta
4000
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3000
2500
2000
1500
1000
500
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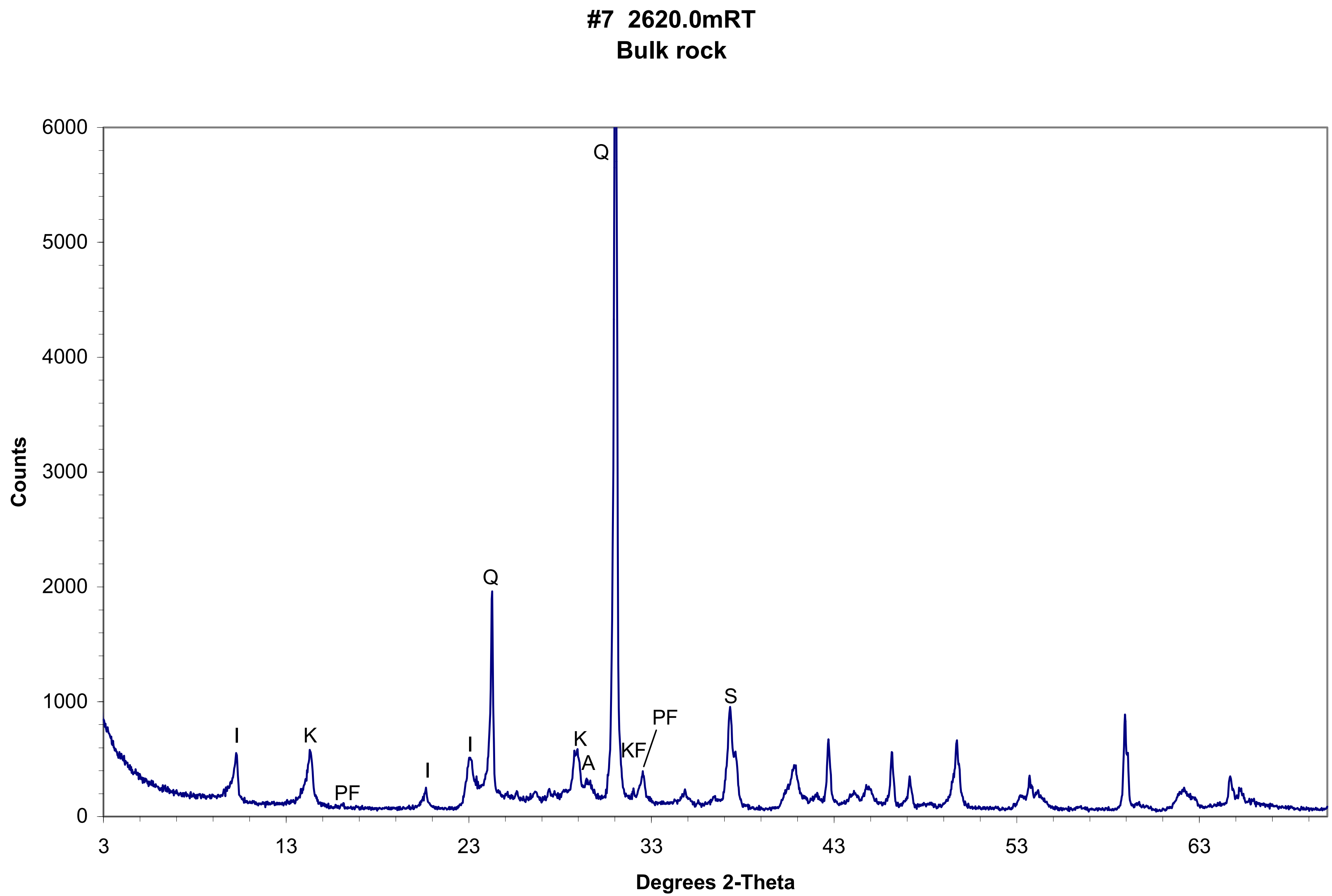
3
8
13
18
23
28
33
38
GLYCOLATED
AIR DRIED
I
K
I
Q
K
Q
KF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3000
4000
5000
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3
13
23
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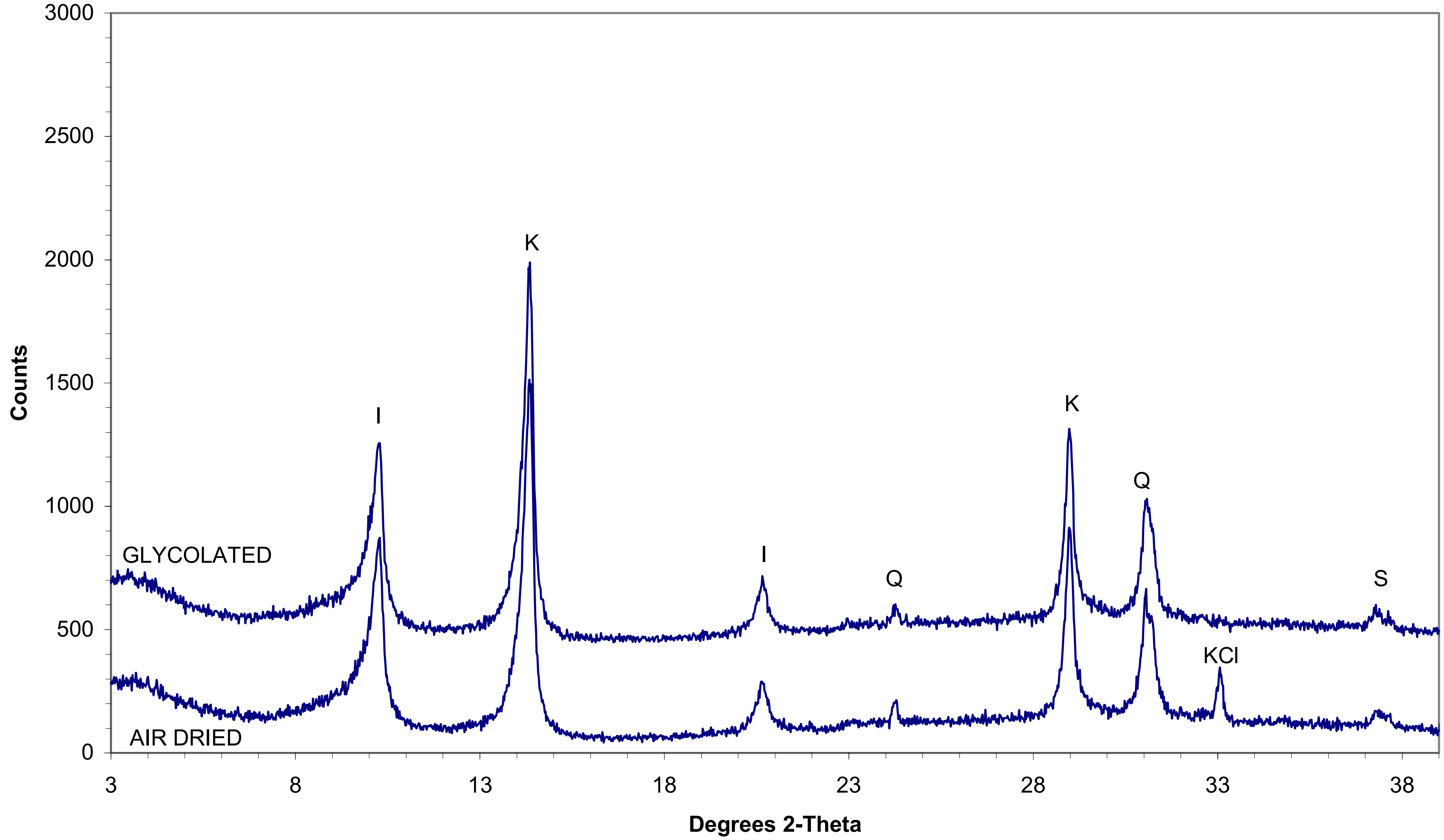
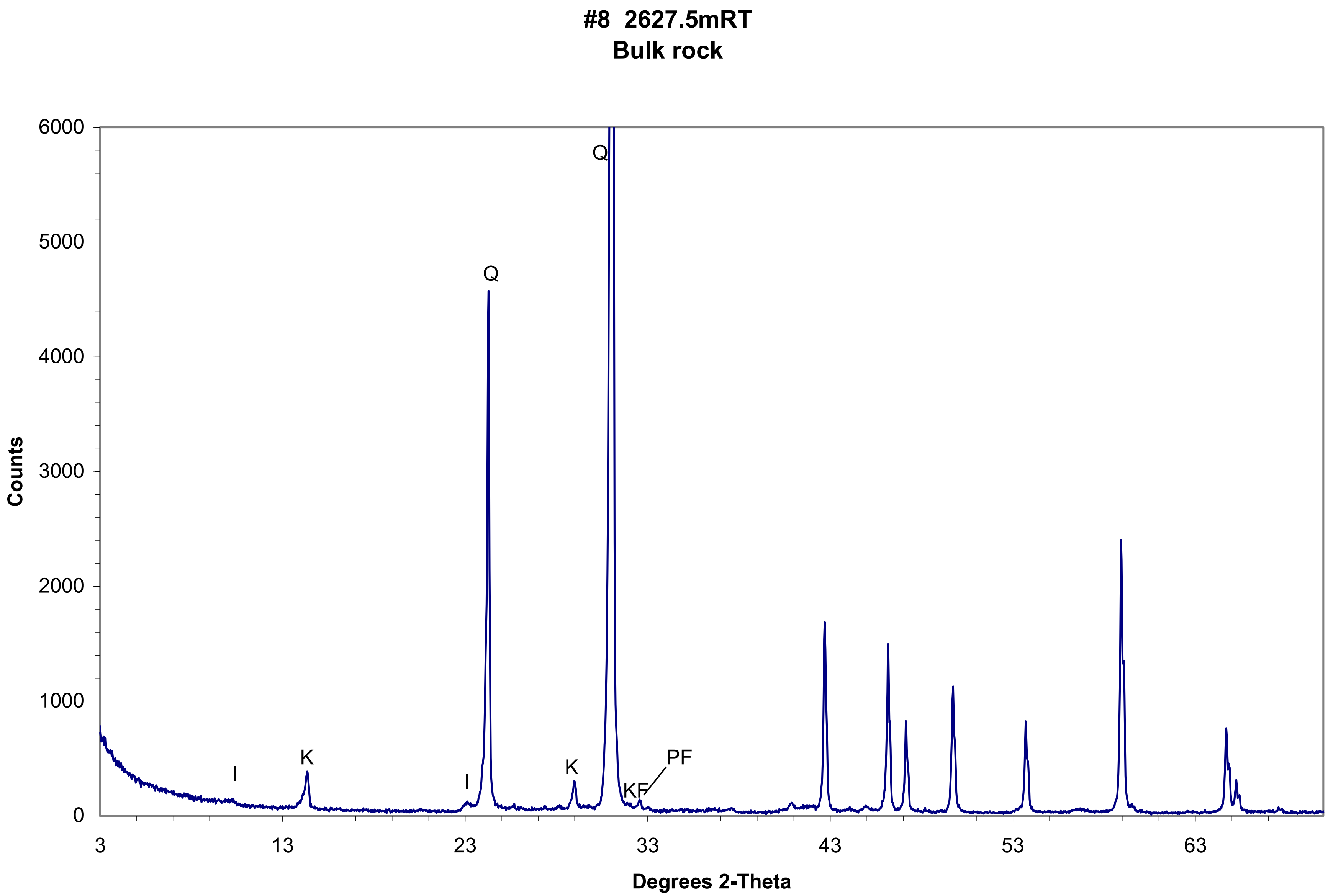
43
53
63
Q
Q
I
K
PF
I
I
K
A
KF
PF
S

#7 2620.0mRT
Fine fraction





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Counts
Degrees 2-Theta
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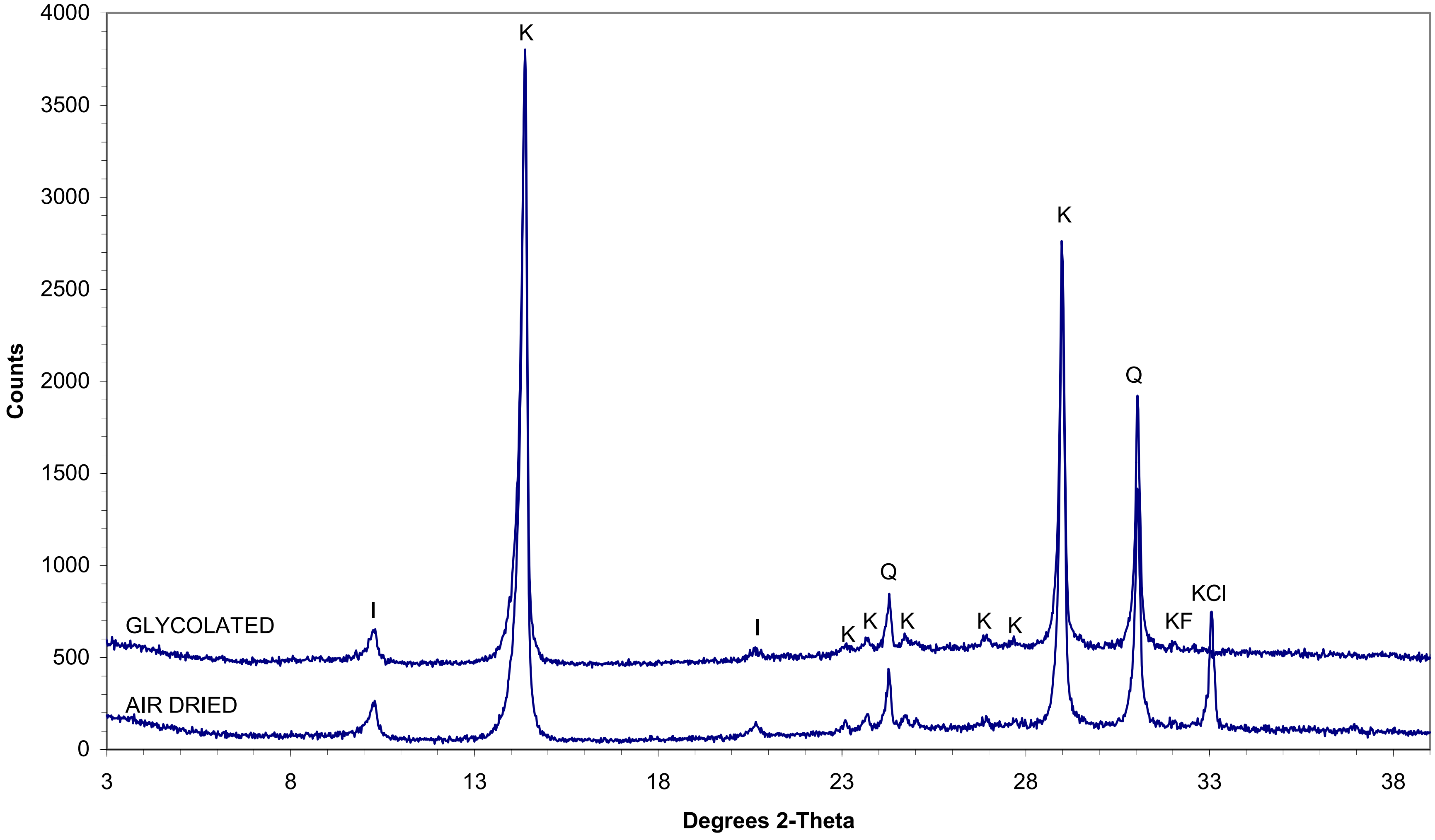
5000
4000
3000
2000
1000
0
3
13
23
33
43
53
63
Q
Q
I
K
I
K
KF
PF

#8 2627.5mRT
Fine fraction



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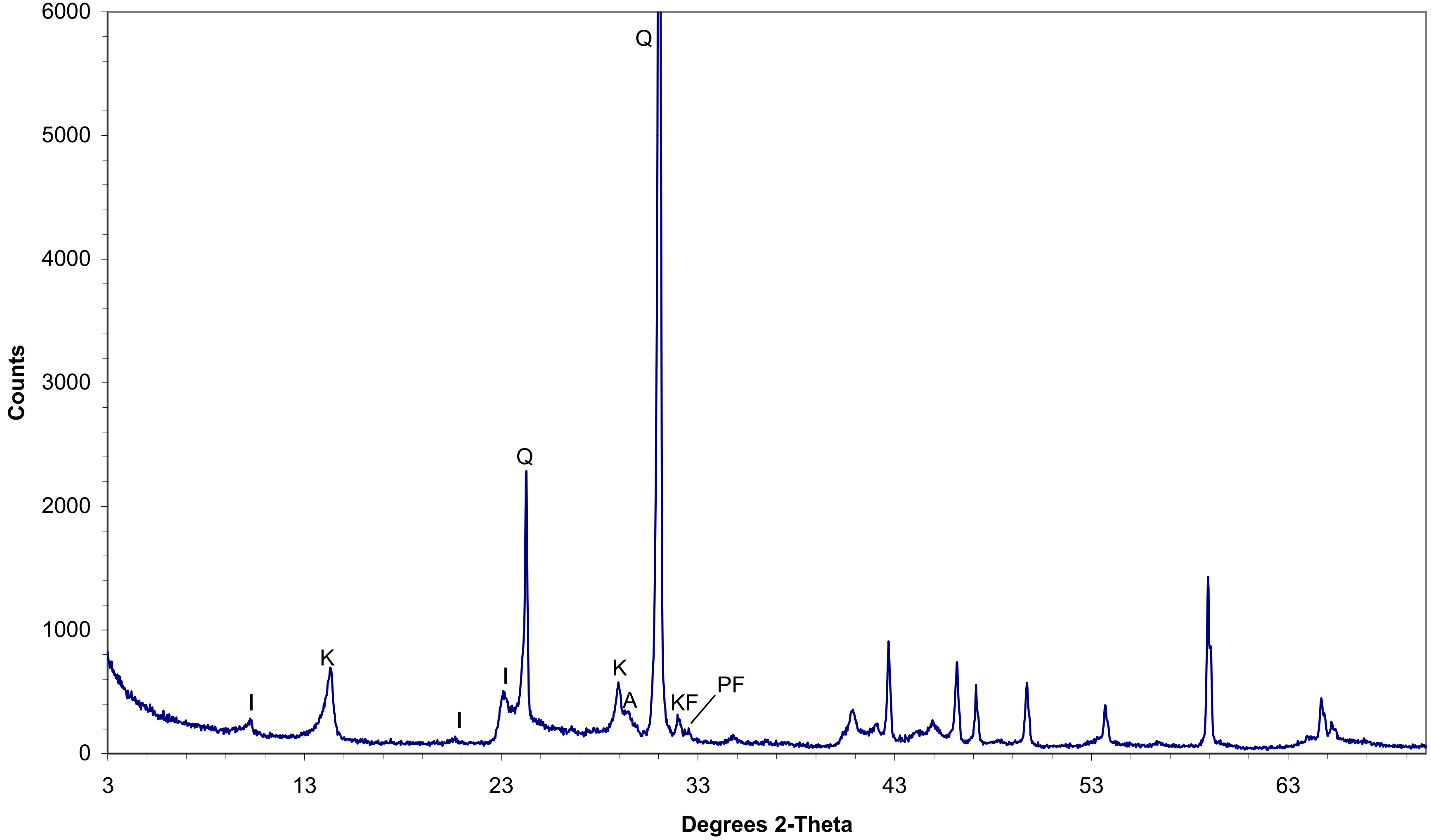
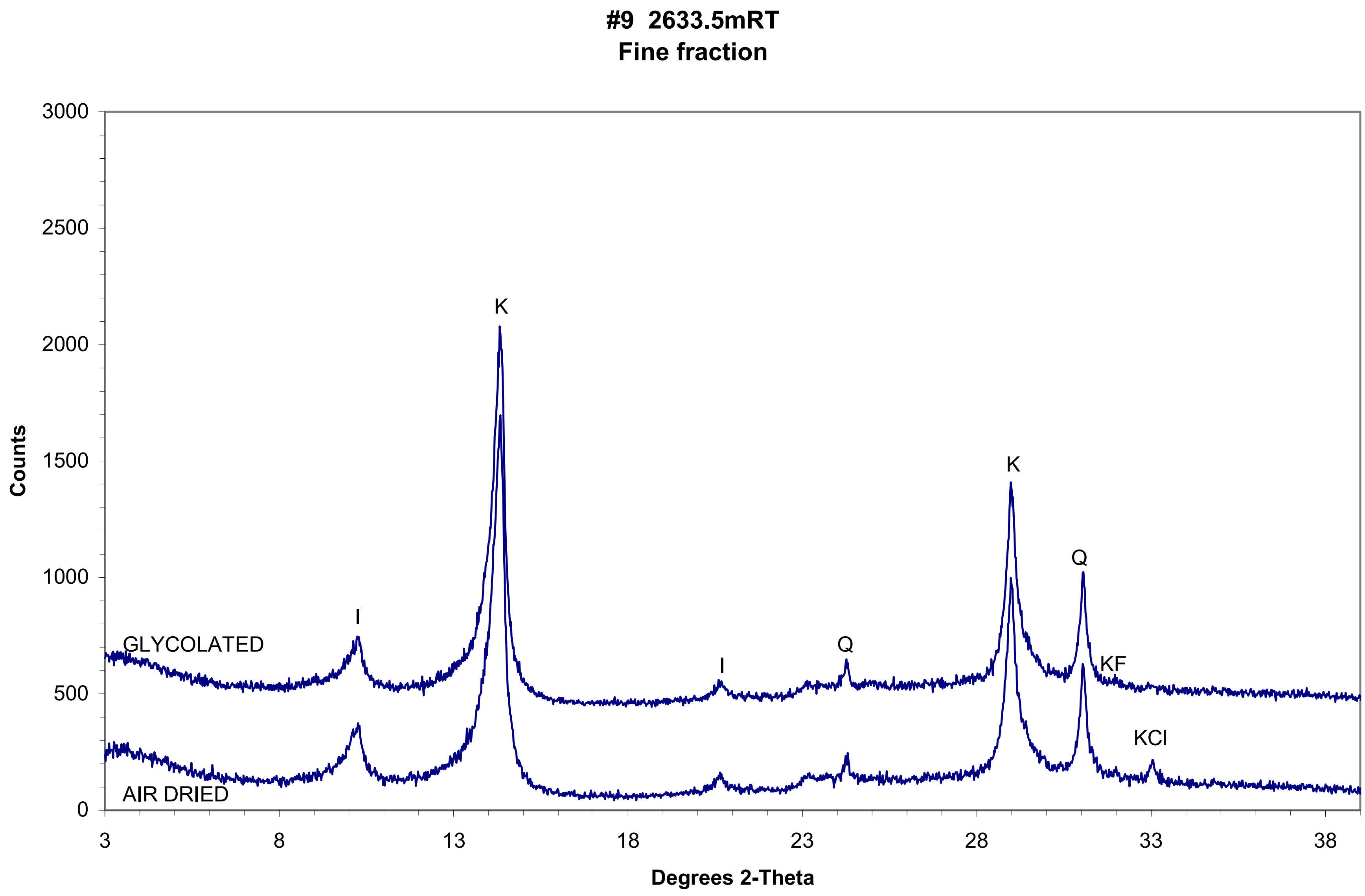
Bulk rock

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1500
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500
0
3
8
13
18
23
28
33
38
Degrees 2-Theta
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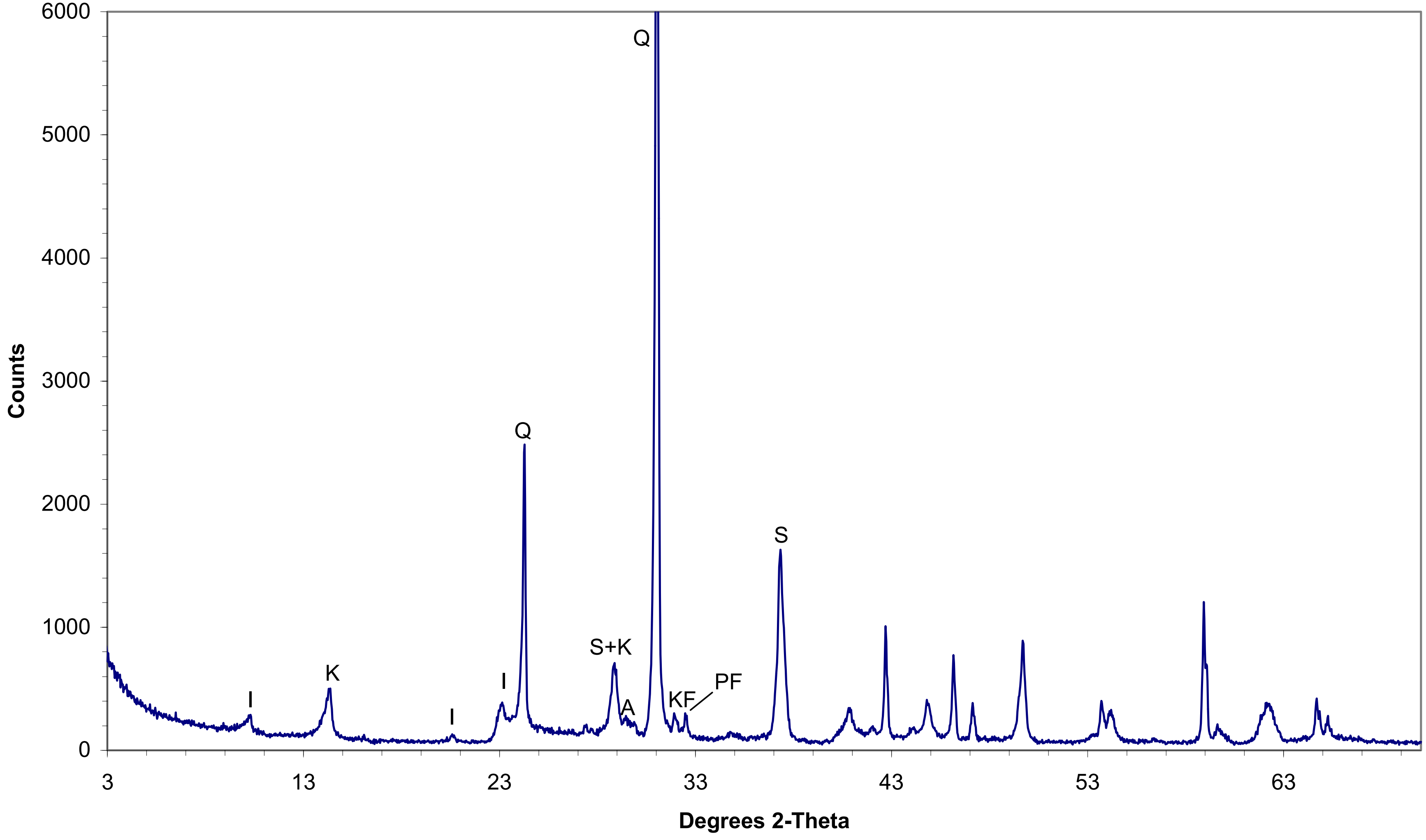
AIR DRIED
I
K
I
Q
K
Q
KF
KCl

#11 2644.0mRT
Bulk rock



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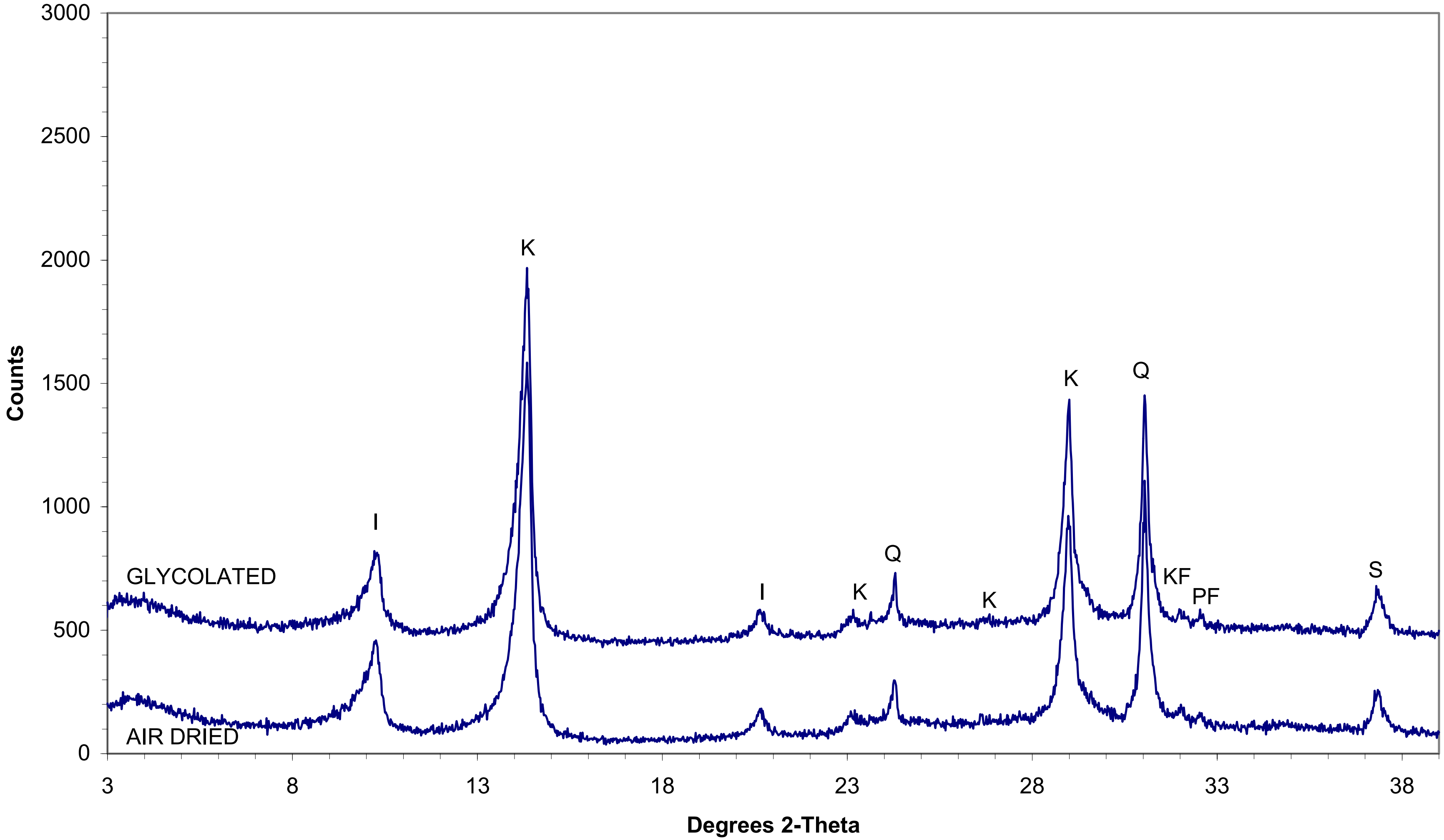
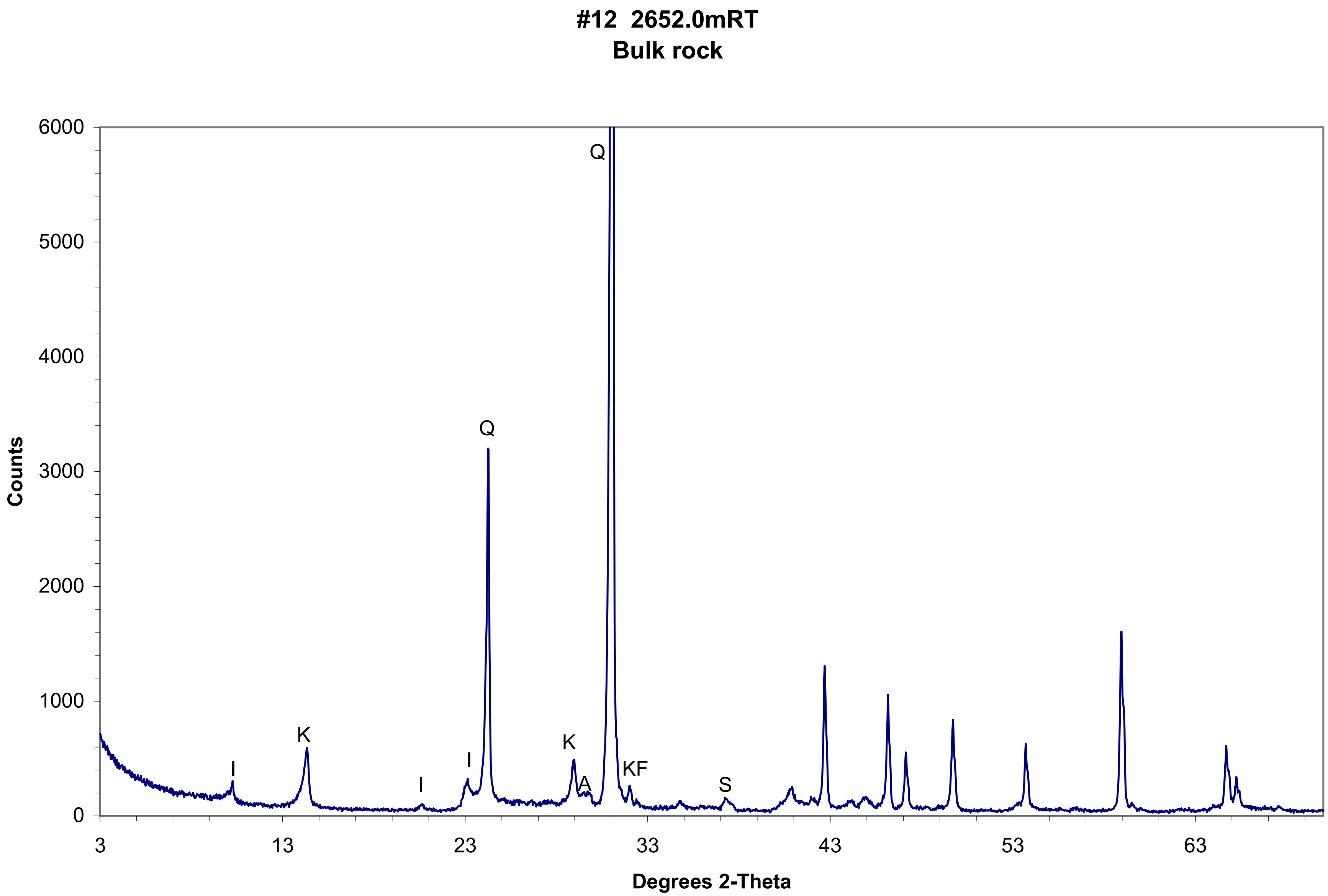
Fine fraction

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Degrees 2-Theta
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23
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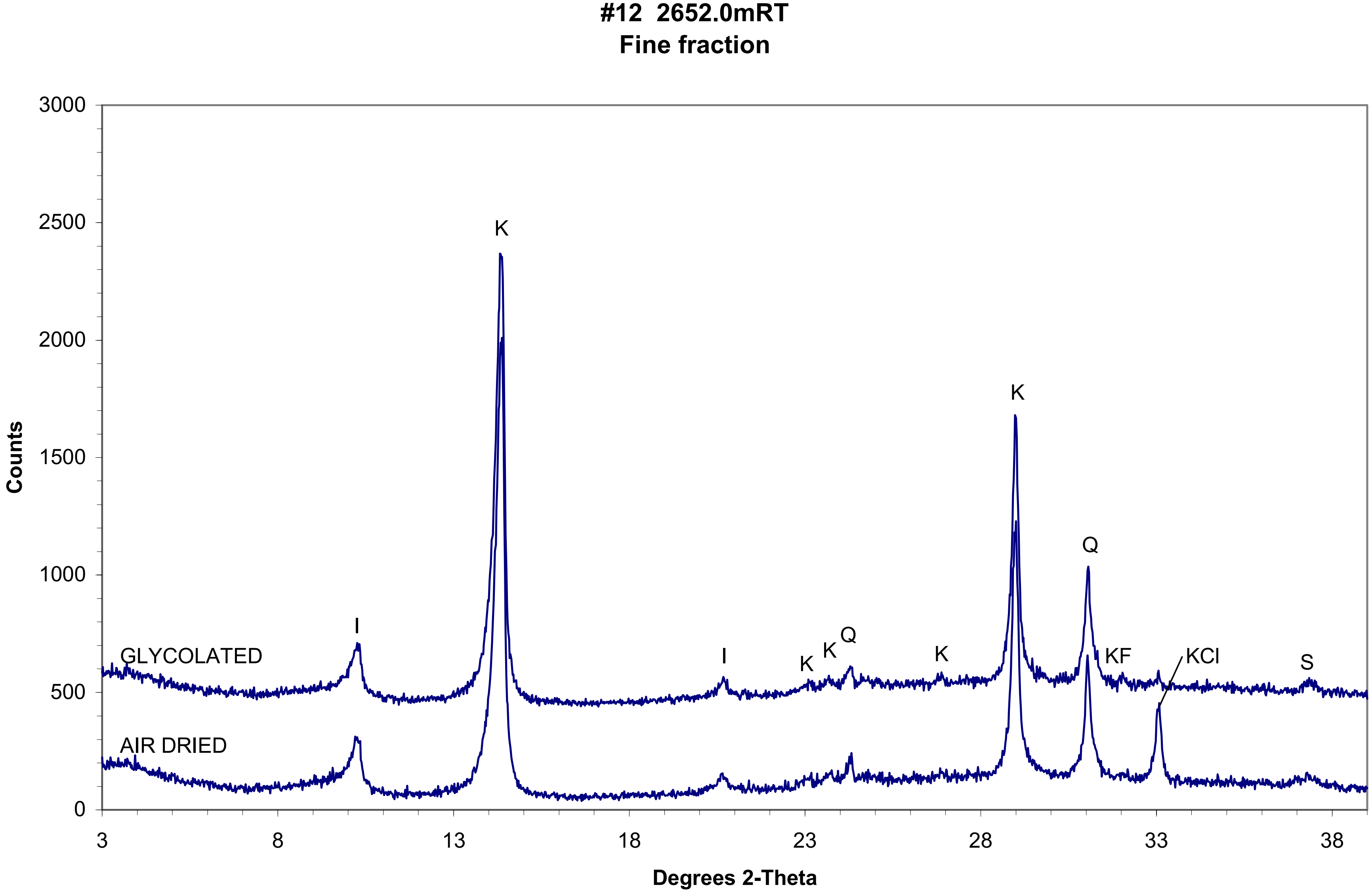
43
53
63
I
K
I
I
Q
K
A
KF
Q
S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1500
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3
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18
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28
33
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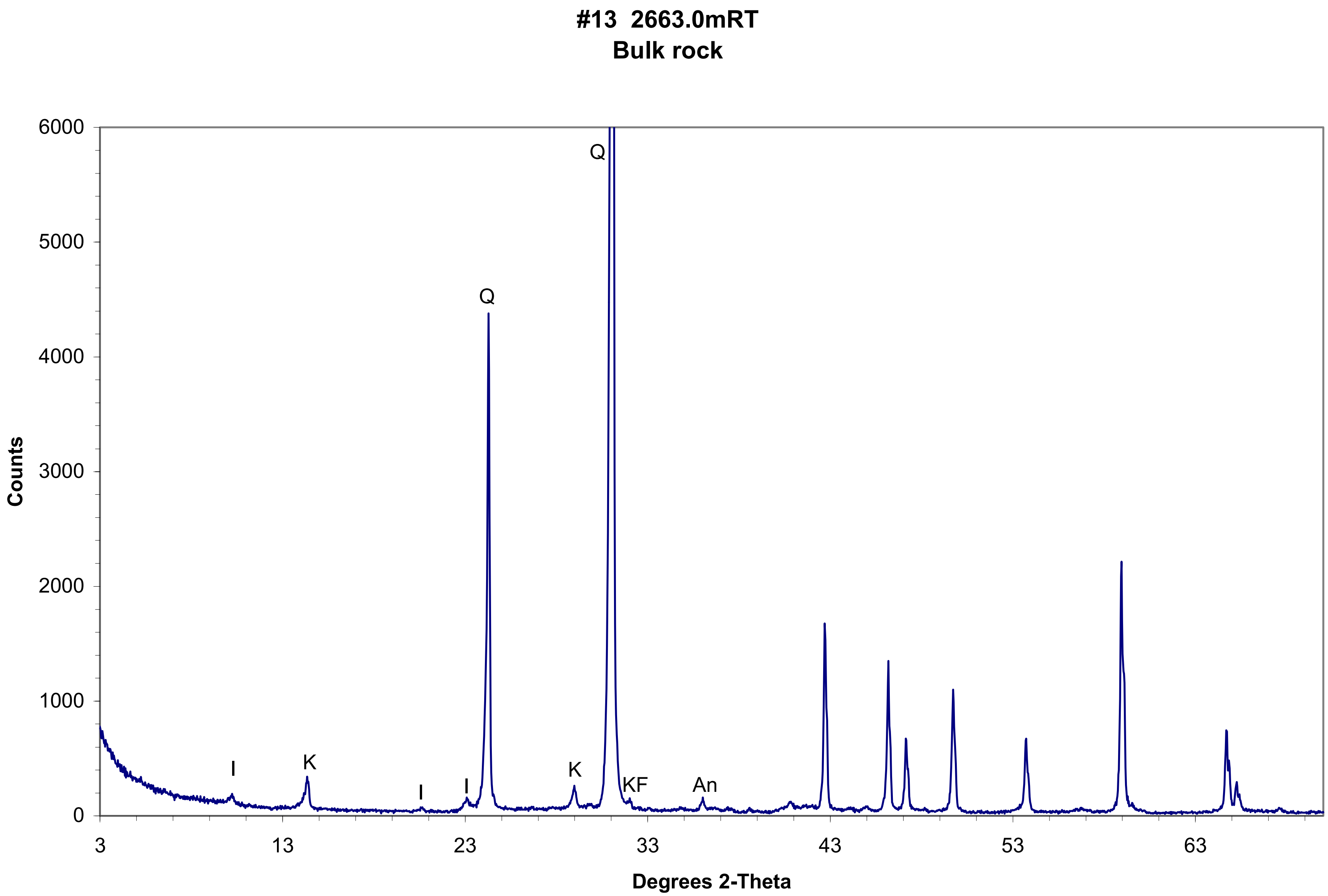
Degrees 2-Theta
GLYCOLATED
AIR DRIED
K
I
I
K
K
Q
K
K
Q
KF
KCl
S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Bulk rock
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43
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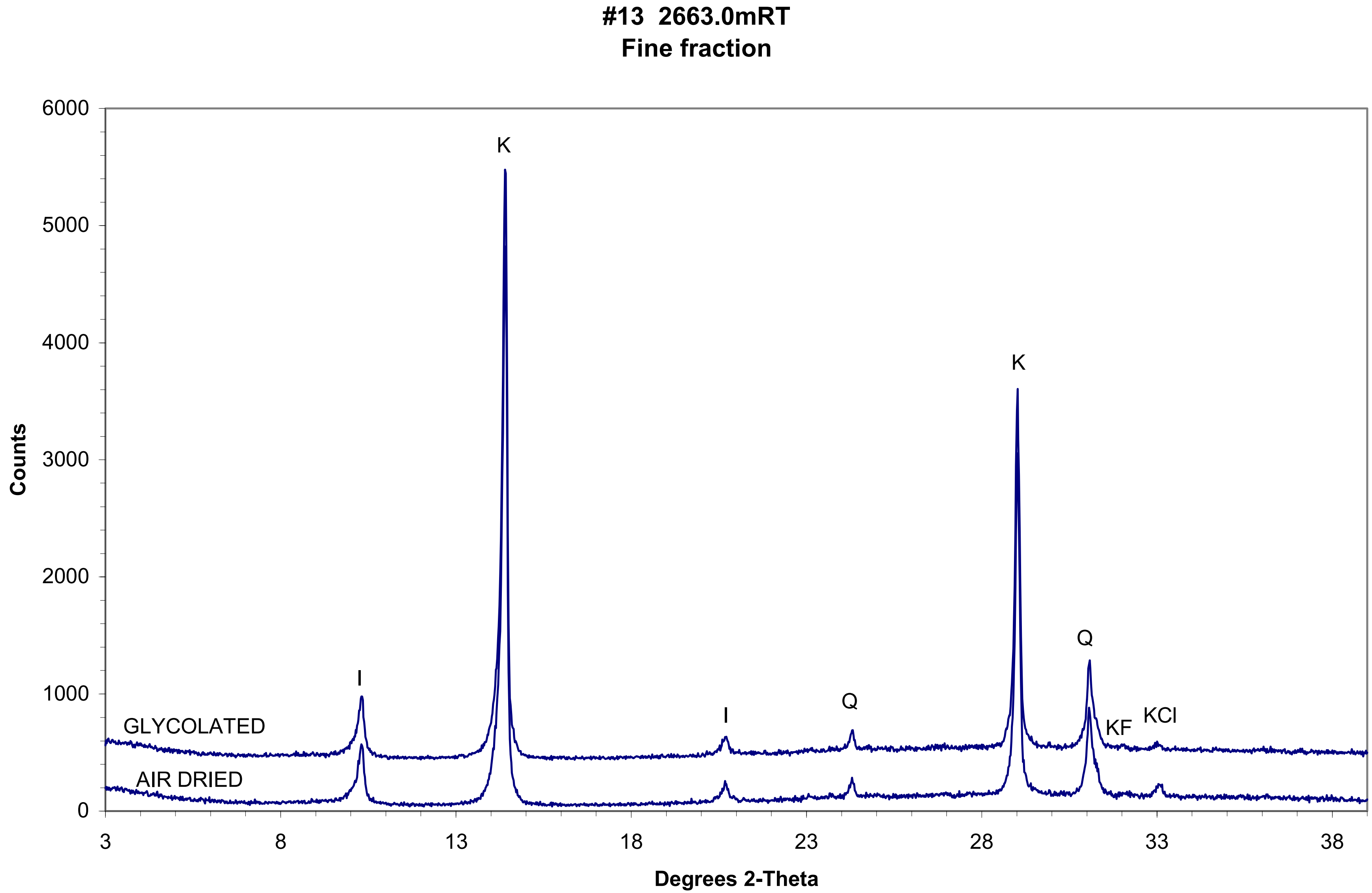
63
Degrees 2-Theta
Q
Q
I
K
I
I
K
KF
An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Degrees 2-Theta
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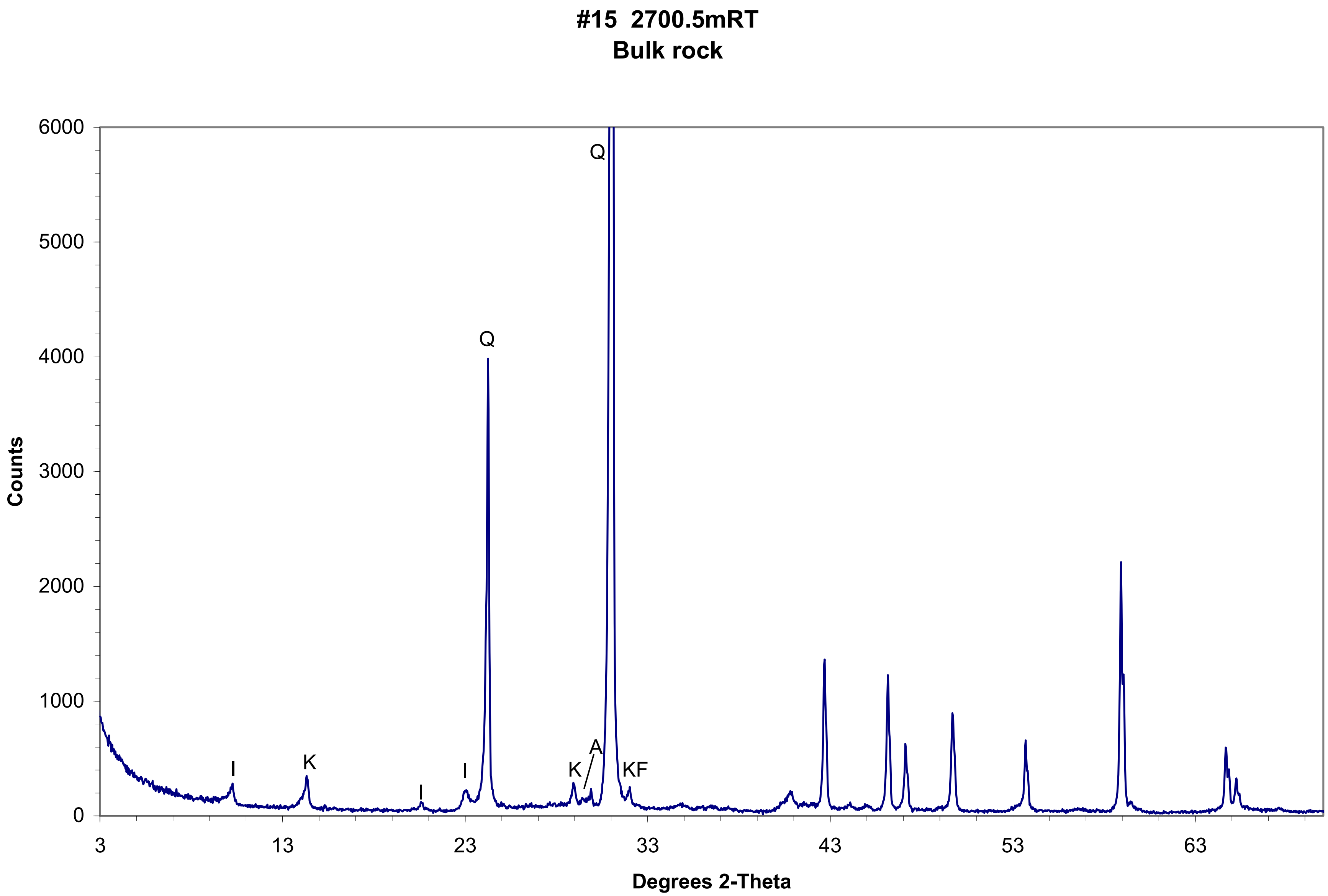
I
Q
Q
KF
KCl
GLYCOLATED
AIR DRIED



