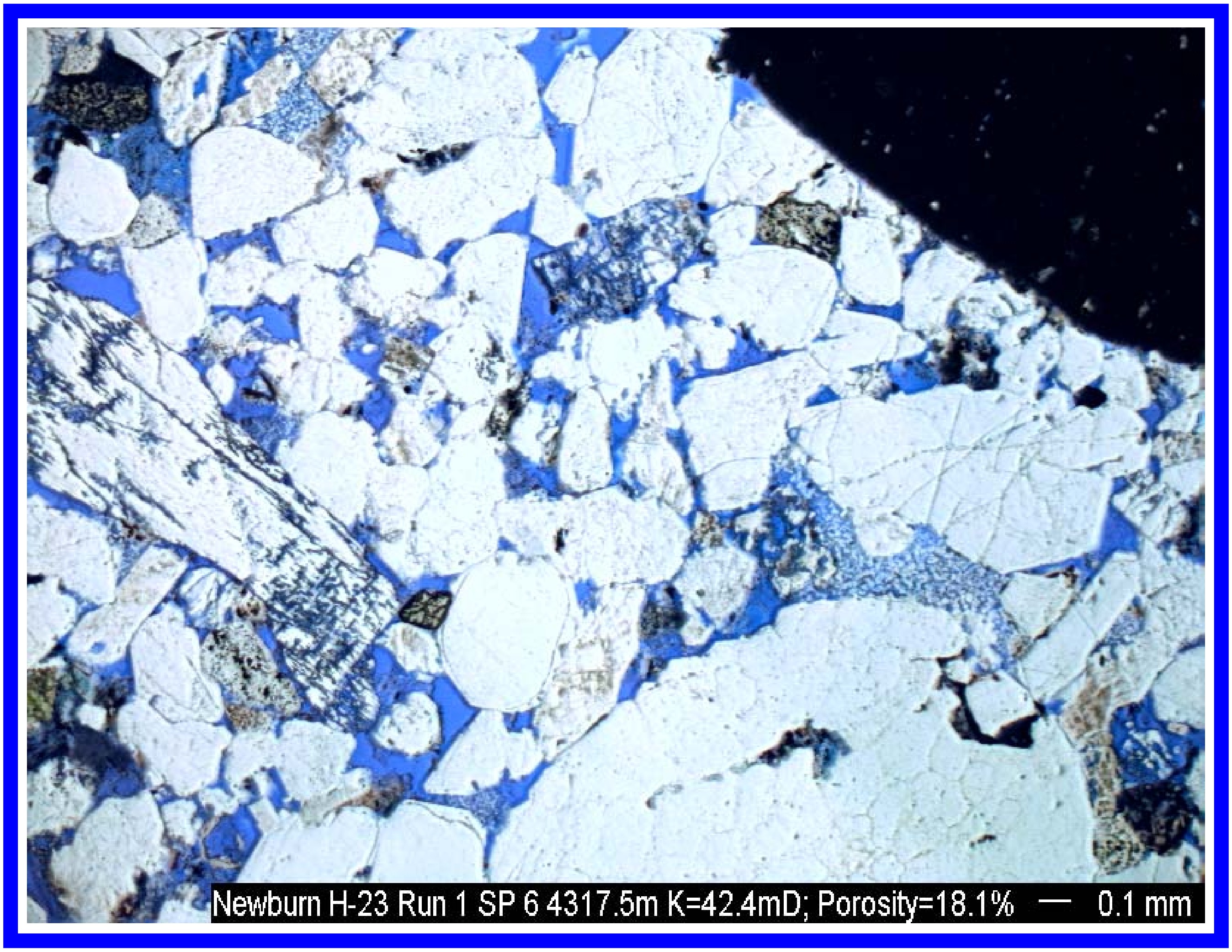
Petrographic Analysis of Sidewall Cores from Newburn H-23, Scotian Slope, Canada



Prepared For:

ChevronTexaco

By:

Beth Haverslew, PGeol.
Altamin Resources (1978) Ltd.

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Executive Summary:

Thin sections prepared from twenty-six sidewall core samples of shale, silty shale, siltstone, sandstone, conglomeratic sandstone and conglomerate from the Newburn H-23 well were submitted for petrographic analysis. Emphasis in the analysis was to determine the composition, texture, controls on porosity and permeability, and the reservoir potential of intervals represented by the analysed samples. The following conclusions were made:

1) Sandstones are generally feldspathic litharenites and quartzose litharenites.

2) Total feldspar as it may affect logs is higher than indicated by point count, because many of the rock fragments contain feldspar.

3) Volcanic rock fragments are common in all the sandstone samples analysed between 4307m and 5962m. Rock fragments and feldspar derived from a probable granitic source are more abundant above 4354.5m (run #1). Volcanic rock fragments and albite-twinned plagioclase are more abundant in the intervals below 5403.6m.

4) Intergranular porosity has been strongly reduced throughout the analysed intervals by strong physical compaction, resulting in closer grain packing, compaction of ductile clasts against other grains and into adjacent pore space; moderate suturing of grain contacts.

5) The finer grained the sample, the more severely intergranular porosity and permeability have been reduced by compaction.

6) Permeability and effective porosity decrease with increased content of ductile clasts and interstitial authigenic or detrital matrix.

7) Proportion of total porosity consisting of microporosity increases with decreasing grain size, increase of interstitial chlorite (runs 2 and 3),; increased ductile and labile clast content; and/or amount of authigenic kaolinite (most significant in run 1 samples).

8) Enhancement of porosity and permeability by dissolution of feldspar (most effective in run 1) and/or rock fragments, and possibly ferroan calcite cement improves the reservoir potential in any of the sand intervals represented by these samples.

9) Grain-rimming chlorite has preserved some intergranular porosity in run 2 samples. Chlorite rims are not present in run 1 samples. Chlorite rims usually completely fill adjacent intergranular pores in run 3 samples, because of the very fine grain size, so only provide microporosity.

10) Although all samples appear to have been deposited in a marine environment, the abundance of early chlorite in runs 2 and 3 samples and lack of chlorite and abundant kaolinite in run 1 suggests that the early pore fluids were more strongly marine in the runs 2 and 3 intervals and were more influenced by meteoric water in the run 1 interval.

INTRODUCTION

Twenty-six thin sections prepared from sidewall cores from the Newburn-23 well (see Figure 1 for location map) were submitted to the Petro-Canada laboratory for petrographic analysis. The purpose of the analysis is to provide information on primary composition, texture, diagenetic mineralogy and diagenetic history, pore system morphology, controls on porosity and permeability and to assess reservoir potential in the intervals represented by these samples.

The samples consist of shales, siltstones, sandstones and conglomeratic sandstones selected from three different sidewall coring runs between 4307 and 5962 meters. Table 1 is a summary of the samples analyzed with core analysis porosity and permeability values, point count porosity values where available, and lithology.

The following report consists of a summary of the petrographic analysis followed by brief individual sample descriptions illustrated by representative annotated digital images. Sample descriptions are followed by Appendix 1, which contains overview photographs of each sample oriented to way-up, where possible, with brief descriptions of sedimentary structures provided by sedimentologist Richard Evoy, PhD.

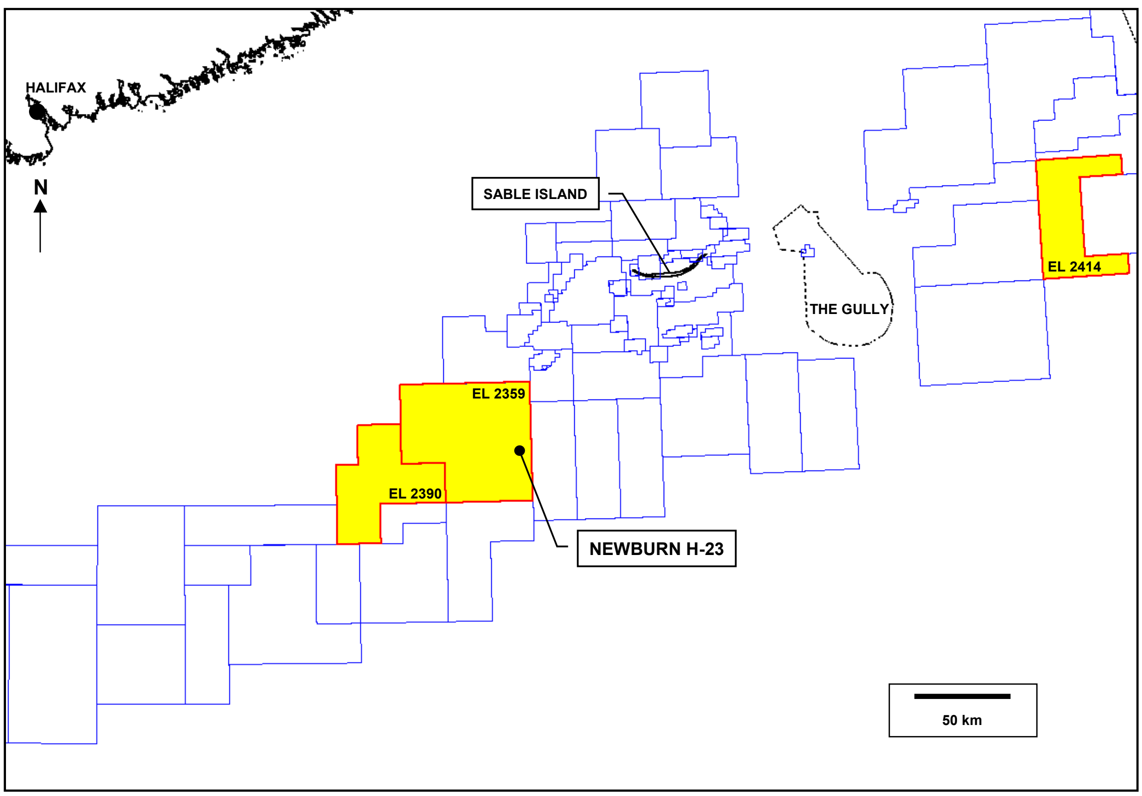


Figure 1: Location map for Newburn H-23

Depth (M)	Sample #	Permeability K air mD	Porosity (%)	PT CT Porosity (%)	Lithology
Run Number 1					
4307.8	SP 18	< 0.01	11.6		Silty shale with thin lenses of argillaceous lithic lower very fine grained sand
4312.8	SP 17	0.01	10.1	1.43	Moderately well sorted angular lower very fine to lower fine grained feldspathic litharenite overlain by moderately sorted, angular to rounded lower very fine to lower coarse grained quartzose litharenite. Both are ferroan calcite cemented,
4313.5	SP 16	0.4	17.5	7.31	Moderately well sorted dominantly upper very fine grained litharenite.
4317.5	SP 6	42.4	18.1	5.76	Poorly to moderately sorted, angular to rounded, upper fine to lower very coarse, dominantly upper medium to lower coarse grained conglomeratic sublitharenite with rounded sideritic shale granules and pebbles.
4318.5	SP 15	2.65	16.5	9.09/13.04	Moderately to moderately well sorted, angular dominantly upper very fine to lower fine grained litharenite overlain by poorly to moderately sorted to bimodal angular to subrounded upper very fine to lower very coarse grained quartzose litharenite
4319.8	SP 14	0.06	8.9	2.28	Poorly sorted angular to rounded upper very fine to upper very coarse, dominantly lower medium grained feldspathic litharenite.
4323	SP 13	0.18	13.1		Matrix-supported to locally grain-supported conglomerate with dominantly upper fine to lower medium grained litharenite matrix.
4325.5	SP 12	0.31	9.3		Silty shale with irregularly distributed concentrations of upper fine to upper very coarse grained angular to rounded quartz, feldspar and lithic sand grains
4349.7	SP 11	0.42	12.4	8.81	Moderately sorted, dominantly subangular, dominantly mid-fine grained litharenite.
4353.5	SP 8	0.28	12.1	4.37	Moderately to moderately well sorted, dominantly subangular, dominantly lower fine grained feldspathic litharenite. Abundant ferroan calcite cement.
4354.5	SP 10	0.8	12.9	1.79	Moderately to moderately well sorted, angular to subrounded, dominantly upper fine grained litharenite overlain by well sorted lithic lower very fine grained sand to coarse silt interbedded with well laminated shale and silty shale.
Run Number 2					
4780.4	SP 23				Rhythmically bedded, normally graded silty shale.
4913.8	SP 24	0.09	9.4		Silty / sandy shale
4960	SP 25				Interbedded, well laminated carbonaceous shale, silty shale and minor siltstone
5063	SP 21				
5100.8	SP 22				
5129	SP 19				
5133.8	SP 18				
5186.5	SP 16				
5189	SP 15				
5195.3	SP 6				
5198.5	SP 5				
5203.8	SP 4				
5208.5	SP 3				
5213.5	SP 2				
5403.6	SP 12	< 0.01	7.2	0	Well sorted, angular to subangular mid-very fine grained argillaceous litharenite.
5406.5	SP 11	0.04	9.1	1.45	Moderately to moderately well sorted, angular to subangular cross-laminated coarse silt to upper medium grained litharenite.
5407	SP 10	0.15	17	4.23	Moderately well sorted angular to subangular dominantly mid very fine grained litharenite with good porosity.
5407.5	SP 9	5.73	18.9	11.43	Well sorted angular to subrounded, dominantly subangular, upper very fine grained quartzose litharenite to sublitharenite.
5408.5	SP 8	6.43	17.9	13.29	Moderately well to well sorted subangular to subrounded, dominantly subangular, upper very fine to lower fine grained quartzose litharenite.
Run Number 3					
5957.8	SP 6	0.02	9.9		Well sorted angular silty lower very fine grained litharenite
5960.5	SP 5	0.02	11.7		Interbedded shale, silty shale and well sorted angular lithic medium to coarse siltstone to silty lower very fine grained litharenite.
5961	SP 9	0.02	13.3	0.74	Well sorted, well laminated angular to subangular dominantly upper very fine grained litharenite.
5961.2	SP 4	0.03	8.8	2.2	Well sorted subangular to subrounded lower fine grained quartzose litharenite to litharenite.
5961.7	SP 3	0.03	12.7	0.5	Moderately well to well sorted, angular dominantly mid-very fine grained litharenite.
5962	SP 2	< 0.01	8.8	1.72	Moderately to moderately well sorted, subangular, coarse silt to lower medium grained, dominantly lower fine grained litharenite.
5962.8	SP 1	0.01	10.2		Interbedded wavy laminated shale, silty shale and argillaceous siltstone.

Table 1: Sample summary list

Summary of Petrographic Analysis

Composition

The rock types present in the sidewall core samples include shale, silty shale, siltstone, sandstone, conglomeratic sandstone and conglomerate. Sometimes more than one rock type occurs in the same sidewall core sample. The following discussion of the composition of the sidewall cores deals primarily with the siltstones and sandstones. A brief discussion of the shales and silty shales can be found in a later section, in the section with individual sample descriptions, and in the overview photomicrographs and descriptions in Appendix 1.

The compositions of 17 of the samples were determined by point count. Sample SP 15, 4317.50M consists of two laminae of significantly different grain size and composition, and these laminae were counted separately, as 15f (fine grained lamina) and 15c (coarser grained lamina). Point count data is presented in Table 2A – rock composition calculated to 100% plus porosity, and Table 2B – bulk rock composition calculated including point count porosity. The composition excluding porosity is preferred to compare original and diagenetic composition between samples, and to relate to core analysis grain density. The composition including porosity is preferred for comparison with bulk density and with core analysis porosity. The accompanying legend explains the rock components counted. Some rock components, such as glauconite, were identified in many of the samples, but do not appear in the point count because even though observed, they were not abundant enough to be encountered during the point count analysis.

Framework grain composition has been recalculated to 100% for the essential QFR components; Q = monocrystalline and polycrystalline quartz; F = all feldspar; R = all rock fragments. In samples, which contain abundant compacted ductile rock fragments with or without authigenic chloritic matrix or compacted interstitial detrital clays, individual rock fragments sometimes are so compacted together that they form a pseudomatrix. In these samples, if individual rock fragments could not be distinguished, they were counted as matrix instead of rock fragments. For this reason, two QFR calculations and ternary diagrams are presented, one using just grains counted as rock fragments for the R component (Figure 2a; Table 3a), and one including rock fragments and matrix (Figure 2b; Table 3b). For the samples with significant matrix, the composition without matrix underestimates the amount of rock fragments relative to quartz and feldspar, and the QFR calculation including matrix with rock fragments overestimates the rock fragment content relative to quartz and feldspar. The QFR diagrams can be used to compare the approximate original detrital compositions of the samples by eliminating authigenic minerals and accessory detrital from the composition. It must be kept in mind, however, that some diagenetic modification of composition has taken place, particularly as a result of the partial to complete dissolution of feldspars and some unstable clasts, and also locally by replacement of grains by carbonates. Original composition of samples which have undergone significant dissolution or grain replacement is both more lithic and more feldspathic.

Newburn H-23																						
Run#	**SWC**	**Depth (m)**	**Qtz**	**PQ**	**Fds**	**LRF**	**CRF**	**Peb**	**Mica**	**Sidcl**	**CD**	**HM**	**Bio**	**CC**	**Dol**	**Sid**	**AQ**	**Kaol**	**Ana**	**Mtx**		**Por**
1	17	4312.80	37.39	2.61	7.54	7.54	8.70	0.00	0.29	2.32	0.29	0.00	0.00	24.93	0.00	0.87	1.16	0.87	0.00	5.51		1.43
1	16	4313.50	31.67	4.00	8.33	17.00	10.00	0.00	0.67	4.33	9.00	0.00	0.00	0.00	0.00	2.33	1.00	0.00	0.00	11.67		7.41
1	6	4317.50	41.88	3.06	2.59	3.29	2.35	40.47	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	2.82	2.35	0.00	0.71		5.76
1	6mtx	4317.50	70.36	5.14	4.35	5.53	3.95	0.00	0.00	0.00	0.00	0.00	0.79	0.00	0.00	0.00	4.74	3.95	0.00	1.19		9.32
1	15f	4318.50	38.33	5.00	12.33	18.67	9.33	0.00	0.33	4.00	4.33	0.00	0.00	0.00	0.00	0.33	1.67	2.00	0.00	3.67		9.09
1	15c	4318.50	58.33	2.33	9.33	7.67	7.67	0.00	0.33	0.67	0.33	0.33	0.00	0.00	0.00	0.33	3.00	9.33	0.33	0.00		13.04
1	14	4319.80	51.67	5.00	6.33	8.00	6.67	0.00	0.33	0.33	0.00	0.00	0.00	20.67	0.00	0.00	0.33	0.67	0.00	0.00		2.28
1	11	4349.70	41.67	5.67	8.67	9.33	11.33	0.00	0.33	1.33	0.00	0.33	0.00	8.67	0.00	2.33	4.67	4.67	1.00	0.00		8.81
1	8	4353.50	43.14	6.57	9.14	10.29	6.86	0.00	0.57	0.57	0.00	0.00	0.00	16.00	0.00	0.57	4.29	0.86	0.00	1.14		4.37
1	10	4354.50	50.36	6.43	6.07	15.71	5.36	0.00	0.00	0.36	0.00	0.00	0.00	7.14	0.00	0.00	1.43	5.36	0.00	1.79		4.44
2	12	5403.60	40.29	1.76	2.06	14.71	4.71	0.00	0.59	0.59	0.29	0.00	0.00	5.88	0.29	0.00	10.29	0.00	0.00	18.53		0.00
2	11	5406.50	43.82	2.94	3.24	13.82	5.59	0.00	0.00	0.00	0.00	0.00	0.00	0.29	1.18	0.00	8.53	1.76	0.59	18.24		1.45
2	10	5407.00	41.47	2.06	4.41	18.24	5.59	0.00	0.29	0.00	0.00	0.00	0.29	0.00	1.76	0.00	2.35	0.29	0.00	23.24		4.23
2	9	5407.50	57.10	5.48	4.19	9.35	7.74	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.97	0.00	6.77	1.61	0.32	6.13		11.43
2	8	5408.50	50.67	5.67	2.67	8.33	8.33	0.00	0.33	0.33	0.00	0.33	0.00	1.67	0.00	0.00	14.33	0.67	0.33	6.33		13.29
3	9	5961.00	36.50	2.25	4.00	18.00	7.75	0.00	0.00	1.00	0.50	0.00	0.00	1.50	1.00	0.00	8.50	0.50	0.25	18.25		0.74
3	4	5961.20	44.75	4.00	5.75	10.75	7.25	0.00	0.25	0.00	0.00	0.00	0.00	1.00	0.75	0.25	10.50	1.25	0.75	12.75		2.20
3	3	5961.70	41.50	2.50	5.00	18.00	5.25	0.00	0.25	0.00	0.25	0.00	0.00	0.00	0.25	0.00	5.00	0.75	0.50	20.75		0.50
3	2	5962.00	50.00	2.75	4.25	11.00	8.25	0.00	0.00	0.00	0.00	0.00	0.00	1.50	2.25	0.00	9.00	1.25	0.25	9.50		1.72

Table 2A: Composition Plus Porosity

Newburn H-23																					
Run#	**SWC**	**Depth**	**Qtz**	**PQ**	**FDS**	**LRF**	**CRF**	**Peb**	**Mica**	**Sidcl**	**CD**	**HM**	**Bio**	**CC**	**Dol**	**Sid**	**AQ**	**Kaol**	**Ana**	**Mtx**	**POR**
1	17	4312.80	36.86	2.57	7.43	7.43	8.57	0.00	0.29	2.29	0.29	0.00	0.00	24.57	0.00	0.86	1.14	0.86	0.00	5.43	1.43
1	16	4313.50	29.32	3.70	7.72	15.74	9.26	0.00	0.62	4.01	8.33	0.00	0.00	0.00	0.00	2.16	0.93	0.00	0.00	10.80	7.41
1	6	4317.50	39.47	2.88	2.44	3.10	2.22	38.14	0.00	0.00	0.00	0.00	0.44	0.00	0.00	0.00	2.66	2.22	0.00	0.67	5.76
1	6mtx	4317.50	63.80	4.66	3.94	5.02	3.58	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	4.30	3.58	0.00	1.08	9.32
1	15f	4318.50	34.85	4.55	11.21	16.97	8.48	0.00	0.30	3.64	3.94	0.00	0.00	0.00	0.00	0.30	1.52	1.82	0.00	3.33	9.09
1	15c	4318.50	50.72	2.03	8.12	6.67	6.67	0.00	0.29	0.58	0.29	0.29	0.00	0.00	0.00	0.29	2.61	8.12	0.29	0.00	13.04
1	14	4319.80	50.49	4.89	6.19	7.82	6.51	0.00	0.33	0.33	0.00	0.00	0.00	20.20	0.00	0.00	0.33	0.65	0.00	0.00	2.28
1	11	4349.70	37.99	5.17	7.90	8.51	10.33	0.00	0.30	1.22	0.00	0.30	0.00	7.90	0.00	2.13	4.26	4.26	0.91	0.00	8.81
1	8	4353.50	41.26	6.28	8.74	9.84	6.56	0.00	0.55	0.55	0.00	0.00	0.00	15.30	0.00	0.55	4.10	0.82	0.00	1.09	4.37
1	10	4354.50	48.12	6.14	5.80	15.02	5.12	0.00	0.00	0.34	0.00	0.00	0.00	6.83	0.00	0.00	1.37	5.12	0.00	1.71	4.44
2	12	5403.60	40.29	1.76	2.06	14.71	4.71	0.00	0.59	0.59	0.29	0.00	0.00	5.88	0.29	0.00	10.29	0.00	0.00	18.53	0.00
2	11	5406.50	43.19	2.90	3.19	13.62	5.51	0.00	0.00	0.00	0.00	0.00	0.00	0.29	1.16	0.00	8.41	1.74	0.58	17.97	1.45
2	10	5407.00	39.72	1.97	4.23	17.46	5.35	0.00	0.28	0.00	0.00	0.00	0.28	0.00	1.69	0.00	2.25	0.28	0.00	22.25	4.23
2	9	5407.50	50.57	4.86	3.71	8.29	6.86	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.86	0.00	6.00	1.43	0.29	5.43	11.43
2	8	5408.50	43.93	4.91	2.31	7.23	7.23	0.00	0.29	0.29	0.00	0.29	0.00	1.45	0.00	0.00	12.43	0.58	0.29	5.49	13.29
3	9	5961.00	36.23	2.23	3.97	17.87	7.69	0.00	0.00	0.99	0.50	0.00	0.00	1.49	0.99	0.00	8.44	0.50	0.25	18.11	0.74
3	4	5961.20	43.77	3.91	5.62	10.51	7.09	0.00	0.24	0.00	0.00	0.00	0.00	0.98	0.73	0.24	10.27	1.22	0.73	12.47	2.20
3	3	5961.70	41.29	2.49	4.98	17.91	5.22	0.00	0.25	0.00	0.25	0.00	0.00	0.00	0.25	0.00	4.98	0.75	0.50	20.65	0.50
3	2	5962.00	49.14	2.70	4.18	10.81	8.11	0.00	0.00	0.00	0.00	0.00	0.00	1.47	2.21	0.00	8.85	1.23	0.25	9.34	1.72

Table 2B: Composition Including Porosity

Legend:
Qtz: Monocrystalline quartz
PQ: Polycrystalline quartz
FDS: All feldspar. Dominantly potassium feldspar, with lesser amounts of albite-twinnned sodic plagioclase. Albite twinning increases downwards; microcline tartan twinning decreases downward.
LRF: All labile rock fragments; includes altered volcanic clasts, shale clasts, chloritic clasts, micaceous pelitic metasedimentary clasts, undifferentiated leached labile clasts.
CRF: Competent rock fragments: includes chert, quartzo-feldspathic volcanic clasts, undifferentiated quartzose and quartzo-feldspathic rock fragments.
Peb: Pebbles in conglomeratic sandstone: mainly sideritic shale, with minor shale, quartz, polycrystalline quartz, uartzo-feldspathic rock fragments.
Mica: Muscovite, biotite, identifiable altered biotite, detrital chlorite
Sidcl: Sideritic clasts: consist of dark brown micritic siderite; some clasts are sideritic shale; some clasts are sideritized biotite
CD: Carbonaceous debris
HM: Heavy minerals: mainly zircon
Bio: Bioclast debris
CC: Ferroan calcite cement
Dol: Ferroan dolomite cement: may include grain-replacive dolomite
Sid: Authigenic siderite, mainly occurring as individual microcrystals
AQ: Authigenic quartz
Kaol: Pore-filling authigenic kaolinite
Ana: Authigenic anatase (TiO_2); occurs as discrete crystals and as fine granular aggregates
Mtx: Detrital matrix clays; interstitial chloritic matrix and grain-rimming chlorite in Runs 2 and 3: pseudomatrix of compacted clasts and where grain boundaries cannot be distnguished from adjacent compacted clasts or matrix.
POR: Point count porosity; does not include microporosity; comparison with core analysis porosity gives and indication of relative amounts of microporosity and macroporosity.

Newburn H-23

SWC	Depth (m)	Q	F	R
17	4312.80	62.70	11.81	25.44
16	4313.50	50.23	11.74	38.03
6mtx	4317.50	84.48	4.87	10.61
15f	4318.50	51.77	14.74	33.45
15c	4318.50	71.12	10.94	17.98
14	4319.80	72.93	8.15	18.88
11	4349.70	61.71	11.30	26.94
8	4353.50	65.41	12.03	22.56
10	4354.50	67.68	7.24	25.11
12	5403.60	66.23	3.24	30.57
11	5406.50	67.38	4.66	27.97
10	5407.00	60.63	6.14	33.18
9	5407.50	74.59	5.00	20.38
8	5408.50	74.42	3.52	22.02
9	5961.00	56.57	5.84	37.59
4	5961.20	67.24	7.93	24.83
3	5961.70	60.86	6.92	32.16
2	5962.00	69.13	5.57	25.23

Table 3A: Newburn H-23 QFR Data: R Includes Rock Fragments Only

SWC	Depth (m)	Q	F	R+MTX
17	4312.80	57.74	10.88	31.38
16	4313.50	43.14	10.08	46.77
6mtx	4317.50	83.41	4.80	11.79
15f	4318.50	49.62	14.12	36.26
15c	4318.50	71.10	10.94	17.97
14	4319.80	72.96	8.15	18.88
11	4349.70	61.74	11.30	26.96
8	4353.50	64.45	11.85	23.70
10	4354.50	66.25	7.08	26.67
12	5403.60	51.25	2.51	46.24
11	5406.50	53.35	3.69	42.95
10	5407.00	45.82	4.64	49.54
9	5407.50	69.53	4.66	25.81
8	5408.50	68.70	3.25	28.05
9	5961.00	44.67	4.61	50.72
4	5961.20	57.18	6.74	36.07
3	5961.70	47.31	5.38	47.31
2	5962.00	61.52	4.96	33.53

Table 3B: Newburn H-23 QFR Data: R Includes Rock Fragments Plus Matrix

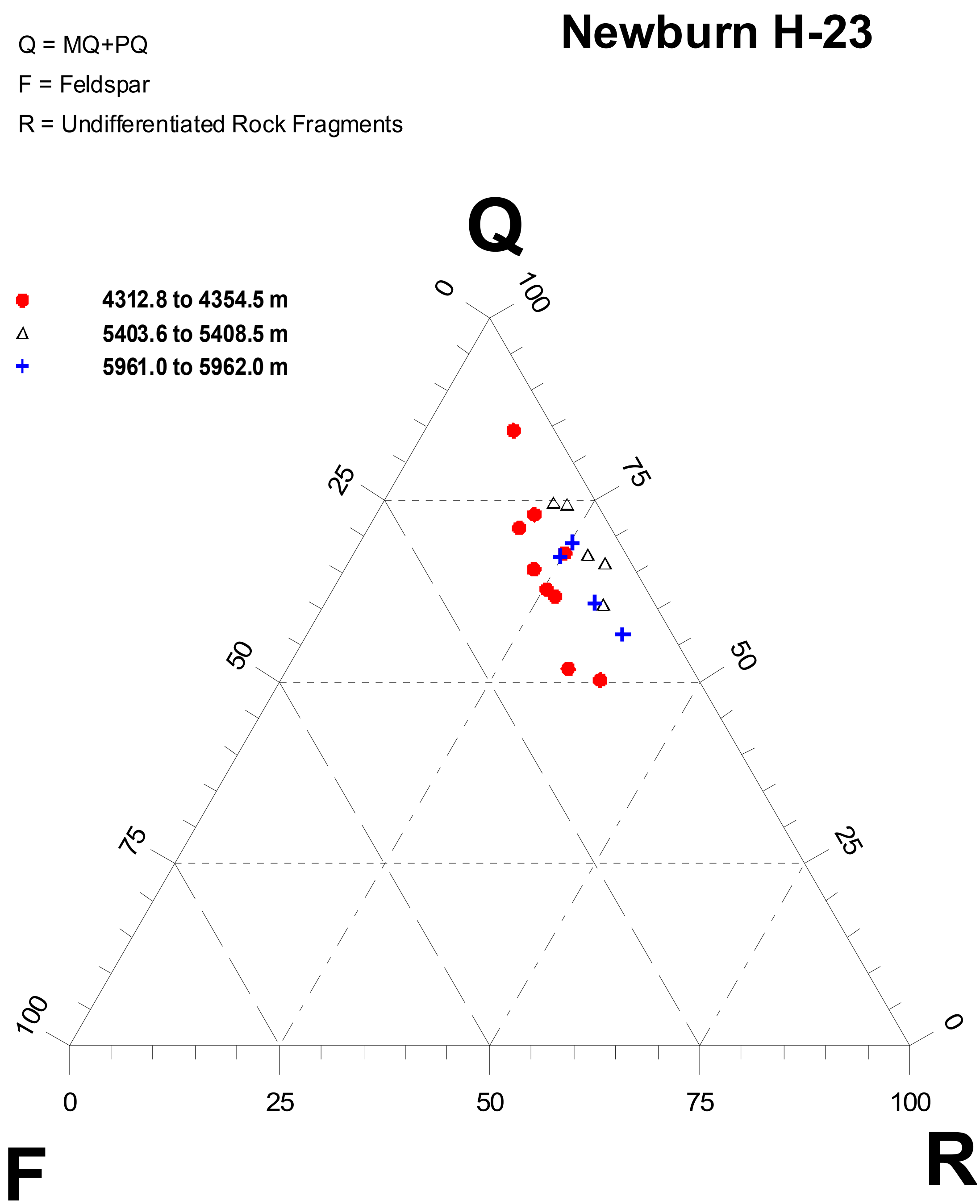


Figure 2A: QFR Diagram (R includes rock fragments only).

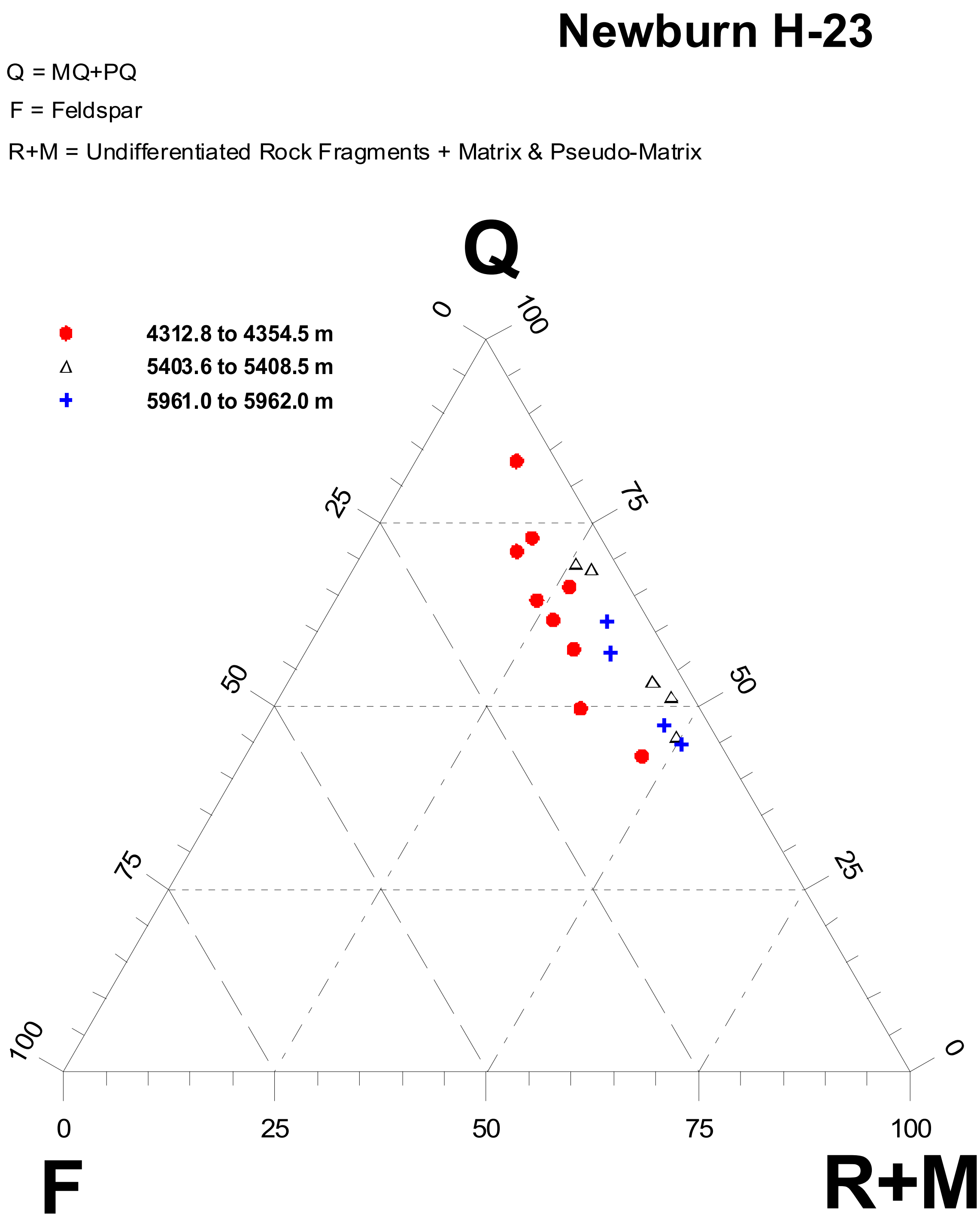


Figure 2B: QFR Diagram (R+M includes rock fragments plus matrix).

If the point count data is to be used as an indication of the amount of feldspar present in the rock for comparison with gamma logs, the feldspar content indicated by the point count data should be considered a minimum. A minor amount of untwinned potassium feldspar inadvertently could have been counted as quartz or competent rock fragments. Feldspar is present in quartzo-feldspathic competent rock fragments and in both competent and labile volcanic rock fragments in all samples.

The samples from run number 1 range from litharenite to sublitharenite based on the QFR calculations, but only one sample, SP 6, 4317.50M is classified as sublitharenite. Since there has been extensive dissolution of both feldspar and rock fragments in this sample, original rock composition was likely closer to quartzose litharenite. All samples analysed from runs 2 and 3 are litharenites based on the QFR diagrams.

Volcanic rock fragments were identified in all samples, and many of the undifferentiated labile and competent grains likely are also of volcanic origin, even though volcanic textures are not preserved, particularly in chloritic and chloritized clasts in samples from runs 2 and 3. Pseudomatrix of compacted, often chloritized rock fragments and chloritic matrix is generally more abundant in the run 2 and run 3 samples. The higher content of chloritic rock fragments in runs 2 and 3 suggest that volcanic detritus may be more abundant than in run 1 samples.

Albite-twinned plagioclase feldspar is generally more common in the run 2 and run 3 samples by visual estimate. Microcline tartan twinning is more common in the run 1 samples than in the run 2 and run 3 samples.

The possible higher content of volcanic detritus in the run 2 and run 3 samples and the apparent higher content of detritus derived from a granitic source (perthite and microcline) suggest that the provenance of the sediments underwent changes between the time of deposition of the run 3 sediments and the time of deposition of the run 1 sediments, either by new source areas being accessed, or unroofing of granitic rocks by erosion in the same source area.

Since the average grain size of sands is coarser in run 1 than in runs 2 and 3, some compositional variations may be a result of hydrodynamics, but in general the previously described differences between runs 1 and runs 2 and 3 are valid.

Diagenesis

The main diagenetic processes which have affected the composition and porosity and permeability conditions in the intervals represented by the sidewall core samples are:

- physical and chemical compaction;
- precipitation of authigenic minerals;
- dissolution of unstable clasts, and possibly other rock components.

<u>Compaction</u>

All samples have undergone reduction of primary intergranular porosity and pore throat size as a result of the rearrangement of grains into closer packing density as a result of physical compaction, and, to varying degrees, by compaction of ductile clasts and matrix into pores, depending on the relative amounts of competent and ductile material. Some grain suturing has also taken place but severe pressure solution is not evident, even along argillaceous and carbonaceous partings.

Authigenic Minerals

The main authigenic minerals which have affected porosity and permeability in these samples are ferroan calcite cement, silica cement, kaolinite and chlorite.

Ferroan Calcite

Where ferroan calcite cement is abundant or pervasive, it completely occludes primary intergranular porosity and severely reduces permeability. Subsequent grain dissolution has usually taken place within the cemented zones, creating secondary moldic porosity and/or intragranular microporosity. This porosity and any pre-existing microporous grains or pore-filling kaolinite account for the measured porosity in samples 17, 14, and 13 in run 1, but such porosity is poorly connected because of the calcite cement.. If dissolution of ferroan calcite cement took place in adjacent intervals, good porosity and connectivity would be created, creating potential reservoir.

In zones where only moderate amounts of ferroan calcite (and in the deeper samples, dolomite) are present, the carbonate moderately reduces porosity and permeability.

Silica

Silica cement as quartz overgrowths on monocrystalline quartz grains is present in all samples, varying from less than 1% to 14.3% by point count. Silica cement has had a variable effect on porosity and permeability in different intervals depending on grain size; on the amount of compaction of quartz grains against ductile clasts; on the amount of quartz plus other competent grains relative to ductile clasts; on the relative timing of silica cementation and ferroan calcite cementation; on the amount of early grain-rimming authigenic chlorite; and possibly on timing of migration of hydrocarbons, if such has occurred. All of the run 1 samples have only minor amounts of silica cement by point count. Silica cement ranges from o.3%-4.2% in this interval, so is not the most significant porosity or permeability controlling property in this zone. Silica cement content ranges from 5% to 14.3% in the run 2 and 3 samples, with the exception of sample SP 10, 5407m, which has 2.4%. The silica cement is lower in this sample because strong compaction of the abundant matrix, pseudomatrix and ductile clasts prevented quartz overgrowth development.

Sample SP 6, 4317.50M has the best potential reservoir properties of all the analysed samples. Even though the matrix sandstone of the conglomeratic sand also has the highest quartz content of all the samples, silica cement has not had as significant an effect in reducing porosity and permeability as it has had in some of the finer grained, less quartzose but more compacted sands (5403.6m, 5961.2m).

Silica cement by point count is more abundant and has a more significant effect in reducing porosity and permeability in the very fine to lower fine grained samples in runs 2 and 3 than in the coarser grained and more quartzose samples. The abundance of silica cement may be accentuated in the point count in finer grained samples relative to coarser grained samples because grains are smaller and better sorted and the edge of a grain is more likely to be encountered, but finer grained samples have more surface area of quartz grains available for cement precipitation than coarser grained samples of the same quartz content, and therefore are more likely to have silica cement occluding pores and pore throats. The sample with the most abundant silica cement by point count, SP 8, 5408.5m, also has one of the highest porosity values measured in run 2, and the best permeability. In this sample, porosity and permeability have been enhanced by grain dissolution. The higher quartz grain and silica cement content have prevented severe compaction of ductile clasts prior to dissolution, and prevented reduction of secondary pore space by compaction, after dissolution.

Kaolinite

Kaolinite is most abundant in the run 1 samples, reducing remnant primary intergranular porosity and secondary dissolution porosity to microporosity. Kaolinite has a more significant effect in reducing permeability than total porosity in this interval.

Chlorite

Authigenic chlorite occurs in run 2 and 3 samples as a grain-rimming clay, as interstitial matrix and as a replacement of labile rock fragments and probably also detrital matrix clays. The presence of occasional oolitic chamosite indicates that chlorite was forming at the depositional interface, so the formation of chlorite rims, interstitial chlorite and chloritization of grains also was taking place during as well as shortly after deposition.

In intervals where chlorite rim development took place on quartz grains and quartz plus other competent grains were relatively abundant compared to ductile clasts, significant reduced intergranular porosity was preserved (Run 2, SP 9, 5407.50M and SP 8, 5408.50M).

In run #3 samples, chlorite is also abundant, but the combination of more abundant compactible clasts and matrix, and very fine grain size results in very little preservation of open reduced intergranular porosity by chlorite rims because of more intense compaction, and small primary pore size. Chlorite often completely fills pores, even if quartz overgrowth development was inhibited.

Other Authigenic Minerals

Other authigenic minerals which are present in all or most samples – siderite, ferroan dolomite (runs 2 and 3), anatase, and pyrite - do not have a significant effect on reservoir quality, but if locally abundant may have an effect on density logs. The authigenic anatase probably has formed from titanium released during alteration of volcanic rock fragments and biotite and dissolution or alteration of iron-titanium oxides and titanium-bearing unstable heavy minerals derived from a volcanic provenance area.

Dissolution

Dissolution of grains or other rock components (detrital matrix, calcite cement) has affected almost all samples to some extent, enhancing total porosity by contributing moldic porosity or microporosity to total porosity. Grain dissolution and possibly dissolution of pore-filling calcite cement has particularly enhanced both porosity and permeability in SP 6 and the coarser grained lamina in SP 15 in run 1.

Table 4 is a shematic summary of the paragenetic sequence of diagenetic minerals and dissolution. There is no quantitative significance to the length of the lines. Thickness of the line is a qualitative comparison of relative significance of parameters to reservoir quality properties. In some cases relative sequence of authigenic mineral formation is interpreted from ambiguous data.

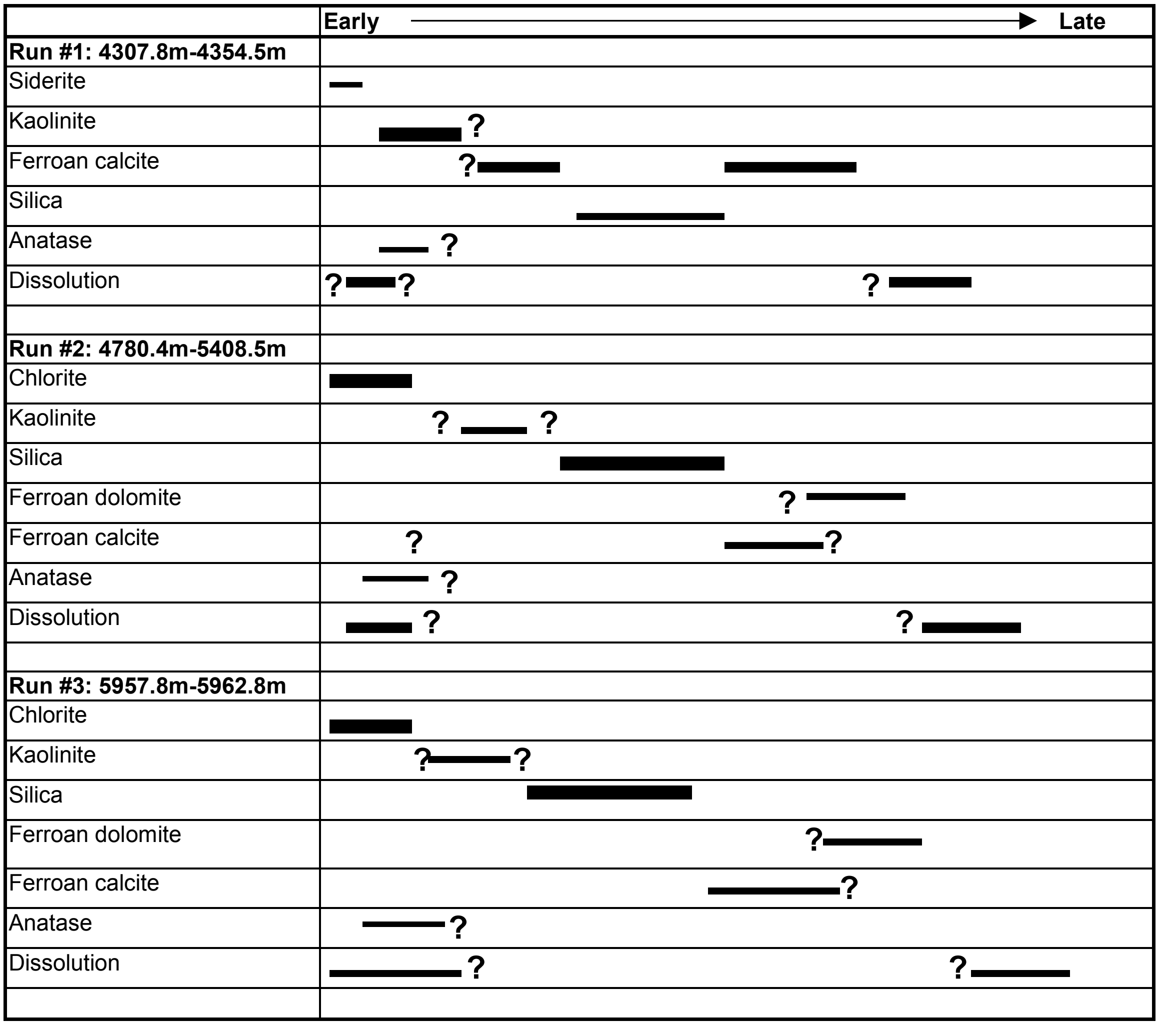


Table 4: Newburn H-23 Schematic Paragenetic Sequence

Shales and Silty Shales

The only shale sample analysed from run 1 (SP 18, 4307.80M) contains silty interbeds which are generally porous. In the shales and silty shales examined from run 2, silty laminae and lenses are generally cemented by ferroan calcite, and shales themselves are often calcareous. The difference in the amount of carbonate cement may be the cause of the difference in the log signature between the run 1 shale and the run 2 shales, but further analysis would be required to determine if that is the case.

Reservoir Quality

As mentioned above, the sample with the best porosity and permeability values of all the samples analysed is sample SP 6, 4317.5m, from run 1. The main controls on porosity and permeability in this sample are the large average grain size of the matrix sand, the high total competent grain content, and the formation of secondary porosity which has enhanced both porosity and permeability. It is possible that some secondary porosity has been formed in this interval by dissolution of calcite cement as well as by dissolution of grains. Potential reservoir quality problems which could be encountered in the run 1 interval include migration of kaolin fines, and high microporosity. With the exception of SP6, a significant proportion of total porosity consists of microporosity in the run 1 samples. Even where point count porosity indicates some open porosity is present, it is generally secondary moldic porosity that is poorly connected.

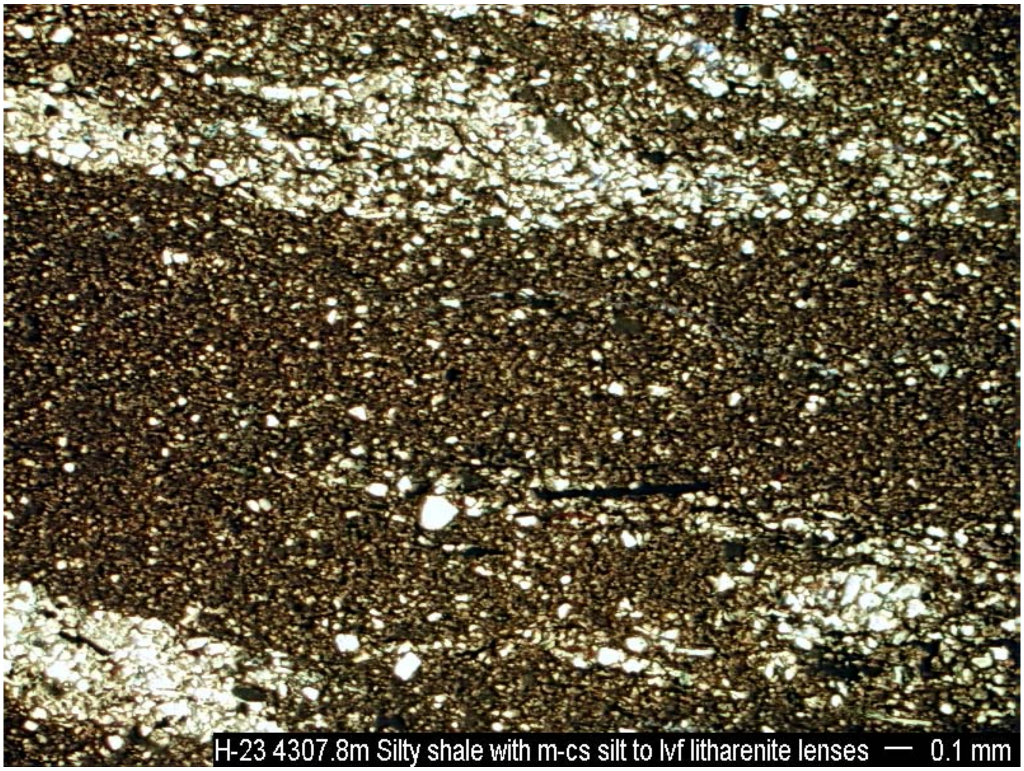
The samples with the best reservoir quality in run 2 are samples SP9, 5407.5m, and SP8, 5408.5m. The good porosity in these samples is a combination of local preservation of primary intergranular porosity by inhibition of quartz overgrowths by chlorite rims; formation of secondary porosity by dissolution of unstable clasts, mainly argillaceous rock fragments and chloritic clasts; and abundant competent grains and silica cement which have prevented reduction of preserved porosity by further compaction.

The main potential reservoir quality problems in the run 2 and run 3 intervals are the high microporosity in most of the samples, and the high iron content in abundant chlorite.

4307.80M SP18 K = < 0.01 mD Porosity = 11.6%

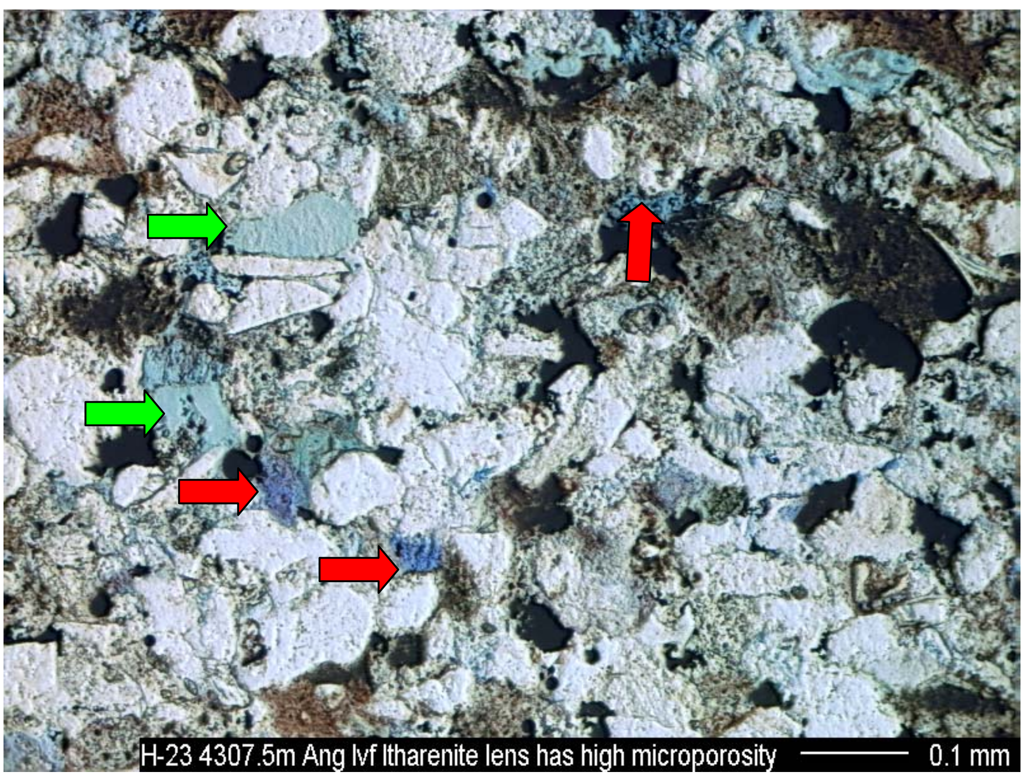
Silty shale with thin (~0.25-1.25mm) lenses and discontinuous laminae of moderately to moderately well sorted argillaceous lithic lower very fine grained sand locally with sand grains to upper fine. Mica is a common accessory grain. Abundant carbonaceous debris. Matrix clay is organic-rich and illitic. Measured porosity consists almost entirely of microporosity in shale and in microporous clasts in sandy/silty lenses.

Newburn H-23 Sidewall Cores 4307.8M SP18



1) Organic-rich shale, silty shale with ~0.25-1.25mm coarse silt to lower very fine grained litharenite lenses and discontinuous laminae.

2) Angular lower very fine grained litharenite lens has high microporosity in leached rock fragments (red arrows), altered glauconite (green arrows) and interstitial detrital matrix clays.



4312.80M SP17 K = 0.01 mD Porosity = 10.1%

This sample contains two distinct laminae: Moderately well sorted angular lower very fine to lower fine grained feldspathic litharenite overlain by a moderately sorted, lower very fine to lower coarse grained quartzose litharenite. Floating subangular to rounded coarse to granule-sized quartz grains occur near the contact with a coarser grained lamina.

Finer Grained Lamina

Framework Grains

Quartz, minor monocrystalline quartz. Feldspar is common, consisting dominantly of alkali feldspar. A few albite-twinned plagioclase fragments are also present. Feldspars are commonly moderately leached and locally are extensively leached.

Rock fragments consist of a variety of altered volcanic clasts, chloritized or chloritic clasts, shale, sideritic shale, undifferentiated fine grained quartzose and quartzo-feldspathic competent clasts, other undifferentiated leached labile rock fragments.

Accessory grains include both biotite and muscovite mica. Biotite is commonly moderately to strongly altered. Glauconite is present in trace to minor amounts but was not encountered in the point count. Sideritic clasts and carbonaceous debris are common.

Authigenic Minerals

- Siderite – trace amounts of siderite occur as individual microcrystals and clusters of microcrystals on grain surfaces.
- Ferroan calcite – pervasive sub-poikilotopic pore-filling calcite completely fills primary intergranular porosity. Calcite cement only locally partly replaces unstable clasts. Most dissolution of feldspar and rock fragments has taken place since ferroan calcite cement precipitation.
- Silica – only very minor amounts of silica cement have precipitated at contacts between adjacent quartz grains. Early ferroan calcite prevented precipitation of quartz overgrowths on quartz grains.

Porosity and Permeability

Intergranular porosity is completely occluded by ferroan calcite cement but some complete dissolution of grains has taken place, forming isolated moldic secondary pores.

Coarser Grained Lamina

Framework Grains

Moderately sorted, angular to rounded lower very fine to lower coarse grained quartzose litharenite.

This lamina is a mixture of very fine to lower fine angular sand as in the finer grained lamina described above, and angular to rounded medium to coarse quartz and feldspar grains.

Detrital grain composition is similar to that of the very fine grained lamina. Rock fragments consist of altered and sometimes leached labile volcanic rock fragments, quartzo-feldspathic volcanic rock fragments, shale, pelitic metasedimentary rock fragments. Minor amounts of sideritic clasts and carbonaceous debris are present, but are not as abundant as in the finer grained lamina.

Altered mica and a trace amount of glauconite are locally present.

Authigenic Minerals

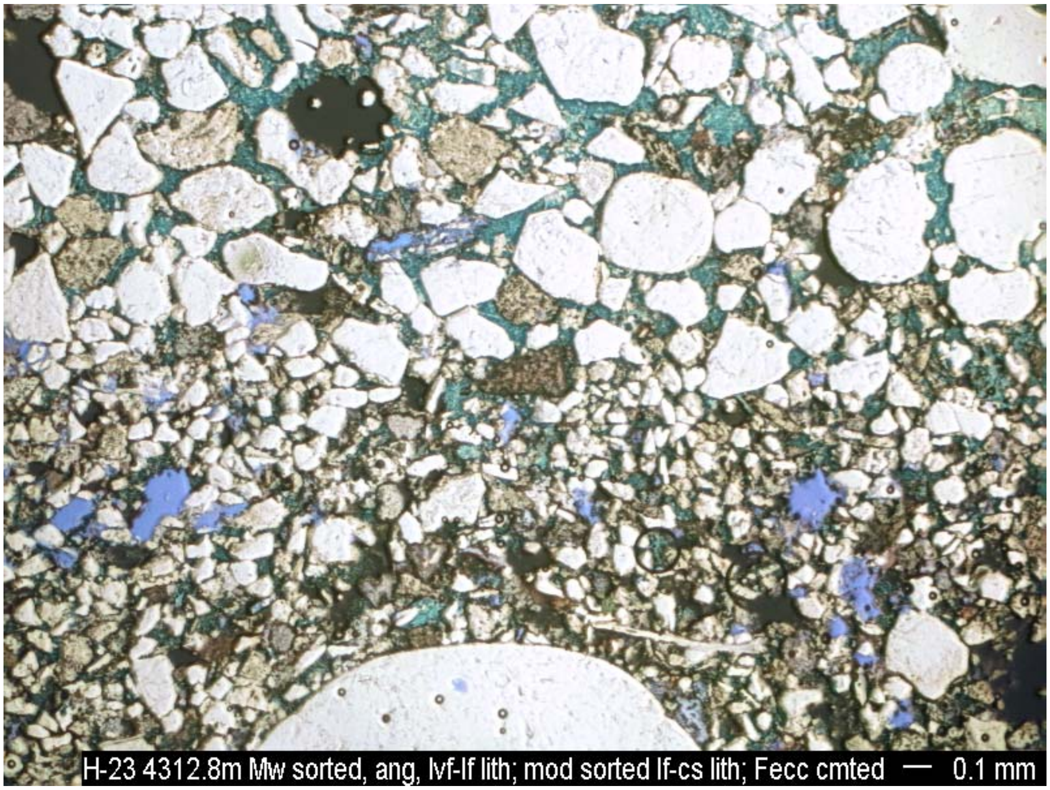
- Siderite – trace early microcrystals on grain surfaces.
- Kaolinite – trace in moldic pores formed by dissolution of unstable clasts – not usually present in leached feldspar.
- Ferroan calcite – pore-filling subpoikilotopic ferroan calcite cement. Calcite locally fills intragranular porosity in some leached feldspar grains, but in other leached feldspar grains intragranular pores are open. Possibly two episodes of dissolution have taken place, or some feldspars were partially leached at the time of deposition. One moldic pore filled by kaolinite was partly filled by later ferroan calcite, which encloses some of the kaolinite. It is not clear if there is one or two episodes of ferroan calcite precipitation in this case. Calcite is in optical continuity with surrounding cement, but staining suggests iron content may be slightly lower in the calcite inside the moldic pore than outside the pore.
- Silica – a trace to minor amount of silica cement occurs as “necked” contacts between adjacent quartz grains where not separated by ferroan calcite cement.

  Little or no quartz overgrowth development took place on quartz grains before ferroan calcite cement.
- $Ti0_2$ – a trace to minor amount of authigenic anatase is locally present. $Ti0_2$ occurs as small discrete crystals, as fine granular coatings on grain surfaces, and as replacement of minor amounts of interstitial detrital clays or argillaceous clasts.

Porosity and Permeability

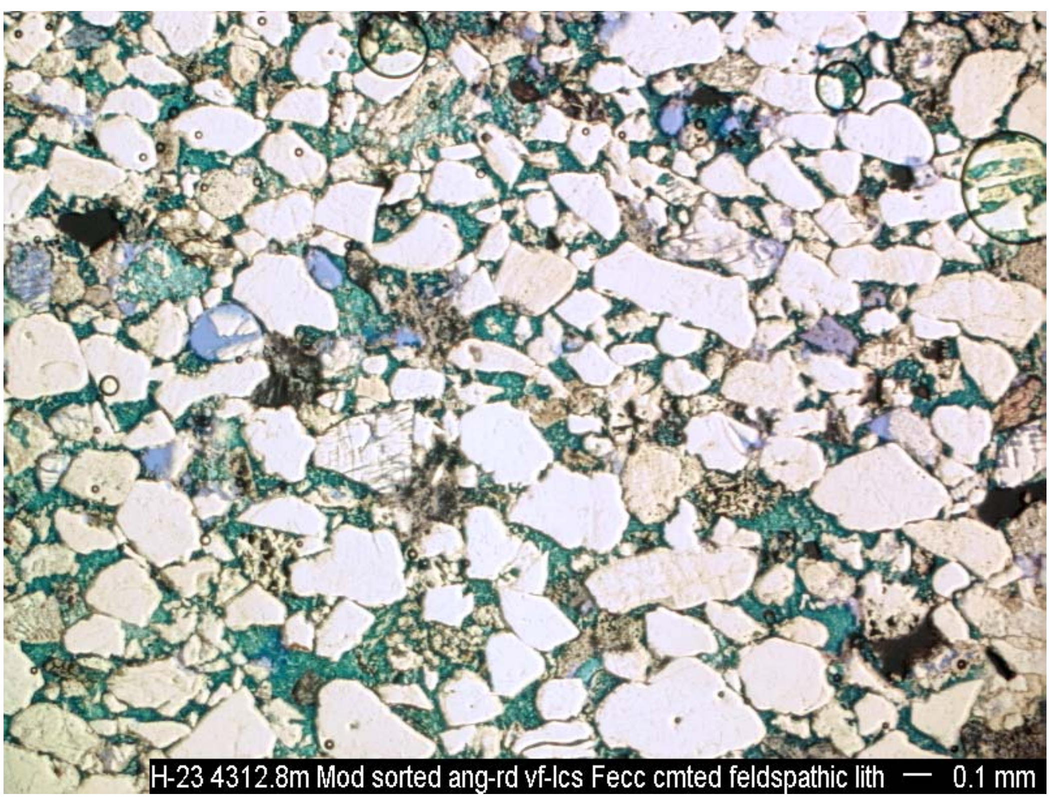
Intergranular porosity is almost completely occluded by pore-filling ferroan calcite cement. Measured porosity consists mainly of moldic dissolution pores where grains have completely dissolved and microporosity in partially leached feldspars and rock fragments. Permeability is very low because ferroan calcite cement isolates secondary pores.

Newburn H-23 Sidewall Cores 4312.8M SP17

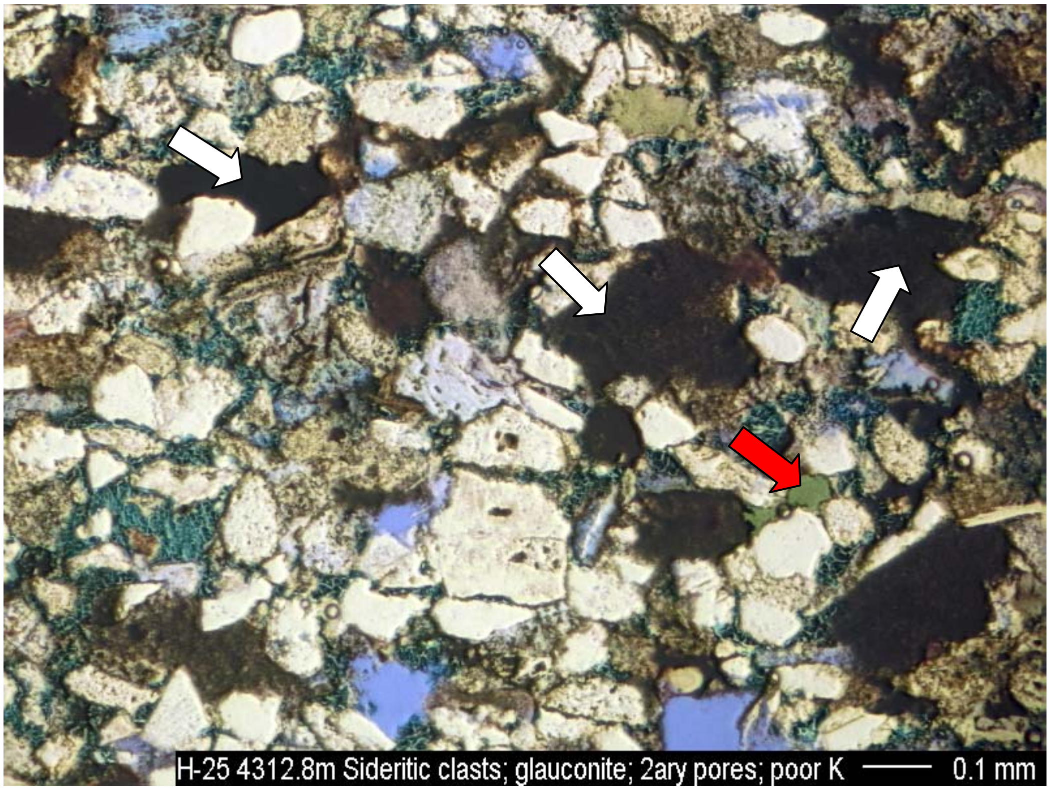


1) Moderately well sorted, angular lower very fine to lower fine grained feldspathic litharenite (bottom half of photo) with floating rounded coarse to granule sized grains (bottom center) occurring near the contact with the coarser grained lamina consisting of moderately sorted angular to rounded lower very fine to lower coarse quartzose litharenite (top).

2) Moderately sorted, angular to rounded, very fine to lower coarse grained ferroan calcite (blue-green) cemented feldspathic quartzose litharenite.



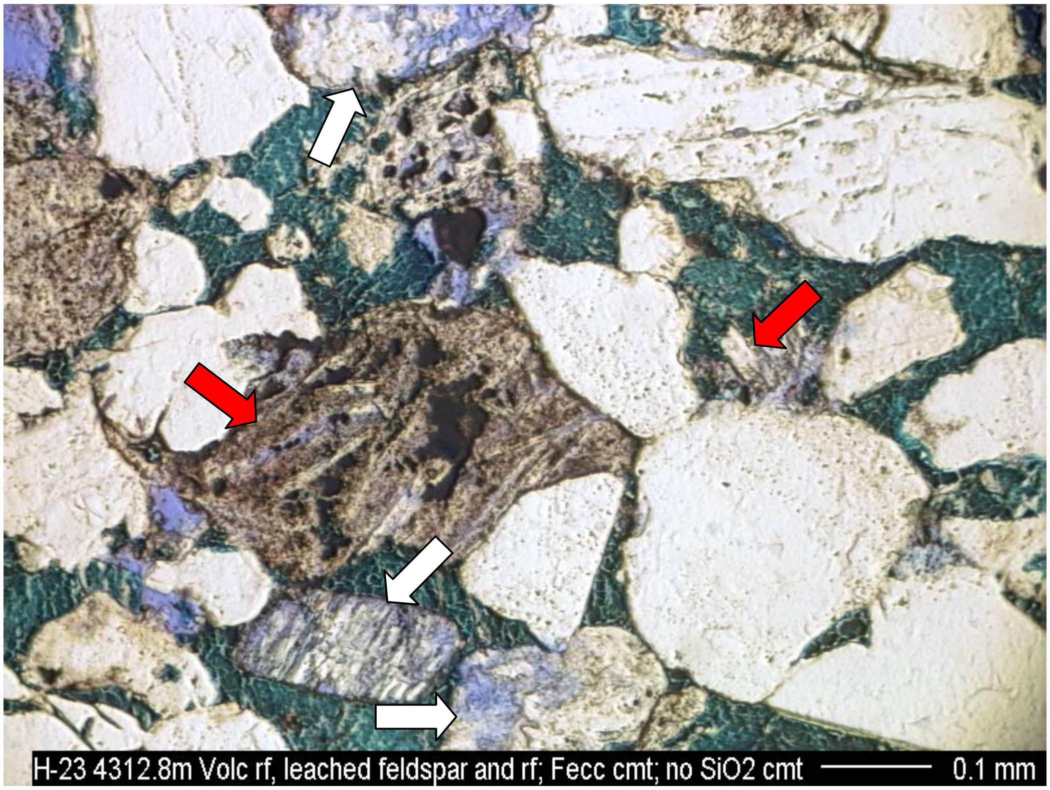
Newburn H-23 Sidewall Cores 4312.8M SP17



3) Sideritic clasts are common in the finer grained lamina (white arrows). Sideritic clasts consist of sideritic shale and possibly sideritized biotite. Glauconite is present in trace amounts (red arrow). Intergranular porosity is severely reduced by compaction of ductile clasts, grain suturing, Ferroan calcite cement.

4) Microcrystalline siderite (red arrows) precipitated on detrital grains before intergranular porosity was almost completely occluded by ferroan calcite (blue).

Newburn H-23 Sidewall Cores 4312.8M SP17

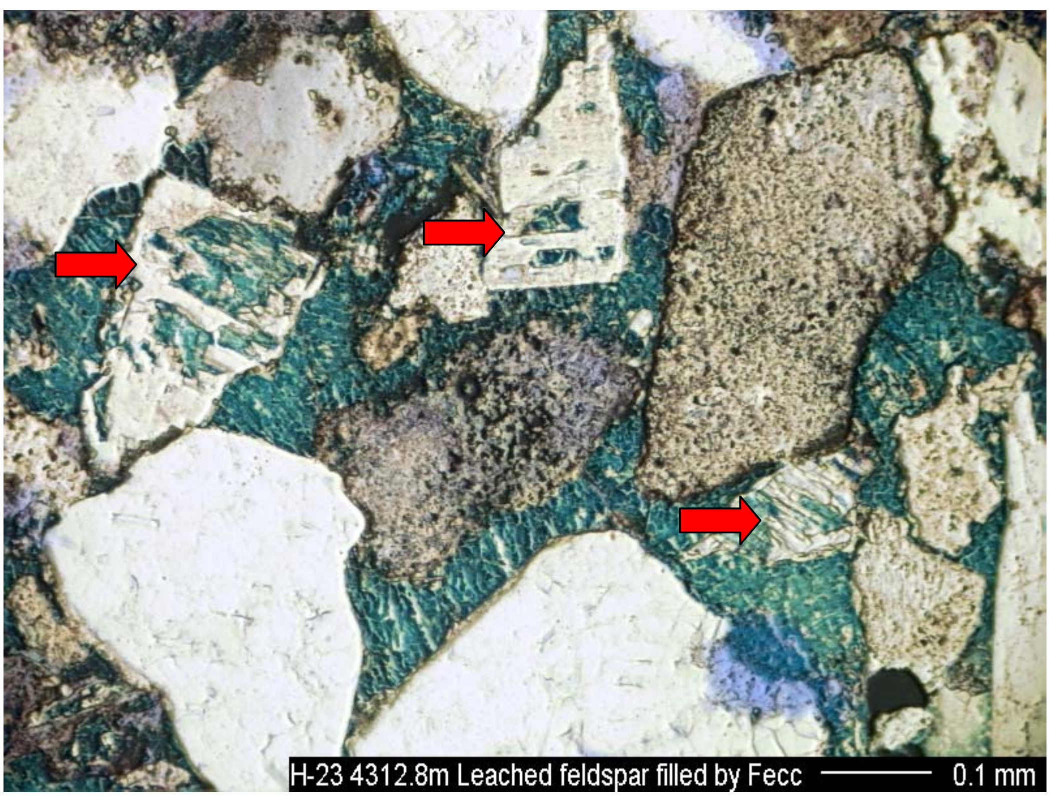


5 and 6) Same field of view under plane polarized light (5) and under crossed polars (6). Little or no silica cement precipitated before precipitation of pore-filling ferroan calcite. Volcanic rock fragments are common (red arrows). Intragranular porosity and microporosity has formed by partial dissolution of feldspars and rock fragments (white arrows). Unleached microcline (tartan twinning, upper right, photo 6)

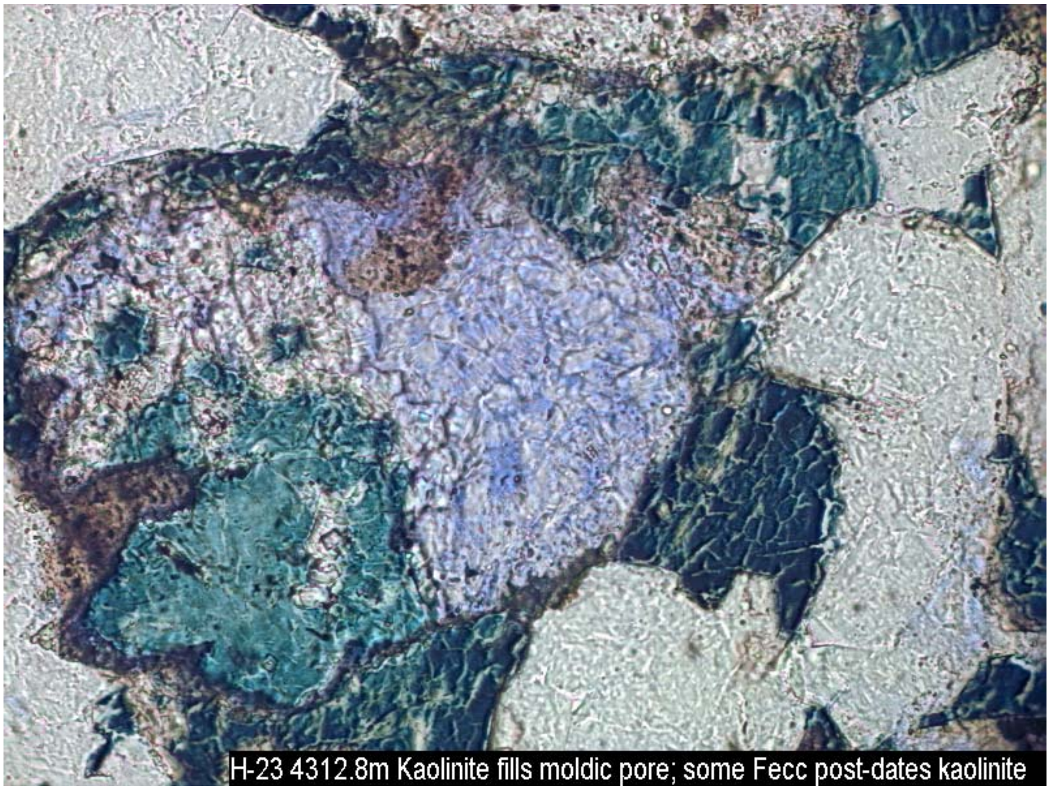
Newburn H-23 Sidewall Cores 4312.8M SP17

7) Dissolution of feldspar (left center) took place after ferroan calcite cementation (blue-green).

8) Some dissolution of feldspar took place before ferroan calcite cementation, as indicated by intragranular dissolution porosity in some feldspar being filled by calcite (arrows).



Newburn H-23 Sidewall Cores 4312.8M SP17



9) Authigenic kaolinite (center) fills a moldic pore formed by complete dissolution of an unstable clast. Ferroan calcite encloses some kaolinite, indicating that some calcite cementation post-dates kaolinite precipitation. Calcite in the moldic pore may represent a different cementation episode. It appears to fill a void rather than being syntaxially and compositionally continuous with the adjacent pore-filling cement.

4313.50M SP16 K = 0.40 mD Porosity = 17.5%

Moderately well sorted, angular to subangular lower very fine to upper fine grained, dominantly upper very fine grained litharenite. Well laminated, with lamination defined by parallel orientation of elongate grains, carbonaceous debris, and concentrations of sideritic clasts.

Framework Grains

Quartz, polycrystalline quartz. Abundant feldspar consists dominantly of potassium feldspar but albite-twinned plagioclase fragments are also present. Albite likely is more abundant than is indicated by the point count data.

Rock fragments are abundant, including shale; a variety of labile altered volcanic clasts; volcanic and other undifferentiated competent quartzo-feldspathic and quartzose rock fragments; quartzite, quartz-mica and micaceous pelitic metasedimentary rock fragments; undifferentiated altered and argillaceous clasts. Altered volcanic clasts and other undifferentiated labile clasts are often leached and microporous.

Mica is a common accessory grain. Biotite is often strongly degraded to kaolinite and/or other clays, or is sideritized.

Carbonaceous debris and sideritic clasts are abundant, commonly concentrated in laminae.

Authigenic Minerals

Minor siderite occurs as individual microcrystals or clusters of microcrystals on grain surfaces and as partial replacement of some rock fragments.

Titanium oxide – authigenic crystals or fine granular aggregates are scattered throughout the pore system.

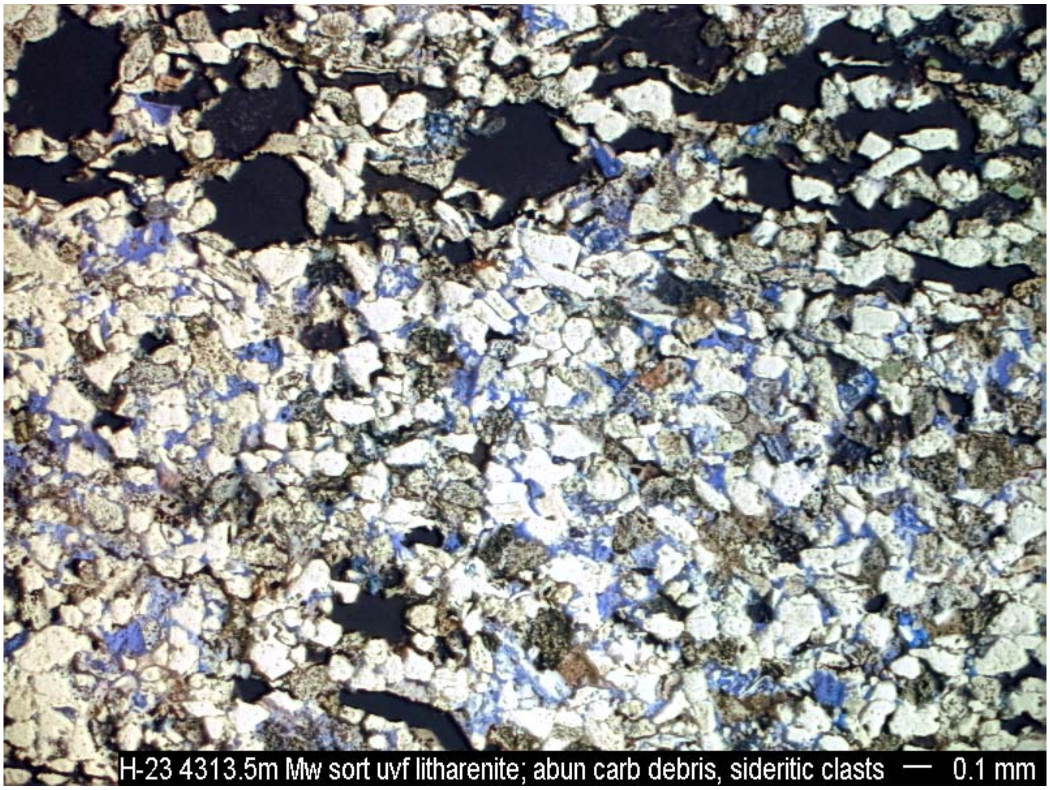
Minor pore-filling kaolinite – kaolinite locally occurs as an alteration or replacement of unstable clasts.

Very minor silica cement, usually occurring where two quartz grains are in contact. Close packing of abundant ductile and labile clasts against quartz grains has inhibited quartz overgrowth development.

Porosity and Permeability

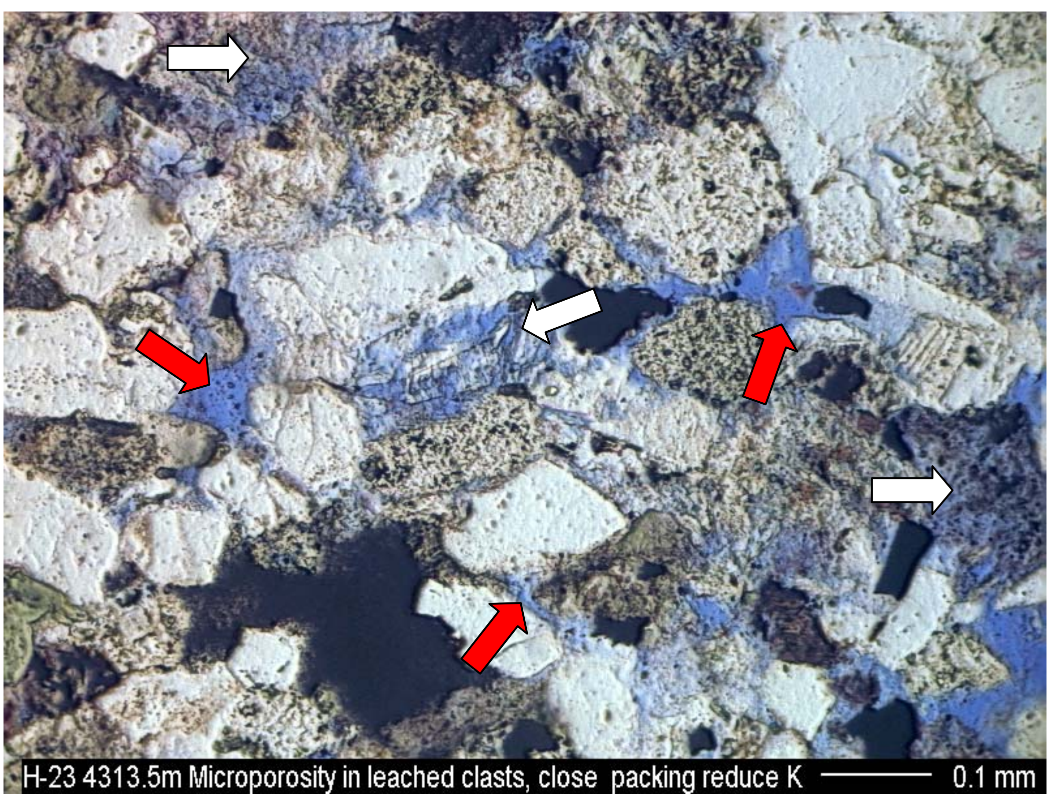
Intergranular porosity is strongly reduced by close grain packing and deformation of ductile rock fragments, micas and carbonaceous debris into adjacent pores. Total porosity is strongly enhanced by the creation of microporosity in leached feldspars and leached rock fragments. Even though porosity has been enhanced by leaching, permeability is severely reduced by the effects of compaction and by the high microporosity component of total porosity.

Newburn H-23 Sidewall Cores 4313.5M SP16

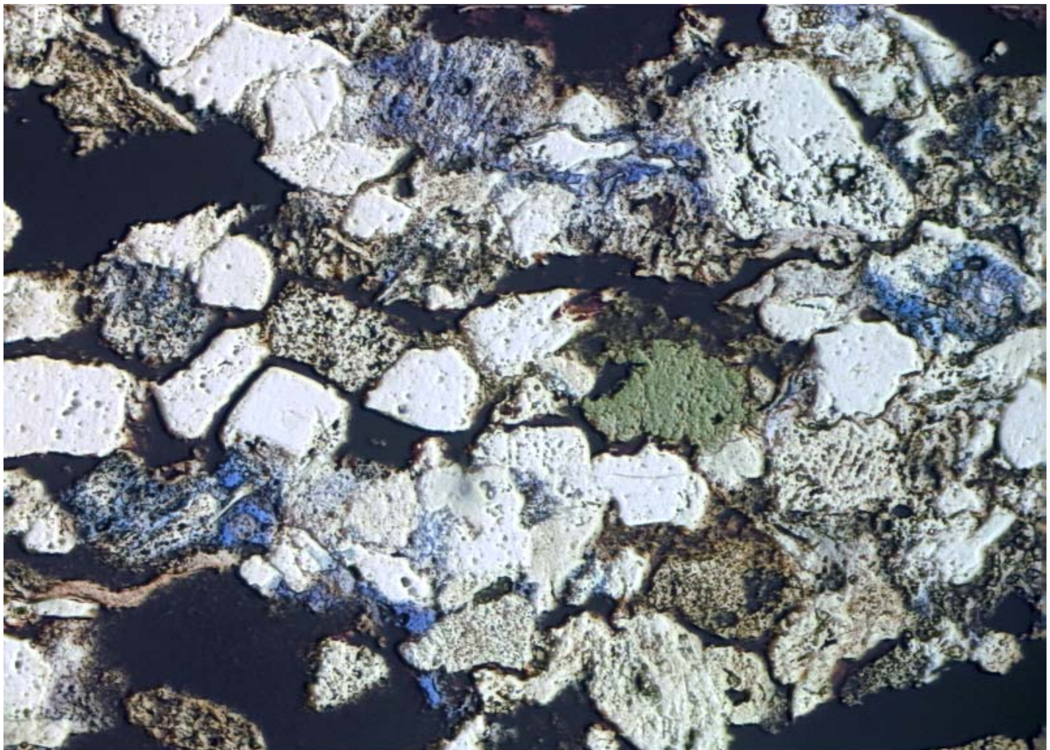


1) Moderately well sorted, angular to subangular lower very fine to upper fine grained, dominantly upper very fine grained, litharenite. Dark lamina at top contains a high concentration of sideritic clasts, carbonaceous debris and mica.

2) Measured porosity of 17% consists of remnant intergranular porosity reduced by close grain packing and compaction of ductile clasts into adjacent pores supplemented by intragranular porosity and moldic porosity in strongly leached clasts (red arrows), and by microporosity in partially leached clasts (white arrows).



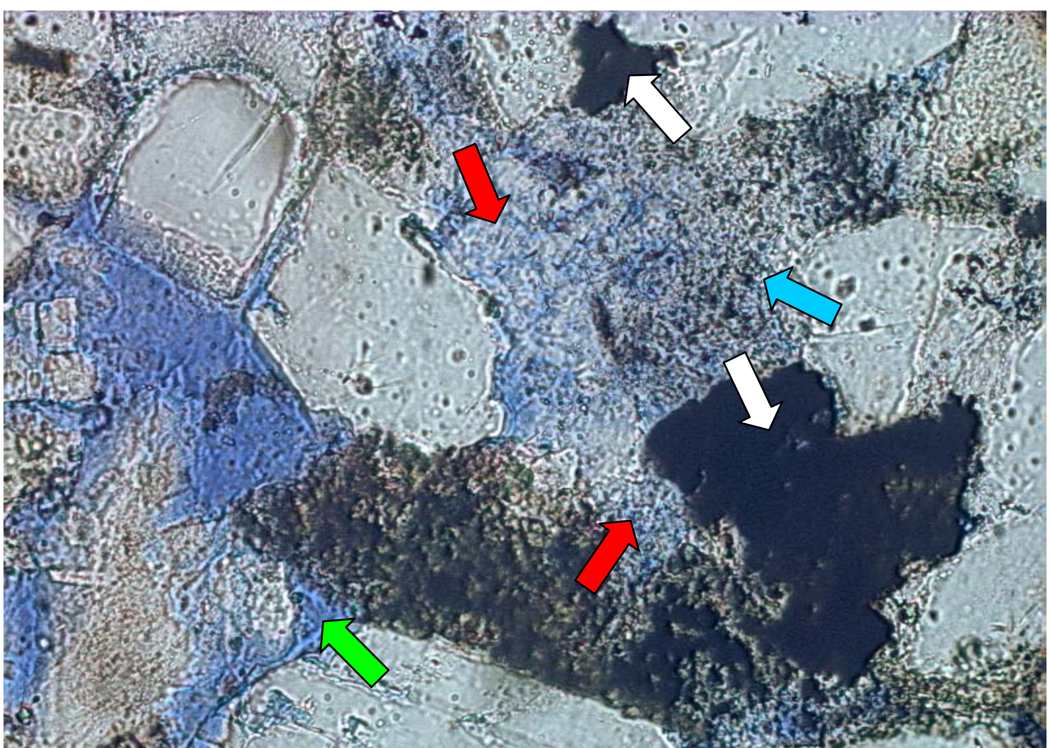
Newburn H-23 Sidewall Cores 4313.5M SP16



H-23 4313.5m Compacted carb debris, sid clasts; glauc; leached rf, fds 0.1 mm

3) Porosity and permeability are severely reduced by compaction of ductile clasts, carbonaceous debris, rock fragments, mica, sideritic clasts and interstitial detrital clays and glauconite (green) against each other and more resistant grains in a carbonaceous lamina. Total porosity is enhanced by partial dissolution of feldspars and rock fragments.

4) Authigenic kaolinite in moldic porosity to microporosity (red arrows). Porosity consists of minor remnant intergranular porosity(green arrow),dissolution porosity (blue, left center and microporosity in leached clasts (blue arrow)Granular aggregates of authigenic TiO2 (white arrows) are scattered throughout the sample.



H-23 4313.5m Kaolinite; TiO2; leached rf; reduce intergr porosity 0.010 mm

4317.50M SP6 K = 42.40 mD Porosity = 18.1%

Poorly to moderately sorted, angular to rounded, dominantly subangular upper fine to lower very coarse, dominantly upper medium to lower coarse grained conglomeratic sublitharenite or matrix-supported conglomerate. Most of the pebbles are well rounded sideritic silty shale. Rounded polycrystalline quartz, quartzite and feldspar grains are also present in the coarse fraction. The point count data for this sample is presented in two ways: a) including pebbles which take up about 40% of the sample, and b) composition of the matrix only.

Framework Grains

In the matrix sand fraction, framework grains consist of monocrystalline quartz, polycrystalline quartz, feldspar and rock fragments. Feldspar grains are dominantly alkali feldspar – orthoclase, microcline and perthite. Feldspars are commonly moderately to very strongly leached, contributing significant secondary dissolution porosity to the total porosity.

Rock fragments consist of competent fine grained quartzose and quartzo-feldspathic clasts, some of which are of volcanic origin, and coarsely crystalline quartzo-feldspathic clasts of probable intrusive origin. Minor labile clasts consist of leached, altered volcanic clasts, shale, leached shale, sideritic or dolomitic shale. Extensive dissolution of unstable clasts has taken place. Some clasts have been replaced by kaolinite.

Abraded echinoderm fragments are present in one thin section.

Authigenic Minerals

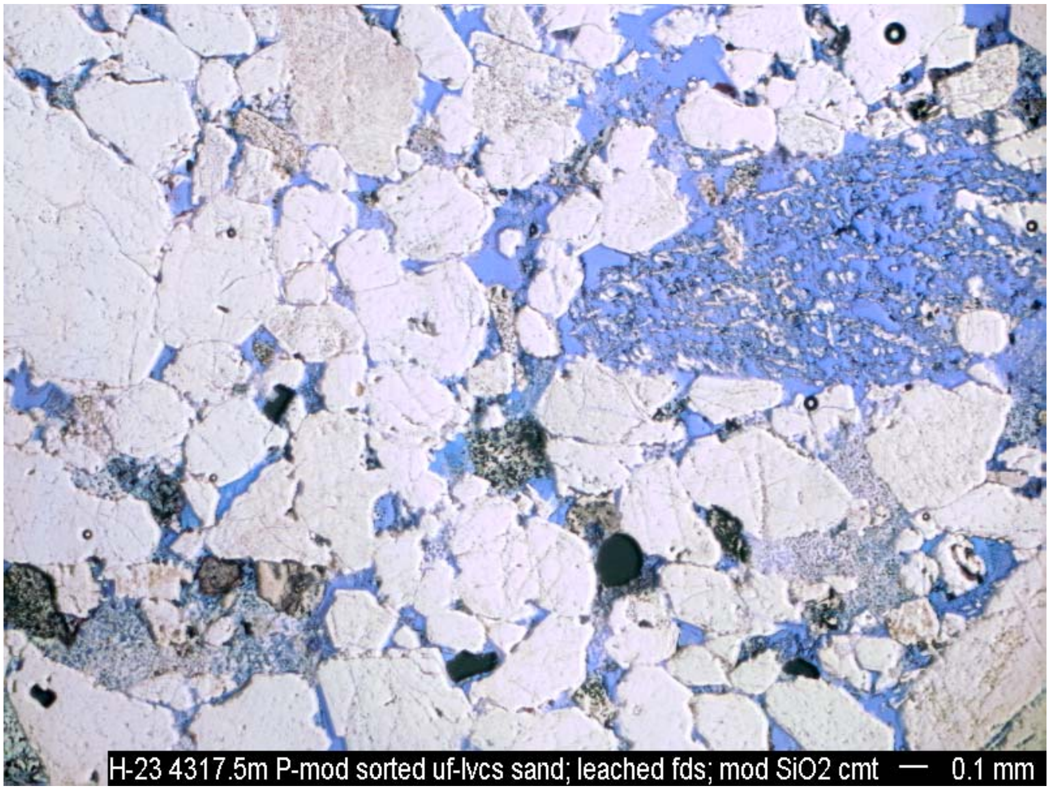
- Kaolinite – occurs filling reduced primary intergranular pores, secondary moldic dissolution pores, and possibly secondary intergranular pores. Kaolinite also partly to completely replaces some unstable rock fragments.
- Siderite – occurs as trace amounts of scattered microcrystals on grain surfaces or partly replacing altered and leached labile rock fragments.
- Silica – moderate quartz overgrowth development has taken place, particularly where adjacent quartz grains are in contact, but silica cement rarely completely occludes intergranular pores.
- Anatase – trace amounts of authigenic anatase crystals are scattered throughout the pore system.
- Calcite – a minor amount of slightly ferroan calcite cement is locally present. Calcite commonly nucleated on abraded echinoderm and other bioclast fragments. Calcite is corroded and previously may have been more extensive.

Porosity and Permeability

Measured porosity of 18.1% consists of remnant intergranular porosity reduced by close grain packing and silica cement; secondary moldic dissolution porosity where grains have been completely or almost completely dissolved; intragranular porosity in partly leached clasts, particularly large feldspar grains; microporosity in leached clasts and in abundant pore-filling kaolinite. Calcite cement locally reduces porosity but is not a significant porosity or permeability reducing factor in the two thin sections of this sample. Some porosity enhancement may have take place by partial dissolution of calcite cement. The point count porosity of the matrix sand is 9.3%. Since the conglomerate pebbles generally do not contribute to total porosity, most of the measured core analysis porosity also is within the matrix sand. Comparison of the point count and core analysis porosity values indicate that approximately half of the porosity is microporosity and half is open reduced intergranular porosity and secondary porosity.

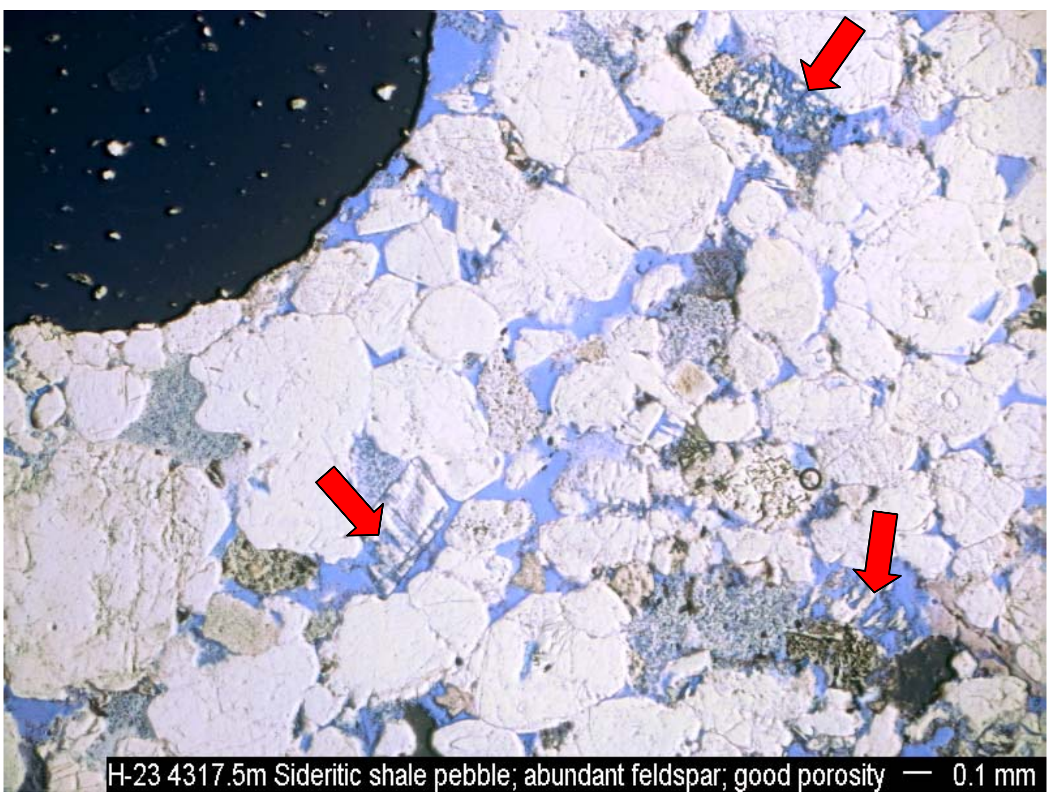
Permeability is good because of the relatively coarse average grain size of the sand, and enhanced by grain dissolution. Permeability is reduced by silica cement, close grain packing and abundant microporous kaolinite.