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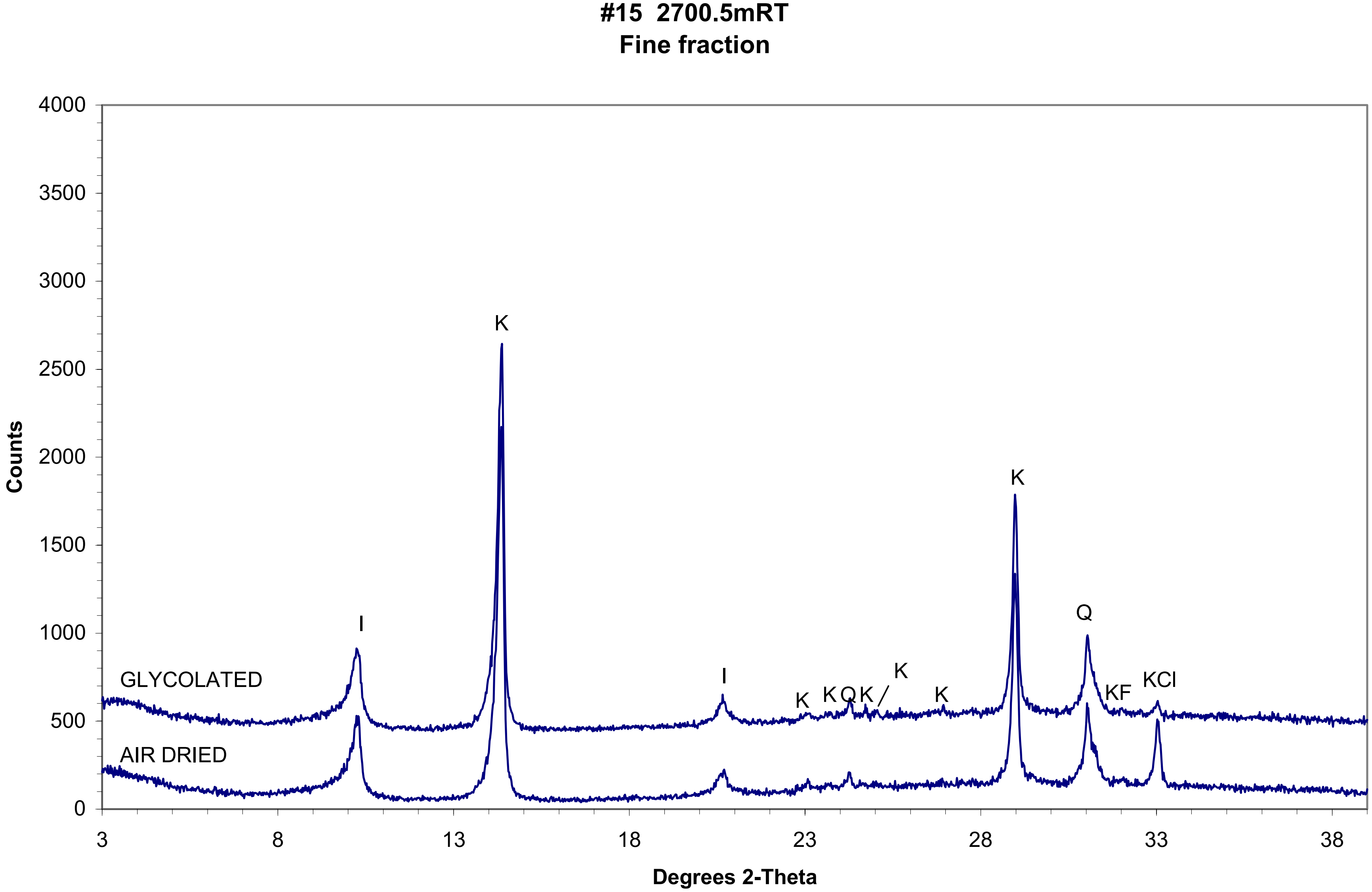
I
I
K
A
KF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Fine fraction
Counts
Degrees 2-Theta
GLYCOLATED
AIR DRIED
I
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I
K
K
Q
K
K
K
K
Q
KF
KCl
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1500
2000
2500
3000
3500
4000
3
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28
33
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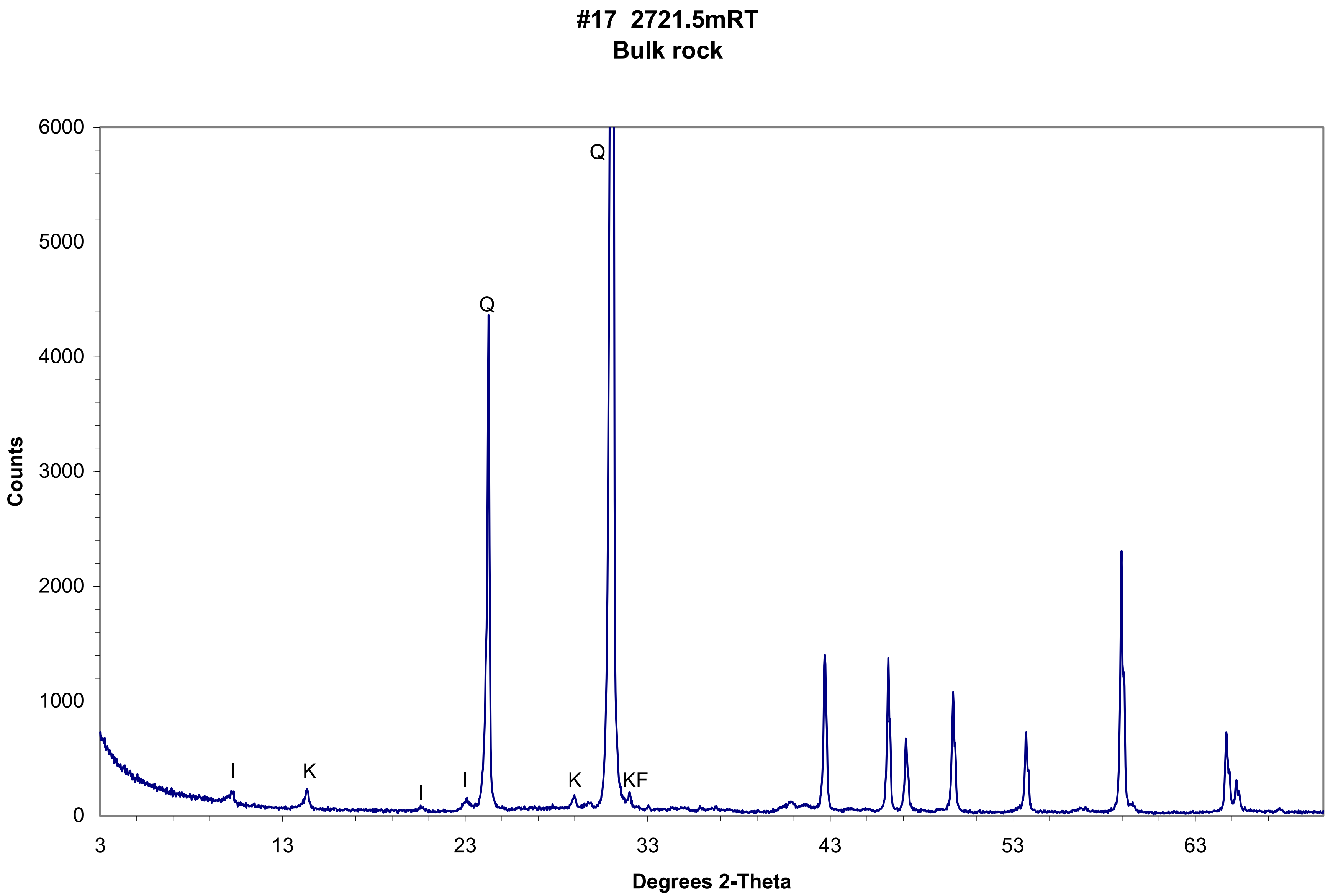
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Degrees 2-Theta
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3000
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43
53
63
Q
Q
I
K
I
I
K
KF

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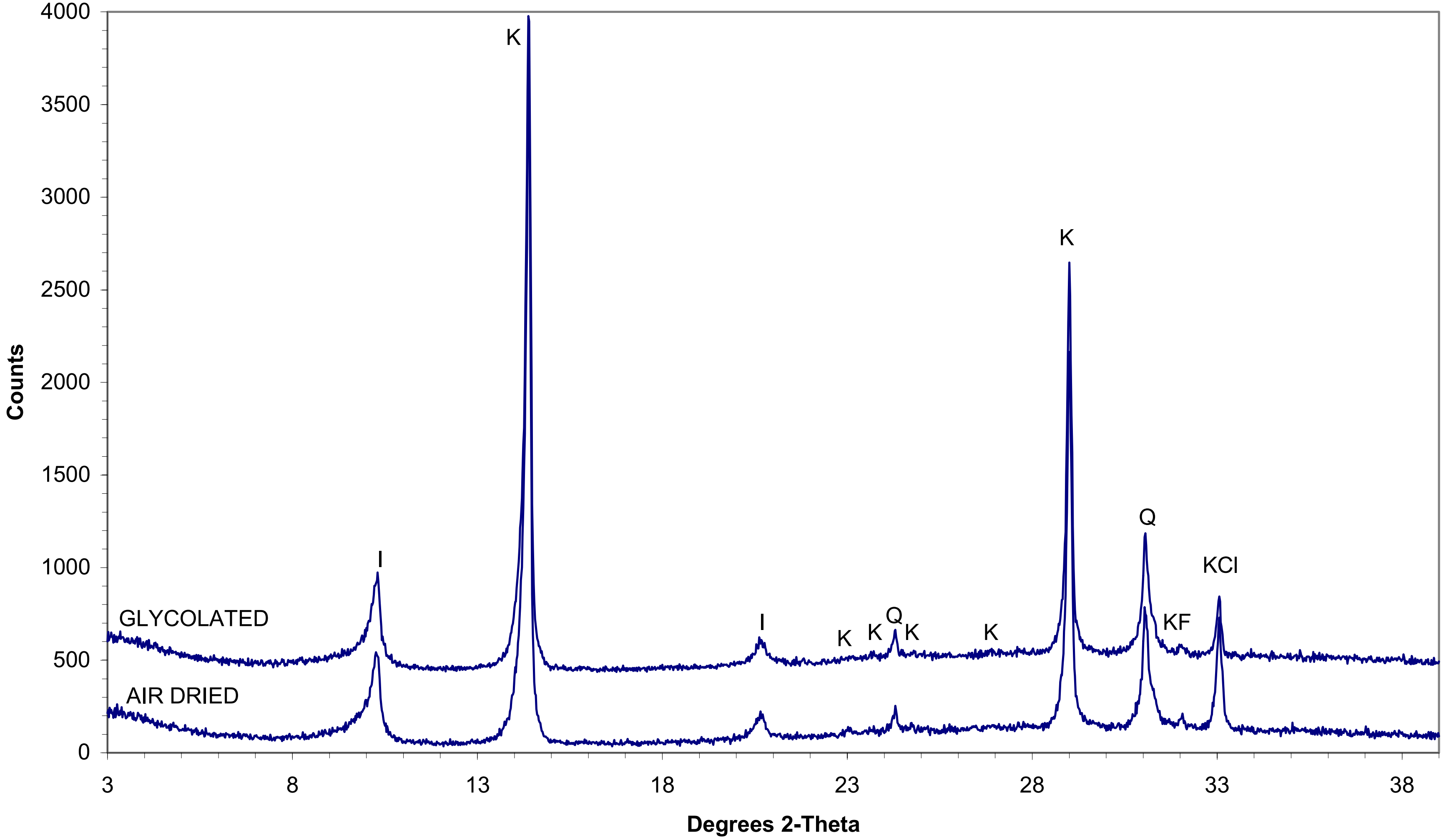
Fine fraction



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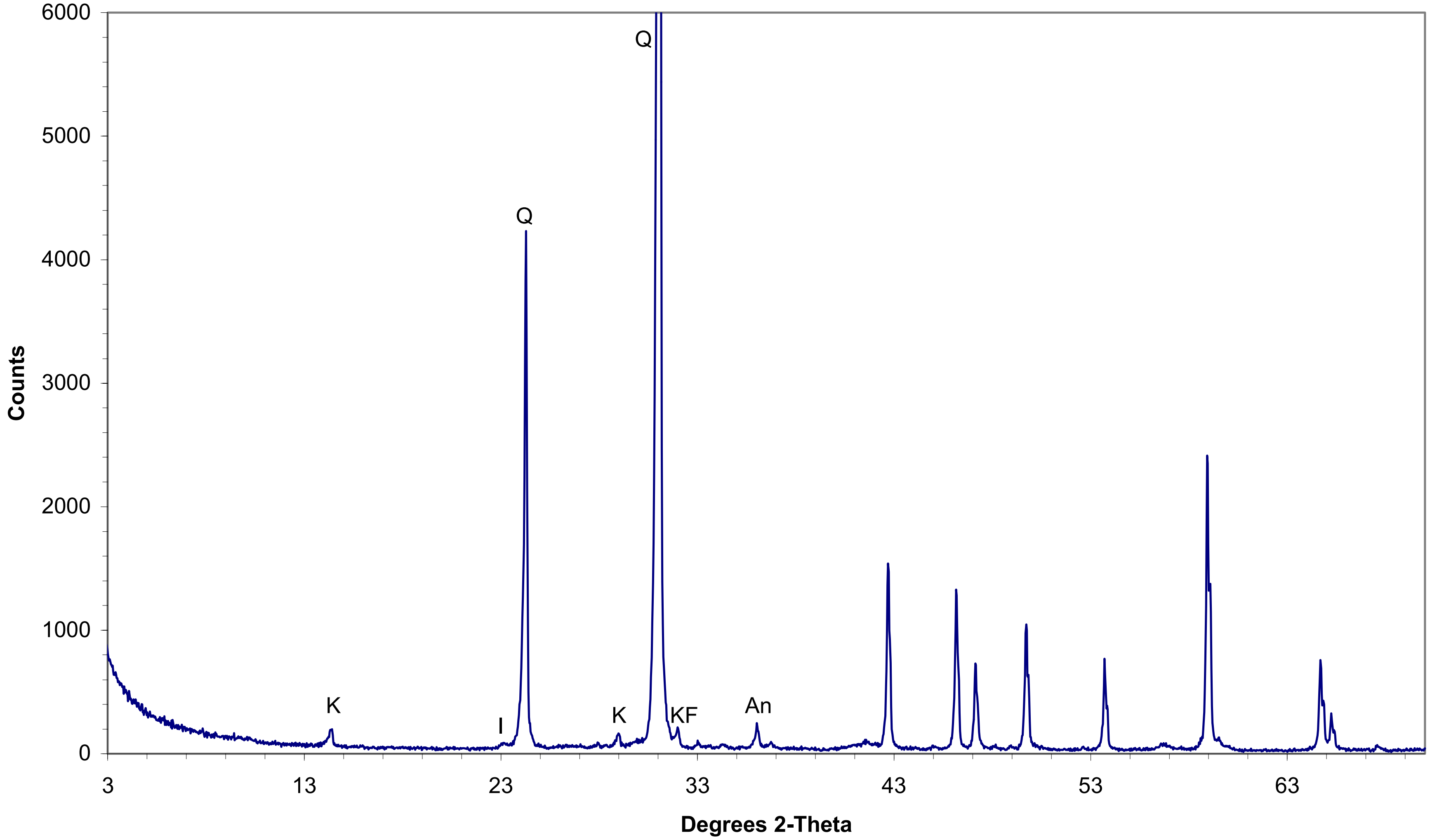
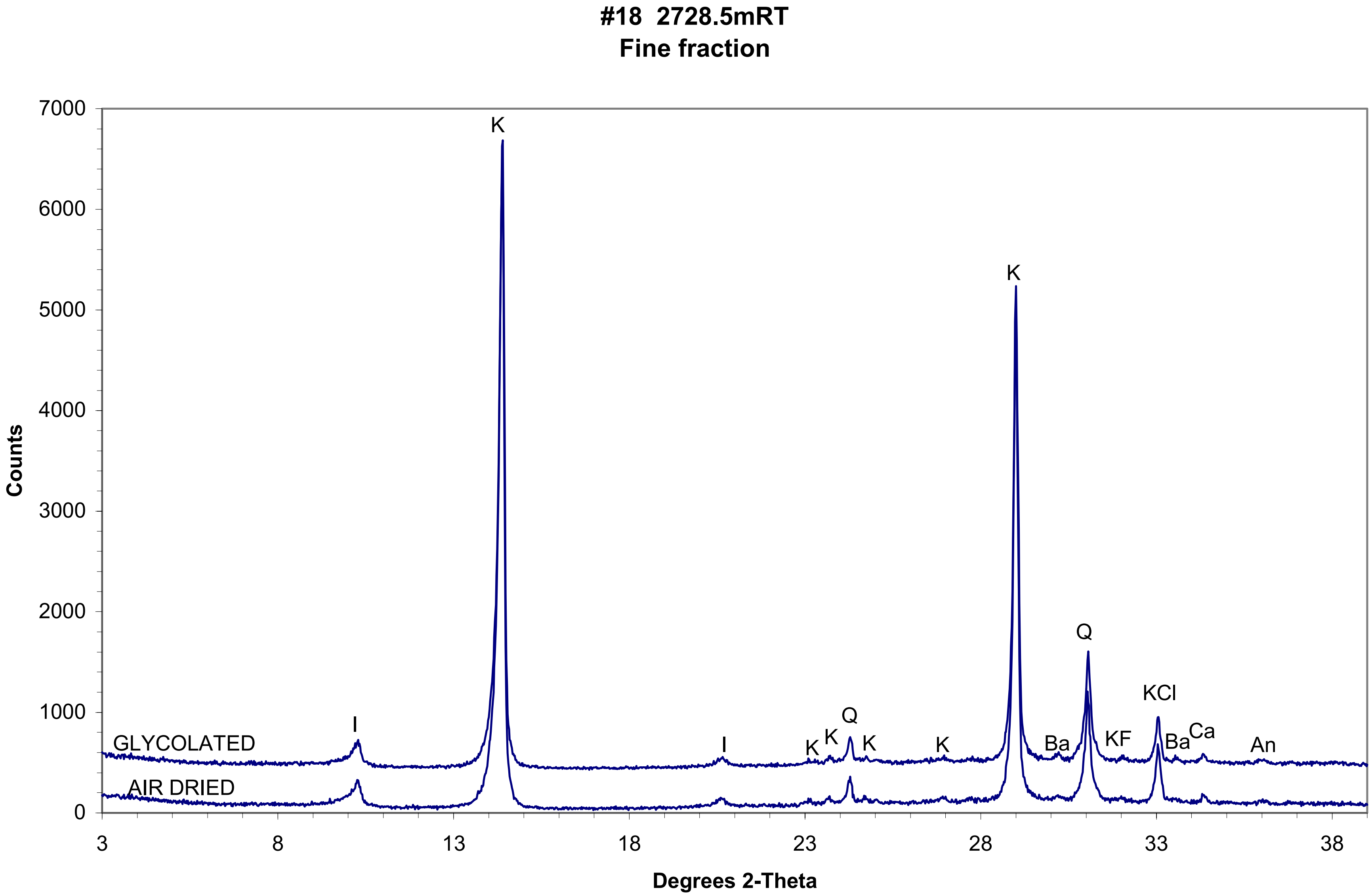
Bulk rock





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Degrees 2-Theta
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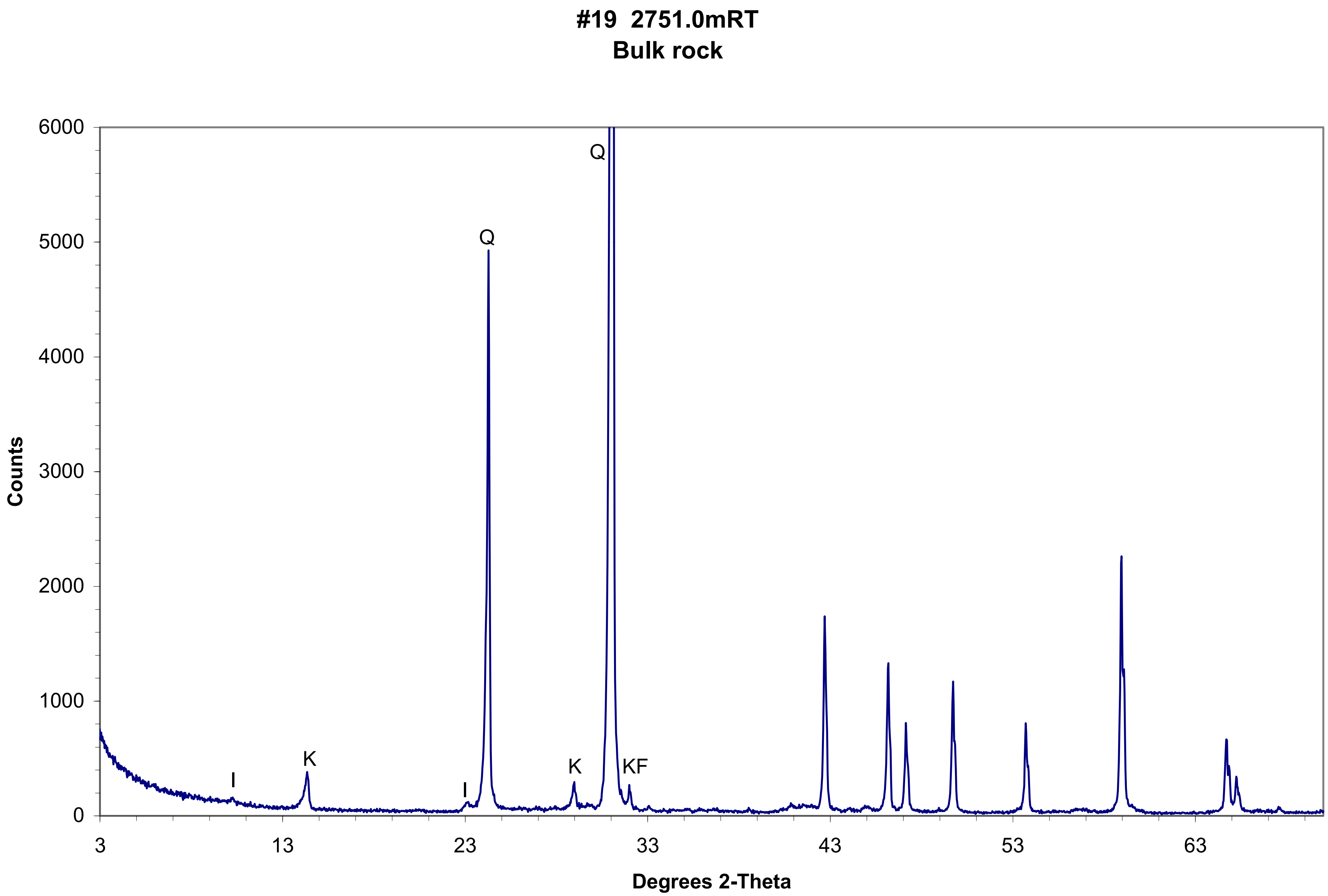
7000
3
8
13
18
23
28
33
38
GLYCOLATED
AIR DRIED
K
K
I
I
K
K
Q
K
K
Q
Ba
KF
KCl
Ba
Ca
An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3
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23
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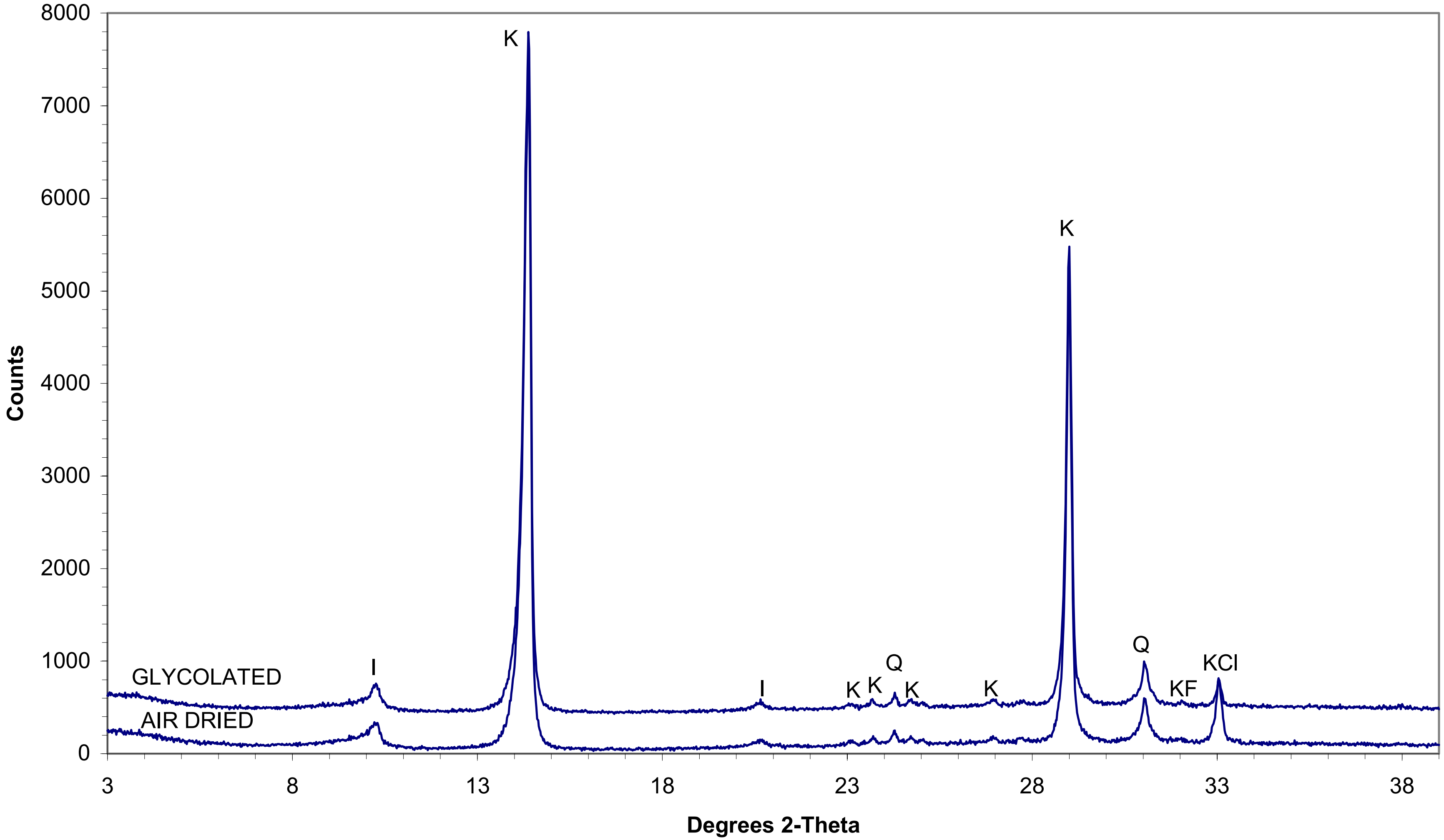
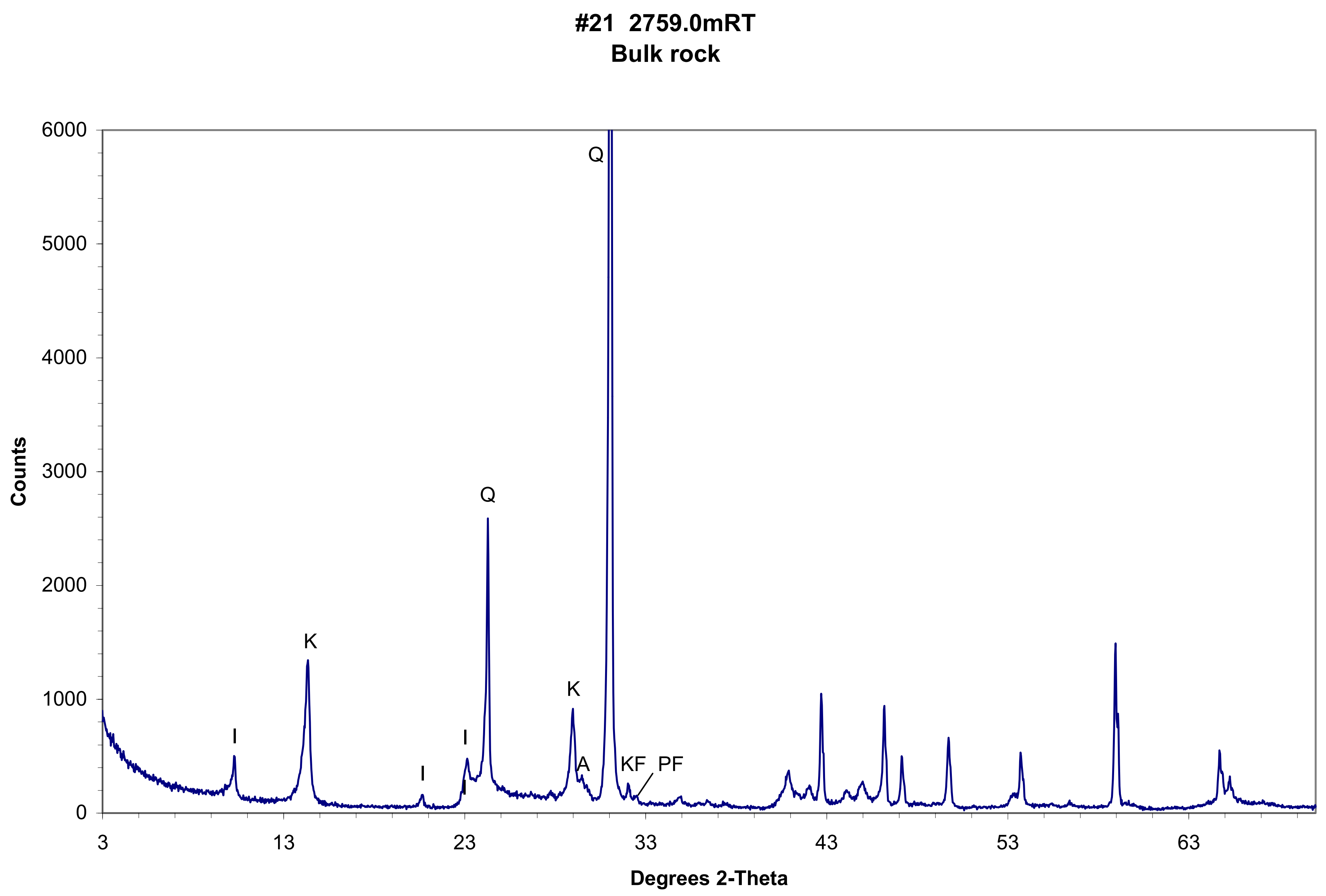
63
Degrees 2-Theta
Q
Q
K
K
KF
I
I

#19 2751.0mRT
Fine fraction

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Bulk rock
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Q
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K
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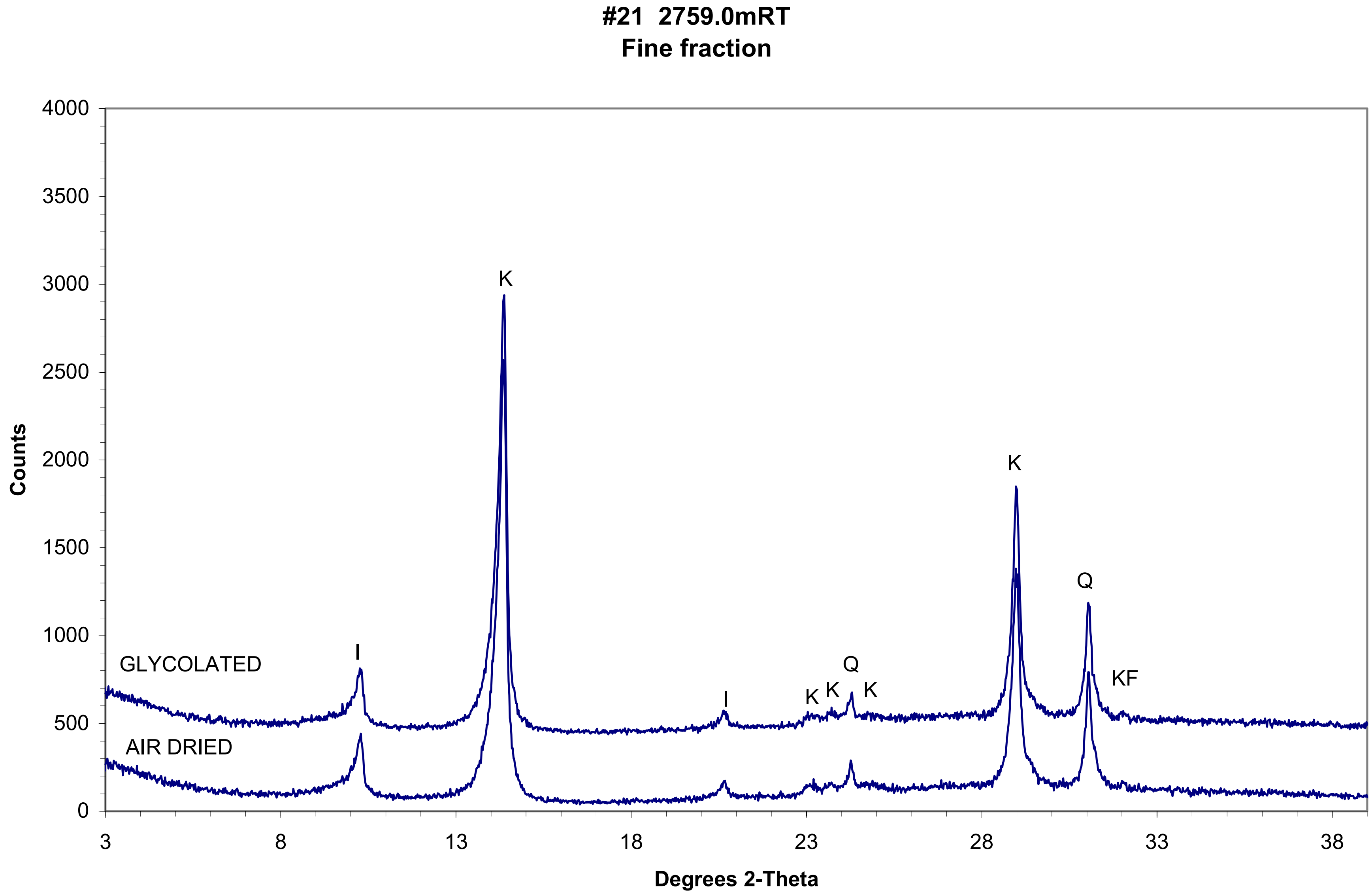
I
I
I
A
KF
PF
3
13
23
33
43
53
63
Degrees 2-Theta



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Fine fraction
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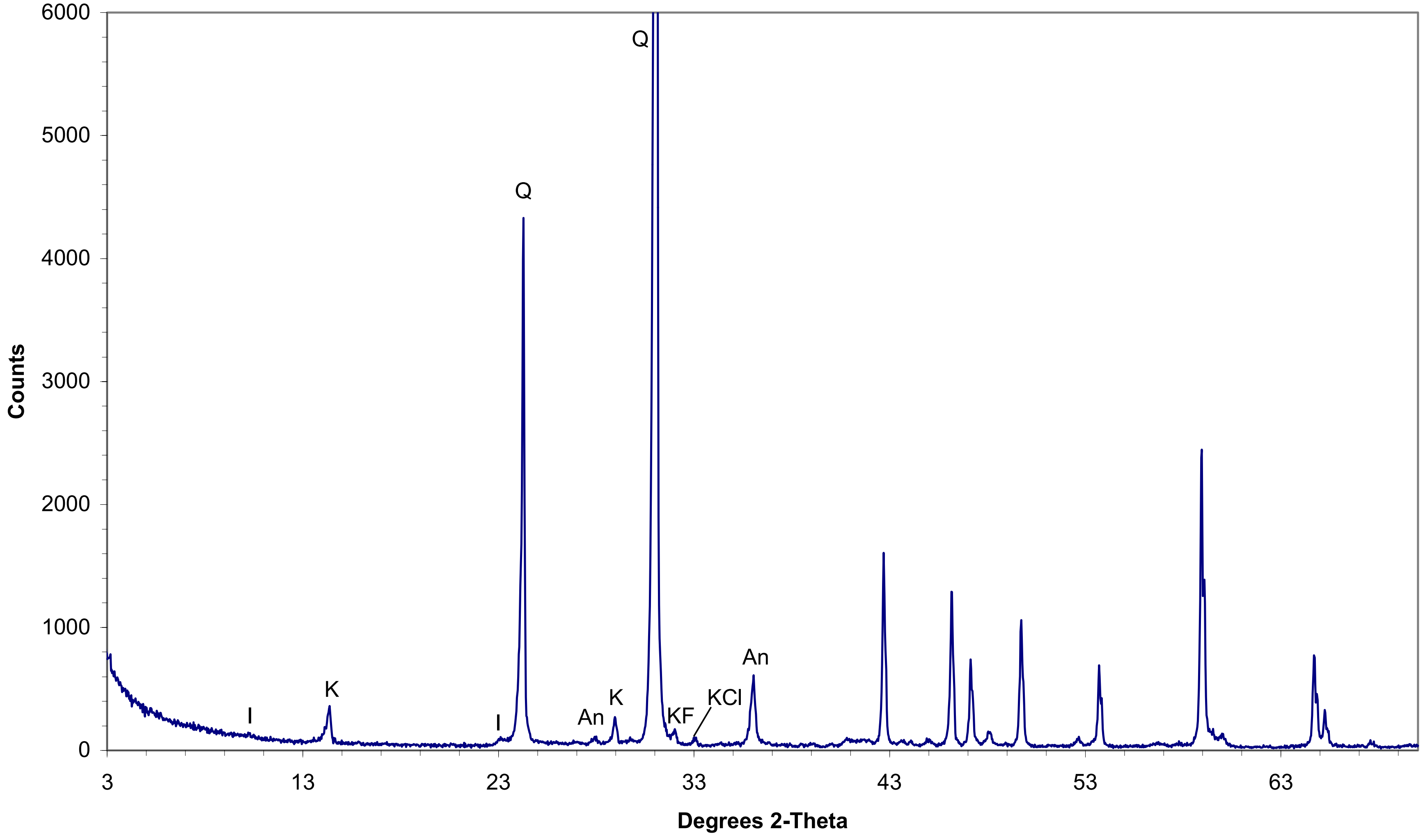
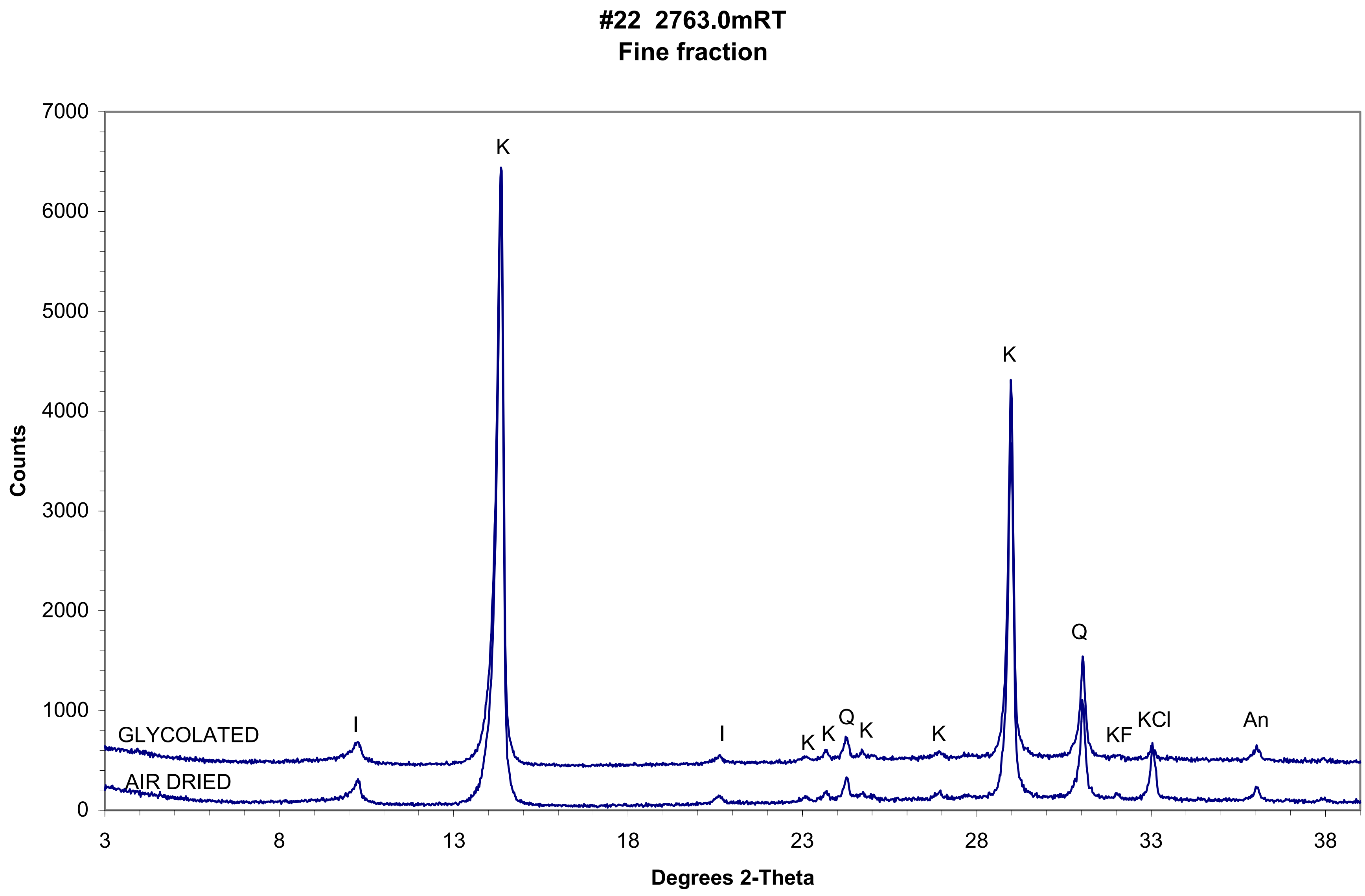
1000
500
0
3
8
13
18
23
28
33
38
GLYCOLATED
AIR DRIED
I
K
I
K
K
Q
K
K
Q
KF

#22 2763.0mRT
Bulk rock

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38
Degrees 2-Theta
GLYCOLATED
AIR DRIED
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K
Q
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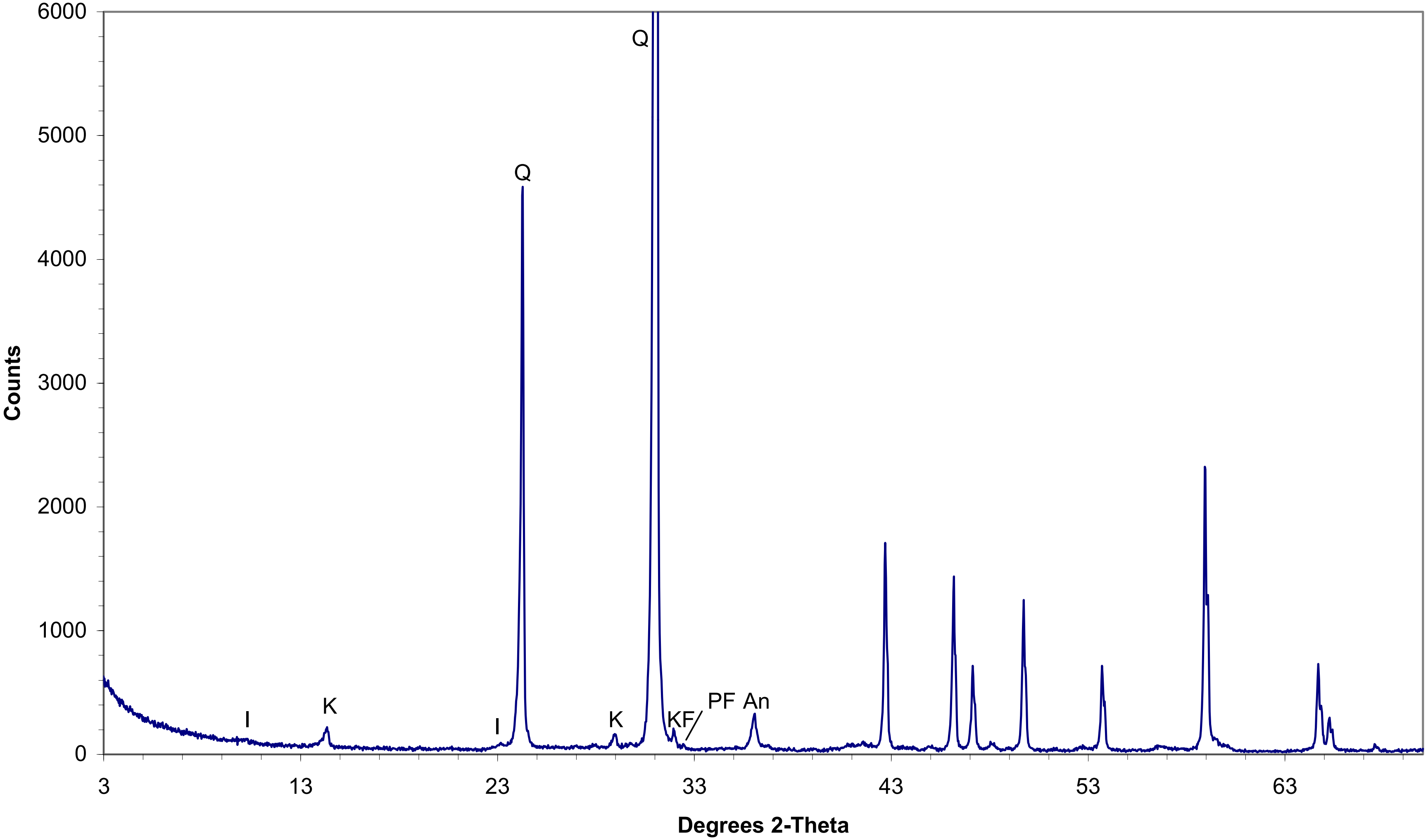
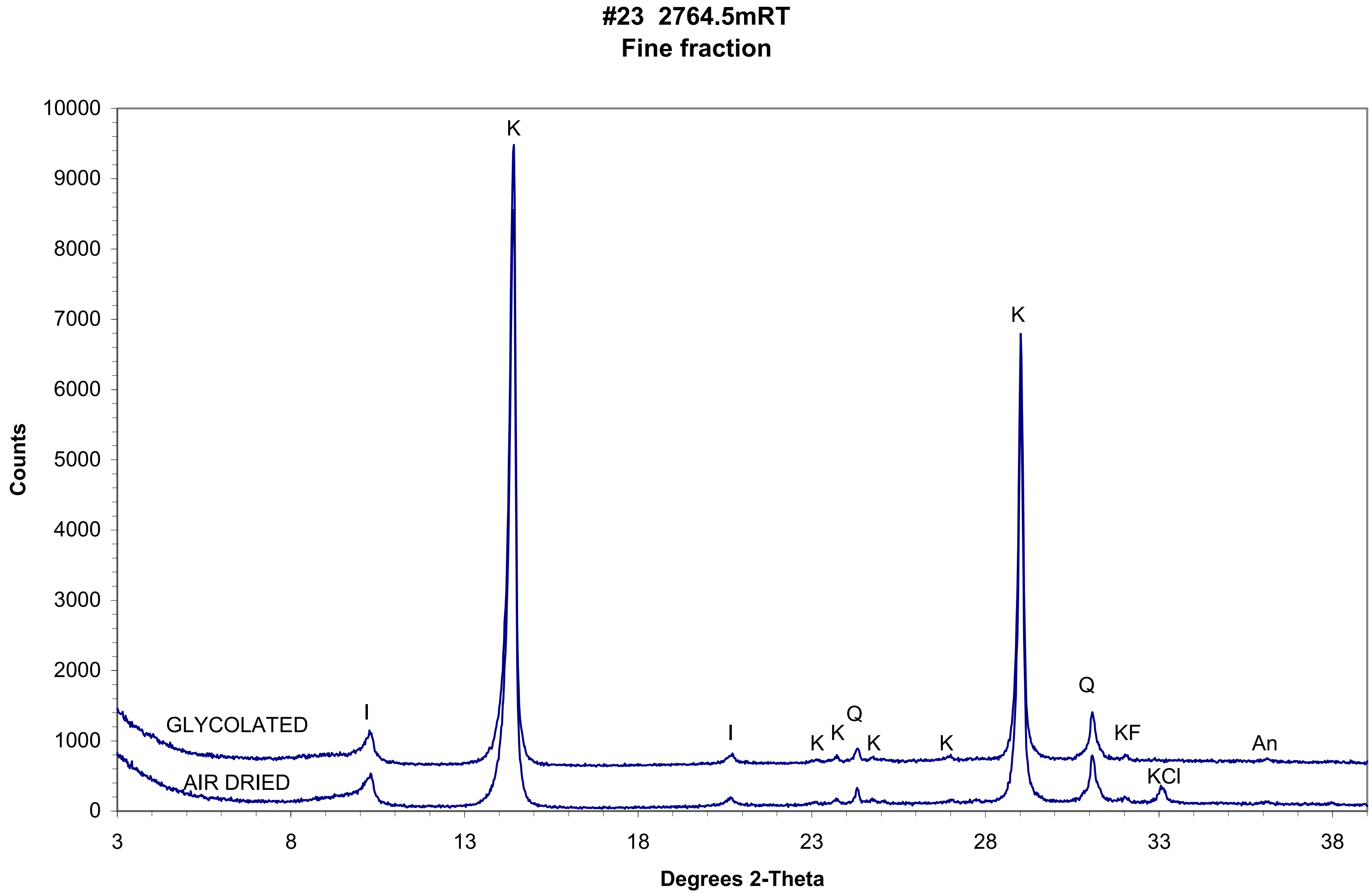
KF
KCl
An

#23 2764.5mRT
Bulk rock

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3
8
13
18
23
28
33
38
GLYCOLATED
AIR DRIED
I
K
I
K
K
Q
K
K
K
Q
KF
KCl
An

APPENDIX 5

PHOTOMICROGRAPHS

PLATE 1: #1 2450.0mRT

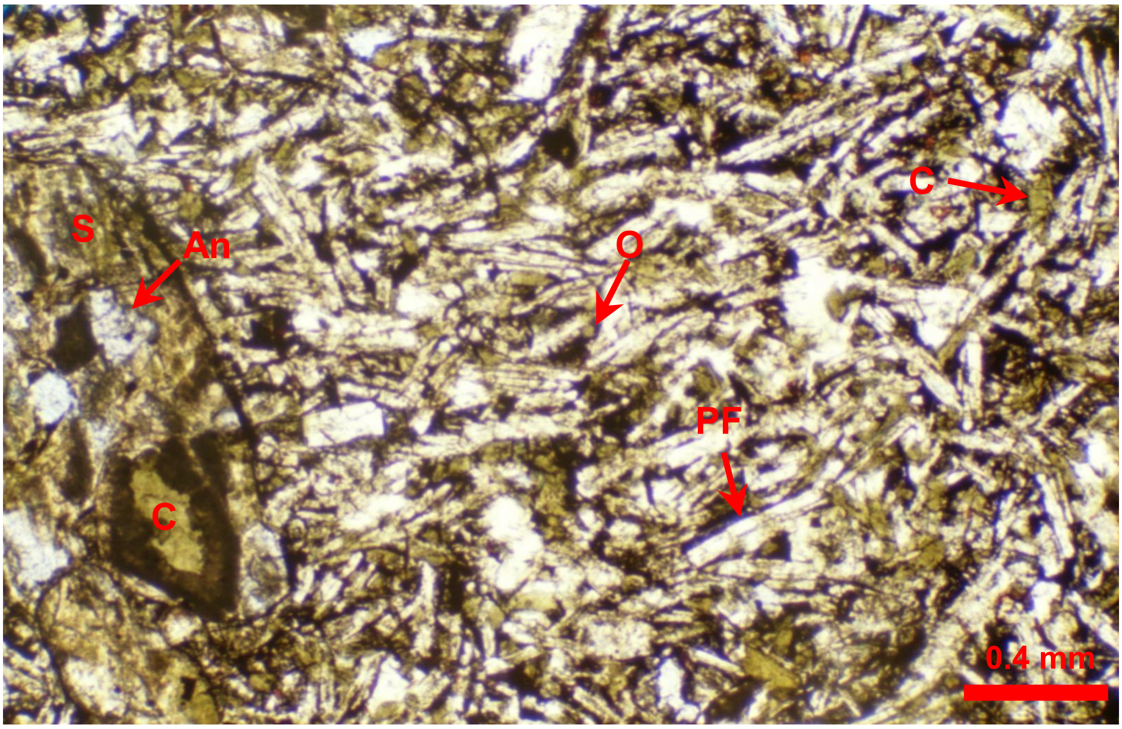
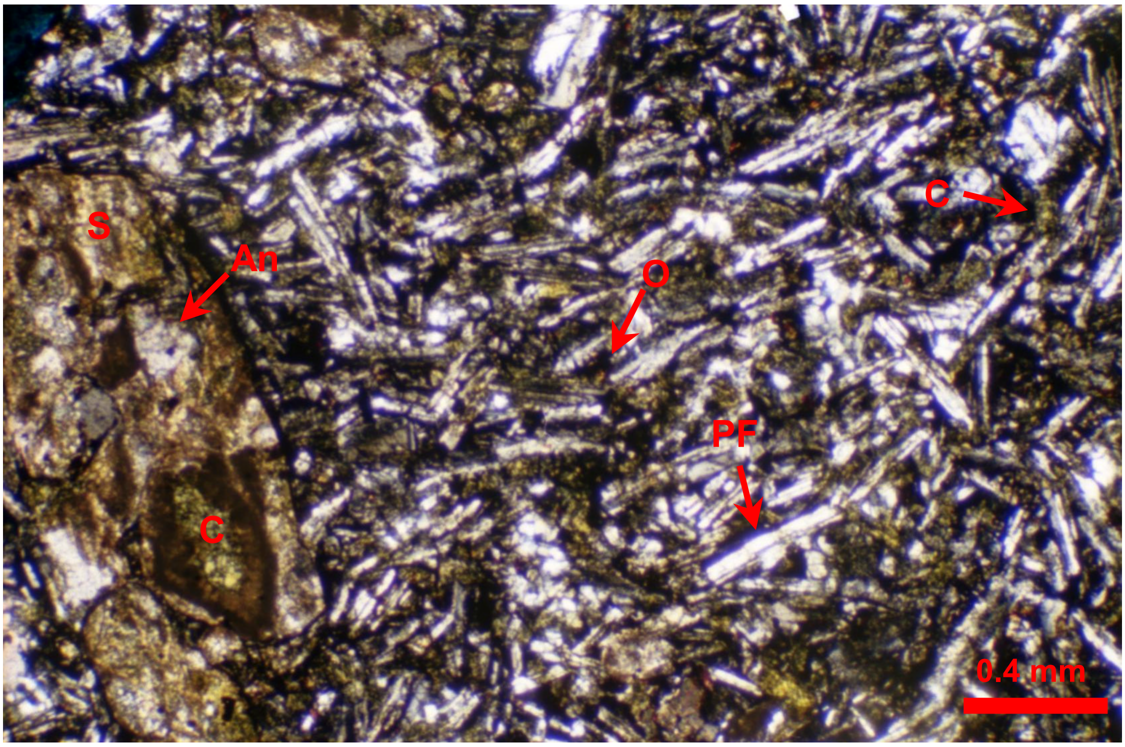


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Altered basaltic volcanic in which interstices between plagioclase laths (PF) are filled by secondary chlorite (C) and opaque oxides (O). A ?pyroxene phenocryst is totally replaced by siderite (S), ankerite (An) (stained faint blue) and chlorite.