Newburn H-23 Sidewall Cores 4317.5M SP6

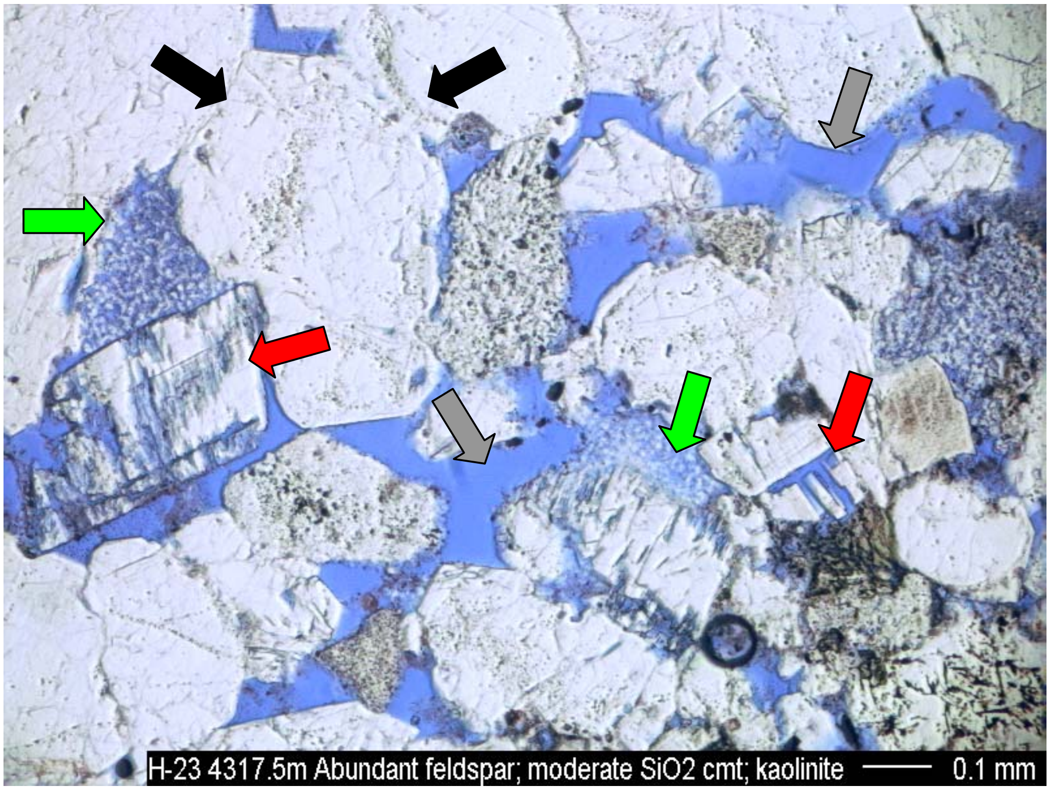


1) Poorly to moderately sorted upper fine to lower very coarse grained conglomeratic sublitharenite. Porosity has been enhanced by strong leaching of some feldspars (upper right) and other unstable clasts.

2) Rounded sideritic shale pebbles are common (upper left). Feldspar and feldspathic rock fragments are often strongly leached (arrows), enhancing total porosity and increasing permeability.

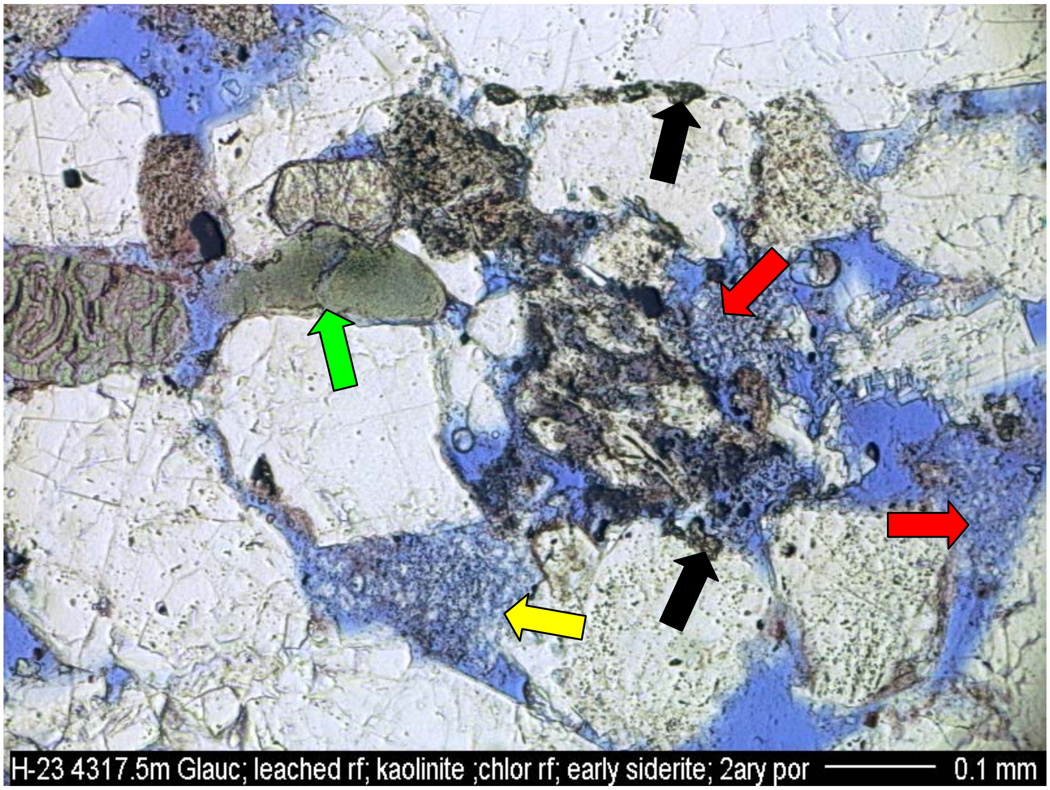


Newburn H-23 Sidewall Cores 4317.5M SP6

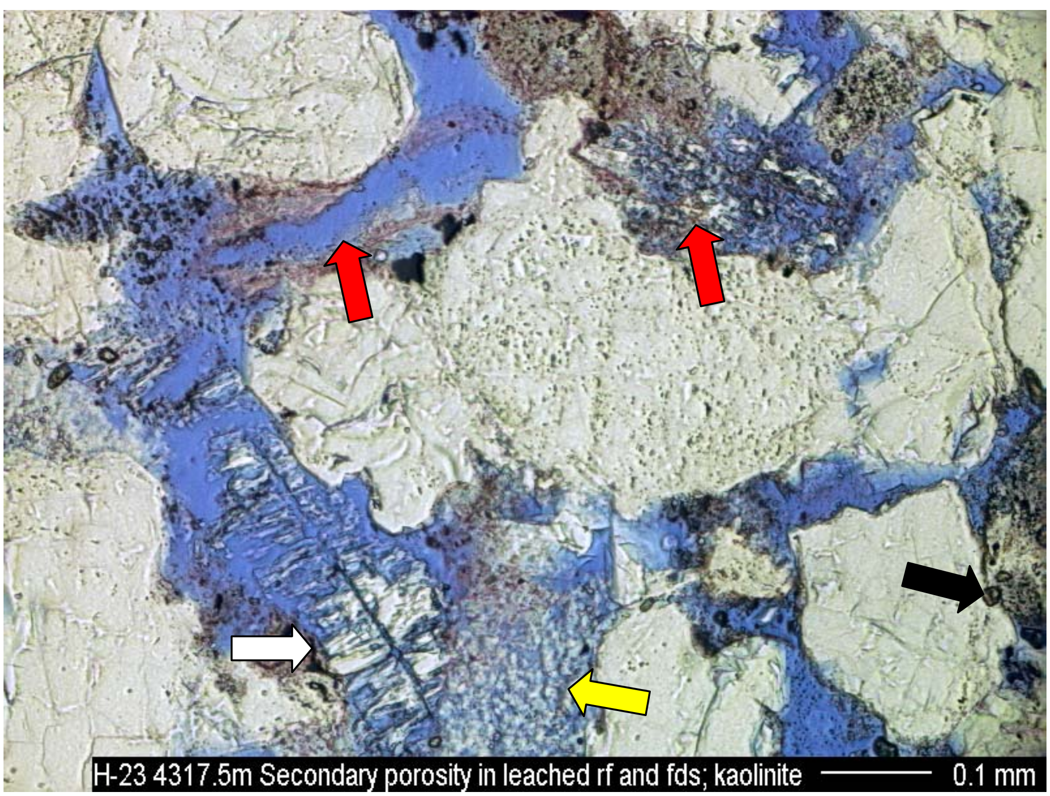


3 and 4) Same field of view under plane polarized light (3) and under crossed polars (4). Measured porosity of 18% consists of primary intergranular porosity reduced by close grain packing and by moderate amounts of silica cement, mainly at quartz grain contacts (black arrows); enhanced by secondary porosity formed by complete dissolution of some unstable clasts (grey arrows) and partial dissolution of abundant feldspar (red arrows) and unstable rock fragments. Porosity is locally reduced to microporosity by pore-filling kaolinite (green arrows).

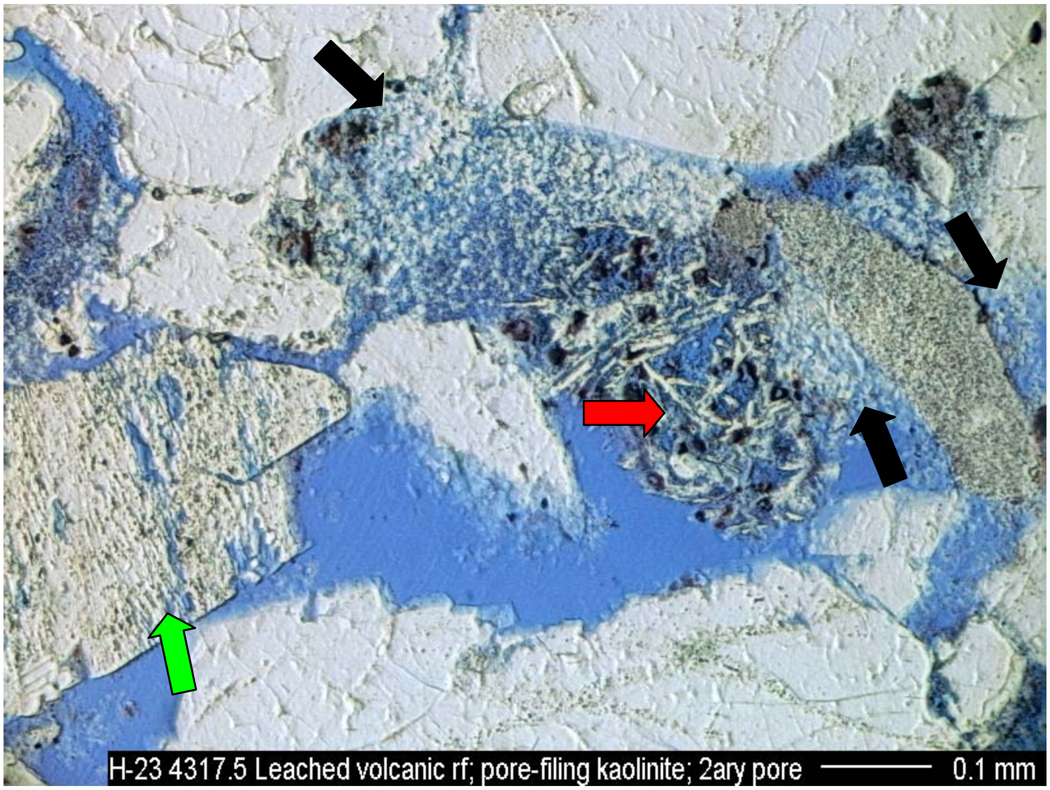
Newburn H-23 Sidewall Cores 4317.5M SP6



5 and 6) Glauconite (green arrow) is present in trace to minor amounts. Secondary porosity has formed by partial to complete dissolution of unstable rock fragments (red arrows) and feldspar (white arrow). A minor amount of early microcrystalline siderite (black arrows) clings to some grains or is compacted between grains. Kaolinite locally fills reduced primary and secondary pores (yellow arrows).



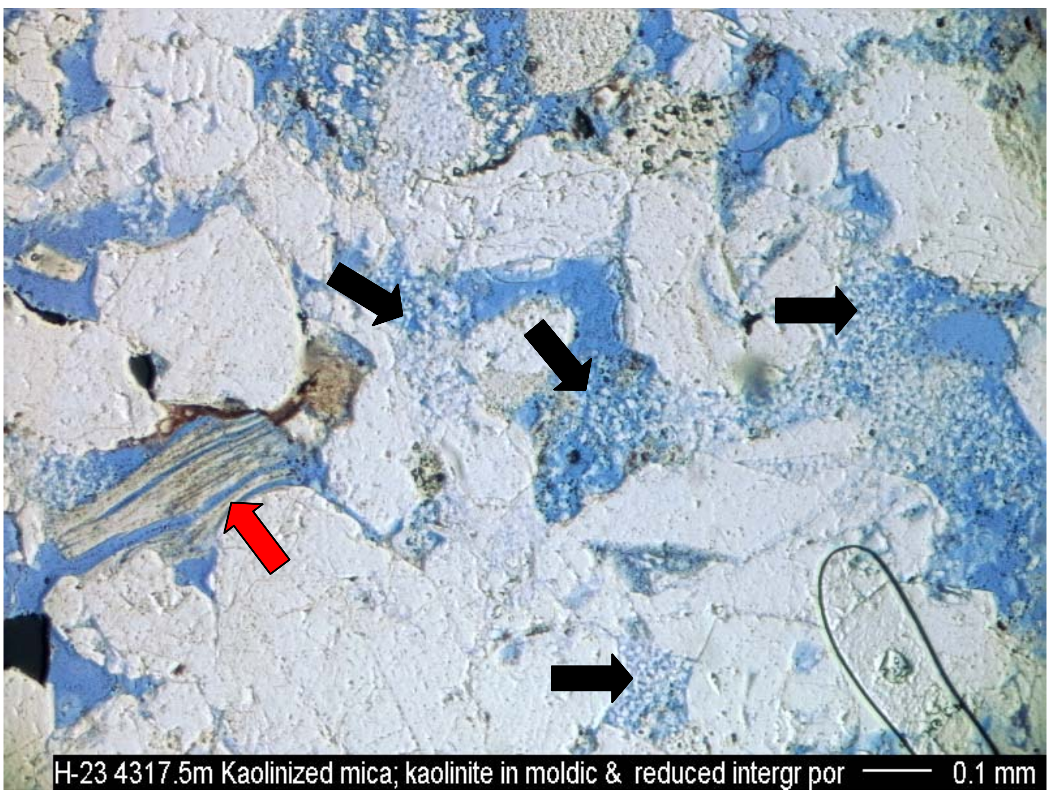
Newburn H-23 Sidewall Cores 4317.5M SP6



H-23 4317.5 Leached volcanic rf; pore-filing kaolinite; 2ary pore 0.1 mm

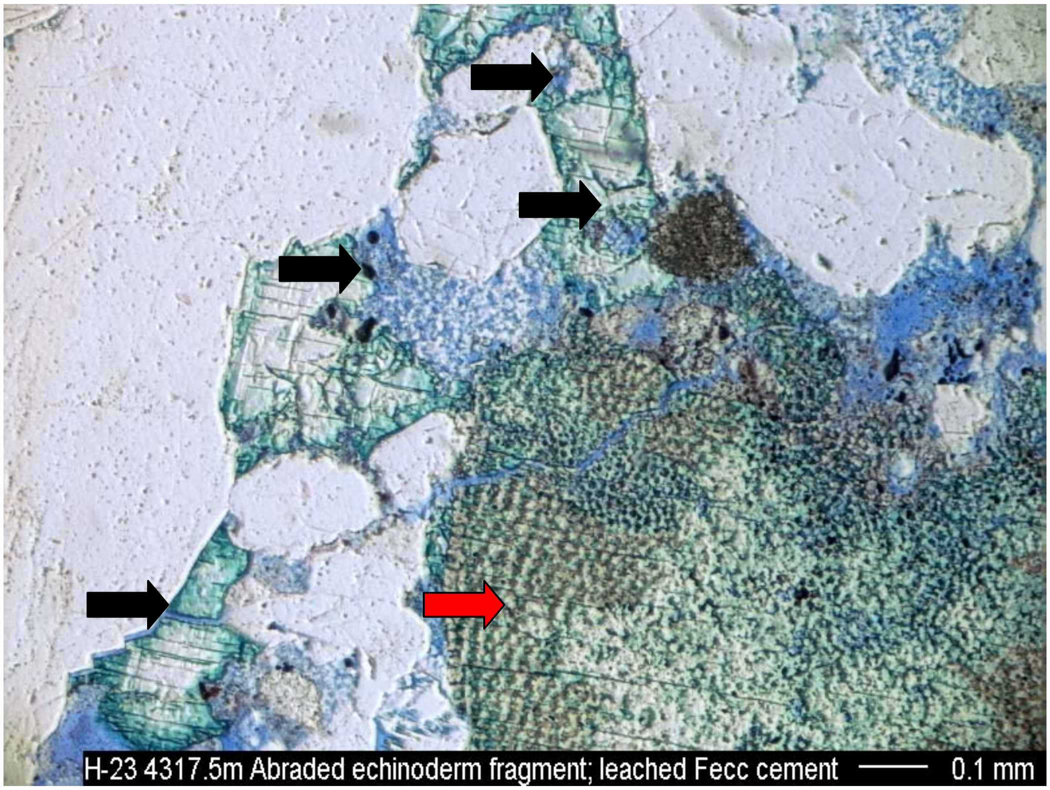
7) Microporosity in leached volcanic rock fragment (red arrow), leached feldspar (green arrow) and pore-filling kaolinite (black arrows), oversized pores (blue, center) have formed by complete dissolution of unstable clasts.

8) Mica, particularly biotite, is often partly altered to kaolinite (red arrow). Aggregates of authigenic kaolinite booklets fill reduced intergranular and secondary dissolution pores (black arrows), reducing open porosity to microporosity and reducing permeability..



H-23 4317.5m Kaolinized mica; kaolinite in moldic & reduced intergr por 0.1 mm

Newburn H-23 Sidewall Cores 4317.5M SP6



9) An abraded echinoderm fragment (red arrow) was overgrown by ferroan calcite cement which subsequently was partly dissolved (black arrows). Some of the remnant intergranular porosity may be secondary intergranular porosity formed by partial dissolution of previously more extensive pore-filling ferroan calcite cement. Kaolinite fills reduced primary and/or secondary intergranular and granomoldic pores.

4318.50M SP15 K = 2.65mD Porosity = 16.5%

This sample consists of two distinct laminae, a finer grained litharenite with abundant carbonaceous debris overlain by a coarser grained quartzose litharenite lamina. The two lamina were analysed separately in the point count.

Finer Grained Lamina

Moderately to moderately well sorted, angular lower very fine to upper fine, dominantly upper very fine to lower fine grained litharenite. Occasional grains to mid-medium carbonaceous debris, mica and sideritic clasts are concentrated in a lamina near the contact with the two finer and coarser grained lamina.

<u>Framework Grains</u>

Quartz, polycrystalline quartz

Feldspar – dominantly alkali feldspar but a minor amount of albite-twinned plagioclase is also present. Some feldspars have not been affected by leaching, others are moderately to strongly leached. It is possible that some moldic pores have formed by complete dissolution of feldspars.

Rock Fragments - abundant altered volcanic clasts. Some green grains are likely chloritic altered volcanic fragments. Other rock fragments include shale, pelitic micaceous metasedimentary clasts, undifferentiated coarse and fine grained quartzo-feldspathic clasts. Sideritic shale clasts and sideritized clasts consisting of dark brown finely crystalline siderite are common, particularly in the more carbonaceous laminae.

Accessory Grains - Mica is a common accessory grain. Biotite and muscovite are often partly kaolinized. Biotite is generally more strongly altered than muscovite. Some of the sideritic clasts may be altered biotite. Fresh and altered glauconite is present in trace to minor amounts. Not all green altered argillaceous clasts are considered to be glauconite. Some likely are altered volcanic clasts.

<u>Authigenic Minerals</u>

- Siderite – occurs as scattered microcrystals, local partial replacement of rock fragments. This siderite is more coarsely crystalline than the micritic siderite in sideritic clasts.
- Kaolinite – the most abundant authigenic mineral is kaolinite, occurring as a filling of open (mostly secondary moldic) pores, as a replacement of unstable clasts, and as local infill of remnant reduced intergranular pores.
- Anatase – scattered crystals and granular aggregates.
- Silica – minor silica cement occurs as quartz overgrowths, usually where quartz grains are in contact with each other. Quartz overgrowth development is strongly inhibited by compaction of ductile clasts against quartz grains.
- Pyrite – trace amounts replace grains or occurs as scattered fine framboids.

<u>Porosity and Permeability</u>

Intergranular porosity and permeability have been severely reduced by compaction and deformation of ductile clasts against each other and more resistant grains and into adjacent pore space in the carbonaceous lamina.

Most porosity consists of secondary moldic porosity where grains have been completely leached, reduced intergranular porosity and microporosity in leached rock fragments and leached feldspars, and in aggregates of kaolinite.

Coarse Grained Lamina

Poorly to moderately sorted to bimodal angular to subrounded upper very fine to lower very coarse grained quartzose litharenite.

The coarse fraction consists dominantly of subangular to subrounded quartz and lesser amounts of feldspar grains. In the finer fraction of the bimodal sand, grain types are similar to the litharenite in the finer grained lamina, but rock fragments are not as abundant. Labile rock fragments are generally strongly leached and often are kaolinized.

Volcanic rock fragments, shale, micaceous pelitic metasedimentary clasts are common.

Glauconite and mica are often strongly leached or are kaolinized.

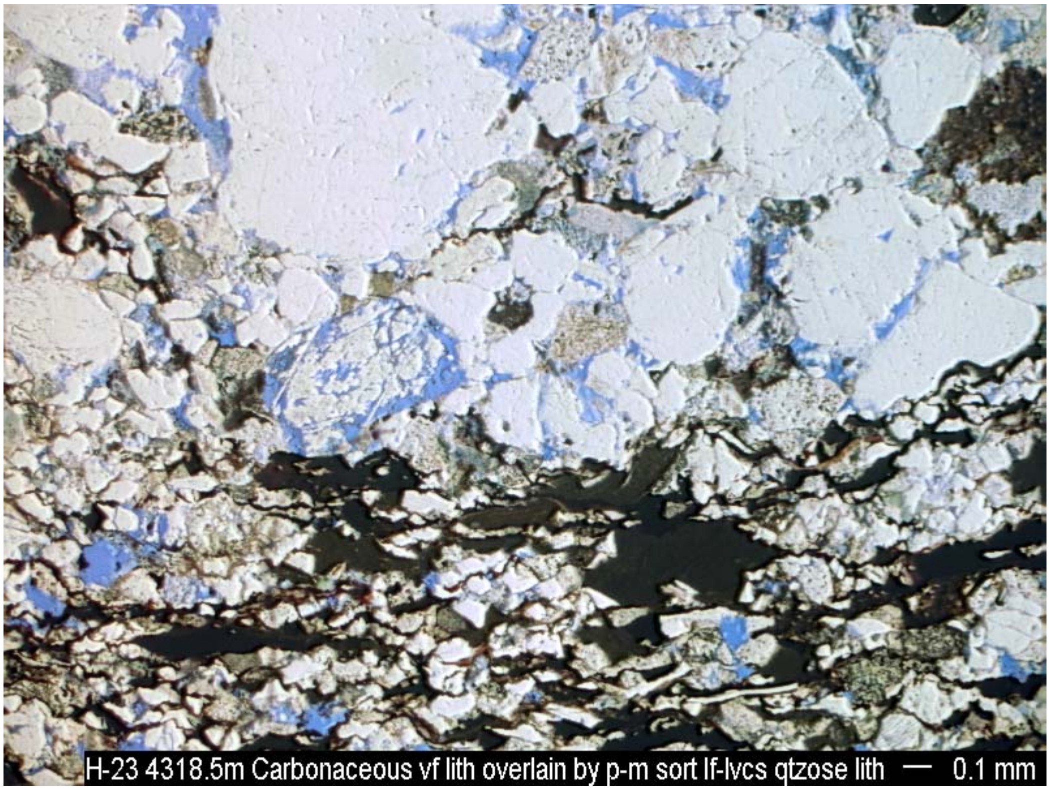
Heavy minerals are present in trace amounts.

Authigenic Minerals

- Silica cement – quartz overgrowths are more extensive than in the finer grained litharenite lamina because quartz grains are more abundant, and grain contacts between quartz grains are therefore more common.
- Kaolinite – aggregates of kaolinite booklets fill reduced primary and secondary dissolution pores formed by partial to complete dissolution of feldspar and rock fragments, and possibly dissolution of previously more extensive calcite cement.
- Calcite – a trace amount of corroded ferroan calcite pore-filling cement is present.
- Anatase – crystals and granular aggregates of authigenic $Ti0_2$ are scattered throughout the pore system.

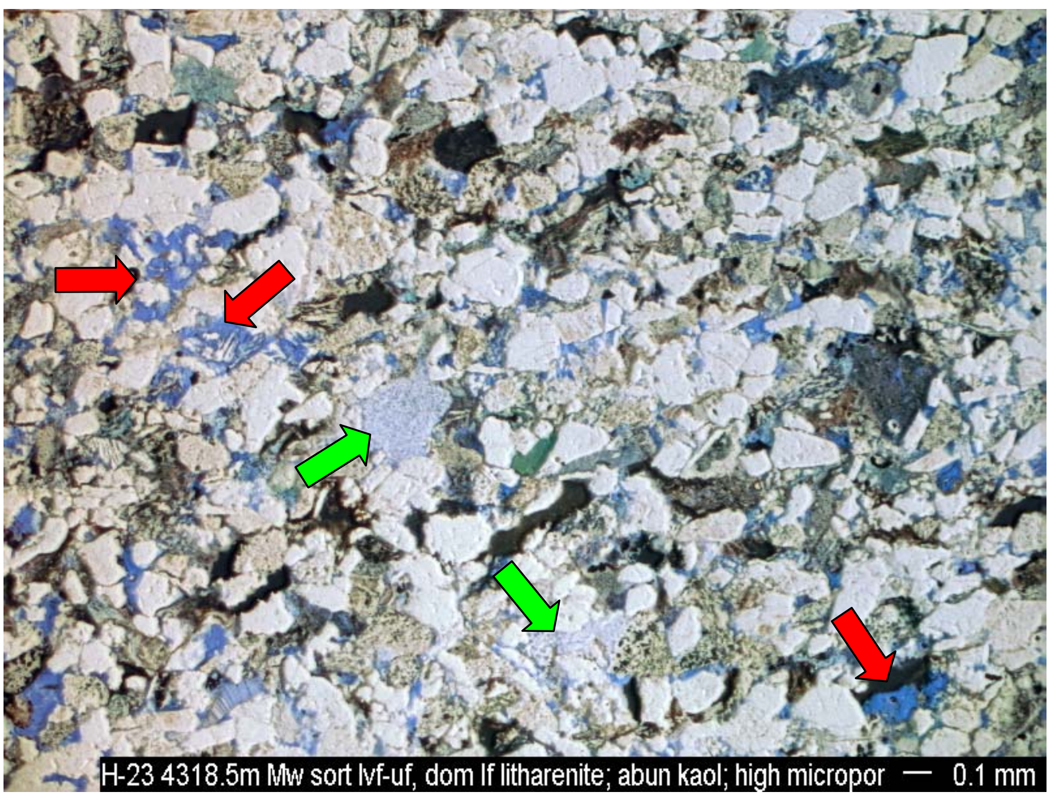
Porosity and Permeability - Primary intergranular porosity and permeability have been strongly reduced by close grain packing, silica cement, pore-filling microporous kaolinite aggregates. The amount of ductile clasts relative to competent grains is considerably lower in this lamina than in the finer grained lamina, so compaction of ductile clasts has not had as significant an effect in reducing porosity and permeability. The finer grain size fraction in this lamina controls the primary pore size and pore throat size. Porosity has been enhanced by partial dissolution of feldspar and rock fragments. There is a larger range in primary grain size than in the finer grained lamina, there is a larger range in primary and secondary pore and pore throat sizes. The coarser grained lamina has a higher proportion of open porosity as indicated by the higher point count porosity and a higher permeability than the finer grained lamina. The measured permeability of 2.65 MD is largely in the coarser grained lamina.

Newburn H-23 Sidewall Cores 4318.5M SP15

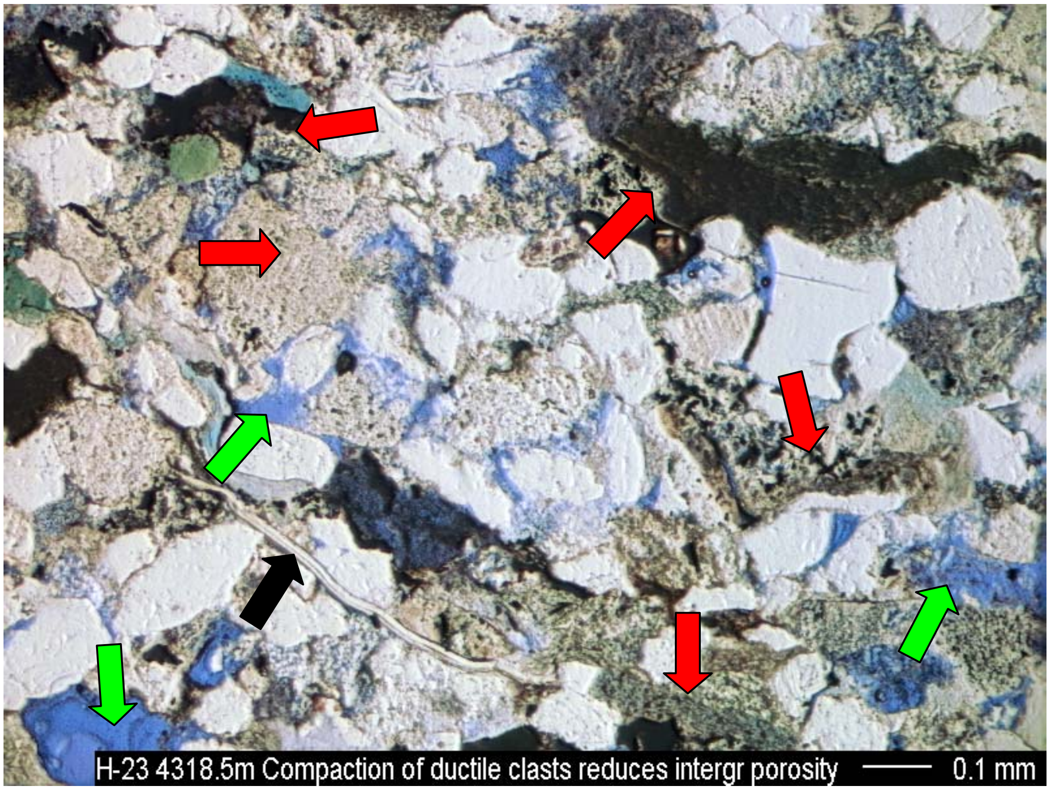


1) Strongly compacted carbonaceous very fine grained litharenite (bottom) is overlain by poorly to moderately sorted lower fine to lower very coarse grained quartzose litharenite (top).

2) Moderately well sorted dominantly lower fine grained litharenite. Intergranular porosity is strongly reduced by close grain packing, deformation of ductile clasts and matrix into adjacent pores, sutured grain contacts. A large proportion of total porosity consists of microporosity in leached clasts and pore-filling kaolinite (green arrows). Open dissolution pores (red arrows) are poorly connected.



Newburn H-23 Sidewall Cores 4318.5M SP15



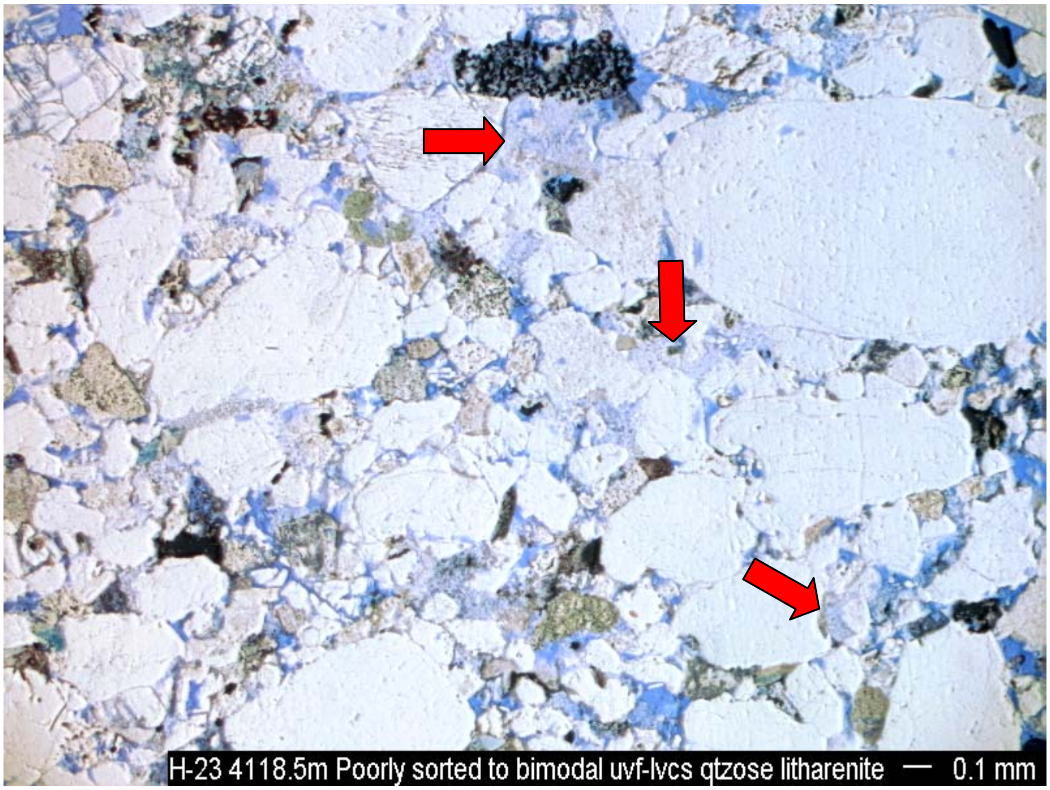
H-23 4318.5m Compaction of ductile clasts reduces intergr porosity 0.1 mm

3) Compaction of ductile rock fragments (red arrows), mica (black arrow) and other ductile clasts against each other and more resistant grains has severely reduced intergranular porosity and permeability. Total porosity has been enhanced by partial to complete grain dissolution (green arrows).

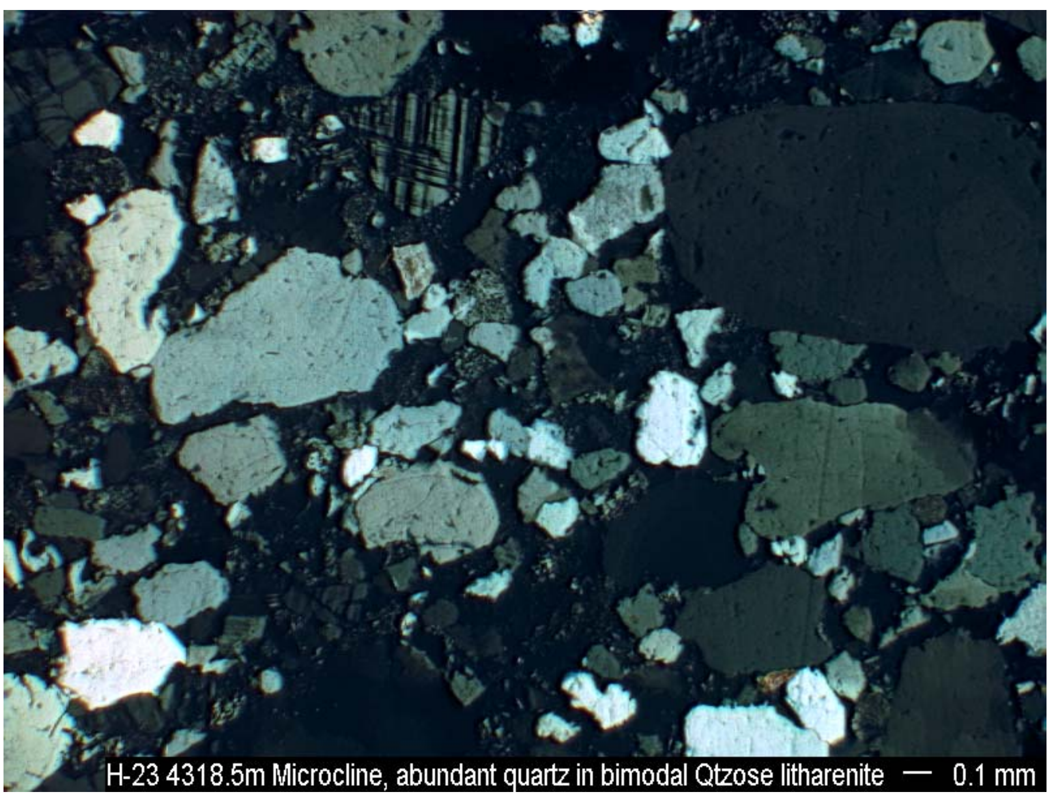
4) Abundant rock fragments include a variety of volcanic clasts, often leached (red arrows), shale, and metasedimentary rock fragments.

H-23 4318.5m Leached and microporous volc rf, sedand metased rf 0.1 mm

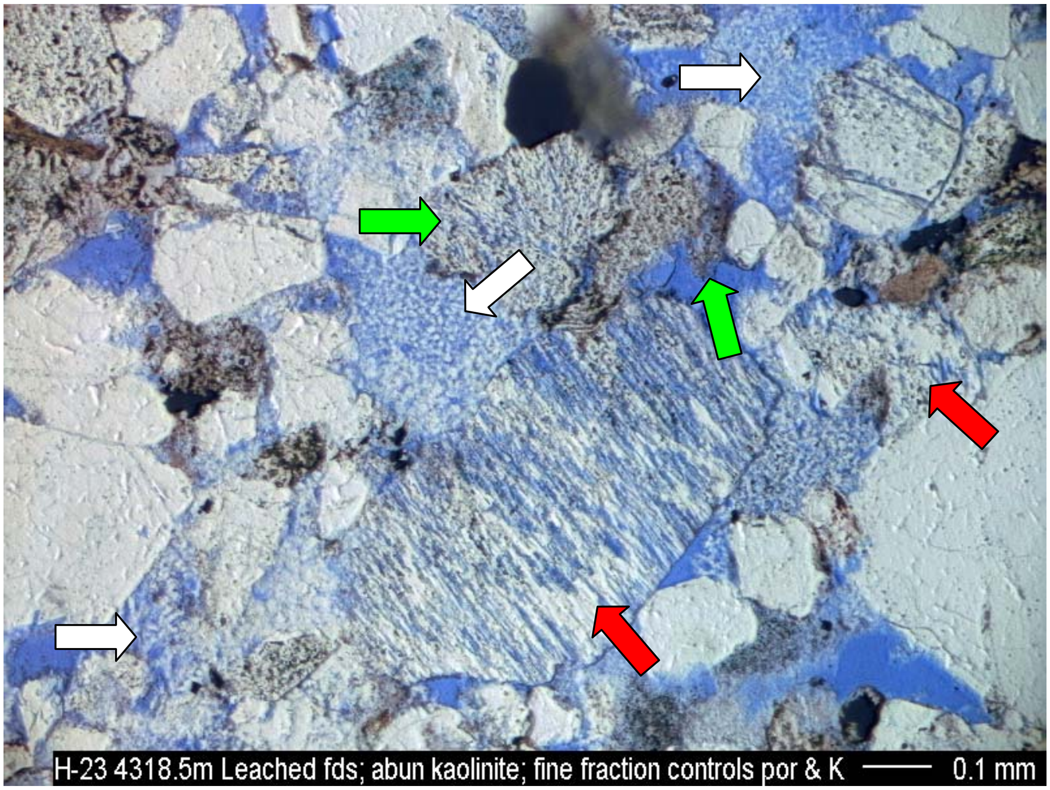
Newburn H-23 Sidewall Cores 4318.5M SP15



5) and 6) Same field of view under plane polarized light (5) and under crossed polars (6). Poorly sorted to bimodal upper very fine to lower very coarse grained quartzose litharenite. Permeability is reduced by the small average grain size of the more abundant fine grain size fraction, and by abundant pore-filling kaolinite (arrows).

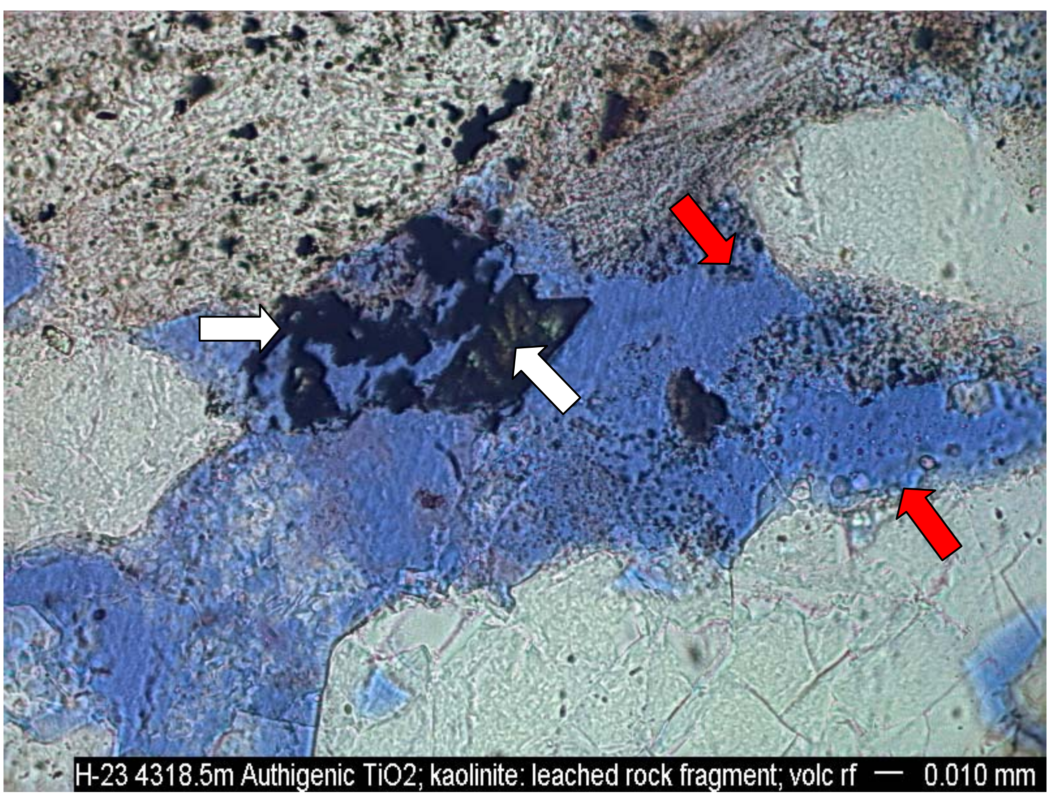


Newburn H-23 Sidewall Cores 4318.5M SP15



7) Total porosity has been enhanced by leaching of feldspars (red arrows) and rock fragments (green arrows). Abundant kaolinite has reduced much of the remnant intergranular porosity and secondary dissolution porosity formed by dissolution of unstable clasts to microporosity (white arrows).

8) Authigenic anatase (TiO_2) crystals are common (white arrows). Volcanic rock fragments (top left) are common. Secondary porosity has formed by extensive dissolution of unstable clasts (arrows).



4319.80M SP14 K = 0.06 mD Porosity = 8.9%

Poorly sorted angular to rounded upper very fine to upper very coarse, dominantly lower medium grained feldspathic litharenite.

Many labile rock fragments have been partially replaced by ferroan calcite cement.

Intragranular porosity in some leached feldspars and rock fragments has been infilled by ferroan calcite, but some open intragranular dissolution porosity is also present, suggesting some leaching has taken place since cement was precipitated.

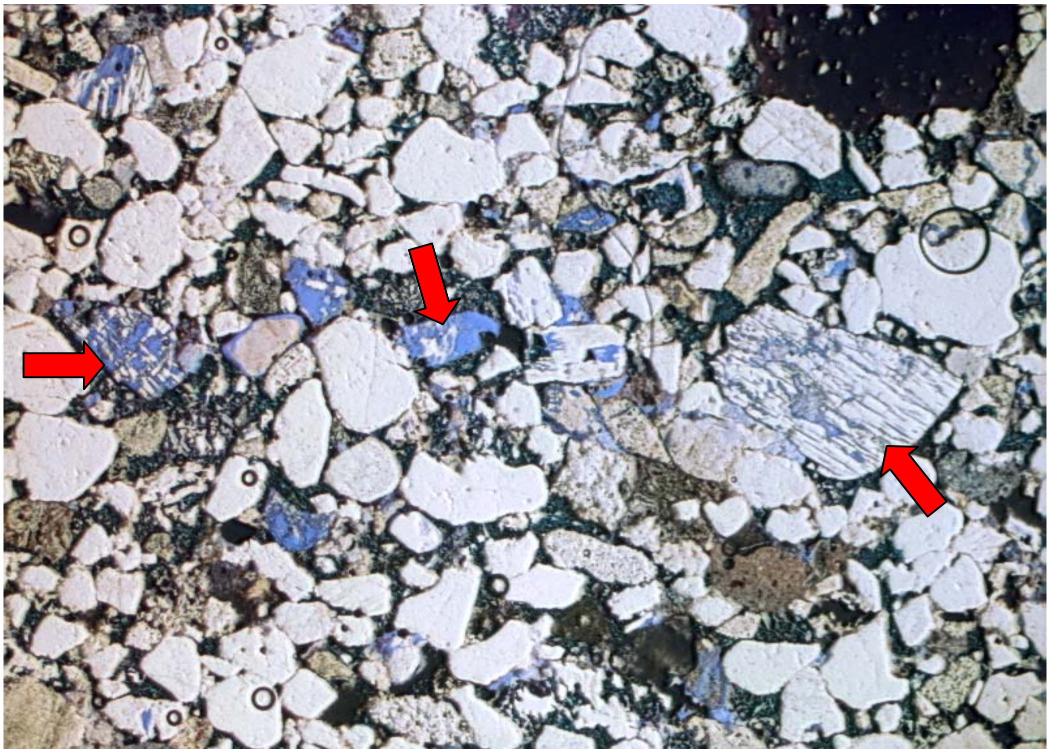
Authigenic Minerals

- Siderite – microcrystals and aggregates of microcrystals on grain surfaces inside (pre-dating) ferroan calcite cement.
- Kaolinite – a minor to moderate amount of kaolinite is present, usually in moldic and intragranular porosity in leached feldspars and rock fragments. Paragenetic sequence is not always clear, but some of the kaolinite pre-dates ferroan calcite.
- Ferroan calcite – Pervasive poikilotopic ferroan calcite cement completely occludes primary intergranular porosity. Calcite is later than siderite, some or all of the kaolinite and authigenic anatase, and may post-date a minor amount of silica cement. Silica cement is only present in very minor amounts, but it is not apparent whether much silica cement would have been able to precipitate if calcite cement were not present, because of inhibition by close packing of ductile clasts and the low incidence of quartz grains in contact with each other and exposed to open pores. A minor to moderate amount of deformation of ductile clasts took place prior to cementation.
- Anatase – scattered authigenic crystals
- Silica – very minor discontinuous terminated quartz overgrowth faces occur inside calcite cement. It is possible that some discontinuous quartz overgrowths are inherited from previous sedimentation and cementation cycles.

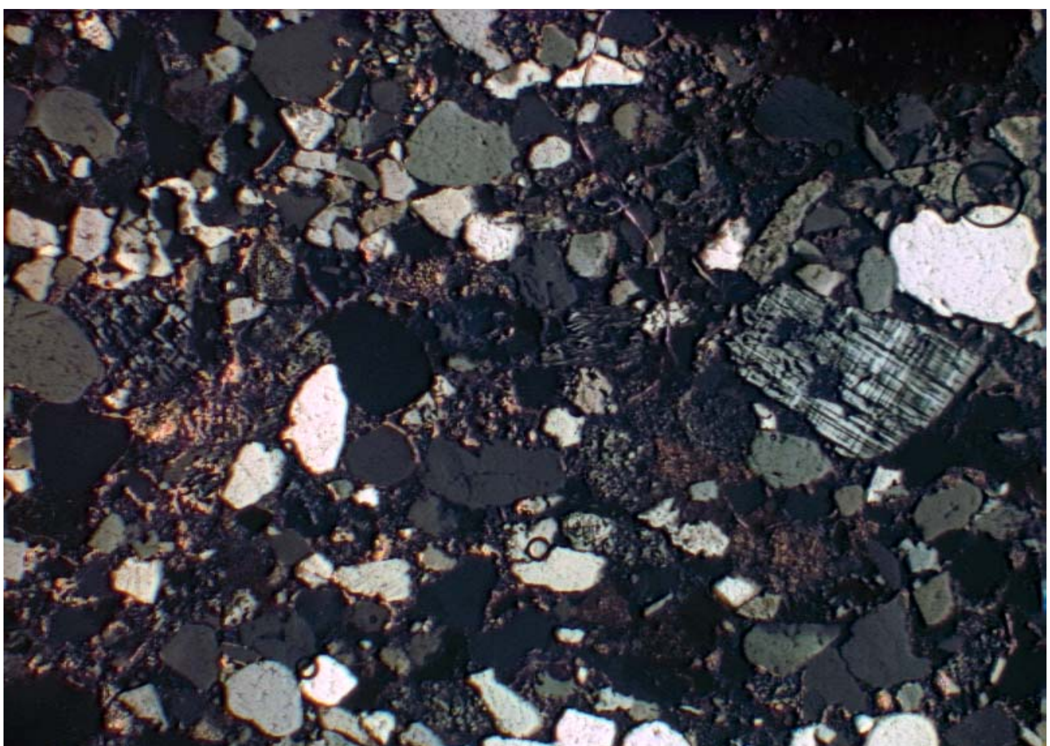
Porosity and Permeability

Intergranular porosity is completely occluded by ferroan calcite cement. Measured core analysis porosity consists of dissolution porosity and microporosity in leached feldspar and unstable rock fragments and altered glauconite grains. Connectivity of porosity is very poor, resulting in very low permeability.