PLATE 2: #1 2450.0mRT cont.

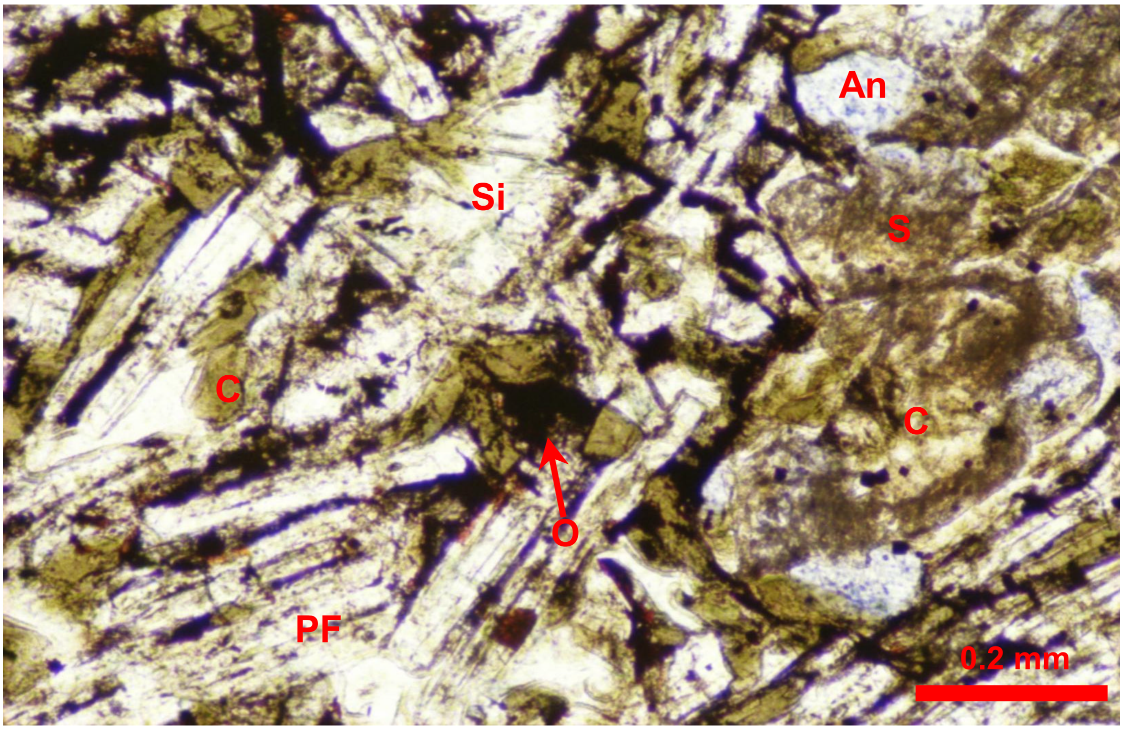
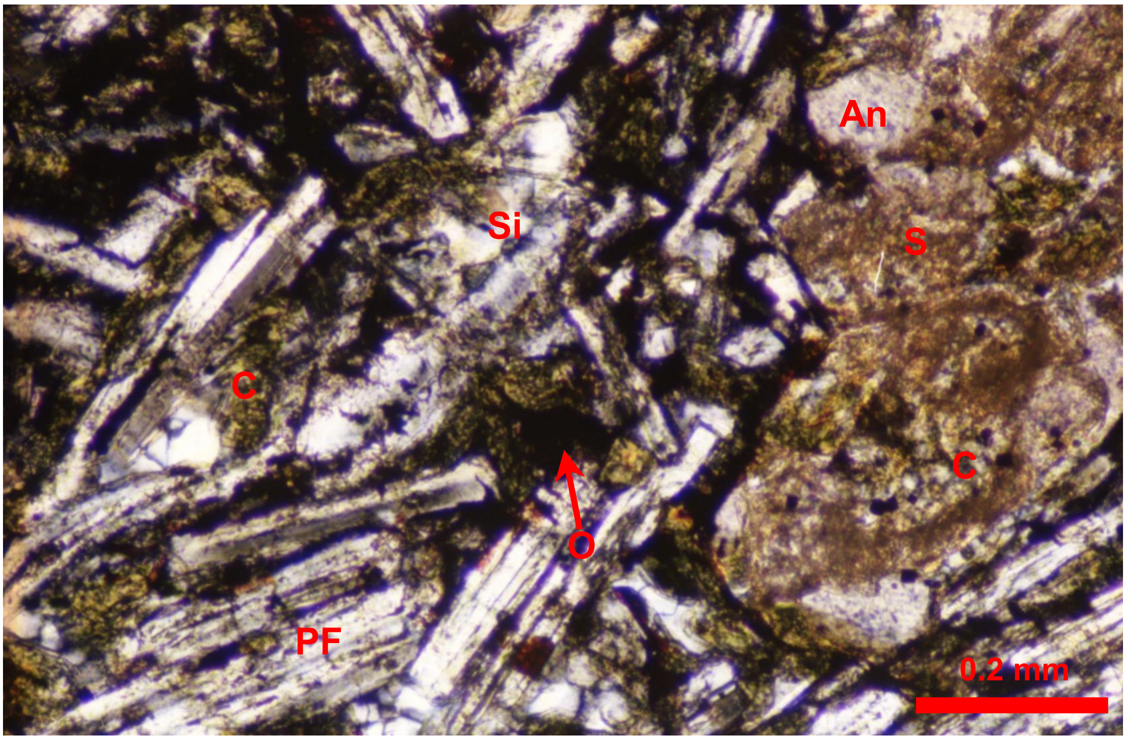


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Interstices between plagioclase laths (PF) are filled by secondary chlorite (C), opaque oxides (O) and finely-crystalline silica (Si), and a ?pyroxene phenocryst is totally replaced by siderite (S), ankerite (An) (stained faint blue) and chlorite.

PLATE 3: #2 2586.0mRT

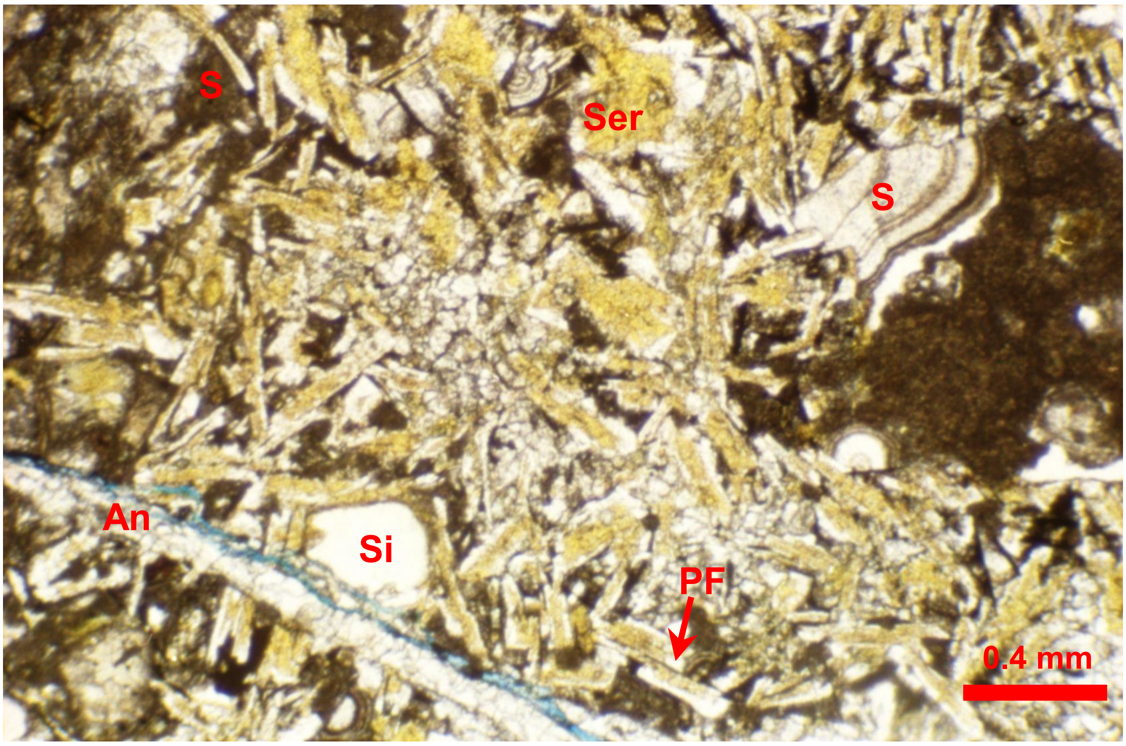
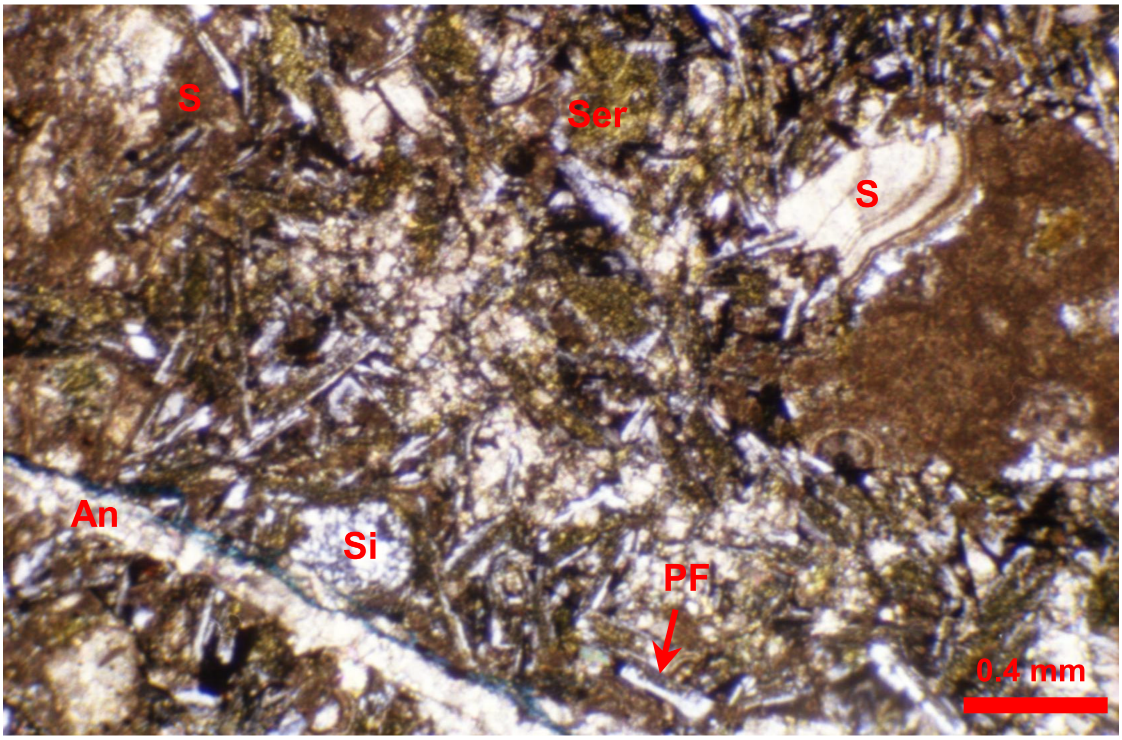


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Altered basaltic volcanic in which plagioclase laths (PF) have undergone extensive alteration to sericite (Ser) (stained yellow). The rock is also largely replaced by microcrystalline and coarsely-crystalline/spherulitic siderite (S), is cut by an ankerite (An)-filled fracture, and contains scattered microcrystalline silica (Si)-filled cavities/amygdales.

PLATE 4: #2 2586.0mRT cont.

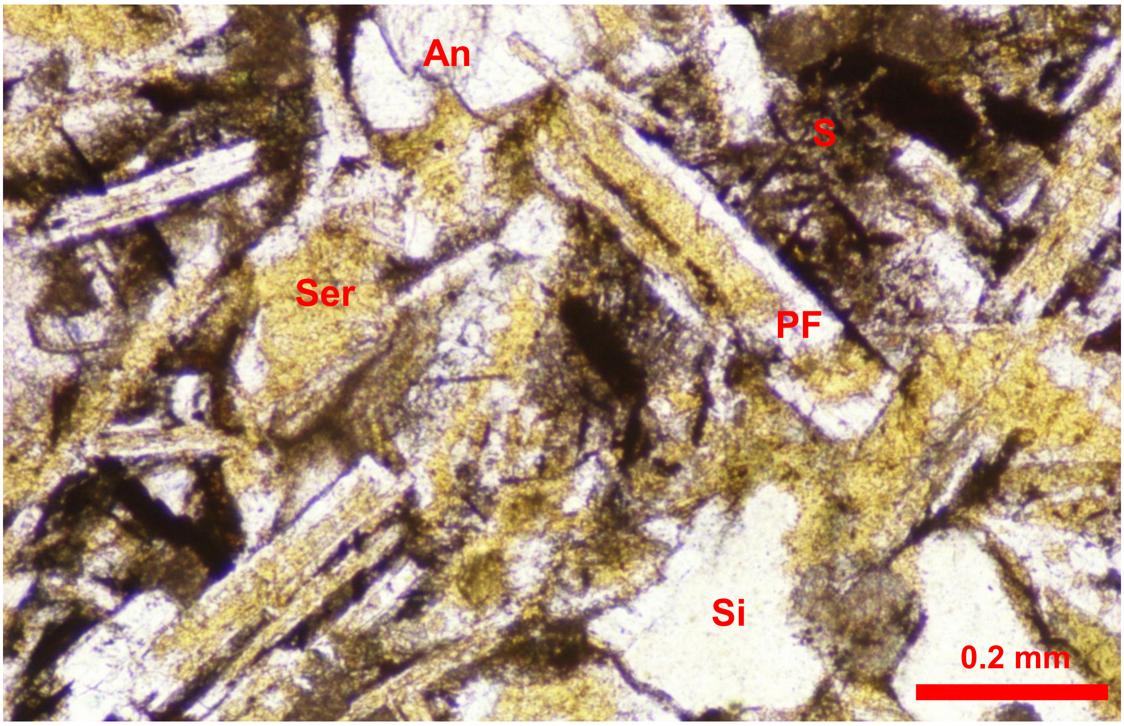
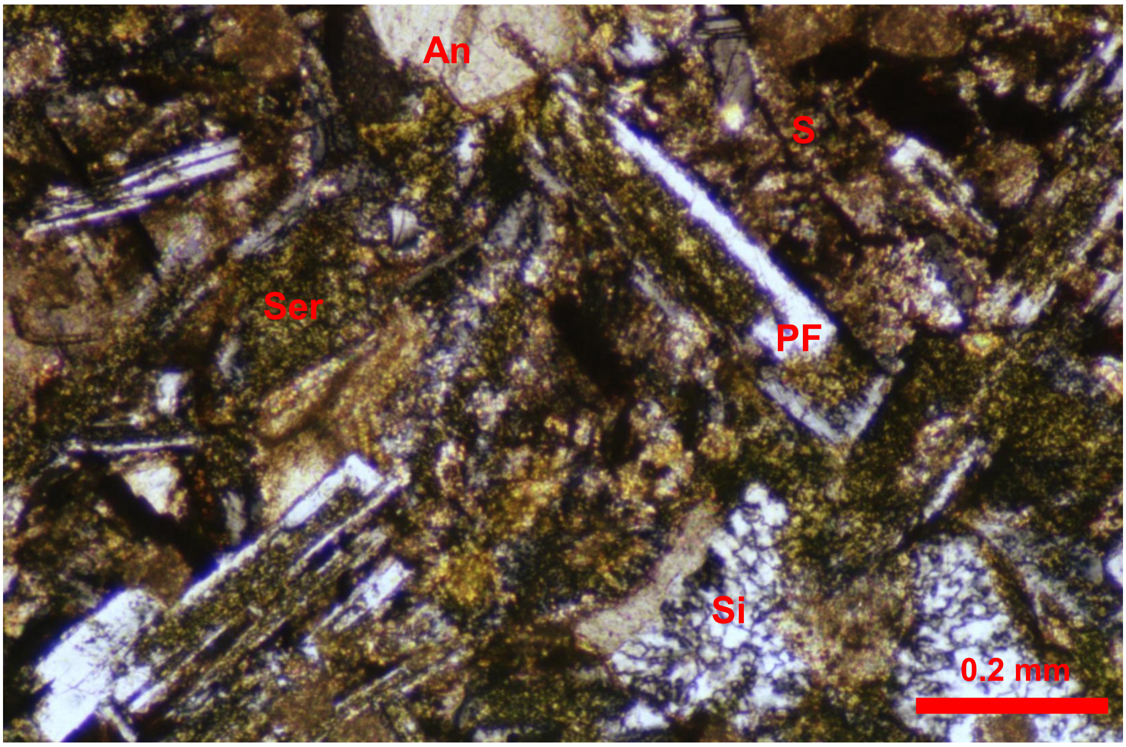


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Most plagioclase laths (PF) are partly replaced by sericite (Ser) (stained yellow). Other secondary minerals besides sericite include ankerite (An), siderite (S) and patchy microcrystalline silica (Si).

PLATE 5: #3 2594.0mRT

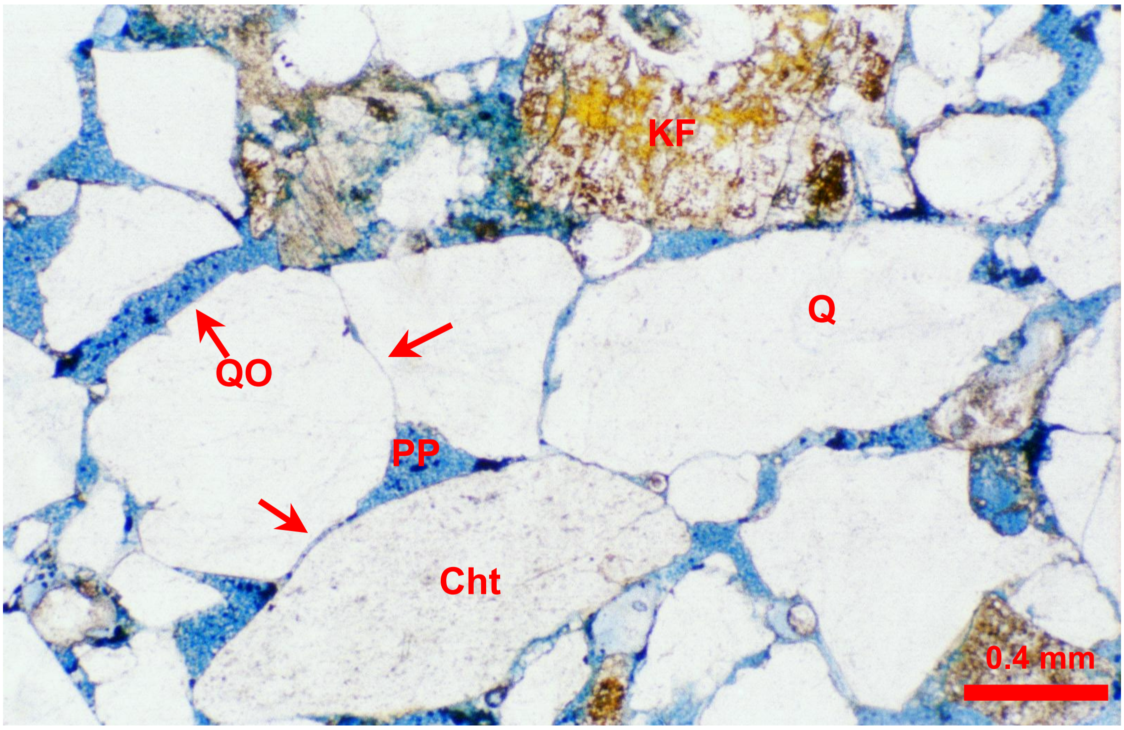
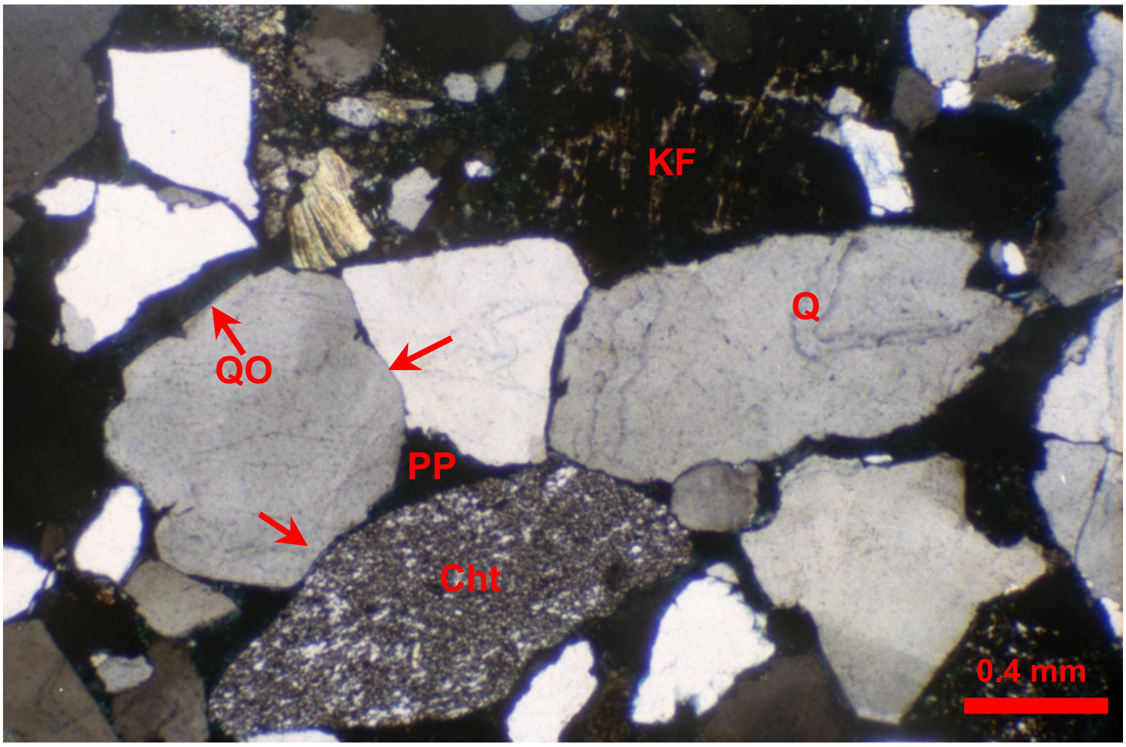


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Abundant primary intergranular porosity (PP) is preserved between quartz (Q), chert (Cht) and granitic K-feldspar (KF) (stained yellow) grains, despite porosity reduction by grain contact dissolution to form long and embayed grain contacts (arrows) and by quartz overgrowth (QO) cementation. Quartz overgrowths fill only a small portion of total available intergranular space. K = 3750md

PLATE 6: #3 2594.0mRT cont.

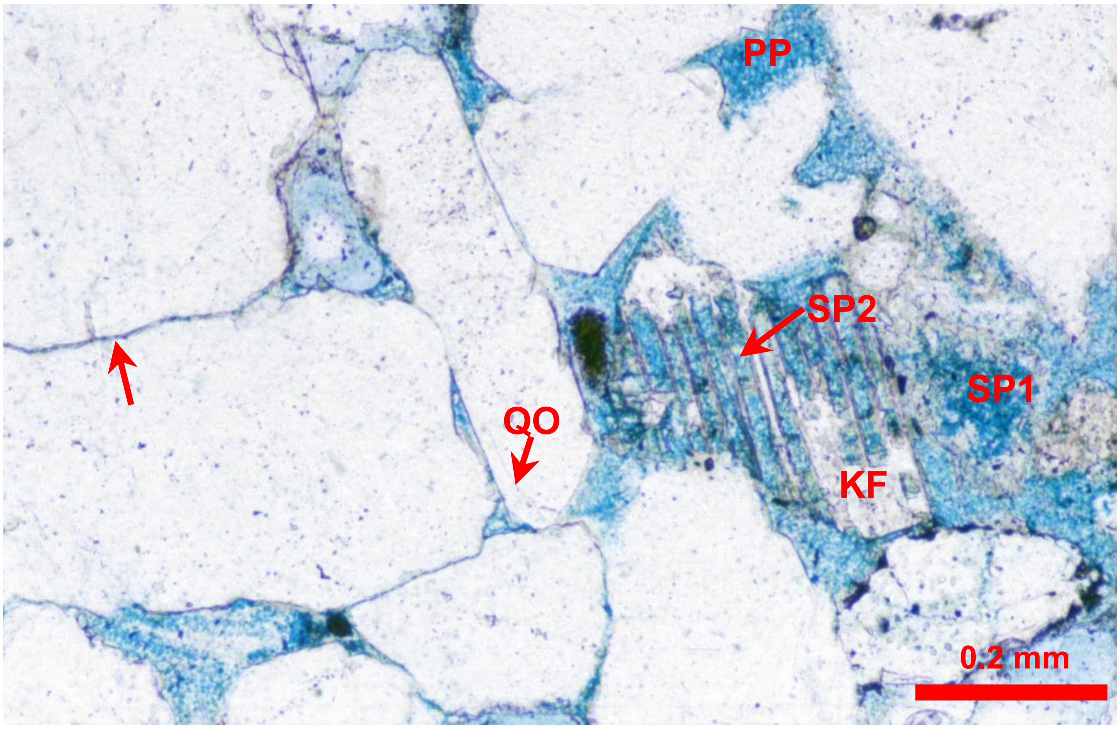
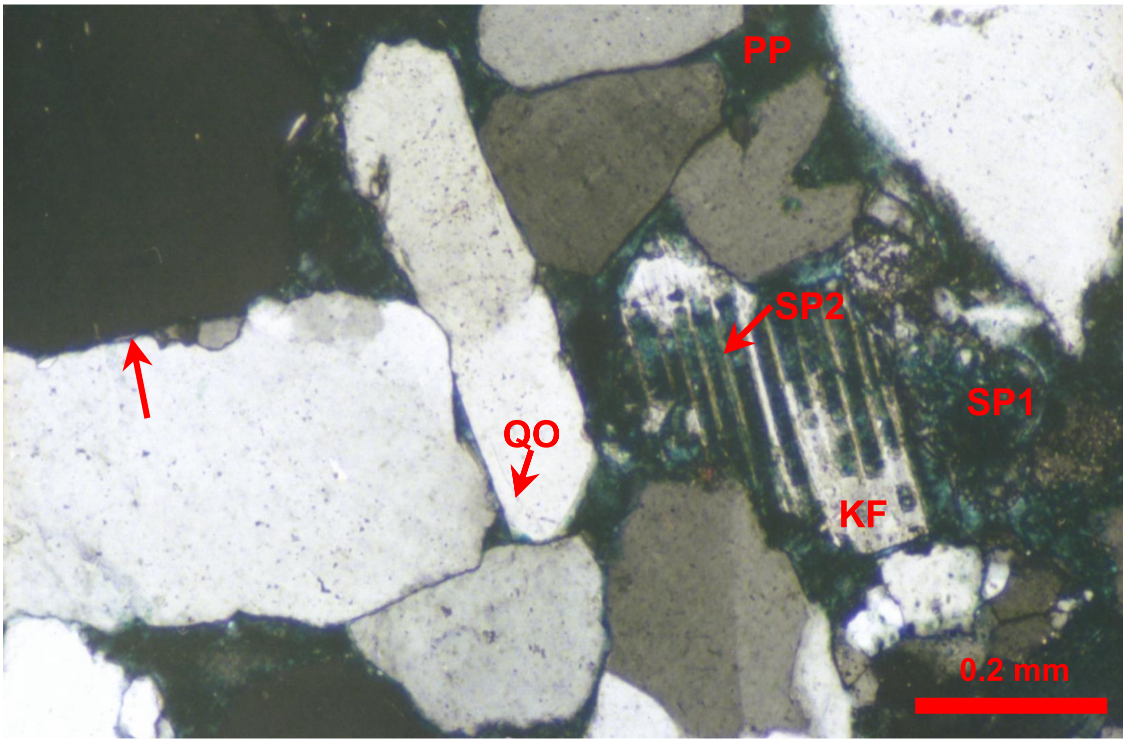


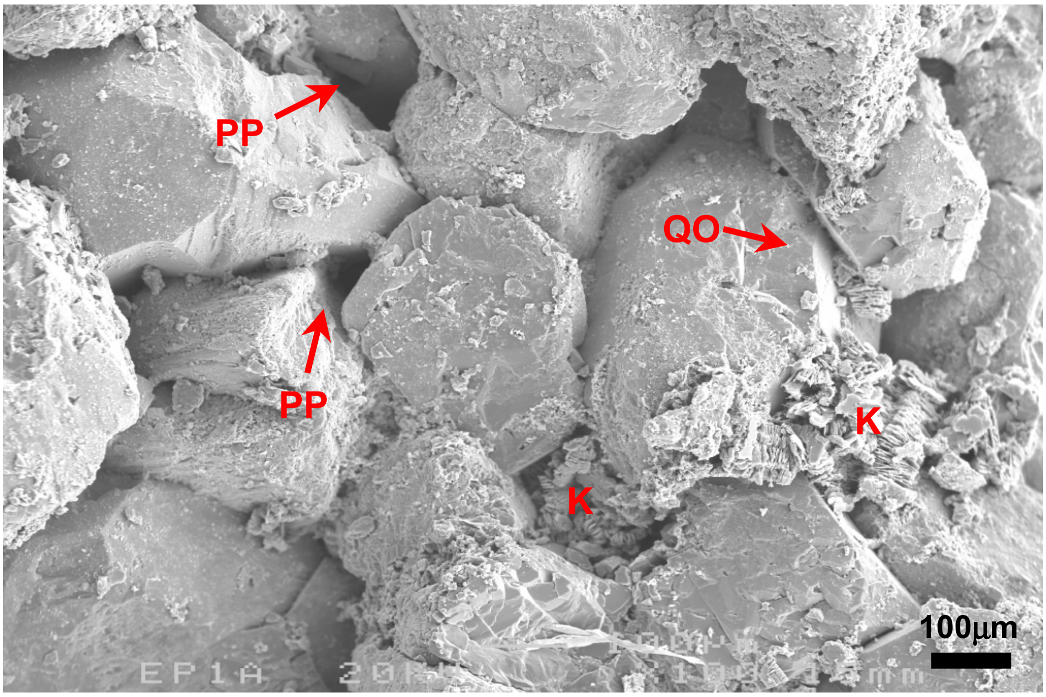
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



High permeability reflects coarse grain size and the presence of abundant, clean primary intergranular porosity (PP) that is supplemented by minor secondary intergranular porosity (SP1). Porosity reduction is the result of grain contact dissolution (arrow) and minor quartz overgrowth (QO) cementation. Secondary intragranular porosity (SP2) is associated with the skeletal remains of a partly dissolved K-feldspar grain (KF). K = 3750md

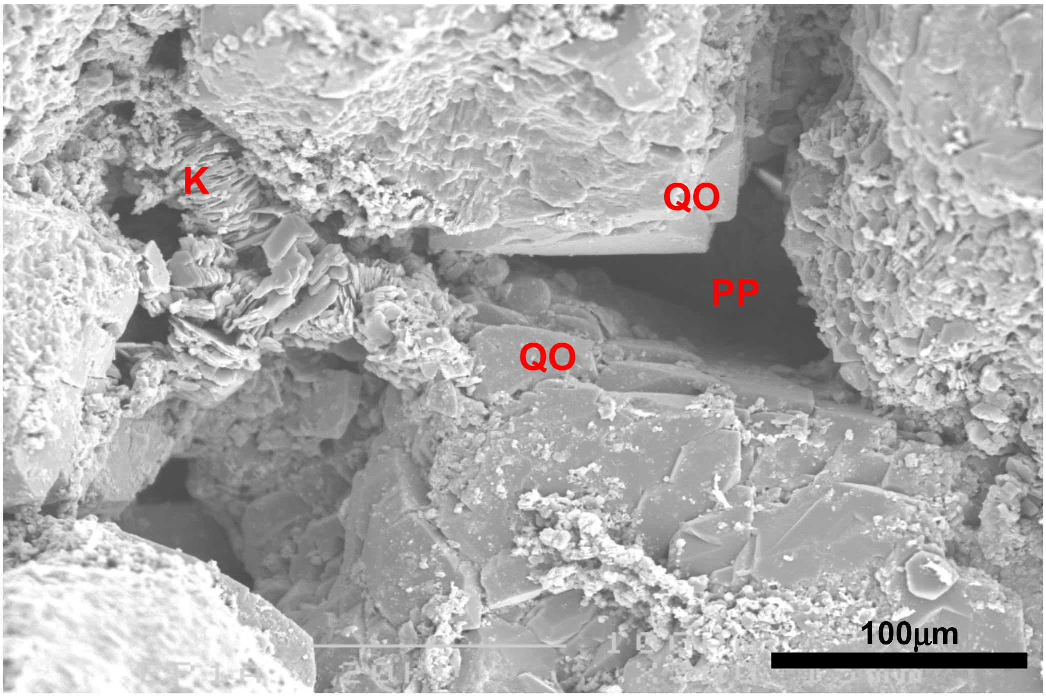
PLATE 7: #3 2594.0mRT cont.

FIGURE 1



SEM micrograph showing the occurrence of common primary intergranular pores (PP) in a poorly quartz overgrowth (QO)-cemented sandstone. Authigenic kaolinite (K) forms sporadic patches that would have little impact on permeability.

FIGURE 2



Detail of a typical primary intergranular pore (PP), the volume of which has not been significantly reduced by development of quartz overgrowths (QO) on bounding grains. A small patch of authigenic kaolinite (K) is the altered remnant of a labile grain.

PLATE 8: #4 2598.0mRT

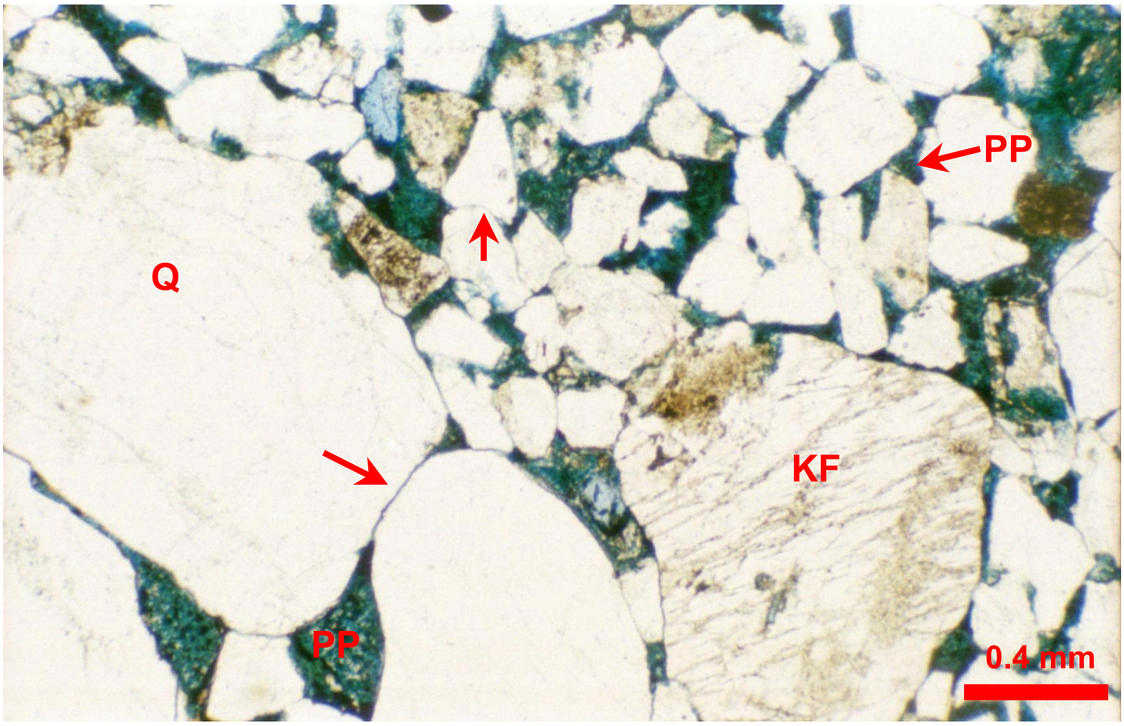
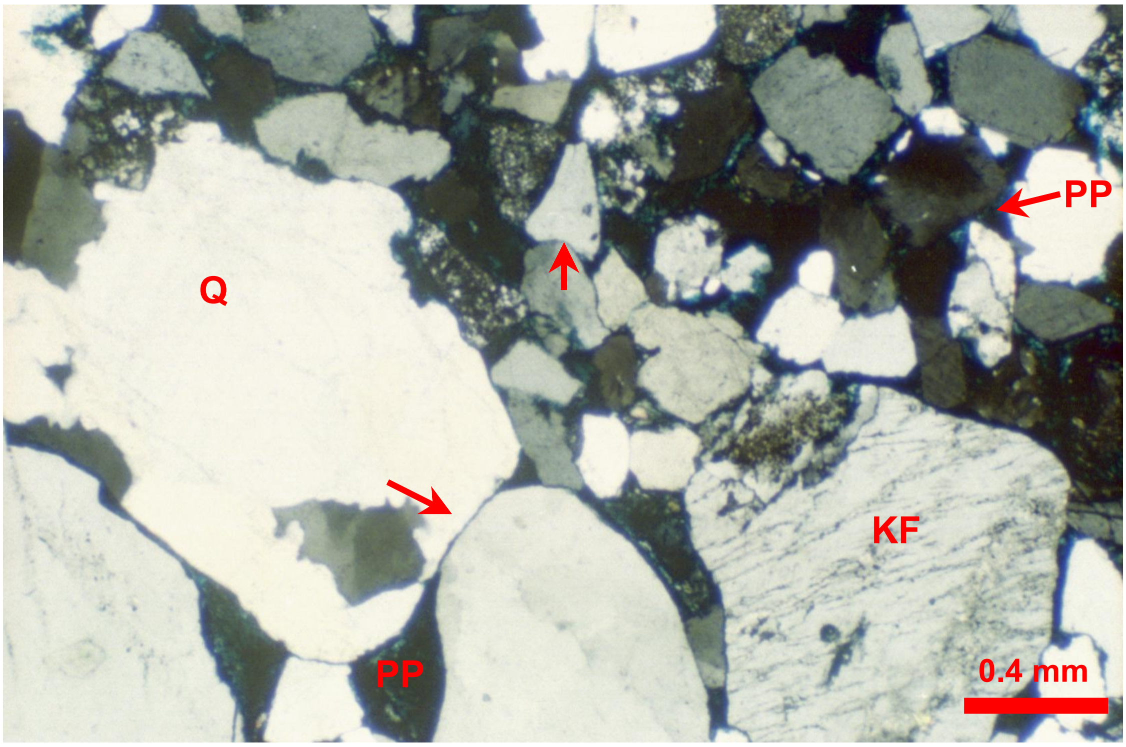


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



In this poorly sorted, very coarse grained sandstone, framework grain packing density has been increased by grain contact dissolution to form long and slightly embayed grain contacts (arrows). However, the sandstone is poorly cemented, clean and consequently contains a system of well interconnected primary intergranular pores (PP). Framework grains are mainly quartz (Q) and granitic K-feldspar (KF). K = 3280md

PLATE 9: #4 2598.0mRT cont.

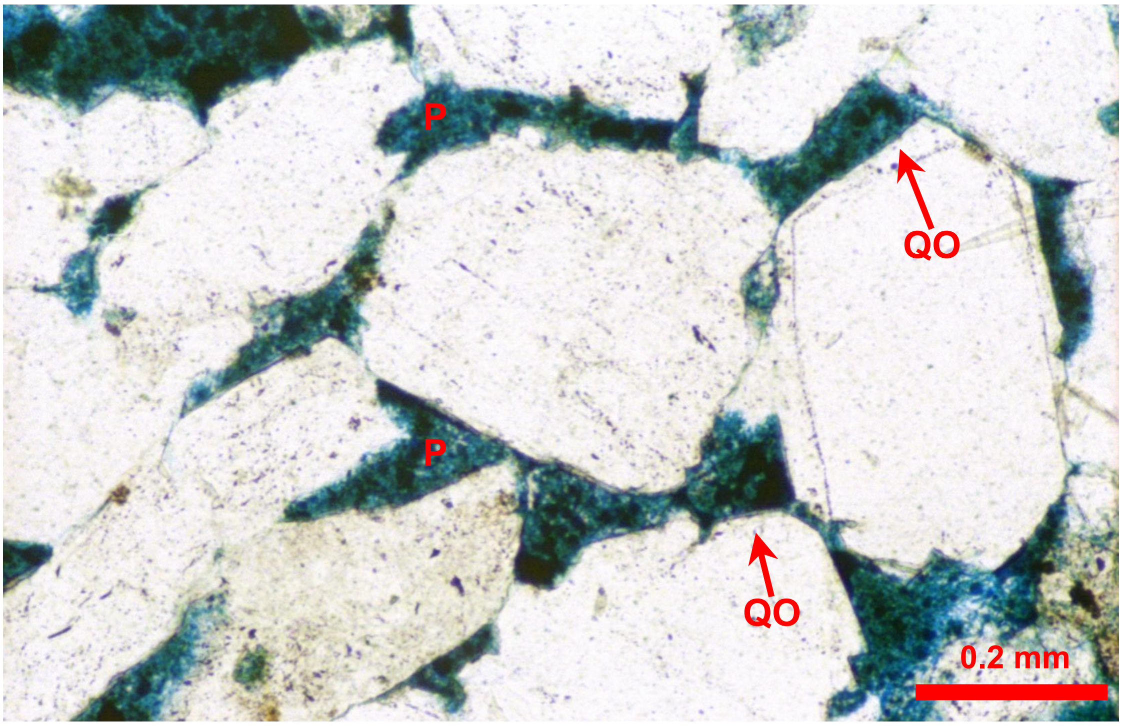
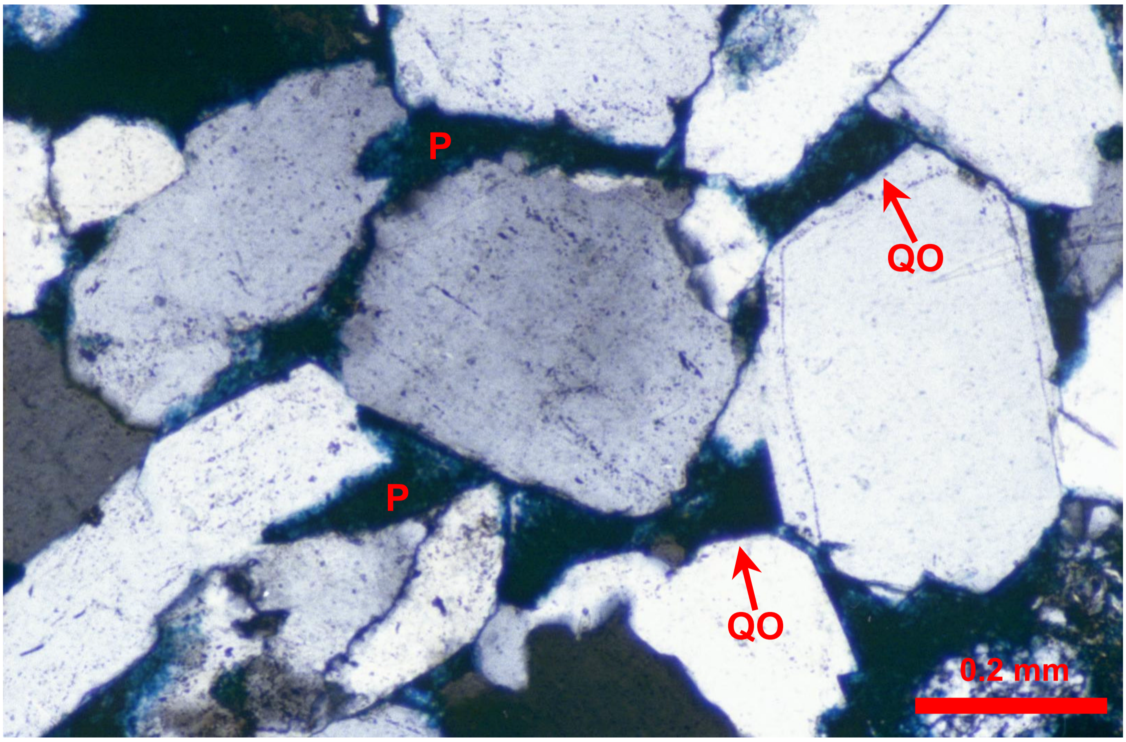


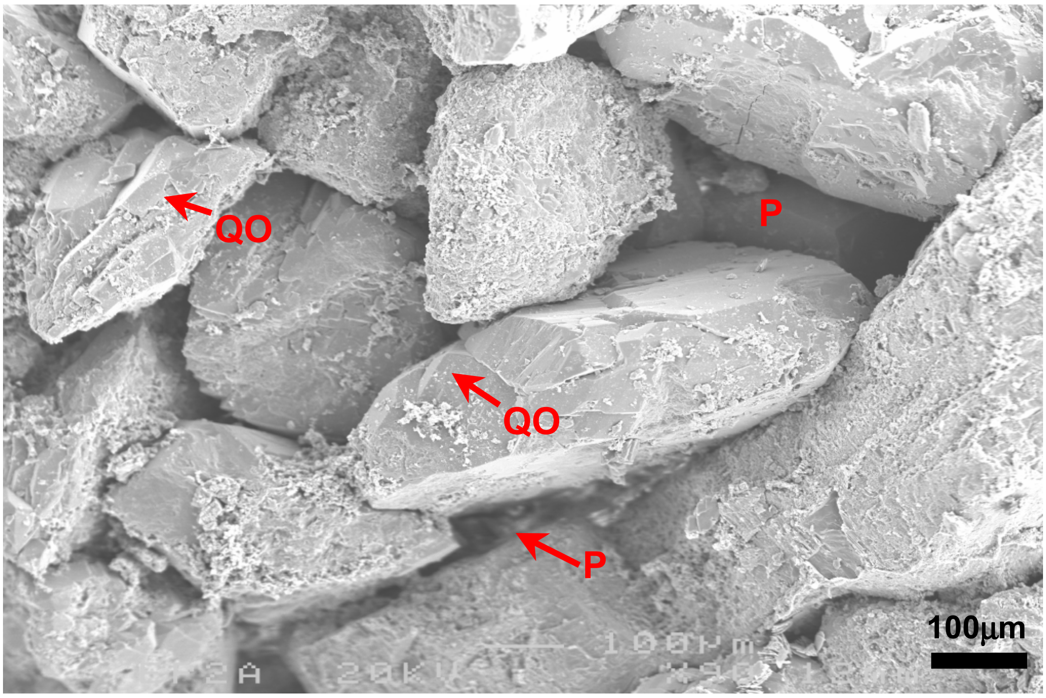
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Clean, evenly distributed, hence well interconnected primary and secondary intergranular pores (P) are preserved between poorly quartz overgrowth (QO)-cemented quartz grains. K = 3280md

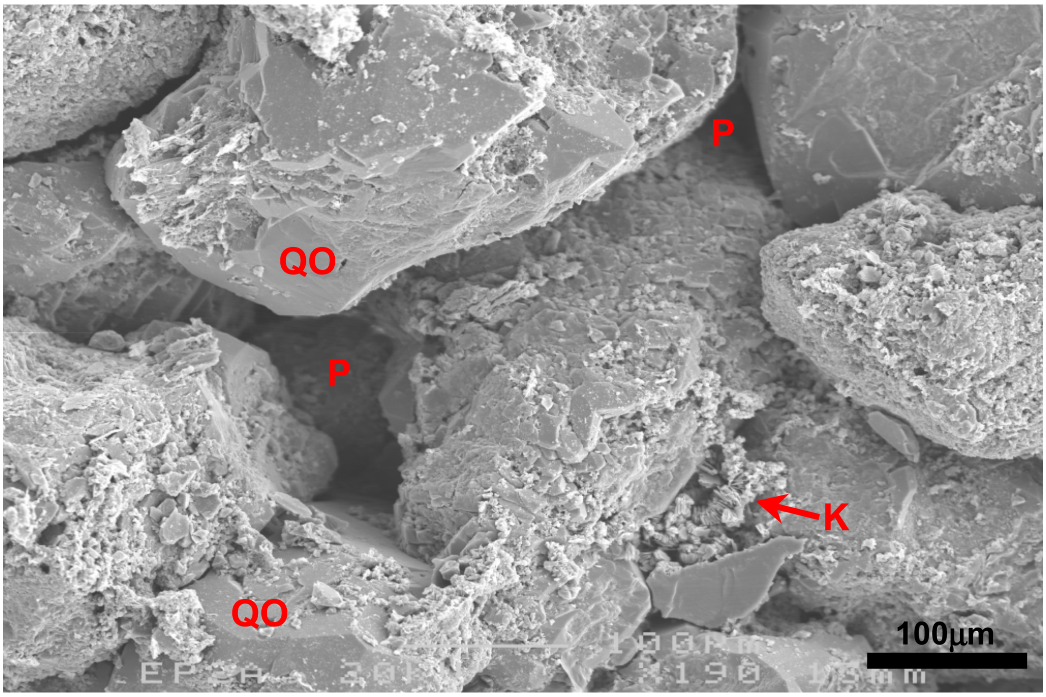
PLATE 10: #4 2598.0mRT cont.