Newburn H-23 Sidewall Cores 4319.8M SP14


H-23 4319.8m Abun leached feldspar in Fecc cmted uvf-uvcs litharenite — 0.1 mm

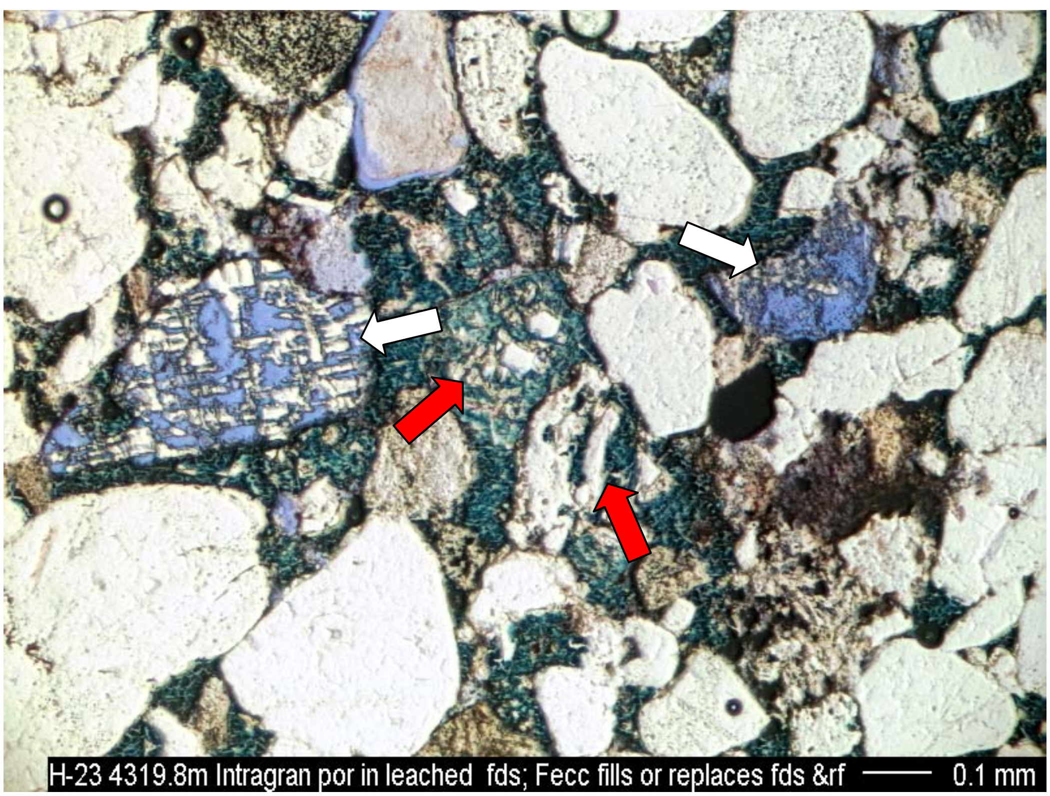
1 and 2) Same field of view under plane polarized light (1) and under crossed polars (2). Ferroan calcite cemented upper very fine to upper very coarse grained, dominantly lower medium grained feldspathic litharenite. Intergranular porosity is almost completely occluded by pore-filling ferroan calcite cement. Much of the measured porosity of 8.9% occurs as dissolution porosity in leached feldspars (arrows) isolated by pore-filling calcite cement, resulting in very poor permeability.


H-23 4319.8m Poorly sorted uvf-uvcs feldspathic litharenite — 0.1 mm

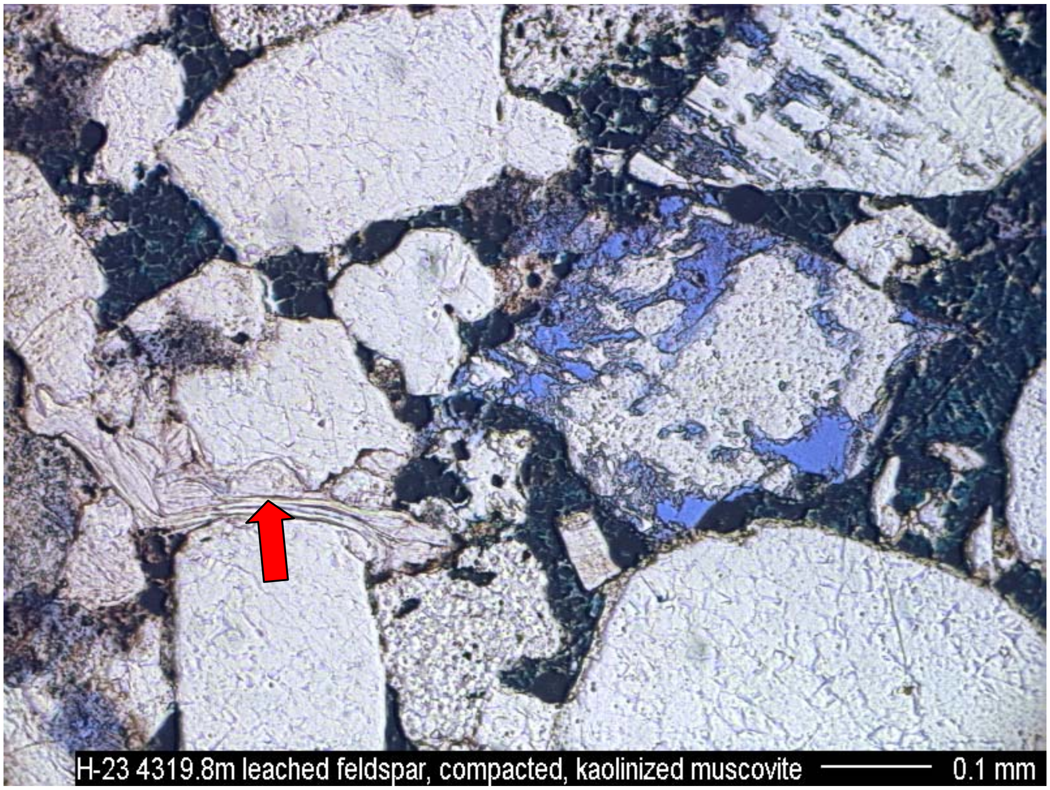
Newburn H-23 Sidewall Cores 4319.8M SP14

3) Altered and deformed biotite (red arrow). At least some of the compaction took place before ferroan calcite cementation (dark blue-green), but little or no silica cementation took place before calcite cementation

4) Ferroan calcite filled some intragranular porosity in clasts that were leached prior to cementation (red arrows). Additional grain dissolution has taken place since cementation (white arrows), forming isolated secondary porosity.

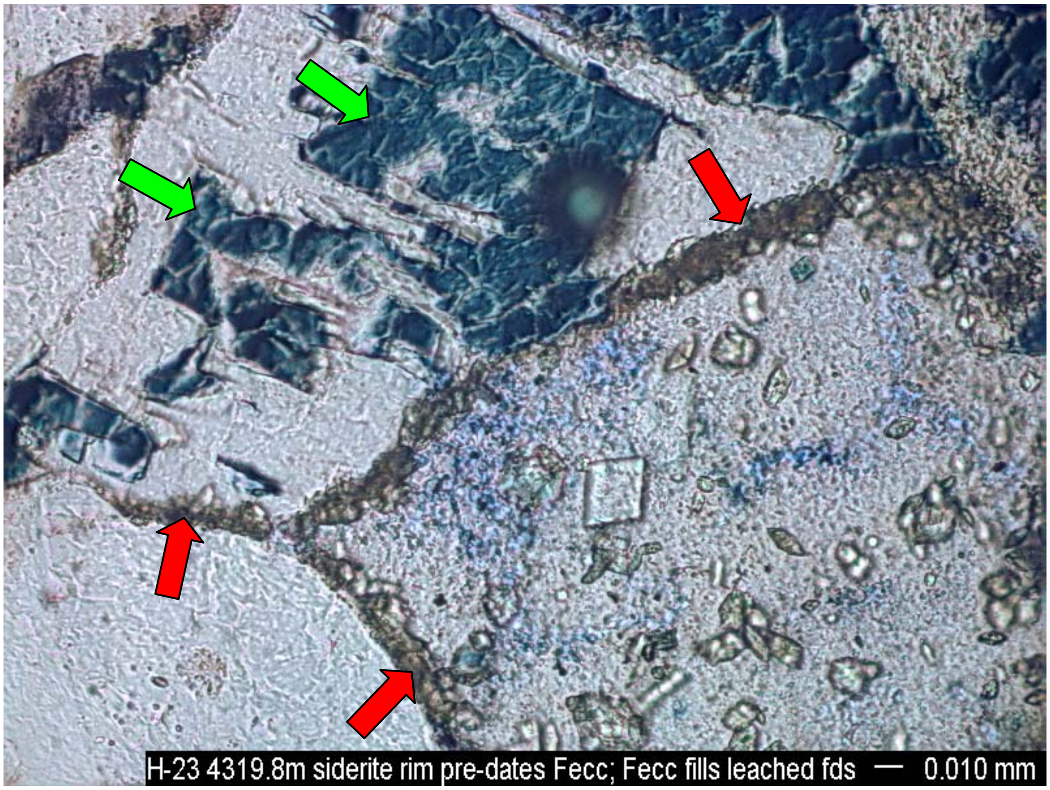


Newburn H-23 Sidewall Cores 4319.8M SP14



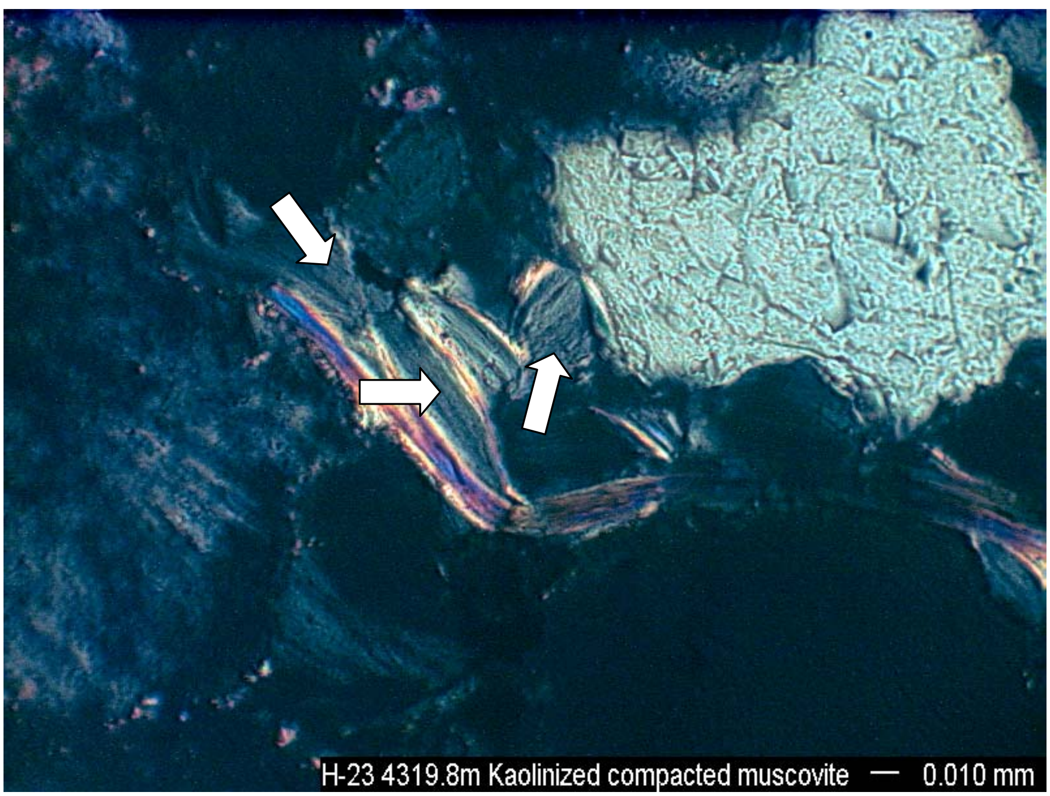
5 and 6) Same field of view under plane polarized light (5) and under crossed polars (6). Most porosity occurs as intragranular dissolution porosity in microcline (upper right), and other alkali feldspars (right center). A muscovite grain (red arrows) was deformed by compaction before ferroan calcite cement precipitated. Mica is partly altered to kaolinite.

Newburn H-23 Sidewall Cores 4319.8M SP14



7) Microcrystalline siderite coated some grain surfaces (red arrows) prior to ferroan calcite precipitation in intergranular pores and in intragranular dissolution pores in feldspars (green arrows) which were either present at the time of deposition, or were formed by dissolution just after deposition.

8) Close view of partly kaolinized (grey birefringence, arrows) compacted muscovite mica. Kaolinization of mica can be an indication of influx of meteoric waters.



4323.00M SP13 K = 0.18 mD Porosity = 13.1%

Matrix-supported to locally grain-supported conglomerate. Well rounded granule to ~1.5 cm shale, silty shale, calcareous shale, sideritic shale and lesser amounts of quartz and polycrystalline quartz grains are enclosed in a matrix of moderately well sorted angular to subrounded upper very fine to upper medium grained, dominantly upper fine to lower medium grained litharenite.

Framework Grains

Monocrystalline quartz and minor polycrystalline quartz.

Feldspar – dominantly microcline, orthoclase, and perthitic alkali feldspar, but a minor amount of albite-twinned sodic plagioclase is also present. Intragranular porosity in leached feldspars commonly is filled by ferroan calcite.

Rock Fragments - Shale, a variety of altered labile and /or feldspathic and/or quartzo-feldspathic volcanic rock fragments, undifferentiated ferroan calcite – or siderite – replaced undifferentiated argillaceous clasts.

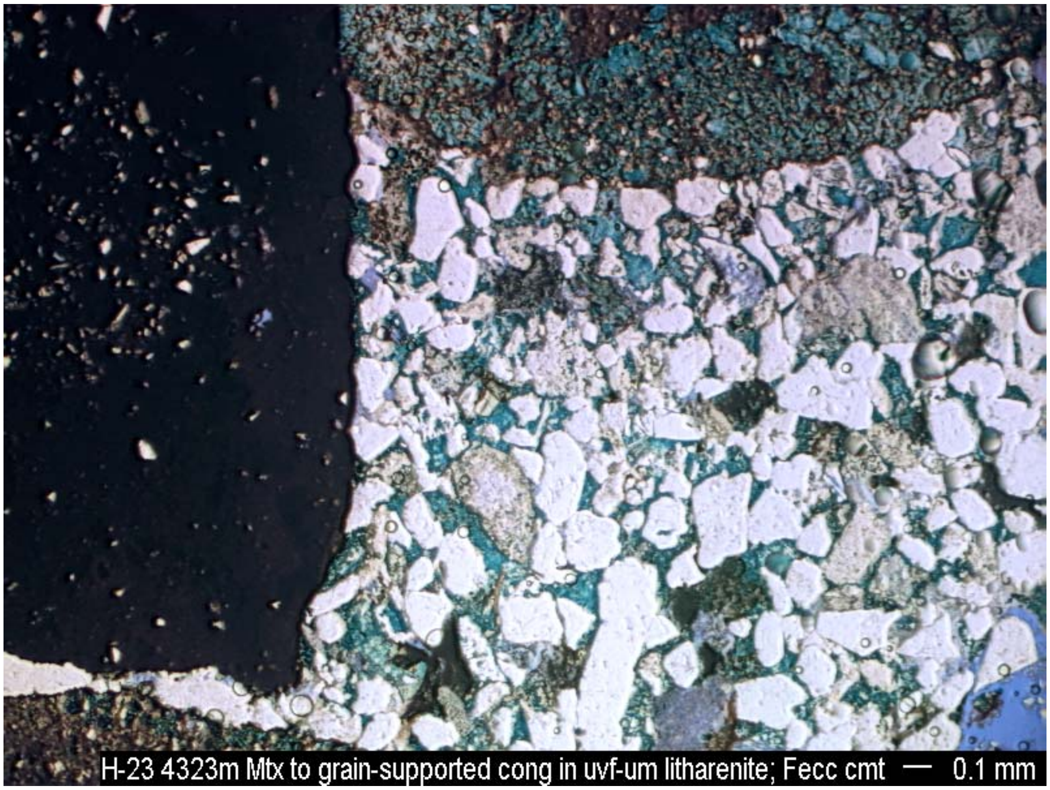
Authigenic Minerals

- Siderite – locally partly replaces argillaceous rock fragments.
- Calcite – pervasive poikilotopic ferroan calcite cement fills primary intergranular porosity, and fills some secondary dissolution porosity in leached feldspar and rock fragments. Ferroan calcite replaces some unstable rock fragments and possibly other unstable clasts (altered micas?).
- Kaolinite – a minor amount of kaolinite is locally present in primary and secondary pores. At least some of the kaolinite appears to have precipitated prior to ferroan calcite cement, but the paragenetic relationship between ferroan calcite and kaolinite is not always evident.
- Silica cement – very little silica cement precipitated as overgrowths on quartz grains prior to ferroan calcite cementation.

Porosity and Permeability

Intergranular porosity is completely filled by ferroan calcite cement. A minor amount of secondary dissolution porosity is locally present, mostly filled by kaolinite. The measured porosity and permeability in this sample may have been artificially enhanced by separation of pebbles from matrix sand and formation of artificial shrinkage porosity around the pebbles after the sidewall cores were cut.

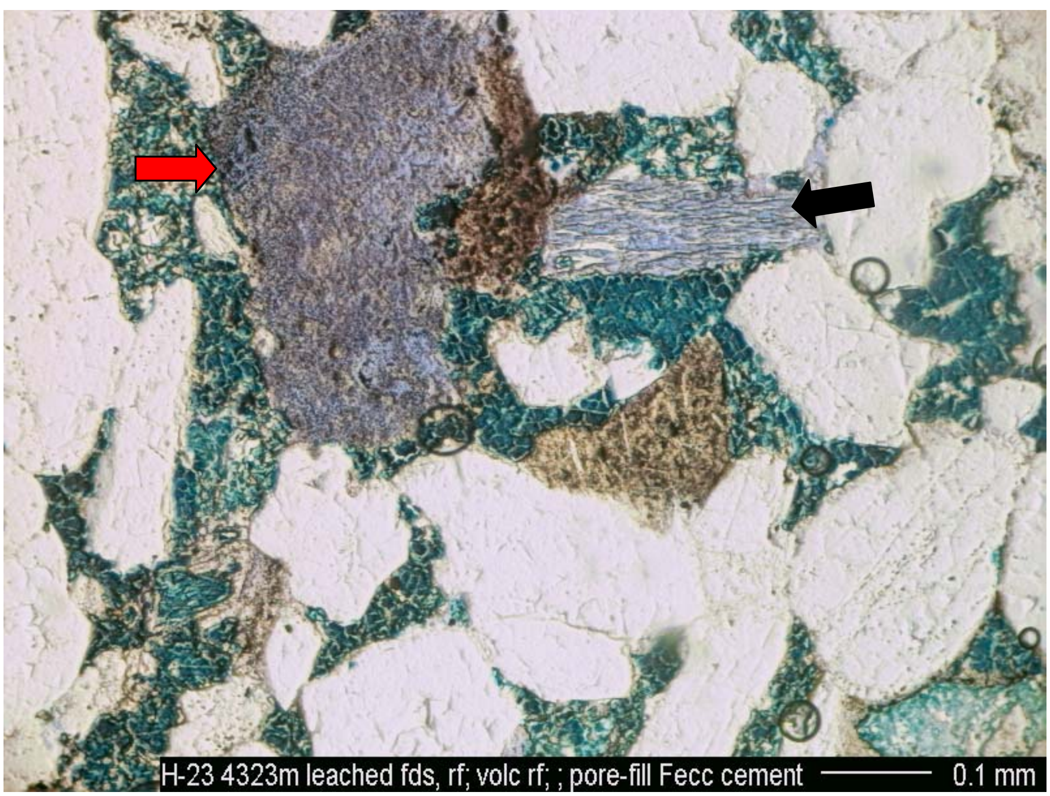
Newburn H-23 Sidewall Cores 4323M SP13



H-23 4323m Mtx to grain-supported cong in uvf-um litharenite; Fecc cmt — 0.1 mm

1) Matrix supported to locally grain supported conglomerate consisting of well rounded granule to ~1.5 cm shale, silty shale (bottom left), calcareous shale, sideritic shale (left) and lesser amounts of quartz grains in a matrix of dominantly upper fine to lower medium grained litharenite. Intergranular porosity is occluded by ferroan calcite cement (blue-green).

2) Isolated microporosity in leached rock fragment (red arrow), leached feldspar (black arrow). Intergranular porosity is occluded by ferroan calcite (blue-green).



H-23 4323m leached fds, rf; volc rf; ; pore-fill Fecc cement — 0.1 mm

4325.50M SP12 K = 0.31 mD Porosity = 9.3%

Silty shale with irregularly distributed concentrations of upper fine to upper very coarse grained angular to rounded quartz, polycrystalline quartz and feldspar

Concentrations of sand may be due to burrowing.

Only a few fine grained quartzo-feldspathic rock fragments of indeterminate origin are present in the sand fraction. A few feldspar grains are leached and microporous.

The shale contains abundant organic matter and ~25% quartz and feldspar grains.

Porosity is entirely microporosity.

Newburn H-23 Sidewall Cores 4325.5M SP12

1) Silty shale with local concentrations (left) of upper fine to upper very coarse angular to subrounded quartz and feldspar grains.

4349.70M SP11 K = 0.42 mD Porosity = 12.4%

Moderately sorted angular to subrounded, dominantly subangular, upper very fine to upper medium grained, dominantly mid-fine grained litharenite.

Framework Grains

Quartz, polycrystalline quartz

Feldspar – mainly alkali feldspar, but microcline tartan twinning is rare or absent and albite twinned plagioclase is more common than in the overlying samples.

Rock fragments – competent feldspathic and quartzo-feldspathic volcanic rock fragments and altered labile volcanic rock fragments are common; other rock fragments include metaquartzite, micaceous and quartz-mica pelitic metasedimentary rock fragments, shale, chert and other undifferentiated quartzose and argillaceous clasts. Sideritic clasts, either sideritic shale or sideritized biotite are also locally present.

Accessory grains include mica, and trace amounts of heavy minerals and glauconite. Biotite is generally strongly altered. Zircon is the most common heavy mineral grain type.

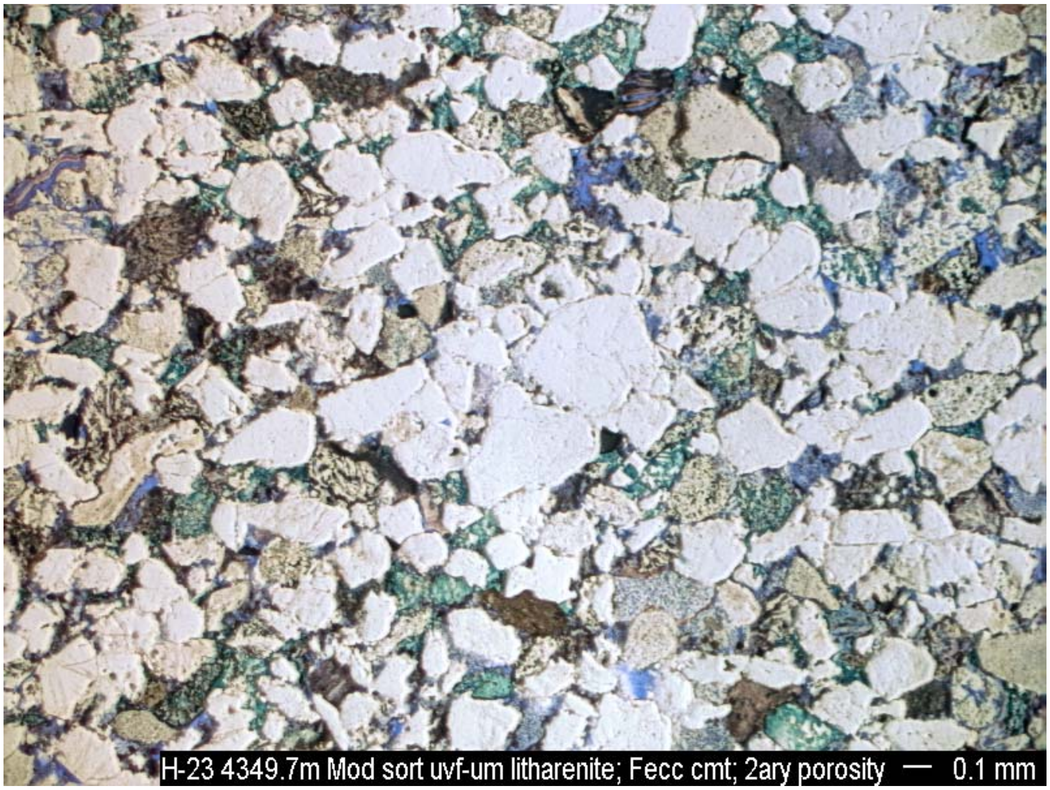
Authigenic Minerals

- Siderite – early siderite microcrystals and clusters of microcrystals cling to grain surfaces
- Kaolinite – fills moldic pores and locally fills intergranular porosity. At least some of the kaolinite is earlier than silica cement and ferroan calcite cement.
- Silica – Irregular quartz overgrowths are present on most quartz grains, particularly where quartz grains are in contact with each other or make up most of the original intergranular pore wall. Quartz overgrowths commonly do not have well-terminated crystal faces, but are intergrown with adjacent rock fragments, authigenic kaolinite, siderite or minor amounts of interstitial detrital matrix clay. Terminated and irregular quartz overgrowths are enclosed within ferroan calcite cement.
- Ferroan calcite – pore-filling poikilotopic ferroan calcite cement is abundant. Calcite cement fills some leached feldspars and rock fragments and replaces some clasts. Some dissolution of ferroan calcite has taken place.
- Anatase – Authigenic anatase crystals and fine granular aggregates are common. Anatase precipitated before ferroan calcite.

Porosity and Permeability

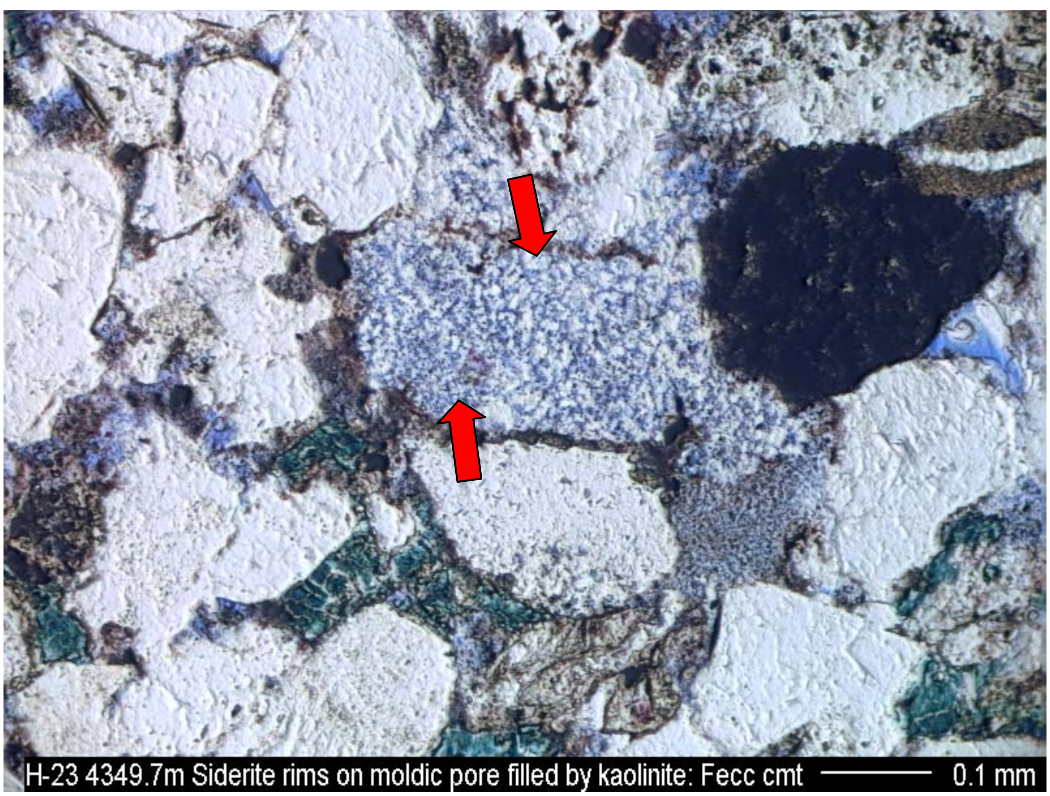
Porosity is mainly secondary, occurring as open pores formed by dissolution of grains or pseudomatrix of unstable clasts and/or detrital matrix, as intragranular porosity in leached clasts, microporosity in leached clasts and pore-filling kaolinite, and secondary intergranular porosity where ferroan calcite has been dissolved. By point count, less than half of total porosity consists of microporosity.

Newburn H-23 Sidewall Cores 4349.7M SP11

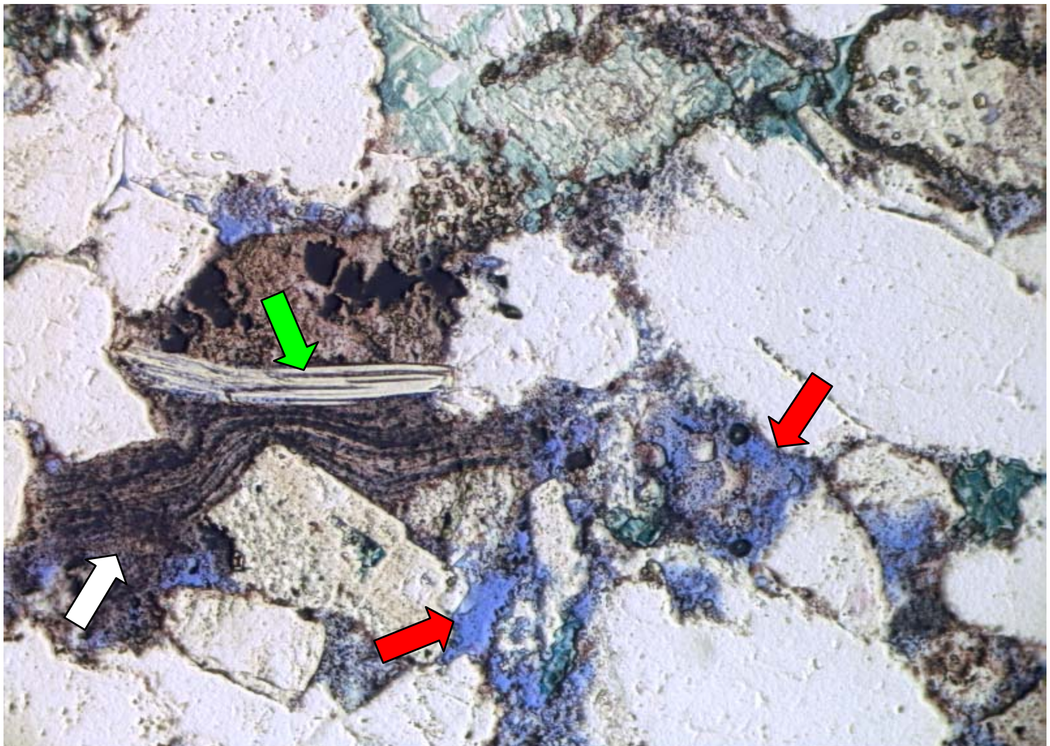


1) Moderately sorted angular to subrounded, upper very fine to upper medium grained, dominantly mid-fine grained litharenite. Intergranular porosity is strongly reduced by ferroan calcite cement (blue-green). Porosity consists of secondary porosity in leached clasts, minor remnant reduced intergranular porosity.

2) Early siderite rimmed an unstable clast which was subsequently dissolved and infilled by kaolinite (red arrows).



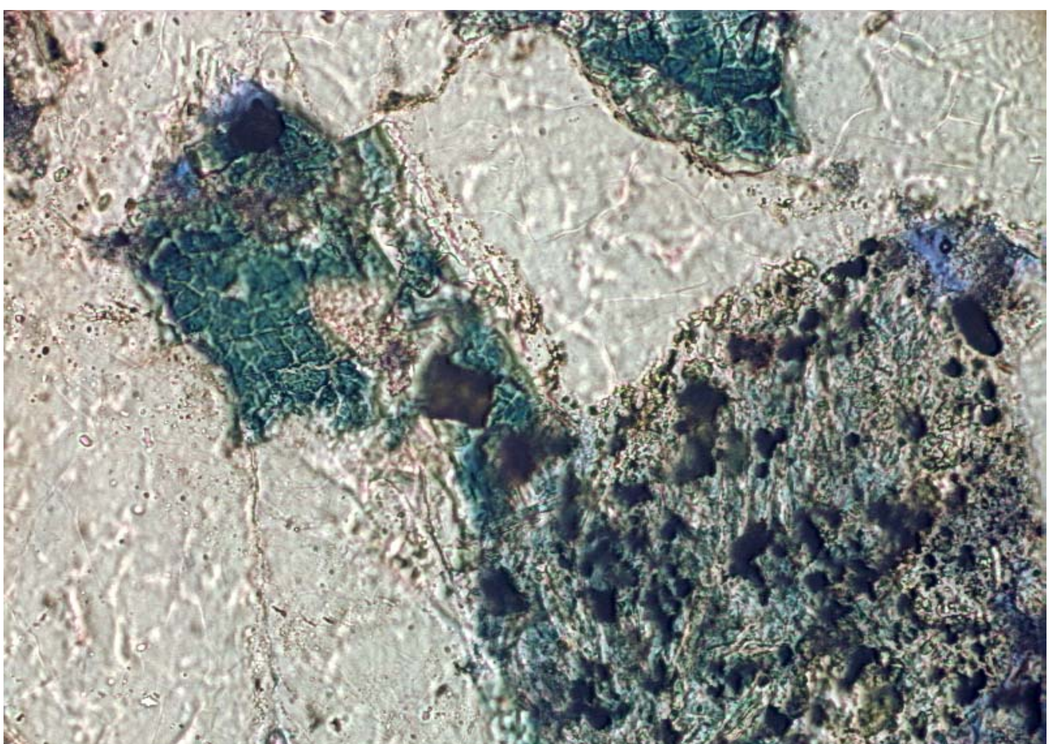
Newburn H-23 Sidewall Cores 4349.7M SP11



H-23 4349.7m Alterd biotite; muscovite; 2ary pores; SiO2 cmt; Fecc cmt 0.1 mm

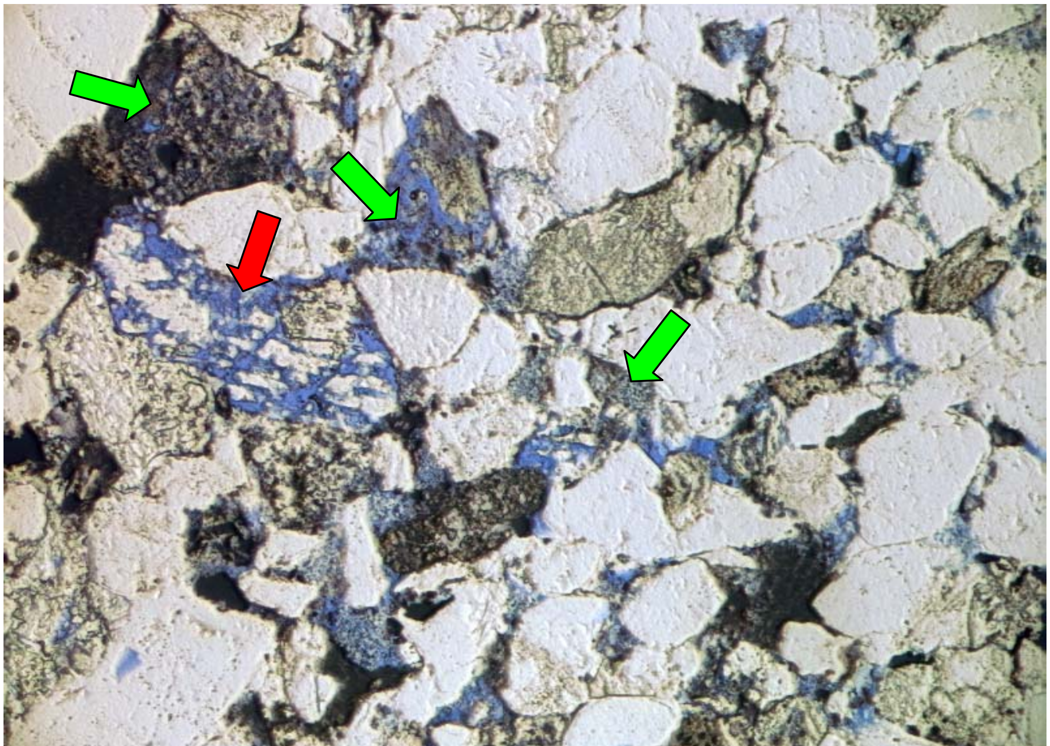
3) Much of the measured porosity of 12.4% is secondary, formed by partial to complete dissolution of unstable grains (red arrows), and possibly also by dissolution of pore-filling and/or grain-replacive ferroan calcite cement. Biotite (white arrow) is commonly altered and degraded. Muscovite is generally less altered than biotite (green arrow).

4) Volcanic rock fragments are common (lower right). Authigenic anatase crystal (dark crystal in center) and minor amounts of silica cement precipitated before ferroan calcite.



H-23 4349.7m TiO2 crystal; volc rf; SiO2 cement inside Fecc cement 0.010 mm

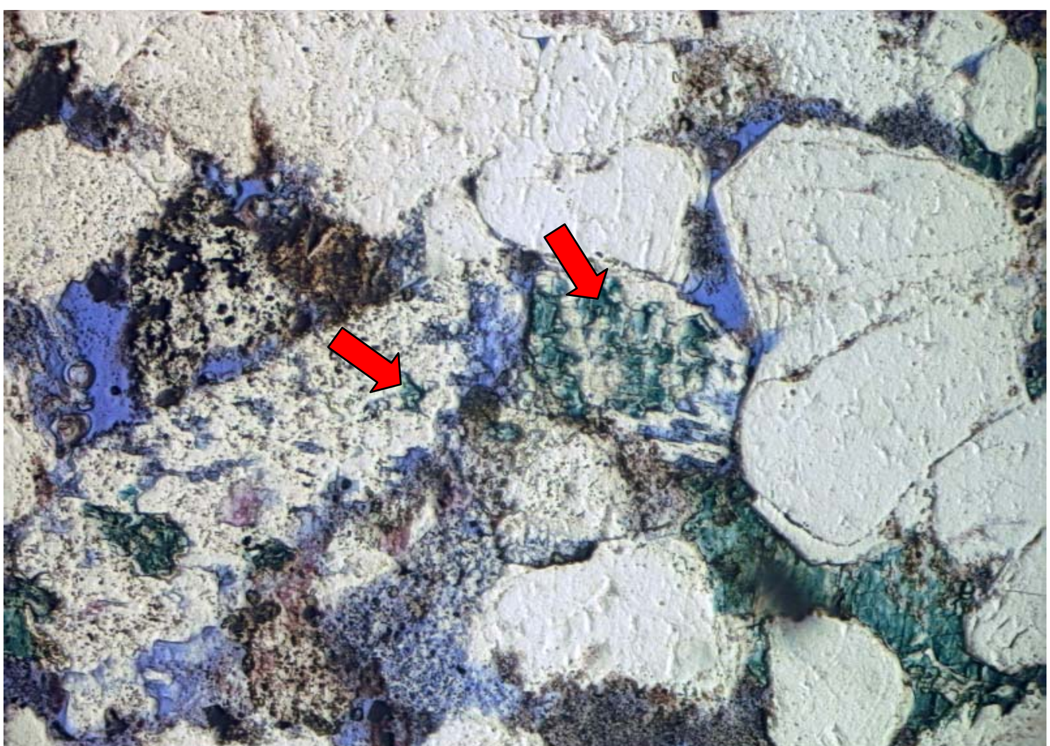
Newburn H-23 Sidewall Cores 4349.7M SP11



H-23 4349.7m Most porosity is 2ary; micropor in kaol, and lched clasts 0.1 mm

5) Most porosity is secondary, occurring as intragranular porosity in leached feldspar (red arrow) and leached rock fragments (green arrows), and as secondary intergranular porosity where pore-filling ferroan calcite has been dissolved. Primary intergranular porosity has been reduced by close grain packing, compaction of ductile clasts, and by ferroan calcite and minor silica cement.

6) Remnants of ferroan calcite cement filling intragranular pores (red arrows) in leached feldspars adjacent to open intergranular pores (blue) suggest that ferroan calcite cement has been dissolved from surrounding open pores (black arrows).



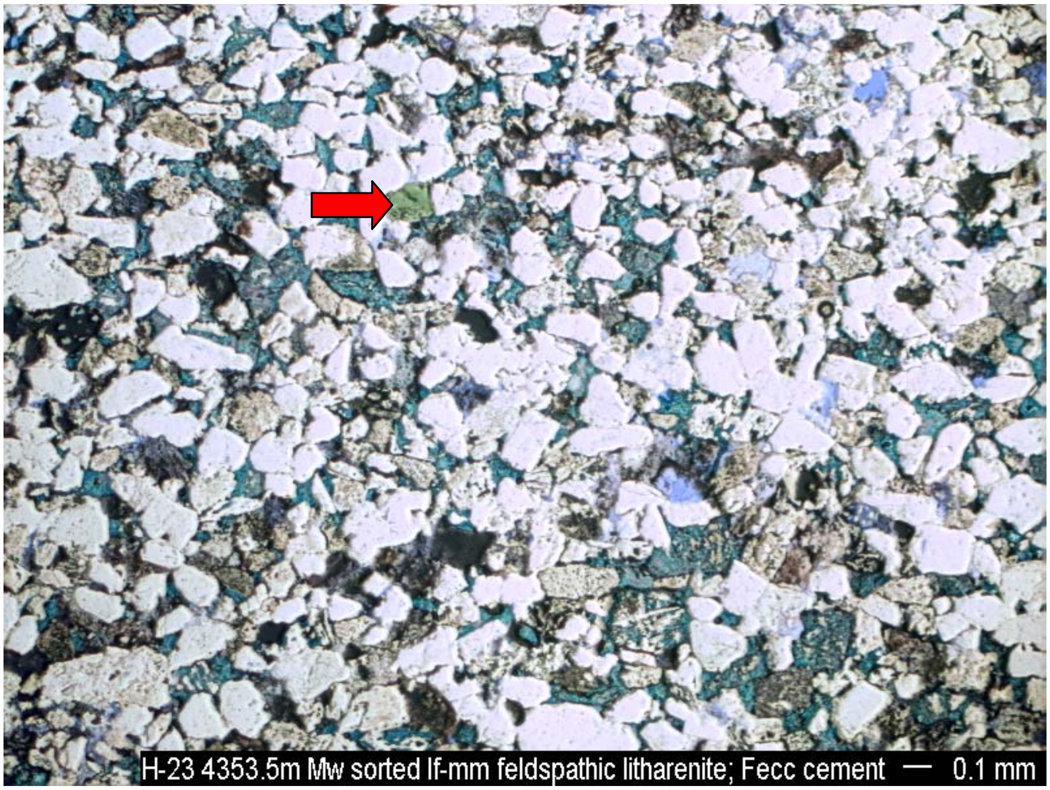
H-23 4349.7m Fecc in leached fds; leached Fecc cmt; SiO2 cmt 0.1 mm

4353.50M SP8 K = 0.28 mD Porosity = 12.1%

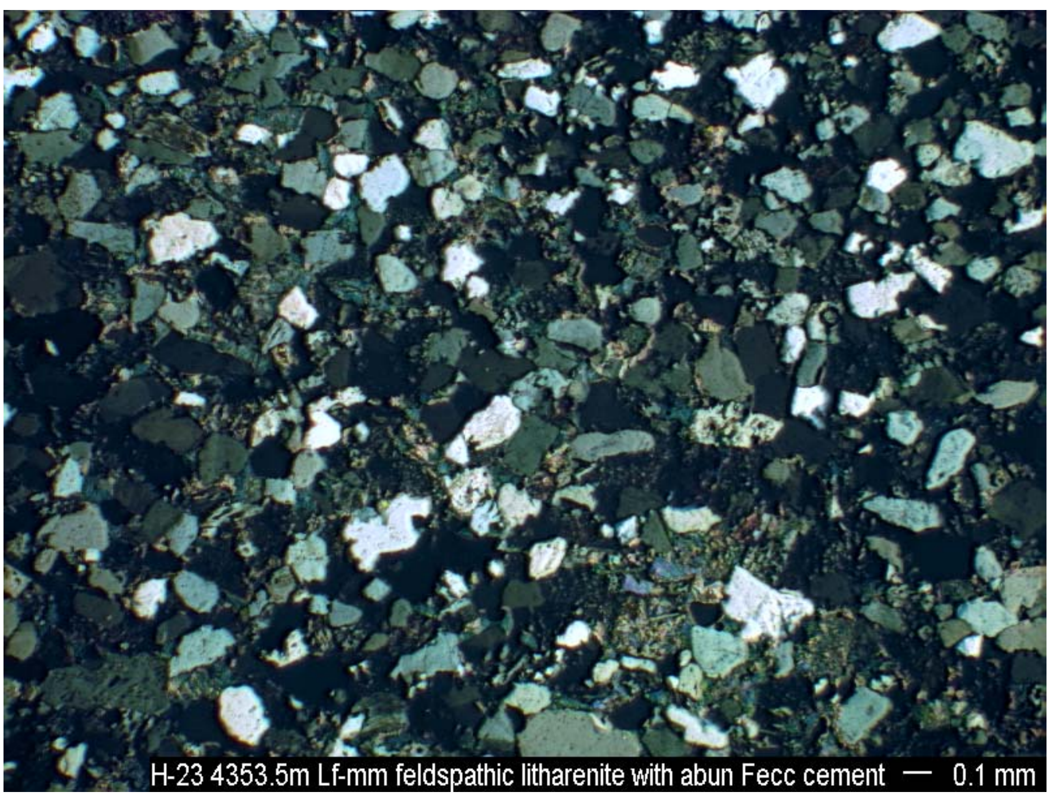
Moderately to moderately well sorted, angular to subrounded, dominantly subangular, lower very fine to mid-medium, dominantly lower fine grained feldspathic litharenite.

Composition and diagenesis are very similar to SP11, but this sample is overall finer grained than SP 11. Measured porosity is similar, but SP 8 has undergone less formation of secondary macroporosity by dissolution, and a higher proportion of total porosity consists of microporosity.

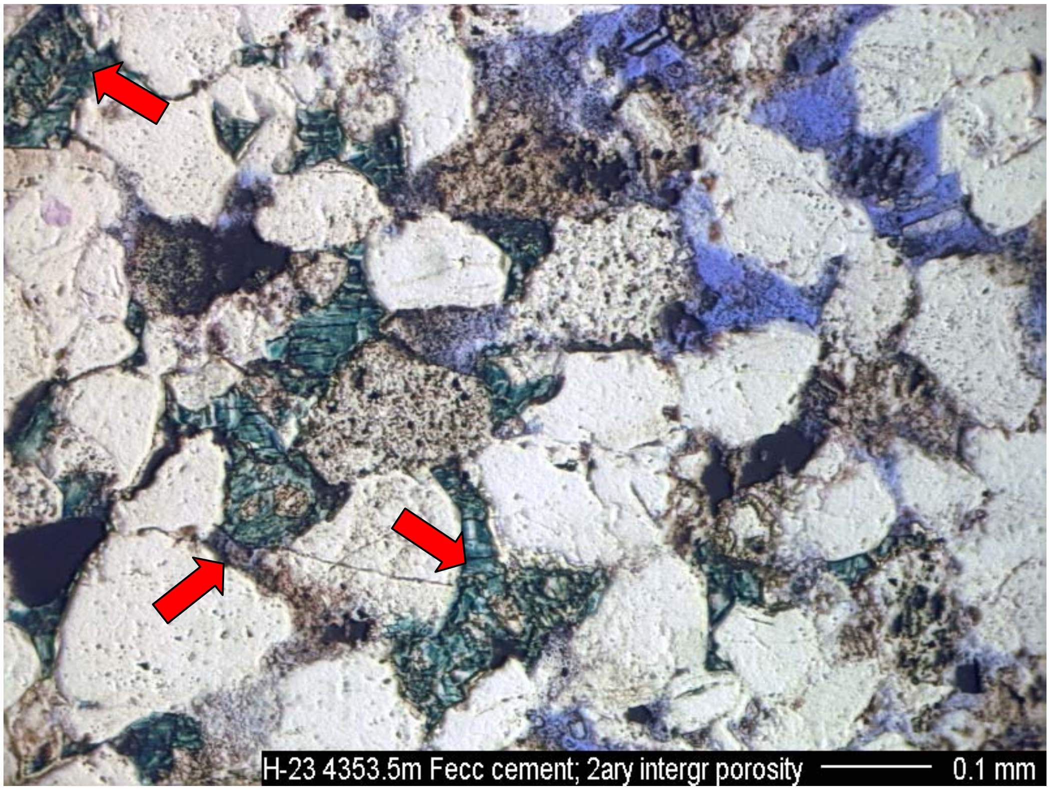
Newburn H-23 Sidewall Cores 4353.5M SP8



1 and 2) Same field of view under plane polarized light (1) and under crossed polars (2). Moderately well sorted angular to subrounded, dominantly lower fine grained litharenite. Primary intergranular porosity is strongly reduced by pore-filling poikilotopic ferroan calcite cement (blue-green). Glauconite (red arrow) is present in trace amounts.

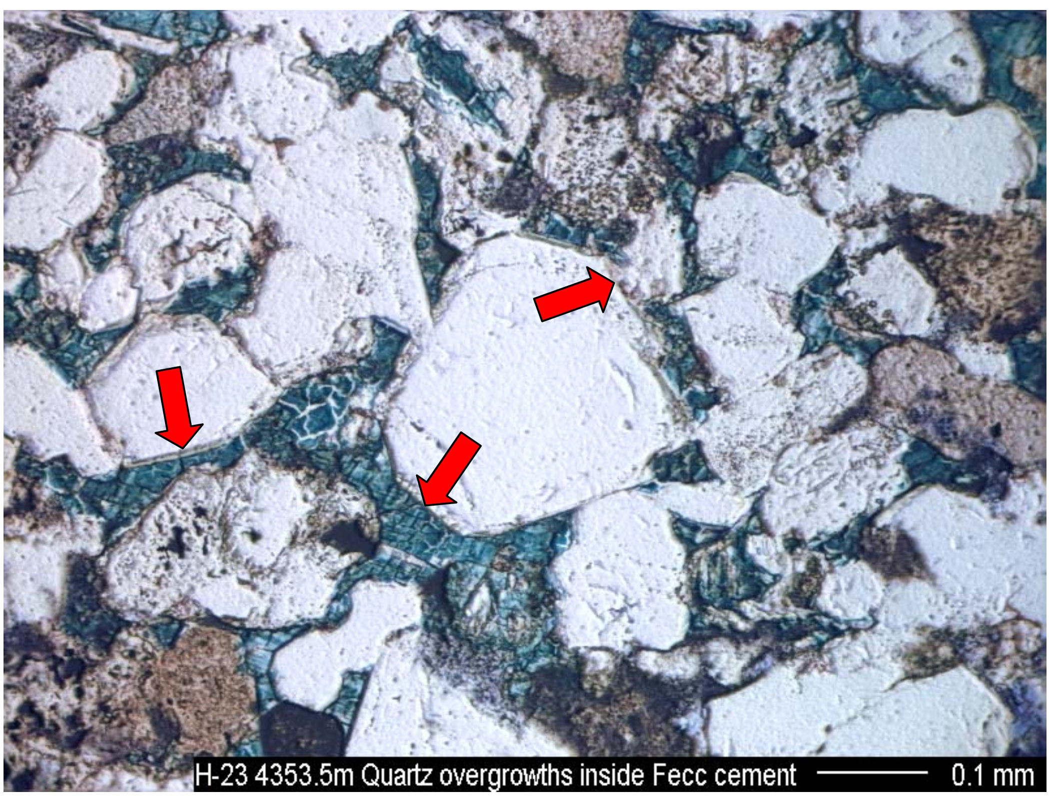


Newburn H-23 Sidewall Cores 4353.5M SP8



3) Pore-filling ferroan calcite cement (red arrows) locally has been dissolved along with unstable rock fragments, resulting in secondary intergranular and secondary moldic porosity (blue areas, right side of photo).

4) Local terminated quartz overgrowth faces inside ferroan calcite cement (arrows) indicate a minor amount of silica cementation took place before ferroan calcite precipitation.



4354.50M SP10 K = 0.80 mD Porosity = 12.9%

Moderately to moderately well sorted, angular to subrounded, lower very fine to upper medium grained, dominantly upper fine grained litharenite in contact with well sorted lithic lower very fined grained sand to coarse silt interbedded with well laminated shale and silty shale.

Framework Grains

Framework grain composition is similar to that of 4353.50M:

Quartz, very minor polycrystalline quartz; feldspar – dominantly alkali feldspar, but microcline twinning rare or absent. Albite twinned grains present, but not as common ad untwinned and perthitic feldspar grains. Some feldspar grains are moderately to strongly leached. Rock fragments include a variety of competent and labile volcanic clasts, often containing feldspar laths; shale; micaceous low grade pelitic metasedimentary clasts; quartzite; chert; undifferentiated labile and quartzose competent grains. Some rock fragments are leached and microporous.

Accessory grains: muscovite; biotite; chlorite; glauconite; heavy minerals.

Authigenic Minerals

Similar in composition and paragenesis to 4353.5M:

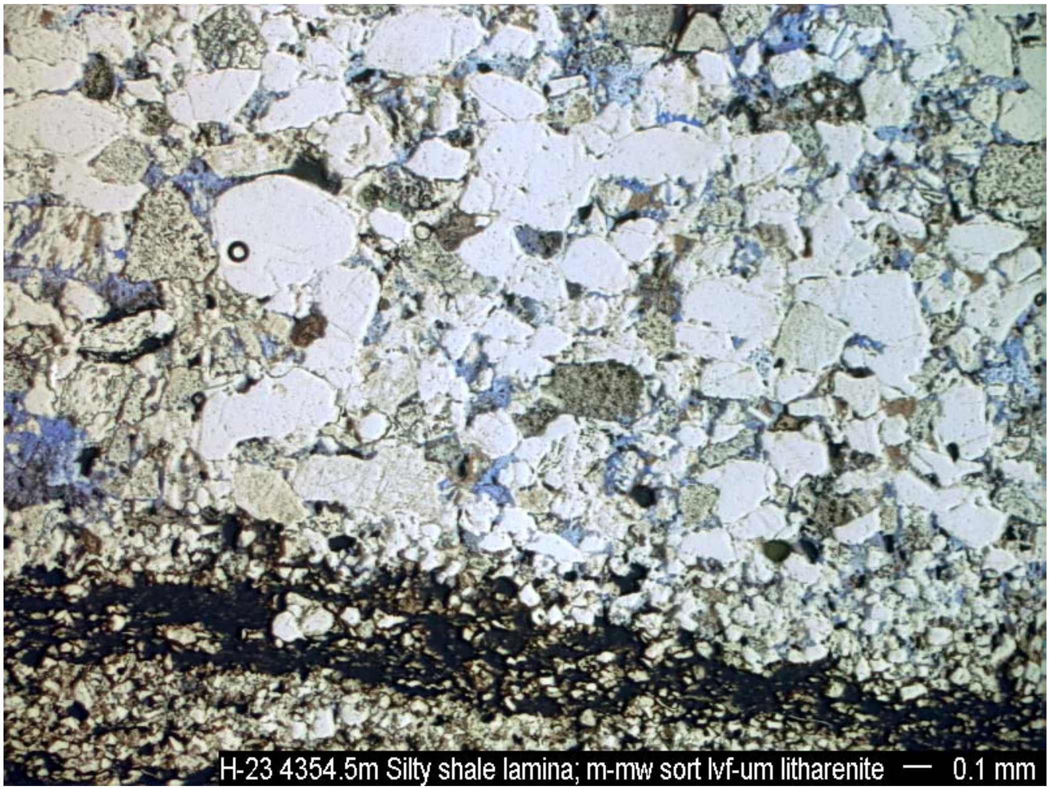
- Siderite, anatase, abundant kaolinite, silica, pore-filling ferroan calcite
- Labile rock fragments and biotite are often altered to clays and locally are partially replaced by siderite.

Porosity and Permeability

Porosity consists dominantly of microporosity in leached clasts and pore-filling aggregates of kaolinite, with lesser amounts of open reduced primary or secondary intergranular porosity formed by partial dissolution of ferroan calcite cement, and granomoldic porosity formed by complete dissolution of unstable clasts.

Primary intergranular porosity and permeability are severely reduced by close grain packing, deformation of ductile clasts into adjacent pores; silica cement; pore-filling ferroan calcite cement; and pore-filling aggregates of authigenic kaolinite.

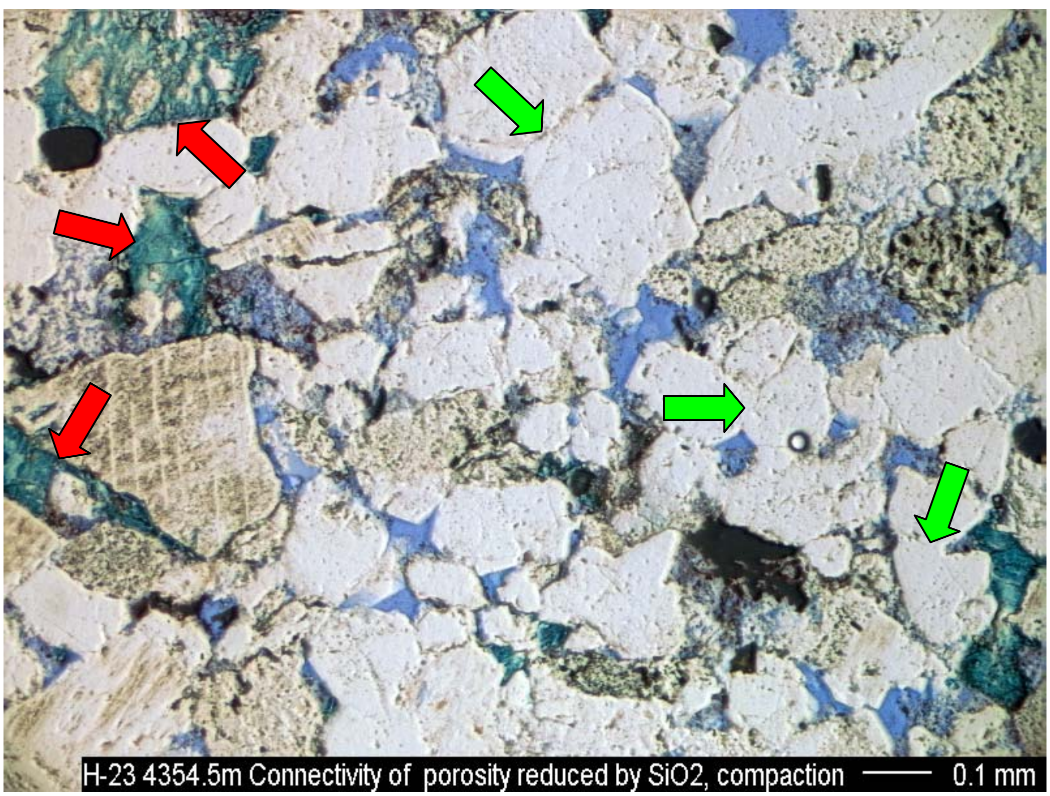
Newburn H-23 Sidewall Cores 4354.5M SP10



H-23 4354.5m Silty shale lamina; m-mw sort lvf-um litharenite — 0.1 mm

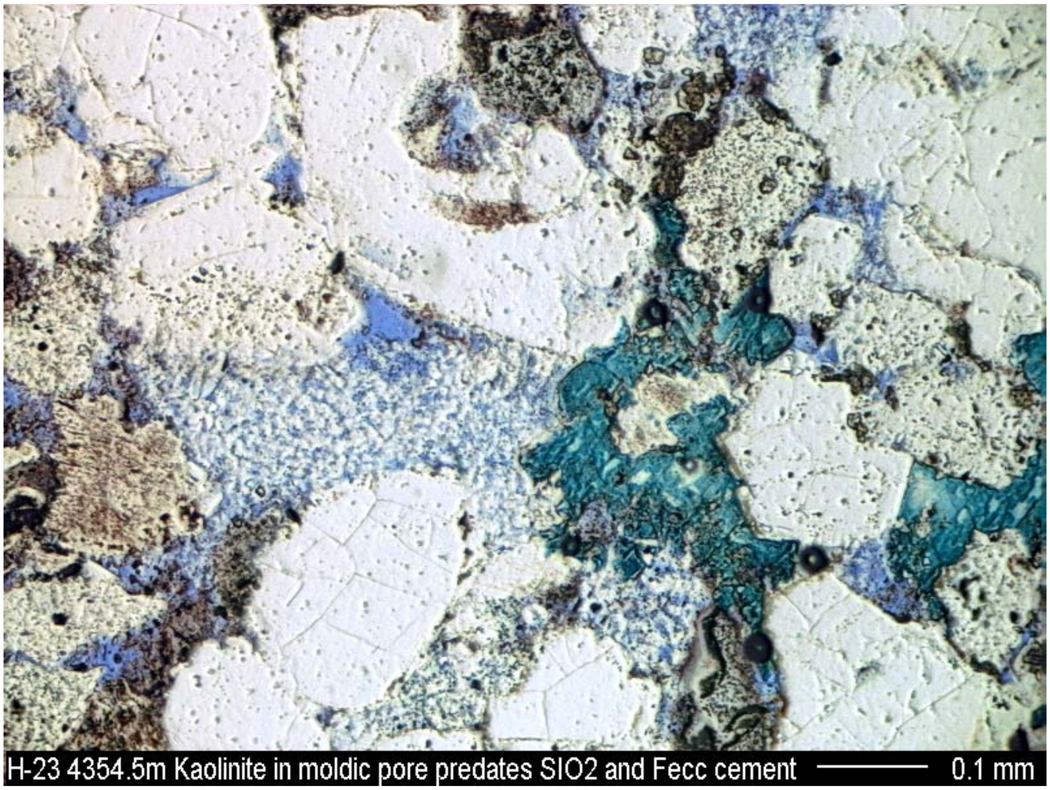
1) Moderately to moderately well sorted lower very fine to upper medium grained litharenite with fair to good intergranular porosity (top part of photo) overlies interbedded siltstone, silty shale and shale.

2) Intergranular porosity and permeability are reduced by ferroan calcite cement (red arrows); by close grain packing, by suturing of grain contacts, by compaction of ductile clasts and by silica cement where quartz grains are in contact with each other (green arrows). Porosity has been enhanced by dissolution of grains and possibly by dissolution of ferroan calcite cement.



H-23 4354.5m Connectivity of porosity reduced by SiO2, compaction — 0.1 mm

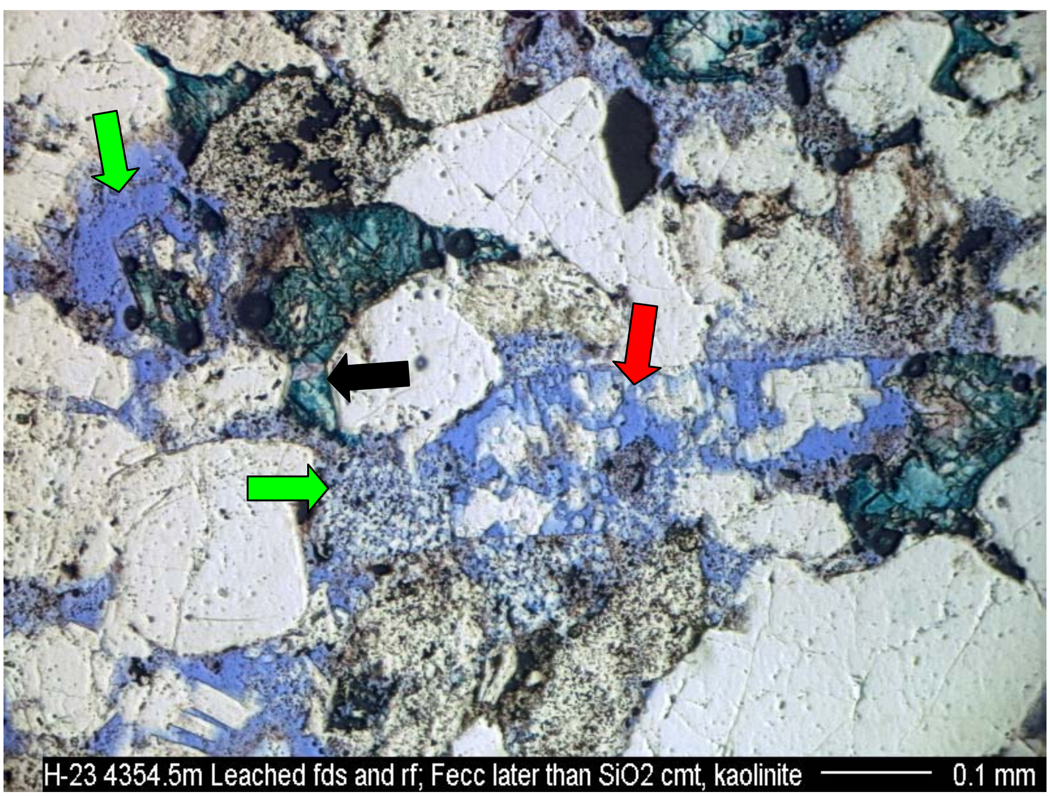
Newburn H-23 Sidewall Cores 4354.5M SP10



H-23 4354.5m Kaolinite in moldic pore predates SIO2 and Fecc cement 0.1 mm

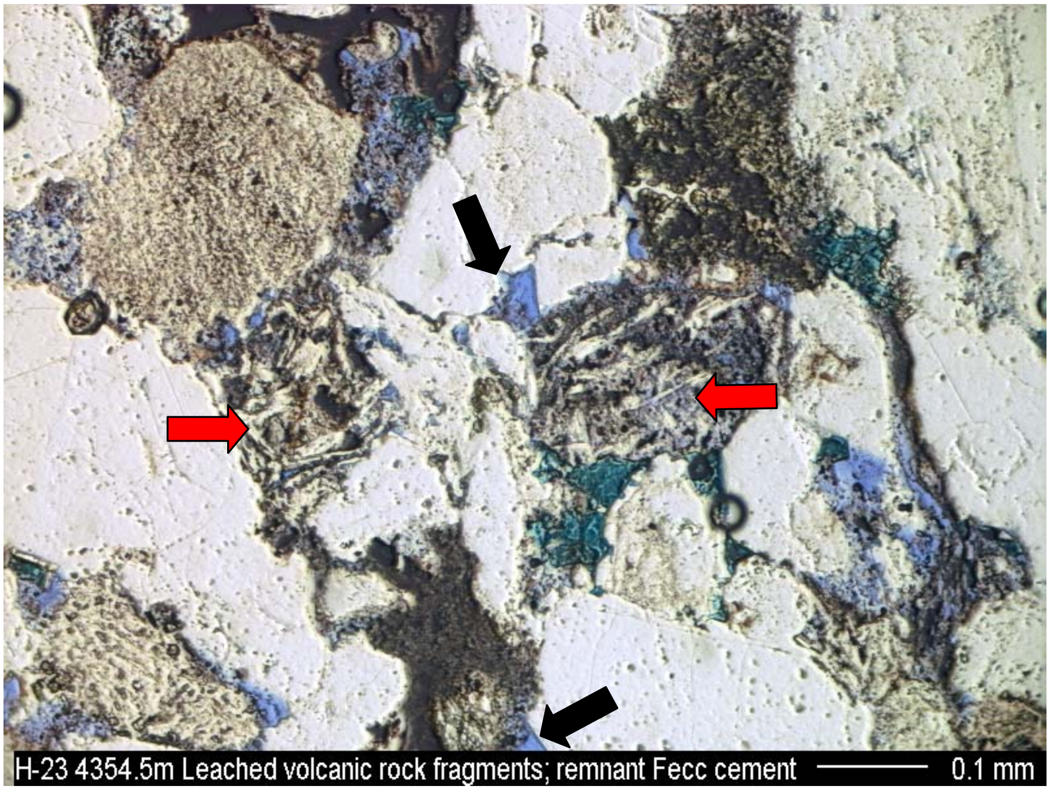
3) Kaolinite fills an oversized pore formed by dissolution of an unstable clast (left center). Pore-filling and locally grain-replacive ferroan calcite cement (blue-green) reduced porosity and permeability.

4) Total porosity has been enhanced by dissolution of feldspar (red arrow) and rock fragments (green arrows). Ferroan calcite post-dates a minor amount of silica cement (black arrow).



H-23 4354.5m Leached fds and rf; Fecc later than SiO2 cmt, kaolinite 0.1 mm

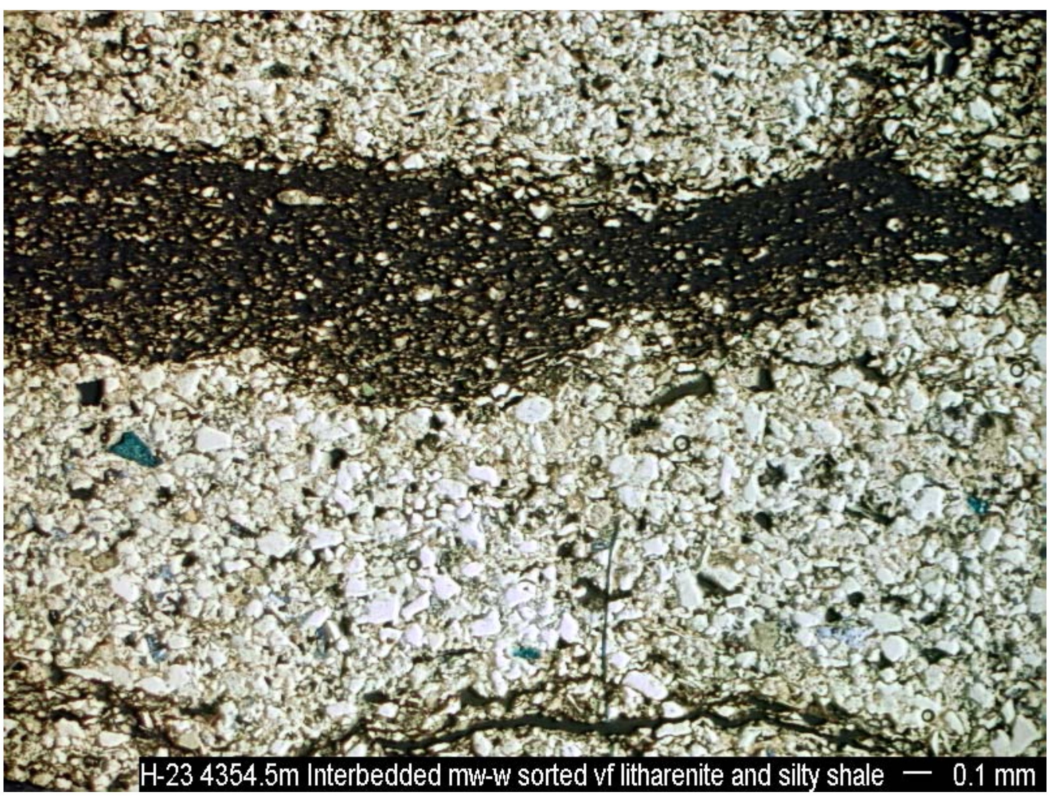
Newburn H-23 Sidewall Cores 4354.5M SP10



H-23 4354.5m Leached volcanic rock fragments; remnant Fecc cement 0.1 mm

5) Volcanic rock fragments are common (red arrows). Volcanic rock fragments and other unstable rock fragments are often leached and microporous. Some open reduced intergranular porosity may have formed by dissolution of previously more extensive ferroan calcite cement (black arrows).

6) Moderately well to well sorted lower very fine grained silty litharenite interbedded with shale and silty shale. Porosity and permeability in this part of the sample is considerably lower than in the coarser grained litharenite.



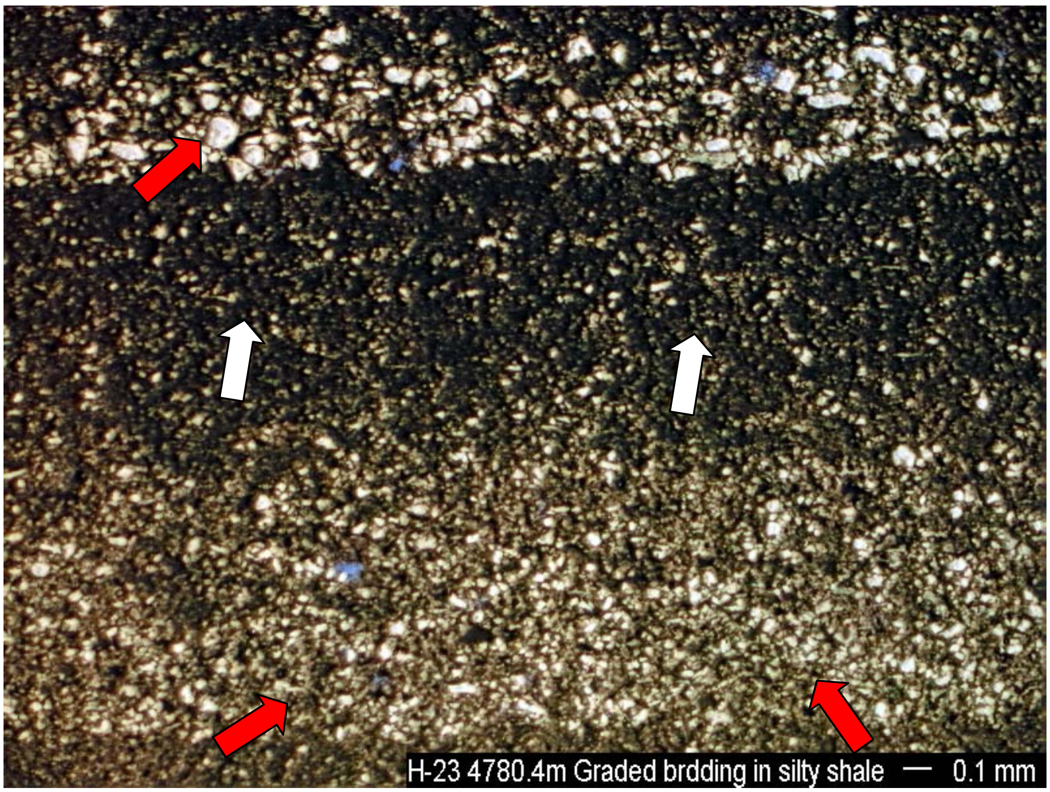
H-23 4354.5m Interbedded mw-w sorted vf litharenite and silty shale 0.1 mm

4780.40M SWC 23

Rhythmically bedded, normally graded silty shale.

Silty fraction consists of angular quartz and feldspar, with minor competent quartzose rock fragments, and minor micaceous and quartz-mica metasedimentary rock fragments. Accessory grains consist of mica and heavy minerals.

Newburn H-23 Sidewall Cores 4780.4M SP23



1) Normally graded bedding in silty shale and shale. Silty shale or locally argillaceous siltstone (red arrows) grades upward into shale with little or no fine silt.

4913.80M SP24 K = 0.09 mD Porosity = 9.4%

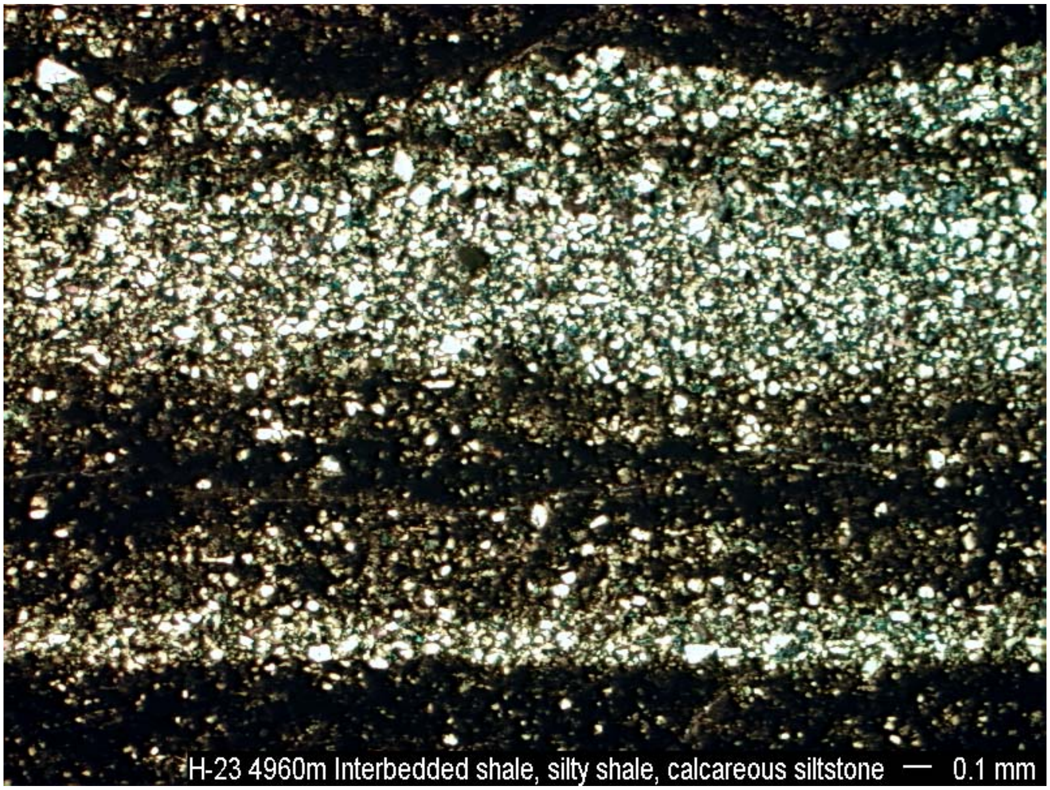
Silty / Sandy shale

Angular to subrounded, dominantly angular silt to upper medium sand in a shale matrix. Bedding has been disrupted, possibly by soft-sediment deformation.

4960.00M SP 25

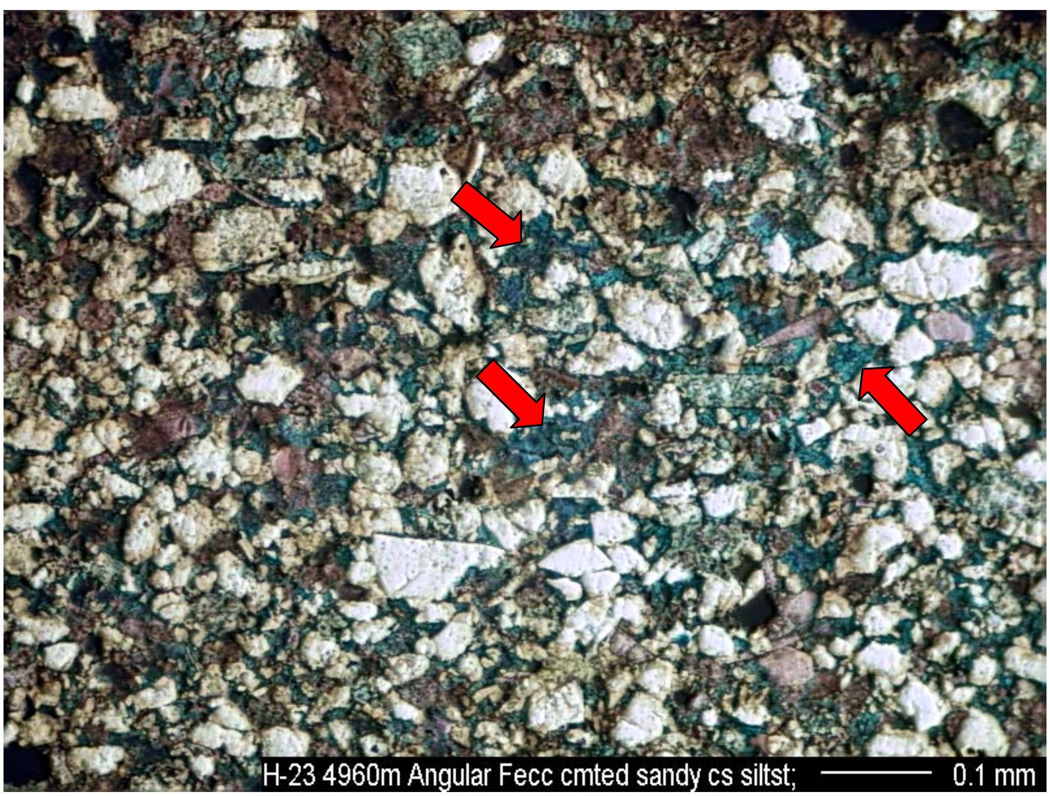
Interbedded, well laminated carbonaceous shale, silty shale and minor siltstone. Siltstone laminae (~1mm) are cemented by ferroan calcite. A few abraded bioclast fragments are present in both the siltstone and the shale laminae. Calcispheres are common. A few foram fragments are also present.

Newburn H-23 Sidewall Cores 4960.0M SP25



1) Interbedded shale, silty shale and calcareous siltstone. Well laminated on ~0.25 - 1mm scale.

2) Close view of angular ferroan calcite cemented (blue-green, arrows) lithic sandy coarse siltstone interbedded with shale..



5403.60M SP12 K = < 0.01 mD Porosity = 7.2%

Well sorted, angular to subangular mid-very fine grained argillaceous litharenite.

Rock fragments consist of shale, micaceous pelitic metasedimentary clasts, chloritic rock fragments, altered volcanic rock fragments, and undifferentiated quartzose and quartzo-feldspathic competent grains.

Ductile argillaceous, micaceous and chloritic clasts are commonly altered and compacted into a pseudomatrix, with obscure grain contacts. Laminae with abundant carbonaceous debris, sideritic clasts (at least in part sideritized biotite) mica and interstitial detrital clay are interbedded with cleaner litharenite with authigenic interstitial chlorite. Mica is a common accessory grain. Biotite is commonly strongly altered.

Kaolinite is present in minor amounts in the sites of altered clasts. A minor amount of ferroan dolomite is locally present in pores or partially replacing grains.

Intergranular porosity and permeability are completely occluded by interstitial detrital clays, early authigenic interstitial chlorite or chloritized detrital clay, silica cement and ferroan calcite cement, and by close packing of grains and deformation of ductile clasts against more competent grains, each other, and into pores.

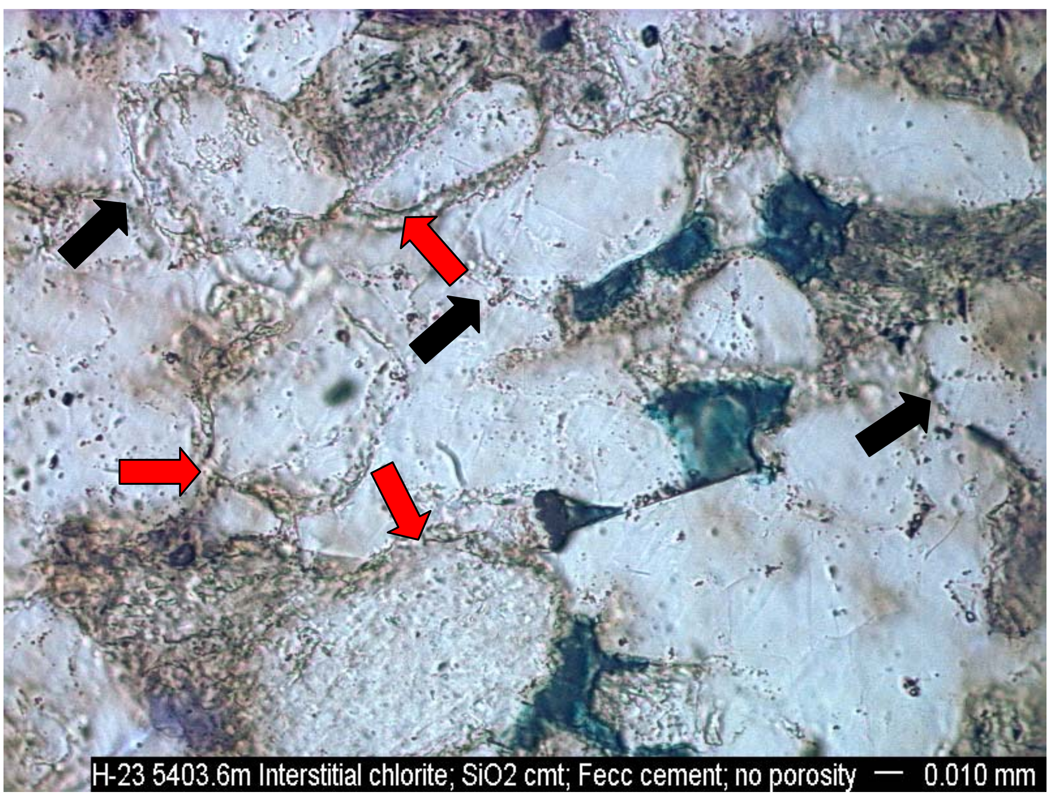
All measured porosity is microporosity.

Newburn H-23 Sidewall Cores 5403.6M SP12

H-23 5403.6m W sorted a-sa, mvf arg litharenite; Fecc, SiO2 cement — 0.1 mm

1) Well sorted, angular to subangular, mid-very fine grained argillaceous litharenite. Intergranular porosity is completely occluded by close grain packing, ferroan calcite cement, silica cement, interstitial detrital clays and interstitial authigenic chlorite.

2) Intergranular porosity is occluded by close grain packing, sutured grain contacts, interstitial detrital clays, chloritized matrix, grain-coating chlorite (red arrows), silica cement (black arrows) and minor ferroan calcite cement (blue).

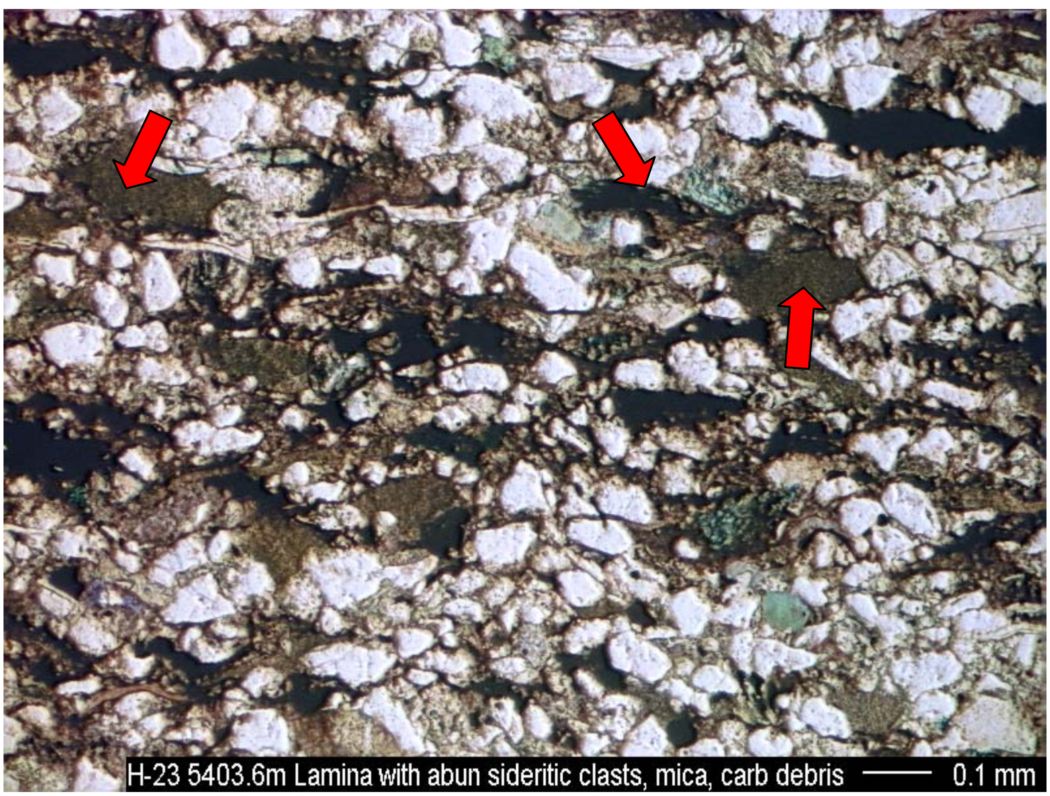


H-23 5403.6m Interstitial chlorite; SiO2 cmt; Fecc cement; no porosity — 0.010 mm

Newburn H-23 Sidewall Cores 5403.6M SP12

3) Compacted ductile rock fragments and altered biotite occlude intergranular porosity (arrows).

4) Sideritic clasts (red arrows), carbonaceous debris (dark brown to black streaks), and micas are concentrated in laminae with more abundant interstitial detrital clays. Altered glauconite (green) is locally present. No intergranular porosity is preserved in compacted argillaceous/ carbonaceous/micaceous laminae.



5406.50M SP11 K = 0.04 mD Porosity = 9.1%

Moderately to moderately well sorted, angular to subangular cross-laminated coarse silt to upper medium grained litharenite. Lamination is defined by variations in grain size and sorting, and by concentrations of heavy minerals, particularly zircon.

Essential framework grains consist of quartz, feldspar and rock fragments. Some of the matrix in the point count consists of pseudomatrix of compacted labile clasts, many of which have been chloritized and are difficult to distinguish from interstitial authigenic chlorite and chloritized detrital matrix.

Silica cement fills intergranular porosity where quartz grains make up all or most of the pore walls, but terminated quartz overgrowth faces generally are not present because of compaction against ductile clasts or interstitial chlorite.

Early authigenic chlorite partially rims some grains.

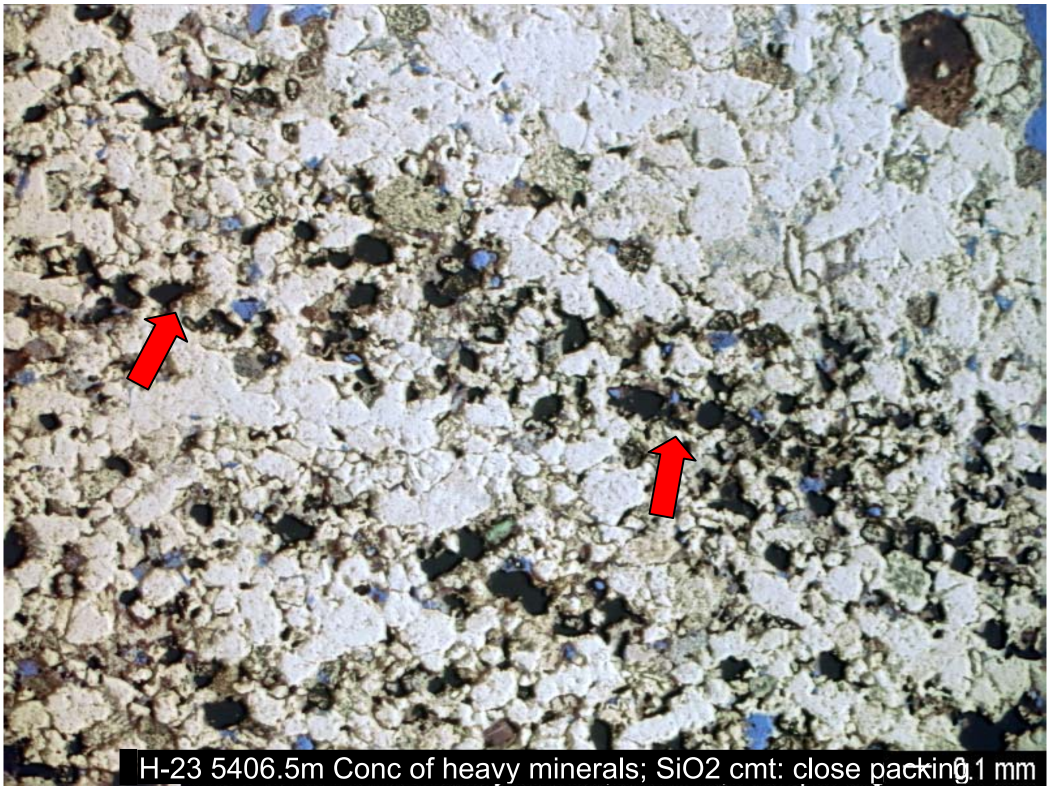
Authigenic kaolinite fills secondary dissolution pores in sites of partially to completely leached clasts, and locally fills reduced intergranular pores. A minor amount of authigenic feldspar occurs as thin overgrowths on feldspar grains.

Primary intergranular porosity is strongly reduced by close grain packing, silica cement, kaolinite and interstitial chlorite.

A trace amount of reduced primary intergranular porosity is preserved where chlorite rims have inhibited quartz overgrowth development, but most remnant intergranular porosity has been reduced to microporosity by pore-filling kaolinite. Open moldic porosity formed by dissolution of unstable clasts is locally present, but the connectivity of the pore system is strongly reduced by close packing, chlorite and quartz overgrowths in pore throats.

Abundant opaque heavy minerals, probably mainly iron-titanium oxides, are often leached, leaving concentrations of moldic pores in heavy mineral laminae.

Newburn H-23 Sidewall Cores 5406.5M SP11



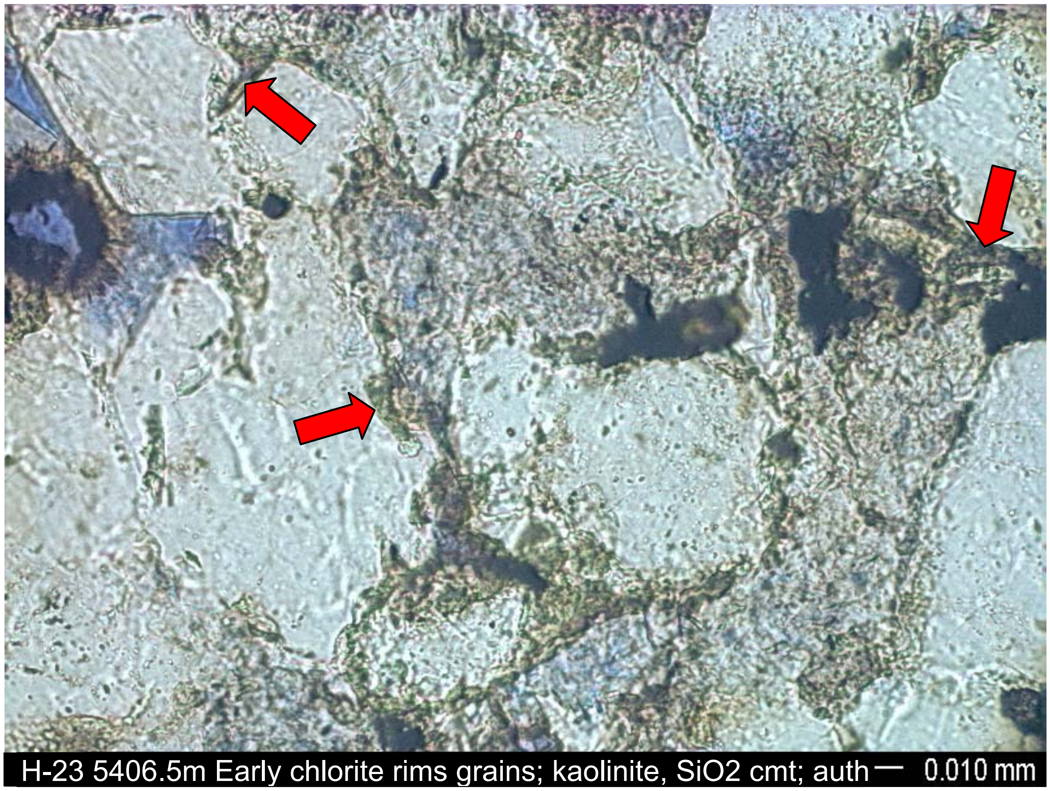
H-23 5406.5m Conc of heavy minerals; SiO_2 cmt: close packing 0.1 mm

1) Heavy minerals are concentrated in laminae in moderately to moderately well sorted, angular to subangular cross-laminated (rippled?) coarse silt to upper medium grained litharenite. Intergranular porosity is strongly reduced by close grain packing, compaction of ductile clasts, interstitial chlorite, and by silica cement.

2) Kaolinite fills oversized secondary and minor reduced intergranular pores (arrows). Compaction of ductile clasts, sutured grain contacts, and silica cement (black arrows) severely reduce intergranular porosity.