FIGURE 1



High permeability reflects the preservation of large, clean intergranular pores (P) between most framework grains. Quartz overgrowths (QO) are poorly developed and thus have little impact on reservoir quality.

FIGURE 2



Although common, quartz overgrowths (QO) are only thinly developed and thus do not greatly reduce porosity (P). Virtually all clay in the sand is authigenic kaolinite (K) that forms sporadic patches where labile grains have altered.

PLATE 11: #5 2602.0mRT

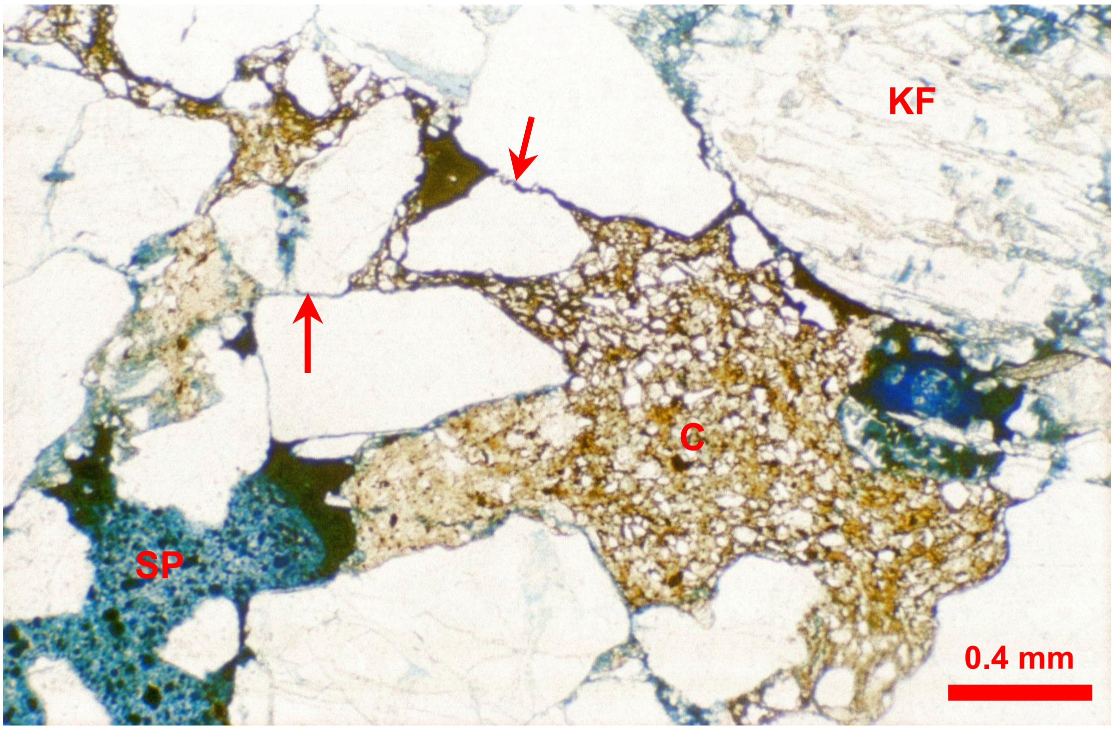
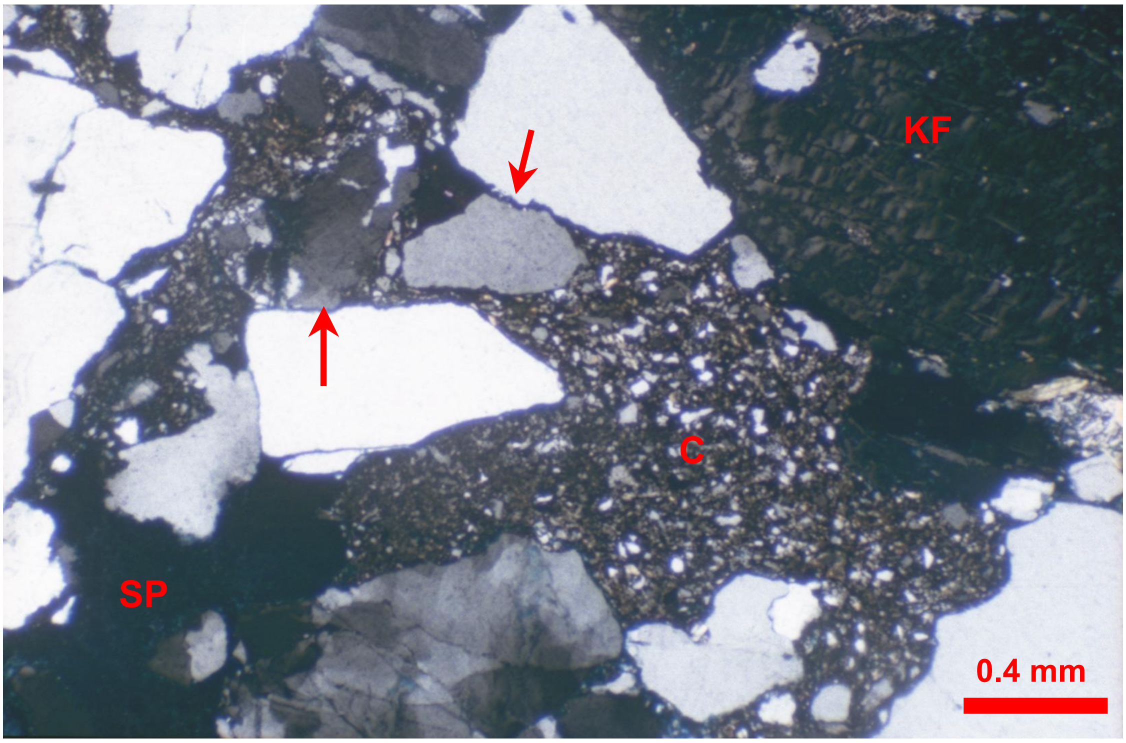


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



This sandstone has lower permeability than the previous two samples due to the presence of patchy detrital clay matrix (C), the presence of which has promoted grain contact dissolution and microstylolitisation (arrows) where the clay matrix is thinly dispersed between grains. Primary pores and secondary grain dissolution pores (SP) are common within clean parts of the sand. Most framework grains are quartz and granitic K-feldspar (KF). K = 1570md

PLATE 12: #5 2602.0mRT cont.

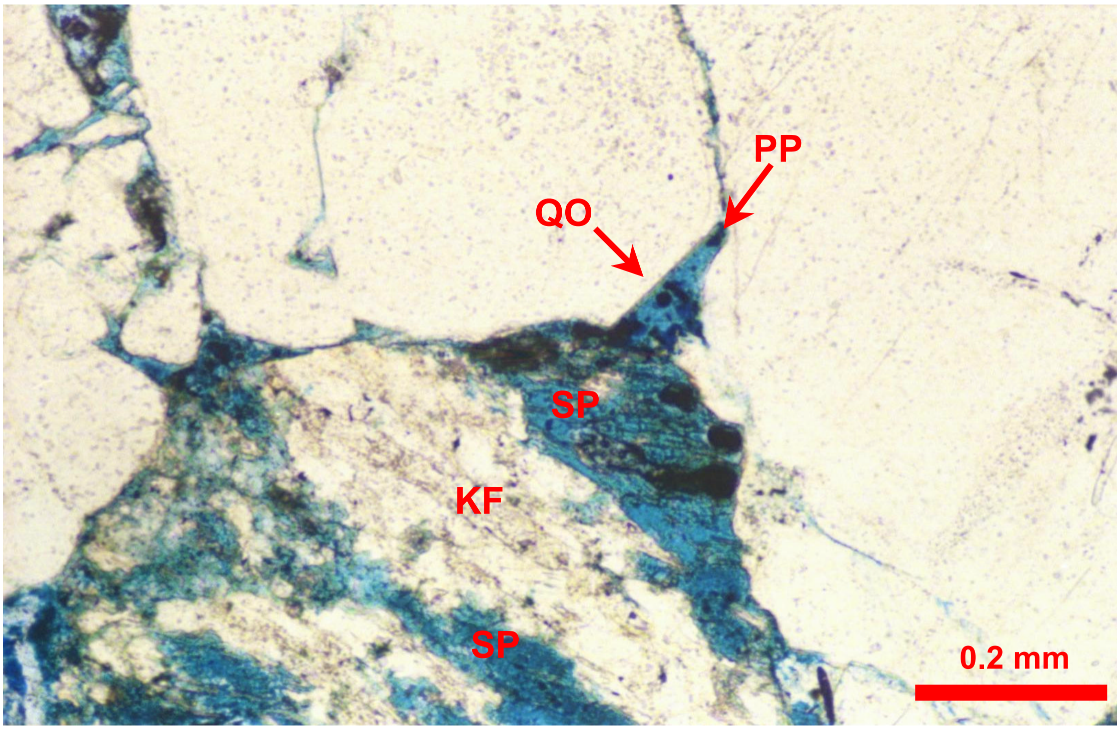
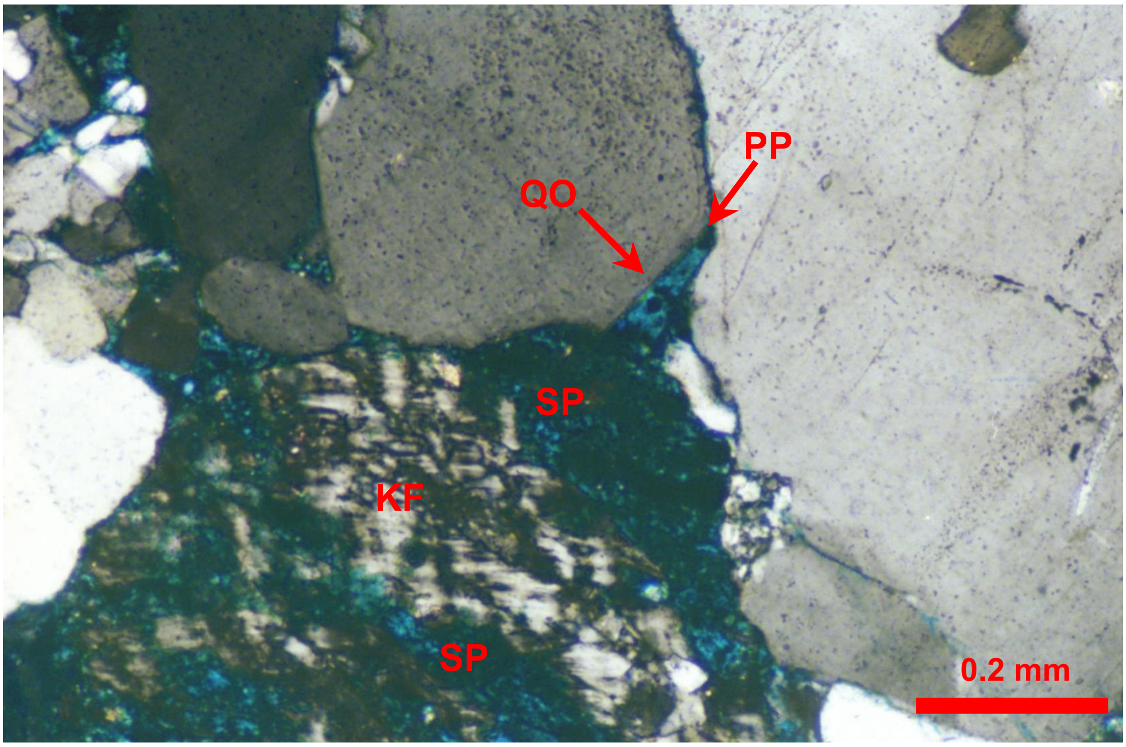


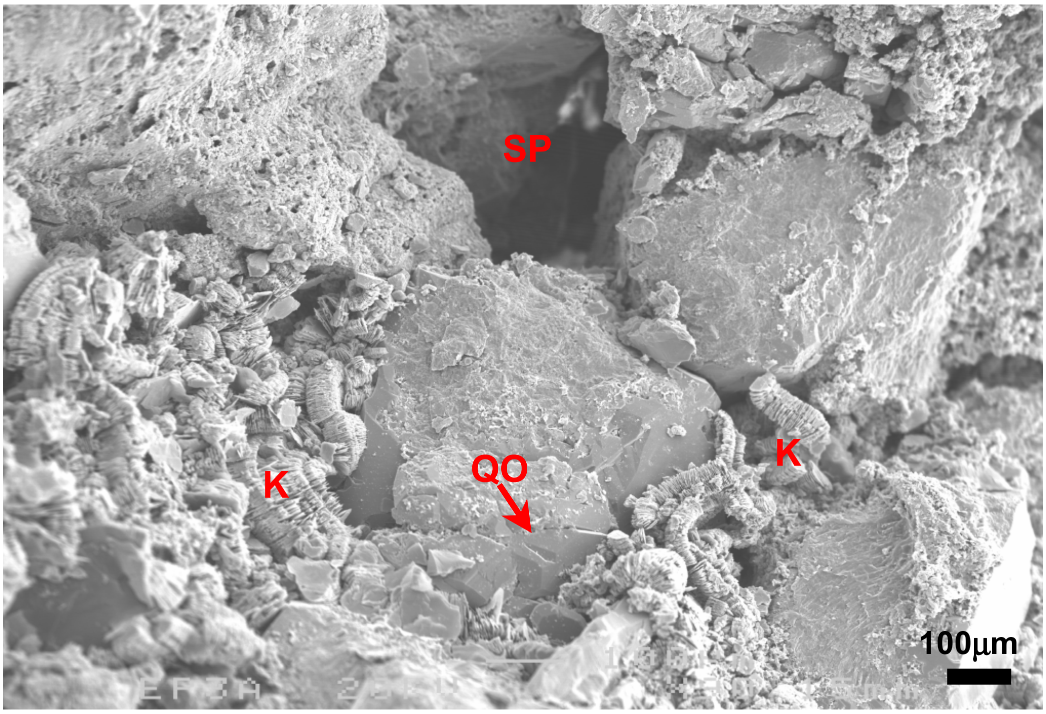
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



High permeability reflects very coarse grain size and the presence of abundant primary intergranular porosity (PP) and secondary K-feldspar (KF) dissolution porosity (SP) throughout most of the sandstone. Where patchy detrital clay (see Plate 11) is absent, porosity reduction is mainly the result of quartz overgrowth (QO) cementation and grain contact dissolution. K = 1570md

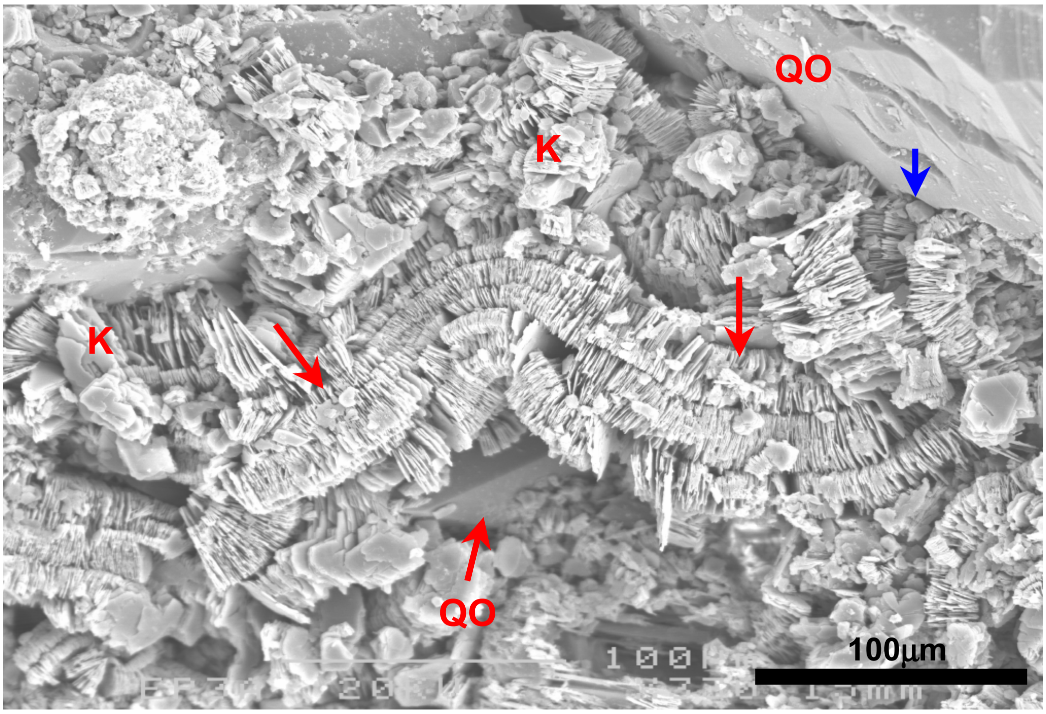
PLATE 13: #5 2602.0mRT cont.

FIGURE 1



Within localised parts of the sandstone, intergranular areas are commonly filled by authigenic kaolinite (K) that appears to have formed by recrystallisation of detrital clay. A large secondary pore (SP) occurs where a labile grain has dissolved, and small quartz overgrowths (QO) thinly envelop quartz grain surfaces that were not totally covered by clay.

FIGURE 2



Detail of pore-filling authigenic kaolinite (K), much of which has a vermicular structure (red arrows). Permeability is reduced by the presence of localised patches of detrital clay and authigenic kaolinite. Some kaolinite plates are enclosed (blue arrow) by later formed quartz overgrowths (QO).

PLATE 14: #6 2610.0mRT

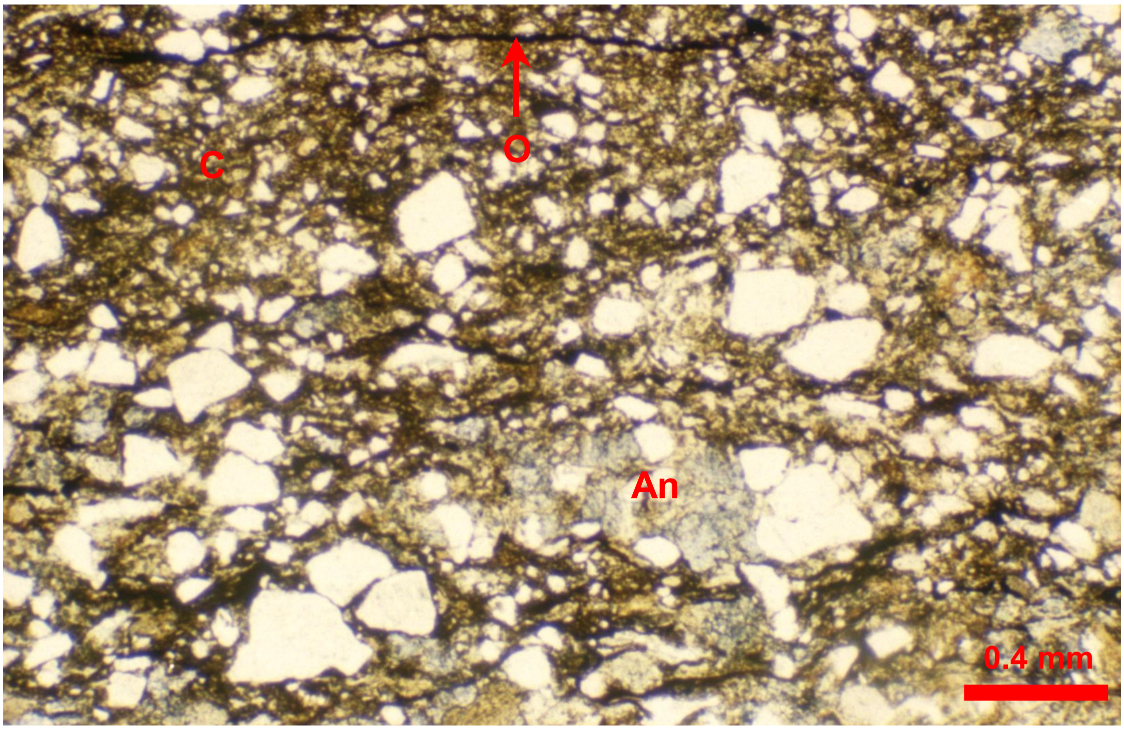
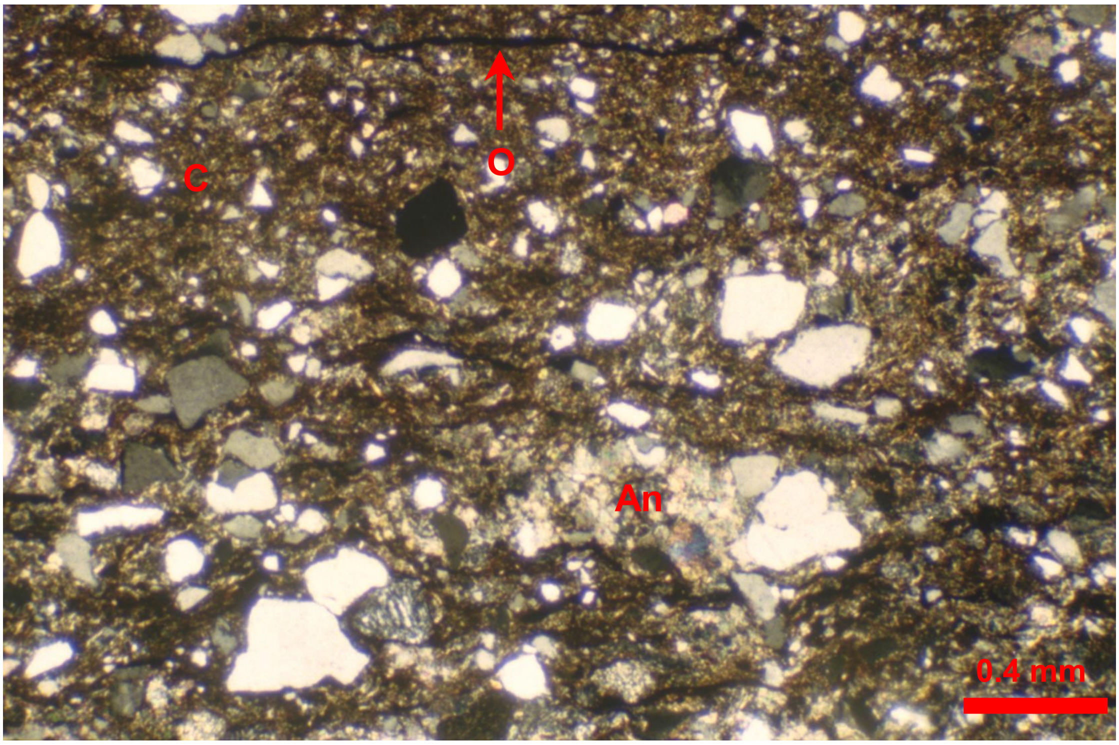


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



This mudrock is composed mainly of sideritic detrital clay matrix (C) that supports silt- to coarse sand-sized siliciclastic grains (mostly quartz and K-feldspar) and organic fragments/stringers (O). Scattered patches of medium-crystalline ankerite (An) (stained faint blue) replace clay.

PLATE 15: #6 2610.0mRT cont.

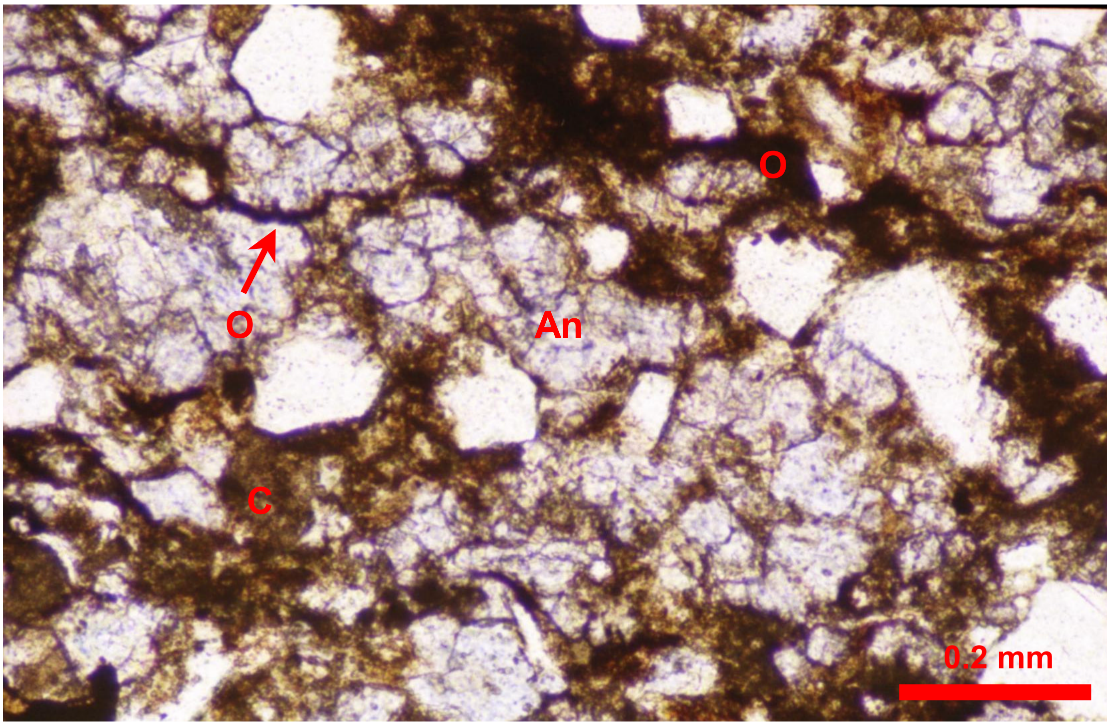
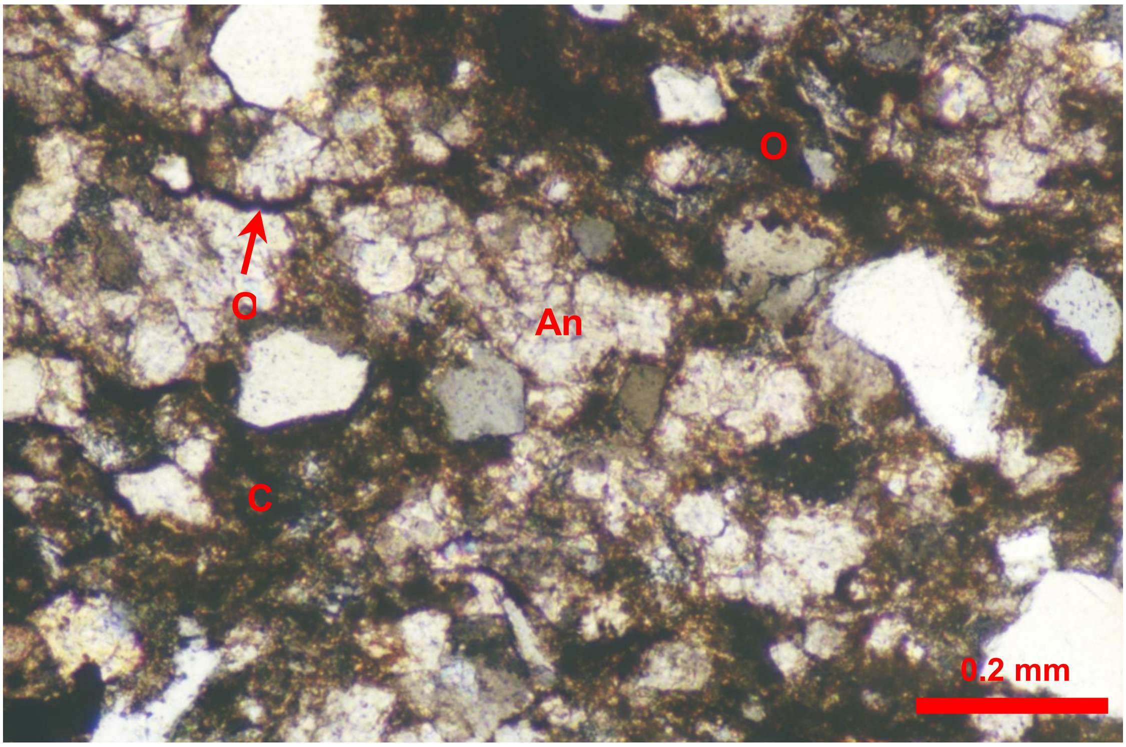


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Medium-crystalline ankerite (An) (stained blue) replaces detrital clay matrix (C) that supports scattered quartz grains and compacted organic fragments (O). The mudrock is totally microporous.

PLATE 16: #7 2620.0mRT

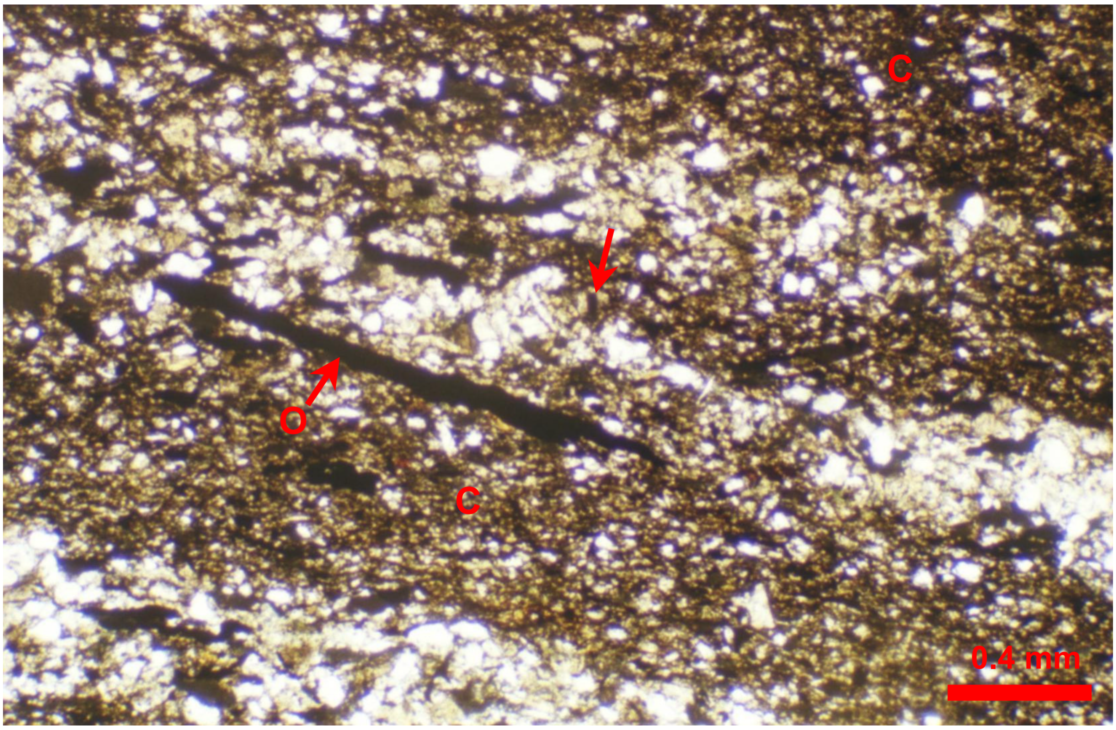
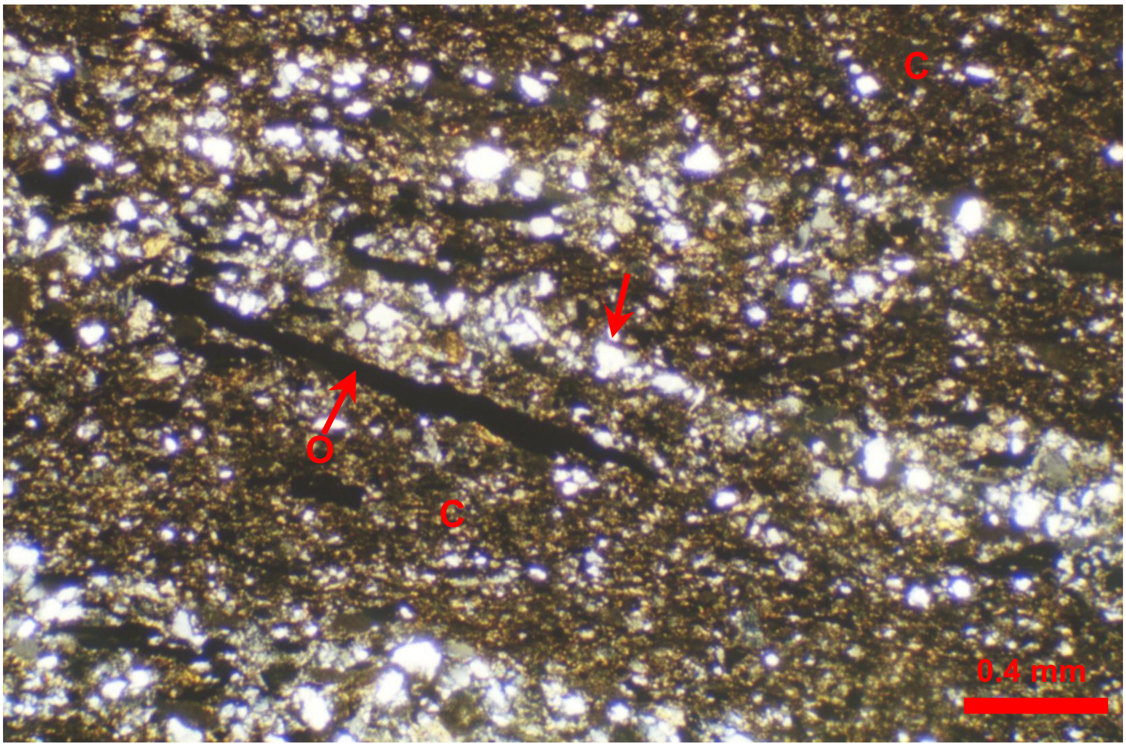


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Very thin, silty laminae (arrow) are included in a mudrock composed mainly of sideritised clay matrix (C), fine organic fragments (O) and silt-sized siliciclastic grains. K = 0.004md

PLATE 17: #7 2620.0mRT cont.

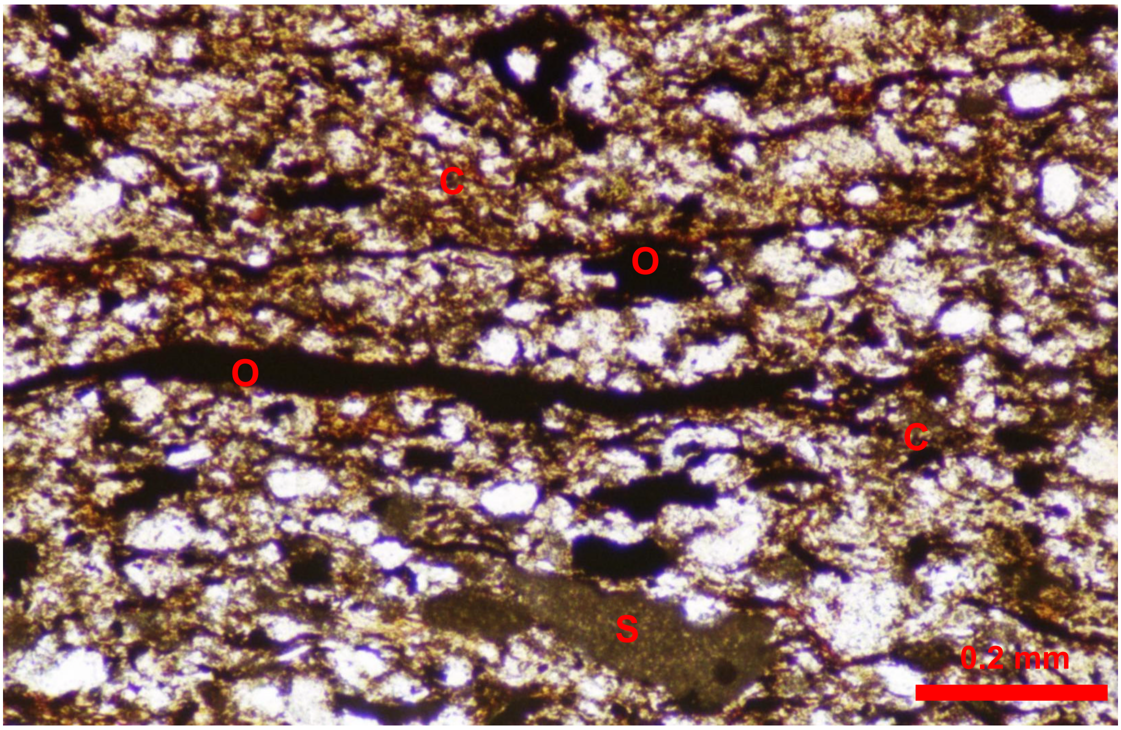
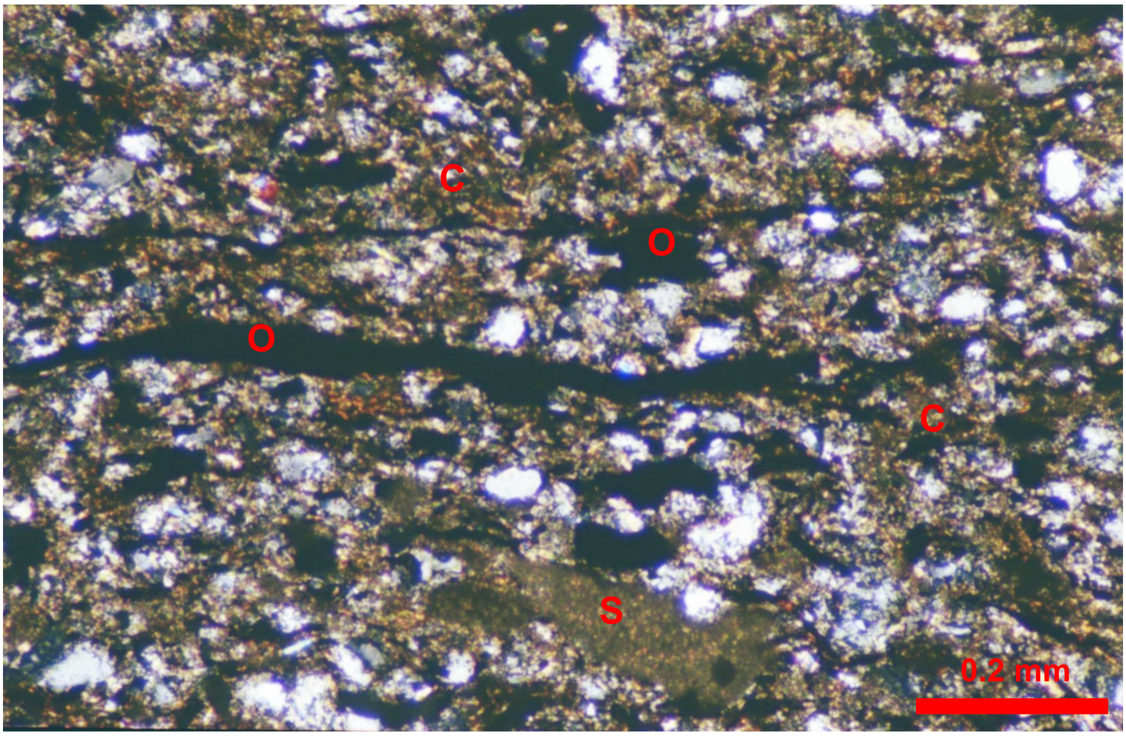


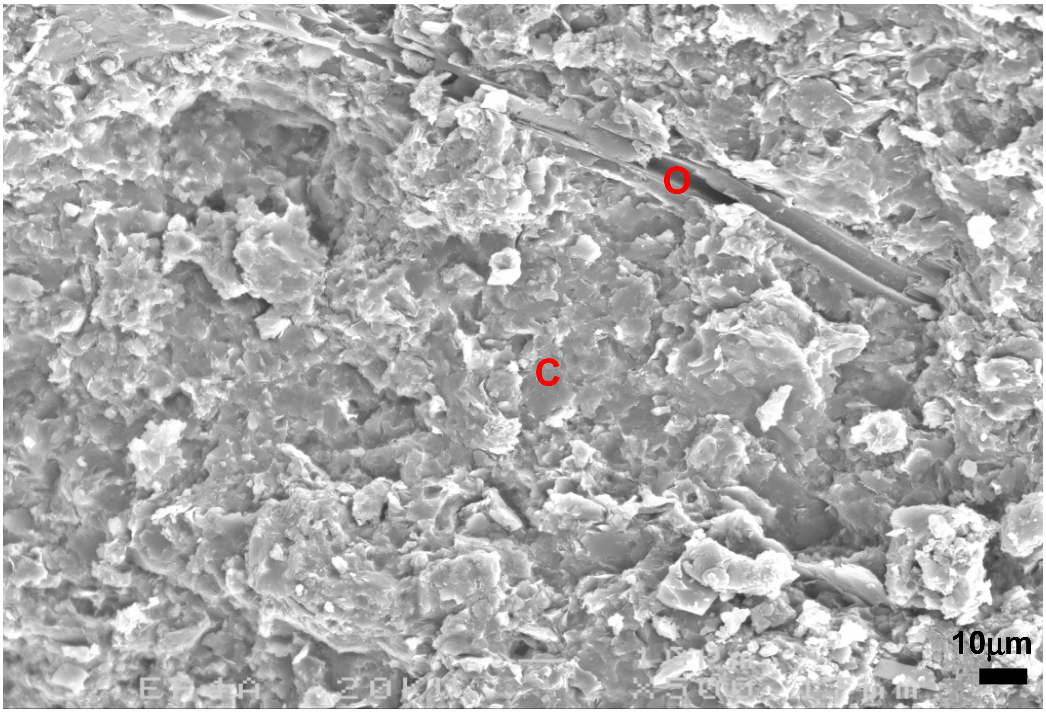
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Silt-sized siliciclastic grains and fine organic fragments/stringers (O) are supported by detrital clay matrix (C) that is largely replaced by microcrystalline siderite (S). K = 0.004md

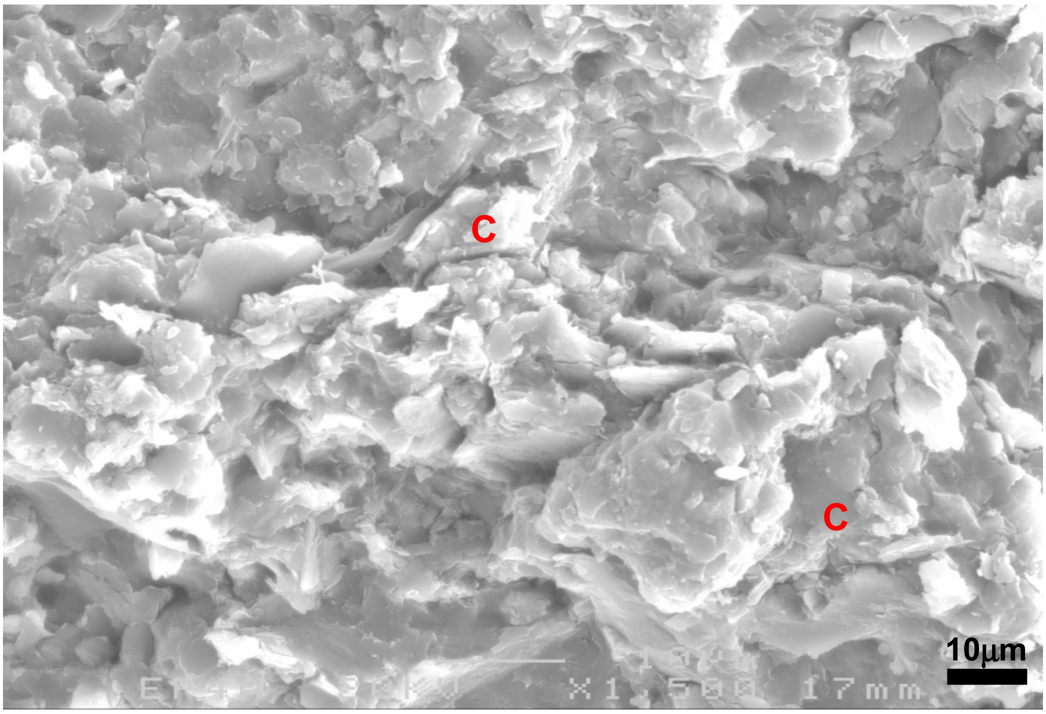
PLATE 18: #7 2620.0mRT cont.

FIGURE 1



SEM micrograph showing a representative area in which well-compacted detrital clay matrix (C) supports an organic fragment (O). Macroporosity is absent and permeability is consequently negligible.

FIGURE 2



Detrital illitic and kaolinitic clay matrix (C) is densely packed and consequently contains little microporosity.

PLATE 19: #8 2627.5mRT

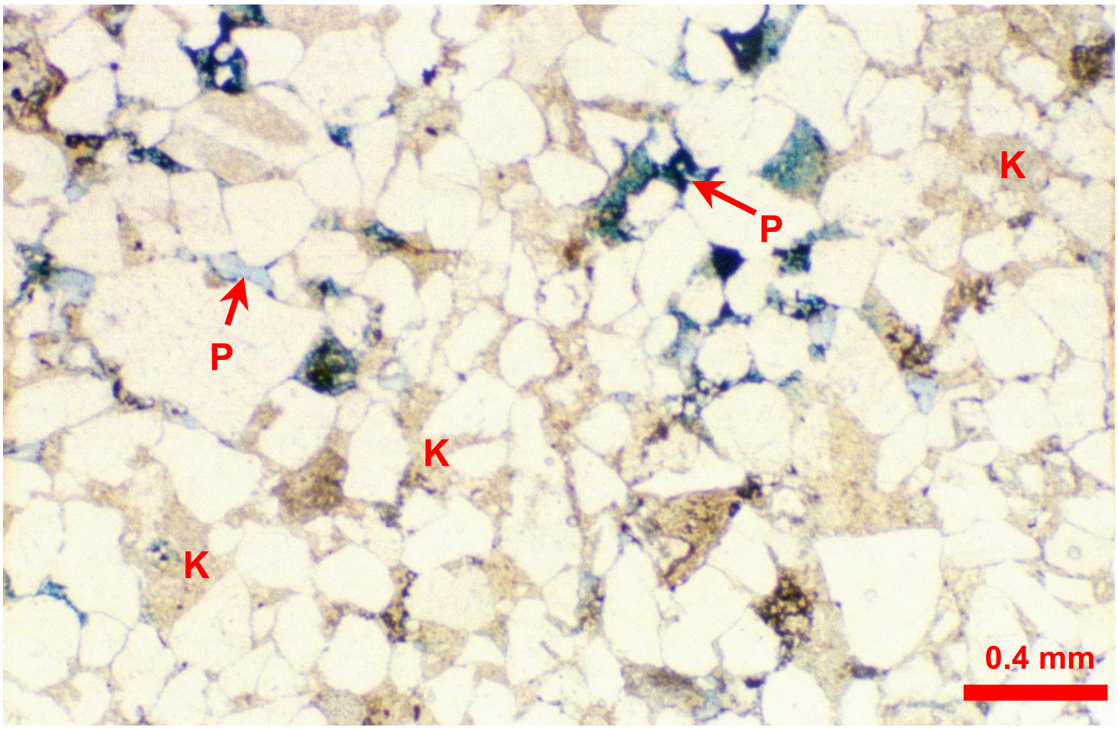
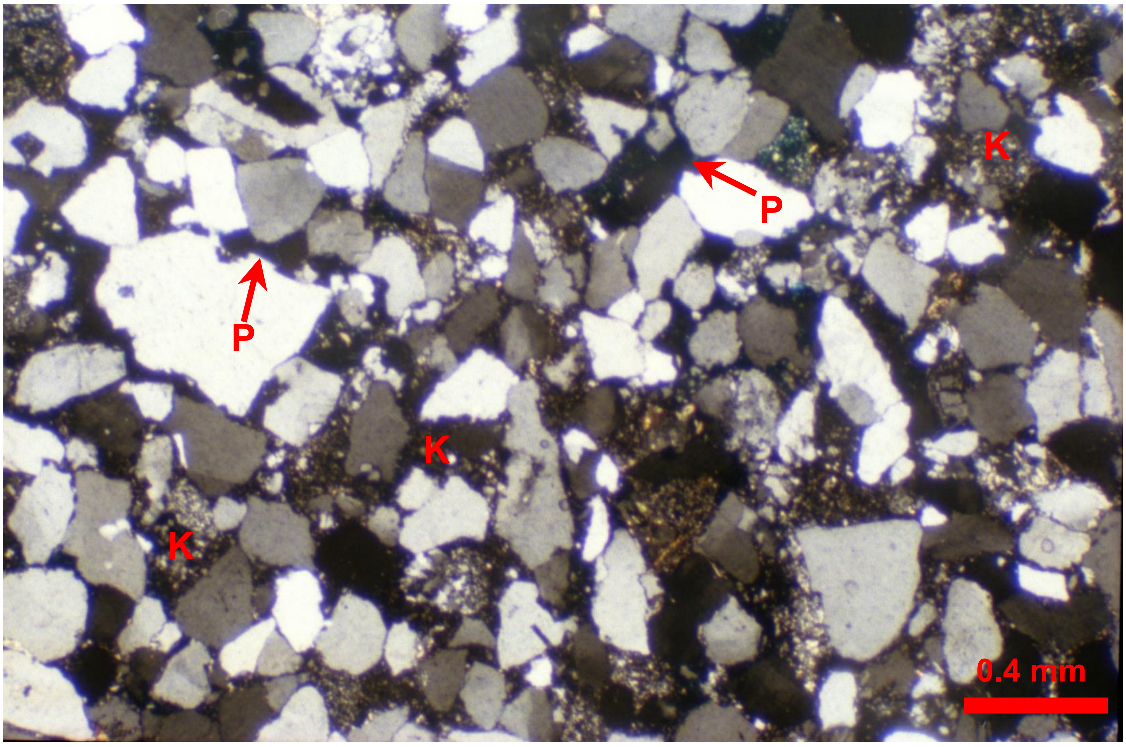


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Intergranular porosity and permeability are reduced by the presence of patchy detrital clay matrix that has recrystallised to kaolinite (K). Macropores (P) are common within areas that are free of clay matrix. K = 135md

PLATE 20: #8 2627.5mRT cont.

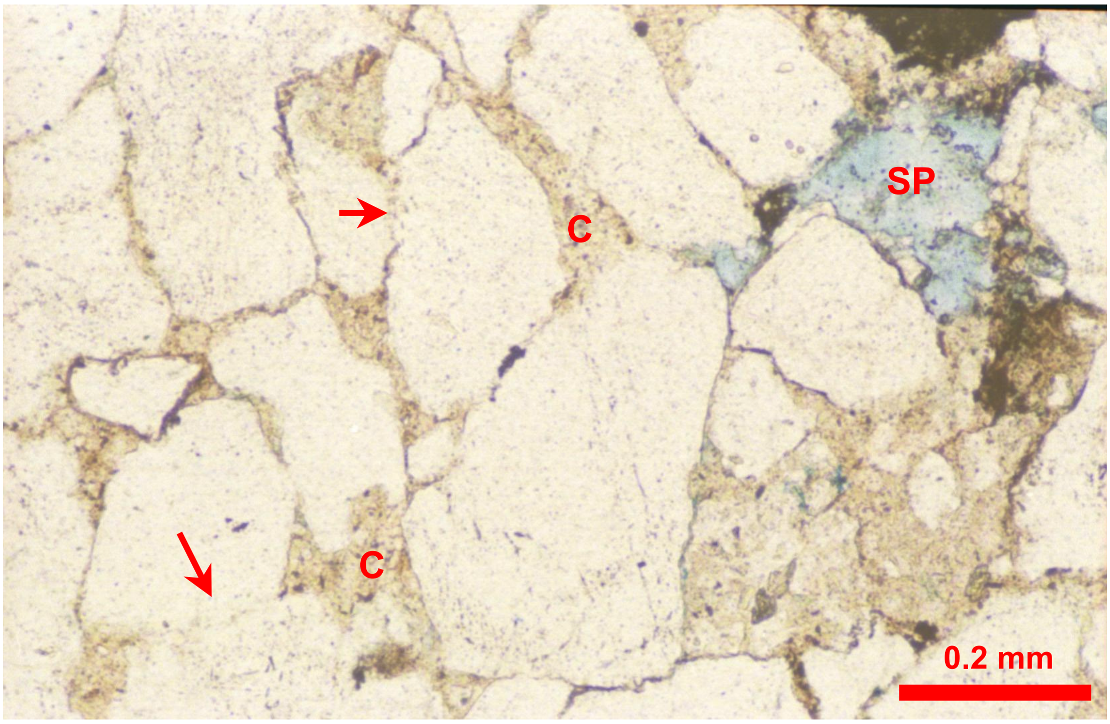
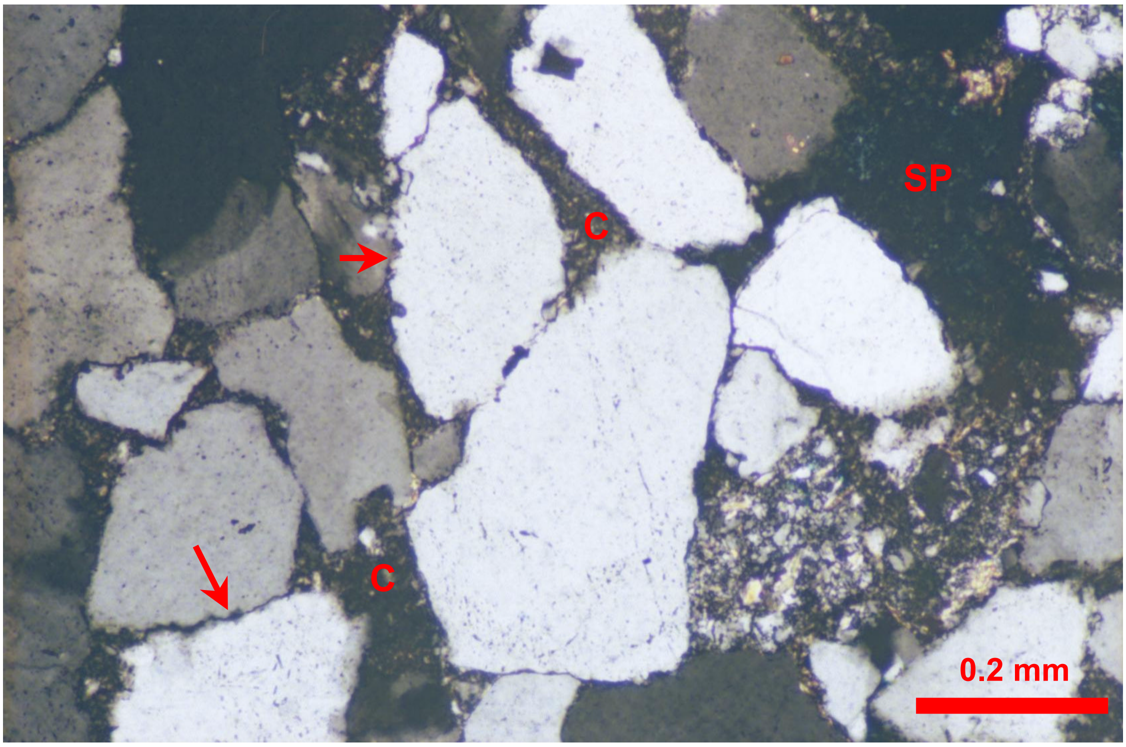


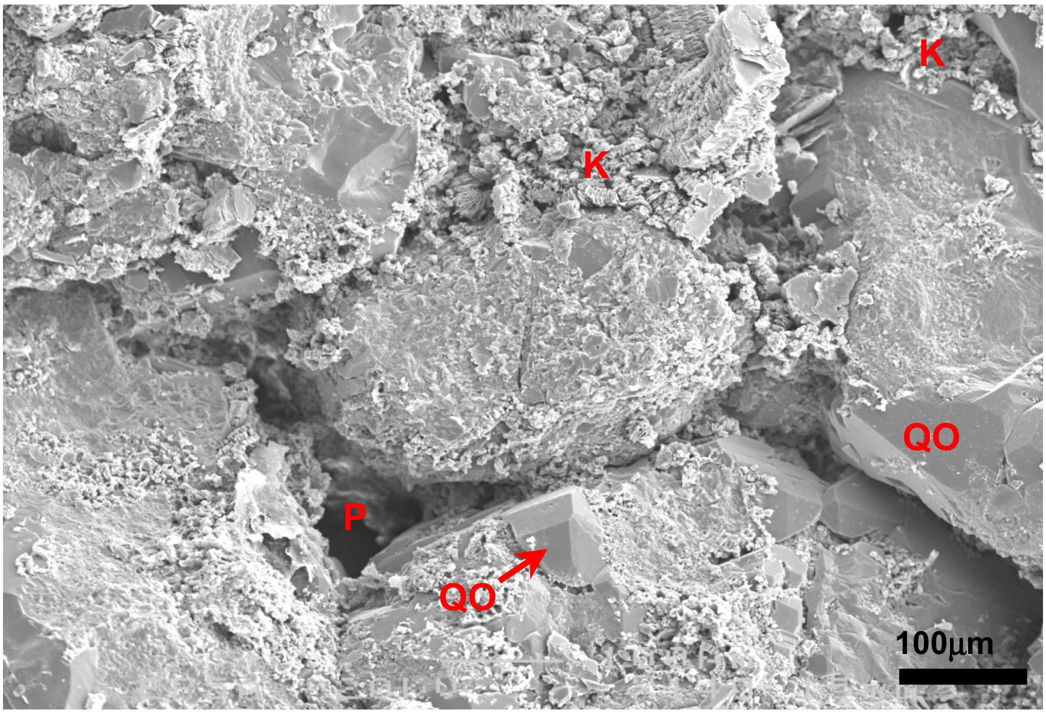
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Within much of the sandstone, kaolinitised detrital clay matrix (C) fills all intergranular spaces and framework grain packing density has been significantly increased by grain contact dissolution and microstylolitisation (arrows). A secondary mouldic pore (SP) marks the former location of a K-feldspar that has completely dissolved. K = 135md

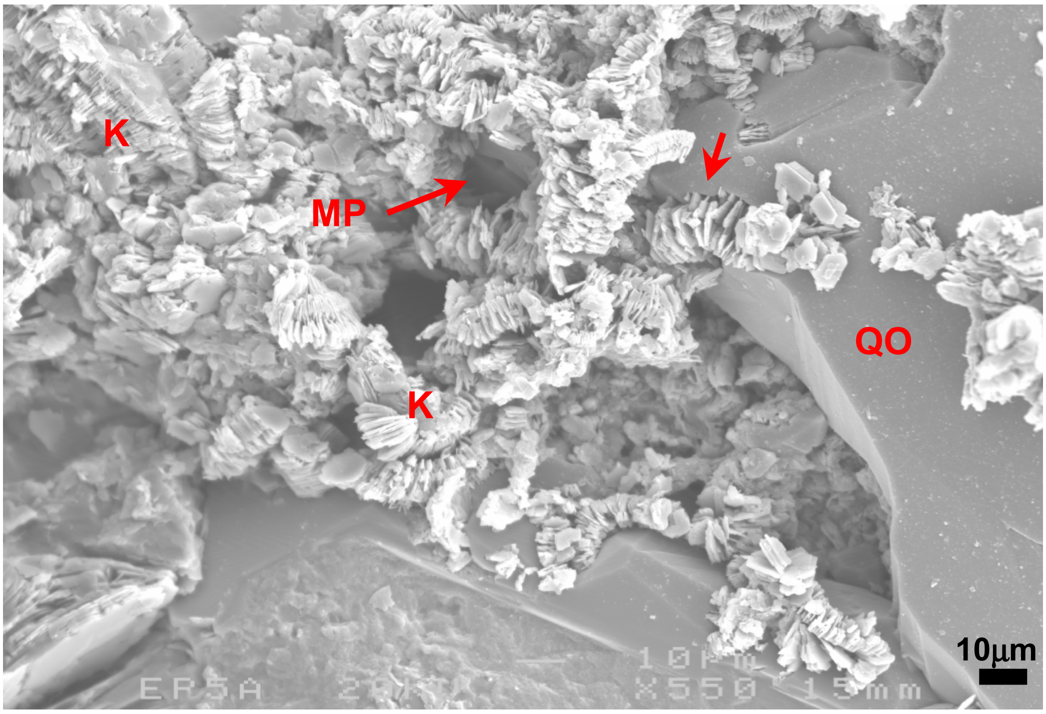
PLATE 21: #8 2627.5mRT cont.

FIGURE 1



Intergranular spaces are commonly occupied by authigenic kaolinite (K) that has formed by recrystallisation of detrital clay matrix. However, despite being cemented by quartz overgrowths (QO), parts of the sandstone that are free of clay matrix contain abundant intergranular porosity (P), the presence of which results in moderate (135md) permeability.

FIGURE 2



Detail of typical pore-filling authigenic kaolinite (K). Some of the kaolinite is partly engulfed (arrow) by later formed quartz overgrowths (QO). The kaolinite is loosely packed and thus highly microporous (MP).

PLATE 22: #9 2633.5mRT

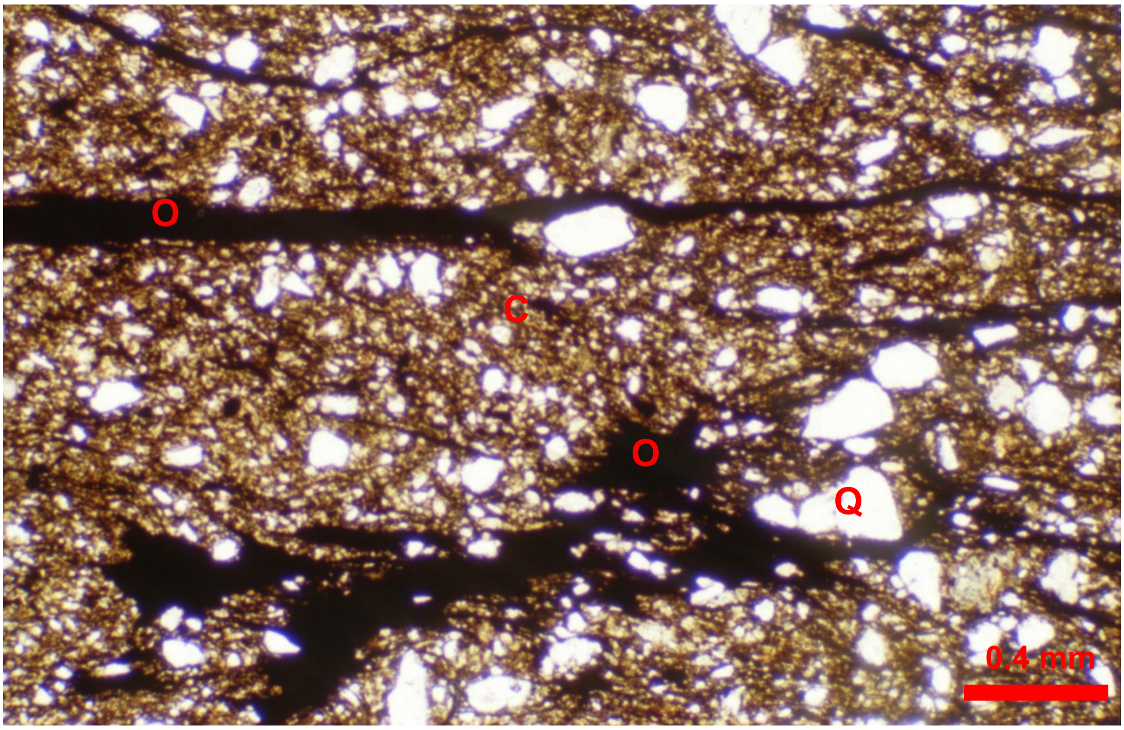
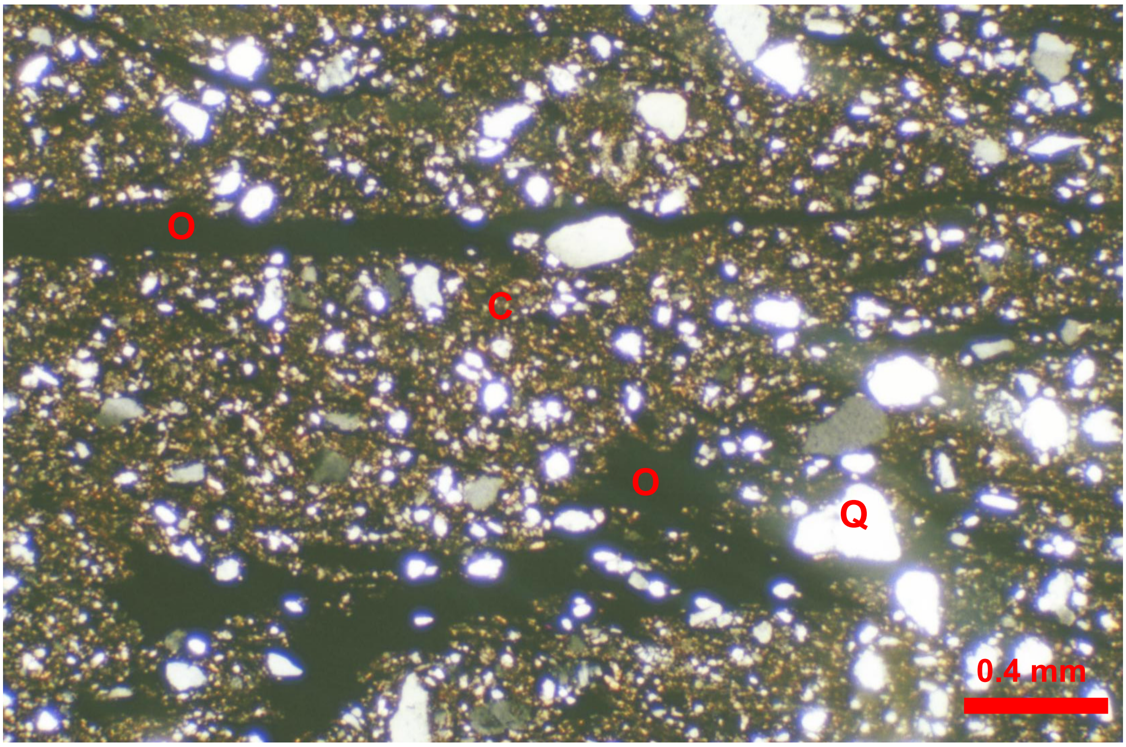


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



This arenaceous mudrock contains abundant clay matrix (C)-supported organic fragments/stringers (O) and uniformly-scattered, silt- and sand-sized siliciclastic grains, most of which are quartz (Q). The measured permeability value of 19.5md is anomalously high due to fracturing.

PLATE 23: #9 2633.5mRT cont.

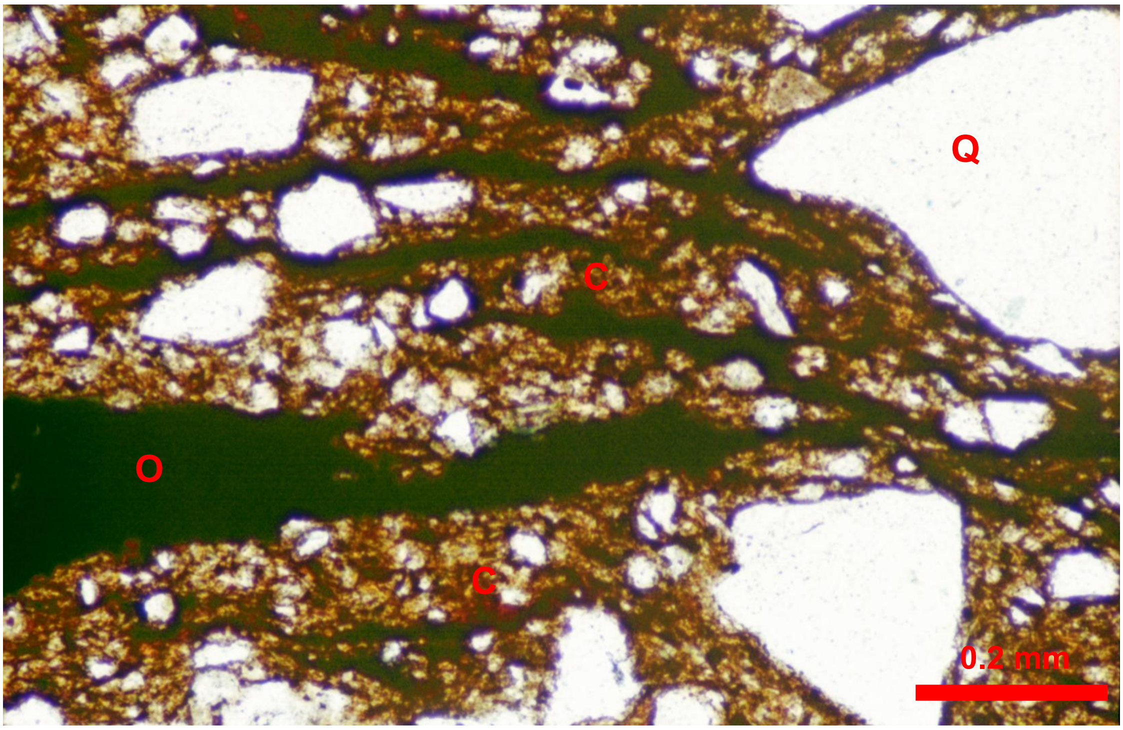
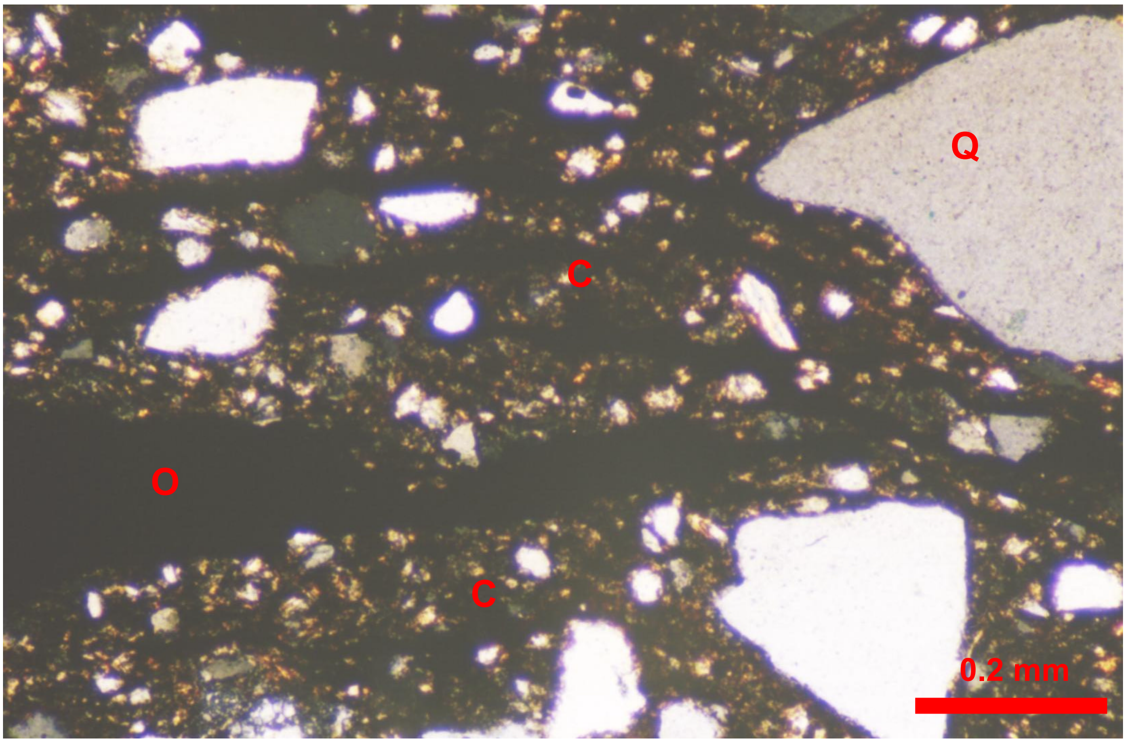


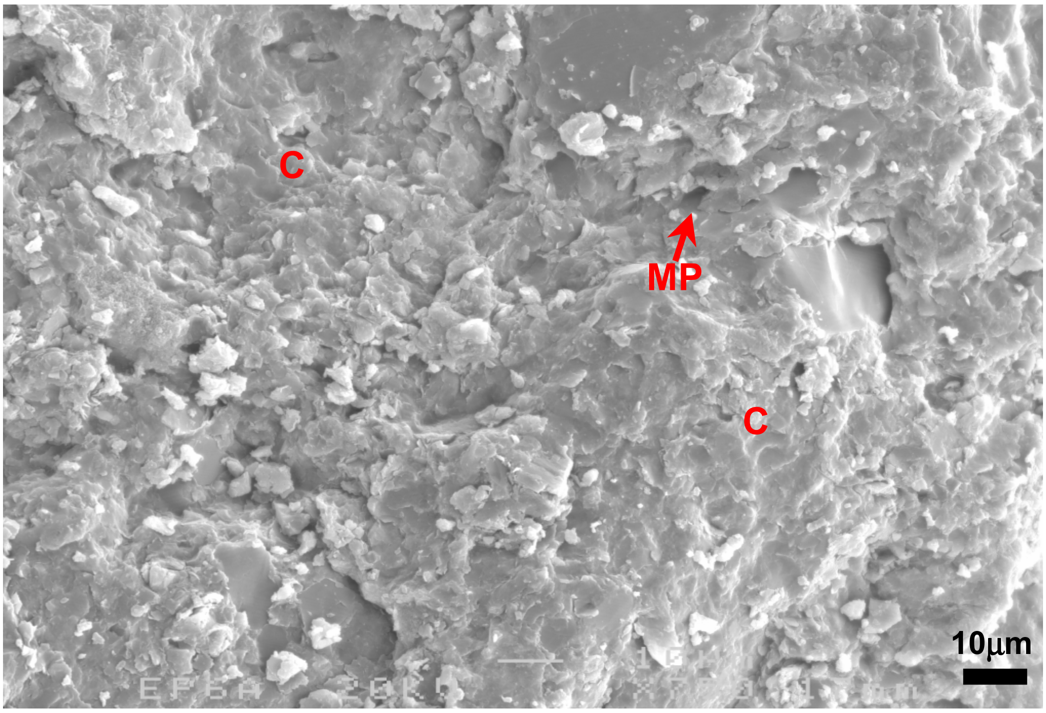
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



The main constituents of this well compacted mudrock are detrital clay (C), quartz grains (Q) and semi-aligned coaly fragments (O). The measured permeability value of 19.5md is anomalously high due to fracturing.

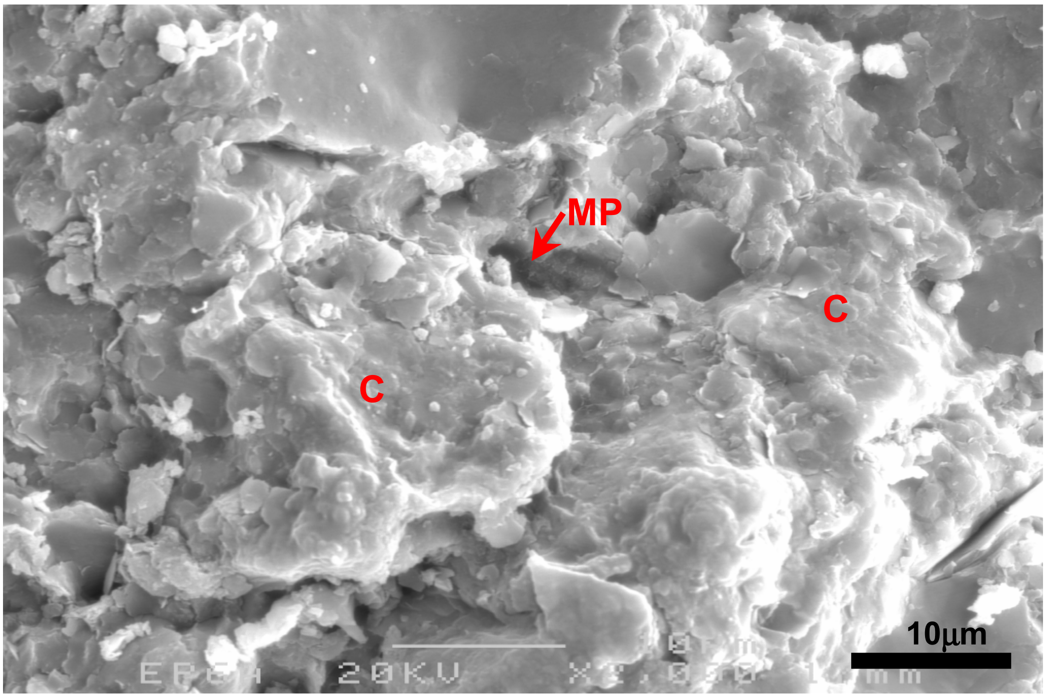
PLATE 24: #9 2633.5mRT cont.

FIGURE 1



Representative area in which well-compacted clay matrix (C) contains no macropores and few micropores (MP).

FIGURE 2



Detail of tightly packed, detrital illitic and kaolinitic clay matrix (C). Micropores (MP) that are associated with clay matrix and organic fragments would account for virtually all of the small amount of porosity in the sample. Permeability would be negligible.

PLATE 25: #11 2644.0mRT

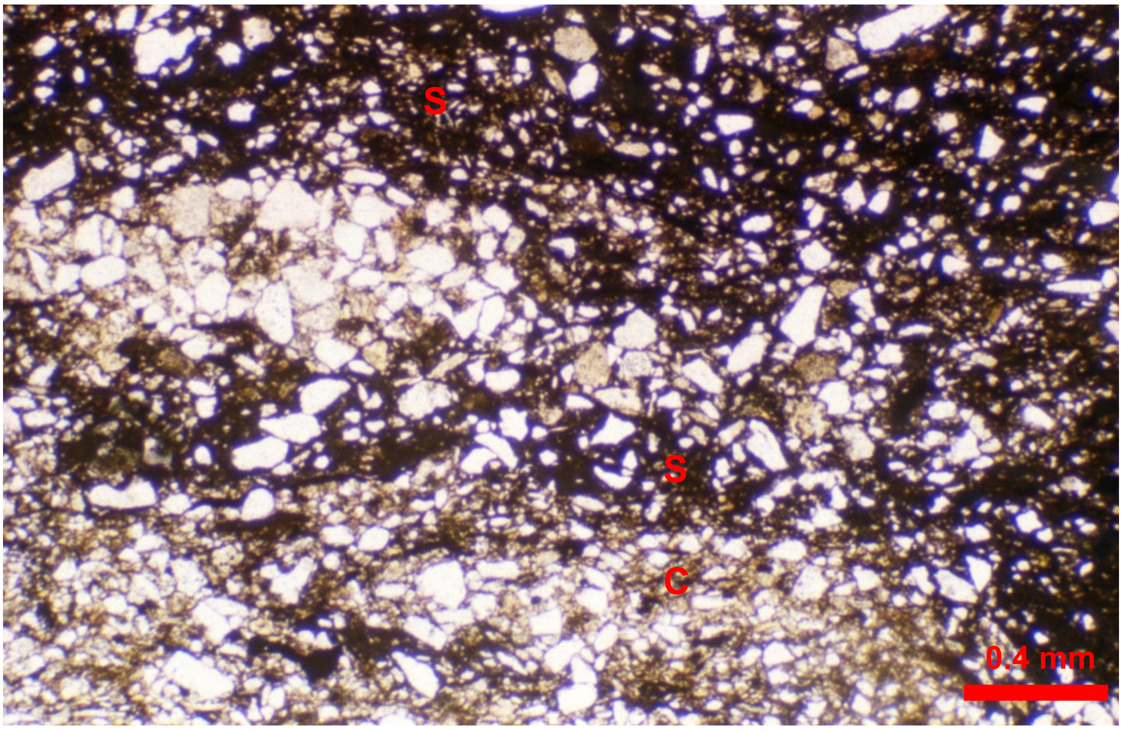
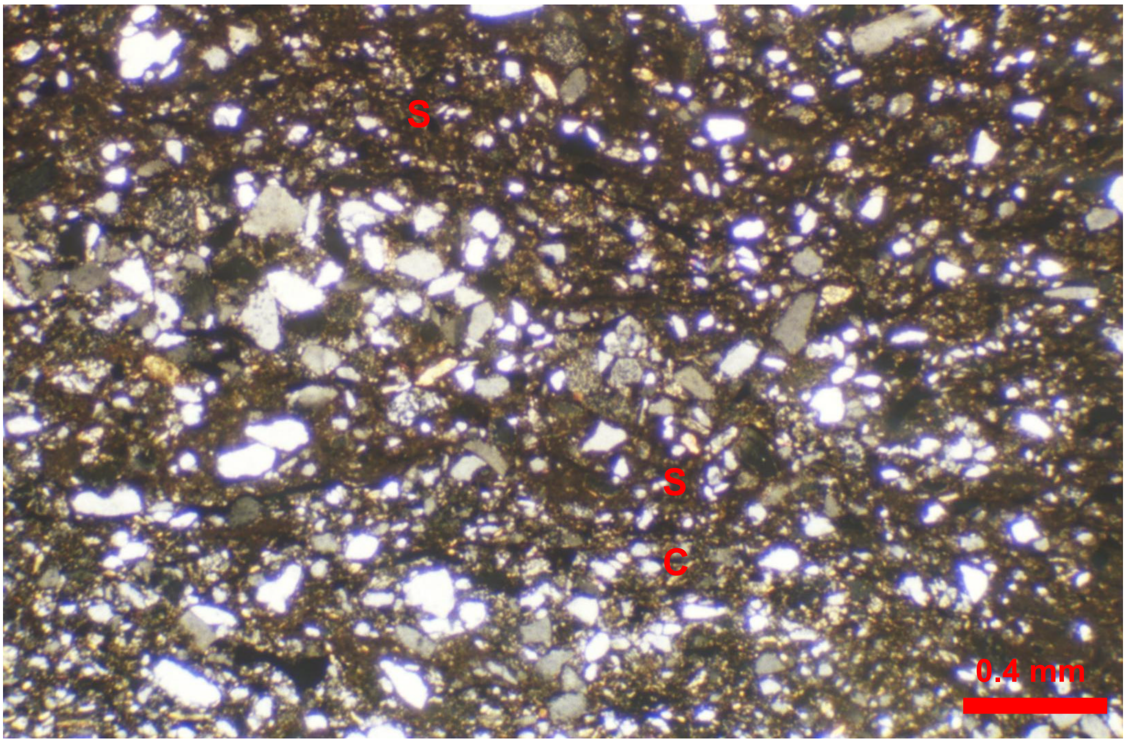


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Arenaceous mudrock in which unevenly distributed detrital clay matrix (C) is extensively replaced by microcrystalline siderite (S), particularly in areas where clay matrix is abundant. All intergranular areas are filled by clay and siderite. K = 0.001md

PLATE 26: #11 2644.0mRT cont.

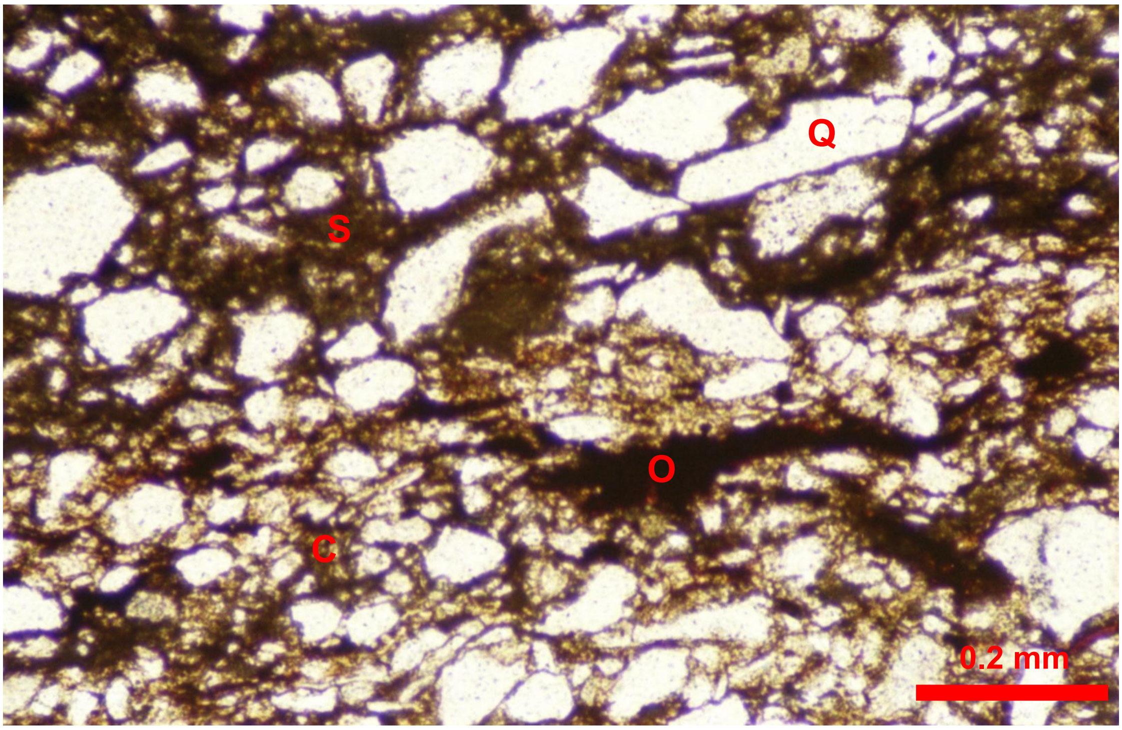
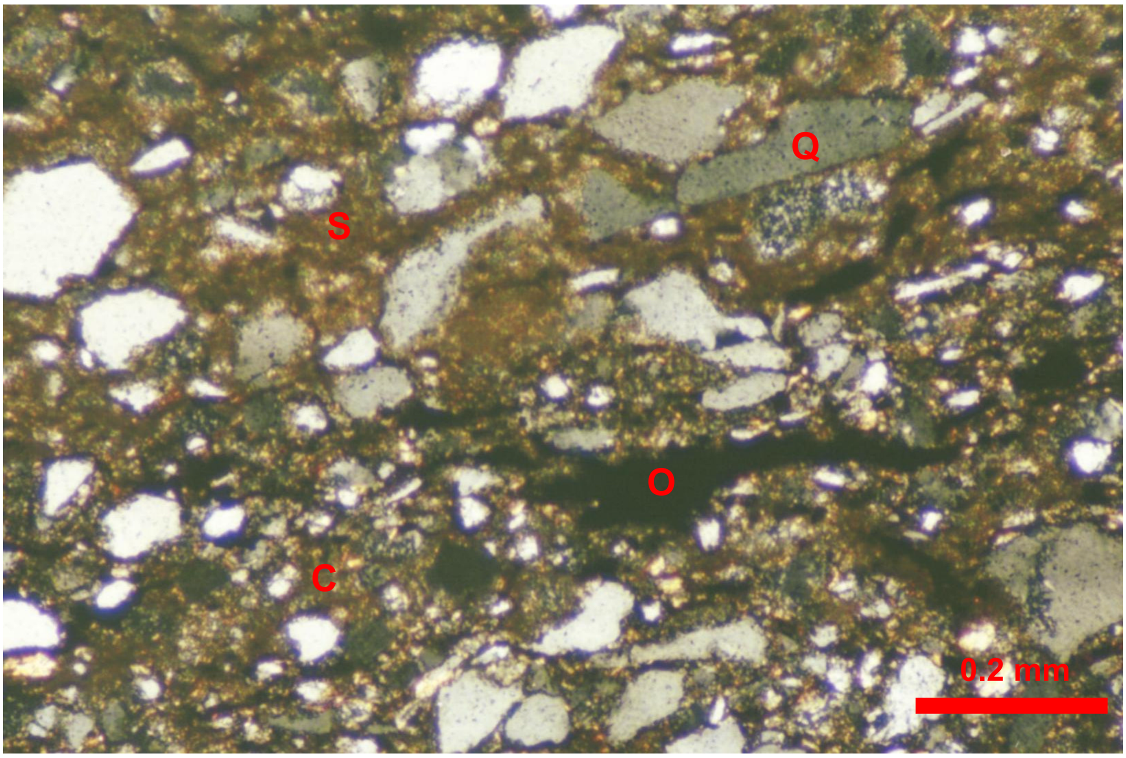


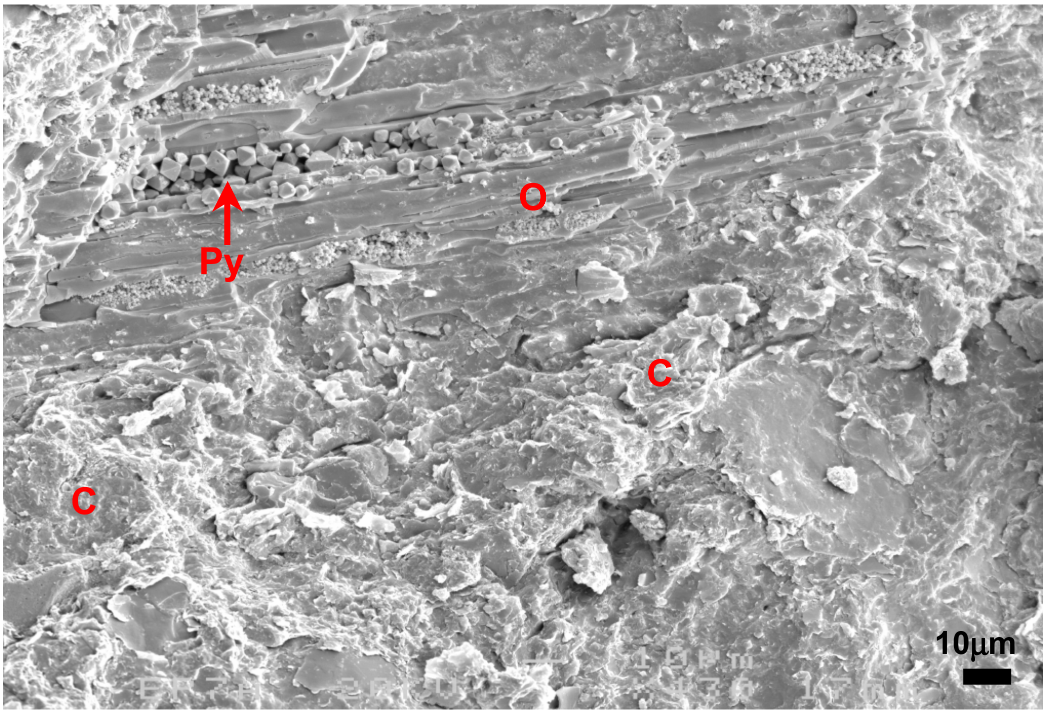
FIGURE 1	Plane polarised light
FIGURE 2	Crossed polarisers



Microcrystalline siderite (S) largely replaces detrital clay matrix (C) that supports organic fragments (O) and silt- and sand-sized quartz grains (Q). K = 0.001md

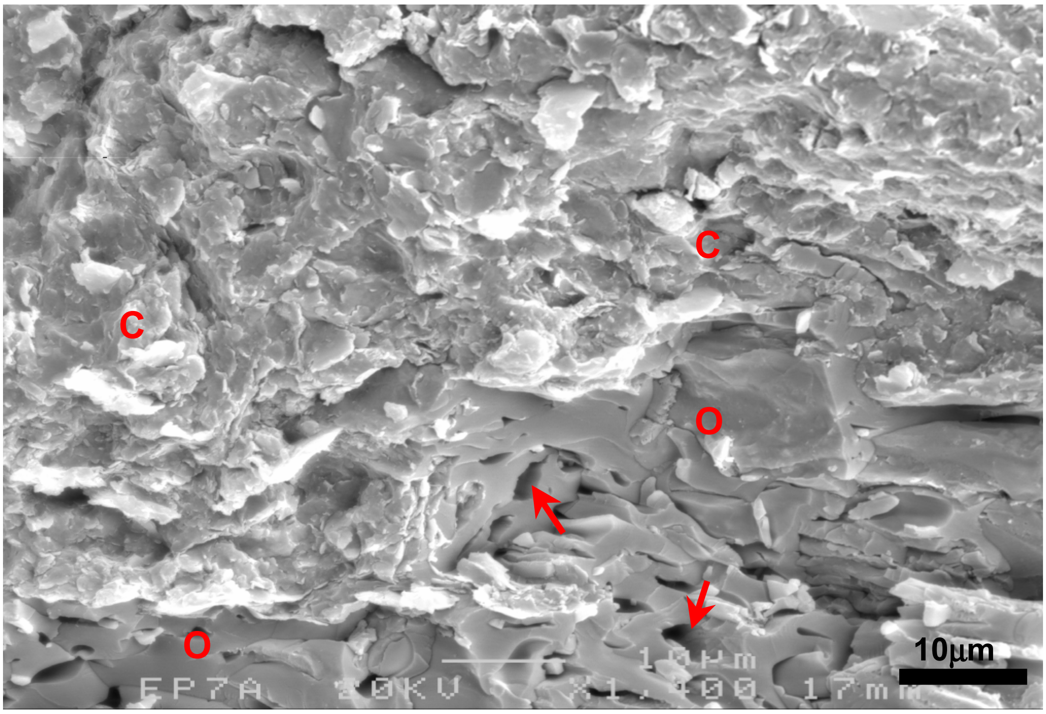
PLATE 27 #11 2644.0mRT cont.

FIGURE 1



An organic fragment (O) is supported by densely packed detrital clay matrix (C) that contains little microporosity. Fine pyrite euhedra (Py) have precipitated within the organic fragment.

FIGURE 2



An organic fragment (O), in which there are remnants of cell lumen (arrows), occurs within densely packed illitic and kaolinitic detrital clay matrix (C) that is almost devoid of microporosity.

PLATE 28: #12 2652.0mRT

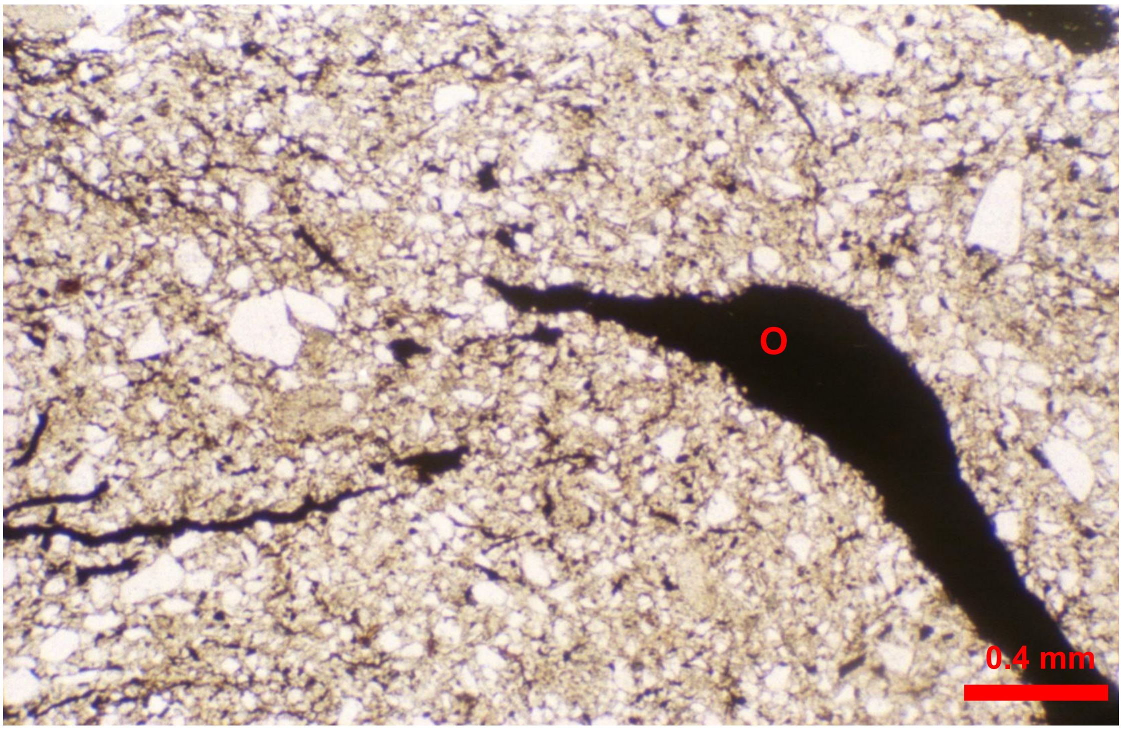
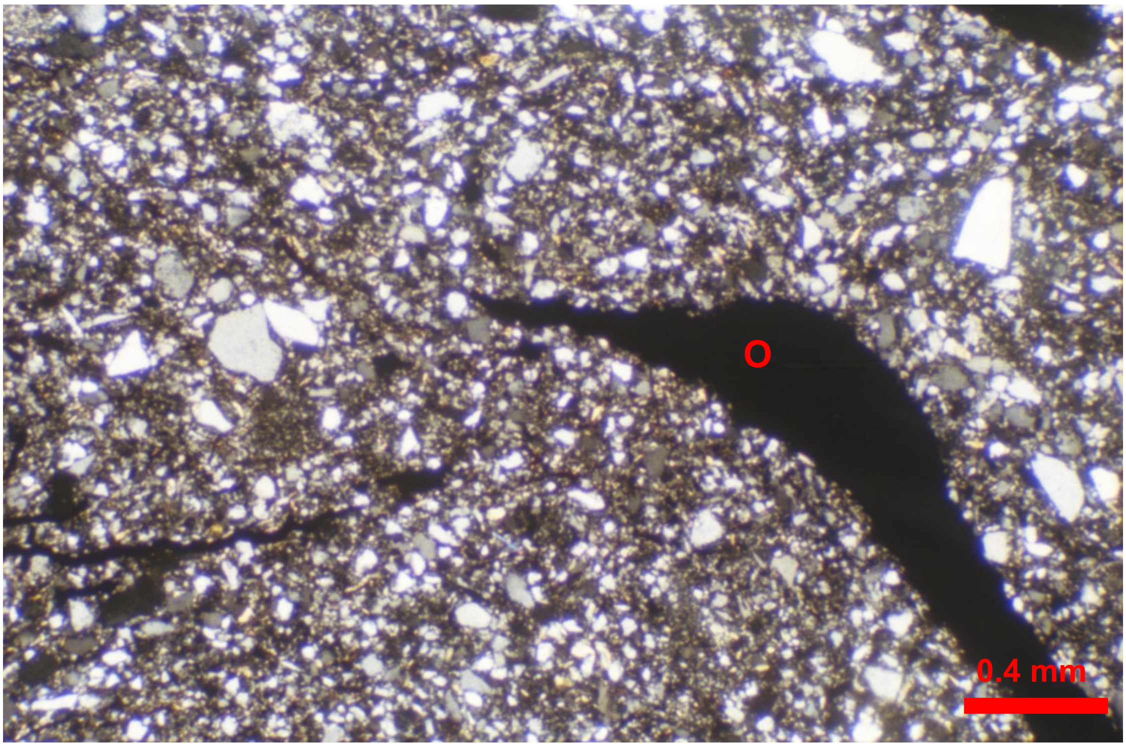


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



This moderately sorted, argillaceous siltstone contains common coaly fragments and stringers (O), many of which are not aligned parallel to bedding. K = 0.018md

PLATE 29: #12 2652.0mRT cont.