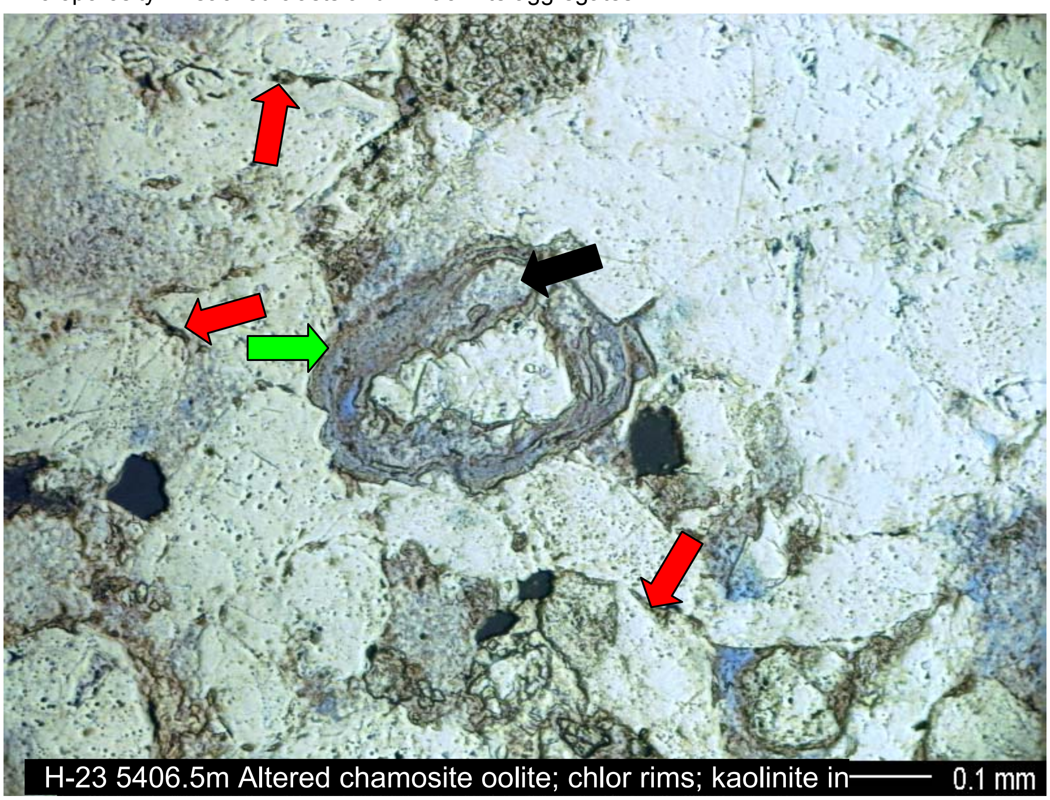
H-23 5406.5m Kaolinite fills 2ary and intrgr pores; SiO_2 cmt; 0.1 mm

Newburn H-23 Sidewall Cores 5406.5M SP11

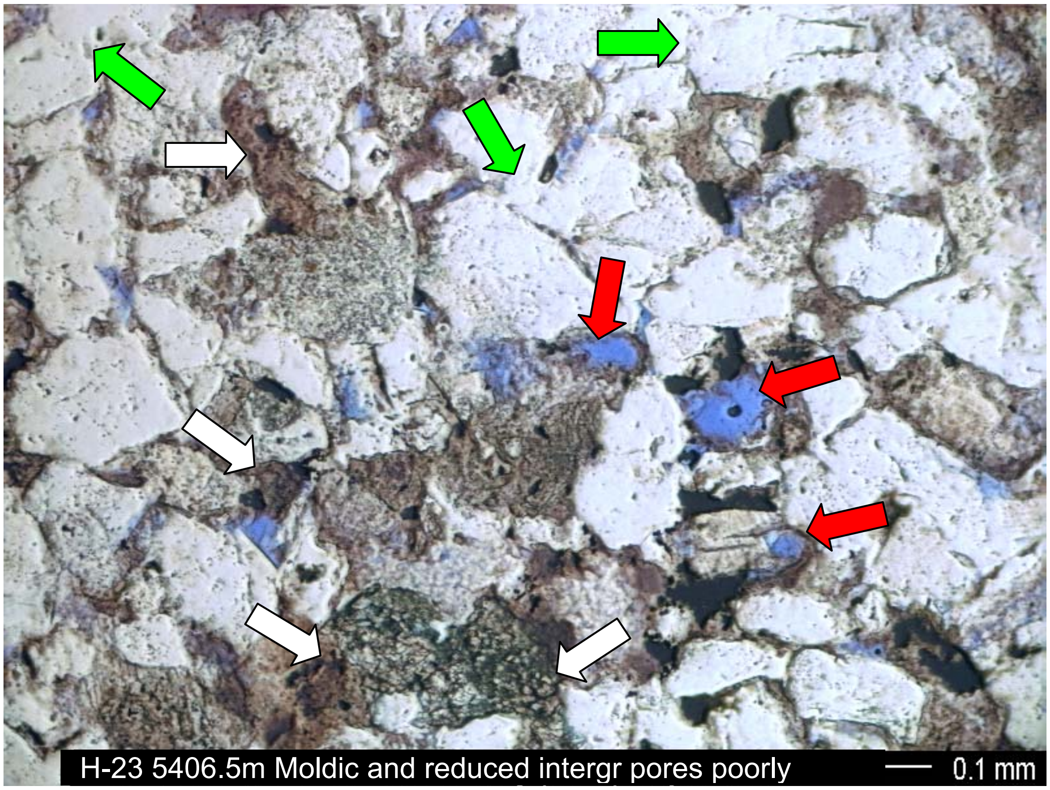

H-23 5406.5m Early chlorite rims grains; kaolinite, SiO2 cmt; auth 0.010 mm

3) Authigenic chlorite (arrows) formed on grain surfaces and in pores, sometimes replacing interstitial detrital clays, early in the diagenetic history. Chlorite rims are discontinuous, so only locally have inhibited quartz overgrowth development.

4) Leached oolitic chamosite (green arrow) on a sand grain host is partly filled by later kaolinite (black arrow). Discontinuous chlorite rims are present on many detrital grains (red arrows). Most porosity is microporosity in leached clasts and in kaolinite aggregates.


H-23 5406.5m Altered chamosite oolite; chlor rims; kaolinite in 0.1 mm

Newburn H-23 Sidewall Cores 5406.5M SP11



5) Remnant reduced intergranular porosity is locally preserved where chlorite rims on monocrystalline quartz grains have inhibited quartz overgrowth development, particularly where competent grains other than monocrystalline quartz make up part of the pore wall. Intergranular porosity is severely reduced by close grain packing, compaction of ductile clasts into adjacent pores (white arrows), and silica cement (green arrows). Total porosity is enhanced by partial to complete dissolution of unstable clasts (red arrows).

5407.00M SP10 K = 0.15 mD Porosity = 17.0%

Moderately well sorted angular to subangular lower very fine to lower fine grained dominantly mid very fine grained litharenite with good porosity.

Framework Grains

Monocrystalline quartz makes up 41.5% of the sample by point count. Feldspar makes up 4.4% and rock fragments make up at least 23.8%.

Rock fragments consist of shale, pelitic metasedimentary fragments, a variety of volcanic clasts and undifferentiated altered argillaceous, micaceous and chloritized clasts.

Accessory grains include mica, heavy minerals and trace amounts of altered glauconite.

Altered rock fragments, micas and glauconite are often leached and microporous. Many unstable micaceous and/or argillaceous clasts have been chloritized.

Authigenic Minerals

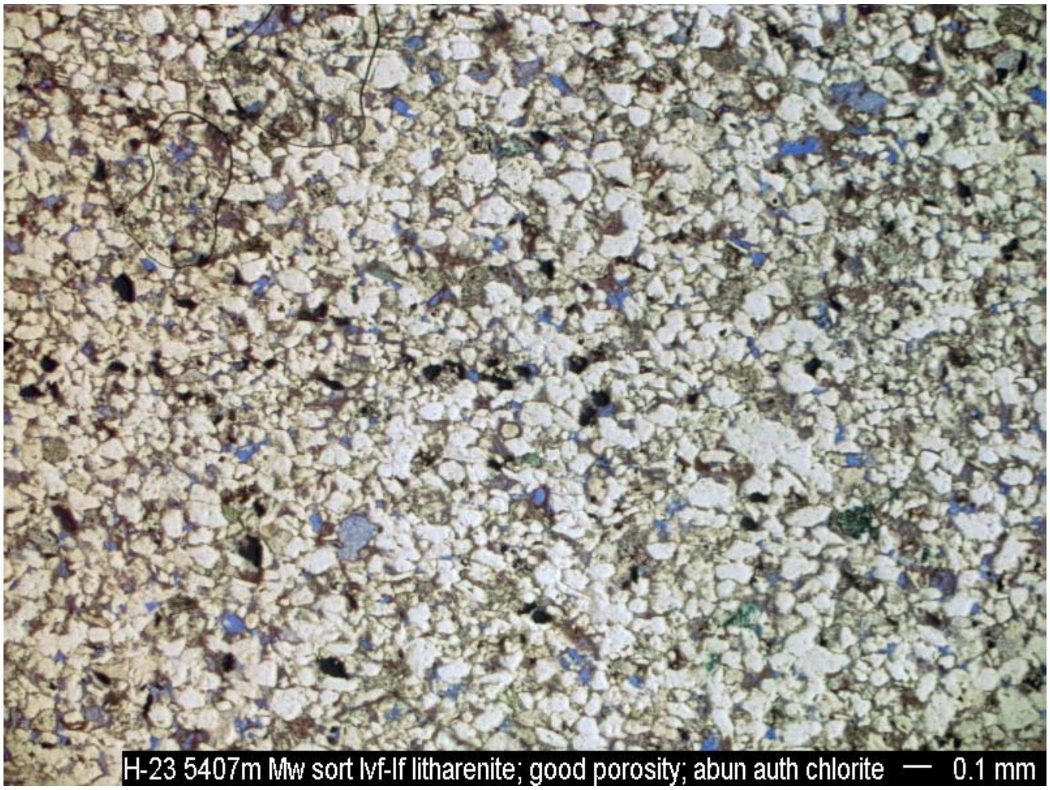
- Chlorite – occurs as rims on detrital grains, as replacement of unstable rock fragments and interstitial detrital clays. Chlorite rims locally have inhibited quartz overgrowth development on quartz grains.
- Ferroan dolomite – minor scattered pore-filling and grain-replacive cement.
- Silica – quartz overgrowths have formed on quartz grains where not inhibited by chlorite rims. Where quartz grains make up all of the pore wall, intergranular pores are strongly occluded by silica cement if chlorite rims are not present.
- Kaolinite – fills secondary moldic pores more than reduced intergranular pores. Kaolinite also fills a micro fracture that cross-cuts bedding.
- Anatase – scattered authigenic crystals.
- Pyrite – trace framboids.

Porosity and Permeability

Measured porosity is 17% in this sample. Porosity consists of reduced primary intergranular porosity preserved where quartz overgrowth development has been inhibited by grain-coating authigenic chlorite and/or where competent grains other than quartz make up the pore wall. Open porosity is enhanced by dissolution of unstable clasts.

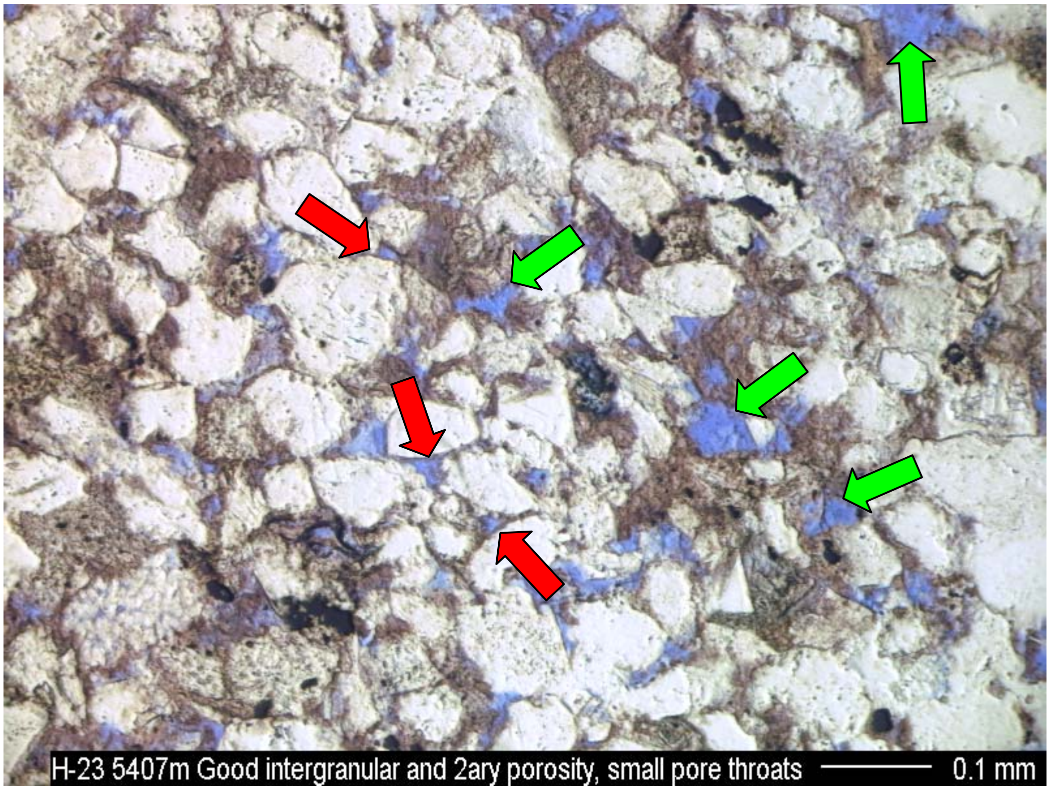
Total porosity consists of reduced primary intergranular porosity, secondary moldic porosity, often adjacent to reduced primary pores and a significant component of microporosity in leached clasts, authigenic and grain-replacive chlorite, and pore-filling kaolinite.

Newburn H-23 Sidewall Cores 5407.0M SP10

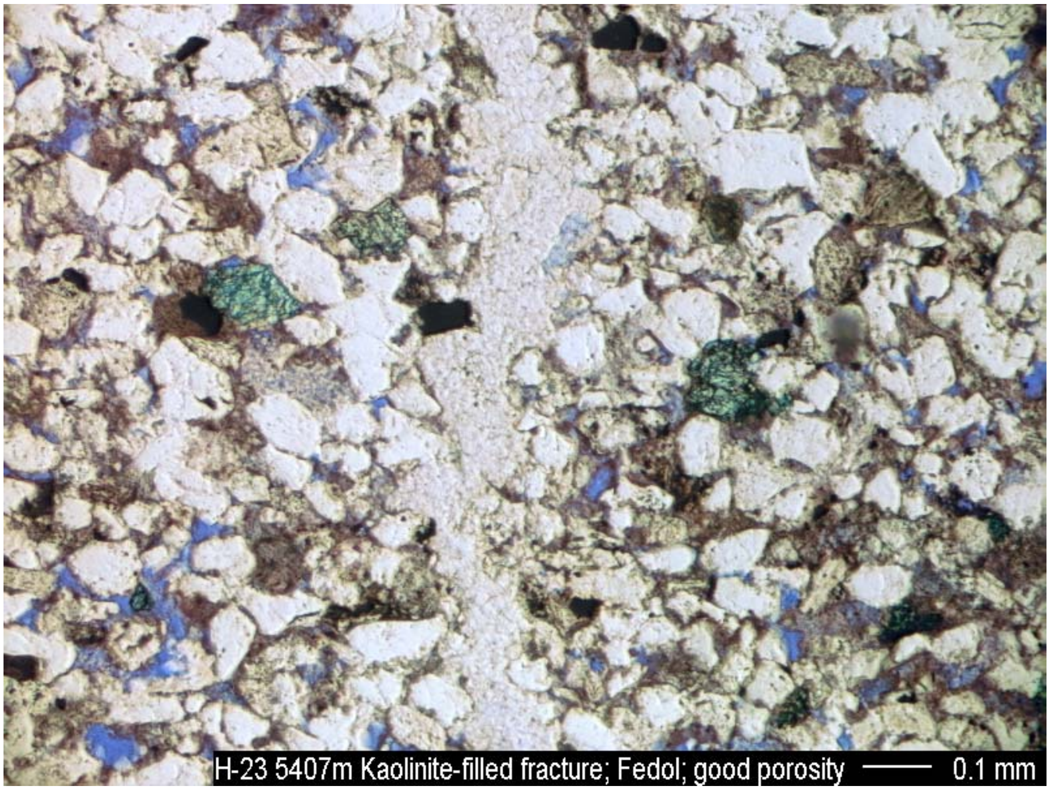


1) Moderately well sorted mid-very fine grained litharenite with good visible porosity (blue) and measured core analysis porosity of 17%.

2) Intergranular porosity has been preserved where grain-coating authigenic chlorite has inhibited quartz overgrowth development (red arrows), particularly where quartz or other competent grains make up most or all of the pore wall.. Total porosity has been enhanced by dissolution of unstable rock fragments and other unstable clasts.

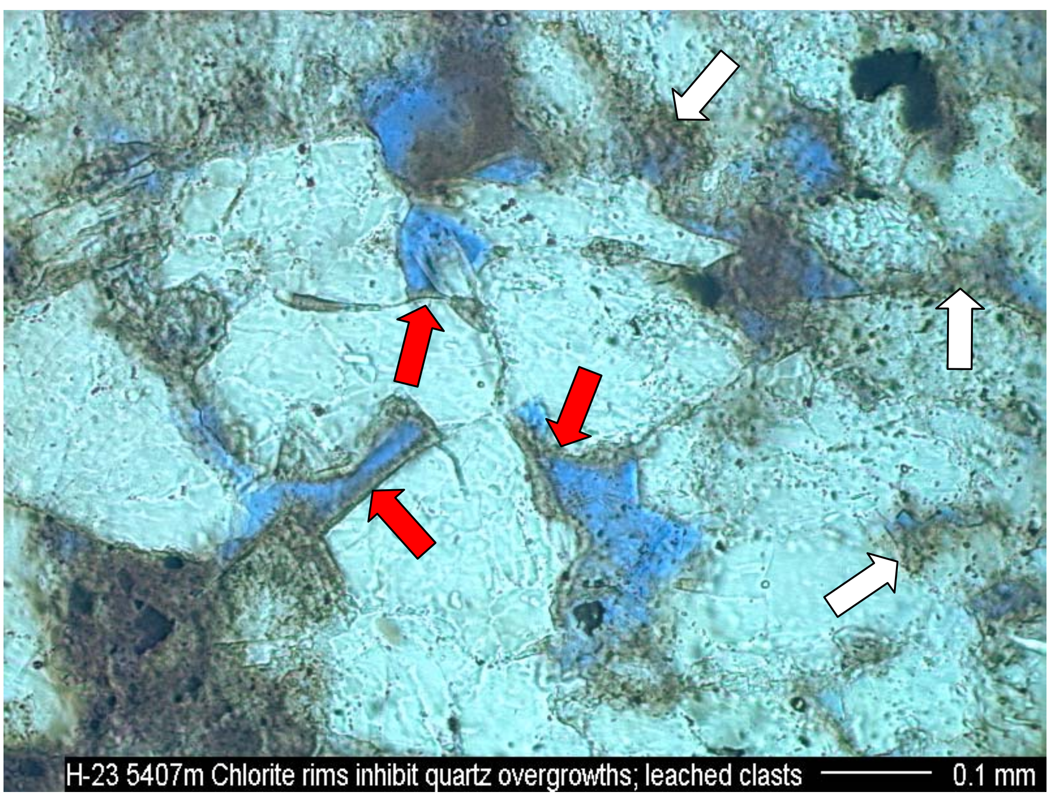


Newburn H-23 Sidewall Cores 5407.0M SP10

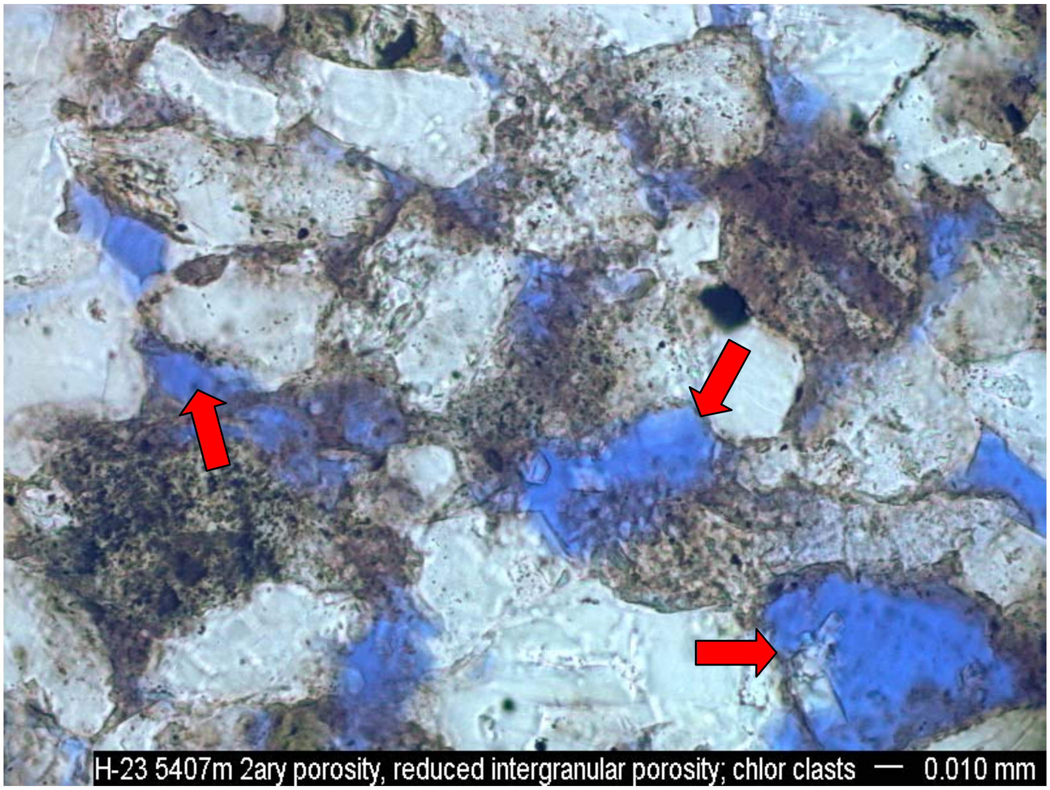


3) A discontinuous microfracture is filled by kaolinite (center). Good reduced intergranular and moldic porosity (blue).

4) Close view of chlorite rims which inhibit quartz overgrowth development, preserving intergranular porosity (red arrows). Suturing of grain contacts, minor amounts of silica cement, interstitial chlorite (white arrows) and chlorite rims reduce pore throat size and permeability.



Newburn H-23 Sidewall Cores 5407.0M SP10



5) Secondary moldic porosity (red arrows) has formed by almost complete dissolution of unstable clasts, many of which were chloritized during or just after deposition of the sand.

5407.50M SP9 K = 5.73 mD Porosity = 18.9%

Well sorted angular to subrounded, dominantly subangular, upper very fine grained quartzose litharenite to sublitharenite. Original grain composition was litharenite, but dissolution of unstable rock fragments and argillaceous clasts has increased the quartz grain content relative to rock fragments in the point count data.

Framework Grains

Monocrystalline quartz makes up 57.1% of the sample and polycrystalline quartz 5.5%. Feldspar grains make up 4.2% and rock fragments make up 17.1%.

Rock fragments consist of a variety of altered labile and competent volcanic clasts, shale, micaceous pelitic metasedimentary clasts, undifferentiated competent quartzose and quartzo-feldspathic clasts, undifferentiated chloritized labile clasts.

Accessory grains include mica, heavy minerals and probable glauconite. Biotite and clasts interpreted as originally glauconite and/or chamosite are generally strongly altered. Trace chamosite oolites.

Authigenic Minerals

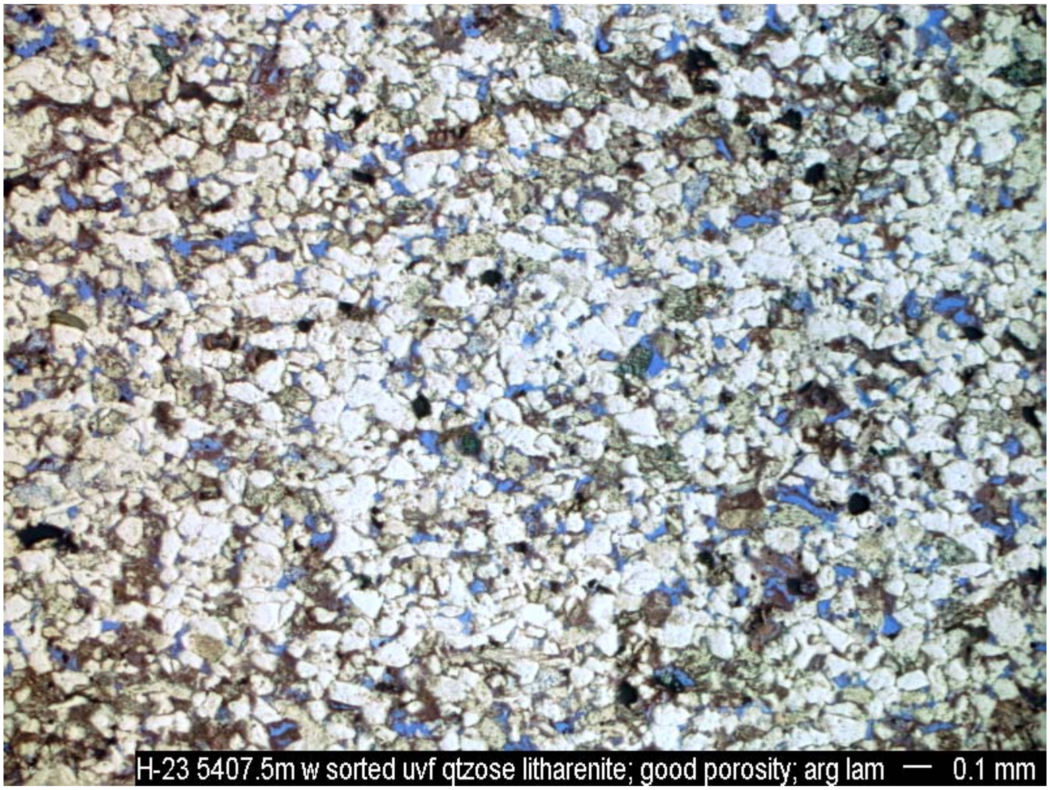
- Chlorite – discontinuous chlorite rim development has inhibited some quartz overgrowth development, preserving intergranular porosity. Chlorite also replaces some unstable clasts and interstitial detrital clays.
- Silica cement – reduces or occludes intergranular porosity where not inhibited by chlorite rims, and minor interstitial detrital clays.
- Anatase – authigenic crystals common, scattered throughout the pore system.
- Kaolinite – moderate to minor amount, scattered throughout the pore system in reduced intergranular pores and moldic and intragranular dissolution pores.
- Ferroan calcite – very minor pore-filling slightly ferroan calcite scattered throughout the pore system
- Non-ferroan to slightly ferroan (?) dolomite – a minor amount of probably slightly ferroan dolomite is scattered throughout the sample, filling pores and often partially replacing adjacent unstable clasts. Dolomite is more abundant than ferroan calcite.
- Siderite – trace amounts of siderite microcrystals are scattered throughout the pore system, clinging to grain surfaces.

Some of the leached chloritic or chloritized clasts may be altered chamosite clasts, or clasts which were altered to chamosite at or very near the depositional surface. The presence of trace amounts of chamosite oolites indicates chamosite was forming on the sea floor, either in site at the depositional surface or up-slope from the site of deposition.

Porosity and Permeability

Primary intergranular porosity has been reduced by close grain packing, by silica cement and by compaction of ductile clasts. The ductile clast content is lower than in SP10, and the competent grain content is higher. Some reduced intergranular porosity has been preserved by grain-rimming chlorite which has inhibited quartz overgrowth development, particularly where competent grains other than quartz make up part of the pore wall. Total porosity has been significantly enhanced by dissolution of unstable clasts. A moderate component of total porosity consists of microporosity in leached and altered labile clasts, authigenic chlorite, and kaolinite aggregates. Permeability is higher in this sample that in SP10 because more open porosity is present and average pore throat size is larger. The point count porosity of 11.4% indicates the positive effect that chlorite rims have had in preserving primary intergranular porosity and that dissolution has enhanced total microporosity. Less than half of total porosity consists of microporosity.

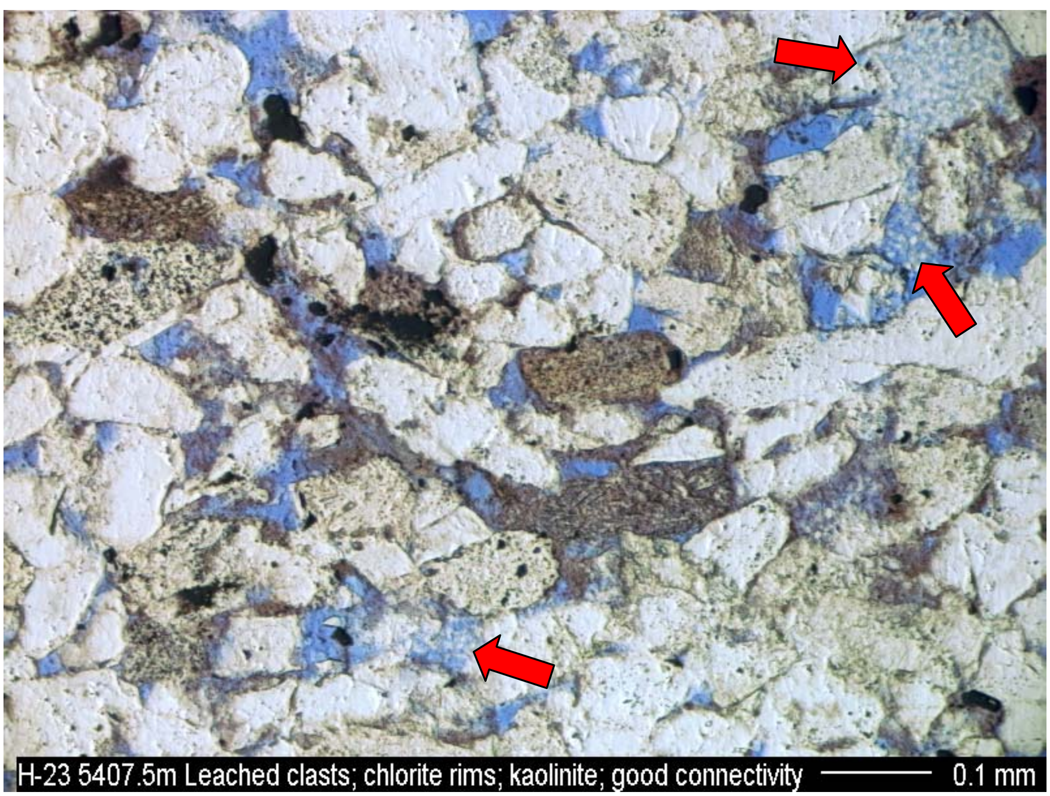
Newburn H-23 Sidewall Cores 5407.5M SP9



H-23 5407.5m w sorted uvf qtzose litharenite; good porosity; arg lam — 0.1 mm

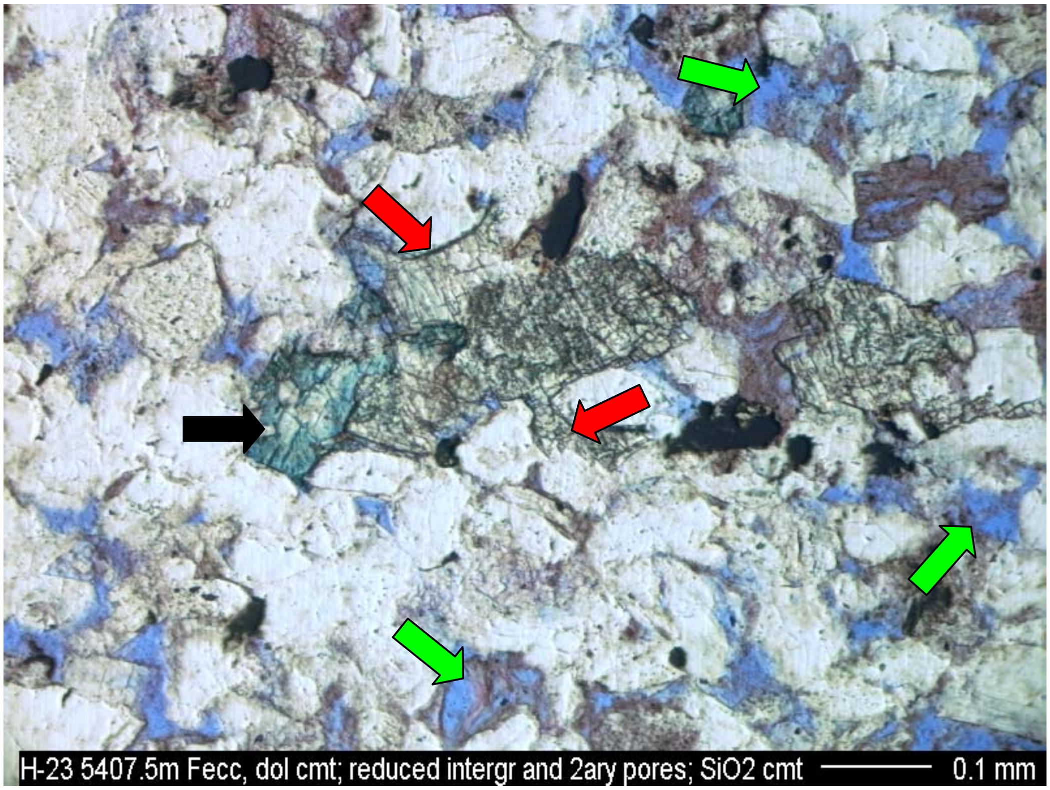
1) Well sorted angular to subrounded, upper very fine grained quartzose litharenite with good remnant reduced intergranular porosity enhanced by granomoldic dissolution porosity (blue). Core analysis porosity is 18.9%

2) Chlorite rims locally preserved reduced intergranular porosity by inhibiting quartz overgrowth development. Total porosity has been enhanced by dissolution of unstable clasts. Kaolinite locally fills secondary pores (red arrows). Grain dissolution has improved permeability and connectivity of the pore system.



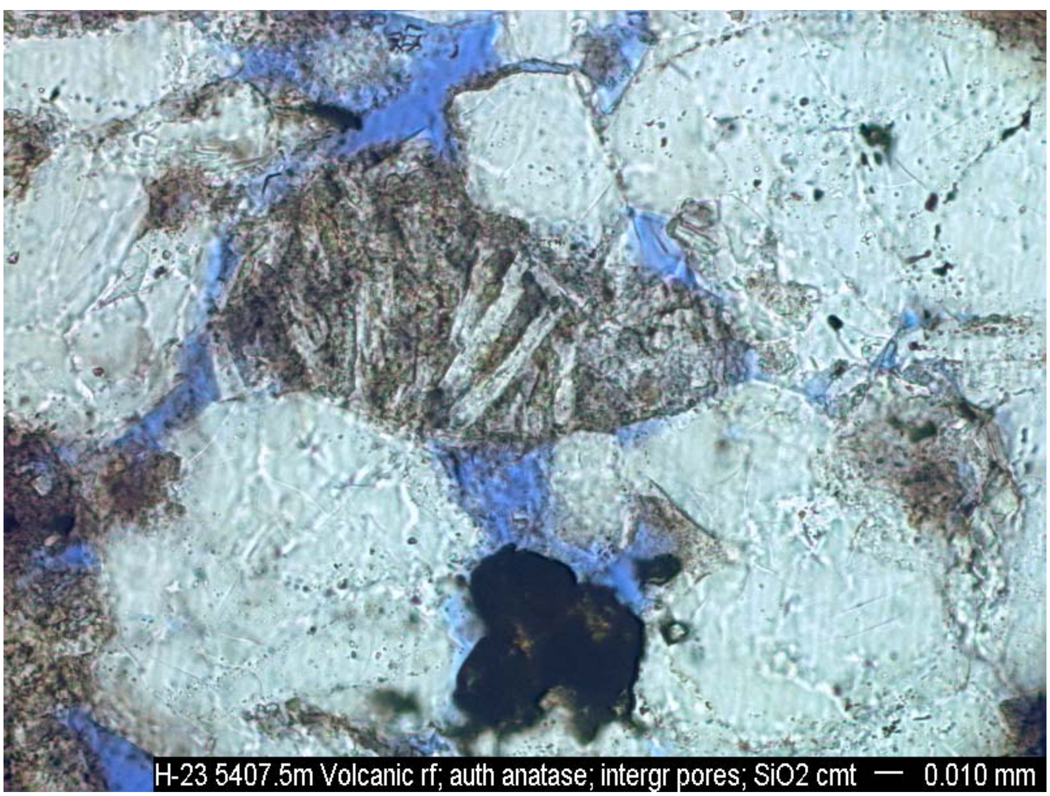
H-23 5407.5m Leached clasts; chlorite rims; kaolinite; good connectivity — 0.1 mm

Newburn H-23 Sidewall Cores 5407.5M SP9



3) Minor amounts of ferroan calcite cement (black arrow) and dolomite cement (red arrows) locally reduce intergranular porosity. Grain dissolution enhances total porosity (green arrows) and pore system connectivity.

4) Volcanic rock fragment with relict feldspar laths (center). Authigenic titanium oxide (bottom center) is common but not abundant. Good connectivity of reduced primary and secondary pores (blue).



5408.50M SP8 K = 6.43 mD Porosity = 17.9%

Moderately well to well sorted subangular to subrounded, dominantly subangular, upper very fine to lower fine grained quartzose litharenite.

Volcanic and other labile clasts are commonly microporous.

Very similar in grain composition and diagenesis to SP9, 5407.50M.

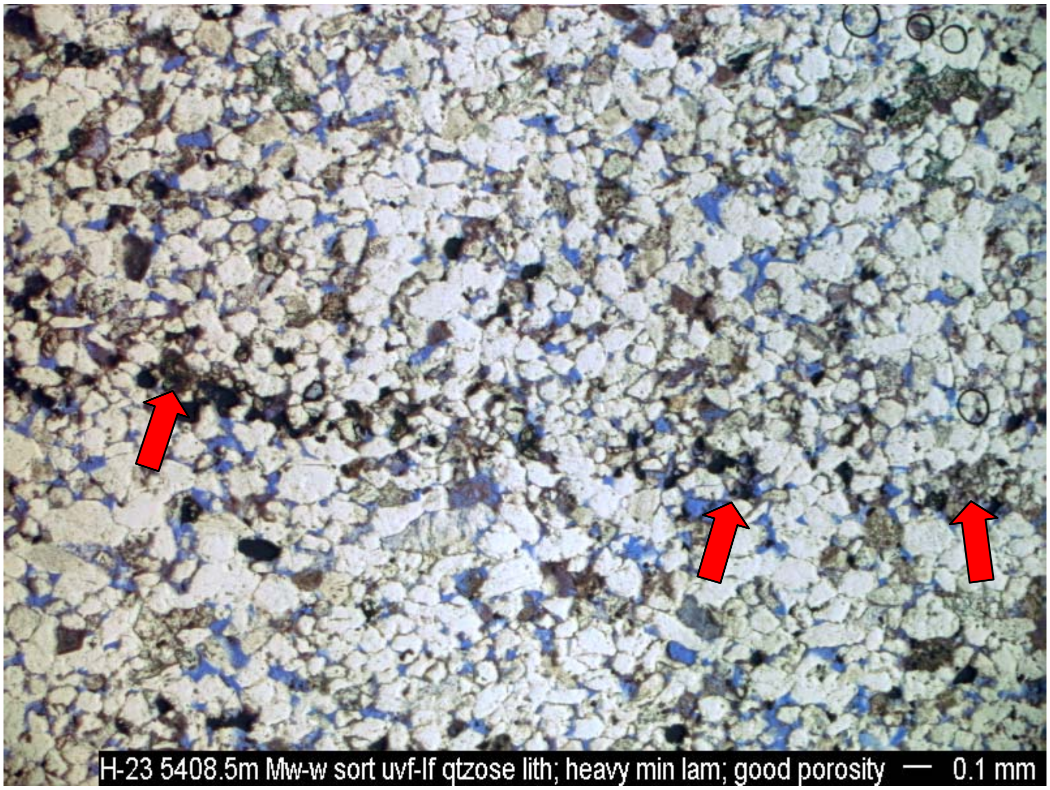
Cross-laminated, with local concentrations of heavy minerals in laminae.

Chlorite rims are not as well developed as in SP10, but have locally inhibited quartz overgrowth development, preserving some reduced intergranular porosity.

Porosity has been significantly enhanced by dissolution of unstable clasts.

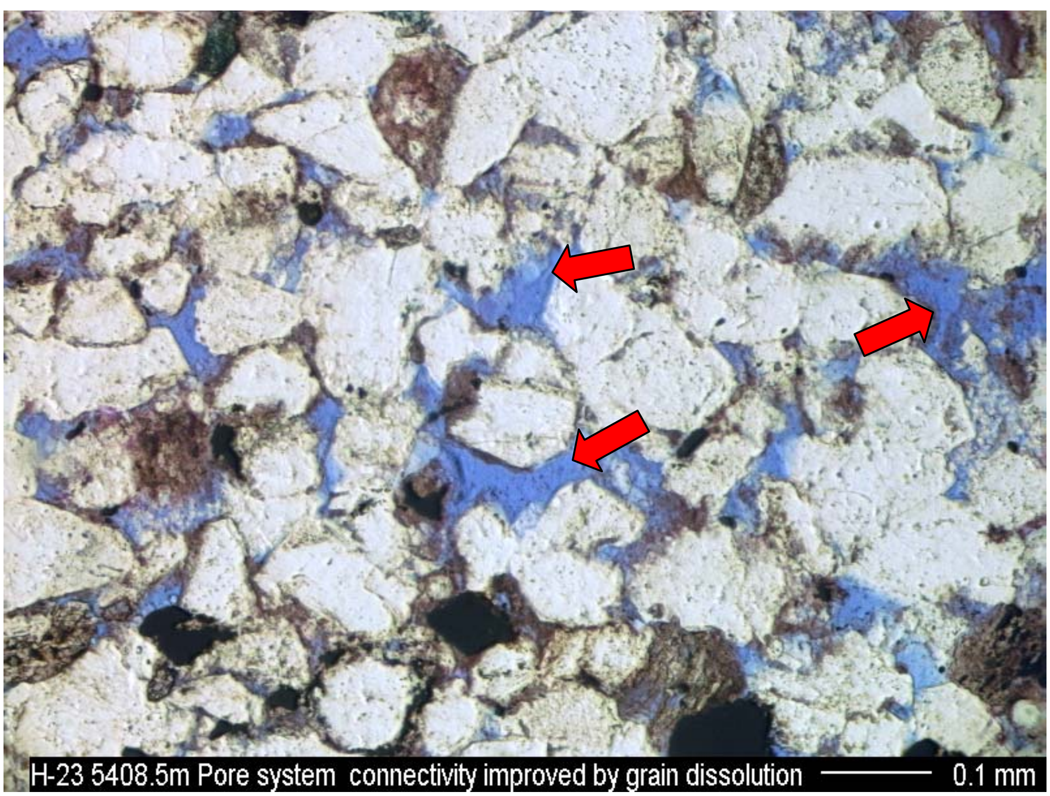
Point count porosity of 13.3% indicates that as in SP 9, more than half of total porosity consists of open reduced intergranular porosity and secondary dissolution porosity. The lower microporosity results in better connectivity of open primary and secondary pores.

Newburn H-23 Sidewall Cores 5408.5M SP8

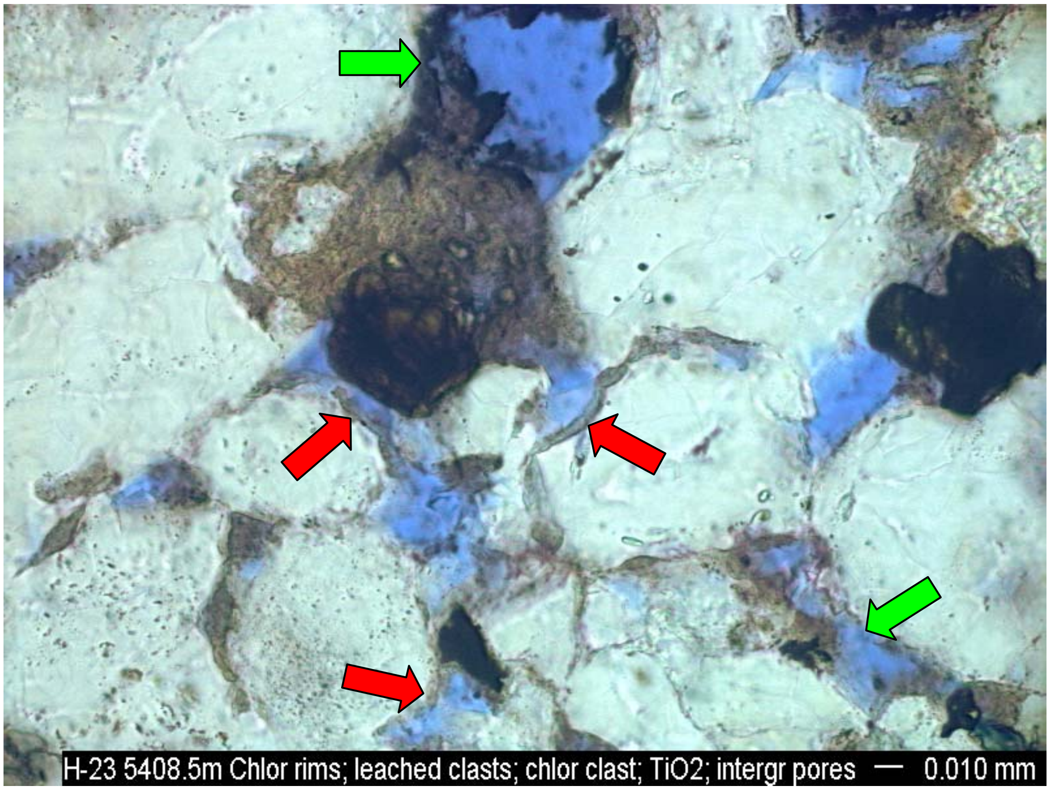


1) Moderately well to well sorted upper very fine to lower fine grained quartzose litharenite with good porosity (blue). Heavy mineral laminae (arrows) are common.

2) Connectivity of reduced intergranular porosity is improved by dissolution of unstable clasts and formation of oversized pores (arrows) and enlarged pore throats.

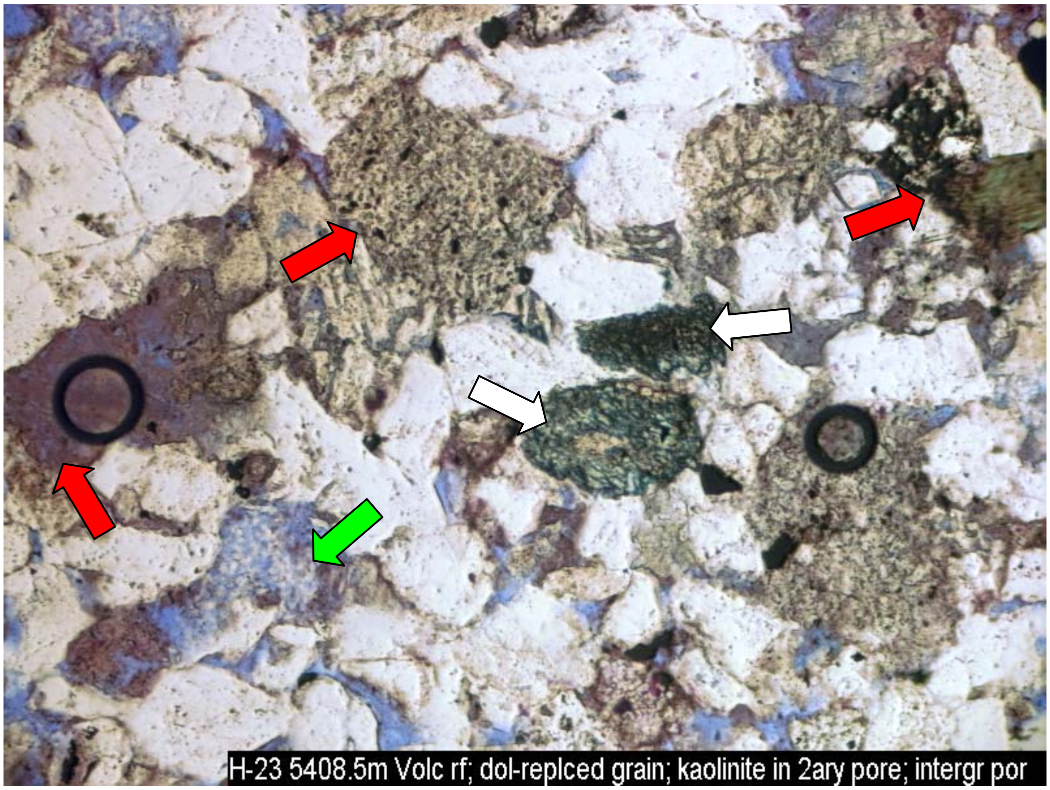


Newburn H-23 Sidewall Cores 5408.5M SP8



3) Discontinuous chlorite rims (red arrows) locally inhibit quartz overgrowth development, preserving reduced intergranular porosity, particularly where grains other than quartz make up part of the pore wall. Chloritic clasts are common. Authigenic titanium oxide (right center) is locally present. Total porosity is enhanced by dissolution of unstable clasts and matrix (green arrows).

4) Intergranular porosity is reduced by close grain packing, compaction of labile volcanic and other ductile clasts (red arrows) against each other and more resistant grains. Dolomite often replaces grains (white arrows) rather than filling intergranular porosity. Kaolinite locally fills moldic pores (green arrow).



5957.80M SP6 K = 0.02 mD Porosity = 9.9%

Well sorted angular silty lower very fine grained litharenite

Many labile rock fragments are chloritized. Biotite is strongly altered. Interstitial detrital clays are often chloritized.