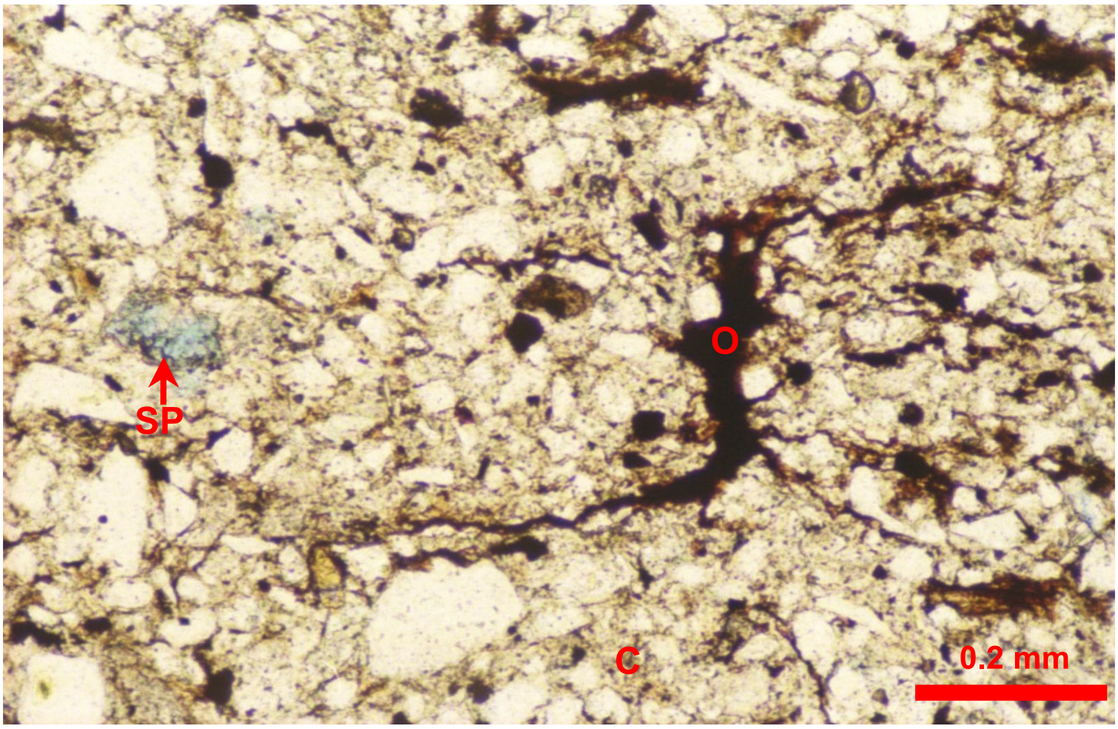
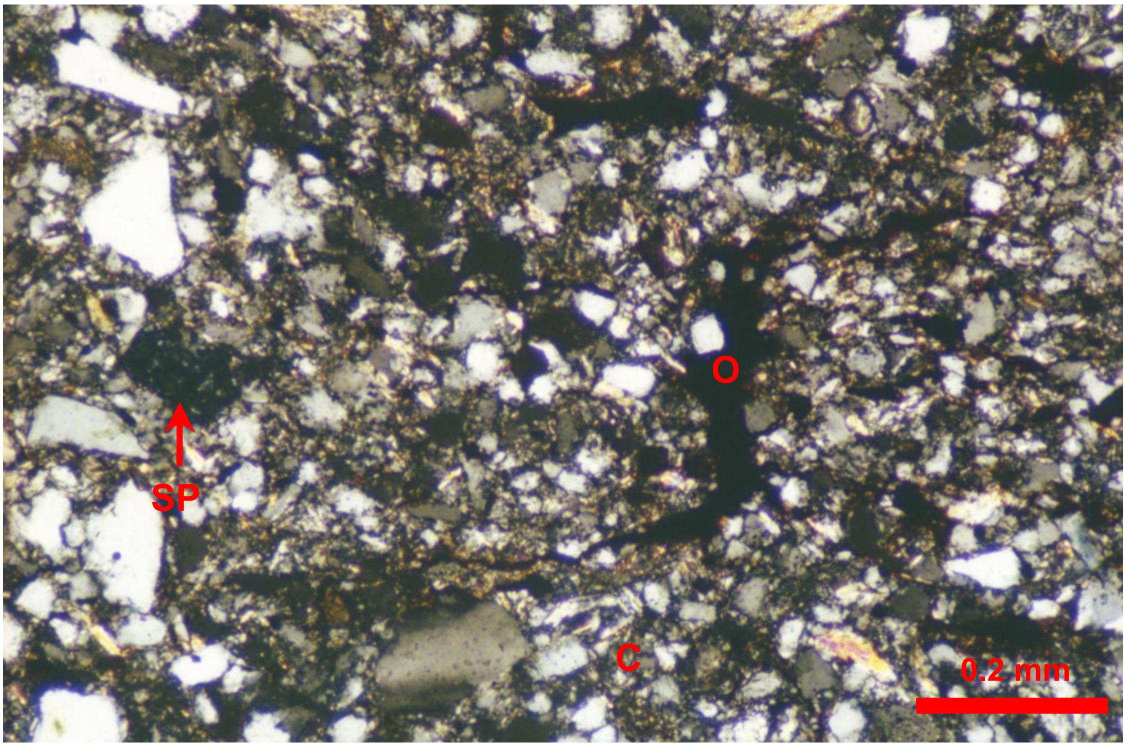


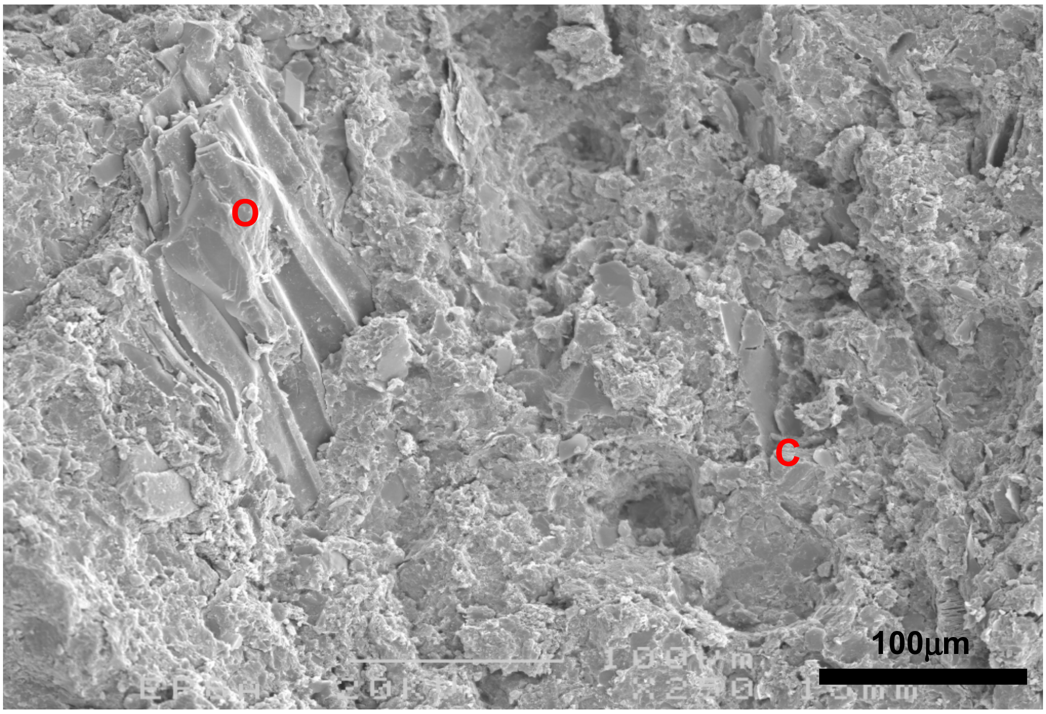
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



A rare secondary mouldic pore (SP) has formed by labile grain dissolution in an argillaceous siltstone in which all intergranular areas are filled by detrital clay matrix (C). Organic fragments (O) are commonly oriented perpendicular to bedding. K = 0.018md

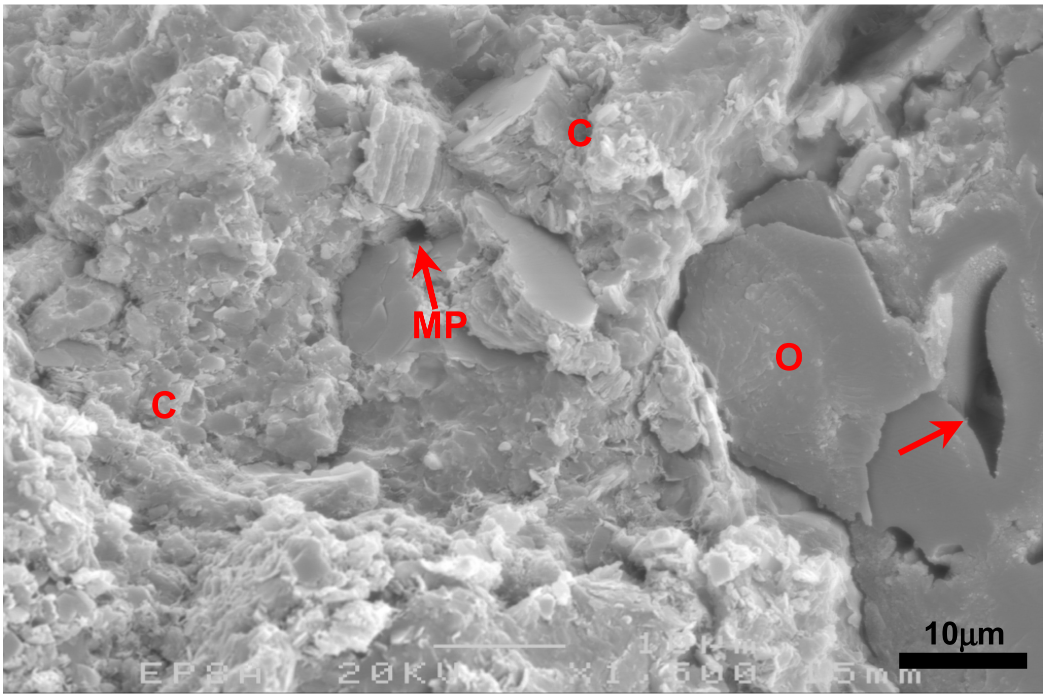
PLATE 30: #12 2652.0mRT cont.

FIGURE 1



SEM micrograph showing a representative area in which well-compacted detrital clay matrix (C) supports an organic fragment (O). Macroporosity is absent and permeability is consequently negligible.

FIGURE 2



An organic fragment (O) occurs within illitic and kaolinitic detrital clay matrix (C) that is densely packed and thus contains little microporosity (MP). A cell lumen (arrow) is preserved within the organic fragment.

PLATE 31: #13 2663.0mRT

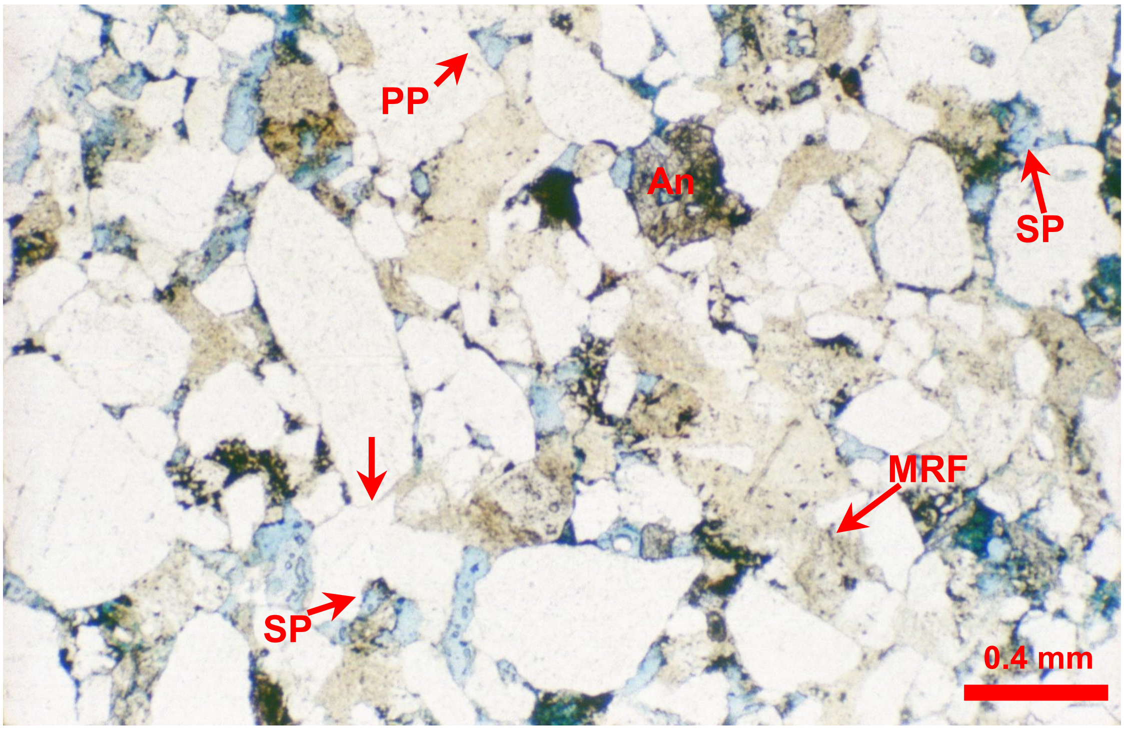
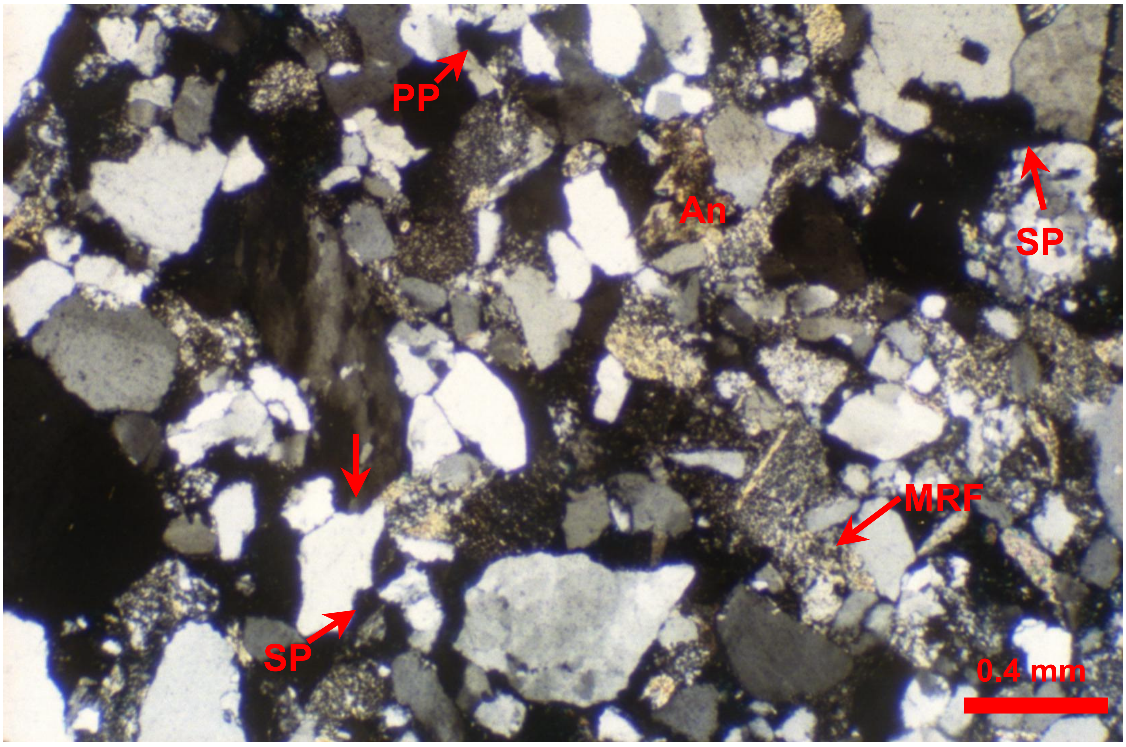


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Although primary pores (PP) and secondary pores (SP) are common, the pores have only moderate interconnectivity due mainly to the porosity-reducing effects of grain contact dissolution (arrow) and compaction of common micaceous/illitic metamorphic rock fragments (MRF). The sandstone is poorly cemented by ankerite (An) and quartz overgrowths (too small to be visible in micrographs). K = 30.8md

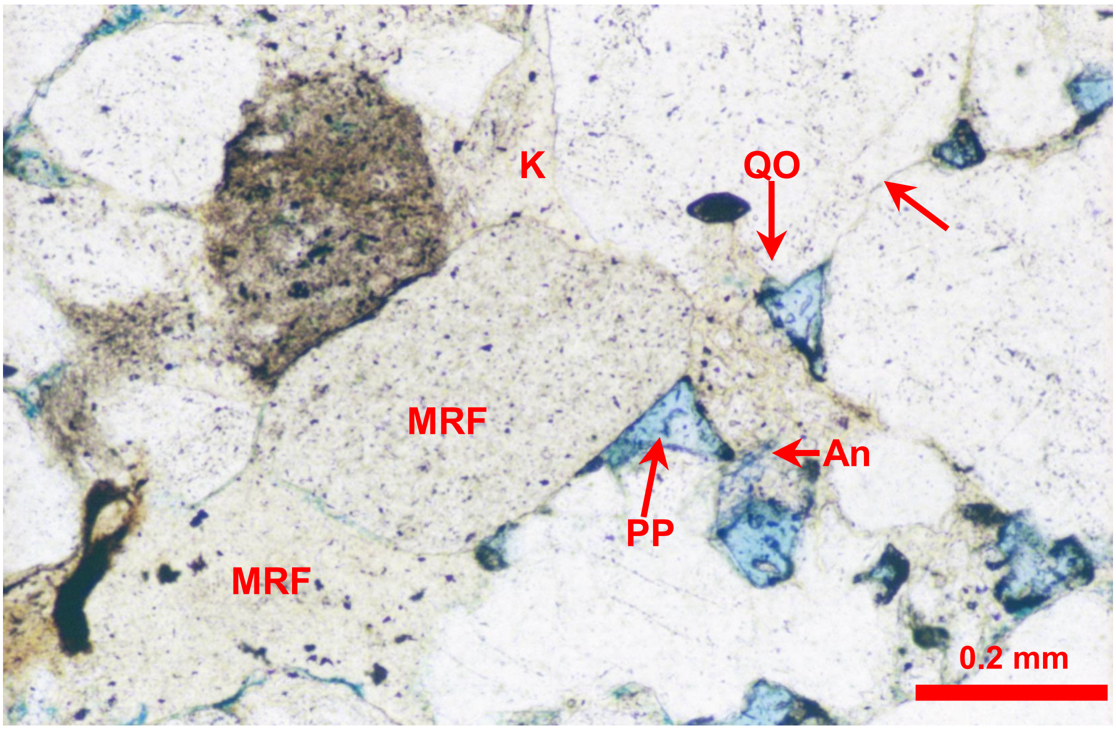
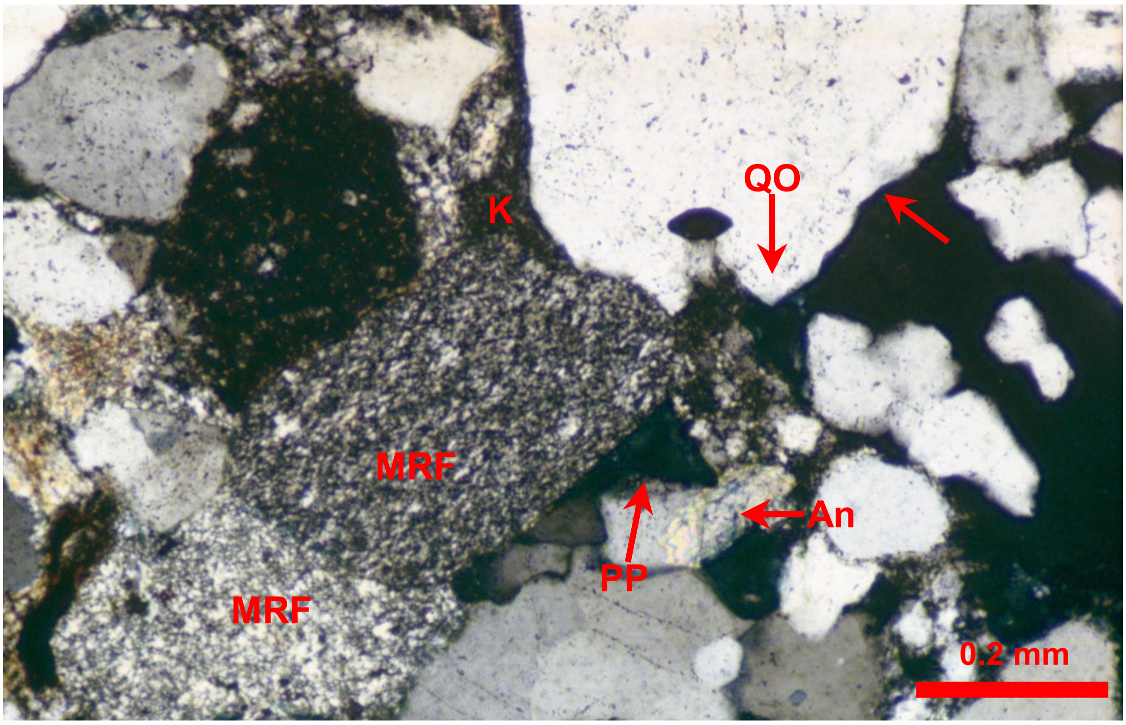


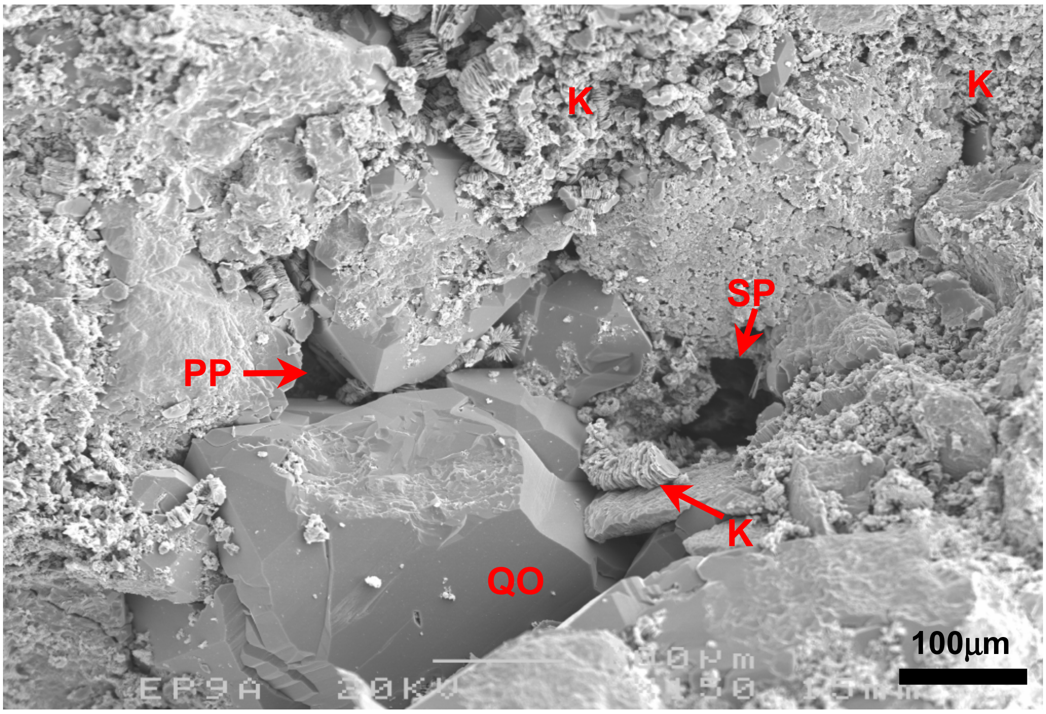
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Small primary intergranular pores (PP) are preserved in a sandstone in which there has been significant porosity reduction by compaction of fine illitic metamorphic rock fragments (MRF), authigenic kaolinite (K) formation, and grain contact dissolution (arrow). Intergranular pores are partly occupied by minor quartz overgrowth (QO) and ankerite (An) (stained blue) cement. K = 30.8md

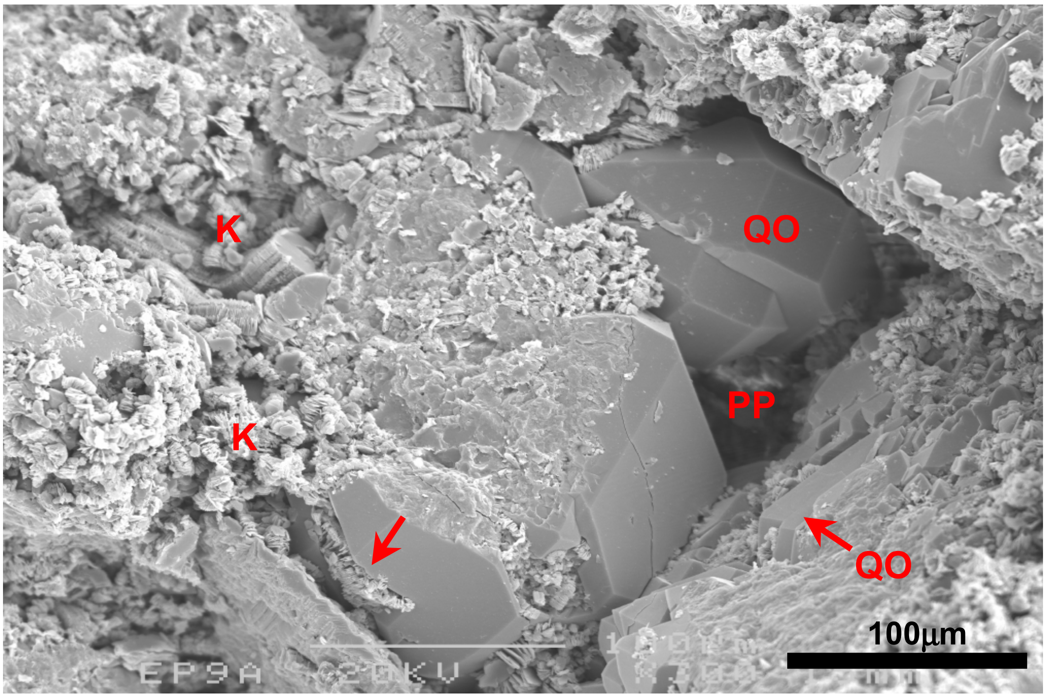
PLATE 33: #13 2663.0mRT cont.

FIGURE 1



A primary intergranular pore (PP) and a secondary grain dissolution pore (SP) would have limited interconnectivity with other macropores in the vicinity due to pore filling by authigenic kaolinite (K) and, of much less importance, localised quartz overgrowths (QO).

FIGURE 2



Quartz overgrowths (QO) only occupy a small portion of a primary intergranular pore (PP) that is preserved between juxtaposed quartz grains. Elsewhere, intergranular spaces are filled by authigenic kaolinite (K) that is the altered remnant of compacted micaceous labile grains. Some authigenic kaolinite is enclosed (arrow) by later formed quartz overgrowths.

PLATE 34: #14 2669.0mRT

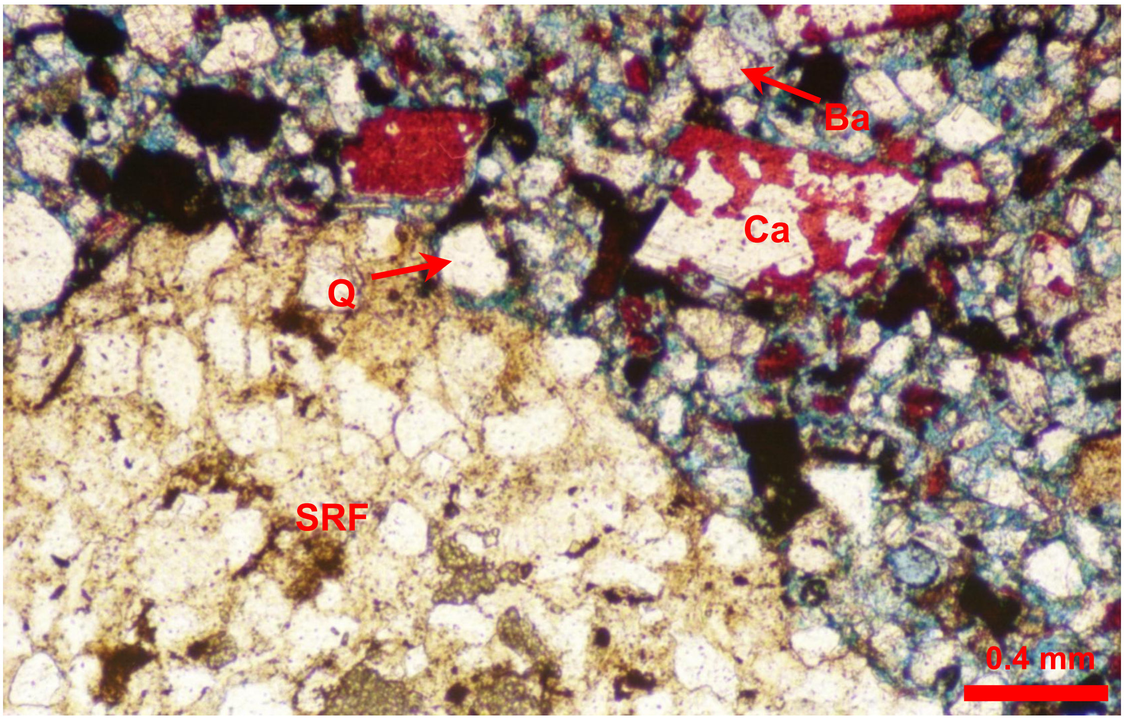
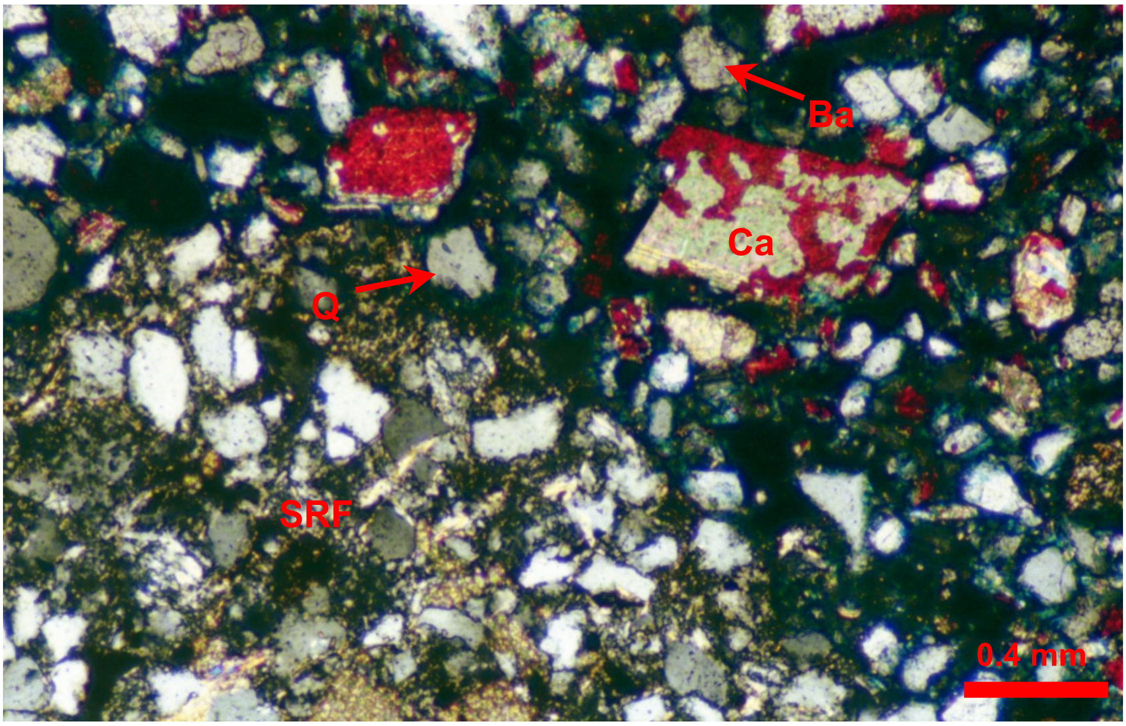


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



This sample is composed mainly of contaminant calcite (Ca) (stained red), barite (Ba) and loose quartz grains (Q) and also includes rare fragments of argillaceous, very fine grained sandstone (SRF).

PLATE 35: #14 2669.0mRT cont.

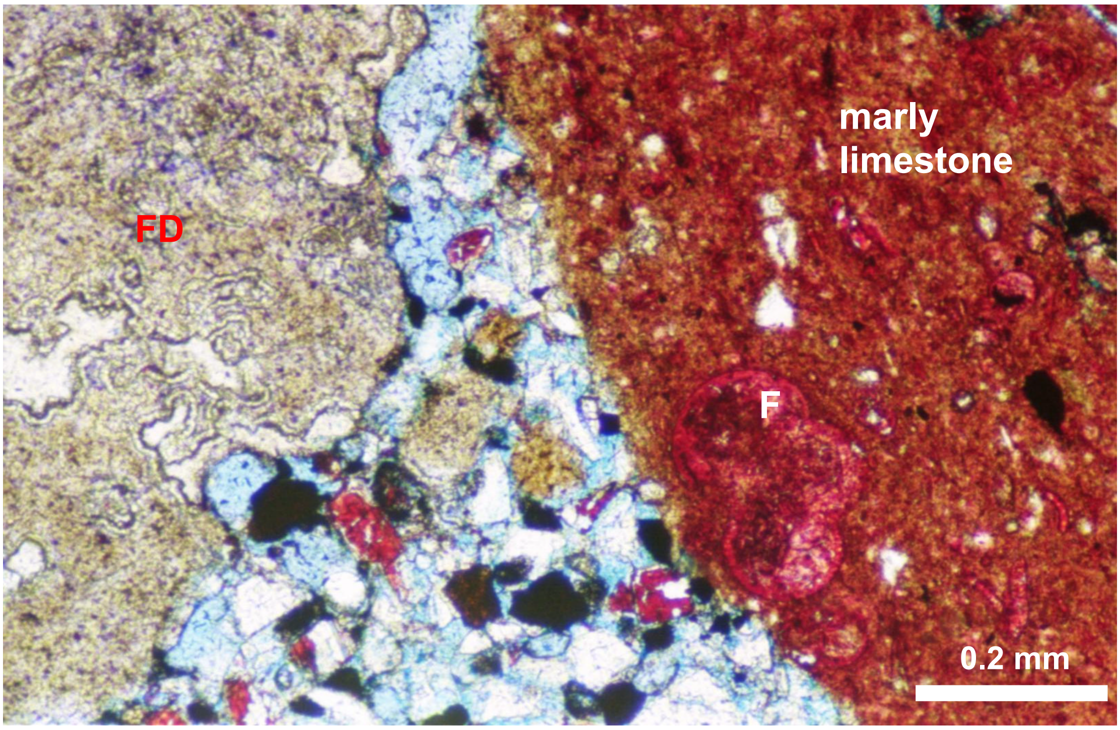
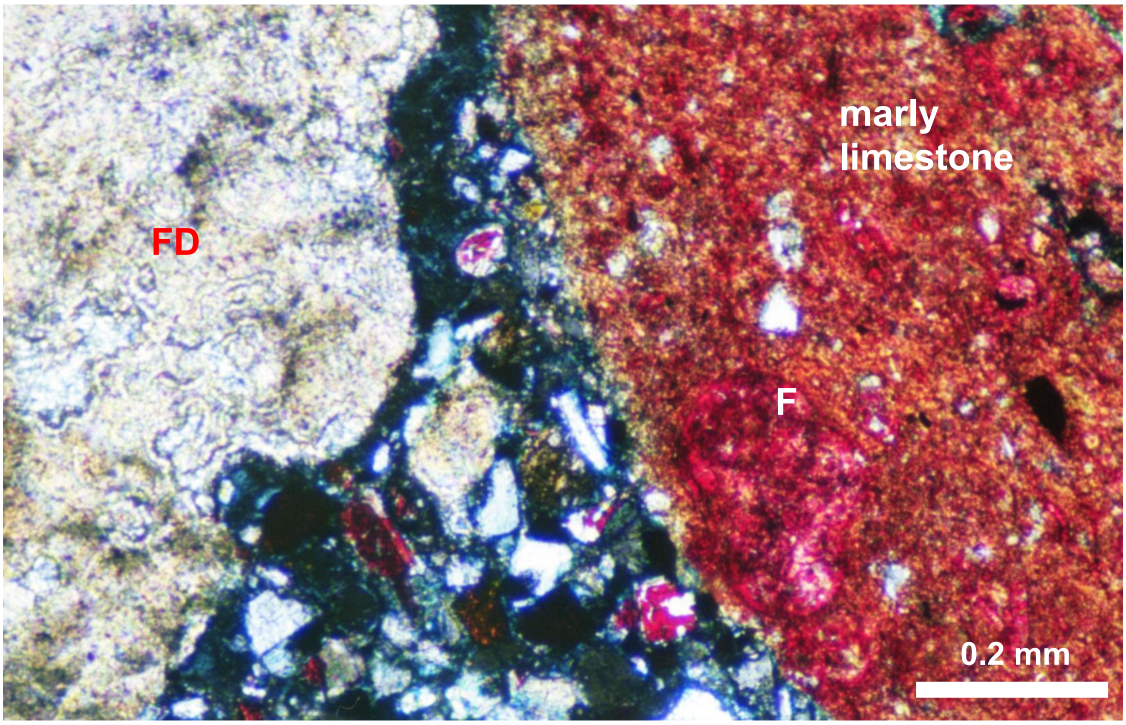


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Components of the sample include rare contaminant fragments of marly foram (F)-bearing limestone (stained red) and ferroan dolomite/ankerite cement (FD). The sample provides no indication of lithology at the sample depth.

PLATE 36: #15 2700.5mRT

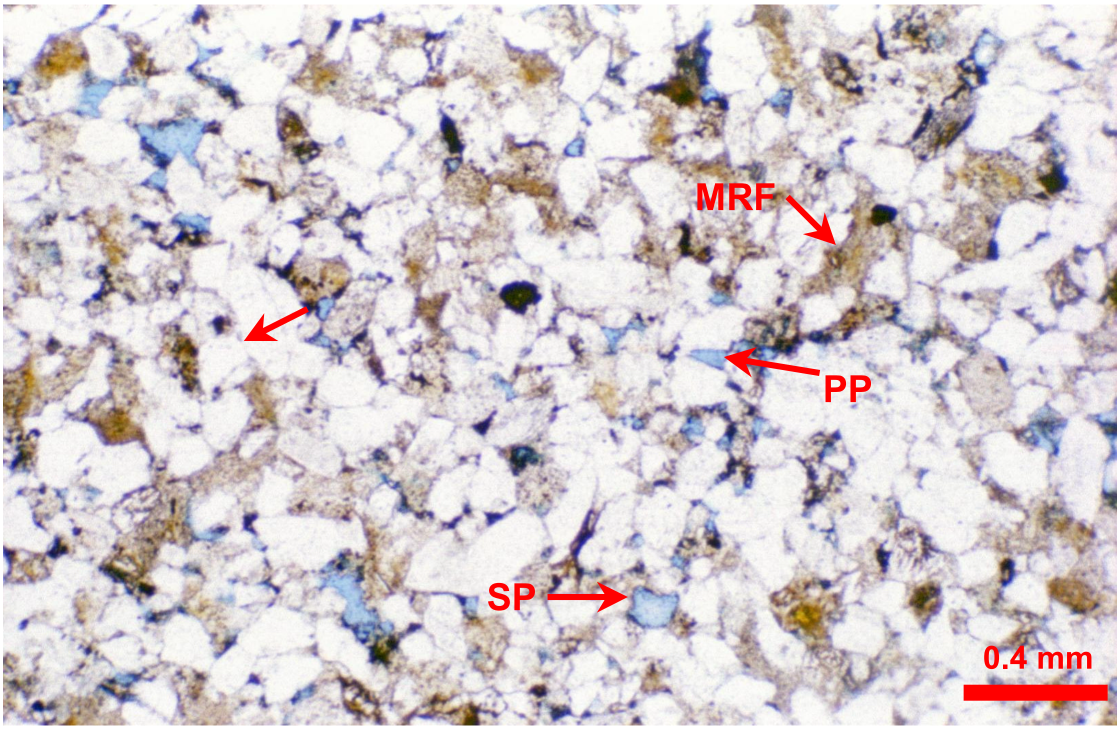
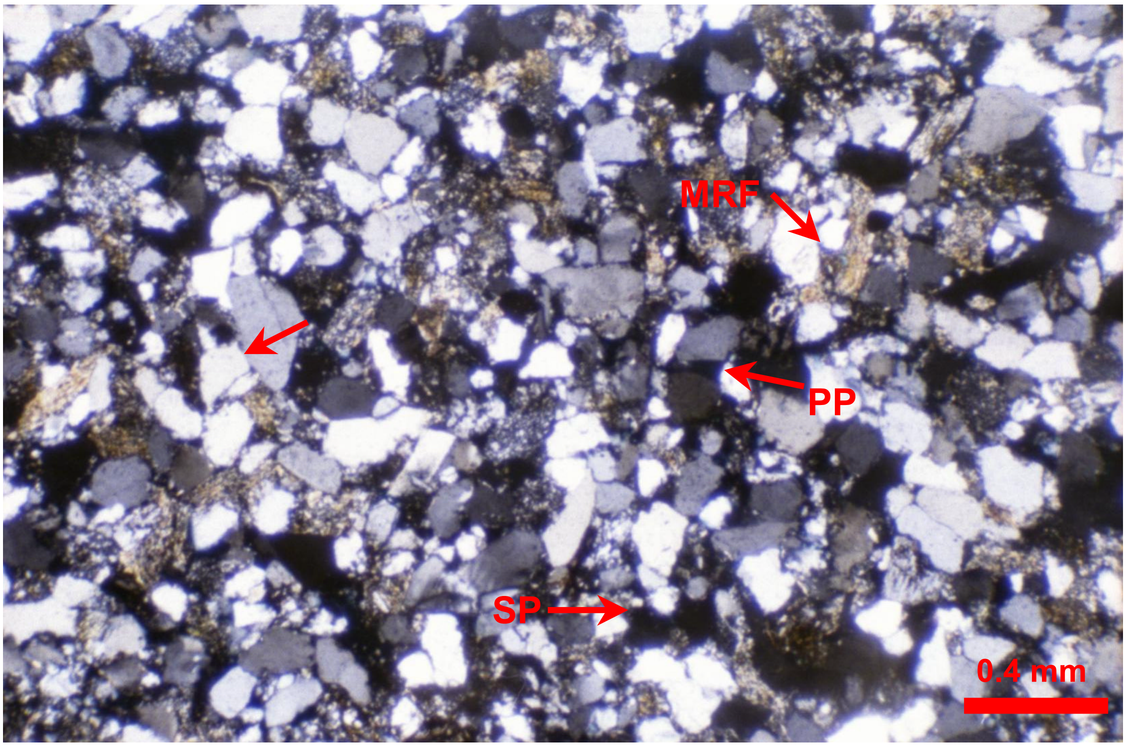


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Fine grained sandstone in which intergranular porosity has been largely eliminated by grain contact dissolution (arrow), compaction of common micaceous metamorphic rock fragments (MRF), and localised quartz overgrowth cementation. Primary intergranular pores (PP) and secondary grain dissolution pores (SP) are too widely separated to be well interconnected. K = 0.73md

PLATE 37: #15 2700.5mRT cont.

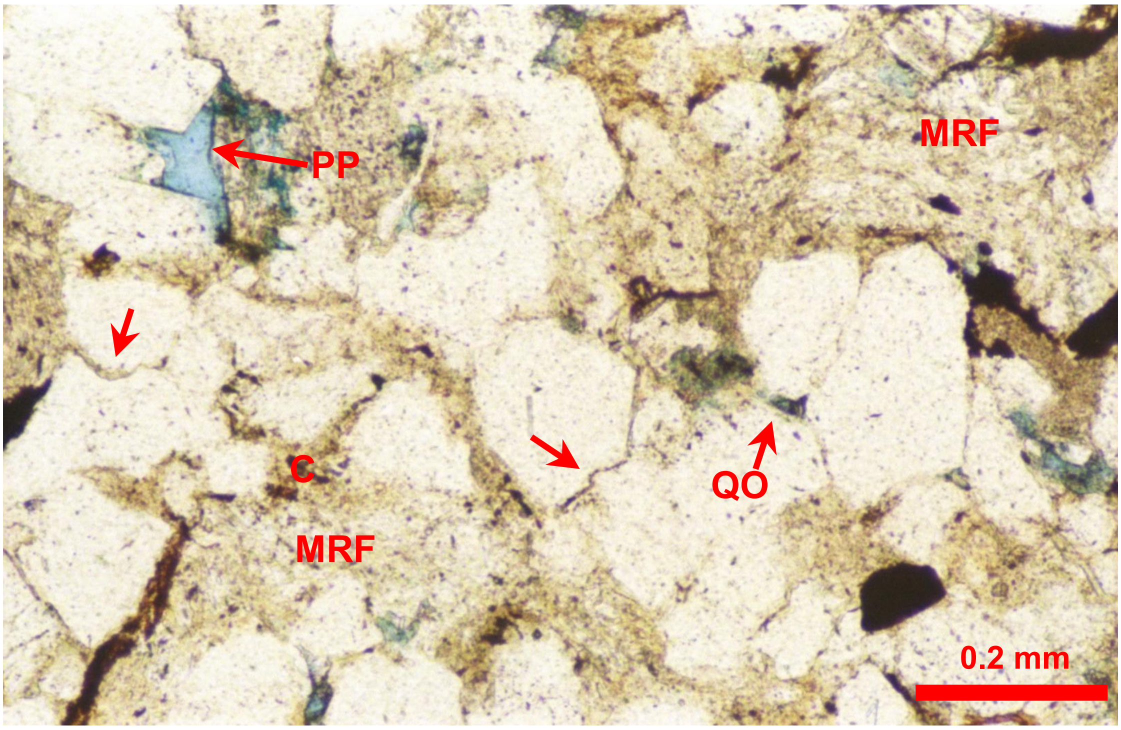
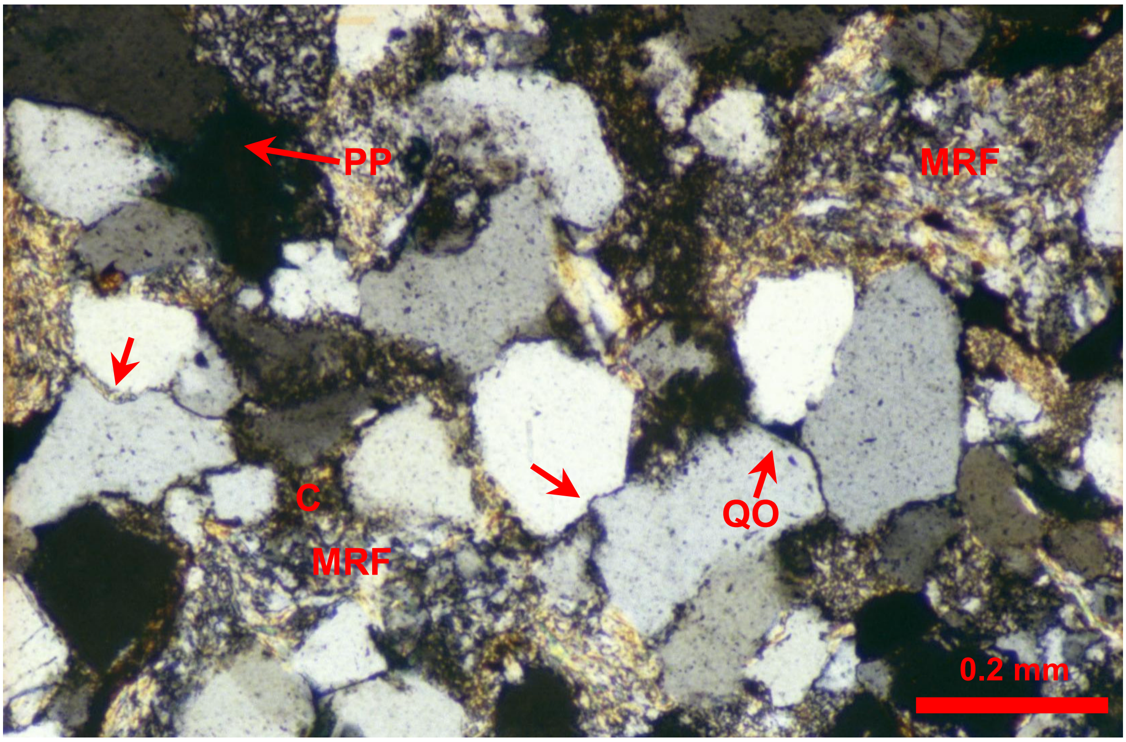


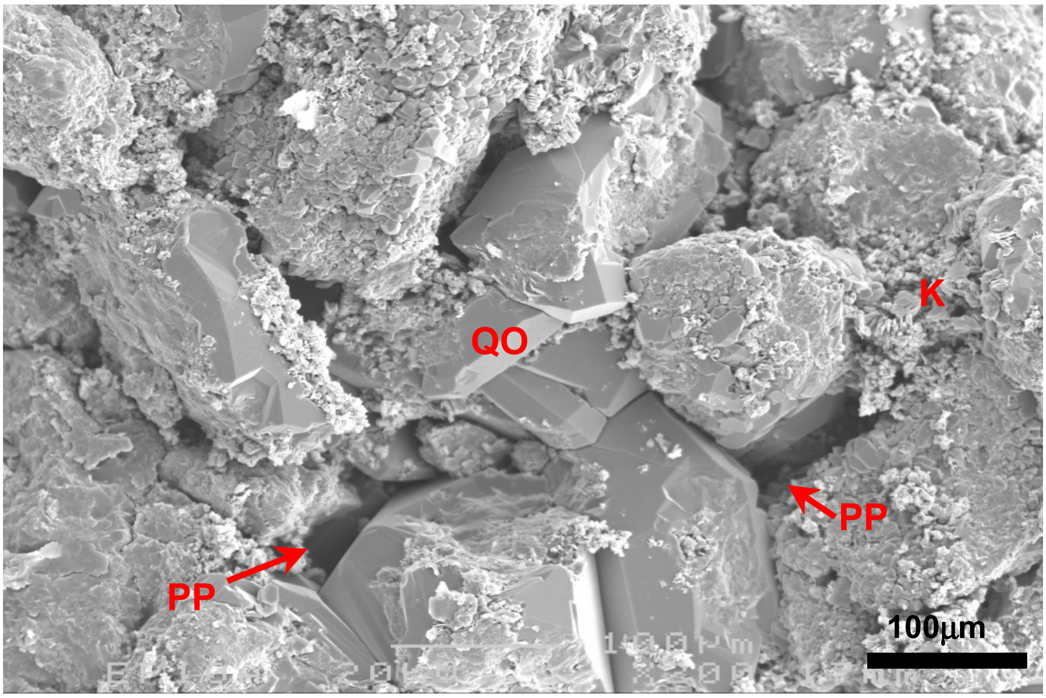
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



An isolated primary intergranular pore (PP) is preserved in a sandstone where there has been extensive intergranular porosity loss by compaction of micaceous/illitic metamorphic rock fragments (MRF), grain welding by grain contact dissolution (arrows), and pore filling by detrital clay matrix (C) and localised quartz overgrowths (QO). K = 0.73md

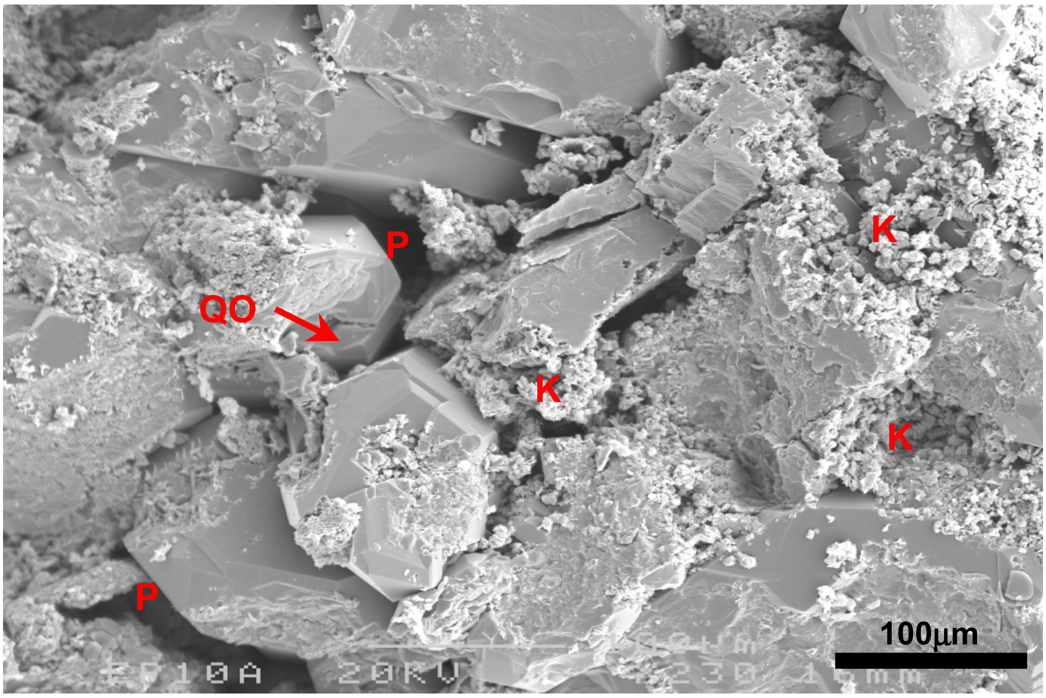
PLATE 38: #15 2700.5mRT cont.

FIGURE 1



Primary intergranular pores (PP) are restricted to areas where quartz grains are juxtaposed, but even in these areas, pores are largely filled by authigenic kaolinite (K) and quartz overgrowth cement (QO).

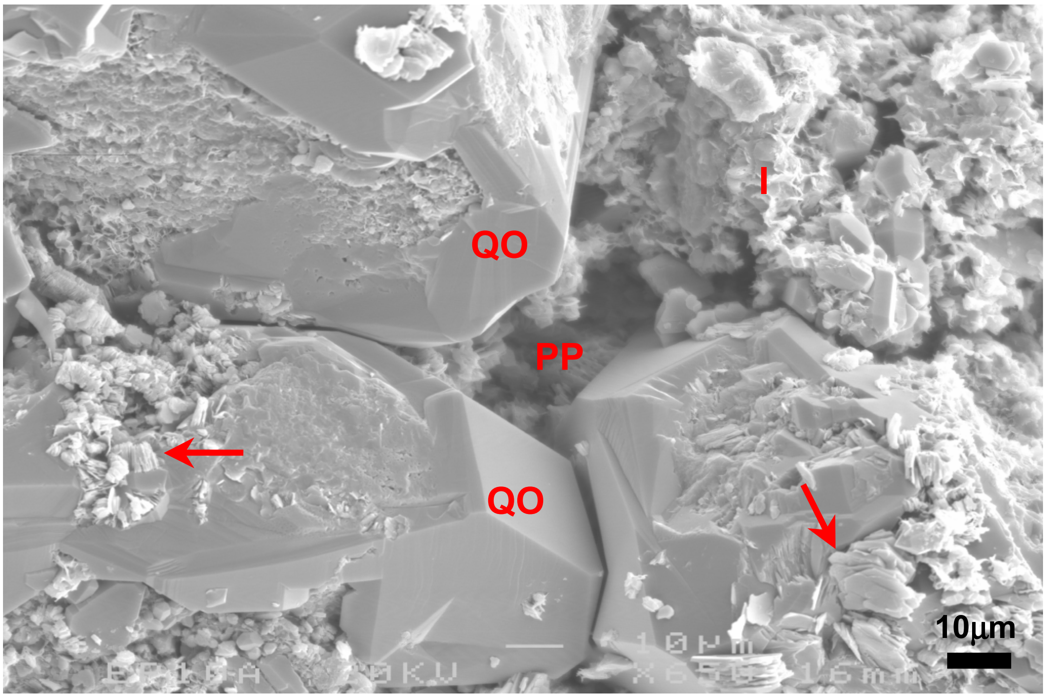
FIGURE 2



Pore throats between intergranular pores (P) are largely choked by authigenic kaolinite (K) and quartz overgrowths (QO). With most intergranular spaces being filled by compacted rock fragments, clay and quartz overgrowths, permeability is low (0.73md).

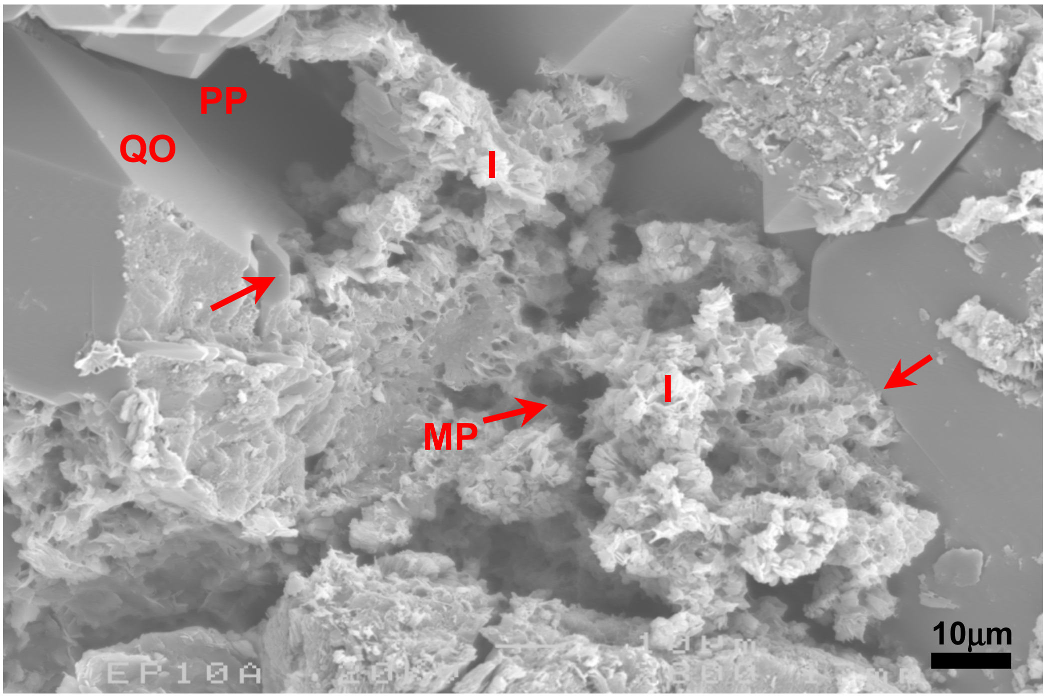
PLATE 39: #15 2700.5mRT cont.

FIGURE 1



A small primary intergranular pore (PP) is bounded by quartz grains that are thinly enveloped by quartz overgrowths (QO) and by a metamorphic rock fragment that has altered to illite (I). Quartz overgrowths enclose (arrows) earlier formed authigenic kaolinite.

FIGURE 2



A micaceous metamorphic rock fragment has altered to illite (I) that is enclosed (arrows) by later formed quartz overgrowths (QO). The presence of the illite, which is highly microporous (MP), would decrease connectivity between a primary pore (PP) and other macropores in the vicinity.

PLATE 40: #17 2721.5mRT

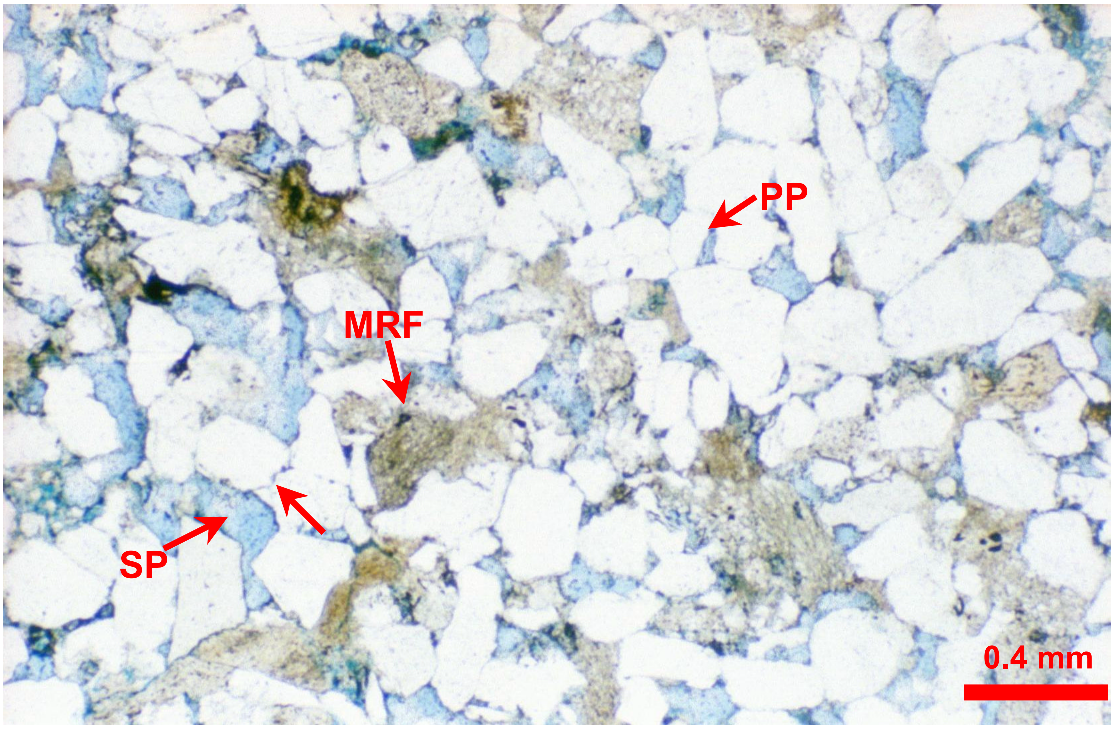
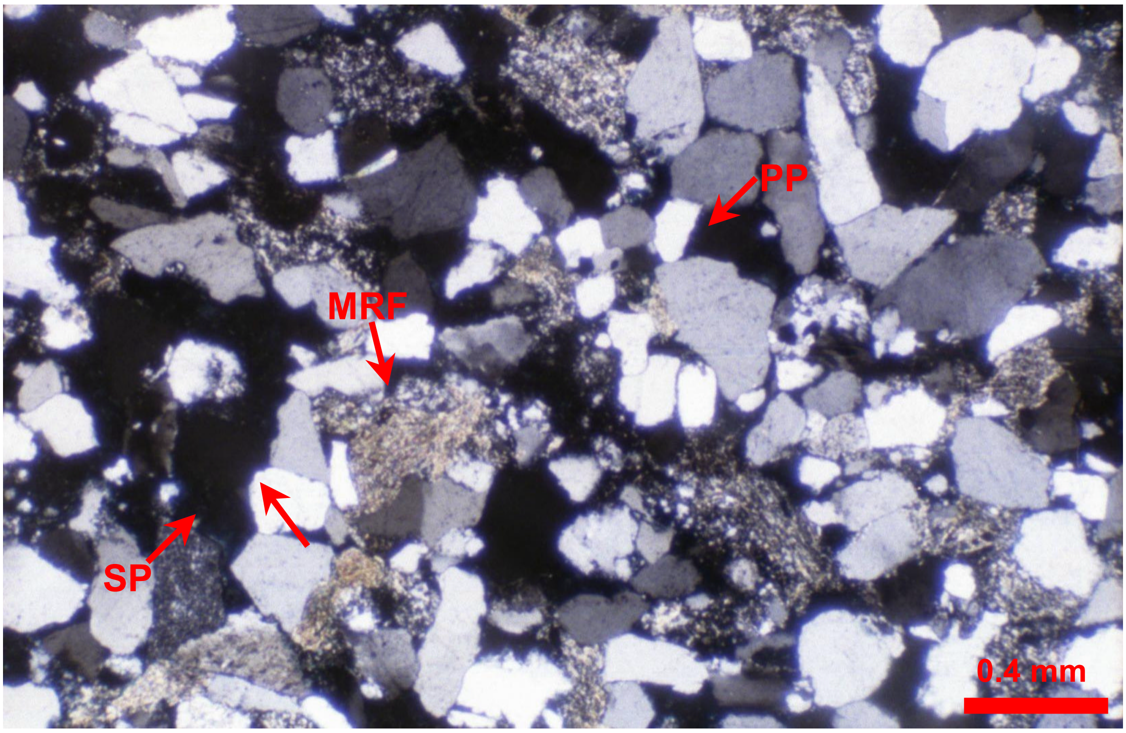


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Despite porosity reduction by grain contact dissolution (arrow), micaceous/illitic metamorphic rock fragment (MRF) compaction and minor quartz overgrowth cementation, this sandstone contains good primary intergranular porosity (PP) that is supplemented by common secondary intergranular pores (SP) that are the result of labile grain dissolution. K = 61.8md

PLATE 41: #17 2721.5mRT cont.

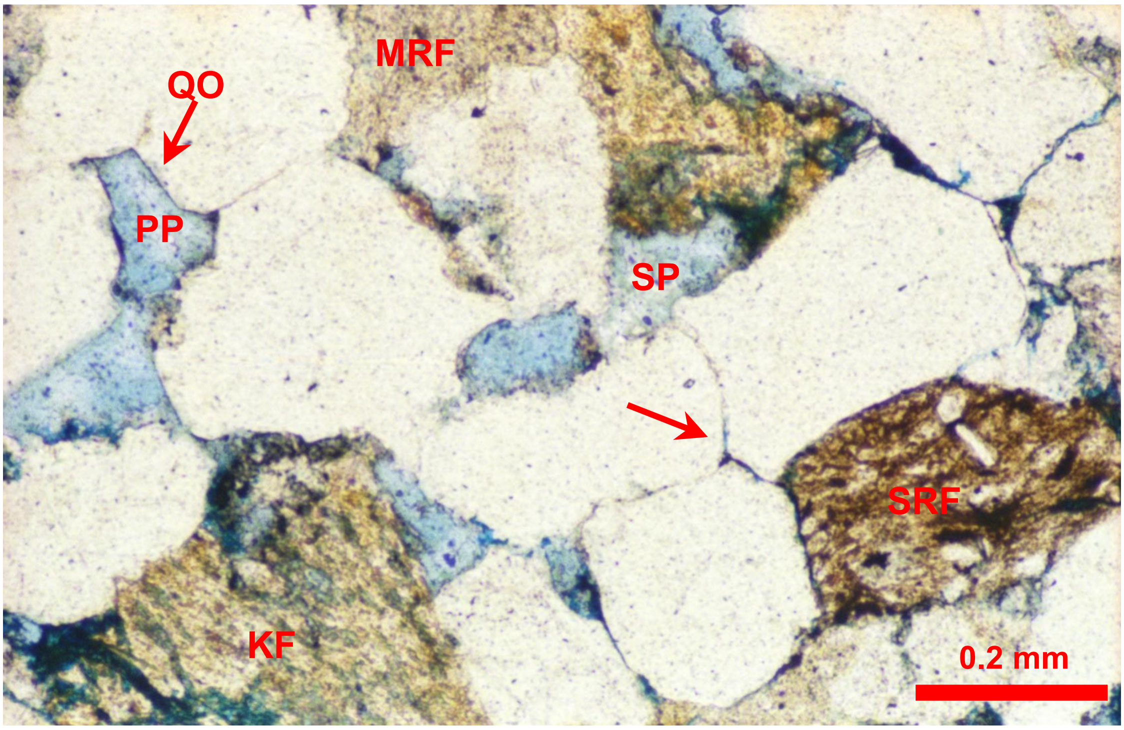
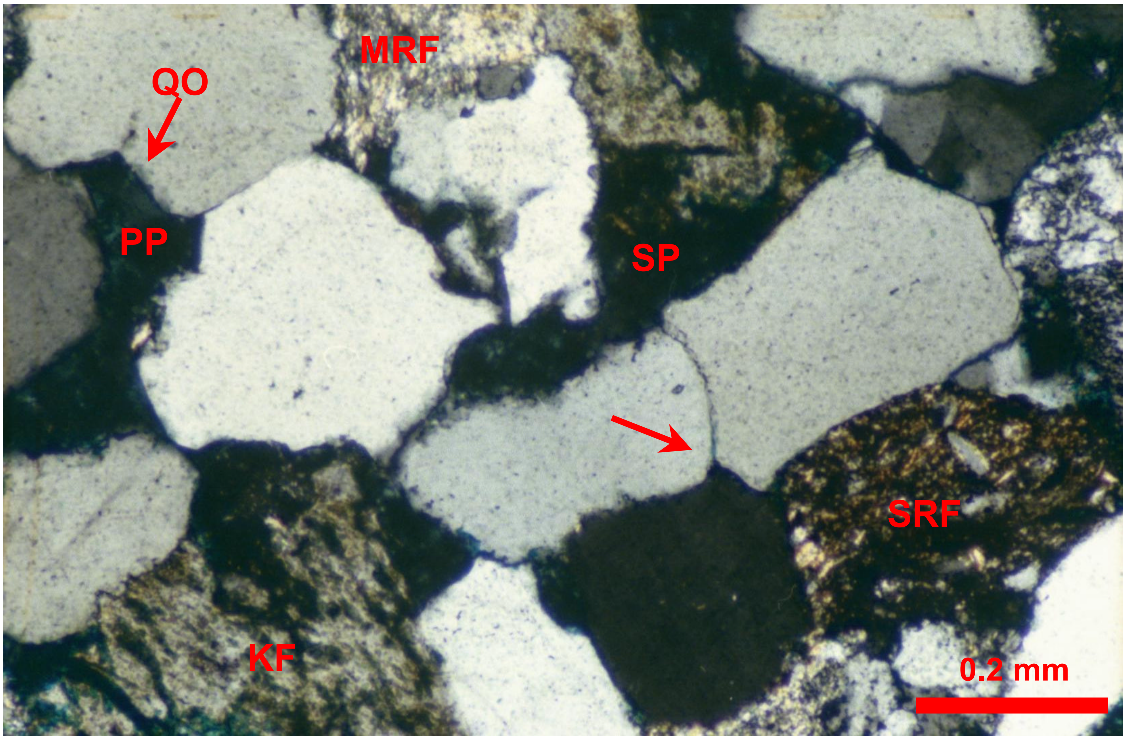


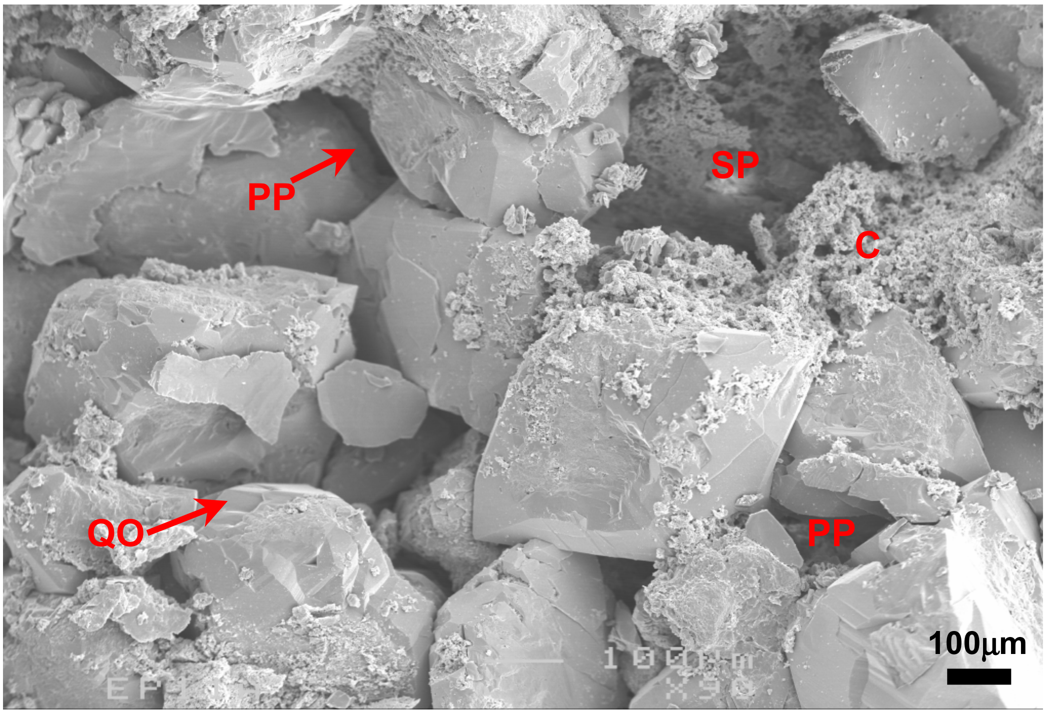
FIGURE 1	Plane polarised light
FIGURE 2	Crossed polarisers



A triple point grain junction (arrow) occurs where all intergranular space between juxtaposed quartz grains has been eliminated by grain contact dissolution and quartz overgrowth cementation. Porosity reduction in the field of view has also resulted from compaction of an argillaceous sedimentary rock fragment (SRF) and an illitic metamorphic rock fragment (MRF). Primary intergranular porosity (PP) is supplemented by scattered secondary pores (SP) that have formed by K-feldspar (KF) (stained yellow) dissolution. Although common, quartz overgrowths (QO) are only a volumetrically minor component of the rock. K = 61.8md

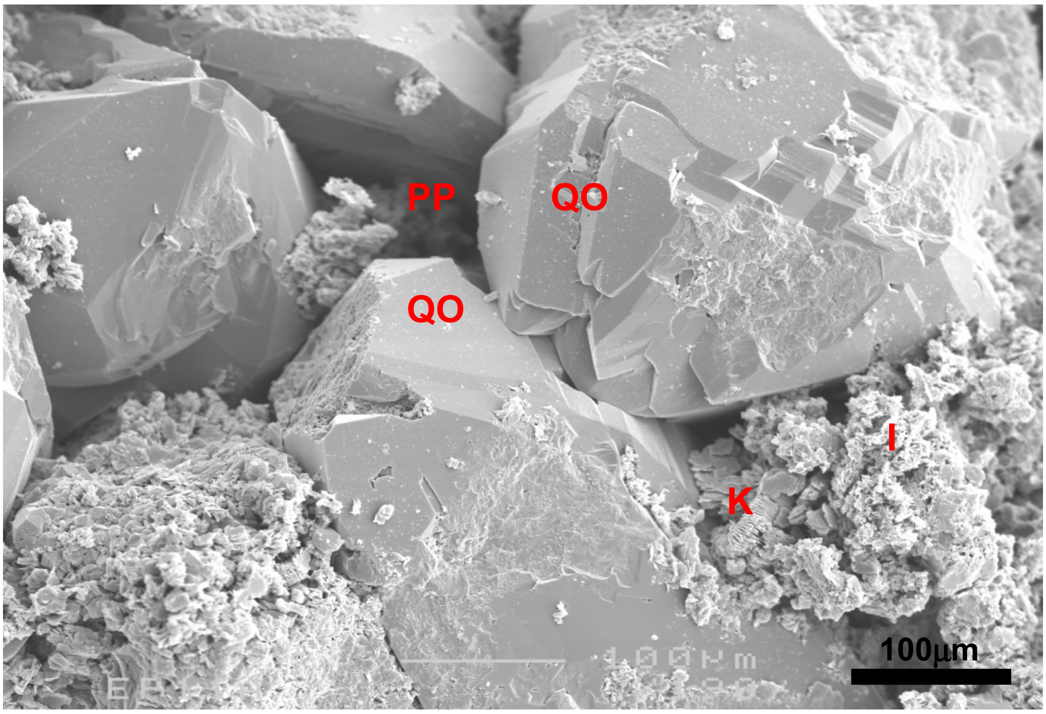
PLATE 42: #17 2721.5mRT cont.

FIGURE 1



Common primary intergranular pores (PP) are supplemented by a large secondary pore (SP) that is partly occupied by authigenic clay (C) that is the altered remnant of the pore precursor grain. Quartz overgrowths (QO) are common, but are only thinly developed and thus occupy only a small portion of total available intergranular space.

FIGURE 2



A primary intergranular pore (PP) is bounded by the planar faces of thinly developed quartz overgrowths (QO), and an adjacent intergranular space is filled by authigenic kaolinite (K) and illite (I) that have formed by alteration of a micaceous metamorphic rock fragment.

PLATE 43: #18 2728.5mRT

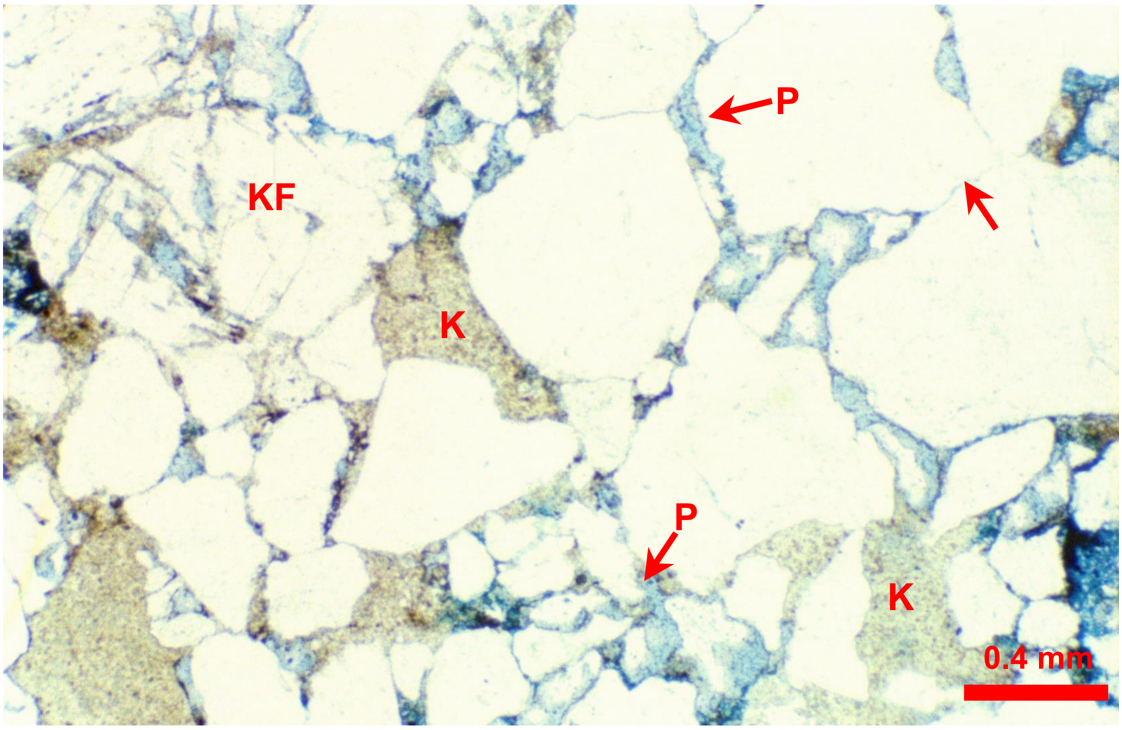
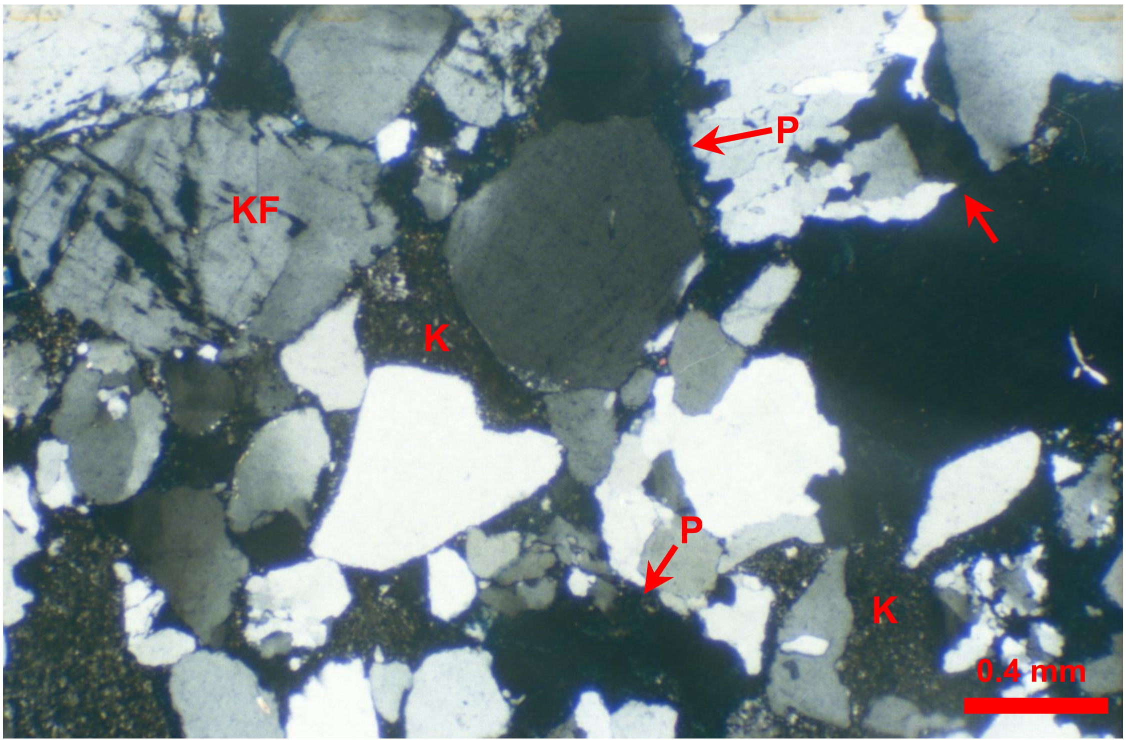


FIGURE 1	Plane polarised light
FIGURE 2	Crossed polarisers



Despite porosity reduction by grain contact dissolution (arrow) and labile grain alteration/compaction to form localised patches of kaolinite pseudomatrix (K), intergranular pores (P) are sufficiently common to result in good permeability. A slightly dissolved granitic K-feldspar grain (KF) is also marked. K = 573md

PLATE 44: #18 2728.5mRT cont.

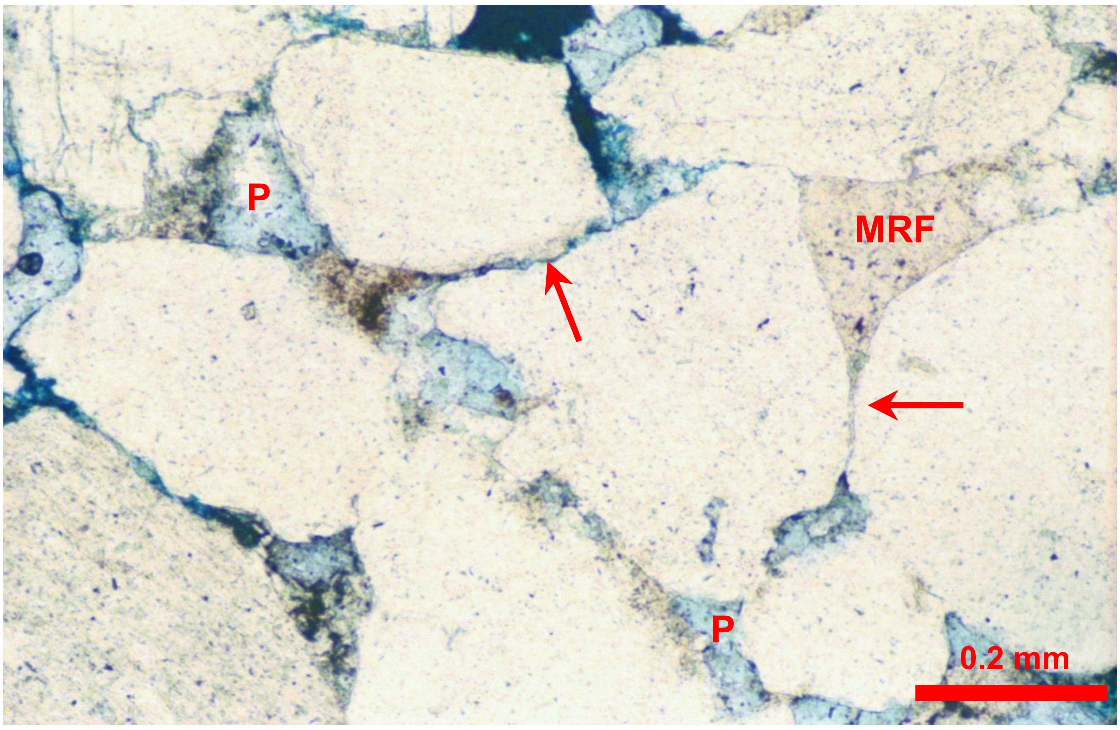
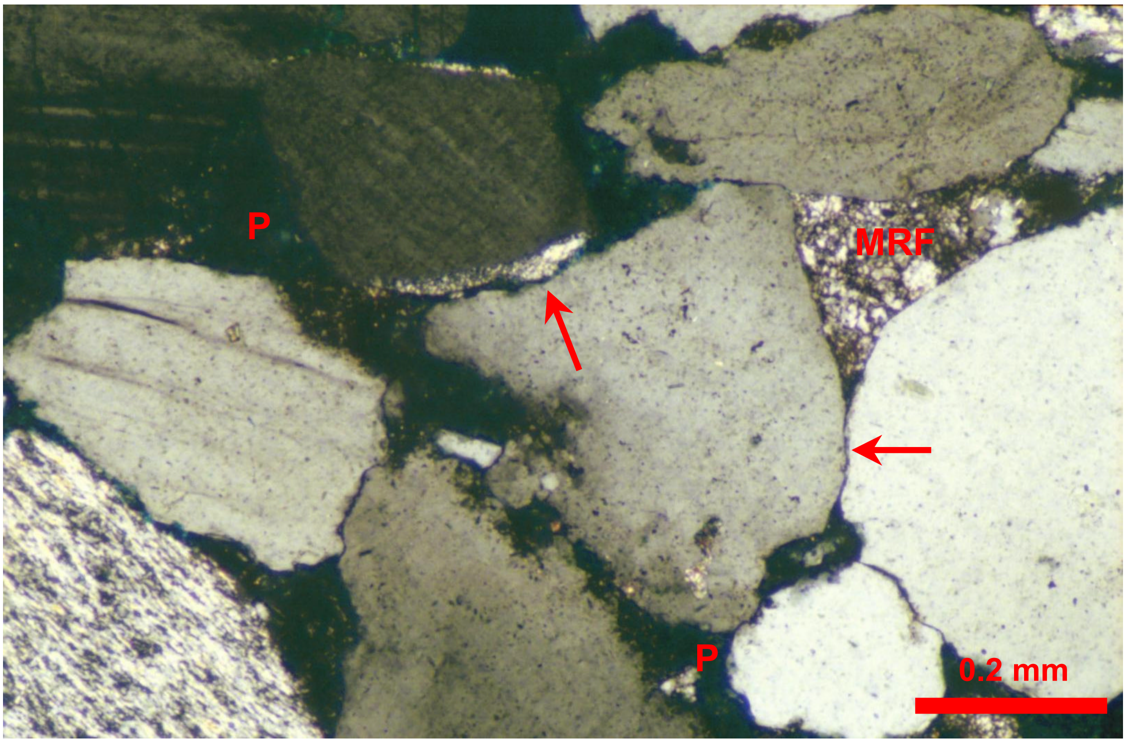


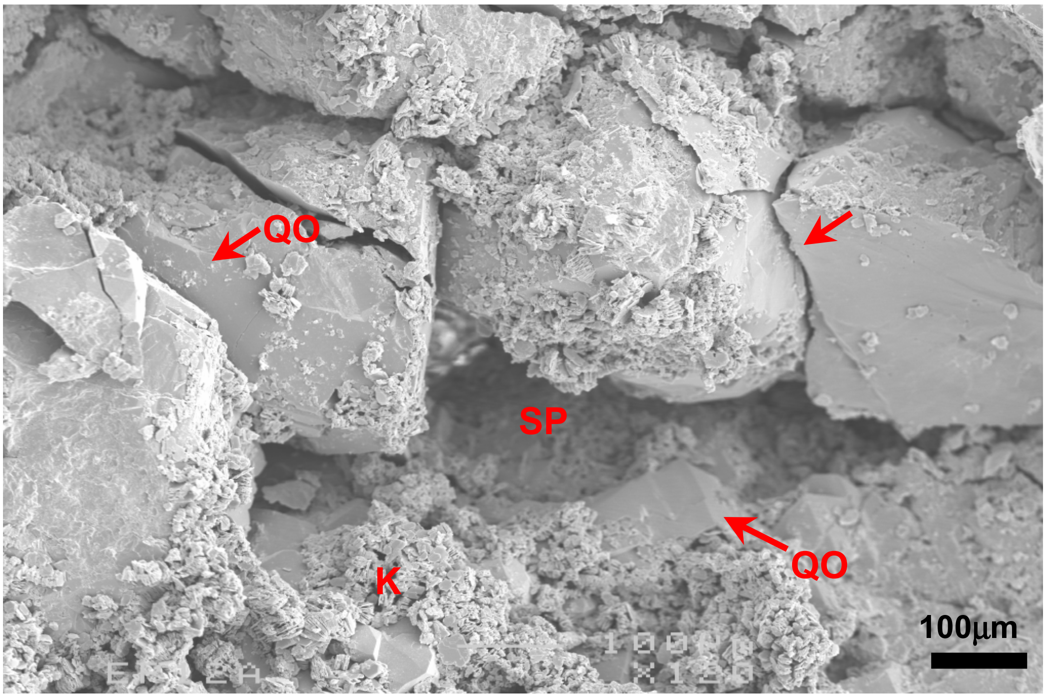
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Framework grain packing density has been increased by grain contact dissolution to form long and slightly embayed grain contacts (arrows) and also by the compactional deformation of an altered metamorphic rock fragment (MRF). However, the sandstone still contains modest amounts of clean intergranular porosity (P), the presence of which, together with the very coarse grain size, results in good permeability. The sandstone contains little quartz overgrowth cement. K = 573md

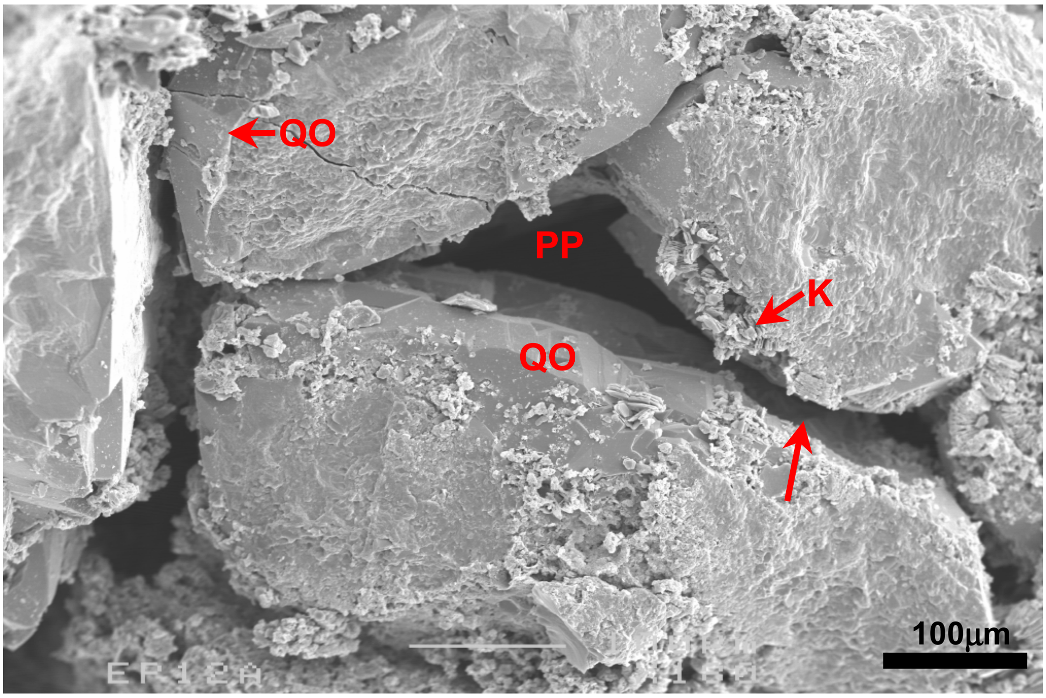
PLATE 45: #18 2728.5mRT cont.

FIGURE 1



Authigenic kaolinite (K) is the altered remnant of a labile grain that dissolved to form a large secondary pore (SP). Pore-bounding quartz grains have welded grain contacts (arrow) resulting from grain contact dissolution and are also locally enveloped by poorly developed quartz overgrowths (QO).

FIGURE 2



The volume of primary intergranular pores (PP) and pore throats (arrow) has been little changed by the development of quartz overgrowths (QO) on pore-bounding quartz grains. Most clay in the sample is authigenic kaolinite (K).

PLATE 46: #19 2751.0mRT

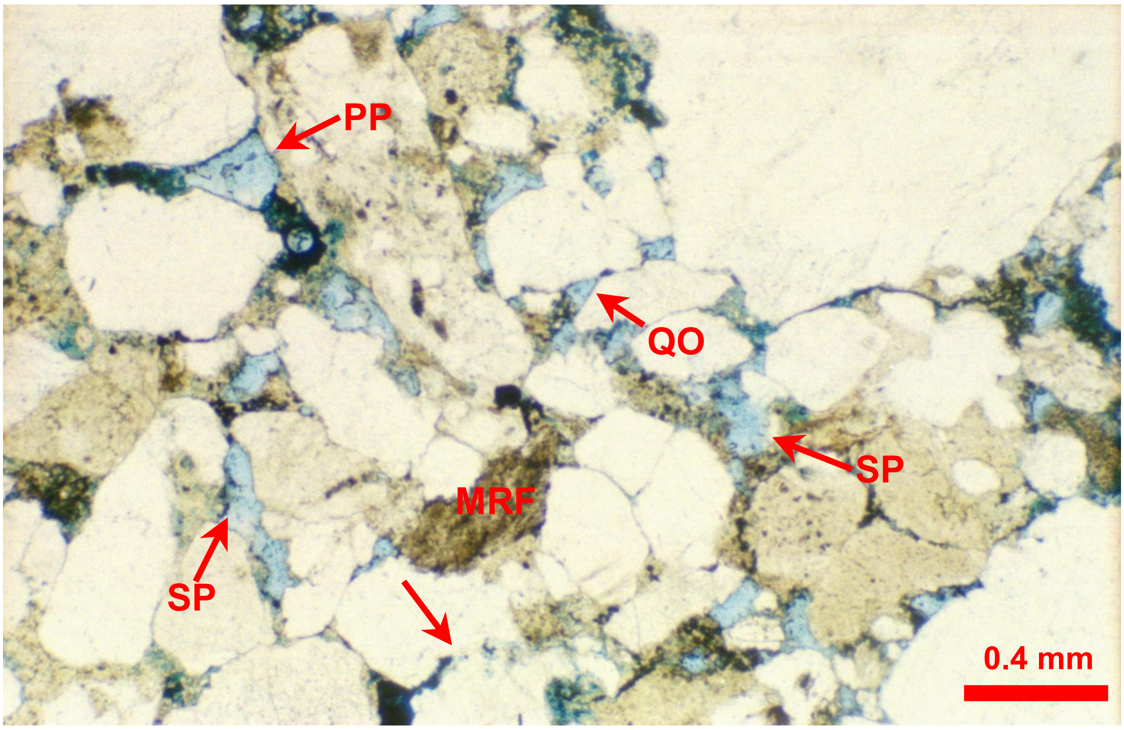
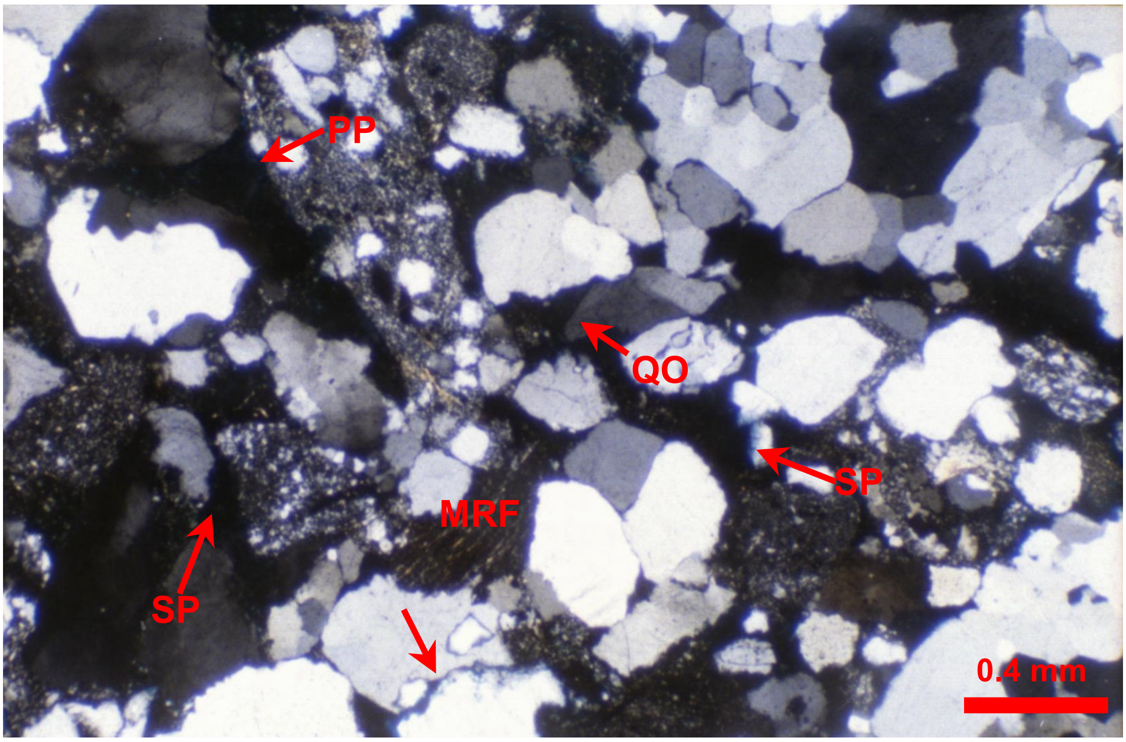


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Although primary pores (PP) and secondary pores (SP) are common, the pores have an erratic distribution due to the porosity-reducing effects of grain contact dissolution (arrow), compaction of ductile metamorphic rock fragments (MRF) and minor quartz overgrowth (QO) cementation, which have completely eliminated pore space between some grains. Accordingly, pores are only moderately well interconnected through the sandstone. K = 57.9md

PLATE 47: #19 2751.0mRT cont.

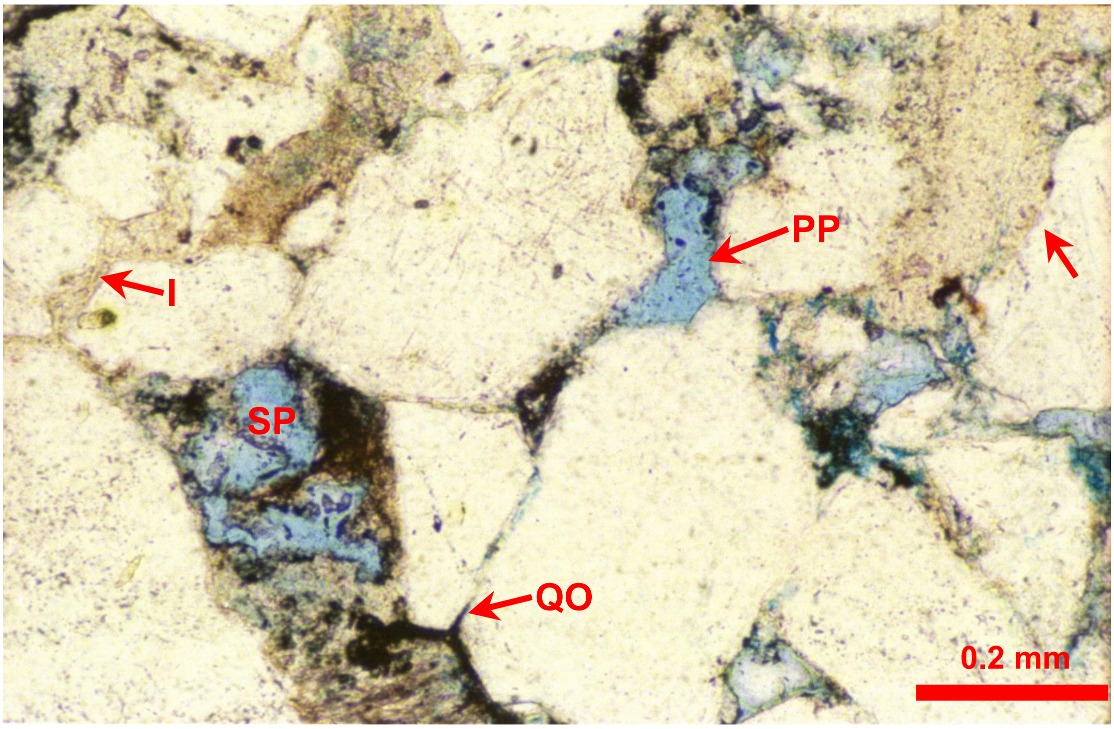
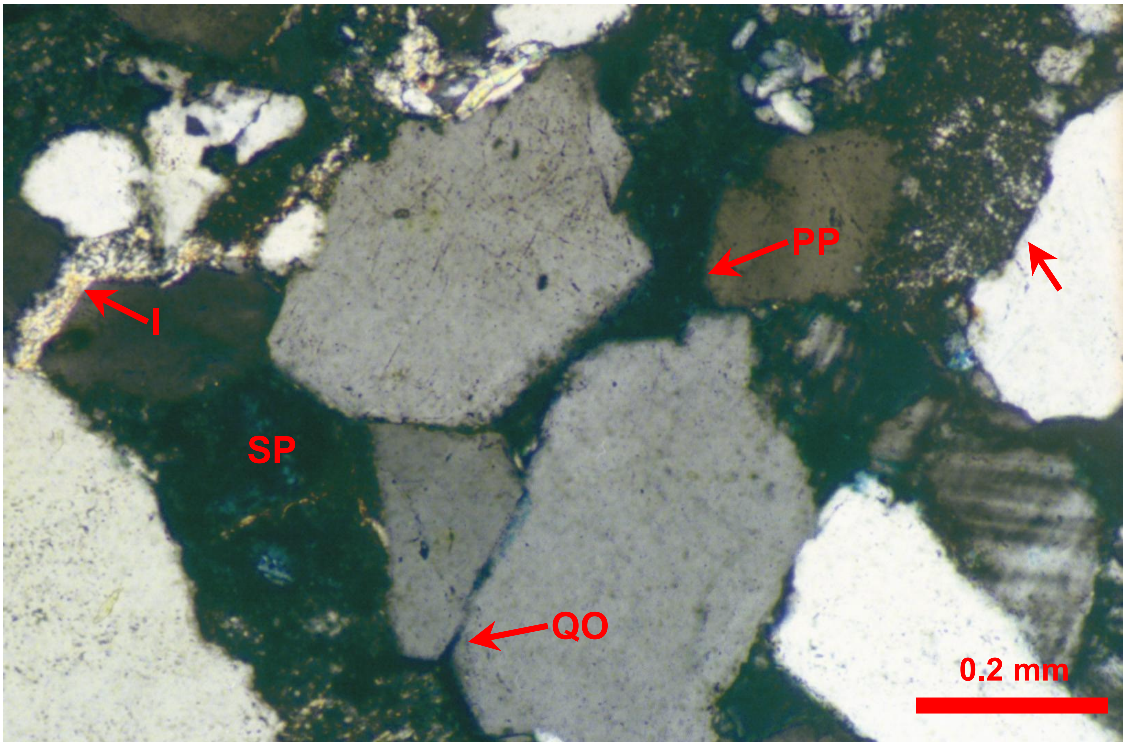


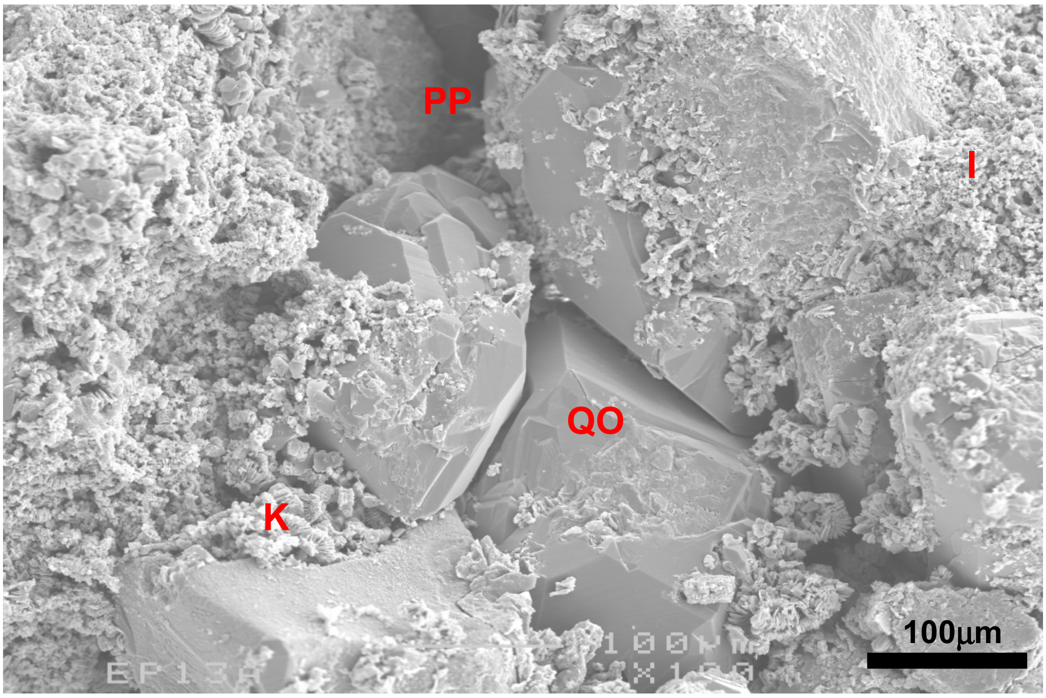
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Connection between primary pores (PP) and secondary pores (SP) is reduced by the effects of grain contact dissolution (arrow), quartz overgrowth (QO) cementation, and the compaction of micaceous metamorphic rock fragments to form localised illitic pseudomatrix (I). K = 57.9md

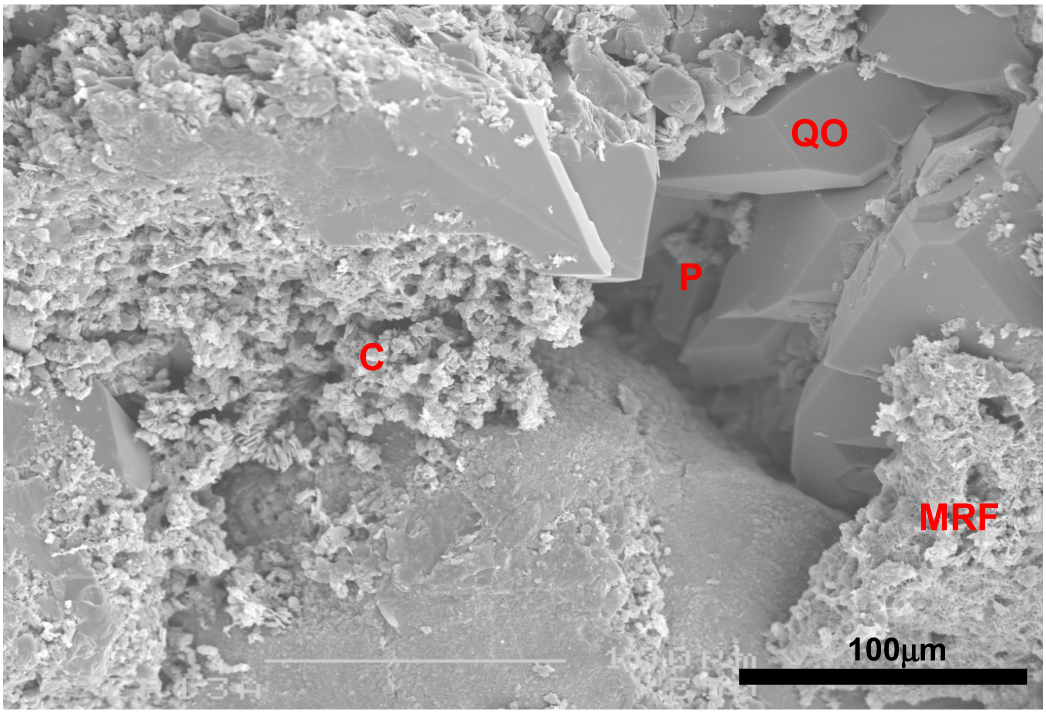
PLATE 48: #19 2751.0mRT cont.