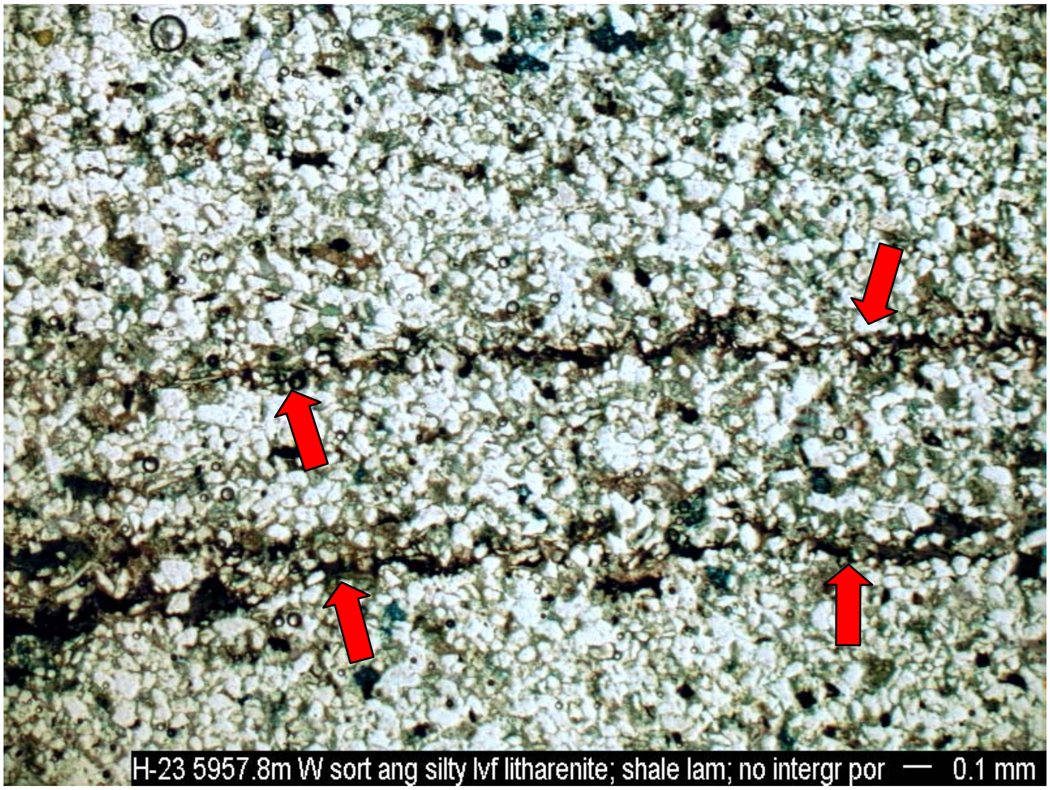
Chlorite is the most abundant authigenic mineral. Minor anatase, silica, trace ferroan dolomite are also present.

Terminated quartz overgrowth faces are not present. Silica cement always fills adjacent pores where present. Silica cement is mainly present where two or more quartz grains are in contact.

Porosity occurs as ineffective microporosity in chloritized clasts and chlorite matrix.

Intergranular porosity is completely occluded by close grain packing, compaction of ductile clasts, detrital matrix and pseudomatrix between grains, authigenic interstitial and grain-coating chlorite and a minor to moderate amount of silica cement.

Newburn H-23 Sidewall Cores 5957.8M SP6



1) and 2) Well sorted, angular silty lower very fine grained litharenite. Well laminated, with local argillaceous/ carbonaceous laminae (red arrows). Intergranular porosity is completely occluded by close grain packing, compaction of ductile clasts and matrix into pores, sutured grain contacts, silica cement and interstitial authigenic chlorite. Labile clasts and detrital matrix clays are often chloritized.

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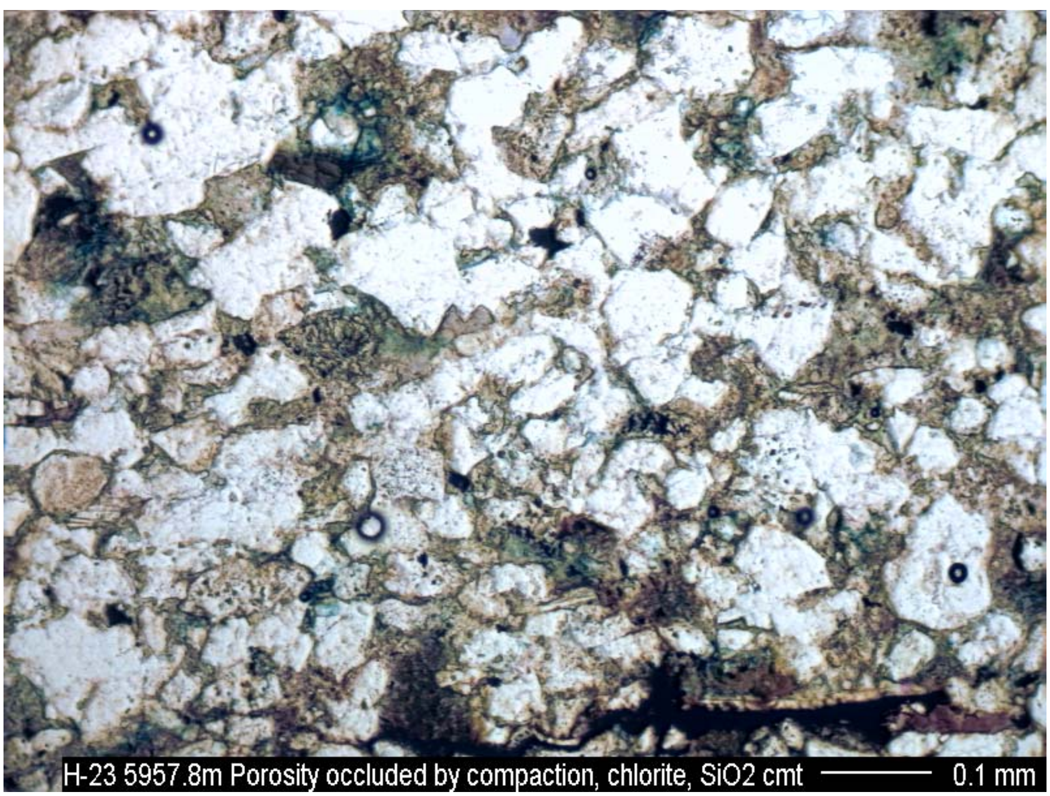
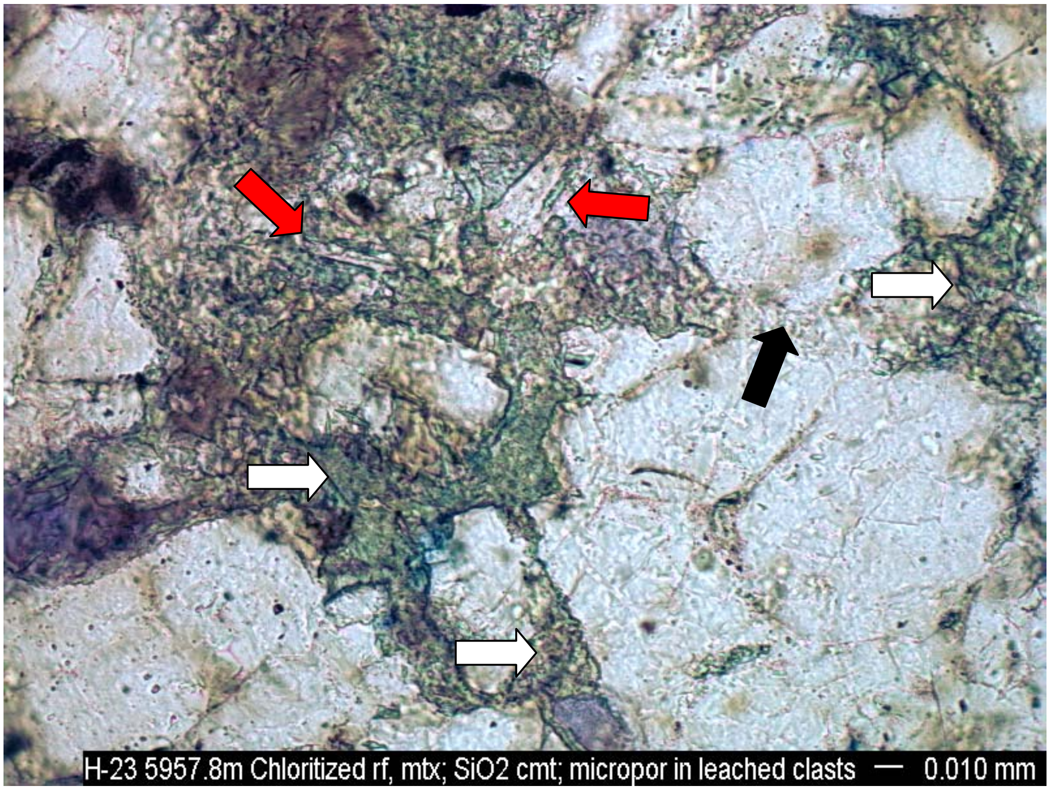


Newburn H-23 Sidewall Cores 5957.8M SP6



3 and 4) Same field of view under plane polarized light (3) and under crossed polars (4). Volcanic rock fragments (red arrows), argillaceous clasts and detrital matrix clays are chloritized (white arrows). Silica cement (black arrow) and compacted ductile clasts and matrix clays reduce intergranular porosity. Minor microporosity is present in leached clasts.

5960.50M SP5 K = 0.02 mD Porosity = 11.7%

Interbedded shale, silty shale and well sorted angular lithic medium to coarse siltstone to silty lower very fine grained litharenite. Mica is a common accessory grain. Bedding is locally disturbed, probably by soft sediment deformation.

Chlorite is the most abundant authigenic mineral, occurring as replacement of labile clasts, and interstitial detrital clays.

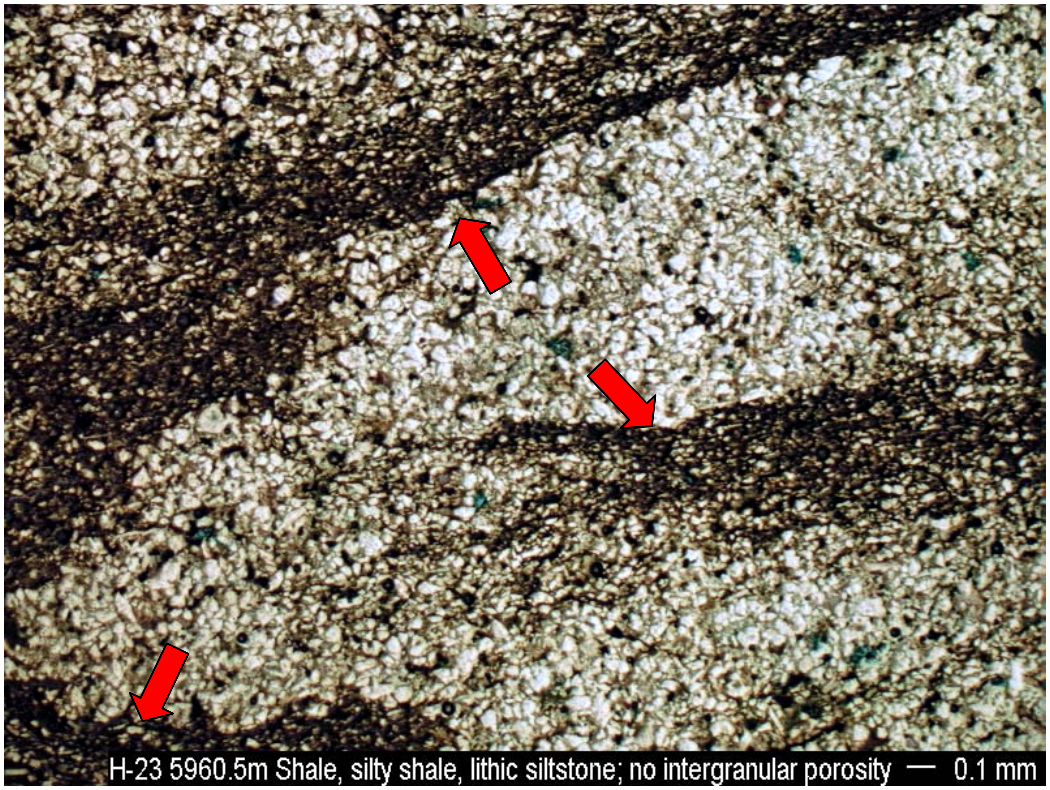
Porosity and permeability are occluded primarily by the effects of close packing, compaction of ductile clasts and interstitial detrital and authigenic matrix clays with pores.

No remnant intergranular porosity.

Any measurable porosity is microporosity in detrital matrix clays and interstitial chlorite.

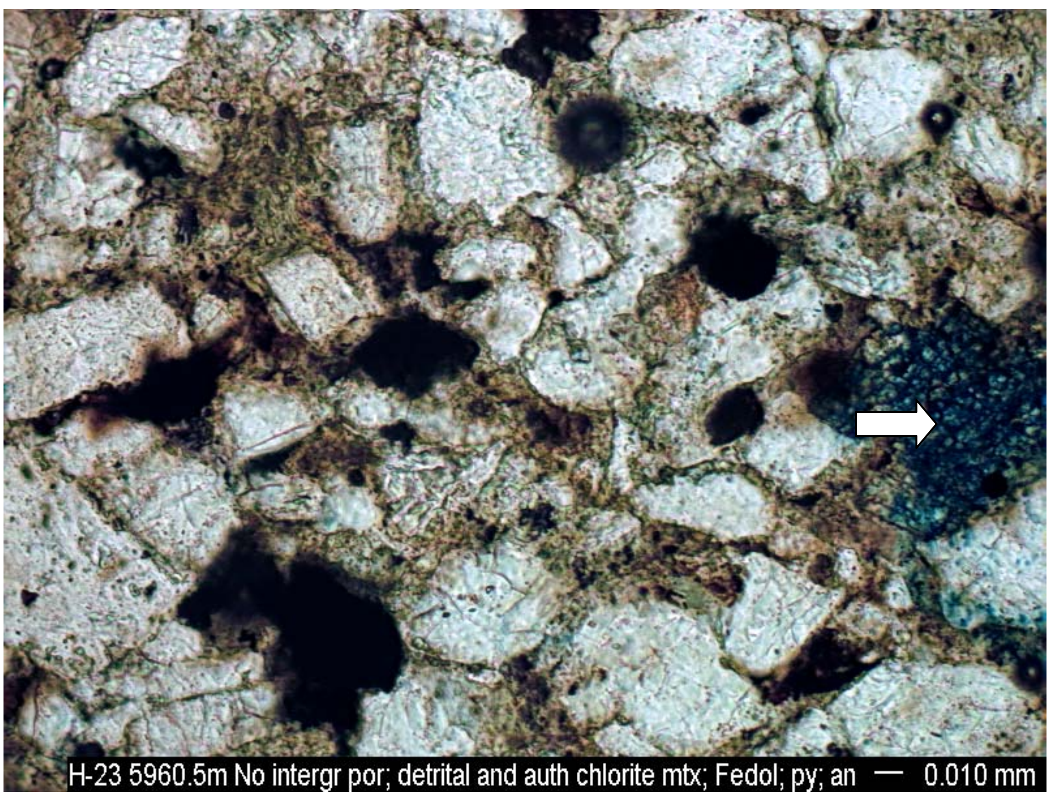
A discontinuous fracture cutting carbonaceous silty shale (sideritic) is filled by kaolinite.

Newburn H-23 Sidewall Cores 5960.5M SP5



1) Fabric disruption (arrows) in shale, silty shale and lithic siltstone may be soft sediment deformation due to fluidization.

2) Intergranular porosity is completely occluded by detrital and authigenic chlorite matrix compacted between grains. Pyrite (black) is disseminated throughout the shale. A minor amount of ferroan dolomite is locally present (white arrow).



5961.00M SP9 K = 0.02 mD Porosity = 13.3%

Well sorted, well laminated angular to subangular lower very fine to lower fine grained, dominantly upper very fine grained, litharenite.

The amount of interstitial detrital clay, mica and carbonaceous debris varies between laminae. Argillaceous clasts and other labile rock fragments, biotite and detrital matrix clay are often chloritized.

Some biotite and argillaceous clasts are sideritized. The sideritic clasts are often concentrated in laminae with other micas, carbonaceous debris and more abundant interstitial detrital clays.

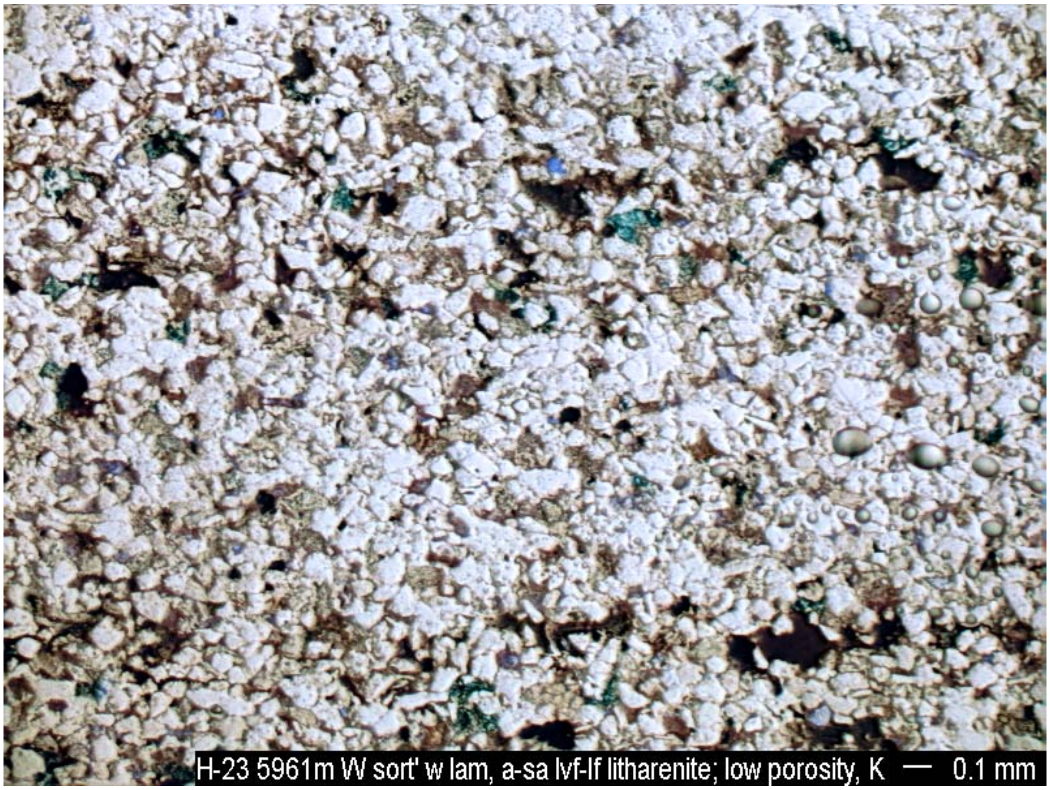
A minor amount of ferroan dolomite is scattered throughout the rock, usually replacing clasts or matrix.

Intergranular porosity is almost completely occluded by close grain packing, by compaction of ductile clasts and matrix clays between more resistant grains and into pores, and by silica cement.

A very minor amount of reduced primary intergranular porosity is locally preserved where chlorite rims have inhibited quartz overgrowth development and ductile clasts or matrix have not been squeezed into pores.

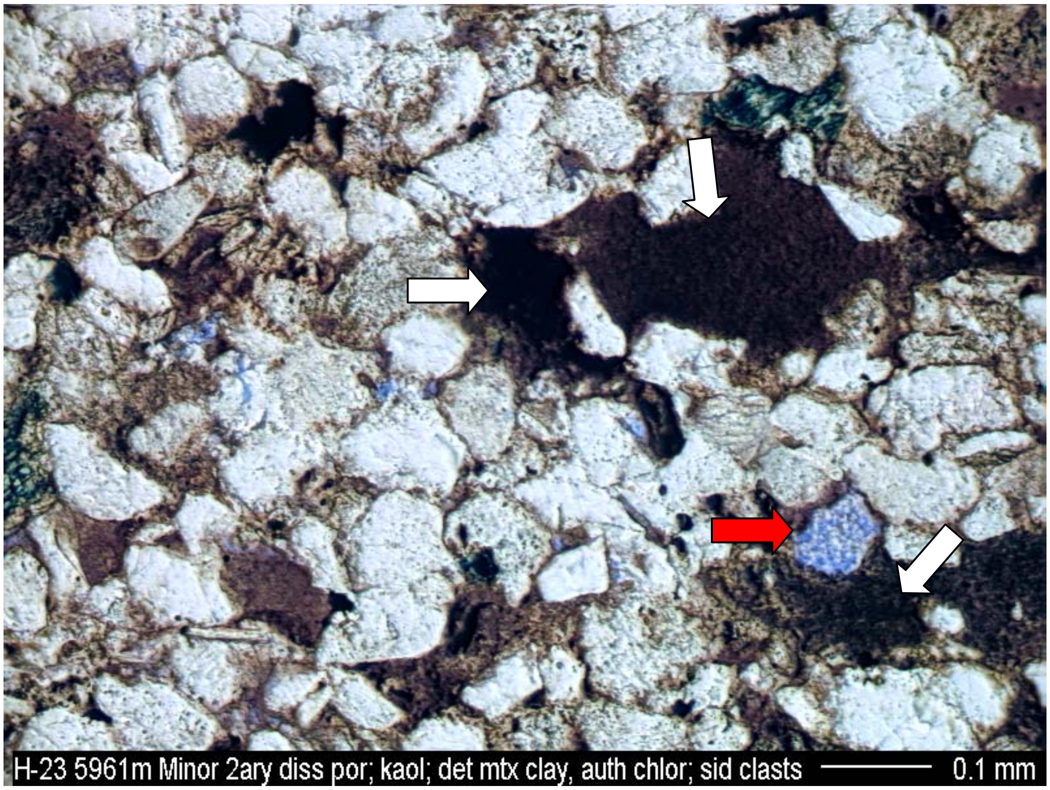
A minor amount of visible porosity occurs as dissolution porosity in leached chloritized or other clasts. A few moldic pores are completely filled by microporous kaolinite aggregates. Most of the measured porosity consists of microporosity in detrital matrix clays, interstitial authigenic chlorite, and in chloritic and other microporous clasts.

Newburn H-23 Sidewall Cores 5961.0M SP9

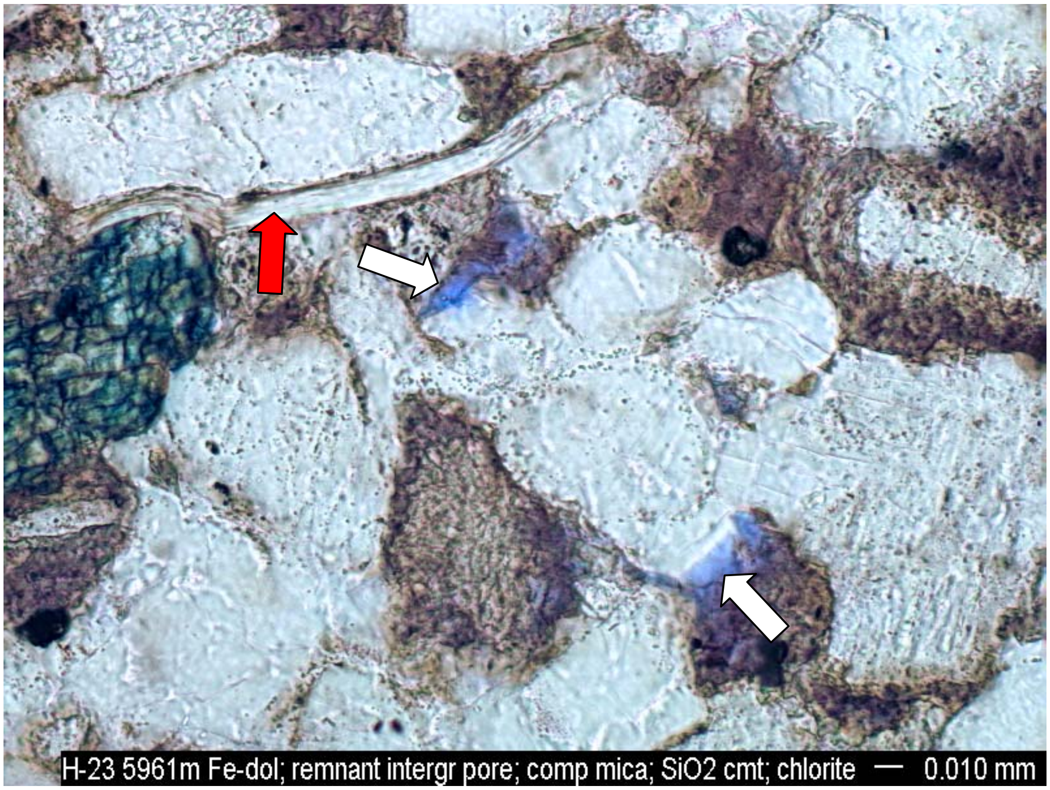


1) Well sorted, well laminated angular to subangular lower very fine grained to lower fine grained litharenite. Intergranular porosity is almost completely occluded by strong compaction of interstitial detrital matrix clay into pores, and by close grain packing.

2) A minor amount of secondary dissolution porosity is isolated by close packing of grains, interstitial clays. Some dissolution porosity is reduced to microporosity by pore-filling kaolinite (red arrow). Sideritic shale clasts are locally present (white arrows).

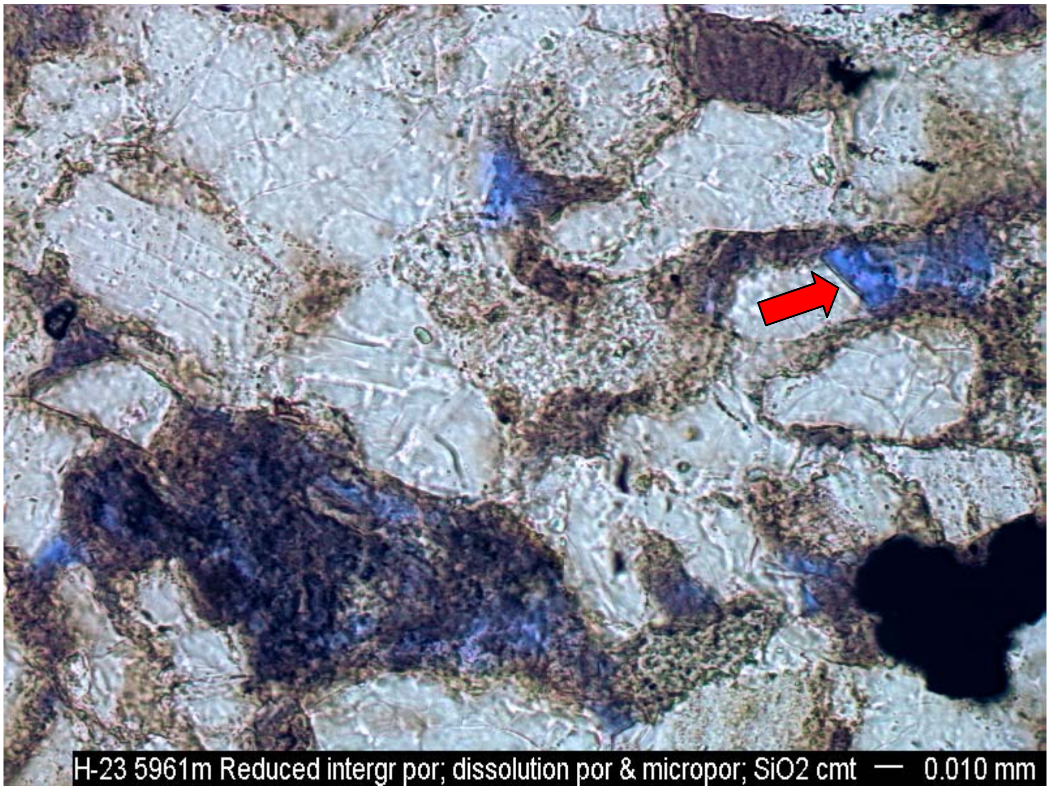


Newburn H-23 Sidewall Cores 5961.0M SP9



3 and 4) Same field of view under plane polarized light (3) and under crossed polars (4). Intergranular porosity is severely reduced by close grain packing, compaction of ductile mica (red arrows), rock fragments and interstitial clays into pores, and by silica cement. Isolated remnant reduced intergranular porosity is locally preserved (white arrows). A trace amount of moldic porosity has formed by dissolution of unstable clasts.

Newburn H-23 Sidewall Cores 5961.0M SP9



5) Primary intergranular porosity is reduced by close grain packing, interstitial clays and by silica cement. Only rarely do terminated quartz overgrowth faces bound open pores (arrow). Most open porosity is secondary porosity formed by dissolution of unstable clasts and matrix.

5961.20M SP4 K = 0.03 mD Porosity = 8.8%

Well sorted subangular to subrounded lower fine grained quartzose litharenite to litharenite. Visually and by point count, this sample is more quartzose than SP 9 (5961.00M). Silica cement is more abundant, making total quartz distinctly higher than in SP 9.

Volcanic rock fragments are common, along with shale and chloritic and micaceous metasedimentary clasts. Labile volcanic clasts and other undifferentiated labile argillaceous clasts and possibly some glauconite have been chloritized. Detrital chamosite clasts are also present.

Authigenic Minerals

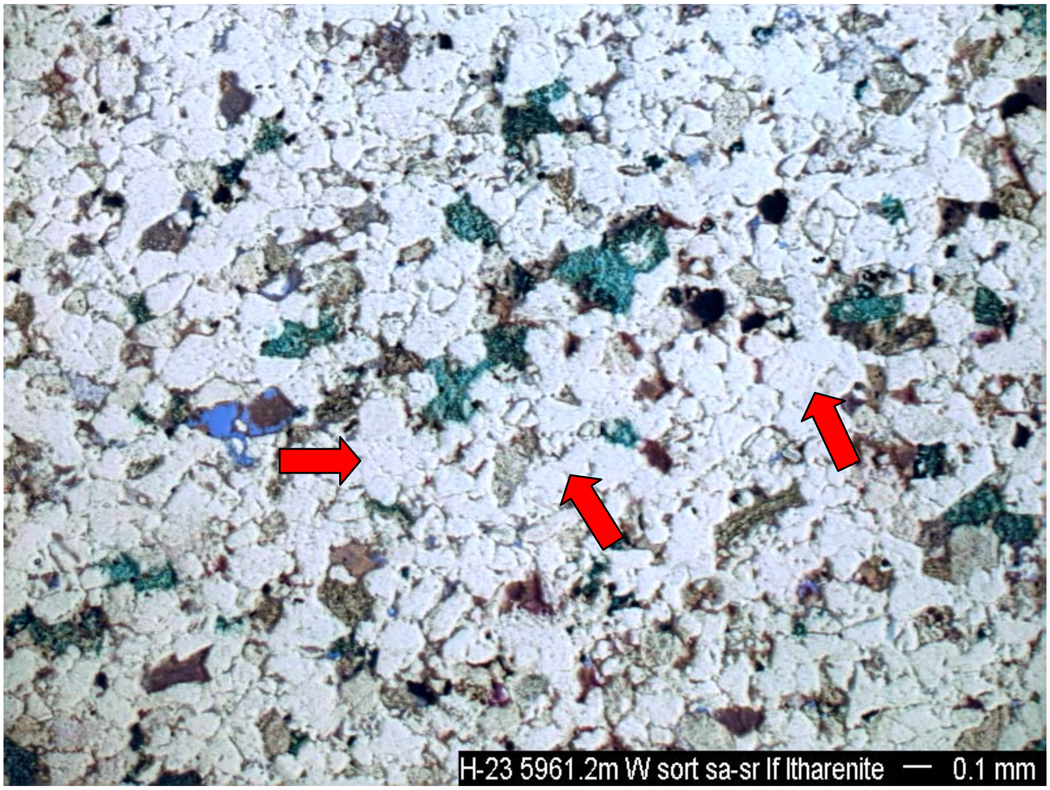
- Chlorite forms discontinuous rims on grains and occurs as patches of bladed microcrystals on grain surfaces, filling reduced intergranular pores, or replacing detrital matrix clays. Chlorite locally inhibits quartz overgrowth development, preserving reduced intergranular pores.
- Silica cement occurs as irregular overgrowths against adjacent grains or matrix. Terminated crystal faces on open pores are rare.
- Kaolinite – a minor to moderate amount of kaolinite locally fills pores, mainly moldic dissolution pores.
- Calcite – a very minor amount of ferroan calcite cement locally fills pores.
- Dolomite – a minor amount of ferroan dolomite occurs as a partial replacement of grains, and locally fills adjacent pores.

A trace amount of abraded bioclast debris is present, including foram and echinoderm fragments.

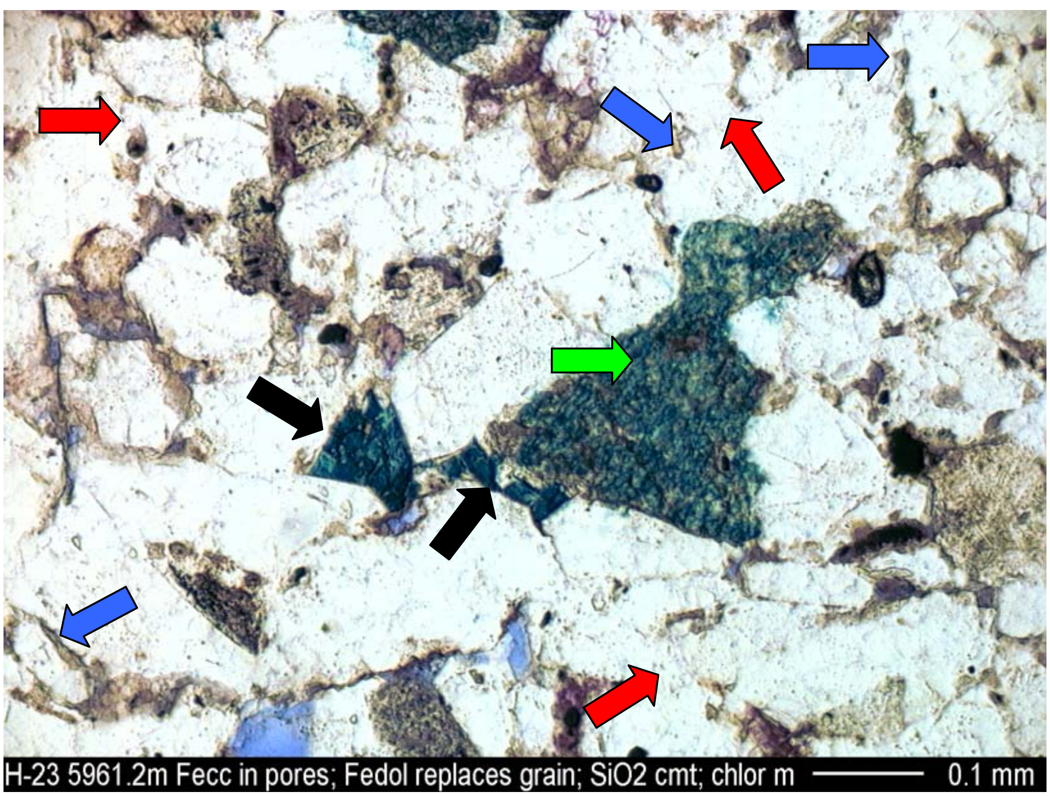
Porosity and Permeability

Most measured porosity consists of microporosity in chlorite matrix, chloritized clasts, leached feldspars and rock fragments, and in pore-filling kaolinite. A minor amount of reduced intergranular porosity preserved where chlorite has inhibited quartz overgrowths and minor open moldic dissolution porosity is poorly connected because of close packing, silica cement, and matrix and grain-coating chlorite.

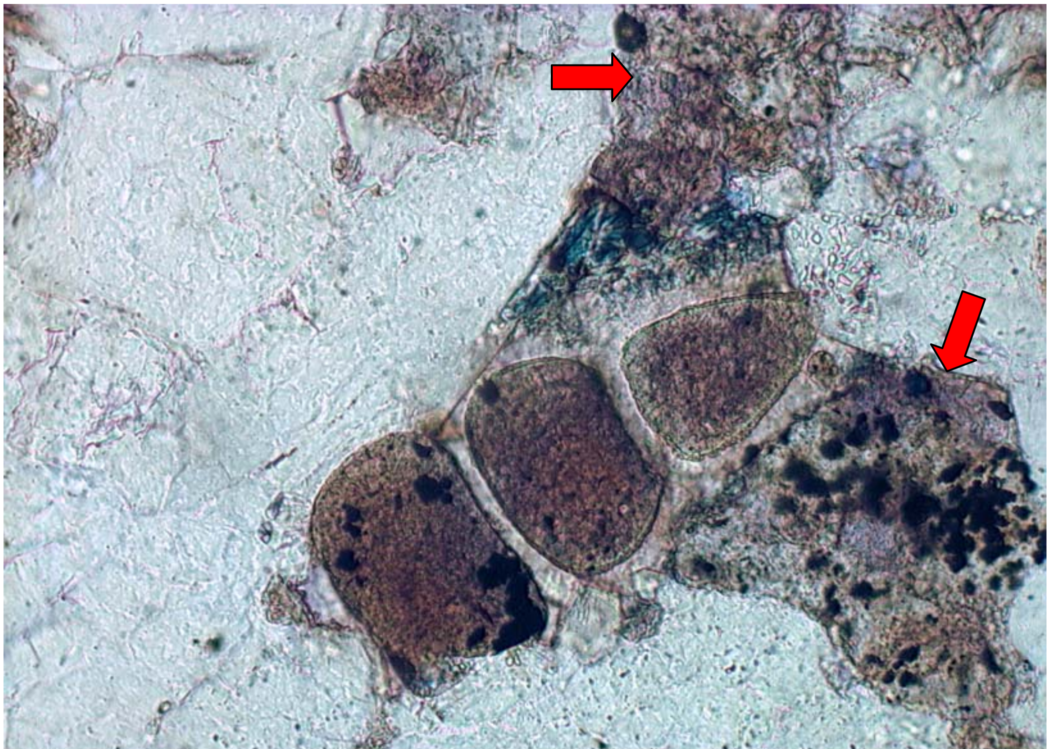
Newburn H-23 Sidewall Cores 5961.2M SP4



1 and 2) Well sorted subangular to subrounded lower fine grained litharenite. Intergranular porosity is almost completely occluded by close grain packing and silica cement (red arrows), scattered ferroan calcite and ferroan dolomite (blue-green). Ferroan calcite usually fills pores [black arrow, (2)] and ferroan dolomite usually partially replaces unstable clasts (green arrow). Discontinuous authigenic chlorite rims do not significantly inhibit quartz overgrowth development (blue arrows).



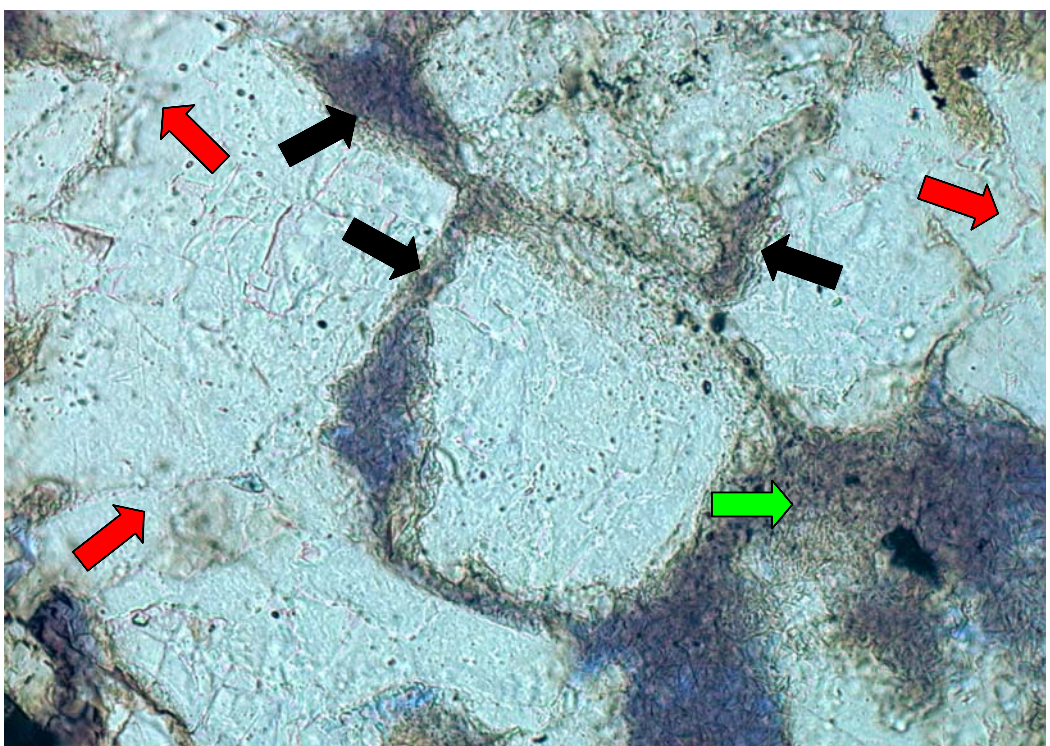
Newburn H-23 Sidewall Cores 5961.2M SP4



H-23 5961.2m Chlor-filled foram; SiO2 cmt;; chloritized rock fragments — 0.010 mm

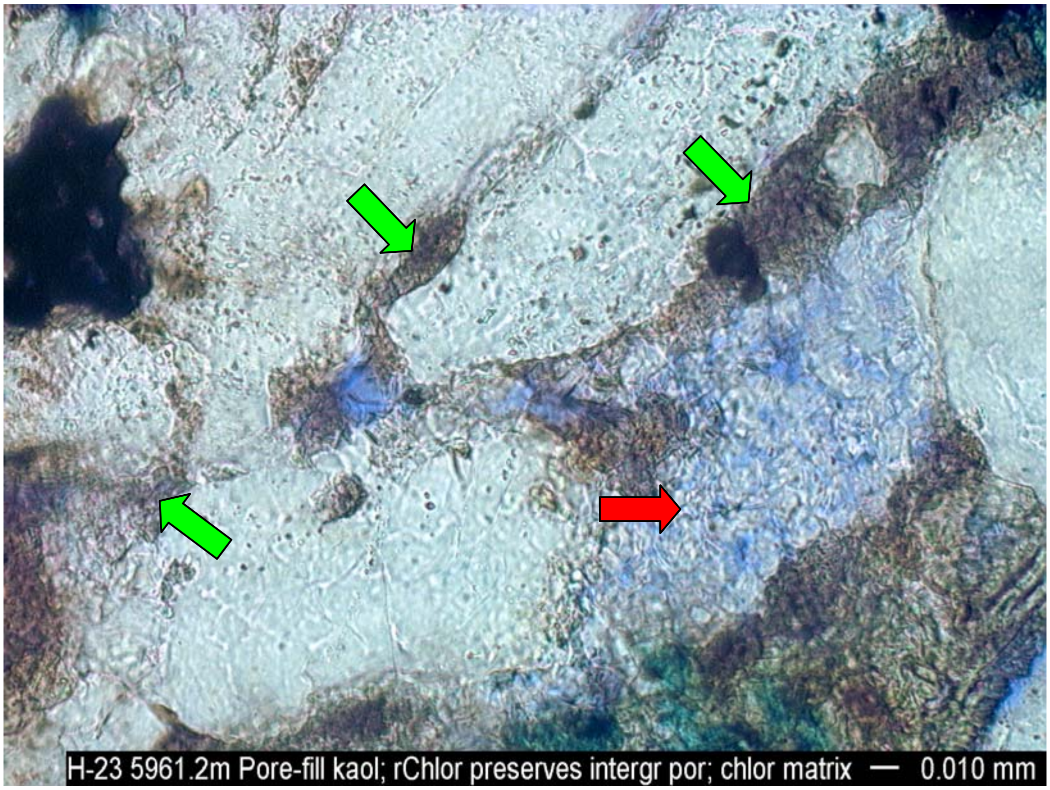
3) A foram fragment (center) is compacted against rock fragments (arrows) and quartz grains (left).

4) Porosity and permeability are severely reduced by close grain packing, silica cement (red arrows) and interstitial chlorite (black arrows). Most porosity is microporosity in chlorite matrix and microporous chloritic clasts (green arrow).



H-23 5961.2m Microporous chlorite mtx and chloritized grain; SiO2 cmt — 0.010 mm

Newburn H-23 Sidewall Cores 5961.2M SP4



5) Microporous aggregates of authigenic kaolinite mainly occur in secondary pores formed by partial to complete dissolution of unstable clasts (red arrow). Early authigenic chlorite locally has prevented quartz overgrowth development, preserving reduced intergranular porosity (black arrow). Most porosity is in microporous chloritic matrix (green arrows).

5961.70M SP3 K = 0.03 mD Porosity = 12.7%

Moderately well to well sorted, angular lower very fine to lower fine, dominantly mid-very fine grained litharenite. The sand has an irregular contact with silty shale. This contact does not appear to be depositional.

Lamination is defined by subparallel orientation of elongate grains, local higher concentrations of mica, carbonaceous debris, sideritic clasts and interstitial detrital matrix clay.

Composition of rock components is similar to that of SP 4 (5961.20M), but the relative amount of ductile rock fragments is significantly higher and the amount of interstitial detrital clay, chlorite matrix and pseudomatrix is higher.

If the measured porosity of 12.7% is accurate, most of this porosity occurs as microporosity in the interstitial matrix and only a small proportion occurs as minor amounts of moldic dissolution porosity.

Newburn H-23 Sidewall Cores 5961.7M SP3

1) Moderately well to well sorted mid very fine grained litharenite. Most porosity is microporosity in interstitial detrital clays and authigenic chlorite..

2) Ferroan dolomite locally replaces unstable clasts (blue-green, white arrows). Interstitial clays, close packing and silica cement almost completely occlude intergranular porosity.

5962.00M SP2 K = <0.01 mD Porosity = 8.8%

Moderately to moderately well sorted, subangular, coarse silt to lower medium grained, dominantly lower fine grained litharenite. The sand is cross-laminated, with lamination defined by differences in grain size and sorting, and by concentrations of carbonaceous debris, micas, sideritized clasts (at least some of which are altered biotite), ductile rock fragments and other ductile argillaceous clasts, and interstitial detrital clays.

Feldspar consists of both potassium feldspar and albite-twinned sodic plagioclase.

Rock fragments consist of abundant labile and competent volcanic clasts, shale, micaceous and quartz-mica metasedimentary rock fragments, undifferentiated quartzose and quartzo-feldspathic rock fragments.

Chloritic or chamositic clasts are common, some of which are likely labile clasts which were chloritized at or just below the depositional surface. Other chamositic clasts may have formed in situ at the depositional surface.

Most labile rock fragments, particularly volcanic clasts, are partially altered to chamosite.

Accessory grains include mica, glauconite and trace to minor amounts of heavy minerals, mainly zircon. Muscovite is generally relatively unaltered, but biotite is moderately altered to completely altered to siderite and/or clays. A trace amount of abraded bioclast debris, often replaced by ferroan calcite, is also present.

Authigenic Minerals

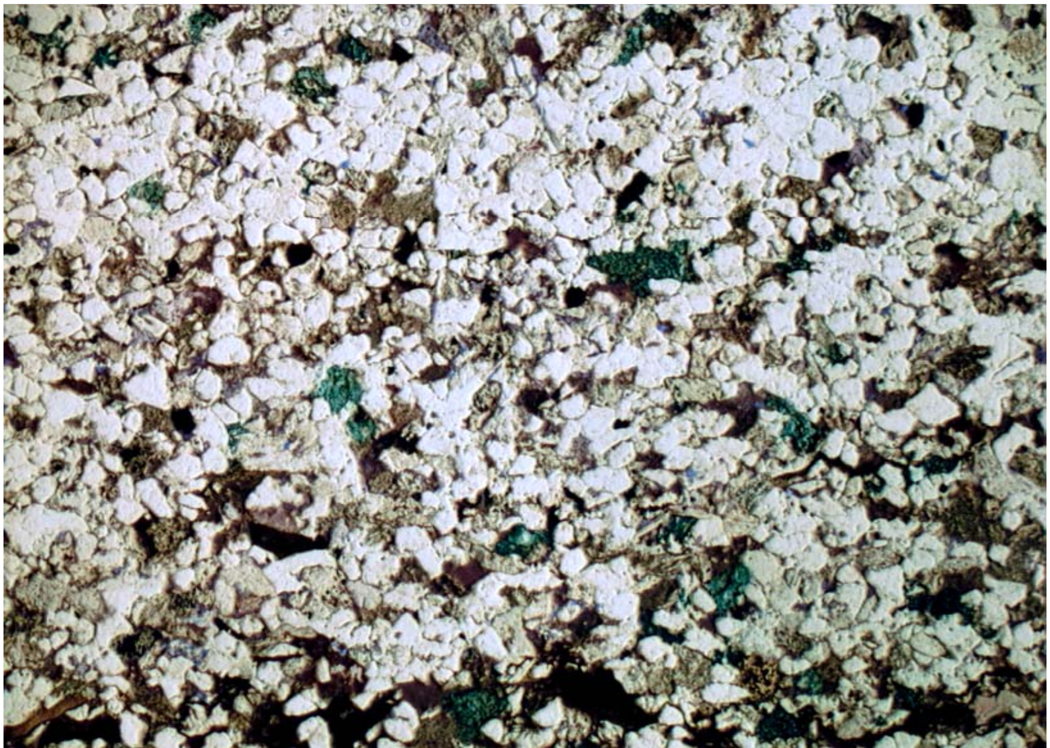
- Chlorite – discontinuous rims on framework grains, replaces labile clasts, occurs as interstitial matrix or as a replacement of interstitial detrital clays.
- Silica – occurs as irregular overgrowths on quartz grains, completely occluding pores where quartz grains make up all of the pore wall. Rarely forms terminated crystal faces. Quartz overgrowths often enclose discontinuous chlorite rims and often fill pores partly bounded by ductile clasts.
- Ferroan dolomite – irregularly scattered throughout the sand, usually partially replacing an unstable clast.
- Ferroan calcite – partially replaces some unstable clasts, and locally fills intergranular pores. Occasionally in contact with terminated quartz overgrowths, indicating ferroan calcite post-dates at least some silica cement.
- Kaolinite – minor kaolinite generally occurs filling moldic pores.
- Anatase – scattered throughout as crystals and granular aggregates.
- Pyrite – trace framboids scattered throughout the rock.

Porosity and Permeability

Primary intergranular porosity has been severely reduced by close grain packing; compaction of ductile carbonaceous debris, mica, rock fragments and interstitial detrital clays into pores; pore-filling and grain-coating authigenic chlorite; silica cement; and by minor amounts of ferroan calcite and ferroan dolomite cements.

Porosity consists mainly of microporosity in chlorite matrix, chloritized clasts, in interstitial detrital clays in more carbonaceous/argillaceous laminae, and in pore-filling kaolinite. A minor amount of porosity occurs as isolated remnant reduced intergranular pores where matrix and grain-rimming chlorite have not completely reduced intergranular porosity to microporosity, and as intragranular and moldic porosity where unstable clasts are partly to completely dissolved.

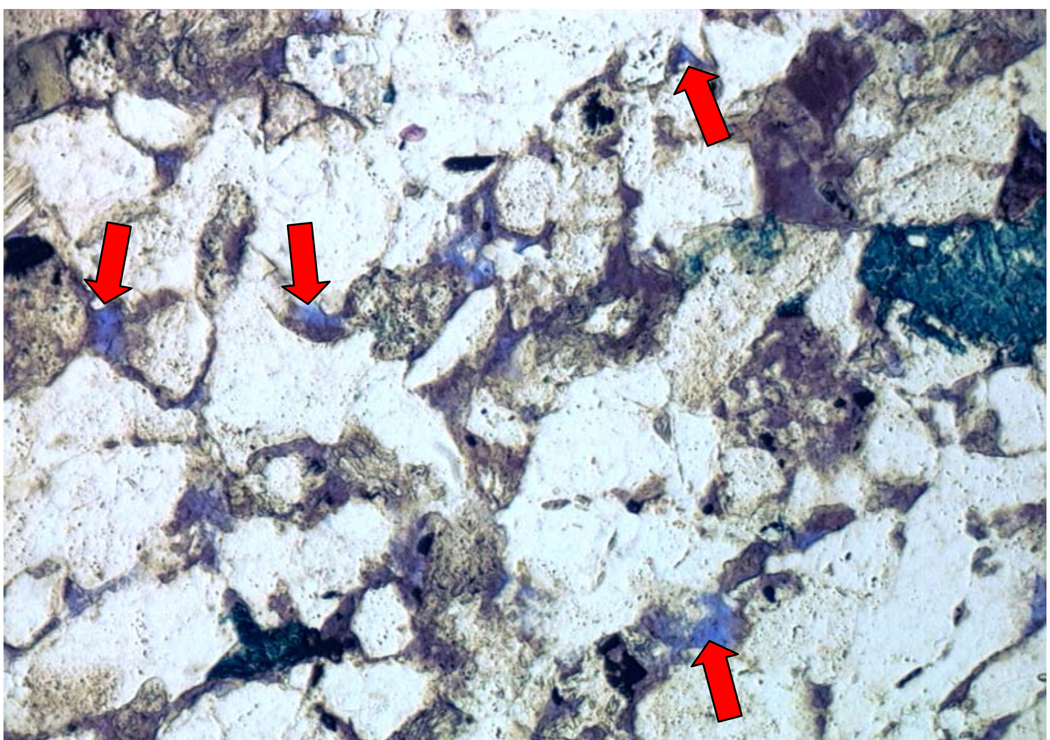
Newburn H-23 Sidewall Cores 5962M SP2



H-23 5962m M-mw sort lf litharenite; close packing; SiO2 cement — 0.1 mm

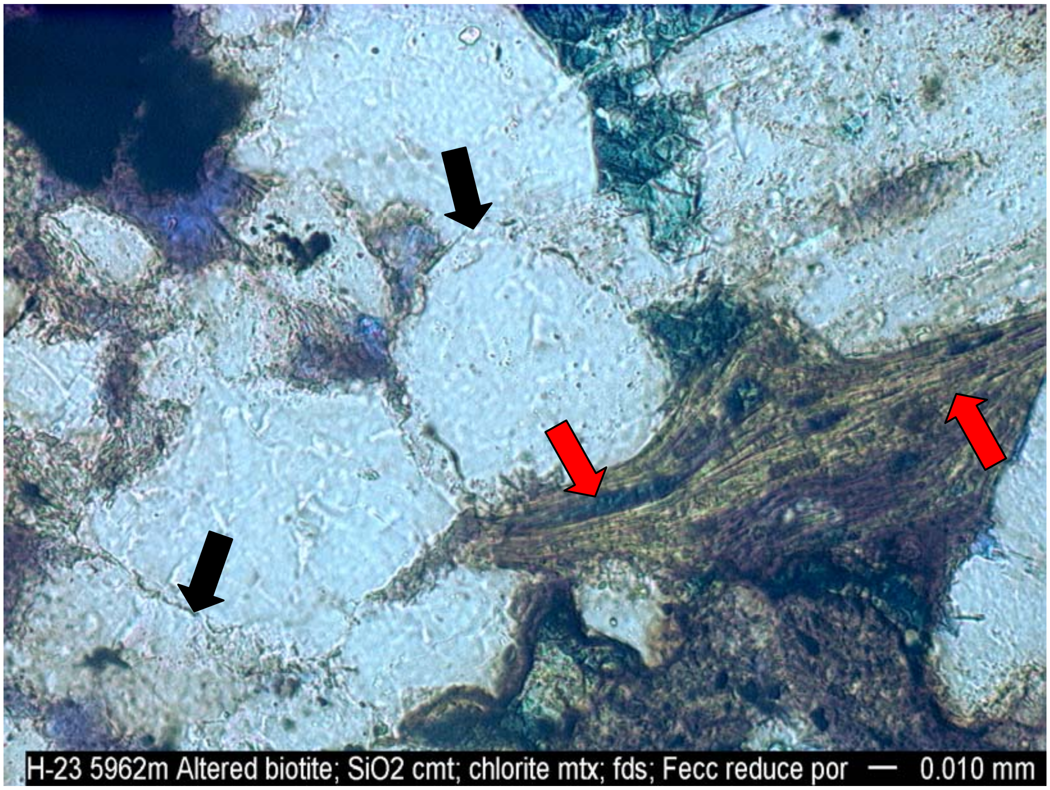
1) Moderately to moderately well sorted, coarse silt to lower medium grained, dominantly lower fine grained litharenite. Intergranular porosity is severely reduced by close grain packing, interstitial chlorite and detrital clays and silica cement. Argillaceous/carbonaceous laminae with more abundant mica and sideritic clasts along bottom of photo.

2) A minor amount of reduced intergranular porosity is preserved where chlorite rims have inhibited quartz overgrowth and chlorite does not completely fill pores (arrows).



H-23 5962m Minor reduced intergr, 2ary porosity; chlorite, SiO2 ceme — 0.1 mm

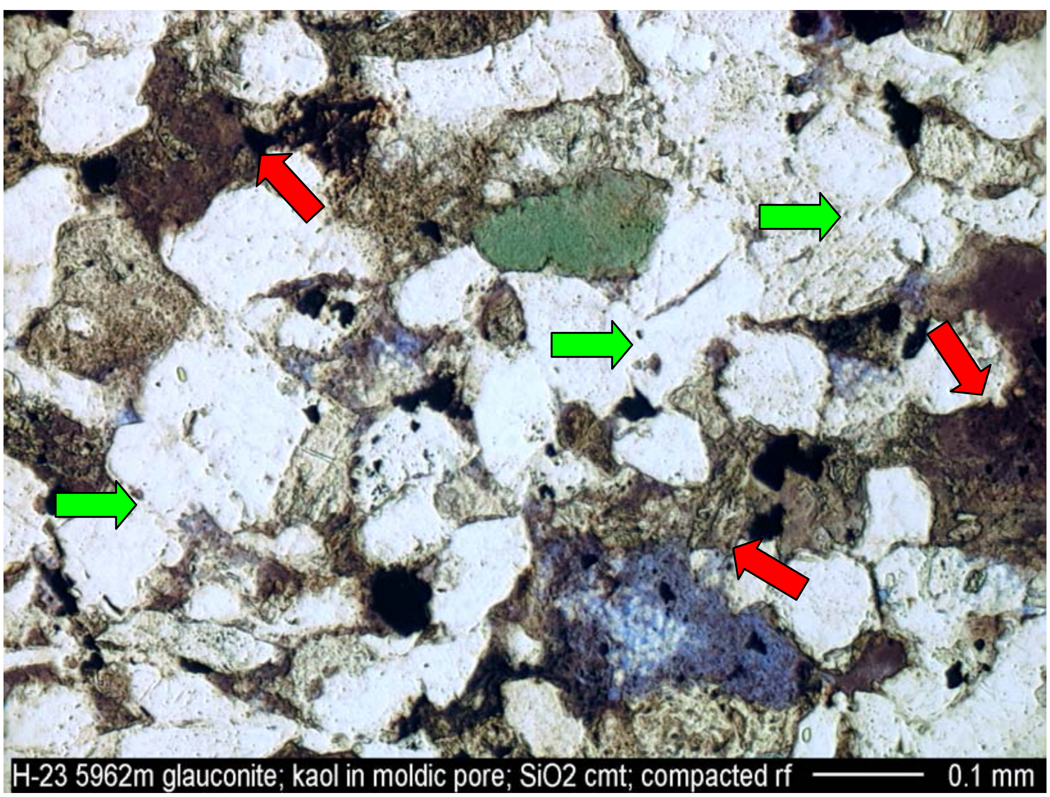
Newburn H-23 Sidewall Cores 5962M SP2



H-23 5962m Altered biotite; SiO2 cmt; chlorite mtx; fds; Fecc reduce por — 0.010 mm

3) Biotite (red arrows) is usually moderately to completely altered. Silica cement strongly reduces intergranular porosity (black arrows) Microporous chlorite matrix is not as abundant as in 5961.70M and 5962.80M, so both microporosity and total porosity are lower.

4) Glauconite (green grain, top center) is a common accessory grain. Compaction of ductile clasts (red arrows), silica cement (green arrows) and matrix clays reduce porosity and permeability.



H-23 5962m glauconite; kaol in moldic pore; SiO2 cmt; compacted rf ——— 0.1 mm

5962.80M SP1 K = 0.01 mD Porosity = 10.2%

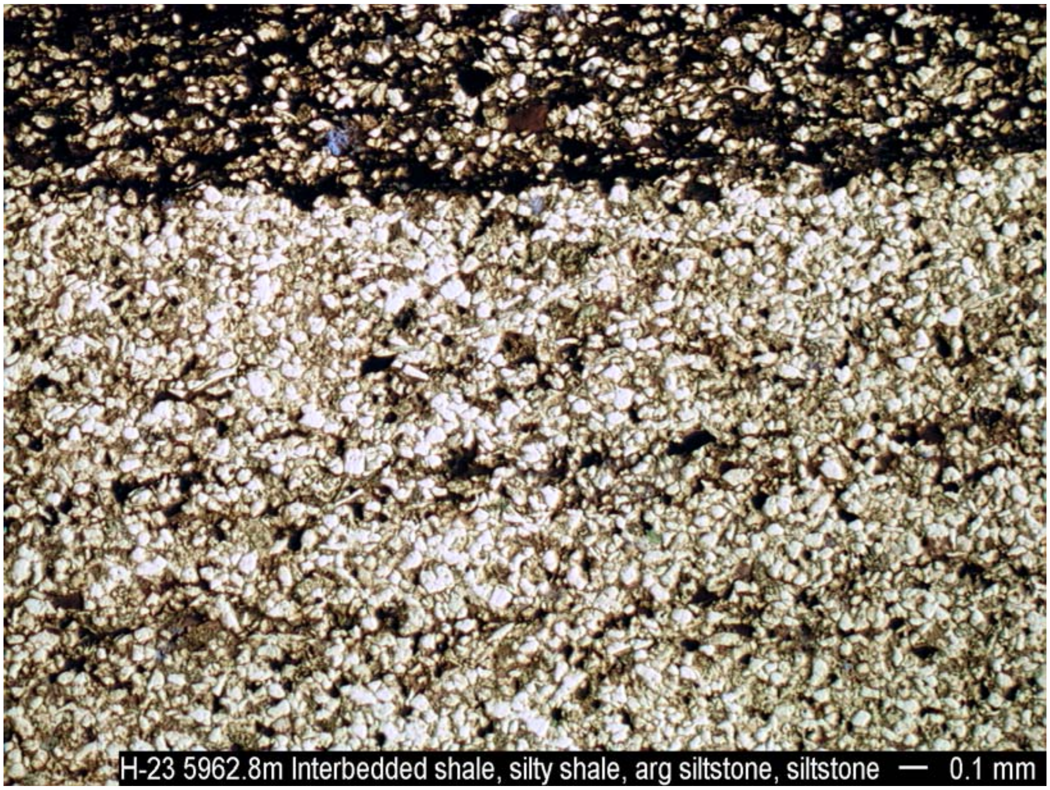
Interbedded wavy laminated shale, silty shale and argillaceous siltstone.

Siltstone is feldspathic and lithic, but quartz makes up about 50% of framework grains. Cleanest siltstone has minor chloritic matrix. Mica is an abundant accessory grain.

Porosity consists almost entirely of microporosity in shale and in interstitial chlorite and detrital clays and in leached and microporous clasts.

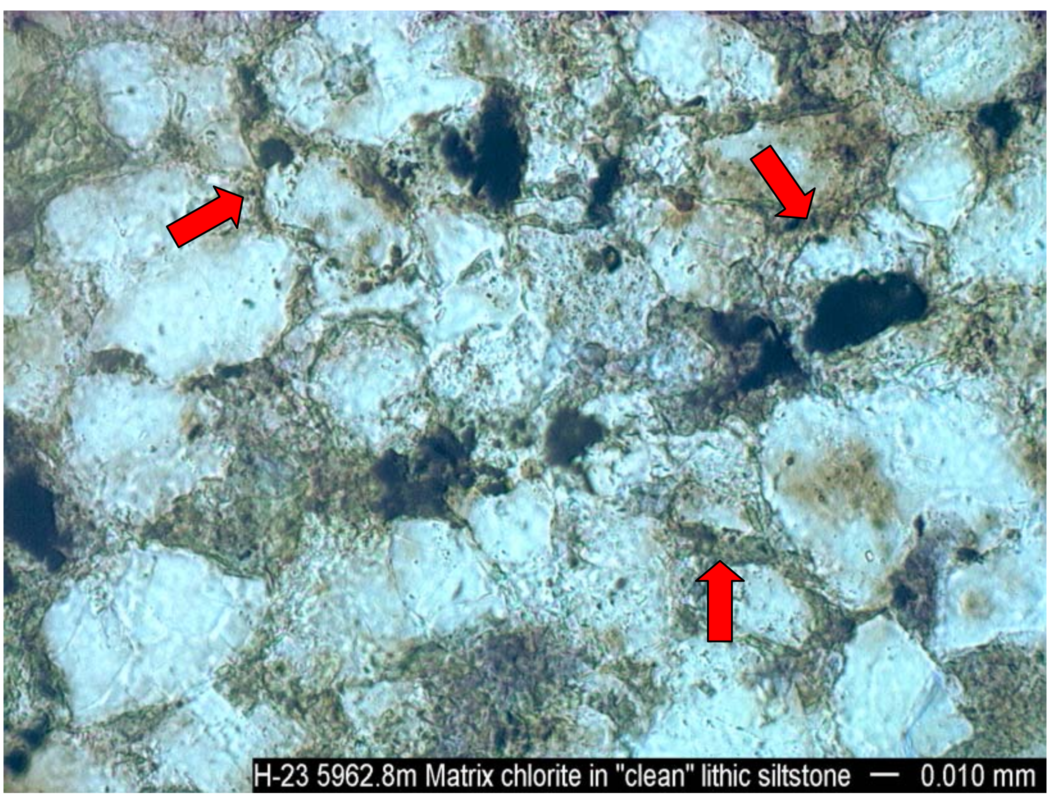
A trace amount of moldic dissolution porosity is locally present.

Newburn H-23 Sidewall Cores 5962.8M SP1



1) Interbedded lithic siltstone, argillaceous siltstone, silty shale and shale has no intergranular porosity. Measured porosity of 10.2% is microporosity in matrix clays.

2) In cleaner siltstone with very little detrital clay, microporous interstitial authigenic chlorite and discontinuous chlorite rims fill intergranular porosity (arrows).



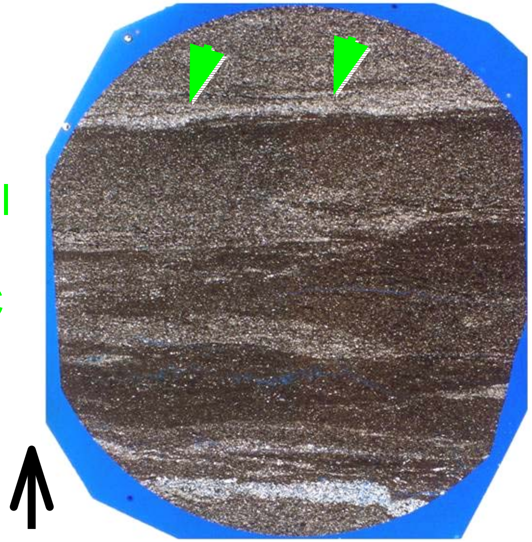
Appendix 1: Overview Photomicrographs

Sidewall Core Run #1

Chevron et al NEWBURN H-23

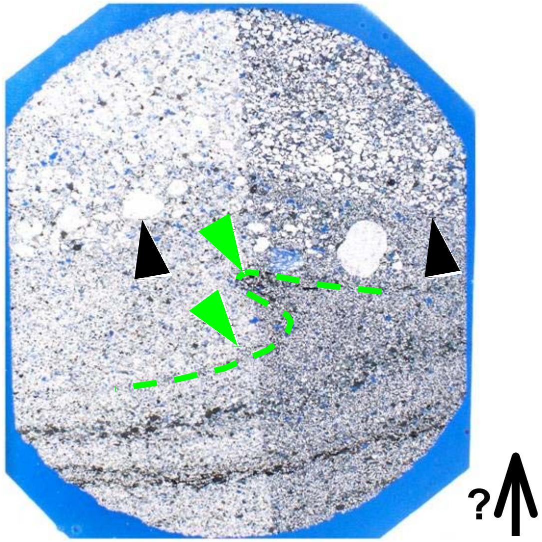
4307.8

Weakly graded beds, Tangential foresets (evident in SWC photos)



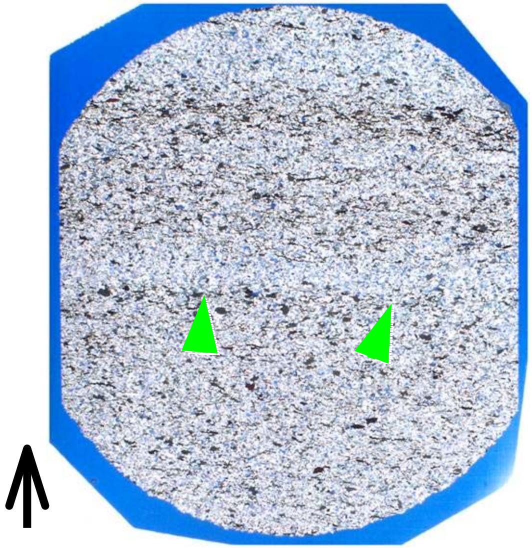
4312.8

Sharp (?erosive) base, Convolute laminations



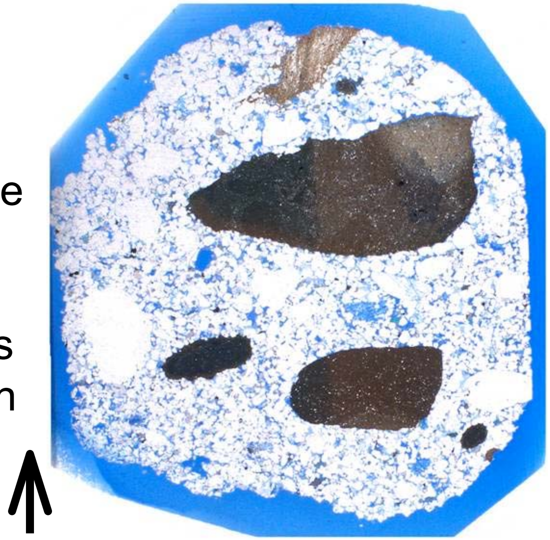
4313.5

Weakly graded beds, Erosive base (evident in SWC photos)



4317.5

Chaotic, poorly sorted sandstone with floating pebbles; from SWC photos this appears to be an erosive lag

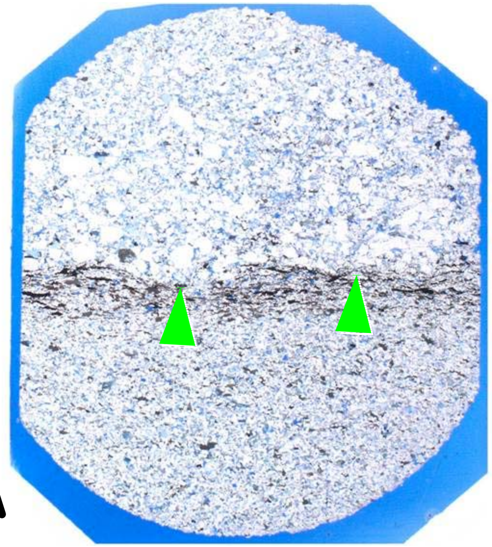


Sidewall Core Run #1

Chevron et al NEWBURN H-23

4318.5

Stacked, normally graded sandstones; Erosive base clearly evident in SWC photos

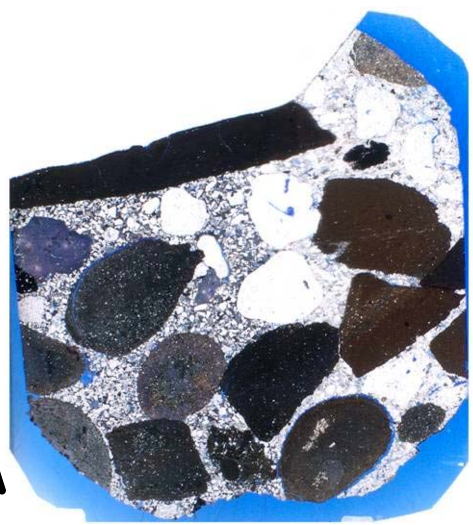


4319.80

Bedding indeterminant

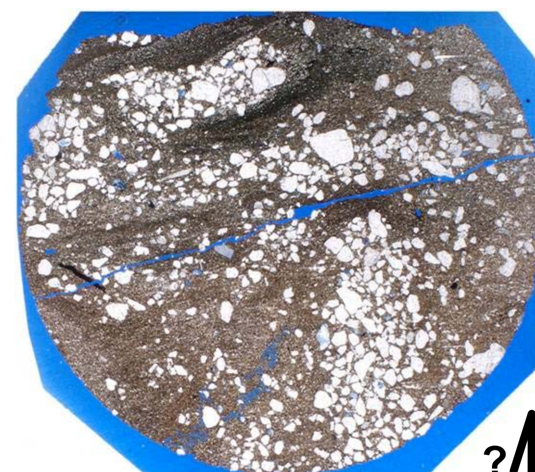
4323.0

Bedding indeterminant; massive, very poorly sorted polymictic conglomerate



4325.5

Bedding indiscriminant (?fluidized)



?

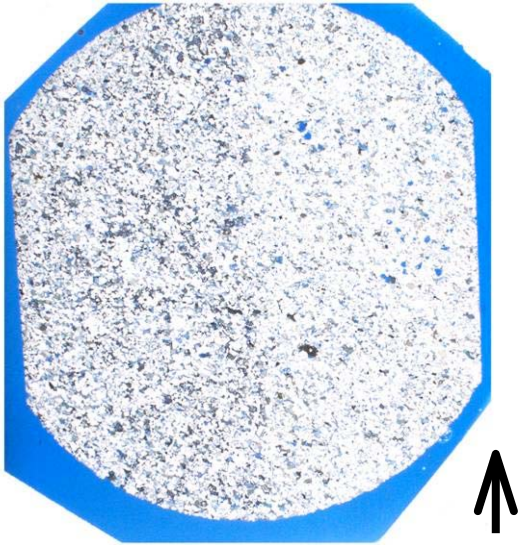
1 cm

Sidewall Core Run #1

Chevron et al NEWBURN H-23

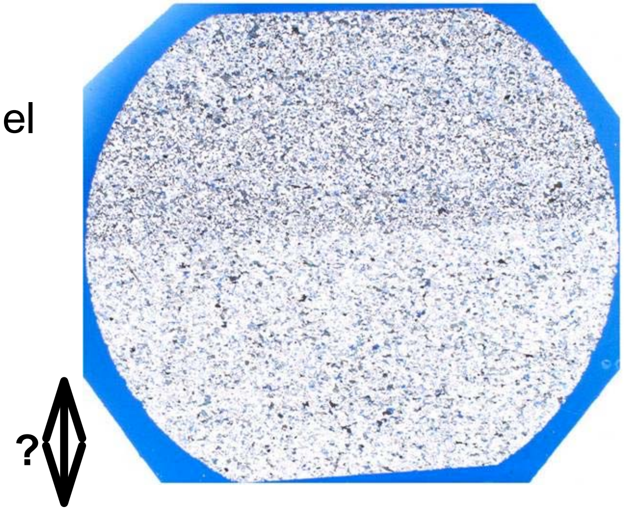
4349.7

Massive, structureless sandstone



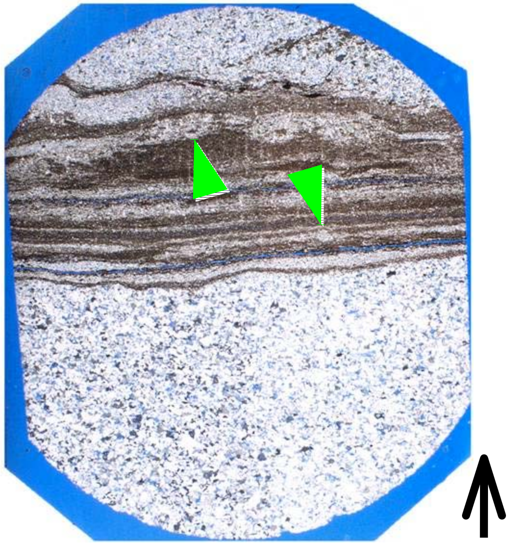
4353.5

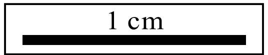
Plane parallel laminated sandstone



4354.5

Flame structures clearly evident in SWC overview photo, Burrows



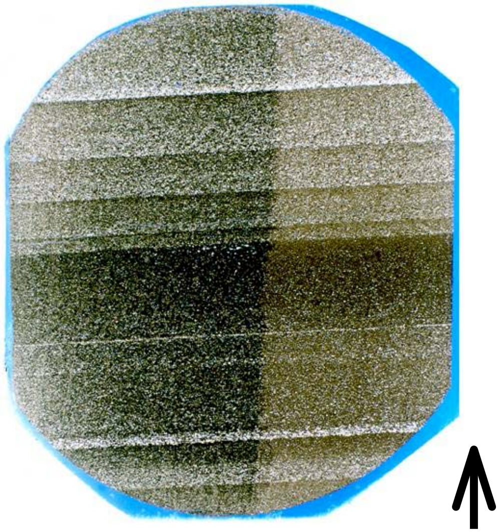


Sidewall Core Run #2

Chevron et al NEWBURN H-23

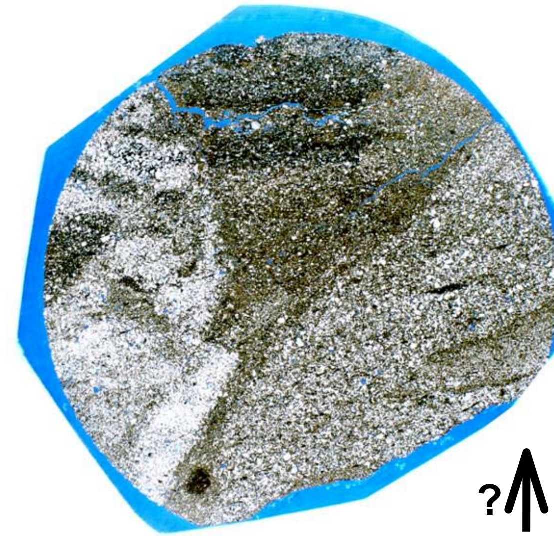
4780.40

Graded beds



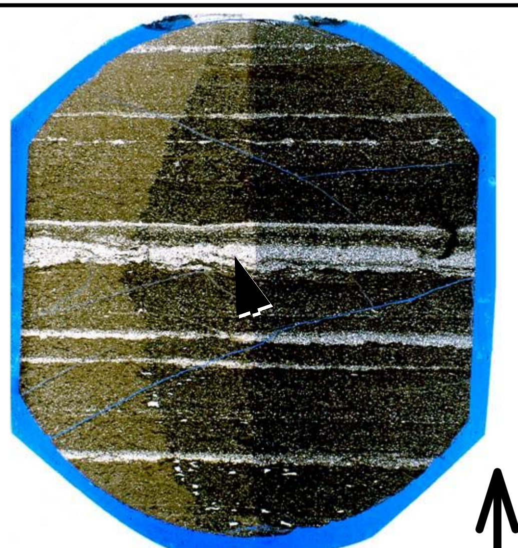
4913.80

Bedding indiscriminant



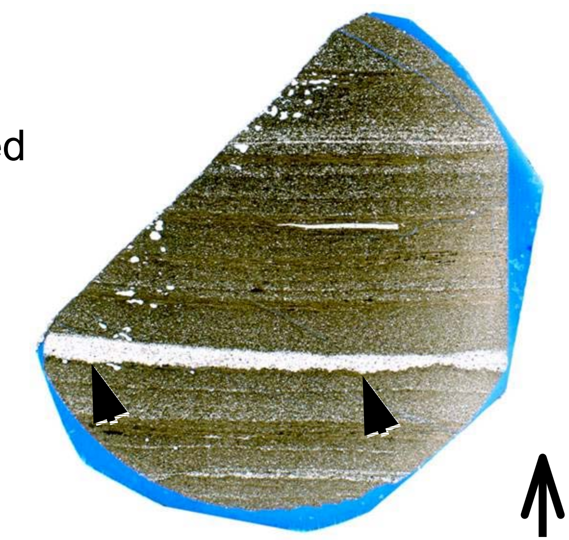
4960.00

Microloaded bed base



5063.0

Microloaded bed base



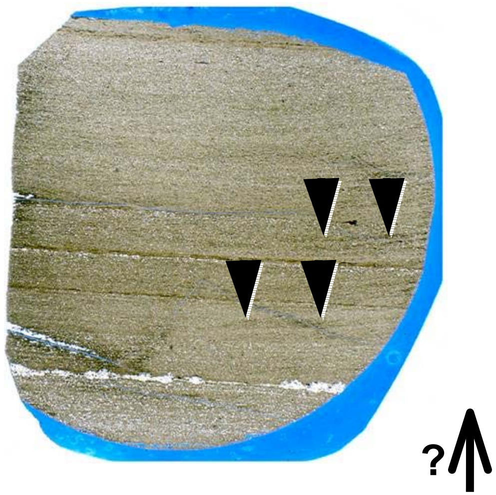
1 cm

Sidewall Core Run #2

Chevron et al NEWBURN H-23

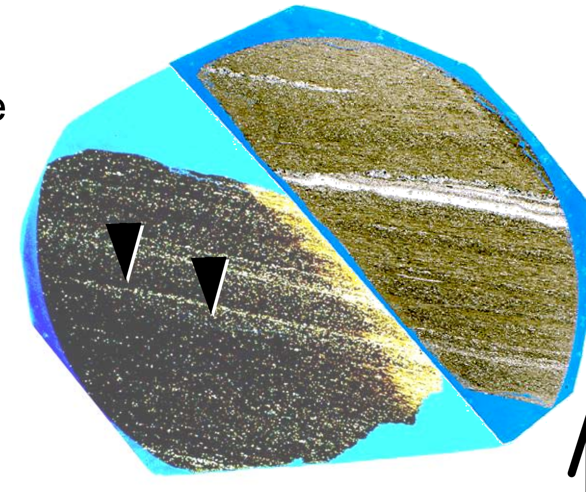
5100.80

Tangential bases to ripple foresets



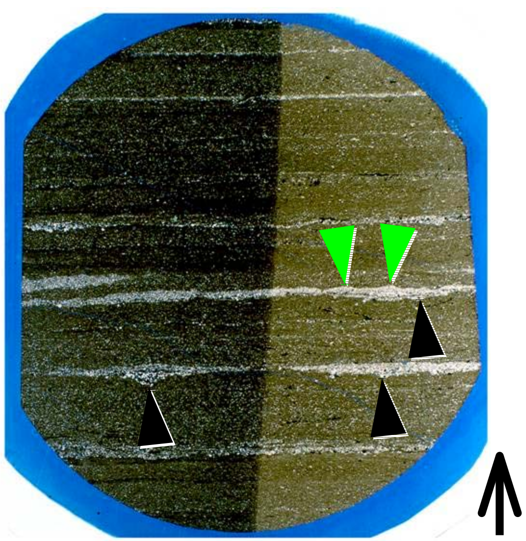
5129.00

Erosive base



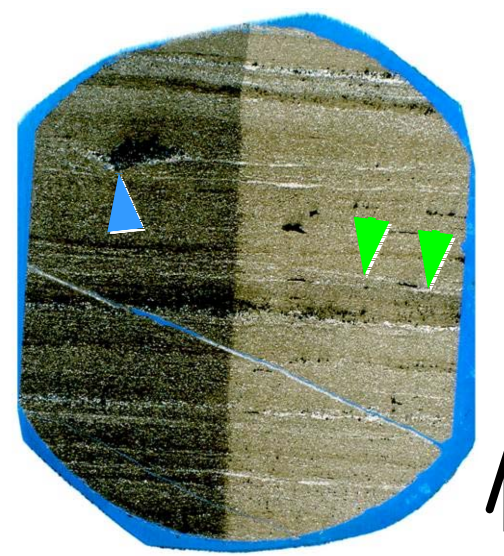
5133.80

Microloaded bed bases,
Starved ripple crests



5186.50

Graded beds,
Low amplitude tangential laminae,
Microloading



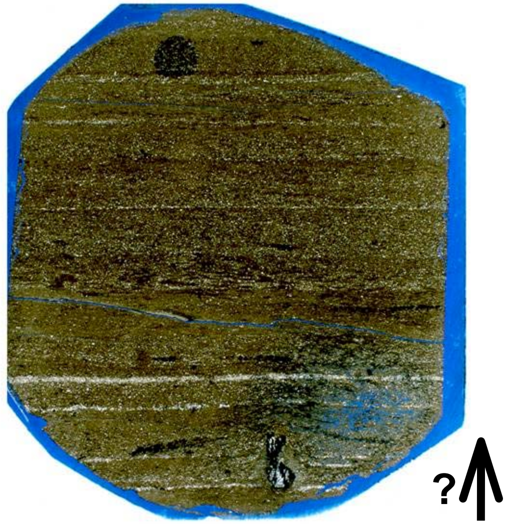
1 cm

Sidewall Core Run #2

Chevron et al NEWBURN H-23

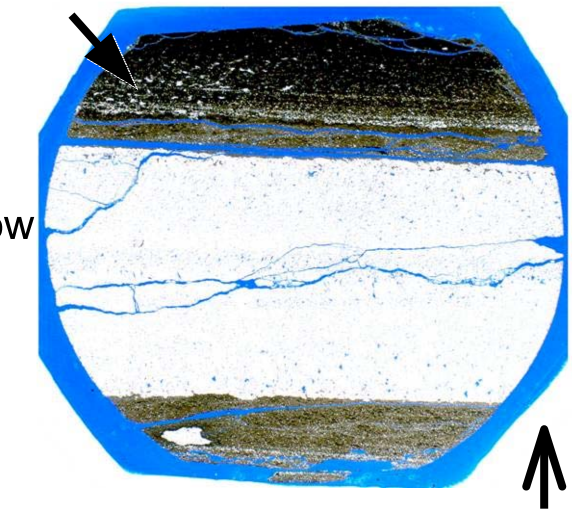
5189.00

Bedding indeterminant (possible orientation of organic flakes?)



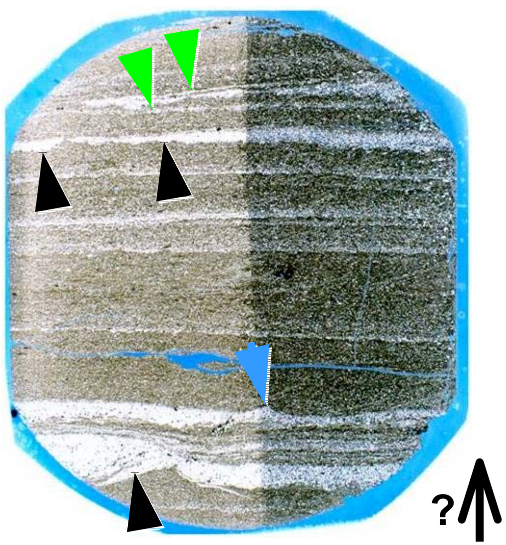
5195.30

Bedding indeterminant (possible burrow fabric?)



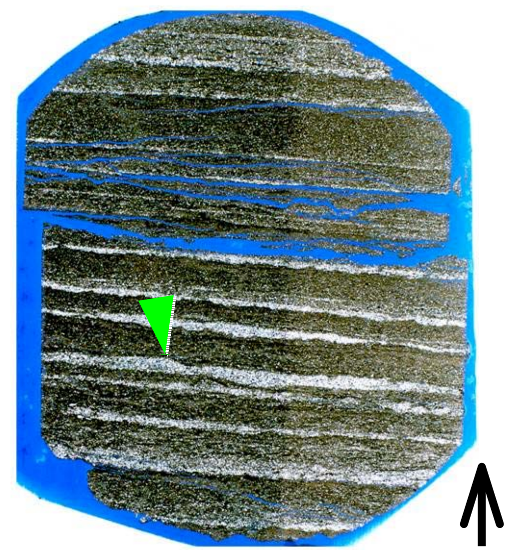
5198.50

Microloaded bed bases, Tangential laminae, Possible ripple crests



5203.80

Micrograded beds, Probable ripple crest



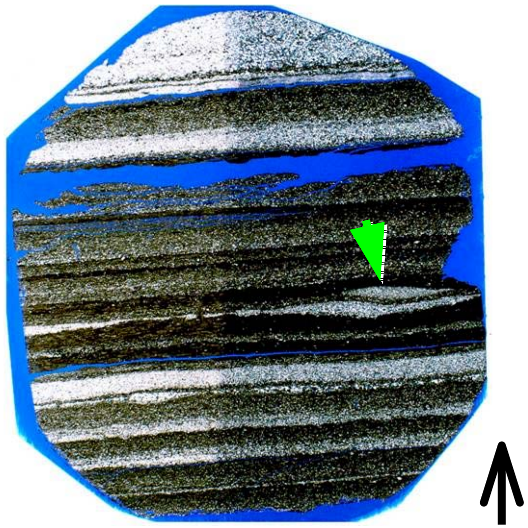
1 cm

Sidewall Core Run #2

Chevron et al NEWBURN H-23

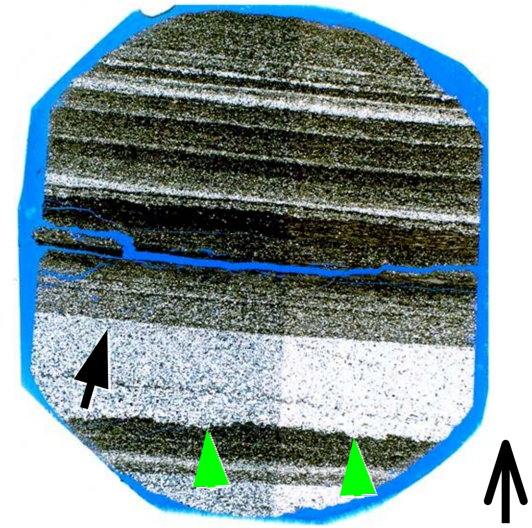
5208.50

Weakly erosive bed bases, Stacked ripple



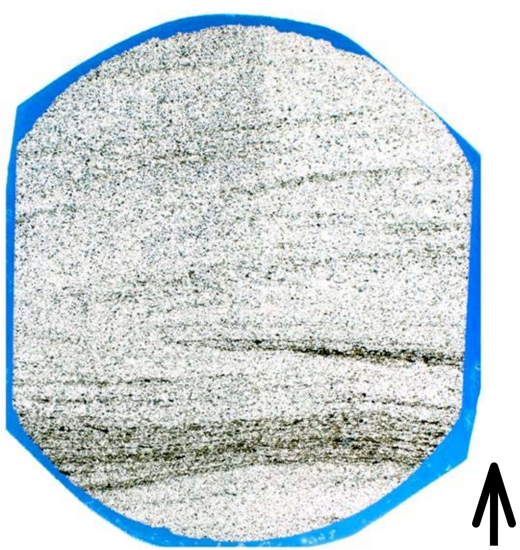
5213.50

Graded bed, Microloaded bed base



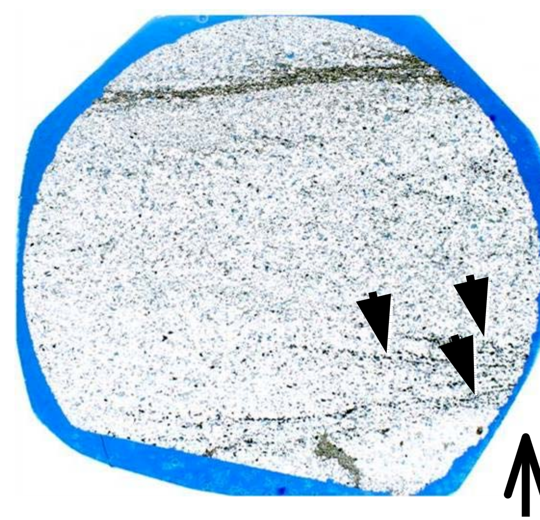
5403.60

Ripple cross stratified sand



5406.50

Ripple cross stratified sandstone with tangential foresets



1 cm

5407.00

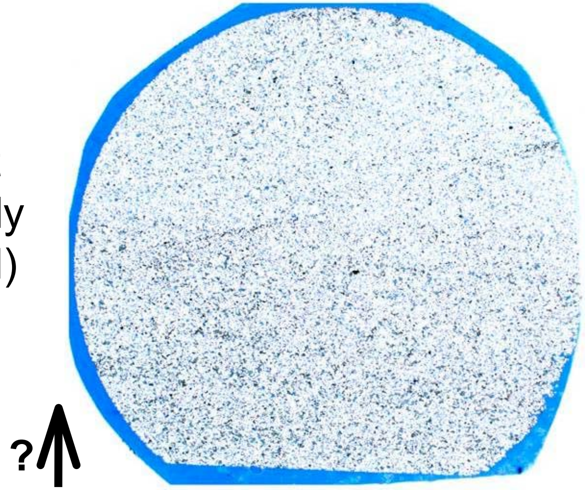
Tops indeterminant (weakly tangential foresets?)

5407.50

Bedding orientation indeterminant

5408.50

Bedding indeterminant (predominantly massive sand)



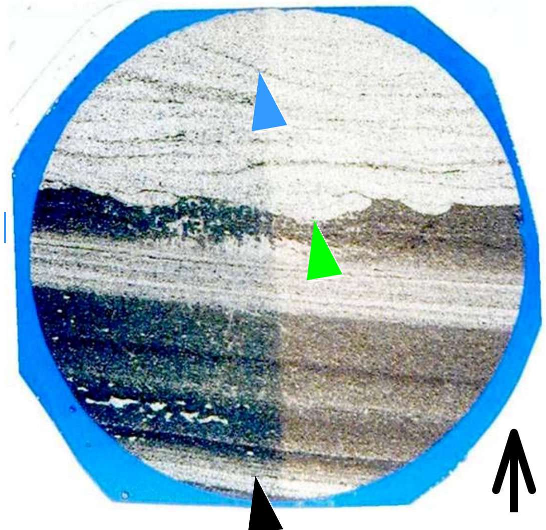
1 cm

Sidewall Core Run #3

Chevron et al NEWBURN H-23

5957.8

Normal grading, Microloaded base, Tangential bases to ripples foresets

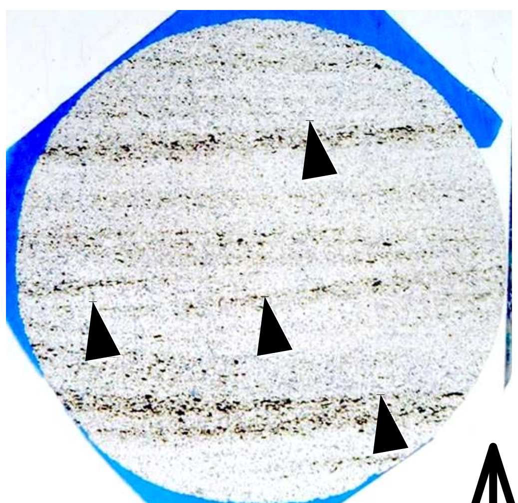


5960.5

It is not clear if this represents an injection feature (fluidization) as shown, or a synaeresis crack

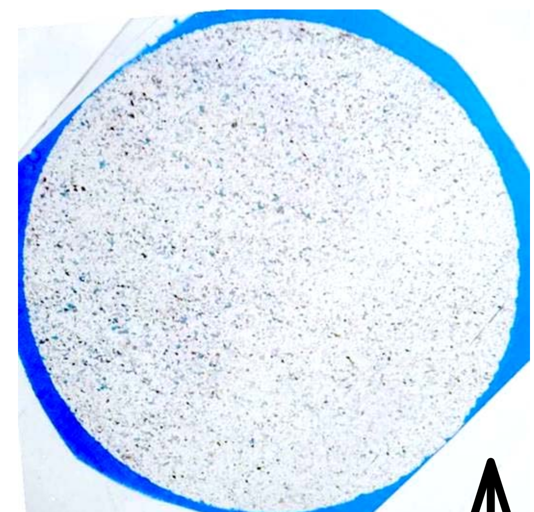
5961.0

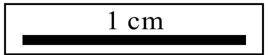
Tangential bases to ripples foresets



5961.2

Massive (structureless) sand



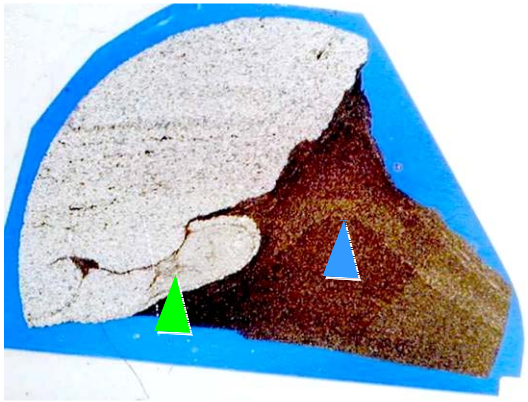


Sidewall Core Run #3

Chevron et al NEWBURN H-23

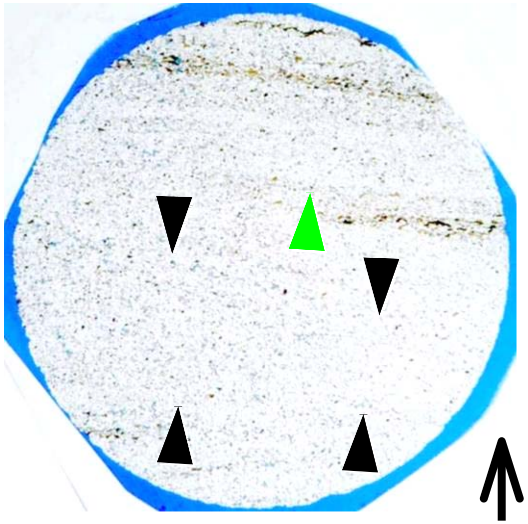
5961.7

Fluidized contact; Probable loading and Flame structure



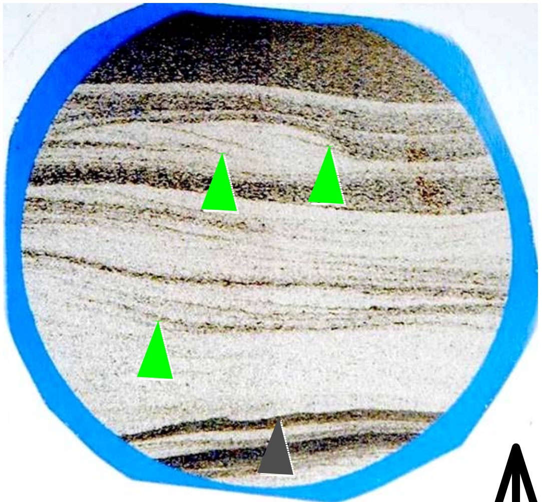
5962.0

Tangential bases to ripples foresets and Possible scour surface



5962.8

Erosive base, Tangential ripple foresets



1 cm