FIGURE 1



Within areas surrounding a primary intergranular pore (PP), intergranular spaces are largely filled by authigenic kaolinitic (K) and illitic (I) clay pseudomatrix that is the altered remnant of compacted micaceous grains. Further porosity loss is due to the precipitation of quartz overgrowths (QO) on quartz grain surfaces that were not completely covered by clay.

FIGURE 2



Permeability is significantly reduced by the presence of compacted metamorphic rock fragments (MRF), authigenic clay (C) and localised quartz overgrowth cement (QO) within intergranular spaces. Quartz overgrowths only partly occupy intergranular pores (P).

PLATE 49: #21 2759.0mRT

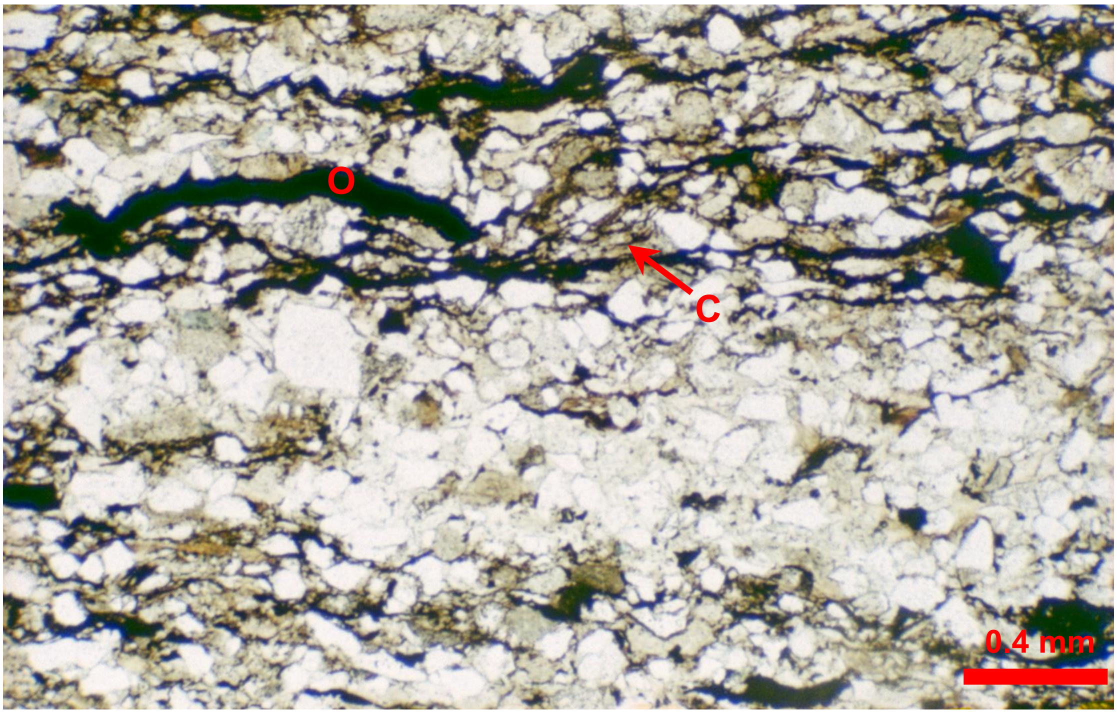
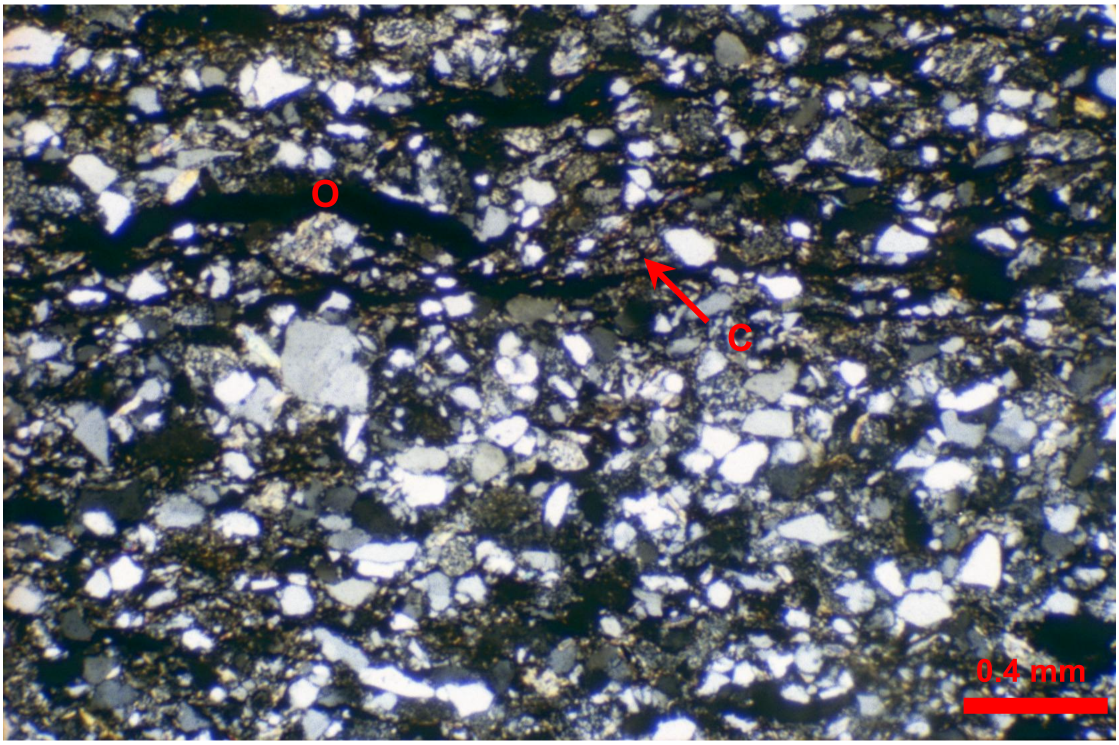


FIGURE 1	Plane polarised light
FIGURE 2	Crossed polarisers



Finely laminated, argillaceous sandstone in which laminae are defined by concentrations of compacted organic fragments (O) and detrital clay (C). Macroporosity is absent. K = 0.010md

PLATE 50: #21 2759.0mRT cont.

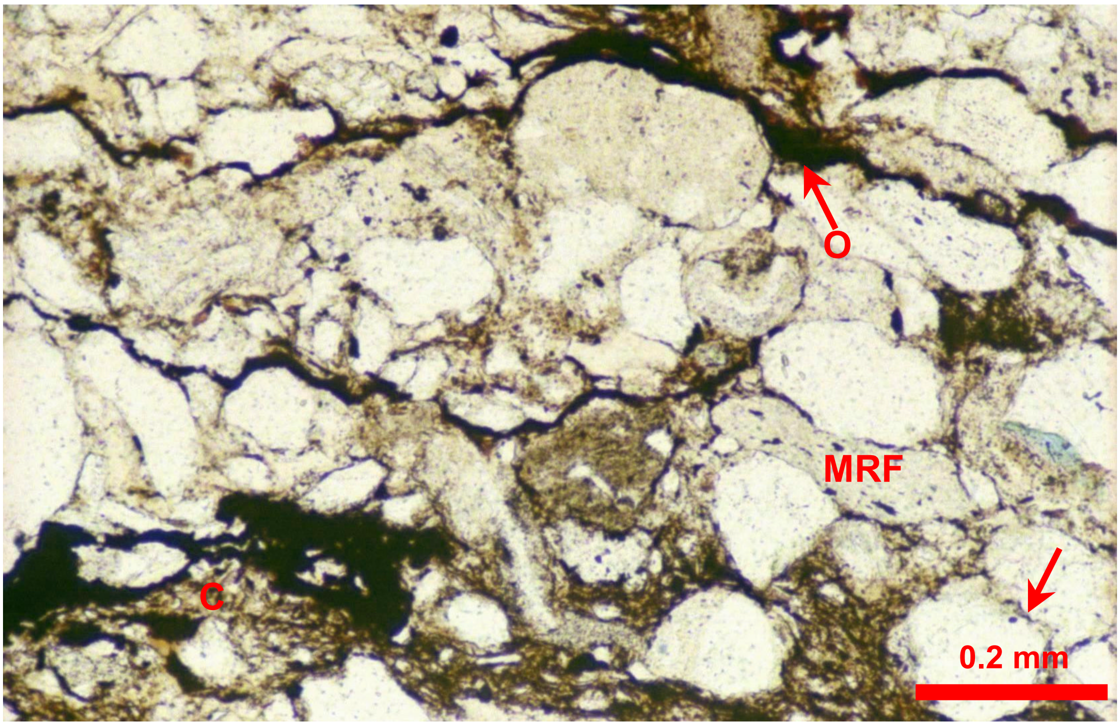
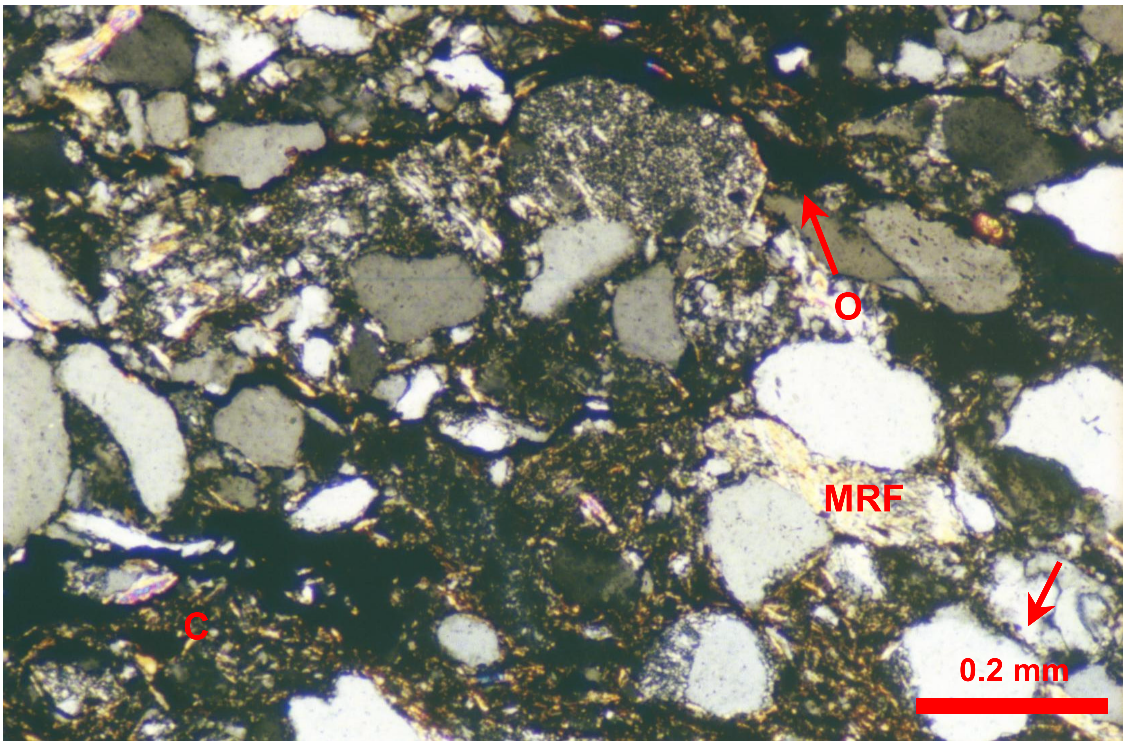


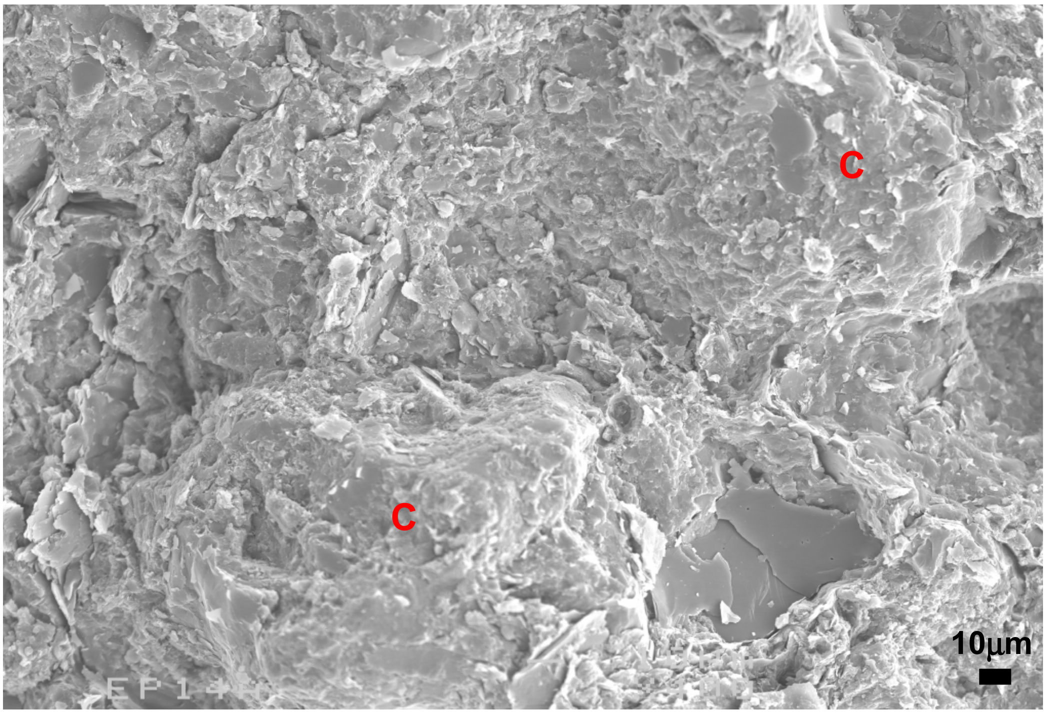
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Intergranular porosity is lacking due to pore filling by detrital clay matrix (C), compaction of micaceous metamorphic rock fragments (MRF) and organics (O), and grain welding by grain contact dissolution (arrow). K = 0.010md

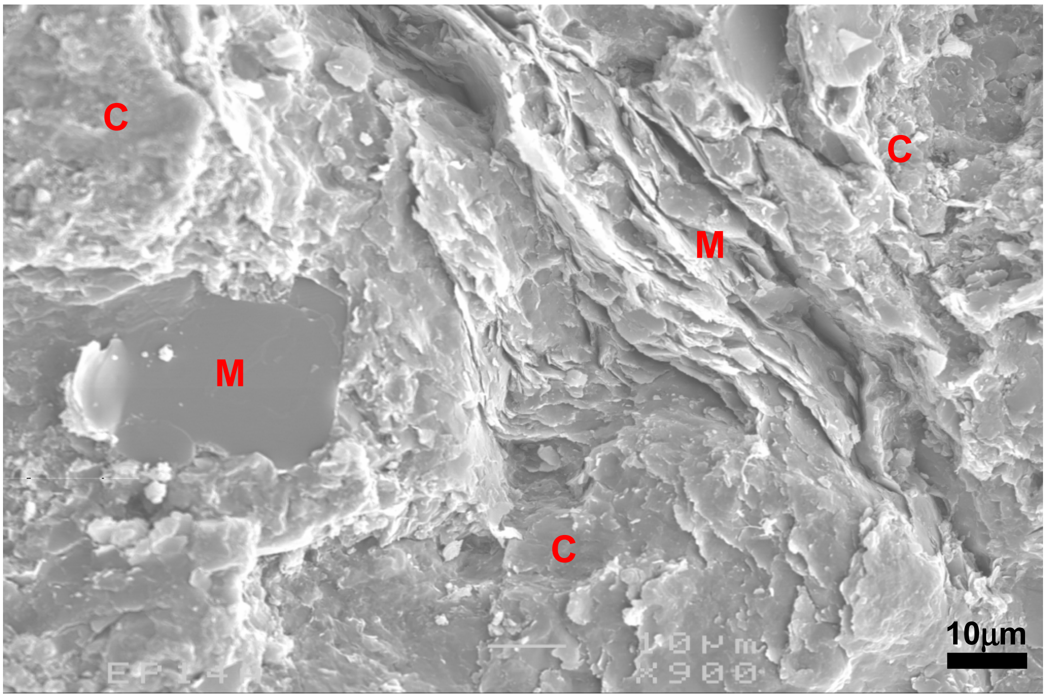
PLATE 51: #21 2759.0mRT cont.

FIGURE 1



Detrital clay matrix is well compacted and consequently contains little microporosity.

FIGURE 2



Detail of tightly packed clay (C) that supports grains of mica (M). Containing no macroporosity and little microporosity, the sample has very low (4.2%) measured porosity.

PLATE 52: #22 2763.0mRT

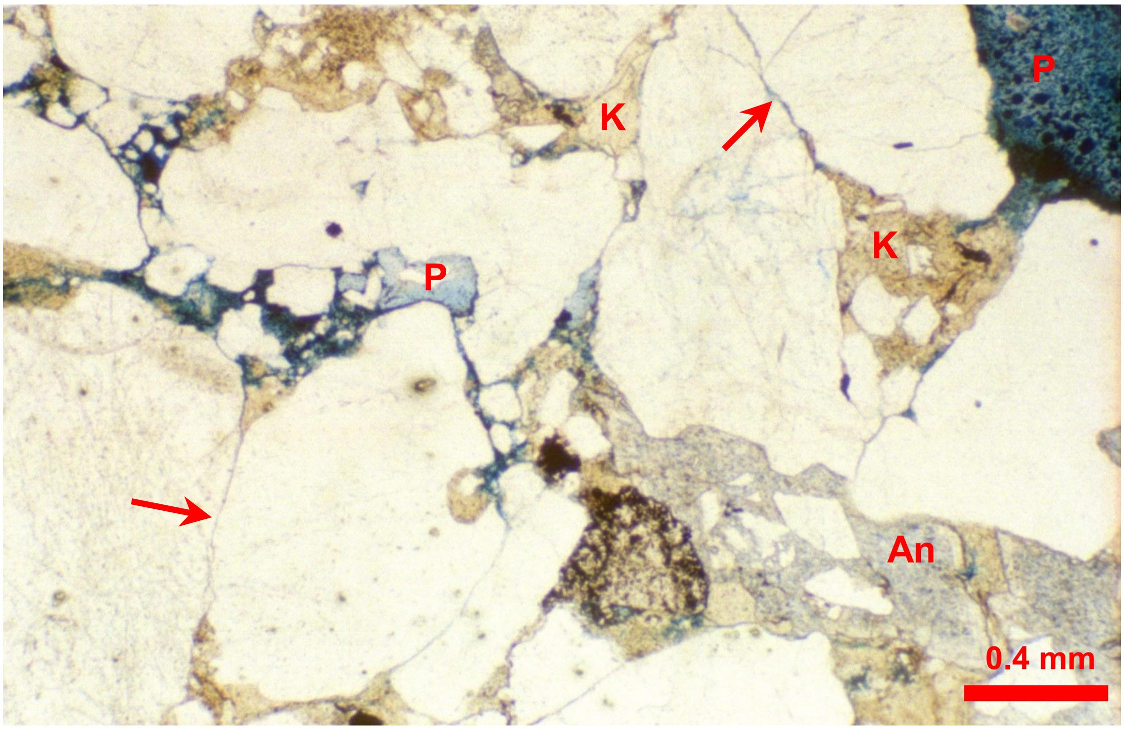
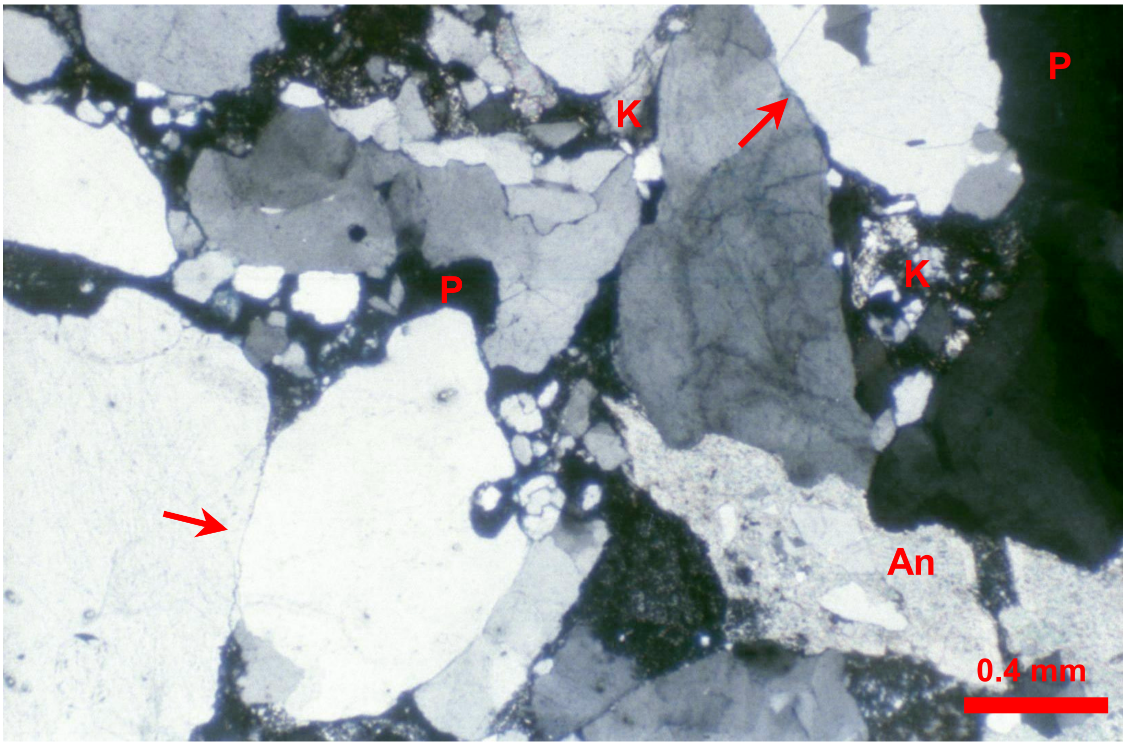


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Porosity has been greatly reduced in this very coarse grained sandstone by patchy ankerite (An) (stained faint blue) cementation, grain welding by grain contact dissolution (arrows), and pore filling by kaolinitic pseudomatrix (K). Macropores (P) are erratically distributed and thus are not very well interconnected. K = 13.1md

PLATE 53: #22 2763.0mRT cont.

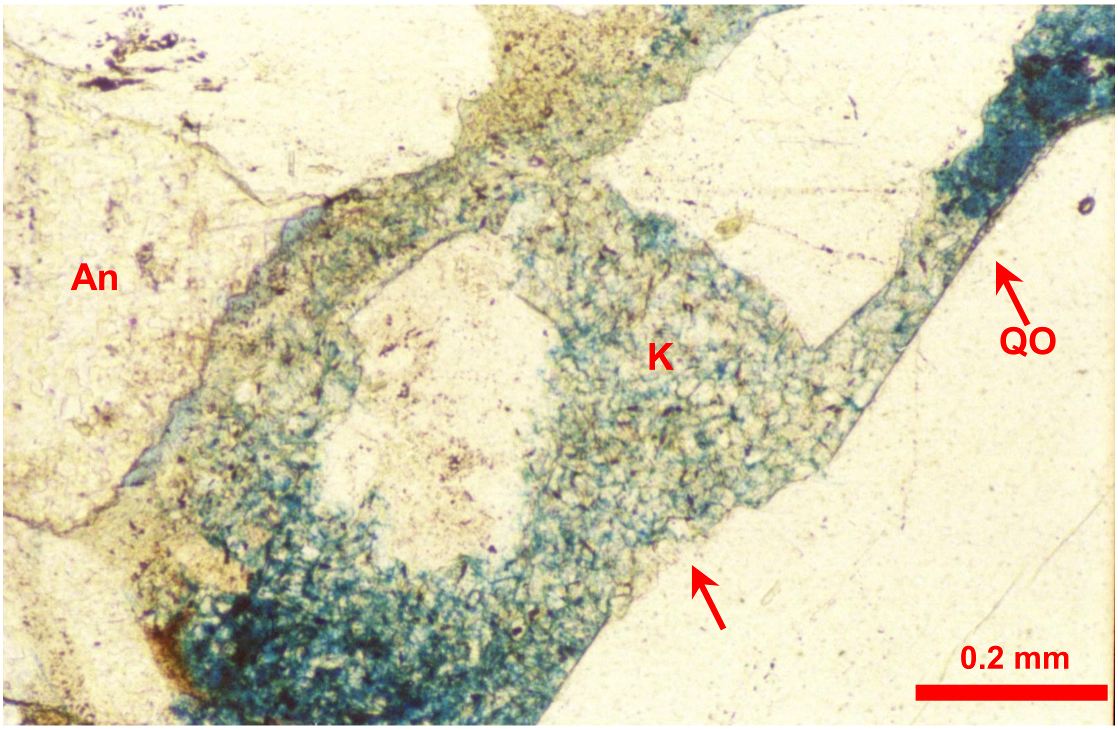
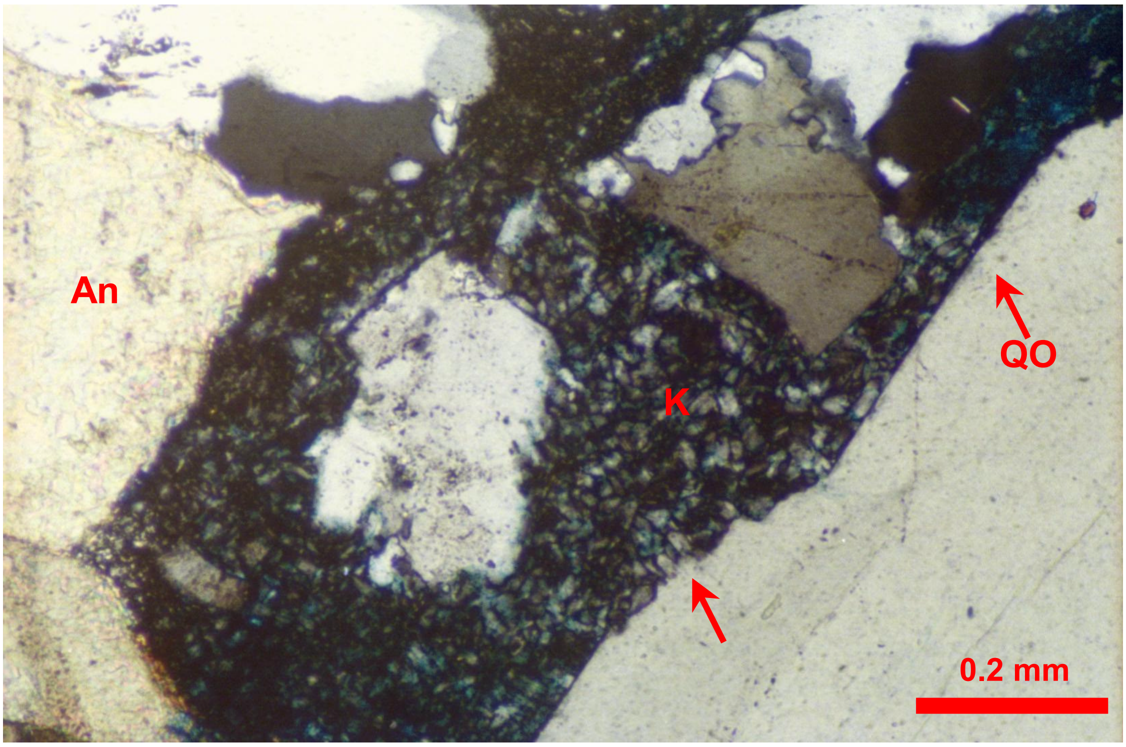


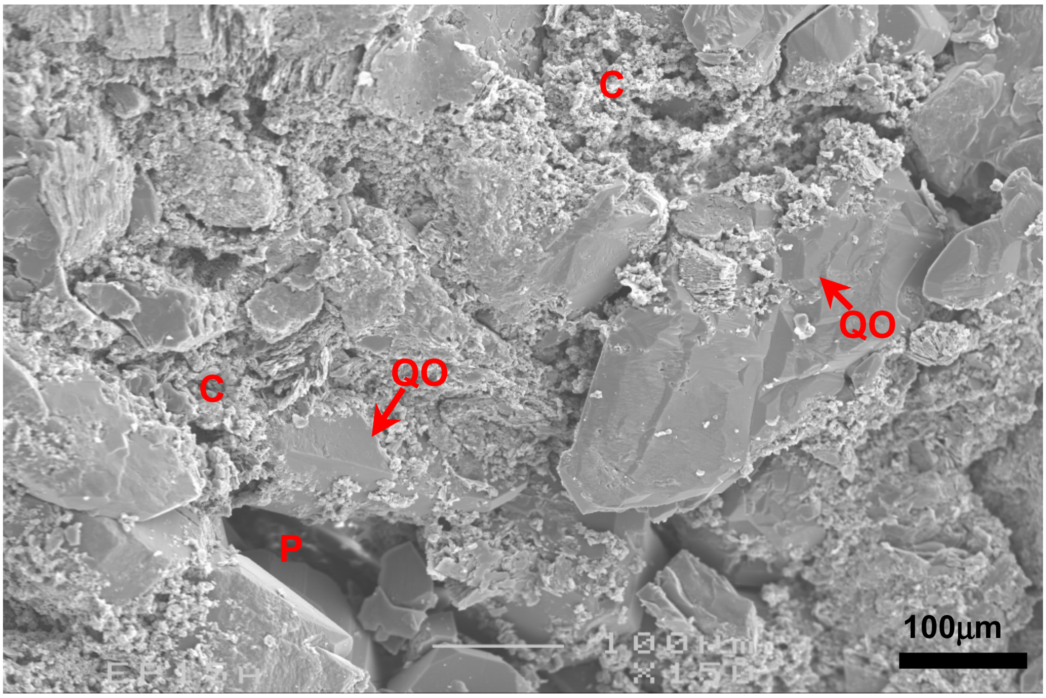
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



The main clay in this sandstone is authigenic kaolinite (K) that forms scattered, compacted patches where labile grains have altered. The marked kaolinite is engulfed (arrow) by a later formed quartz overgrowth (QO) and is replaced by later formed ankerite (An). Abundant microporosity is associated with the kaolinite. K = 13.1md

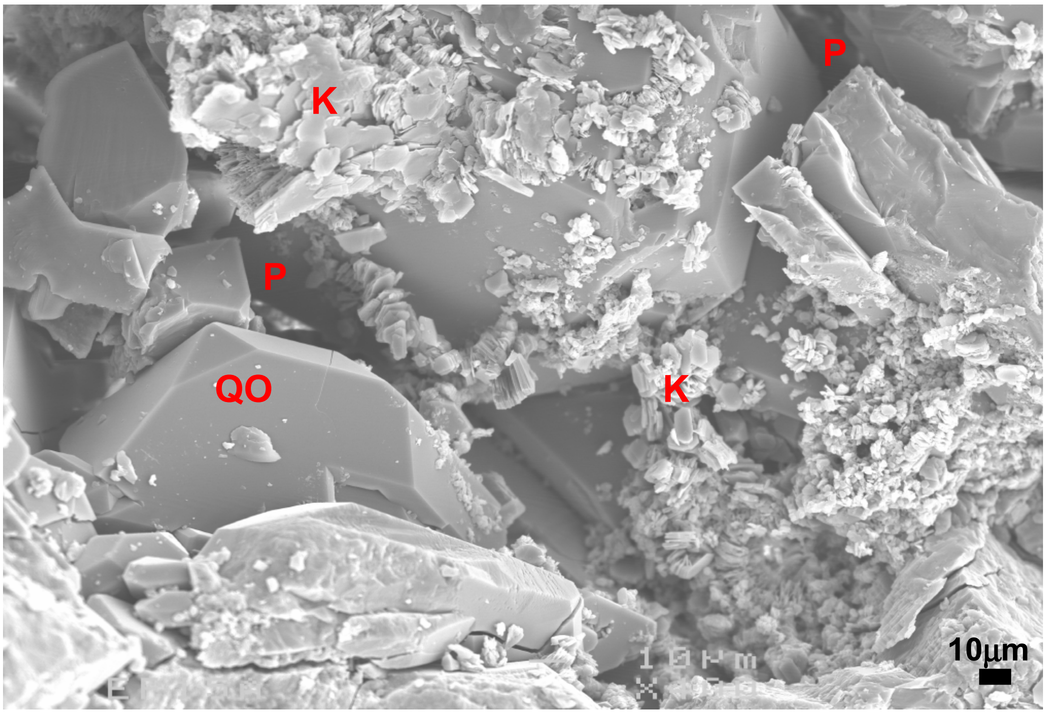
PLATE 54: #22 2763.0mRT cont.

FIGURE 1



An isolated intergranular pore (P) occurs in a sandstone where intergranular spaces between well compacted framework grains are occupied by authigenic kaolinitic clay (C) and minor quartz overgrowth cement (QO).

FIGURE 2



Despite being very coarse grained and moderately macroporous, this sample has relatively low permeability (13.1md), which partly reflects the presence of authigenic kaolinite (K) and quartz overgrowths (QO) within some pores (P) and pore throats. Other causes of porosity reduction in the sample are ankerite cementation and grain contact dissolution.

PLATE 55: #23 2764.5mRT

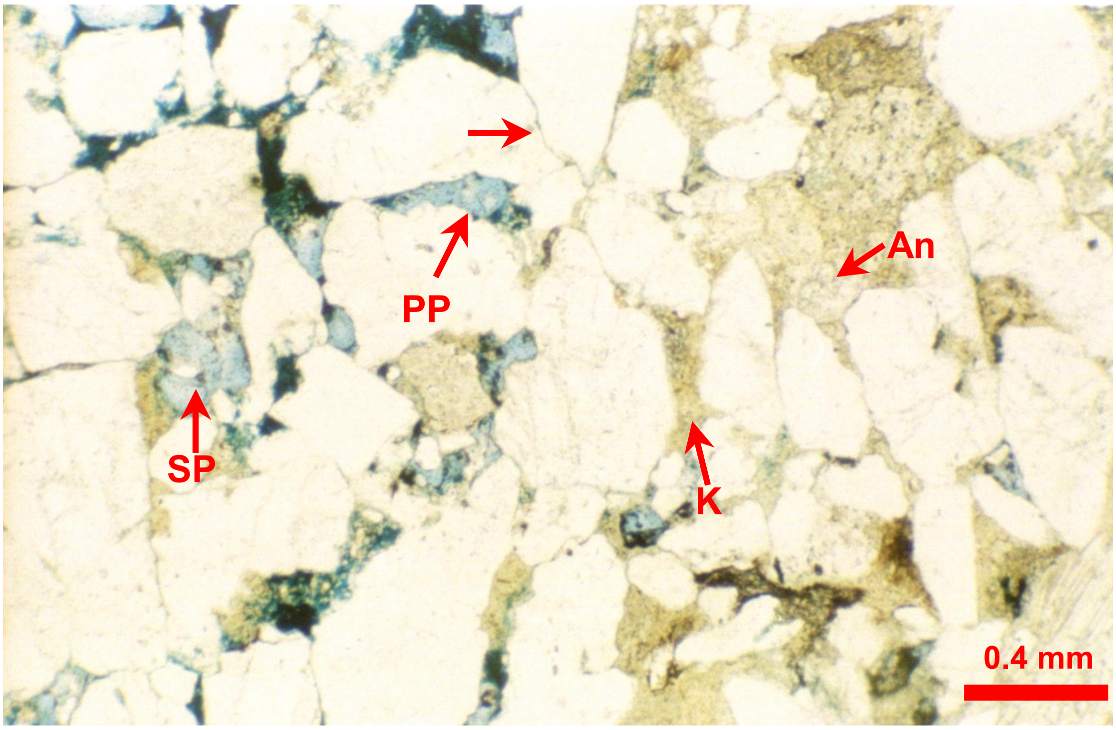
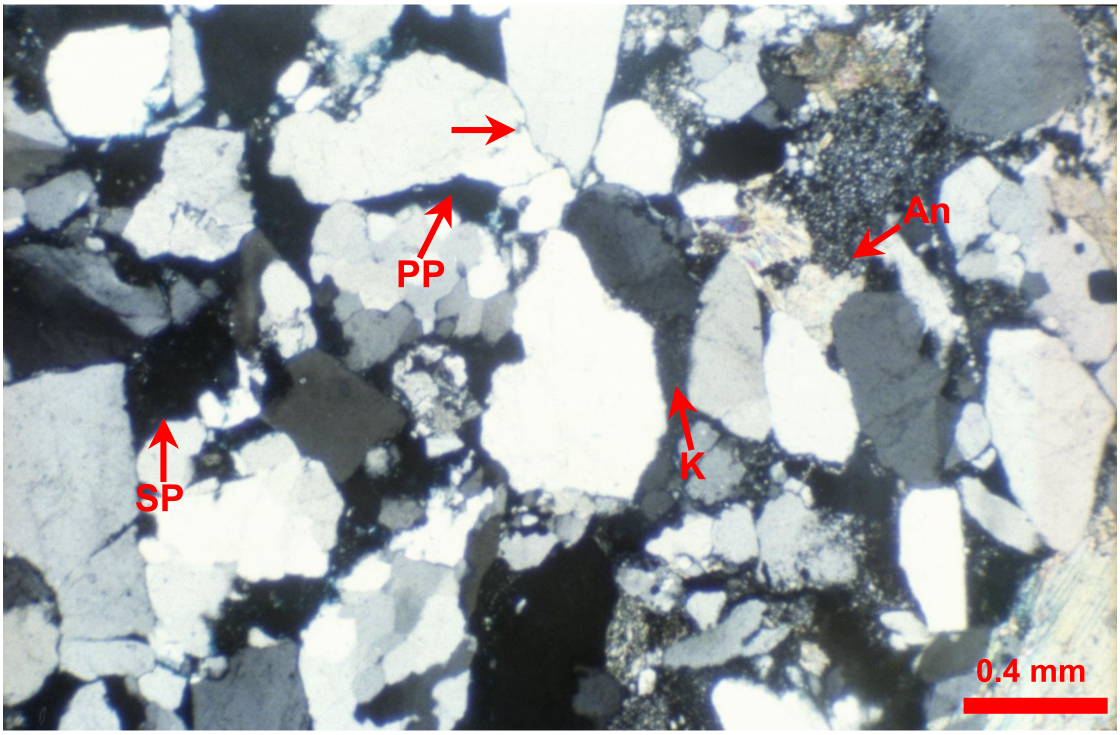


FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Within part of this sample, intergranular areas are largely filled by authigenic kaolinite pseudomatrix (K), some of which is recrystallised detrital clay matrix. Porosity reduction is also the result of ankerite (An) cementation and grain contact dissolution (arrow). Clean parts of the sample contain abundant primary porosity (PP) and secondary grain dissolution porosity (SP). K = 118md

PLATE 56: #23 2764.5mRT cont.

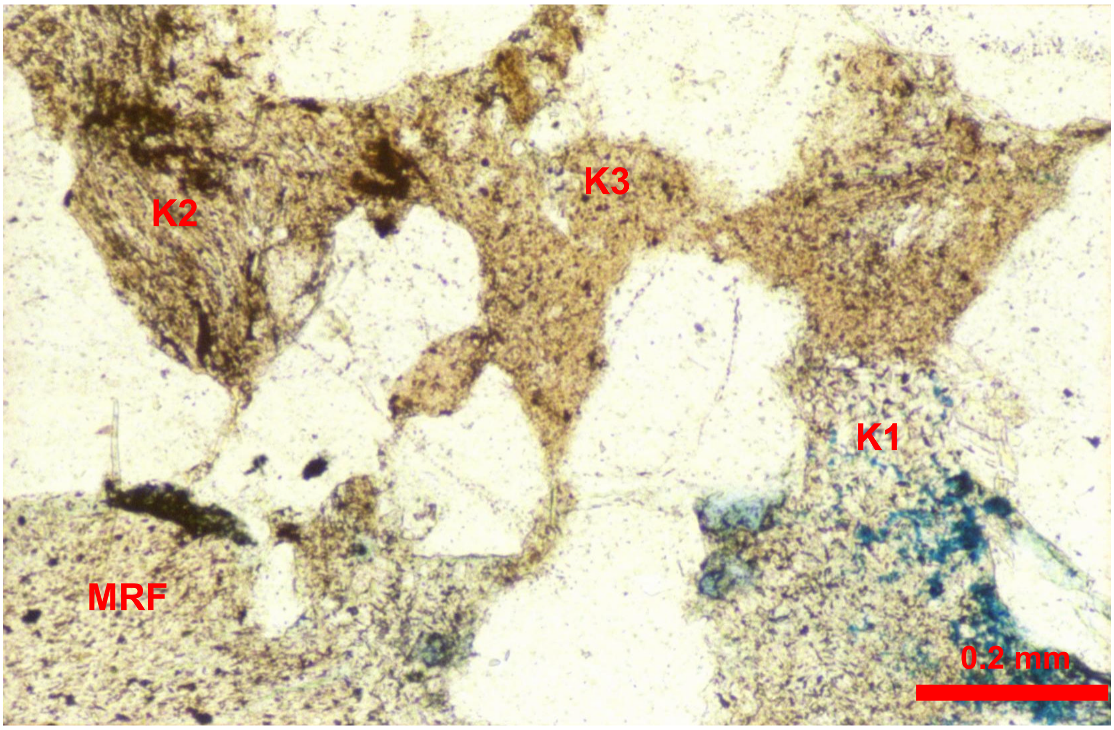
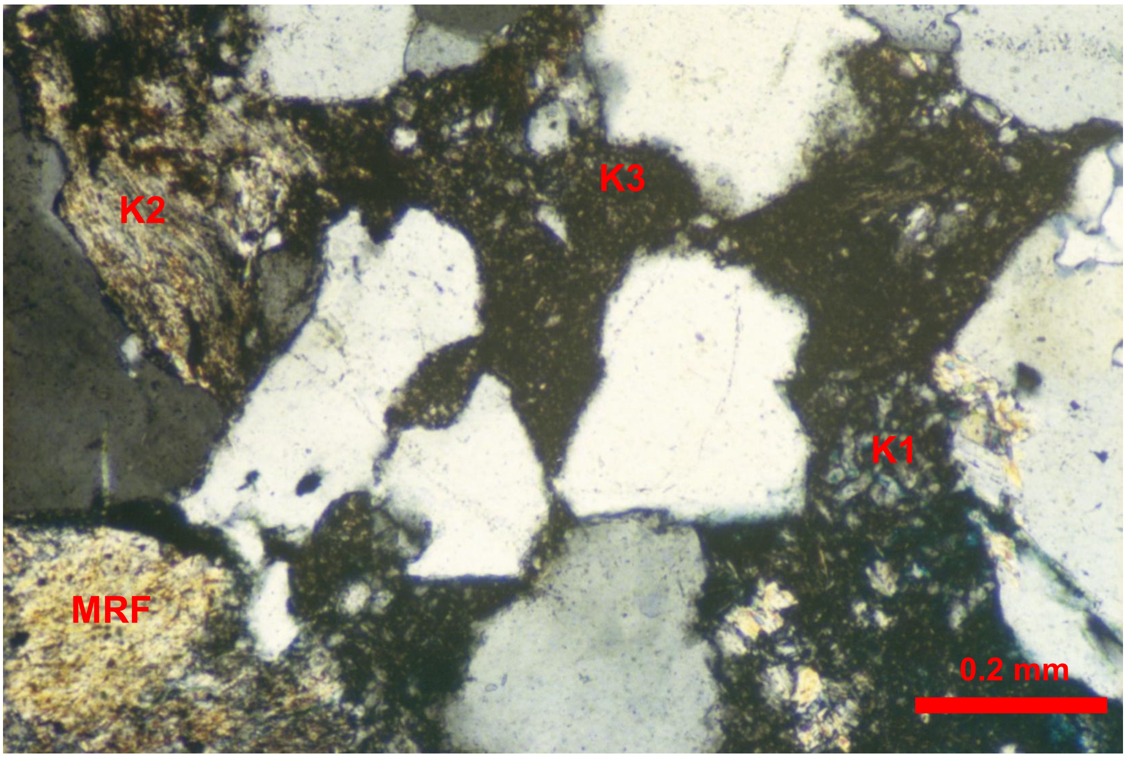


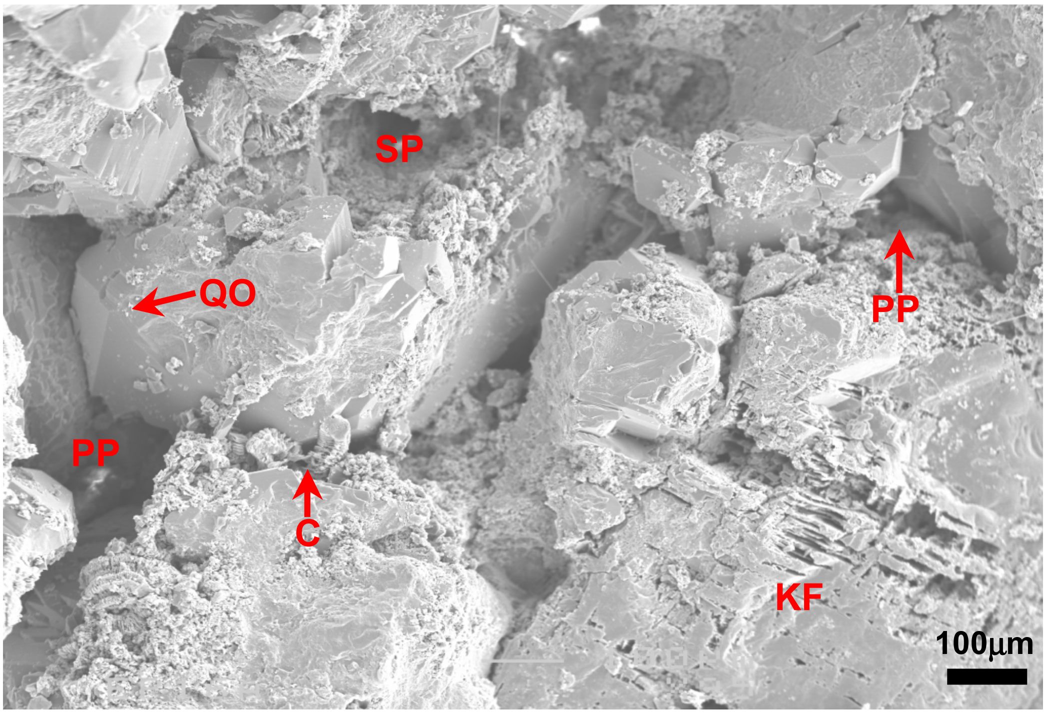
FIGURE 1 Plane polarised light
FIGURE 2 Crossed polarisers



Detail of a microporous part of the sample where intergranular areas are mainly filled by authigenic kaolinite that has formed by alteration of a micaceous metamorphic rock fragment (K1) and a biotite grain (K2) and by recrystallisation of localised detrital clay matrix (K3). A compacted micaceous metamorphic rock fragment (MRF) is also marked. K = 118md

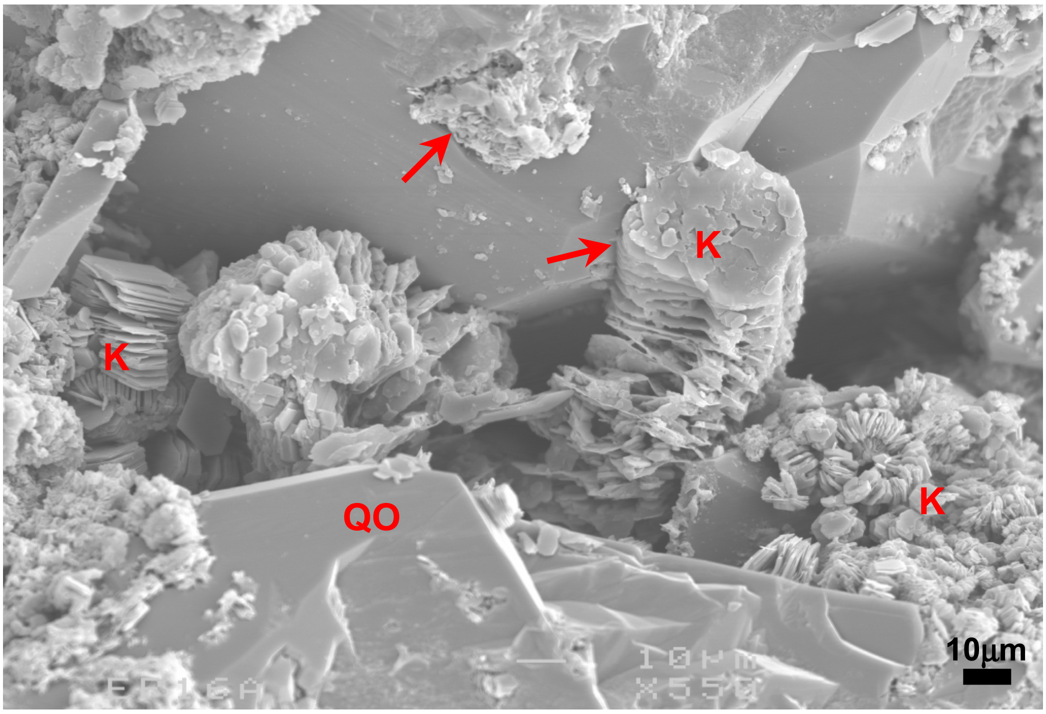
PLATE 57: #23 2764.5mRT cont.

FIGURE 1



This SEM micrograph shows a relatively clean part of the sandstone where large primary intergranular pores (PP) and secondary grain dissolution pores (SP) are preserved between poorly quartz overgrowth (QO)-cemented quartz grains and a slightly dissolved K-feldspar (KF) grain. One pore throat is occupied by authigenic clay (C).

FIGURE 2



Detail of authigenic clay marked in the previous micrograph. The clay is mainly kaolinite (K) that most likely formed by alteration of a micaceous grain. The pore throat in which the kaolinite occurs is bounded by quartz overgrowths (QO) that enclose (arrows) some of the kaolinite. Clay in all the sandstone samples is mainly authigenic kaolinite that has formed by labile grain alteration.